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ON MYRMEKITE

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ABSTRACT

A new theory is presented for the origin of myrmekite which is believed to be formed by the incorporation of recrystallizing quartz in growing albite. The albite is exsolved from orthoclase. The rod-like form of the quartz is explained. Drescher-Kaden's work (1948) is discussed. It is believed that myrmekite can be of assistance in elucidating the complex history of formation of granites.

INTRODUCTION

For many years, various theories have been put forward for the origin of myrmekite. None of the theories has been universally accepted, although such work as that of Sederholm (1916) will long remain admired for its lucid descriptions and discussions.

Becke (1908) suggested that the potash in orthoclase was replaced by soda and lime in late magmatic solutions, the lime setting free quartz in the process. This implies a definite ratio of quartz to plagioclase, in any one growth, depending upon the Na/Ca ratio of the plagioclase. That this is not always so was shown by Sederholm (1916, p. 137). Nevertheless, Sederholm, with some caution, supported Becke's theory but also thought that a skeletal crystal of plagioclase could be filled with quartz, as suggested by Michel-Lévy.

Schwantke's ingenious theory, whereby a hypothetical silicate, $Ca(AlSi_3O_8)_2$, supposedly held in solid solution in the feldspars, would release silica (giving the quartz of the myrmekite) on reverting to anorthite, was supported by Spencer (1945). He stressed the necessity of a local source of the material in a closed system, rather than a source in late magmatic solutions. However, the existence of this silicate is still not proved.

Sarma and Raja (1959) suggested that myrmekite is the result of a break-down of unstable portions of plagioclase under conditions of stress. For typical myrmekite, where its plagioclase is more Na rich than the plagioclase of the rock, they suggested that the anorthite molecule of plagioclase has broken down under stress to give epidote and quartz, the quartz forming vermicules in the Na-enriched plagioclase. Sederholm (1916, p. 139) has urged caution in suggesting dynamic metamorphism when dealing with such delicately preserved structures as myrmekite.

Drescher-Kaden (1948) is the latest worker to treat the subject at length. He came to the conclusion (p. 102) that the same solutions which give the orthoclase of granites and granitized rocks corrode plagioclase along "Smekal defects." The solutions deposit silica, while the removed cations fill empty spaces in the lattice of the plagioclase. Drescher-Kaden's theory is widely quoted at the present day (*e.g.* Voll, 1960; Augustithis, 1962), and his work will be discussed after the presentation of the following theory.

The Character of Myrmekite

The definition of myrmekite, laid down by Sederholm (1916 p. 1) as an intergrowth of plagioclase and vermicular quartz (*i.e.* quartz in the form of rods of a more or less wavy form) is rigidly adhered to.

The characters any theory must explain, are:

1. The vermicular habit of the quartz. Drescher-Kaden is the only worker to have ever attempted an explanation of this character.

2. Association with K-feldspar. Most investigators, including Sederholm and Drescher-Kaden, are agreed that this is essential to the formation of the myrmekite. Apparent exceptions, which are very few, do not necessarily invalidate this rule. Any exception may be truly apparent, due to the lack of a third dimension in rock sections, or due to the fact that K-feldspar has been later removed from the rock.

3. The plug-like form. This is not invariably the form but is so common as to warrant explanation in any theory. It is not explained by many workers. Sometimes the myrmekite is corroded or has had a later growth of non-myrmekitic plagioclase added to it, but even in these cases, the original plug-like form is often still discernible.

4. Association with mortar textures. (In the examples given by the writer, these are demonstrably cataclastic, in that they contain micas, smeared out from those which still exist in the uncrushed portions). This character, which applies only to the non-corroded fresh myrmekite, has not been explained by many investigators. It is a very important association, and has been pointed out by several workers. For example, Eskola (1914 p. 27) writes " . . . and it (myrmekite) occurs as a rule at places where the big microclines are bordered by a granulated mass.": Gilluly (1933) writes "Myrmekite is common in albitized quartz diorite but absent in unaffected quartz diorite . . . and mortar textures are common in albitized quartz diorite." Also Sederholm (1916 p. 128) writes "In this case it seems obvious that the mortar structure is due to a crushing of a solid rock and cannot be regarded as a 'protoclastic' structure, and also that the myrmekite has originated posterior to the trituration, or is about of the same age."

5. The greater acidity of the plagioclase in the myrmekite in comparison with the plagioclase in the rock. In common myrmekite this always seems to be the case, and the plagioclase of the myrmekite is usually albite-oligoclase.

Statement of the Theory

Albite, exsolved from orthoclase, will grow on a plagioclase seed in a cataclastic texture, or grow in structural continuity onto a neighboring plagioclase crystal. As far as the immediate environs of the myrmekite are concerned, the albite is growing in volume (in the solid state) while the quartz is not, and will exert a confining pressure on any quartz which

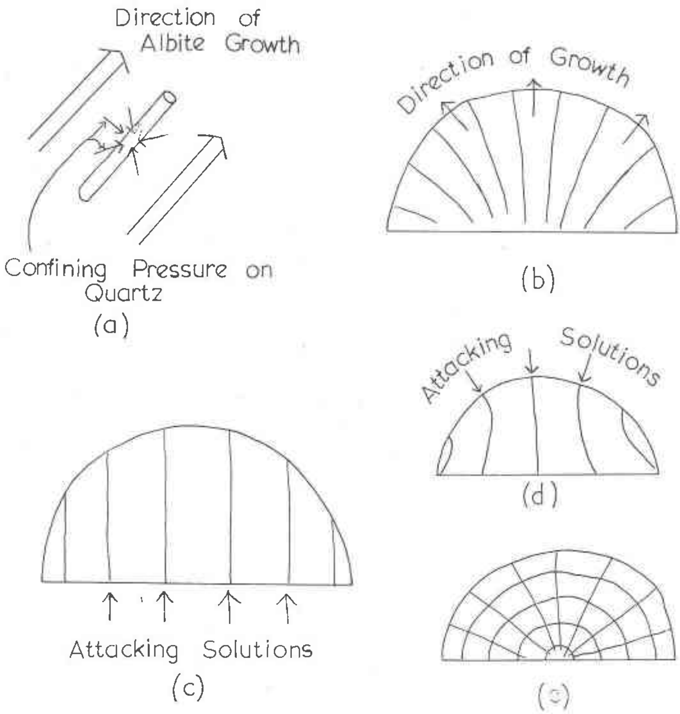

Fig. 1. (*Explanation in text.*)

is changing its form due to recrystallization. The growth is towards the source of the albite, so that plug-like forms will be convex towards the orthoclase, and the confined quartz will develop as rods in this direction (Figs. 1a and 1b).

Exsolution of albite from orthoclase is generally accepted as a common process (*e.g.* Gates, 1953, pp. 58–59; Voll, 1960, p. 524). Tuttle and Bowen (1958 p. 139) also support the contention that albite will migrate to the grain boundaries of orthoclase by exsolution, and quote Schwartz's work on sulfide solid solution . . . "The complete segregation of the minor constituent into grains is most surprising and brings out a fact which has been very little considered in geologic theory; that is that even more or less granular mixtures of two constituents may represent a breakdown of a solid solution that existed at higher temperatures." The redistribution of feldspar material involves complex readjustment, and although voids in the orthoclase doubtless exist on the atomic scale, detailed measurements of its composition or mass are not practicable on the material studied by the writer. Much of the exsolution seems to be, as Gates suggested, associated with shearing, the albite collecting in fractures or on the grain boundaries of the orthoclase. That the albite, associated with fractures and grain boundaries, does not occur any distance from orthoclase, is strong evidence for its exsolution; the albite should have a more general distribution if it were introduced in late solutions. It might be noted that solid diffusion occurs on this sort of scale fairly readily when perthitic feldspars are homogenized on heating.

In comparison with feldspars, quartz is very easily strained and sheared, and it is a common observation in granitic rocks that unbroken feldspar crystals are found embedded in a cataclastic quartz matrix. This is not surprising considering the common association of granites and fold belts. The granites studied by the writer are in the Lannilis area of Finistère, and are affected by Bretonian (?) and Sudetian folds. The strained quartz has free energy which will tend to restore order by recrystallization (Voll, 1960, p. 506), and this occurs fairly readily. In the absence of quartz, albite will form a non-myrmekitic rim to the plagioclase.

This theory necessitates no introduction of material or fluid. The listed characters 2 and 4 of myrmekite, are an integral part of the theory. Character 3 will often result, and character 5 is explained in that nearly pure albite will be exsolved from orthoclase. Most important, the theory explains the origin and form of the quartz rods.

Some examples In rocks of the area studied by the writer, two generations of myrmekite are found. These are correlated with two granitizations, both followed by shearing (Bretonian and Sudetian folding). The later myrmekite is found only rarely, because the granitization between the two fold periods was of minor extent, the albite introduction consequently small, and the quartz, sheared by the later movement, is still highly strained. However, in the Sudetian mylonites the clue to the origin of myrmekite is found in incipiently developed myrmekite. The example shown in Fig. 2 illustrates the development of fine rods of quartz, confined to develop in the direction of growth of the new albite. The albite has been exsolved from, and has convex forms towards, the unbroken orthoclase crystal. The origin of the quartz is found in the cataclastic ground mass, bordering and still remnant in the myrmekite. This myrmekite must have formed after the shearing and appears to be growing out of the cataclastic ground mass.

Other examples of the later myrmekite show more typical forms, but the quartz rods are always very fine. The myrmekite is usually surrounded by strained quartz, suggesting that if the quartz completely recrystallized, a coarser development of myrmekite would have developed (Fig. 3).

The earlier myrmekite is more common. In some cases its relation to mortar texture can still be seen (Fig. 4). These examples occur where the second granitization has not been intense, but nearly always there are traces of corrosion of the typical plug form. Where the second granitization has resulted in a regrowth of orthoclase, then the old myrmekite plugs are included in it and corroded. The quartz rods shown in Fig. 5 extend into the including orthoclase from an older myrmekite: a channel of orthoclase cuts into the myrmekite (just under the 'K') and encloses a quartz rod. This example suggests that the plagioclase was corroded more quickly than was the quartz. In another example, (Fig. 6), there is one plug of plagioclase with evidence of corrosion; one area in the orthoclase where a number of quartz rods occur without their enclosing plagioclase; adjacent to these is a rectangular shaped outline, which is a band of sericite marking the position of a sericitized plagioclase which has been completely replaced. These older myrmekites are usually highly sericitized in contrast to the later myrmekite.

An interesting detail is seen in the myrmekite of Fig. 7. Three-dimensional detail was seen by racking up and down the microscope tube (Fig. 8). The rods can be seen to coalesce in larger grains of quartz. The interpretation placed on this can be illustrated in stages (Fig. 9). Crystals of orthoclase and plagioclase are separated by sheared quartz; albite, exsolved from the orthoclase, grows on the plagioclase and includes sheared quartz fragments; quartz recrystallizes and forms myrmekite with the albite. Drescher-Kaden (1948, p. 102) in his theory does not recognize that the rods can and do coalesce; it must be remembered that it is a very fortunate secton that actually cuts through the place of coalescence. In this, and nearly all myrmekite, the quartz within each growth has a single orientation. Drescher-Kaden found that the orientation has no relationship with the crystal structure of either the plagioclase or orthoclase. Yet he goes on to write (p. 100, in translation)—"Whether this plagioclase structure was itself still in the process of generation (exsolution, thus simultaneous formation of plagioclase— and quartz), or produced a preferred orientation in the quartz by being already present, is not distinguished with certainty by this, though it makes the latter likely." How can the plagioclase structure exert an influence on the orientation of quartz, when it may be in any orientation with respect to the plagioclase? If the rods coalesce, then it is to be expected that the quartz has a single orientation on recrystallization.

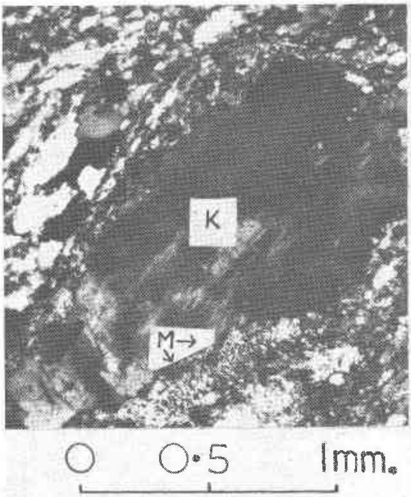

Fig. 2

Fig. 4

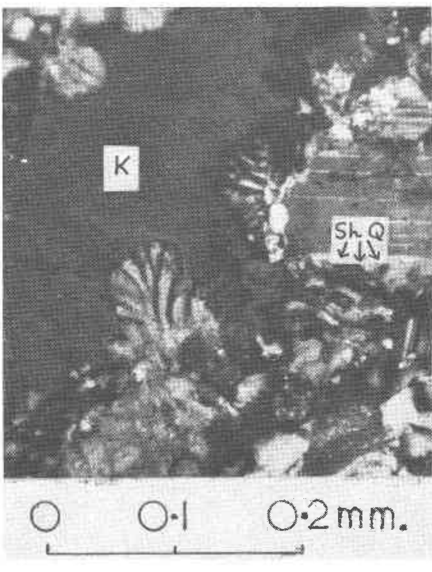

Fig. 3

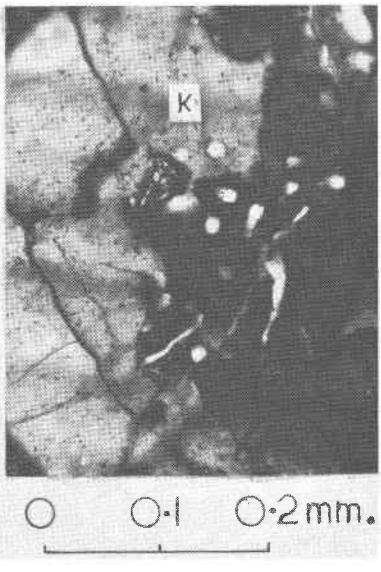

Fig. 5

Explanation of Figures

K=Orthoclase, M=Myrmekite, Mi=Micas, P=Plagioclase, Q=Quartz, Sh=Sheared.

Fig. 2. Incipient myrmekite grown out of a cataclastic matrix into orthoclase.

Fig. 3. Fine myrmekite grown from plagioclase into orthoclase, and surrounded by strained quartz.

Fig. 4. Older myrmekite, which is sericitized, grown on an old shear plane, now represented by sheared micas.

Fig. 5. In extinction is a plagioclase crystal. This was corroded by orthoclase and quartz rods are now isolated from the plagioclase.

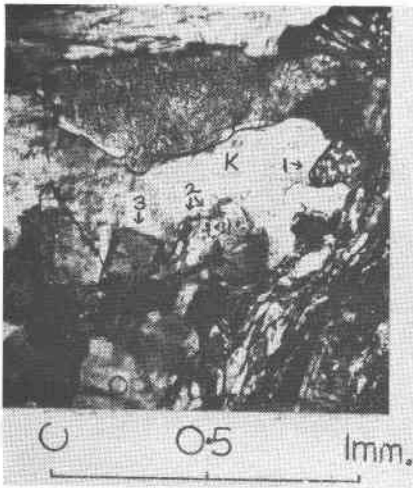

Fig. 6

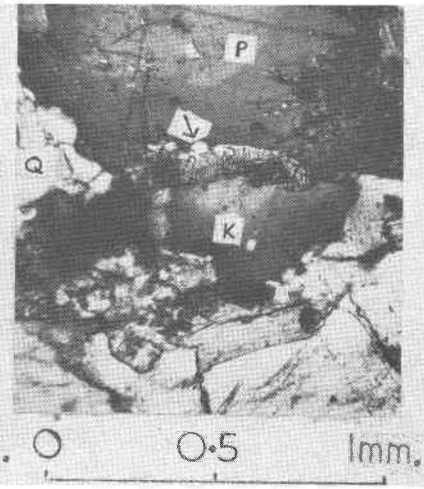

Fig. 7

Fig. 11

Fig. 12

Fig. 6. An older and corroded myrmekite plug (1), a number of quartz rods, no longer in plagioclase (2), and a sericite band, marking the previous position of a plagioclase crystal (3), in orthoclase.

Fig. 7. Myrmekite between plagioclase and orthoclase. The arrow indicates the quartz bleb enlarged in Fig. 8.

Fig. 11. Lundy Isle Granite. An orthoclase crystal with a layer of myrmekite. The orthoclase has completely replaced the plagioclase.

Fig. 12. Lundy Isle Granite. Orthoclase has replaced the plagioclase of myrmekite on the left. The quartz rods continuing into the unreplaced plagioclase were sheared in the direction of the twin-lamellae.

The presence of older corroded myrmekite is taken as indicating a period of shearing in an essentially granitic rock, prior to the final introduction of granitic material. This latter introduction of material tended to destroy such evidence as association of myrmekite with shear zones. Even so, to the writer, it seems unlikely that there should be more than one true explanation of a structure so characteristic in form and composition as myrmekite. The conclusion that the two myrmekite stages are related to shear movements is substantiated by field work. A structural study in the field readily demonstrates the two movements (work in preparation).

These two stages of myrmekite growth are the same as Drescher-Kaden's myrmekite types I and II. If his theory were correct, one would expect to find a correlation between areas of intense late granitizing activity (circulating siliceous solutions) and areas of abundant myrmekite formation. In the granites studied there are areas where the feldspars have been deeply corroded by these late quartz solutions (which were enriched in volatiles), and yet very little myrmekite is found here. Specimens were especially collected in such regions, and sections were also cut of rocks neighboring quartz veins, which are the last signs of activity. No especial abundance of myrmekite was ever found. There is however a distinct correlation between regions of Bretonian or Sudetian shearing and myrmekite abundance.

Drescher-Kaden (1948) interprets his two stages of myrmekite in terms of a single penetration of the rock by granitizing solutions. This is almost certainly a gross oversimplification for many granites. Considering the complexity of fold movements, which are so often associated with granites, it is unlikely that granitization was achieved in one sequence of crystallization. Certainly in the Lannilis region of Finistère, two entirely distinct granitizations occurred.

In the theory put forward by Drescher-Kaden, it is difficult to understand why the metasomatizing solutions do not attack all the plagioclase. Other plagioclases escape myrmekitization by virtue of special intergranular films (p. 102). It seems unlikely to the writer, that the solutions would not be able to penetrate more or less the whole of the rock along the intergranular boundaries and especially along mortar zones. One would have expected the myrmekite of Fig. 4 in this paper to have been attacked in this process from the side neighboring the mortar texture, where solutions could surely migrate easily. This would give plug myrmekite as in Fig. 1c. This is not found.

The writer would expect two possible forms of myrmekite, if Drescher-Kaden's theory were valid.

1. If the "intertruncular-regions" are transformed into "blocks" of ideal structure faster than the feldspar is penetrated by solutions, then the quartz rods formed should be

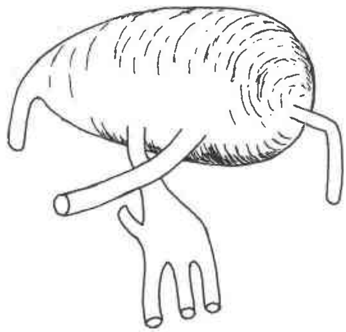

FIG. 8. (*Explanation in text.*)

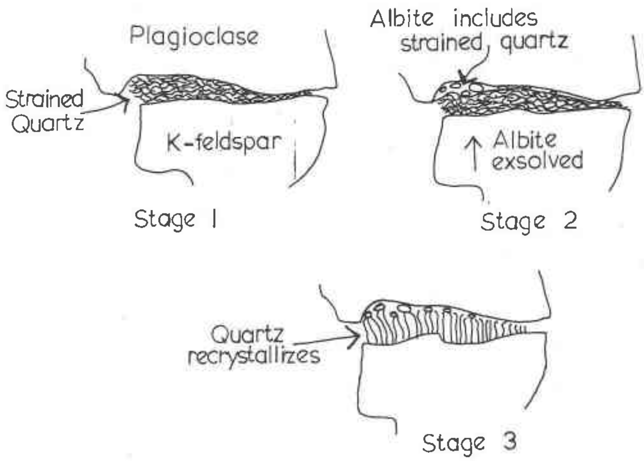

FIG. 9. (*Explanation in text.*)

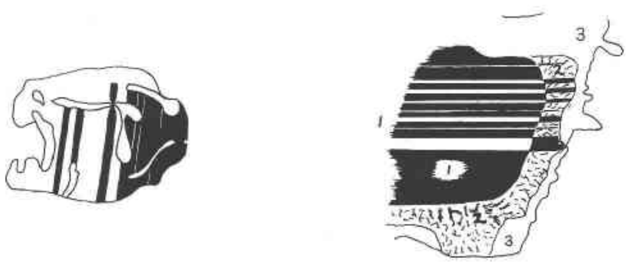

FIG. 10. (*Explanation in text.*)

diverging from each other towards the center of a myrmekite plug (Fig. 1d).

2. If the solutions penetrate faster, then a network of rods should be formed, following the network of "Smekal defects" (Fig. 1e).

In fact the typical myrmekite form, in which the rods converge towards the center, cannot be formed by this process.

The myrmekite type I of Drescher-Kaden (1948) is formed by the myrmekitization of plagioclase already in the rock. This old plagioclase is being corroded by the orthoclase. To quote (p. 42) in translation, "Orthoclase corrodes as penetrations and alters the grain boundaries of plagioclase grains under partial myrmekitization." The older myrmekite often has a plug-like form, and Drescher-Kaden realizing this (p. 47) contends that the plug-like myrmekite did not grow but was corroded into this shape. It seems strange that convex forms grew in the case of myrmekite type II, but were corroded into similarly convex forms in the case of myrmekite I.

An important feature of a myrmekite study is to recognize the possibility of secondary albite twinning in plagioclase (and stressed myrmekite). The writer, following Vance (1961), has found that most albite twinning in the granites studied, is mechanical and secondary. Drescher-Kaden (1948) does not recognize this possibility. He puts forward his Fig. 33 (reproduced in Fig. 10a), which to the writer shows very typical secondary twin phenomena, as an example of the stage of homogenization (elimination of twinning), which is part of his sequence of myrmekitization. Albite rims are formed in his sequence by a process of leaching, or removal of Ca. The sequence (p. 56, in translation) is: "Increase of acidity of margin with retention of twin-lamellae; reversal of extinction of the twin-lamellae; finally complete homogenization of the marginal zone or of the altered region." It should, however, be noted that any crystal with an oligoclase core and albite rim will show a reversal of extinction. Figure 10b is reproduced from Drescher-Kaden (1948, Fig. 30) and is the one with which he illustrates his three stages of leaching. The writer's interpretation of this feldspar's history would be: albite, exsolved from a neighboring orthoclase crystal, grows onto the original plagioclase crystal (1) in the presence of recrystallizing quartz which gives the myrmekite edge (2), later stress giving secondary twinning with the phenomenon of reversed extinction as the twin lamellae pass from the crystal core to the albite rim; further growth of albite, exsolved from a neighboring orthoclase crystal, with no recrystallizing quartz present (3), and not followed by stress.

This latter interpretation demonstrates the use to which the present theory of myrmekite can be put in elucidating the history of the complex granitic rocks.

Some Examples from the Lundy Island Granite

It is relatively easy to have confidence in this theory for the granitized and folded rocks studied by the writer. But difficulties are anticipated in connection with the apparently less complex "intrusive" granites. Even so, it is possible that many of these were intruded as a crystal mush, and myrmekite brought out of its place of origin. From an examination of a few slides of the Lundy Island granite it appears probable that the plagioclase, micas and some quartz were broken and sheared before finally being brought to their present position by a fluid which crystallized into orthoclase and quartz. The granite is certainly not a result of a single sequence of crystallization. One slide clearly shows that the plagioclase had myrmekite rims and is in various stages of replacement by orthoclase. This finally results in a myrmekitic intergrowth of orthoclase and quartz (Fig. 11). Perhaps contemporaneously with intrusion, shearing took place, at which time the plagioclase was mechanically twinned. Figure 12 shows rods of quartz embedded in the replacing orthoclase. The albite, not replaced, was sheared, and the rod-like nature of the quartz almost completely destroyed. The fact that the quartz in the albite was sheared, and the myrmekite rods destroyed, and yet the rods in the orthoclase are intact, indicates that the replacing orthoclase was in the medium of a liquid when shearing took place, and that the temperature was relatively high. The unusual way in which the quartz in the albite has been drawn along the twin lamellae is explained by this high temperature. It was noted that the quartz rods in orthoclase have the appearance of having been packed closely together, this presumably being the result of movement occurring before the orthoclase crystallized.

Conclusions

The theory presented attempts to explain myrmekite formation in terms of fairly well established events in the history of the majority of granitic rocks. Although this process does not require any circulating solutions, myrmekitization is not divorced from the essential processes of granite formation, because granite formation and folding are usually closely associated.

Myrmekite-like intergrowths between minerals other than quartz and plagioclase can result from replacement of one or perhaps both of these minerals by others. In other circumstances the principles of this theory of formation of common myrmekite may apply to different minerals.

The more that granites are studied, the more complex they seem to be, as far as interpretation of the formation of their constituent minerals is concerned. This is especially true of the textures of the feldspars. It is hoped that the theory of myrmekite given here will help to explain some of this complexity. A paper, which will attempt to coordinate this study of myrmekite with microscopic and field evidence for two granitizations and their associated fold movements, is in preparation.

Acknowledgments

The writer wishes to thank Dr. F. Coles Phillips for much discussion during this work, for bringing his attention to the interesting myrmekite from the Lundy Island Granite, for help in the translation of German and for reading the manuscript. Mr. E. W. Seavill and Mr. R. J. Godwin took the photographs.

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