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MYRMEKITE OF THE SITHONIA GRANODIORITE

by

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Abstract : *Myrmekite intergrowths in the granodiorite of the Sithonia Peninsula at the area of Chalkidiki are studied.*

The myrmekite-like intergrowths between vermicular quartz and biotite have been characterized as symblectite whereas intergrowths between plagioclase and vermicular quartz in contact with the potash feldspar have been termed as myrmekite.

Among the great variety of intergrowths that have been found, the preponderant ones have been illustrated and described.

The numerous theories that have been proposed on the myrmekite origin are discussed in brief.

Then the myrmekite formation of the Sithonia granodiorite is examined and a polygenetic character of its origin is proposed.

It has been suggested that the myrmekite intergrowth found on the plagioclase enclosed by K-feldspar is derived by solid state exsolution whereas an interaction between soled state exsolution and metasomatic process facilitated by geological events has been proposed for all other kinds of myrmekite intergrowths in the Sithonia granodiorite.

INTRODUCTION

The Sithonia plutonic complex covers extensive area in the middle leg of the Chalkidiki Peninsula in Northern Greece. The mineralogy, petrography and petrogenesis of this plnton have recently been discussed in detail elsewhere by *Soldatos* et al (1976) and *Sapountzis* et al (1976). The predominant rocks exposed form a granodioritic sequence with subordinate granite, quartzmonzodiorite and tonalite. The granodiorite is homogenous by nature and composed essentially of quartz, plagioclase (An_{17} to An_{35}), potash feldspar (orthoclase and microcline), brown and green biotite (*Sapountzis*, 1976) and small amounts of hornblende, muscovite and epidote.

Within the above rocks and more commonly into the granodiorite, intergrowths between vermicular quartz and plagioclase, as well as between vermicular quartz or plagioclase and biotite have been found.

In the present paper the description of the numerous forms of these intergrowths and the explanation of their origin is attempted.

DEFINITIONS:

Although the term myrmekite applies strictly to an intergrowth of vermicular quartz and plagioclase, similar textural intergrowths of a variety of other minerals have been described under the same term, e.g. *Lacroix* (1907) described intergrowths of potash feldspar and sodalite in Vesuvius eruptive rocks. *Shand* (1906, 1910) described myrmekite intergrowths of potash feldspar with nepheline or sodalite in alkaline rocks. *Tilley* (1958) described vermicular intergrowths of albite and nepleline and *Widenfalk* (1972) intergrowths of potash feldspar and nepheline. *Shelley* (1968) described intergrowths between epidote and quartz as well as between amphibole and quartz, and *Wager* & *Brown* (1968) described intergrowths of basic plagioclase and quartz. This term has also been used for intergrowths between such phases as ilmenite, magnetite pyrite and spinel (*Gierth* & *Krause*, 1973) as well as between quartz and sodic plagioclase in the absense of K-feldspar.

To avoid confusion, *Phillips* (1974) suggested that, such intergrowths, are best referred to as "Symplectites" and proposed to use the term myrmekite for a rock texture in which vermicular quartz is in intergrowth with sodic plagioclase and both phases being in contact with potash feldspar. The above intergrowth, is likely to occur between adjacent plagioclase and potash feldspar crystals or between two or more adjoining potash feldspar grains.

According to the definitions cited above, the intergrowtbs between vermicular quartz and biotite (Fig. 1) as well as between vermicular plagioclase and biotite should be characterized as symplectites whereas all the other intergrowths observed in the rocks of the Sithonia plutonic complex should be called myrmekites.

The typical phase of myrmekite is likely to be found in any granitic or gneissic - in a general sense - rock, which contains quartz, sodic plagioclase and potash feldspar. It is believed however, that there is a relationship between the myrmekite and the amount of the calcium content in the rock, e.g. granodiorites contain well grown myrmekites but albitic-orthoclase leuco-granites are free of myrmekite (*Phillips* 1964, *Hubbard* 1966).

SOME MYRMEKITE EXAMPLES FROM THE SITHONIA GRANODIORITE.

In the Sithonia granodiorite the intergrowths of myrmekite occur in all different petrographical types but commonly the rock which have suffered a stress or cataclasis contain higher amounts of myrmekite.

Among the great variety of myrmekitic shapes that have been found on the rocks are the following:

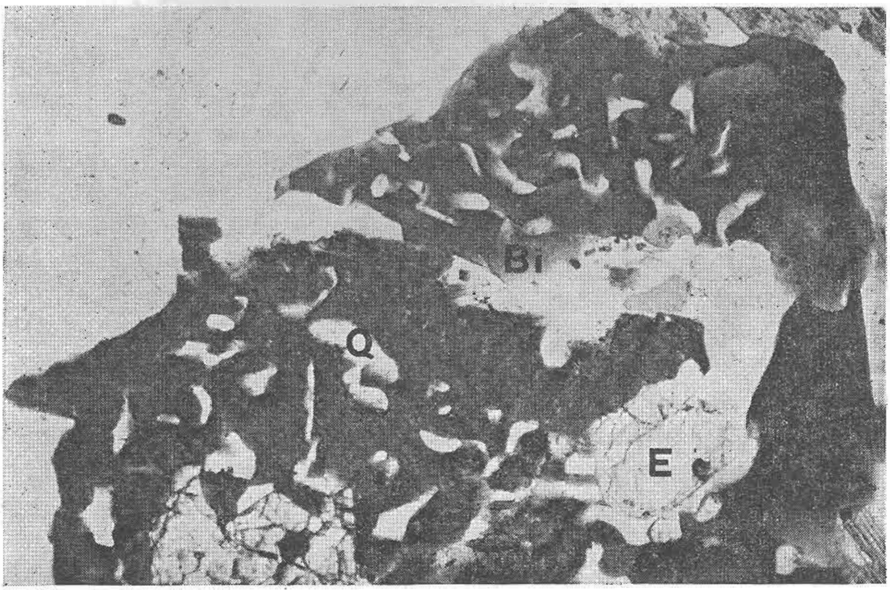

Fig. 1. Biotite-quartz intergrowth which is characterized as "symbleetites". Bi=biotite Q = Quartz E = epidote Nicols // X 125

a) Myrmekite occurred at boundaries of K-feldspar crystals with either plagioclase or another potash feldspar grain; for each mineral pair the type of myrmekite depends on whether they are in contact or not with the rest of quartzofeldspathic mass. Commonly the above myrmekite intergrowths have a lobate or bulbous shape exhibiting markedly curved surfaces against the K-feldspar (Fig. 2). Sometimes the myrmekite intergrowths are presented replacing partly the plagioclase crystal having an irregular form (Fig. 3).

b) Trails of myrmekite occurred as partial rims in potash feldspar or plagioclase. The quartz stems are perpenticular to the interfaces of the rimmed crystals or following approximately the twinns lamellae of the pre-existing plagioclase crystal (Fig. 4).

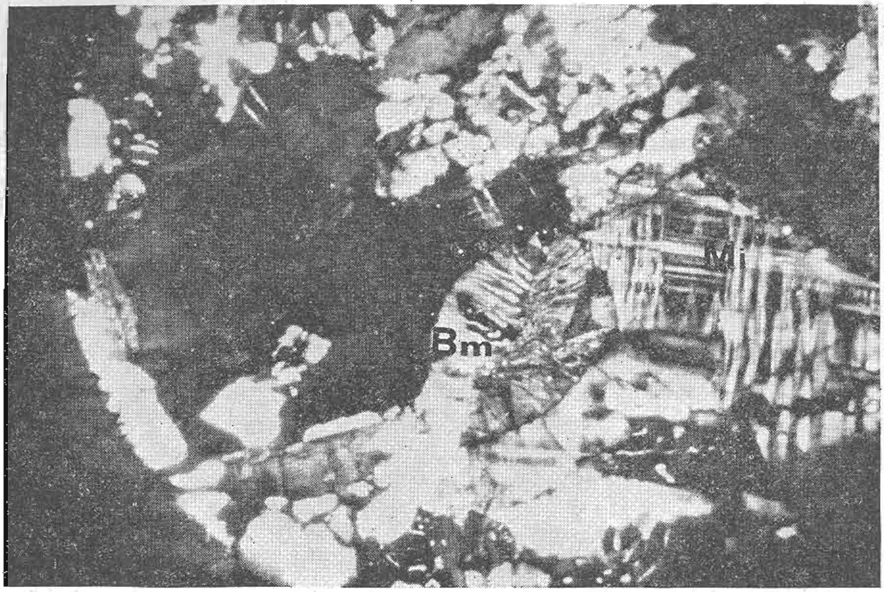

Fig. 2. Markedly bulbous myrmekite projecting into potash feldspar. Mi = Microcline Bm = bulbous myrmekite Crossed nicols X 55

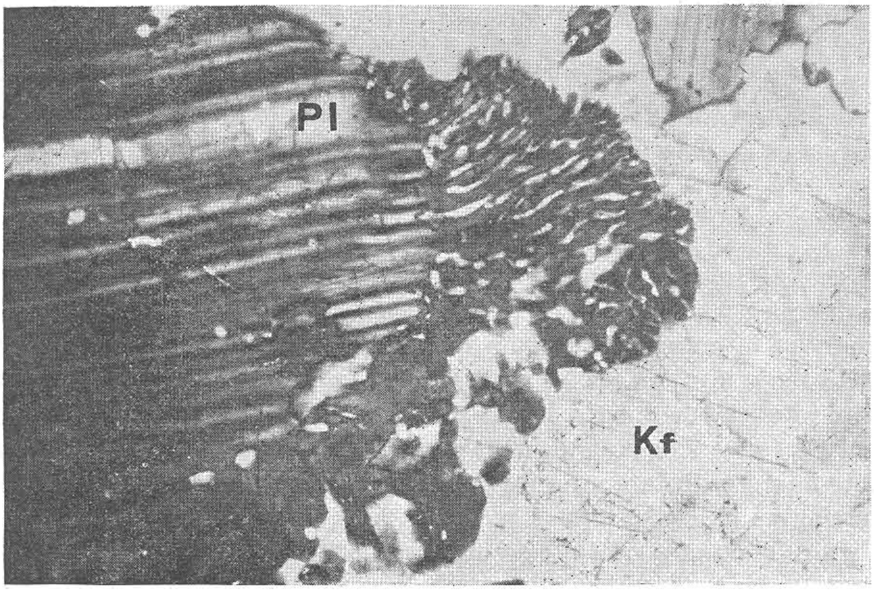

Fig. 3. Myrmekitised plagioclase partly surrounded by K-feldspar. Crossed nicols X125

c) Lobate of myrmekite advancing on either side in a crash band cutting microcline crystal developed about a matted trail of muscovite, apparently the result of mechanical deformation (Fig. 5).

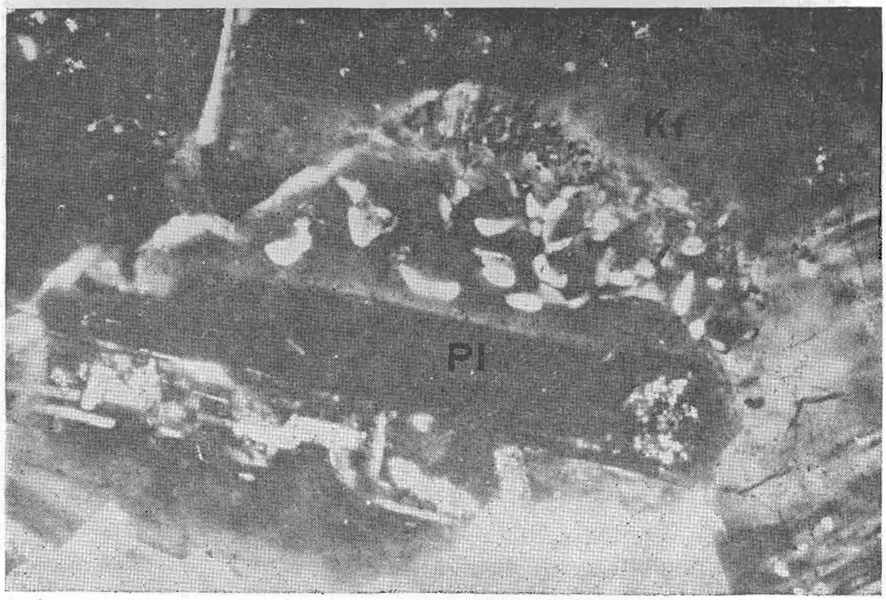

Fig. 4. Twinned plagioclase myrmekitised in contact with K-feldspar where the fine quartz canals following the twin lamellae direction. Crossed nicols X 170

d) Groundmass myrmekite which has grown on many of the grain boundaries of the quartzofeldspathic mass. They have an irregular shape and commonly surround K-feldspar grains. Sometimes this kind of myrmekite seems to be projecting into potash feldspar or plagioclase that are in contact to the above mass. (Fig. 6).

e) Most limited is the case where plagioclase inclusions within K-feldspar crystals are partly (Fig. 7) or wholly myrmekitised (Fig. 8).

Morphology of some myrmekite intergrowths may be interpreted as reflecting the decreasing degree of suitability of growth foundation found by the exsolving phases in some of the interfacial types (*Hubbard,* 1966).

Statement of The Theory.

For many years the problem of the myrmekite formation has been

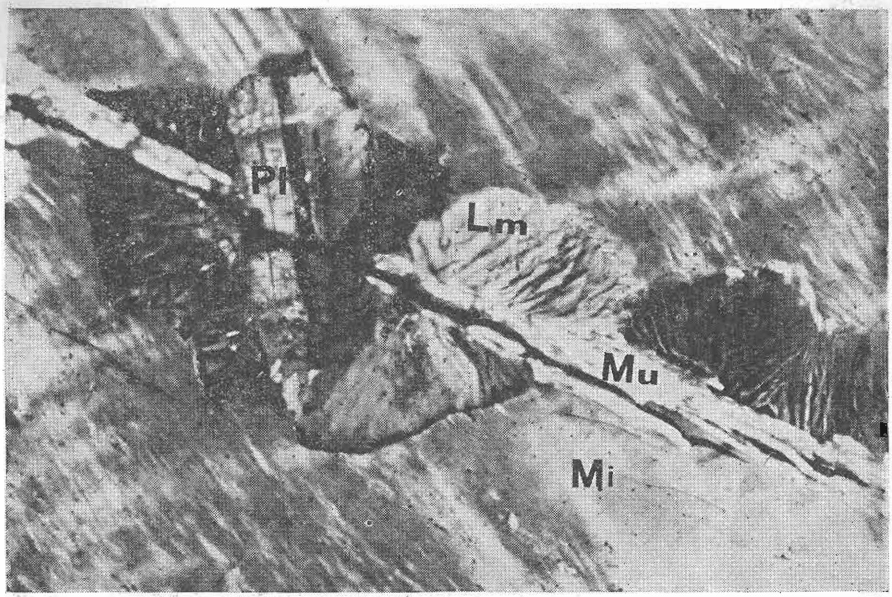

Fig. 5. Lobate myrmekite and plagioclase on both sides in a crash band of a cut microcline crystal. A trail of muscovite flakes pass through this optically continuous potash feldspar crystal. Mi = microcline Mu = muscovite Lm = lobate myrmekite Pl = plagioclase. Crossed nicols X 125

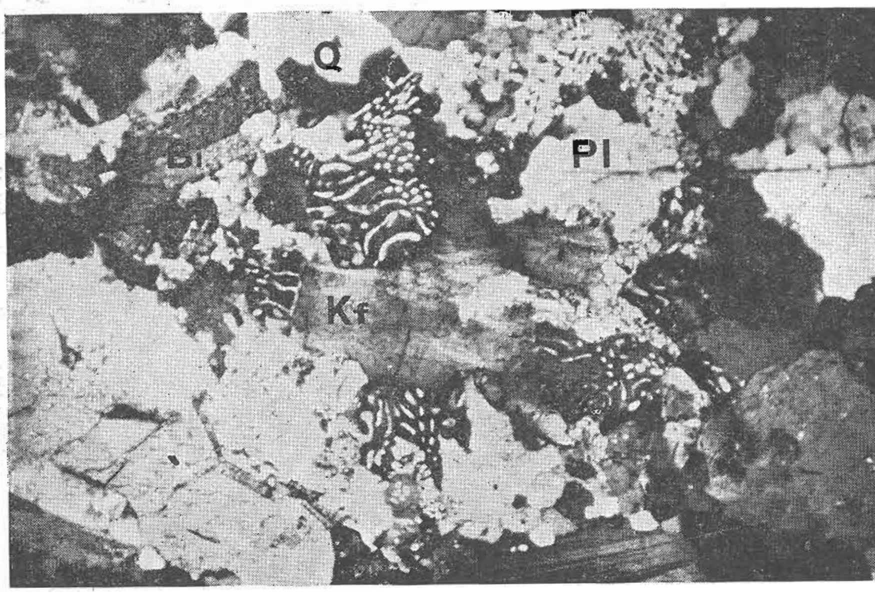

Fig. 6. Plagioclase-K-feldspar-quartz and biotite make up the graundmass where myrmekite has been formed in great amount. Bi = biotite, Kf = K-feldspar, Pl = plagioclase; Q = Quartz. Crossed nicols X 70

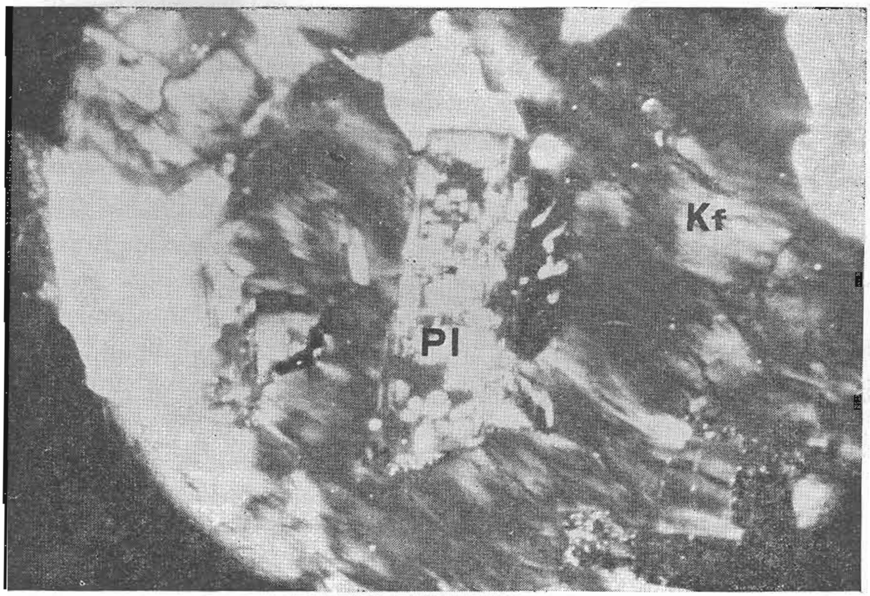

Fig. 7. Myrmekite developed at the right side of a plagioclase inclusion within a K-feldspar crystal. Crossed nicols X 55

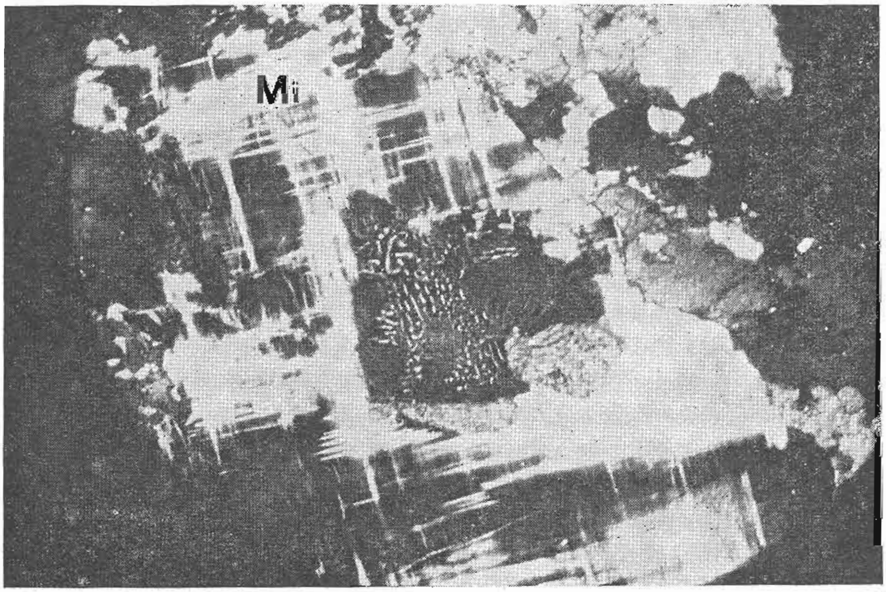

Fig. 8. A wholly myrmekitised plagioclase included in K-feldspar crystal. Crossed nicols X 55

discussed by a great number of workers and various theories about the origin of myrmekite have been put forward. None of the theories has been universally accepted, although such work as that of *Sederholm* (1916) will long remain admired for its lucid description and discussion.

According to *Bhattacharyya* (1971) the hypotheses for the genesis of myrmekite fall in four groups.

I. Replacement of potash feldspar by plagioclase.

II. Replacement of plagioclase by potash feldspar.

III. Exsolution quartz and plagioclase from high temperature potash feldspar at the interface with already existing plagioclase or another crystal of neighbouring potash feldspar.

IV. Migration of exsolved plagioclase from potash feldspar into recrystallizing marginal quartz grains under condition of stress.

Ashworth (1972) classified broadly into two groups the existing views on the origin of myrmekite.

The former deals mainly with the replacement of potash feldspar by plagioclase and can be called metasomatic and the latter is based essentially on exsolution from potash feldspar.

Phillips (1974) who has been dealing for a long time with the subject relating to myrmekite in a recent review paper titled "Myrmekite one hundred years later" has found convenient to discuss the genesis of myrmekite under the following six groups.

I. Simultaneous or direct crystallization. This group relate to the notion that myrmekite forms as the result of late-stage simultaneous crystallization of plagioclase and quartz from a melt of solution. *Sathe* (1964), *Siddhanta* & *Akella* (1966) and *Makhlayev* (1973) have given various degrees of support to the simultaneous crystallization hypothesis.

II. Replacement of potash feldspar by plagioclase. This group is based on the classical theory concerning the replacement origin of myrmekite that is attributable to *Becke's* (1908) hypothesis who suggested that the plagioclase–quartz intergrowths are formed by calcium-and sodium - rich late magmatic solutions acting on potash feldspars, the calcium setting free quartz in the process.

Becke's theory of replacement has heen supported essentially by *Sederholm* (1916), *Anderson* (1937), *Bugge* (1943) and later by *Eskola* (1956), *Binns* (1966), *Barker* (1970), *Shuldiner* (1972) e.t.c.

III. Replacement of plagioclase by potash feldspar. It is based on the concept of the late stage replacement of phases such as plagioclase and biotite by potash feldspar and it has been sometimes linked with myrmekite genesis. This hypothesis which was reported by *Edelman* (1949), *Erdmannsdorffer* (1950) has olso been supported by *Drescher-Kaden* (1948) who concluded (p. 102) that the same solutions which give the orthoclase of granites and granitized rocks corrode plagioclase along "smekaf defects". The solution deposit silica, while the removed cations fill empty spaces in the lattice of plagioclase. *Drescher - Kaden's* theory is widely supported later by *Osterwald* (1955), *Schreyer* (1958), *Voll* (1960), *Augustithis* (1962, 1973), *Bhattacharyya* (1971) e.t.c.

IV. Solid state exsolution. The hypothesis of this group is based on the exsolution (unmixing) theory of *Schwantke* (1909) who proposed that myrmekite is exsolved as quartz-plagioclase phases from high temperature alkali feldspar, holding Ca and "high silica" as a hypothetical molecule $CaAl_2Si_2O_{16}$. *Phillips* (1964) porposed that each Ca in a high temperature alkali feldspar was accompanied by a vacant cation site. On cooling the crystals of alkali feldspar release orthoclase, albite and the above *Schwantke's* molecule which, reverted to An and four molecules of silica, reacts with the albite molecule and gives the myrmekite following the reaction given by *Phillips* et al (1972):

$$\underbrace{\left\{\begin{array}{l} x\ KAlSi_3O_8 \\ y\ NaAlSi_3O_8 \\ z\ Ca\square(AlSi_3O_8)_2 \end{array}\right\}}_{\text{alkali feldspar where}} \rightarrow \underset{\text{orthoclase}}{x\ KAlSi_3O_8} + \underbrace{\underset{\text{plagioclase}}{y\ NaAlSi_3O_8 .\ z\ CaAl_2Si_2O_8} + \underset{\text{quartz}}{4SiO_2}}_{\text{myrmekite}}$$

$\square$ stands for vacant cations sites and $x > y >> z$

The exsolution hypothesis has a lot of advandages and was believed to have had some foundation in experimental work (*Carman* & *Tuttle* 1963, 1967 and *Wyart* & *Sabatier*, 1965). But *Orwille* (1972) set up an upper limit of about 1 weight per cent on the amount of excess silica that may be contained in plagioclase as *Schwantke's* component.

This exsolution vacancy theory, first proposed by *Phillips* (1964), has been supported or partly supported in recent years by an increasing number of workers e.g. *Hubbard* (1966, 1967, 1969), *Carstens* (1967), *Mehnert* (1968), *Phillips* & *Ranson* (1968), *Barth* (1969), *Widenfalk* (1969), *Phillips* (1972, 1973), *Kennan* (1972), *Phillips* et al (1972), *Phildips* & *Carr* (1973), *Phillips* & *Stone* (1974) e.t.c.

V. Recrystallizing quartz involved with blastic plagioclase, the notion that myrmekite forms as a special type of poikiloblastic texture has been proposed by *Shelley* (1964, 1966, 1968, 1970, 1973) who believes that myrmekite forms as the result of the constriction of pre-existing quartz within albite exsolved from orthoclase in rim and intergranular positions, a relationship that the exsolution theory demands.

Shelley's theory has had the support of *Garg* (1967), *Gupta* (1970) and *Parslow* (1971).

VI. Miscellaneous hypotheses, including combinations of some of the hypotheses listed under I to V above. This group contain hypotheses and a lot more discusion about myrmekite formation. *Hills* (1933) has said that the development of myrmekite is associated with the formation of a biotite-quartz symplectite. *Roques* (1955) and *Misar* (1958) suggested a siliceous metasomatism as a mechanism for myrmekite genesis. *Sarma & Raja* (1958, 1959) and *Sarma* (1969) suggested that myrmekite is the result of a break-down of unstable portions of relatively basic plagioclase expelling Ca and Al under metamorphic conditions of stress. e.t.c.

There were also different aspects on the myrmekite formation within granitic rocks in Greece which have been proposed by Greek workers (*Paraskeyopoulos* 1952, *Melidonis* 1963, *Papadakis* 1965, *Dimitriadis* 1974) but all of these are not out of the above mentioned hypotheses.

Discussion

Since the great variety of myrmekite shape has been found in the Sithonia plutonic complex, clearly there are problems in applying any hypothesis to myrmekite formation in general. We have little doubt that myrmekite formation in these rocks is polygenetic.

Neither the direet crystallization hypothesis not the *Becke's* (1908) theory in which myrmekite is formed as the result of the replacement of K-feldspar by plagioclase can explain the Sithonia myrmekite which is formed partly or wholly on the margins of the enclosed, by potash feldspar plagioclases. It does not seem possible either that any liquid was involved in the process of replacement. The restricted position of these internal myrmekite intergrowths which is cut off from the rest minerals of the rock leads us to believe that this kind of myrmekite stressed the necessity of a local source of the material in a close system-rather than a source in late magmatic solution.

Thus, the theory that myrmekite derived from a hypothetical molecule $Ca(AlSi_3O_8)_2$ on exsolution from high temperature alkali feldspar proposed by *Schwantke* seems to be the more plausible explanation for this kind of myrmekite production.

The widespread myrmekite intergrowths in the Sithonia granodiorite are those which are developed in bulbous or lobous form along the crystal boundaries of potash feldspar or between the contact of plagioclase and K-feldspar as well as the intergrowths within the quartzofeldspathic groundmass. It has been observed that the myrmekite intergrowths within the mentioned rocks are growing more, as the cataclasis of the rock is higher.

The idea that a variety of myrmekite could be associated with rocks having suffered a stress, was presented first by *Eskola* (1914) who writes... "and it (myrmekite) occurs as a rule at places where big microclines are bordered by a granulate muss"; also by *Sederholm* (1916) in his description of myrmekite in granites showing signs of mechanical metamorphism. He 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". *Binns* (1966) has also noted that a direct abundance relationship exists between myrmekite and cataclasis. *Bhattacharyya* (1971) reported that the higher stress favoured the formation of myrmekite along marginal contacts between K-feldspar and plagioclase. *Parslow* (1971) states that myrmekite is more extensive in the sheared rocks of the N.E. part of the Cairnsmore pluton (Scotland). Therefore we can say that there partly exists a relationship of dependence between cataclasis and stress for the preponderence of myrmekite intergrowths on the mentioned positions of the Sithonia rocks. This fact combined with the microscopic observation of the great variety of myrmekite intergrowths leads us to accept that the simple exsolution theory proposed previously by us for the internal myrmekite around the inclusion plagioclase by K-feldspar cannot adequately explain some other myrmekite formed in the Sithonia granodiorite.

The simultaneous growth of plagioclase and potash feldspar is unlikely, since the plagioclase provides evidence of the complex history in having a highly altered and corroded core and zones of oscillatory-zoning whereas the K-feldspar having no signs of such - history has replaced some of the plagioclase crystals (*Soldatos* et al 1976).

The above replacement combined with the cataclases provides the possibility to accept *Drescher* - *Kaden's* theory, because strees acts partly by virtue of proving channels for migration of material along grain boundaries and permits entrance of solution from outside. But *Drescher-Kaden* (1948) had argued that the K-feldspar came after the myrmekite whereas we have found cases that the myrmekite ocurred exclusively where the old plagioclase was in contact with K-feldspar.

Moreover, the greater development and more regular morphology of myrmekite at potash feldspar - potash feldspar boundaries than potash feldspar - plagioclase interfaces, and the tendency for more a myrmekite accummulation at the margins of microcline megacrysts in the Sithonia granodiorite may be taken to suggest that the myrmekites are generally associated with K-feldspar, and that this is essential for the formation of myrmekite in the Sithonia granodiorite. Most investigators, including *Sederholm* and *Drescher - Kaden* agree with this association of K-feldspar and myrmekite; *Selley's* (1970) assumption that myrmekite develops in rocks with no potash feldspar cannot be accepted for the Sithonia myrmekite.

The irregular distribution of myrmekite warts that have been observed along the boundaries of some feldspar grains, might result from the influence of different pressure on migration and precipitation. Stress should also certainly assist in promoting exsolution and migration of the components of myrmekite to grain boundaries if indeed myrmekites form by exsolution in the Sithonia area.

We have not observed myrmekite where plagioclase and K-feldspar crystals happened to be parallel and the selective deposition of myrmekite adjucent to some particular microcline crystals may be explained by energy consideration to the most non coherent grain.

Widenfalk (1969) has noted that, in solid state the gradient of chemical potential which is the main driving force promoting exsolution is in part a function of the grain boundary energy. *Phillips and Carr* (1973) also regarded that diffusion of K, Na and Ca and the precipitation of any exsolved phase is facilitated by non coherent interfaces. Thus granulation of groundmass feldspar and the other minerals of the rock during the cataclasis provides numerous relatively fine-grained unhedral plagioclase nuclei and so the grain boundary surface existing between these matrix could lead to a greater potential for the deposition and growth of exsolved material at their margin.

The above granulation also provides a random orientation within the mineral of rock leading to non-coherent boundaries. The deposition on a large number of apparently randomly oriented possible nuclei, provides more favourable sites for the deposition of exsolution (*Ramberg,* 1962; *Carstens*, 1967; *Widenfalk,* 1969). In addition, as suggested by

Ashworth (1972), metasomatic processes could interact lacally with exsolution in megacryst margin situations. Thus myrmekite might tend to accummulate more at the margins of megacrysts than within them, as it was found on the microcline crystals of the Sithonia pluton complex.

With no considerable hesitation we conclude that there is no single origin for myrmekite intergrowths of the Sithonia granodiorite. An exsolution from adjoining K-feldspar grain is at least a major feature for at least many forms, but some material from other source e.g. feldspar grains is incorporated into myrmekite and rarely is myrmekite unaflected by later reactions.

Consequently, an interaction between exsolution and metasomatic processes is considered to be the most plausible explanation for the formation of the Sithonia myrmekite.

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ΠΕΡΙΛΗΨΙΣ

ΜΥΡΜΗΚΙΤΑΙ ΤΟΥ ΓΡΑΝΟΔΙΟΡΙΤΟΥ ΤΗΣ ΣΙΘΩΝΙΑΣ

Ὑ π ὸ

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Εἰς τὴν παροῦσαν ἐργασίαν μελετῶνται μυρμηκιτικαὶ συμφύσεις ἐντὸς τῶν γρανοδιοριτικῶν πετρωμάτων τῆς χερσονήσου Σιθωνίας εἰς τὸν χῶρον τῆς Χαλκιδικῆς.

Αἱ συμφύσεις μεταξὺ σκωληκομόρφου χαλαζίου καὶ βιοτίτου χαρακτηρίζονται ὡς συμπλεκτῖται, ὡς μυρμηκῖται δὲ αἱ τοιαῦται μεταξὺ χαλαζίου καὶ πλαγιοκλάστου ἐν ἐπαφῇ πρὸς καλιοῦχον ἄστριον.

Μεταξὺ τῶν μεγάλης ποικιλίας εὑρεθεισῶν μορφῶν συμφύσεως ἀπεικονίζονται καὶ περιγράφονται αἱ περισσότερον διαδεδομέναι.

Συζητῶνται ἐν περιλήψει αἱ διάφοροι κατὰ καιροὺς προταθεῖσαι ἀπόψεις περὶ τῆς γενέσεως τῶν μυρμηκιτικῶν συμφύσεων.

Ἀκολούθως ἐξετάζεται ὁ τρόπος δημιουργίας τῶν μυρμηκιτῶν εἰς τὸν γρανοδιορίτην τῆς Σιθωνίας καὶ ἐκφράζεται ἡ ἄποψις ὅτι πρόκειται μᾶλλον περὶ πολυγενετικοῦ χαρακτῆρος συμφύσεων. Αἱ ἐφανιζόμεναι μορφαὶ μυρμηκιτῶν ἐπὶ πλαγιοκλάστων ἐγκεκλεισμένων ἐντὸς καλιούχων ἀστρίων θεωρεῖται ὅτι προέκυψαν ἐκ διαμείξεως εἰς στερεὰν κατάστασιν, ἐνῷ αἱ ποικίλαι ἄλλαι μορφαὶ ὑποστηρίζεται ὅτι προῆλθον ἀπὸ ἀλληλεπίδρασιν διεργασιῶν διαμείξεως εἰς στερεὰν κατάστασιν καὶ μετασωματώσεως, τὴν λειτουργίαν τῶν ὁποίων διηυκόλυνε κατὰ περιοχὰς ἡ ἐξασκηθεῖσα ἐπὶ τῶν ἐν λόγῳ πετρωμάτων πίεσις.