

MYRMEKITE IN CHARNOCKITE FROM SOUTH-
WEST NIGERIA

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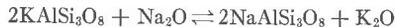
ABSTRACT

The petrography and mineralogy of the myrmekite and perthite in a sequence of charnockitic rocks from S.W. Nigeria are described and the origin of the myrmekite discussed. Myrmekite is concluded to have formed by exsolution processes parallel to and contemporaneous with the perthitization; both components of the myrmekite being derived from the original significantly calcium-bearing, high-temperature alkalic feldspar crystallizations. The primary plagioclase of the rock played an essentially passive role as a preferentially suitable foundation for myrmekite growth; myrmekite also forming, though with less regular morphology, at alkali feldspar-alkali feldspar interfaces. Where later stress effected the rocks, reaggregation of the exsolution products led to modification of pre-existing myrmekite and the formation of new myrmekite-like feldspar-quartz intergrowths at suitable interfaces.

INTRODUCTION

Perthite and myrmekite are strongly developed in a sequence of charnockitic rocks from S.W. Nigeria. A petrographic study has been made of these textures in an attempt to clarify their inter-relationships.

Two divergent schools of thought persist concerning the development of myrmekite. The first instigated by Becke (1908), considers myrmekite to be a replacement phenomenon resulting either from the replacement of orthoclase by sodium-rich plagioclase (*e.g.*, Becke, 1908) or the replacement of plagioclase by orthoclase (*e.g.*, Drescher-Kaden, 1948; Osterwald, 1955). Such replacements result in the production of free quartz, *viz.*:



Following Schwankte (1909), other workers consider that myrmekite is directly linked with perthite exsolution. This theory is based on the assumption that the dissolved calcium component of a high temperature alkalic feldspar has a molecule of the form $\text{Ca}(\text{AlSi}_3\text{O}_8)_2$ which, on reversion to "normal anorthite" on exsolution, would liberate free quartz:



Schwankte expressed doubt concerning his hypothesis since he could observe no quartz release resulting from internal perthite exsolution, but Spencer (1945) was later able to demonstrate liberation of quartz in vein perthite exsolution. Phillips (1964) explained the nature of the "high-silica anorthite molecule" in terms of lattice vacancies, considering each

calcium ion accepted in solution in a high-temperature orthoclase monovalent anion lattice to be accompanied by a corresponding vacant lattice site, thus allowing maintenance of electrostatic charge balance. The current experimental work of Carman and Tuttle (1963) has shown not only the feasibility of a molecule of the form $\text{CaAl}_2\text{Si}_6\text{O}_{16}$ in solid solution in alkali feldspar but indicates that the extent of solution of this molecule at high temperatures may be extensive.

While accepting the source of the plagioclase of myrmekite to be perthite exsolution, some workers consider the quartz to come from a dissociated source. Shelley (1964), for example, describes myrmekite which he explains as forming through incorporation of recrystallizing quartz from crush-zones into albite exsolving from perthite.

Rocks of suitable composition crystallizing under charnockitic environmental conditions would seem to be ideal for myrmekite development by exsolution processes. The present study was undertaken to ascertain in how far the petrography and mineralogy of the myrmekites of the Nigerian charnockites support such an origin.

Geological Setting. Small areas of country underlain by rocks of charnockitic affinity are a common, though minor and sporadic, feature of the Basement Complex of Nigeria and indeed throughout West Africa south of the Sahara. In S.W. Nigeria massive charnockites persist as local relics within the dominantly migmatitic rocks which typify the so-called Older Granite Cycle of Nigeria. The charnockite series range in composition from norite to granite; all massive, medium- to coarse-grained rocks, black to greenish-black in color. The rocks discussed in this paper are from a mainly granodioritic mass forming a range of low, rounded hills near Iwo, the Oke-Patara Group, and from the granitic component of a large complex outcropping around Ikerre, the Ikerre Group.

General Petrology. The rocks of the Oke-Patara Group are predominantly granodioritic, accompanied by minor quartz-dioritic and granitic variants. Contact relationships are nowhere displayed, but the rare, angular xenoliths of silimanite-garnet-orthoclase-quartz-schist suggest some mobility during emplacement of the rock in a high-grade metamorphic terrain. There is no indication of the rocks having been effected by the Older Granite Cycle metasomatism. Pyroxene, both hypersthene and diopside in varying proportions, are the major mafic minerals; typically highly schillerized and with minor, marginal diaphoresis to amphibole and/or biotite. Biotite also occurs to a minor extent as a primary mineral, displaying the characteristic foxy-red pleochroism of biotite in

charnockitic rocks. Quartz is mainly interstitial and is dark blue-gray in color.

The plagioclase is antiperthitic, optical determinations giving a range of composition for the plagioclase of An_{28-35} and a partial chemical analysis (with the included alkali feldspar) indicating a bulk composition of $Or_{10}Ab_{57}An_{33}$. Twinning is generally strongly developed, many of the larger plagioclase grains are bent or shattered and in some instances, polygonization and crystal annealing textures can be recognized. Rounded pyroxene inclusions are common and in some crystals, where a weak diffuse zoning may be recognized, there is a striking concentration of the inclusions in the cores. Peripheral myrmekite is very common.

Alkali feldspar occurs as large irregular crystals and in antiperthite. The large grains are always highly micropertthitic, the fine film perthitic lamellae commonly showing a zonal distribution. A poikilitic texture is general with idiomorphs of plagioclase, pyroxene, biotite and quartz. Partial chemical analyses gave the composition $Or_{59}Ab_{31}An_{10}$ and powder x -ray $\Delta=0.06$ ($\Delta=12.5(131-131)$, Goldsmith and Laves 1954), showing substantial disorder. Some Carlsbad twinning was noted.

The rocks of the large Ikerre Group are dominantly granitic though diorite and norite also outcrop locally. The granites are typically very coarse-grained, dark greenish-black rocks but have been severely altered marginally by the metasomatism of the Older Granite Cycle; marked in the field by a strikingly abrupt loss of the dark coloration. The rocks considered here are from the central unmetasomatized granites. Though pyroxene, particularly hypersthene, again is characteristic, hastingsitic amphibole is a further essential mafic mineral in these rocks. Biotite remains in accessory amounts as a primary mineral. Quartz is abundant, mainly in large irregular interstitial aggregates showing the characteristic blue-gray coloration of the charnockites.

The plagioclase, unlike that of the Oke-Patara granodiorite, is completely free from inclusions and is only very locally noticeably antiperthitic, but myrmekite is again common. Twinning is poorly developed, and zoning was not noted. Universal stage determinations gave a compositional range of An_{20-24} , whereas partial chemical analysis gave $Or_7Ab_{73}An_{20}$.

The alkali feldspar of the Ikerre granite is petrographically similar to that of the Oke-Patara granodiorite. Single crystals greater than 2 cm in greatest dimension are not uncommon. Partial analysis gave the composition $Or_{66}Ab_{28}An_6$ and x -ray $\Delta=0.10$ ($\Delta=12.5(131-131)$, Goldsmith and Laves, 1954).

The main compositional data for the two rocks are tabulated in Table 1.

TABLE 1. COMPOSITIONAL DATA

			Feldspars		
Oke-Patara		Ikerre	Oke-Patara		Ikerre
a) Whole rock analyses					
SiO ₂	56.23	63.91	PLAGIOCLASE		
Al ₂ O ₃	17.70	14.92	i) <i>Optical</i>		
Fe ₂ O ₃	1.87	1.20	Main phase	An ₃₂	An ₂₃
FeO	4.86	5.32	Myrmekite	An ₂₅	An ₁₈
MgO	3.21	0.80	ii) <i>Flame photometry</i>		
CaO	5.63	2.85	CaO% by wgt.	6.5	5.7
Na ₂ O	4.46	3.44	Na ₂ O% by wgt.	6.7	8.2
K ₂ O	3.53	5.57	K ₂ O% by wgt.	1.7	1.1
TiO ₂	1.27	0.88	<i>i.e.</i>	Or ₁₀ Ab ₅₇ An ₃₃	Or ₇ Ab ₇₃ An ₂₀
H ₂ O ⁺	0.35	0.22	iii) <i>X-ray</i>		
H ₂ O ⁻	0.06	0.10	Δd (131-131)	0.175	0.157
MnO	0.16	0.18	ALKALI FELDSPAR		
Totals	99.33	99.39	i) <i>Flame photometry</i>		
b) Norms					
Q	—	13.50	K ₂ O% by wgt.	9.8	11.0
or	20.57	32.80	Na ₂ O% by wgt.	3.5	3.3
ab	37.73	28.82	CaO% by wgt.	2.1	1.1
an	18.35	8.90	<i>i.e.</i>	Or ₅₉ Ab ₃₁ An ₁₀	Or ₆₆ Ab ₂₃ An ₆
di	7.72	4.58	iii) <i>X-ray</i>		
hy	9.89	6.78	Δ = 12.5(131-131)	0.06	0.10
ol	—	—	Oke-Patara		Ikerre
mt	2.78	1.86	c) Modes		
il	2.43	1.67	quartz	2.8	10.8
plag	56.08	37.72	orthoclase	13.6	50.7
ore	5.21	3.53	plagioclase	50.7	18.1
			mafics*	27.2	13.5
			myrmekite	5.7	6.9

* Dominantly pyroxene but includes biotite, amphibole and ore.

Notes: 1. Rock analyses—Central Analytical Laboratory, U. of Uppsala.

2. Flame photometric analyses—B. Almqvist and I. Lindqvist. Interference in Ca determination suppressed by addition of LaCl₃ to solution (Lindqvist, in preparation). Determinations on material drilled from several crystals from the analyzed rock for each group.

THE PERTHITES

Four morphological types of perthitic intergrowth characterize the alkali feldspars of the S.W. Nigerian charnockites:

a) *Film perthite*—fine, lenticular, parallel lamellae which may or may not show concentric zoning of variable concentration. All have identically orientated lattices for any alkali feldspar grain, quasi-parallel to the orthoclase host lattice (Fig. 1).

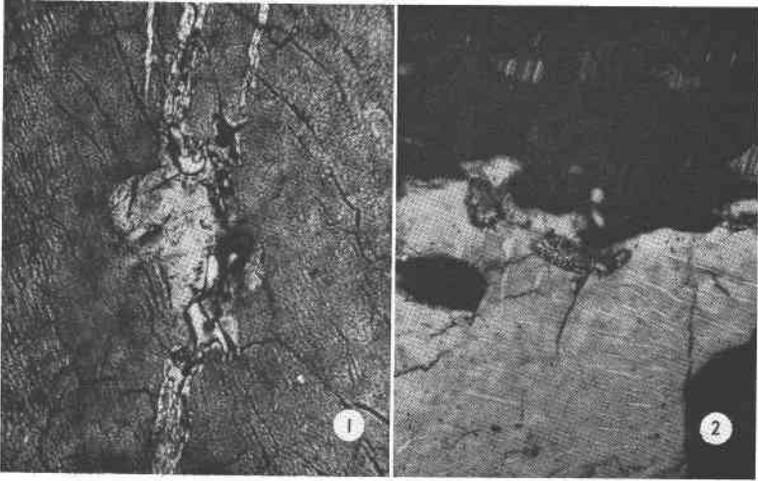


FIG. 1. Vein perthite with quartz blebs in central thickening. Note aureole free from film perthite around the vein perthite. Stained orthoclase-micropertthite, Oke-Patara Group granodiorite. $\times 400$, crossed polars.

FIG. 2. Contact of fractured portion (top, dark) and main body (bottom, light) of a fractured microperthite crystal. Twinned bead perthite, rod perthite and alternate orientated myrmekite intergrowths are all displayed. Note the clearly marked connection of the rod perthite with the crystal discontinuities. Stained orthoclase-micropertthite. Oke-Patara Group granodiorite. $\times 400$, crossed polars.

b) *Vein perthite*—relatively coarse, irregular plagioclase aggregates, always elongate, generally with wedge-shaped terminations and thickening at the center. Their lattices are again orientated quasi-parallel to that of their hosts (Fig. 1).

c) *Rod perthite*—fine, rod-shaped plagioclase aggregates radiating from grain interfaces with lattice orientation quasi-parallel to host (Fig. 2).

d) *Bead perthite*—small, angular, irregular patches commonly aggregated in groups with common lattice orientation, closely parallel to that of the host (Fig. 2).

The first two types are common to both the granodiorite and the granite while the latter two are found only in fractured grains in the granodiorite, and there to the exclusion of film and vein perthite.

Film perthite is the dominant morphological type and was found in all the grains examined. The irregular vein perthites are surrounded by zones free of film perthite, the dimensions of these zones varying in rough concordance with the width of the adjacent portion of the vein perthite (Fig. 1). Characteristically, the central thickenings of the vein perthite contain irregular blebs of clear quartz (Fig. 1). The film perthite lamellae and the vein perthite of any given crystal all have the same lattice orientation, quasi-parallel to the host orthoclase. The connection of the rod perthite to the crystal periphery or fracture surfaces is ubiquitous. At these loci, where the neighbor is feldspar, the rod perthite terminates in a myrmekite-like intergrowth of quartz and plagioclase

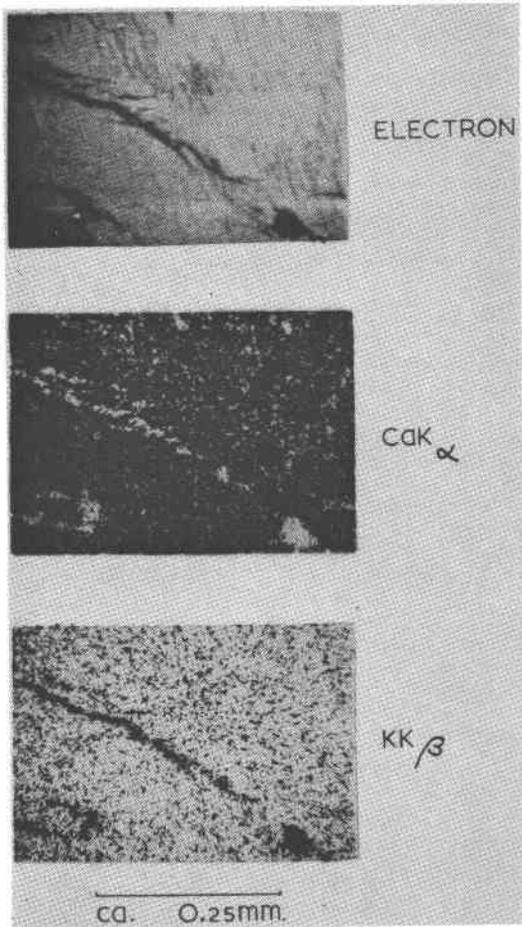
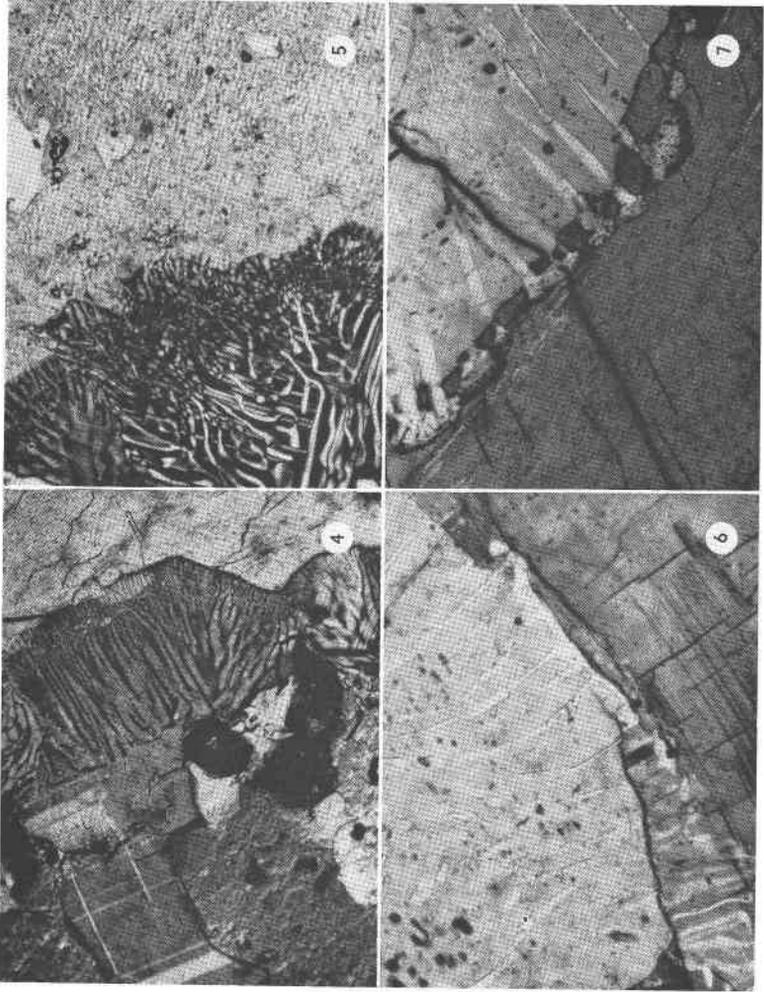


FIG. 3. The back-scattered electron photograph and the CaK_α and KK_β x-ray fluorescence photographs for the same small area of an orthoclase-micropertthite crystal. (See text.)

(Fig. 7). Patch perthite is restricted to the fracture fragments of large crystals, the main bodies of which usually bear rod perthite passing to the fracture interface. The plagioclase of the patch perthite is typically strongly twinned. Vein and film perthite never occur in the zones containing rod or patch perthite, though in the same crystal, remote from the fracture locus, the former types may be abundant.

A qualitative x-ray fluorescence microprobe investigation (Cambridge Microscan System) was made to determine the distribution of Ca and K within the perthites. This showed the perthitic plagioclase to contain no detectable potassium and the orthoclase no calcium. This is graphically illustrated in Fig. 3 which compares the back-scattered



electron photograph with the CaK_α and the KK_β x -ray fluorescence photographs for the same small area of alkali feldspar (FH 292—Ikerre Group granite). The white spots of the x -ray fluorescence photographs indicate and locate the presence of the phase under study. The rigidity of compositional demarcation of the vein perthite is clear. An overlay shows that the apparently scattered spots of the CaK_α photograph and the corresponding black areas of the KK_β photograph mark fine film perthite just visible on the black-scattered electron photograph. Unfortunately no data on the Na distribution could be obtained by microprobe methods.

THE MYRMEKITES

Myrmekite, microscopic assemblages of intergrown plagioclase and quartz only (Sederholm, 1897), was found to be strongly developed in the Oke-Patara granodiorite and rather less so in the Ikerre granite. In either rock, the location of this type of intergrowth is completely restricted to interfaces between perthitic alkali feldspars with a neighboring feldspar; plagioclase or another alkali feldspar grain. The petrography of the myrmekite was seen to vary depending on whether the interface involved alkali feldspar and plagioclase or two grains of alkali feldspar and also on whether the alkali feldspar was of the "normal" or the "strained" type (*i.e.*, with film and vein perthite or rod and patch perthite), as shown below.

Interfaces involving "normal" alkali feldspar

(a) *Alkali feldspar-plagioclase contacts*

1) Myrmekite forms as an overgrowth on the plagioclase, growing at

FIG. 4. Myrmekite at interface between plagioclase and orthoclase-micropertthite. Note convexity to orthoclase, the fine quartz-plagioclase intergrowth immediately adjacent to the orthoclase with convergence of the quartz to coarser rods towards the primary plagioclase, the mimicking of the primary plagioclase lattice by the myrmekite plagioclase and the radiation of quartz rods to parallel the direction of myrmekite growth. The tendency for delimitation of the plagioclase to myrmekite contact by parallel quartz is also shown. Oke-Patara Group granodiorite. $\times 200$, crossed polars, feldspar stained.

FIG. 5. Complex myrmekite intergrowth at a triple interface (2 plagioclases and one orthoclase-micropertthite). Note the fine quartz lamellae passing across the myrmekite-orthoclase interface (center of photograph) and the general serrate nature of the interface. Oke-Patara Group granodiorite. $\times 400$, crossed polars, feldspar stained.

FIG. 6. Strained interface between fracture fragment of orthoclase micropertthite and plagioclase. Note interconnection of rod perthite at interface and disturbed earlier myrmekite. Oke-Patara Group granodiorite. $\times 300$, crossed polars, feldspar stained.

FIG. 7. Myrmekite-like terminations to rod perthite at fracture interface. Photomicrograph of other side of fracture fragment illustrated in Fig. 6. Oke-Patara Group granodiorite. $\times 400$, crossed polars, feldspar stained.

the expense of the alkali feldspar. A convex surface to the alkali feldspar is often well developed (Fig. 4).

2) The structural detail of the primary plagioclase is adopted by the myrmekite plagioclase (*e.g.*, twinning).

3) The contact of the myrmekite with the plagioclase is typically well-marked and angular. It is very occasionally demarcated by aggregation of myrmekite quartz parallel to the contact.

4) In the immediate vicinity of the myrmekite-alkali feldspar contact there is generally a narrow zone of myrmekite in which the quartz rods are finer and more tightly packed than in the main body where the quartz has coalesced to distinct, well-separated rods. The two quartz forms are interconnected, giving rise to a polychotonous texture at the rather abrupt conjunction of the two zones. In both types the quartz is normally elongated quasi-parallel to the direction of growth of the myrmekite (Fig. 4). More irregular developments also occur.

5) At some contacts, especially where the convex form of the myrmekite is well developed, the interface with the orthoclase is castellate or serrate, some of the fine quartz lamellae of 4 above passing from the myrmekite across the interface and continuing for a short distance into the orthoclase (Fig. 5).

6) Myrmekite is never formed at interfaces between perthite plagioclase and its orthoclase host.

(b) *Alkali feldspar-alkali feldspar contacts*

1) Myrmekite is less strongly developed than at alkali feldspar-plagioclase interfaces.

2) The myrmekite does not have the regular morphology characteristic of those built on plagioclase but occurs as small blebs, usually with greater extension parallel to the interface than at right angles to it. The quartz component is finely and rather irregularly distributed.

3) The myrmekite typically develops as a double row of blebs, one row growing into each alkali feldspar grain. The plagioclase components of the myrmekite intergrowths of any row all have the same lattice orientation, concordant with the perthite lamellae contained in the alkali feldspar *at the opposite side of the interface* (Fig. 2).

4) There is often, but not always, a deficiency of film perthite in the alkali feldspar marginal to myrmekite developments.

Interfaces involving "strained" alkali feldspar

(a) *Alkali feldspar-plagioclase contacts*

1) Myrmekites at these contacts have a highly irregular morphology but most commonly take the form of long narrow strips of alternating plagioclase and quartz roughly paralleling the interface (Fig. 6).

2) The direct connection of the myrmekite with rod perthite is normally clear, the plagioclase rods passing across the interface into the myrmekite (Fig. 6).

3) The proportion of quartz to plagioclase in these intergrowths is low.

(b) *Alkali feldspar-alkali feldspar contacts*

1) Myrmekite pods form the terminations of rod perthite units where they have crossed an interface to a neighboring alkali feldspar grain. Continuity of lattice is maintained between the rod perthite plagioclase and the corresponding myrmekite plagioclase (Fig. 7).

2) The quartz content of these myrmekites is low and lacks any regularity of disposition.

3) Intermixing of myrmekite types occurs at the interface of fractured fragments with sensibly unstrained neighboring alkali feldspar grains.

The compositions of the myrmekite plagioclases were determined optically (by extinction methods) for each group. The values quoted in Table 1 are mean values for the central portions of the myrmekite, the slight variation noted between the extremities of individual intergrowths being indeterminable by the methods available.

DISCUSSION

The results of this study indicate a close genetic relationship between the myrmekite and the associated perthite; the unaltered intergrowths with the exsolution phase of perthitization and the stress-modified types with a stress-instigated perthite reaggregation.

The charnockitic nature of the rocks suggests genetic conditions of high crystallization temperatures under high enclosing pressures with slow cooling in a relatively volatile free environment (*e.g.*, Barth, 1962). Such a milieu would favor internal localized readjustments and crystal transformations with maintenance of close thermodynamic equilibrium between the crystalline phases and their environment. The high formation temperature would enhance acceptance of significant calcium (with greater stable concentration of lattice vacancies) in the crystallizing alkali feldspars, and the subsequent slow cooling would give significance to the quantitatively small energy increments of the crystal interfaces, rendering them attractive nucleation sites in exsolution. Such a system would be essentially closed, wholesale material redistribution being inhibited by paucity of interstitial transporting medium. During the significant period in the history of the charnockites conditions were thus ideal for myrmekite formation by the exsolution schema of Schwankte, as expanded by later workers.

A consideration of the petrographical and mineralogical features of the unaltered myrmekite and associated perthite shows agreement with such a genetic process having been operative. The restriction of myrmekite to interfaces involving perthitic alkali feldspar, the association of quartz with internal vein perthite, the relatively high content of calcium in the exsolved plagioclase and the occurrence of myrmekite at alkali feldspar-alkali feldspar as well as alkali feldspar-plagioclase interfaces are all factors supporting an exsolution origin for the myrmekite. The morphology of the quartz in the well-formed myrmekites is also significant in this context. The finely divided form of the quartz at the myrmekite-alkali feldspar interfaces represents a higher energy state than the coarser rods towards the primary plagioclase. This suggests that the source of quartz (as well as the plagioclase) is the exsolving alkali feldspar rather than the intergranular, since polyfurcation of the quartz from the coarse lower energy form to the fine sub-division at the growth front would be energetically prohibitive in a cooling system. The alternative possibility of arriving quartz permeating along the interface between the advancing myrmekite and the alkali feldspar is very unlikely, especially in cases such as that illustrated in Fig. 5 where the myrmekite-alkali feldspar interface is serrated, the fine quartz rods transgressing the interface.

Becke (1908) reported a sympathetic increase in quartz proportion in myrmekite with increase in anorthite in the plagioclase component and interpreted this finding on the basis of myrmekite development by replacement. An increase in quartz proportion with increasing plagioclase basicity would also be expected in exsolution myrmekite growth. In the equation, $\text{Ca}(\text{AlSi}_3\text{O}_8)_2 \rightarrow \text{CaAl}_2\text{Si}_2\text{O}_8 + 4\text{SiO}_2$, the volumes of the products are strongly dominated by the oxygen components and therefore approximately equal volumes of anorthite and quartz should be produced. Rough computations using micro-photograph enlargements showed approximate equality of proportion of anorthite to quartz (using the optically determined average anorthite values and assuming the densities of anorthite and albite to be essentially the same). It is proposed to study this question more thoroughly using more refined data and over a wide range of plagioclase compositions so that valid comparisons may be made with Becke's findings.

The role of the primary plagioclase of the rock in exsolution perthite growth would appear to be the essentially passive one of supplying a preferentially suitable foundation. The possibility of componential interdiffusion can not be discounted, however. The greater development and more regular morphology of myrmekite at alkali feldspar-plagioclase than alkali feldspar-alkali feldspar interfaces and the complete

absence of the intergrowth at interfaces of the perthitic alkali feldspar with non-feldspar minerals may be interpreted as reflecting the decreasing degree of suitability of growth foundation found by the exsolving phases at these interfacial types, *i.e.*, increasing lattice dissimilarity between the nucleating plagioclase and the available growth foundation.

The restriction of rod perthites to strained crystals, the complete absence of exsolution perthite types in their neighborhood and their ubiquitous connection with crystal interfaces where pre-existing myrmekite has been modified, with loss of the characteristic morphology of the exsolution myrmekites, are all petrographic features which may best be explained as resulting from reaggregation of the exsolution products from the original ternary alkalic feldspar crystallizations under the influence of late applied stress. The stress re-activated interfaces would present preferential loci for reaggregation resulting in intermingling of old and new myrmekite components or at newly developed interfaces (*i.e.*, fracture interfaces) development of new myrmekite-like feldspar quartz intergrowths.

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