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12. MYRMEKITE IN THE SANTA ROSA MYLONITE ZONE, PALM SPRINGS, CALIFORNIA

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Introduction

Myrmekite, containing tiny quartz vermicules, has been reported in the Santa Rosa mylonite zone (Fig. 1). Simpson (1984, 1985) and Simpson and Wintsch (1989) suggested that this myrmekite formed by Ca- and Na replacement of K-feldspar under strain-related conditions but only on the sides of K-feldspar megacrysts which are parallel to the S-surfaces and at right angles to the shortening (Z) direction of the strain. Other studies of the mylonite zone and orientations of minerals in the Santa Rosa mylonite zone have also been done by O'Brien *et al*. (1978), Erskine and Wenk (1985), and Theodore (1970).

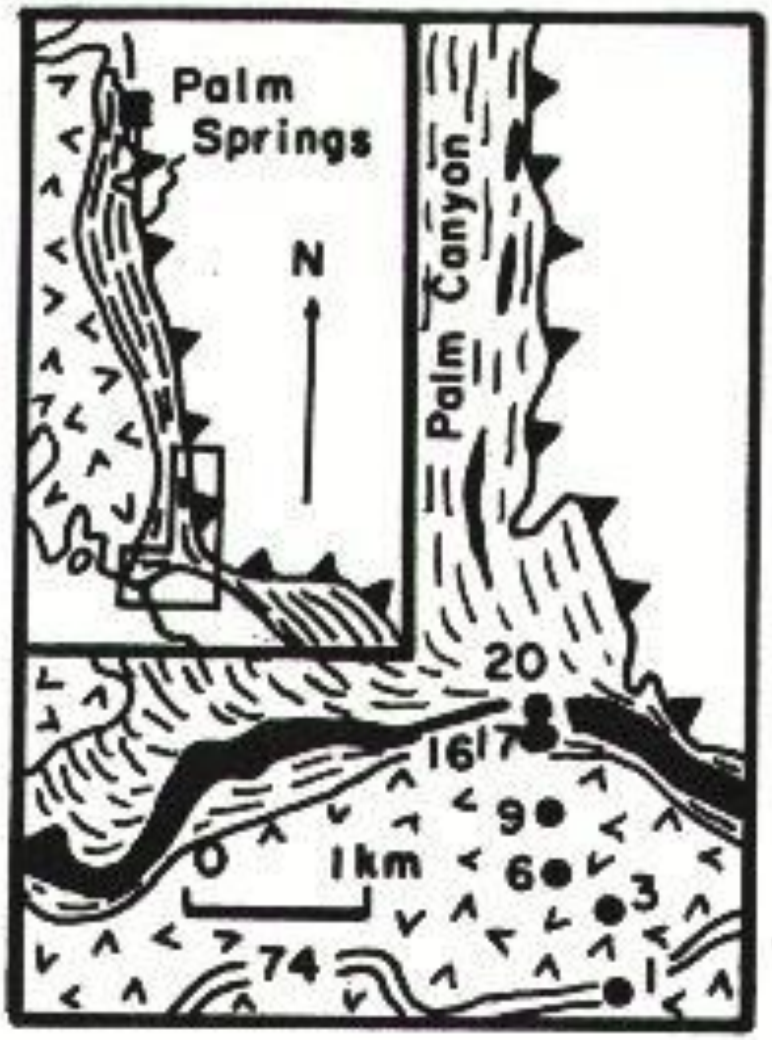

Fig. 1. Map of Santa Rosa mylonite zone south of Palm Springs, California, and north of Highway 74 (Pines to Palms Road). Symbols: v = biotite-hornblende diorite; parallel lines = mylonite zone; solid black = intense mylonite zone; solid triangles along line = west-directed thrust-fault plane. Numbers 1, 3, 6, 9, 16, 17, and 20 represent sites among 21 samples collected north of Highway 74 at various intervals on a continuous traverse at right angles to the strike of the foliation. A medium-grained biotite-hornblende diorite at site 1 lack deformation, but cataclasis begins at site 3 and increases in intensity to site 16 where abruptly the rocks become fine-grained and obviously mylonitic. The site studied by Simpson and Wintsch (1989) is south of Palm Springs, California, and can be found in the SE 1/4, NW 1/4, Section 14, of the Palm View Peak 7 1/2 Minute Quadrangle, California, west of the Indian Reservation Visitor Center. Map is modified after Simpson and Wintsch (1989).

The purpose of this study was to examine this myrmekite-bearing mylonite zone (Fig. 1) and associated rocks to see if myrmekite always occurred on the S-surfaces and whether first appearance of myrmekite could be found. Field and thin section studies show that the mapped mylonite zone near Palm Springs (Fig. 1) does *not* consist of rock which has been mylonitized throughout its total width but instead contains interlayers of undeformed rock, partly deformed rock, and mylonitized rock. The width of these layers ranges from one meter to several meters wide, and each layer extends parallel to the others. It is logical to investigate whether all layers, deformed and undeformed, represent the same rock type.

Forty-four samples of mylonite and associated rocks were collected in and near the Santa Rosa mylonite zone. Among these samples twenty-one were collected north of Highway 74 across a transition from a biotite-hornblende diorite to the mylonite zone (Fig. 1); three were collected from the diorite along highway 74; and twenty were from the same area where Simpson and Wintsch (1989) collected.

Petrography of the three types of layers, south of Palm Springs

1. *Undeformed layers*.

Layers that are undeformed consist of medium-grained (1-4 mm) felsic diorite containing either (1) biotite and plagioclase (An_{25-32}) or (2) biotite, hornblende, and plagioclase (An_{25-32}). The plagioclase is albite-twinned, and larger crystals are also Carlsbad-twinned; some crystals show normal zoning.

Neither type of undeformed felsic diorite contains K-feldspar or myrmekite.

2. *Slightly deformed layers.*

Where the felsic diorite layers are slightly deformed, K-feldspar is first seen in a non-uniform distribution in interiors of some deformed plagioclase to form antiperthite (Fig. 2).

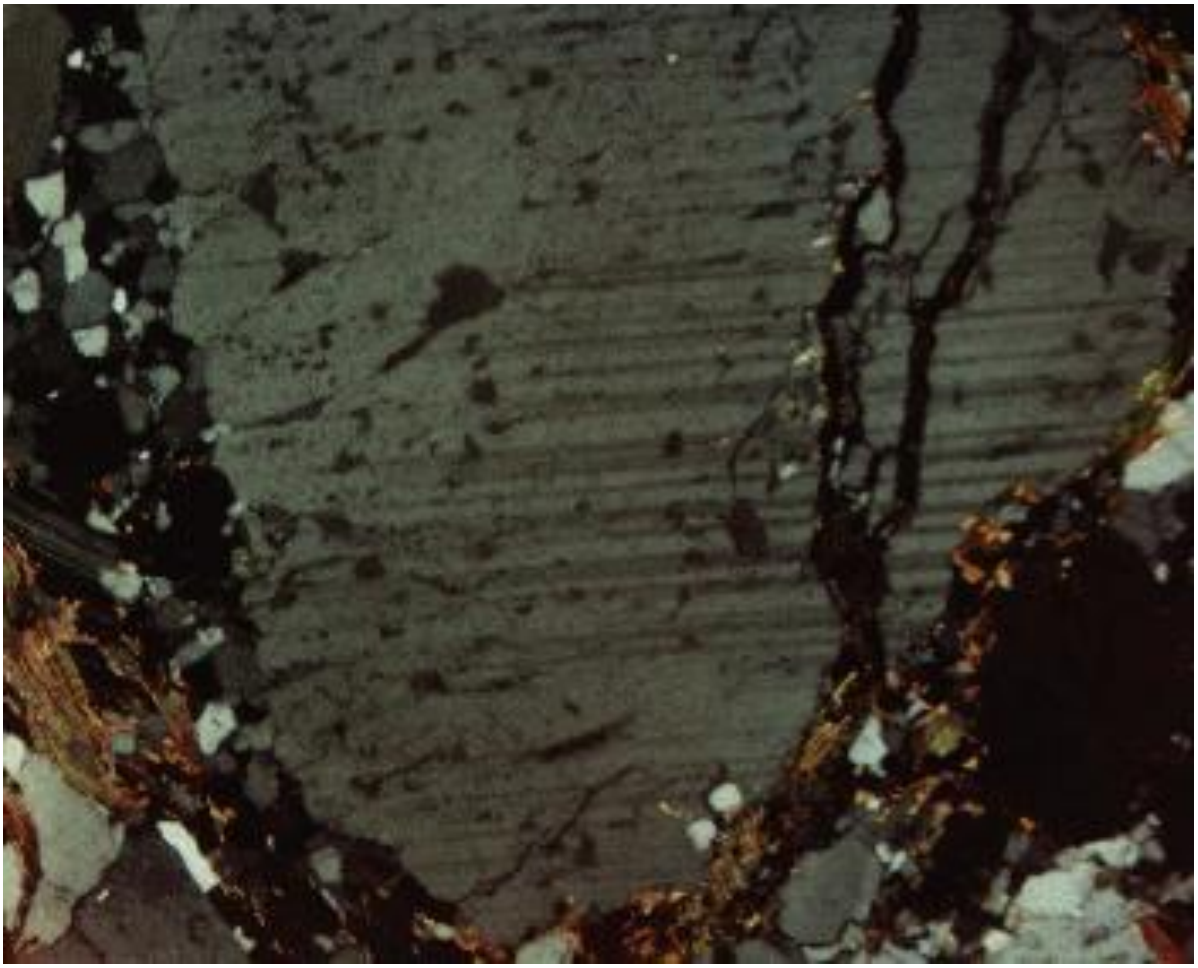

Fig. 2. Plagioclase (light gray) with irregular islands of K-feldspar (dark gray) to form antiperthite.

In these same slightly-deformed felsic diorite layers, myrmekite is first observed in areas showing greater deformation than where antiperthite forms. This myrmekite *has the same-sized quartz vermicules as occur in the more-strongly deformed adjacent mylonite*, described by Simpson and Wintsch (1989). The first appearance of myrmekite, however, is (1) between two K-feldspar crystals, (2) between K-feldspar and an exterior plagioclase crystal (Fig. 3), and (3) between K-feldspar and a plagioclase crystal (Fig. 4) or plagioclase island (inclusion) in the K-feldspar (Fig. 5). In the latter two cases where remnants of plagioclase are present in K-feldspar, they may be in optical continuity with the immediate adjacent larger plagioclase crystal. In all places the myrmekite has different relationships with adjacent minerals from that found in the strongly deformed mylonite.

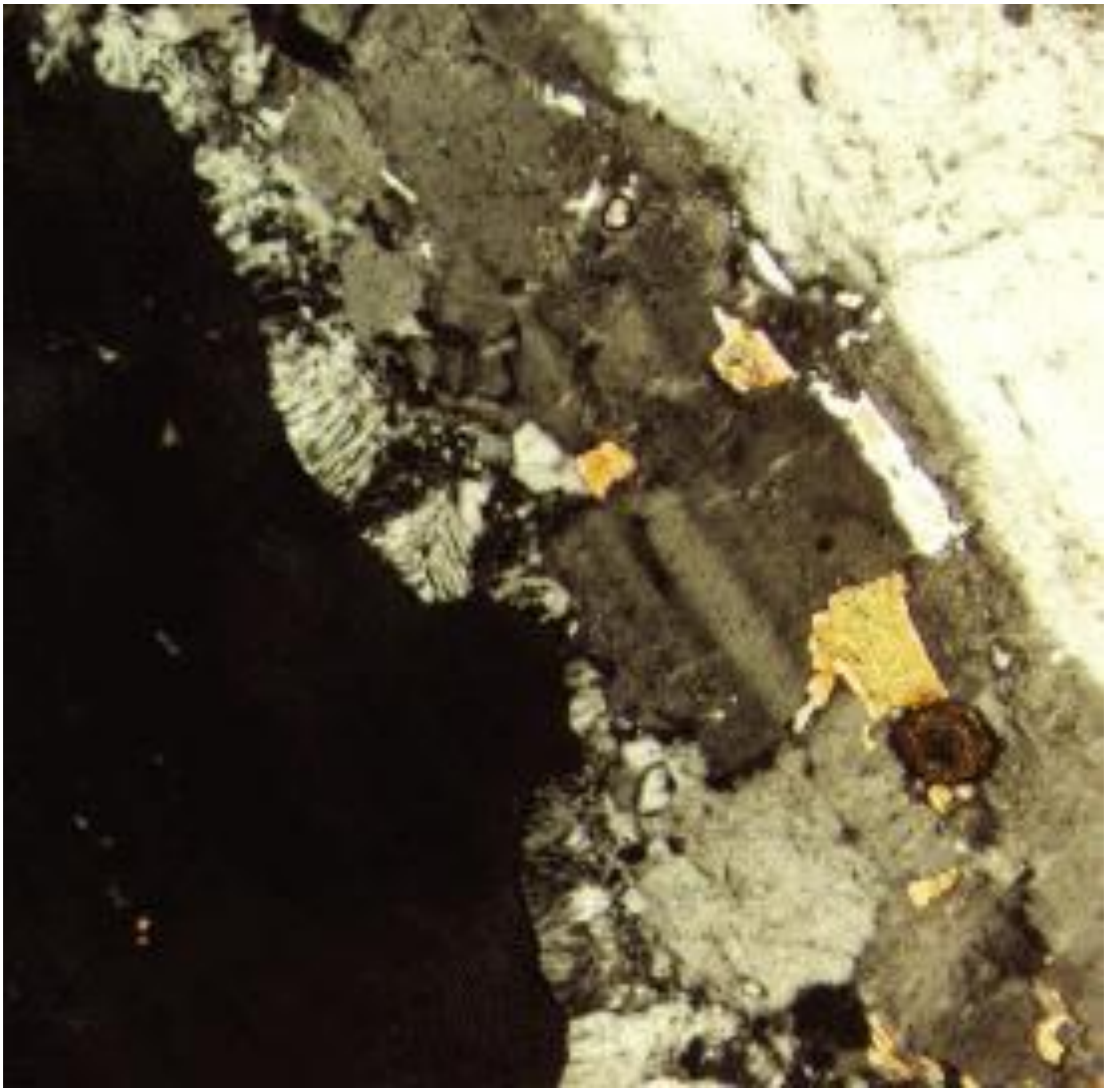

Fig. 3. Myrmekite occurring between a K-feldspar crystal (black) and a Carlsbad-twinned plagioclase crystal (white and light gray). Inclusions of quartz (white), biotite (tan), and allanite (round brown grain) occur in the plagioclase. Rock has not been mylonitized, so plagioclase, quartz, biotite, and allanite have not been granulated.

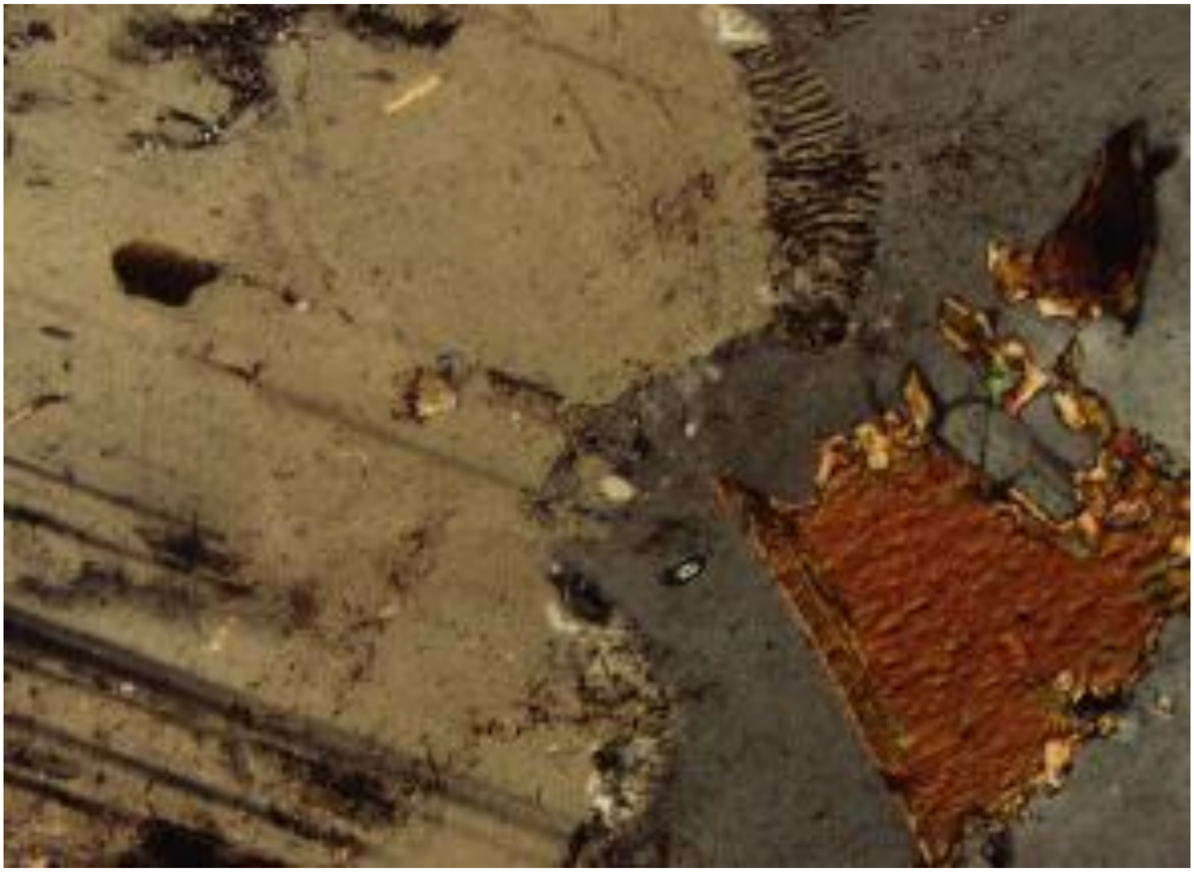

Fig. 4. Myrmekite on the borders of an enclosed plagioclase crystal (light tan) adjacent to a K-feldspar crystal (gray). Biotite (brown) occurs as an inclusion in the K-feldspar. Rock has not been mylonitized.

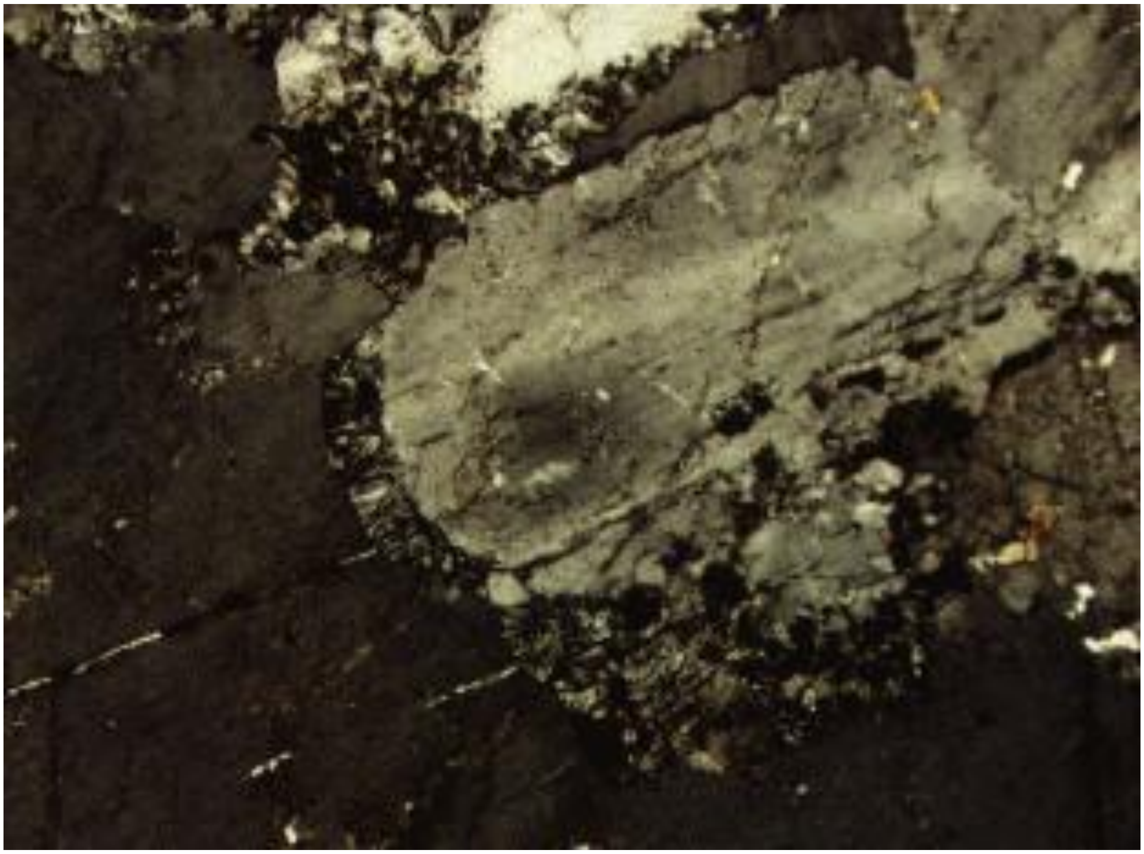

Fig. 5. Myrmekite on the borders of an enclosed plagioclase crystal (light gray) inside a K-feldspar crystal (dark gray). Rock has not been mylonitized.

Also present in the slightly deformed felsic diorite are quartz blebs or stringers in biotite (symplectites) bordering quartz-free biotite. The symplectites and quartz-free biotite are, in some places, partly enclosed by adjacent K-feldspar, and the biotite of the symplectites is optically continuous with the nearby tiny biotite inclusions containing quartz blebs in the K-feldspar.

3. *Mylonitic layers*.

Felsic diorite layers that are strongly deformed as mylonite have nearly the same mineralogy as the undeformed and slightly deformed adjacent layers except that the grain size is smaller, feldspars and quartz are more abundant, and the ferromagnesian silicates, less abundant. Many grains are oriented in stringers or ribbons bounding larger K-feldspar and plagioclase augen (1 mm long). Some mylonite layers contain broken remnants of hornblende and biotite; others contain only biotite. Most large K-feldspar crystals (1 mm long) occur oriented parallel to strain (S) directions, but a few are found in the shear (C) directions (Simpson and Wintsch, 1989).

Simpson and Wintsch (1989) show photomicrographs and schematic sketches of myrmekitic intergrowths of plagioclase (An_{28}) and quartz on two sides of K-feldspar augen which "parallel the S-surfaces and face the incremental shortening direction." These investigators also reported the following: (1) "...myrmekite also occurs along some augen margins that are adjacent to C surfaces, at about 45 degrees to the incremental shortening direction." (2) "...myrmekite has never been found on the ends of the augen that face the incremental stretching direction. In these 'tail' regions there are subgrains and equigranular recrystallized K-feldspar grains..." (3) Some myrmekite grains are comma-shaped and "...give a deflection sense consistent with the sense of shear across the sample..." But these comma-shaped myrmekite grains are rare. (4) Myrmekite occurs along C- and S-surfaces where K-feldspar porphyroclasts are absent, particularly where small K-feldspar grains are interspersed. (5) Myrmekite may also occur along edges of larger K-feldspar tails of augen. (6) Oligoclase porphyroclasts that occur between ribbons of quartz contain irregular zones filled with K-feldspar. And (7), small K-feldspar grains at the sides of these porphyroclasts are interpreted to be recrystallized K-feldspar that has grown in low-pressure regions.

Discussion

The interpretations of Simpson (1984, 1985) and Simpson and Wintsch (1989) are based on the assumption (1) that the K-feldspar megacrysts are primary components of the original rock prior to deformation and (2) that strain on the K-feldspar allows some K to be displaced and perhaps lost from the system as Ca- and Na-bearing fluids replace borders of the K-feldspar to produce myrmekite with tiny quartz vermicules (Fig. 6 and Fig. 7).

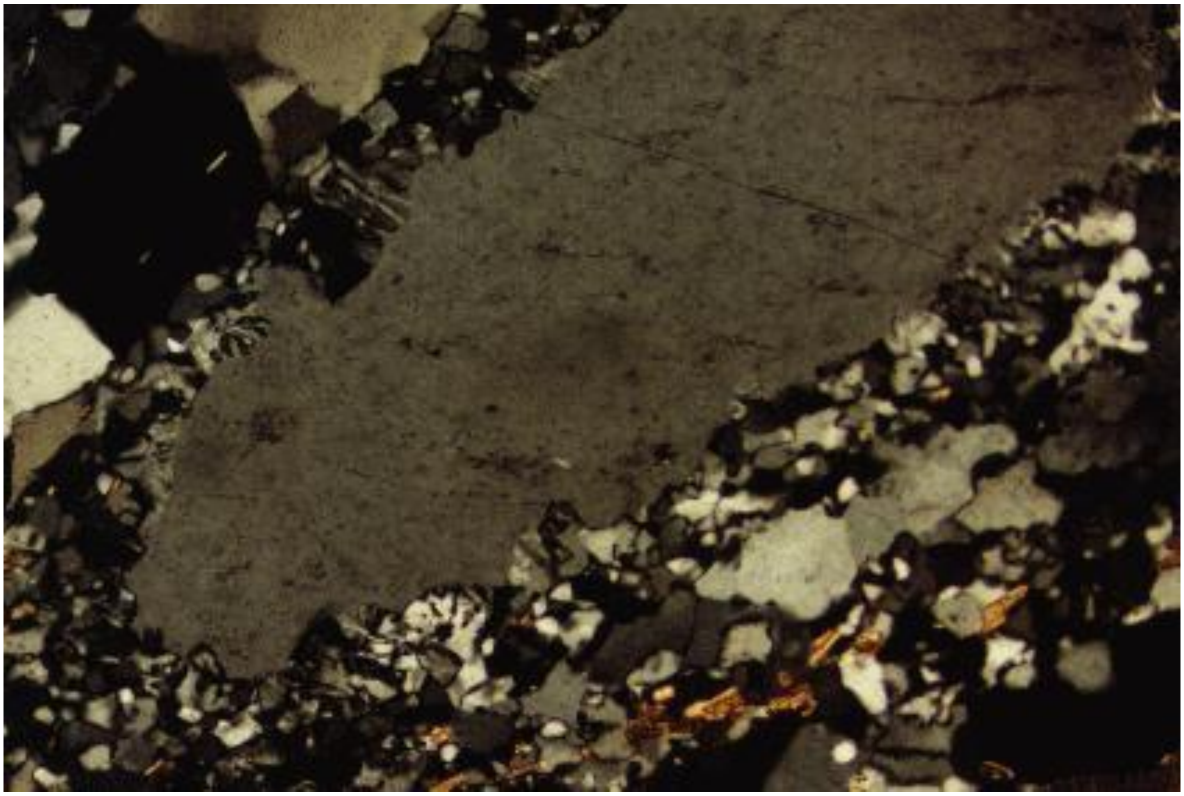

Fig. 6. K-feldspar megacryst (light gray) bordered by myrmekite with tiny quartz vermicules and enclosed in a granulated ground mass of quartz, plagioclase, and biotite.

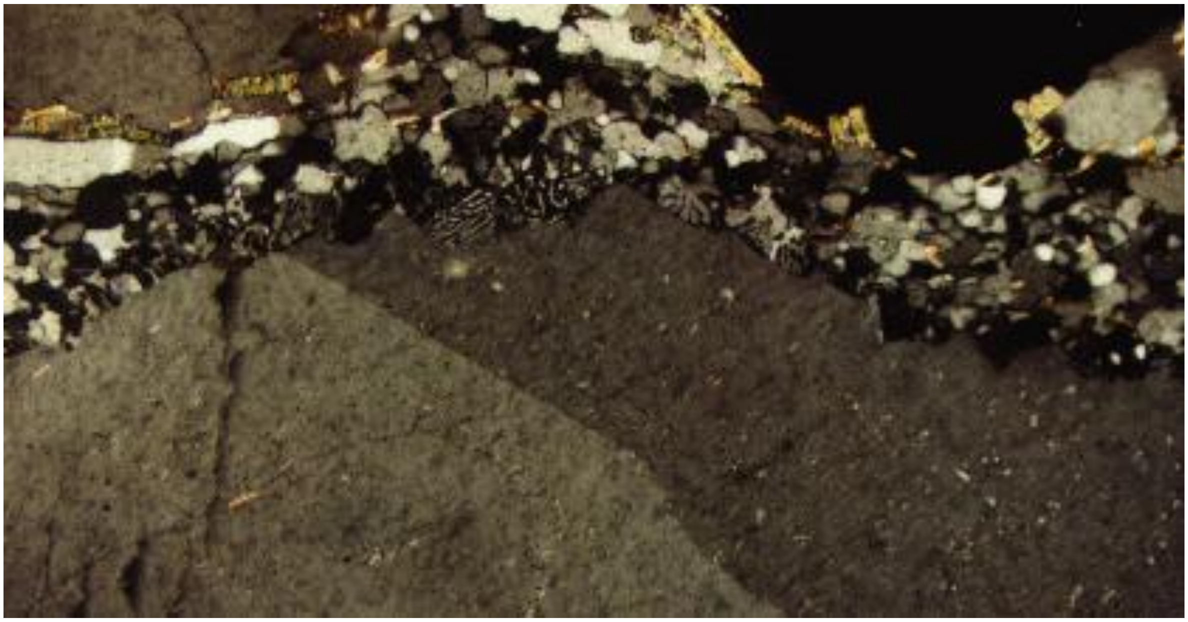

Fig. 7. Carlsbad-twinned K-feldspar megacryst (light gray) bordered by myrmekite with tiny quartz vermicules and enclosed in a granulated ground mass of quartz, plagioclase, and biotite.

Studies of the adjacent undeformed and slightly deformed rocks, however, show that *the original rock had no K-feldspar*, thus calling into question the assumption that the K-feldspar is primary. Furthermore, the first appearance of K-feldspar is *not* as isolated, independent, primary crystals, but in the form of antiperthite inside some but not all plagioclase grains (Fig. 2). Myrmekite does *not* appear until the K-feldspar occurs as larger crystals, and, therefore, myrmekite must somehow be correlated with the appearance of K-feldspar rather than its removal. Where myrmekite first occurs the coexisting K-feldspar is *not* aligned parallel to any strain direction nor is the myrmekite on the sides of K-feldspar crystals facing a shortening direction. Instead, the *myrmekite occurs between K-feldspar and plagioclase* (Fig. 3, Fig. 4, and Fig. 5) *or between two K-feldspar crystals*. Furthermore, tiny islands of plagioclase and biotite in the K-feldspar, which are optically continuous with adjacent larger grains of plagioclase and biotite, are unusual if the K-feldspar is primary. A significant fact is *that myrmekite formation precedes the mylonitization and is not facilitated by strain of the K-feldspar lattices on the sides of the K-feldspar crystals parallel to strain directions*.

The primary differences between the slightly deformed rocks and those that are mylonitized are (1) the granulation and reduction in grain size of the slightly deformed rocks and (2) the destruction of the textural relationships between myrmekite and coexisting plagioclase and K-feldspar. Because plagioclase crystals are being stressed and altered in the slightly deformed rocks to permit introduction of K, they are relatively weakened and more easily sheared than K-feldspar which is replacing some of these plagioclase crystals and recrystallizing to form relatively strong K-feldspar crystals. For that reason, remnant, less-broken K-feldspar tends to remain as augen in the mylonitic rocks, whereas former plagioclase crystals (with myrmekite borders against the K-feldspar) tend to break and become fragmental parallel to the strain directions, leaving most of the myrmekite behind, attached to the K-feldspar. The stretching of broken grains in the strain direction would create ribbons of tiny plagioclase grains mixed with fragmental, myrmekite, quartz, and biotite grains.

The absence of myrmekite at the ends of K-feldspar crystals in the direction of lengthening, reported by Simpson and Wintsch (1989) is logically explained because in these relatively-low pressure sites, the Ca and Na in the plagioclase can be completely displaced from the original plagioclase by the introduction of K to form K-feldspar. In these places, Ca and Na can readily move in fluids that escape the system, and, therefore, no myrmekite is formed.

The plagioclase porphyroclasts containing irregular islands of K-feldspar in the mylonitized layers (Simpson and Wintsch, 1989) is logically explained as places where interiors of altered plagioclase crystals were partly replaced by K-feldspar, as occurs in the less-deformed layers where antiperthite forms adjacent to the mylonitic layers. The tiny grains of K-feldspar that border the plagioclase porphyroclasts need *not* be formed by recrystallization of transported K that is displaced by Ca- and Na-metasomatism of supposed primary K-feldspar crystals but are merely broken granules of K-feldspar which have resulted from the granulation of former K-feldspar that replaced the plagioclase.

Remnant deformed hornblende crystals in some of the strongly mylonitized layers whose appearances are the same as hornblende crystals in adjacent undeformed layers give support to the hypothesis that those layers now containing K-feldspar were derived from layers that formerly did *not* contain K-feldspar.

Unreported by Simpson and Wintsch (1989) is the occurrence of faint remnants of myrmekite (ghost myrmekite, quartz-bleb clusters) in veins (Fig. 8) or as isolated patches inside some K-feldspar crystals in the mylonite felsic diorite. This ghost myrmekite further supports the hypothesis that Ca and Na cannot be the replacing agents of K-feldspar because the K-feldspar encloses these different kinds of remnant myrmekite.

As further evidence for the origin of myrmekite by incomplete K-feldspar replacement of deformed plagioclase crystals, a similar transition between undeformed, slightly deformed, and strongly deformed mylonite occurs in biotite-hornblende diorite in the area north of Highway 74 (Fig. 1). Here, former diorite lacking K-feldspar and myrmekite becomes progressively deformed northward toward the Santa Rosa mylonite zone. The first appearance of K-feldspar and myrmekite occurs where the diorite shows the first field evidence of deformation (Fig. 1a, site 3). The only difference between this area and that near Palms Springs is that the myrmekite in deformed rocks near Highway 74 contains coarser quartz vermicules than in the myrmekite in mylonitic rocks near Palm Springs. The greater thickness of quartz vermicules in the myrmekite near Highway 74 corresponds with the higher Ca-content of the primary plagioclase (An_{30-40}) in diorite in this area.

If myrmekite were formed by Ca- and Na-metasomatism of K-feldspar, one might also expect to find myrmekite in the low-grade mylonite zones in the Borrego Springs area (southwest of the Santa Rosa mylonites), but myrmekite is absent here (Simpson, 1985). The absence of myrmekite in the Borrego Springs mylonitic rocks can be explained by the K-feldspar replacement model because the original plagioclase in this area is so sodic (less than An_{20}), that during K-feldspar replacement of deformed plagioclase crystals, so much Na is displaced by the K that this Na moves into and recrystallizes other deformed plagioclase crystals as albite. In that process the Na consumes all residual Si so that no Si is left over to form tiny quartz vermicules that would occur in myrmekite.

K-metasomatism as an alternative model for the origin of myrmekite

On the basis of the aforesaid reasoning, an alternative model in which K-feldspar progressively but locally incompletely replaces plagioclase to form myrmekite is suggested. For further descriptions of this mechanism, see:
http://www.csun.edu/~vcgeo005/Nr1Myrm.pdf;
http://www.csun.edu/~vcgeo005/Nr2Myrm.pdf;
http://www.csun.edu/~vcgeo005/Nr3Myrm.pdf.

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