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20. FAILURE OF THE EXSOLUTION SILICA-PUMP MODEL FOR THE ORIGIN OF MYRMEKITE: EXAMINATION OF K-FELDSPAR CRYSTALS IN THE SHARPNERS POND TONALITE, MASSACHUSETTS, USA

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Introduction

Evidence from studies of K-feldspar and myrmekite in the same terrane as that examined by Castle and Lindsley (1993) shows that when these investigators formulated their "exsolution silica-pump model" for the origin of myrmekite, an inadequate analysis was made of the feldspars in transitions to adjacent non-myrmekite-bearing rocks. In their proposed model the myrmekite originates "in response to kinetic effects associated with the exsolution of calcic alkalic feldspar into discrete potassium feldspar and plagioclase phases." This hypothesis was an "outgrowth of the speculations of Tuttle (1952) and Tuttle and Bowen (1958) intended to explain many 'subsolvus' granites." Castle and Lindsley suggested that the diffusion rates of tetrahedral Al and Si through an exsolving ternary feldspar in the presence of excess silica result in quartz concentrating as vermicules in myrmekite where Ca and Al are coupled in plagioclase. Therefore, the "exsolution silica-pump model" depends upon the prior existence of a K-rich, high-temperature, alkali feldspar whose composition is "close to the crest of the solvus, where the potential for subsolvus exsolution is high." Such a composition would produce nearly equal percentages of K-feldspar and plagioclase.

As an example of myrmekite created by the "exsolution silica-pump" method, Castle and Lindsley (1993) showed a photomicrograph of wartlike myrmekite projecting into microcline in a granodiorite sub-facies of the Middle-Paleozoic Sharpners Pond biotite tonalite in northeastern Massachusetts near Middleton, 20 miles (32 km) north of Boston (Castle, 1965; Harrison et al., 1983). If the myrmekite in this granodiorite were to meet the requirements of the "exsolution silica-pump" model, then the myrmekite must only coexist with nearly equal amounts of K-feldspar and plagioclase in the granodiorite and not where the K-feldspar occurs in trace amounts in transitions to the adjacent biotite tonalite. In addition, both the K-feldspar and the plagioclase must have relatively-uniform, unzoned compositions that are characteristic of feldspars formed by exsolution. Examinations of the rocks in the Sharpners Pond terrane (Fig. 1) show that these conditions, which would be required for the Castle and Lindsley model to be valid, are not met and that the myrmekite cannot have formed by the "exsolution silica-pump" method.

Fig. 1. Geologic map of the Sharpners Pond tonalite, containing a biotite facies (sbt, orange), a biotite-hornblende facies (sbh, light-green), and a hornblende facies (sd, dark-green). An un-named adamellite-granodiorite (ysa, blue) and the Newburyport quartz diorite (nqd, pinkish-red) are also shown. Modified after Fig. 7.7 of Harrison et al. (1983).

Petrography and field relationships

Outcrops of the massive biotite tonalite facies of the Sharpners Pond tonalite are well exposed on the north shore of Middleton Pond (Fig. 2, site A). The tonalite here is foliated, medium-grained, and variable in color: light-gray to dark-gray to black. Outcrops of the granodiorite sub-facies of the biotite tonalite occur west of Wills Hill on Lake Road (Fig. 2, site B). The granodiorite here occurs in deformed biotite tonalite.

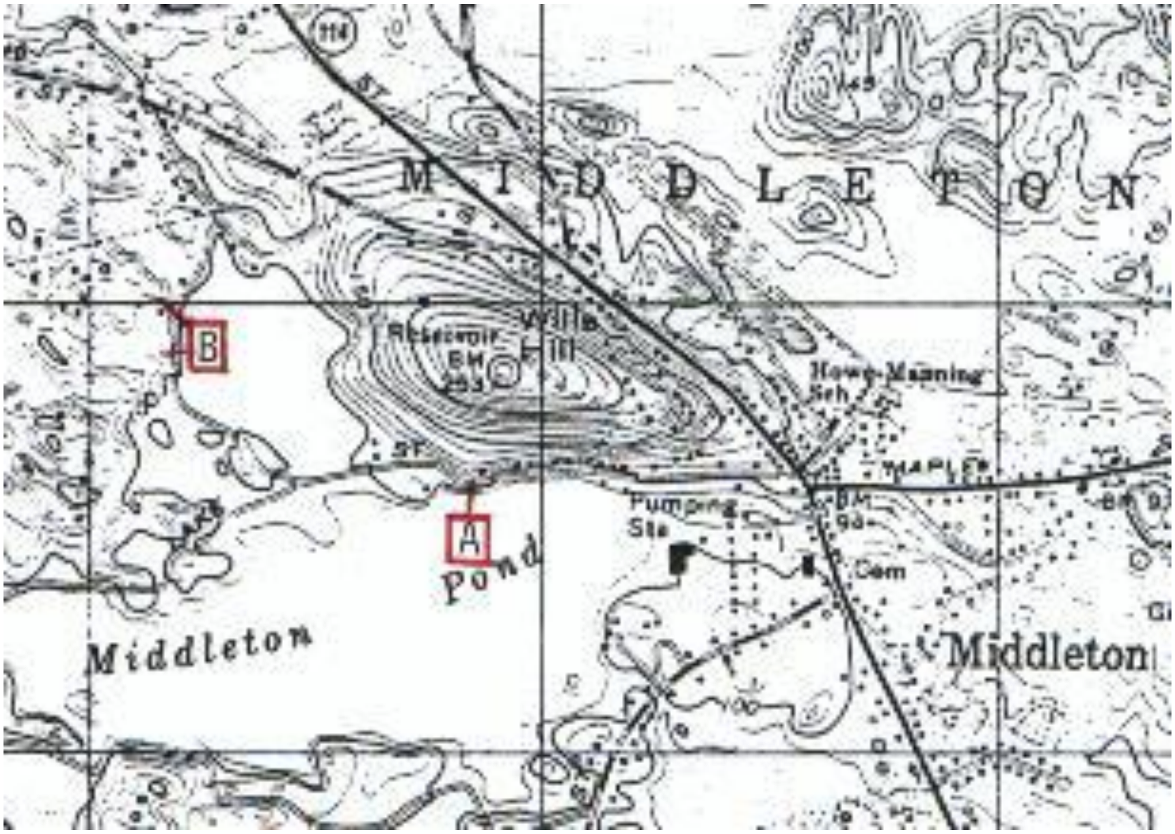

Fig. 2. Portion of the Reading, Massachusetts, 7.5 Minute Quadrangle Map near Middleton, Massachusetts. Site A locates outcrops of massive, foliated, Sharpners Pond biotite tonalite (Fig. 1), and site B, outcrops of the granodiorite sub-facies. Grid pattern equals one square kilometer.

Microscopic studies of the Sharpners Pond biotite tonalite show that it commonly contains biotite (5-20 vol. %), hornblende 0-5 vol. %), zoned plagioclase (28-60 vol. %), and quartz (26-31 vol. %) with trace amounts of sphene, magnetite, allanite, apatite, and K-feldspar. Epidote, muscovite, and chlorite are common alteration products. In the granodiorite sub-facies of the Sharpners Pond biotite tonalite, the same mineralogy is present except that (1) biotite and plagioclase percentages are less, (2) hornblende disappears, and (3) percentages of quartz (31-40 vol. %) and K-feldspar (5-33 vol. %) increase relative to that in the tonalite.

Myrmekite and two kinds of K-feldspar

The K-feldspar in the biotite tonalite differs from that in the granodiorite sub-facies. In the tonalite the K-feldspar is interstitial, non-perthitic, and non-myrmekite-bearing; generally composes less than 2 vol. % of the rock; and has sharp contacts with adjacent quartz, biotite, and plagioclase crystals and with inclusions of these same minerals (Fig. 3).

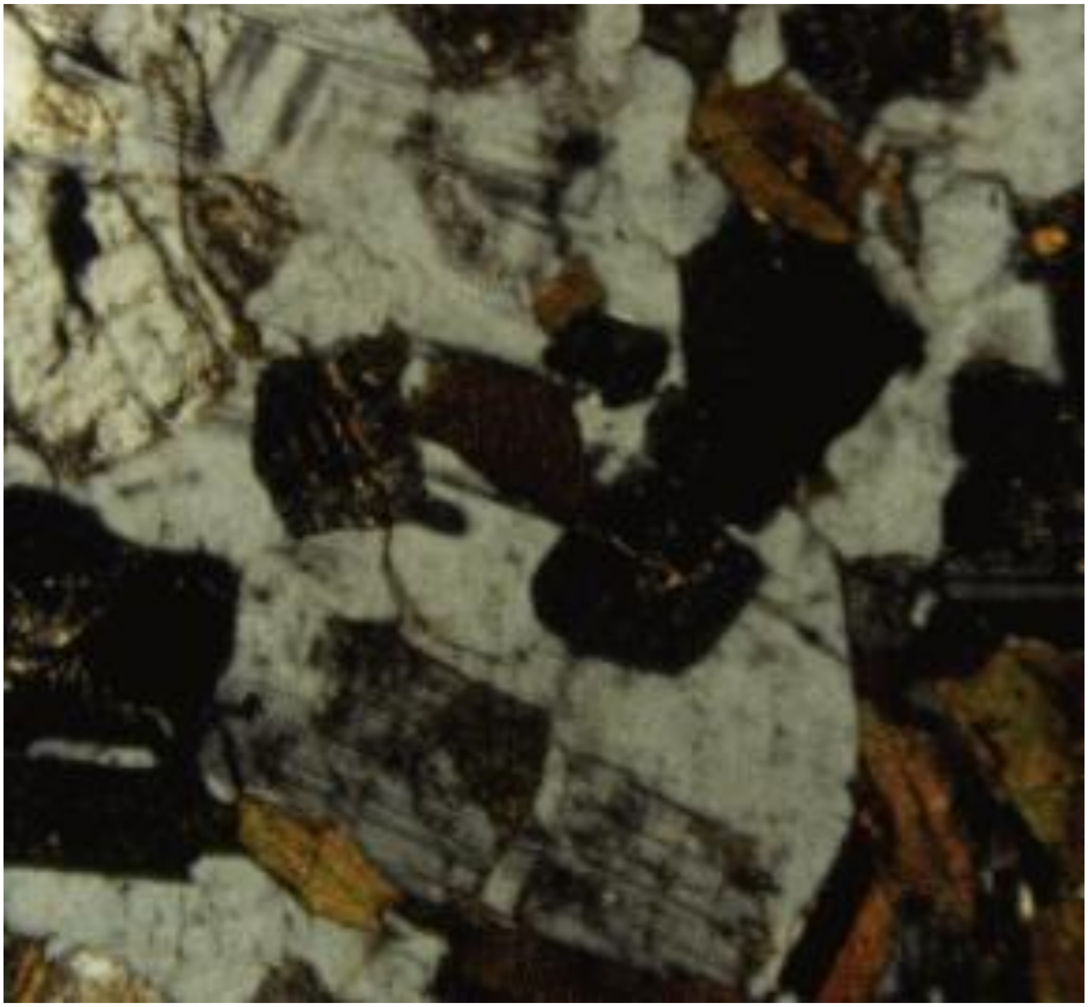

Fig. 3. Photomicrograph showing interstitial primary K-feldspar (light gray) with sharp contacts against oblong inclusions of quartz, biotite, and plagioclase (dark crystals). The inclusions lack parallel optic orientation with each other. The K-feldspar composes less than 1 vol. % of the biotite tonalite in this sample.

In contrast, in the granodiorite and in the transition to the granodiorite some K-feldspar crystals are interstitial and interpreted to be formed originally in the biotite tonalite, but other K-feldspar crystals exist as (a) tiny islands in the interiors of deformed plagioclase crystals (Fig. 4 and Fig. 5) or (b) occur as larger crystals that (1) are perthitic, containing tiny plagioclase lamellae that are sparse and irregularly distributed, (2) enclose tiny, irregular inclusions of plagioclase which are optically parallel, either to each other and/or to a larger plagioclase crystal adjacent to the K-feldspar, (3) penetrate adjacent broken plagioclase crystals (Fig. 6 and Fig.7), and (4) coexist with bordering wartlike myrmekite (Fig. 8).

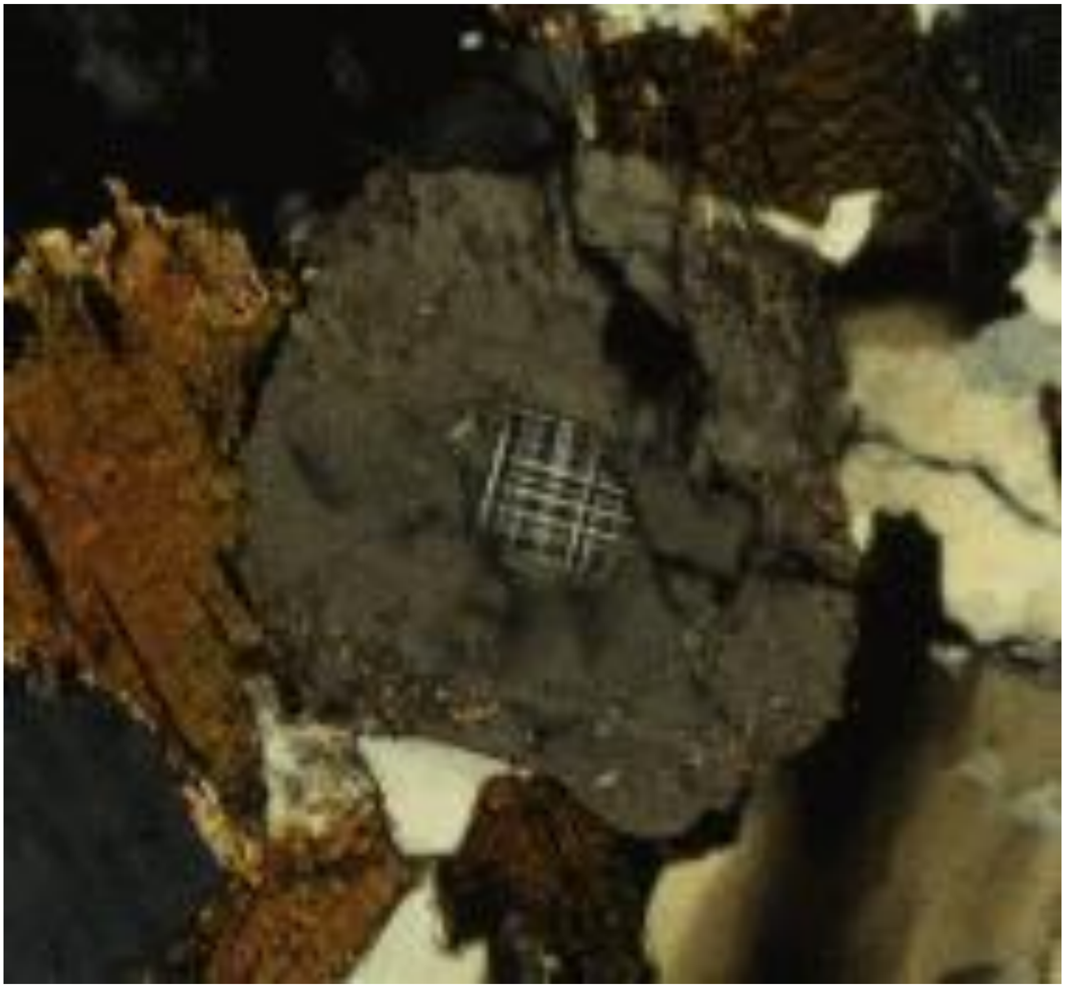

Fig. 4. Photomicrograph showing K-feldspar (cross-hatch pattern) in the core of a plagioclase crystal (tan) in granodiorite. Quartz (wavy extinction, cream), biotite (brown). Sample is from a transition zone between tonalite and granodiorite.

Fig. 5. Photomicrograph of K-feldspar (cross-hatch pattern, rectangular) in interior of plagioclase in granodiorite. Biotite (brown); quartz (white, cream, mottled extinction). Sample is from a transition zone between tonalite and granodiorite.

Fig. 6. Photomicrograph of K-feldspar (shades of gray, cross-hatch pattern, upper right) penetrating and replacing the rim of a zoned and altered plagioclase crystal along irregular fractures. A ragged biotite crystal (dark brown) occurs in the plagioclase. Sample is from granodiorite.

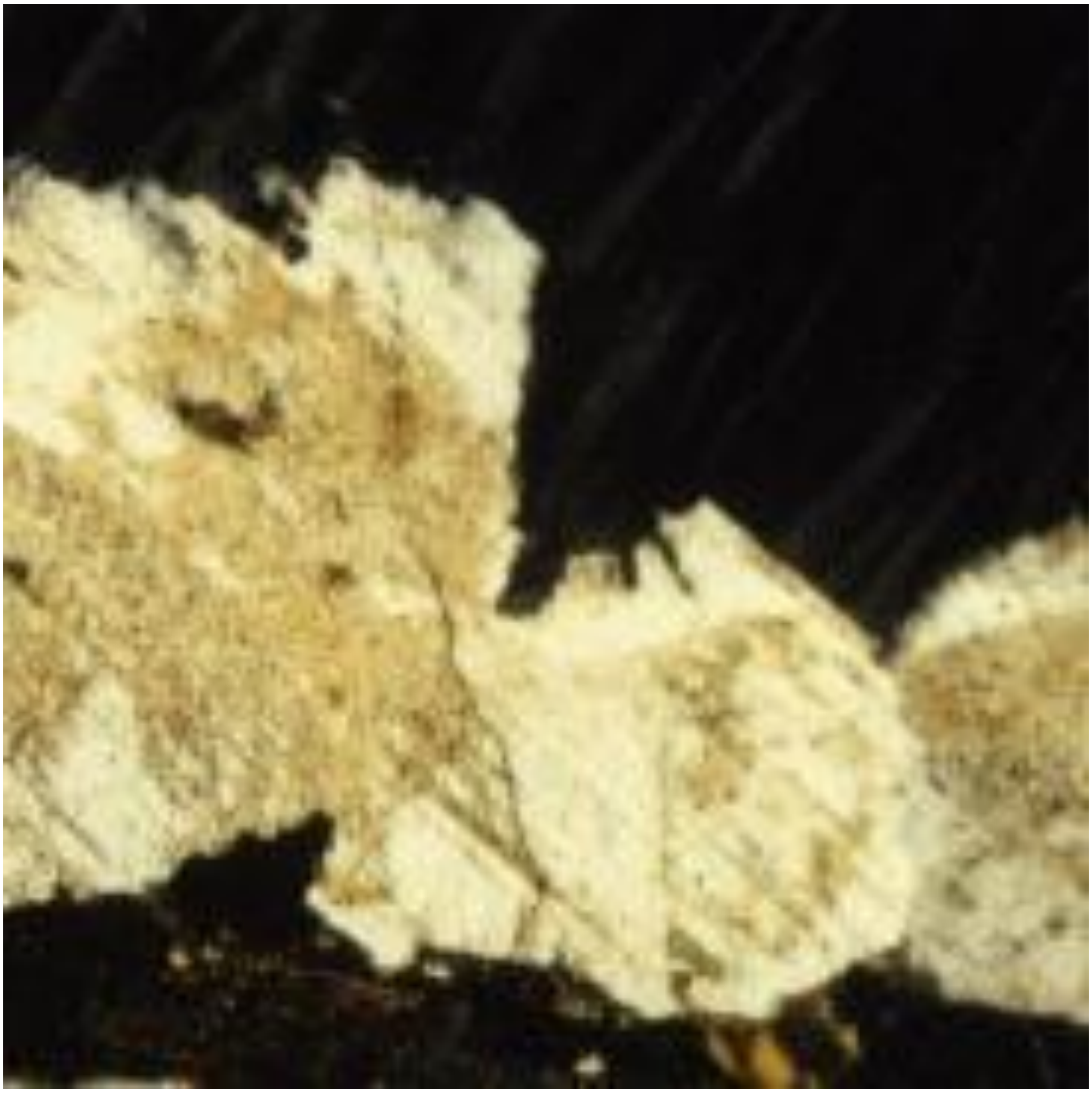

Fig. 7. Photomicrograph of K-feldspar (black and gray, top) in granodiorite containing inclusions of plagioclase islands which are in optical continuity with a larger plagioclase crystal (cream, tan) outside the K-feldspar. The K-feldspar embays and penetrates remnants of the plagioclase. Sample is from granodiorite.

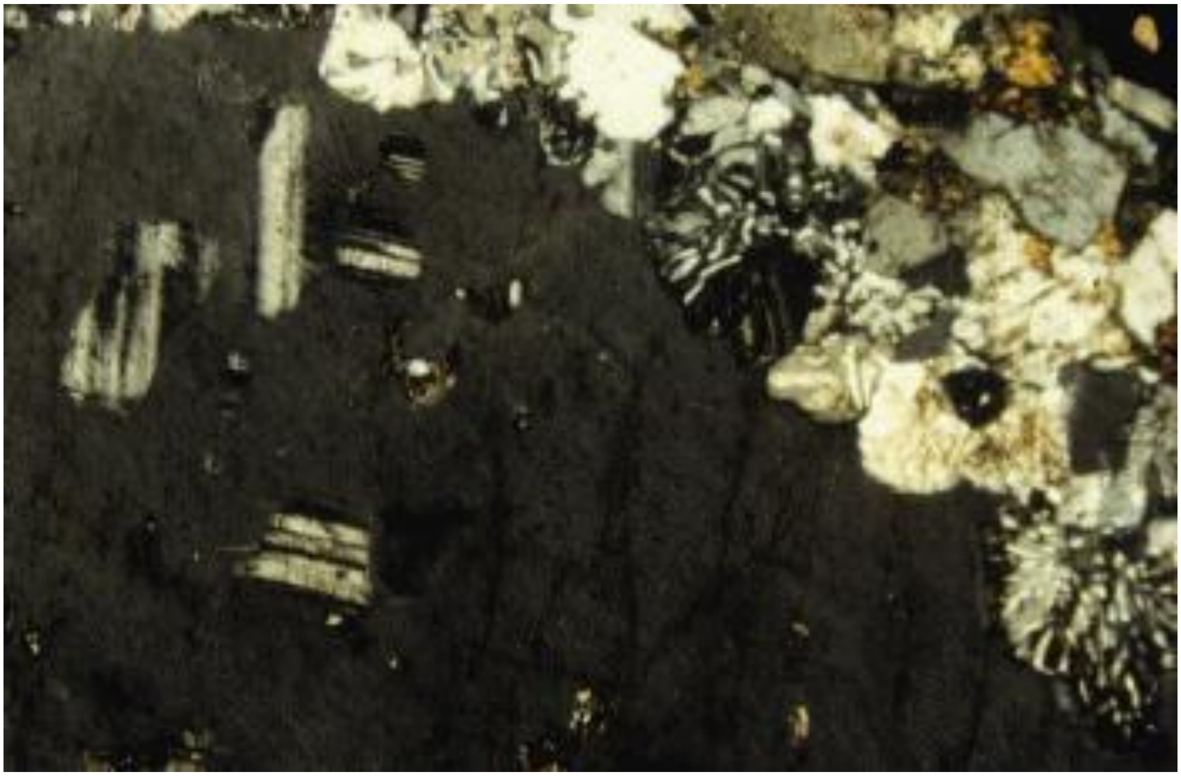

Fig. 8. Photomicrograph of aggregate myrmekite grains with tiny quartz vermicules (lower left) bordering K-feldspar (gray, upper right) in the granodiorite sub-facies of the Sharpners Pond biotite tonalite. Remnants of larger albite-twinned plagioclase crystals occur as inclusions in the K-feldspar and have optical continuity with each other.

Significantly, the K-feldspar crystals are undeformed, where the adjacent plagioclase crystals in the granodiorite are commonly deformed, containing bent albite-twin lamellae. In some places one-half of a deformed Carlsbad-twinned plagioclase crystal may be partly replaced in the interior by K-feldspar but not in the other half. In the transition between biotite tonalite and the granodiorite, K-feldspar progressively appears in the interiors of deformed plagioclase crystals in the tonalite and then increases gradually in abundance until some plagioclase crystals are completely replaced, thus changing the tonalite composition into granodiorite. Equally significant is the fact that *myrmekite appears in the transition in the earliest stages of introduction of secondary K-feldspar where the proportions of K-feldspar to plagioclase would plot far from the crest of the solvus*. A third significant fact is that in the granodiorite many of the plagioclase crystals are normally zoned and have the same appearance as that found in the biotite tonalite, and *zoned plagioclase crystals would be uncharacteristic of plagioclase formed by exsolution below the solvus* (Fig. 9).

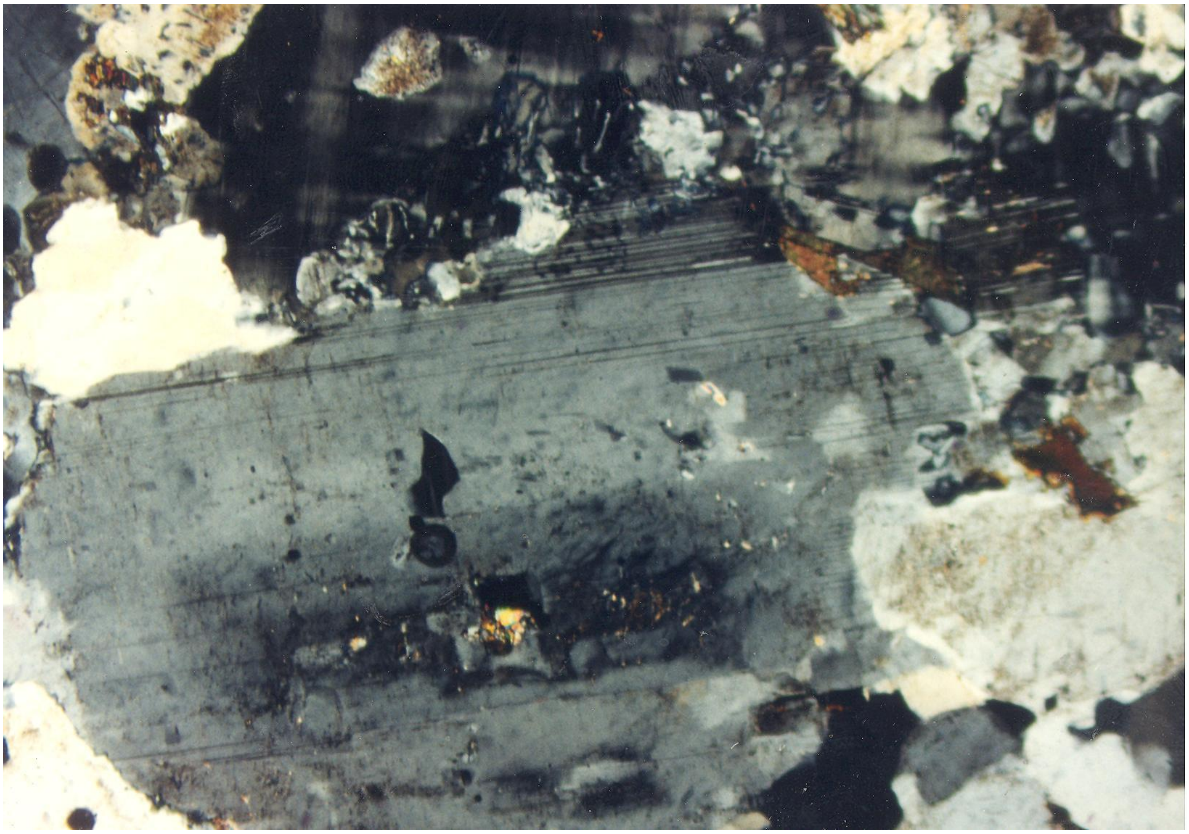

Fig. 9. Photomicrograph of myrmekite projecting into K-feldspar (black, top) and optically continuous with zoned non-quartz-bearing plagioclase (shades of gray, bottom) in granodiorite associated with the Marlboro plagioclase amphibolite.

Discussion

Transitions from undeformed biotite tonalite (containing zero to trace amounts of interstitial primary K-feldspar) through a zone of deformation into granodiorite, which contain remnants of fractured and deformed plagioclase crystals of the tonalite, show that there would have been no primary, high-temperature, calcic alkalic feldspar of sufficient volume (0 to 2 vol. %) in the original tonalite from which myrmekite and abundant K-feldspar (5 to 33 vol. %) could form in the manner proposed in the exsolution silica-pump model (Castle and Lindsley, 1993). The replacement of deformed plagioclase crystals in the biotite tonalite by K-feldspar support the hypothesis that the myrmekite forms in deformed rocks where incomplete interior replacement of plagioclase by secondary K-feldspar occurs (see presentations 1, 2, and 3 in this web site). The K needed to form this secondary K-feldspar is readily available from coexisting, deformed, abundant biotite that is replaced by quartz.

The exsolution silica-pump model is further shown to be spurious on the basis (1) that in many other terranes to which this model would be expected to be applied, the volumes of myrmekite locally exceed the volumes of adjacent alkalic feldspar, and, therefore, exsolution would be illogical; and (2) the plagioclase in the myrmekite is too calcic for the myrmekite to have formed by exsolution from the available volume of K-feldspar (see presentation number 13 in this web site). That is, experimentally, it has been shown that high-temperature K-feldspar can contain no more than 16 wt. % dissolved Ca (Carmen and Tuttle, 1964), and much greater amounts would be necessary to account for the Ca in the myrmekite in many terranes. The only aspect of the exsolution silica-pump model that is plausible is the fact that the myrmekite is produced where residual Ca, which locally was not displaced totally by K, is coupled with Al in the plagioclase. The greater diffusion of tetrahedral Al relative to residual Si in the altered plagioclase during replacement results in excess silica that is recrystallized in quartz vermicules.

Conclusion

The Sharpners Pond terrane is significant because it contains two kinds of K-feldspar crystals: (1) an early, interstitial, high-temperature, magmatic species generally lacking plagioclase lamellae and (2) a later, engulfing, lower-temperature, metasomatic, perthitic species, which contains sparse, tiny, plagioclase lamellae of irregular and unequal distribution. The magmatic K-feldspar was formed late in the crystallization of the biotite tonalite and filled interstices between the earlier-formed biotite and plagioclase crystals. In these places the sharp boundaries between the K-feldspar, plagioclase, and biotite and the lack of myrmekite fit the criteria for direct crystallization of the K-feldspar from a melt (see presentation 19 in this web site). The metasomatic K-feldspar is bordered by wartlike myrmekite and occurs in sheared rock, commonly first appearing in the interiors of broken or deformed plagioclase crystals or penetrating plagioclase crystals along fractures. This secondary K-feldspar then increases in abundance through a transition zone to change the tonalite composition into granodiorite. In hand specimen the primary magmatic K-feldspar is white and indistinguishable from plagioclase in the black tonalite, whereas the secondary metasomatic K-feldspar stands out as pink crystals against the black biotite and white plagioclase and quartz of the granodiorite.

In transitions from undeformed tonalite through zones of deformation into granodiorite, the biotite decreases in abundance as the quartz content of the rock increases toward the granodiorite. The disappearance (destruction) of biotite releases K, Mg, Fe, and Al to ambient fluids. Some of that Fe becomes oxidized as the ferric ion, and trace amounts are incorporated in the secondary K-feldspar, imparting a pink color. This relationship raises the possibility that pink K-feldspar crystals in Precambrian granites may have a similar replacement origin where these crystals are also bordered by myrmekite.

The Sharpners Pond terrane is an example of an early intrusion of hot, wet, K-rich magma in which the K crystallized mostly in a tonalite rather than in K-feldspar in quartz monzonite (adamellite), granodiorite, or granite. After this tonalite magma solidified, collisional forces caused deformation that created openings into which hydrous fluids could be introduced to cause the tonalite to evolve into granodiorite by metasomatism. These replacements, which converted much of the biotite to quartz and much of the plagioclase to K-feldspar, occurred in the same volume formerly occupied by the tonalite. Therefore, there is no "room problem."

References

Carmen, J. H., and Tuttle, O. F., 1964, Experimental study bearing on the origin of myrmekite: Geological Society of America Special Paper 76, p. 29.

Castle, R. O., 1965, A proposed revision of the subalkaline intrusive series of northeastern Massachusetts: U. S. Geological Survey Professional Paper 525C, p. C74-80.

Castle, R. O., and Lindsley, D. H., 1993, An exsolution silica-pump model for the origin of myrmekite: Contributions to Mineralogy and Petrology, v. 115, p. 58-65.

Harrison, W., Flower, M., Sood, M., Tisue, M., and Edgar, D., 1983, Crystalline rocks of northeastern United States: ANL/ES-Argonne National Laboratory, v. 137, 414 p.

Tuttle, O. F., 1952, Origin of the contrasting mineralogy of extrusive and plutonic salic rocks: Journal of Geology, v. 60, p. 107-124.

Tuttle, O. F., and Bowen, N. L., 1958, Origin of granite in the light of experimental studies in the system $NaAlSi_3O_8$ - $KAlSi_3O_8$ - SiO_2 - H_2O: Geological Society of America Memoir 74, 153 p.