Significance of myrmekite

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ABSTRACT

The origin and petrogenetic significance of myrmekite is a long standing problem with potential implications for the origins of some granitic rocks on a plutonic scale. Myrmekite should be recognized as being a clue to vast metasomatic changes in some mafic plutonic rocks and in metamorphic and sedimentary rocks that have been subjected to deformation and micro-fracturing that opens the system to movements of hot hydrous fluids. These fluids bring in K and Si and subtract Ca, Mg, and Fe and in the replacement process K-feldspar bordered by myrmekite is formed. Examples are given to show the significance of myrmekite and where these metasomatic changes have occurred.

INTRODUCTION

Studies by Putnis and Putnis, 2007; Putnis, 2009; Putnis and John, 2010; Putnis and Austrheim, 2010; and Putnis and Ruiz-Agudo, 2013, show that mineral-water interface reactions occur that cause minerals to develop a porosity so that fluids can flow through a granitic rock and produce large scale replacements. Undoubtedly, tectonically created fracturing plays a major role in permeability development and introduction of fluid into rocks (Jamtveit and Yardley, 1997), but replacement reactions by dissolution-precipitation require that fluid infiltrates every part of a rock and that these fluids move through pores created in the crystals as primary elemental components are replaced. In previous studies, how fluids move through rocks were generally restricted to hydraulic fractures and grain boundaries (e.g., Kostenko et al., 2002), but the production of pores in crystals by a reactive fluid greatly increases the number of possible fluid pathways and the rock's permeability. As long as there is sufficient fluid and mass transport through the created pores, granitic plutons can be reequilibrated on a large scale. Literally, the fluid can react its way through a granite body by-passing some minerals with which there may be no reaction, or with which a reaction generates a non-porous product which effectively seals the mineral off from the fluid (Putnis, 2009). Examples of such metasomatic changes on a large plutonic scale are given by Putnis et al., 2007, and this article has had 130 citations as of August, 2021, reported by Google Scholar, and this many citations indicate that igneous petrologists are beginning to recognize the existence and extent to which metasomatic granitic rocks occur.

In some granitic rock sharp contacts, xenoliths, and cross cutting dikes are thought to be clues of a magmatic origin of a plutonic rock, but studies by Roddick (1982) show that these relationships are not always indicators of a magmatic origin. For example, cross-cutting dikes, remnant xenoliths, and sharp contacts in myrmekite-bearing granitic rocks occur near Temecula, California, in which metasomatic granite is produced that replaces primary biotite-hornblende diorite (**Fig. 1**). That is, former micro-fractured, recrystallized, and metasomatically replaced rocks occur up to a sharp contact where metasomatic fluids cannot penetrate (Collins and Collins, 2013).

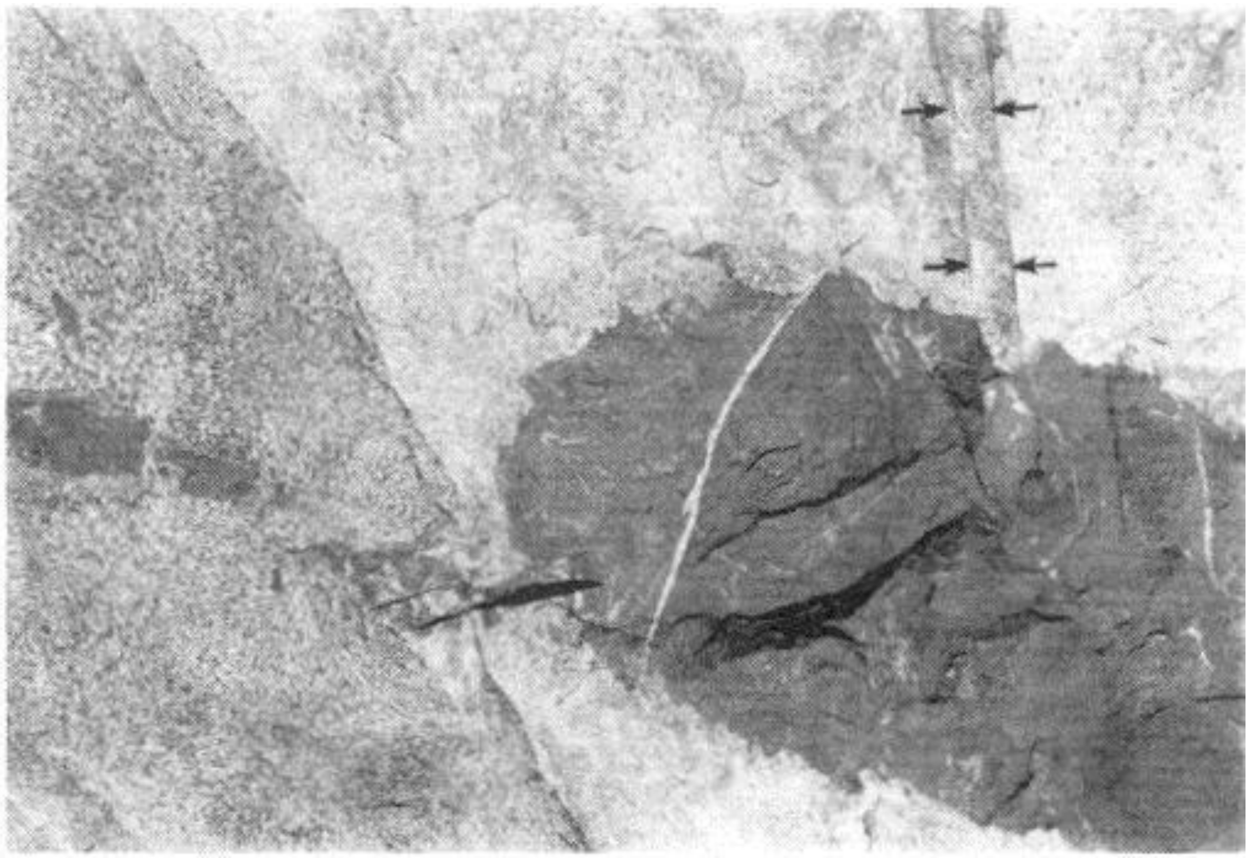

Fig. 1. Sharp contact of metasomatic granite (white areas) against relatively un-deformed biotite-hornblende quartz diorite (left side), Temecula, California. Remnant dike of andesite porphyry (black) with same composition as diorite.

On that basis, the following observations can be made about rocks subjected to metasomatic processes and their different environments. Myrmekite commonly is associated with its occurrence in plutonic igneous rocks, but it also can occur in metamorphic and sedimentary rocks where deformation and micro-fracturing can allow K-bearing fluids to penetrate these rocks.

ORIGIN OF MYRMEKITE AND GHOST MYRMEKITE

Wart-like myrmekite is observed to form in micro-fractured rock where incomplete replacement of plagioclase by K-feldspar occurs (**Figs. 2**, **3**, and **4**).

Fig. 2. Typical myrmekite with quartz vermicules projecting into border of K-feldspar (gray). Colored grains are biotite.

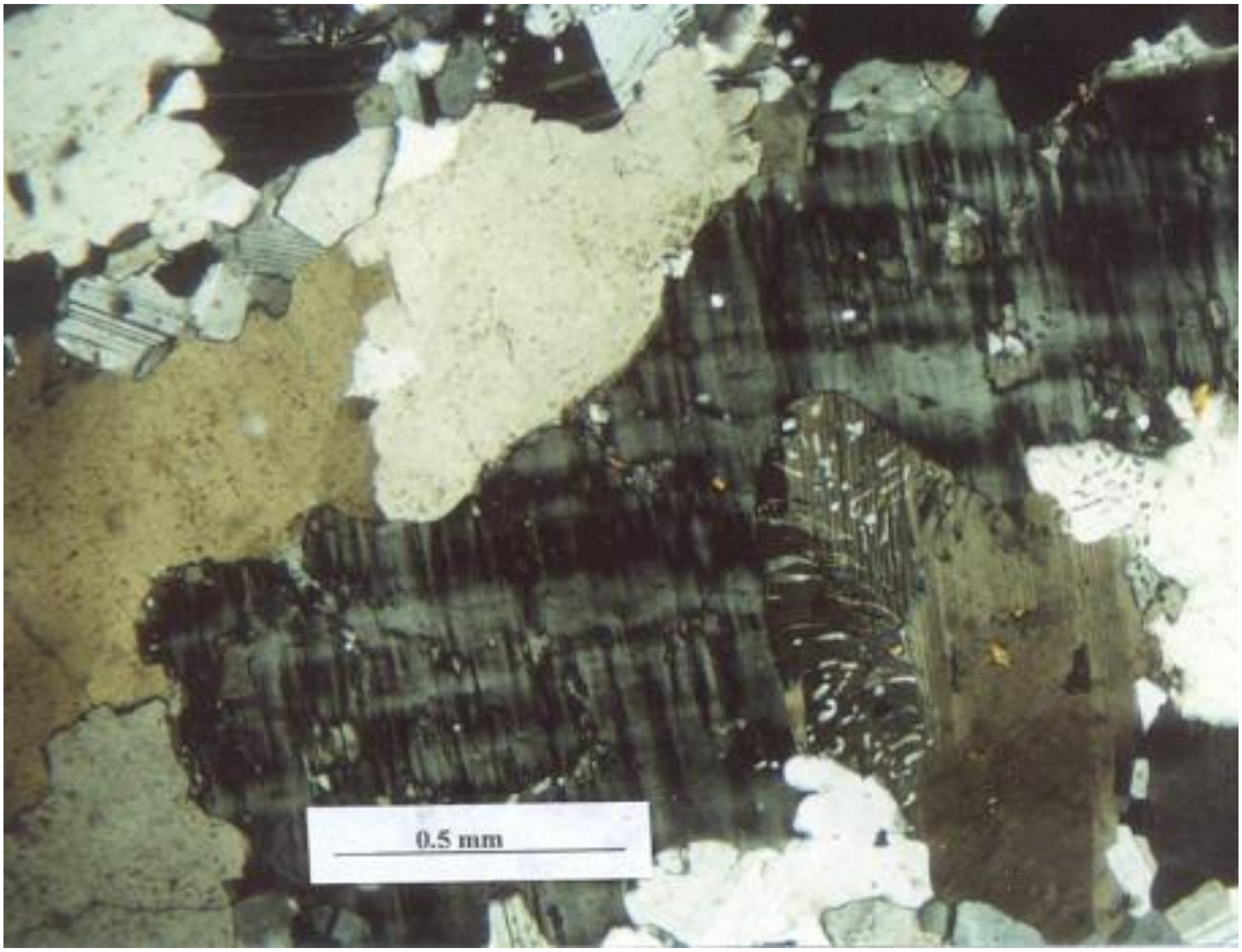

Fig. 3. Myrmekite (right side) projecting into grid-twinned microcline, Temecula, California.

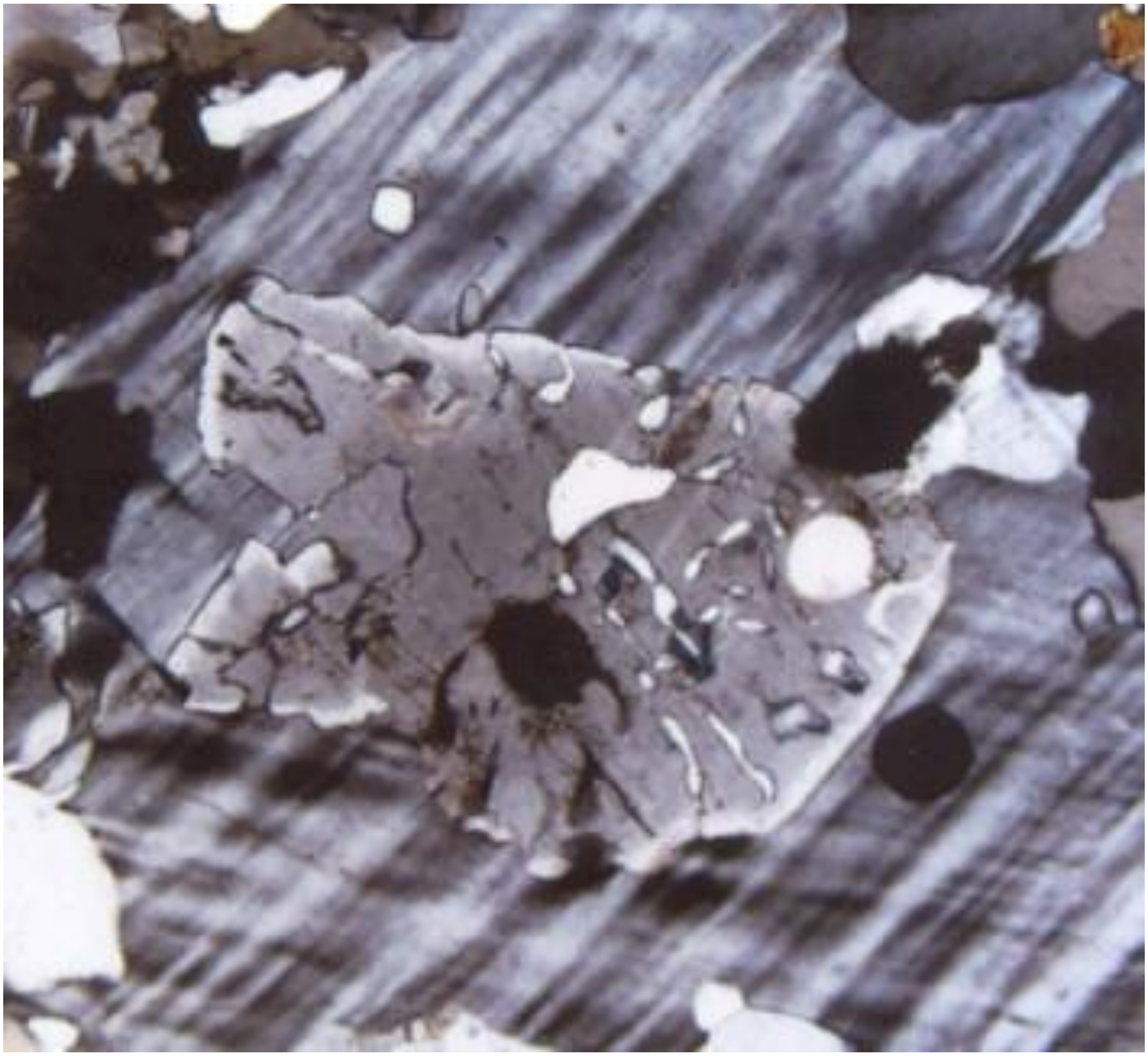

Fig. 4. Myrmekite in Wanup pluton

This myrmekite (**Figs. 2** and **3**) has vermicular quartz in which the thicker parts are adjacent to non-quartz bearing plagioclase but then the quartz vermicules taper to thinner dimensions toward the K-feldspar. So much Ca and Al are locally subtracted from the original relatively-calcic primary plagioclase crystal that too much Si remains that can completely fit into a more-sodic recrystallized plagioclase crystal and this left-over silica becomes the quartz vermicules. Past interpretations have theorized that wart-like myrmekite is formed where late-stage post-magma-crystallization fluids have brought in Ca and Na that react with margins of primary K-feldspar to produce the myrmekite, and mass-for-mass balanced equations are written to justify this interpretation. But thin section studies show that the above explanation is what happens and that volume-for-volume equations are required (Collins and Collins, 2002a).

After myrmekite is formed, in some places renewed deformation and micro-fracturing allows more K to come in and replace the plagioclase in the myrmekite next to the quartz and absorb some of the quartz into the lower-density K-feldspar composition and volume to leave clusters of tiny oval quartz grains, which are "ghosts" of the myrmekite that used to be there. Hence, the name "ghost myrmekite." Diameters of these quartz grains are similar to the sizes of the original widths of the quartz vermicules prior to K-replacement. For example, ghost myrmekite in myrmekite near myrmekite (**Fig. 3**) has such tiny uart blebs that they are barely visible (**Fig. 5**),

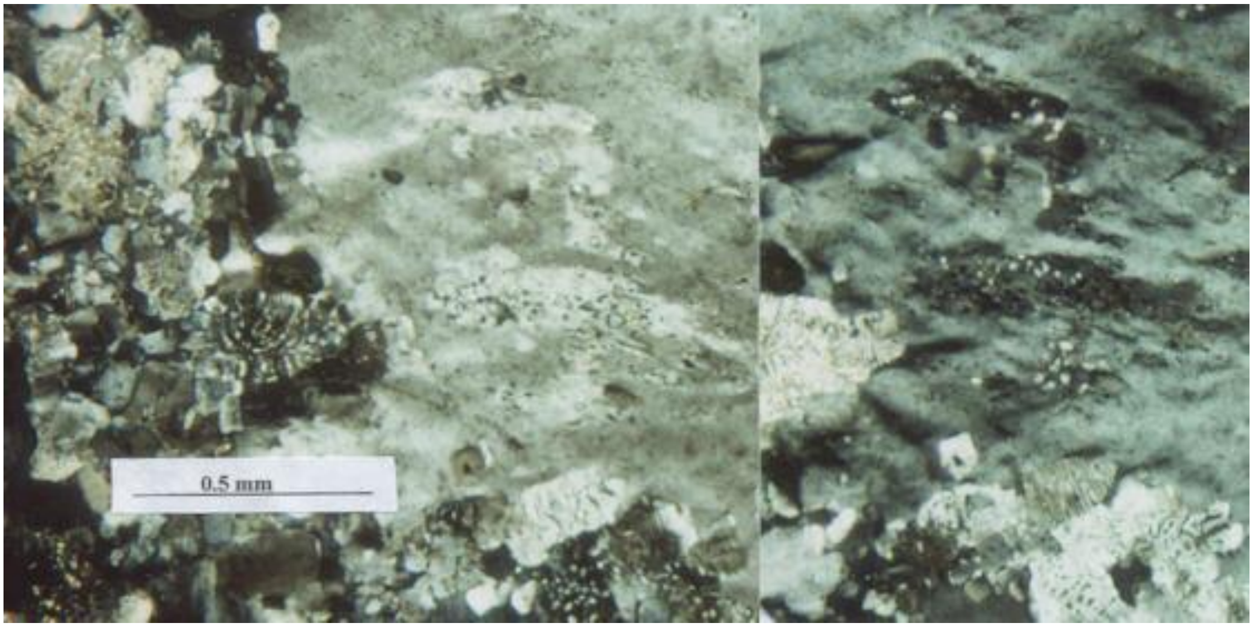

Fig. 5. Ghost myrmekite in microcline, Temecula, California. Tiny white quartz ovals (right side).

Quartz blebs, however, in ghost myrmekite in the Rubidoux Mountain leucogranite (Collins, 1997a) are much larger (**Figs. 6** and **7**).

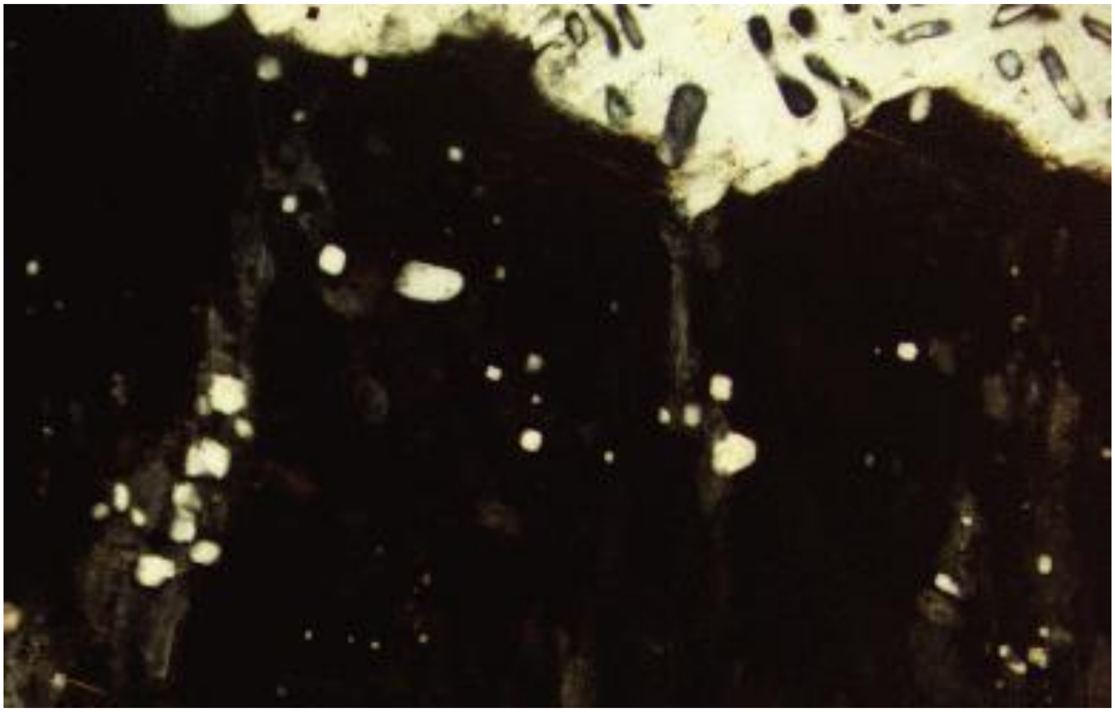

Fig. 6. Ghost myrmekite and myrmekite in Rubidoux Mountain leucogranite.

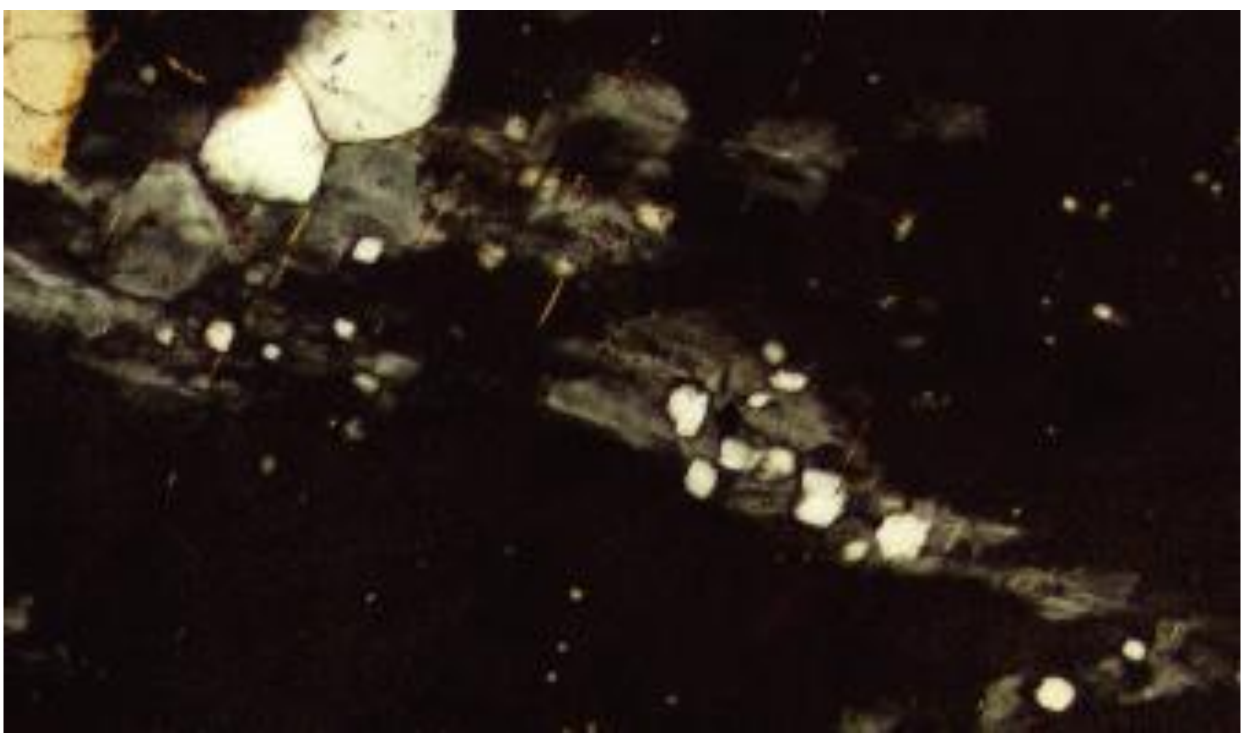

Fig. 7. Ghost myrmekite, Rubidoux Mountain leucogranite.

Whereas quartz blebs in ghost myrmekite in the Wanup pluyon (Collins, 2001 are much coarser (**Figs. 8** and **9).**

Fig. 8. Myrmekite with coarse quartz vermicules in megacrystal granitic rock near base of Wanup pluton, south of Route 69. Microcline (black) with scattered quartz blebs (white); some quartz blebs are the same size as those in the myrmekite, and others are tiny in ghost myrmekite. Plagioclase (albite-twinned; light and dark gray); quartz (mottled gray).

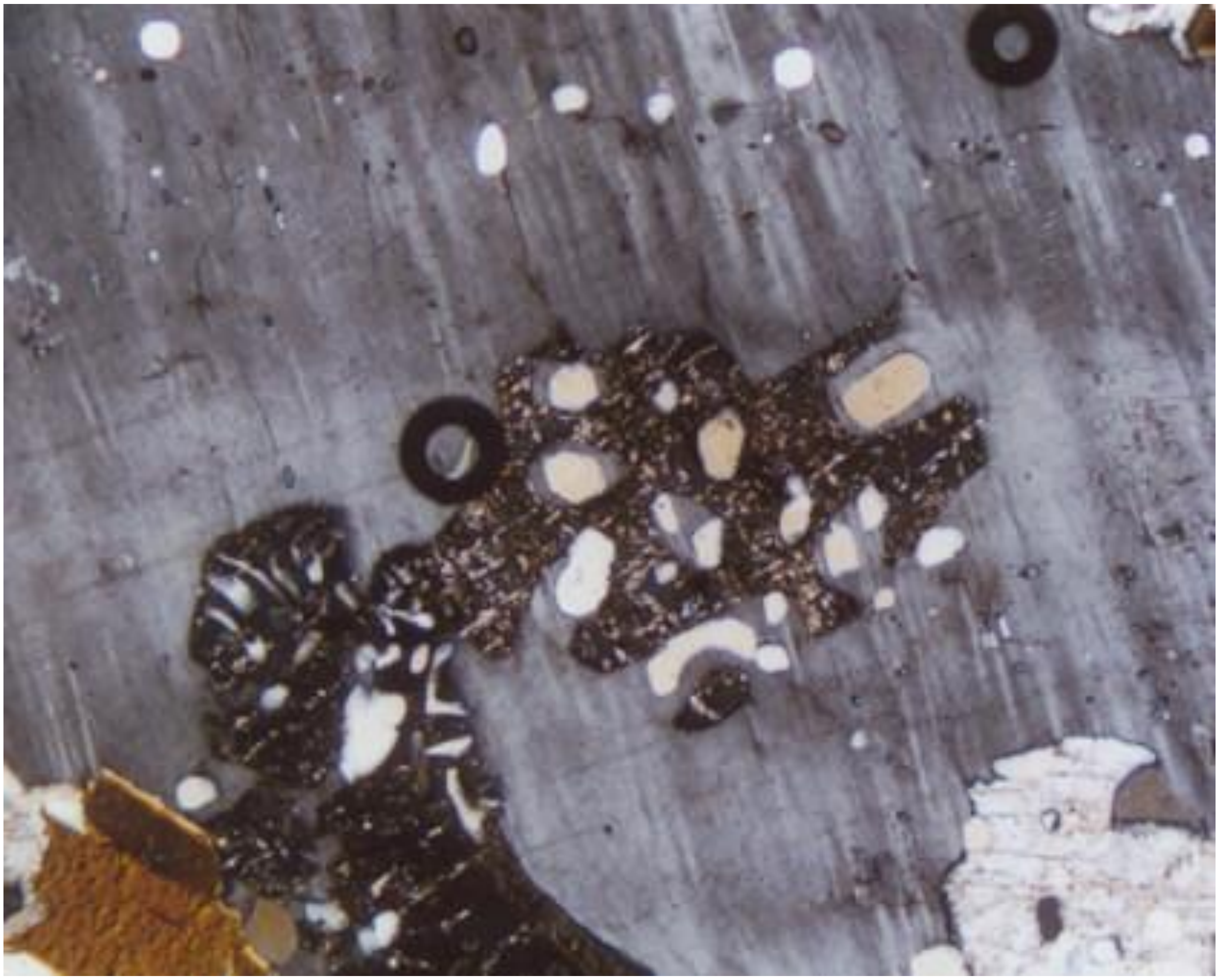

Fig. 9. Ghost myrmekite in microcline. Wanup pluton.

But not in every place, as in **Figs. 10** and **11**.

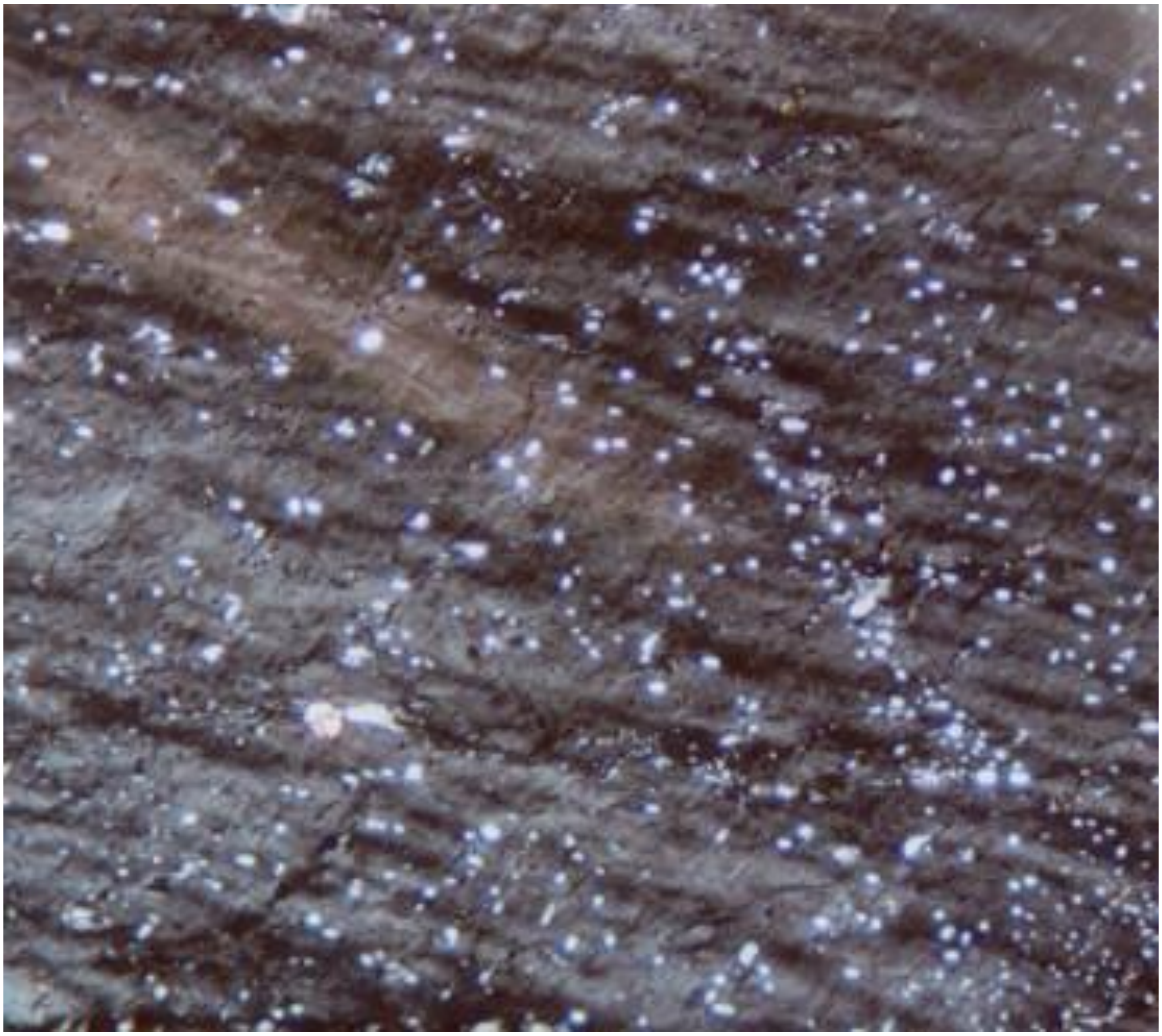

Fig. 10. Ghost myrmekite in microcline (grid-twinned; gray), occurring in megacrystal granitic rock near base of Wanup pluton, south of Route 69.

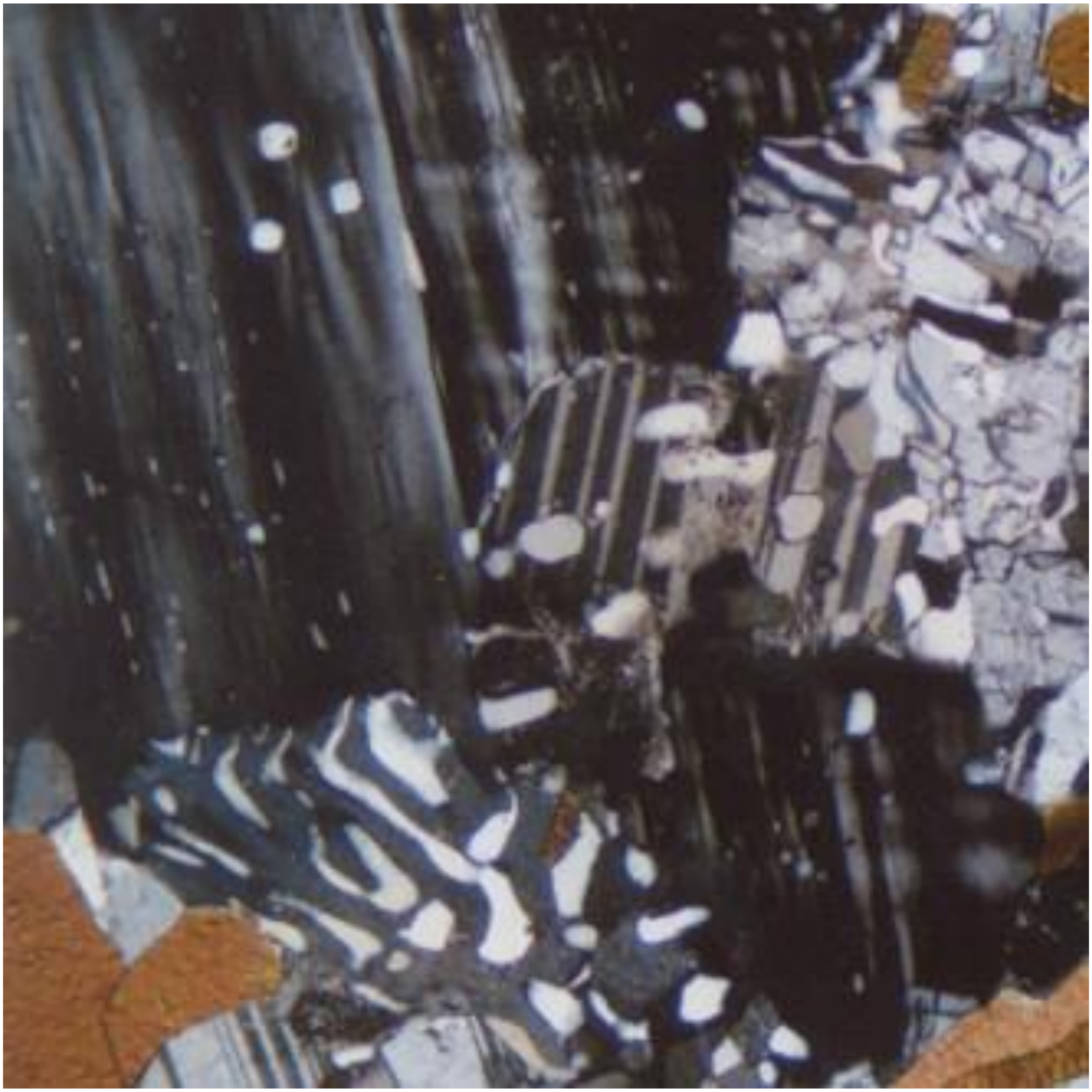

Fig. 11. Ghost myrmekie and myrmekite, Wanup pluton.

K-FELDSPAR MEGACRYSTS

Megacrysts of K-feldspar are generally considered to be phenocrysts that have crystallized from magma. This is true for most Sierra Nevada plutonic rocks in California where clusters of orthoclase megacrysts occur with no coexisting myrmekite, but in the centers of shear zones (Tikoff and Greene, 1997) that extend northwest-southeast in the eastern parts of this mountain range, isolated K-feldspar megacrysts occur that are bordered by myrmekite and are formed by replacement of micro-fractured primary plagioclase crystals (Collins and Collins, 2013).

Similar K-feldspar megacrysts, more than 10 cm long, were considered to be phenocrysts by Brand (1985) and Brand and Anderson (1982) in the Twentynine Palms pluton, but Collins (1997b) found them to be locally bordered by myrmekite and progressively increased in size from 0.5 cm (**Fig. 12**) to 3 cm (**Fig. 13**) as more K was introduced into the micro-fractured rock.

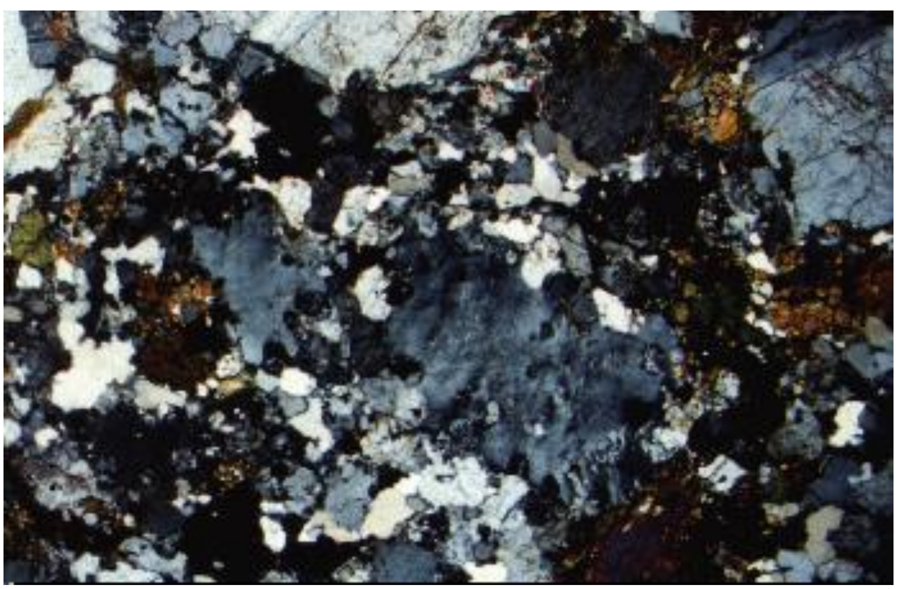

Fig. 12. Early stage K-feldspar megacryst forming in hornblende diorite, showing cataclastic texture. Broken groundmass matrix,

consisting of hornblende (brown and green), quartz (clear-white and gray), and plagioclase (gray and dark gray), surrounds larger islands of albite-twinned plagioclase (white to gray). In center and center left are two microcline crystals (dark gray) with irregular borders against the granulated groundmass. Microcline is in earliest stages of replacement and contains minor wartlike myrmekite with tiny quartz vermicules (barely visible) along borders of the microcline.

Fig. 13. Megacrystal Twentynine Palms quartz monzonite, containing K-feldspar crystals, up to 3 cm long.

The original rock is a hornblende diorite lacking biotite, so it is illogical that this rock has produced megacrysts of K-feldspar from magma. Therefore, the K must have come from a source below the diorite, and locally inclusions of biotite schist occur containing more than 50 volume percent biotite that would supply this K.

Also, Vernon and Paterson (2002) suggested that zoned orthoclase megacrysts (Fig. **14**) in the Papoose Flat pluton in eastern California were also phenocrysts.

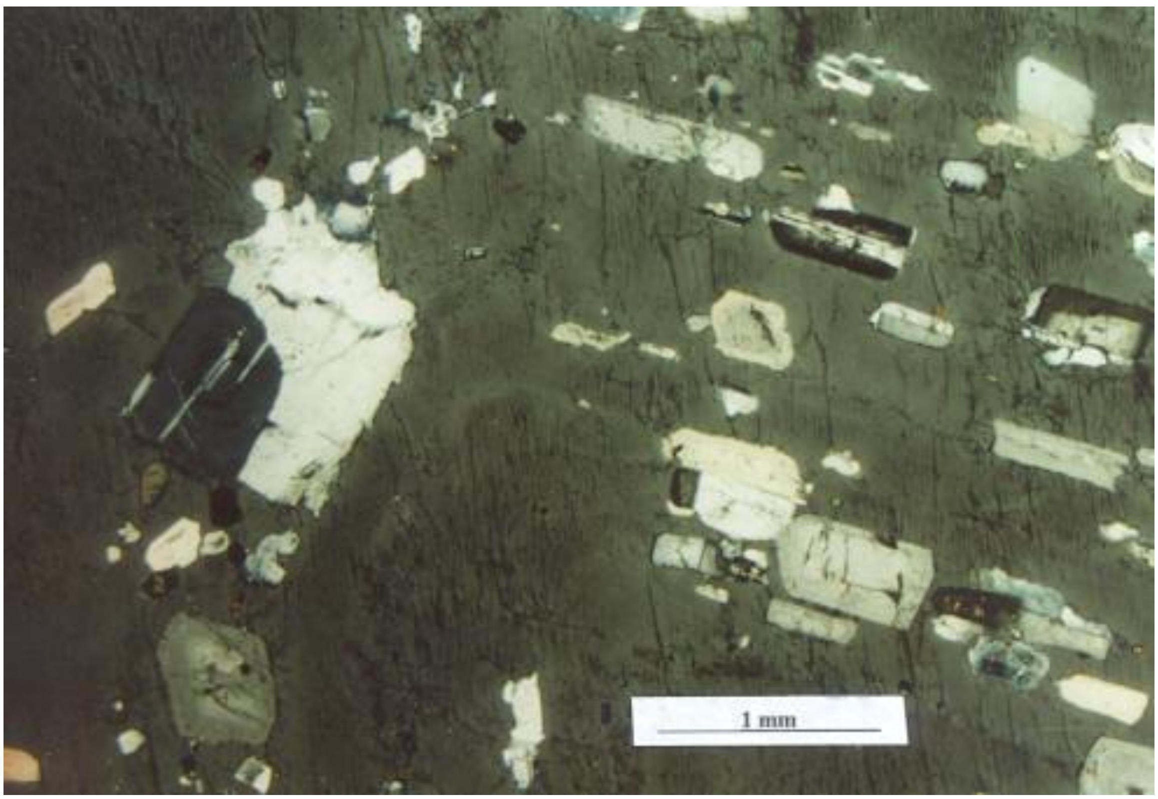

Fig. 14. Inner corner of zoned orthoclase megacryst, Papoose Flat pluton. Note scalloping of crystals and tiny quartz ovals (left corner).

But thin section studies show that the K-feldspar grows around granulated ground mass minerals (**Figs. 15** and **16**).

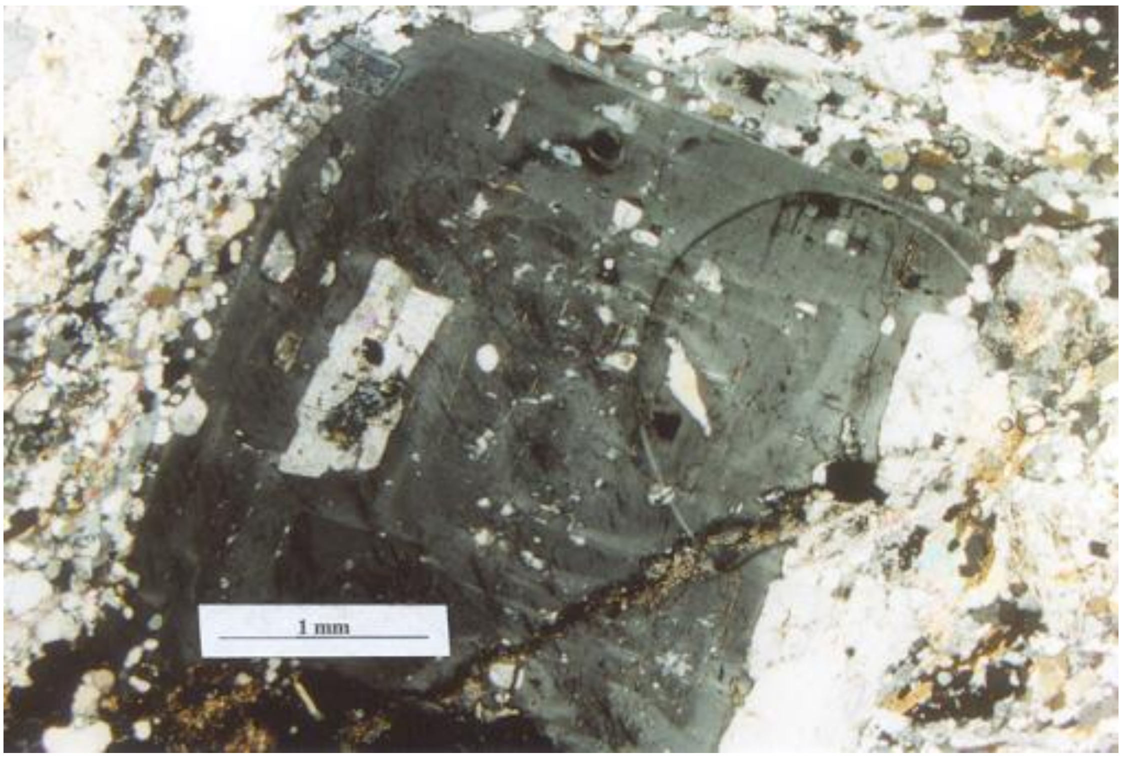

Fig. 15. Early stage first appearance of growth on K-feldspar megacrysts in Papoose Flat pluton. Ground mass bordering the K-feldspar is strongly granulated/.   One elongate plagioclase inclusion (left side) is parallel to the zoning and is about the same size as other plagioclase crystals in the granulated groundmass. Biotite (brown). In its outer border, the orthoclase

encloses tiny granulated inclusions (left side and top right). Note that the orthoclase extends beyond corner (upper right) penetrates and encloses rounded inclusions and that this orthoclase is optically continuous with the main crystal and has not resulted from deformation of the orthoclase to form a "tail."

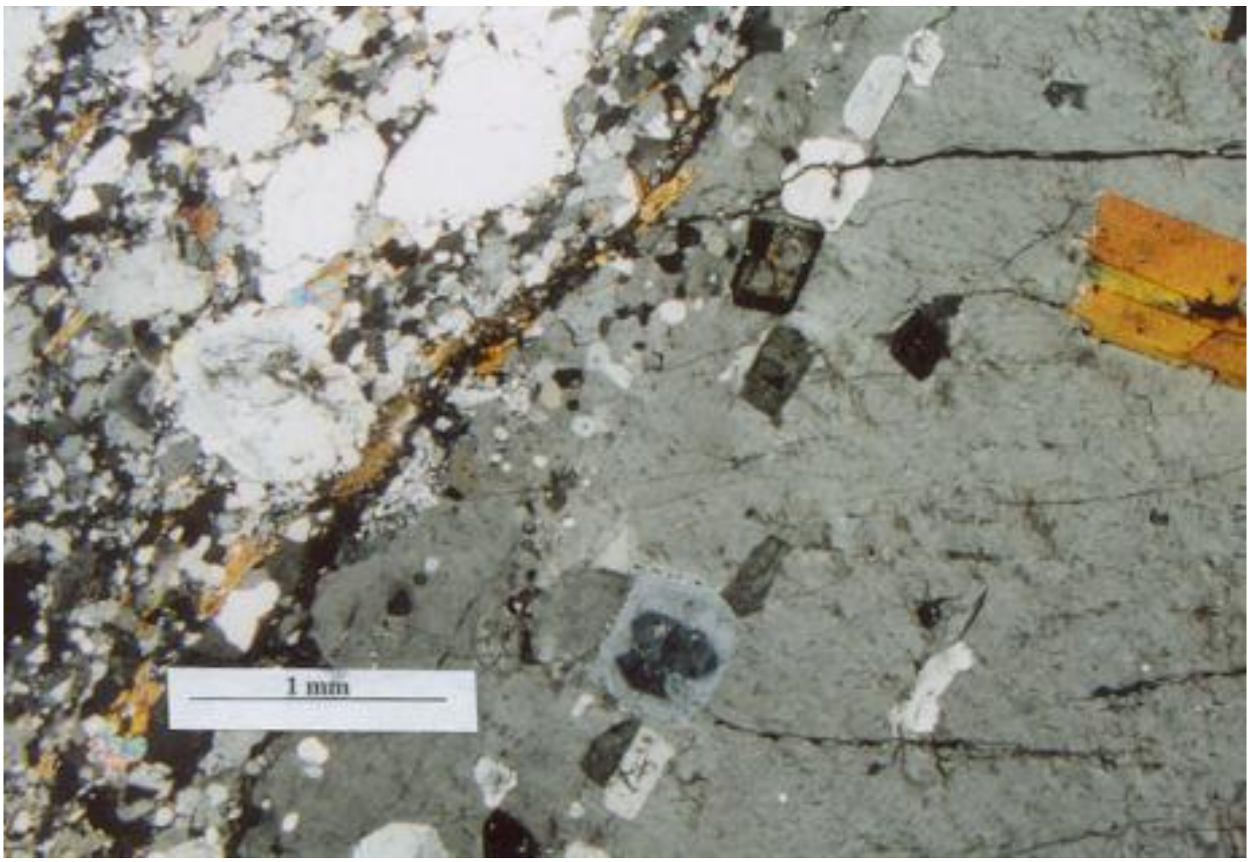

Fig. 16. K-feldspar in Papoose Flat pluton, showing growth of a megacryst to enclose granulated ground mass minerals of quartz, plagioclase, and biotite (tan). Many quartz grains become tiny quartz ovals in the K-feldspar.

They contain myrmekite on their borders (**Fig. 17**.

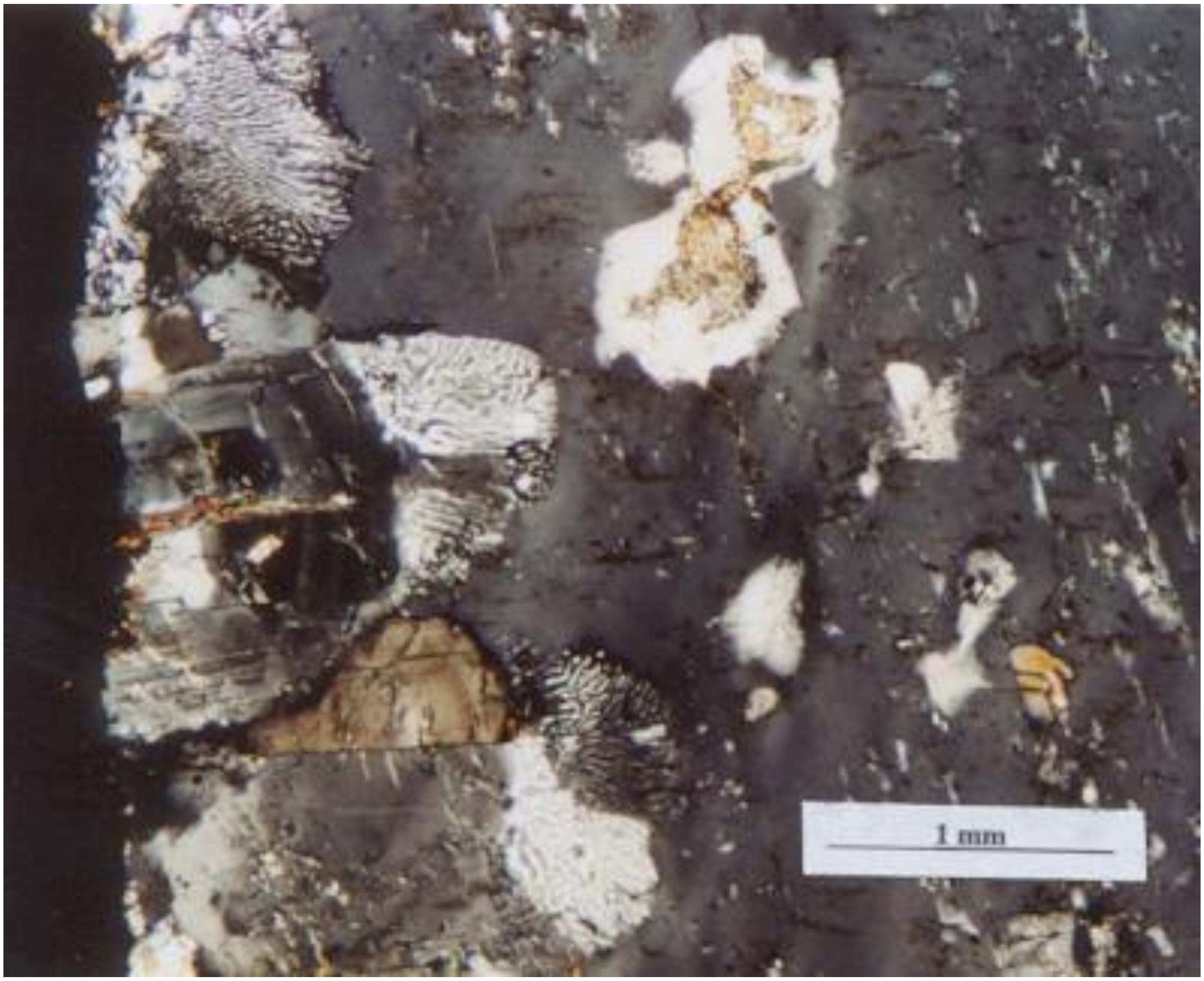

Fig. 17. Myrmekite at end of zoned plagioclase crystal in ground mass along border of K-feldspar megacrysts, Papoose Flat pluton.

Also, the megacrysts contain inclusions of crystals that occur in the adjacent granodiorie ground mass (**Fig. 18** and **19**). Vernon and Paterson (2002) ignore these inclusions as well as the myrmekite.

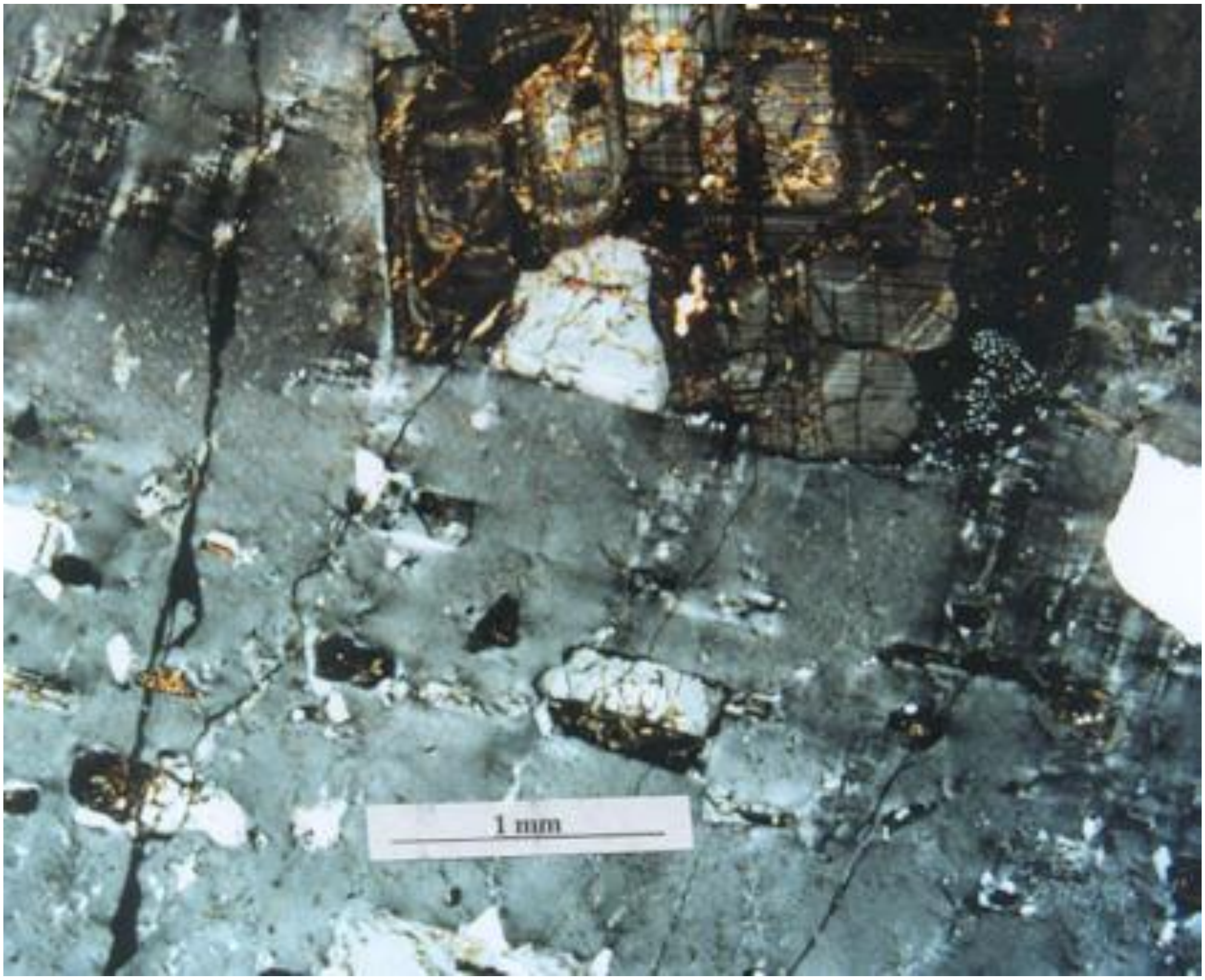

Fig. 18. Inclusion of ground mass crystals, parallel-aligned, zoned plagioclase crystals (top center) in the interior of a K-feldspar megacrysts in the Papoose Flat pluton.. Lower right corner of the inclusion is myrmekite with tiny quartz vermicules (left of cream-white quartz crystal). This interior inclusion means that the entire pluton was crystallized and solid prior to the K-bearing fluids were introduced through micro-fractures to form the K-feldspar megacryst that engulfed the inclusion. Crystal faces along the bottom side of the inclusion are parallel to a former crystal face of the K-feldspar megacryst.

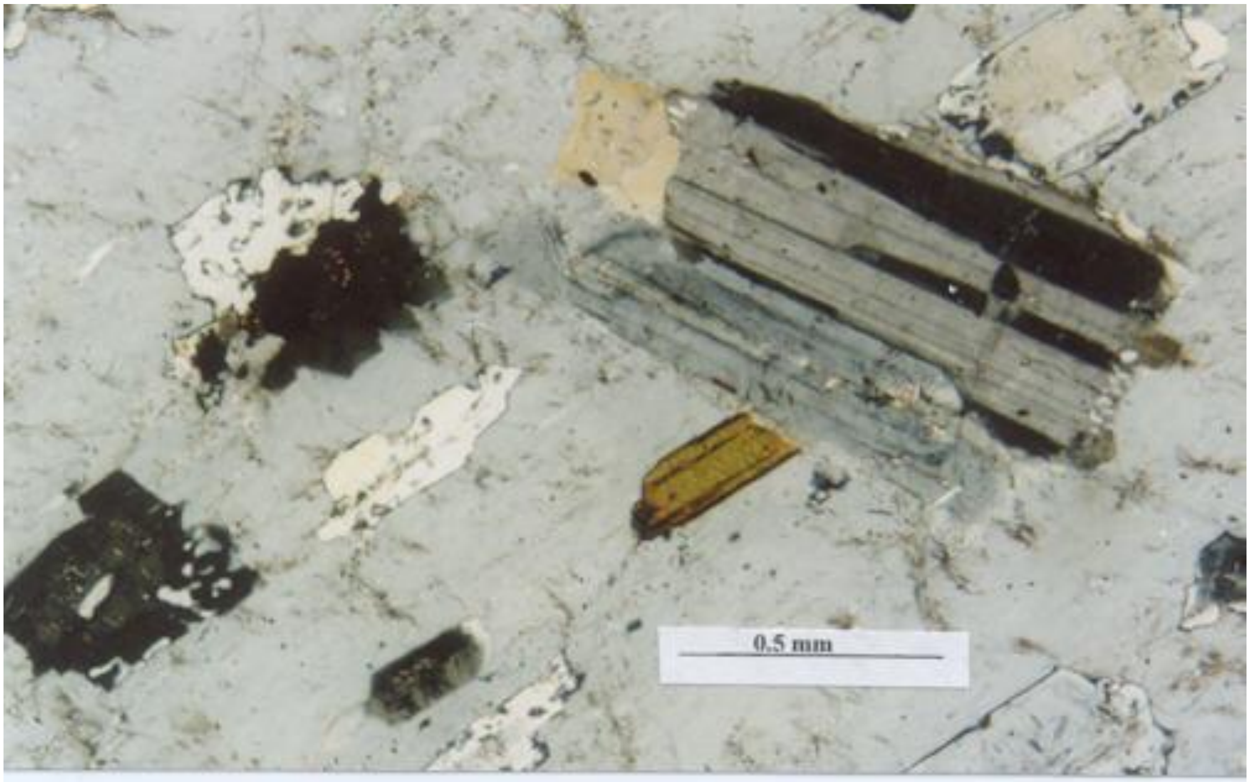

Fig. 19. Inclusion of myrmekite in interior of K-feldspar megacrysts, Papoose Flat pluton (whte grain with quartz vermicules, upper left).

Collins and Collins (2002b and 2013) showed that the orthoclase replaces oriented small plagioclase and quartz crystals in granodiorite, and because the orthoclase volume requires more silica in its structure than the equivalent volume of plagioclase, the ground mass quartz grains are mostly consumed or scalloped (**Fig. 20**) during replacements,leaving remnant tiny ovals of quartz (**Fig. 21**) in the orthoclase rather than quartz with a cuneiform texture that forms in a magmatic granite.

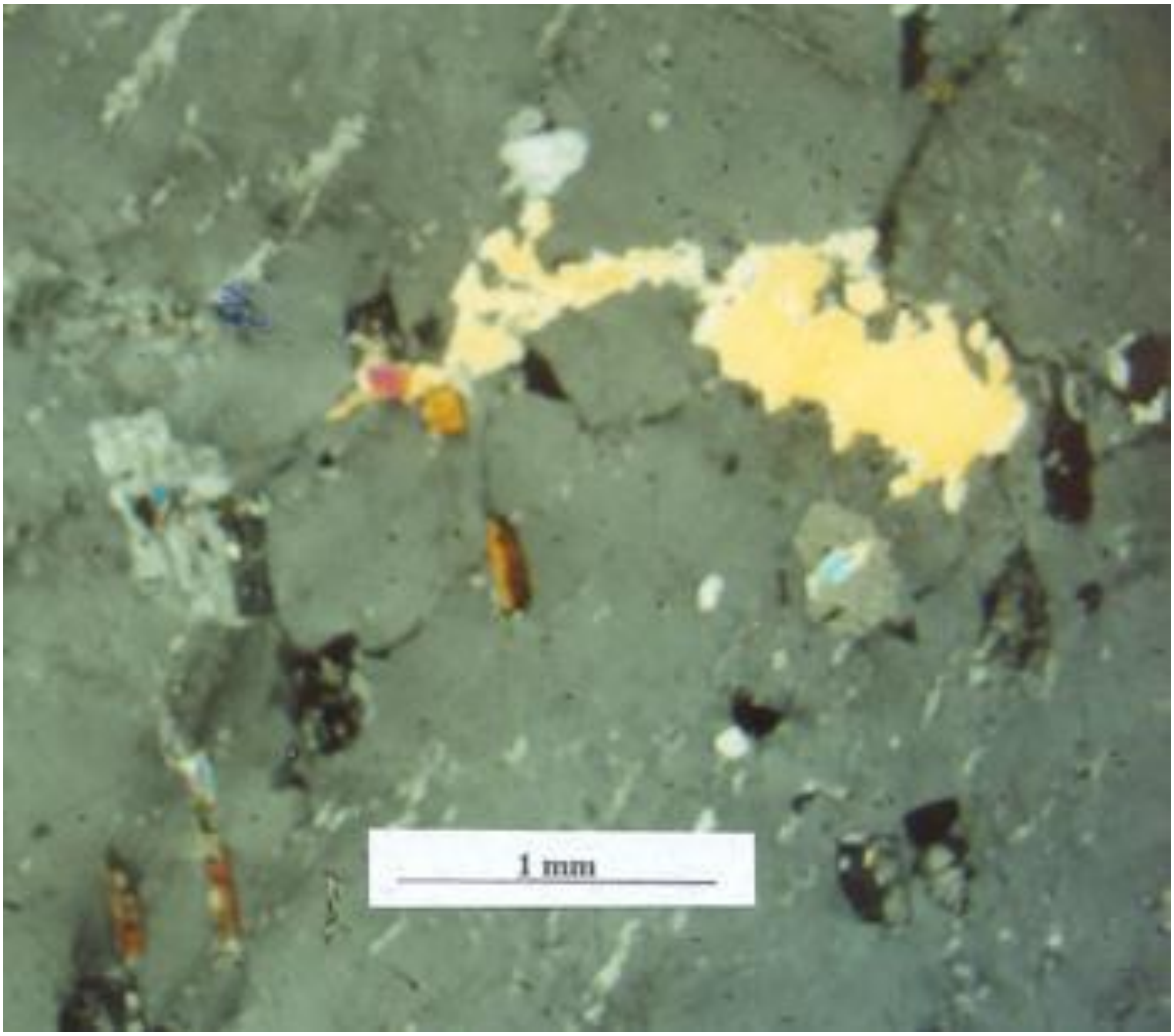

Fig. 20. Scalloped quartz inclusion in K-feldspar megacrysts, Papoose Flat pluton

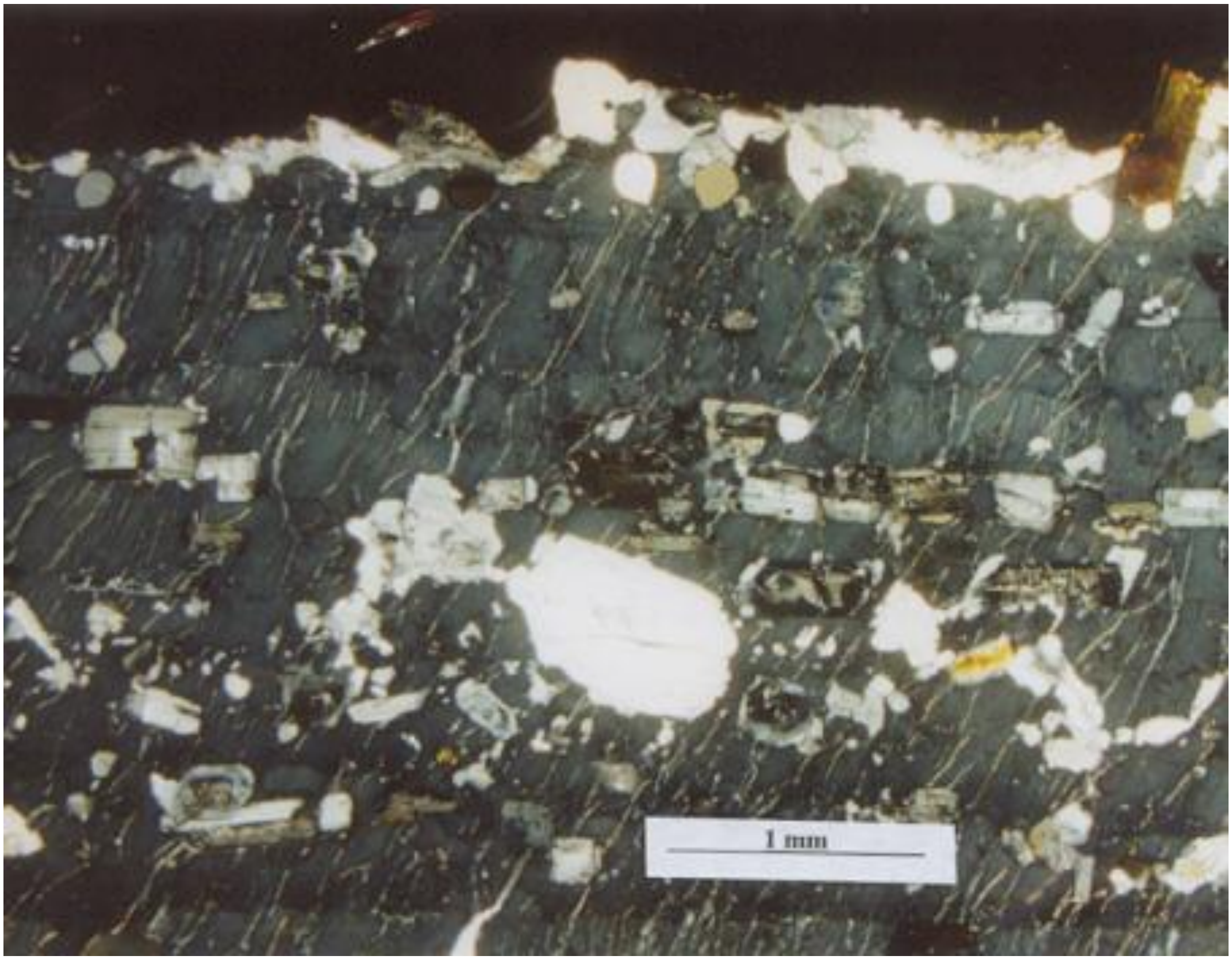

Fig. 21. K-feldspar megacryst with ground mass quartz grains along margin converting to round quartz ovals.

Here, it is clear that volume-for-volume equations must be used to understand the replacement processes. Moreover, these same K-replacement processes produced zoned orthoclase megacrysts (**Fig. 22**) in the Campito Sandstone (arkose) wall rock of the pluton.

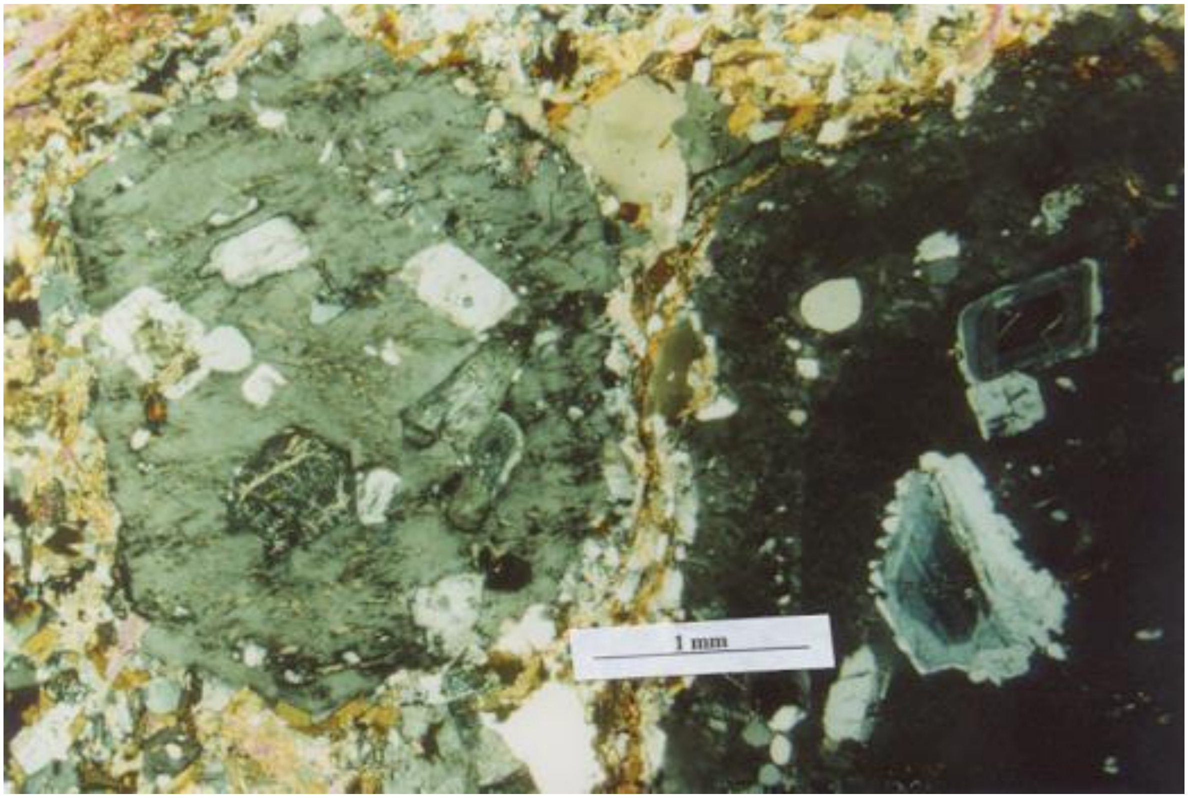

Fig. 22, Early stage of orthoclase megacryst replacing grains of zoned plagioclase in the ground mass Campito Sandstone (arkose).

Here the zoned K-feldspar megacrysts contain tiny biotite crystals that are in the arkose (**Fig. 23**). Therefore, these megacrysts cannot have been formed by magmatic processes.

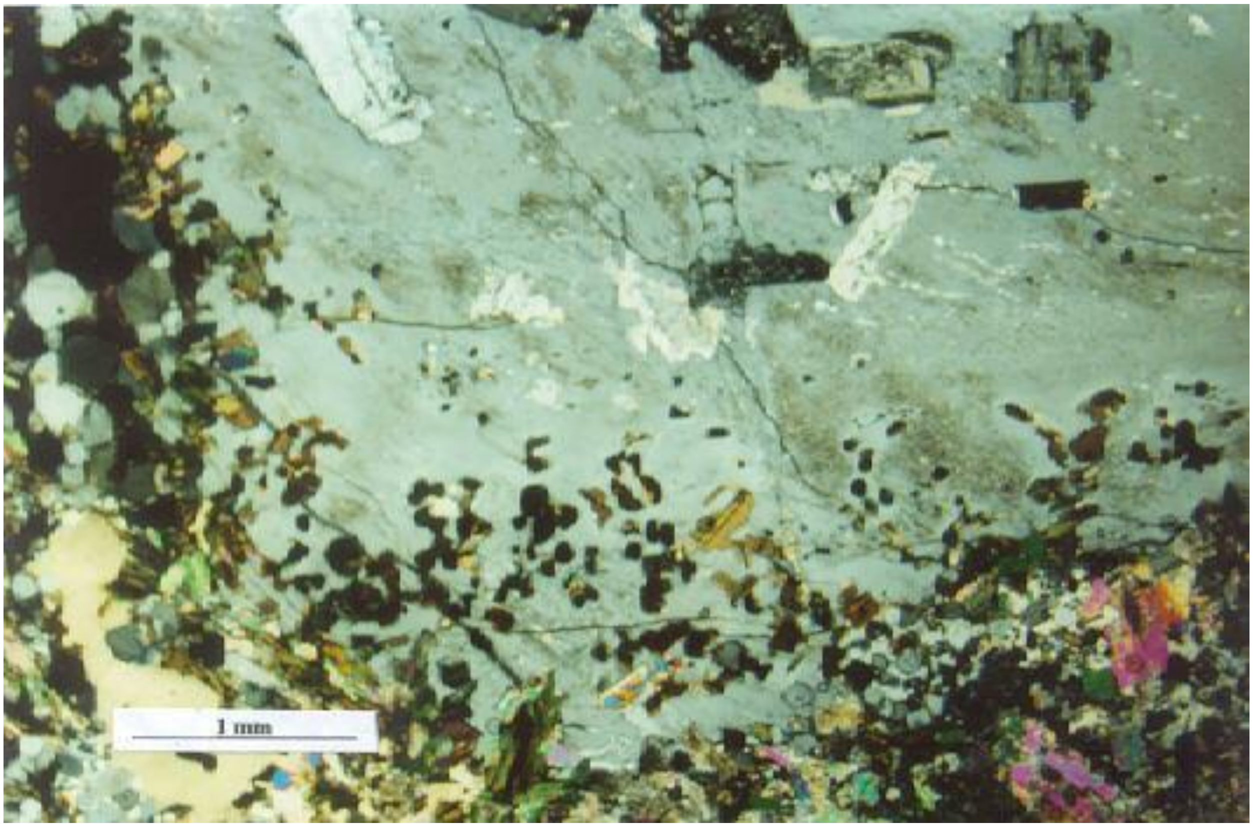

Fig. 23. Border of K-feldspar megacryst replacing ground mas minerals of the Campito Sandstoe (arkose). Tiny inclusion of biotite in the ground mass are being enclosed in the border of the growing megacryst.

In Norway large megacrysts of K-feldspar were thought to be rapakivi-type K-feldspar phenocrysts crystallized from magma (Sylvester, 1963; Sylvester, 1964; Andersen et al., 2001; and Andersen et al., 2007), but they are primarily located in the rim of the diapir-shaped Vrådal pluton with a circular cross-section (**Fig. 24**) rather than in the core where late-stage large crystals of K-feldspar would be expected to be formed (Collins and Collins, 2913).

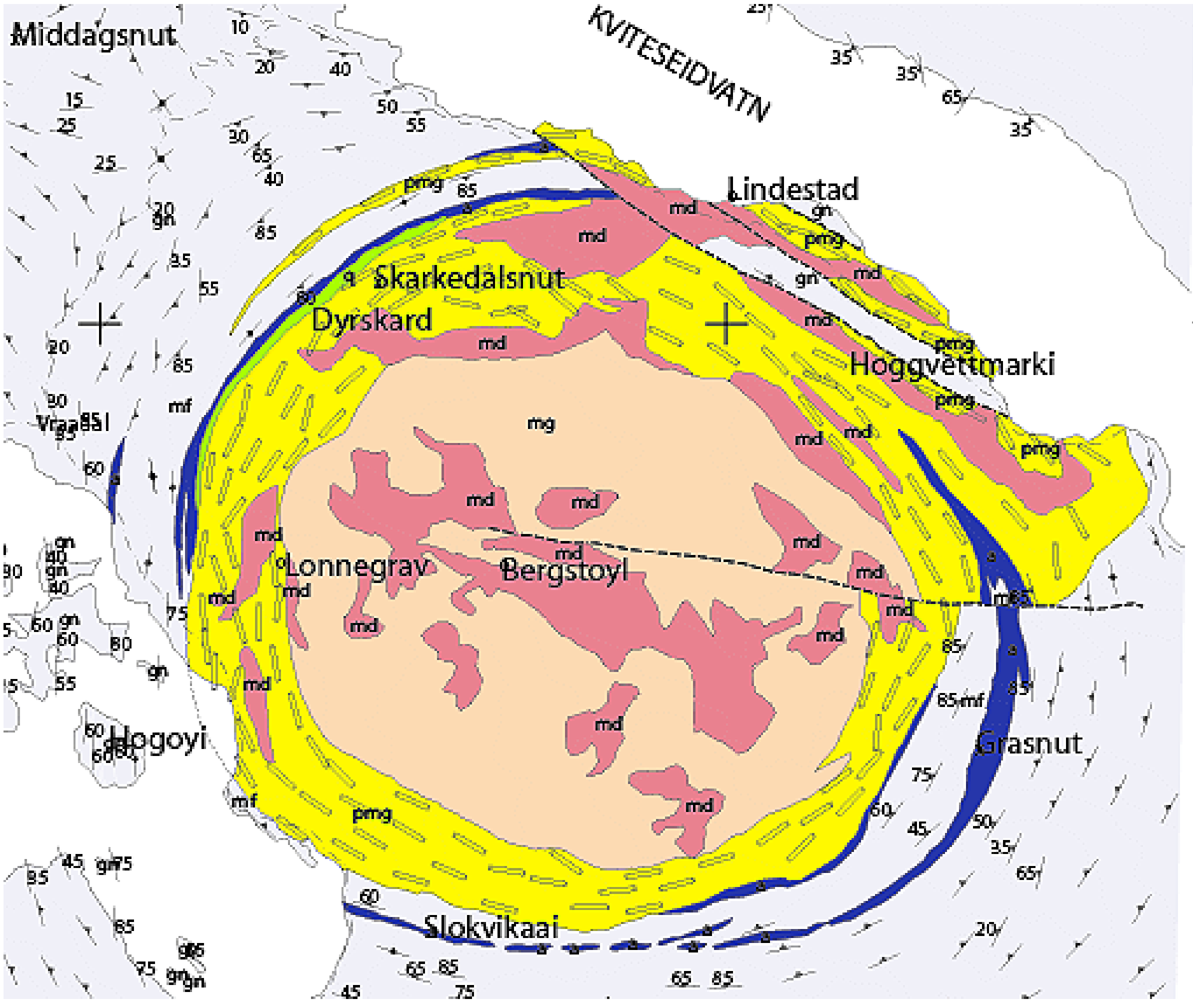

Fig. 24. Geologic map of Vrådal pluton, Telemark, south Norway (Sylvester 1998). Gneiss (gray); schistose amphibolite (blue); quartzite (green); diabase (dark pink), core granite (pale pink); border facies megacrystic granite (yellow). Diameter of diapir is about 6 km

Here, it is the subsequent buoyant rise of the solidified diapiric pluton that sheared crystallized rock near its rim and allowed K-bearing fluids to move through micro-fractures to replace former plagioclase crystals of the pluton to form K-feldspar megacrysts (**Fig. 25**) whose lengths oriented parallel to the rim (**Fig. 26**).

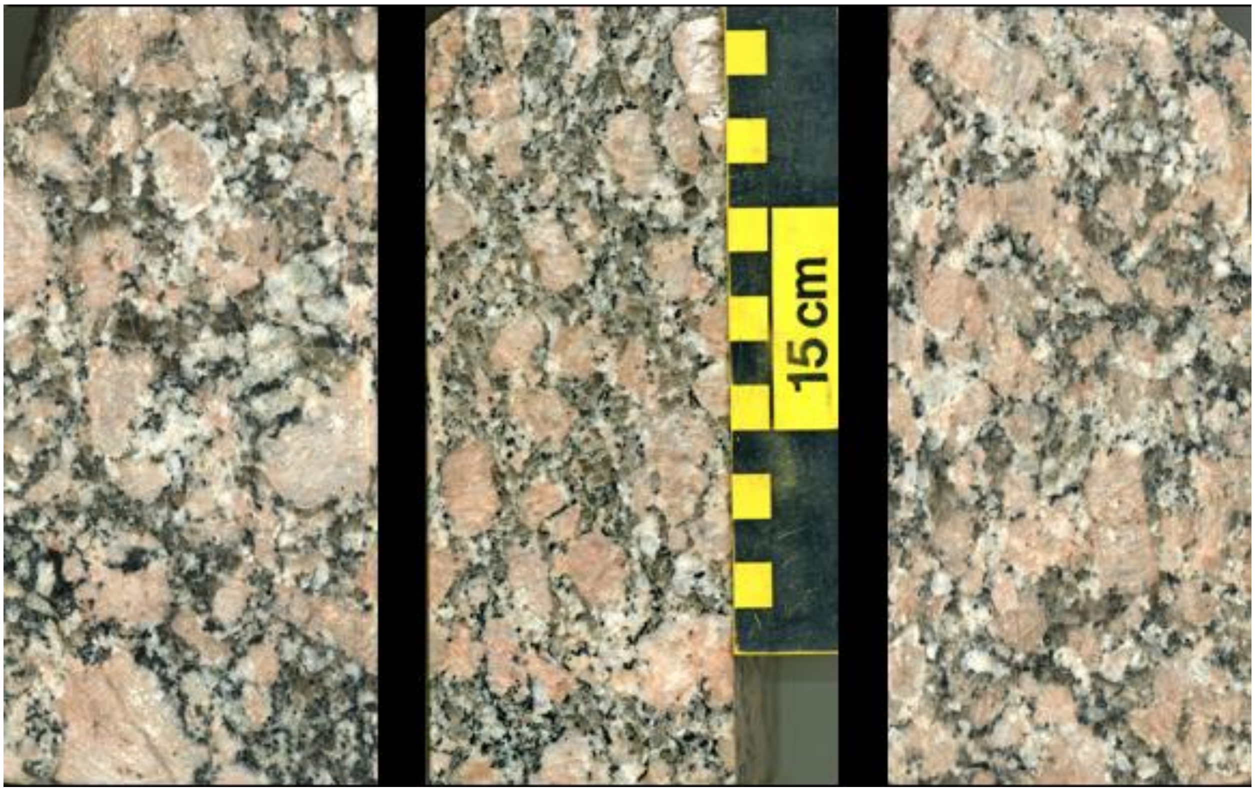

Fig. 25. Megacrysts of K-feldspar in the Vrådal pluton

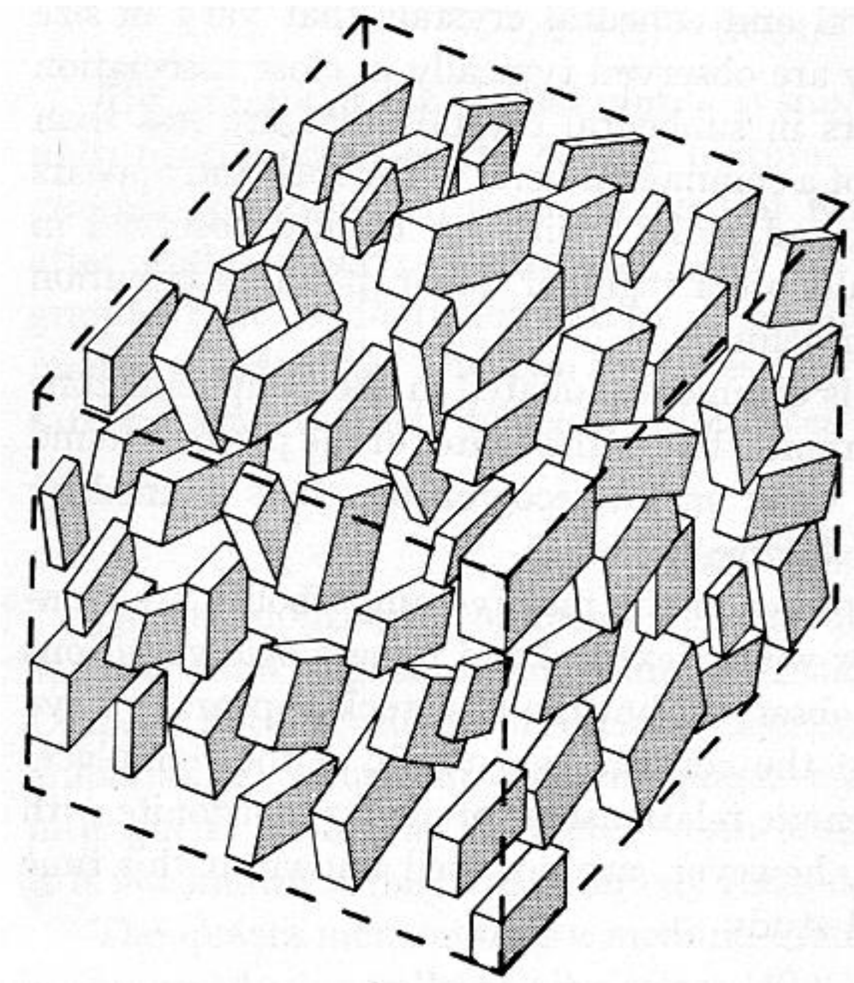

Fig. 26. Schematic diagram of how matchbox-shaped K-feldspar megacrysts define a foliation in the border facies of the Vrådal pluton. Preferred orientation of K-feldspar megacrysts with ac axes parallel to contact and pluton margin.

These fluids also produced myrmekite that bordered the megacrysts (**Fig. 27**).

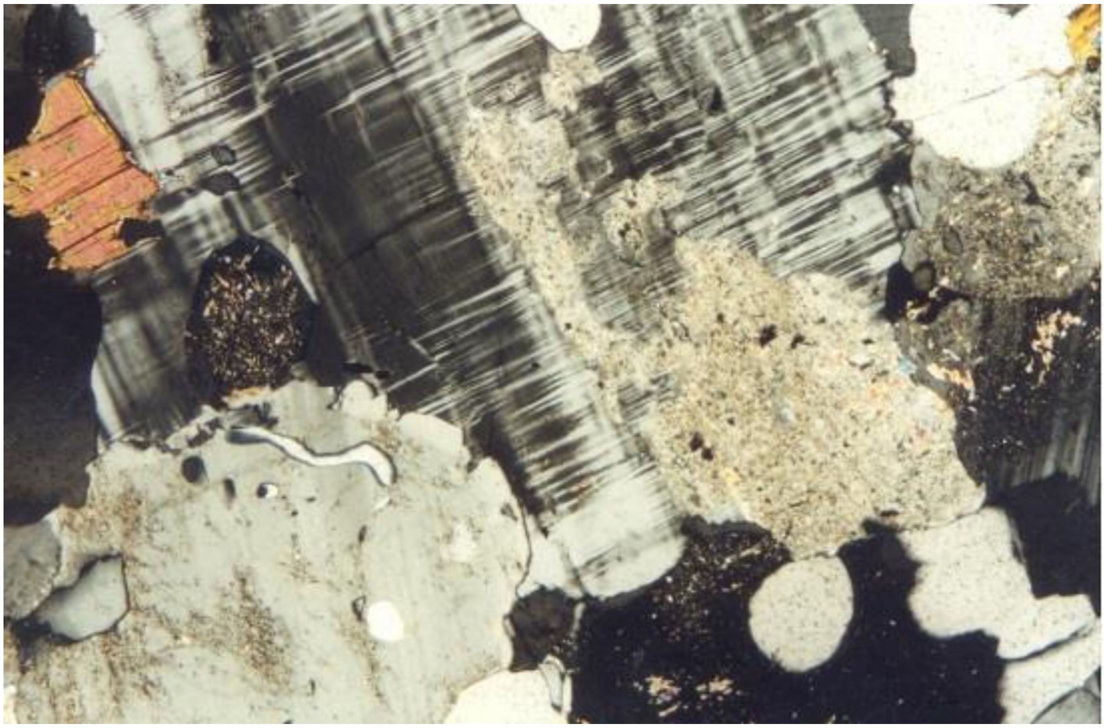

Fig. 27. Myrmekite in Vrådal pluton (lower left quadrant) projects into microcline (grid twinned). One white squiggly-vermicule is seen, but five other vermicules (ovoid) are also present. Albite-twinned plagioclase (altered speckled tan) projects into the microcline and its albite twin-planes (barely visible) are parallel to one of the grid-twins of the microcline. Quartz is white and biotite is reddish tan.

These fluids also moved through the adjacent Tellemark Gneiss to replace fractured and broken crystals of plagioclase to form K-feldspar outside the pluton (**Fig. 28**).

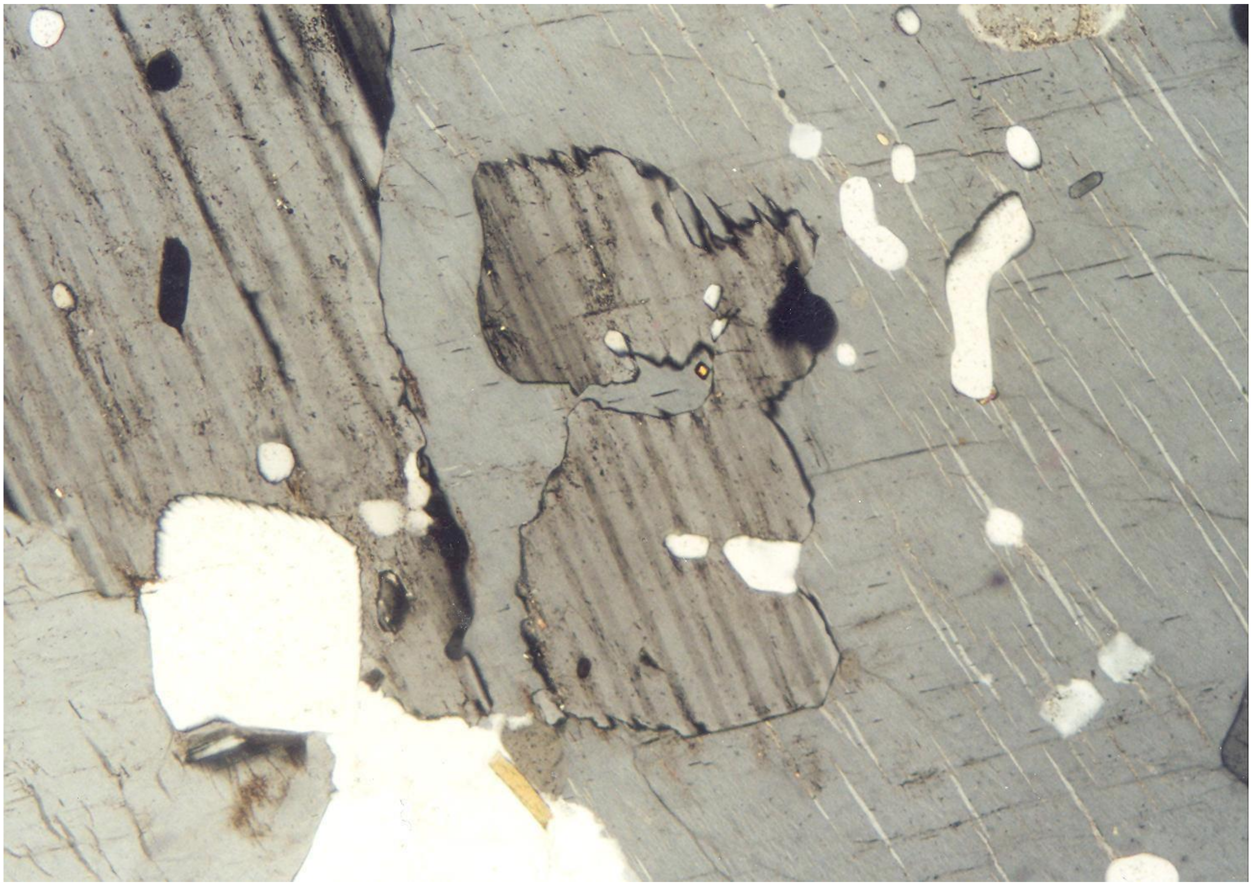

Fig. 28. Perthitic K-feldspar (light gray; right side) replaced parts of a broken albite-twinned plagioclase crystal (light tannish gray; left side) and enclosed and partially replaced quartz (remnant ovoid grains; white; right side). K-feldspar has penetrated and replaced plagioclase (center grain) along albie-twin lamellae. Sample is from the Telemark gneiss that borders the Vrådal pluton.

So, the location of metasomatic fluids that produced the K-feldspar crystals is structurally controlled and did not form in the core of pluton as the result of magmatic differentiation processes.

PARALELL ALIGNMNENT OF FELDSPAR TWINNING

In the previous figure (**Fig. 28**), note that one of the grid-twin directions in the perthitic K-feldspar that replaces the adjacen plagioclase aligns with the albite twin direction of this plagioclase crystal. This alignment is common in many places where myrmekite formed during K-replacement of the interiors of plagioclase crystals occurs. Examples are shown in **Figs. 29, 30, 31**, and **32**.

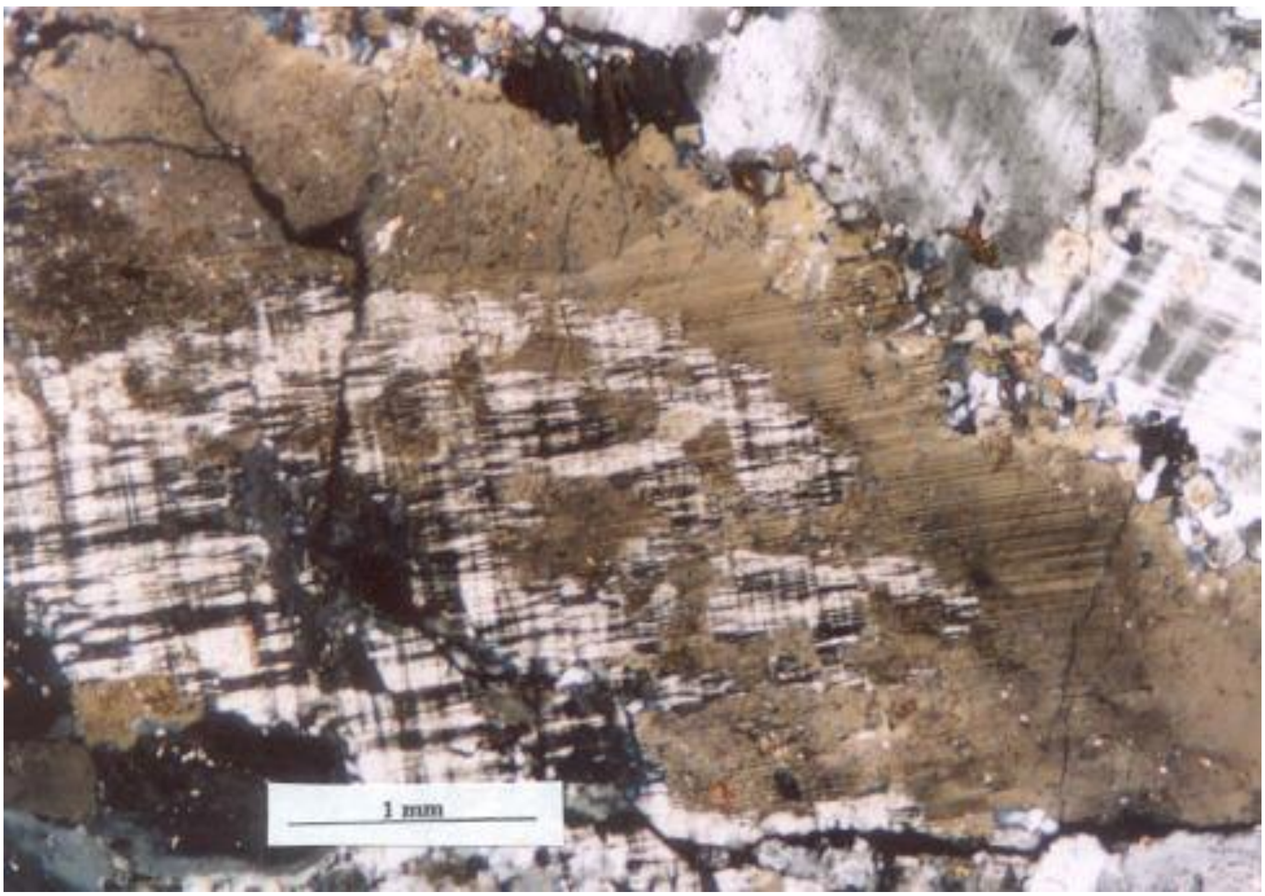

Fig. 29. Microcline replacing plagioclase interior with parallel twin planes

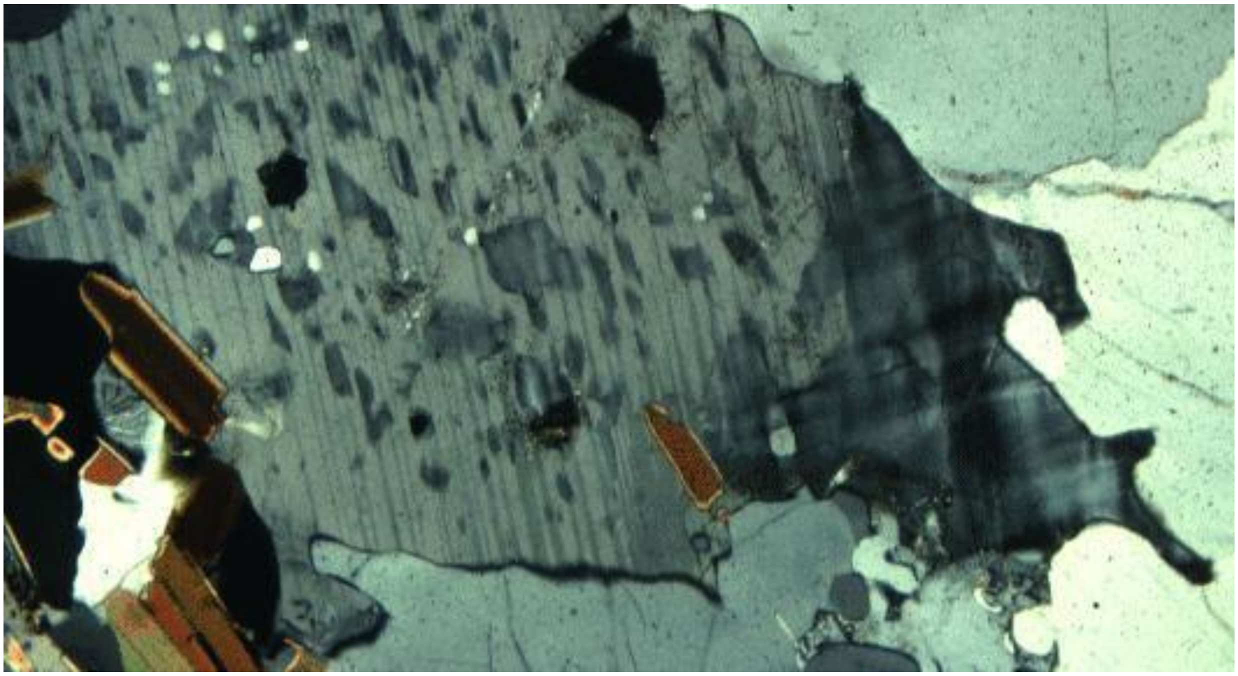

Fig. 30. Microcline with twin plane parallel aligned with albite twin planes where microcline is replacing the plagioclase in its interior.

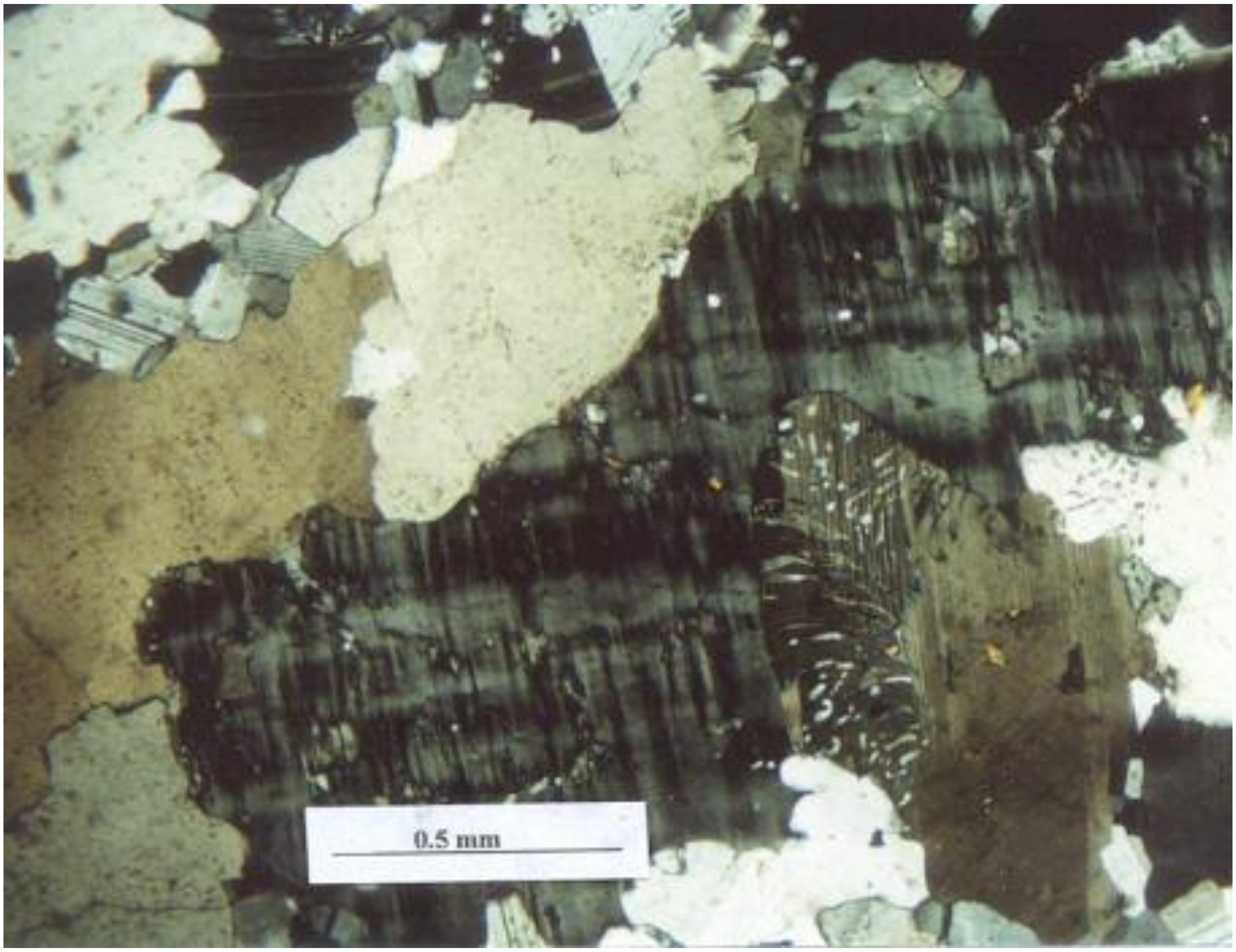

Fig. 31. Microcline and myrmekite with nearly parallel twin planes in non-quartz bearing portion of the myrmekite.

Fig.32. Microcline (black, grid-twinned) replacing zoned plagioclase with parallel alignment of twinning.

Fig. 33 shows an example of where a Carlsbad-twinned plagioclase is replaced at its end with K-feldspar that inherits this Carlsbad twinning. The K-feldspar truncates the former calcic core of the plagioclase that is now speckled with sericite.

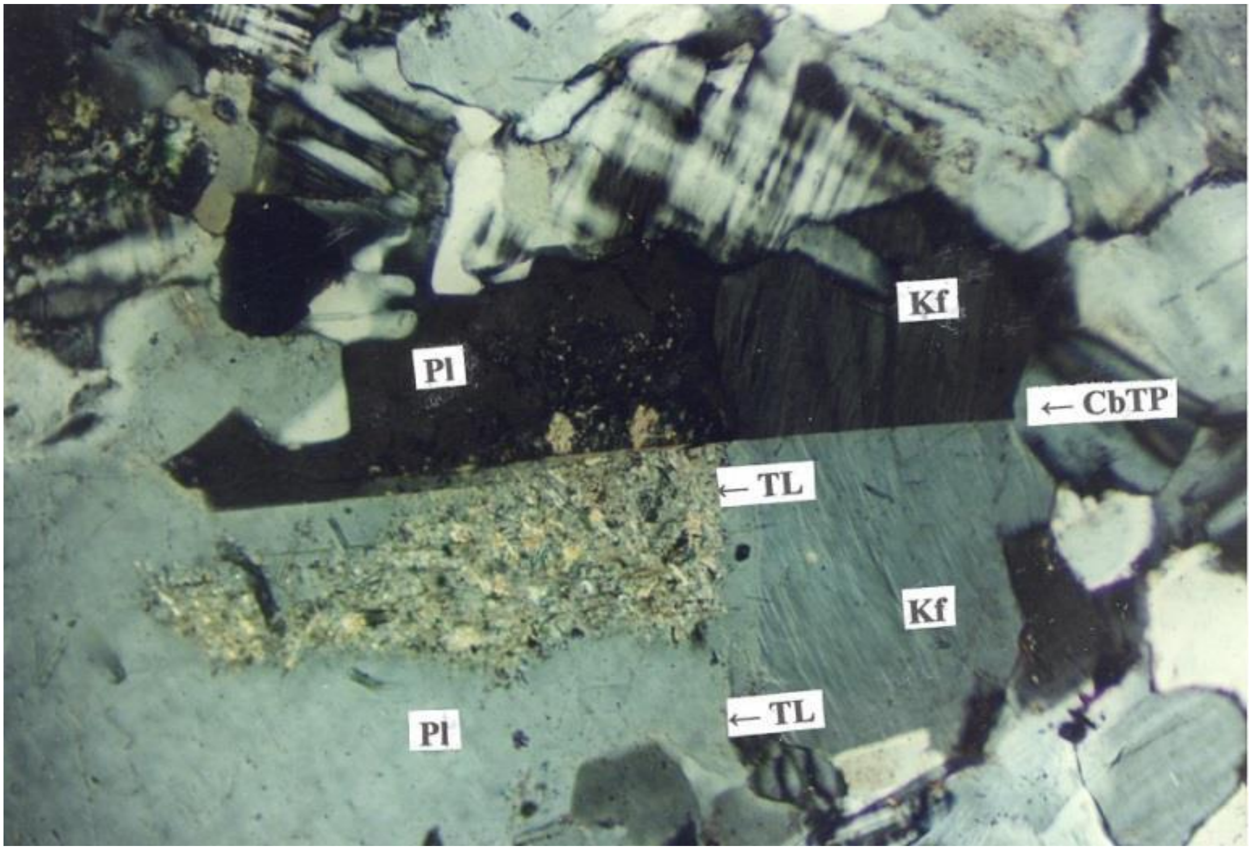

Fig. 33. K-feldspar replacing zoned Carlsbad-twinned plagioclase

STRUCTURAL CONTROL AND VOLUME LOSSES

Hagner (Newhall et al., 1949) found that where primary diorite in the Laramie Range of Wyoming became deformed and foliated, the trend of the foliation became progressively bent into an S-shaped pattern and as the bending increased, the rock became more granitic, and where the bending was greatest, the composition of the rock was changed into granite. Harrison (1951) found that this granite contained myrmekite (Collins, 2021). These changes occurred on a plutonic scale by metasomatic processes over many cubic kilometers as well as in an outcrop scale of less than a cubic meter.

In the Gold Butte anticline of Nevada (), Fryxell et al. (1982) thought that garnet-sillimanite-cordierite gneisses were former metasedimentary rocks (metapelites) that were intruded by diorite and gabbro, but careful studies and sampling of this anticline on both limbs of the anticline (**Fig. 35**) (Collins, 1997c) showed that the northwest limb preserved several un-deformed layered sequences of diorite and gabbro that are interlayered with ultramafic layers.

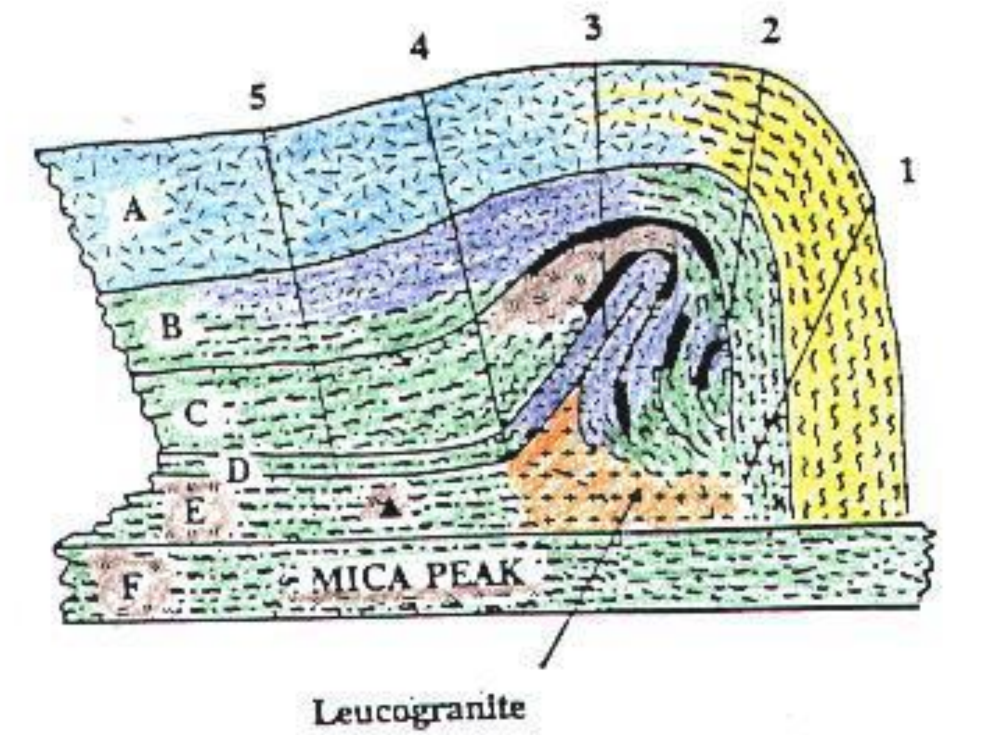

Fig. 35. Schematic of Gold Butte anticline with layered diorite-gabbro sequences in the north east limb and garnet gneisses in the southeast limb. The leucogranite is a syenite.

But that around the nose of the anticline to the southeast limb where these rocks were progressively deformed, they are transformed by metasomatic processes into garnet gneisses (**Fig. 36**), garnet-sillimanite gneisses, or garnet-sillimanite-cordierite gneisses, depending on the calcium and aluminum content of the plagioclase and the Mg-Fe content of the ferromagnesian silicates in the original rock.

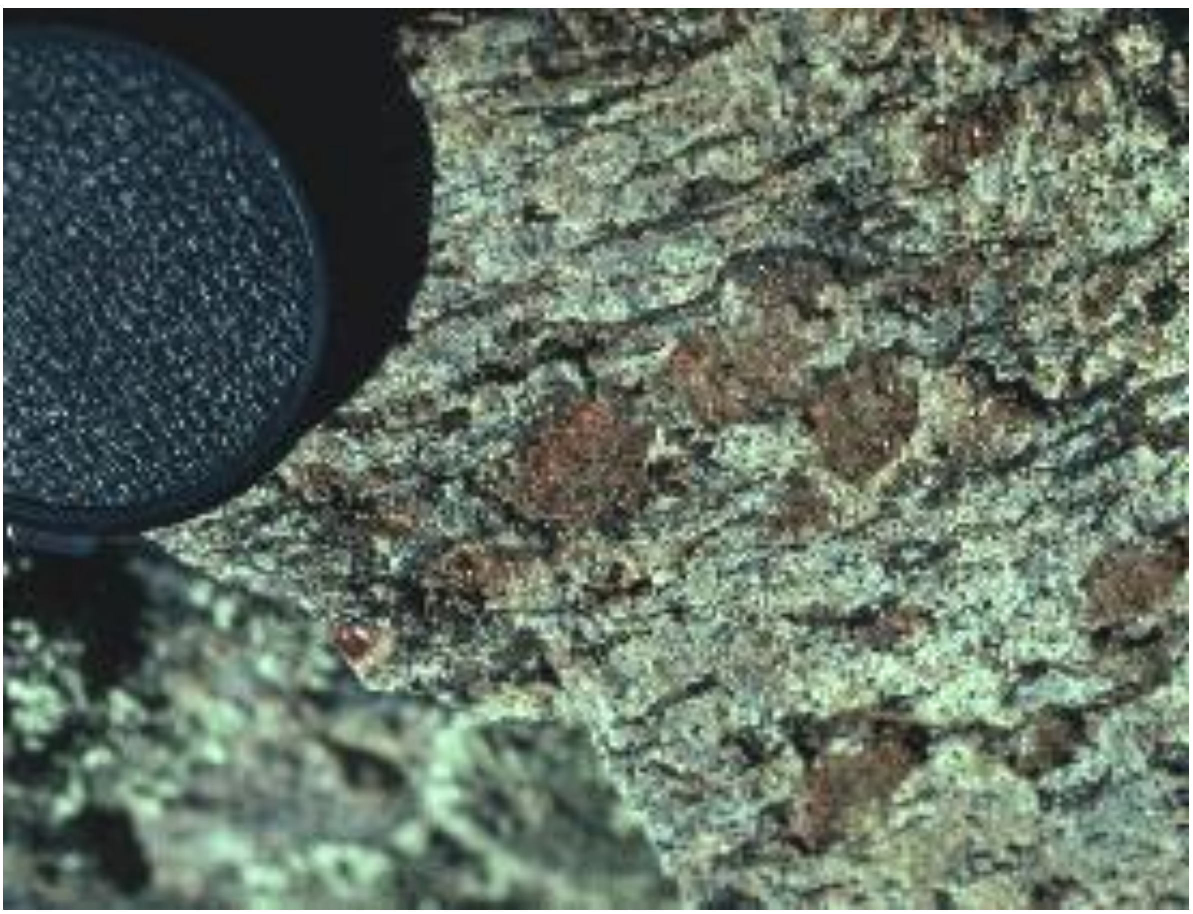

Fig. 36. Garnet gneiss in southeast limb of Gold Butte anticline. Lens cap for scale.

Where these rocks were originally biotite-bearing and, thus, had a source of potassium, K-feldspar bordered by myrmekite was formed (**Fig. 37**).

Fig. 37. Myrmekite in the Gold Butte anticline.

But where biotite was absent, the plagioclase in the rock became progressively more sodic away from the nose of the fold, and the rock composition eventually became a felsic leucogranite/syenite (**Figs. 35** and **38**) rather than granite.

Fig. 38. Fine-grained leucogranite/syenite with tiny garnet crystals in the most deformed part of the Gold Butte anticline (the compressed core of the anticline). Lens cap (5-cm-wide) for scale

In this anticline the Fe in hornblende and pyroxenes of the original diorite and gabbro and some Al in plagioclase that became more sodic went into the almandine garnet and some

Mg, Fe, and Al went into cordierite. Moreover, the extraction of Ca from replaced and recrystallized plagioclase in the southeast limb resulted in a volume loss as this limb was compressed to form a tighter anticline, but some of this volume loss was compensated for by the formation of abundant garnet crystals which have a higher density than the minerals in the original diorite and gabbro layers.

SPLIT ROCK POND ANTICLINE IRON ORES

Collins (1988) has shown that Fe released by the metasomatic replacement and recrystallization of amphibolites can result in the formation of mineable concentrations of magnetite as an iron ore in the Split Rock Pond anticline (**Fig. 39**).

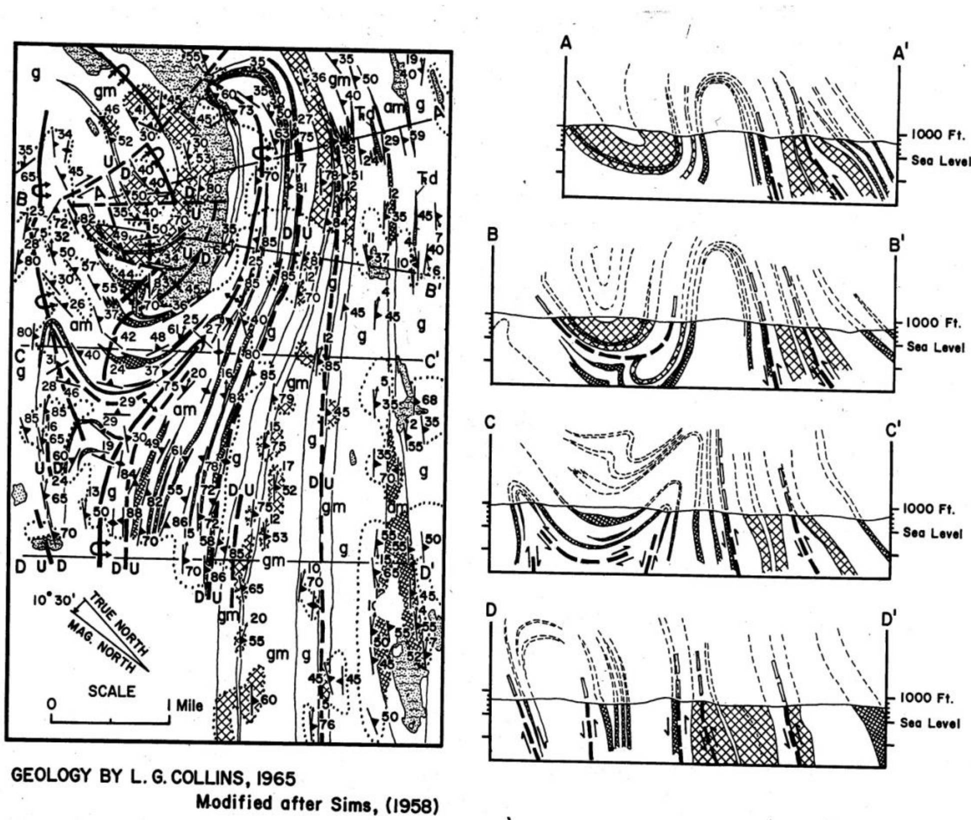

Fig. 39. Split Rock Pond anticline, New Jersey Precambrian terrane.

These amphibolites grade from iron rich biotite-orthopyroxene-plagioclase (An-80) units in the nose of a steeply plunging isoclinal fold to produce either (a) Mg-rich hornblende-diopside-plagioclase (An-10) skarns with adjacent magnetite concentrations or (b) myrmekite-bearing biotite-garnet-sillimanite-K-feldspar gneisses where the former amphibolite contained abundant biotite as a source of K and where very calcic plagioclase supplied large amounts of Al. On that basis, these Al-rich gneisses cannot have once been former metapelites. Volume losses occur as the ferromagnesian silicates (density 3) are converted to magnetite (density 5), allowing the anticline in which the iron ores occur to become isoclinal.

Another example of structural control occurs in the Isabella L-shaped diorite-gabbro mass in the Isabella pluton in southern California **(Fig. 40**) where several hundred granite dikes penetrating it on its north side.

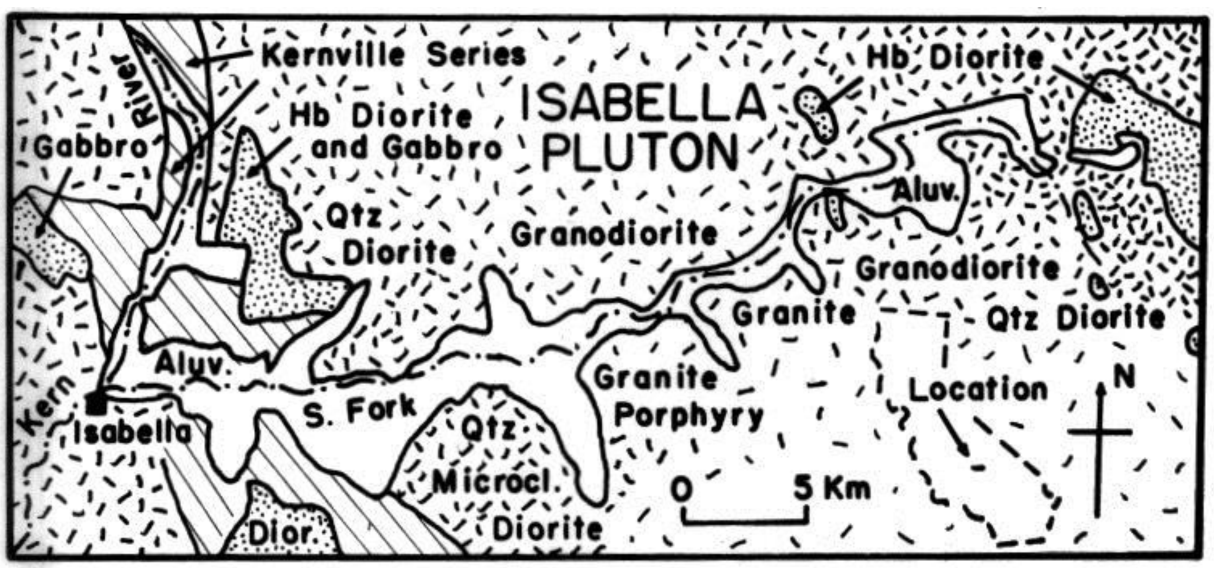

Fig. 40. Geologic map showing the location of an “L-shaped” horblende (Hb) diorite and gabbro mass (left side, speckled area) in the Isabella pluton.

Two alternatives show what happens if (A) the granitic dikes were formed by injection of magma into fractures, resulting in expansion to make room for the magma or if (B) loss of elemental components causes shrinkage to occur (**Fig. 41**). If these dikes resulted from injection of magma, the added mass should have expanded the pluton, opening it like a fan (**Fig. 41**).

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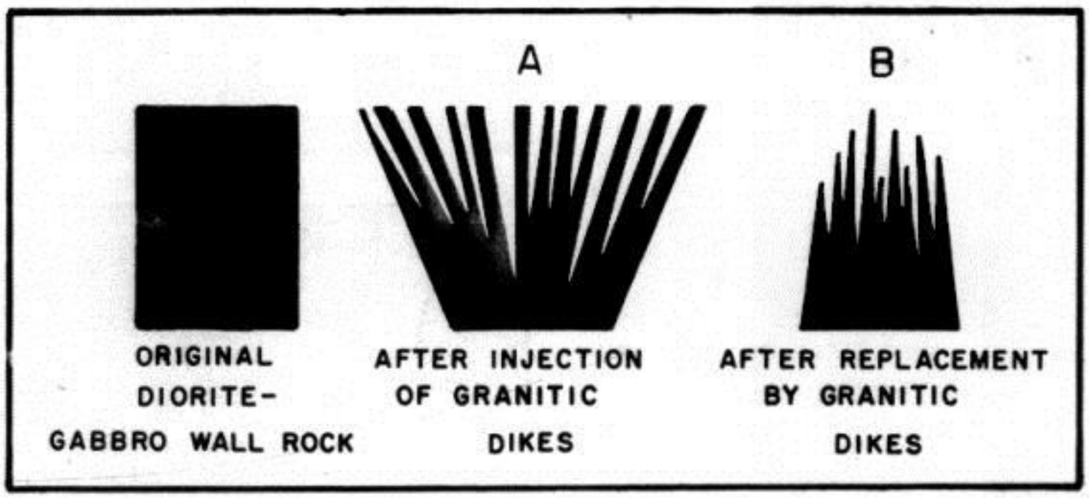

Fig. 41. Two alternatives show what happens if (A) the granitic dikes were formed by injection of magma into fractures, resulting in expansion to make room for the magma or if (B) loss of elemental components causes shrinkage to occur.

Instead, this pluton has shrunk to a relatively pointed end as Ca, Mg, and Fe have been extracted, leaving a granite residue in former micro-fractured shear-places as hundreds of granite dikes. K-feldspar bordered by myrmekite in metasomatically replaced diorite grades across foliation to these dikes (Collins, 1989).

Pala pegmatites in southern California have watermelon tourmalines, pollucite, and emeralds growing as crystals in cavities in the pegmatites bordered by biotite-bearing diorite wall rocks (Jahns, 1954). A few hundred meters away from one studied pegmatite along strike, the diorite is un-deformed, but toward the pegmatite, the diorite is deformed, micro-fractured, and K-feldspar forms (bordered by myrmekite) and then grades into the gem-bearing pegmatite. On that basis, the gems in the pegmatite formed in place from elements (Li, B, Be) carried from distant recrystallized diorite, and loss of mass (Ca, Mg, and Fe) occurred to produce the openings in which the gem crystals could grow rather than the gem minerals crystallizing from magma that was injected into the diorite from an outside deep granite magma source (Collins, 1988). Injected magma should not leave a cavity. Obviously, temperatures eventually got hotter than 550 degrees C where the pegmatite crystallized.

METAPELLITES AND MYRMEKITE

Kyanite and sillimanite in many places are produced by high temperature metamorphism of former aluminum-rich kaolinite-bearing shales (pelites), but this need not be true in all geologic environments. For example, kyanite and tourmaline-bearing rocks in the Cargo Muchacho Mountains in southeastern California can be traced from relatively un-deformed biotite-hornblende diorite through a zone of deformation in which K-feldspar and myrmekite are progressively produced and then eventually gradually into where the K-feldspar and plagioclase are mostly converted to muscovite-phyllite containing kyanite and occasional schorl tourmaline (Collins, 1998) It is clear that in this place such rocks are not metapelites because of the observed transitional changes. This creation of Al-rich minerals happens where hydrous fluids were less capable of removing insoluble Al from the micro-fractured, replaced, and recrystallized rocks in comparison to the greater solubility of Ca, Na, Mg, and Fe.

Near Cooma, Australia, is the Cooma pluton (**Fig. 42**) containing a granodiorite composed of biotite, cordierite, plagioclase, orthoclase, and quartz, and this pluton is bordered by a metamorphic aureole in metasedimentary rocks (metapelites and metapsammites) which grade from low- to high-grade zones with an outer biotite zone that progressively converts toward the pluton to cordierite, andalusite, K-feldspar, and sillimanite zones and finally to a migmatite zone adjacent to the pluton.

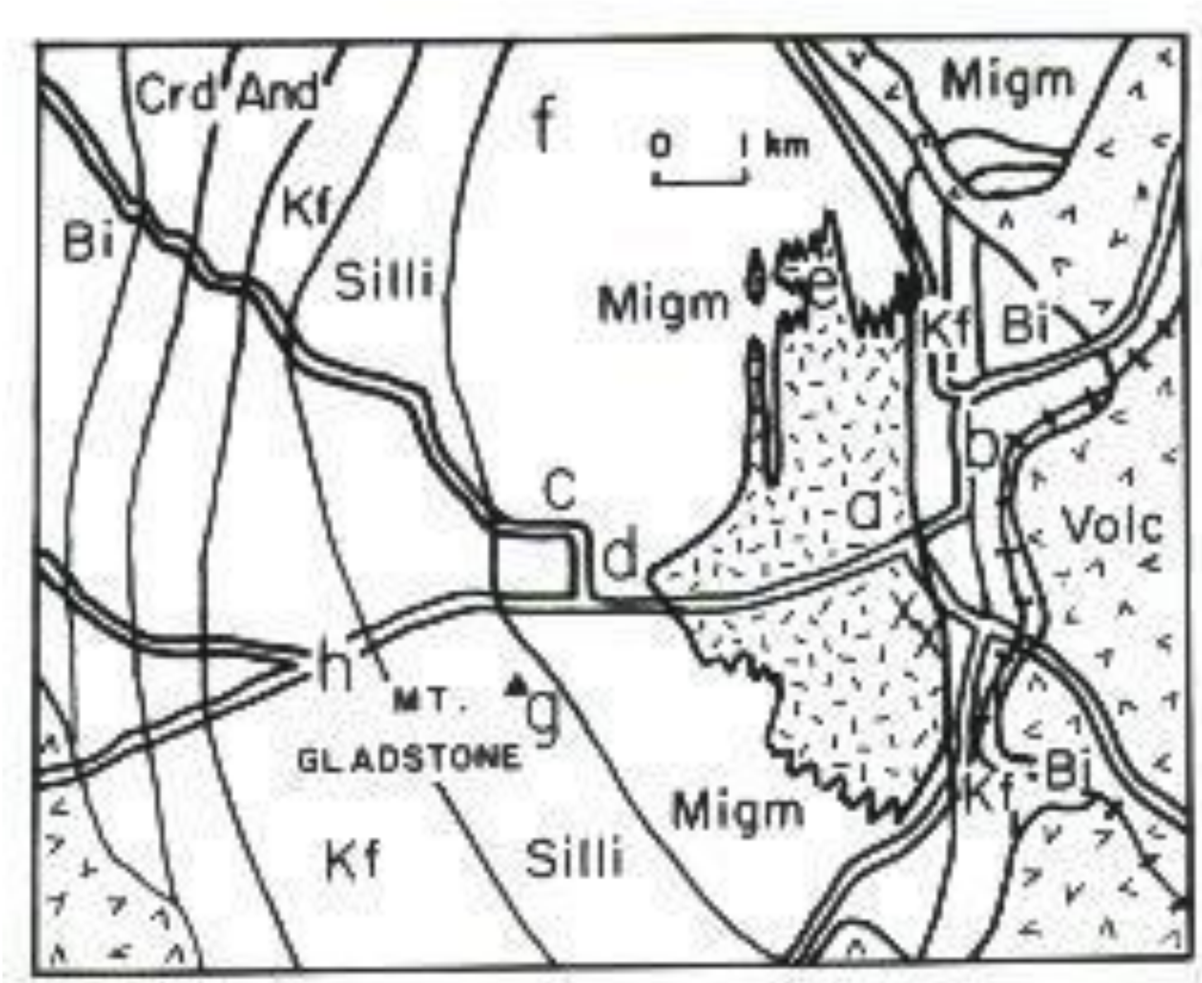

Fig. 42. Geologic map of Cooma Complex. Bi = biotite; Crd = cordierite; And = andalusite; Kf = orthoclase; Silli = sillimanite; Migm = migmatite. Dash pattern = Cooma granodiorite; Volc = younger volcanic cover. East side of Cooma pluton has sillimanite through biotite zones, but zones are too narrow to plot on figure; the migmatite zone is missing.

Flood and Vernon (1978) interpreted the pluton to be the result of anataxis of a former pelite. However, the orthoclase is bordered by myrmekite both in the pluton and in the metasedimentary rock unit (**Fig. 43**) bordering the pluton.

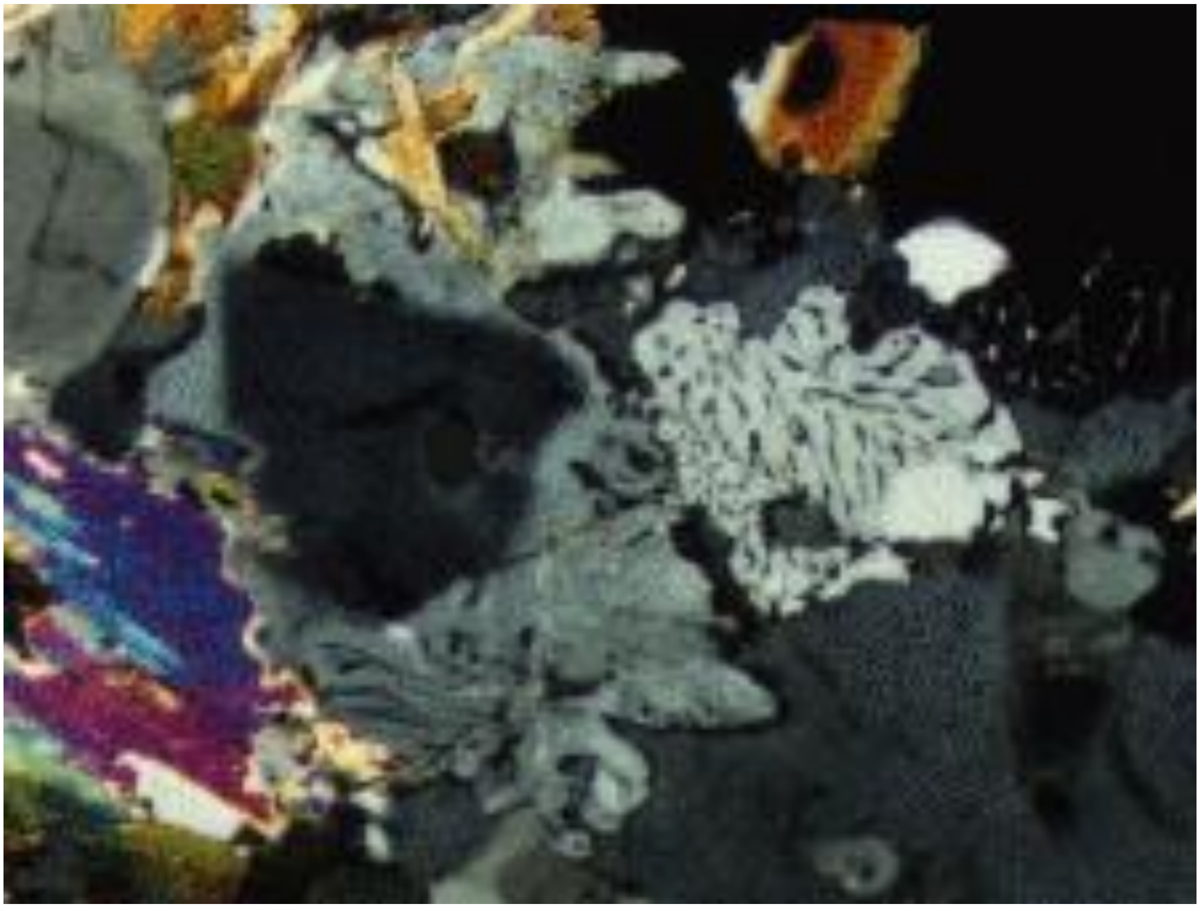

Fig. 43. Myrmekite in wall rock Cooma.

Myrmekite does not crystallize from magma. The interior of the pluton contains a homogenized jumbled mixture of biotite, cordierite, plagioclase, orthoclase, and quartz crystals, but at the north end, the metasedimentary myrmekite-bearing rock unit still retains its parallel foliation/bedding orientation and myrmekite content, and this foliation/bedding can be traced south gradually into progressively disoriented layering and then into the jumbled mixture of minerals in the pluton. So, it is clear that the pluton and the adjacent metasedimentary rocks have been locally subjected to strong deformation that opened the system to K-bearing metasomatic fluids that produced the orthoclase and myrmekite (Collins, 1988).

P**o-HALOS IN BIOTITE AND MYRMEKITE**

It is clear that myrmekite forms in rocks that have an open system for hydrous-fluid movements as a result of micro-fracturing that allow metasomatic replacement processes to occur. What is generally not realized is that such an environment is precisely the place where Po-halos can form in recrystallized biotite (**Fig. 44**).

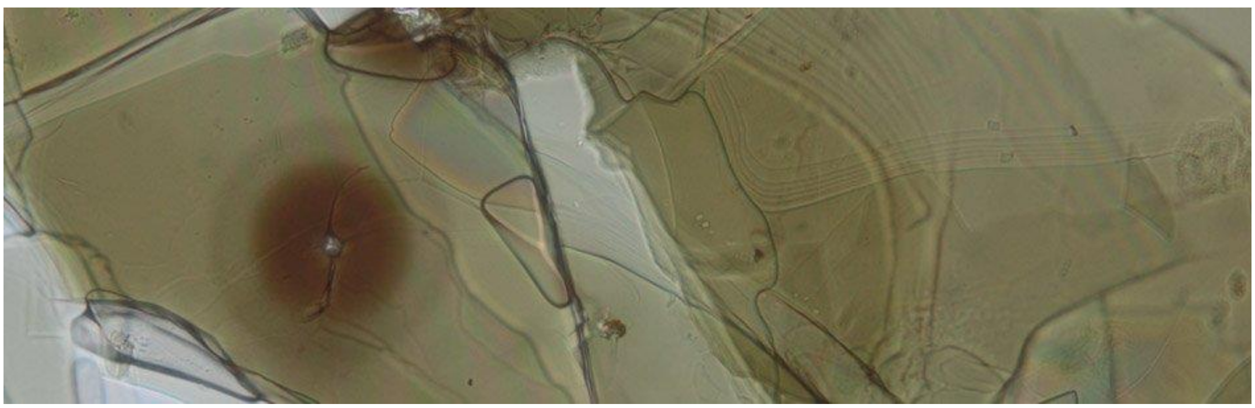

Fig. 44. Po-14 halo in biotite,.

Biotite-bearing granitic rocks that have not been subjected to micro-fracturing and introduction of hydrous fluids commonly contain U-halos (Fig. around tiny inclusions of zircon crystals (**Fig. 45**) but no Po-halos.

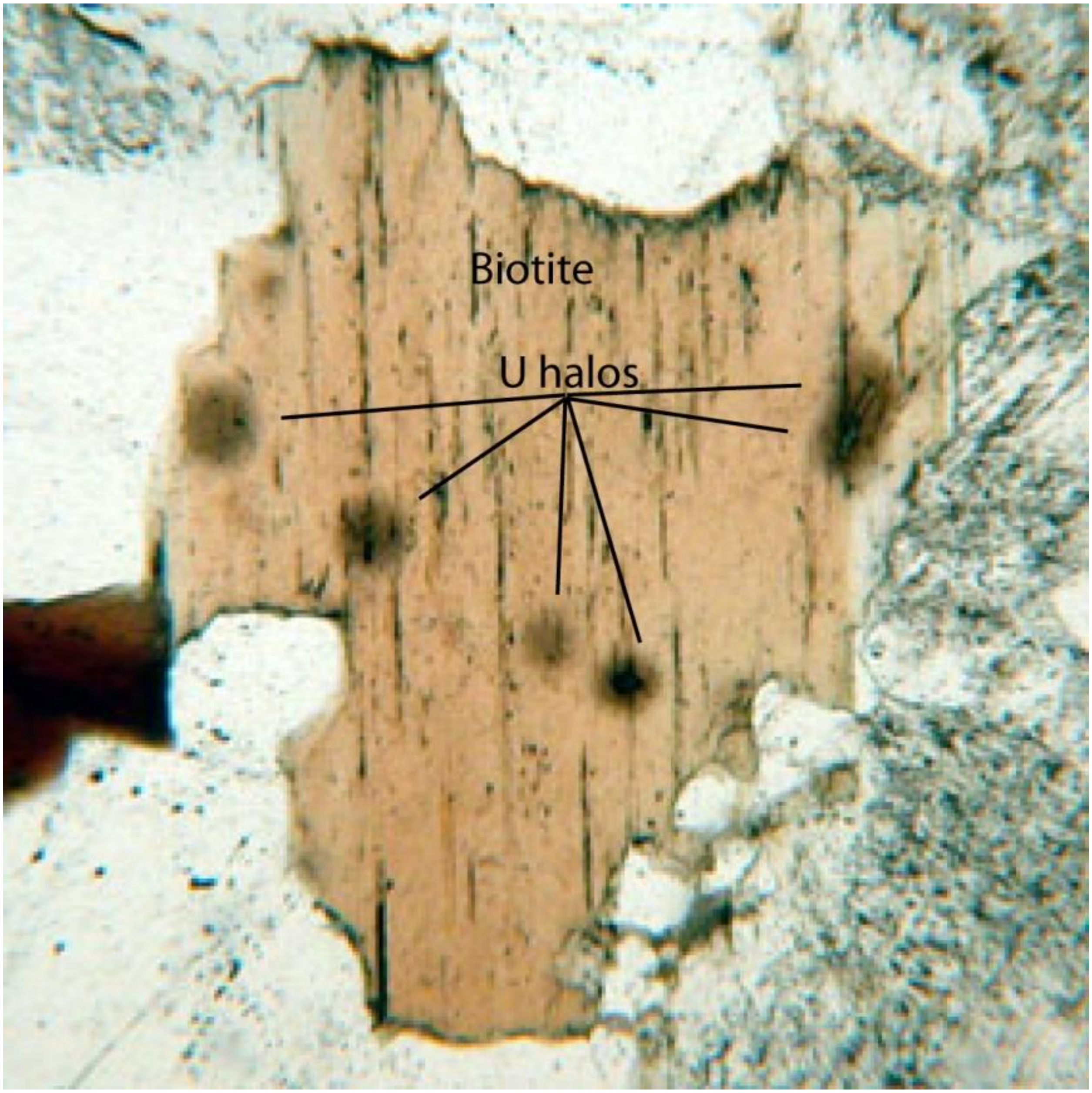

Fig. 45. U-halos around tiny zircon crystals in biotite.

However, where myrmekite is found, the biotite crystals generally lack U-halos in biotite but may contain Po-halos if there was once nearby U-bearing zircon or uraninite crystal sources (Collins and Collins, 2010)

Ca- AND Na-METASOMATISM AND MYRMEKITE

Not mentioned so far in this article is myrmekite formed by Ca- and Na-metasomatism instead of K-metasomatism. In that case, where primary magmatic K-feldspar is replaced by Ca- and Na-bearing hydrous fluids, because the volume occupied by the structural crystal lattice of K-feldspar contains more silica than can be accommodated by the replacing volume of the plagioclase of the myrmekite, extra silica is left over that makes the quartz vermicules, as found at Alastaro, Finland (Collins, 1997d). Here, in some places entire crystals of K-feldspar, 2.5 cm long, are replaced by hundreds of myrmekite grains (**Fig. 46**).

Fig. 46. Aggregate myrmekite. Photo is part of a mosaic of magnified images of an altered K-feldspar megacryst (2.5 cm long in unmagnified form) near Alastaro, Finland. The mosaic extends for about 2 m long and 1 m wide. Some unreplaced remnant inclusions of quartz and biotite are scattered among the myrmekite grains. The photo includes about one sixth of the mosaic area. Source: Collins (1997d, Figure 7b).

Also, the quartz vermicules formed by this kind of metasomatism tend to have equal thickness instead of being tapered, and the myrmekite can be bordered by biotite, quartz, K-plagioclase, and plagioclase rather than only K-feldspar (**Figs. 47** and **48**) (Collins and Collins, 2013).

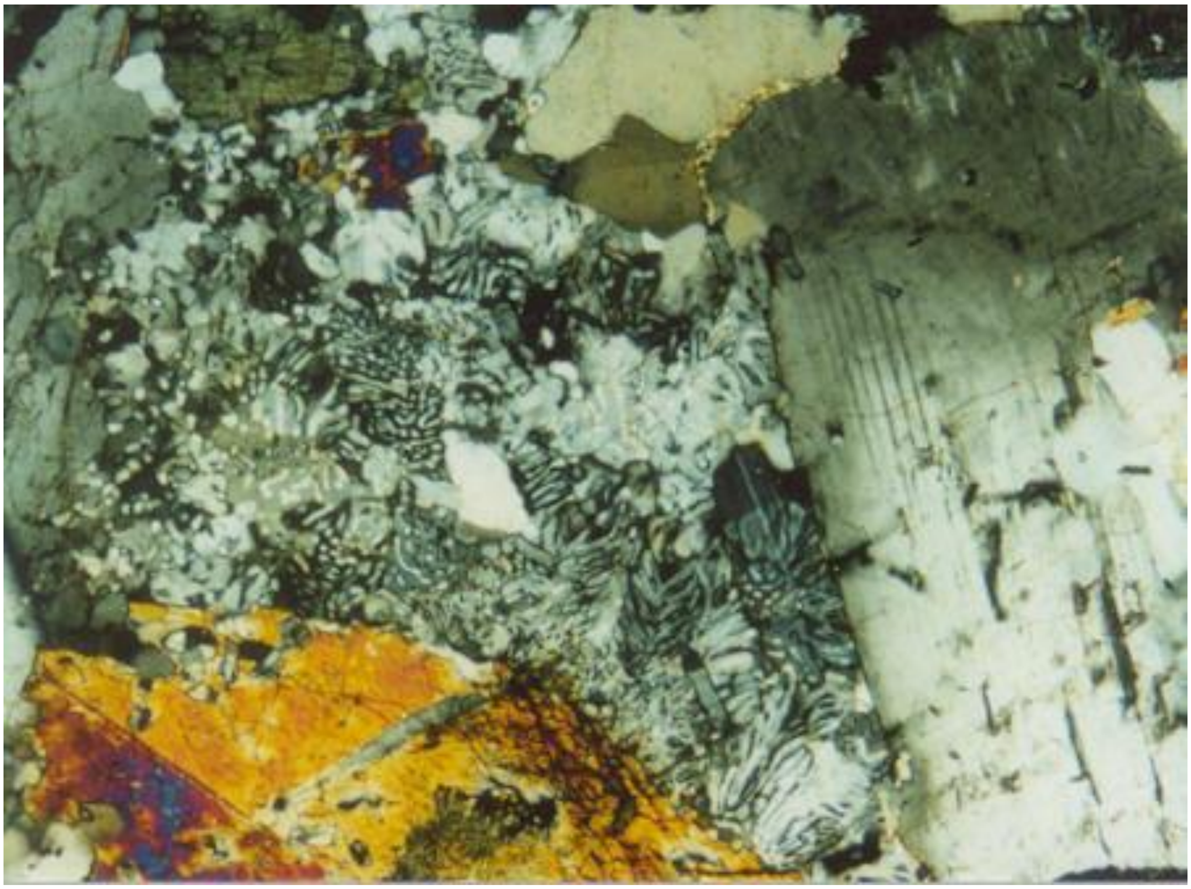

Fig. 47. Aggregates of myrmekite (left side) formed around the plagioclase crystals (right side; albite twinned; white and gray) in diorite, which may have resulted from Ca-metasomatism of sodic plagioclase. Quartz (cream; white). Biotite (brown). From the Alvand plutonic complex, Hamadan, Iran. Source: Behnia and Collins (1998, Figure 2.

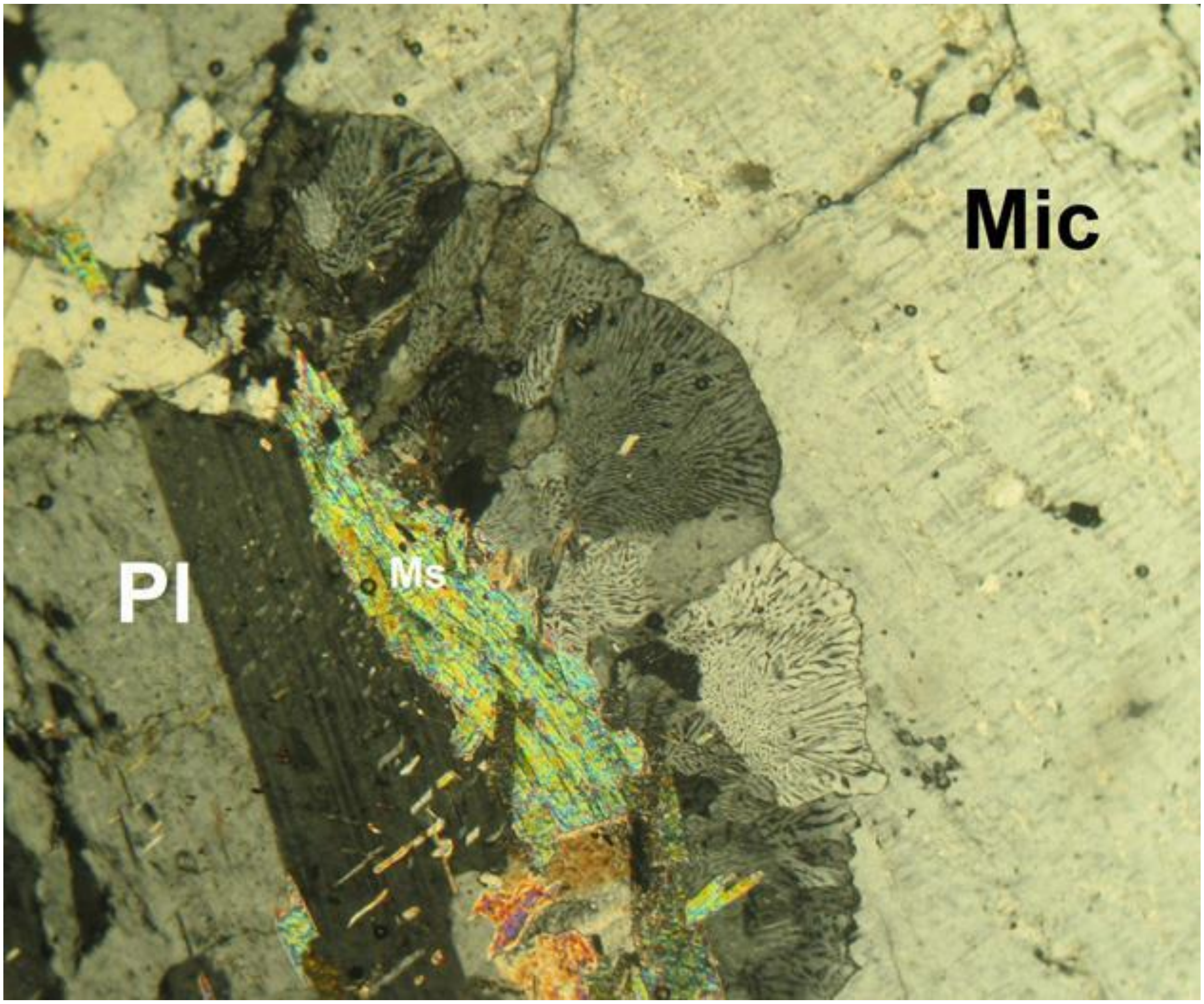

Fig. 48. Wartlike myrmekite from Iran. Microcline (Mic; right side). Albite- and Carlsbad-twinned plagioclase (Pl; left side). Muscovite (Ms; green, blue, and red). Biotite (tan). Quartz (cream white; upper left). Image is from monzogranite sample from the Alvand plutonic complex, Hamedan, Iran. Photo contributed by Ali Sepahi.

MYRMEKITE AND PLATE TECTONICS

In the evolution of the Earth's continental crust down-going subducting plates provide water that rises to produce the various magmatic masses that go through magmatic differentiation processes. But after cooling and solidification, continued plate tectonics thrust and deform the solidified masses at temperatures below 550 degrees C. These movements create foliation in the igneous masses, shearing, micro-fracturing of crystals, folding of the foliated rocks into S-shaped masses with low-pressure sites in centers of the S, and folding into tight anticlines with sliding limbs that open up avenues for hot hydrous fluids to bring in K and Si and extract Ca, Mg, and Fe. In that way the mineral and chemical compositions of the original masses are changed into K-feldspar (plus myrmekite), sodic plagioclase, and quartz in granite which are stable minerals below 550 degrees C.

CONCLUSIONS

Myrmekite in a thin section should be a signal that the rock in which it occurs has been subjected to a great deal of change in its chemical and mineralogical composition and that these changes likely can result in a volume loss, as in rocks in the Gold Butte anticline. Moreover, such volume losses may occur because of the removal of Ca, Mg, and Fe even though K and Si may have been added to produce K-feldspar in place of plagioclase and as quartz is added in place of ferromagnesian silicates. In that process some or all of the high-temperature ferromagnesian silicate minerals, except perhaps for some biotite, may no longer be present. Metasomatism always destroys the evidence for pre-existing minerals.

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