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29. The K-replacement modifications of the Kavala megacrystal granodiorite and the Sithonia euhedral-epidote-bearing, hornblende-biotite granodiorite in northern Greece

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Introduction

Two of the many granitic plutons visited during the September 2-8, 1998, Eurogranites '98 field trip in northern Greece (Sideris *et al.*, 1998) have particularly interesting textures or mineralogy. These granitic rocks are the megacrystal Kavala granodiorite (Christofides *et al.*, 1995, and Kyriakopoulos *et al.*, 1989), which was examined at Stop 23, and the euhedral-epidote-bearing, hornblende-biotite granodiorite of the Sithonia pluton (Christofides *et al.*, 1990), which was investigated at Stop 32. These granitic rocks are in the Circum-Rhodope Belt (Fig. 1) and have a *primary magmatic* origin. In addition to their magmatic features, however, they exhibit textural features that suggest that magmatism was not the only process affecting these rocks in their histories.

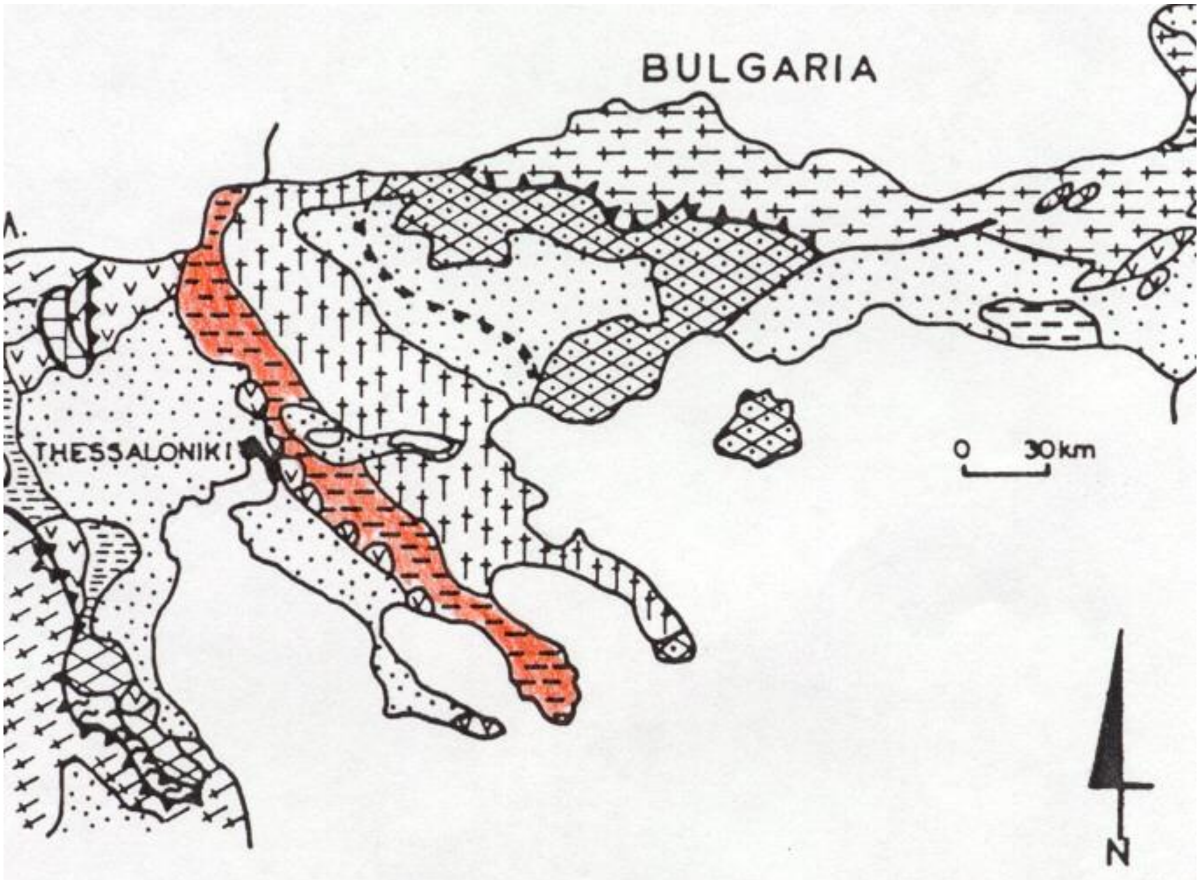

Fig. 1. Geologic map of northern Greece modified after figure in the guidebook, Sideris *et al.*, 1998). The Circum-Rhodope Belt is colored red.

The Kavala megacrystal granodiorite

Outcrops of the Kavala megacrystal granodiorite (Fig. 2) at Stop 23 of the field trip are certainly eye-catching. Thick layers containing cataclastically deformed microcline megacrysts in a groundmass of biotite, hornblende, feldspars, and quartz alternate with thinner mafic bands containing plagioclase, hornblende, and biotite and leucocratic bands consisting mostly of quartz and microcline (Fig. 3 and Fig. 4). Bands are a few mm wide; layers are as much as 10 m. wide.

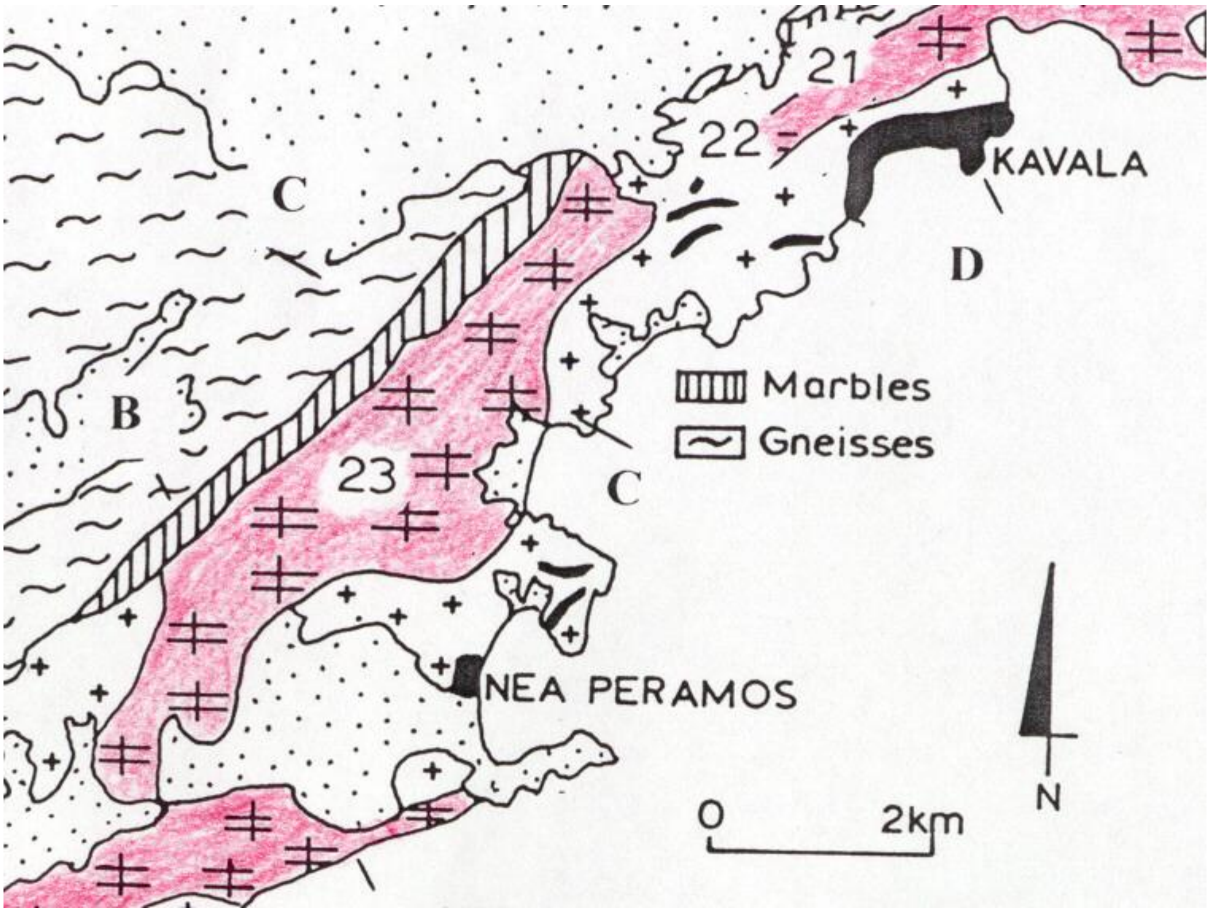

Fig. 2. Geologic map of the Kavala pluton (modified after sketch map in Sideris *et al.*, 1998). Area of megacrystal rock is shown in pink. Site 23 is in the center.

Fig. 3. Foliated megacrystal Kavala granodiorite with remnants of biotite- and hornblende-rich bands. Photo taken at Stop 23, 15 km from Kavala City on road to Chalkidiki. Chisel is 20 cm long.

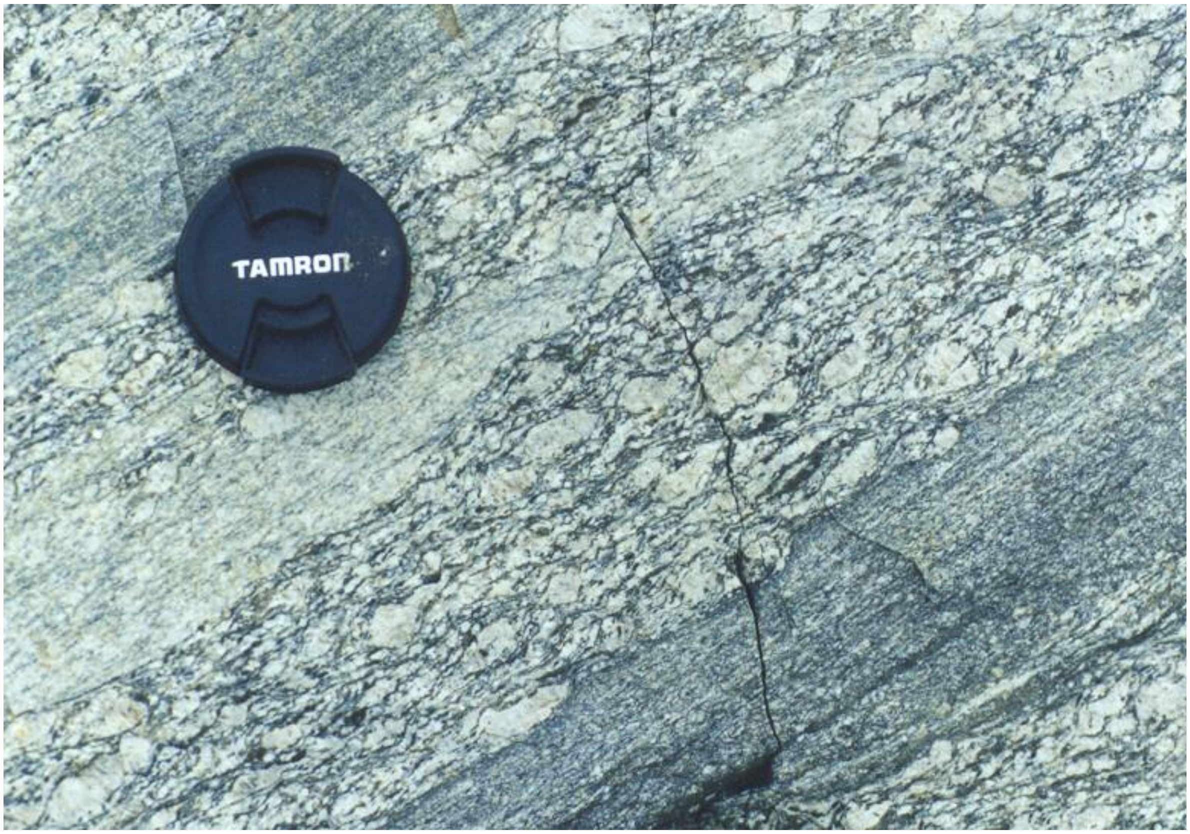

Fig. 4. Foliated megacrystal Kavala granodiorite with three different mylonitic bands showing different percentages of remnant biotite and hornblende that are incompletely replaced by quartz. Photo taken at Stop 23, 15 km from Kavala City on road to Chalkidiki. Tamaron lens cap is 5.5 cm wide.

On the basis of the appearance of these layers, Sideris *et al.* (1998) suggested that they can *"be considered a simple result of a fractional crystallization as the bands and layers are always parallel to the ab plane of the deformation. The bands and layers formation is straightly related to the tectonism, and they should be characterized para-intrusive and para-crystalline."* This tectonism is suggested to produce a *"whole series of reactions among the mineral constituents, recrystallization, crystaloblastesis, exchanges of material, and metamorphic differentiation took place only under the influence of the mechanical deformation."* A careful examination of these different bands and layers (Fig. 3 and Fig. 4) in the field, however, suggest that this interpretation is only partly correct.

If metamorphic differentiation had occurred in which components of quartz and K-feldspar had separated from the primary magmatic rock and migrated to the leucocratic zones, then enrichment of biotite and hornblende should occur in the mafic band immediately adjacent to the leucocratic zones while still farther away remnants of K-feldspar and quartz in undifferentiated rock that did not diffuse should still remain. No such relationships are observed (Fig. 3 and Fig. 4). Furthermore, a close-up view of a megacrystal granodiorite layer shows that the microcline megacrysts were not formed by a separation of quartz- and microcline-components from the mafic bands because these megacrysts *enclose* remnants of biotite and hornblende (Fig. 5).

Fig. 5. Close-up of megacrystal Kavala granodiorite at Stop 23, showing remnants of biotite and hornblende crystals in some megacrysts. Pinkish microcline megacrysts also have inclusions of white plagioclase and rims of white myrmekitic plagioclase. Megacrysts are the same size as shown in Fig. 3 and Fig. 4.

Likewise, if fractional crystallization in magma in the Kavala pluton were to happen, then abrupt changes would have to occur, back and forth, of crystals settling from (1) melts rich in SiO_2-content to produce quartz and K-feldspar in one layer to (2) melts poor in SiO_2-content to produce biotite-hornblende-plagioclase in the adjacent layer. Such abrupt compositional changes with broad differences in SiO_2-content in closely-spaced cyclic layers are highly unlikely.

How then are the different bands and layers formed if metamorphic differentiation and fractional crystallization are ruled out? The clue to their formation is found in the textures that indicate K-metasomatism. In early stages, incomplete replacements of deformed plagioclase by microcline create myrmekite and island remnants of plagioclase which are in parallel optical continuity with larger plagioclase crystals outside the microcline (Fig. 6 and Fig. 7). During this process interiors of former Carlsbad-twinned plagioclase crystals were replaced by the microcline, and, thereby, the microcline crystals inherited the Carlsbad-twinning form the plagioclase. See examples of this kind of progressive interior replacements also in the Waldoboro complex in Maine (http://www.csun.edu/~vcgeo005/Nr6Waldoboro.pdf).

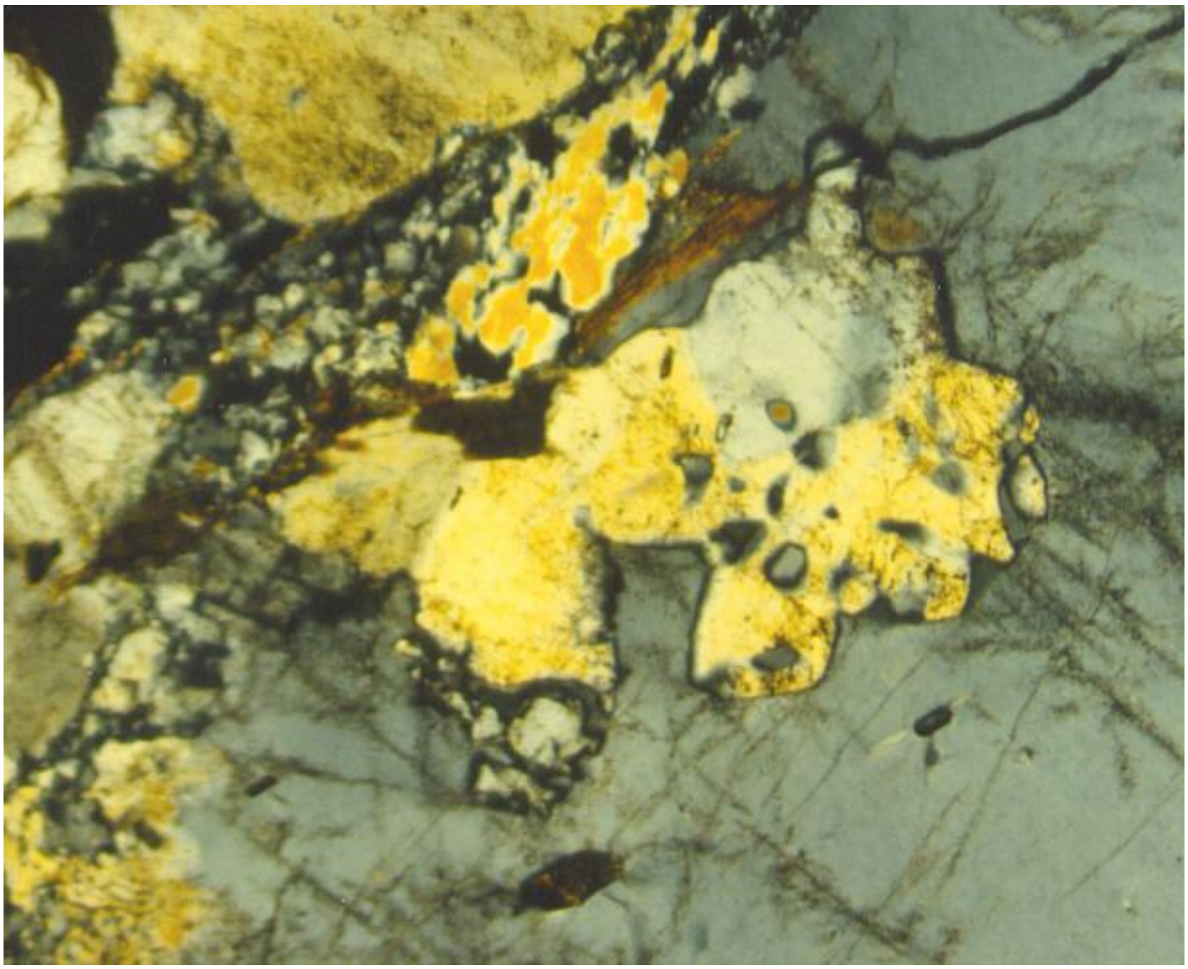

Fig. 6. Microcline (light gray; right side) encloses and embays myrmekite (cream and gray) with relatively coarse quartz vermicules (ovals). Border of microcline shows strong cataclasis. Part of the plagioclase (lower left of center; light gray below cream) is penetrated and replaced along fractures by the microcline.

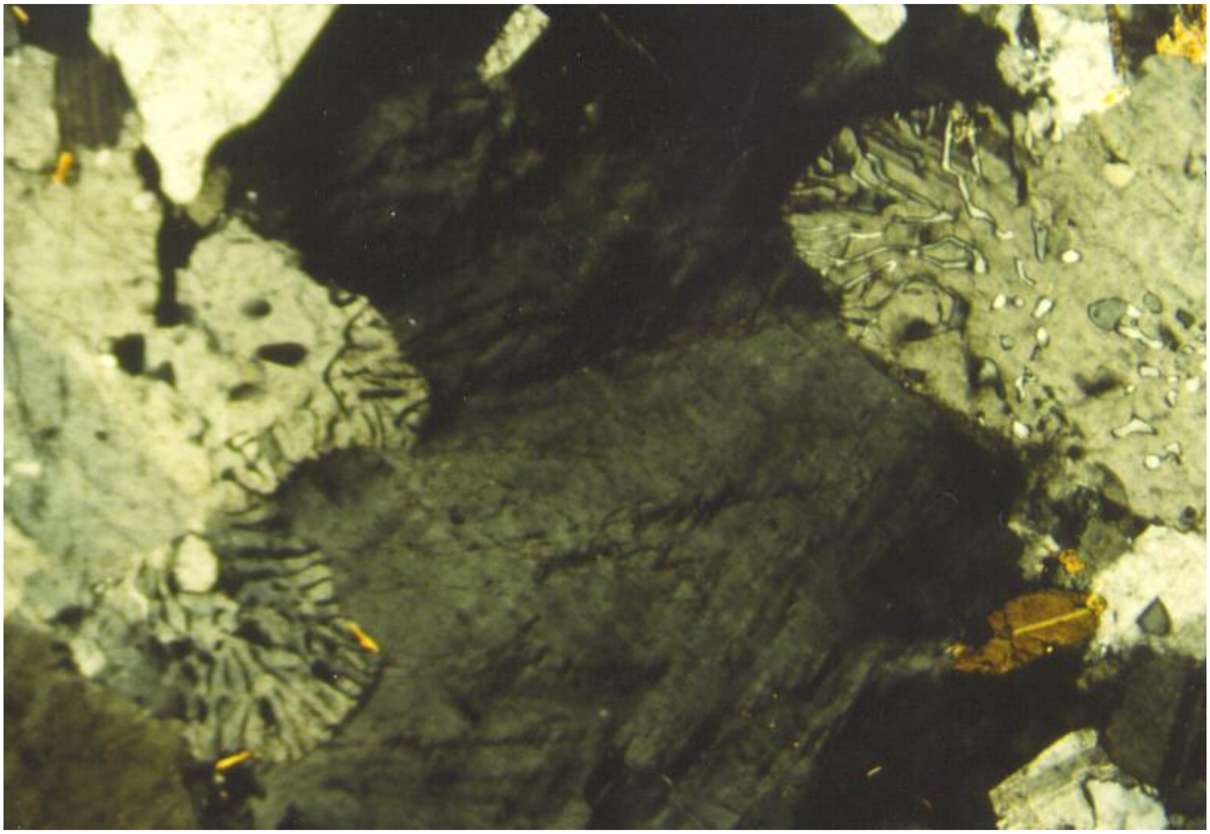

Fig. 7. Microcline (center; black, gray) penetrates and replaces non-quartz-bearing part of plagioclase next to the myrmekite (upper left quadrant; light gray and cream) along fractures (upper part of myrmekite; left side). Myrmekite also occurs on right side. Biotite (brown, light tan).

On the basis of these kinds of replacements, the model presented here is that the original plutonic rock was (1) relatively massive, lacking layering, (2) entirely composed of a biotite-hornblende diorite or tonalite, lacking K-feldspar megacrysts, and (3) progressively deformed along definite planar bands, likely in a thrust zone. The first types of layers that were produced are the mafic bands, which would have been those parts of the tonalite or diorite which were not strongly deformed and replaced. These bands would be remnants of the original tonalite or diorite. The second type would be produced where the deformation was moderate, breaking grain boundary seals and fracturing crystals. Megacrysts of microcline would form, replacing plagioclase and enclosing remnants of broken biotite and hornblende. These places became the wide zones (layers) of megacrystal granodiorite. Note the isolated K-feldspar megacryst in the mafic band in Fig. 3

which indicates that K-bearing fluids moved into the mafic band at this place to replace deformed plagioclase.

The third type would be produced where deformation was intense and concentrated along narrow bands. The crystals would be crushed, recrystallized, and replaced, and then crushed again during renewed movements, so that this localized system was kept open to progressive and more complete metasomatism. In these places, the leucocratic bands (Fig. 4) would form. Here, the broken plagioclase crystals were almost entirely replaced by the K-feldspar (microcline), and most of the broken biotite and hornblende crystals were replaced by quartz. Because of the repeated deformation, no large microcline crystals could form, and annealing (recrystallization) during the replacements would eliminate much of the evidence for the strong cataclasis. Myrmekite in the leucocratic bands, however, provides support for the metasomatic history.

The aforesaid replacements, related textures, and formation of the three types of layers would have evolved prior to the later mechanical deformation that is observed in the outcrops, as evidenced by the deformation of the microcline. Sideris *et al.*, (1998) suggested that the most common of the alterations that resulted from the observed mechanical deformation *"are breakdown of the anorthic component of the plagioclase; biotite and quartz recrystallization; garnet, ilmenite, titanite, magnetite, and rutile formation; alteration of hornblende to Fe-poor actinolitic hornblende; and finally the formation of epidote, chlorite, hematite, and the second generation of plagioclase."* Some of these alteration minerals were likely formed during the late cataclastic deformation. However, during the earlier K-replacements of the plagioclase to produce the microcline, the K displaces Ca, Na, and some Al. The displaced Al would go into the garnet and epidote that commonly occur in the Kavala megacrystal granodiorite. The displaced Na would enter other altered and deformed plagioclase crystals to form more-sodic plagioclase that is unzoned, and this plagioclase would become the secondary plagioclase that is reported in the granodiorite. Titanite, ilmenite, and magnetite are likely remnant primary minerals of the former tonalite or diorite.

The Sithonia hornblende-biotite granodiorite pluton

The Sithonia plutonic complex also occurs in the Circum-Rhodope Belt (Fig. 1 and Fig. 8) and is situated in the central eastern part of the Chalkidiki peninsula (Christofides *et al.*, 1990). In many places it has a cataclastic texture and a well oriented fabric. Leucocratic dykes, intrusive relationships with Permian to Jurassic flysch and Jurassic metabasites, and contact metamorphic effects clearly indicate that the intrusions were shallow.

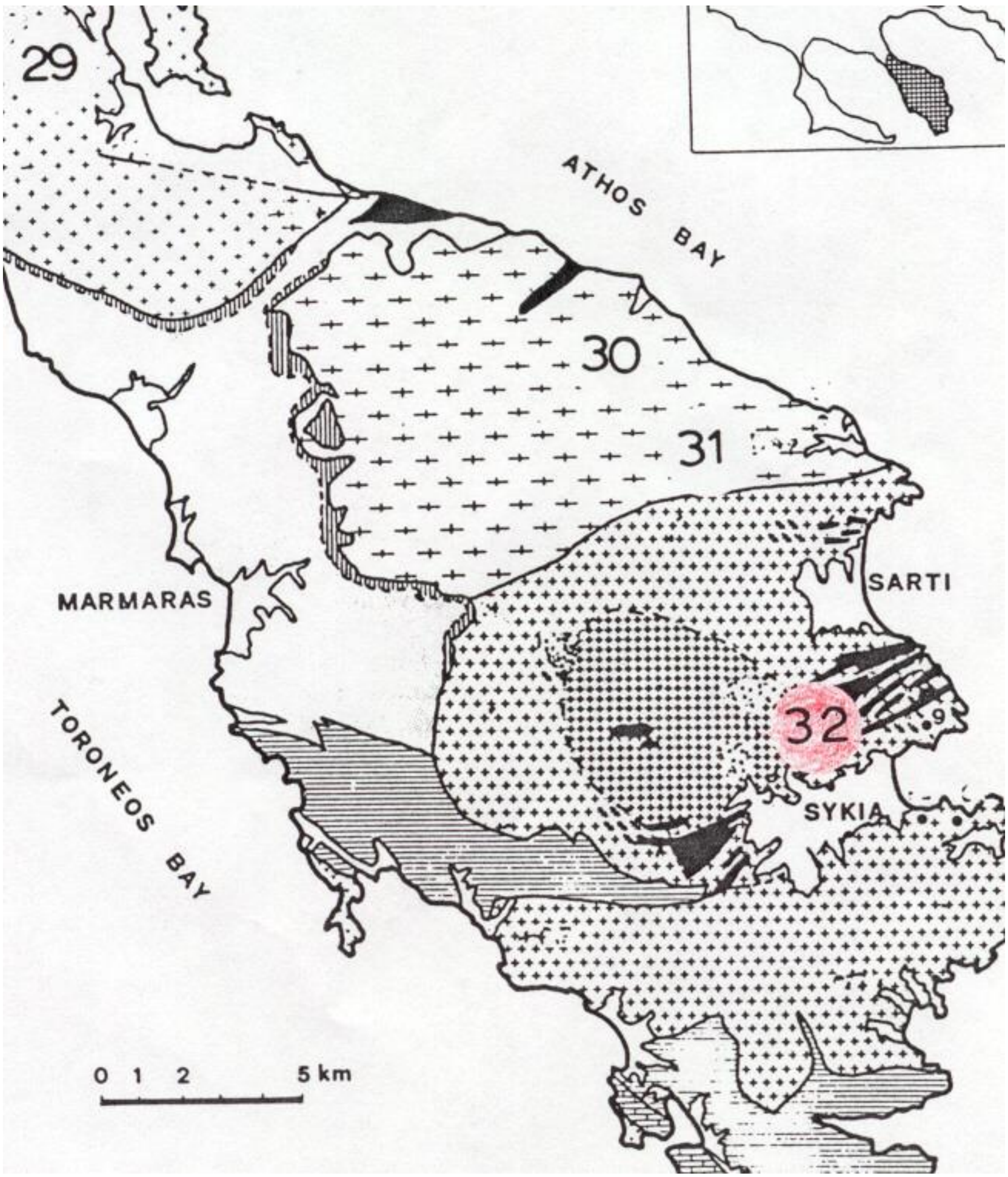

Fig. 8. Sketch of location of the Sithonia complex, indicating Stop 32 in pink. (Modified after figure in Sideris *et al.*, 1998)

At Stop 32 the Sithonia hornblende-biotite granodiorite is described as having subhedral to euhedral epidote (Christofides *et al*., 1990). This euhedralism has generally been interpreted to suggest a deep (high-pressure-temperature) origin for the rock (Zen and Hammarstrom, 1984). However, because the zoned plagioclase crystals indicate a relatively shallow emplacement rather than deep emplacement, the euhedral epidote must have been formed near the surface. Presence of myrmekite (Fig. 9 and Fig. 10) with relatively coarse quartz vermicules indicates that the original plagioclase was relatively calcic (Collins, 1988). When this plagioclase was replaced by microcline, calcium and aluminum would have been released to form the epidote. The strong deformation could have created space for crystal faces to form on the epidote, producing the euhedralism. Therefore, euhedralism of epidote cannot always be used as an indicator of high P-T conditions for a rock's formation.

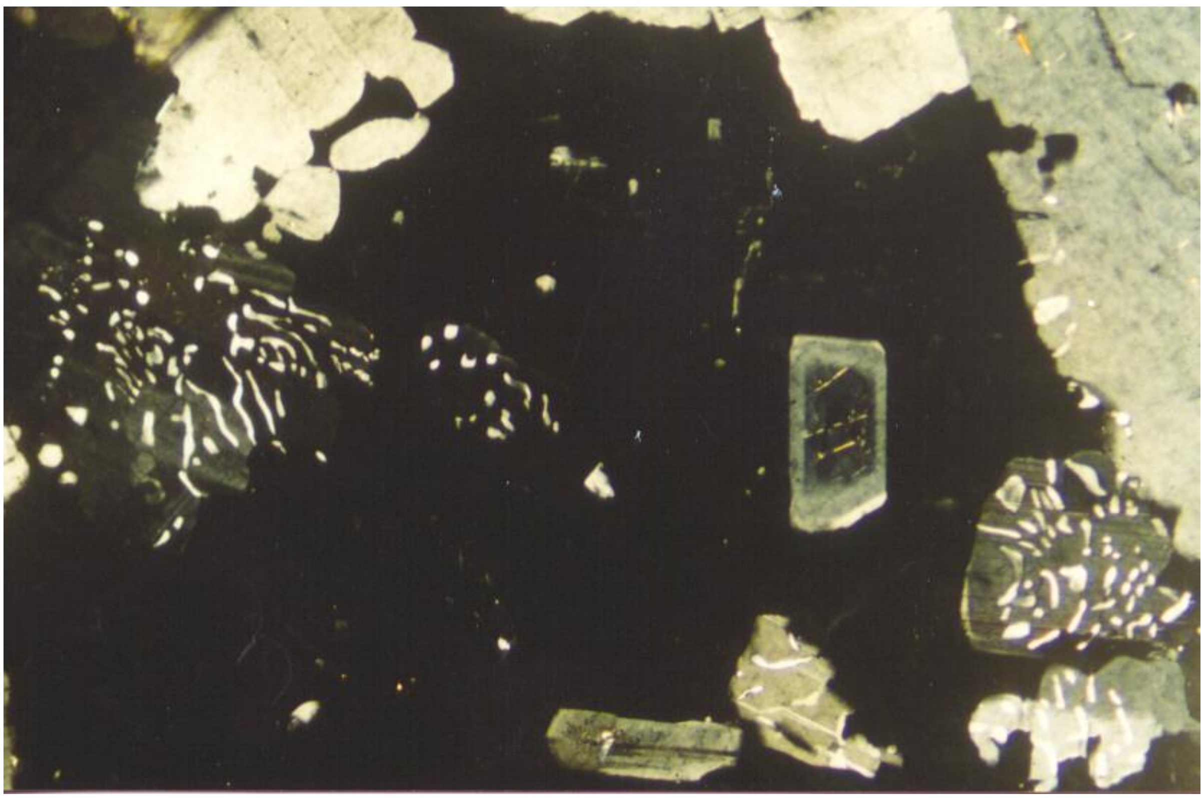

Fig. 9. Myrmekite enclosed in microcline (black). Microcline penetrates and replaces plagioclase (light tan) along fractures in upper left part of illustration. Zoned plagioclase crystal is also enclosed in the microcline.

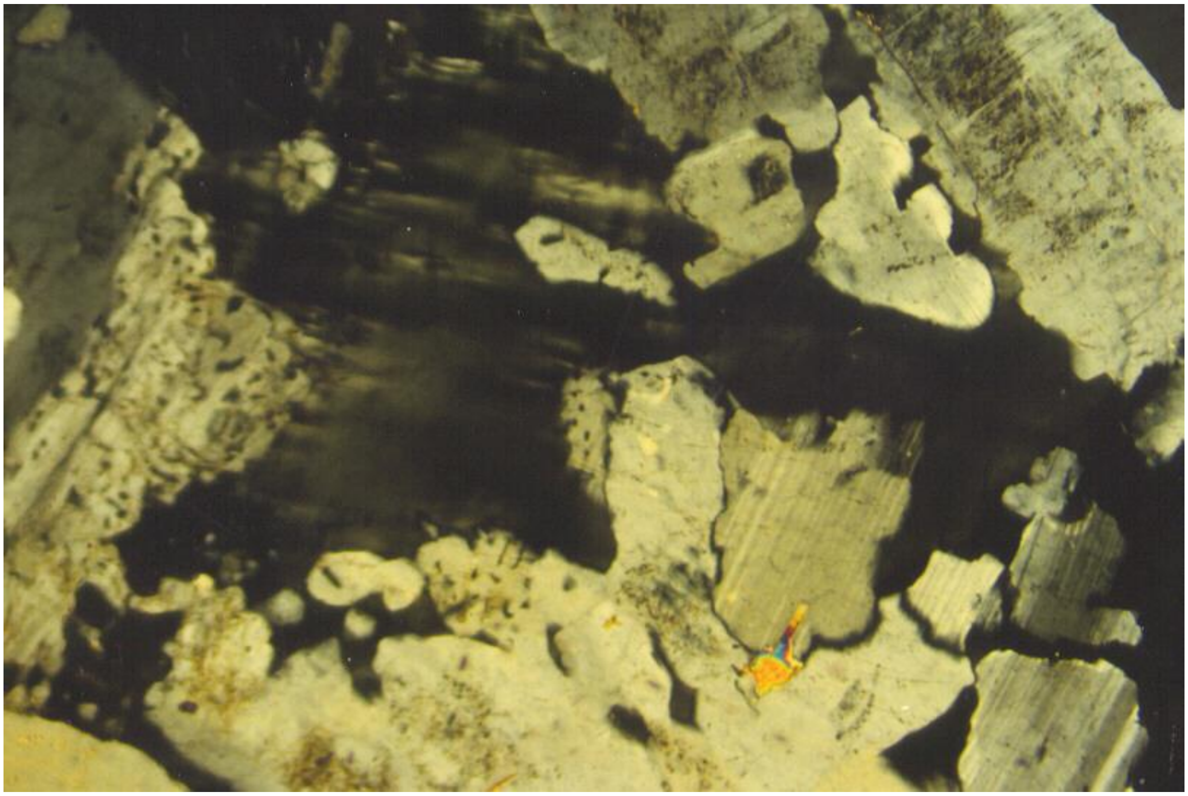

Fig. 10. Myrmekitic plagioclase (light tan) replaced by microcline (black) along fractures throughout lower part of illustration and upper right. Quartz vermicules (black) are relatively tiny.

References

Christofides, G., D'Amico, C., Del Moro, A., Eleftheriadis, G., and Kyriakopoulos, C., 1990, Rb/Sr geochronology and geochemical characters of the Sithonia plutonic complex (Greece): European Journal of Mineralogy, v. 2, p. 79-87.

Christofides, G., Neiva, A. M.R., Soldatos, T., and Eleftheriadis, G., 1995, Petrology of the Kavala pluton (eastern Macedonia, Greece): Geological Society of Greece, Special Publication No. 4, Proceedings of the XV Congress of the Carpatho-Balcan Geological Association, September 1995, Athens, Greece, p. 489-494.

Collins, L. G., 1988. *Hydrothermal Differentiation And Myrmekite - A Clue To Many Geological Puzzles*: Athens, Theophrastus Publications, 387 p.

Hunt, C. W., Collins, L. G., and Skobelin, E. A., 1992, *Expanding Geospheres, Energy And Mass Transfers From Earth's Interior*: Calgary, Polar Publishing Co., 421 p. Order from: http://www.polarpublishing.com

Kyriakopoulos, K., Pezzino, A., and Del Moro, A., 1989, Rb-Sr geochronological, petrological, and structural study of the Kavala plutonic complex (N. Greece): Bulletin of the Geological Society of Greece, XXIII/2, p. 545-560.

Sideris, K., Katerinopoulos, A., Magganas, A., and Kyriakopoulos, K., 1998, Eurogranites '98 Macedonia and Thrace, Northern Greece: Department of Geology, National University of Athens, September 2-8, 1998.

Zen, E-An, and Hammarstrom, J. M. 1984, Magmatic epidote and its petrologic significance: Geology, v. 12, p. 515-518.