Epidote nodules in the sheeted intrusive complex of the Troodos Ophiolite, Cyprus

Gail Lipfert
Department of Geological Sciences, University of Maine, Orono, ME
Faculty Sponsors: Lori Bettison-Varga, The College of Wooster; C.V. Guidotti, University of Maine

INTRODUCTION

The Troodos ophiolite has a well-exposed sheeted intrusive complex that has been extensively studied. The field area for this project lies within the Solea graben, identified by Varga and Moores (1985) as one of three fossil axial valleys formed by the eastward migration of a slow-spreading ridge crest. The Solea graben is defined by sheeted dikes dipping toward the graben axis. The sheeted intrusive complex has been rotated along listric normal faults that merge into a low angle detachment zone (Varga and Moores, 1985). Massive sulfide deposits of the Troodos complex contain 'black smoker' chimney fragments similar to those near present day medium- to fast-spreading ridge axes (Oudin and Constantinou, 1984) providing evidence of fossil hydrothermal activity. The sheeted intrusive complex of the Troodos ophiolite has experienced both low grade greenschist alteration (Gass and Smewing, 1973) and massive epidotization. This epidotization altered the dikes to epidosite, a granular rock composed primarily of epidote and quartz, with little or no remaining diabasic texture. Schiffman and Smith (1988) showed depletion of ^{18}O, Al_2O_3, Na_2O, K_2O, Zr, Cu and Zn, and the enrichment of CaO and Sr in the epidosites in comparison to the other dikes. Schiffman and Smith (1988) suggested that the epidosites represent fossil upflow zones responsible for the sulfide deposits. The epidotization occurred at temperatures of 310°- 370° C in response to fluids whose $d^{18}O$ values and salinities compare to those of Upper Cretaceous sea water (Schiffman and Smith, 1988).

Three major epidosite zones have been identified in the Solea graben: the detachment zone (a low angle shear zone at Lemithou), the large, northeast-trending central zone, and a small northern zone (Bettison-Varga et al., 1992; Schiffman and Smith, 1988). Within some of the epidosites are unusual orbicular nodules containing concentrations of epidote. The samples for this study are from four localities, (1) the detachment zone directly above the dike-gabbro contact, (2) the central zone, (3) Phterikhoudhi canyon near the upper section of the sheeted intrusive complex, and (4) Spilia near a gabbro contact (fig. 1). Phterikhoudhi and Spilia are not within the previously described epidotsite zones. The epidote nodules ('eggs') are most numerous, best exposed, and largest (2cm -10cm in diameter) at Lemithou and in Phterikhoudhi canyon. This study attempts to determine where, when, and how the formation of epidote nodules fits into the epidotization process.

PETROGRAPHY

Some portions of the epidotized zones are characterized by the presence of distinct spheroid, ovoid, or generally rounded nodules of coarse-grained epidote. These epidote 'eggs' occur in a variety of forms. Although mostly occurring as spheroidal masses having sharp contact with the groundmass, some display exotic bullseye patterns, double rims of quartz, or a more diffuse contact. Commonly, the centers of the 'eggs' are concentrated in coarse-grained epidote. Most of the epidote nodules are within a fine-grained, equigranular, often diabasic groundmass consisting of plagioclase, quartz, and either amphibole, clinopyroxene, or chlorite, with accessory sphene and opaques. The epidote 'eggs' are also found within the epidosite, but not as commonly. Within the epidosite the contrast is primarily in grain size, texture, and modal percentages. The sizes of the 'eggs' in both diabase dike and epidosite range from 0.5mm to 12cm. with most of them falling between 0.5cm and 4cm. The samples can be separated into three general categories that will be referred to as type A, type B, and type C.

'Eggs' of type A are generally small, 0.5mm - 4mm diameter spheres and ovoids that have a very sharp contact with the groundmass. They commonly contain euhedral quartz crystals pointing inward and lining the edge, radiating epidote crystals and, in some cases, carbonate and/or chlorite. The epidote is coarse-grained (up to 1mm long), clear, and intersects other epidote grains along simple or straight grain boundaries. These characteristics are indicative of growth impingement structures (Stanton, 1972). The epidote is commonly interstitial to, or nucleates on, the euhedral quartz crystals. In two samples, plagioclase crystals in the groundmass appear to line up parallel to the perimeter of the 'egg'. All these samples come from the central zone and from Phterikhoudhi Canyon. The best examples come from the diabase dike, although some are found in epidosite.

The epidote nodules of type B show a diabasic texture within the epidote crystals. Lath shapes are retained in the epidote crystals by the presence of quartz inclusions. The larger epidote crystals commonly are composed of a criss-crossing of numerous lath shapes. Many epidote crystals show 'skeletons', clusters of dark parallel lines that occasionally cross other clusters.

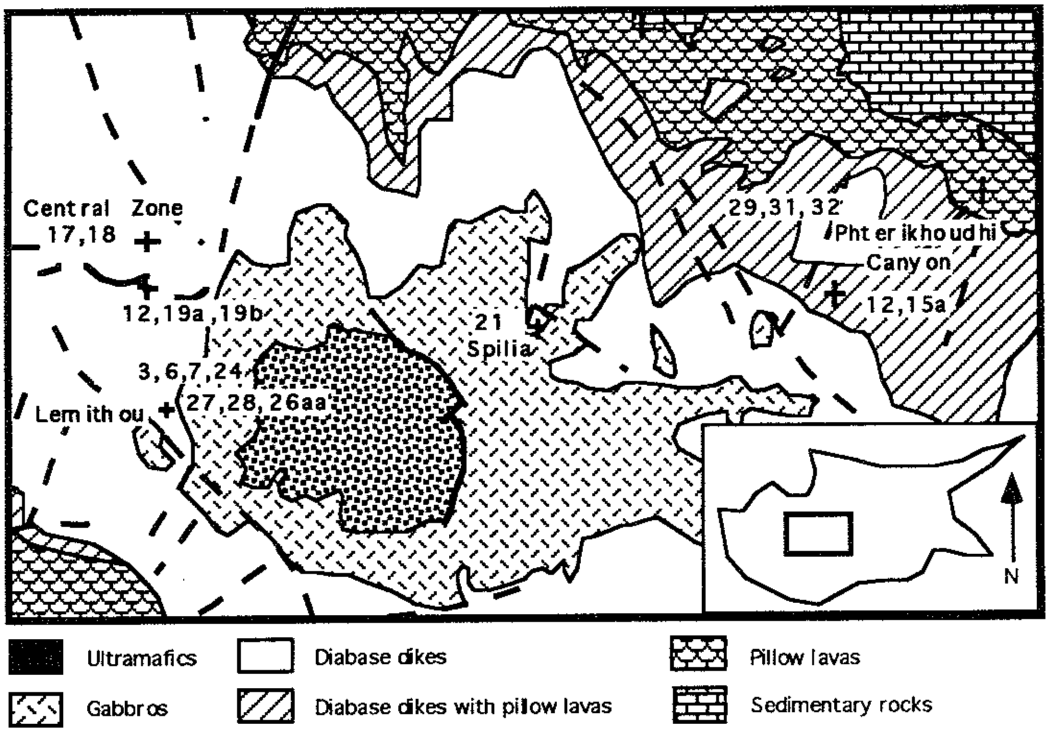

Fig. 1 Sample localities. Adapted from Geological Map of Cyprus, Geological Survey Department, Revised edition, 1995.

Some of the type B samples have concentric zoning patterns. Epidote concentration increases toward the center and the crystal size coarsens (Table 1). When chlorite is present, it decreases toward and is absent from the center of the 'egg'. Epidote is clearer toward the center, being free of inclusions and 'skeletons'. The diabasic texture, however, is commonly retained away from the center. A metasomatic front can be seen in all the overgrowth samples, occurring as a dark rim 'messy' epidote at the 'egg'-groundmass contact (fig. 2).

In type C, the characteristics of type A occurs near the center of the nodules, and the characteristics of type B occurs surrounds the center.

Several samples (15a, 18a) show silicification of epidote crystals. Confined to patches associated with type A, the centers of large, 6mm in diameter, quartz crystals are found containing the radiating remains of epidote. Many of the samples show veins of epidote connecting the 'eggs', but others have no clear evidence of veining.

In several of the dikes at Lemithou, the centers have been epidotized, giving a two-tone appearance to the rocks (fig. 3). Epidote 'eggs' occur towards the center line of the epidotized zone.

Table 1. Modal % of epidote across a nodule

SAMPLE #	EDGE	INTERMEDIATE	CENTER
27	59	62	72
28	32	-	72
1c	1	69	71

DISCUSSION

In type A nodules, the euhedral shape of quartz and epidote crystals, the presence of growth impingement structures, and the tangential plagioclase laths around some nodules support an interpretation of growth into a void. With the exception of two larger 'eggs', it is assumed that type A nodules represent amygdules.

The presence, in type B nodules, of a metasomatic front, the concentric zoning patterns, the relict ingeous texture within epidote crystals, the inclusion of 'skeletons' (interpreted as remnants of previous phases), indicate that epidote overgrew the groundmass by diffusion. Textural evidence suggests that the epidote has replaced plagioclase, and in some cases, amphibole.

The central cores of type C show many of the characteristics of type A, growth into a void, while the outer part of the nodules show the overprinting characteristics of type B. A proposed mechanism for type C nodules is the nucleation of epidote onto an amygdule seed, and the diffusion of epidote into the groundmass

Blue-green striping, the parallel formation of unaltered diabase dike (blue) and epidosite (green) in sharp contact with each other, is found in outcrop throughout the epidotized areas of the sheeted intrusive complex. At Troodos, it is believed that epidotization occurred in reaction to the upwelling of high temperature fluids along fractures in attenuated crust during tectonic extension and rotation of the sheeted intrusive complex along normal listric faults which flatten in detachment zones, and during intrusion of gabbro (Varga and Moores, 1985; Bettison-Varga et al., 1995). It has been suggested that the epidote eggs represent point source manifestations of the same processes that formed the blue-green striping. The evidence from this study does not support this suggestion. First, the epidote nodules are found within the epidosite in sharp contact with the epidotized groundmass. This suggests that striping and nodule formation are not synchronous in these samples. Second, in the epidosite, the primary textures are obliterated, whereas they are commonly retained in the 'eggs', particularly away from the centers. Within the epidosite containing the nodules there appears to be more obliteration of the primary texture away from the nodules, but this is not a clear relationship.

Epidote concentrations described in the literature (Harrigan and MacLean, 1976; Rose and Bird, 1994; Percival and Helmstaedt, 1978) have some similarities with the Troodos nodules. Rose and Bird (1994) suggest that the formation of CaAl-silicate concentrations by hydrothermal metamorphism was enhanced by the porosity of the leucocratic segregations found along the centers of doleritic dikes. This restriction of epidotization to the centers of dikes is found in Troodos (fig. 3), however, more commonly, entire dikes are epidotized (Bettison-Varga et al. 1995)

Percival and Helmstaedt (1978) describe zoned epidote nodules in shallow-water sedimentary rocks, but their proposed mechanism of formation by the metamorphism of calcareous concretions is not applicable to the epidote nodules of Troodos.

CONCLUSION

Other than the possibility of amygdules in the central zone and at Phterikhoudhi canyon, there is little evidence for a primary porosity. Gas- or water-filled vesicles and the upflowing hydrothermal fluids allowed for the formation of the type A nodules, the growth of epidote crystals into a void. Using the type A nodules as a seed, epidote overgrew the groundmass in a radial manner by diffusion. The seed for the type B 'eggs' which lack coarse-grained, type A centers is difficult to determine, however, they show the same radial diffusion.

REFERENCES CITED

Bettison- Varga, L., Varga, R.J. and Schiffman, P., 1992, Relationship between ore-forming hydrothermal systems and extensional deformation in the Solea graben spreading center, Troodos ophiolite, Cyprus: Geology, v.20, n. 987-990.

Bettison-Varga ,L., Schiffman, P., Janecky, D.R.,1995, Fluid-rock interaction in the hydrothermal upflow zone of the Solea Graben, Troodos Ophiolite, Cyprus, *in* Schiffman, P. and Day, H.W., eds., Low-grade metamorphism of mafic rocks: Geological Society of America Special Paper, p. 81-100.

Gass, I.G. and Smewing, J.D., 1973, Intrusion, extrusion and metamorphism at constructive margins: evidence from the Troodos Massif, Cyprus: Nature, v. 242, p. 26-29.

Harrigan, D.B. and MacLean, W.H., 1976, Petrology and geochemistry of epidote alteration patches in gabbro dykes at Matagami, Quebec: Canadian Journal of Earth Sciences, v. 13, p. 500-511.

Oudin, E. and Constantinou, G., 1984, Black Smoker chimney fragments in Cyprus sulphide deposits: Nature, v. 308, p. 349-353.

Percival, J.A. and Helmstaedt, H., 1978, Zoned epidote nodules from sedimentary rocks of the Eastport Formation, southwest New Brunswick: Canadian Journal of Earth Sciences, v. 15, p. 1194-1200.

Rose, N,M, and Bird, D.K., 1994, Hydrothermally altered dolerite dykes in East Greenland: implications for Ca-metasomatism of basaltic protoliths: Contributions to Mineralogy and Petrology, v. 116, p. 420-432.

Schiffman, P and Smith, B.M., 1988, Petrology and O-isotope geochemistry of a fossil seawater hydrothermal system within the Solea graben, northern Troodos ophiolite, Cyprus: Journal of Geophysical Research, v. 93, p. 4612-4624.

Stanton, R.L., 1972, Ore petrology: New York, McGraw-Hill, 713 p.

Varga, R.J. and Moores, E.M., 1985, Spreading structure of the Troodos ophiolite, Cyprus: Geology, v. 13, n. 12, p. 846-850.

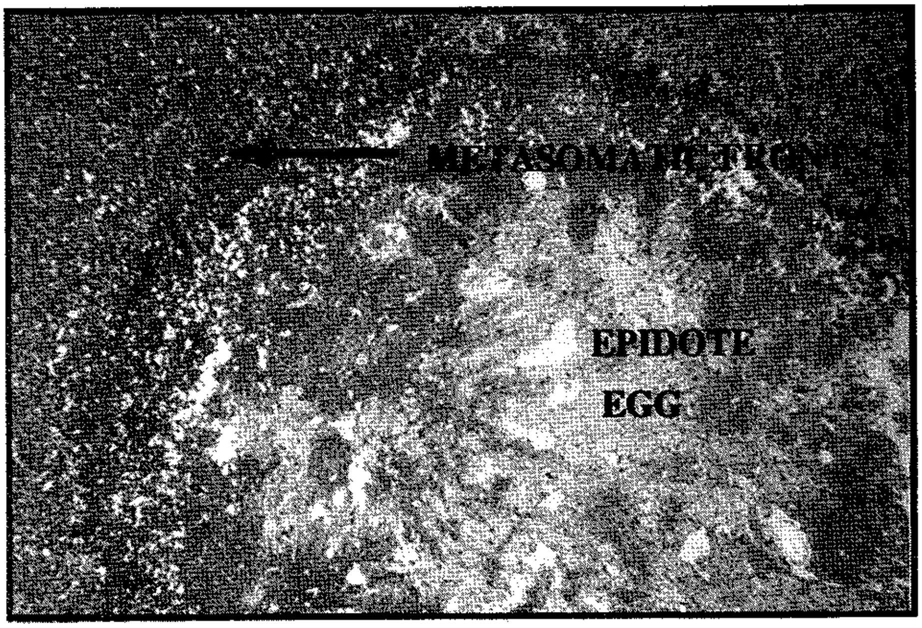

Fig 2 Microphotograph showing the metasomatic front at the 'egg'-groundmass contact of a coarse-grained 'egg'.

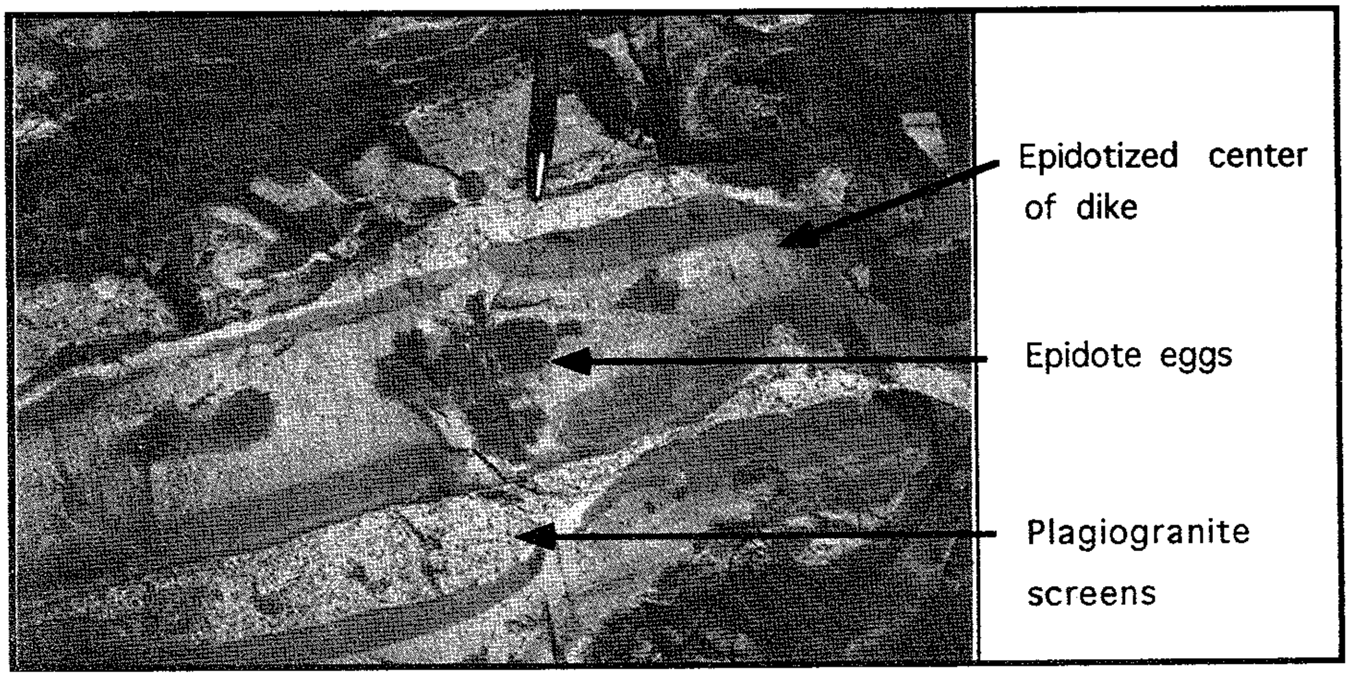

Fig. 3 A two-tone diabase dike injected into plagiogranite screens (in outcrop) showing epidote 'eggs' in the central epidotized zone of the dike.