# Epidotizing fluid temperature and composition at the sheeted dike-plutonic contact, Troodos ophiolite, Cyprus

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## Introduction

The Troodos ophiolite is located on the island of Cyprus and is one of the most complete ophiolite sequences in the world. Between the sheeted dike complex and the upper gabbros are located isolated, lenticular plagiogranite bodies (Kelley and Robinson, 1990). Hydrothermal epidotization is common in all three of these bodies, however Richardson et al. (1987) claim that the base for a seawater derived hydrothermal system is at the dike-gabbro boundary. Because the gabbros and some of the plagiogranite bodies lie beneath this base, there is some question as to where the fluids involved in this epidotization came from.

Previous work (Schiffman et al., 1987, 1990; Schiffman and Smith, 1988; Kelley and Robinson, 1990; Kelley et al., 1992) has attempted to answer this question of the origin of the hydrothermal fluids. However, the authors still have differing views on the possible origin for the fluid at this depth. This study will use fluid inclusion data to determine the possibilities of fluid origin in the epidotized bodies. Epidote hosted fluid inclusions were chosen to be the focus of this study to determine if the fluid from which the epidote formed was: 1)modified seawater, 2)a brine formed by phase separation of seawater, or 3)a magmatic hydrothermal fluid.

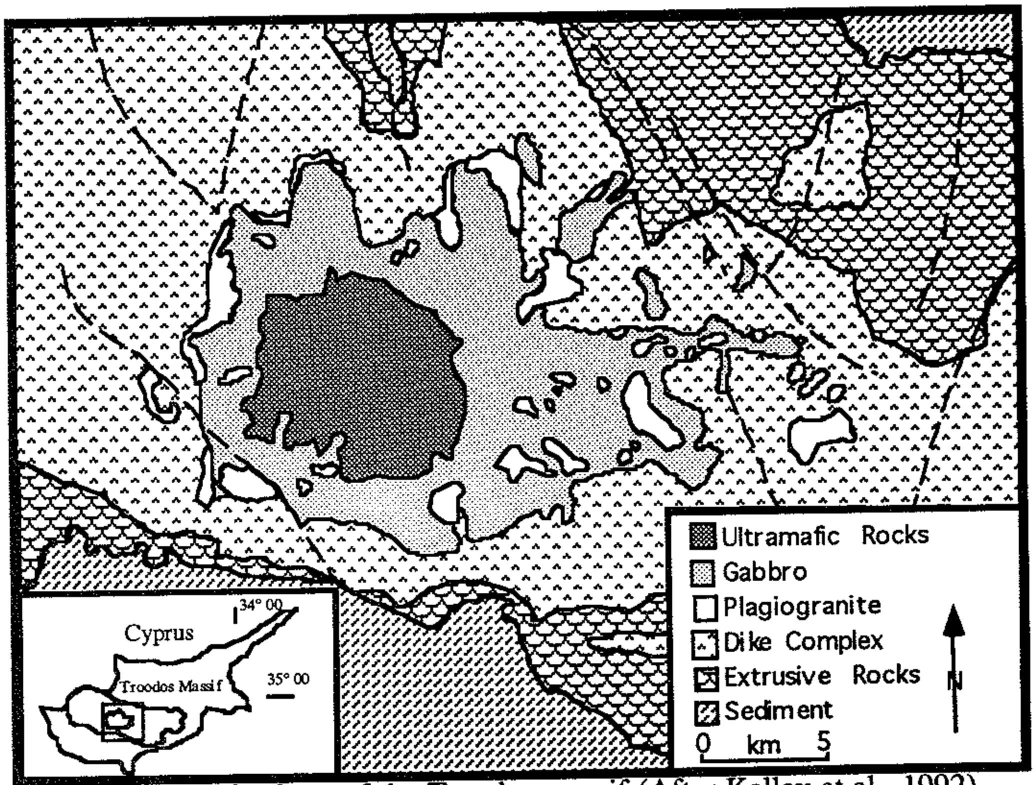


**Figure 1.** Geology of the Troodos massif (After Kelley et al., 1992)

## Methods

**Field Methods.** The extent of alteration found in the plagiogranites to form epidosites (quartz+epidote+/-chlorite+/-sphene) varies from 5% to 100% alteration. Samples were selected from the outcrops based upon the amount and coarseness of epidote grains present in the hand specimen. Sketches of the outcrop were made and photographs were taken of each sample area to aid later analysis.

**Fluid Inclusion Methods.** Each sample was cut into a thin section and placed on a Fluid Inc. adapted U. S. Geological Survey gas-flow heating and freezing stage to perform microthermometric analysis of the inclusions. Homogenization temperatures were recorded when the vapor bubble disappeared when heated. The temperatures have not been corrected for pressure and should be viewed as the minimum temperature of the original epidotizing fluid. Inclusions trapped at the estimated 500 bars of pressure would have a homogenization temperature correction of about 100 °C increase.

The inclusions were then frozen and allowed to thaw and the temperature that the last ice crystals melt at is recorded to be used as a freezing point depression to determine the salinity of the fluid in terms of weight percent NaCl.

## Results

**Fluid Inclusion Results.** A total of 127 fluid inclusions were analyzed for temperature and salinity. All inclusions studied were two-phase inclusions. Most of the inclusions were dominated by the liquid phase, but a few inclusions were evenly split between the two phases, or the vapor phase was slightly dominant. The inclusions were normally found as singular, primary inclusions meaning that they were trapped when the crystal originally formed. On occasion, small groups of these primary inclusions were found. Secondary inclusions trapped when the hydrothermal fluid entered existing crystals were also found in the form of planes of inclusions trapped along healed microfractures within the epidote.

The homogenization temperatures of the inclusions in epidote ranged from a minimum of 242 °C to a maximum of 393.3 °C with an average of 328.5 °C. The size of the inclusions was variable with a maximum of 20 microns, but they were rarely greater than 6 or 7 microns. All inclusions homogenized into the liquid phase indicating that the fluid was originally trapped in the absence of a vapor phase (Roedder, 1984).

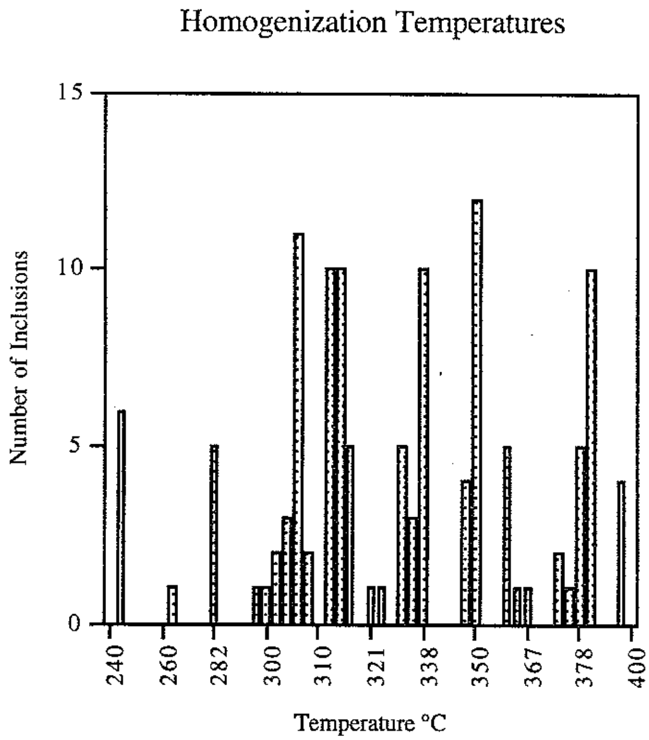


**Figure 2.** Homogenization temperatures of all inclusions studied.

| Specimen number (chip) | Host lithology | Host mineral | Temperature range °C |
|---|---|---|---|
| CP-1-96(1) | Plagiogranite | Epidote | 307-331 |
| CP-1-96(2) | | Epidote | 317-359 |
| CP-1-96(3) | | Epidote | 300-376 |
| CP-4-96(1) | Plagiogranite | Epidote | 338-393 |
| CP-4-96(2) | | Epidote | 265-309 |
| CP-5-96(1) | Plagiogranite | Epidote | 242-301 |
| CP-5-96(2) | | Epidote | 298-333 |
| SH95-23 | Epidosite Dike | Epidote | 333-379 |

**Table 1.** Homogenization temperature ranges by samples studied.

Results from the freezing of the inclusions has been inconclusive. Problems in observing when ice crystals form and melt has prevented accurate recording of freezing point depressions. The lack of solid halite daughter crystals within the inclusions would indicate that the fluid in the inclusions has a low salinity. This observation supports previous work in the area (Kelley et al., 1992) that has shown the compositions of fluid inclusions with this range of homogenization temperatures to have a moderate to low salinity (<17 wt% NaCl).

## Discussion.

The documented presence of high temperature, high salinity inclusions from the Troodos ophiolite (Kelley and Robinson, 1990; Kelley et al., 1992), Mid-Atlantic Ridge (Stakes and Vanko, 1986), and other locations has been explained by three models. Preserved as three phase inclusions, these brine fluids could have been formed by phase separation of seawater or magmatic fluids as suggested by two of the models (Kelley and Robinson, 1990; Vanko et al., 1992). In both of these models, the fluid cools and crosses the two-phase curve allowing the condensation of a small amount of a brine liquid from a vapor-like fluid. The third model used to explain the presence of the brine states that there was exsolution of the brines directly from the magma chamber, with phase separation only a minor factor in the formation of these brines (Kelley et al., 1992)

The lack of three phase inclusions found in epidote, the lower temperatures of homogenization for these inclusions, and the documented presence of brines in quartz shows that there was more than one fluid in the hydrothermal system. The limited salinity data also reflects a lower salinity for the inclusions in epidote. The model used for this system places the brine fluid circulating through the system first, creating hydrothermal quartz and leaving high temperature and high salinity inclusions in the quartz. It is currently unclear which of the three models for brine generation is applicable to the Troodos ophiolite, but current data supports the exsolution of the brines from the magmatic source (Kelley et al., 1992). Then the lower temperature and lower salinity fluid began to circulate through the system creating the hydrothermal epidote and more hydrothermal quartz. The low salinity and low homogenization temperature indicate it is unlikely that the fluid was derived from the magma source below the crust. Seawater permeating down into the crust along faults and fractures in the rocks would be a more likely origin of the low salinity fluid. There would be some modification of the seawater resulting in a limited increase in salinity, but the salinity did not reach the point where halite daughter crystals could precipitate out of the solution.

## Conclusions.

The epidote found in plagiogranite bodies of the Troodos ophiolite was formed by a fluid with an uncorrected temperature ranging from 242 °C to 393.3 °C. Although the exact composition of the fluid cannot be determined, the lack of three phase inclusions containing halite daughter crystals makes it reasonable to assume that the fluid from which the epidote formed had a low salinity and was seawater derived.

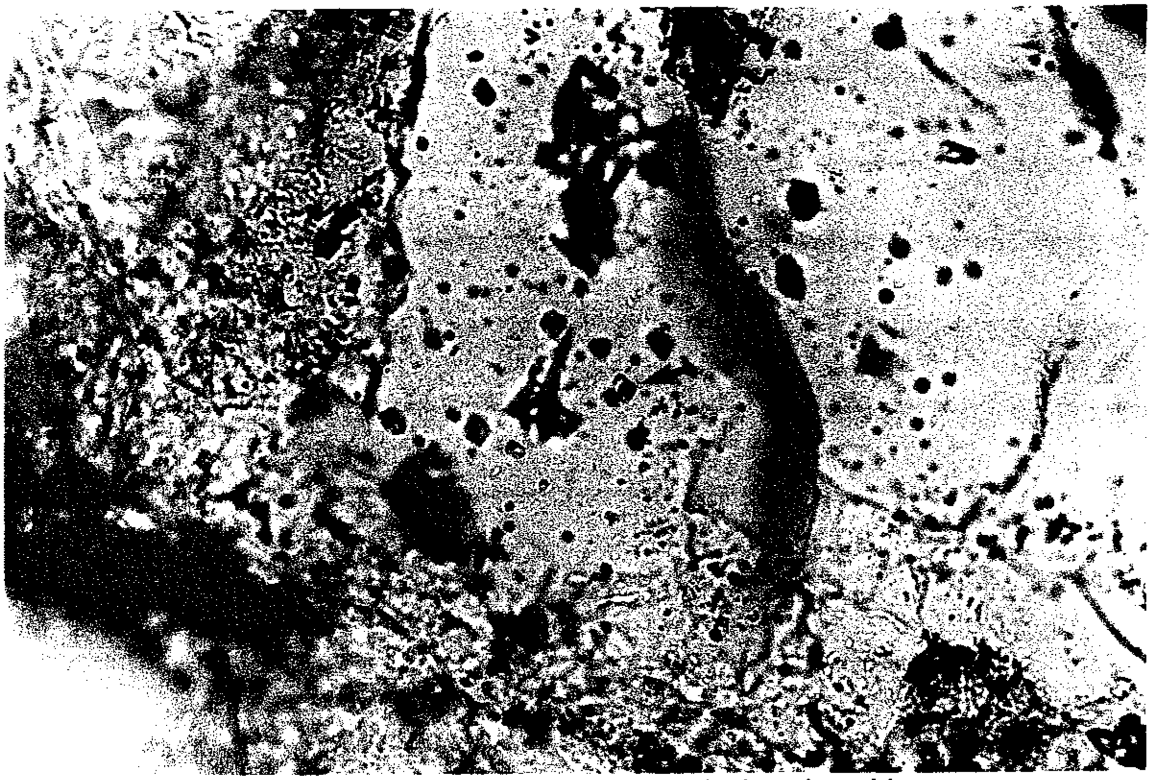

**Figure 3.** Two-phase fluid inclusions in epidote

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