ARAGONITE PSEUDOMORPHS AS KINEMATIC INDICATORS OF SYROS ISLAND, GREECE

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INTRODUCTION

Aragonite is the high pressure, low temperature polymorph of $CaCO_3$. The rocks of Syros have undergone high pressure, low temperature deformation and metamorphism during subduction as result of the Alpine orogeny followed by a greenschist overprint, which may have been the result of exhumation deformation (Wijbrans et al., 1993). The subduction event formed the high grade metamorphic rocks found on the island today. Although the carbonate rocks of Syros passed through the aragonite stability field during the Alpine high pressure, low temperature metamorphism, aragonite is not found on the island. There are two conceivable possibilities why aragonite is not present on Syros: either it never formed or it has not been preserved, reverting completely to calcite during exhumation.

Marble crops out across Syros. Because of its tectonic history and the possibility of aragonite formation, Syros is an ideal location to study the question of aragonite preservation. This project examines crystallographic preferred orientations (CPO's) in calcite marbles to see if they reflect inversion from aragonite.

SYROS MARBLE

On Syros, a sequence of north to northeast dipping alternating pelitic schists, marbles and metabasites (Dixon and Ridley, 1987) crop out. The marbles tend to be at least several meters thick and generally form the topographic highs on the island. The appearance of the marble varies from location to location. In some places, the marble is banded due to variations in the graphite content. The graphite banding helped to identify bedding in the massive marbles, which is typically parallel to foliation.

At the outcrop scale, the marbles commonly display a massive fabric. Mica orientation defines the foliation, parallel to foliation. Compositional bands are defined by variations in graphite, mica content, and grain size. Calcite exhibits a grain shape fabric in which calcite forms needles elongated at a high angle to foliation. The needle-like forms vary from outcrop to outcrop, and some outcrops show no sign of needle-like fabrics. The needles are, on average 2-3 mm thick and 2-3 cm long. They are organized in stacked rows, with each row composed of needles of similar height, but with needle height varying slightly from row to row. These needle-like forms have been considered to be pseudomorphs after aragonite (Brady et al., 2004) and are the subject of this project.

The relationship of the calcite needle-fabric to other meso-scale structures is variable. In some locations, the needles maintain a constant orientation across folds of compositional layers. In others, the needles change orientation around clasts of eclogite that occur in a matrix of marble. In some outcrops, the needles are entirely straight, whereas in other outcrops the needles are wavy, bent in more than one direction while maintaining the needle form.

There is an optically observable CPO to the marbles that have the needle morphology. Under crossed-polars, the calcite needles preferentially go extinct when their long directions are oriented parallel to the analyzer and polarizer.

Calcite grains in the marble are twinned and show a variety of morphologies. The calcite twins are thick, sometimes curved, with tapered ends and multiple twin directions in a single grain. The individual samples vary in their twinning descriptions; there are some samples with only straight twins, and others with both straight and curved twins with variable thickness. Burkhard (1993) breaks down twins into four types based on geometry and visual details, which lead to interpretations about temperature and timing of deformation. The Syros marble twins classify as type II and type III (Burkhard, 1993).

METHODS

Crystallographic fabrics of calcite from Syros marbles were determined using a Scanning Electron Microscope with an Electron Backscatter Diffractometer (SEM/EBSD). With the SEM/EBSD, the electron beam of the SEM diffracts off of the surface of a highly-tilted (70°) polished sample to produce an electron-diffraction or Kikuchi pattern (Fig. 1) on a phosphor screen in the EBSD detector. The Kikuchi pattern depends on the crystal structure and orientation of the mineral that produced the pattern. Each band in a Kikuchi pattern corresponds to diffractions from a single lattice plane. Using an automated EBSD, Kikuchi patterns can be collected, indexed and the crystal orientation determined in a few milliseconds. CPO's of calcite were determined by rastering the electron beam of the SEM across the Syros marbles, determining the orientation of calcite at each point in the raster.

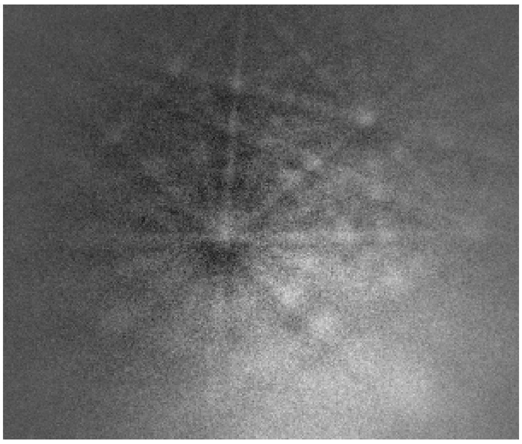

Figure 1: Kikuchi or EBSD patterns of calcite. Kikuchi patterns are related to the symmetry of the crystal lattice, the spacing, angles and the orientation between lattice planes of the mineral.

The CPO is shown both as an image in which different orientations are color-coded and as stereographic projections or pole figures of the orientations of any crystal plane or direction of interest.

Deformation of calcite produces a strong CPO that reflects the strain path, deformation mechanism and temperature of deformation (Schmid et al., 1987). Low temperature deformation of calcite by twin gliding creates strong c-axis and e-plane maxima. Higher temperature deformation by dislocation glide tends to produce multiple c-axis maxima as well as weaker a-, r- and f-axis concentrations. We examined c-axis, a-axes, e-twin plane and r- and f- pole figures to see if the CPO in the Syros marbles was compatible with either low or high temperature calcite deformation.

RESULTS

The calcite pole figures for the marbles of Syros form three distinct patterns. The first group of samples shows a strong CPO with a strong c-axis maximum parallel to the calcite needles and three a-axis maxima in the foliation each approximately 120° apart suggesting that the calcite is dominated by a single orientation (Fig. 2). The second group has a moderate c-axis maximum again parallel to the long axis of the calcite needles but with no a- axis or e-plane maxima (Fig.3). The

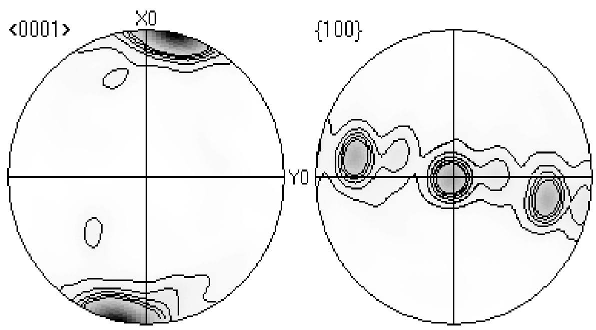

Figure 2: Pole figure for sample JMD-03-10b that shows the single crystal effect: one oblique strong c-axis maximum with three distinct a-axis maxima. The sample is oriented so that foliation is E-W vertical and calcite needles are N-S horizontal.

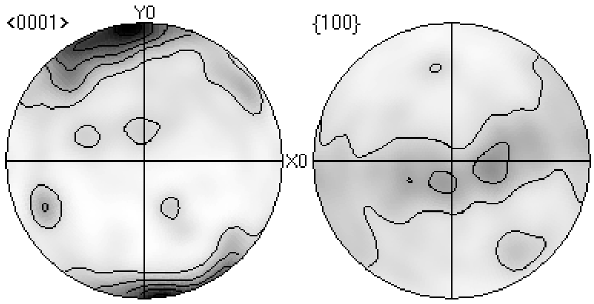

Figure 3: Pole figure for sample JMD-03-29b that shows a single, slightly oblique c-axis maximum paired with a range of a-axis values along a plane normal to the c-axis. The sample is oriented so that foliation is E-W vertical and calcite needles are N-S horizontal.

third category displays multiple (generally two) c-axis maxima, but no a-axis, e-plane, r or f-axis maxima.

These CPO's are unlike those commonly produced by either low temperature or high temperature calcite deformation (Schmid et al., 1987). Low temperature calcite deformation by twin gliding has occurred in the Syros marbles producing the twins that are visible optically. However, these marbles do not have an e-plane CPO, indicating that the strong c-axis CPO is not the result of low temperature deformation. The lack of an e-plane CPO was unexpected given the twin plane morphology and suggests that only minimal strain was accommodated by twin gliding. The multiple c-axis CPO is superficially similar to those produced by high temperature dislocation glide mechanisms. However, no CPO's exist for the r- and f-glide planes, indicating that the c-axis CPO could not have formed by dislocation glide in calcite. These CPO's may be the result of aragonite deformation by dislocation glide. If so, the CPO was retained in the marbles upon inversion to calcite during exhumation from the aragonite stability field.

CONCLUSIONS

Carbonate rocks on Syros passed through the aragonite stability field but no aragonite is found there today. Some marbles have acicular calcite grains, commonly oriented nearly perpendicular to foliation. These marbles have strong calcite CPO, with a moderate to strong c-axis maximum but without a CPO for any of the common calcite-slip systems. This CPO may be the result of a fabric formed in the marbles in the aragonite stability field prior to their inversion to calcite. As such, these CPO's are the only remnant of the aragonite left on Syros.

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