GRAPHITIC SCHISTS OF SYROS, GREECE

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INTRODUCTION

The Cycladic island of Syros is composed of a sequence of alternating calcareous schists and marbles with scattered metabasaltic belts, all of which have experienced high-pressure metamorphism during the Alpine Orogeny (Figure 1). Paleontologic evidence indicates that the rocks are originally Mississippian in age, and comprise the thickest metamorphosed sedimentary sequence in the Aegean, likely the result of tectonic thickening of an accretionary wedge. The rocks show evidence of two metamorphic events. The first is an Eocene high pressure metamorphism, which is followed by a post-tectonic Miocene greenschist overprint that is less well developed in the northern region of the island (Dixon and Ridley, 1987). The purpose of this project is to begin an analysis of the metamorphic history and sedimentary protolith (or protoliths) of the graphitic schists that characterize the northern section of the island.

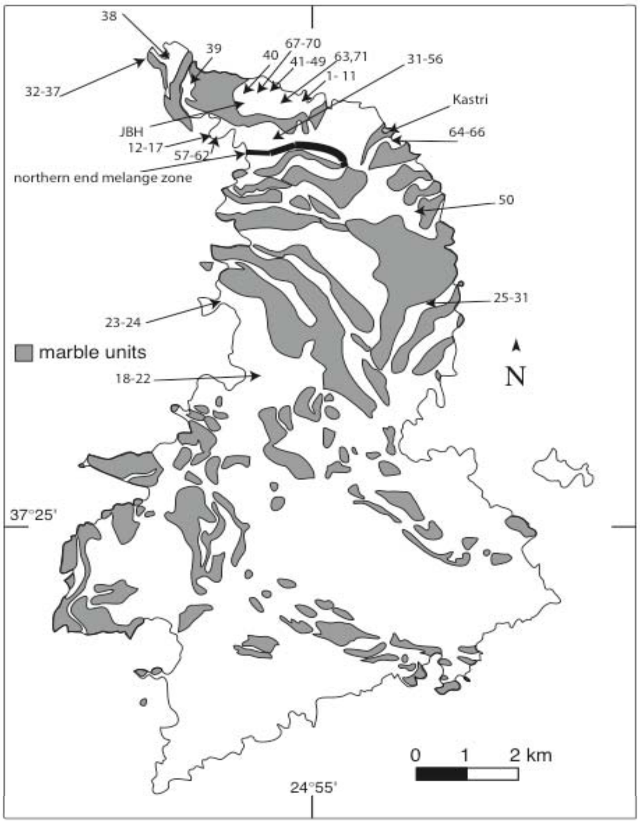

Figure 1: Sample location map, showing the generalized geology of Syros, modified from Höpfer and Schumacher (1997).

METHODS:

Graphitic schists were sampled primarily on the northern end of the island. Here, massive graphitic schist outcrops are bounded by the eclogite mélange zone to the south, and alternate with the Upper Marble unit. Schist units in this area range from those with little discernable Calcite content to Calcite-rich, though it is believed that they all belong to the same calc-sedimentary protolith. Sixty-six samples were taken from the northern end of the island. The rocks are weathered with strong foliation dipping consistently to the northwest. Pseudomorphs after Lawsonite, after Garnet, after Pyrite, and possibly after other minerals are visible in surface weathering textures. Fine serpentinite interbedding was present in contact with the mélange zone, but contacts with other units were predominantly sharp. Elsewhere on the island, most graphitic schist samples are calcareous, but exhibit different mineral assemblages from the massive northern units. The sampled areas include: Delfini Beach (samples 23-24), Agios Dimitrios (samples 25-31, Loula Beach (sample 50), and Kini (samples18-22).

DATA

Twelve thin sections were selected for examination on the basis of location diversity within the northern end as well as on the diversity of metamorphic textures and mineral assemblages. The samples were very fine-grained in thin section. Therefore, some mineral identification was done using the SEM-EDS as well as with a light microscope.

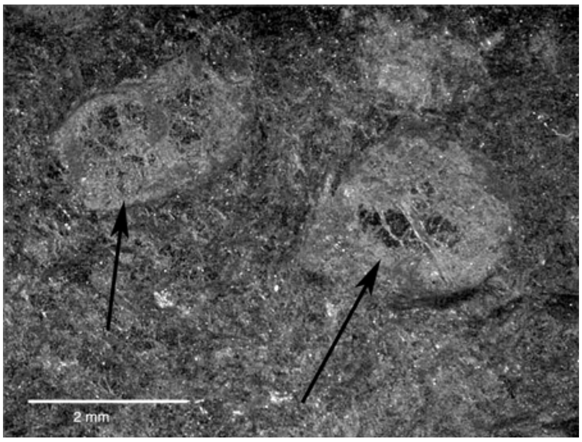

Figure 2: Sample LFL-03-53 (plane light). The approximate mode of the rock is 21% Phengite, 20% Glaucophane, 15% Chlorite, 13% Garnet, 10% Quartz, 7% Graphite, 7% Titanite, 5% Hornblende, 2% Rutile. Garnets (shown) are ~2 mm in diameter and rimmed by retrograde chlorite. A few Garnets in this sample are completely replaced by Chlorite.

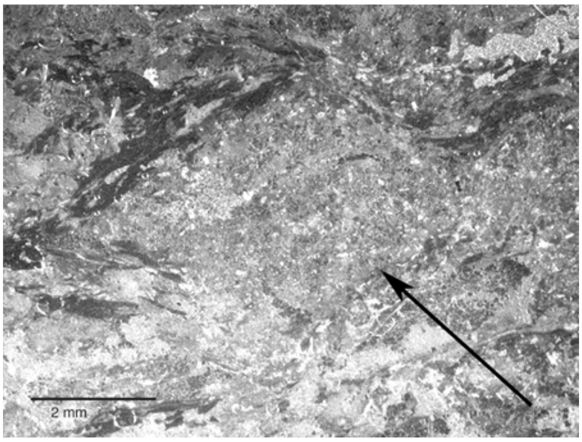

Figure 3: Sample LFL-03-65 (plane light). The approximate mode of the rock is 40% Quartz, 18% Calcite, 15% Phengite, 8% Hematite, 5% Glaucophane, 5% Graphite, 5% Titanite. This rock preserves a pseudomorph after Lawsonite with a boundary preserved by Glaucophane with C-axes aligned parallel to the field of view. The pseudomorph is composed of albite, quartz, titanite, and phengite/paragonite.

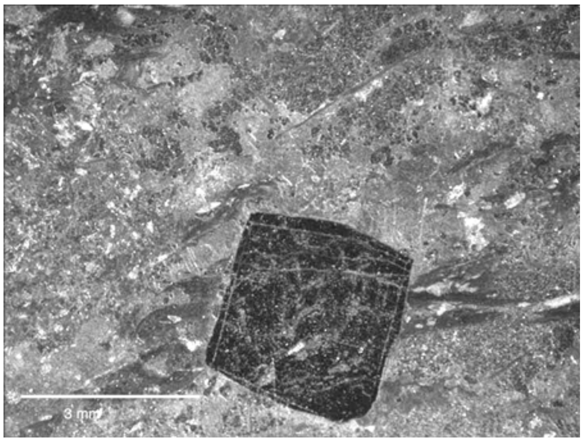

Figure 4: Sample LFL-03-65 (in plane light). This pseudomorph of Hematite after Pyrite postdates the main fabric. The pre-Pyrite growth metamorphic fabric of Glaucophane can be seen running E-W on either side of the crystal.

TEXTURES, ASSEMBLAGES:

Assemblages are relatively uniform for samples across the north end of the island. They all include Graphite and Quartz, along with: (Phengite, Albite, Chlorite, Calcite, Pyrite, Titanite), (Garnet, Phengite, Glaucophane, Titanite, Clinozoisite), (Phengite, Garnet, Glaucophane, Chlorite, Graphite, Titanite, Rutile, Tourmaline), or (Calcite, Phengite, Garnet, Glaucophane, Titanite, Chlorite, Clinozoisite, Hematite). The fabric of multiple generations of metamorphic minerals, pseudomorphs, and retrograde reactions results from a complex P-T path. All pseudomorphs show evidence of postdating the main fabric. The pseudomorph of Hematite after pyrite in sample 65 indicates a period of high-pressure metamorphism followed by an influx of sulfur bearing fluids (which facilitated Pyrite growth) and a subsequent event of oxidizing conditions that replaced Pyrite with Hematite. The pseudomorph after Lawsonite in Sample 65 indicates a high-temperature, low-pressure prograde decompression due to tectonic uplift.

GARNET COMPOSITION

Garnet composition analysis shows primarily zoned almandine garnets with significant amounts of Magnesium and Calcium. A small amount of Manganese was also present. Magnesium and Manganese are of a higher concentration within the Garnet centers and decrease towards the rims. Garnet compositions were consistent with those measured by J. Pohl, J. Schepker, and J. Wingender (2003) for Syros.

Figure 5 is a ternary plot that shows Garnet compositions for samples 02, 13, 53, and 60, all of which contain zoned Garnets. These Garnets are 1-3 mm in diameter. Sample 2 exhibits Garnets in conjunction with pseudomorphs after Lawsonite and a strong Phengite metamorphic fabric. Sample 13 contains intact Garnet in a Glaucophane- rich matrix also bearing Clinozoisite group minerals. Sample 53 exhibits Garnets rimmed by retrograde Chlorite, and in some cases completely replaced by Chlorite. Sample 60 contains Garnet with Chlorite inclusions.

Figure 5 shows outer edge vs. core compositions for Garnets from these samples, illustrating the magnesium zonation consistent with increased temperature during Garnet growth.

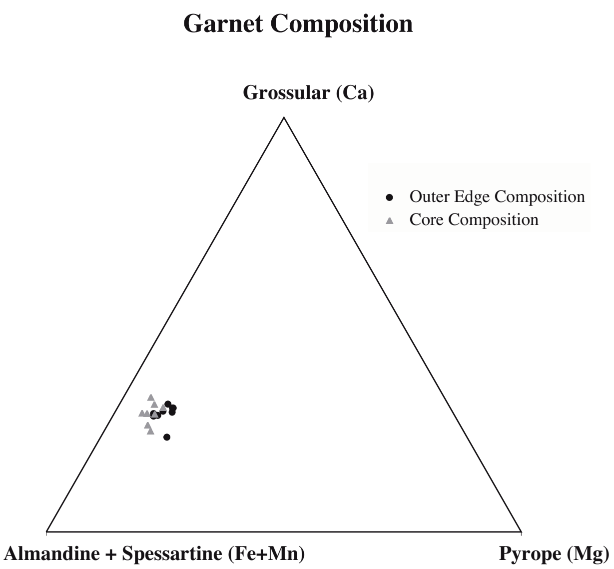

Figure 5: Measured compositions of Garnet shown as molar proportions of the Garnet end members.

GEOTHERMOMETRY

Geothermobarometric calculations were preformed based on solid-state reactions occurring independently of fluid partial pressures (Spear, p 516). The Garnet-Phengite Fe-Mg exchange thermometer, most recently calibrated by Hynes and Forest (1988), was used to calculate maximum temperature experienced by adjacent Phengite and Garnet rims. This reaction is useful because there is a small ΔV of reaction, thus a small pressure sensitivity. The exchange that occurs is as follows:

$$Mg_3Al_2Si_3O_{12} + 3KFeAlSi_4O_{10}(OH)_2 =$$

$$Fe_3Al_2Si_3O_{12} + 3KMgAlSi_4O_{10}(OH)_2$$

(pyrope) + (annite) =

(almandine) + (phlogopite)

Data for geothermometry was obtained with an SEM/Oxford ISIS analysis. Four testing sites were selected on samples with intact Garnet in contact with Phengite. Two areas of sample 60, and one area of each on Sample 02 and Sample JBH were analyzed. Due to instrument focusing or human error, the weight percent totals for each of the tested areas was not 100%, and the resulting data had to be adjusted to produce complete stoichiometry while maintaining Mg/Fe ratios for entry into GTB v 2.0 by Kohn and Spear (2001**).**

Two feasible temperatures were obtained from these calculations, 397.1ºC, and 400.3º C, both from sample 60. Temperature values of 604.4º C (from sample 02), and 643.1ºC (from sample JBH), were discarded because they are inconsistent with other data for Syros. These feasible results are shown as vertical lines on the Kyanite/Silimanite/Andalusite diagram in Figure 6.

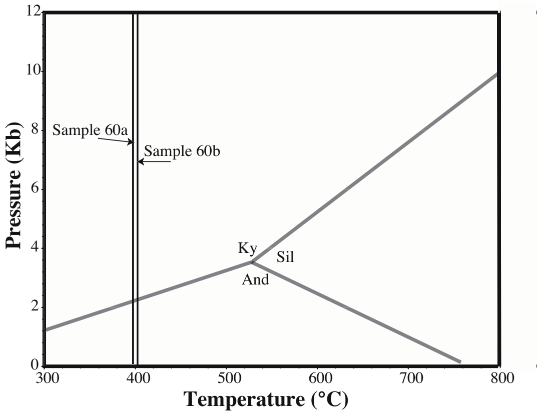

Figure 6: Geothermometry results for samples 60a and 60b.

DISCUSSION:

Based on the assemblage similarities of the examined samples, it is likely that the graphitic schists of Syros north of the north-end mélange zone derive from a single sedimentary protolith, with current mineral differences due to varied P/T path conditions. Both the prograde and retrograde metamorphic history for this unit is decidedly complex, with textures varying at different localities. Interesting textures include multiple generations of high-pressure metamorphic minerals of blueschist as well as greenschist facies within the same rock. Blueschist facies minerals present include Glaucophane as well as (pseudomorphs after) what is assumed to be primary Lawsonite. Greenschist faces minerals include Chlorite and Albite. Also of interest are garnets contained within Lawsonite pseudomorphs.

Further work should include more thorough analysis of the graphitic schists to the south of the north-end mélange zone for comparison with the Northern unit, as well as detailed chemical zoning analysis and accurate geothermobarometry for a greater number of samples.

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