MINERAL ASSEMBLAGES OF HIGH-PRESSURE, QUARTZ-MICA SCHISTS FROM SYROS, CYCLADES, GREECE

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INTRODUCTION

The island of Syros lies within the blueschist belt of the Attico Cycladic metamorphic complex. Syros is underlain by north dipping, thrust faulted sheets of alternating marbles, metapelites and acidic metavolcanics (Okrusch and Bröcker, 1990; Ridley, 1984). These units are locally juxtaposed with mafic meta-igneous rocks. They are also associated with highly deformed serpentinites and with a serpentinite-matrix mélange zone to the north. Recent studies suggest that the island was metamorphosed under blueschist facies conditions at approximately 80 Ma, during the Alpine orogeny (Cheney et al., 2000; Bröcker and Enders, 1999). There is also local evidence of a greenschist overprint, widely accepted to be a late Oligocene/early Miocene event (Wijbrans et al., 1993). Although greenschist facies mineral assemblages almost completely overprint certain localities on the southern extremity of the island, the majority of rocks on Syros largely escaped the greenschist overprint event. They therefore preserve earlier, blueschist and eclogite facies mineral assemblages.

METHODS

Fifty-two samples were collected from sixteen localities on the island. An effort was made to collect all the mineral assemblages at each outcrop for petrographic and chemical analysis. Rocks collected by other project participants augmented this sample collection. The fabrics of ninety thin sections were described and the mineral assemblages from each outcrop were noted and plotted on the NFM projection shown in Figure 1. The composition of minerals from selected samples was determined using the

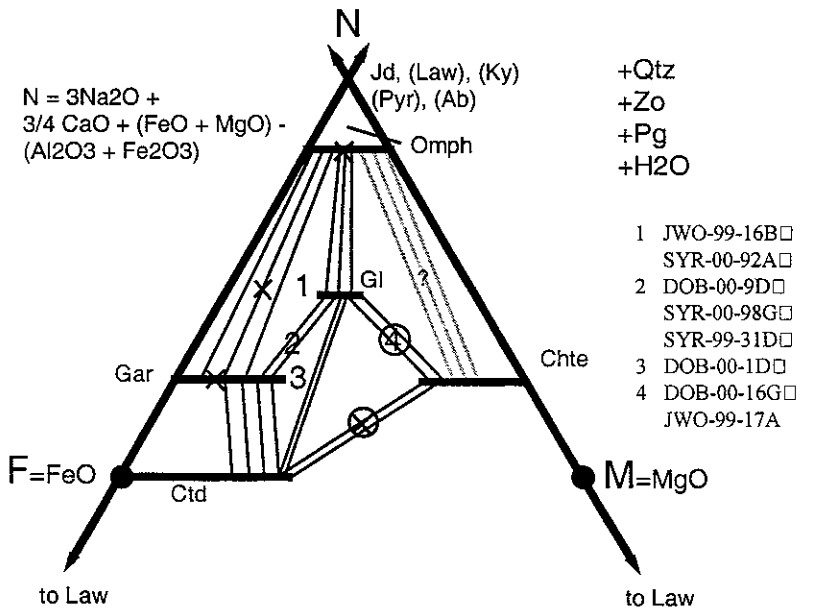

Figure 1. NFM Projection from quartz, zoisite and paragonite onto the plane NaALO2-FeAl2O4-MgAl2O4. Phases are plotted schematically. Xs and numbers mark approximate bulk compositions as estimated from assemblages seen in thin section. Numbers refer to samples analyzed using the SEM/EDS and circled symbols are + garnet. Chlorite-omphacite may not be stable with these other assemblages.

SEM/EDS system. This data were corrected for ferric iron using different stoichiometric constraints.

PETROGRAPHY

Based on fabric relationships, three basic sets of assemblages were recognized in these rocks. The matrix assemblage includes blueschist facies groundmass minerals and porphyroblasts. Inclusions in the matrix minerals comprise the inclusion assemblage and replacement minerals make up the overprint assemblage.

The matrix assemblage consists of phengite + quartz ± paragonite ± garnet ± blue amphibole ± epidote ± chloritoid ± chlorite ± clinopyroxene ± rutile ± titanite ± iron-titanium oxides. A white mica schistocity is bent around garnet in most of the samples, and in some samples, is folded into a crenulation cleavage. Minerals that truncate this fabric, and each other, are evidence that the matrix assemblage is the result of several generations of mineral growth. Chemical zoning, especially in epidote group minerals and blue amphiboles, suggests the influence of continuous reactions. The accessory minerals rutile, titanite and iron-titanium oxides are commonly found intergrown with each other in the groundmass.

The inclusion assemblage preserves relict clinopyroxene, mostly in garnet, suggesting that these rocks underwent a pre-blueschist, eclogite facies metamorphic event, also evidenced on the nearby island of Sifnos by the stability of jadeite + quartz and omphacite + garnet (Lister and Raouzaios, 1996). Blue amphibole, chloritoid, epidote, chlorite, quartz, phengite and paragonite also occur as inclusions in garnet, as do the accessory groundmass minerals.

The overprint assemblage is characterized by replacement and overgrowth textures of chlorite, biotite, albite and white mica. Generally attributed to the greenschist overprint, these minerals completely replace matrix assemblage minerals in some samples. Albite porphyroblasts contain white mica inclusions aligned with the external schistocity, and are themselves elongate in the direction of this fabric in some samples. This preferred orientation suggests that deformation may have accompanied porphyroblastic albite growth. In addition, these rocks contain titanite that has overgrown matrix white mica and carbonate that appears to fill fractures, both of which may be part of the greenschist overprint.

MINERAL COMPOSITION

An SEM/EDS system was used to explore mineral compositions from eight samples. Samples were chosen to represent different matrix and inclusion assemblages. The matrix assemblages of the samples chosen are listed in figure 1. Compositions of the most important minerals are described below.

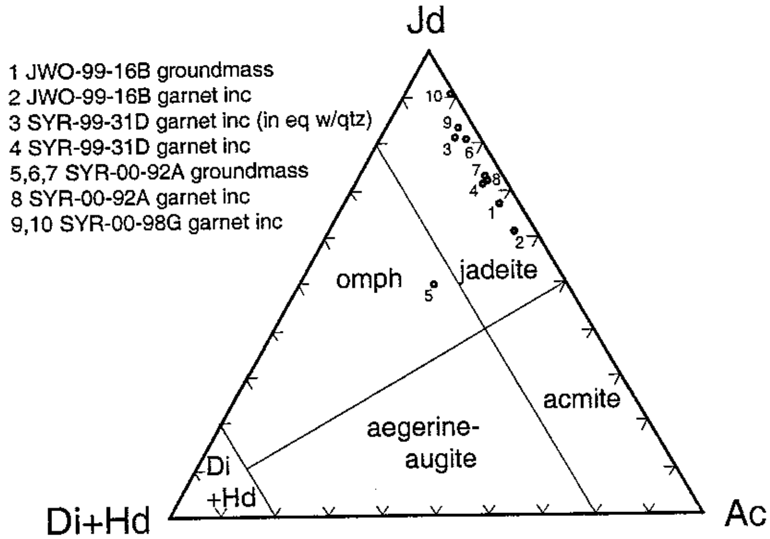

Figure 2. Averaged Clinopyroxene composition. Most pyroxenes plot along the jadeite-acmite sideline within the jadeite zone of this triangle. The omphacite is not likely in equilibrium with the matrix minerals.

Clinopyroxene compositions plot on the jadeite-acmite sideline of the Jd, Ac, Di + Hd ternary diagram (Figure 2). The composition that plots in the middle of the triangle is from a central grain of a groundmass "clump" of clinopyroxene. The grain with this composition is not likely in equilibrium with the matrix minerals as the surrounding grains, which are in equilibrium, plot with the rest of the clinopyroxenes.

SEM/EDS analyses quantified zoning in epidote and blue amphibole, and revealed chemical zoning in garnet. Epidotes generally have Fe3+ rich cores and Al rich rims, though some epidote inclusions in garnet are zoned with relatively Fe3+ rich rims. (Fe3+)/(Fe3+)+Al values for epidote vary between .0084 and .252, but are more commonly between approximately .18 and .24. Ferric iron corrections of epidote analyses were carried out under the assumptions that 1) all the oxygen sites are full and that 2) all the iron is ferric.

Ferric iron in blue amphibole was estimated using the method described in Leake et al (1997), averaging the resulting compositions when the stoichiometric assumptions •Mg=13 or •Na=15, and Si=8 were imposed. Where zoned, blue amphiboles show concentric, core to rim Fe2+/Mg and Fe3+/Al zoning. A plot of amphibole compositions is shown in Figure 3. The blue amphiboles are all glaucophane or ferroglaucophane in composition, as determined by the sodic amphibole nomenclature defined by Leake et al (1997).

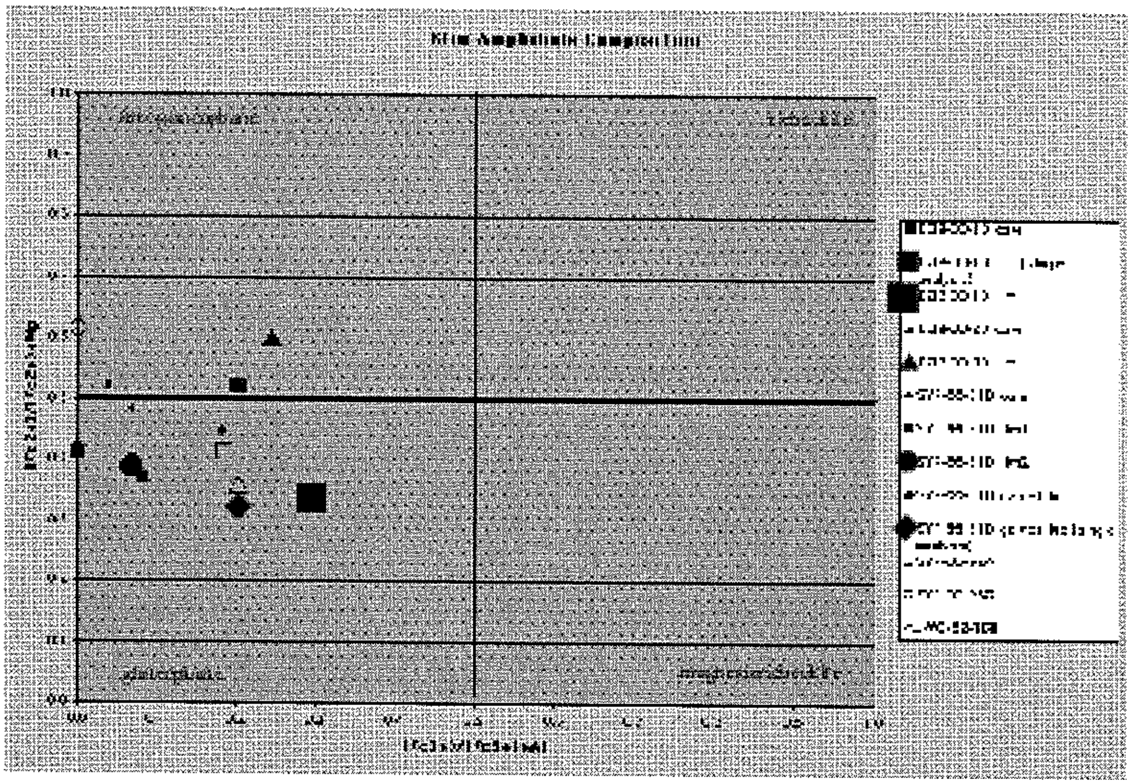

Figure 3. Composition of blue amphiboles. Amphiboles were corrected for ferric iron using several stoichiometric assumptions, including Si=8 for a lower bound and •Mg=13 and •Na=15 for upper bounds. The greatest lower bound and least upper bound that yielded reasonable stoichiometries were averaged to obtain an estimated composition. Zoned amphiboles occur in some samples and are characterized by compositions of rims vs. cores. Included in the chart are single analyses that have good weight percent totals, but are noticeably different from the averages.

Garnet zoning is shown schematically by microprobe x-ray maps and is quantified by garnet traverses (Figure 4) and individual analyses. Most garnets have spessartine - almandine zoning, resulting from the substitution of Fe for Mn during growth. Compositions of Alm_6-Alm_7 are typical, except for the small, >1/10 mm, garnets found in samples from two outcrops that have cores of $Spess_{40}$ and Alm_{30}.

The albite and paragonite in all of these rocks have virtually pure end member compositions. In addition, select titanite analyses reveal high aluminum levels, from 2-6 weight percent, that are indicative of high pressure, as are the phengites, which have silica contents of approximately 3.3 - 3.4 p.f.u.

CONCLUSIONS

The two main goals of this study are to constrain the P-T paths of the quartz-mica schists of Syros and, in a broader sense, to understand phase relationships in high-pressure metapelites. Plotting assemblages of minerals, with their determined compositions, on the NFM diagram reveals possible equilibria among high-pressure metapelitic minerals. Ferric iron is ignored by this diagram and is considered separately as a factor affecting these assemblages. Comparison of inclusion, matrix and overprint topologies from the same outcrop help define reactions among these minerals. Because comparison between outcrops show that all of these rocks plot on the same diagram without crossing tie lines, it is concluded that the metapelites on Syros are all approximately the same grade and that differences in assemblage across the island are due to variations in bulk composition. However, the relic assemblage gar + jd + ctd found in some samples is evidence of a previous, higher grade of metamorphism.

Two reactions are used to constrain pressures for these rocks. If the presence of ab or ky is assumed where clinopyroxene is in equilibrium with quartz, the reactions ab → jd + qtz and jd + qtz → ky can be used as lower and upper bounds, respectively, on peak pressure. Along with these reactions, the variation in compositions of zoned garnets is used to estimate P-T paths during garnet growth.

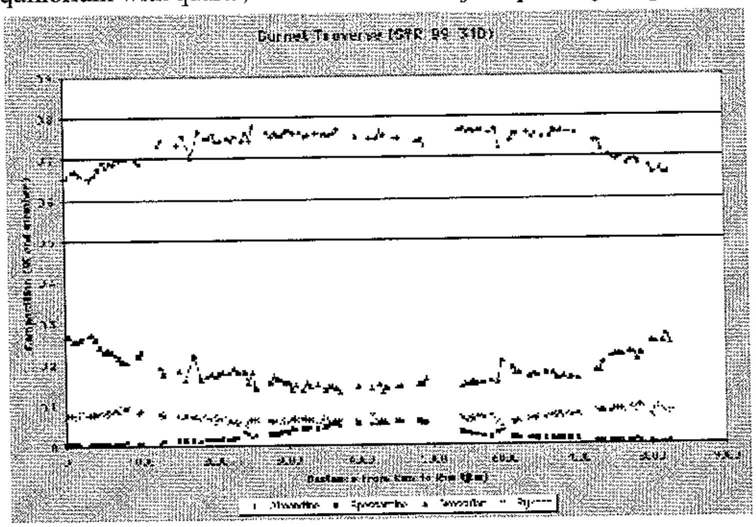

Figure 4. Traverse across a garnet from SYR-99-31D quantifying undulatory zoning. Notice that unlike the analyses of the majority of garnets studied, this traverse shows almost perfectly defined calcium-iron and manganese-magnesium substitutions.

The program GTB 2.0 (by Spear, F.S. and Kohn, M.J., 1990) was used for geothermobarometry. Assuming temperatures between 350 and 450• C, derived from garnet-phengite thermometry, preliminary estimates of the peak pressure for the quartz-mica schists of Syros are between 8 and 11 Kbars. The actual pressure was likely higher because these numbers were derived from the lower bound reaction, ab → jd + qtz.

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