TECTONOMETAMORPHIC EVOLUTION OF CYCLADIC SUBDUCTION ZONE ROCKS: THE SYROS BLUESCHIST-ECLOGITE TERRANE II

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REGIONAL INTRODUCTION

The Cycladic islands are located in the Aegean Sea, southeast of mainland Greece (Figure 1). These islands contain high pressure metamorphic rocks that represent the crustal roots of the Cycladic (Alpine) orogenic belt. This orogen was fragmented during continental extension that followed collapse of the terrane in the Aegean area (Lister and Raouzaios, 1996). The high pressure metamorphic rocks (Figure 1) now preserved in the islands are believed to be the dismembered roots of the mountain belt formed during Eurasia-Africa subduction, which began in the Mesozoic.

The Cyclades are part of the Attic-Cycladic complex, an island belt of crystalline rocks linking continental Greece with Turkey (Figure 1). The complex consists of two main tectonic units. The upper unit contains various intercalated fragments of ophiolites, Permian sedimentary rocks and high temperature metamorphic rocks. In contrast, the lower unit is polymetamorphic and consists of a series of thrust sheets containing pre-Alpine basement, Mesozoic marble, metavolcanics and metapelites. The polymetamorphic nature of this lower unit is manifested by: 1) high-pressure, blueschist facies metamorphism 2) medium-pressure regional metamorphism and 3) contact metamorphism associated with the intrusion of granitic rocks (Schliestedt et al., 1987).

The high-pressure rocks are best preserved on the islands of Sifnos and Syros. Mineral assemblages vary with protolith and include metabasalts with clinopyroxene (omphacite) + garnet + glaucophane + epidote, felsic metavolcanics with jadeite + quartz, metapelites with muscovite + glaucophane + garnet + epidote, marbles containing dolomite + calcite ± quartz ± epidote ± phlogopite, ultramafic rocks and, quartzites (Schliestedt, 1986; Ridley, 1984b: Dixon and Ridley, 1987). Maximum metamorphic condition for the high-pressure event of 460°C and 14 kilobars at Sifnos may be somewhat lower than P-T conditions on Syros, where eclogites are more common (Schliestedt, 1986; Dixon and Ridley, 1985).

The second metamorphic event has been related by Wijbrans et al. (1993) to widespread late Oligocene/ early Miocene extension throughout the Attic-Cycladic belt. This younger event overprints the earlier blueschists and eclogites, culminating at Naxos in a migmatite dome. However on most islands and in particular on Syros and Sifnos, this second event is recorded in the rocks as a pervasive- yet localized- greenschist facies overprinting. Reversal of movement along subduction zone faults may have been responsible for exhuming deeply buried (>50 km) rocks.

The rocks on these islands are isoclinaly folded and extensively sheared and flattened. Four generations of deformation have been recognized in terms of fabric and porphyroblast relations in rocks from Sifnos by Lister and Raouzaios (1996). Thus rocks from Syros and Sifnos have been intensely deformed and significantly recrystallized so that most of the original igneous and sedimentary textures have been obliterated (Lister and Raouzaios, 1996; Dixon and Ridley, 1987).

GEOLOGY OF SYROS

As developed by Schumacher et al. (2000) and shown on Figure 2, the rocks of Syros can be broadly divided into two tectono-stratigraphic units: (I) metasedimentary and metavolcanic rocks and (II) remnants of oceanic crust. Unit I consists of of volcano-sedimentary rock types. The lowermost rocks of

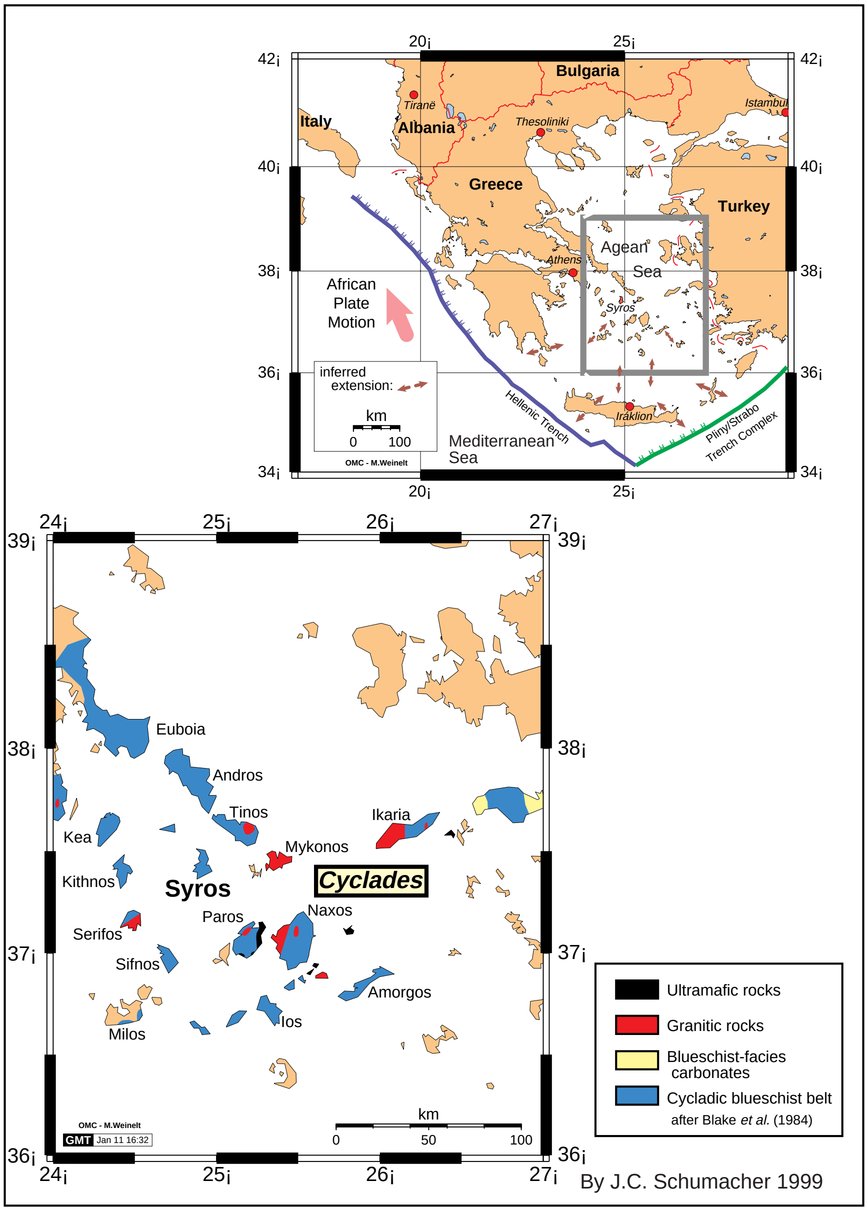

Figure 1. Tectonic map of the Agean Sea with the location of Syros and the Cycladic Islands (top) and the important rock types in the Attic-Cycladic complex (bottom).

Unit I are metamorphosed felsic tuffs that may contain felsic clasts, mafic schists, marbles, and finely-laminated manganese cherts. These rocks give way upwards to a section dominated by marbles. The two main lower marble horizons are typically dolomitic, in part, and are separated from each other by glaucophane-schists, greenschists (retrograde), and minor quartzites and manganese cherts.

Unit II consists of several discrete, fault-bounded packages of blueschist/eclogite-facies mafic rocks that contain minor serpentinite. The mafic rocks occur with a variety of textures and modes but most are either fine grained, glaucophane-rich blueschists or coarse-grained (>1cm), massive omphacite- or glaucophane-rich rocks. Previous workers (e.g. Dixon and Ridley, 1987) have interpreted these rock types as metabasalt and metagabbro, respectively. This hypothesis has been verified by 38 new whole-rock XRF and INAA analyses for 18 fine-grained and 20 coarse-grained samples reported by Brady et al. (2000).

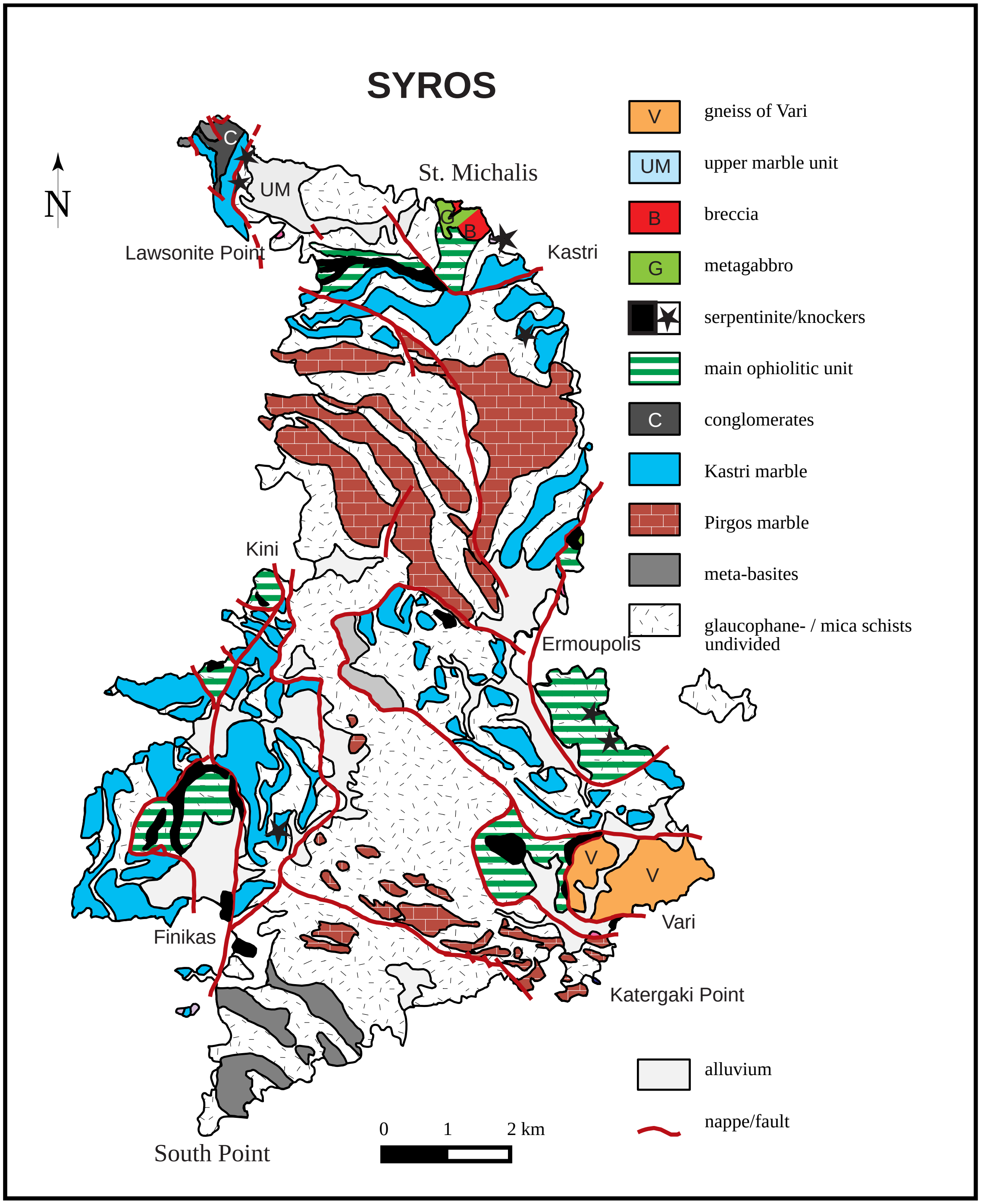

Figure 2. Generalized Geology of Syros modified from H pfer and Schumacher (1997)

Their results have shown that the protoliths of the coarse-grained mafic rocks are indeed gabbros that have been chemically differentiated by fractional crystallization, whereas the protoliths of the fine-grained mafic rocks are largely undifferentiated ocean floor basalts. This interpretation is consistent with the conclusions of previous workers based on field (Dixon, 1969), geochemical (Seck et al., 1996), and isotopic (Putlitz et al., 2000) data. This result raises the interesting question of why a coarse-grained igneous protolith should lead to a coarse-grained metamorphic rock containing all new minerals. The massive character of the original gabbros appears to have had a strong influence on their metamorphism (coarse texture, little hydration) and deformation (little fabric, coherent blocks) during subduction and exhumation.

The occurrence of multiple generations of high-pressure minerals, hornblende as inclusions in glaucophane, intricate chemical zoning of high-pressure minerals, and partial to complete "euhedral" pseudomorphs of lawsonite that contain inclusions of garnet all attest to the complexity of the PTt path that was followed by these rocks during subduction. Some glaucophane, the lawsonite, and the pseudomorphs appear to postdate the main fabric. According to Dixon and Ridley (1987), there is but one penetrative fabric that affects nearly all in the rocks of Syros. This foliation is defined by high-pressure minerals and is parallel to lithologic contacts. In general, foliation is subhorizontal to gently dipping and is associated with a stretching lineation whose orientation varies across the island. Shear sense criteria associated with this lineation give contradictory senses of shear. Further, petrographic observations of intrafolial folds and mineral inclusion patterns suggest that foliation and lineation are fabrics that represent more than one deformation event. There is some strain partitioning reflected by the massive cores of the metagabbros and some of the breccias.

Cheney et al. (2000) have reported ^{206}Pb/ ^{238}U ages from zircon in two blueschists. Ion microprobe spot ages were obtained from three zircon grains in sample SYR99-19A and one zircon grain in sample SYR-7A. The zircon grains selected for dating are large, euhedral and their textual occurrence is consistent with syn- to post- kinematic growth. Some of the euhedral zircon grains are partially included in blue amphibole whereas others cross cut the fabric. There are no grains that are wrapped by the fabric. Thus these zircons grains appear to have grown during metamorphism in accord with the interpretation of Bröcker and Enders (1999) for a zircon in an omphacitite also from the north end of Syros. The result of 83±10 Ma from sample SYR99-19A is remarkably consistent with the 78±1 Ma TIMMS age reported by Bröcker and Enders and probably represent the true metamorphic age for all the rocks, as they suggested. Sample SYR-7A is a glaucophanite from the Kampos melange zone and the zircon ages from one euhedral grain range from 81±2 to 54–4. These dates may indicate activation of the melange zone and continued metamorphism . Of interest is that Brocker and Enders also reported similar young ages of 60 Ma and 63 Ma zircon ages in a jadeite rock on Tinos which they also attributed to a younger "event". These results lend credibility to the occurrence of pre-Eocene high pressure metamorphism in the Aegean. This 80 Ma Cretaceous event may record heating following the slowing of the subducted slab. The younger Eocene dates reflect later lower pressure retrograding of these rocks and the continuing evolution of the accretionary wedge.

STUDENT PROJECTS

The main focus of the 2000 Cycladic Subduction Project was to describe and evaluate the results of relatively recent subduction on a variety of protoliths. Due to the opportunities presented by the mapping program of John Schumacher and his students, and the results of our 1999 KECK research projects, this year s projects were again conducted solely on the island of Syros. These projects focused upon the mineralogic and textural consequences of the processes involved in the evolution of the Syros Blueschist-Eclogite Terrane. In order to cover the geologically diverse island, both geographically and by rock type, student projects ranged in scope from a study of a single rock type that occurs over most of the island to studies of the relationships among many rock types from a single exposure. Six of the students described the rock types and structural relationships in specific geographic areas whereas four of the studies were focused upon specific subjects.

The southern tip of the island consists of a sequnce intercalated mafic and felsic rocks. Previous workers (e.g., Dixon and Ridley, 1987) have characterized these rocks as greenschists that have overprinted preexisting blueschist assemblages. Debbie Prinkey (College of Wooster) and Beth Valaas (Carleton) are studying different aspects of the greenschists that typify the southern tip of the island. In particular, Debbie is using whole rock geochemistry to assess the protoliths of both the felsic and mafic rocks and to compare them to a similar sequnce at Katergaki point (Fig 2). Beth is studying the texture and mineralogy of the greenschist facies overprint. Aurélia Walton (Beloit) and Sonya Hernandez (Colorado College) worked in the Airport Ophiolite on the southern edge of the harbor at Ermoupoli (Fig. 2). Aur lia mapped and described the petrography and geochemistry of the rock sequence. Sonya studied a set of reaction zones between the serpentinite and the blueschists in the sequnce. These reaction zones provided the bluest of blue schists observed on Syros. Jill Richard (Mt Holyoke) and Andrei Sinitsin (Amherst) have studied different aspects of an unusual breccia originally described by Ridley (1984) in the vicinity of St Michalis (Fig.2) on the north end of the island. This breccia is spatially associated with the contacts between a metagabbro and its envelope of host rocks. The gabbro is one of a group of mafic rocks that have been mapped as the St Michlais mafic suite. Andrei has focused upon the petrologic and geochemical description of the St. Michalis mafic suite. Jill has examined in some detail the petrographic, structural and geochemical relationships between the breccia matrix and the breccia fragments along the northern contact of the metagabbro.

An unusual feature of several rock types on Syros is the occurrence of different mineralogical pseudomorphs. Two of the most common are pseudomorphs those after lawsonite and those after aragonite. Lindsey Able (Smith College) is studying the significance of the occurrence and distribution of zoisite-rich pseudomorphs after lawsonite in several different lithologies including blueschists and carbonaceous phengite schists. Lindsey is focusing on describing the variation in mineralogy comprising different types of pseudomorphs in these rocks. One particularly unusual feature common in the marbles are elongate rods of calcite, typically oriented at a high angle to compositional layering, that appear to be pseudomorphs after aragonite. Grace Biancardi (Mt. Holyoke) is conducting a fabric and structural analysis of the orientation and distribution of these pseudomorphs.

Dan Breecker (Amherst) and Michelle Arsenault (Smith) have studied the two most common rock types on Syros in order to access variation in metamorphic pressures and temperatures over the whole island. Dan is focused upon the fabric, mineralogy and phase relationships of the phengite-quartz schists. These schist contain varying amounts of glaucophane, choritoid, garnet, jadeite as well as titanite, paragonite, and rutile. Michelle is studying the systematic mineralogy of impure calcite marbles that locally contain variable amounts of glaucophane, omphacite, garnet, and/or phengite.

JANUARY WORKSHOP

The participants in the 2000 Greece-Syros Keck project assembled for a collaborative workshop at Amherst College over the weekend of 12-14 January, 2001.The student projects are interdependent in that they each rely to some extent on the results of their colleagues work. Accordingly, the workshop provided students and faculty with the opportunity to exchange data, and results, and to share experiences and problems encountered in their endeavors.

The group assembled Friday evening for a pizza dinner followed by several hours of slides from the summer and discussions of outcrops and localities on Syros.

On Saturday morning, Jack Cheney reviewed the scope of the project and its objectives. We then turned our full attention progress reports by each of the ten students in attendance. Each report consisted of a 15 minute oral presentation accompanied by data such photomicrographs, projection of critical thin-sections, maps, chemical data, and mineral composition data. The informal setting provided ample opportunity for questions, discussion, and sharing of results, methods, problems and concerns. During the afternoon, we reconvened for a review and discussion of Mediterranean geology in general and the geology of Syros in particular led by Professor Michelle Markley. We then got out the microscopes and spent the rest of their day reviewing and comparing minerals and fabric in each other s thin sections.

On Sunday, the workshop was organized around s a detailed discussion of minerals we had encountered in the rocks from Syros. This involved thinking about the crystal chemistry of several minerals including omphacite, blue amphibole, phengitic mica and the epidote family. We also discussed ferric iron corrections of SEM data for these mineral as well as way to graphically represent their compositions.

The workshop also provided an opportunity for four of the students to complete the mineral analysis portion of their studies using the SEM/EDS systems at Amherst and Smith. Aurélia Walton (Beloit), Beth Valaas (Carleton) and Sonya Hernandez (Colorado College) arrived the week preceding the workshop and Debbie Prinkey (College of Wooster) stayed for several days following the workshop.

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