

PETROLOGIC AND CHEMICAL EXAMINATION OF THE BLUESCHISTS OF SYROS, GREECE

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INTRODUCTION

Syros, Cyclades, Greece is a locality known for the exposure and preservation of high pressure/low temperature blueschist facies metamorphic rocks. The island is located southeast of the Greek mainland in the Aegean Sea, and consists of alternating marbles, pelitic schists, meta-basites, serpentinites and one feldspathic unit (Dixon and Ridley, 1987). Along the eastern coast of Syros, just south of the port of Ermoupolis, is a mafic sequence of metamorphosed and deformed glaucophanites, meta-gabbros, and serpentinites that makes up the "Airport Mafic Sequence".

There are two types of blueschist that occur together within this mafic sequence. The most common type of blueschist (type 1) makes up most of the Airport Mafic Sequence and is widespread on Syros. It characteristically consists of glaucophane, omphacite, garnet, white mica, titanite, epidote group minerals and rutile (Dixon and Ridley, 1987). The second kind of blueschist (type 2) is uncommon on the island and occurs in thin discontinuous bands between altered ultra-mafic bodies and type 1 blueschist. These rocks consist entirely of glaucophane, titanite, rutile, white mica and epidote minerals. Both types of blueschist are shown schematically in Figure 1. The minerals that are present in type 1 but not type 2 include omphacite and garnet. The metamorphic boundaries between the two types of blueschist cut across penetrative north/northeast dipping foliated and folded layers that I presume to represent original compositional layering. The differences in mineral phases in each rock, along with the crosscutting metamorphic boundaries, suggest that there has been a redistribution of cations due to metamorphism.

The spatial relationships observed in the field suggest that type 1 blueschist may have reacted to type 2 blueschist by movement of metamorphic fluids through the rock during the hydration of the ultramafic bodies in the mafic sequence. This study examines the mineralogical differences between the two types of blueschist using spatial and structural field relationships, petrography, scanning electron microscopy, and electron microprobe analysis.

METHODS

Lithological units, spatial relationships, and structural elements such as foliation, folds, faults and shear zones were examined and documented at one primary site and two subsidiary sites where the type 1-type 2 blueschist transition occurs in the Airport Mafic Sequence. Samples were collected along detailed transects across the metamorphic zones including blackwall reaction rims (chlorite/actinolite schist, actinolite schist, and serpentine). In the lab thirty thin sections were used to identify all mineral phases and to examine textural relationships in order to identify equilibrium assemblages. Five of the thin sections were chosen for chemical analysis. The five thin sections that were chosen for analysis are representative of the best-defined sequences of type 1, type 2, and transitional blueschist at each sample site. The emphasis for SEM/EDS analysis is on three samples [1C, 1D, 1E] from site 1 because the field relationships are clearest there. These samples are plotted by weight percent in Figure 2 and by mineral abundance in Figure 3. Two samples from sites 2 [2J] and 3 [3C] were analyzed using the electron microprobe.

FIELD DESCRIPTION

The metamorphic sequence present at the primary sample site (S1) includes chlorite/actinolite schist, actinolite schist, type 2 blueschist with eclogitic boudins, and type 1 blueschist with eclogitic and meta-gabbro boudins. Figure 4 is a schematic diagram of spatial relationships and sample locations along a transect that is sub-parallel to foliation. The contacts between the blueschist types are discontinuous and perpendicular to the throughgoing structural features.

The band of actinolite schist varies in width from 8 to 12 centimeters. The chlorite/actinolite schist layer ranges from 35 to 45 centimeters in width. It consists of mostly actinolite with chlorite and trace amounts of titanite and epidote. Type 2 blueschist layers are typically between 20 and 150 centimeters in width and mainly glaucophane and titanite are visible in hand sample. Omphacite rich boudins are between

15 and 225 centimeters wide. The rest of the rock is type 1 blueschist, which exhibits glaucophane, omphacite, garnet and rutile in hand sample. The zones of transition from type 1 to type 2 blueschist are typically 10 to 15 centimeters wide.

The second and third sample sites (S2 and S3) show reaction zones with the same type of blackwall/blueschist interaction as the primary site. They differ from S1 because there are more faults and shear zones nearby. The scale of the lithological banding is smaller, on the scale of 2 to 15 centimeters, and at S3 the banding is parallel to foliation and compositional layering. The rock sequence at S2 and S3 also includes serpentinite that is in contact with the chlorite/actinolite schists.

PETROGRAPHIC DESCRIPTION

Serpentinite: The serpentinite is from site 3. It is fine grained and is composed of serpentine [91%] and magnetite [9%]. The magnetite is evenly distributed within the rock and is preferentially oriented in lineations on planes of foliation. The serpentine is greenish yellow in hand sample and green/yellow to transparent in thin section.

Actinolite Schist: The actinolite schist consists of actinolite [80%], chlorite [19%], and trace amounts of rutile and titanite [1%]. The rock is medium to coarse grained. The minerals are distributed in alternating bands of actinolite and chlorite, which in thin section show a crenulation fabric. Most of the titanite crystals are idiomorphic but there is some titanite growing around the rutile that is in the rock.

Chlorite/Actinolite Schist: The assemblage for the chlorite/actinolite schist is actinolite [64%] and chlorite [33%] with trace amounts of epidote [2%], titanite and rutile [1%].

Type 1 Glaucophane Schist: Type 1 blueschists consist of glaucophane [~50%], white mica [1-4%], epidote group [6-10%], titanite [3-7%], rutile [1-2%], omphacite [13-30%], garnet [0-12%], ± chlorite, quartz, apatite, ilmenite and calcite. They are fine grained and foliated with fairly even mineral distribution. Glaucophane crystals show very weak chemical zonation and light blue to violet pleochroism. Omphacite, garnet and epidote crystals are broken and sheared. The omphacite and garnet show poikiloblastic texture with inclusions of glaucophane and rutile. Some clinopyroxene and garnet crystals have rutile with an overgrowth of titanite and glaucophane grains growing between broken fragments or along cracks in the grains. Most of the rutile in the rock is overgrown by titanite.

Type 1/Type 2 Transition: Transitional blueschists consist of glaucophane [52-59%], white mica [1-6%], epidote group [0-3%], titanite [3-6%], chlorite [0-1%], omphacite [17-27%], and garnet [0-6%], ± quartz, rutile, apatite, ilmenite. They are also fine grained and foliated with even mineral distribution. Mineral crystals appear to be the same as type 1 blueschist in thin section. The main difference is the mineral proportions.

Type 2 Glaucophane Schist: The assemblage for type 2 blueschist is glaucophane [79-92%], white mica [0-7%], epidote group [0-3%], titanite [6-10%], ± quartz, rutile, albite, chlorite, and ilmenite. These rocks are foliated, a darker shade of blue and are very fine grained, more so than type 1 or transitional blueschist. The glaucophane shows strong color zonation. The titanite, which is twinned, is evenly distributed through the rock but there are areas where crystallization of titanite, white mica, and epidote minerals is concentrated. The rutile in the rock is overgrown by titanite and it appears as both xenoblastic grains or as acicular crystals.

SEM

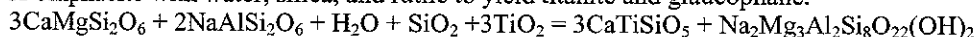
Type 1, type 2, and transitional blueschist were sampled along 2 to 6 meter transects at the primary site. White mica, garnet, omphacite, titanite, epidote, and glaucophane were analyzed with an SEM/EDS on samples 1C, 1D, and 1E along a 2 meter transect. Samples and their respective locations are labeled in figure 4.

All the blueschist samples in the airport mafic sequence contain white mica. SEM analysis revealed that three types of mica are present in the glaucophane rocks: phengite, paragonite, and muscovite. The garnet in the type 1 and transitional blueschist is closest to an almandine composition with some Ca and Mg components. They show weak chemical zoning that is not evident in thin section. Oxides of Si, Fe, Mg, and Ca increase while Mn, and Al decrease from core to rim. The omphacite in these samples does not display chemical zonation in thin section or in the SEM. The only noticeable change in the omphacite composition is a minor increase in MgO from type 1 blueschist toward type 2. There is not as much deviation in titanite composition as there is in percentage of titanite from one rock type to the other as described in the previous section. Epidote group minerals are in both type 1 and type 2 blueschist. Type 2 blueschist contains minerals that are close to the clinozoisite/zoisite members while type 1 and transitional

blueschist seem to have minerals close to both epidote and zoisite composition. The epidote, which is only in type 1 and transitional glaucophane schist, has a high Fe₂O₃ constituent and much lower CaO and Al₂O₃ components. Glaucophane, which changes in abundance from type 1 to type 2 blueschist, also shifts slightly in chemistry. Figure 5 is a plot of major oxide components (y-axis) over distance from the altered ultramafic rocks (x-axis) for representative blueschist samples 1C-1E. It shows a general increase of Al₂O₃ and SiO₂ and an increase in MgO, CaO, and Na₂O out toward type 1 blueschist, sample 1E.

DISCUSSION

The phases that disappear during the change from type 1 blueschist to type 2 are omphacite and garnet. The proportions of mica, chlorite, quartz and rutile are comparable from one rock type to the other. Type 2 blueschist generally contains 30% -50 % more glaucophane, up to 50% less epidote group minerals and as much as twice as much titanite. The absence of omphacite and garnet and reduction in abundance of epidote in type 2 blueschist suggests the release of calcium from these type 1 blueschist minerals into the metamorphic system. The doubled abundance of titanite in these rocks in comparison to type 1 blueschist suggests that some of this calcium has gone towards the growth of more titanite. The measurement of more calcic rims in garnet toward the type two blueschist and the change from both iron bearing and calcic epidote minerals in type one blueschist to only calcic epidote minerals in type two blueschist supports the proposal that calcium was abundant and mobile during metamorphism. The sodium from the omphacite most likely contributed to the production of more glaucophane since other mineral phases in type 2 blueschist do not include sodium in their structures. Therefore sodium was also mobile in this system. One reaction that may have taken place during the migration of fluid toward the ultramafic body includes the reaction of omphacite with water, silica, and rutile to yield titanite and glaucophane.



Excess calcium in the system from garnet and epidote may have gone into the blackwall reaction rind to contribute to the production of actinolite and titanite in the actinolite schist, since actinolite and titanite are both calcic minerals. Minor shifts in magnesium, aluminum and silica content in minerals such as glaucophane and garnet suggest that these elements were also mobile but to a lesser extent.

CONCLUSIONS

The crosscutting relationship between the two types of blueschist and the folds and foliation of layering suggests that the mineralogical differences are not due to original composition. Petrographic work on samples from a primary site and some from two subsidiary sites provided information about what mineral phases react out from one blueschist to the other as well as what changes in abundance occur amongst remaining minerals. This work coupled with the chemical data collected on representative samples of each type of blueschist revealed trends that suggest that mobile cations included calcium, sodium and some transfer of magnesium, aluminum, and silica. The migration of these cations from type 1 blueschist toward type 2 blueschist contributed to the growth of more titanite and glaucophane. The abundance of calcium in the rock may have contributed to the growth of calcic minerals between the ultramafic body and the blueschist as well.

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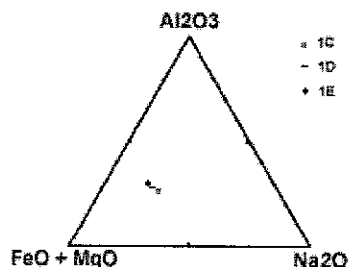


Figure 2: Ternary diagram of representative blueschist samples by wt %. 1C (type 2 B.S.), 1D (transitional), 1E (type 1 B.S.).

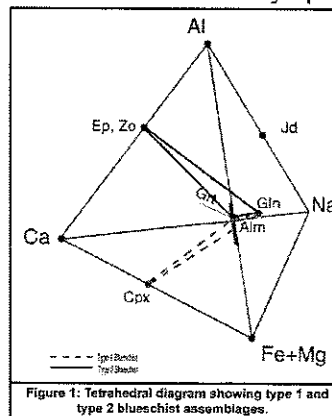
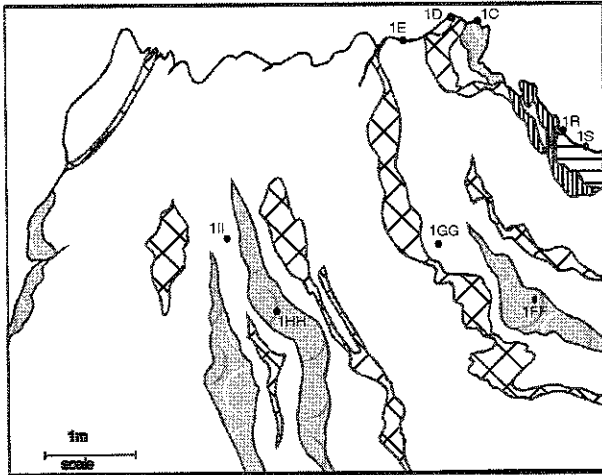
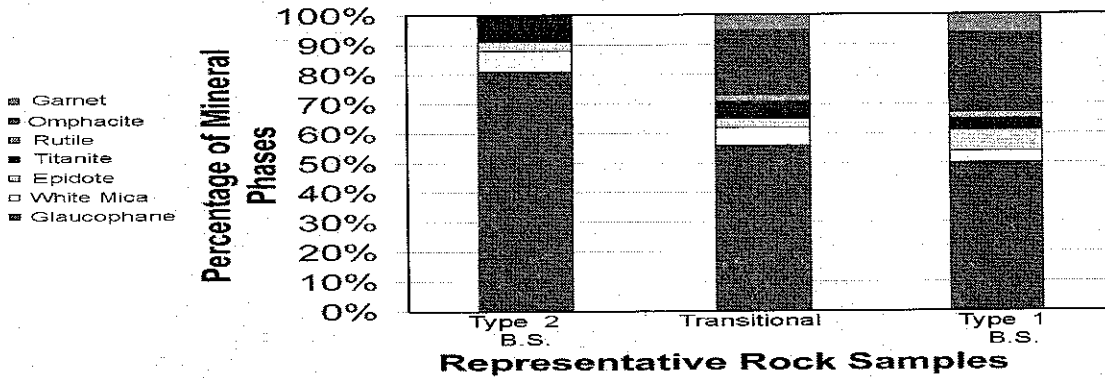


Figure 1: Tetrahedral diagram showing type 1 and type 2 blueschist assemblages.

Mineral Percentage in Thin Section



- Chlorite/Actinolite Schist (1S)
- Actinolite Schist (1R)
- ▨ Calcite Vein
- ⊠ Omphacite Boudins (1F, 1M)
- Type 1 Blueschist (1E, 1GG, 1II)
- ▨ Type 2 Blueschist (1C, 1FF, 1HH)
- ▨ Transition zone (1D)

Figure 4: Schematic Sketch of an outcrop wall that runs roughly parallel to foliation at Site 1. View point is from the SW toward the NE. Sample numbers are marked at their respective locations along the sampling transect.

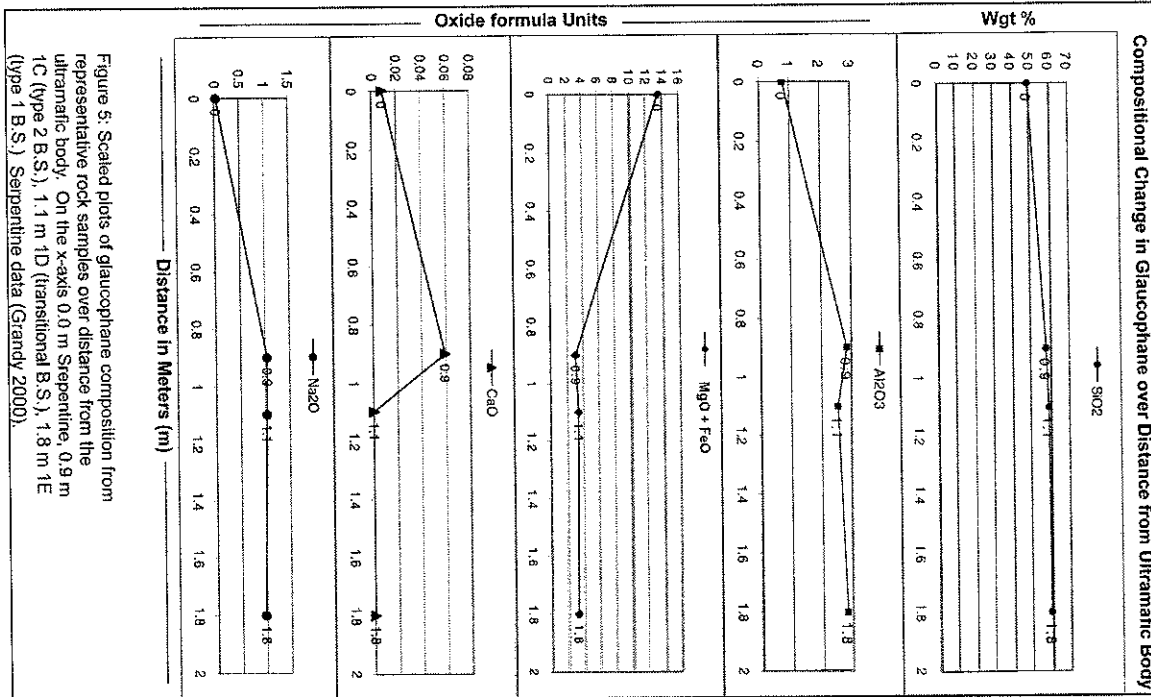


Figure 5: Scaled plots of glaucophane composition from representative rock samples over distance from the ultramafic body. On the x-axis 0.0 m Serpentine, 0.9 m 1C (Type 2 B.S.), 1.1 m 1D (transitional B.S.), 1.8 m 1E (Type 1 B.S.) Serpentine data (Grandy 2000).