CALC-SILICATE MARBLES OF SYROS GREECE

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INTRODUCTION

The island of Syros is located in the Greek Cyclades and is part of a crystalline metamorphic complex that extends from Attica, Greece to Turkey. The Cyclades have undergone at least two periods of metamorphism including a Cretaceous high-pressure blueschist facies event (Bröcker and Enders, 1999; Cheney et al., 2000), and a Miocene greenschist partial overprint (Schliestedt et al., 1987).

Syros is primarily composed of repeated sequences of northerly dipping marbles, calcareous schists, and metamorphosed mafic rocks. The marbles occur in numerous locations on the island in thick, tabular layers and contain various high-pressure metamorphic minerals. This study examines the mineral assemblages, modes, and the chemical composition of various minerals within the marbles in an effort to further constrain the temperature and pressure conditions under which they formed.

METHODS

Marble samples were collected from seven different sites on the island (Figure 1) based on mineral identification in hand sample. Forty-seven samples were cut into thin section, of which, seventeen were described petrologically. Eight representative samples were then chosen based upon mineral diversity and geographic location for analyses using the JEOL 6400 SEM/EDS (Table 1).

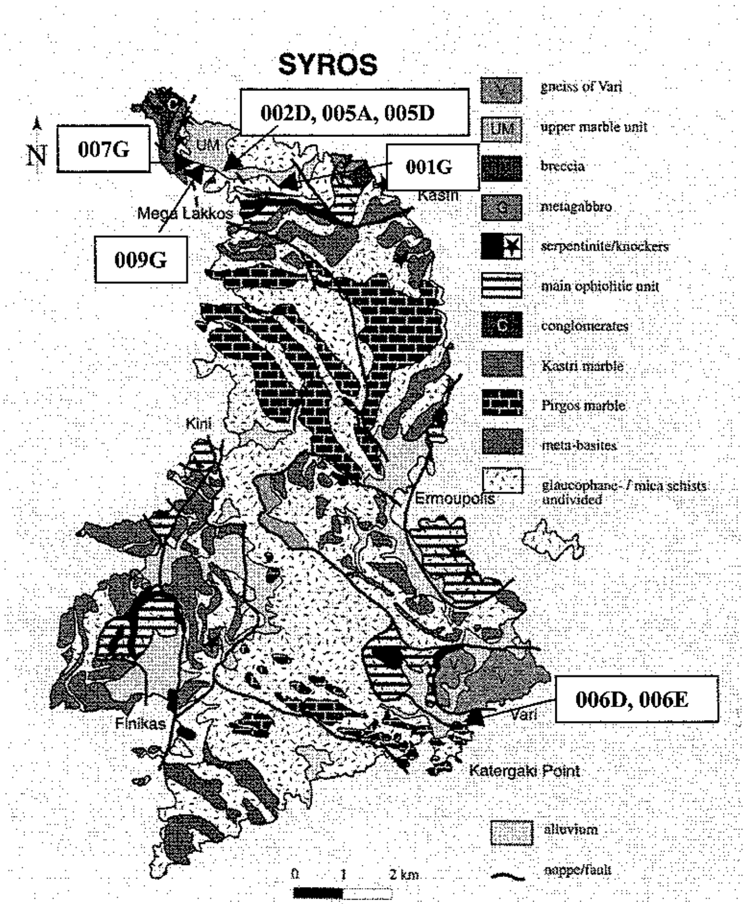

Figure 1. Geological map of Syros, Greece with site locations noted (modified after Höpfer and Schumacher, 1997).

PETROGRAPHY

The marbles of Syros are composed principally of calcite (70-90%), but contain pervasive columnar structures believed to be pseudomorphs of aragonite. The aragonitic columns vary in size, are oriented perpendicular to bedding, and are observed up to 6 cm in length and 1-2 mm across (Grace Bianciardi, this volume). Marble textures range from fine to course grained with most samples exhibiting 10-

30% impurities. The mineral assemblage calcite + quartz + white mica + dolomite + blue amphibole was observed in all six representative samples. In addition to this assemblage, all contained one or more of the following minerals: garnet, epidote, clinozoisite, chlorite, titanite, apatite, and paragonite (Table 1). Of primary interest are the assemblages calcite + quartz + dolomite, titanite + calcite + quartz, and calcite + quartz + epidote.

sample	Cc	dol	qz	glauc	mica	epid	garnet	chl	mnz	apat	tour	feld	omph	titan	rutile	parag
001B	X		X	X	X			X		X				X		?
001G	X		X	X	X	X		X								
002C	X	X	X	X	X	?		X	?							
002D	X	X	X	X	X	X					X			X		
002E	X		X	X	X		X									
002K	X		X		X			X				X				
003D	X	X	X		X		X									
005A	X	X	X		X	X	X	?	?	X				X		
005D	X	X	X	X	X	X					X					
006D	X	X	X	X	X	X	X			X				X		X
006E	X	X	X	X	X		X									
007C	X	X	X		X				?							
007E	X	X	X		X	X							X			
007G	X	X	X	X	X	X						?	X	X		
008B	X		X		X	X										
009G	X			X	X		X	X								
009H	X					X										

(shaded) Indicates samples to be analyzed on the SEM

Table 1. Samples analyzed and described petrographically. Samples were chosen based on varied mineral assemblage and geographic location. Eight representative samples were then chosen for analysis on the SEM/EDS.

CHEMICAL COMPOSITIONS AND MINERAL TEXTURES

Garnet: Most of the garnets present are poikyoblastic in nature (Figures 2 & 3), although a few are found to be intact (Figures 2 & 4). The garnets were found to be 58%-70% Almandine, 24%-36% grossular, 1.0-12% spessartine, and 3%-4% pyrope (Table 2). Slight zoning was observed, with the core higher in Fe than the rims. In addition, Al, Mg, and Ca were lower in the core than the rim.

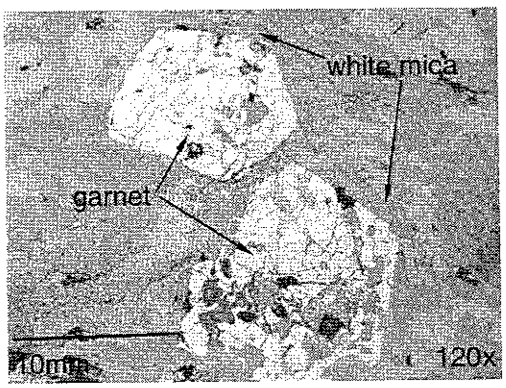

Figure 2. Backscattered electron image of garnets in white mica. The garnet in the upper left is fairly intact while the garnet in the lower right exhibits poikyoblastic texture. 120x

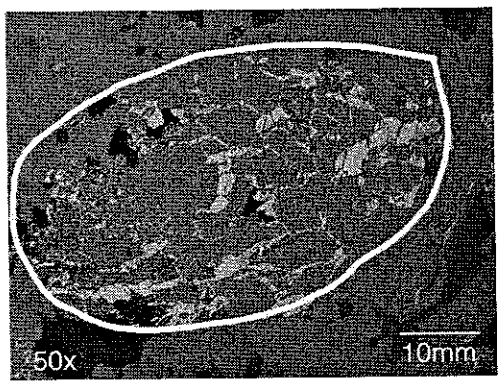

Figure 3. Backscattered electron image of a poikyoblastic garnet in calcite. 50x

	002E	003D	006D-1	006D-1	006D-2	006D-2
			core	rim	core	rim
SiO2	37.52	37.94	37.30	38.32	37.61	38.06
Al2O3	20.91	22.04	21.95	22.12	21.62	21.84
FeO	26.32	23.14	28.83	26.45	27.08	25.58
MnO	4.93	0.55	1.07	1.01	1.00	0.91
MgO	0.48	1.83	1.17	1.75	1.61	1.74
CaO	9.54	14.32	9.84	11.74	10.95	11.84
Total	99.70	99.82	100.16	101.39	99.87	99.97
Normalized on the basis of 12 O						
Si	3.02	2.98	2.97	2.99	2.99	3.01
Al	1.99	2.04	2.06	2.03	2.02	2.03
Fe 2+	1.77	1.52	1.92	1.73	1.80	1.69
Mn	0.34	0.04	0.07	0.07	0.07	0.06
Mg	0.06	0.21	0.14	0.20	0.19	0.21
Ca	0.82	1.21	0.84	0.98	0.93	1.00
Total	8.00	8.00	8.00	8.00	8.00	8.00

Table 2. Garnets sampled are predominantly almandine (58%-70%). Most Garnets show only slight zonation with cores enriched in iron.

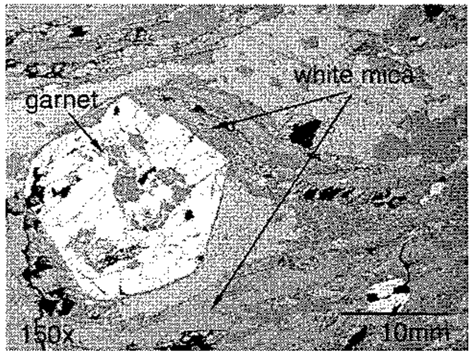

Figure 4. Backscattered electron image of a garnet "wrapped" in white mica and calcite. Quartz inclusions are common in the garnet.

	005A-1	005A-2	005A-3	005A-4
SiO2	38.53	38.39	39.50	39.36
Al2O3	23.07	23.72	22.72	23.83
Fe2O3	15.68	15.57	15.69	14.67
MnO	0.55	0.38	0.54	0.50
CaO	22.89	22.97	22.65	22.72
Total	100.72	101.03	101.10	101.08
Number of ions on the basis of 12.5 O				
Si	3.00	2.98	3.06	3.03
Al	2.12	2.17	2.07	2.17
Fe 3+	0.92	0.91	0.91	0.85
Mn	0.04	0.03	0.04	0.03
Ca	1.91	1.91	1.88	1.88
Total	7.98	7.99	7.95	7.96

Table 3. Chemical analyses of epidote.

Epidote: The four samples of epidote analyzed (Table 3) all came from the same rock (005A) and so are not representative of an overall range found on the island. Sample 005A contains approximately 24% Al, 15% Ferric Iron, and 23% Ca. These figures are consistent with the ranges reported by Deer, Howie, and Zussman (1992).

White micas: White micas are present in all the marble samples (Table 1) and all have essentially the same chemical composition (Table 4). High silica content indicates phengite. Al content ranges from 24 to 28 wt.%, ferrous iron ranges from 2.4 to 5.1wt %, and K is present in amounts around 10 wt %.

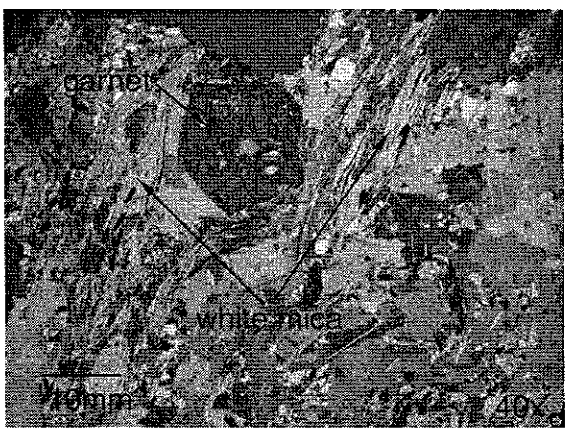

Figure 5. Photomicrograph of white micas surrounding a garnet. The white micas are compositionally most like phengite.

Dolomite: Dolomite occurs in several samples and exhibits two distinctive textures: clusters of fine-grained crystals, 20-150μm across, (Figure 6), and larger sub-rounded crystals, 1-2mm across. Chemical analysis was performed on the larger crystals and indicates the following wt % compositions: approximately 17% Mg, 28% Ca, 6% Fe, and <1% Mn (Table 5). These data indicate a composition between dolomite and ankerite as reported by Deer, Howie, and Zussman (1992).

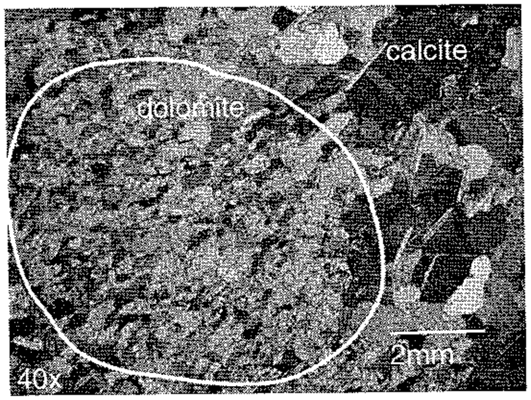

Figure 6. Photomicrograph of fine-grained dolomite. Individual crystals are 20-150 μm across.

	005D-1	005D-2	005D-3
FeO	6.14	5.83	5.17
MnO	0.76	0.46	0.57
MgO	17.18	18.26	17.01
CaO	28.77	28.82	28.94
CO2			
Mg	2.47	2.58	2.49
Fe2+	0.5	0.46	0.42
Mn	0.06	0.04	0.05
Ca	2.97	2.92	3.04

Table 5. Dolomite analyses. Compositions include iron indicating an ankeritic dolomite.

	005A-1	005A-2	006D-1	006D-2
SiO2	51.90	51.71	51.93	53.11
TiO2		0.41		
Al2O3	24.08	23.88	28.24	28.21
FeO	4.87	5.11	2.50	2.39
MgO	2.95	2.92	2.90	2.89
CaO	0.16			
Na2O	0.35			0.62
K2O	10.17	10.10	10.09	10.04
Total	94.48	94.13	95.66	97.26
Number of ions on the basis of 11 O				
Si	3.53	3.53	3.43	3.45
Ti		0.02		
Al	1.93	1.92	2.20	2.16
Fe 2+	0.28	0.29	0.14	0.13
Mg	0.30	0.30	0.29	0.28
Ca	0.01			
Na	0.05			0.08
K	0.88	0.88	0.85	0.83
Total	6.97	6.93	6.90	6.93

Table 4. Mica analyses. Chemical analyses indicate that the micas are predominantly phengite.

DISCUSSION

The high pressure mineral assemblages found in the Syros marbles are unusual in that they are not typically observed in marbles at all. Minerals assemblages such as calcite + quartz + dolomite and garnet + phengite will be used to help constrain the temperature and pressure conditions to which the marbles were subjected. The assemblages, which are dependent on both bulk composition of the protolith and fluid composition, seem to indicate a water-rich, CO_2- poor environment. The presence of titanite instead of rutile, coexisting with calcite and quartz indicates a low value of CO_2 (Ballevre, 1994). It is our goal to better understand the effects of a high pressure- low temperature metamorphic event on marbles that typically do not get subducted.

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CALCITE NEEDLES IN SYROS MARBLES

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INTRODUCTION

The rocks on the Greek island of Syros are part of a suite of high pressure metamorphic rocks which outcrop all across the Cyclades. There is a complex metamorphic history recorded in the rocks here, including a Cretaceous or Eocene high-pressure blueschist event and a Miocene, extension-related greenschist overprint. The Island of Syros is mostly composed of schists, which alternate with north-dipping pure and "impure" marbles, and some smaller outcrops of breccia and metagabbro [Dixon and Ridley 1987]. Calcite in the marbles here shows a needle-like texture. Needles are generally sub-vertical, sub-perpendicular to the marble foliation (see Figures 1 and 2) and range in length from 1 cm to 6cm.The origin of these needles, the significance of their alignment with respect to local structures and understanding why these needles might be oriented sub-perpendicular to the foliation make up the bulk of this study.

OBSERVATIONS

The structural data collected about the needles focuses on three types of structures: i) within boudins or clasts (Figure 3), ii) surrounding boudins or clasts (Figure 4) or iii) in folded layers (Figure 5). In the first setting (within boudins or clasts in a marble matrix), the calcite needles exhibit one of two behaviors. Either the needles appear to be parallel to each other within the clast and parallel to the needles in surrounding clasts (6 times out of 10 documented cases; Figure 3) or the needles are not uniformly oriented. In this second situation (4 cases out of 10) the needles were either parallel within the clast but not parallel to surrounding calcite needles (3 cases) or were fanned within the boudin (1 case). The needles in both scenarios are most often sub-vertical and sub-perpendicular to surrounding foliation and the long axis of the boudin. In cases where the clast shape records a sense of shear, the calcite needles remain parallel to each other and do not appear deformed by the shear. There are two documented cases in two different parts of the island where the calcite needles within the clast are bent to some degree.

In the second setting (when calcite needles were found in a layer wrapping around boudinaged layers or clasts of another rock type), the needles occur in two distinct ways. Either the calcite needles fan around the boudin, remaining sub-perpendicular to the shell of the boudin (in seven cases out of 8; Figure 4) or the needles remain perpendicular to the local foliation and then lie flat on the top of the boudin (one case). In some cases the needles wrap completely around an isolated clast or boudin (parallel to local foliation), and in others, the needles fan around the boudin but then return to perpendicular to local foliation at the pinched out ends of the boudin.

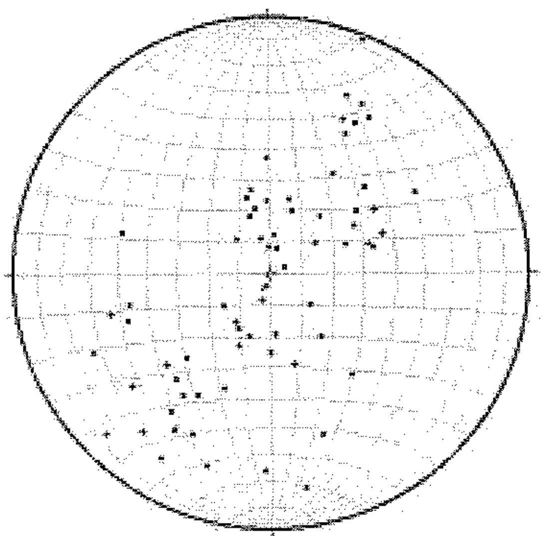

Figure 1. Calcite needle orientation across Syros.

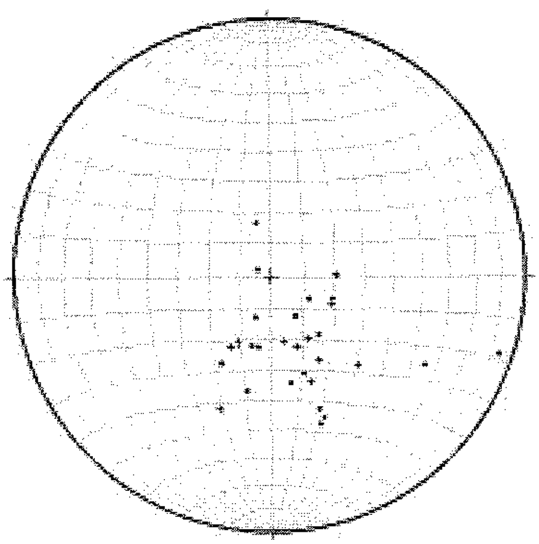

Figure 2. Poles to foliation across Syros.