WHOLE-ROCK GEOCHEMISTRY OF SCHISTS FROM SYROS, CYCLADES, GREECE

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INTRODUCTION

The island of Syros is located within the Attic-Cycladic Metamorphic Belt and preserves rocks with eclogite and epidote-blueschist-facies mineral assemblages (Okrusch and Brocker, 1990). Locally, these high-pressure, low temperature rocks are overprinted by greenschist-facies mineral assemblages. Two lithotectonic units have been identified on Syros: enclaves of mafic rocks and volcano-sedimentary rocks consisting of widespread schists and marbles. Mafic rocks occur in discrete, fault-bounded units around the island and are juxtaposed with the volumetrically dominant felsic schists and marbles. The schists are interpreted as metamorphosed volcanics and volcaniclastic sediments, whereas the marbles are metamorphosed limestones (Putlitz et al., 2000). Fine-grained and coarse-grained mafic rocks are interpreted to be meta-basalts from an ocean floor setting and meta-gabbros, respectively (Dixon and Ridley, 1987).

Preliminary chemical analyses of the schists of Syros (Prinkey, 2001; Sinitsin, 2001) and the neighboring island of Sifnos (Mocek, 2001), have suggested a range of possible protoliths, from MORB to island arc-affinities. This study focuses on quartz-white mica schists that encompass a wide range in composition from mafic to felsic. The goal is to determine the tectonic setting of rock protoliths to better characterize the types of material that entered the relic subduction zone. Major oxide and trace element geochemical analyses are used to determine protoliths and to characterize the tectonic setting of these protoliths.

METHODS

Thirty-five schists were collected from ten localities on Syros. Although the emphasis was felsic schists, intermediate and mafic schists were also collected where interlayered with the felsic rocks. Four locations (Lia Beach Trail, Palm Beach, San Michalis, and Katergaki) were extensively sampled due to complex cross-cutting and structural relations of felsic and mafic rocks in these outcrops. In this way, samples were collected representing a wide range of mineral assemblages and geographical locations. All thirty-five samples were petrographically described, and the freshest twenty-five rocks of these were selected for chemical analyses. Major oxide and trace element compositions were determined by ICP-MS at Acme Analytical Labs in Vancouver, B.C.

PETROGRAPHY

Each location contains a variety of rock types and most of the samples contain a strong foliation and/or lineation of quartz+white mica. Only a few samples have massive fabrics and these are either greenschist-facies schists or rocks dominated by jadeitic pyroxene.

Based on mineral assemblages, the rocks can be subdivided into four groups. Group 1 consists of felsic rocks that contain greater than 70 percent quartz+white mica with minor amounts of garnet±albite±chlorite±epidote. Group 2 consists of blue amphibole-bearing mineral rocks that range from mafic to intermediate and also contain quartz+white mica±garnet. Variable amounts of greenschist-facies minerals (±epidote±chlorite±albite) are present. Foliation is defined by blue amphibole+quartz+white mica and wraps around garnet where present. Group 3 consists of rocks with the greenschist-facies mineral assemblage quartz+white mica+garnet±chlorite±epidote±albite. Group 4 consists of rocks composed principally of jadeite+quartz, with lesser amounts of white mica±albite±garnet±blue amphibole±omphacite±acmite. They have massive fabrics and contain 0.5-1.0 centimeter rims of albite that surround jadeite. The rocks also contain minor amounts of rutile, titanite, apatite, calcite, and/or opaques.

Mineral compositions from nine selected samples were obtained using the SEM/EDS at Amherst. Blue amphibole ranges from glaucophane to ferroglaucophane, and white micas are paragonite and phengite. Garnets are almandine rich (60-80 percent) with lesser and varying grossular content (10-40 percent). They are typically zoned with almandine component decreasing and grossular and spessartine increasing by ten to twenty percent towards the core. Clinopyroxene compositions include jadeite, aegerine-augite, acmite and omphacite. Both omphacite and jadeite occur in the groundmass of some samples whereas aegerine-augite and acmite only occur as thin rims around albite.

WHOLE-ROCK GEOCHEMISTRY

Group	Sample	SiO2	Al2O	Fe2O	MgO	CaO	Na2O	K2O	TiO2	La	Ce	Pr	Yb	La	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
1	26a	73.8	14.1	2.44	0.9	0.9	2.48	1.8	0.22	21	45	5	2	21	19.3	3.4	0.6	3.05	0.49	2.6	0.5	1.43	0.25	1.51	0.26
1	11b	75.1	12.8	3.08	1	0.1	3.24	2.8	0.23	28	65	7	5	28	29	5.9	1.3	6.47	1.18	6.6	1.5	4.54	0.78	5.17	0.79
1	21	75.8	12.1	3.44	0.3	1.1	3.66	1.3	0.17	8	27	3	6	8	14.7	4.4	1	4.99	0.89	6.3	1.5	4.63	0.82	5.67	0.96
1	38b	76.1	14	1.57	0.6	1.4	3.65	0.4	0.18	37	93	12	12	37	55.4	13	1.4	14.1	2.74	18	3.8	11.07	1.7	12.37	1.69
1	18	76.5	13.5	1.76	0.5	0.1	2.86	3	0.09	49	80	7	1	49	23.3	3.4	0.5	2.21	0.31	1.5	0.3	0.77	0.14	1.18	0.23
1	23d	77.5	13.6	1.89	0.6	1.1	2.4	0.5	0.17	24	58	7	8	24	27.8	5.7	1	6.44	1.41	8.7	2	6.45	1.13	7.87	1.14
1	4a	80.5	11.6	1.66	0.5	1.5	2.22	0.2	0.2	8	25	4	4	8	20.6	5.4	1.1	6.56	1.29	7.6	1.5	4.58	0.7	4.26	0.64
1	37b	81.8	8.77	1.3	0.6	3.1	0.73	1.1	0.19	16	35	5	3	16	21.2	4.6	0.8	4.69	0.78	4.9	1	2.69	0.4	2.98	0.39
2	4b	50.1	15.3	13.2	5.5	8.3	3.84	0.3	1.29	12	28	3	3	12	16.9	4.5	1.3	4.48	0.9	5.1	1.1	3.06	0.48	2.97	0.48
2	35c	56.7	13.9	11.1	2.7	5.2	5.99	0.6	1.94	16	46	7	8	16	38.4	10	3.1	12.3	2.25	13	2.8	8.02	1.19	8.09	1.19
2	23f	58	15.1	8.34	6.5	1.4	3.16	2.7	0.83	27	57	6	3	27	25.4	4.6	0.9	3.9	0.63	3.7	0.7	2.05	0.34	2.51	0.4
2	20	65.4	13.6	4.71	1.6	6.3	2.94	1.9	0.51	58	97	9	2	58	34.9	6	1.6	4.9	0.76	3.8	0.8	2.19	0.35	2.37	0.37
2	12a1	70.1	14	5.39	2.4	0.7	3.59	0.3	0.48	4	11	1	2	4	7.6	2.1	0.6	2.62	0.54	3.4	0.7	2.28	0.35	2.45	0.43
2	1c3	70.6	13.9	4.14	1.2	5.1	2.35	0.3	0.44	9	24	3	4	9	15.3	4.4	1.4	5.38	1.04	6.2	1.3	3.98	0.62	3.92	0.65
2	16b	75.2	13	3.44	0.9	1.8	1.99	1.1	0.3	5	13	2	4	5	9.7	3.2	0.8	4.17	0.81	5	1.2	3.22	0.58	3.59	0.6
3	28a1	49.7	18.6	10.2	4.2	7.7	2.91	1.8	1.1	26	57	7	3	26	27.9	5.5	1.4	5.14	0.87	4.8	0.9	2.7	0.46	2.98	0.46
3	44	54.5	16	10.4	8	0.3	3.37	0.2	0.53	3	3	1	1	3	3.7	1.1	0.4	1.11	0.24	1.3	0.3	0.66	0.1	0.85	0.11
3	23b1	55.3	14.8	8.46	7.4	2.2	4.44	2	1.79	12	31	4	6	12	20.1	5.8	1.4	7.12	1.35	8.3	1.9	5.73	0.93	6.07	0.87
3	37a	62.7	11.8	4.68	1.5	9.5	1.07	0.3	0.36	22	44	5	4	22	25	5.3	1.3	5.73	1	5.7	1.2	3.58	0.61	3.93	0.63
3	43a-b	65.3	15.1	6.37	1.6	4.7	2.07	0.8	0.62	10	21	3	3	10	11.6	2.8	0.8	3.25	0.6	3.9	0.9	2.45	0.37	2.69	0.38
3	9a	67.5	13.3	6.59	1.8	1.5	3.01	1.6	0.46	4	9	1	3	4	5.8	1.7	0.6	2.31	0.52	3.3	0.7	2.25	0.39	2.62	0.39
3	42	70.8	12.8	4.28	0.9	3.9	1.94	0.9	0.41	9	19	2	3	9	10.5	2.5	0.7	3.14	0.54	3.6	0.9	2.51	0.39	2.9	0.4
4	5	57.5	21.8	1.6	2.6	1.6	7.8	3.9	0.26	11	32	4	10	11	18.9	5.3	0.6	6.2	1.73	12	2.6	8.31	1.48	10.1	1.41
4	23a1	67.8	14.2	6.01	0.8	1.4	7.06	0.3	0.63	19	53	7	12	19	36.8	9.9	2.1	12	2.23	14	3.2	10.35	1.87	11.92	1.87
4	35b1	69.7	15.1	3.86	0.3	1.3	7.71	0.1	0.32	20	54	7	11	20	33.9	8.9	1.8	9.85	1.99	13	3	9.45	1.63	11.27	1.74

Table 1: Major oxides and Rare Earth Element data for analyzed rocks, ordered by the mineral assemblage groupings described above.

The analyzed rocks have chemical compositions consistent with igneous protoliths ranging from basalt to rhyolite, with a greater concentration of samples in the dacite and rhyolite fields, as shown in Figure 1. Felsic rocks with silica contents greater than 70-75 weight percent either have sedimentary protoliths or are meta-volcanic rocks that have undergone alkali leaching or silica enrichment. Alkali leaching may have occurred because Na and K are scattered when plotted versus SiO_2 (figure not shown), indicating that they may have been relatively mobile during metamorphism. Group 1 felsic rocks mostly plot as rhyolite, with one sample in the dacite field. Group 2 blue amphibole-bearing rocks are basalts, basaltic-andesites, and andesites. Group 3 greenschist-facies rocks plot in the dacite field. Group 4 jadeite rocks contain the highest concentration of alkalis and with one exception, plot as dacite and rhyolite.

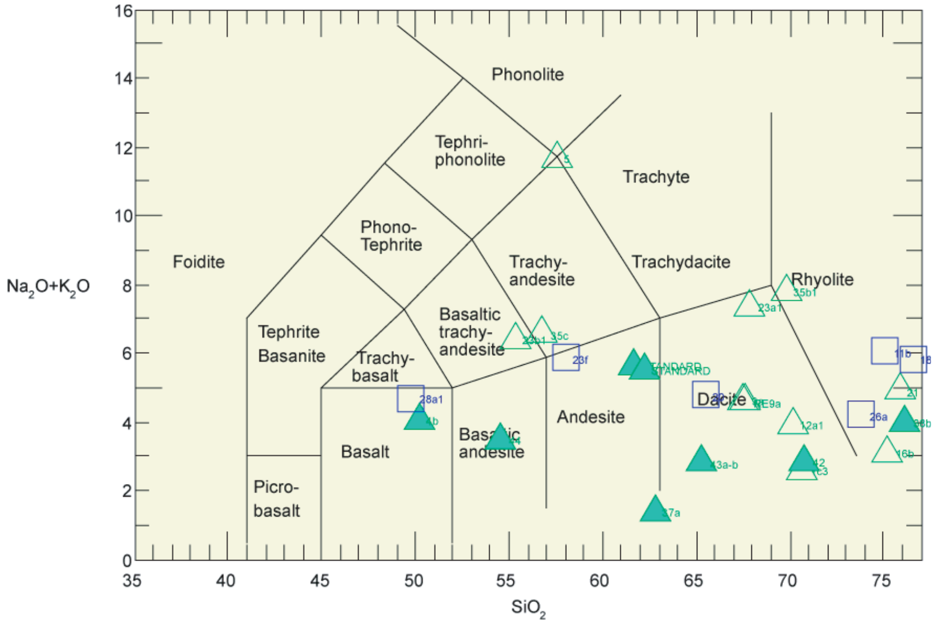

Figure 1: Total Alkalis vs. Silica plot. Three "rhyolitic" samples are not shown because they contain greater than 77 percent SiO_2. Symbols are representative of REE slope versus chondrite (see Figure 3).

Rare Earth Element (REE) data are used to characterize the rocks because they are typically immobile during metamorphism (Rollinson, 1993). Rocks from the four petrographic groupings do not neatly separate into groups on the REE plots. When plotted on chondrite-normalized REE plots, the rocks can be split into three types based on their slope. Type 1 rocks have highly negative slopes, with La ~100 times chondrite and La/Yb ratios >100 (Figure 2). Most of these rocks are from the felsic category, but a greenschist and blueschist are also present. Type 2 and Type 3 rocks have slightly negative slopes and flat slopes, respectively with values 8-100 times chondrite (Figure 2). Type 2 contains mostly felsic rocks, with three greenschist-facies rocks. Type 3 contains rocks from all of the petrographic categories, and the bulk are blue-amphibole-bearing rocks and jadeite-rocks.

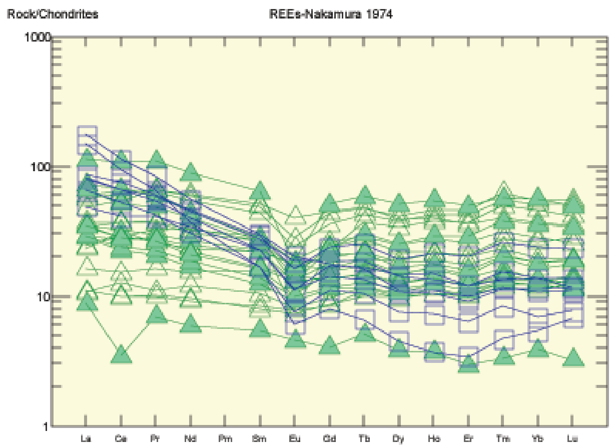

Figure 2. Rocks plotted relative to chondrite. Symbols represent slope of REE. Squares are the most LREE enriched, filled triangles are slightly LREE enriched, and open triangles have flat slope.

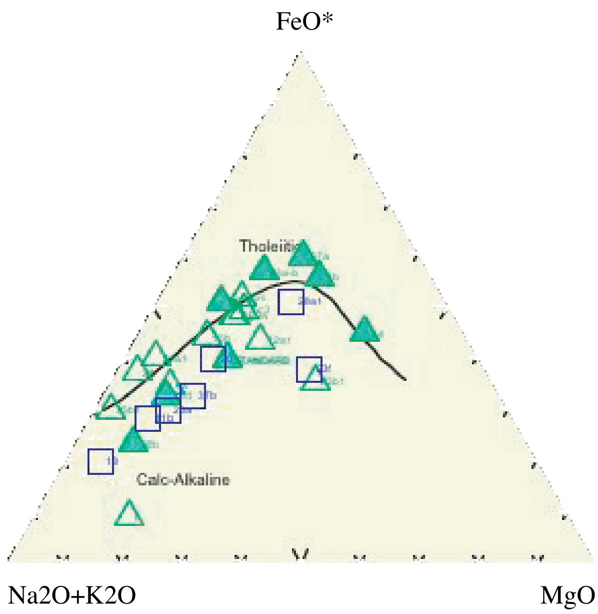

Figure 3. AFM Diagram showing the majority of rocks plotting in the calc-alkaline field, with a few plotting as tholeiitic. After Irvine and Barager (1971).

Most of the samples have negative europium anomalies, depletion of Ti, Nb, Sr, and Ba, and enrichment of Zr and Th. Depletion of Nb and enrichment of Th are commonly associated with arc rocks (Mocek, 2001). Similar depletions and enrichments are found in jadeite-gneisses and blueschists on the neighboring Cycladic island of Sifnos (Mocek, 2001).

An AFM diagram (Figure 3) shows most of the samples plotting in the calc-alkaline field. Mafic samples with low amounts of K_20 are tholeiitic.

SUMMARY

A range of protoliths appear to be represented in the schists of Syros. A subset of blueschist- and greenschist-facies rocks that plot as tholeiites on an AFM diagram and have low amounts of K_2O may represent ocean floor basalts (Brady, 2000). Many of the calc-alkaline rocks show chemical similarities to Sifnos rocks that may have arc protoliths (Mocek, 2001). Felsic rocks with minor amounts of greenschist-facies minerals have highly LREE-enriched patterns similar to chlorite-actinolite rocks on Sifnos (Mocek, 2001). Blue-amphibole bearing rocks with flat slopes relative to chondrite, Nb troughs, and Th enrichment are similar to that in blueschists from Sifnos (Mocek, 2001). Jadeite-bearing rocks on Syros have flat REE patterns similar to those of jadeite-gneisses on Sifnos, but are more enriched relative to chondrite (Mocek, 2001).

Additional analysis is needed to relate mineral assemblages and bulk chemistry in the schists of Syros and to compare and results with previous analyses from Syros and Sifnos. We continue to explore chemical indicators of sedimentary versus volcanic protolith to evaluate the extent of possible mixing of sedimentary and igneous material in these rocks.

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