# Tectonometamorphic evolution of impure carbonate rocks located on Syros, Greece

**Robert R. Tonnsen**
Department of Geology, Whitman College, Walla Walla, WA 99362
*Faculty sponsor: John Winter, Whitman College*

## INTRODUCTION

Pure calcite marbles are boring rocks, petrologically speaking. The most significant information that can be derived from a pure marble to constrain metamorphic conditions involves the calcite-aragonite high-pressure transformation. Fortunately, not all marbles are 100% calcite: some contain "impurities" possibly originating as pelitic or lithic sediments interlayered during original deposition of the limestone, or possibly tectonically emplaced during metamorphism. These impurities undergo chemical reactions during metamorphism producing diagnostic minerals that can be used in constraining metamorphic conditions. This study applies petrographic techniques and chemical analysis of these "dirty" marbles in an attempt to constrain the tectonometamorphic conditions that affected the island of Syros.

Syros mainly consists of blueschist/eclogite facies rocks with a greenschist facies overprint that is most extensive at the southern end of the island (Dixon and Ridley, 1987). The principle metasediments found on Syros are marble and pelitic schist. Interspersed with the metasediments are small quantities of metamorphosed mafic rocks and serpentine lenses (Figure 1). The carbonate-rich rocks are the focus of this study. Although the carbonate is predominantly calcite at present, calcite pseudomorphs of aragonite are common. Aragonite is indicative of high-pressure metamorphism (>8kb at 300°C) (Raymond, 1995). In addition, less abundant "dirty" marbles, consisting mostly of calcite but containing other minerals including glaucophane, epidote, omphacite, dolomite, quartz, phengite, and garnet, are found on Syros. This study analyzes some impure marbles to determine the effects of high-pressure blueschist facies metamorphism on calcite-rich mineral assemblages. The carbonates provide an opportunity to use a single rock type to evaluate variations in metamorphic grade and tectonometamorphic evolution over the entire island by

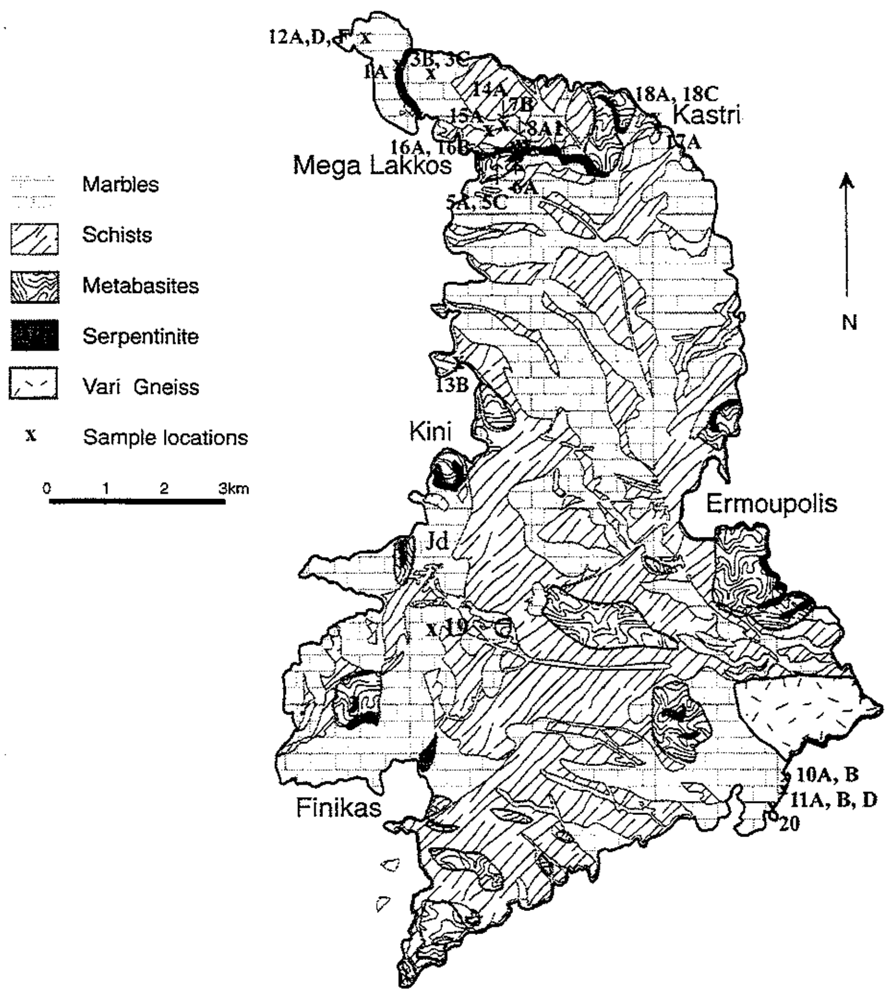


**Figure 1.** The geology of Syros, including sample locations of the carbonate rocks used in this study (modified after Dixon and Ridley (1987).

| Sample | Minerals |
|---|---|
| G1A | cal-qtz-gln-ep-wm-dol-grt-plag |
| G3B | cal-qtz-ep-wm-do-omp-spn |
| G3C | cal-qtz-gln-ep-wm-chl-sulfide |
| G5A | cal-qtz-gln-ep-wm-dol-chl-plag |
| G5B | cal-qtz-gln-wm-chl?-plag-phl? |
| G6A | cal-gln-ep-wm-do-chl-omp-ap? |
| G7B | cal-wm-do-grt-chl-omp±plag |
| G8A1 | cal-qtz-gln-wm-dol-grt-chl-plag-bt? |
| G10A | cal-qtz-wm-dol |
| G10B | cal-qtz-wm-dol |
| G11A | cal-qtz-gln-wm-dol-grt-chl-zo |
| G11D | cal-qtz-gln-ep/czo-wm-grt |
| G12A | cal-qtz-wm-chl-plag-spn |
| G12D | cal-qtz-wm-chl-plag-opaque? |
| G12F | cal-qtz-gln-wm-dol-chl-plag |
| G13B | cal-qtz-gln-ep/czo-wm-grt-chl-plag-spn |
| G14A | cal-qtz-gln-ep-wm-dol-omp-spn |
| G15 | cal-qtz-gln-wm-dol-chl-plag-spn |
| G16A | cal-qtz-gln-wm-dol-grt |
| G16B | cal-gln-wm-dol-grt-omp-plag |
| G17B | cal-qtz-wm-dol-opaque |
| G18A | cal-qtz-gln-ep-wm-dol-plag |
| G18C | cal-qtz-gln-ep-wm-dol-omp-plag-spn |
| G19A | cal-qtz-wm-dol |
| G20 | cal-qtz-wm-grt-chl-plag-bi-opaque |

**Table 1.** Mineral assemblages of samples

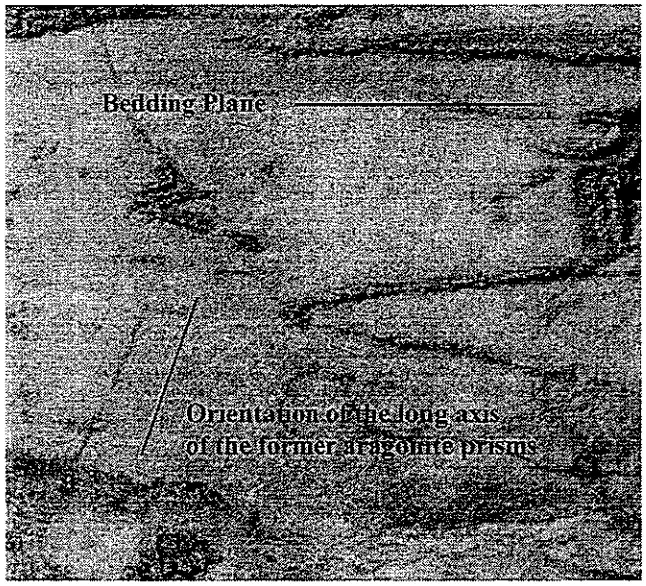


**Figure 2.** Calcite pseudomorphs of aragonite in a massive marble. Lines represent the long axis of the pseudomorphs and general orientation of the bedding surface. Also in the picture is an isoclinal fold offset by a small-scale normal fault.

comparing rocks taken from different localities throughout Syros.

Thin–section study was used to determine mineral assemblages and modes. The scanning electron microscope with an energy dispersive x-ray spectrometer (SEM/EDS) was used to determine the composition of specific minerals. This chemical information will be used in conjunction with the mineral assemblages and established geothermobarometers in an attempt to better constrain tectonometamorphic conditions. However, this work is still in progress, so the present paper is largely descriptive and presents the data without full interpretation of the metamorphic evolution of Syros.

## DATA

**Sampling.** The rocks used for this study were collected based on visible minerals found within impure carbonate rocks in the field. Samples were collected from locations throughout the island of Syros, with most collected from the northern end (Figure 1). Outcrops of carbonate-rich rocks are located proximal to pelitic schist, melange, meta-conglomerate, and marble quarries. Calcite pseudomorphs of aragonite are common in the marbles. The long axes of the former aragonite prisms are commonly oriented sub-perpendicular to the bedding in the marbles. Where folds are visible, the aragonite prisms are oriented sub-perpendicular to the axial surfaces of the folds (Figure 2).

**Petrography.** Mineral assemblages are affected by the partial to complete greenschist facies overprint of the blueschist facies mineral assemblages (Table 1). Associations of primary interest for geothermobarometry include quartz+ dolomite, omphacite+ garnet, jadeite+ quartz, and garnet+ chlorite. A calcite vein in one sample shows no evidence of undergoing high-pressure metamorphism, as it does not contain aragonite pseudomorphs. This suggests a period of carbonate-rich fluid infiltration that occurred post-blueschist facies metamorphism. Samples taken from the meta-conglomerate have a thorough greenschist facies overprint in the matrix, but contain calcite clasts that show aragonite pseudomorphs as well as omphacite-garnet clasts. This suggests that the "meta-conglomerate" was either formed during the greenschist facies metamorphism, or that the matrix was more susceptible to the greenschist facies overprint.

**Chemical composition.** Three carbonate-rich rocks were analyzed by using the SEM/EDS located at Amherst College in Massachusetts. The samples were selected on the basis of their mineral diversity and their geographic distribution (Figure 1): sample G18 is taken from the northeast corner of Syros and is stratigraphically located in a melange, sample G16B is taken from the northwest from an intensely folded sequence of pelitic and carbonate metasediments, and sample G11B is taken from the southern end where the greenschist facies overprint is most extensive. The amphibole, garnet, pyroxene, and epidote compositions have been adjusted for $Fe^{3+}$ content by using a program supplied by John Brady (Professor, Smith College). The two garnet traverses as well as other garnet compositions are shown in Figure 3; the amphibole compositions are shown in Figure 4; and the pyroxene compositions are shown in Figure 5.

## DISCUSSION

**Garnet.** The garnet traverses both (Figure 3a, 3b) show consistent chemical compositions throughout with zoning only present near the rims. The rim compositions themselves, especially noticeable in the garnet traverse of sample G16B (Figure 3a), have consistent chemical percentages as well. Intermediate compositions occur between the core and the rim. The zoning of these garnets could have occurred by separate metamorphic events that produced two stages of garnet growth.

The rim compositions could be caused by a secondary growth phase of the garnets. Due to the abrupt change from a Fe-rich core to a Mn-rich rim, the zoning does not represent a gradual change in chemical partitioning during formation of the garnets. However, equilibration conditions could change due to infiltration of a fluid phase or possibly the introduction of a new phase during the late stages of garnet growth. The new phase could possess a stronger affinity for iron than garnet and thus cause the Mn-rich rims. The evolution of the garnets, when confirmed, may provide important constraints on the geologic history of the island.

In the ternary diagram (Figure 3c), it is clear that the garnet compositions cluster in three areas. The differences could be caused by differing bulk compositions of the rock, or by separate metamorphic events. If it is assumed that the entire island underwent similar metamorphic events, the differences in compositions could be attributed to bulk compositions, with the Mn-rich cluster likely produced by a separate metamorphic event. Intermediate compositions

Figure 3a

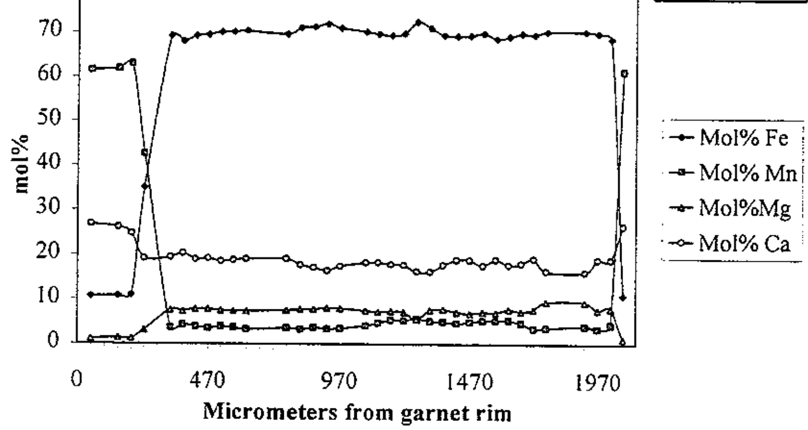


Figure 3b

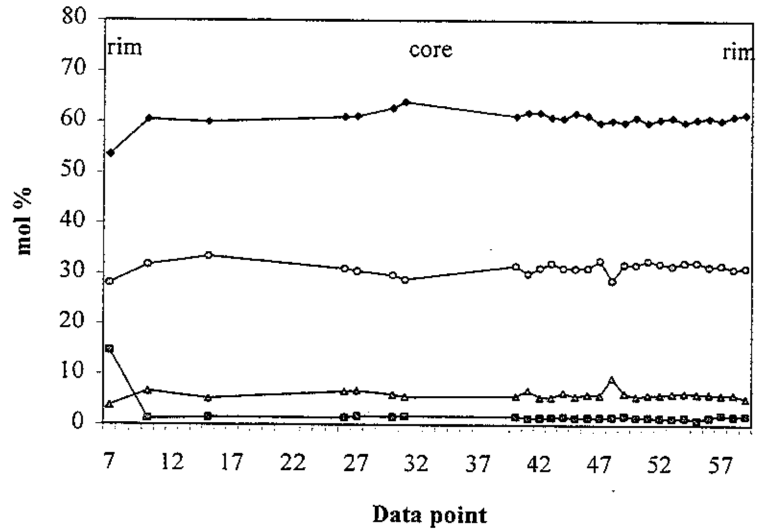


Figure 3c

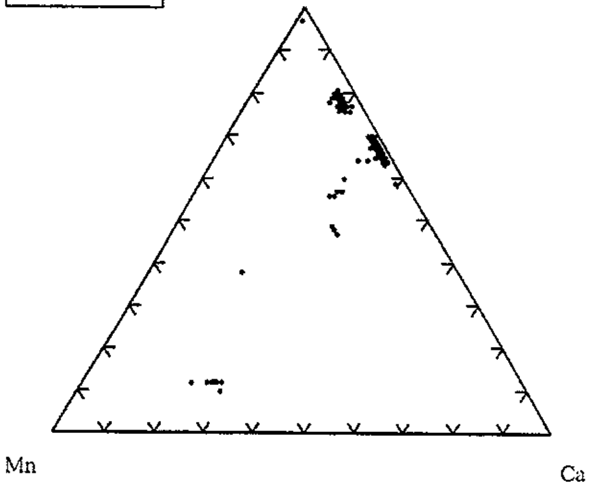


**Figure 3.** Garnet compositions: (a) traverse of a garnet from sample G16B, (b) traverse of a garnet from sample G11G, (c) compositions of garnets including both traverses and data from other garnets found in the three SEM/EDS samples.

may represent data from the rim-core transition.

Calibrated geothermobarometers that incorporate garnet that could possibly be applied to these mineral compositions include: garnet-chlorite, garnet-epidote, garnet-phengite, GRIPS, GADS-GAHS, and possibly garnet-plagioclase-muscovite-quartz.

**Pyroxene.** The pyroxenes in the impure marbles are mostly omphacite and jadeite. Depending on the equilibrium mineral assemblages, the data on pyroxene composition may be used in conjunction with established geothermobarometers to constrain metamorphic conditions. The omphacite-garnet relationship and the jadeite-quartz relationship could apply to the carbonate rocks.

**Dolomite.** The dolomite + quartz relationship among coexisting calcite could also provide constraints on metamorphism. The dolomite composition is approximately $Mg_{0.7}Fe_{0.3}Ca_{1.0}(CO_3)_2$.

**White Mica.** There are two micas found in the carbonate rocks: phengite and paragonite. Paragonite is only found in sample G11G where the greenschist facies overprint is most extensive. The samples from the northern end contain white micas with a phengite composition leading to the possible use of phengite barometry.

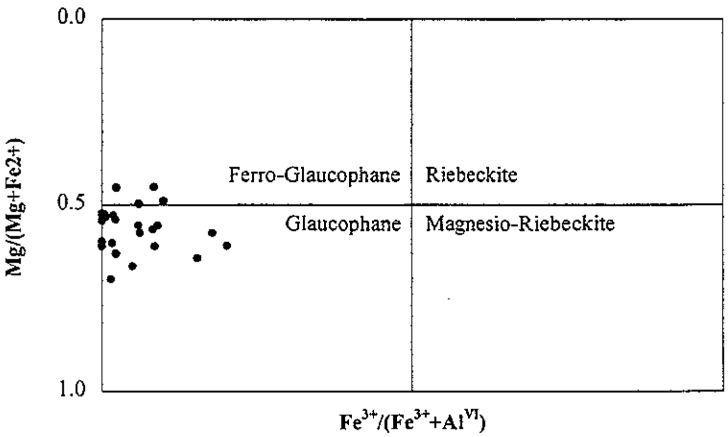


**Figure 4.** Amphibole classification from Leake et al. (1997)

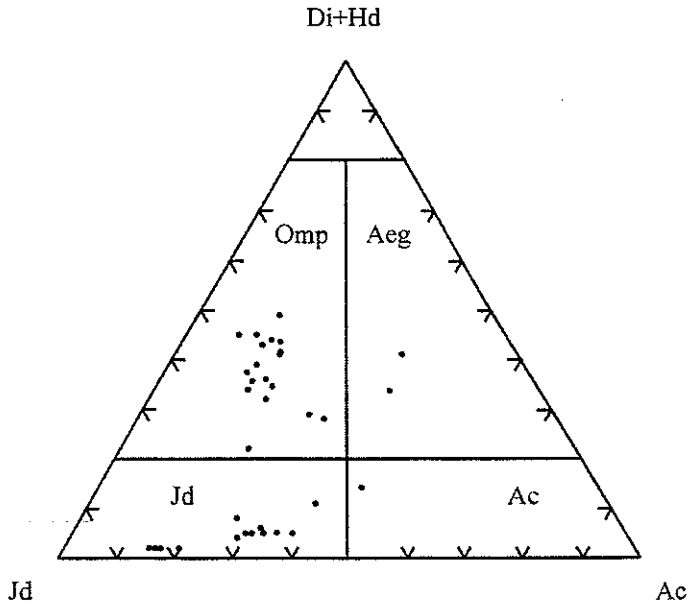


**Figure 5.** Pyroxene compositions

## SUMMARY

Marbles and impure marbles on Syros consist principally of calcite, commonly grown as polycrystalline pseudomorphs of aragonite. Impure marbles contain other minerals in addition to calcite: quartz, phengite, glaucophane, epidote, dolomite, garnet, omphacite, plagioclase, chlorite, titanite, and rutile. Garnet compositions are almandine (60-70%) and grossular (20-30%) rich. Some garnets have sharp rims with high spessartine (60%) contents. These and other features of the impure marbles are being used to constrain the tectonometamorphic history of the rocks on Syros.

## REFERENCES CITED

Dixon, J. E., and John Ridley, 1987, Excursion guide to the field trip on Syros, *in* Helgeson, H. C., ed., Chemical Transport in Metosomatic Processes: D. Reidel Publishing Company, p. 489-500.

Leake, Bernard E., A.R. Woolley, C. E.S. Arps, W. D. Birch, M. C. Gilbert, J. D. Grice, F. C. Hawthorne, A. Kato, H. J. Kisch, V. G. Krivovichev, K. Linthout, Jo Laird, J. A. Mandarino, W. V. Maresch, E. H. Nickel, N. M.S. Rock, J. C. Schumacher, D. C. Smith, N. C. N. Stephenson, L. Ungaretti, E. J.W. Whittaker, and G. Youzhi, 1997, Nomenclature of amphiboles: Report of the Subcommittee on Amphiboles of the International Mineralogical Association, Commission on New Minerals and Mineral Names: American Mineralogist, vol. 82, p. 1019-1037.

Raymond, Loren A., 1995, Petrology: The Study of Igneous, Sedimentary, and Metamorphic Rocks: Volume III: Metamorphic Petrology: Wm. C. Brown Communications, Inc., p. 702-705.