PROCEEDINGS OF THE TWENTY-SIXTH
ANNUAL KECK RESEARCH SYMPOSIUM IN
GEOLOGY

April 2013
Pomona College, Claremont, CA

Dr. Robert J. Varga, Editor
Director, Keck Geology Consortium
Pomona College

Dr. Jade Star Lackey
Symposium Convener
Pomona College

Carol Morgan
Keck Geology Consortium Administrative Assistant

Christina Kelly
Symposium Proceedings Layout & Design
Office of Communication & Marketing
Scripps College

Keck Geology Consortium
Geology Department, Pomona College
185 E. 6th St., Claremont, CA 91711
(909) 607-0651, keckgeology@pomona.edu, keckgeology.org

ISSN# 1528-7491

The Consortium Colleges       The National Science Foundation       ExxonMobil Corporation
KECK GEOLOGY CONSORTIUM
PROCEEDINGS OF THE TWENTY-SIXTH ANNUAL KECK RESEARCH
SYMPOSIUM IN GEOLOGY
ISSN# 1528-7491
April 2013

Robert J. Varga
Editor and Keck Director
Pomona College
185 E 6th St., Claremont, CA 91711

Christina Kelly
Proceedings Layout & Design
Scripps College

Keck Geology Consortium Member Institutions:
Amherst College, Beloit College, Carleton College, Colgate University, The College of Wooster,
The Colorado College, Franklin & Marshall College, Macalester College, Mt Holyoke College,
Oberlin College, Pomona College, Smith College, Trinity University, Union College,
Washington & Lee University, Wesleyan University, Whitman College, Williams College

2012-2013 PROJECTS

TECTONIC EVOLUTION OF THE CHUGACH-PRINCE WILLIAM TERRANE: SHUMAGIN ISLANDS
AND KENAI PENINSULA, ALASKA
Faculty: JOHN GARVER, Union College, CAMERON DAVIDSON, Carleton College
Students: MICHAEL DELUCA, Union College, NICOLAS ROBERTS, Carleton College, ROSE PETTETTE,
Washington & Lee University, ALEXANDER SHORT, University of Minnesota-Morris, CARLY ROE, Lawrence
University.

LAVAS AND INTERBEDS OF THE POWDER RIVER VOLCANIC FIELD, NORTHEASTER N OREGON
Faculty: NICHOLAS BADER & KIRSTEN NICOLAYSEN, Whitman College.
Students: REBECCA RODD, University of California-Davis, RICARDO LOPEZ-MALDONADO, University of
Idaho, JOHNNY RAY HINOJOSA, Williams College, ANNA MUDD, The College of Wooster, LUKE FERGUSON,
Pomona College, MICHAEL BAEZ, California State University-Fullerton.

BIOGEOCHEMICAL CARBON CYCLING IN FLUVIAL SYSTEMS FROM BIVALVE SHELL
GEOCHEMISTRY - USING THE MODERN TO UNDERSTAND THE PAST
Faculty: DAVID GILLIKIN, Union College, DAVID GOODWIN, Denison University.
Students: ROXANNE BANKER, Denison University, MAX DAVIDSON, Union College, GARY LINKEVICH, Vassar
College, HANNAH SMITH, Rensselaer Polytechnic Institute, NICOLLETTE BUCKLE, Oberlin College, SCOTT
EVANS, State University of New York-Geneseo.

METASOMATISM AND THE TECTONICS OF SANTA CATALINA ISLAND: TESTING NEW AND
OLD MODELS
Faculty: ZEB PAGE, Oberlin College, EMILY WALSH, Cornell College.
Students: MICHAEL BARTHELME, Cornell College, WILLIAM TOWBIN, Oberlin College, ABIGAIL SEYMOUR,
Colorado College, MITCHELL AWALT, Macalester College, FREDY AGUIRRE, Franklin & Marshall College,
LAUREN MAGLIOZZI, Smith College.

GEOLOGY, PALEOECOLOGY AND PALEOCALIMATE OF THE PALEOGENE CHICKALOON
FORMATION, MATANUSKA VALLEY, ALASKA
Faculty: CHRIS WILLIAMS, Franklin & Marshall College, DAVID SUNDERLIN, Lafayette College.
Students: MOLLY REYNOLDS, Franklin & Marshall College, JACLYN WHITE, Lafayette College, LORELEI
CURTIN, Pomona College, TYLER SCHUETZ, Carleton College, BRENNAN O’CONNELL, Colorado College,
SHAWN MOORE, Smith College.
CRETACEOUS TO MIocene EVOLUTION OF THE NORTHERN SNAKE RANGE METAMORPHIC CORE COMPLEX: ASSESSING THE SLIP HISTORY OF THE SNAKE RANGE DECOLLEMENT AND SPATIAL VARIATIONS IN THE TIMING OF FOOTWALL DEFORMATION, METAMORPHISM, AND EXHUMATION
Faculty: MARTIN WONG, Colgate University, PHIL GANS, University of California-Santa Barbara.
Students: EVAN MONROE, University of California-Santa Barbara, CASEY PORTELA, Colgate University, JOSEPH WILCH, The College of Wooster, JORY LERBACK, Franklin & Marshall College, WILLIAM BENDER, Whitman College, JORDAN ELMIGER, Virginia Polytechnic Institute and State University.

THE ROLE OF GROUNDWATER IN THE FLOODING HISTORY OF CLEAR LAKE, WISCONSIN
Faculty: SUSAN SWANSON, Beloit College, JUSTIN DODD, Northern Illinois University.
Students: NICHOLAS ICKS, Northern Illinois University, GRACE GRAHAM, Beloit College, NOA KARR, Mt. Holyoke College, CAROLINE LEBRIOLA, Colgate University, BARRY CHEW, California State University-San Bernardino, LEIGH HONOROF, Mt. Holyoke College.

PALEOENVIRONMENTAL RECORDS AND EARLY DIAGENESIS OF MARL LAKE SEDIMENTS: A CASE STUDY FROM LOUGH CARRA, WESTERN IRELAND
Faculty: ANNA MARTINI, Amherst College, TIM KU, Wesleyan University.
Students: SARAH SHACKLETON, Wesleyan University, LAURA HAYNES, Pomona College, AYSSA DONOVAN, Amherst College.

INTERDISCIPLINARY STUDIES IN THE CRITICAL ZONE, BOULDER CREEK CATCHMENT, FRONT RANGE, COLORADO
Faculty: David Dethier, Williams College, Will Ouimet, U. Connecticut.
Students: CLAUDIA CORONA, Williams College, HANNAH MONDRACH, University of Connecticut, ANNETTE PATTON, Whitman College, BENJAMIN PURINTON, Wesleyan University, TIMOTHY BOATENG, Amherst College, CHRISTOPHER HALCSIK, Beloit College.

Funding Provided by:
Keck Geology Consortium Member Institutions
The National Science Foundation Grant NSF-REU 1062720
ExxonMobil Corporation
Keck Geology Consortium: Projects 2012-2013
Short Contributions—Catalina Island Project

METASOMATISM AND THE TECTONICS OF SANTA CATALINA ISLAND: TESTING NEW AND OLD MODELS
Faculty: ZEB PAGE, Oberlin College, EMILY WALSH, Cornell College.

EVOLUTION OF THE CATALINA SCHIST: INSIGHTS FROM EPIDOTE-BLUESCHIST
MICHAEL D.C. BARTHELMESES, Cornell College
Research Advisors: Zeb Page, Emily O. Walsh

THERMOBAROMETRIC MODELING OF THE CATALINA AMPHIBOLITE UNIT: IMPLICATIONS FOR TECTONIC AND METASOMATIC MODELS
HENRY TOWBIN, Oberlin College
Research Advisor: F. Zeb Page

PETROLOGY AND GEOTHERMOMETRY OF GARNET AMPHIBOLITE BLOCKS, SANTA CATALINA ISLAND, CA
ABIGAIL SEYMOUR, Colorado College
Research Advisor: Christine Siddoway

PETROLOGY AND PSEUDOSECTION MODELING OF A GARNET BLUESCHIST BLOCK-IN-MELANGE, SANTA CATALINA ISLAND, CA
MITCHELL AWALT, Macalester College
Research Advisor: Karl Wirth

SANTA CATALINA ISLAND: GARNET QUARTZITE’S FROM THE CATALINA SCHIST IN THE VALLEY OF OLLAS
FREDY AGUIRRE, Franklin and Marshall
Research Advisor: Stanley Mertzman

GEOCHEMICAL EVIDENCE FOR THE ORIGIN OF MINERALOGICAL RINDS SURROUNDING GARNET-AMPHIBOLITE BLOCKS IN A SUBDUCTION ZONE MÉLANGE, CATALINA ISLAND, CALIFORNIA
LAUREN MAGLIOZZI, Smith College
Research Advisor: John B. Brady
PETROLOGY AND PSEUDOSECTION MODELING OF A GARNET BLUESCHIST BLOCK-IN-MELANGE, SANTA CATALINA ISLAND, CA

MITCHELL AWALT, Macalester College
Research Advisor: Karl Wirth

INTRODUCTION

Geological Setting

The Catalina Schist is critical to our understanding of tectonics along the California borderland. Much like the Franciscan rocks to the north and south, it contains a diverse metamorphic suite that records Cretaceous subduction along the western border of North America. While the formation of the Franciscan and the Catalina Schist are still widely debated, the rocks of Catalina Island occupy an important geographical and temporal gap in our understanding of the California margin.

Within the Catalina Schist are juxtaposed garnet-amphibolite, epidote-amphibolite, epidote-blueschist, lawsonite-blueschist and lower grade rocks that record subduction between 115 and 95 Ma (Platt 1975; Grove et al. 2008). Platt (1975), who described the first consistent model for the formation of the Catalina Schist, proposed that a newly formed subduction zone resulted in an inverted thermal gradient. Colder, subducted crust thrust beneath hotter hanging wall rocks produced an inverted sequence of metamorphic facies, with amphibolite structurally overlying greenschist and blueschist rocks.

Recent study of the evolution of the California borderland and the Peninsular Ranges Batholith (PRB) indicates a genetic correlation between the Catalina Schist and the PRB (Silver and Chappell 1988). Emplacement of the PRB, however, began during the Middle Jurassic, long before the formation of the Catalina Schist (Shaw, Todd, and Grove 2003). Grove et al. (2008) suggest that a preexisting subduction zone resulting in the formation of the PRB would not be able to retain enough heat over 20-30 Ma to satisfy Platt’s hypothesis.

In addition to the age of the PRB, Grove and Bebout (1995) and Grove et al. (2008) examined a garnet blueschist block-in-mélange and its significance for Catalina’s subduction history. White mica $^{40}$Ar/$^{39}$Ar age spectra obtained from the garnet blueschist block (the same block analyzed in this study) indicate a maximum age of 150-160 Ma and suggest derivation from the hanging wall of a pre-existing Jurassic subduction complex (Grove and Bebout 1995). Grove et al. (2008) reexamined the block using Rb-Sr geochronology on Na-amphibole and phengite, and determined an age of 135 Ma. They present this block as a major problem for the nascent subduction model proposed by Platt (1975) and suggest that subduction-parallel megathrust and subduction erosion allowed for the emplacement of younger and lower grade rocks beneath higher-grade facies.

Study Area

This study examined the validity of the Platt (1975) and Grove et al. (2008) models by examining the petrology and geochemistry of the garnet blueschist block analyzed by Grove et al. (2008). The metamorphic rocks of Catalina Island comprise a suite of coherent metasedimentary and metamafic rocks interleaved with block-bearing mélange (Platt 1976; Grove and Bebout 1995). The meter – kilometer thick lawsonite blueschist mélange on Catalina contains numerous higher-grade tectonic blocks. Metasedimentary protoliths with a high proportion of shale seem to be a prerequisite for transport of...
these blocks within a subduction zone (Cloos 1982). As described by Platt (1976), much of the lawsonite-blueschist mélange is metagreywacke. Recent work by Ernst (2006) shows that mélange transport of tectonic blocks is the result of buoyancy driven ascent and faulting.

The exotic blocks within the Catalina Schist represent a variety of lithologies and protoliths, including metagreywacke, metapelite, and metabasalt. Within the Catalina lawsonite blueschist mélange, we find one such block on the western margin of the island (Fig. 1, Page et al., this volume). This block is identifiable because it is not only topographically distinct, but it also contains garnet – a rare constituent of the lawsonite blueschist. The block covers a surface area of approximately 500 square meters, making it sizeable compared to other blocks within the lawsonite blueschist (Fig. 1, 2a). It contains numerous quartz-rich veins, lenses, and sheared zones.

METHODS

This study is based on seven samples from the Catalina lawsonite blueschist. Five of these samples were collected directly from the garnet blueschist block. Another sample was taken from a streambed just West of the block (Fig. 1). A sample of blueschist mélange from Shark Harbor (A0712124-1) was collected for comparison with the block. The five samples were collected from different portions of the block.

At Oberlin College, four samples (12C-02, 12CAT12a1, A0709121-2, and A0712121-1) were cut into billets for thin sections. Petrography and SEM analysis were conducted at Macalester College using a JEOL JSM-6610LV scanning electron microscope. Whole-rock geochemical analyses were conducted on all samples (excluding 12CAT12a1) using Macalester’s Philips PW2400 X-ray Fluorescence Spectrometer.

Thermobarometric modeling was conducted using Theriaik/Domino software (de Capitani and Petrakakis 2010). Whole-rocks compositions were normalized to the NCKFMASHTO system for input into the program. The NCFMASHTO system has proven useful when dealing with rocks with a large constituent of glaucophane because of its ability to partition ferrous and ferric iron (Diener et al. 2007). Potassium was added to the system to account for the presence of muscovite. Mixing models provided by Berman (1988, and others cited therein) and modified by de Capitani were used for mineral phase calculation.

RESULTS

Petrography

Samples of the garnet blueschist block have a mineral assemblage consisting of glaucophane + lawsonite + phengite + garnet + sphene ± quartz. Relative abundances of the minerals vary between samples, but glaucophane, lawsonite, and phengitic white micas are ubiquitous as the primary phases. All samples display a weak schistosity defined by glaucophane and lawsonite. One sample (A0709121-2) displays a crude crenulation cleavage (Fig. 2b). Samples exhibit varying amounts of quartz. Sample 12C-02 is quartz poor, whereas other samples contain 20 to 30 percent quartz. The assemblage does not represent full equilibration,
and garnet is interpreted as a relict of previous facies assemblages.

Elongate glaucophane is typically wrapped around garnet porphyroblasts. Two varieties of glaucophane are visible. One is typically euhedral to subhedral and is often fractured. This variety displays cores of glaucophane and darker rims of crossite (Fig. 2b-c). The second is typically elongate and fibrous and displays less intense zoning, although it is present.

Garnet occurs as ≤1 mm porphyroblasts in most samples, and often contains numerous inclusions of lawsonite, phengite, titanite, and rutile (Fig 2d). Garnet is typically idioblastic to hybidioblastic. Garnets throughout all samples lack evidence of zoning. Using less mobile trace elements (e.g., Nb, Zr, Y), the garnet blueschist rocks are classified as andesite and dacite. In contrast, the sample of Shark Harbor blueschist mélange contains 76.53 wt. percent silica. The minor and trace elements show similar patterns of variation. Using less mobile trace elements (e.g., Nb, Zr, Y), the garnet blueschist rocks are classified among glaucophane, phengite, and lawsonite. Note zoning in glaucophane minerals in the top left. Plain light. Scale bar = 100 µm. D) Garnet porphyroblasts among glaucophane, phengite, and lawsonite. Plain light. Scale bar = 100 µm. D) Photomicrograph of 12C-02, same view as previous. Numerous inclusions are visible within garnet porphyroblasts. Crossed nicols. Scale bar = 100 µm.

Garnet occurs as 50.01 to 69.78 weight percent in the garnet blueschist block (Fig. 3a), classifying these rocks as andesite and dacite. Like glaucophane, lawsonite seems to occur in two distinct varieties. One variety is more mottled and may be pseudomorphous after plagioclase. Inclusions of titanite, glaucophane and rutile occur within larger lawsonite grains.

**Whole-Rock Geochemistry**

Major and minor element geochemical analyses for the samples are given in Table 1. Whole-rock SiO$_2$ ranges from 50.01 to 69.78 weight percent in the garnet blueschist block (Fig. 3a), classifying these rocks as andesite and dacite. In contrast, the sample of Shark Harbor blueschist mélange contains 76.53 weight percent silica. Aluminum concentrations are similarly varied, ranging from 14.55 to 10.55 wt. % Al$_2$O$_3$. Iron analyses also show similar variation (Table 1). In summary, the whole-rock compositions show considerable variation within the ~100 m block, suggesting that it was originally compositionally heterogeneous, or that many of the major elements have been mobilized during metamorphism.

The minor and trace elements show similar patterns of variation. Using less mobile trace elements (e.g., Nb, Zr, Y), the garnet blueschist rocks are classified as andesite and dacite. In contrast, the sample of Shark Harbor blueschist mélange contains 76.53 weight percent silica. Aluminum concentrations are similarly varied, ranging from 14.55 to 10.55 wt. % Al$_2$O$_3$. Iron analyses also show similar variation (Table 1). In summary, the whole-rock compositions show considerable variation within the ~100 m block, suggesting that it was originally compositionally heterogeneous, or that many of the major elements have been mobilized during metamorphism.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Rock Type</th>
<th>Rock Type</th>
<th>Rock Type</th>
<th>Rock Type</th>
<th>Rock Type</th>
<th>Rock Type</th>
<th>Rock Type</th>
<th>Rock Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site</td>
<td>Block - Top</td>
<td>Block - Top</td>
<td>Block - Top</td>
<td>Block - Top</td>
<td>Block - Top</td>
<td>Block - Top</td>
<td>Block - Top</td>
<td>Block - Top</td>
</tr>
<tr>
<td>Block 1</td>
<td>Gt-blueschist</td>
<td>Gt-blueschist</td>
<td>Gt-blueschist</td>
<td>Gt-blueschist</td>
<td>Melange</td>
<td>Gt-blueschist</td>
<td>Melange</td>
<td>Melange</td>
</tr>
<tr>
<td>Block 2</td>
<td>Gt-blueschist</td>
<td>Gt-blueschist</td>
<td>Gt-blueschist</td>
<td>Gt-blueschist</td>
<td>Gt-blueschist</td>
<td>Melange</td>
<td>Melange</td>
<td>Melange</td>
</tr>
<tr>
<td>Sample 1</td>
<td>12C-02</td>
<td>12C-02</td>
<td>A0709121-2</td>
<td>A0709122-1</td>
<td>A0712121-1</td>
<td>A0712124-1</td>
<td>H2709c</td>
<td>12C-02b</td>
</tr>
<tr>
<td>SiO$_2$</td>
<td>50.11</td>
<td>50.01</td>
<td>69.78</td>
<td>51.85</td>
<td>64.62</td>
<td>76.53</td>
<td>64.45</td>
<td>62.58</td>
</tr>
<tr>
<td>TiO$_2$</td>
<td>1.766</td>
<td>1.767</td>
<td>0.627</td>
<td>1.040</td>
<td>0.832</td>
<td>0.336</td>
<td>0.704</td>
<td>0.750</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>14.55</td>
<td>14.52</td>
<td>10.17</td>
<td>12.22</td>
<td>10.55</td>
<td>6.08</td>
<td>11.43</td>
<td>11.41</td>
</tr>
<tr>
<td>Fe$_2$O$_3$</td>
<td>14.83</td>
<td>14.82</td>
<td>6.95</td>
<td>9.44</td>
<td>8.98</td>
<td>7.63</td>
<td>8.19</td>
<td>8.10</td>
</tr>
<tr>
<td>MnO</td>
<td>0.602</td>
<td>0.600</td>
<td>0.104</td>
<td>0.106</td>
<td>0.203</td>
<td>0.363</td>
<td>0.137</td>
<td>0.137</td>
</tr>
<tr>
<td>MgO</td>
<td>5.46</td>
<td>5.16</td>
<td>2.79</td>
<td>3.91</td>
<td>4.48</td>
<td>2.71</td>
<td>4.13</td>
<td>4.10</td>
</tr>
<tr>
<td>CaO</td>
<td>5.10</td>
<td>5.10</td>
<td>2.47</td>
<td>3.50</td>
<td>3.13</td>
<td>3.07</td>
<td>2.89</td>
<td>2.87</td>
</tr>
<tr>
<td>Na$_2$O</td>
<td>3.94</td>
<td>3.95</td>
<td>1.56</td>
<td>2.90</td>
<td>3.21</td>
<td>2.82</td>
<td>2.84</td>
<td>2.83</td>
</tr>
<tr>
<td>K$_2$O</td>
<td>1.63</td>
<td>1.63</td>
<td>1.92</td>
<td>1.91</td>
<td>1.15</td>
<td>1.17</td>
<td>1.17</td>
<td>1.17</td>
</tr>
<tr>
<td>P$_2$O$_5$</td>
<td>0.178</td>
<td>0.183</td>
<td>0.087</td>
<td>0.122</td>
<td>0.097</td>
<td>0.227</td>
<td>0.148</td>
<td>0.148</td>
</tr>
<tr>
<td>LOI</td>
<td>2.97</td>
<td>2.99</td>
<td>2.32</td>
<td>2.97</td>
<td>2.28</td>
<td>1.03</td>
<td>2.47</td>
<td>2.47</td>
</tr>
<tr>
<td>Minor Elements (ppm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sr</td>
<td>569</td>
<td>569</td>
<td>1023</td>
<td>564</td>
<td>369</td>
<td>704</td>
<td>803</td>
<td>803</td>
</tr>
<tr>
<td>Rb</td>
<td>44.5</td>
<td>45.0</td>
<td>50.2</td>
<td>50.1</td>
<td>50.2</td>
<td>50.2</td>
<td>50.2</td>
<td>50.2</td>
</tr>
<tr>
<td>Cs</td>
<td>0.227</td>
<td>0.227</td>
<td>0.227</td>
<td>0.227</td>
<td>0.227</td>
<td>0.227</td>
<td>0.227</td>
<td>0.227</td>
</tr>
<tr>
<td>Ba</td>
<td>0.178</td>
<td>0.183</td>
<td>0.087</td>
<td>0.122</td>
<td>0.097</td>
<td>0.227</td>
<td>0.148</td>
<td>0.148</td>
</tr>
<tr>
<td>LOI</td>
<td>2.97</td>
<td>2.99</td>
<td>2.32</td>
<td>2.97</td>
<td>2.28</td>
<td>1.03</td>
<td>2.47</td>
<td>2.47</td>
</tr>
</tbody>
</table>

Table 1. Major and minor whole-rock geochemical analyses of the Catalina garnet blueschist block and lawsonite blueschist mélange. Total iron in the analyses is reported as Fe$_2$O$_3$. Element abundances that are below detection are indicted with “bd”. Figure 2. Clockwise from top left. A) Photograph of the garnet blueschist block (For scale, note geologists at base of hill in foreground). B) Photomicrograph of sample A0709121-2 showing crenulation cleavage. Cleavage is defined by elongate glaucophane and lawsonite. Note zoning in glaucophane minerals in the top left. Plain light. Scale bar = 100 µm. C) Garnet porphyroblasts among glaucophane, phengite, and lawsonite. Plain light. Scale bar = 100 µm. D) Photomicrograph of 12C-02, same view as previous. Numerous inclusions are visible within garnet porphyroblasts. Crossed nicols. Scale bar = 100 µm.
as basalt and andesite (Fig. 3b), and they plot well within the field of island arc tholeiite (Fig. 3c). Trace elements in the garnet blueschist block consistently plot along a trend between sample 12C-02 and Shark Harbor blueschist mélange (Figures 3a-f) suggesting “mixing” between these two components.

**Thermobarometry**

Pseudosection modeling using Theriak/Domino proved difficult for the garnet blueschist block. Stable assemblages similar to those of the garnet blueschist block can be modeled with Theriak/Domino, but the presence of omphacitic and jadeitic pyroxenes in modeled assemblages is unlike those observed (Figure 4), perhaps a function of how iron is partitioned or the availability of water.

**DISCUSSION**

The association of glaucophane and lawsonite is diagnostic of the high-P, low-T conditions of metabasites (Saha et al. 2005). The assemblage is similar to compiled mineral associations of blueschist facies metabasites from the Franciscan series (Saha et al. 2005; Krogh, Oh, and Liou 1994). While the presence of abundant phengitic white mica is more distinctive of blueschist facies metapelites, the overall mineral assemblage is suggestive of a more mafic protolith.

The major element geochemistry of the block is distinctly different than typical basalt compositions (e.g., higher SiO₂ and lower Fe₂O₃ and MgO; Table 1), supporting a metasedimentary origin (Grove and Bebout 1995). The high SiO₂ concentrations observed in the block (this study) could thus be attributable to metasomatic addition, consistent with the findings of Bebout and Barton (2002). Sample 12C-02 lacks any indication of silica addition via shearing or by metasomatism (e.g., quartz veins or matrix quartz) and has a composition similar to basalt (Figure 3a-f). In this scenario, the different samples from the block may record varying degrees of metasomatism or “sediment addition” by structural interleaving. If true, then the present-day top of the block may reflect near-parental geochemistry. Mafic blueschist and eclogite blocks studied by Saha et al. (2005) and Sorensen (1984), the latter from Catalina, also plot near sample 12C-02, suggesting a mafic metavolcanic origin for the garnet blueschist block. In this model, the other portions of the block with higher SiO₂ may represent a metasomatic rind on a basaltic block.

There is considerable evidence that the protolith of the garnet blueschist block was a mafic volcanic. Despite the apparent mobility of some elements (e.g., SiO₂, Fe₂O₃, MgO), ratios among less mobile elements (e.g., Zr, Ti, P) are less variable (Figures 3b-d). In addition, these are similar to those of N-MORB and island arc tholeiite, similarly observed by Saha et al. (2005). Ratios among mobile elements generally exhibit greater variation (e.g., Al₂O₃/TiO₂; Fig. 3e), suggesting that they experienced considerable mobilization (Saha et al. 2005; Sorensen 1984). Typically non-mobile elements (e.g., Th) show variation associated with typical subduction zone alteration (Fig. 3f)(Bebout 2007).

The observed chemical variation is unexpected for such a small block, so the heterogeneity likely resulted from the development of a rind by metasomatic processes, by tectonic interleaving of metavolcanic and metasedimentary rocks, or by both. Together, the new geochemical data suggest that the block originated as a mafic volcanic generated in a supra-subduction zone setting. This conclusion is similar to the model proposed by Grove and Bebout (1995).

The mineral assemblage in the garnet blueschist block is atypical from many other garnet-bearing blueschists because it lacks an obvious retrograde overprint. The lack of phases such as chlorite, epidote, and clinopyroxene, and the presence of garnet without replacement are hard to reconcile. Assemblages containing garnet and lawsonite are common in blueschist associated with lawsonite-eclogite rocks (Brovarone et al. 2011; Davis and Whitney 2006; Wei and Clarke 2011). Davis and Whitney (2006) report garnet-bearing lawsonite blueschist assemblages connected to lawsonite eclogite rocks. Using pseudosection modeling, they determined maximum metamorphic conditions to be 12 kbar and 380 °C. Brovarone et al. (2011) also report coexistence of lawsonite eclogite and lawsonite blueschist. They find
equilibrium conditions around 22 – 23 kbar and 515 ºC. At these conditions only a very small quantity of omphacite is reported for the equilibrium assemblage. The assemblages of these studies (glaucophane + lawsonite + phengite + quartz ± garnet ± omphacite ± chlorite and glaucophane + actinolite + lawsonite + garnet + phengite + titanite ± minor omphacite and chlorite, respectively) are comparable to one another and similar to the assemblage of the Catalina garnet blueschist. Their findings show that garnet and lawsonite bearing lawsonite schist can occupy a broad range of metamorphic conditions and at times lack significant amounts of pyroxene.

Comparison with these studies suggests that the Catalina garnet blueschist rocks may have experienced a short period of near-eclogite facies metamorphic conditions. The small size of garnets and their lack of zoning may be attributable to a very brief episode at these conditions. Inclusions of rutile and lawsonite within the garnets indicate that during this short period of growth, these two phases were also present. A representative equilibrium assemblage diagram of sample 12C-02 suggests that the garnet blueschist block may have experienced high-P conditions similar to those produced by Brovarone et al. (2011) (Fig. 4). Almandine garnet compositions (Alm\textsubscript{56} Sps\textsubscript{19} Prp\textsubscript{8} Grs\textsubscript{17}) predicted by the pseudosection are similar to those observed in hand samples (Alm\textsubscript{52} Sps\textsubscript{25} Prp\textsubscript{2} Grs\textsubscript{21}). Cores and rims of glaucophane and two generations of lawsonite may represent two growth phases, one preceding and during near-eclogite facies equilibration, and the second phase after mélange transport to blueschist facies conditions. The lack of omphacite in the garnet blueschist block is difficult explain considering it represents a large proportion (approximately 20%) of the equilibrium assemblage. It is possible that fluid saturation allowed the replacement of these pyroxenes by glaucophane. There are a number of other caveats associated with this conclusion. The lack of compositional zonation in garnet is perplexing because this is common in multi-stage equilibration in subduction zones (Krogh, Oh, and Liou 1994). The late metasomatism that is recorded in the block may also have influenced the mineral assemblage in a way we have not yet perceived.

Nevertheless, this study provides evidence for subduction of basaltic crust generated in a supra-subduction zone that was then exposed to a short period of near-eclogite facies conditions. It is possible that after a brief period at eclogite conditions (23 – 25 kbar and 450 – 550 ºC), this block was then quickly brought to blueschist facies conditions where it equilibrated. The distinct mineralogy that separates it from other Catalina blueschists lends it to a much different P-T-t path than that of the blueschist mélange. The existence of this garnet blueschist block that experienced these conditions would require a thermally mature, long-lived subduction zone proposed in the Grove et al. (2008) subduction model. Future study of the garnet blueschist block should...
focus on more advanced pseudosection modeling and dating to further constrain the P-T-t path of the block.

ACKNOWLEDGEMENTS

I would like to thank Zeb Page, Emily Walsh, and Sarah Penniston-Dorland for making this an exciting and rewarding research experience. I thank Karl Wirth for his patience, constant support and commitment to this project. I am also indebted to Jeff Thole, whose guidance in laboratory work and sample preparation was invaluable. I would like to thank Macalester College and Oberlin College for the use of their facilities. Finally, a hearty thanks to Fredy Aguirre, Mike Barthelmes, Lauren Magliozi, Abby Seymour, and Henry Towbin for making this entire experience a very enjoyable one.

REFERENCES


USA.” *Journal of Metamorphic Geology* 12 (2): 121-134.


