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

April 2013
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METASOMATISM AND THE TECTONICS OF SANTA CATALINA ISLAND: TESTING NEW AND OLD MODELS

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EMILY O. WALSH, Cornell College
SARAH PENNISTON-DORLAND, University of Maryland

INTRODUCTION

The metamorphic rocks of Santa Catalina Island, California, have been used as a natural laboratory to study fluid flow and metasomatism in subduction zones for over 20 years (e.g., Bebout, 2007). A number of field, geochronological, and geochemical studies that have sought to better understand the nature of the slab-mantle interface in subduction zones depend on a tectonic interpretation of the island's metamorphic rocks that has recently been called into question. A new tectonic model was proposed by Grove et al. in 2008, to challenge the long-standing model of Platt (1975). However, both models are based in part on thermobarometry that is over 20 years old and that warrants reexamination using more modern techniques. This Keck project seeks to add to our understanding of Catalina geology and to clarify and test the competing tectonic hypotheses. The six student projects provide detailed descriptions of lithologies that have yet to appear in publication and apply cutting edge petrologic tools, such as thermodynamic modeling of equilibrium assemblages and trace-element thermometry to key samples to better constrain the thermal history of the Catalina Schist.

CATALINA GEOLOGY

Franciscan-like subduction-related metamorphic rocks (blocks of garnet-bearing blueschist, eclogite, and amphibolite) were recognized on Catalina by the first half of the twentieth century (Woodford, 1924; Bailey, 1941). However, the modern era of Catalina geology began with detailed mapping and a tectonic model by Platt (1975). The metamorphic rocks of Santa Catalina Island (sometimes referred to as the Catalina Schist) consist of mappable units of metasedimentary and metaultramafic rock that range from lawsonite-blueschist to amphibolite facies, with increasing grade correlated with structural height (Fig. 1). Platt's initial subdivision of the island into blueschist, greenschist, amphibolite, and ultramafic units bounded by shallowly dipping thrust faults has been refined, with the "greenschist" unit now defined as epidote amphibolite and epidote blueschist overprinted with greenschist-facies assemblages, and the "ultramafic" unit is now interpreted as an amphibolite-facies mélange (Grove and Bebout, 1995). The mapped metasedimentary units consist of both coherent and mélange zones intercalated on the cm to km scale (Sorensen, 1986; Bebout and Barton, 1993). Metamafic tectonic blocks (garnet blueschist, garnet amphibolite) with metasomatic selvages are found within these mélanges at various structural levels of the island (Platt, 1975; Sorensen, 1986; Grove et al., 2008).

The highest-grade metasedimentary units from Catalina record peak conditions of 7-12 kbar and 650-750°C based on cation thermometry and fluid inclusion barometry (Platt, 1975; Sorensen and Barton, 1987). The unusually high temperatures and Barrovian-like assemblages of the highest-grade rocks became the basis for Platt's interpretation that the Catalina Schist was formed in a nascent subduction zone (1975). In this model, the amphibolite-facies rocks were formed at the initiation of subduction and recorded high temperatures due to the proximity of the hot mantle wedge; the inverted metamorphic gradient of underthrust lower-grade units recorded the subsequent cooling of the trench (Platt, 1975; Cloos, 1985; Peacock, 1987). Recent analysis of detrital zircon ages from Catalina metasedimentary rocks has revealed that accretion of the Catalina schist occurred over at least a 20 My period, with the lowest-grade units containing detrital zircons younger than the 115 Ma metamorphic age yielded by the high-grade rocks (Grove et al., 2008). Furthermore, a single garnet blueschist block found in the blueschist-facies mélange yields an ~150 Ma age suggesting that the highest-T Catalina rocks formed after the development of a thermally mature subduction regime. Based on these data, a new model was proposed by Grove et al. (2008), in which the highest-grade rocks on Catalina were not formed in the subduction channel, but by underthrusting of forearc rocks between an existing subduction-zone and the Peninsula Ranges batholith. Final assembly of Catalina is proposed to have taken place by subduction-erosion of the intervening forearc material (Grove et al., 2008).

Petrologic, geochemical, and chronological constraints on Santa Catalina Island have been used to document extensive fluid flow and metasomatism due to devolatilization of sediments during subduction (e.g., Sorensen and Grossman, 1989; Bebout, 1991; 2007; King et al., 2007). Many blocks in the amphibolite/ultramafic mélange have talc or tremolite metasomatic selvages or reaction rinds similar to those found in the Franciscan Complex. However, the newly revised tectonic model of Grove et al. (2008) posits that the highest-grade rocks did not form in the subduction channel at all, but in a subduction-parallel thrust at a higher thermal gradient. If the amphibolite facies rocks on Catalina did not form in a subduction zone, it is possible that a substantial body of literature must be reinterpreted in light of the new tectonic model.

PROJECTS

The Catalina Keck group spent approximately 3 weeks together on the island. Field work was focused on a NE-SW transect across the center of the Catalina Schist exposures at all structural levels. Upper Cottonwood Canyon, a single, large garnet-blueschist block on the SW side of the island and the Valley of Ollas from near the Catalina Airport to Ripper's Cove were areas of particularly intense study (Fig. 1). Midway through the field component of the project, high-interest samples were sent to Oberlin College for thin-section preparation. The final week of the project

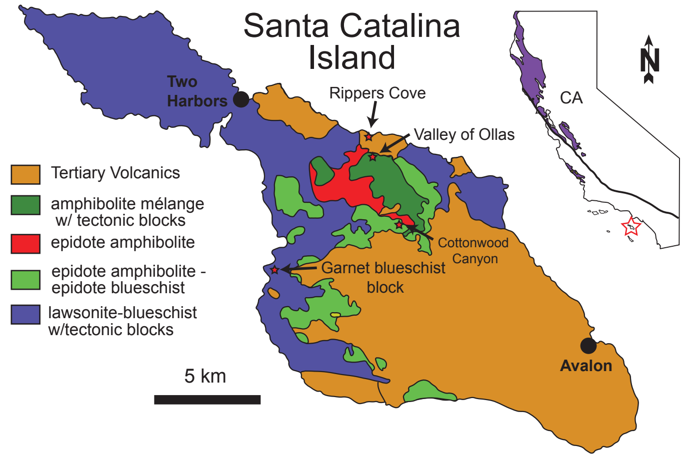

Figure 1. Geologic sketch map of Santa Catalina Island after Platt (1975) and Grove and Bebout (1995). Study localities are indicated by stars. Inset: Map of California showing the Franciscan Formation in purple and the location of Santa Catalina Island (star).

was spent at Oberlin, and preliminary petrography using both optical and electron microscopes was undertaken while the rest of the samples were prepared and catalogued.

Fredy Aguirre (Franklin and Marshall College) undertook a petrographic and whole-rock geochemical study of a suite of garnet quartzites from the Valley of Ollas (Figs. 1, 2a). Although these rocks have been mentioned in the literature (Platt, 1975; Bebout and Barton, 1991; Grove and Bebout, 1995), this is the first detailed description of their composition and mineralogy. Garnet quartzites appear both as tectonic blocks in mélange and in more coherent slices of metasedimentary rock. They are strongly layered with mm-scale garnet- and amphibole-rich layers and show various deformation structures.

A large garnet-blueschist block (Figs. 1, 2b) hosted by the lawsonite-blueschist unit in the SW of Catalina has gained critical importance in discussions of the tectonic evolution of the island. Evidence of a poorly-constrained metamorphic age that pre-dates the metamorphism of Catalina amphibolite has been used to suggest a long-lived subduction zone in the region prior to 115 Ma (Grove and Bebout, 1995; Grove et al., 2008). **Mitchell Awalt** (Macalester College) has undertaken the first detailed petrographic and geochemical description of this rock. Although described as a metasedimentary rock, it appears to be a variably metasomatized and veined mafic rock that

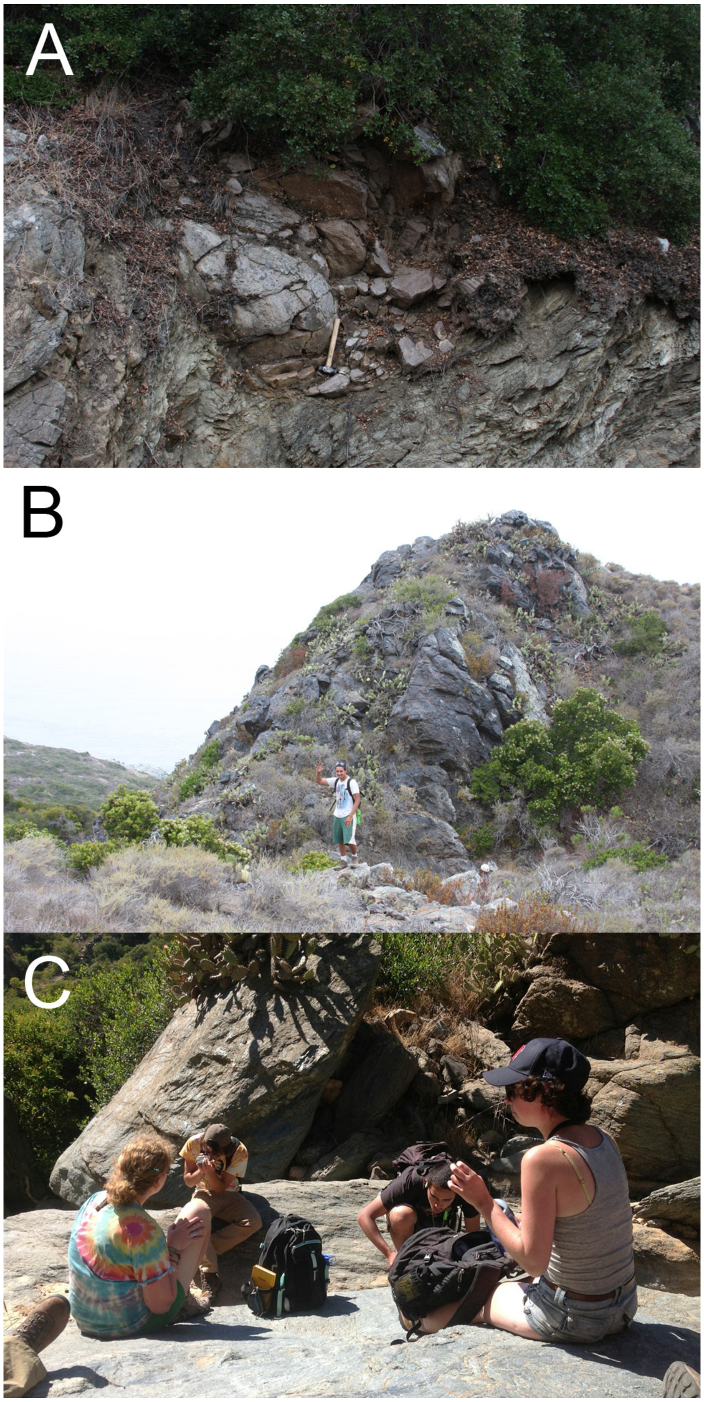

Figure 2. Catalina field photographs. (A) Garnet quartzite block in matrix mélange (contact below hammer) in the Valley of Ollas (Aguirre, this volume); (B) Garnet lawsonite blueschist block (Awalt, this volume); (C) Epidote blueschist in Cottonwood Canyon (Barthelmes, this volume).

is both garnet and lawsonite-bearing. Preliminary pressure-temperature estimates based on equilibrium assemblage diagrams are suggestive of peak conditions as high as 22 kbar and 500˚C. These conditions require formation in a mature, long-lived subduction zone, and are consistent with the Grove et al. (2008) tectonic model.

The Grove et al. (2008) tectonic model is based on the contrasting histories of the highest-grade and lowest-grade portions of the Catalina Schist, leaving the tectonic history of the mid-grade (epidote-blueschist and epidote-amphibolite) units ambiguous. In some areas, the units appeared to transition smoothly from lowest to highest grade, while detrital zircon ages of the epidote-blueschist and epidote-amphibolite units lie between the ages of the lowest and highest grade units (Grove et al., 2008). **Mike Barthelmes** (Cornell College) provides additional constraints on the new tectonic model by describing the composition and mineralogy of the intermediate-grade epidote-blueschist and epidote amphibolite units (Fig. 2c) from Upper Cottonwood Canyon (Fig. 1).

A number of studies have looked at the geochemical differences between metamafic blocks, tremolite-rich reaction rinds, and the mélange matrix (e.g., Sorensen and Grossman, 1989; Bebout and Barton, 2002). More recently, unexpected mineralogical diversity (including neoformed garnet, Fig. 3a) has been found in some rinds on garnet-hornblende blocks (Penniston-Dorland et al., 2011). **Lauren Magliozzi** (Smith College) has extended the mineralogical characterization of these rinds to 3 different blocks from Rippers Cove (Fig. 1). The presence of garnet in these products of metasomatism and mechanical mixing may eventually provide valuable information on the metamorphic conditions during rind formation.

Abby Seymour (Colorado College) investigated a suite of garnet amphibolites from the Valley of Ollas and Cottonwood Canyon (Figs. 1, 3b). Unlike the majority of garnet-hornblende tectonic blocks on Catalina these samples contain macroscopic plagioclase and are similar to samples that were used to describe partial melting during metamorphism (Sorensen and Barton, 1987). Detailed textural descriptions based on optical microscopy and X-ray mapping help further elucidate the metamorphism of these rocks. Abby also applied

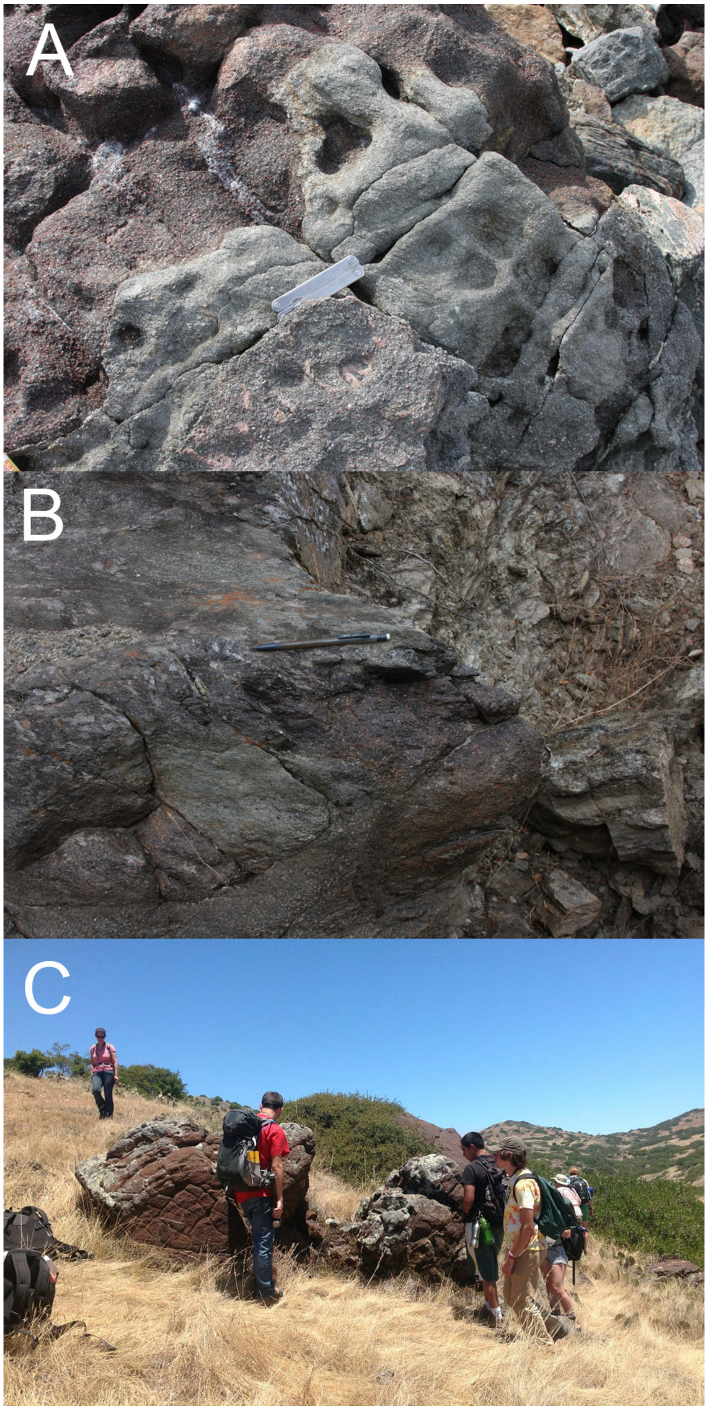

Figure 3. Catalina field photographs. (A) Garnet-hornblendite block and rinds at Ripper's Cove (Sample RIP1, Magliozzi, this volume), Core of block is at upper left (RIP1A), tremolite-rich rind is in the center of view behind scale (RIP1B), Garnet-rich rind (RIP1C) is below scale and contains both coarse and fine garnets; (B) Small garnet-hornblende block in tremolite-rich mélange, Valley of Ollas (Seymour, this volume, Sample 712C-1); (C) Plagioclase-free garnet-clinopyroxene-hornblende block, Upper Cottonwood Canyon (Towbin, this volume, Sample 12C-3).

Ti-in-rutile thermometry to two tectonic blocks from the amphibolite-facies mélange. These samples record surprisingly low temperatures of formation of ~500˚C.

Henry Towbin (Oberlin College) investigated another suite of garnet-hornblende tectonic blocks from the highest-grade portions of the Catalina Schist. Unlike those studied by Seymour, Towbin's clinopyroxene-bearing blocks (Fig. 3c) appear plagioclase-free in hand sample, are extremely-garnet-rich, and, consequently, silica poor. Careful textural descriptions coupled with thermodynamic modeling confirm the hypothesis that these unusual lithologies are likely restites, and the result of the extraction of a melt from an Fe-rich tholeitic protolith.

Taken together the results from these projects address questions of fluid flow, protolith, and conditions of metamorphism for a selection of lithologies from Santa Catalina Island, some of which are described here in detail for the first time.

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