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EVOLUTION OF THE CATALINA SCHIST: INSIGHTS FROM EPIDOTE-BLUESCHIST

MICHAEL D.C. BARTHELMES, Cornell College
Research Advisors: Zeb Page, Emily O. Walsh

INTRODUCTION

The Catalina Schist is a suite of rocks underlying the Californian borderlands that have been metamorphosed at blueschist through amphibolite facies. Cropping out above sea-level exclusively on Santa Catalina Island, an amphibolite unit is underlain by rocks metamorphosed at progressively lower grades juxtaposed by low angle faults. Preserving a late Cretaceous subduction zone environment, the Catalina Schist is enigmatic for its high temperature/pressure (T/P) amphibolite-facies metamorphism and inverted thermal gradient, both unusual in subduction-related metamorphism. In light of this, Grove et al. (2008) proposed a model of slab-parallel forearc thrusting of protoliths to a position beneath the magmatic arc. The magmatic arc (the Peninsular Ranges Batholith) provided the heat for high T/P metamorphism of amphibolite, epidote-amphibolite and possibly epidote-blueschist; subsequent crustal shortening due to subduction erosion later juxtaposed these units with lawsonite-blueschist and lower grade rocks formed in the subduction zone proper. Originally interpreted as a single greenschist unit (Platt, 1975) and sharing a greenschist overprint, the epidote-blueschist and epidote-amphibolite had been considered contiguous. However, recent detrital zircon dates from a single sample of epidote-blueschist indicate accretion of forearc protolith ~6 My. after peak metamorphism of the epidote-amphibolite (Grove et al., 2008). The epidote-blueschist may have formed in the subduction zone or at an intermediate location and received its greenschist overprinting when it was eventually thrust beneath the amphibolite. Lacking additional information, the tectonic history of the epidote-blueschist component of the Catalina Schist remains incomplete. Here, petrologic comparison of the epidote-blueschist, epidote-amphibolite and amphibolite units provides constraints for the metamorphic evolution of the epidote-blueschist.

BACKGROUND

The Catalina Schist was first mapped by Platt (1975), using petrologic analysis of samples and field relationships to identify three tectonic units distinct in their metamorphic mineral assemblages. The middle-grade Catalina Greenschist Unit is distinguished from the underlying low-grade Catalina Blueschist Unit by porphyroblasts of epidote and clinozoisite as well as retrograde greenschist-facies chloritization. The overlying Catalina Amphibolite Unit is heavily deformed and features a high-grade mineral assemblage of hornblende-zoisite, hornblende-garnet, and garnet-quartzite. Platt's (1975) units are juxtaposed across two major post-metamorphism thrust-faults. Recognizing similarities in rock assemblage and deformational history, Platt (1975) identified the Catalina Schist units as different parts of a zoned metamorphic complex featuring an inverted thermal gradient. Some mechanism provided heat above the slab for unusually high greenschist- and amphibolite-facies metamorphism. Platt (1975) hypothesized that the Catalina Schist originated in a newly-formed subduction zone, and that the hot upper mantle hanging-wall heated the cold subducting wedge from above to create the inverted thermal gradient.

However, recent detrital zircon U-Pb dates (Grove et al., 2008) from the units of the Catalina Schist have refuted this model of formation. Peak amphibolite-facies metamorphism occurred at 115 Ma and blueschist-facies at ~95 Ma, suggesting a sequential formation over ~20 My. Furthermore, a unique garnet-blueschist block within lawsonite-mélange yields 40Ar/39Ar and Rb-Sr ages of 135 Ma (Grove et al., 2008) implying ongoing subduction 20 My. prior to formation of the Catalina Schist.

The Catalina Schist

The original maps of Platt (1975, 1976) are expanded by Grove and Bebout (1995) into units of more specific metamorphic grade. Significant differences in mineral assemblage and a lack of metamorphic gradation divide the Greenschist unit into epidote-amphibolite- and epidote-blueschist-facies. Both show the abundant chloritization of a greenschist overprint and porphyroblasts of epidote/clinozoisite but are otherwise largely unalike in mineral assemblage. The differences between the epidote-amphibolite and epidote-blueschist units are significant and suggest unique histories of metamorphism and accretion. The Blueschist unit also shows variation in metamorphic grade with underlying lower-grade rocks cropping out on the west end of Santa Catalina Island (Grove and Bebout, 1995). The higher-grade rock in contact with the epidote-blueschist unit is placed into lawsonite-blueschist facies, the lower-grade rocks into lawsonite-albite facies.

A revised map of the Catalina Schist (Fig. 1) consists of distinct tectonic units juxtaposed by faulting and overlain by an ultamafic mélange of material metamorphosed at amphibolite-facies. The structurally highest unit underwent peak amphibolite-facies metamorphism ~115 Ma at estimated conditions of P = ~8-11 kbar and T = 640-750°C (Sorensen, 1988). The amphibolite unit is thoroughly deformed and recrystallized and the rocks feature coarse metamorphic textures (Platt, 1975). The epidote-amphibolite unit, metamorphosed at <105 Ma (Grove et al. 2008), is also coarsely textured and shares a greenschist-facies overprint that also appears in the underlying epidote-blueschist unit (Grove et al. 2008).

The epidote-blueschist unit structurally divides the high-grade amphibolite unit and the lawsonite-blueschist unit. It is of intermediate metamorphic grade and shares traits with the high- and low-grade rocks. Coarse epidote/clinozoisite grains and greenschist-facies overprinting are often products of high T/P metamorphism and occur in the high-grade units of the Catalina Schist. Higher-grade minerals are absent however, and the abundant glaucophane is evidence of low T/P conditions. Comparison of youngest detrital zircon ages (Grove et al., 2008) appears to ally the epidote-blueschist more closely to the lawsonite-blueschist. However, detrital zircon results are only available for a single usable sample of the epidote-blueschist.

Bottommost of the Catalina Schist are rocks that were metamorphosed to lawsonite-blueschist- and lawsonite-albite-facies ~97 Ma (Grove et al., 2008). Consisting of metasediments that have been uniformly metamorphosed at low temperatures, this type of rock is a common product of blueschist-facies metamorphism within a subduction zone.

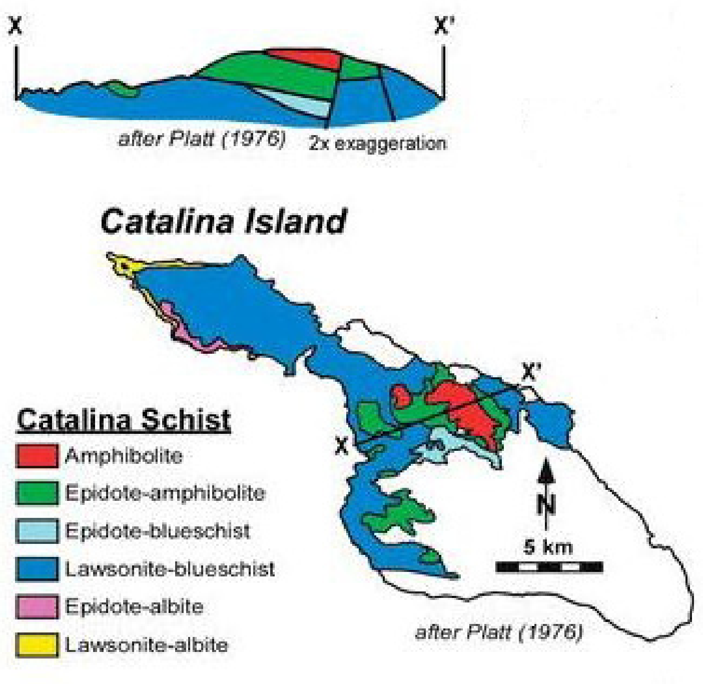

Figure 1. Grove et al.'s (2008) revision of Platt's (1976) geologic map of Catalina Island.

Tectonic Model

Platt's (1975) hypothesized model of an inverted thermal gradient created in a newly formed subduction zone requires synchronous metamorphism of all units of the Catalina Schist. U-Pb dating of detrital zircons from the different units of the Catalina Schist (Grove et al., 2008) instead indicates a ~20 My. history of metamorphism and accretion. Additionally, 40Ar/39Ar and Rb-Sr ages of 135 Ma from a block of garnet-blueschist is evidence of subduction prior to formation of the Catalina Schist. The nascent subduction model is not supported by chronologic data and the high-grade rocks are difficult to fit into a subduction zone setting. Even if heat for high T/P metamorphism existed above the slab, a retrograde blueschist overprint is expected as the unit cools. No blueschist overprinting is present in the amphibolite-facies rocks.

To reconcile these contradictions Grove et al., (2008) proposed a model of subduction erosion and underplating for the accretion of the Catalina Schist. Subduction erosion is crustal shortening by underthrusting of forearc material during active subduction and is observed in about half of contemporary convergent margins (Grove et al., 2008). ~115 Ma in the forearc of an existing Cretaceous subduction zone along the southwestern margin of North America, a megathrust displaced Early Cretaceous rocks beneath the magmatic arc of the PRB. Stalled at a position beneath the magmatic arc and far from the cold downgoing slab, the rocks underwent amphibolite-facies metamorphism. Accretion of the epidote-amphibolite unit as an imbricate thrust at ~113 Ma followed and both units underwent greenschist-facies metamorphism for up to 10 My. until uplift and cooling (Grove et al., 2008). There is insufficient data to constrain the origin of the epidote-blueschist, although Grove et al. (2008) suggests possible formation at an intermediate position in the forearc and subsequent accretion and greenschist-facies metamorphism beneath the epidote-amphibolite.

Formation of the lawsonite-blueschist and lower grade rocks took place within the subduction zone and were accreted ~97 Ma. The onset of the Laramide orogeny ~95 Ma marked a dramatic shallowing of the angle of subduction and an inward migration of the magmatic arc (Grove et al., 2008). Associated uplift and continued forearc erosion juxtapose the units across low angle faults that identify the present contacts of the Catalina Schist.

METHODS

FIELDWORK

Cottonwood Canyon runs southwest from the Airport to the shore, cutting a cross-section through the Catalina Schist which crops out extensively in the canyon. Starting from the bottom of the canyon in apparent epidote-blueschist facies, I collected 11 samples up valley through apparent epidote-amphibolite and amphibolite facies rocks until reaching a massive fault contact with amphibolite-mélange. There is no observable contact of the epidote-blueschist and epidote-amphibolite units in Cottonwood Canyon; instead actinolite-mélange with epidote-amphibolite and garnet-quartzite blocks occurs between the samples (12CAT14b6, 12CAT14b9) that show a distinct change in mineralogy and texture in thin-section. The change is less apparent in the field; only a slight change in color from blue-green to grey-green identifies the difference in hand sample.

RESULTS

EPIDOTE-BLUESCHIST

Figure 2. 12CAT14b5. Well-zoned but fractured epidote-clinozoisite porphyroblasts among quartz aggregate and foliated chlorite. Crossed polars.

Figure 3. 12CAT14b5. Foliations of chlorite and glaucophane deflect around a zoisite porphyroblasts, evidence that the greenschist-facies chloritization occurred after growth of epidote-clinozosite and zoisite porphyroblasts. Crossed polars.

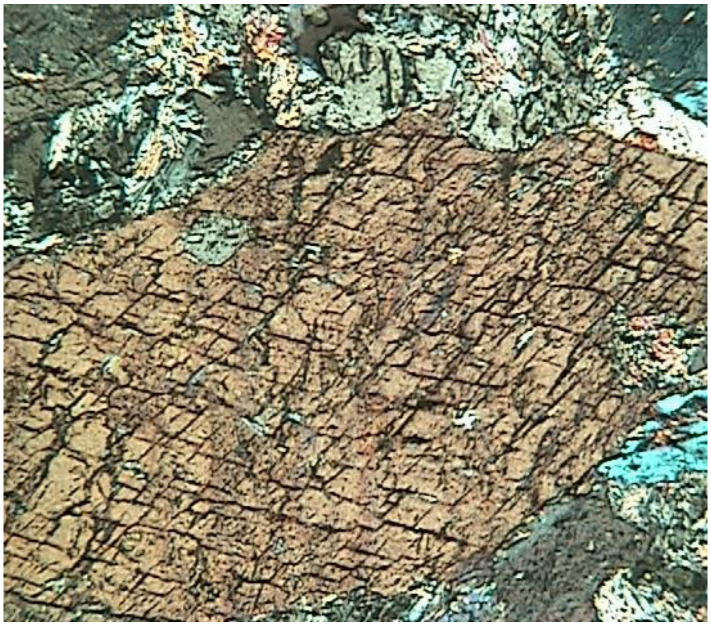

Figure 4. 12CAT14b11. Massive amphiboles including cummingtonite-grunerite and hornblendes (pictured), along with clinozoisite porphyroblasts characterize the ambhibolite thin sections. Crossed polars.

The mineral assemblage of each sample is similar and distinctly epidote-blueschist. Large grains of zoned epidote-clinozoisite and zoisite (fig. 2) are abundant, as well as subhedral lawsonite and pumpellyite grains and patches of sausseritized plagioclase. Small elongate grains of glaucophane, chlorite and muscovite form broad foliated swathes with aggregates of quartz and calcite inclusions (fig. 3). Glaucophane and muscovite also occur as small isolated euhedral grains.

A highly folded foliation, deformation and intergrowths of larger crystals, and quartz grains that show strong alignment under the gypsum plate are evidence of uniform stress. Micaceous symplectites are common on the grain borders of epidote-clinozoisite porphyroblasts. Quartz grains are elongated parallel to the foliation.

EPIDOTE-AMPHIBOLITE

An apparent epidote-amphibolite cropping out past the contact-obscuring mélange zone, the thin section of 12CAT14b9 is different in appearance than previous samples. Large prismatic amphiboles and zoned epidote-clinozoisite grains create a brick pattern which is deformed in places. Zoisite occurs consistently as well-formed almond shaped grains. The areas of deformation include aggregates of quartz, calcite and mica. Small veins of foliated chlorite and mica exist.

The final sample of amphibolite was collected near the fault contact with block-and-mélange zone. Large subhedral to euhedral amphiboles grains dominate the thin section (fig. 4), while subhedral quartz grains form smaller aggregates and exist between grains. Areas of deformation and recrystallization feature fractured epidote grains often with intergrowths of bladed mica. Mica also exists as euhedral grains, among quartz aggregates or independently.

DISCUSSION

The epidote-blueschist unit is unusual within the already-unique California Schist; metamorphosed at T/P conditions similar to those common in subduction zones, it also shares characteristics with the anomalously high T/P amphibolite believed to have formed in a forearc megathrust. Outcrops of the epidote-blueschist and epidote-amphibolite are similar enough to have been originally mapped as one unit (Platt, 1975). When observed in thin-section however, there are significant differences in mineral assemblage and texture. The contrast in texture is especially distinct; strongly foliated fine grains dominate the epidote-blueschist, compared to coarse blocky grains of the high-grade rocks. The change in metamorphic texture appears abruptly and clearly distinguishes the units. Although epidote, zoisite and chlorite are shared significantly, hornblende exists exclusively in the high-grade rocks and glaucophane in the epidote-blueschist. Grains of epidote and particularly clinozoisite appearing in the high-grade samples are often well-formed and regular; epidote in the epidote-blueschist is more often fractured and recrystallized. Chlorite is present in every sample as foliated veins of recrystallized mica and occasionally as small subhedral grains.

A clear, non-gradational change in metamorphic texture and mineral assemblage is evidence that accretion of the epidote-blueschist unit of the Catalina Schist occurred post-metamorphism. If the epidote-blueschist had formed in the same megathrust as the high-grade rocks, we would expect to see a graded change of shared features reflecting a continual thermal gradient. The subduction erosion model of crustal shortening in the forearc allows formation of a second megathrust behind the amphibolite-facies thrust within which epidote-blueschist facies metamorphism occurred (Grove et al., 2008). The regional thermal gradient is affected by the cold slab as well as the hot batholith; emplacement nearer the trench would support lower-grade metamorphism while still allowing formation of relatively high T/P minerals.

Comparison shows that the epidote-blueschist and epidote-amphibolite clearly record unique metamorphic histories. Their greenschist overprint and current field relationship do however indicate converging tectonic histories. Continued erosion of the forearc resulting in accretion of the epidote-blueschist by underplating the epidote-amphibolite produces the present day contact. Association with the high-grade units during cooling and exhumation included the epidote-blueschist in the common greenschist-facies overprinting. The accretion of the subduction zone metamorphic suite to the high-grade rock of the forearc completes the Catalina Schist.

Textural and mineralogical features observed in thin section support Grove et al., (2008)'s hypothesis that the epidote-blueschist unit formed in a forearc thrust not associated with the high-grade units. Secondary thrusting in the forearc fits easily into the subduction erosion model. Subduction erosion is also explains present-day contacts of rock originally metamorphosed along a broken thermal gradient. The scarcity of datable grains leaves the chronology vague, but confirmation that the epidote-blueschist unit was independently metamorphosed and accreted post-crystallization is a valuable detail in the evolution of a late Cretaceous subduction model.

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