Zirconium in Rutile Thermometry: Temperature Estimates for Metamorphic Rocks of the Catalina Schist

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GEOL 394

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Introduction

The Catalina Schist is a subduction-related metamorphic terrane that formed off of California's southern coast 114 ± 0.6 Ma (Anczkiewicz, 2004). It comprises both mélange and coherent units of varying metamorphic grade (figure 1). Peak conditions of metamorphism have been constrained to P = ~0.8-1.1 GPa and T = ~640-750 °C via traditional thermobarometry (Sorenson and Barton, 1987). These temperatures are hotter than those reached in typical long-lived subduction zones, which is a unique characteristic of the Catalina Schist (figure 2). Several models of the tectonic environment that might produce these high T conditions have been proposed in the literature. The models are based in part on temperature data, thus illustrating the importance of temperature work on the Catalina Schist. The application of the Zr in rutile thermometer to the Catalina Schist provides an opportunity to potentially reveal new information about the temperatures its rock record, and in turn, the environment that produced them.

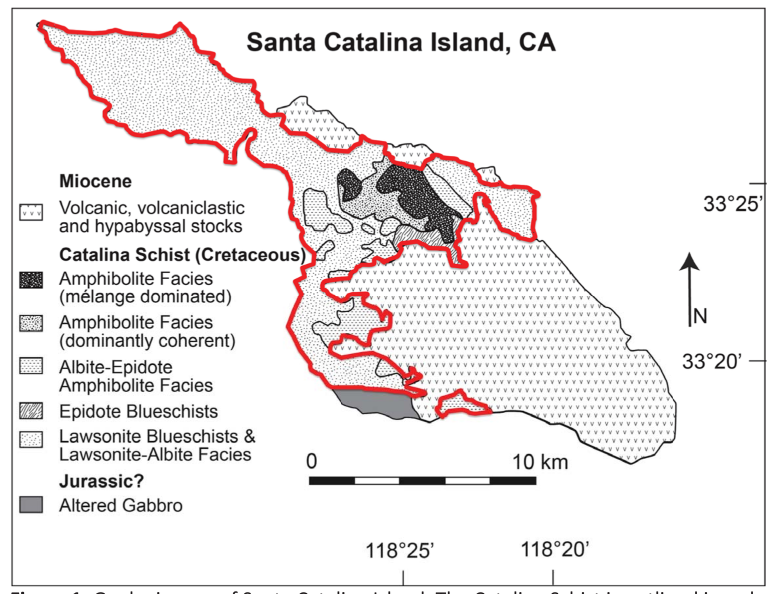


Figure 1: Geologic map of Santa Catalina Island. The Catalina Schist is outlined in red (Grove and Bebout, 1995).

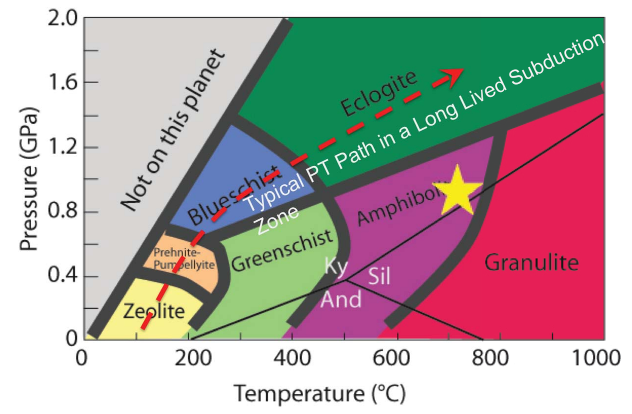
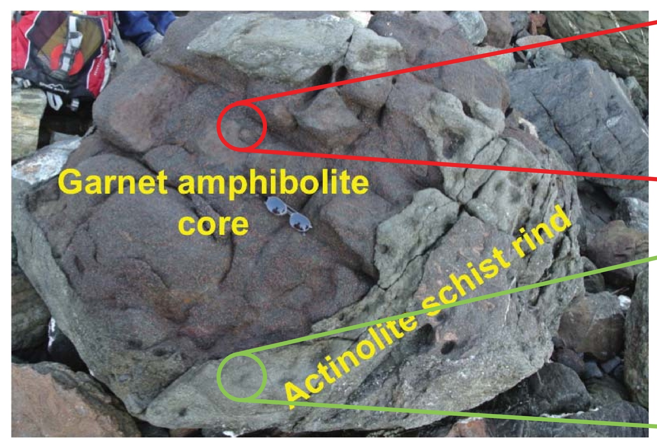


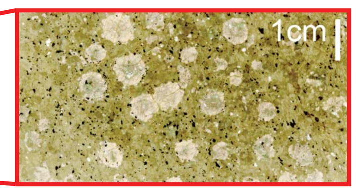
Figure 1: Pressure-temperature diagram illustrating metamorphic facies boundaries. Dashed red arrow indicates the typical PT path that subducted packages of rock follow in a long-lived subduction zone (i.e. blueschist to eclogite facies metamorphism). Yellow star denotes the location in PT space of the higher temperature units of the Catalina Schist (after Spear, 1993).

Objectives

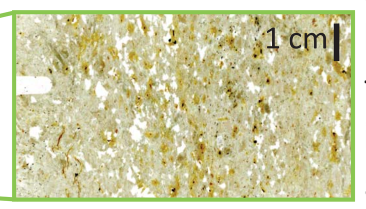
The Zr concentration in rutile of four samples from the Catalina Schist was measured via EPMA. The Zr concentration was input into a Zr in rutile thermometer calibration in order to obtain temperature estimates.



Field photograph of the core and rind of the amphibolite block. Photo credit: S. Penniston-Dorland



A10-3d: Garnet amphibolite thin section



A10-3a: Actinolite Schist thin section

Samples A10-3d and A10-3a come from the core and rind, respectively, of a single block that originates from the mélange-dominated amphibolite unit. They were selected for analysis to determine if the block as a whole records a consistent temperature or, if the fluid-rock interaction that produced the rind affected the Zr concentration in rutile in the rind.

A12A-5: Garnet quartzite thin section

Sample A12A-5 is from a garnet quartzite block from the same unit as the amphibolite block pictured above. It was selected for analysis to determine whether there is consistency in the temperature recorded within the unit.

GB12-1a: Garnet blueschist thin section

Sample GB12-1a is from a garnet blueschist block from the lawsonite blueschist unit. It was selected for analysis because presently, no temperature data for this lithology have been reported in the literature. This study is the first to do so, and as such, makes an important contribution to the overall body of knowledge of the Catalina Schist.

H_0: There is no difference in the temperature recorded by the four samples.

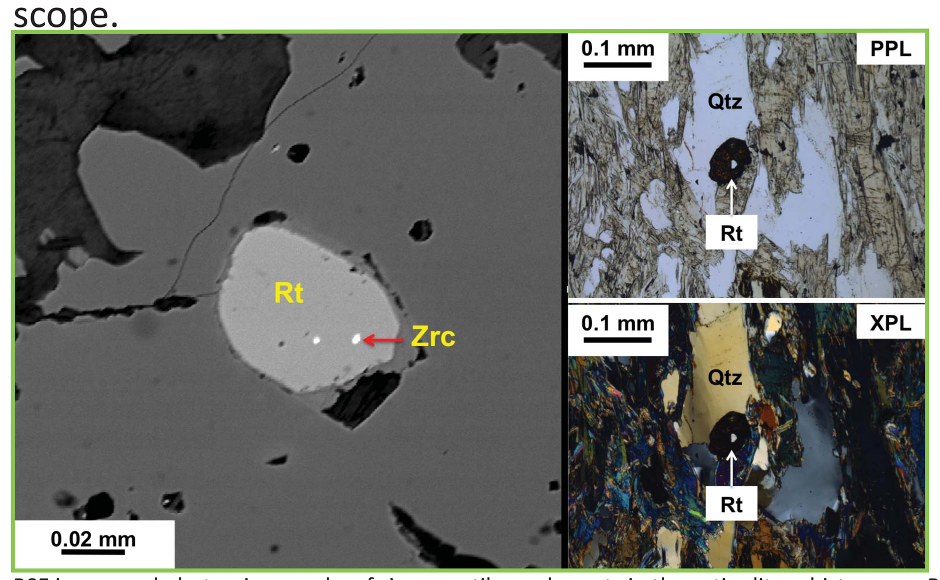
Analytical Methods

Rutile grains were identified and selected for analysis by using a petrographic microscope. Considerations for rutile selection included size, crystal habit, alteration, and location of the rutile. After the rutile grains were selected and their location within the sample was noted on a thin section map, the Zr concentraion of the grains was measured via EPMA. Provided that the grains were large enough, mulitple runs on each grain were performed in order to determine whether or not the Zr concentration is homogeneous across the grain. The Zr concentration was input into the following thermometer calibration, which was developed by Tomkins et al. (2007):

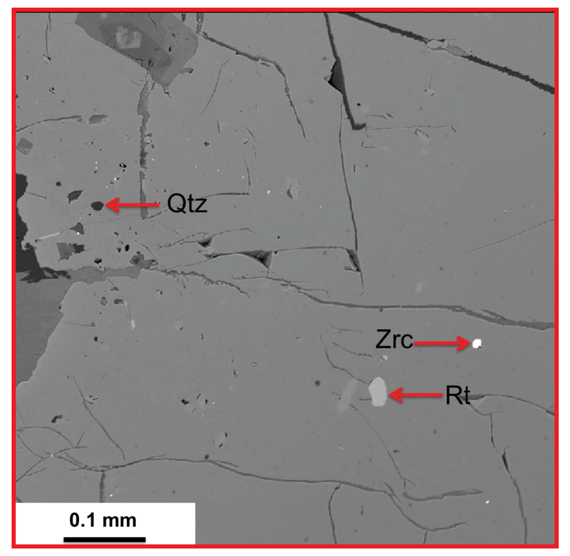
$$T(°C) = \frac{(83.9+0.410P)}{(0.1428-R\ln\phi)}$$

where P is pressure in kbar, R is the gas constant (0.0083144 kJ/K), and ϕ is Zr concentration in ppm. Values of 0.8 GPa, 0.9 GPa, 1.0 GPa, and 1.1 GPa were used for P because the peak pressure conditions experienced by the Catalina Schist have been constrained to ~0.8-1.1 GPa (Sorenson and Barton, 1987).

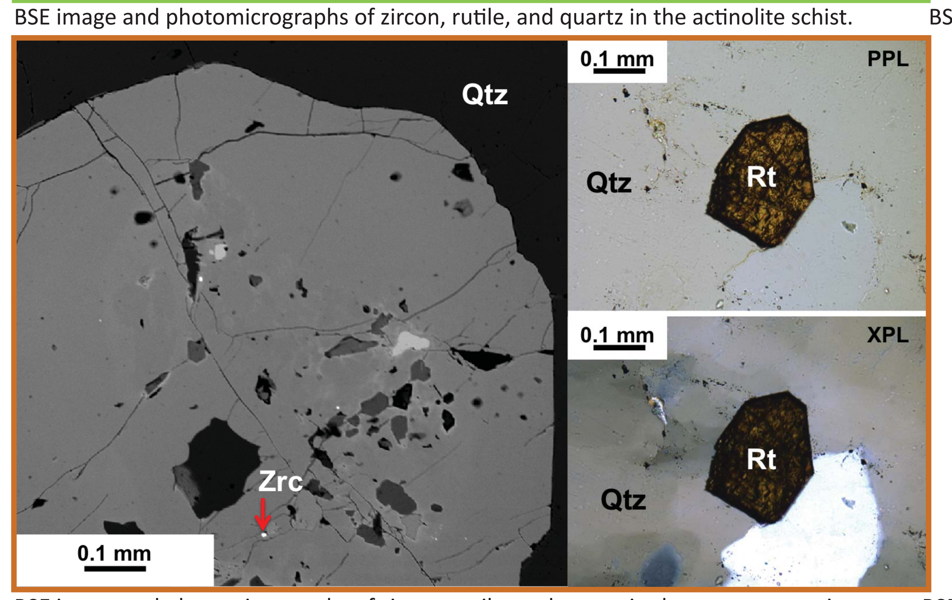
The above Zr in rutile calibration is based on the assumption that zircon, rutile, and quartz were reacting with eachother during rutile growth. It is not possible to demonstrate that these minerals were in equilibrium during rutile growth, but the mineral assemblage of zircon, rutile, and quartz was documented with back scattered electron (BSE) images that were captured from the EPMA and/or photomicrographs that were captured with the petrographic microscope.



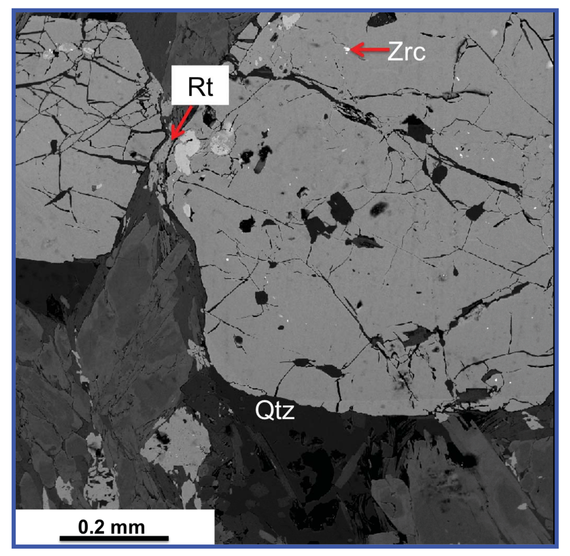
BSE image and photomicrographs of zircon, rutile, and quartz in the actinolite schist.



BSE image of zircon, rutile, and quartz in the garnet amphibolite.

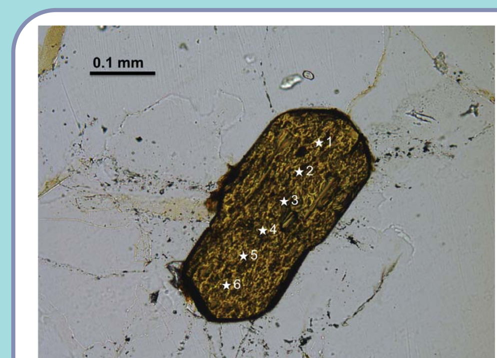


BSE image and photomicrographs of zircon, rutile, and quartz in the garnet quartzite.



BSE image of zircon, rutile, and quartz in the garnet amphibolite.

Example Analysis and Uncertainty



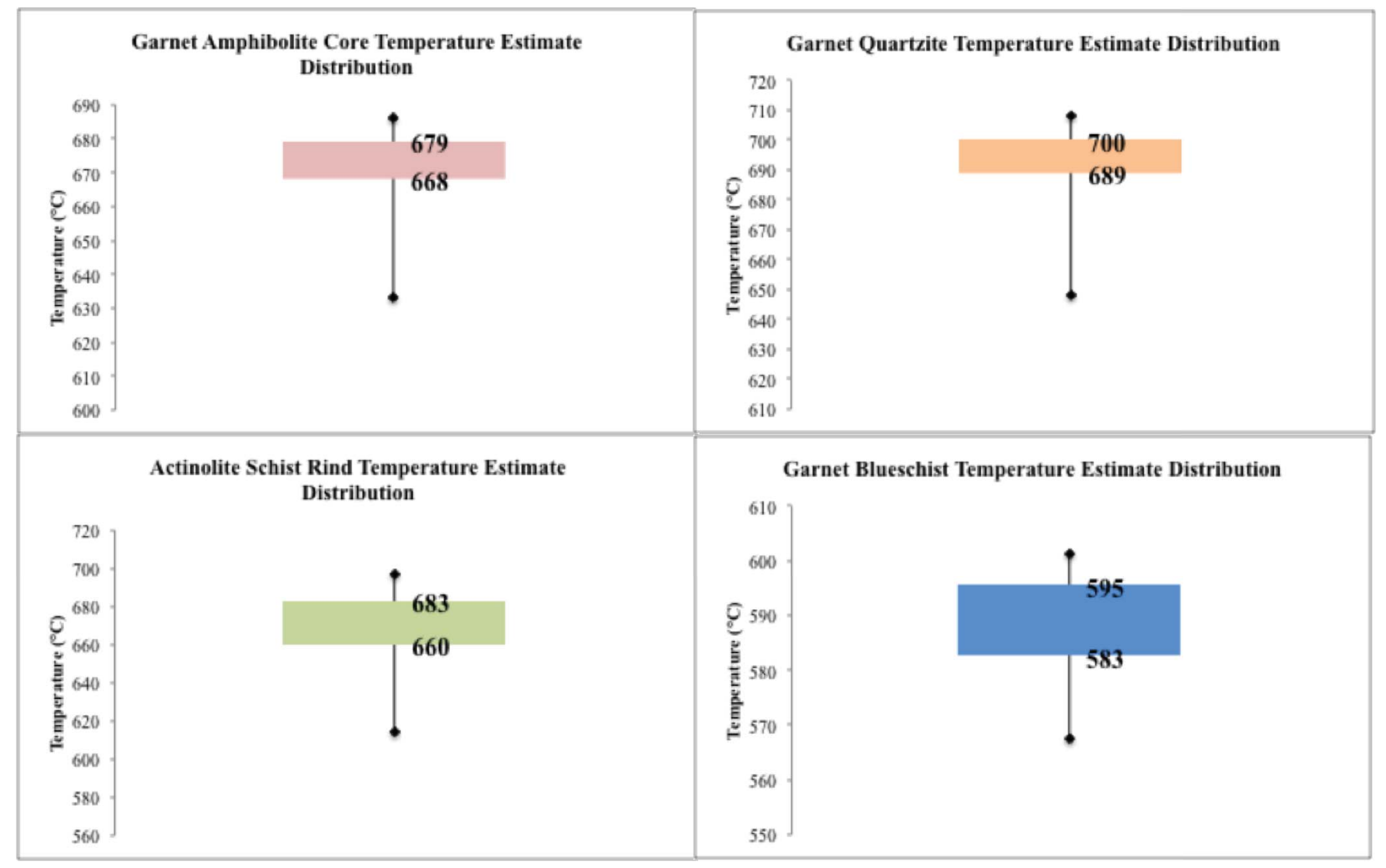
Photomicrograph of a rutile grain with traverse run numbers denoted by stars.

Run No.	Zr (ppm)	Zr 2σ Abs. Uncert.	T (°C) P = 1.0 GPa Upper	T (°C) P = 1.0 GPa Lower
1	495	38	698	685
2	523	39	703	690
3	529	38	704	691
4	479	38	696	682
5	523	38	703	690
6	505	38	700	687

Measurements corresponding to above traverse. Zr concentration is homogenous across this grain.

An example of a rutile grain traverse and corresponding measurements are pictured at left. The uncertainties due to counting statistics on Zr concentrations measured with the EPMA are approximated by a modified version on the equation $2\sigma=2(\sqrt{N}/N\times100)$ where N is the number of X-ray counts detected by the probe for Zr. For each run, the uncertainty on Zr concentration defines a range of temperatures calculated from the Zr in rutile thermometer. For example, the concentration of Zr measured in run #1 is 495 ± 38 ppm and the corresponding temperature range is 685-698 °C when P=1.0 GPa .

Results



Boxplots showing the interquartile range of T estimates for one of the pressure conditions considered (P=1.0 GPa).

Statistical t tests were used to determine if there is a significant difference in the temperature recorded by any two samples. The results of the t tests indicate that all samples except the core and rind of the amphibolite block record significantly different temperatures. H_0 can be only be rejected for samples that record different temperatures.

Conclusions

Rutile grains from both the core and rind of the amphibolite block record the same temperature, suggesting that the fluid-rock interaction that produced the rind did not change the Zr concentration of rutile in the block as a whole. This amphibolite block comes the same unit of the Catalina Schist as the garnet quartzite block. Although they are from the same mappable unit, these samples record different temperatures, with the garnet quartzite being the hotter of the two blocks. The disparity in temperature recorded by these two blocks may represent a difference in metamorphic and tectonic history of different parts of the amphibolite unit. The garnet blueschist block records the lowest and most statistically different temperature of the four samples that were analyzed in this study. This study presents the first temperature estimates for this lithology of the Catalina Schist.

References

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Acknowledgements

I thank my advisors, Dr. Sarah Penniston-Dorland and Dr. Phil Piccoli, for their support and assistance with this project. I also thank Julia Gorman, Leigh Roble, and Natalie Sievers for all of their useful advice through each stage of senior thesis.