



Exploiting Quartz to Constrain *Pressure-Temperature-time-Deformation* Histories in Metamorphic Rocks Through Recent Innovations in Thermobarometry and Geospeedometry

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Despite the abundance of quartz in continental crust, it has only recently been exploited for thermobarometric purposes. We are using trace element content, cathodoluminescence (CL) characteristics, fabric properties, extent of recrystallization, elastic properties and chemical diffusivities of quartz to better understand the pressure-temperature-time-deformation ($P-T-t-D$) histories of metamorphic rocks. The Ti-in-quartz thermobarometer has significant potential for unveiling important information on the metamorphic history of rocks, since quartz is commonly present in multiple microstructural settings (e.g. matrix, veins, inclusions) and zoning may be present in single crystals that reveal information about the reequilibration, recrystallization and growth histories of quartz. CL imaging provides a qualitative way to obtain such information, and provides a domain framework for targeted quantitative analyses. We illustrate such analyses with examples from Vermont, India and Greece.

A recent study in metapelites from central-eastern Vermont revealed crystals that have low Ti cores (interpreted to be preserved early prograde growth), with mantles that grade to higher Ti, attributed to temperature increase during fabric development and liberation of Si during crenulation cleavage development in the micaceous matrix. Low-Ti overgrowth rims that form sharp boundaries with these graded mantles may be later retrograde overgrowths. Forward modeling the expected volume of quartz present in the rock in $P-T$ space may be implemented to confirm periods of quartz production/precipitation and dissolution. Rocks from the Sutlej Valley (north-west India) have matrix quartz grains with triple junction grain boundaries indicating extensive recovery. CL imaging, however, reveals high Ti ribbons that may be indicative of chemically-preserved paleo-microstructures. At the temperatures and metamorphic rates experienced by these samples, grain boundaries during recovery may not redistribute impurities, but rather behave passively.

A recent advance in implementing Raman spectroscopy on quartz inclusions in porphyroblasts facilitates accurate geobarometry for the time of porphyroblast growth. The method requires that elastic parameters of the host and inclusion are determined, but is independent of the composition of these phases. A recent application of this technique to garnets from blueschists in Sifnos, Greece, resulted in $P-T$ paths for garnet growth from 19.5 kbar at 460 °C to 21.5 kbar at 550 °C. These results are in good agreement with recent studies attempting to constrain peak metamorphic histories for these rocks through equilibrium assemblage diagrams and trace element thermobarometry. Preliminary Raman work from the Sutlej Valley samples suggests peak pressures of c. 6.3 kbar approaching the Main Central Thrust. It may be advantageous to couple this geobarometer with Ti-in-quartz on inclusions in garnet to elucidate thermobarometric information relative to microstructural context and deformation history. An additional benefit to this technique is that pressure constraints needed for Ti-in-quartz thermobarometry may now be independently constrained and requires no knowledge of stable mineral assemblages, component activities or mixing parameters. Titanium diffusion from host (garnet) to included quartz may also be implemented to obtain geospeedometry information to estimate the duration of metamorphism. The integration of microstructural analysis with these various techniques may allow for a better understanding of the $P-T-t-D$ histories of rocks than previously obtained using conventional techniques.