Geophysical Research Abstracts
Vol. 17, EGU2015-8185-4, 2015
EGU General Assembly 2015

Timescales of ductility in an extensional shear zone recorded as diffusion profiles in deformed quartz

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We document rutile needles that were in the process of exsolving from quartz during ductile shearing, and we apply the Arrhenius parameters for Ti diffusion in quartz to extract the timescales over which diffusion transpired. By constraining temperature conditions of deformation using multiple independent thermometers in the same rocks (Ti-in-quartz, Zr-in-rutile, quartz fabrics and microstructures), we estimate the longevity of a ductile shear zone that accommodated extensional collapse in the North American Cordillera.

Eocene exhumation of the Pioneer core complex, Idaho, USA, was accommodated by the brittle-ductile Wildhorse detachment system that localized in a zone of sheared metasediments and juxtaposes lower crustal migmatite gneisses with upper crustal Paleozoic sedimentary units. Deformation in the Wildhorse detachment was partly accommodated within a continuous sequence ($\sim$200 m) of quartzite mylonites, wherein quartz grains are densely rutilated with microscopic rutile needles that are pervasively oriented into the lineation direction. We apply high-resolution spectroscopic CL analysis to map the Ti concentration field in quartz surrounding rutile needles, revealing depletion halos that indicate exsolution as Ti unmixes from quartz. Linear transects through depletion halos show that concentration profiles exhibit a characteristic diffusion geometry. We apply an error-function diffusion model to fit the measured profiles to extract the temperature or time recorded in the profile. Assuming modest temperature estimates from our combined thermometry analysis, results of diffusion modeling suggest that the quartzite shear zone was deforming over an integrated 0.8 – 3.1 Myr. If samples are permitted to have deformed in discrete intervals, our results suggest deformation of individual samples for timescales as short as 100 kyr. By comparing samples from different levels of the shear zone, we find that deformation was sustained in higher levels of the shear zone for longer duration than in samples deeper into the footwall, which we interpret to reflect progressive downward propagation of a widening ductile zone. Considering the complex nonlinear feedbacks between the temperature- and time-dependence of both lattice diffusion and work hardening of microstructures, our approach introduces a unique opportunity to link timing with kinematics to reconstruct the thermomechanical evolution of a deforming shear zone.

As a parallel test of this method, we have applied it to rock deformation experiments where it reproduces the approximate number of hours over which the experiment was conducted, further exemplifying the validity of this approach for constraining earth events.