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Isotopic dating of deformation histories of metamorphic rocks: The impact of dissolution precipitation creep

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Grain-scale processes related to rock deformation and fluid-mediated mineral reactions have a fundamental impact on the close-system and resetting behaviour of radiogenic isotope systems as geologically meaningful ages are only obtained for samples with (i) initial isotope homogeneity within the dated mineral volumes and (ii) complete isotopic resetting during deformation processes.

Dissolution precipitation reactions influence the resetting of radiogenic isotope systems in the geochronologically relevant minerals monazite and titanite in rocks deformed by ductile deformation. Fluid-mineral interaction in combination with deformation leads to different dissolution precipitation reactions involving monazite and titanite:

(i) Volume-conserving coupled dissolution precipitation resulted in zones of distinct chemical composition separated by a sharp reaction front due to a fluid migrating into older grains. This process implies phase separation and precipitation of secondary inclusions (locally adjacent to pores). However, it is not effective in accommodation of deformation. Moreover, in-situ grown radiogenic Pb is not completely released from reprecipitated zones, and, thus, dating these zones would not yield geologically relevant ages.

(ii) Monazite and titanite dissolved and precipitated as new grains in the immediate vicinity of the older host grains, and farther along grain and phase boundaries within the rock matrix. When occurring under differential stresses, this mechanism is capable of accommodating deformation as is indicated in our samples by shape preferred orientation of newly precipitated grains. To a first approximation such dissolution precipitation creep (DPC) becomes operative, when fluids are present and stress is too low to activate dislocation creep. The process can be described at the grain-scale by dissolution of grains at grain boundaries that are under high stress and subsequent transport of the dissolved ions to and precipitation on pore/vein walls and grain boundaries that do not support the maximum principal stress. Material transport preferentially occurs by diffusion in grain boundary fluids and by fluid migration. The chemical zoning of precipitating minerals reflects variations in the local chemical system. This process has a high potential to completely reset the radiogenic isotope systems.

Dislocation creep, during which lattice deformation triggers recrystallization, is associated with a different mode of mass transfer on the microscale. As crystals with high dislocation densities are replaced at broadly the same location by recrystallized (sub)grain aggregates with low dislocation densities, material transport does not exceed the dimension of recrystallized grain aggregates. Therefore, DPC more effectively supports mixing and redistribution/homogenization of elements/isotopic compositions over larger distances than dislocation creep.

Monazite and titanite participate in DPC together with major mineral phases and accessories, locally forming porphyroblasts indicating the overall sense of shear. The deformation mechanism DPC leads to the resetting of U-Th-Pb isotopic ages of monazite and titanite, and is recorded in their microtectonic features. Consequently, this allows dating distinct monazite/titanite precipitation pulses and accordingly, deformation increments, and is essential for understanding the geodynamic history of rocks.