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What Really Controls Mica Rb-Sr Closure Temperature?

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The interpretation of closure ages and temperatures from slowly-cooled terrains and cooling and exhumation rates derived from them depends on our understanding of grain-scale geochemical transport and kinetic processes. However, at present, closure temperatures can rarely be accurately predicted, revealing our poor understanding of grain-scale geochemical processes.

Traditional treatments of the closure process in the mica Rb-Sr system concentrate on the diffusion of radiogenic ^{87}Sr (^{87}Sr*) in the mineral grain in question, assuming equilibration with an "infinite reservoir" (Dodson, 1973), while more recent studies assume a finite exchange reservoir and incorporate the effect of finite diffusion rates in both source and sink minerals for ^{87}Sr* (Jenkin et al., 1995; Jenkin, 1997).

We have examined a phlogopite-bearing meta-carbonate from the amphibolite grade Central (Lepontine) Alps in order to attempt to elucidate what really controls the mica Rb-Sr closure temperature. Oxygen isotope data suggest that the rock cooled as a closed system. The phlogopite is 90 mol.% phlogopite end member and has high Rb (~900 ppm) compared to Sr (~0.3 ppm), giving precise Rb-Sr ages. Isotopic results suggest that the closure process may be even more complicated than hitherto supposed: a). The biotite is not undergoing Sr-isotope exchange with an infinite reservoir, b). The biotite Rb-Sr age does not decrease with decreasing grain size, as predicted by diffusion models and indicated by Ar-Ar data, but instead increases. The latter is due to Rb-loss during cooling, suggesting that retrograde chemical exchange of Rb and Sr among minerals during cooling may be as important as isotopic exchange in controlling Rb-Sr mineral ages.

Sub-peak-metamorphic temperatures obtained by calcite-dolomite thermometry (450-500 ºC) and feldspar thermometry (300-400 ºC) attest to retrograde exchange of Ca and Mg between calcite and dolomite, and Na and K between K-feldspar and plagioclase. It should not be too surprising therefore that Rb and Sr also re-equilibrated among minerals during cooling. Ion probe traverses of Rb and/or Sr concentrations across phlogopite, calcite and K-feldspar grains reveal that both Rb and Sr show systematic core-rim variations: Sr in calcite and Rb in phlogopite both decrease towards grain boundaries. However, both Rb and Sr increase towards grain boundaries in K-feldspar. These results suggest that grains in the rock are acting as single diffusion domains and that grain boundaries act as fast diffusion pathways. The gradients are interpreted as indicating the direction of transport of elements during cooling as the result of closed-system cation exchange, a process suggested by Ganguly & Ruiz (1987). In contrast, closure temperature calculations based on classic Dodson-type models assume parent and daughter element concentrations are homogeneous across grains and do not change with time. Furthermore gradients of elemental Sr in calcite appear to be opposite to gradients in ^{87}Sr/^{86}Sr, indicating that the chemical and isotopic systems are decoupled.

This study suggests that closure in mica Rb-Sr systems will depend both on the factors that control isotopic exchange (grain size, mode, ^{87}Sr diffusion coefficients) and those that control chemical exchange (grain size, mode, Rb and Sr diffusion coefficients, Rb and Sr contents of phases and their partition coefficients). Understanding the combined effects of chemical and isotopic equilibration on the closure temperatures in this system should allow us to provide better constraints on metamorphic cooling and exhumation histories.

Theoretical aspects of the chemical exchange model are developed further in the poster by Townley et al.

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