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Tracking mineral growth and fluid-rock interaction in metamorphic and igneous environments with high-resolution stable isotope analysis

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Geologic processes can be dated with excellent precision using for example U-Pb chronometers in zircon and monazite, with a precision of up to ~0.5‰ relative. Thus processes as fast a few thousand to tens of thousands of years can be dated. Recent progress in understanding of metamorphic and igneous processes has resulted in the suggestion that many of them occur over even shorter time scales, from a few days to a few thousand years only. This presentation will focus on the advances and limitations encountered in our efforts to use diffusion chronometry to understand mechanisms and duration of water-rock interaction in contact metamorphism, as well as to unravel crystallisation times in extrusive igneous systems.

The stable isotope compositions (O, C) of carbonates interacting with magmatic fluids at high temperatures permit the tracing of even small amounts of fluid flow. We present a detailed petrologic, secondary ion mass spectrometry (SIMS), and cathodoluminescence study of forsterite-calcite reaction veins crosscutting large (>50m) dolomite xenoliths of the Bergell intrusion (Alps, Italy). Similar veins are found on the border of the Adamello tonalite, in pure dolomites (Alps, Italy). In both case studies, dolomite crystals at the vein boundary are characterized by up to 100μm thick, homogenous recrystallization zones with lower δ^{18}O, δ^{13}C, and slightly higher Fe and Mn concentrations. δ^{18}O, and δ^{13}C isotope profiles were measured with SIMS, in part with spot sizes as small as 3μm, while FEG-EMPA imaging was used to establish Fe and Mn gradients in 2-D images. The obtained profiles can be fitted to a symetric diffusion equation. On the same sample, we obtained similar diffusion times for O and C isotope profiles (~5 Myrs), while times obtained for Mn and Fe diffusion were several orders of magnitude shorter (<1000 yrs). These differences highlight the need for accurate diffusion data, which allows for the evaluation of the diffusion mechanism. Yet, isotopic diffusion is likely to be very different than elemental diffusion.

In another study we demonstrate, using NanoSIMS analysis of Ti and diffusion chronometry, a very rapid growth (e.g. in 1-100 years) of quartz phenocrysts from rhyolites and ignimbrites from the Chon Aike igneous province. Detailed analysis of several consecutive zones in the same crystal resulted in some cases in decreasing residence times from the centre to the rim, but in a few cases irregular, or even inverse relationships were seen. Since quartz crystals were cut through their morphological centre – which should result in cuts perpendicular to the zoning – we believe this not to be an effect of intersection geometry, but rather due to the fact that Ti in quartz was not initially a step function. Initial smooth boundaries will result in overestimation of the diffusion time. This shows, that detailed models for the growth of after quartz phenocrysts are needed, to allow better estimates of the initial boundary conditions used for diffusion modelling.