New developments in Li-chronometry: determining the timescales of fluid-rock interaction

Timm John (1), Johannes C. Vrijmoed (1), and Yuri Podladchikov (2)

(1) Institute of Geological Sciences, Freie Universität Berlin, Germany (timm.john@fu-berlin.de), (2) Institute of Earth Sciences, University of Lausanne, Switzerland

Fluid-rock interactions occur on scales ranging from submicron to tens of kilometres. They play a key role in controlling mineral stability, plate dynamics, and element cycling by changing petrophysical properties and chemical composition of the involved rocks. For example, fluid-rock interaction facilitates strain localisation leading to tectonic responses to plate motion, it enhances element mobilisation essential for the formation of ore deposits, and it may induce melt formation in volcanic arc settings. In many cases, the absolute age of the reaction products can be obtained using conventionally applied radiogenic dating techniques. In contrast, constraining timescales of individual processes represents one of the key challenges in solid Earth science today. To quantify the duration of relatively short-lived processes lithium chronometry is shown to be very effective because Li is a fast diffusing element.

Li chronometry relies on fitting numerical simulations to Li variations measured in preserved mineral assemblages that are clearly formed by a fluid-rock interaction process. Successful application of Li chronometry has to involve (1) correct interpretation of the mineral and rock record of key outcrops, (2) precise and accurate measurements of Li isotope composition and concentration, and (3) an adequate model including the essential physics to simulate the evolution Li concentration and isotope composition.

In this contribution, we focus on the development of numerical models to simulate fluid-mediated transport that may result in changes of the mineral assemblage of the affected rock. Our model is based on conservation of mass, concentration and fluid momentum. The initial background porosity is determined experimentally and the transient effects on the porosity evolution are directly linked to the mass transport and the change in the mineral assemblage by chemical reactions. The fluid-rock partition coefficient of Li changes due to the continuous change of the assemblage of the rock forming minerals in the model. This allows us to use Li as a passive recorder of the fluid-rock interaction accompanying changes of the rock record. Importantly, Li represents a trace-element in the solid and the fluid, Li fluid-solid exchange is controlled by dissolution-precipitation processes and Li transport occurred exclusively in the fluid. By fitting the simulated to the observed Li profiles the duration of the fluid-rock interaction process is determined.

We show case studies indicating that:
1. Local thermodynamic equilibrium is a valid assumption for fluid-mediated processes at high fluid-rock ratios and elevated temperatures.
2. Outcrop scale fluid induced replacement reactions occur on time-scales of months to thousands of years rather than millions of years.
3. Transient, reaction induced porosities may reach values that are 5-10 times greater than background.