



Microphysical models of fluid-driven metamorphism within the Earth's lithosphere

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The reaction of fluids with rocks is fundamental for Earth's dynamics as they facilitate heat/mass transfer and induce volume changes, weaknesses and instabilities in rock masses that localize deformation enabling tectonic responses to plate motion. During these fluid-rock interactions, it is the ability of a rock to transmit fluid, its permeability, that controls the rates of metamorphic mineral reactions. However, although some geological environments (e.g., sediments) are open to fluids, most of the crystalline lithosphere is nearly impermeable. Surprisingly though, even in rocks that are nominally impermeable widespread fluid-rock interactions are observed leading to the question: How can fluids migrate through vast amounts of nominally impermeable rocks? In this contribution, I review the current knowledge about the microphysical mechanisms of fluid pathway generation during reactive transport processes within low-permeability, crystalline rocks. I focus on two end-member scenarios that represent some of the most important fluid-driven metamorphic mineral reactions on Earth. The first example focuses on the hydration and carbonation of ultramafic rocks (peridotites and serpentinites). Using multi-scale electron and X-ray imaging combined with estimates from continuum mechanics I discuss the positive and negative feedbacks of reaction-induced fracturing and the "force of crystallization". I present an interface-scale fracturing mechanism that is consistent with reaction microstructures produced during olivine hydration (1) and compare those to natural observations and experiments of olivine and serpentine carbonation. In a second example, I focus on the fluid-driven alteration of feldspar, the most abundant mineral family within the Earth's crust (2). Using field-based observations and novel multi-dimensional, multi-scale imaging combined with high-performance molecular dynamics simulations, I show that regional-scale, fluid-driven mineral reactions are potentially controlled by the creation of nanoscale (10-100 nm) fluid pathways in which novel transport phenomena emerge that are impossible in larger pores. Although the pathways themselves are minuscule, transport through them may control element redistribution throughout vast amounts of the Earth's lithosphere. Lastly, I present preliminary in situ synchrotron tomography results investigating the dynamic development of reaction-induced porosity in a salt analogue system.

References:

- (1) Plümper O., Røyne A., Magraso A., Jamtveit B. (2012). The interface-scale mechanism of reaction-induced fracturing during serpentinization. *Geology* 40(12), 446-455.
- (2) Plümper O., Botan A., Los C., Liu Y., Malthe-Sørensen A., Jamtveit B. (2017) Fluid-driven metamorphism of the continental crust governed by nanoscale fluid flow. *Nature Geoscience*. 10(1) 685-690.