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Can serpentinization induce fracturing? Fluid pathway development and the volume increase enigma

Oliver Plümper (1,2), Bjørn Jamtveit (2), and Anja Røyne (2)

(1) Department of Earth Sciences, Utrecht University, Utrecht, Netherlands, (2) Physics of Geological Processes (PGP), University of Oslo, Oslo, Norway (oliver.pluemper@fys.uio.no)

Serpentinization of ultramafic rocks has first-order effects on global element cycles, the rheology of the oceanic lithosphere, plays a key role in plate tectonics by lubricating subduction zones and has been linked to the origin of life due to the creation of abiogenic hydrocarbons. In addition, the capability of ultramafic rocks to safely store enormous amounts of carbon dioxide through mineral reactions may provide a unique solution to fight global warming. However, all the aforementioned processes are reliant on the creation and maintenance of fluid pathways to alter an originally impermeable rock. Although the forces that move tectonic plates can produce these fluid pathways by mechanical fracturing, there is ample evidence that serpentinization reactions can 'eat' their way through a rock. This process is facilitated by solid volume changes during mineral reactions that cause expansion, fracturing the rock to generate fluid pathways. Natural observations of serpentinization/carbonation in ultramafic rocks indicate that the associated positive solid volume change alone exerts enough stress on the surrounding rock to build up a fracture network and that the influence of external tectonic forces is not necessary. Through various feedbacks these systems can either become self-sustaining, when an interconnected fracture network is formed, or self-limiting due to fluid pathway obstruction. However, extensively serpentinized outcrops suggest that although crystal growth in newly opened spaces would reduce permeability, serpentinization is not always self-limiting as porosity generation can occur concomitantly, maintaining or even increasing permeability. This is consistent with theory and demonstrates that fluids transported through fracture networks can alter vast amounts of originally impermeable rock. Nevertheless, whether serpentinization can actually generate these fracture networks is still a matter of debate and only a few scientific investigations have focused on this topic so far. Here, we investigate the feasibility of reaction-induced fracturing and pore space evolution during serpentinization by combining microstructural investigations using scanning/transmission electron microscopy and synchrotron micro-tomography of natural samples with theoretical considerations on the forces exerted during solid volume increasing reactions. We particularly focus on the interface-scale mechanism of reaction-induced fracturing (Plümper et al. 2012) and the establishment of microstructural markers (e.g., inert exsolutions in olivine) to identify volume changes and estimate crystallization pressures (Kelemen and Hirth 2012). Our investigations suggest that reaction-induced fracturing during serpentinization is possible and during certain physico-chemical circumstances a positive feedback to alter vast amounts of originally impermeable rock is established.

Plümper O., Røyne A., Magraso A., Jamtveit B. (2012) The interface-scale mechanism of reaction-induced fracturing during serpentinization. Geology. 40, 1103-1106.
Kelemen, P. B. & Hirth, G. (2012) Reaction-driven cracking during retrograde metamorphism: Olivine hydration and carbonation. Earth and Planetary Science Letters 345, 81-89.