



Reaction-induced fracturing during olivine serpentinization: A mechanistic investigation at the interface scale

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Serpentinization of the Earth's impermeable upper mantle is one of the most fundamental metamorphic hydration reactions. It governs lithospheric weakening, geochemical subduction zone input and possibly even the formation of life-essential building blocks. Serpentinization relies on fluid pathway generation due to low initial permeability and the large positive solid volume change associated with hydration. Although these pathways can be produced as a tectonic stress response, there is substantial evidence that the volume increase during olivine serpentinization itself generates stresses sufficient to fracture the rock. Nonetheless, the actual fracturing mechanism during olivine serpentinization is largely unexplored.

Unconstrained batch experiments (Okamoto et al. 2011, this study) produce comparable hierarchical fracture patterns to those found in natural samples demonstrating that no external forces (e.g., tensile stress) are required for fracturing to take place. Combining this with the observation that fluid-mediated mineral replacement advances via an interface-coupled dissolution-reprecipitation mechanism (e.g., Putnis 2009) without solid-state diffusion into the dissolving mineral indicates that classical (stress) corrosion cracking mechanisms cannot describe fracturing during olivine serpentinization. By uniting micro- and nanostructural characteristics ubiquitous to serpentinized olivine grains with a coupled diffusion-reaction-deformation model and crack growth theory this study explores the sub-critical fracturing mechanism at the interfacial scale. We present a new multistep reaction process and test the feasibility of a molecular wedge-assisted fracturing mechanism based on the following ubiquitously identified features: (1) no rotation of grain domains during fragmentation, (2) isotropic fracture orientation distribution with a uniform average width of individual finite length serpentine veins, (3) cumulative fragment area distribution with a log-normal scaling behavior following a hierarchical fracturing model, (4) etch pit development at olivine-lizardite reaction interfaces, (5) crack initiation at these surface perturbations and (6) amorphous layer formation during olivine dissolution prior to serpentine nucleation (e.g., Rumori et al. 2004).

Based on these observations we propose an entirely self-propagating reaction-driven fracturing process, where fractures nucleate at dissolution-induced surface perturbations assisted by a molecular wedge of amorphous 'gel', followed by further olivine dissolution and serpentine (\pm brucite) reprecipitation coupled with the force of crystallization. This process results in the observed hierarchical fracture network.

Our results suggest that the mechanical force needed to advance serpentinization at the grain-scale does not rely on external forces but is due to interface-coupled, chemomechanical feedback during olivine re-equilibration in the presence of a fluid phase. Nevertheless, the influence of tectonic forces will need to be accounted for at larger scales.

References: Okamoto et al. (2011), Chem. Geol. 289, 245-255; Putnis (2009), RIMG 70, 87–124; Rumori et al. (2004), Eur. J. Mineral. 16, 731-741