Kinetics of silica metasomatism during serpentinization revealed by hydrothermal experiments on olivine-quartz-seawater system at 300 °C

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Silica activity in the fluids is a key factor for controlling the progress of serpentinization. At the crust-mantle boundary, mass transfer of silica would occur, and causes reaction zoning of talc in the serpentinite. Such metasomatic zoning of forsterite–serpentine–talc–quartz has been modeled by diffusional mass transport processes coupled with multiple precipitation-dissolution reactions (Lichtner et al., 1986). These models, which assume the local equilibrium between fluid and minerals, predict the development of the monomineralic layers of serpentine and talc, but the detailed mechanism for the development of the silica metasomatic zone has not been examined experimentally. For understanding the temporal and spatial variation of progress on serpentinization in the oceanic lithosphere, the effects of silica transport on serpentinization rate needs to be constrained.

In this study, we conducted hydrothermal experiments (300°C, 8.6 MPa) on olivine (Ol)–quartz (Qtz)–H_2O system. By using tube-in-tube type hydrothermal experiments vessel, mineral powders are reacted with 0.5 mol/kg H_2O NaCl solution, and spatial distribution of minerals (reactant and product) after experiments was observed. After 2055 h reaction, the mineralogy of the reaction products in the Ol-hosted region changed with increasing distance from the Ol–Qtz boundary, from talc to serpentine + magnetite + brucite. After 2055 h reaction, talc was formed 0 - 2.0 mm from the Ol–Qtz boundary in Ol-hosted region, while brucite was formed > 5 mm from the Ol–Qtz boundary in Ol-hosted region. In Qtz-hosted region, no minerals were formed after the experiments.

The observed mineral distribution is explained by coupled processes involving silica diffusion and seven overall reactions in a porous medium: talc after olivine, serpentine after olivine, brucite after olivine, talc after serpentine, serpentine after talc, brucite after serpentine, and serpentine after brucite. To estimate the probability density function for the rate constants, we applied exchange Monte Carlo method (Hukushima and Nemoto, 1996; Oyanagi et al., 2018), which is one of the Markov chain Monte Carlo methods. The observed mineral distribution in the Ol-Qtz-H_2O experiments was successfully reproduced by numerical reactive transport model. Our kinetic model suggests that the rate of the brucite silicification reaction is controlled by the diffusion rate whereas the other six overall reactions are kinetically controlled during experiments with high porosity.

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