SCG60-15 会場:201A 時間:5 月 25 日 16:15-16:30

前弧マントルにおけるかんらん岩の加水反応速度に関する実験的研究
Experimental study on the hydration rate of peridotites at forearc mantle wedge conditions

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Recent ground water studies in southwestern Japan suggest that slab-derived fluid upwells through the forearc mantle wedge without significant reaction with the country rocks (e.g., Kazahaya et al. 2014; Kusuda et al., 2014), which may provide a clue to understanding the hydrological budget in forearc regions. The rate of serpentinization is one of the primary parameter for constraining the flow regime of slab-derived fluid in the stagnant forearc mantle wedge. Hydration experiments for kinetic studies have been vigorously conducted previously at relatively low P-T conditions (up to ca. 350 ℃ and 0.3 GPa), in which olivine reacts with water to form the low T serpentine variety lizardite (or chrysotile) and brucite. However, antigorite is expected to be the dominant serpentine variety under the higher P-T condition corresponding to the forearc mantle wedge (350 to 650 ℃ and 1.0 to 2.0 GPa). Moreover, serpentine formation needs a silica source in addition to olivine (e.g., orthopyroxne) at the temperature above 450 to 500 ℃ due to the instability of phase assemblage serpentine + brucite.

In order to constrain the serpentinization rates of peridotite under the mantle wedge conditions, we conducted piston-cylinder experiments at temperature of 400 ℃ (brucite-present condition) and 500 to 580 ℃ (brucite-absent condition), and pressure of 1.3 and 1.8 GPa. Three types of starting materials were prepared from the crushed powder of a San Carlos lherzolite xenolith: 1) olivine (Ol), 2) orthopyroxene (Opx) + clinopyroxene (Cpx) and 3) Ol + Opx. Hereafter these systems are abbreviated as OL, OPX+CPX and OL+OPX respectively. The starting materials were reacted with 15 wt% distilled water for 4 to 19 days. The hydration reaction proceeded in all the experiments, except for the OL system under the brucite-absent conditions. Based on Raman spectroscopy results and crystal shapes, the synthesized serpentine minerals were identified as lizardite in most of the runs except for antigorite in the OL+OPX system at 1.8 GPa. The Al_2O_3 in the system possibly stabilized the aluminous lizardite (Caruso and Chernosky, 1979). In the OL+OPX system, the reaction progress followed a diffusion-controlled rate law in the brucite-present condition and an interface-controlled rate law in the brucite-absent conditions. The rate constants were estimated to be 1.5×10^{-16} m^2/s and 8.7×10^{-12} to 1.5×10^{-11} m/s in the brucite-present and the brucite-absent condition, respectively.

We applied the experimentally-obtained hydration rates of peridotites to a reactive-transport model for the stagnant mantle wedge hydration. In the case of grain-scale pervasive flow, slab-derived fluid is completely fixed in the mantle wedge peridotite. Otherwise, aqueous fluid possibly penetrate all the way through the mantle wedge via crack-like pathways (we assumed the vertical distance of 10 km) with a spacing $>$0.025 to 0.80 m in the brucite-present conditions and $>$2.6 to 4600 m in the brucite-absent condition. This indicates that slab-derived fluid may upwell easily through a cold forearc mantle wedge like in Western Shikoku rather than a warm forearc mantle wedge like in Cascadia.

キーワード: 前弧, マントル, 流体, 蛇紋岩, アンチゴライト, 反応速度論
Keywords: forearc, mantle, fluid, serpentinite, antigorite, kinetics