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Growth kinetics of forsterite reaction rim at high pressure

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Element diffusion is one of the most important processes which control rheology of the minerals. For example, a strain rate in the diffusion creep is generally rate-limited by slowest diffusing element among the major elements in the mineral. From previous studies, Si is known as the slowest diffusing element among the major components in olivine, and O is the fastest below pressure of 1 GPa at wide range of grain size (e.g. Hirth and Kohlstedt, 2003). However, effect of pressure on the relative diffusion-rate among component spices of olivine is not well known. In order to assess major element diffusion in olivine, we have carried out forsterite reaction rim growth experiments under high pressure.

The forsterite rim was formed by the chemical reaction, MgO (periclase) + $MgSiO_3$ (enstatite) => Mg_2SiO_4 (forsterite). The starting materials were single crystal periclase and powder or sintered polycrystal enstatite. The forsterite rim width and grain size lead us to quantify a diffusion coefficient of the rate-limiting species of the forsterite rim growth. A Pt paste, which acts as a marker defining the slowest diffusing element in the forsterite major elements, was placed between periclase and enstatite. These samples were put in a welded Pt capsule to maintain dry condition. The reaction rim growth experiments were carried out by using Kawai-type multi-anvil apparatus at temperature of 1673 and 1873 K and pressure of 5.7-12.7 GPa with duration of 0-780 min. After experiments, the Pt marker position and the forsterite rim were observed using scanning electron microscope.

The Pt marker position was always found on the periclase and forsterite phase boundary. This indicates that Si is the slowest diffusing element among the major elements of forsterite at all studied conditions. Assuming the O is the fastest diffusing element in forsterite under studied P-T conditions, Mg diffusion in forsterite is judjed to be the rate-limiting process in the rim growth. Gardes et al. (2011) also showed that Si is the slowest diffusing element in major elements of forsterite at 1.5 GPa based on rim growth experiments. The results of this study and Gardes et al. (2011) suggest that Si diffusion limits the strain rate of olivine in the entire upper mantle.

It is not clear whether the rate-limiting step of the forsterite rim growth is Mg lattice diffusion or Mg grain boundary diffusion solely from our results. We calculated lattice and grain boundary diffusion coefficients of Mg assuming these diffusion processes, respectively, are rate-limiting in the rim-growth. The activation volumes are determined to be 7 cm^3mol^{-1} for lattice diffusion and 10 cm^3mol^{-1} for grain boundary diffusion, respectively.

Keywords: forsterite, high pressure, rim growth, diffusion