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Role of Mg-O grain-boundary diffusion in rheology and grain-growth in the Earth's mantle

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Material and heat transports in the Earth highly depends on rheology and grain-growth kinetics of the constituent materials. Although rheology and grain-growth in single phase aggregate have been studied extensively, knowledge of those in multi-phase system is still limited. Sundberg and Cooper (2008) pointed out the importance of a creep mechanism in which strain is produced by Mg-O grain-boundary diffusion accompanied with reaction at olivine-orthopyroxene phase boundary in the Earth's upper mantle. Tasaka and Hiraga (2013) showed that grain-growth in forsterite-enstatite two-phase system is rate-limited by growth of secondary phase through Mg-O grain-boundary diffusion. These reports suggest that Mg-O grain-boundary diffusion plays important role both in rheology and grain-growth. Recently, our group reported Mg-O grain-boundary diffusion coefficients in forsterite and $MgSiO_3$ perovskite (Maruyama et al., 2013; Nishi et al., 2013). In this study, theoretical model using our Mg-O grain-boundary diffusion data are compared with available rheological and grain-growth data, and importance of these mechanisms are discussed.

Flow-law were calculated for Mg-O grain-boundary diffusion creeps accompanied by reaction at forsterite-enstatite phase boundary (upper mantle) or accompanied by grain-growth of periclase (lower mantle) using Coble's (1963) equation and results by Maruyama et al. (2013) and Nishi et al. (2013). The derived flow-law for the upper mantle shows ~3 orders of magnitude faster strain-rate than that of creep experiments by Tasaka et al. (2013) which suggests this mechanism is not realistic. Although no comparable creep data was reported for the lower mantle, the derived flow-law shows faster strain-rate than that by Si lattice diffusion creep that was assumed in Xu et al. (2011) and the mechanism is a possible candidate deformation mechanism in the most part of lower mantle.

Grain-growth in the forsterite-enstatite two phase system was studied by Tasaka and Hiraga (2013) experimentally and it is already shown that grain-growth in this system is rate-limited by growth of secondary phase through Mg-O grain-boundary diffusion. Based on the same manner as Tasaka and Hiraga (2013), grain-growth law was calculated for the lower mantle assemblage $MgSiO_3$ perovskite-periclase system using Ardell's (1972) theory and Nishi et al.'s (2013) results. Derived grain-growth law was generally consistent with the grain-growth data in $MgSiO_3$ + MgO system reported by Yamazaki et al. (1996). Yamazaki et al.'s results can be explained by initial rapid growth from metastable texture and subsequent normal grain-growth which is rate-limited by Mg-O grain-boundary diffusion. Based on this interpretation, grain-size in the lower mantle is estimated to reach several hundred micro meter by 10^6 years.

Keywords: Upper mantle, Lower mantle, Rheology, Grain-growth, Olivine, Mg-perovskite