Diffusion mechanisms of creep and grain growth of two-phase polymineralic rocks: Constraints on grain size and viscosity of the lower mantle

*Atsuro Okamoto[1], Takehiko Hiraga[1]

1. Earthquake Research Institute, The University of Tokyo

The phase (mineral) transition which occurs during downwelling flow to the lower mantle produces micron-size grains. Such fine grains grow to the size observed in the upper mantle rocks (i.e., 1~10 mm) during one cycle of the mantle convection (Solomatov and Reese, 2008). The grain growth is likely to be most significant at the lowermost mantle where temperature is the highest and the duration for the grain growth is the longest. When polycrystalline materials deform by diffusion creep mechanism, their viscosities are proportional to the square or the cube of grain size. Thus, if the lower mantle and D” layer deform by diffusion creep, viscosities of these regions are highly controlled by the grain growth.
Grain growth in two-phase rocks, whose microstructure is comparable to that of D” layer, requires diffusion of atoms with a long-distance, which is almost equivalent to the size of the grains. Such diffusion is also a necessary process during diffusion creep. In this study, we examine diffusion mechanisms that control creep and grain growth rates based on experimental results of creep and grain growth of two-phase aggregates. We estimate the flow property of D” layer when its deformation is accompanied with grain growth.
We synthesized highly-dense fine-grained (~1 mm) forsterite + periclase (10 vol%) polycrystals by using vacuum sintering technique (Koizumi et al., 2010). The constituent minerals of the aggregates consist of the similar elements of the D” layer minerals such that the mechanisms controlling its creep and grain growth are expected to be identical to that in D” layer. I performed uni-axial compressional creep experiments on the forsterite + periclase aggregate at atmospheric pressure and high temperature (1150 ~ 1400°C). I also conducted grain-growth experiments at different temperatures ranging from 1300°C to 1450°C for 500h to obtain temperature dependency of grain growth. Hanging the samples fixed with theromocouple at different locations from the central heating zone in the furnace enables to obtain the precise grain growth data from various temperatures even by a single experiment. I observed microstructures of the aggregates after the experiments using scanning electron microscope.
I calculated grain boundary diffusivities from creep and grain growth rates using theoretical models of grain growth and grain boundary diffusion creep (Coble creep), finding both diffusivities are essentially identical. Based on this result, I conclude that the creep and grain growth in forsterite + periclase aggregate is controlled by the common diffusion mechanism. When creep and grain growth rates are determined by a common diffusivity, viscosity of the aggregate during its diffusion creep accompanied with grain growth should follow $\eta = Ct / d$ where η is viscosity, C is a material constant, t is annealing time under constant temperature and d is grain size. I applied this time–grain size–viscometer to the lowermost mantle with substituting 1~10 mm and 100 Myr and obtained 10^{18} ~ 10^{19} Pa·s as the maximum viscosity of the lowermost mantle. This value does not contradict with the previous estimate of the very low viscosity (~10^{16} Pa·s) of the lowermost mantle, which is based on the decay time of the Chandler wobble and Earth’s tidal deformation (Nakada and Karato, 2012).

Keywords: Diffusion creep, Grain growth in the lower mantle, Time-Grain size-Viscometer

