Grain growth kinetics in the system forsterite-diopside-water

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Grain size of rocks is an important microstructural parameter for physical properties of rocks. Plastic flows of rocks by diffusion-creep and superplasticity strongly depend on grain size. As well as dynamic recrystallization, grain growth kinetics is the most important mechanism in controlling grain size, which is crucial for understanding the rheological behavior of the interior of the Earth.

Several grain growth experiments have been conducted for monomineralic rocks (e.g., Tullis and Yund, 1982). Grain growth kinetics is affected not only by temperature but also by chemical environments such as water fugacity (e.g., Karato, 1989) and oxygen fugacity (Nichols and Mackwell, 1991) and is drastically enhanced by water in olivine aggregates (Karato, 1989).

Most of natural rocks are composed of more than two major mineral phases. It has been known that grain growth kinetics in bimineralic rocks is known to be quite different from that in monomineralic ones (e.g., Ohuchi and Nakamura, 2006). The effects of water on monomineralic and bimineralic rocks are also expected to be different. In this study, we have carried out grain growth experiments of synthetic wehrlites under aqueous fluid-saturated condition in order to understand the effects of water on grain growth kinetics in peridotites by comparing the results in dry condition (Ohuchi and Nakamura, 2006).

Grain growth experiments in aqueous fluid-bearing wehrlites of various forsterite/diopside ratios (i.e., 9/1, 8/2, 7/3, 5/5, 3/7, 2/8, and 1/9) were conducted at 1200 degC and 1.2 GPa for 1.5-763 hours under water-saturated condition using a piston-cylinder apparatus. The starting materials for dunite, clinopyroxenite and wehrlites were prepared from iron-free gel powder. The starting materials were packed into Pt-lined, four-hole Ni capsules, and then 1.0-1.5 wt. percent of distilled water was added with a microsyringe. Back-scattered electron images of the run products were obtained with a scanning electron microscope for observation of microstructure. Diameters of the circles having the same area as each grain were measured by using image-processing software, then mean grain sizes of forsterite and diopside in each sample were obtained.

In forsterite-rich wehrlites (higher than 80 vol. percent of forsterite), normal grain growth of diopside and abnormal grain growth of forsterite proceeded. Grain growth rate of forsterite and diopside was as fast as those under dry condition. In relatively forsterite-poor wehrlites (lower than 70 vol. percent of forsterite), normal grain growth of both forsterite and diopside proceeded. The k4 values(growth rate constant calculated with an assumption of n=4; n: grain growth exponent) for forsterite and diopside in the wehrlites under wet condition are 1.6-6.6 times larger than those under dry condition. This shows that water increased the growth rate constant. The n-values of forsterite and diopside in the wehrlites were 2.1-4.8 and 1.8-4.5, respectively. In contrast to the high n-values (larger than 3) reported for the wehrlites in dry condition, n-values of the dominant phase in wet wehrlites tend to show low values (ca. 2). Our experimental results suggest that fast grain growth of the dominant phase by normal grain growth with n=2 proceeds in the fluid-saturated upper mantle, resulting in a large difference between wet and dry conditions. This is because grain growth rate with n=2 is quite faster than that with n higher than 3. Relatively high effective viscosity would be maintained by the enhanced grain growth in wet upper mantle in the case of grain size sensitive creep.