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Grain growth mechanisms in forsterite-diopside system

Tomohiro Ohuchi[1]; Michihiko Nakamura[1]

[1] Inst. Mineral. Petrol. Econ. Geol., Tohoku Univ.

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 is the most important process in controlling grain size and microstructures of rocks (i.e., grain shapes and spatial distribution of mineral phases and fluid) which are crucial for understanding the rheological properties 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 has been found to be 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). Grain growth kinetics in bimineralic rocks is known to be quite sluggish because of Zener pinning (e.g., Olgaard and Evans, 1986).

Grain growth may be proceeded by some different mechanisms such as grain boundary migration, Ostwald ripening and coalescence. These mechanisms are futher rate-limited by more microscopic elementary processes such as diffusion. Despite its importance, grain growth mechanism has been rarely deduced from the grain growth experiments in rocks. In this study, we have carried out grain growth experiments of synthetic wehrlites under aqueous fluid-saturated condition in order to understand both grain growth mechanisms and rate-limiting processes.

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 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 run products were obtained for microstructural analysis. Diameters of the circles having the same area as each grain were measured by using image-processing software, then mean grain sizes and grain size distribution of forsterite and diopside in each sample were obtained.

Normal grain growth proceeded in relatively forsterite-poor wehrlites (lower than 70 vol. percent of forsterite). Normalized grain size distributions suggested that not only grain boundary migration and Ostwald ripening but also coalescence contributed to the grain growth of forsterite and diopside in dunite, clinopyroxenite, and the wehrlites. In forsterite-rich wehrlites (higher than 80 vol. percent of forsterite), normal grain growth of diopside and abnormal grain growth of forsterite proceeded. Abnormal grain growth of forsterite also proceeded in Fo70Di30 wehrlite after the cease of normal grain growth. Abundant diopside grains are included in the forsterite abnormal grains. Volume fractions of diopside inclusions in forsterite abnormal grains are up to 11 vol. percent and lower than those in bulk-rock. Mean grain size of forsterite abnormal grains is 20-200 micrometers, though that of matrix grains of forsterite is less than 4 micrometers. These observations show that forsterite abnormal grains grew with preferential precipitation of forsterite and dissolution of diopside around the forsterite abnormal grains. This solution-precipitation process around the abnormal grains was caused by high curvature of the interphase boundaries between the diopside grains and the forsterite abnormal grains. Microstructures of abnormal grains suggest that such grains are formed by coalescence of relatively large matrix grains. Our experimental results suggest that coalescence contributes to grain growth in natural rocks.