

Deformation experiments of mantle materials at the conditions of deep Earth interior

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Introduction

Knowledge on rheology of mantle materials is indispensable in understanding thermal evolution and material transport in the Earth. Since rheological properties strongly depend on temperature and pressure, it is critically important to conduct deformation experiments at P - T conditions corresponding to the deep mantle for accurate understanding of Earth's interior. Recently, quantitative rheological measurements at relatively high pressures (up to 10–20 GPa) and high temperatures (up to 1000–2000 K) are possible by using large-volume presses in conjunction with synchrotron radiation. In this presentation, our recent results on rheology under Earth's deep mantle conditions determined by deformation experiments using deformation-DIA apparatus are discussed.

Mechanical property of fine-grained forsterite

In order to understand mechanical behavior in grain-size-sensitive creep in the deep upper mantle condition, deformation experiments on dry fine-grained (grain size of $\sim 1 \mu\text{m}$) forsterite were performed at $P = 3\text{--}5$ GPa, $T = 1473\text{--}1573$ K and strain rate of $9 \times 10^{-6}\text{--}2 \times 10^{-4} \text{ s}^{-1}$ [1]. The stress-strain rate data together with data at 0.1–300 MPa by Tasaka et al. (unpublished data) were analyzed using a flow law equation for diffusion creep ($n = 1, p = 2$) and dislocation creep accommodated grain-boundary sliding (GBS, $n = 3.5, p = 2$). Based on the analysis, the activation volume both for diffusion creep (V_{diff}^*) and GBS (V_{GBS}^*) of olivine was determined to be $\sim 8 \text{ cm}^3/\text{mol}$. Calculation based on the present results implies that typical mantle deformation conditions are close to the mechanism boundary between the diffusion creep and the GBS.

Mechanical property of wadsleyite

Uniaxial deformation experiments on wadsleyite were carried out at $P = 14\text{--}16$ GPa and $T = 1500\text{--}1700$ K with strain rates of $3.4\text{--}15 \times 10^{-5} \text{ s}^{-1}$ [2]. Results suggest that flow strength of wadsleyite is more sensitive to water content than that of olivine.

Lattice preferred orientation (LPO) of olivine

The effects of hydrogen and pressure on LPO of olivine were investigated through simple-shear deformation experiments under asthenospheric upper mantle conditions ($P = 2.1\text{--}5.2$ GPa, $T = 1490\text{--}1830$ K) [3,4]. Formation of the A-type olivine fabric developed by the (010)[100] slip system was observed under water-depleted ($C_{\text{OH}} < 650 \text{ H}/10^6\text{Si}$ in olivine), while B-type fabrics by the (010)[001] slip system (or B-type like fabric) were predominantly formed under water-rich conditions ($>1000 \text{ H}/10^6\text{Si}$). The water-induced olivine LPO transition from A-type to B-type (-like) fabric results in flow-parallel and flow-perpendicular shear wave splitting under water-depleted and water-rich conditions, respectively.

[1] Nishihara et al. (2011) Abstract MR11A-2170 presented at 2011 Fall Meeting, AGU. [2] Kawazoe et al. (2011) *A. Mineral.* **96**, 1665-1672. [3] Ohuchi et al. (2011) *Earth Planet. Sci. Lett.* **304**, 55-63. [4] Ohuchi et al. (2011) *Earth Planet. Sci. Lett.* **317-318**, 111-119.

Formation condition of monohydrocalcite from Ca-Mg-CO₃ solutions

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Monohydrocalcite ($\text{CaCO}_3 \cdot \text{H}_2\text{O}$: MHC) is rare mineral in geological settings. MHC has been most frequently found in the recent sediment in saline lakes [1]. It also was found from the calcareous sinter of cold spring of Shiowakka, Hokkaido, Japan [2]. A lot of kinds of calcium carbonate minerals, including calcite, vaterite, ikaite and MHC, were also occurred in Shiowakka. MHC occurred in only summer season and frequently associated with green algae. In order to understand the preferential formation of MHC with green algae, we conducted synthesis experiments of carbonate minerals from various concentrations of Ca, Mg and CO_3 to clarify the formation condition of MHC.

The mixing solutions containing CaCl_2 and MgCl_2 was prepared in the reaction vessels, and Na_2CO_3 solution was added to 50mL of the mixing solutions. The initial concentrations of Ca, Mg and CO_3 in the solutions were 0.025–0.1M, 0–0.05M and 0.03–0.1M, respectively. Immediately after Na_2CO_3 solutions were added to the solution, the whitish suspensions were formed in the reaction vessels. The syntheses experiments were conducted in closed polycarbonate vessels at 25 °C, and the resulting suspension was constantly stirred and aged with mix-rotor for 24 h. After the aging time, the suspensions were filtered. The solids were analyzed by X-ray diffraction and examined by scanning electron microscope. The filtrates were analyzed for the concentration of CO_3 by alkalinity titration. The Ca, Mg and Na concentrations of filtrates were measured by high-performance liquid chromatography.

Four mineral assemblages were obtained from all of the experimental conditions from the XRD results. They are mixture of vaterite and calcite, mixture of aragonite and calcite, MHC and amorphous material. Based on the observations, the formation conditions of MHC can be summarized that the initial Mg concentration is more than 0.01 M and the CO_3/Ca ratio of the initial solutions are more than 1. The IAP of the reacted solutions with MHC formations were greatly higher than anhydrous calcium carbonates. The activity of Ca^{2+} is lower than that of CO_3^{2-} when MHC was formed. Furthermore, the activities of Mg^{2+} and CO_3^{2-} in the solution after MHC and amorphous material formation were almost equilibrium with respect to nesquehonite. By integrating the formation conditions of MHC from both initial solution and reacted solution, we considered that MHC formation requires simultaneous formation of magnesium carbonate (nesquehonite), i.e., the concentration of CO_3^{2-} in the solution must be high enough to produce both MHC and magnesium carbonate.

In Shiowakka, the pH increase by photosynthesis of green algae. The local concentration of CO_3^{2-} near the green algae must increase drastically. Increase of the contribution of CO_3^{2-} to HCO_3^- enables to the formation magnesium carbonate even spontaneously with MHC formation. Thus, the MHC is selectively formed in summer season associated with green algae.

[1] Fukushi et al. (2011) *Sci. Technol. Adv. Mater.* **12**, 064702.
[2] Ito (1993) *Ganko*, **88**, 485-491.