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Rheology of fine-grained forsterite aggregate under deep upper mantle conditions

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Under the conditions of the Earth's mantle, both diffusion creep and dislocation creep can be the dominant deformation mechanism depending on physical and chemical environments. These two mechanisms are quite different in terms of stress dependence of viscosity and development of lattice-preferred orientation. Thus it is important to understand the dominant deformation mechanism in the mantle. Previous studies on rheology of olivine under high-pressure ($>$3 GPa) mostly focused on dislocation creep (e.g. Kawazoe et al., 2009; Durham et al., 2009). Knowledge of diffusion creep of olivine under deep upper mantle condition ($>$100 km) has been quite limited. In order to clarify the dominant deformation mechanism in the upper mantle, we have conducted deformation experiments at high-pressure and high-temperature using fine-grained forsterite aggregate.

Experiments were carried out using a D-DIA apparatus "D-CAP (deformation cubic-anvil press)" installed at NE7 beamline, PF-AR, High Energy Accelerator Research Institute, Tsukuba, Japan. The samples are sintered aggregate of 90%forsterite + 10%enstatite with average grain size of ~1.7 um. High-pressure was generated by MA6-6 assembly (e.g. Kawazoe et al., 2010) using cubic (Mg,Co)O pressure medium and WC and cBN anvils with 5 mm truncation edge length. High-temperature was generated using graphite furnace and was monitored by WRe thermocouple. Deformation experiments were conducted at pressure of 3-5.5 GPa, temperature of 1573 K, and uniaxial strain rate of 7 x 10^{-6}- 2 x 10^{-4} s^{-1}. Sample stress was measured by two-dimensional X-ray diffraction using monochromatized synchrotron X-ray (50 keV) and imaging plate detector (e.g. Nishihara et al., 2009). Sample strain was measured by X-ray radiography. The OH concentration in starting material and recovered samples was determined based on FTIR analyses (Paterson, 1982).

Steady state flow stress was determined at each deformation condition. The stress-strain rate data taken at "dry" conditions ($<$50 H/10^6Si) together with data at 0.1 MPa by Tasaka et al. (unpublished data) were analyzed using a flow law equation for diffusion creep (n = 1) and dislocation creep (n = 3.5) (e.g. Hirth and Kohlstedt, 2003). Based on the analysis, the activation volume ($V*_{dif}$) for diffusion creep of olivine was determined to be ~9 cm^3/mol. Karato and Wu (1993) discussed that diffusion creep is the dominant deformation mechanism below ~200 km depth using assumed value of $V*_{dif}$ = 6 cm^3/mol (estimated from dislocation recovery experiments). Present result ($V*_{dif}$ ~ 9 cm^3/mol) implies that diffusion creep is predominant only at deeper part of upper mantle.