NE7A/2010G136

Rheology of fine-grained forsterite at high-pressure

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Introduction

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. [1,2]). 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.

Experimental method

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 [3]. The samples are sintered aggregate of 90%forsterite + 10%enstatite with average grain size of ~1 µm. High-pressure was generated by MA6-6 assembly using cubic (Mg,Co)O pressure medium and WC anvils with 5 mm truncation edge length [4,5]. High-temperature was generated using graphite furnace and was monitored by WRe thermocouple. Deformation experiments were conducted at pressure of 3.0–5.3 GPa, temperature of 1473–1573 K, and uniaxial strain rate of 9×10^{-6}–2×10^{-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. [6]). Sample strain was measured by X-ray radiography. H_2O concentration in starting material and recovered samples was determined based on FTIR analyses [7].

Results and discussion

Steady state flow stress was determined at each deformation condition. Fig. 1 shows stress-strain curves determined at T = 1473–1573 K and P ~ 3.5 GPa. 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 (unpublished data) were analyzed using a flow law equation for diffusion creep (n = 1, p = 2) and dislocation creep accommodated grain-boundary sliding (GBS, n = 3.5, p = 2) [8,9]. Based on the analysis, the activation volume for diffusion creep (V^*_{dif}) and GBS (V^*_{GBS}) of olivine was determined to be ~7 and ~11 cm^3/mol, respectively. Calculation based on the present results implies that the diffusion creep is the predominant deformation mechanism at the most conditions of pressure, temperature and strain-rate in the upper mantle.

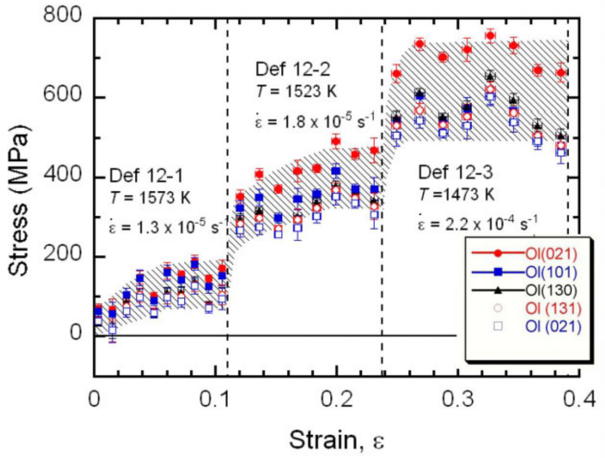

Fig. 1. Stress-strain curves of fine-grained forsterite (d ~ 1 µm) at T = 1473–1573 K and P ~ 3.5 GPa. Steady state creep was achieved during each deformation condition.

References

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