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Plastic Deformation of San Carlos Olivine at High Pressure

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Rheological properties of mantle minerals are critical to the understanding of the dynamics of the Earth's deep interior. Due to the limitations in experimental techniques, previous studies on rheological properties of mantle minerals are either limited to low-pressure or low-temperature, or inaccurate in the determination of differential stress and strain in the specimen. The present modeling of mantle flow is mostly inferred from the extrapolation of relatively low-pressure data to mantle high-pressure condition assuming that a known pressure dependence. However, the effect of pressure (represented by activation volume) on the rheological properties of olivine is still under controversy. Therefore, the deformation experiment carried out at mantle pressure condition may be more capable of representing the flow of mantle. Here we report the results of the direct experimental studies of plastic deformation of San Carlos olivine $(Mg, Fe)_2SiO_4$ under upper mantle conditions. Macroscopic differential stress and strain rates have been measured in-situ in the large-volume high-pressure apparatus using our newly developed techniques.

The aim of the present study is to determine which deformation process, diffusion creep (grain-size sensitive) or dislocation creep (grain-size insensitive), dominates olivine deformation in the mantle. San Carlos olivine specimens having different average grain sizes were experimentally deformed side by side, at upper-mantle pressure (8 GPa) and up to 1805 K, in a multi-anvil high-pressure apparatus coupled with x-ray synchrotron radiation. Opposing pistons inside the cell assembly were used as pressure/stress generator. Each couple of specimens experienced identical pressure (P), temperature (T) and stress condition. Specimen lengths were monitored during relaxation experiments by in-situ x-ray radiography. The microstructures of the run products quenched at different condition were investigated by transmission electron microscopy (TEM). A new method, which uses time-resolved x-ray images for measuring specimen macroscopic strain rates in the range 10^{-4} – 10^{-6} s^{-1}, was used to detect the strain of samples. We show that olivine flow at high pressure is grain-size insensitive (as shown in Figure 1), which suggests that dislocation creep is the dominant deformation process in the upper mantle. TEM investigation of deformed specimens confirms that dislocation glide was an active mechanism during the high-pressure deformation experiments. In addition, TEM evidenced the increase of grain-size for fine samples and decrease for coarse samples (Figure 2). The samples show much lower differential stress at high temperature and high pressure compared with the estimation reported in the literature. These observations, together with our TEM investigations, suggest that pressure effect on the plastic deformation of San Carlos olivine may be small. It also indicates that dynamic recrystallization may play a significant role in assisting olivine plastic deformation in the upper mantle.

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