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Plastic deformation of dry, fine-grained olivine aggregates under high pressures

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Abstract

This study investigates the effect of pressure on diffusion creep of dry San Carlos and synthetic (prepared by sol-gel method) olivine. We prepared dry (water content <9 ppm wt) fine-grained (<1 μm grain size) olivine and deformed the samples (both San Carlos and sol-gel olivine) in the same sample assembly under high pressure ($P = 2.9–8.8$ GPa) and moderate temperatures ($T = 980–1250$ K) at a fixed strain rate. The evolution of the sample's strength was studied using radial X-ray diffraction from various diffraction planes. We found that San Carlos and sol-gel olivine show similar rheological behavior (when normalized to the same grain size). Stress estimated by the radial X-ray diffraction increases with time and initially shows similar values for all diffraction planes. In many cases, stress values start to depend on the diffraction planes in the later stage, and time dependence becomes minor. The microstructural observations show that grain size increases during an experiment. The results are interpreted using a theory of radial X-ray diffraction and the theoretical models of diffusion and dislocation creep. We conclude that the initial stage of deformation is by diffusion creep, but deformation in the later stage is by dislocation creep. For dislocation creep, our results are in reasonable agreement with previous low-temperature dislocation creep results after correcting the temperature effect. For diffusion creep, we obtain an activation volume of 7.0 ± 2.4 cm^3/mol that is substantially smaller than the values reported on dislocation creep but agrees well with the results on grain growth. By comparing the present results on dry olivine with the previous results on wet (water-saturated) olivine, we found that water enhances diffusion creep but only modestly compared to dislocation creep. The difference in the pressure and water content dependence between diffusion and dislocation creep has an important influence on the dominant deformation mechanisms of olivine in the upper mantle.

Keywords: Dry olivine, rheology, mantle, deformation, activation volume, diffusion creep, dislocation creep, Physics and Chemistry of Earth's Deep Mantle and Core