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Intragranular plasticity vs. grain boundary sliding (GBS) in forsterite: Microstructural evidence at high pressures (3.5–5.0 GPa)

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Abstract

The plasticity of the mantle is still not well constrained, and satisfactory mineral-physics-based rheological laws are still missing. Despite olivine being the major component of the upper mantle, it is still debated which deformation mechanism (dislocation creep, diffusion creep, grain boundary sliding) dominates deformation. High-pressure research developments (state-of-the-art presses, synchrotron experiments, and so on) as well as competitive analysis utilities (software analysis, microscopy, and so on) allow considering intra- and intergranular mechanisms (grain boundary sliding accommodated by diffusion/dislocation creep) simultaneously. To study the contribution of individual deformation mechanism to the overall deformation in the upper mantle, we deformed polycrystalline forsterite at 3.5–5.0 GPa, 1000–1200 °C, $2 \times 10^{-5} s^{-1}$ at different strains in a 6-axis Mavo press. Split-cylinder experiments allowed to characterize an "internal" surface of the sample before and after the deformation experiments. Intra- and intergranular deformation was tracked using a focus ion beam milled reference grid on this surface. Grain internal misorientation where obtained from electron backscatter diffraction (EBSD) data. Both techniques suggest the dominance of intragranular deformation, in agreement with the fact that the samples have been deformed in the dislocation creep regime, as usually defined. Moreover, strain markers and out-of-plane displacements of grains provide the first microstructural evidence for a contribution of grain boundary sliding to plastic deformation at upper mantle pressure. Whether these displacements are grain boundary sliding or involve grain boundary migration cannot be clarified, given the resolution of the strain markers. Our EBSD data suggest that grain boundary processes become increasingly relevant at temperatures above 1100 °C and ensure homogenous plastic strain distribution in the aggregate.

Keywords: Forsterite, crystal slip plasticity, grain boundary sliding, EBSD, deformation; Understanding of Reaction and Deformation Microstructures