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Stress evolution and associated microstructure during transient creep of olivine at 1000-1200 °C

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As the major constituent of Earth's upper mantle, olivine largely determines its physical properties. In the past, deformation experiments were usually run until steady state or to a common value of finite strain. Additionally, few studies were performed on polycrystalline aggregates at low to intermediate temperatures (< 1100 °C). For the first time, we study the mechanical response and correlated microstructure as a function of incremental finite strains. Deformation experiments were conducted in uniaxial compression in an internally heated gas-medium deformation apparatus at temperatures of 1000 and 1200 °C, at strain rates of 10^{-6}s^{-1} to 10^{-5} s^{-1} and under 300 MPa of confining pressure. Sample volumes are large with > 1.2 cm3. Finite strains range from 0.1 to 8.6 % and corresponding differential stresses range from 71 to 1073 MPa.

Deformed samples were characterized by high resolution electron backscatter diffraction (EBSD) and transmission electron microscopy (TEM). EBSD maps with step sizes as low as 0.05 μm were acquired for the first time without introducing artifacts. The grain size ranges from 1.8 to 2.3 μm, with no significant change in between samples. Likewise, the texture and texture strength (J- and BA-index), grain shape and aspect ratio, density of geometrically necessary dislocations, grain orientation spread, subgrain boundary spacing and misorientation do not change significantly as a function of finite strain, stress or temperature. The dislocation distribution is highly heterogeneous, with some grains remaining dislocation free. TEM shows grain boundaries acting as low activity sites for dislocation nucleation. Even during early mechanical steady state, plasticity seems not to affect grains in unfavorable orientations. We find no confirmation of dislocation entanglements or increasing dislocation densities being the reason for strain hardening during transient creep. This suggests other, yet not understood mechanisms affecting the strength of deformed olivine, such as grain boundaries acting as agent of deformation or as dislocation sources. To progress, we plan to map disclinations (rotational topological defects) to estimate their contribution to the transient deformation regime.

At last, extrapolated to strain rates of the mantle (e.g. 10^{-14} s^{-1}), olivine-rich rocks show a strength in the order of 0.5 to 1 GPa at temperatures of 1000 °C and below, matching the requirements of a not so soft lithospheric mantle, able to upkeep large orogens for millions of years.