Fabric transition in olivine due to temperature and stress at high pressures

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The crystallographic fabric induced by deformation of mantle rocks reflects the dominant dislocation slip system and results in both rheological and seismic anisotropy in the upper mantle. The strength of the individual slip systems in olivine single crystals and the development of crystallographic fabric in olivine aggregates have been studied experimentally mainly in the high-temperature creep regime, with few measurements in the low-temperature plasticity regime. While a climb-controlled mechanism is important at higher temperatures and lower stresses, the dislocation slip mechanism in the low-temperature plasticity regime is considered to be glide-controlled. At low temperatures and high stresses, deformation of olivine aggregates follows an exponential flow law because dislocation motion requires a stress-dependent activation enthalpy for overcoming the Peierls barrier. In order to understand deformation mechanism and the dominant slip systems in the low-temperature plasticity regime, we investigated fabric evolution in olivine aggregates deformed experimentally at different temperatures changing from low to high at high pressures.

Samples were polycrystalline aggregates of San Carlos olivine with a grain size of 5-10 μm. Deformation experiments were carried out using the D-DIA apparatus at X-ray beamline X17B2 in the National Synchrotron Light Source (NSLS), Brookhaven National Laboratory. Samples were deformed to strains of 20-30% at a constant displacement rate of 0.1-6.8 x 10^{-5} /s, temperatures of 673-1573 K, pressures of 4-9 GPa, and differential stresses of 0.6-3.8 GPa. Creep data at the highest temperature (T = 1573 K) and lowest stress indicated a dislocation, power-law creep mechanism, while creep results at lower temperatures (T < 1273 K) and higher stresses revealed an exponential flow mechanism (Mei et al., 2010).

After deformation experiments, we determined the crystallographic fabric (CPO, crystallographic preferred orientation) in the deformed samples using electron backscattered diffraction (EBSD). At the highest temperature (T = 1573K) and lower stresses (σ < 1 GPa), the poles of the (010) planes concentrated parallel to the maximum principal stress. This concentration of (010) planes is more dispersed at a temperature of 1473 K. In contrast, at lower temperatures (T < 1373 K) and higher stresses (σ > 2 GPa), the poles of the (100) planes concentrated parallel to the maximum principal stress. The change of crystallographic fabric in deformed samples is roughly consistent with the change of deformation mechanisms based on the analyses of mechanical data as stated above. This transition in slip plane associated with a change in temperature and stress is consistent with a difference in dominant slip systems of (010)[100] at higher temperatures and low stresses and (100)[001] at lower temperatures (Bai et al., 1991; Durham and Goetze, 1977; Tielke, 2016), indicating that the dominant slip system in the glide-controlled low-temperature plasticity regime differs from that in the high-temperature climb-controlled creep regime.

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