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High pressure and temperature deformation experiments on San Carlos olivine and implications for upper mantle anisotropy

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Crystallographic preferred orientation developed in olivine due to shearing in the mantle is thought to be the prominent reason behind seismic anisotropy in the upper mantle. Seismic anisotropy in upper mantle can be observed up to a depth of ∼350 km with a marked drop in the strength of anisotropy seen around 250 km. Studies on natural rock samples from the mantle and deformation experiments performed on olivine have revealed that olivine deforms mainly through dislocation creep with Burgers vectors parallel to the [100] crystallographic axis under low pressure conditions (up to 3 GPa). Under similar pressures, evidence of [001] slip has been reported due to the presence of water.

In order to understand the deformation mechanism in olivine at pressures greater than 3 GPa, we have performed experiments using the deformation DIA multi-anvil apparatus. The DIA consist of 6 square faceted anvils that compress a cubic high-pressure assembly. The deformation DIA possesses two vertically acting opposing inner rams, which can be operated independently of the main compressive force to deform the sample assembly. The experimental setup consists of a hot-pressed sample of polycrystalline dry San Carlos olivine 0.2 mm cut from a 1.2 mm diameter core at 45°. This slice is sandwiched between alumina pistons also cut at 45° in simple shear geometry. Experiments have been performed at 3, 5 and 8 GPa at a deformation anvil strain rate of $1.0\text{x}10^{-4}$ $s^{-1}$and temperatures between 1200-1400°C.

Deformed samples were cut normal to the shear plane and parallel to the shear direction. Then the sample was polished and analyzed using electron back scattered diffraction (EBSD) to identify the crystallographic preferred orientation (CPO). The fabric that developed in olivine deformed at 3 GPa mainly resulted from the [100] slip on the (010) plane. Samples deformed at 5 GPa showed both [100] and [001] slip. On the other hand, samples deformed at 8 GPa and 1200°C, show deformation mainly through slip of the [001] slip on the {0hk} plane. These observations can be interpreted as resulting from the progressive hardening of [100] slip with respect to [001] slip with increasing pressure. TEM observations have been made on several of the recovered samples in order to correlate the developed CPO with the action of specific dislocations. Samples deformed at 8 GPa and 1200°C show straight edge dislocations in the plane normal to the diffraction vector, g: 004. Whereas, experiments performed at 1400°C and 8 GPa resulted in very few visible subgrains in the SEM orientation contrast image and only very weak CPO could be observed. TEM study on this sample shows that [001] & [100] edge dislocations were co-activated in climb-configuration which resulted in no perceptible CPO.

These results lead us to believe that the transition that occurs between a-slip to c-slip with increasing pressure is rather a gradual process. On the other hand our results imply that at depths over 250 km in the upper mantle, temperatures may be high enough to reinitiate [100] slip. Co-activation of both a-slip and c-slip will not lead to any CPO and the mantle will become seismically isotropic in this scenario. This might be the reason for isotropic behavior of mantle below 250 km depth.