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Micromechanical testing of olivine grain boundaries

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The mechanics of olivine deformation play a key role in large-scale, long-term planetary processes, such as the response of the lithosphere to tectonic loading or the response of the solid Earth to tidal forces, and in short-term processes, such as the evolution of roughness on oceanic fault surfaces or postseismic creep within the upper mantle. Many previous studies have emphasized the importance of grain-size effects in the deformation of olivine. However, most of our understanding of the role of grain boundaries in deformation of olivine is inferred from comparison of experiments on single crystals to experiments on polycrystalline samples.

To directly observe and quantify the mechanical properties of olivine grain boundaries, we use high-precision mechanical testing of synthetic forsterite bicrystals with well characterised interfaces. We conduct nanoindentation tests at room temperature on low-angle (13^{o} tilt about [100] on (015)) and high-angle (60^{o} tilt about [100] on (011)) grain boundaries. We observe that plasticity is easier to initiate if the grain boundary is within the volume tested. This observation agrees with the interpretation that certain grain-boundary configurations can act as sites for initiating microplasticity.

As part of continuing efforts, we are also conducting in-situ micropillar compression tests at high-temperature (above 600^{o} C) within similar bicrystals. In these experiments, the boundary is contained within the micropillar and oriented at 45^{o} to the loading direction to promote shear along the boundary. In these in-situ tests, our hypothesis is that the low-angle grain boundary displays a higher viscosity relative to the high-angle interface. Key advantages of performing in-situ experiments are the direct observation of grain-boundary migration or sliding, simplified kinematics of a single boundary segment, and potentially changes in style of deformation with different grain-boundary character.

These small deformation volume experiments allow us to qualitatively explore the differences between the crystal interior and regions containing grain boundaries. Overall, the variation in strain and temperature in our small scale experiments allows the fundamental investigation of the response of well characterised forsterite grain boundaries to deformation.