Water and melt decoupled from deformation in the Josephine Peridotite, SW Oregon

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The presence of trace amounts of water in the nominally anhydrous minerals of the upper mantle impacts mantle rheological properties such as viscosity. The Josephine Peridotite of SW Oregon, USA, is a prime location to study the relationship between water and ductile deformation due to the preservation of small-scale shear zones (<1-30 m wide) that represent the very early stages of localized deformation. To understand the role of water in the formation of these shear zones, we measured water concentrations and olivine lattice preferred orientations (LPO) in sample transects from three separate shear zones.

From LPO measurements, obtained using electron backscatter diffraction, we determined that two of the shear zones (SZA and SZG) are dominated by [100](001) slip, while the third shear zone (SZP) exhibits more typical [100](010) slip. The usual explanation for this change in slip slip system is increased water content in the samples with [100](001) slip. However, secondary ion mass spectromentry measurements of water concentrations in orthopyroxene show that SZA and SZP have very similar water contents, with SZA having a slightly lower water content (SZA: 196 ± 23 ppm; SZP: 214 ± 13 ppm). Instead, the change in LPO may be controlled by the orientation of pre-existing LPOs relative to the applied tectonic stresses.

The shear zone transects also allow us to examine the role of water weakening in the localization of deformation. We found that water increases with increased aluminum content in orthopyroxene across all three shear zones, suggesting a correlation between volatile content and melt interaction. However, in two shear zones (SZP and SZA), both water and melt (using aluminum as a proxy) are lowest where deformation is greatest, counter to the hypothesis that the weakest and most deformed portion of the shear zone would have the highest water content. Instead, the samples with the highest water contents are a few meters away from the zone of greatest deformation.