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Anisotropic viscosity and fabric evolution from laboratory experiments and field observations

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Crystallographic alignment of grains during solid-state deformation imparts anisotropic material properties to the bulk rock, which results in significant macroscopic anisotropy in viscosity. The majority of previous laboratory studies on geological materials have performed experiments on relatively untextured samples, making it difficult to quantify the magnitude of anisotropy. Here we present results of laboratory deformation experiments that first produce strong crystallographic fabrics and then test the viscosity of these textured aggregates in multiple stress states. Our results are used in a model for shear zone evolution to reproduce field measurements of strain variation across a natural shear zone.

Two sets of deformation experiments were performed in a gas-medium apparatus at 1473 K and 300 MPa confining pressure. In the first set of experiments (Hansen et al., Nature, 2012), large-strain torsion imparts a fabric in which the dominant [100] orientation is parallel to the shear direction and the dominant [010] orientation is normal to the shear plane, typical of a fabric due to shear on the (010)[100] slip system. Subsequent tension parallel to the initial torsion axis occurs with most grains having unfavorable orientations for slip on available slip systems. In the second set of experiments, samples were initially deformed in tension and subsequently deformed in torsion, with the torsion axis parallel to the initial tensional load. Tension imparts a fabric in which the dominant [100] orientation is parallel to the tension direction, with girdles of [010] and [001] axes. Subsequent torsion occurs with some grains having favorable orientations for (100)[001] slip and other grains having unfavorable orientations for slip on available slip systems. Electron-backscatter diffraction maps of axial sections of samples reveal that the crystallographic fabric reorients into a more favorable orientation at a shear strain of $\sim$1.5. In both sets of experiments the viscosities are $\sim$1 order of magnitude larger in the unfavorable orientation than in the favorable orientation.

The results of these experiments are used to model strain localization in a shear zone in the Josephine Peridotite (SW Oregon) in which crystallographic fabrics follow a similar evolution to that observed in our second set of experiments (Warren et al., EPSL, 2008). Synthetic strain profiles calculated using measured water contents, grain sizes, and laboratory-derived flow laws cannot reproduce the observed degree of strain localization. Viscous anisotropy is included in the calculation by incorporating a fabric tensor into laboratory-derived flow laws. The elements of this tensor are derived from the results of the deformation experiments. The rotation rate of the fabric anisotropy relative to the reference frame of the shear zone is defined using the crystallographic fabric evolution observed in the field. The degree of localization is more closely approximated when fabric evolution is taken into account, demonstrating that viscous anisotropy is an important component in the formation of lithospheric shear zones.