



Geodynamic consequences of anisotropic mantle viscosity

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Olivine, the primary mineral in the upper mantle, is anisotropic in its mechanical properties. As a result, significant shearing of the upper mantle causes olivine crystals to form a preferred orientation, which we can observe, for example, using seismic wave propagation. The crystallographic alignment of olivine grains also results in anisotropic viscous behavior that may result in significant changes in effective viscosity as the direction of flow changes. Recent laboratory measurements have provided crucial constraints on viscosity during complicated deformation paths. However, the employed laboratory experiments are only able to test a small number of deformation paths, making direct application to mantle deformation difficult. Thus, in our previous work, we used the existing experiments to define and calibrate a mechanical model of slip system activity and texture development within olivine aggregates that can predict the viscous response for arbitrary deformation paths.

Here we use the previously calibrated model to explore the mechanical response of an olivine aggregate in a wide range of deformation paths that are relevant to the shearing upper mantle. We find that texture development due to simple shear in a single direction causes the effective viscosity to decrease by a factor of ~ 10 . Once the texture is well developed, we change the direction of shear. We find the largest resistance to shearing on a plane parallel to the initial shear plane but in a direction perpendicular to the initial shear direction. In this case, the effective viscosity after the change in kinematics is initially two orders of magnitude greater than it is for the initial deformation, but then gradually decreases with increasing strain. In contrast, changing the plane of shearing to one perpendicular to the original shear plane results in one order of magnitude drop in the effective viscosity, which then gradually increases with increasing strain.

The initial stage of simple shear in our numerical experiments is analogous to the texture forming flow in the upper mantle/asthenosphere as oceanic lithosphere moves away from the ridges. Our mechanical models predict that it will be difficult to then shear this textured asthenosphere in a perpendicular direction. Therefore, the anisotropic viscosity of the asthenosphere may offer significant resistance to changes in plate motion direction. In contrast, the anisotropic viscosity of the upper mantle may be especially conducive to shear on a vertical plane, which may help to promote subduction initiation. More generally, we conclude that textured rocks in the asthenosphere, and the anisotropic viscosity that they induce, should significantly influence the geodynamics of plate motions and their interaction with the convecting mantle.