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Interplay between Tectonic Plate Motions, Anisotropic Viscosity, and the Development of Rock Fabrics in the Asthenosphere

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Basal tractions on plates contribute to the force balance that determines plate motions, and arise from the shearing deformation beneath the plates. Because basal-traction amplitudes depend on the anisotropic olivine fabrics that form within asthenospheric rocks, the tectonic force may change with time as asthenospheric fabrics evolve. To explore this interaction, we developed a stochastic model of olivine fabric development in which grain rotations are controlled by available slip systems and the rate of rotation slows as ideal orientations are approached. We constrain this process by quantitatively comparing calculated fabrics to those developed in recent laboratory experiments on olivine aggregates. We then constrain the anisotropy in viscosity of the aggregates using laboratory observations of strain-rates that result from stresses applied to aggregates with known crystallographic fabrics. This effort allows us to constrain both the rate of anisotropic fabric development and the magnitude of anisotropic viscosity that should result from these fabrics. We applied this understanding to a model of a simple plate tectonic system to test its response to asthenospheric fabric development. Starting from an initially random orientation of olivine crystals, we find that increasing olivine fabric alignment causes asthenospheric viscosity to drop approximately an order of magnitude after the asthenosphere accumulates a shear strain of 100–500%. For reasonable asthenospheric parameters, this occurs after a few 10s of millions of years. Once this asthenospheric fabric forms, anisotropic viscosity exerts significant resistance to motion perpendicular to the orientation of the crystallographic fabric, which impedes changes in plate motion even if plate driving forces change direction. Thus, asthenospheric fabrics may permit only gradual changes in plate motions, in agreement with the overall stability of plate motions. More abrupt changes in plate motions, which are occasionally observed in the plate tectonic record, may require a disruption to the anisotropic fabric across large regions of the asthenosphere. Such disruptions may result from small-scale convection or widespread plume arrival from below.