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Does anisotropic mantle viscosity impede changes in plate motion?

Ágnes Király (1), Clinton P. Conrad (1), Mathew Domeier (1), and Lars N. Hansen (2)

(1) Center for Earth Evolution and Dynamics, University of Oslo, Oslo, Norway, (2) Department of Earth Sciences, University of Oxford

The movement of tectonic plates is the most observable expression of mantle dynamics. In the Pacific basin, plate movement is mainly driven by slab pull toward subduction zones and ridge push away from mid-ocean ridges. These forces are resisted by deformation of the underlying asthenosphere, which means that the viscosity of the asthenosphere determines the velocity of a plate. Within the asthenosphere, viscous deformation is controlled by the slip systems of olivine, which is anisotropic both in its elastic and in its viscous properties. When the mantle is sheared, the olivine grains turn into the shear direction, and accumulate a lattice preferred orientation (LPO) in the shear direction. Laboratory experiments suggest that this developing LPO effectively decreases the viscosity in the direction of the LPO, resulting in faster deformation and enhanced texture development. Furthermore, an elevated viscosity applies to shear deformation across the LPO. This suggests that anisotropic viscosity in the asthenosphere may impede changes in plate motions.

To model the anisotropic viscous behavior of mantle olivine, we combine a micro-mechanical deformation model with a texture development model, based on olivine slip system parameters extracted from laboratory measurements. We apply these models to a simple plate system that assumes shear deformation within a 200 km thick layer of asthenosphere made of equal-sized olivine grains. The shear deformation is driven by the motion of a rigid lithosphere with a driving force acting on one side, thus creating a 1 MPa shear stress on the asthenosphere. After a period of strain that generates olivine LPO, we change the direction of the driving force. Our results show that although the amplitude of the driving force is not changed, the plate velocity decreases because the mantle is now forced to shear at an angle to olivine LPO. The amplitude of change in plate velocity and the time it needs to recover its original velocity depends on the angle over which the driving force is changed and the time period over which this change occurs. Furthermore, we find that plate motion changes occur more slowly above LPO textures that are initially more well-developed.

Our results imply that changes in the direction of plate movement happening in less than a few millions of years are unlikely and should be associated with a large decrease in plate velocity. However, plate tectonic reconstructions show that plates can exhibit large and rapid changes in direction, for example as revealed by the Hawaii-Emperor bend. This volcanic chain suggests that the Pacific plate has changed its direction by 60˚ at around 47-42 Ma. On the other hand, plate reconstructions also suggest that around 20 Ma the net slab pull force on the Pacific plate changed direction with $\sim$20˚, but did not produce an immediate change in plate motion direction. Here we collect information about the movement and the driving forces of the Pacific plate and compare it to our models with anisotropic mantle viscosity, in order to look for evidence of plate motion locking caused by anisotropic viscosity.