Chemical Homogenization in the Upper Mantle by Grain Mixing

ELVIRA MULYUKOVA* & DAVID BERCOVICI

Deptartment of Geology & Geophysics, Yale University, PO Box 208109, New Haven CT 06520, (*correspondence: elvira.mulyukova@yale.edu)

The efficiency of mantle homogenization through time is governed by the rates of mechanical stirring and chemical diffusion of the mantle's different compositional domains. Chemical diffusion of most mantle elements is extremely slow and thus mixing would require a significant degree of stirring and stretching. However, geochemical data points to the existence of chemical heterogeneity on all length scales, suggesting that stirring is inefficient and the mantle is poorly mixed; this view is challenging to reconcile with some of the geodynamical models, which predict efficient mixing due to vigorous mantle convection. In addition to chemical diffusion (atomic scale process) and stirring (continuum scale process), mantle rocks, which are polycrystalline materials, are also known to interact on the mineral grain scale. Specifically, rocks are made up of different minerals and exhibit various degrees of mineral mixing at the grain scale. Intriguingly, the well mixed polymineralic zones exhibit a strongly reduced grain size, are mechanically weak and undergo strain localization. Meanwhile, the poorly mixed monomineralic regions are coarse-grained and appear to be strong and less deformed. We developed a new theory for grain scale mixing, driven by stresses acting on the material interface. The theory takes into account the effect of mixing on grain size evolution in a deforming polymineralic medium, and the associated effect on the rheology. Mixing at the grain scale increases the surface area of the compositional interface, facilitating chemical diffusion. Furthermore, even when the individual materials have similar rheological properties, weakening by grain size reduction focuses strain in the vicinity of the interface, effectively separating the domain into weak, fine-grained, chemically homogenized regions, and strong, coarse-grained, unmixed regions. In addition, since the rate of grain mixing, and the associated weakening, is determined by stress, the coupled history of deformation and grain mixing gives rise to mechanical anisotropy, which feeds back into the geodynamics of mantle stirring. Our model shows that chemical homogenization by grain mixing is most efficient and has the strongest impact on rheology in the shallow mantle. We hypothesize that mixing occurs as material passes through the upper mantle and is processed through the lithosphere: both near a ridge, but also as mantle glues onto the lithosphere as it thickens and then gets deformed in subduction and collision zones.