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A phase change model for (one of) the LAB(s)

Nina S. C. Simon (1,2)

(1) Institute for Energy Technology - IFE, Dep. of Environemntal Technology, Kjeller, Norway (nina.simon@ife.no), (2) Dep. Earth Sciences, Bergen University, Bergen, Norway

Based on a large seismic dataset, Rychert and Shearer (1) globally mapped a sharp interface at a depth that varies with tectonic environment and lies at 95 km underneath Precambian shields and at about 70 km underneath ocean islands. They interpreted this boundary as the lithosphere-asthenosphere boundary. I propose here a simple explanation for this discontinuity that has also been observed by other authors using different methods. The explanation is based on the dependence of olivine viscosity on the hydrogen content in olivine and the re-distrubtion of water between the main peridotite-forming minerals that is expected to occur at the garnet-in phase transition.

The garnet-in reaction (simplified: olivine + Al-rich pyroxenes + spinel = olivine + Al-poor pyroxene + garnet) takes place in the mantle at pressures corresponding to 40-90 km, depending on temperature and degree of depletion (Cr/Al ratio) of peridotite. This reaction correlates with a strong drop in alumina content in orthopyroxene, the second most abundant mantle mineral after olivine. In addition, the modal amount of orthopyroxene decreases (depending on composition). The solubility of hydrogen in orthopyroxene directly correlates with the alumina content (2). Mierdel et al. (2) proposed that this drop in hydrogen solubility may lead to release of free water and hydrous melting. This may be true for oceanic regions, but the bulk water content in depleted lithospheric mantle is low and all water can be accommodated in nominally unhydrous minerals. Therefore, I propose that the release of hydrogen from orthopyroxene results in an increase in hydrogen in olivine, which leads to a reduction in olivine viscosity. Since olivine is the most abundant mantle mineral olivine viscosity governs the deformation of the mantle. The magnitude of this jump in viscosity should be relatively independent of initial peridotite composition and bulk water content. The garnet-in boundary and the associated hydrogen re-distribution may therefore explain the discontinuity imaged by geophysical methods, in particular underneath old shields where alternative explanations fail. The phase change mechanism operates globally in all peridotitic mantle. The depth of the boundary depends on degree of melt depletion (and temperature) and is predicted to be shallowest in fertile lithosphere and deepest in refractory cratonic lithosphere, consistent with the observations. The coupling between the composition-dependent petrological phase change and mantle rheology may also contribute to the decoupling of the oceanic lithosphere from the asthenosphere (LAB sensu strictu) and the constant maximum thickness of old oceanic lithosphere.

1. C. A. Rychert, P. M. Shearer, Science 324, 495, (2009).
2. K. Mierdel, H. Keppler, J. R. Smyth, F. Langenhorst, Science 315, 364, (2007).