Mineralogical effects in deep subduction

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Subducting slabs in the upper mantle exhibit seismic velocities and densities which are anomalous relative to the surrounding mantle. While part of this signature is purely thermal in nature, the lower temperatures of slabs also perturb equilibrium mantle phase relations, and they may also induce disequilibrium behavior such as metastable persistence of low-pressure minerals. Thus, a petrological signal is also present in upper mantle slab signatures. Indeed, the component of slab density anomalies arising from the distribution of mineral phases should give rise to buoyancy forces which have been invoked as important factors in determining slab stress fields, deep seismicity patterns, and subduction velocities (Yoshioka et al., 1997; Tetzlaff and Schmeling, 2000; Bina et al., 2000). Furthermore, latent heat effects associated with possible metastable behavior in slabs have been proposed as triggering mechanisms for quasi-adiabatic shear instabilities and deep seismogenesis (Bina, 1998; Branlund et al., 2000).

Nonetheless, images of subducting slabs assembled from seismic tomography have often been interpreted solely in terms of temperature effects. This is particularly true of slab signatures imaged in the lower mantle, where complex series of phase transitions such as those characterizing slab mineralogy under upper mantle conditions are largely absent. However, significant seismic velocity anomalies may arise from local heterogeneity in chemical composition (e.g., spatial variations in Mg, Fe, and Si contents) as well as from variations in temperature. Thermal and chemical variations should behave differently as functions of depth, due both to differential pressure-dependence of the relevant elastic moduli and to conductive temporal decay of thermal perturbations. Thermal and chemical variations may differ in their dynamical effects, too, as these variations give rise to associated density anomalies of differing magnitudes and signs.

Subducting oceanic lithosphere consists of chemically differentiated layers of harzburgitic and gabbroic rocks which overlie lherzolites. Upon entering the lower mantle, these overlying layers would be seismically fast relative to the surrounding mantle due to their chemistry alone, the former by several tenths of a percent and the latter by up to several percent, due to the coupled effects of Si-enrichment and Mg-depletion. These petrologically-derived velocity anomalies should increase in amplitude with increasing depth, and they will be complemented by thermally-derived fast velocity anomalies which should decrease in amplitude with increasing depth (although the latter will decay through thermal assimilation of slab material over time). On the other hand, the pattern of density anomalies relative to the surrounding mantle will be quite different, with chemical signatures of both signs (denser gabbro, lighter harzburgite) superimposed on the thermal signature of increased slab densities. Thus, joint thermal and chemical variations in subducted lithosphere may be responsible for apparent RMS amplitude variations with depth in lower mantle seismic velocity anomalies (Bina and Wood, 2000).

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