Some new experimental constraints on the transition-zone water filter model

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Partial melting plays an essential role in the geochemical evolution of a planet. In most of the previous models of chemical evolution of Earth, only partial melting near the surface (i.e., beneath mid-ocean ridges) is considered. However, recent mineral physics observations suggest that partial melting may also occur at ∼410 km if sufficient water is present in the transition zone. If the melt produced there is denser than the upper mantle mineral but less dense than the transition zone mineral, the melt will be trapped and hence a large amount of incompatible elements will be sequestered in the deep mantle [*Bercovici and Karato*, 2003].

We have conducted three sets of experimental studies to test this hypothesis: (1) the measurements of electrical conductivity of wadsleyite and ringwoodite as a function of hydrogen content to infer hydrogen (water) content in the transition zone [*Huang et al.*, 2005], (2) the measurements of density of hydrous ultramafic silicate melts to see if a melt produced at ∼410 km is trapped there and (3) the measurements of dihedral angles between silicate melt and olivine to obtain insights for the process of melt segregation.

Electrical conductivity and hydrogen [Huang et al., 2005]

Electrical conductivity of wadsleyite and ringwoodite was measured as a function of hydrogen content and temperature at transition zone pressures (∼14-16 GPa). The functional relationship between hydrogen content and temperature was determined and used to infer hydrogen content in the transition zone. We found that the electrical conductivity in these minerals is relatively insensitive to temperature but highly sensitive to hydrogen content. By comparing laboratory data with geophysically inferred electrical conductivity in the transition zone, the hydrogen content in the transition zone is estimated to be ∼0.1-0.2 wt% (in the Pacific). This exceeds an estimated critical value for partial melting in the upper mantle (∼0.05wt%), and suggests that partial melting occurs at ∼410 km in these regions.

Density of hydrous ultramafic melt [Matsukage et al., 2005]

The density of hydrous ultramafic melt was determined under the conditions equivalent to ∼400 km depth. The major element composition was chosen based on the study by [*Litasov and Ohtani*, 2002]. 5wt% of water was added (as brucite) and the density of melts was determined by the sink/float method. The addition of water reduces the melt density but the density of water is found to increase significantly with pressure and at ∼14GPa (∼2.5-3.0 g/cc), the influence of water to reduce the melt density is relatively small. After the corrections for the effects of oxygen fugacity, our results imply that hydrous ultramafic melts will be denser than the upper mantle minerals but less dense than the transition zone minerals in most cases (except for very high temperatures) and therefore the melts will be trapped at 410-km boundary.

Dihedral angle between olivine and silicate melts under high pressures

The dihedral angle between a melt and mineral controls the way in which melt is separated from solid and the way in which partial melting affects physical properties of materials. Under most conditions, the dihedral angles for silicate and silicate melts are between ∼30 to ∼100 degrees, and consequently, melt occurs either in isolated pockets (for >60 degree) or in a tubules (if angle is less than 60 degrees but non-zero). We have conducted an experimental study to determine the dihedral angle between hydrous silicate melts and olivine, and found that the dihedral angle decreases with pressure and finally goes to zero at ∼7-8 GPa. Above this pressure, the angle is zero and consequently, the melt will completely wet the olivine grain-boundaries.

Some consequences of these new results on the water filter model will be discussed.

References:

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