Distribution of H2O in the mantle: constraints on mantle circulation

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The distribution of H_2O in the mantle is both an expression and an influence on the dynamics of mantle convection, but the total H_2O stored in Earths mantle remains highly uncertain. Estimates vary by approximately an order of magnitude, from less than a quarter of the mass of H_2O in the worlds oceans to $\sim$4 ocean masses. Furthermore, the distribution of H_2O in the mantle may be heterogeneous on a large scale, but apart from the upper mantle above 410 km, there are considerable uncertainties regarding concentrations of H_2O in various regions of the mantle. Resolving these conflicts and narrowing the uncertainty in inventory of H_2O in the different portions of the mantle remain among the chief challenges to understanding the global deep H_2O cycle.

Constraints from basalt geochemistry indicate that the upper mantle reservoir sampled by mid-ocean ridges has 50-200 ppm H_2O. If this abundance applies to the whole mantle, then the total H_2O in the mantle is 1/6 to 1/2 of the water in the oceans. However, the transition zone may contain much greater concentrations of H2O and different lines of evidence suggest that the lower mantle could be either much wetter or much drier than the upper mantle.

A wet transition zone?

The large H_2O storage capacity of transition zone minerals, combined with stability of dense hydrous magnesian silicates (DHMS) to great depths in subducting slabs, gives strong appeal to the hypothesis that appreciable amounts of H_2O are stored between 410 and 670 km. However, because the 410 km discontinuity is not thought to be a barrier to convection, the upper mantle and TZ may be well-mixed and have similar H_2O contents. The water-filter hypothesis of Bercovici and Karato (2003) posits that pervasive hydrous melting at 410 km may produce a TZ with dramatically enhanced H_2O and trace element inventories relative to the upper mantle. A critical component of the model is that the dehydrated residue must have a H_2O content (50-200 ppm) equal to that observed in the upper mantle. Present understanding of the H_2O storage capacity of upper mantle minerals suggests that residues would be much more H_2O rich, though experimental data are as yet incomplete. A key point, however, is that the upper mantle water concentration places a stringent limit to the possible hydration state of the transition zone.

Water, the lower mantle, and the source of plumes

Geochemical constraints show that the source regions of oceanic island basalts are H_2O-rich, having on the order of 300-1000 ppm H_2O. Combined with geochemical arguments that the sources of plumes reside in the deep mantle, this may suggest that regions of the lower mantle are H_2O-rich. In contrast, recent experimental results indicate that the H_2O storage capacities of the principal minerals in the lower mantle are very low on the order of a few 10s of ppm. This conflict may have one of three resolutions (1) plumes do not originate from the lower mantle (2) dry plumes from the lower mantle entrain H_2O rich material as they pass through the transition zone, or (3) the lower mantle hosts high H_2O storage capacity minerals that have not yet been identified.