What can seismology tell us about water in the mantle transition zone?

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Laboratory experiments have shown that the major minerals of the mantle transition zone – although nominally anhydrous – have the capacity to incorporate small weight percentages of water into their crystal structures. Integrated over large regions, these small incorporations can sum to volumetrically significant quantities of water which alter the seismic properties of the rock considerably. We investigated the extent to which it may be possible to use seismology to detect water within the mantle transition zone, given the limitations of experimental data and seismic observations, and the fact that the seismic properties are also influenced by other thermochemical parameters.

We performed an extensive literature search of mineral experimental data, to generate a compilation of the water storage capacities, elastic parameters and phase boundary data for potentially hydrous minerals in the transition zone, and used thermodynamic modelling to compute synthetic seismic profiles of density and velocity at transition zone conditions. Large uncertainties on the mineral phase equilibria (ca. 2 GPa) and elastic properties produce a wide range of seismic profiles. In particular, there is a lack of phase boundary data at temperatures corresponding to those along a 1300°C adiabat or hotter, which may be expected at transition zone pressures. As such, the depths of the 410 and 660 discontinuities cannot reliably be used to map the water content of the transition zone. Further, while average velocities and densities inside the transition zone clearly decrease with increasing water content, increasing temperature has the same effect. It is therefore difficult to distinguish changes in temperature from changes in water content, and the conventional view of a slow and thick transition zone for water and slow and thin transition zone for high temperature should be regarded with caution. A better diagnostic may be the average velocity gradients of the transition zone, which increase with water content (but decrease with temperature). The significance of this effect depends on the degree of water saturation and partitioning between the NAMs.

Seismology is better able to constrain the thickness of the transition zone than velocity gradients, so we suggest the most useful input from future experiments would be tighter constraints on 1) the phase relations between hydrous olivine and its high-pressure polymorphs, especially at high temperatures, and 2) experimentally-observable correlations between bulk and shear moduli and their corresponding pressure derivatives.