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Using seismology to map water in the mantle transition zone

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Water has a major influence on tectonic and other geodynamic processes, yet little is known about its quantity and distribution within the deep Earth. Laboratory experiments on "nominally anhydrous" minerals (NAMs) have shown that in the transition zone these minerals can contain significant amounts of water (up to ∼3.3 wt%). We investigate if it is possible to use seismic observations to distinguish between a hydrous and anhydrous transition zone. We perform 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 use thermodynamic modelling to compute synthetic seismic profiles of density, Vp and Vs at transition zone temperatures and pressures. We find that 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 data at temperatures corresponding to those along a 1300 °C adiabat or hotter, which may be expected at transition zone pressures. Comparing our hydrous transition zone models with equivalent profiles at anhydrous conditions, we see that the depths of the 410 and 660 discontinuities cannot at present be used to map the water content of the transition zone due to these uncertainties. Further, while average velocities and densities inside the transition zone clearly decrease with increasing water content, there is a near-perfect trade-off with increases in temperature. It is therefore difficult to distinguish thermal from water effects, 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 for water may be given by the average velocity gradients of the transition zone, which increase with increasing water content (but decrease for increasing temperature). However the significance of this effect depends on the degree of water saturation and partitioning between the NAMs. Since seismology is better able to constrain the thickness of the transition zone than velocity gradients, our study indicates that the most useful input from future mineral physics experiments would be to better constrain the phase relations between hydrous olivine and its high-pressure polymorphs, especially at high temperatures. Additionally, the uncertainties on the mineral seismic properties could be reduced significantly if the experimentally-observable correlations between bulk and shear moduli and their corresponding pressure derivatives would be published.