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Seismic observations of transition zone discontinuities, and their mineral physical interpretation

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The transition zone discontinuities at 410 and 660 km separate the upper mantle from the lower mantle. Their characteristics determine the style of mantle convection in the Earth and can be used to infer mantle temperature and composition. Here, we study the seismic signature of the transition zone discontinuities by stacking large collections of seismic SS, PP, P'P' and Pds phases. The long period SS and PP precursors are sensitive to wide discontinuities and velocity gradients, while short period P'P' can only detect sharp discontinuities. SS and Pds are sensitive to shear, while PP and P'P' are sensitive to compressional velocity. These different sensitivities provide a means of investigating hypotheses about the mineral physical explanation for observed discontinuities. In general, we find that seismology and mineral physics agree on the level of complexity at the transition discontinuities: a simple 410, a more complicated 520 and a highly complicated 660-km discontinuity are consistently found in both disciplines.

Our data show that signals from the 410 and 520 km discontinuities are strongly frequency dependent. The 410 km discontinuity is easily observed in most data, but is absent, or only weakly visible in short period P'P' precursors. The 410 km discontinuity is generally explained by phase transition from olivine into wadsleyite. The sharpness of this phase transition may be reduced by the addition of water, potentially explaining its weak signature in short period data.

The 520 km discontinuity, which is robustly observed in SS and PP precursors and occasionally in Pds phases, is sometimes split into two discontinuities, at about 500 and 560 km depth. We cannot explain the split peaks by the olivine phase transition from wadsleyite to ringwoodite only; we require the additional phase transition from garnet to Ca-perovskite. Both these transitions have quite wide mixed phase intervals, making the 520 km discontinuity unobservable in short period P'P' data.

The 660 km discontinuity shows an even more complicated behavior. Seismic phases sensitive to shear (SS and Pds) always show signals from the 660 km discontinuity, which are often split or characterized by very wide peaks. On the other hand, the 660 km discontinuity is rarely seen in long period PP precursors, but is clearly observed in short period P'P'. These observations again require the existence of multiple phase transitions on a global scale at the base of the transition zone. Commonly used mantle models (i.e. pyrolite and piclogite) contain a mixture of olivine and garnet, which each have different phase transitions at 660 km depth. The complicated seismic structure also requires lateral variations in temperature and/or minor elements such as Al in the mantle transition zone. This will influence lower mantle slab penetration and upwelling of plumes differently from region to region.