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Seismic Structure of the Transition Zone and its Mineral Physical and Geodynamical 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 are usually interpreted in terms of phase changes in olivine. Seismic reflections of these discontinuities have routinely been observed on a global scale in precursors to the SS phase (e.g. Flanagan & Shearer, 1998). Here we extend this research to PP precursors and report work in which large collections of both SS and PP traces are stacked. Such stacks show clear reflections from the transition zone discontinuities and provide a means of investigating hypotheses about the mineral physical explanation for observed discontinuities.

The 410 km discontinuity can be seen in both SS and PP precursors and both data types give very similar maps of the discontinuity topography. The 660 km discontinuity had been apparently absent in previous studies of PP precursors, posing major problems for models of mantle composition. We report, for the first time, that the 660 km discontinuity can be seen in PP precursors in addition to SS precursors. Our observations reveal a very complicated structure with single and double reflections ranging in depth from 640 to 720 km. A weaker and possibly non-global discontinuity at approximately 520 km depth has also been observed. We find in both SS and PP precursors that this discontinuity is split in certain regions, while in other regions one discontinuity is observed.

These observations 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. First, in the olivine component there is the transition from ringwoodite to perovskite and magnesiowüstite. Secondly, in the residuum there is a transition from majorite garnet to perovskite. The combination of these phase changes leads to a delicate balance that can impede or enhance convection and also lead to multiple discontinuities around 660 km depth, depending on the local temperature and mantle models (Weidner & Wang, 1998, Hirose, 2002). Computations of reflection amplitudes for different models show that our observations are consistent with a pyrolite composition. The splitting observations of the 520 km discontinuity can be explained in a similar way (Deuss & Woodhouse, 2001).

Our results indicate that transition zone discontinuities cannot be interpreted simply in terms of olivine phase transitions only and imply that phase transformations in the garnet components are of major importance for understanding the structure of the Earth's mantle and its convective state. 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. Thus, the characteristics of the 660 km discontinuity and its impedance contrast can no longer be taken as a global constant when modelling mantle convection.