Statistical Distribution of Seismic Velocities in Earth's Deep Mantle and Dynamical Implications

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The existence of strong differences between elastic shear (S) and compression (P) wave velocity variations in Earth's mantle has long been recognized as a characteristic that might only be explained by the presence of significant chemical and/or phase heterogeneity, with important implications for the dynamics and evolution of Earth's interior. Making a one-to-one comparison between tomographic models for P and S velocity (V_P and V_S) variations for a particular geographic region is ill-posed, however, their global statistical distributions reveal several robust characteristics. We find that all of the V_P and V_S model distributions at a given depth are surprisingly Gaussian-like throughout the lower mantle. On the other hand, a distinct low velocity feature is present in V_S distributions below ≈2200 km depth that is not present at long periods or is relatively weak at short periods in V_P models. While the numerical damping required to stabilize tomographic inversions affects the amplitude of seismic velocity variations, the presence of anomalously low V_S material cannot be explained as an artifact, nor can the absence of a similarly strong feature in long period V_P models be ascribed to under-resolution. We propose that this kind of feature can be partly explained by laterally variable occurrences of post-perovskite in the D" layer, however, the persistence of anomalously slow V_S at heights up to ≈700 km or more above the core-mantle boundary is incompatible with a post-perovskite origin and might only be explained by the presence of laterally discontinuous piles of chemically distinct material and/or some other kind of phase heterogeneity. The origin of the Gaussian-like distribution of seismic velocities is puzzling since it has no straightforward explanation in terms of mantle convection. Nevertheless, there exist large discrepancies between tomographic models with respect to the width of the Gaussian-like portion and modeled peak of the distributions (indicating the most abundant velocity at a given depth) and the model baseline value. This reveals the ill-posed nature of attempting to calculate quantities such as $R = d\ln V_S/d\ln V_P$, however, adjusting the baseline values to the peak of the distributions and scaling by the ratio of standard deviations provides a clearer picture of differences between V_P and V_S, even though quantitative estimates of such differences are uncertain by more than a factor of two. Although not uniquely constrained, and subject to large errors, the results appear to be simply explained by the existence of chemical piles about 700 km in radial thickness and occupying 2±0.3% of the mantle's volume. This is similar to the volume abundance of continental lithosphere, although the smaller surface area of the core-mantle boundary requires thicker "roots" than their shallower counter-parts.