Measuring the composition and temperature of Earth's mantle: integrating thermochemical models and seismic observations of the transition zone

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The mantle transition zone (MTZ) constitutes a significant change in Earth's thermal structure, composition, and rheology. The region is delineated by abrupt seismic discontinuities that arise from mineral phase transitions. These changes in mineralogy influence dynamical flow, with implications for mixing of compositional heterogeneities and chemical segregation. The observed deflection of both cold down-going slabs and hot upwellings seen in seismic tomography models leads to an on-going debate whether convection encompasses the entirety of thee mantle, or occurs in semi-independent layers. Here, we integrate large seismic datasets with mineral physics modelling to simultaneously invert for new maps of mantle temperature and composition, and address the question of convective scales across the MTZ (and by association the whole mantle).

Observations of the MTZ discontinuities require hundreds of thousands of seismograms stacked together to reveal the subtle seismic phases that interact with these structures. Our study combines observations of precursors to the seismic waves SS and PP to obtain global maps of the shear and compressional wave discontinuity depths and amplitudes. We present a new algorithm based on machine learning to automatically identify seismic wave phases, and show its application to compile a new ScSdScS precursor dataset. Our joint S and P global maps of the 410 and 660-km discontinuities using these reflections are produced using an "adaptive stacking" methodology based on Voronoi tessellation, which automatically adjusts its parameterization to account for topography, data coverage, and noise.

In our results as well as past studies, it is noted that the seismic phase P660P is primarily absent in many regions. Using thermochemical modelling, we show that this phase's appearance in data stacks is associated with high temperatures. Combining all of our measurements across the SS and PP methods, we perform a Bayesian inversion to obtain joint maps for temperature and composition that incorporates the shear and compressional wave depths and amplitudes. Our results show that the edges of regions of high temperature are correlated to surface features (hotspots and seamounts), suggesting the presence of stagnant hot material beneath the MTZ providing a secondary source of upwelling plumes. The data inversions further identify basalt enrichment in regions associated with recent subduction, indicating the segregation of oceanic crust from lithosphere within these layers.