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Thermal, chemical and partial melting: origin of the low-velocity layer atop the mantle transition zone

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A seismically low-velocity layer (LVL) above the mantle transition zone has been identified in numerous regions around the world. As the LVL is thought to present the partial melting in the upper mantle, several attempts have been made to infer the melt fraction within the layer. However, the inference of melting extent has remained a non-unique inverse problem because local variations in thermal and compositional controls could give rise the identical seismic structures.

In this work, we examine the LVL identified at 350-km depth below the western US, where the S-wave speeds are in average 2% lower compared with the global model. The observed shear impedance contrast has been previously interpreted as the melt triggered by the Farallon plate subduction and/or the Yellowstone plume. To simulate the velocity variations when seismic wave travelling through the upper mantle, we employ a forward model that incorporates four primary controls: (1) mantle potential temperature, (2) basalt fraction in the peridotite, (3) melt volume fraction and (4) dihedral angle at the melt-grain triple junctions. The forward model is then embedded in an inversion scheme for solving the controlling factors that account for the velocity reductions. Iterative application of the inversion approach thus allows all possible solutions for the inverse problem to be derived.

Our modelling results show that an infinite number of different solutions can reproduce exactly the same seismic structures. Nevertheless, a small fraction of melt exists in every solution. Considering the whole range of solutions, we estimate the lower bound as 0.55% for the regional-averaged melt volume fraction. The model work also encapsulates the thermal condition as it suggests the average potential temperature in the upper mantle beneath the region is not likely to exceed 1570 K. Therefore, the seismic anomalies beneath the western US are on a large scale resulting from the interplay between the thermal, chemical and partial melting effects. However, the melting extent varies strongly in spatial distribution and the melt is absent in part of the low-velocity zone, suggesting the existence of the LVL may not necessarily indicate the partial melting. The application of the modelling approach therefore provides a new insight for understanding the origin of the LVL from local to global scales.