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Supplementary Materials for

Globally distributed subducted materials along the Earth's core-mantle boundary: Implications for ultralow velocity zones

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Figs. S1 to S7
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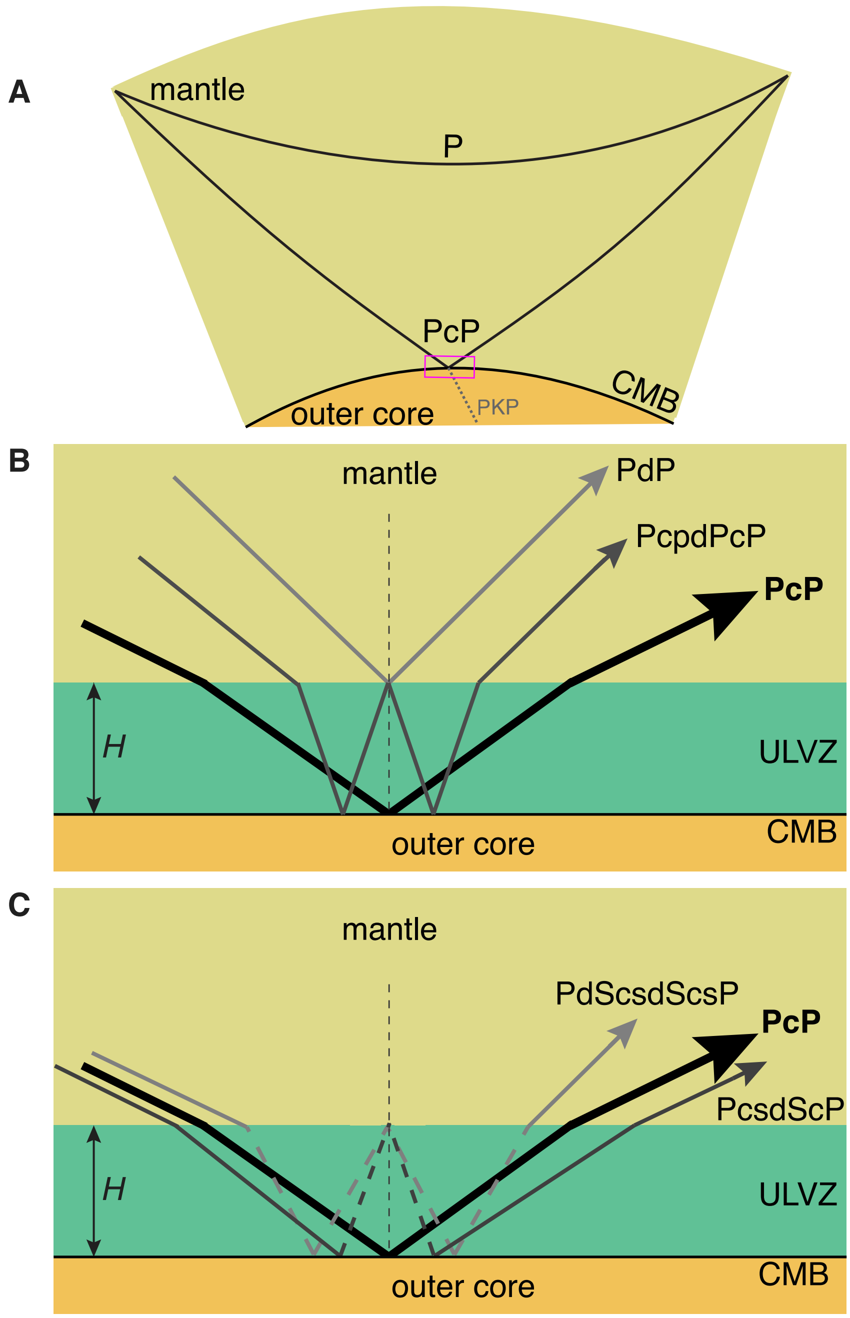


Figure S1. Ray path cartoons. (A) Sketch illustrating the direct P and PcP ray paths through the mantle. For reference, PKP in the outer core is also shown. The small pink box highlights the region shown in the later panels. (B-C) PcP interactions with a ULVZ. *H* indicates ULVZ thickness, solid ray paths are P-waves, dashed ray paths are S-waves, and phases are denoted with different colors on each panel. Panel separation is just provided for clarity. In (B) the PdP pre-cursor and PcpdPcP post-cursor result from reflections along the top and from the underside of the mantle-ULVZ boundary, respectively. In (C), two additional underside reflections from the mantle-ULVZ boundary are shown: PcsdScP and PdScsdScsP.

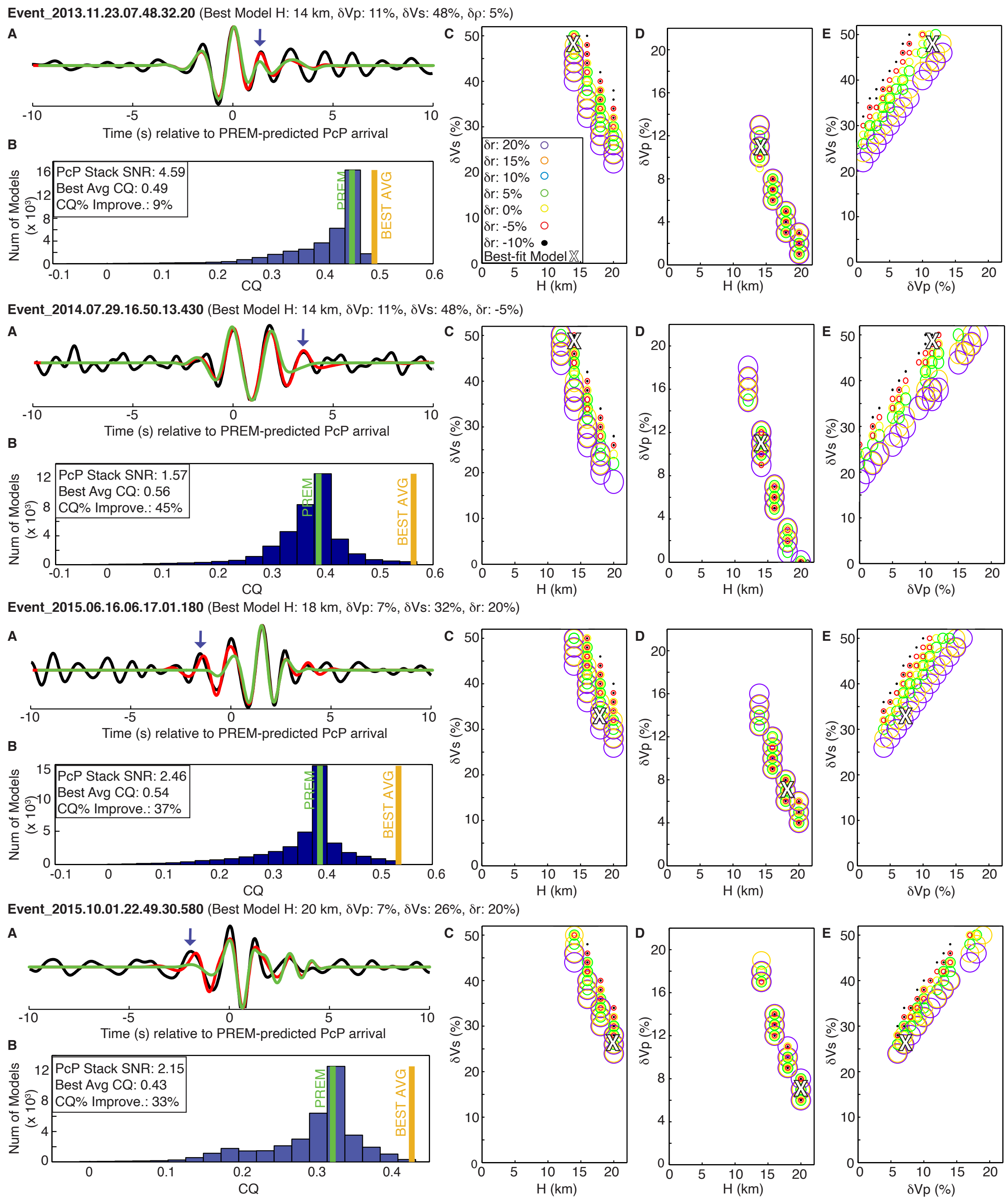
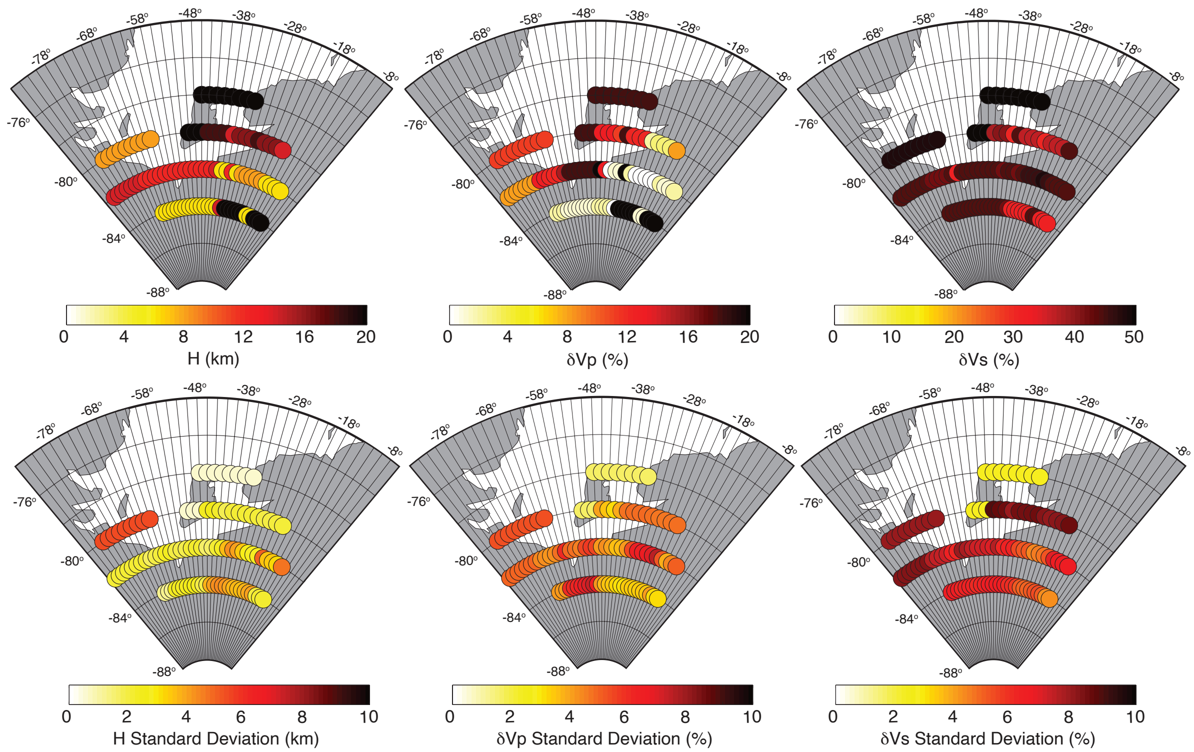


Figure S2. Synthetic modeling results from four example events. For each event, (A) shows the HIPR-weighted PcP_{obs} stack (black) along with PcP_{syn} from the best-fit model (red) and PcP_{syn} from PREM (green). The best-fit ULVZ parameters are listed next to the event ID (H: ULVZ thickness). Arrows indicate PcP pre- or post-cursors. (B) Histograms showing the range of CQ values across all synthetic models. The CQ values for PREM and the average CQ over the top 100 best-fit models are marked by green and orange lines, respectively. The PcP_{obs} SNR, the average CQ value, and the average percent CQ improvement over PREM are listed on the upper left (note: again, all averages are over the top 100 best-fit models). (C-E) Scatter plots showing the range of ULVZ parameters for the top 100 best-fit models. Different $\delta\rho$ values are represented by different symbol colors, as noted in the legend in the top row, and symbols are sized so that they can be nested since models that only differ by $\delta\rho$ will plot atop one another. For reference, the parameters corresponding to the best-fit model (A) are indicated by the white X on each scatter plot. Note that the first example event falls below our CQ improvement over PREM threshold (10%), but the event is still best-fit by a ULVZ-inclusive model; therefore, this event provides possible though uncertain ULVZ evidence. The other events meet all three criteria described in the paper and hence provide robust ULVZ evidence. Additionally modeling examples are provided in Hansen et al. (*15*).

Antarctica-Weddell Sea



South New Zealand

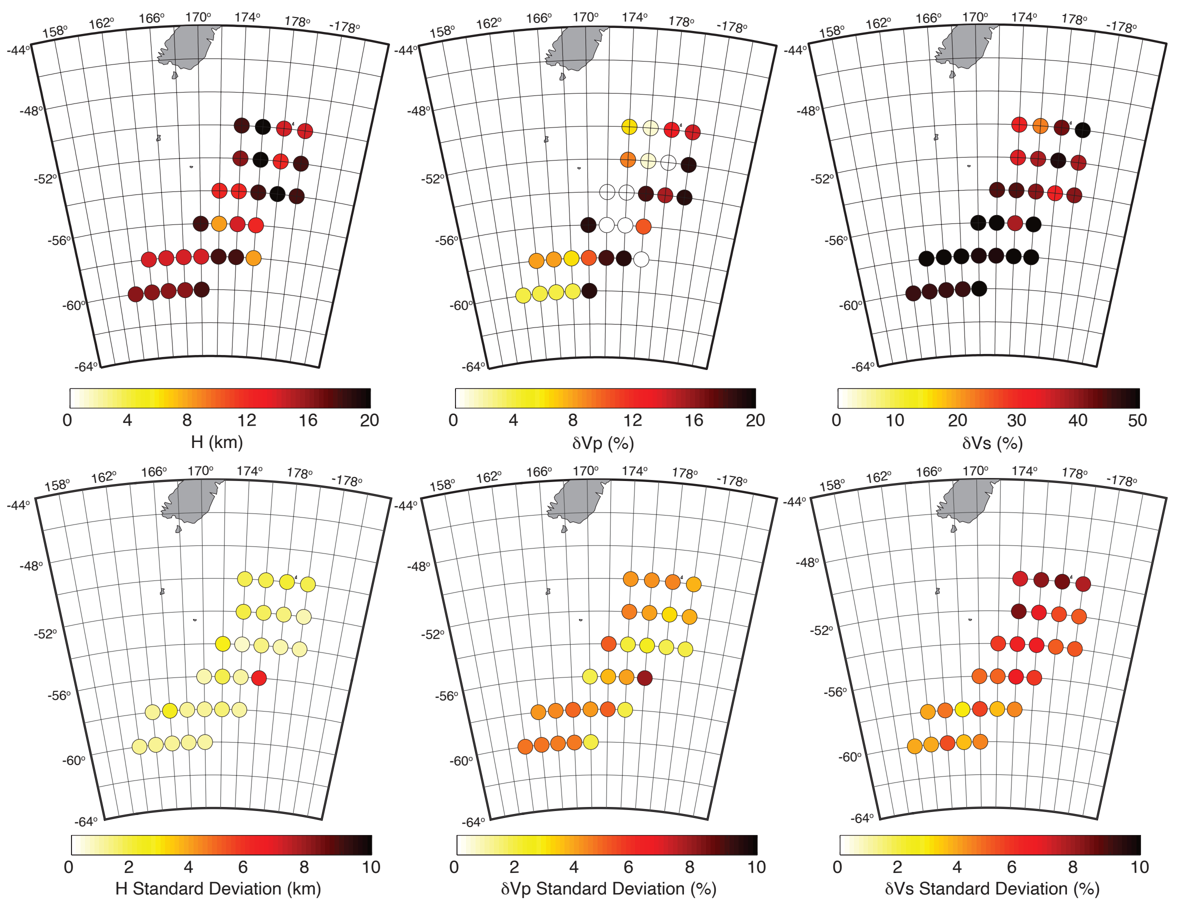


Figure S3. Bin examples for two different geographic families (see Fig. 4). Each circle represents one of the examined bins. In the top row for each family, the bins are color-coded to illustrate the best-fit ULVZ characteristics for the events within that bin (based on the sum of $CQ(j,k)_{weighted}$, see equation 3). In the bottom row for each family, the bins are color-coded by the standard deviation of the corresponding ULVZ parameters for that bin. Maps in the first column correspond to ULVZ thickness (H), those in the second column correspond to δV_P, and the third column corresponds to δV_S.

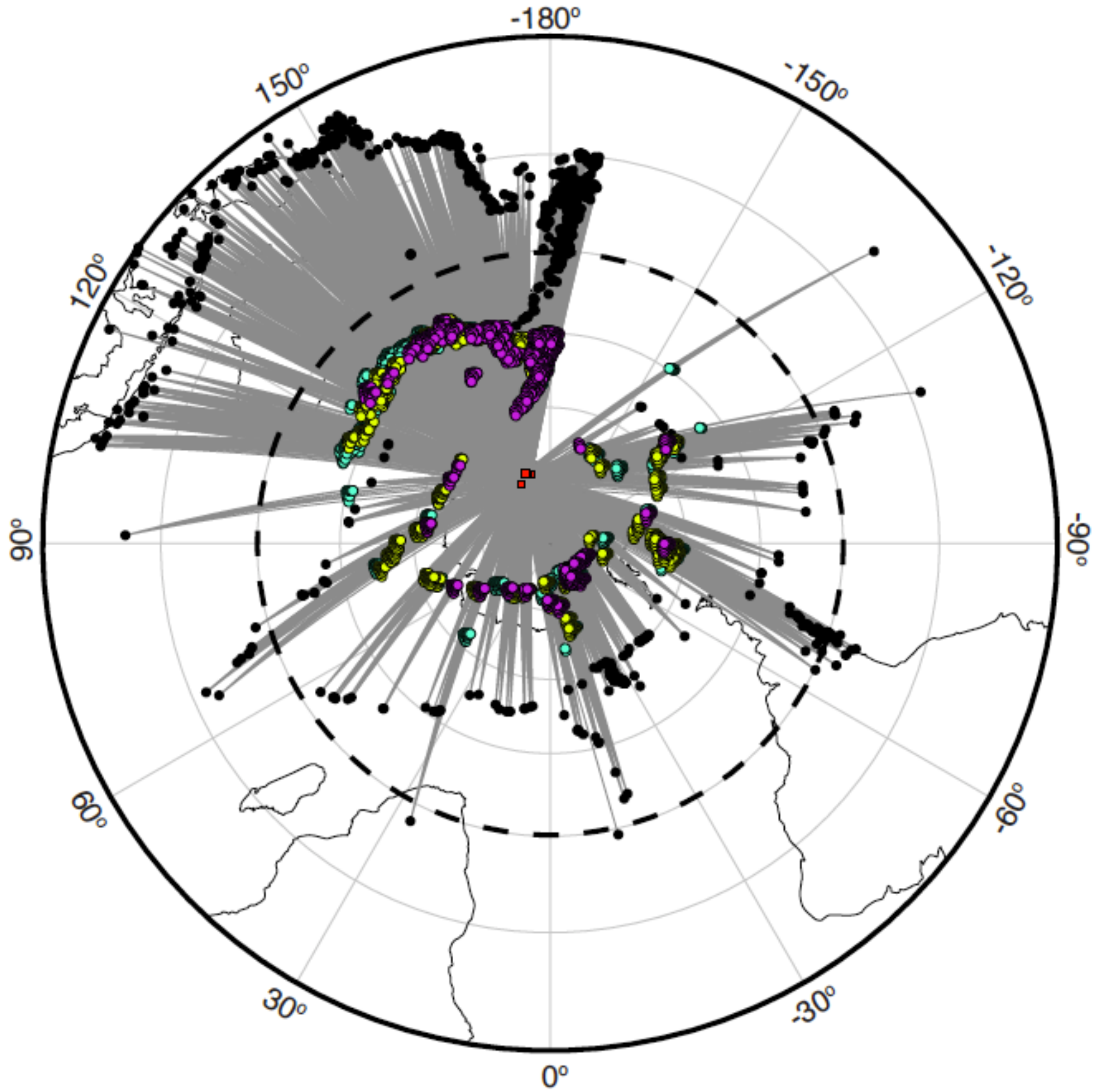


Figure S4. TAMNNET-recorded PcP events. All 822 events (black dots) initially examined for PcP arrivals. Red squares denote the TAMNNET stations, and gray lines indicate the source-receiver PcP ray paths. Colored dots denote PcP CMB bounce points. Blue indicates events that were dismissed for one of the following reasons: emergent, low SNR or complex P arrivals or too few station-records to generate a robust stack. Yellow indicates events with PcP issues, including other, interfering seismic phases, low SNR, or complex waveshapes. Purple denotes events selected for ULVZ analysis.

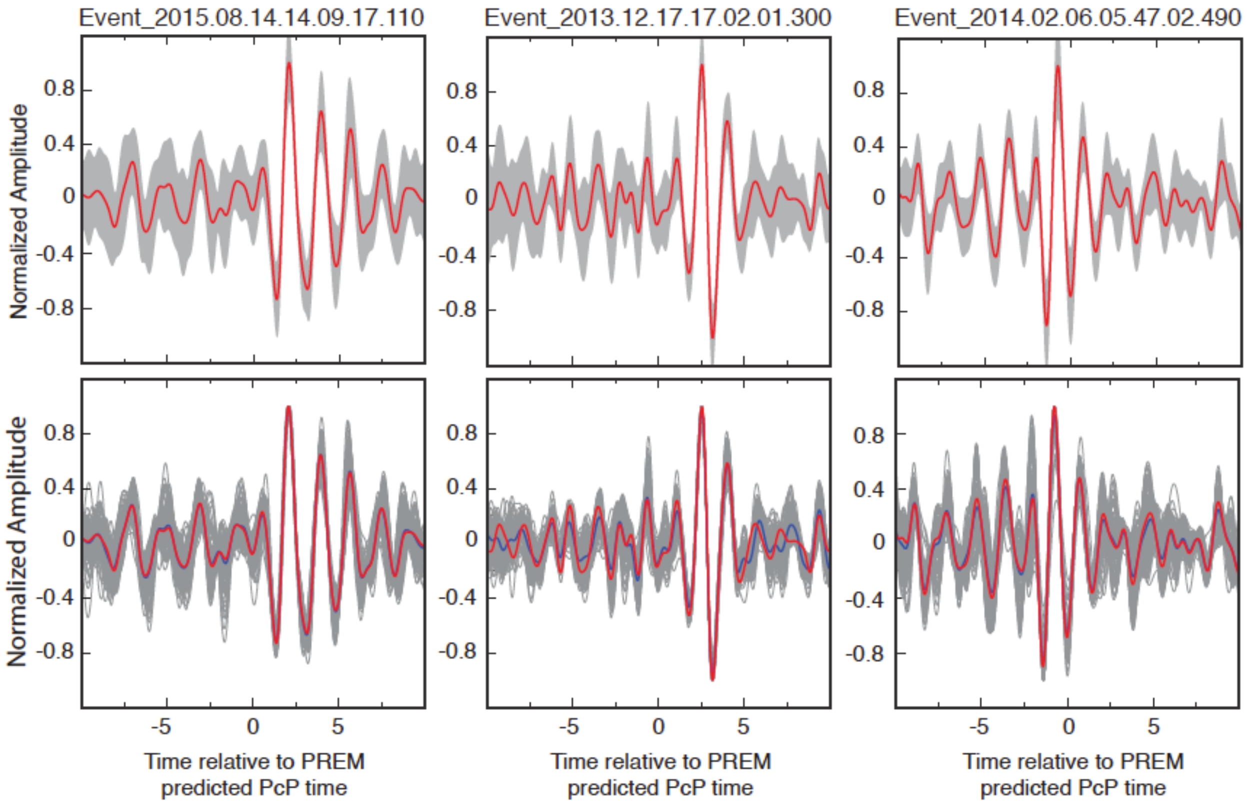


Figure S5. Different uncertainty estimates for PcP stacks. Each column corresponds to an example event. In all panels, the HIPR-weighted PcP stack is shown by the red line. (top row) Gray shading shows stack standard deviation. (bottom row) Gray lines show 100 bootstrapped PcP stacks, generated by randomly selecting and stacking waveforms for the given event. Dark blue line shows the average of the 100 bootstrapped stacks.

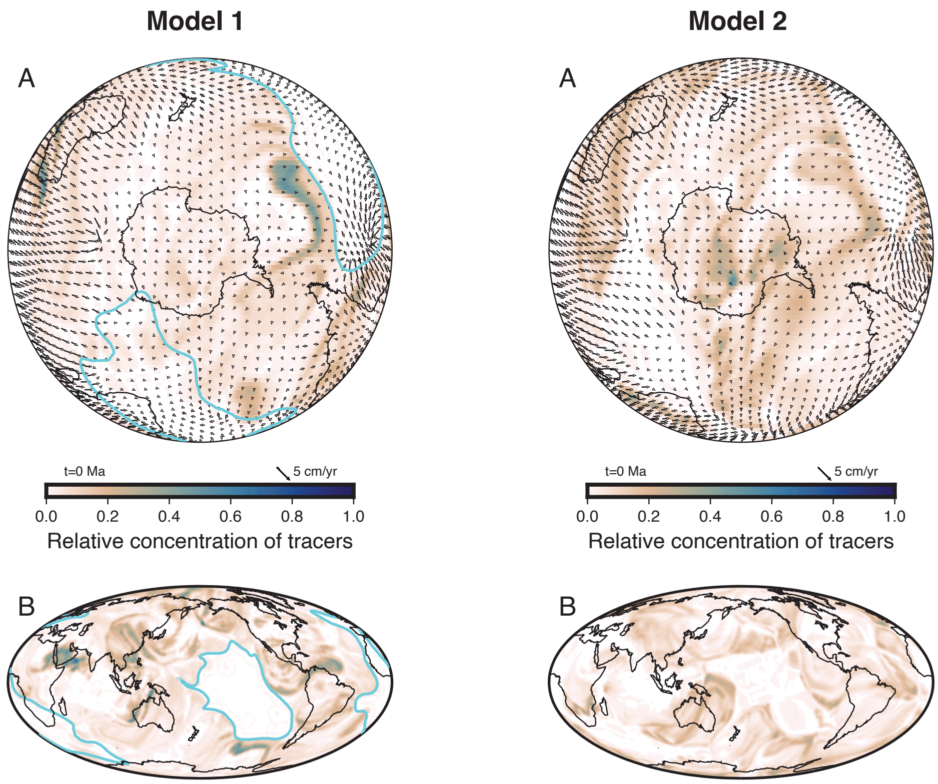


Figure S6. Distribution of subducted materials in the lowermost 300 km of the mantle. In Model 1 (left panels), the LLVPs are simulated by thermochemical piles, the boundaries of which are marked by the cyan lines. In Model 2 (right panels), the LLVPs are assumed to have purely thermal origins. (A) Distribution of subducted materials in the lowermost 300 km of the mantle, viewed from South Pole. Colors highlight the relative concentration of tracers, with higher (lower) concentrations representing higher (lower) abundances of subducted materials. Arrows indicate mantle flow velocity along the CMB. (B) Same as (A) but in global view.

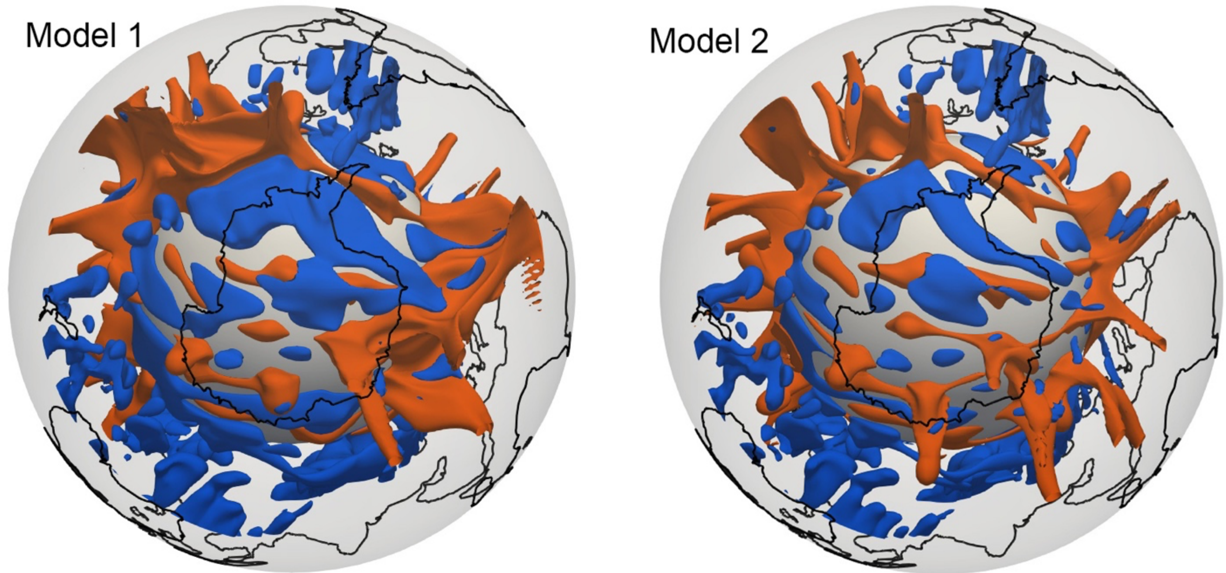


Figure S7. Three-dimensional snapshots of the temperature fields for Model 1 and Model 2 at present-day. Red and blue colors denote the iso-surfaces of temperature anomalies at 0.08 and -0.08, respectively.

Movie S1. Geodynamic modeling animation for Model 1. Panels are the same as those shown for Model 1 in Figure 5, illustrating how the distribution of subducted materials and the temperature field along the CMB change between 224 Ma and present. This movie file can also be accessed at https://doi.org/10.5281/zenodo.7651446.

Movie S2. Geodynamic modeling animation for Model 2. Panels are the same as those shown for Model 2 in Figure 6, illustrating how the distribution of subducted materials and the temperature field along the CMB change between 224 Ma and present. This movie file can also be accessed at https://doi.org/10.5281/zenodo.7651446.

Movie S3. Example tracer paths through the geodynamic models. The paths of five random tracers (denoted by the circle, square, triangle, diamond, and hexagon symbols), which advect from the upper mantle into the lowermost 50 km of the mantle near Antarctica, are highlighted. The symbol color represents the associated tracer depth at a given point in time. The video is generated with timesteps of about 10 Myrs, but the tracers (Movies S1 and S2) are advected with a much shorter timestep. Given this, when some tracers (symbols) first appear in the video, they are already advected to deeper depths than their starting locations at 300 km. Plate boundary colors on the map indicate the divergency of plate velocity, with red indicating divergence and blue indicating convergence (subduction). This movie file can also be accessed at https://doi.org/10.5281/zenodo.7651446.