EGU25-14576, updated on 21 May 2025
https://doi.org/10.5194/egusphere-egu25-14576
EGU General Assembly 2025

Cold Mantle Transition Zone Gap Formed by Progressive Tearing of the Segmented Western Pacific Slab

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Complex interactions between plate subduction, mantle flow, and the overriding plate govern the dynamics of subduction zones. Numerous studies have highlighted the critical role of subduction processes in redistributing thermo-chemical domains within the mantle, significantly influencing mantle dynamics and plate tectonics. However, debates persist regarding the thermal conditions and dynamic models of the mantle affected by stagnant slabs. The physical state and long-term dynamics of the mantle surrounding stagnant slabs in the mantle transition zone (MTZ) remain poorly understood, partly due to the lack of detailed reconstructions of subduction history and robust constraints on mantle temperatures.

The northwestern Pacific region, with its extensive subduction history spanning over 40 million years and involving multiple oceanic plates with episodic plate boundary modifications, provides an ideal setting for studying subducting slab structures and their associated tectonic and dynamic processes. High-resolution seismic tomography of the MTZ beneath the coastal margins of northeast Asia has revealed a narrow channel of low-velocity anomalies surrounded by high-velocity regions, indicating the presence of segmented western Pacific stagnant slabs. The geometric features of these imaged structures likely reflect rapid plate boundary reorganization during the Cenozoic in the western Pacific, driven by continuous lateral extension and tearing of the retreating Pacific slab. This process has led to the formation of a laterally extended MTZ gap characterized by moderate mantle temperatures (Tp ~1350–1450°C), as determined through joint analyses of seismic velocities and mantle phase transition thicknesses.

We propose that the current MTZ gap in the western Pacific exhibits minimal thermal anomalies capable of inducing focused mantle upwellings. Our observations suggest that mantle dynamics around the stagnant slabs would be largely passive, unless thermochemical sources capable of driving active convection are present. This further implies that active mantle upwellings, if they existed, were spatially and temporally constrained during past slab segmentation processes.