

Seismic Evidence Linking Dehydration to the Low-Velocity Layer Above the 410 km Discontinuity

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Running title: *Dehydration melting at 410 km and Low-Velocity Layer Formation*

Key Points

- Dehydration melting attributed to low-velocity layer formation atop 410 km
- P410s amplitude variations controlled by water content at 410 km
- Pacific slab subduction constrains deep water circulation in NE China

Abstract: The low-velocity layer above the 410 km discontinuity is widely attributed to dehydration-induced melting in the upper mantle, yet direct seismic evidence for this linkage has remained scarce. Northeast China, situated at the leading edge of the Northwest Pacific subduction zone, provides an exceptional natural laboratory due to the deep subduction and stagnation of the Pacific slab. Using teleseismic waveform data from 327 broadband stations, we extracted 40,236 high-quality P-wave receiver functions and applied common conversion point (CCP) stacking along the 42°N profile (115°E–130°E) to image mantle discontinuities and probe the origin of the low-velocity layer. Our results

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reveal pronounced lateral heterogeneity: regions with a well-developed low-velocity layer exhibit sharp and strong P410s phases, whereas adjacent regions lacking such a layer show markedly weakened or absent signals. Forward modeling demonstrates that the transitional thickness of the 410 km discontinuity—closely governed by water content—exerts a first-order control on P410s amplitudes, with broader discontinuities progressively diminishing converted-wave energy and weak-P410s regions yielding an average P410s/P660s amplitude ratio of 0.46 ± 0.07 . Modeling based on the IASP91 velocity structure suggests an $\sim 11 \pm 3$ km gradient layer at the 410 km discontinuity. These spatial correlations provide direct seismic evidence that dehydration at the 410 km discontinuity sharpens the phase boundary and enhances converted phases, whereas persistent hydration broadens the transition zone and weakens P410s signals. This study offers new constraints on deep water circulation, mantle material transport, and the role of Pacific slab subduction beneath the East Asian continental margin.

Keywords: 410 km discontinuity; Low-velocity layer; Dehydration melting; P-wave receiver functions; Pacific slab subduction

1. Introduction

The mantle transition zone plays a pivotal role in Earth's deep water cycle, with the 410 km discontinuity marking a key boundary where hydration and dehydration processes strongly influence seismic properties (e.g., Bercovici & Karato, 2003; Karato et al., 2013). A low-velocity

layer immediately above this discontinuity has often been attributed to dehydration-induced melting (e.g., Hier-Majumder and Courtier, 2011; Fomin and Schiffer, 2019; Han et al., 2020; Li et al., 2021; Li et al., 2025; Sun et al., 2021; Chen et al., 2026); however, whether this feature truly originates from water release at 410 km remains uncertain. This question arises in light of Green et al. (2010), who argue that subducting lithosphere carries negligible water below 400 km depth and instead propose that continental lithosphere delamination perhaps governs deep water cycling. Other models likewise contend that the mantle transition zone contains little water (Houser, 2016), with a dry mantle transition zone inferred from the electrical conductivity of wadsleyite and ringwoodite (Yoshino et al., 2008) and from geomagnetic diurnal variations (Zhang et al., 2022). Resolving this debate requires direct seismic evidence that can link the low-velocity layer above the 410 km discontinuity to slab dehydration-driven partial melting at that depth. Establishing such a connection forms the starting point of this study.

Northeast China provides an exceptional natural laboratory to investigate this problem. The Pacific slab has subducted to great depths and stagnated in the mantle transition zone (e.g., Li et al., 2008; Ye et al., 2011; Zhao et al., 2009; Li et al., 2013; Lu et al., 2020; He et al., 2025), creating conditions favorable for testing the relationship between slab-derived water release, mantle melting, and seismic discontinuity sharpness. Previous studies have reported heterogeneous seismic signals in this region (e.g., Ai et al., 2007; Huang et al., 2014; Tang et al., 2023; Han et al., 2020; Guan and Niu, 2017; Yang et al., 2021; Zhu et al., 2026), but the physical mechanism controlling the amplitude and character of converted phases remains poorly constrained.

In this study, we employ a dense broadband seismic array and high-resolution receiver function imaging to probe the mantle discontinuities beneath Northeast China (Figure 1). By focusing on the transitional thickness and amplitude variations of the 410 km discontinuity, we aim to resolve whether dehydration processes directly sharpen the phase boundary and generate the low-velocity layer. This approach allows us to address a fundamental question: How does slab-derived water influence the seismic expression of the 410 km discontinuity and the formation of the low-velocity layer in the mantle transition zone?

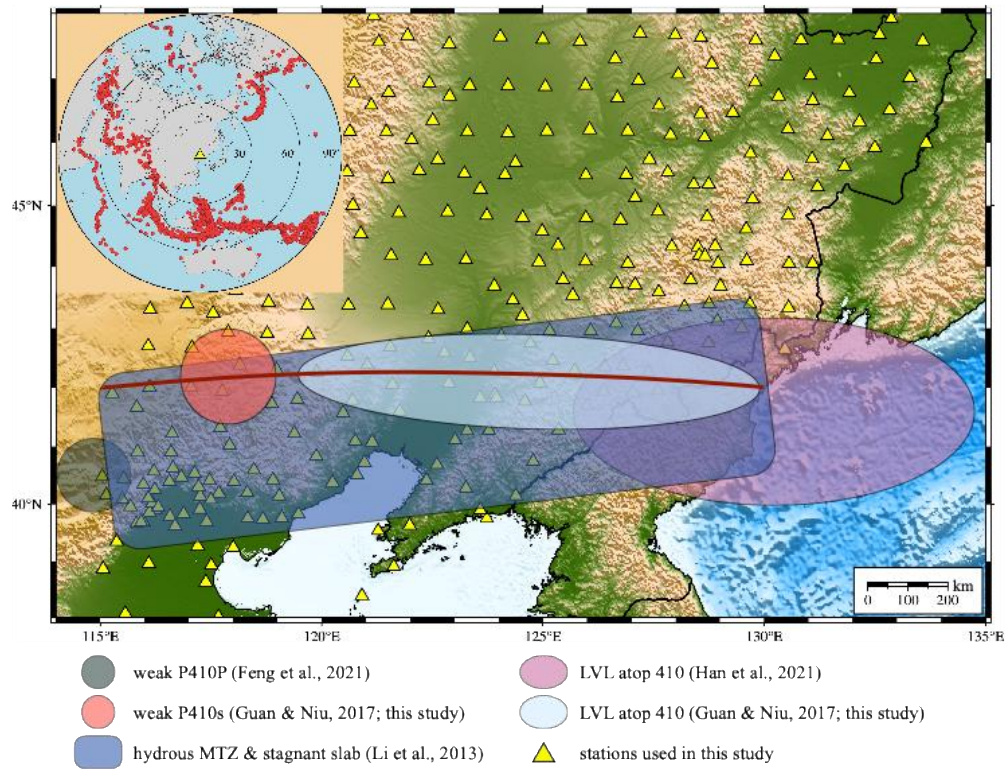


Figure 1. Distribution of seismic stations and previous study results in the study area. Yellow triangles denote seismic stations; the inset in the upper left shows one station and the distribution of recorded earthquakes (red solid circles). Previous studies are also indicated: weak P410P inferred from ambient noise interferometry extracting body-wave reflections (Feng

et al., 2021) and weak P410s inferred from receiver function studies (Guan and Niu, 2017), with their study regions marked by filled circles; hydrous MTZ and stagnant slab based on triplication waveform modeling (Li et al., 2013), shown as filled rectangles; and detection of the low-velocity layer (LVL) above 410 km (Han et al., 2021; Guan and Niu, 2017), represented by filled ellipses. The present study focuses on the N42° profile, indicated by the red solid line.

2. Data and Analysis

We used teleseismic three-component waveform data recorded by 327 broadband seismic stations in Northeast China and adjacent regions, including 200 permanent stations from the China seismic network and 127 temporary stations from the NECESSArray (Figure 1). Events with moment magnitudes $M_w \geq 5.5$ and epicentral distances between 30° and 90° were selected to ensure clear teleseismic P arrivals and reliable receiver-function estimates. After event selection, 4576 earthquakes were retained for subsequent processing.

The raw SAC waveforms were preprocessed by removing the mean and linear trend, applying a taper, resampling to 0.025 s, and band-pass filtering between 0.05 and 1.0 Hz. For each event-station pair, a 130 s time window was extracted from 10 s before to 120 s after the theoretical P-wave arrival. The horizontal components were then rotated into the radial and transverse directions according to the event back azimuth.

P-wave receiver functions were computed using frequency-domain water-level deconvolution of the radial component by the vertical component. A water level of 0.01 and a Gaussian factor of 1.0 were adopted. We carefully selected receiver functions with high signal-to-noise ratios. For each station, an individual receiver function was rejected if its maximum absolute

amplitude within the pre-P window (10–2 s before the direct P arrival) exceeded that of the station-averaged receiver function in the same window. After quality control, 40,236 high-quality P-wave receiver functions were retained for common conversion point (CCP) imaging. Seispy, a Python module for batch calculation and postprocessing of receiver functions (Xu and He, 2022), was employed for receiver function computation and CCP stacking.

3. Results and Discussion

3.1 The CCP stacking of receiver functions

Common conversion point (CCP) stacking was performed along an east-west profile at 42°N between 115°E and 130°E. The IASP91 model (Kennett and Engdahl, 1991) was used as the reference velocity model for ray tracing and time-to-depth conversion. Receiver functions were migrated to depths of 0–800 km with a depth interval of 1 km. Circular CCP bins with a radius of approximately 1° were used to gather receiver functions, and the profile was sampled at an interval of 11 km. CCP stacking results of receiver functions along the N42° profile are presented in Figure 2, with results from Guan and Niu (2017) plotted for comparison. Overall, our results consistently reveal the same major features as those reported by Guan and Niu (2017). It is also noted that, as shown in Fig. 2, the signals in this study appear slightly different from those of Guan and Niu (2017). This difference may reflect variations in data coverage, imaging methodology, and figure presentation, rather than fundamental discrepancies in the underlying structure. Importantly, our analysis focuses on the lateral variations of relative amplitudes rather than their absolute values, so such amplitude differences do not affect our interpretation. In addition, we employed the IASP91 1-D velocity model for time-to-depth conversion, whereas Guan and Niu (2017) used a regional velocity model. Because our analysis focuses more on

lateral variations and the P410s/P660s amplitude ratio rather than absolute depths, the choice of velocity model does not significantly affect our conclusions. Regional models vary considerably, making it difficult to select one fairly; therefore, we prefer to use a global 1-D model to ensure consistency and comparability.

The most striking observations are as follows: along this transect, the P660s signal shows little lateral variation and consistently appears as a clear, prominent phase, with the only anomaly being a markedly delayed P660s in the easternmost segment, indicating a locally depressed 660 km discontinuity. In contrast, the P410s signal exhibits pronounced lateral variability. In the western segment (117–119°E), P410s is very weak, whereas farther east it becomes distinct. Moreover, above the clear P410s phases in the eastern region, an additional polarity-reversed signal is observed, representing the presence of a low-velocity layer (LVL) above the 410 km discontinuity. No such LVL signal is detected in the 117–119°E segment. Previous studies have attributed this LVL to melts generated by dehydration (Han et al., 2021). In the southwestern part of the weak-P410s region (Figure 1), Feng et al. (2021) reported weak P410P signals, extracted via ambient noise interferometry as body-wave reflections from the 410 km discontinuity.

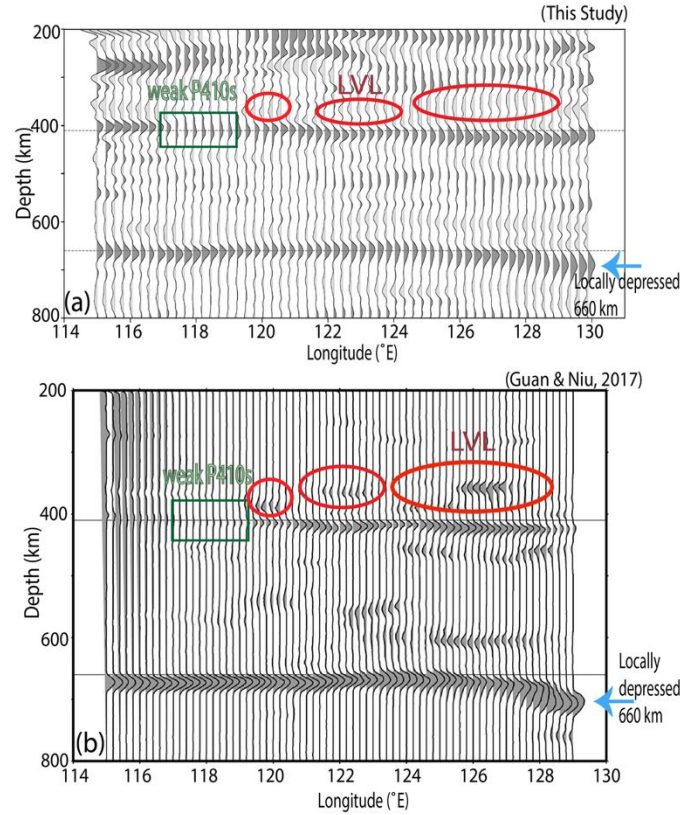


Figure 2. Common conversion point (CCP) stacking results along the N42° profile. (a) Results from this study. (b) Results from Guan and Niu (2017) for comparison. The red ellipses highlight the low-velocity layer (LVL) above the 410 km discontinuity, while the green rectangles mark regions of weak P410s signals. Both our results and those of Guan and Niu (2017) consistently reveal weak P410s amplitudes and widespread LVL development above 410 km.

To better illustrate the lateral variations in the CCP stacking results, we performed a fourth-root vespagram analysis of receiver functions along the N42° profile. Two longitudes were selected along this transect, 118°E and 126°E. As shown in Figure 3, the results more clearly demonstrate that weak P410s signals occur in the western segment at 118°E, whereas prominent P410s signals are observed in the eastern segment at 126°E. In addition, a low-

velocity layer (LVL) is detected above the 410 km discontinuity at 126°E, but no such LVL is observed at 118°E where weak P410s occurs.

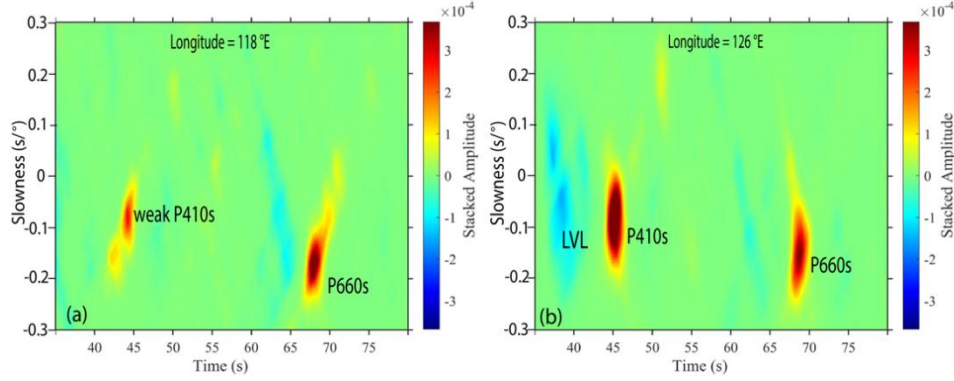


Figure 3. Fourth-root vespagram analysis of receiver functions along the N42° profile.

(a) Longitude 118°E and (b) Longitude 126°E. The results highlight the presence of weak P410s signals in the western segment, while the eastern segment exhibits prominent P410s. In addition, a low-velocity layer (LVL) is detected above the 410 km discontinuity.

3.2 Thickness of the 410 km discontinuity as the primary control on P410s amplitudes

To investigate the factors responsible for weak P410s signals, we conducted synthetic receiver function calculations to examine how variations in the transitional thickness at the 410 km discontinuity influence P410s amplitudes, as illustrated in Figure 4. The theoretical results clearly show that increasing thickness leads to a pronounced reduction in P410s amplitude. Once the thickness exceeds ~20 km, the P410s signal becomes so weak that it is nearly unobservable.

These findings demonstrate that the transitional thickness exerts a dominant control on P410s amplitudes. In other words, the first-order factor governing P410s strength is the width of

the phase transition at 410 km, whereas other influences, such as compositional variations, play a secondary role.

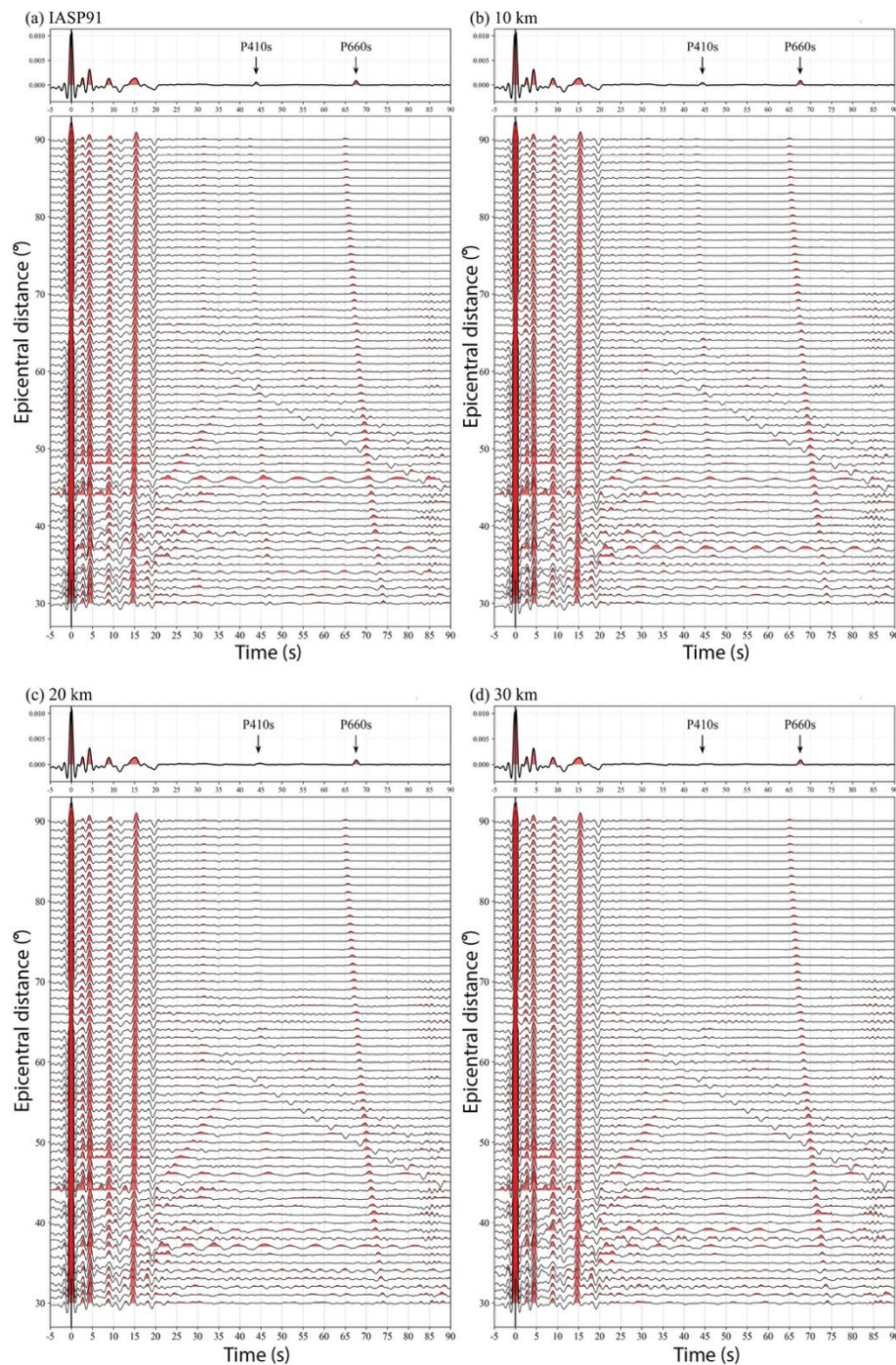


Figure 4. Synthetic receiver function calculations illustrating the effect of transitional thickness at the 410 km discontinuity on P410s amplitudes. (a) IASP91 velocity model

with a sharp 410 km discontinuity. (b) Transitional thickness of 10 km. (c) Transitional thickness of 20 km. (d) Transitional thickness of 30 km. The theoretical results clearly demonstrate that increasing thickness significantly reduces P410s amplitudes; when the thickness exceeds 20 km, the P410s signal becomes so weak that it is nearly unobservable.

3.3 Estimation of transitional thickness of 410 km discontinuity

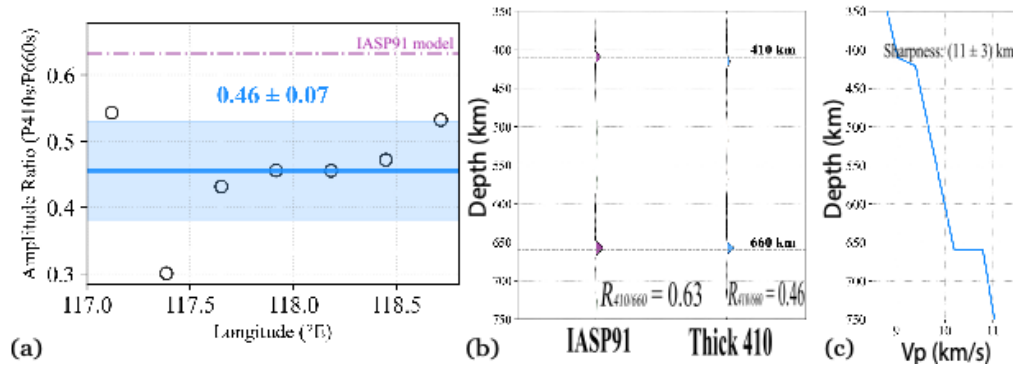


Figure 5. Estimation of the transitional thickness of the 410 km discontinuity in regions with weak P410s signals. (a) Amplitude ratio of P410s/P660s, with the observed value of 0.46 significantly lower than the IASP91 model ratio of 0.63. (b) Comparison of receiver function waveforms between observations and the IASP91 model. (c) Derived thickness 11 km of the 410 km discontinuity and the corresponding one-dimensional velocity model, with depths other than 410 km taken from the IASP91 model.

As shown in Figure 5, we constrained the transitional thickness of the 410 km discontinuity in regions with weak P410s signals using the P410s/P660s amplitude ratio. Our analysis focused on the longitude segment 117–119°E, where CCP stacking was applied to

obtain receiver functions. For each longitude within this range, we calculated the P410s/P660s amplitude ratio from the stacked receiver function and then averaged seven values across the segment to derive a representative ratio. Amplitudes were measured using a peak-to-zero approach rather than peak-to-peak, as receiver functions are dominated by pulse-like signals and peak-to-zero provides a more stable metric. We recognize that amplitudes may be affected by factors such as source radiation patterns, focusing/defocusing effects, and heterogeneous structures. Although these influences cannot be fully eliminated, our averaging strategy, the use of CCP stacking, and reliance on the P410s/P660s ratio help mitigate random variations and enhance the robustness of the amplitude measurements.

Our workflow to constrain the 410 km thickness is as follows: we first derived the observed P410s/P660s amplitude ratio from CCP stacking results, and then constructed a series of synthetic models to fit this ratio. In these models, the velocity structure at 660 km is taken directly from the IASP91 model, while the 410 km structure is also based on IASP91 but modified by introducing a transitional thickness. By systematically varying the thickness of the 410 km discontinuity, we determined the values that best reproduce the observed ratios across the profile. Our approach involved iteratively varying the transitional thickness to match the observed amplitude ratios, and through this trial-and-error procedure we obtained the final estimate of 0.46 ± 0.07 corresponds to a transitional thickness of 11 ± 3 km, demonstrating that the 410 km discontinuity is broadened rather than sharp.

Mineral physics experiments provide strong evidence that such transitional discontinuities are associated with hydration, as the presence of water increases the width of the phase transition (Smyth and Frost, 2002). The estimated thickness of 11 km is noticeably greater

than the ~7 km expected for an anhydrous 410 km discontinuity in subduction zones (Katsura et al., 2004). Vinnik et al. (2019) similarly reported widths ranging from 10 to 22 km in the eastern Yangtze Craton using P-wave receiver functions, consistently exceeding the 7 km value predicted under dry conditions, in agreement with our findings.

In this analysis, we considered only the effect of hydration on P410s amplitudes, specifically its control on the transitional thickness of the 410 km discontinuity. We argue that this thickness exerts a first-order influence on amplitude variations, whereas compositional effects are likely secondary. Although the use of the P410s/P660s amplitude ratio reduces the impact of source radiation patterns, our results rely on the IASP91 velocity model (Kennett and Engdahl, 1991). Previous studies suggest that basaltic enrichment may occur near the 660 km discontinuity (e.g., Feng et al., 2021; Zhou and He, 2024). If basalt enrichment is also present in our study area, it would reduce the velocity contrast at 660 km and lower P660s amplitudes (Zhang et al., 2019). In that case, explaining the observed low P410s/P660s ratio would require an even greater reduction in P410s amplitude, implying a thicker 410 km transitional layer. Thus, our estimate of 11 km may represent a lower bound, and the actual thickness could be larger. Future seismic investigations that better constrain the velocity structure near 660 km will provide more accurate compositional constraints on mantle transition zone discontinuities. Unfortunately, we are not able to quantitatively constrain the water content from the estimated transitional thickness at 410 km. Establishing such a constraint requires a quantitative mineralogical relationship between discontinuity thickness and hydration, which is currently lacking.

3.4 Temporal evolution of MTZ hydration and dehydration melting

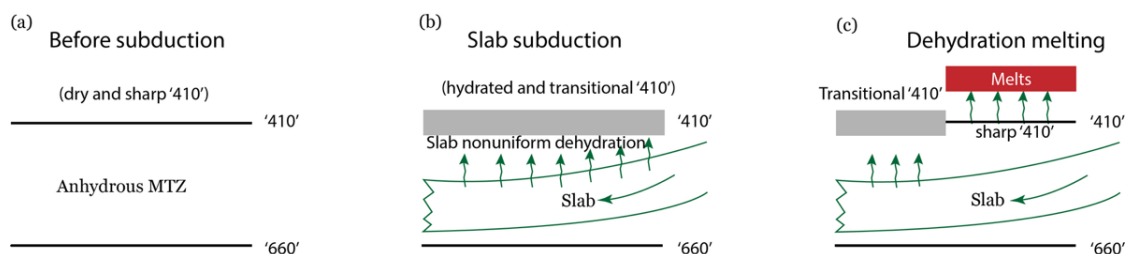


Figure 6. A conceptual model to explain temporal evolution of mantle transition zone hydration and dehydration melting. (a) Before slab subduction: anhydrous MTZ with a sharp 410 km discontinuity. (b) Slab subduction and dehydration: hydration broadens the phase transition, producing a transitional 410 km discontinuity. (c) Continued slab dehydration: saturation triggers dehydration melting and a low-velocity layer above 410 km, while western regions remain transitional due to insufficient hydration.

To explain our seismic observations, we propose a time-evolving model of mantle transition zone (MTZ) hydration and dehydration melting, as illustrated in Figure 6. Prior to the arrival of subducting slabs at the MTZ, when slab-derived hydration has not yet occurred, the transition zone remains essentially anhydrous. Under these conditions, the 410 km discontinuity is sharp.

Once slab subduction and slab dehydration begin, the MTZ undergoes progressive hydration. This process broadens the phase transition at 410 km, transforming the discontinuity into a transitional boundary. With continued slab dehydration, hydration of the MTZ increases until saturation is reached. At this stage, dehydration triggers partial melting, producing the low-velocity layer observed above the 410 km discontinuity. Following dehydration, the discontinuity reverts from transitional back to sharp.

In contrast, regions to the west exhibit insufficient hydration, never reaching saturation. Consequently, dehydration and melting do not occur, and no low-velocity layer develops above 410 km. Here, the discontinuity remains transitional, leading to reduced P410s amplitudes—consistent with our observations of weak P410s signals.

Taken together, the lateral variations in P410s amplitude and the presence or absence of the low-velocity layer above 410 km reflect the evolutionary sequence of the MTZ: from anhydrous, to hydrated, and ultimately to dehydration-induced melting. We acknowledge, however, that this temporal evolution model is speculative and should be regarded as a conceptual framework. Its validity requires further testing through geodynamic simulations and mineral physics experiments. Nevertheless, the model highlights the scientific novelty of our work by linking present-day spatial variations to a possible evolutionary sequence of mantle hydration and dehydration melting.

3.5 Stishovite and Al-bearing stishovite as deep-mantle water carriers

Recent studies have emphasized the role of silica polymorphs, particularly stishovite, as potential carriers of water into the deep mantle. Two complementary lines of work provide contrasting insights into the water storage capacity of stishovite under extreme conditions.

The first study focused on pure stishovite without the influence of additional elements (Wang et al., 2026). High-pressure experiments demonstrated that stishovite exhibits significant water solubility only at relatively low temperatures, even lower than those characteristic of cold subduction zones. At the higher temperatures typical of the deep Earth, however, its water solubility decreases sharply and becomes negligible. These findings suggest that pure stishovite

cannot effectively transport water into the deep mantle, clarifying its limited role in deep Earth water cycling and indicating that earlier reports of high water solubility may reflect either related phases or experimental artifacts.

In contrast, a second study examined Al-bearing stishovite and its denser polymorph, post-stishovite (Liu et al., 2026). Laboratory experiments revealed that both phases can incorporate up to ~2 wt.% of water under deep mantle pressures and temperatures, with water storage capacity positively correlated with Al_2O_3 content. Importantly, variations in Al_2O_3 and H_2O concentrations influence the depth of the stishovite–post-stishovite transition, potentially explaining the occurrence of seismic scatterers across a broad depth range in the mid-mantle. This highlights the role of chemical heterogeneity in subducted lithologies in shaping the complex seismic structures observed in the Earth’s interior.

Taken together, these studies indicate that while the role of pure stishovite in deep water recycling is strongly limited by temperature effects, Al-bearing stishovite appears increasingly effective at storing water under higher pressures and temperatures. Thus, Al-bearing stishovite can be regarded as a plausible and potentially important mineralogical carrier for transporting water into the deep mantle, although its relative significance compared to other mantle minerals remains subject to ongoing investigation.

3.6 Alternative pathways of deep water transport

It is well established that the mantle transition zone (MTZ) can be hydrated either through the subduction of hydrous plates or by hydrous mantle upwelling, potentially rooted at the base of the mantle in the form of plumes (Bercovici & Karato, 2003). A key question, however, is whether other mechanisms of water transport are equally or even more significant.

Building on our previous studies, we highlight two additional processes that should be considered important pathways for recycling water back into the mantle.

The first involves subducting passive margins containing crustal (ultra)mafic intrusions, which can deliver substantial water flux into the mantle (Pan and He, 2023). The second is the subduction of water-rich seamounts (He et al., 2022; He et al., 2025). Notably, Chesley et al. (2021) suggest that a subducting seamount may transport 3.2 to 4.7 times more water into the deep mantle compared to normal, unfaulted oceanic lithosphere.

As noted above, the principal mineral phases capable of transporting water into the deep mantle are the high-pressure polymorphs of silica, particularly stishovite. Both subducting continental margins and seamounts contain higher concentrations of silica compared to typical oceanic crust. Consequently, they represent two highly plausible carriers for delivering water into the deep mantle.

4 Conclusions

Our seismic imaging across Northeast China provides direct evidence that dehydration at the 410 km discontinuity sharpens the phase boundary and enhances converted phases. Regions with a well-developed low-velocity layer exhibit strong P410s signals, whereas water-bearing 410 km discontinuity lacking dehydration show broadened transitions and weakened amplitudes. Forward modeling confirms that the thickness of the 410 km gradient layer, governed by water content, exerts a first-order control on P410s amplitudes. These findings establish a robust link between mantle hydration state and seismic discontinuity sharpness, offering new constraints on

deep water circulation, mantle material transport, and the role of Pacific slab subduction beneath the East Asian continental margin.

Acknowledgments

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References:

- Ai, Y., Chen, Q., Zeng, F., Hong, X., & Ye, W. (2007). The crust and upper mantle structure beneath southeastern China. *Earth and Planetary Science Letters*, 260(3–4), 549–563. <https://doi.org/10.1016/j.epsl.2007.06.009>
- Bercovici, D., & Karato, S.-I. (2003). Whole-mantle convection and the transition-zone water filter. *Nature*, 425(6953), 39–44. <https://doi.org/10.1038/nature01918>
- Chen, J., Yu, H., Fu, S., Xu, F., Zhang, B., & Fei, H. (2026). High Melt Fraction Induced by the Dehydration Melting Near the 410-km Discontinuity. *Geophysical Research Letters*, 53(16). <https://doi.org/10.1029/2025gl121527>
- Chesley, C., Naif, S., Key, K., et al., 2021. Fluid-Rich Subducting Topography Generates Anomalous Forearc Porosity. *Nature*, 595(7866): 255–260. <https://doi.org/10.1038/s41586-021-03619-8>

- Feng, J. K., Yao, H. J., Wang, Y., Poli, P., and Mao, Z. (2021). Segregated oceanic crust trapped at the bottom mantle transition zone revealed from ambient noise interferometry. *Nat. Commun.*, 12(1), 2531. <https://doi.org/10.1038/s41467-021-22853-2>
- Fomin, I., & Schiffer, C. (2019). Water, Hydrous Melting, and Teleseismic Signature of the Mantle Transition Zone. *Geosciences*, 9(12), 505. <https://doi.org/10.3390/geosciences9120505>
- Green II, H. W., Chen, W. P., Brudzinski, M. R., 2010. Seismic Evidence of Negligible Water Carried below 400-Km Depth in Subducting Lithosphere. *Nature*, 467(7317): 828– 831. <https://doi.org/10.1038/nature09401>
- Guan, Z., & Niu, F. (2017). An investigation on slowness-weighted CCP stacking and its application to receiver function imaging. *Geophysical Research Letters*, 207(6), 811. <https://doi.org/10.1002/2017gl073755>
- Han, G., Li, J., Guo, G., Mooney, W. D., Karato, S.-I., & Yuen, D. A. (2020). Pervasive low-velocity layer atop the 410-km discontinuity beneath the northwest Pacific subduction zone: Implications for rheology and geodynamics. *Earth and Planetary Science Letters*, 116642. <https://doi.org/10.1016/j.epsl.2020.116642>
- He, X., Tao, J., Cao, Y., Pan, F., He, E., Cao, L., & Zheng, Y. (2022). No seamount subduction, no magmatic arc? *Earth and Planetary Physics*, 6(4), 1–6. <https://doi.org/10.26464/epp2022031>
- He, X., He, M., Li, Y., Hu, J., Pan, F., Wang, Z., & Lei, J. (2025). Changbaishan Volcanism: Is Seamount Subduction the Missing Piece? *Journal of Earth Science*, 36(5), 2337–2340. <https://doi.org/10.1007/s12583-025-0181-x>
- Hier-Majumder, S., & Courtier, A. (2011). Seismic signature of small melt fraction atop the transition zone. *Earth and Planetary Science Letters*, 308(3–4), 334–342. <https://doi.org/10.1016/j.epsl.2011.05.055>
- Huang, R., Xu, Y., Luo, Y., & Jiang, X. (2014). Mantle Transition Zone Structure Beneath Southeastern China and its Implications for Stagnant Slab and Water Transportation in the Mantle. *Pure and Applied Geophysics*, 171(9), 2129–2136. <https://doi.org/10.1007/s00024-014-0837-4>

- Houser, C. (2016). Global seismic data reveal little water in the mantle transition zone. *Earth and Planetary Science Letters*, 448(C), 94–101. <https://doi.org/10.1016/j.epsl.2016.04.018>
- Karato, S., Bercovici, D., Leahy, G., Richard, G., & Jing, Z. (2013). Earth's Deep Water Cycle. *Geophysical Monograph Series*, 289–313. <https://doi.org/10.1029/168gm22>
- Katsura, T., Yamada, H., Nishikawa, O., Song, M., Kubo, A., Shinmei, T., Yokoshi, S., Aizawa, Y., Yoshino, T., Walter, M.J., Ito, E. and Funakoshi, K. (2004). Olivine-wadsleyite transition in the system (Mg,Fe)₂SiO₄. *Journal of Geophysical Research* 109: doi: 10.1029/2003JB002438.
- Kennett, B. L. N., and Engdahl, E. R. (1991). Traveltimes for global earthquake location and phase identification. *Geophys. J. Int.*, 105(2), 429–465. <https://doi.org/10.1111/j.1365-246X.1991.tb06724.x>
- Li, G., Gao, Y., Zhou, Y., Ju, C., Shi, Y., & Cui, Q. (2021). A low-velocity layer atop the mantle transition zone beneath the western Central Asian Orogenic Belt: Upper mantle melting induced by ancient slab subduction. *Earth and Planetary Science Letters*, 117287. <https://doi.org/10.1016/j.epsl.2021.117287>
- Li, G., Zhou, Y., Bai, L., & Gao, Y. (2025). Low-velocity layer atop mantle transition zone and its dynamic effects in Chinese mainland and adjacent regions. *Reviews of Geophysics and Planetary Physics*. <https://doi.org/10.19975/j.dqyxx.2024-062>
- Li, J., Chen, Q.-F., Vanacore, E., & Niu, F. (2008). Topography of the 660-km discontinuity beneath northeast China: Implications for a retrograde motion of the subducting Pacific slab. *Geophysical Research Letters*, 35(1), 1839–7. <https://doi.org/10.1029/2007gl031658>
- Li, J., Wang, X., Wang, X., & Yuen, D. A. (2013). P and SH velocity structure in the upper mantle beneath Northeast China: Evidence for a stagnant slab in hydrous mantle transition zone. *Earth and Planetary Science Letters*, 367, 71–81. <https://doi.org/10.1016/j.epsl.2013.02.026>
- Liu, D., Yang, Y., Fei, H., Wang, F., Purevjav, N., Ye, Y., et al. (2026). A Systematic Study of the Pressure and Temperature Dependences of H₂O and Al₂O₃ Solubility in Al-bearing Stishovite and Post-Stishovite. *Journal of Geophysical Research: Solid Earth*, 131(8). <https://doi.org/10.1029/2025jb033119>

- Lu, M., Lei, J., Zhao, D., Ai, Y., Xu, X., & Zhang, G. (2020). SKS Splitting Measurements in NE China: New Insights Into the Wudalianchi Intraplate Volcanism and Mantle Dynamics. *Journal of Geophysical Research: Solid Earth*, 125(3). <https://doi.org/10.1029/2019jb018575>
- Pan, C., & He, X. (2023). Subducting passive continental margins with crustal (ultra)mafic intrusions: An underappreciated mechanism for recycling water back into the mantle. *Earth and Planetary Physics*, 7(5), 1–6. <https://doi.org/10.26464/epp2023074>
- Smyth, J. R., & Frost, D. J. (2002). The effect of water on the 410-km discontinuity: An experimental study. *Geophysical Research Letters*, 29(10), 123-1-123-4. <https://doi.org/10.1029/2001gl014418>
- Sun, Y., Hier-Majumder, S., Tauzin, B., Walter, M., Ballmer, M., Xu, Y., & Kim, S. (2021). Evidence of Volatile-Induced Melting in the Northeast Asian Upper Mantle. *Journal of Geophysical Research: Solid Earth*. <https://doi.org/10.1029/2021jb022167>
- Tang, Z., Julià, J., Mooney, W. D., Mai, P. M., Yu, H., & Wu, Y. (2023). Seismic image of the mantle transition zone beneath northeastern China: evidence for stagnant Pacific subducting slab, lithospheric delamination and mantle upwelling. *Geophysical Journal International*, 235(2), 1872–1887. <https://doi.org/10.1093/gji/ggad335>
- Xu, M., & He, J. (2022). Seispy: Python Module for Batch Calculation and Postprocessing of Receiver Functions. *Seismological Research Letters*. <https://doi.org/10.1785/0220220288>
- YANG Fan, ZHANG Han, LI Juan, WANG Xin, CHEN QiFu. 2021. Topography of mantle transition zone discontinuities beneath Northeast China imaged by receiver function with Ps scattering kernel. *Chinese Journal of Geophysics (in Chinese)*, 64(12): 4406-4424, doi: 10.6038/cjg2021P0213
- Ye, L., Li, J., Tseng, T.-L., & Yao, Z. (2011). A stagnant slab in a water-bearing mantle transition zone beneath northeast China: implications from regional SH waveform modelling. *Geophysical Journal International*, 186(2), 706–710. <https://doi.org/10.1111/j.1365-246x.2011.05063.x>

- Yoshino, T., Manthilake, G., Matsuzaki, T., & Katsura, T. (2008). Dry mantle transition zone inferred from the conductivity of wadsleyite and ringwoodite. *Nature*, 451(7176), 326–329. <https://doi.org/10.1038/nature06427>
- Vinnik, L., Deng, Y., Kosarev, G., Oreshin, S., Zhang, Z., & Makeyeva, L. (2019). Sharpness of the 410-km discontinuity from the P410s and P2p410s seismic phases. *Geophysical Journal International*. <https://doi.org/10.1093/gji/ggz507>
- Wang, F., Chanyshiev, A., Man, L., Song, Y., Wang, L., Ishii, T., et al. (2026). Limits of Water Storage in Stishovite at Deep Mantle Conditions. *Geophysical Research Letters*, 53(13). <https://doi.org/10.1029/2025gl120078>
- Wessel, P., and Smith, W. H. F. (1991). Free software helps map and display data. *Eos Trans. Am. Geophys. Union*, 72(41), 441–446. <https://doi.org/10.1029/90EO00319>
- Zhao, D., Tian, Y., Lei, J., Liu, L., & Zheng, S. (2009). Seismic image and origin of the Changbai intraplate volcano in East Asia: Role of big mantle wedge above the stagnant Pacific slab. *Physics of the Earth and Planetary Interiors*, 173(3–4), 197–206. <https://doi.org/10.1016/j.pepi.2008.11.009>
- Zhang, H., Egbert, G. D., & Huang, Q. (2022). A relatively dry mantle transition zone revealed by geomagnetic diurnal variations. *Science Advances*, 8(31), eabo3293. <https://doi.org/10.1126/sciadv.abo3293>
- Zhang, M., Sun, D. Y., Wang, Y., and Wu, Z. Q. (2019). Fine structure of the 660-km discontinuity beneath southeastern China. *Geophys. Res. Lett.*, 46(13), 7304–7314. <https://doi.org/10.1029/2019GL082639>
- Zhou, B. X., and He, X. B. (2024). No basalt accumulation and segregation atop the 660-km discontinuity beneath the Sea of Okhotsk. *Earth Planet. Phys.*, 8(4), 1–11. <http://doi.org/10.26464/epp2024034>
- Zhu, S., Deng, Y., Xu, Y.-G., Chen, Y., Zhang, Z., Li, H.-Y., et al. (2026). Heterogeneous stagnant slab controls focused crustal recycling and volcanic clustering. *Nature Communications*. <https://doi.org/10.1038/s41467-026-76463-x>