

JGR Solid Earth

RESEARCH ARTICLE

10.1029/2026JB033948

Key Points:

- The Mantle Transition Zone (MTZ) beneath Tibet averages ≥ 0.31 wt.% H_2O , with its southern part in a relatively cold and dry state
- A low-velocity layer atop the MTZ beneath southern Tibet indicates hydrous melt, formed by upwelling of water-rich MTZ material
- This mantle upwelling likely supplied water essential for generating Miocene porphyry copper deposits in the southern Tibetan Plateau

Supporting Information:

Supporting Information may be found in the online version of this article.

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Citation:

Wu, Y., Tian, X., Liang, X., Li, Y., & He, X. (2026). Seismic evidence for hydration of the mantle transition zone beneath Tibet and its implications for water-rich mantle upwelling. *Journal of Geophysical Research: Solid Earth*, 131, e2026JB033948. <https://doi.org/10.1029/2026JB033948>

Received 31 JAN 2026
Accepted 25 AUG 2026

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Seismic Evidence for Hydration of the Mantle Transition Zone Beneath Tibet and Its Implications for Water-Rich Mantle Upwelling

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Abstract Seismic studies have suggested widespread thickening of the mantle transition zone (MTZ) beneath the Tibetan Plateau, which is commonly attributed to the foundering of cold lithosphere. However, the spatial pattern of MTZ thickening does not consistently align with the distribution of high-velocity anomalies, suggesting that other factors, such as hydration, also influence MTZ structure. In this study, we employ a dense broadband seismic array combined with existing regional deployments to obtain improved receiver function images of the MTZ beneath Tibet. After correcting for upper mantle heterogeneity using a recent high resolution tomographic model, we combine MTZ thickness anomalies with mean S-wave velocity perturbations to quantify lateral variations in temperature and water content. Our results show that the MTZ beneath the plateau contains on average at least 0.31 wt.% H_2O and is underlain by a low-velocity layer (LVL) immediately above the 410-km discontinuity. These features exhibit a pronounced north-south asymmetry: the northern MTZ is relative warm and water-rich, whereas the southern MTZ is cooler and drier but overlain by a more extensive LVL. We propose that piece of cold lithosphere sank into the southern MTZ has displaced water-rich mantle material from the MTZ into the upper mantle, leading to dehydration above the MTZ, formation of the LVL, and giving rise to a water-rich mantle upwelling. These processes likely played a key role in generating Miocene porphyry copper deposits in the southern Tibetan Plateau.

Plain Language Summary Beneath the Tibetan Plateau, the mantle transition zone (MTZ)—a layer between about 410 and 660 km depth—is widely observed to be thicker than normal. This thickening has often been attributed to sinking cold lithosphere. However, the pattern of thickening does not always match the distribution of high seismic velocities expected from cold material, suggesting that water also affects the MTZ's structure. In this study, we use receiver functions to map the MTZ thickness beneath Tibet. Combined with seismic velocity models, we estimate variations in temperature and water content. Results show that the MTZ beneath central Tibet holds a significant amount of water—on average at least 0.31% by weight. Both water content and temperature exhibit a clear north–south contrast: the northern MTZ is warmer and more hydrated, whereas the southern MTZ is cooler and drier but overlain by a more extensive melt layer. We propose that sinking lithosphere has displaced water-rich material from the MTZ upward into the upper mantle. This process likely generated a hydrated mantle upwelling beneath southern Tibet, which may have supplied water for the formation of the Gangdese porphyry copper deposits during the Miocene.

1. Introduction

The India–Asia collision since ~ 50 – 65 Ma has produced the Tibetan Plateau (Yin & Harrison, 2000), whose crust reaches a maximum thickness of ~ 80 km (Nábělek et al., 2009; Zhang et al., 2011), which is twice the global average continental value of ~ 40 km (Mooney et al., 1998; Wedepohl, 1995), whereas its lithospheric mantle remains comparatively thin (Zhang et al., 2014). The apparent missing part of mantle lithosphere has motivated different models invoking slab break-off of the subducting Indian plate and convective delamination of Tibetan lithosphere (Chen et al., 2017). Because there is a significant increase in both density and viscosity (Fukao et al., 1992; Ringwood & Irifune, 1988) in the lower mantle beneath the mantle transition zone (MTZ), the subducted or foundered lithosphere fragments may become neutrally buoyant or stagnate within MTZ.

The MTZ, bounded by the 410-km (D410) and the 660-km (D660) discontinuities, is controlled by olivine-wadsleyite and ringwoodite-bridgmanite phase transitions (Ringwood, 1975). There two transitions response

Writing – review & editing: Xiaobo Tian, Xiaofeng Liang, Yibing Li, Xiaobo He

oppositely to temperature: cold anomalies thicken the MTZ; hot anomalies thin it (Bina & Helffrich, 1994). Hydration also exerts a strong influence, as wadsleyite and ringwoodite can have a substantial water content and their hydration both thickens the MTZ and lowers the seismic velocities (Higo et al., 2001; Hirschmann, 2006; Smyth & Frost, 2002). These properties make MTZ topography and velocity structure sensitive tracers of mantle thermochemical state, slab dynamics, and deep water cycle.

Significant thickening of the mantle MTZ has been identified beneath the Tibetan Plateau, spanning multiple tectonic domains including the Lhasa Terrane (Xu et al., 2020; Yue et al., 2012), the Qiangtang Terrane (Duan et al., 2017), and various segmented belts across Southern and Central Tibet (Tang et al., 2024; Wu et al., 2022), which has been attributed to the presence of delaminated continental lithosphere. However, these thickened areas do not consistently correlate with the high-velocity anomalies typically associated with cold lithosphere (Li et al., 2008; Liang et al., 2023; Miao et al., 2024). Since both low temperatures and increased hydration can thicken the MTZ—but hydration decreases mantle velocities—this discrepancy suggests that hydration likely plays a key role in the observed structural variations.

In this study, we leverage a newly deployed dense seismic array in the Lhasa block together with existing regional networks to improve MTZ imaging beneath central Tibet. By applying receiver-function common-conversion-point stacking with corrections from a high-resolution 3D S-wave velocity model, we obtain robust estimates of D410 and D660 depths and reveal a widespread low-velocity layer above D410. We then jointly interpret MTZ thickness anomalies and mean S-wave velocity perturbations to quantify lateral variations in MTZ temperature and water content. These results provide new constraints on the interplay among lithospheric foundering, MTZ hydration, and volatile transport, and allow us to evaluate their role in driving rifting, magmatism, and metallogeny in southern Tibet.

2. Data and Methods

We collected new seismic data from our newly deployed broadband seismic array in the Lhasa block, which is a quasi-linear array comprised of 55 seismometers with a dense station spacing of ~ 10 km (TB30, 2021–2023). The remaining 362 stations belong to previous seismic experiments of SANDWICH (Liang, Tian, et al., 2016), HI-CLIMB (XF, 2002–2005), INDEPTH II and INDEPTH III (XR, 1997–1999), HIMINT (YL, 2001–2002), and Namche Barwa Tibet (XE, 2003–2004), the TP Broadband Experiment (XC, 1991–1992), and Bhutan PASSCAL (XA, 2002–2003) (Figure 1).

We selected teleseismic events with epicentral distances ranging from 30° to 90° and magnitudes greater than 5.0. All raw seismic waveforms were windowed from 10s before to 180s after the theoretical P arrival times and rotated into vertical, radial, and transverse components. We then calculated the radial receiver function using the iterative time-domain deconvolution method (Ligorria & Ammon, 1999) with a Gaussian coefficient 1.0 applied to eliminate high-frequency noise. A total of 68,539 receiver functions (RFs) is obtained after careful manual selection. To check the quality of the RFs, we stack all RFs in 0.001 s/km ray parameter bins from 0.04 s/km to 0.08 s/km (Figure 2). We can easily identify the converted phase from the D410 and D660, which fit well with the theoretical Ps-P time difference based on IASP91 model (Kennett & Engdahl, 1991).

The common conversion points (CCP) stacking approach (Zhu, 2000) was applied to illustrate the MTZ structures. At greater depths, the ray parameters of P arrival cannot represent that of Ps phase accurately, therefore we adopt Ps ray parameters in different depths to calculate the Ps-P time difference (Gao & Liu, 2014a). The ray paths of all the RFs and the locations of piercing points were obtained based on the IASP91 model. The distribution of piercing points at depths of 410 and 660 km is shown in Figure 3a. We stacked the RFs located in a circular bin with a radius of 75 km and a spacing interval of 50 km, then the peaks of P410s and P660s were identified as the maximum amplitudes within specific depth intervals. The number of piercing points within circular bins is shown in Figure 3b. The standard deviations were obtained by the bootstrap approach (Efron & Tibshirani, 1986), with the 95% confidence interval of each bin calculated from 2000 bootstrap results. The thickness of MTZ was estimated as the depth interval between the depths of D410 and D660. Considering the influence of velocity anomalies in the upper mantle, we adopted several 3D models to correct the Ps-P time difference.

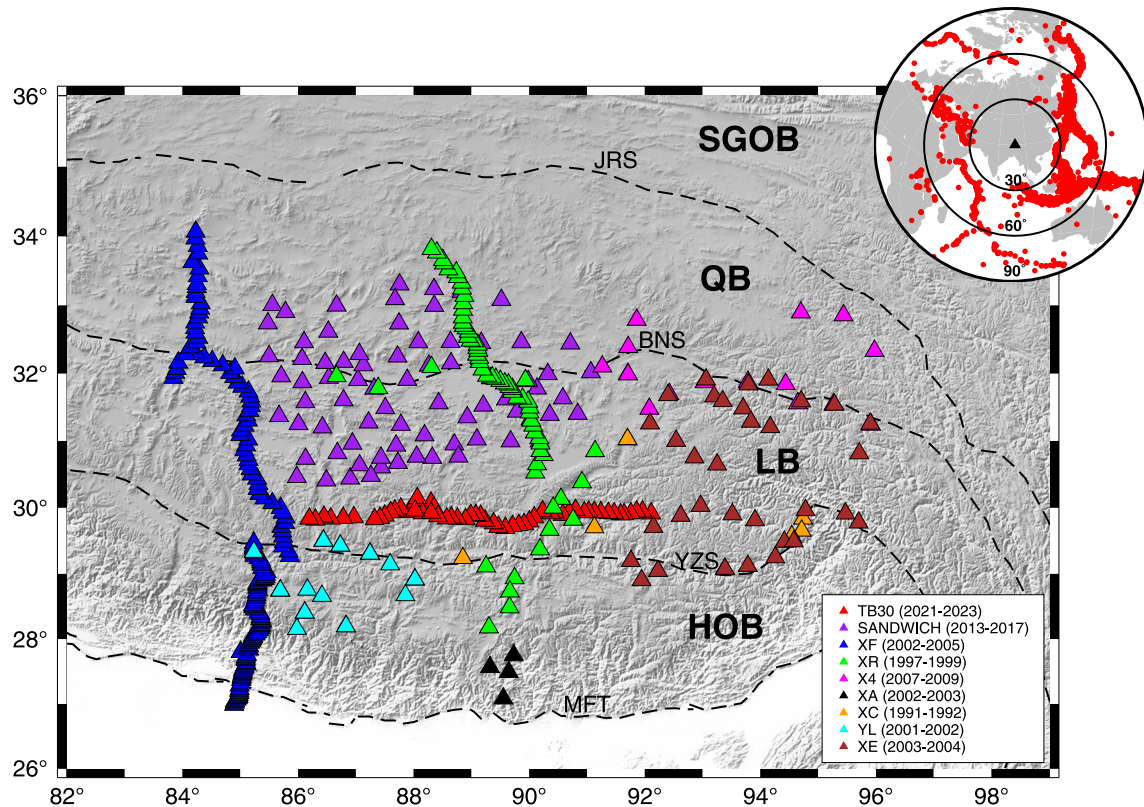


Figure 1. Seismic stations used in this study. The top right inset shows the distribution of teleseismic events used in this study. LB: Lhasa Block; QB, Qiangtang Block; HOB, Himalayan Orogenic Belt; SGOB, Songpan-Ganze Orogenic Belt; MFT: Main Frontal Thrust; YZS: Yarlung–Zangbo Suture; BNS: Bangong–Nujiang Suture; JRS: Jinsha River Suture.

3. Result

In Figure 4, the discontinuity depths and resulting MTZ thickness, obtained from the 1D IASP91 model and subsequently corrected using two 3D tomographic models (Li et al., 2008; Liang et al., 2023). The 3D velocity corrections were performed using Seispy (Xu & He, 2022). Following the approach of Xu et al. (2018), we derived the S-wave velocity anomalies from the P-wave velocity model of Li et al. (2008) using the $\ln V_s - \ln V_p$ relationship established by Cammarano et al. (2003). Both the P-wave and S-wave velocity models of Liang et al. (2023) were utilized for the 3D velocity corrections. The depths of the D410 and D660 obtained from different velocity reference models vary significantly, while the thickness of the MTZ corresponding to different velocity reference models show relatively small differences (Figure 4). The distribution of the discontinuity depths and MTZ thickness are shown in Figure 5. The CCP stacks using the one-dimensional IASP91 model yielded a mean D410 depth of 409.78 ± 9.85 km and a mean D660 depth of 663.34 ± 6.91 km, resulting in an average MTZ thickness of 253.56 ± 9.4 km. For the 3D corrections, applying the Li et al. (2008) model produced a mean D410 depth of 392.84 ± 10.37 km and a mean D660 depth of 647.02 ± 11.3 km with a corresponding MTZ thickness of 254.18 ± 12.9 km, while the correction using the Liang et al. (2023) model resulted in a mean D410 depth of 410.19 ± 9.46 km, a mean D660 depth of 666.12 ± 5.8 km, and an MTZ thickness of 255.93 ± 10.56 km.

To assess the robustness of our discontinuity topography and the effectiveness of the 3D velocity corrections, we calculated the correlation coefficient (CC) between the D410 and D660 depths for each velocity reference model. A low CC indicates that velocity anomalies in the crust and upper mantle have been properly accounted for, as systematic biases from these structures would otherwise cause synchronous upward or downward shifts in both discontinuities, leading to a high CC (Gao & Liu, 2014b). Our analysis (Figure 5) shows that the correction using the Liang et al. (2023) model yields the lowest CC, indicating it is the most effective at removing upper mantle velocity artifacts. This model's superior performance is likely attributable to its seismic dataset, which

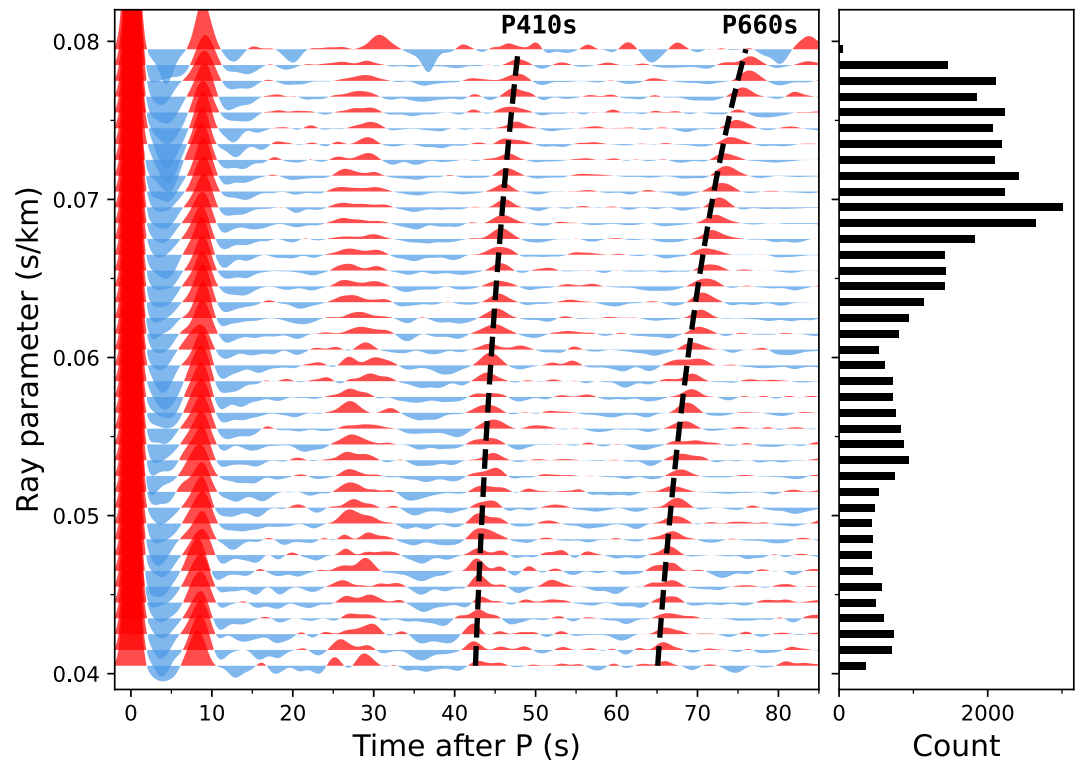


Figure 2. Global images of the amplitude of stacked all RFs. The two dashed lines in the left panel indicate the converted phases from the 410 and 660 km mantle discontinuities, according to the ray parameters of the IASP91 model. The right panel shows the stacking numbers of RFs in each ray parameter.

incorporates all available temporary seismic arrays from the past three decades, thereby significantly enhancing the imaging resolution of deep structures. Therefore, we adopt the corrected CCP results from the Liang et al. (2023) model for our further analysis. The CCP results reveal that thickened MTZ regions are predominantly located in the southern part of our study area (Figure 4i). The comparison in Figure S1 in Supporting Information S1 shows that our observed MTZ thickening zone is generally consistent with the findings of Miao et al. (2024). Across the study region, MTZ thickening is primarily resulted from the depression of the 660-km boundary, with a secondary contribution from the uplift of the 410-km boundary in the southernmost extent. Since MTZ thickness is less sensitive to upper-mantle velocity anomalies, it provides a more robust diagnostic. Consequently, our model conclusions rely primarily on these thickness variations.

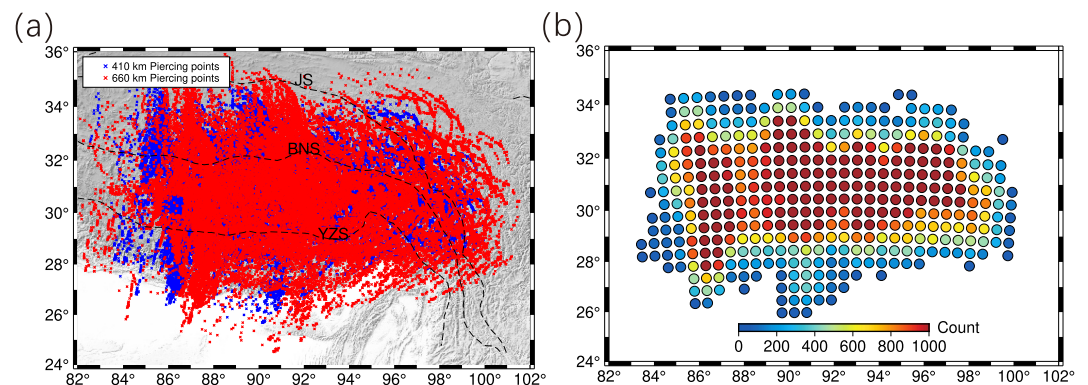


Figure 3. (a) Blue and red dots denote Ps piercing points at 410 and 660 km depth, respectively. (b) Number of piercing points within circular bins where the D410 peaks were selected.

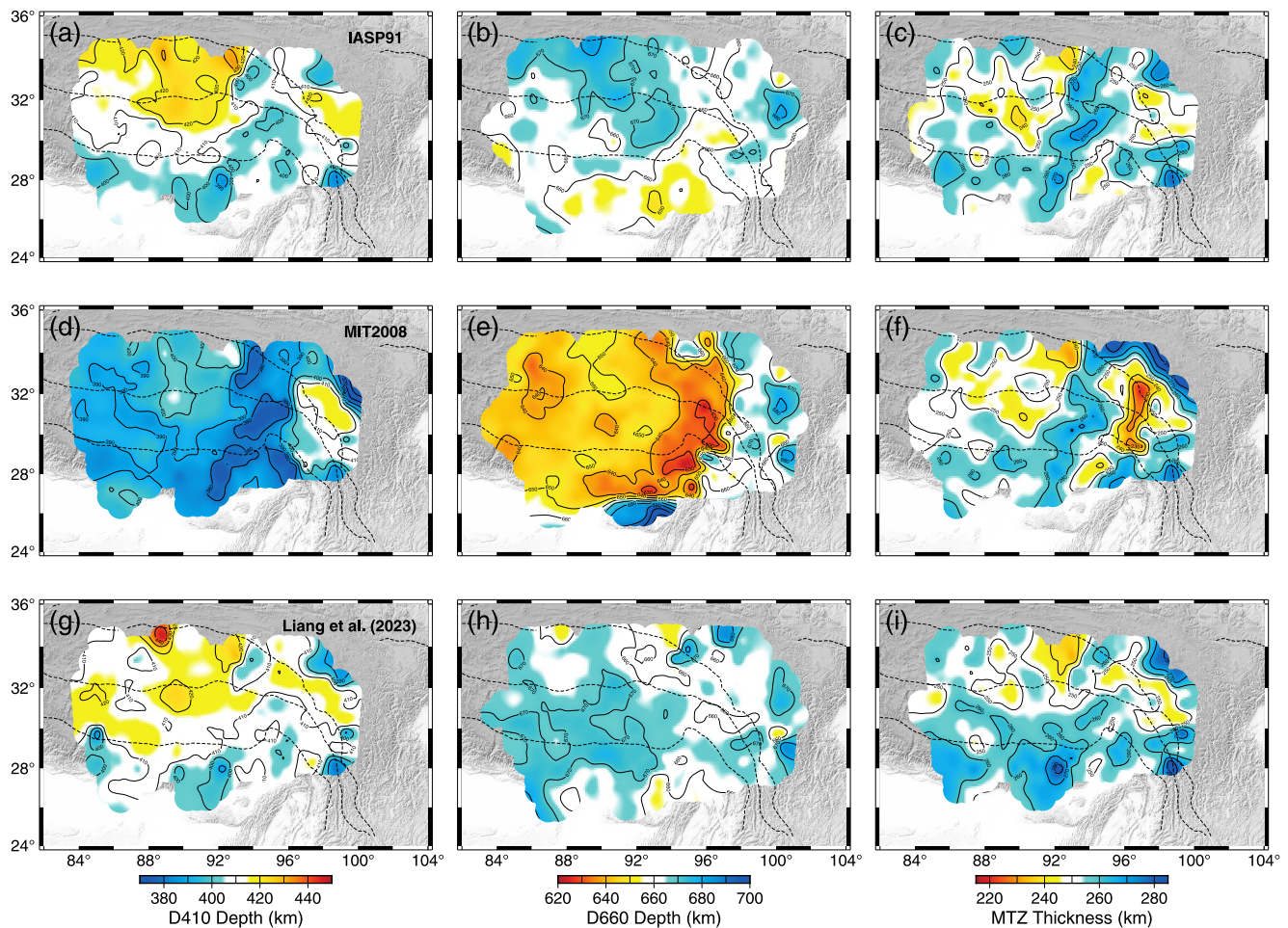


Figure 4. Topographies of the D410, D660, and MTZ thickness derived by (a–c) the IASP91 model, (d–f) the velocity model from Li et al. (2008), and (g–i) the velocity model from Liang et al. (2023).

We further investigated these features by overlapping the velocity model from Liang et al. (2023) onto four profiles across the study area (Figure 6), with the stacking bin sliding at a 25 km interval to better resolve lateral variations in interface depths. While these profiles confirm a strong spatial correspondence between MTZ thickening and high-velocity anomalies in some locations (circles A and B in Figure 6e), they also reveal several areas where significant MTZ thickening is clearly associated with low-velocity anomalies (circle C in Figure 6e). In addition, we have identified negative phases above the D410 in all our profiles. In receiver functions, such a signature of a negative phase overlying a positive one typically indicates a low-velocity layer (LVL).

4. Discussion

4.1. Topography of MTZ

The MTZ beneath the Tibetan Plateau is characterized by widespread high-velocity anomalies, which are interpreted as stalled, cold lithospheric fragments (Chen et al., 2017; Li et al., 2008; Liang et al., 2023). Our analysis reveals a strong spatial correlation between the high-velocity anomalies and significant MTZ thickening (circles A and B in Figure 6e). We argue that this thickened MTZ represents foundered lithospheric material, while its origin remains debated among hypotheses of delaminated Tibetan crust, the Neo-Tethyan slab, or the Indian continental plate (Wu et al., 2022; Xu et al., 2020; Yue et al., 2012). We note that although localized seismic phases near 700 km are observed in the southwestern part of the study area (Figure S3 in Supporting Information S1), potentially corresponding to the garnet-to-perovskite phase transition when basalt fraction is high in the bottom of MTZ (Fukao et al., 2001; Vacher et al., 1998; X. Yang, Xie, et al., 2025), such signals are

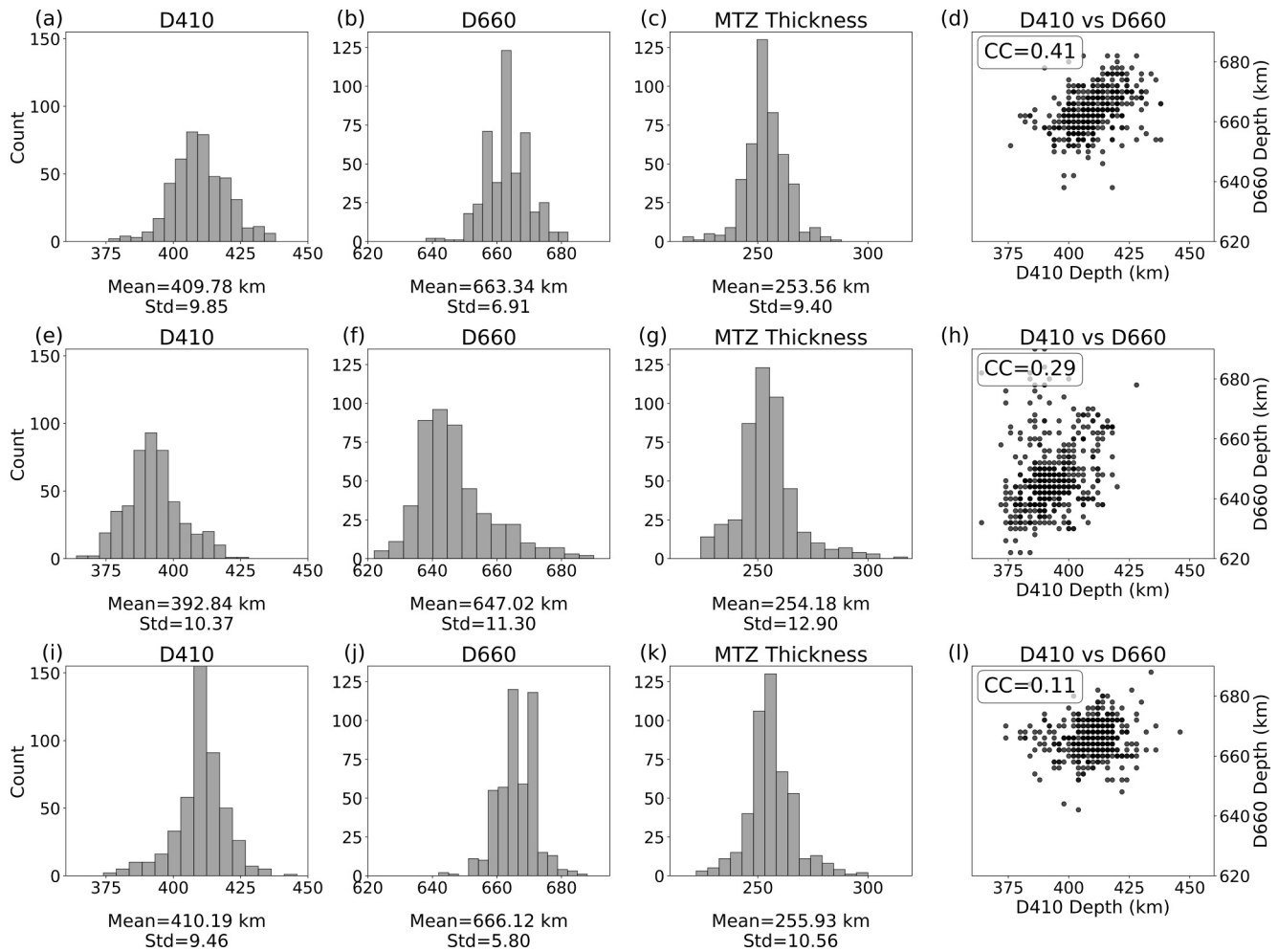


Figure 5. Histograms presenting the distribution of the discontinuity depths and MTZ thickness, and correlation plots between the resulting 410 and 660 depths. Panels (a–d, e–h, and i–l) are the results derived by the 1-D IASP91 model, the velocity model from Li et al. (2008), and the velocity model from Liang et al. (2023), respectively. CC represents the correlation coefficient. The standard deviation is abbreviated as std.

only sporadic. Therefore, we ultimately focused on measuring the discontinuity near 660 km. The MTZ thickening is predominantly concentrated in southern Tibet, with the most pronounced anomaly (>20 km of thickening) centered at 92°E, 28°N (circle B in Figure 6e). Using the Clapeyron slopes from Katsura and Ito (1989) (+3.1 MPa/K for the '410' and −2.0 MPa/K for the '660'), the 20 km of thickening MTZ would imply a thermal anomaly of approximately −150 K.

In contrast, we also observe a significant region of MTZ thinning (>10 km) centered at 93°E, 33°N (circle D in Figure 6e), suggesting a hot mantle upwelling. The sinking of the Neo-Tethyan oceanic slab into lower mantle in the south inevitably drives an lower mantle counterflow, causing this thermal upwelling to the north (Xu et al., 2020). This deep mantle process is likely linked to surface geology, as slab detachment and the resulting mantle upwelling offer a compelling explanation for Cenozoic magmatism in the Lhasa and Qiangtang blocks (Chung et al., 2005).

4.2. Water Content and Temperature Variations Within the Transition Zone

We observe a strong spatial correlation where significant MTZ thickening coincides with low-velocity anomalies (circle C in Figure 6e), which suggests that mechanisms other than low temperatures are responsible for the MTZ thickening. We propose that the presence of hydration is a key factor in these low-velocity regions. To quantify this, we estimate lateral variations in MTZ temperature and water content based on MTZ thickness and mean S-

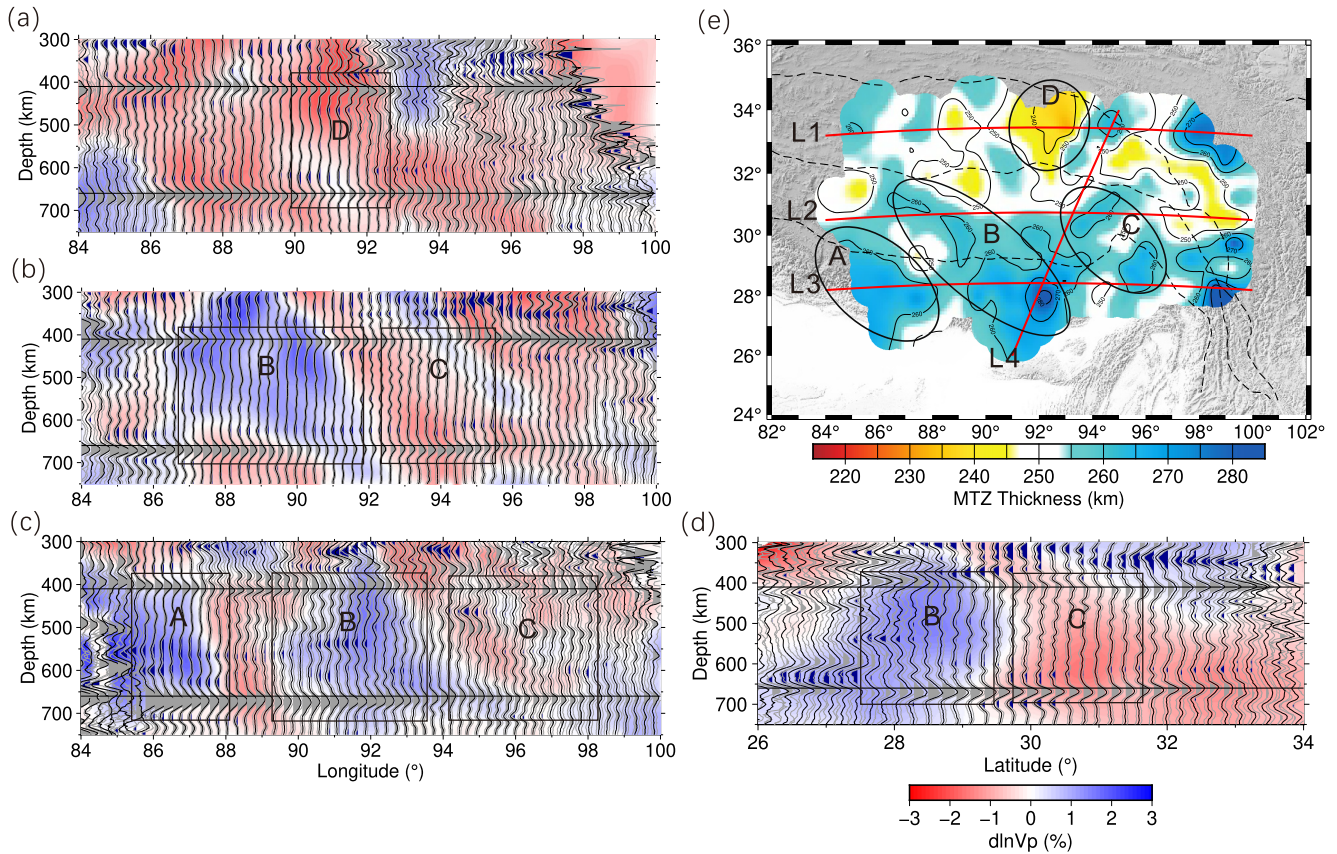


Figure 6. Cross sections created using the CCP Stacking method, with time-delay corrections calculated using the 3-D velocity model from Liang et al. (2023). The red solid lines marked as profiles L1–L4 in (e) correspond to (a–d). Profiles (a–d) are plotted as a conventional receiver function where significant positive and negative arrivals are in dark gray and blue, respectively. The black and gray lines denote the average P-wave receiver functions and their 95% confidence level, respectively, obtained from 2,000 bootstrapping iterations. The black horizontal lines indicate the reference depths at 410 and 660 km. (e) The black circles A and B denote the MTZ thickening region corresponding to high-velocity anomalies, while the black circle C denotes the MTZ thickening region corresponding to low-velocity anomalies, and black circle D indicates the MTZ thinning region.

wave velocity perturbations, following the approach of Meier et al. (2009). Assuming a linear relationship between these parameters, the following system of equations can be written:

$$\begin{cases} \frac{\partial d}{\partial T} \delta T + \frac{\partial d}{\partial H_2O} \delta H_2O = \delta d \\ \frac{\partial \ln V_s}{\partial T} \delta T + \frac{\partial \ln V_s}{\partial H_2O} \delta H_2O = \delta \ln V_s \end{cases}$$

where δd and $\delta \ln V_s$ are observed perturbations in MTZ thickness and mean S-wave velocity, respectively. δT and δH_2O are the water content and temperature anomalies to be determined. The partial derivatives $\partial d / \partial T$, $\partial \ln V_s / \partial T$ and $\partial \ln V_s / \partial H_2O$ are taken from experimental studies (Irifune et al., 2008; Litasov et al., 2006; Smyth & Jacobsen, 2006; Stixrude & Lithgow-Bertelloni, 2005; Schulze et al., 2018; Wang et al., 2021). By further derivation, the relationship between water content and the derivative $\partial d / \partial H_2O$ is as follows:

$$\delta H_2O = \left(\frac{\partial d}{\partial T} \delta \ln V_s - \frac{\partial \ln V_s}{\partial T} \delta d \right) / \left(\frac{\partial d}{\partial T} \frac{\partial \ln V_s}{\partial H_2O} - \frac{\partial \ln V_s}{\partial T} \frac{\partial d}{\partial H_2O} \right)$$

Based on our observed MTZ thickness anomalies (δd) and mean S-wave velocity anomalies ($\delta \ln V_s$) derived from Liang et al. (2023), we can draw a series of curves showing the variation of the water contents with different $\partial d / \partial H_2O$ values (Figure 7). By selecting different $\partial d / \partial H_2O$ values, varying water contents can be calculated.

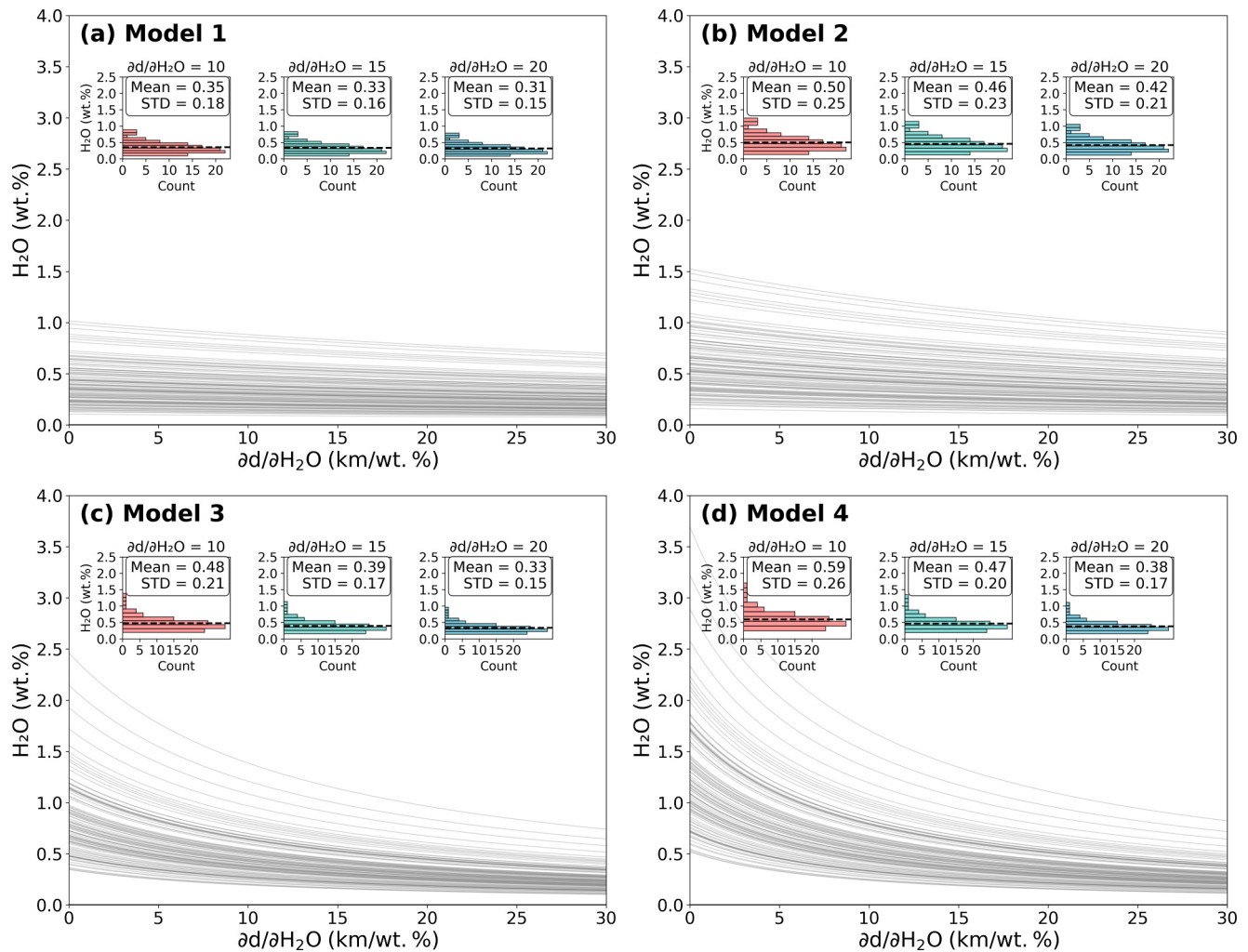


Figure 7. Estimation of water content in the MTZ using different experimental parameters in Table 2. (a–d) correspond to Model1–Model4, respectively. The inset histograms show the statistical results of water content for $\partial d / \partial H_2O$ values of 10, 15, and 20.

The selected parameters are listed in Table 1. By choosing different parameters, we constructed four distinct models (Table 2). The mean water content results calculated by the four models with different $\partial d / \partial H_2O$ values are shown in Figure 7. Our results reveal that the MTZ beneath the plateau contains a minimum average water content of 0.31 wt.%. Based on parameter Model one in Table 2, we obtain the most conservative estimate of water content. The calculated distributions of water content and temperature anomalies based on Model 1 are presented in Figure 8 for a $\partial d / \partial H_2O$ value of 15. Their corresponding standard deviations can be found in Figure S2 in Supporting Information S1.

Table 1
Parameters From Experimental Studies for Water Estimation

Parameter	Value	References
$\partial d / \partial T$	-0.19 km K^{-1}	Litasov et al. (2006)
$\partial \ln V_s / \partial T$	$-6 \times 10^{-5} \text{ K}^{-1}$	Stixrude and Lithgow-Bertelloni (2005)
	$-3.1 \times 10^{-4} \text{ K}^{-1}$	Irfune et al. (2008)
$\partial \ln V_s / \partial H_2O$	$-0.021 \text{ (wt. \%)}^{-1}$	Smyth and Jacobsen (2006)
	$-0.014 \text{ (wt. \%)}^{-1}$	Wang et al. (2021)

Table 2
Parameters Chosen for the Four Different Models

Parameter	Value	Models
$\partial d/\partial T$	-0.19 km K^{-1}	All Models
$\partial \ln V_s/\partial T$	$-6 \times 10^{-5} \text{ K}^{-1}$	Model 1 and Model 2
	$-3.1 \times 10^{-4} \text{ K}^{-1}$	Model 3 and Model 4
$\partial \ln V_s/\partial H_2O$	$-0.021 \text{ (wt.\%)}^{-1}$	Model 1 and Model 3
	$-0.014 \text{ (wt.\%)}^{-1}$	Model 2 and Model 4

4.3. The Low-Velocity Layer Atop the 410 km Discontinuity

The widespread detection of the LVL situated immediately above the D410 is also compelling evidence for a hydrous MTZ. For comparison, we projected the manually picked LVLs onto our CCP results and found that LVLs are notably more widespread in the south (Figure 8a). The presence of such an LVL is a key prediction of the “transition zone water filter” model, which posits that a hydrous MTZ can lead to the formation of a partial melt layer at its upper boundary through hydrous upwelling (Bercovici & Karato, 2003). This feature is particularly prominent in the southern part of our study area, an observation significantly enhanced by our newly deployed TB30 seismic array (Figure S3 in Supporting Information S1).

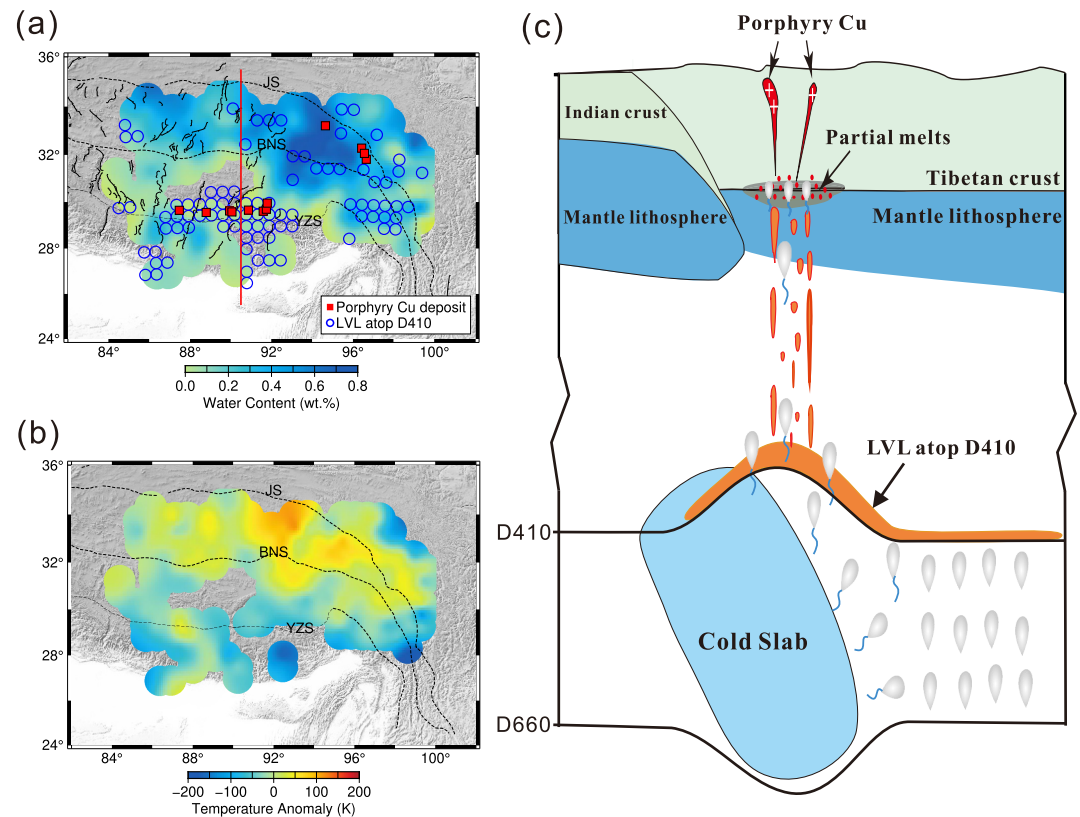


Figure 8. (a) The calculated water content distribution with the low-velocity layer at the top of 410 km is shown by blue hollow circles, porphyry copper deposits indicated by red squares, based on data from Yang and Cao (2024), and the red solid line corresponds to the location of the schematic diagram. (b) The calculated temperature anomalies distribution. (c) The cartoon cross-sections illustrate an overview of the current mantle dynamics beneath southern Tibet. The thickening area of the MTZ with high-velocity anomalies found beneath the Lhasa Block is related to the detached cold continental lithosphere. The low-velocity layer atop the MTZ is related to the hydrous upwelling from the MTZ triggered by the cold slab delamination. The upwelling of hydrous melts from MTZ will further drive the development of the magmatism and mineralization, mainly the porphyry Cu deposits.

To ensure it is not an artifact of data processing, we have rigorously tested the authenticity of the LVL signal of the TB30 array. As shown in Figure S3 in Supporting Information S1, the negative seismic phases corresponding to the top of the LVL are persistent across the profile. By applying slant stacks (Figure S4 in Supporting Information S1), we found that the slowness of the negative phase is greater than zero, which rules out the possibility of them being multiple phases from shallow discontinuity. To further preclude that they are sidelobes of the primary P-to-s conversion at 410 km (P410s), we conducted a multi-frequency analysis by applying varying Gaussian filters (Figure S5 in Supporting Information S1). As shown in Figure S6 of Supporting Information S1, the depth of the negative phase (trough of wave) remains stable across different frequency bands, rather than gradually approaching the P410s phase (wave peak) with increasing frequency. In addition, we do not observe a symmetric sidelobe following the P410s phase. We therefore conclude that the observed negative phases atop the D410 are robust signals representing a distinct structural feature.

To constrain the properties of this layer, we performed synthetic waveform modeling (Herrmann, 2013). By modifying the IASP91 reference model, we found that introducing an LVL with a shear-wave velocity (vs.) reduction of 3%–5% relative to the ambient mantle produces synthetic receiver functions that closely match our observations (Figure S7 in Supporting Information S1). Based on the calibrations of Freitas et al. (2017), a Versus anomaly of −4% within the LVL corresponds to an estimated 0.7% melt, which further implies an H₂O content of 16.5 wt%. An estimated total water content of 0.22 ± 0.02 wt.% in the MTZ source region was further derived by Freitas et al. (2017) using melt-peridotite partition relationships. The discrepancy between our seismological estimate and Freitas et al. (2017) likely stems from methodological differences: they inferred MTZ water content indirectly from shallow mantle melting, whereas we directly linked transition-zone seismic velocities to structural water in nominally anhydrous minerals.

4.4. The Effect of Hydrous MTZ

Our analysis reveals a pronounced north-south asymmetry in the MTZ: the northern MTZ is characterized by higher temperatures and elevated water content, whereas the southern MTZ is distinctly colder and drier (Figures 8a and 8b). However, a prominent LVL is widespread atop the D410 in the south. We attribute this spatial discrepancy—the LVL's presence above the drier southern MTZ rather than the wetter northern MTZ—to localized hydrous upwelling. This dynamic process transports hydrous materials from the MTZ upward, triggering partial melting immediately above the D410. The tomographic results from Liang, Chen, et al. (2016) reveal distinct low-velocity anomalies in the upper mantle, supporting the presence of such upwelling. Comparable partially molten layers atop the MTZ induced by subducted slabs have also been reported beneath northwestern Xinjiang (G. Li et al., 2022) and the Hindu Kush (Li et al., 2023). We propose a dynamic model (Figure 8c) wherein the foundering cold slab drips into the MTZ, perturbing and displacing hydrous mantle material. As this material ascends and crosses the D410, it undergoes decompression melting, generating the observed LVL. This hydrous melt may then continue to ascend, infiltrating the overlying lithosphere. This dynamic mechanism is supported by high-resolution geodynamic simulations (J. Yang, Faccenda, et al., 2025), which found that viscous drag flow driven by the subducting slab can upwell hydrous MTZ materials into the upper mantle and induce dehydration melting.

Deep mantle dynamics, particularly upwelling from the hydrous MTZ, are increasingly recognized as critical drivers of major geological events, including continental rifting, magmatism, and metallogeny (Lv et al., 2024; Yu et al., 2023). This process begins when upwelling from the MTZ transports significant water to the upper mantle, weakening the overlying lithosphere by promoting softening and facilitating crustal extension. Concurrently, this influx of water significantly lowers the asthenospheric solidus, enabling extensive partial melting at lower temperatures than required under anhydrous conditions. This mechanism explains Tibet's magmatic evolution: Paleocene-Eocene magmas were relatively dry during final Neo-Tethyan slab dehydration, whereas Oligo-Miocene magmas became hydrous after slab breakoff, as recorded by 26–8 Ma potassic and ultrapotassic rocks (Wang et al., 2014).

This hydrous magmatism, in turn, has direct metallogenic implications. High magmatic water content is essential for forming magmatic-hydrothermal systems, such as porphyry copper deposits (Hou & Zhang, 2015). The formation of porphyry copper deposits typically requires dehydration of subducted oceanic slabs (Sun et al., 2017). Indian slabs lack oceanic-crust basalts and serpentinites, so they do not contain abundant hydrous minerals (amphibole, serpentine, etc.) and cannot steadily release hydrous fluids at 100–200 km depth the way

oceanic slabs do (Rupke, 2004). Therefore, we suggest that hydrous upwelling from the MTZ was a key mechanism that enriched the upper mantle, produced the necessary hydrous magmas, and ultimately contributed to the formation of southern Tibet's porphyry Cu deposits.

5. Conclusion

By integrating data from newly deployed seismic arrays with existing networks, we have constructed a comprehensive topographic map of the MTZ beneath the central Tibetan Plateau. Through the joint analysis of receiver functions and the tomographic velocity model, we constrained the thermal and water content distribution of the MTZ. Our results indicate a minimum average water content of 0.31 wt.% in the MTZ, characterized by significant north-south heterogeneity, with the northern plateau being notably more hydrated. Structurally, we identified thickened MTZ regions characterized by high-velocity anomalies south of the BNS, consistent with the presence of subducted slab fragments. Furthermore, the detection of a LVL immediately above the D410 suggests the upward release of volatiles from the hydrated MTZ. Based on these new observations, we propose that the upward migration of this hydrated mantle material—potentially triggered by lithospheric delamination—acts as a key mechanism driving the development of the southern Tibetan rift system and its associated magmatism and mineralization.

Our current understanding of the water content and temperature distribution in the MTZ remains subject to limitations to some extent. On one hand, this is partly due to the limited resolution of thickness measurements and seismic wave velocities within the MTZ, as well as the existence of multiple laboratory-derived values for the derivatives of temperature and water content with respect to both thickness and seismic velocity—key parameters essential for solving the relevant models. On the other hand, other factors that may influence the thickness and seismic wave velocities of the MTZ, such as chemical anomalies if exist in the MTZ, have been overlooked in the present study.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Availability Statement

The RFs used in this study are available via (Wu et al., 2026).

Acknowledgments

Thanks to the field team for deploying the seismic stations inside the Tibetan Plateau. We gratefully acknowledge IRIS for sharing part of the data. The migration process is done with Seispy (Xu & He, 2022). We are grateful to all team members involved in this work and we also thank Fan Yang, Mijian Xu, and Shitan Nie for their constructive discussions. We thank Stephen S. Gao and two anonymous reviewers for their insightful comments. This research was supported by the National Key R&D Program of China (Grants 2022YFF0800901) and the National Natural Science Foundation of China (Grants 42450005 and 42030308). Most figures were generated using the Generic Mapping Tools (Wessel et al., 2013).

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