

Geophysical Research Letters®



RESEARCH LETTER

10.1029/2023GL106363

Key Points:

- H - κ - c results reveal two isolated patches with high crustal V_p/V_s in the southern Tibetan Plateau (TP), suggesting crustal partial melting
- The disconnection between the two patches does not support present-day eastward crustal flow in the southern TP
- Correlation with mantle observations indicates that two patches may be related to tearing of the Indian mantle lithosphere

Supporting Information:

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

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Citation:

Gong, J., Li, J., & Li, M. (2023). Isolated crustal partial melting in the southern Tibetan Plateau from H - κ - c method. *Geophysical Research Letters*, 50, e2023GL106363. <https://doi.org/10.1029/2023GL106363>

Received 15 SEP 2023
 Accepted 22 OCT 2023

Isolated Crustal Partial Melting in the Southern Tibetan Plateau From H - κ - c Method

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Abstract The crustal thickness and average V_p/V_s ratio are basic parameters to understand the current state and the tectonic processes in the Tibetan Plateau (TP). We gather receiver functions in the central-southern TP and extract spatial variation of crustal thickness and V_p/V_s ratio using the H - κ - c method with careful quality control and stability analysis. Our results highlight the regions with high V_p/V_s ratios in the central-southern Qiangtang block and two isolated patches around the Yarlung-Zangbo suture, suggesting crustal partial melting. The disconnected high- V_p/V_s patches imply a restrained pattern for present-day crustal flow in the southern TP. Further correlation with mantle observations suggests that the high V_p/V_s region in the north can be attributed to mantle upwelling after lithospheric delamination, and the two isolated patches in the south may be related to the tearing of the Indian mantle lithosphere.

Plain Language Summary The Tibetan Plateau (TP), as the Third Pole, is known for its unusual characteristics and hot debate on how it uplifts and grows. To better understand this, we collect available receiver function data in the central-southern part of the TP, and use an improved method to study the crustal thickness and the average V_p/V_s ratio. The crustal V_p/V_s ratio is a good indicator for partial melting in parts of the crust. In our results, the crust in the central-southern Qiangtang block and two isolated regions near the Yarlung-Zangbo suture has high V_p/V_s ratio, indicating the crust in these areas may have been partially melted. A partially melted crust is favorable for crustal flow to develop, and the crustal flow is considered to be an important mechanism of plateau growth. However, the high- V_p/V_s patches in the southern TP are too disconnected to develop large-scale crustal flow. By comparing with mantle observations, we think the crustal partial melting is related to mantle upwelling and heating, caused by lithosphere detachment in the northern TP and Indian slab tearing in the south, respectively.

1. Introduction

The Tibetan Plateau (TP) is the highest plateau in the world, formed by the Cenozoic Indo-Asian continental collision (Yin & Harrison, 2000). Its diverse geological features provide ample opportunities to study the tectonic processes thereof. Based on previous observations and modeling, different mechanisms for its uplift and growth have been proposed, such as rigid block extrusion (Molnar & Tapponnier, 1975; Tapponnier et al., 2001), continuous deformation (England & Houseman, 1986; P.-Z. Zhang et al., 2004), mid-lower crustal flow (Clark & Royden, 2000; Royden et al., 1997, 2008), convective removal of mantle lithosphere (England & Houseman, 1989; Molnar et al., 1993), tearing of the Indian mantle lithosphere (Chen et al., 2015; Hou et al., 2004, 2006; Li & Song, 2018), and so on. However, these models are still in hot debate. For example, toward the crustal flow model, the connectivity among the interpreted partial melting zones is crucial but not yet well constrained. Previous observations on that are mainly low seismic velocities (e.g., Bao et al., 2015; Huang et al., 2020; Yang et al., 2012), but lower velocity can be caused by many factors (composition, temperature, water or melt content, etc.). Compared to P or S velocity, the ratio between them (V_p/V_s) is considered to be a better indicator of partial melting (e.g., Ji et al., 2019; Watanabe, 1993), and thus an important parameter to probe into. The expanding seismic instrumentation heretofore provides reasonable spatial coverage for seismic study in the central-southern part of the TP, which enables us to gain comprehensive insights into these mechanisms.

The receiver function (RF) embodies near-station structural response by removing the instrument response and the effective source time function from teleseismic waveforms (Langston, 1979). The straightforward exposition of Earth structures makes RF a major tool for investigating the crustal and upper mantle interfaces (Hu et al., 2015). The H - κ method (Zhu & Kanamori, 2000) for RF is commonly used to extract first-order local crustal features due to its direct and quick access to crustal thickness (H) and average V_p/V_s ratio (κ). However,

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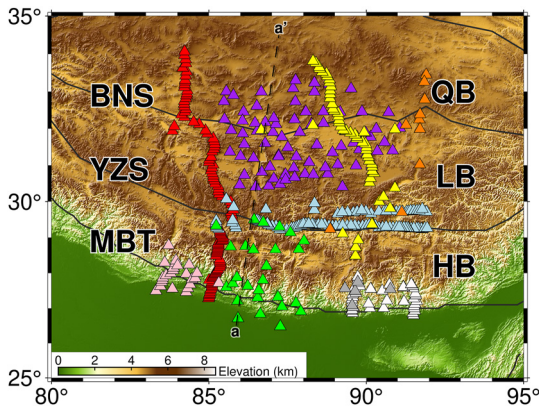


Figure 1. Station distribution and topography of the study region. Triangles represent station locations, with the color indicating the data source: (1) Hi-CLIMB (Himalayan-Tibetan Continental Lithosphere during Mountain Building): red and pink, with the H - κ - c results at red ones sourced from Li and Song (2021); (2) HIMNT (Himalayan Nepal Tibet Seismic Experiment): green; (3) SANDWICH (Seismic Array Integrated Detection for a Window of Indian Continental Head): purple; (4) INDEPTH (International Deep Profiling of Tibet and the Himalaya) II and III: yellow; (5) stations from Shi et al. (2020): light-blue; (6) GANSSER (Geodynamics and Seismic Structure of the Eastern Himalaya Region): white; (7) Bhutan Pilot: gray; (8) complementary stations: dark-orange, including five Tibet 91–92 stations and five INDEPTH IV stations. aa' is the projection line used in Figure 2. Acronym: MBT, Main Boundary Thrust; YZS, Yarlung-Zangbo suture; BNS, Bangong-Nujiang suture; HB, Himalaya block; LB, Lhasa block; QB, Qiangtang block.

in practical applications, the method's presupposition for a flat Moho and isotropic crust may lead to biased results in regions with tilted interfaces and/or anisotropic medium (Hammond, 2014; Kaviani & Rumpker, 2015; Li et al., 2017, 2019). To address this limitation, Li et al. (2019) proposed a generalized H - κ - c method, which utilizes harmonic correction to adjust time shifts in RFs caused by dipping interfaces and crustal anisotropy before H - κ stacking. Applications of the H - κ - c method to different tectonic regions, such as the South China (Deng et al., 2019; Han et al., 2023), the Tien Shan (Cui et al., 2022; B. Zhang et al., 2020), the central-western TP (Li & Song, 2021), the eastern TP (Tan & Nie, 2021), and the Central Midcontinent in US (Xiao et al., 2022), have demonstrated its wide applicability.

Here, to investigate the arc-perpendicular and arc-parallel variation of H and κ in the central-southern TP, our study region (Figure 1), which is close to a rectangular, cuts across the Himalaya block (HB), the Lhasa block (LB), and the central-southern part of the Qiangtang block (QB), from south to north, covering ~ 83 – 92°E from west to east. These blocks are bounded or separated by the Main Boundary Thrust (MBT), the Yarlung-Zangbo suture (YZS), and the Bangong-Nujiang suture (BNS), respectively (Yin & Harrison, 2000). Our results provide comprehensive spatial variations on H and κ in this region, forming the largest data set with the highest resolution from receiver functions here to date. The results offer updated constraints for characterizing the block differences, the transitional features near block boundaries, as well as the localized anomalies, and particularly highlight two isolated patches with possible partial melting in the southern TP.

2. Data and Methods

The P-wave receiver functions (P-RFs) in this study are retrieved from a series of seismic networks over the years in the central-southern TP (see Table S1 in Supporting Information S1 for detailed information). While many of them are collected from previous studies, RFs at GANSSER, Bhutan Pilot and five INDEPTH IV stations are newly processed to fill in the data gaps at the southeast and northeast corners. The seispy code (Xu & He, 2022) is utilized to calculate the RFs. We request ZNE-component waveform data from IRIS for events with a magnitude of 5.5 or greater and an epicentral distance between 30° and 95° . Waveforms are detrended, filtered to 0.05–2 Hz frequency band, rotated to the ZRT (Vertical, Radial, Transverse) coordinate system, and calculated to radial and transverse RFs using the time-domain deconvolution method (Ligorria & Ammon, 1999) with a Gaussian factor of 2.5. Subsequently, anomalous RFs (e.g., containing abnormal low-frequency oscillation or unrealistically large pulse) are also manually checked and removed. Finally, RFs at 364 stations are processed with the H - κ - c method in this study.

Given that the time-separation between P and Ps phase (or multiples) will shift relative to back-azimuth (BAZ) due to dipping interfaces and/or crustal anisotropy, the H - κ - c method (Li et al., 2019) uses harmonic fitting to correct the RFs before H - κ stacking. To examine the stability of grid-searched harmonic parameters relative to the grid-searching window, we disturb the reference model to obtain the perturbations of outputs (harmonic parameters, plus H and κ). The best corrections are chosen according to the following aspects: (a) waveform clarity along harmonic fitting curves; (b) discrepancy in time-separations obtained by H - κ formulas (Zhu & Kanamori, 2000) and harmonic corrections; (c) spatial smoothness of Ps-P time separation and crustal thickness between an ambiguous station and its nearby stations. Additionally, stations would be discarded when meeting the following criteria: (a) maximum BAZ deficiency exceeding 120° ; (b) RFs strongly affected by thick sediments (e.g., Li & Song, 2021); (c) indistinguishable Ps-like signals in RFs. It is noteworthy that Rumpker et al. (2014) suggested 90° as a threshold for the BAZ gap to ensure the recovery of the $\cos 2\theta$ feature. We choose the BAZ gap threshold of 120° instead, to compromise the limited spatio-temporal span of instrumentation hitherto in TP. Figure S2a in Supporting Information S1 shows the resulting data coverage under different thresholds. Text S1 in Supporting Information S1 discusses the influence of such compromise, in terms of a forward modeling test using Raysum code (Frederiksen & Bostock, 2000) and H - κ - c results under different BAZ gap thresholds.

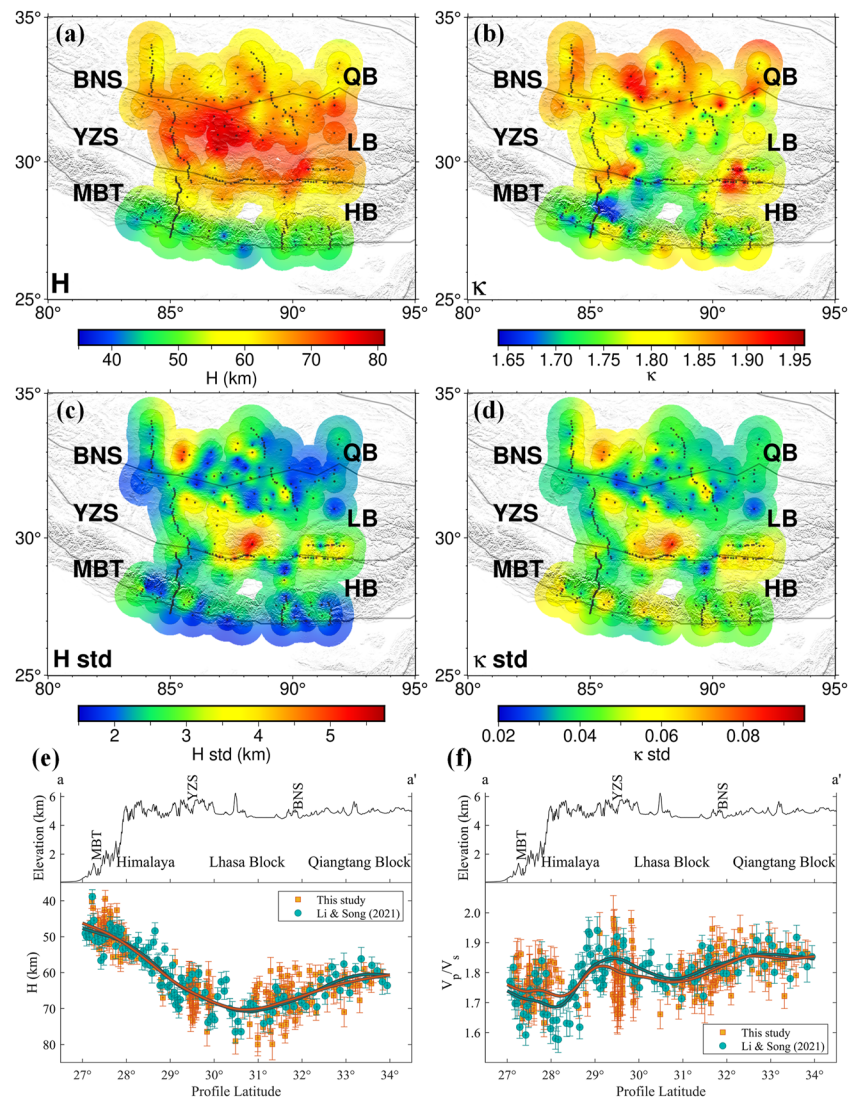


Figure 2. The H - κ - c results in the central-southern Tibetan Plateau. Upper panels: Spatial variation of (a) crustal thickness H and (b) V_p/V_s ratio κ . Black dots represent stations used for interpolation. The opaque-colored regions, bounded by gray contours, indicate areas within 45 km of the stations. The translucent colored regions outside gray contours indicate areas within 45–90 km of the stations. Middle panels: Uncertainty of H - κ stacking for (c) H and (d) κ , respectively. Lower panels: (e) H and (f) κ projected onto profile aa' in Figure 1. The colored curves are smoothing spline fits for the measurements. The projection is carried out along body-fitted grids (Figure S1 in Supporting Information S1) bounded by block boundaries.

A Matlab app Hkc-Pick is developed to streamline the screening and archiving process. Following the selection process, 230 newly processed stations are preserved. Together with 122 Hi-CLIMB stations where H - κ - c results are already provided by Li and Song (2021), a final set of H - κ - c results at 352 stations are adopted for further analysis.

3. Results

The spatial variation patterns and uncertainty estimates of H and κ from the H - κ - c method are shown in Figure 2. To better display the variations in H and κ from south to north, we project all results onto profile aa' in Figure 1, which is parallel to the direction of Indo-Asian collision (i.e., arc-perpendicular) in the study region (Figures 2e and 2f). The projection is carried out along body-fitted grids (Figure S1 in Supporting Information S1) bounded by the MBT, YZS, and BNS. The uncertainty estimates (standard deviations) for H and κ are shown in both map view (Figures 2c and 2d) and profile view (Figures 2e and 2f) as well. Most of the stations present similar

uncertainty levels, although three stations with both large uncertainties in H and κ are preserved to compromise the limited station coverage there. Figure S10 in Supporting Information S1 compares the uncertainty estimates before and after the harmonic corrections. Overall, the standard deviations of H and κ are reduced from an average of ~ 4.16 km, ~ 0.065 to an average of ~ 2.57 km, ~ 0.045 , corresponding to $\sim 62\%$ and $\sim 51\%$ variance reduction in H and κ , respectively.

Our results for crustal thickness (H) are consistent with those of Li and Song (2021), as they exhibit similar tendencies along the collision direction. The crust thickens rapidly in the HB, increasing from ~ 45 km in the southernmost to ~ 65 km in the northernmost HB. The crustal thickness undulates gently from the YZS to the central-southern QB. The average H (the fitting curves in Figure 2e) reaches a maximum of ~ 70 km in the LB and decreases to ~ 62 km in central-southern QB. The spatial variation of H also reveals apparent arc-parallel undulation within the LB. In the central LB, the H reaches the maximum value of ~ 80 km at $86.5\text{--}88.0^\circ\text{E}$ and decreases outwards.

Different from H , the κ shows more arc-parallel undulations (Figures 2b and 2f). The averaged arc-perpendicular trend of κ in this study is similar to the trend from Li and Song (2021), though the absolute values for each part could differ. In general, the κ is relatively low in the central-southern HB. The two sutures and the central-southern QB present a higher average κ compared to the central-southern HB and the central LB. Besides, our results show a more scattered pattern in the plateau interior compared to Li and Song (2021) along the projected profile (Figure 2f). The most scattered part can be found at the YZS, which is characterized by two high κ regions near 86°E and 91°E (>1.85 and averaged ~ 1.91), respectively, separated by a low κ region (averaged ~ 1.73) in between.

4. Discussion

4.1. Different H and κ Patterns Among Blocks and Sutures

A quantitative description of the overall feature of H and κ across the Tibetan blocks and sutures is carried out by considering block boundaries with a certain width (Table S2 and Figure S3 in Supporting Information S1). We calculate the range and the root-mean-square error (RMSE) for the fitted arc-perpendicular trend in Figures 2e and 2f. Several differences among these compartments are clearly revealed, as discussed below.

From the MBT to HB (till the YZS), H shows rapid crustal thickening, with smaller lateral variation than its arc-perpendicular uplift (Figure 2a). However, κ shows salient lateral scatteredness. An east-west propagation separated by the Sikkim region (around 88.5°) can be observed, with lower κ in the west and higher in the east in general (Figure 2b). The low κ values in the Nepal region were also reported by Zhou (2013). The separation is also reflected by the time separations of Moho-related phases in an arc-parallel view (Figures S4c and S4d in Supporting Information S1), and observed in arc-parallel gravity anomaly (Hetényi et al., 2016). The mechanism for the segmentation in the HB remains unclear. One possible cause is the concomitant mechanical effect from the subduction of the Indian basement ridges during the Indo-Asian collision (Dal Zilio et al., 2020).

Near the YZS, lateral variation in H is moderate (Figure 2a). Two isolated patches of high- κ values stand out, which may indicate localized crustal partial melting (Figures 2a and 3a). The existence of the western patch (P2 in Figure 3) has been previously reported by several works (e.g., Li & Song, 2021; Yang et al., 2022; Zhou, 2013) using the Hi-CLIMB array. In this study, its possible lateral extension is well depicted by combing more nearby arrays. The eastern patch (P1) is robustly observed for the first time with the updated station coverage, although two local high- κ points have been found in some previous studies with sparse stations (Yang et al., 2022; Zhou, 2013). See Sections 4.2 and 4.3 for more detailed discussions about the mechanism of the two high- κ patches.

The LB, or more accurately, the central part of the LB (shown approximately by the trapezium in Figure 3), reaches the thickest crust, averaged ~ 70 km and maximum ~ 80 km (Figure 2a). The challenge of sustaining such an extremely thick crust requires higher crustal strength and differentiation level, as well as lower heat production (Jaupart et al., 2016; Mareschal & Jaupart, 2013), especially for the crust near the maximum. The κ is at an intermediate to relatively low level (averaged ~ 1.78) among the κ measurements within the plateau (Figure 2b), which may indicate limited crustal partial melting in the central LB, and the crust of the central LB might be mechanically stronger in general compared to the QB and parts of the YZS.

The crustal thickness of central-southern QB is relatively homogeneous in the arc-parallel direction and gradually thinning along the arc-perpendicular direction (Figure 2a), as indicated by a wider range for the fitted

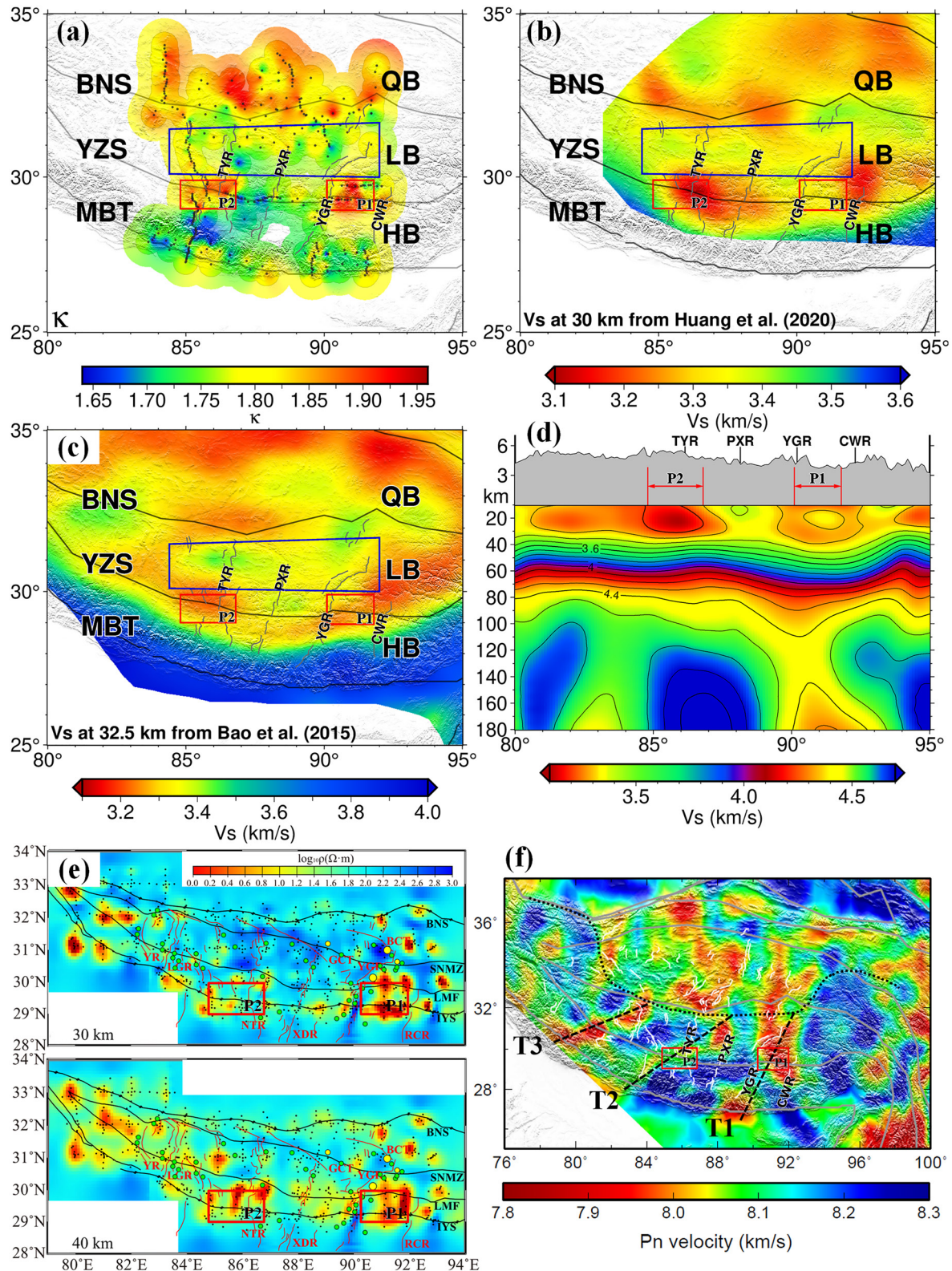


Figure 3. Comparison with other geophysical observations. The blue trapezium depicts a rough depiction of the central part of the Lhasa block. Red rectangles mark two high- κ patches near the Yarlung-Zangbo suture (YZS). (a) κ variation map from our H - κ - c results (same as Figure 2b). (b) V_s slice at 30 km depth from Huang et al. (2020). (c)–(d) V_s slice at 32.5 km depth and cross-section along the YZS, respectively from Bao et al. (2015). (e) Horizontal slices of 3-D electrical resistivity model at 30 and 40 km depth sourced from Jin et al. (2022). (f) Pn velocity map from Li and Song (2018). Selected surface rifts in the southern Tibetan Plateau (Styron et al., 2010) are also plotted. Acronyms: TYR, Tangra-Yumco rift; PXR, Pumqu-Xainza rift; YGR, Yadong-Gulu rift; CWR, Cona-Woka rift.

arc-perpendicular trend (60.3–64.4 km) compared to a smaller RMSE (2.91 km; Table S2 in Supporting Information S1). The central-southern QB and the BNS present primarily high κ values (averaged ~ 1.85 ; Figure 2b), which may suggest crustal partial melting. The high- κ regions in this area seem to be more connected compared to those along the YZS, but the lateral station coverage here is not as dense. Thus, it requires even higher resolution/coverage to evaluate the connectivity of possible partial melts in the northern TP.

4.2. Implications on Partial Melting and Crustal Flow

We observe three regions with particularly high crustal V_p/V_s ratios (>1.85), one large area north of the BNS, and two isolated patches (P1 and P2) near the YZS (Figures 2b and 3a). To further evaluate the validity of the two localized patches, we perform bootstrap tests for the high- κ stations ($\kappa > 1.85$) near the YZS (Figures S7a and S7b in Supporting Information S1). The range for κ standard deviation is 0.011–0.055 from bootstrap results, which is comparable to the corresponding uncertainty estimates from H - κ - c stacking (Figure 2d and Figures S7c and S7d in Supporting Information S1; 0.024–0.077 for range). Figures S7a and S7b in Supporting Information S1 also indicate that for most bootstrapped stations, the κ ranges considering the uncertainty level are higher than 1.85 (with only four exceptions which have minimums of 1.81–1.84). Therefore, both ways of uncertainty estimation confirm that these high- κ values are robust measurements.

Liu et al. (2021) inferred the crustal-averaged κ value of 1.85 would allow the existence of a ~ 20 -km-thick crustal flow layer based on the V_p/V_s ratio under 8% melt fraction (Jamieson et al., 2011; Watanabe, 1993). Therefore, these high- κ regions in our study would be favorable to crustal partial melting. To further entrench the existence of crustal partial melting, different observations are required, as anomalies in a single geophysical property can be attributed to various causes.

In the northern TP, widespread crustal partial melting in the QB and the Songpan-Ganzi block has been proposed based on low velocity zones (LVZs) in the mid-crust (e.g., Figures 3b and 3c), low resistivity (e.g., Dong et al., 2020; Rippe & Unsworth, 2010; Unsworth et al., 2004), strong L_g attenuation (L.-F. Zhao et al., 2013), and geochemical observations for varied eras (e.g., Q. Wang et al., 2016; Wu et al., 2019). These observations are often considered to indicate the possible eastward crustal flow from the plateau interior, just as how this end-member model was elucidated (Royden et al., 1997, 2008). Our results of high- κ values in the central-southern QB are consistent with these observations. However, for partial melting zones to be able to flow, one necessary (but not sufficient) condition is connectivity, as the proposed crustal flow cannot be facilitated by fragmented partial melts. The observations listed above seem to have reasonable connectivity to some extent (e.g., Figures 3a–3c), but as mentioned above, the data coverage in the northern TP may not be dense enough, so further validation is still needed.

In the southern TP, the existence of crustal partial melting regions P1 and P2 is further supported by LVZs in the mid-crust (e.g., Figures 3b–3d; the exact locations may differ in different models due to data/method discrepancies), low resistivity (Figure 3e, Jin et al., 2022; Rippe & Unsworth, 2010; Sheng et al., 2022; G. Wang et al., 2017 for P1; Sheng et al., 2019; Wei et al., 2010 for P2), and high seismic attenuation near P1 (Sharma & Mitra, 2018; Xie et al., 2004; L.-F. Zhao et al., 2013). However, the two regions seem to be isolated, which limits the flowability toward certain directions, as discussed below.

Firstly, a conspicuous intermediately low- κ region (averaged ~ 1.73) intervenes between the two high- κ patches (averaged ~ 1.91). Relatively higher mid-crustal velocity in this region is found in different V_s tomography results (e.g., Figures 3b–3d), and relatively higher resistivity is also observed here (Figure 3e, Jin et al., 2022; Wei et al., 2010 for the west of P1). Besides, discontinuous mid-crustal LVZs in this region are shown by migration, amplitude analysis and waveform inversion of RFs (Hetényi et al., 2011). These indicate a limited east-west flowability between P1 and P2, as the allowable partial melting layer could be much thinner and/or insufficient in melt fraction between them. Therefore, the observed disconnection between the two patches does not support present-day eastward crustal flow in the southern TP.

Secondly, the central LB mainly presents an intermediate to relatively low κ level (averaged ~ 1.78 , Figure 3a), which limits the extent of partial melting. Previous magnetotelluric results reveal an apparently increased resistivity (and thus inferred viscosity) throughout the crust at the northern LB (Dong et al., 2020; Rippe & Unsworth, 2010), which is adverse to a north-south flow across the LB. Moreover, the large-scale high velocity zones (Figures 3b and 3c) in the LB may indicate preexisting rigid zones, as suggested by various studies (Huang

et al., 2020; Lu et al., 2022; Sheng et al., 2019; Zhu et al., 2011). These zones could potentially impede the development of crustal flow. In a word, we suggest a limited north-south present-day crustal flow across the LB within our study region, compatible with the inference by Dong et al. (2020) and Nie et al. (2023).

Our findings indicate the current crustal rheology in the southern TP is less likely to be dominated by the eastward crustal flow as illustrated by Royden et al. (2008), neither by a direct large-scale eastward flow here, nor by joining the possible eastward flow in the northern TP. If dominant crustal flow had existed in the southern TP at earlier stages, this would indicate a declining process of crustal flow has taken place here. If crustal flow is a less well-developed process in the southern TP throughout, this would call for a revision of a more detailed crustal flow model at the southern TP. Meanwhile, we need to point out that our results can not exclude the existence of crustal flow in other parts of the TP (e.g., the northern or the eastern TP) or possible flow directions for places lack of sufficient data coverage (e.g., an eastward flow from P1 or westward flow from P2).

4.3. Mantle Contribution to Crustal Partial Melting

In the northern TP, the delamination of the mantle lithosphere under the QB and the Songpan-Ganzi block, followed by the upwelling of the asthenosphere, is suggested by various observations (e.g., Bao et al., 2015; Jiménez-Munt et al., 2008; Owens & Zandt, 1997; Tilmann et al., 2003; Turner et al., 1993). These processes would enhance the heat transfer from the asthenospheric mantle and contribute to partial melting in the crust. The prevailing high- κ feature of the central-southern QB in our results is consistent with this interpretation (Figure 3a). However, the above explanation does not work for the two isolated patches in the south, since it is generally considered that the Indian mantle lithosphere has underthrust at least passing the YZS (e.g., Li & Song, 2018; Liu et al., 2020; Nábělek et al., 2009; Wei et al., 2016; B. Zhang et al., 2023; J. Zhao et al., 2010). Therefore, no large-scale mantle upwelling exists in the southern TP and different mechanisms are required for these isolated patches.

In addition to crustal observations for isolated partial melting at P1 and P2 (Section 4.2), mantle observations also provide some new insights. Lithospheric scale V_s profile (Figure 3d) suggests the linkage between mid-crustal LVZs and mantle LVZs, which can be further associated with Pn LVZs in the uppermost mantle (Figure 3f; Li & Song, 2018). The mantle LVZs can also be observed in the V_s model by Chen et al. (2015) and the V_p model by Wei et al. (2016) (Figure S11 in Supporting Information S1). Li and Song (2018) proposed that these mantle LVZs are resulted from the tearing of the Indian mantle lithosphere. Among the proposed tears, T1 coincides with P1, and T2 coincides with P2 (Figure 3f and Figure S11 in Supporting Information S1). The slab tearing can exert various influences on the overriding crust, including thermal impacts, as delineated by geological and geochemical studies (e.g., Hou et al., 2006, 2023; R. Wang et al., 2022). This indicates the isolated crustal partial melting patches may be attributed to the crustal response to slab tearing and subsequent localized mantle upwelling through the tearing belts. Note that such a competitive mechanism for crustal partial melting raises more careful evaluation when trying to validate the crustal flow model from present-day geophysical observations, as slab tearing is proposed to be a more recent event than outward growth of the TP (Ding et al., 2022).

While slab tearing can provide a reasonable explanation for isolated crustal partial melting in the southern TP, it is worthwhile to discuss why no salient partial melting belts across the whole LB are observed, since the traces of tearing belts seem to cross over it (Figure 3f). A possible explanation is that the crust near the YZS is considered to be juvenile, while the central LB retains older crustal composition (Lu et al., 2022; Zhu et al., 2011), which leads to differences in inhibiting the intrusion of hot material and conductive heat transfer from the asthenosphere.

5. Conclusion

We construct updated maps of crustal thickness and V_p/V_s ratio in the central-southern TP by applying the H - κ - c method to accessible RF data. Careful quality control processes based on the traits of H - κ - c procedure are adopted to better extract first-order features in this region. Our results show that the crustal thickness takes a rapid increase of ~ 20 km in the HB, reaching the maximum of ~ 70 km on average in the LB, and then gently decreases northward. The V_p/V_s ratio measurements show more arc-parallel variations. High V_p/V_s regions (>1.85) occur in the central-southern QB and two patches near the YZS, which indicate possible crustal partial melting. The generally high V_p/V_s feature in the central-southern QB can be attributed to mantle upwelling after lithospheric delamination, and the two isolated high- V_p/V_s patches in the south may be related to localized upwelling from tearing

of the Indian mantle lithosphere. Our results, together with other seismic velocity and resistivity observations, suggest that a present-day eastward crustal flow near the YZS is not supported due to the disconnection between the isolated melting regions, and also a limited north-south crustal flow across the LB within our study region.

Data Availability Statement

The figures were prepared using Generic Mapping Tools (Wessel et al., 2019a, 2019b; licensed under LGPL version 3 or later, available at <https://www.generic-mapping-tools.org/>) and Matlab 2022a (The MathWorks Inc, 2022). The modified H - κ - c code with stability analysis, associated with this manuscript, is licensed under Creative Commons Attribution 4.0 International and available at <https://doi.org/10.5281/zenodo.8158700> (Gong et al., 2023a). The Matlab app Hkc_Pick (version 1.0.0) for selecting stability analysis results and archiving H - κ - c results is licensed under MIT and available at <https://doi.org/10.5281/zenodo.8158587> (Gong et al., 2023b). The H - κ - c results and newly processed receiver functions in this study are provided as supplementary data sets. Figures for H - κ - c results can be downloaded from <https://doi.org/10.5281/zenodo.8317789> (Gong et al., 2023c).

Acknowledgments

We appreciate the Editor Lucy Flesch and two anonymous reviewers for the detailed constructive suggestions and comments, which helped to improve this article greatly. This study is funded by the National Natural Science Foundation of China (42174069, U1939204), and the National Key R&D Program of China (2022YFF0800601). We thank Lupei Zhu, Yuming Zhou, Danian Shi, Zhen Liu, and Shitan Nie for providing the array RF data. We benefited from discussions with Xiaodong Song, Yangfan Deng, Yudi Pan, and Yu Zhang.

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