

Response to Reviewer 1 Comments

We thank the reviewer for the thorough review and constructive comments, which have significantly helped improve the quality of our manuscript. We have carefully considered all points raised. Our point-by-point responses and the planned revisions are detailed below.

General Comments:

We acknowledge the comment regarding the need for careful English editing. We thoroughly revised the entire manuscript to improve clarity, readability, and adherence to the conventions of scientific writing. This includes correcting colloquial expressions, improving grammatical accuracy, and ensuring a formal tone throughout.

Q1: In lines 58–66 of the introduction, the text appears to summarize the main conclusions of the study. It may be more appropriate to move this content to the conclusion section.

Response: Agreed. We reorganized the “Introduction” section, and deleted the summary of the main conclusions from the introduction. The introduction was revised to maintain its focus on presenting the research problem, context, and objectives.

Q2: The manuscript states that the crustal-upper mantle structure remains ambiguous due to limited resolution. Could the authors clarify the actual resolution of the present data and indicate whether it is higher than in previous studies? Additionally, please specify which aspects remain unresolved and how this study’s findings differ from prior work.

Response: Our data provides higher resolution of velocity structure in the same study area. Compared to the “Golmud-Ejin” wide-angle reflection and refraction profile acquired in 1992, we used dense shot interval and station spacing, and higher yield explosive. The geophones we used are much more sensitive to the seismic waves than the ones before (the detailed parameters are shown as follows).

Seismic profile	Shot interval	Station spacing	TNT	Record medium
Golmud-Ejin	80-200 km	4 km	1.5 T	Tape
This study	40-60 km	2-3 km	1.5-3 T	Digital

Q3: Please note that in scientific writing, en dashes (–) rather than hyphens (-) should be used to indicate numerical ranges (e.g., 0.3–1.0 km/s). Please pay attention to the use of definite articles (e.g., ‘the’) to improve grammatical accuracy. Additionally, check the capitalization of all proper nouns, including geographic names, tectonic units, and geological terms, and maintain consistency throughout the manuscript.

Response: We performed a thorough check and correction of the entire manuscript to: 1) replace all hyphens with en dashes in numerical ranges, 2) carefully review and

correct the use of definite articles ('the') for grammatical accuracy, and 3) standardize the capitalization of all proper nouns and ensure consistency throughout the text.

Q4: In the “Crustal Velocity Structure Implications” parts, how does this velocity value inform the structure implications? Providing explicit links between the velocity data and geological implications would strengthen this section.

Response: We considered that placing the “Crustal Velocity Structure Implications” between the “Velocity Structure” and “Discussion” sections was somewhat structurally unconventional. To improve the logical flow of the manuscript, this subsection has been integrated into the “Introduction” section.

Q5: “The crustal velocity structure proposes an unusual scenario where the deepest Moho is found in the central Jiuquan basin, rather than the North Qilian Shan with the highest elevation. Could you explain it in the manuscript?”

Response: Yes, we have carefully considered this observation. We propose that the North Qilian Shan and the Jiuquan Basin share a common basement, which explains their comparable Moho depths. Although the Moho beneath the Jiuquan Basin is slightly deeper, the North Qilian Shan exhibits a higher surface elevation, indicating a significantly thicker crust overall when topographic compensation is taken into account.

Q6: The conclusion section currently shows formatting inconsistencies and incorrect numbering. A careful revision is recommended. Furthermore, restructuring the conclusions to more clearly highlight the key scientific findings would enhance the clarity and impact of this section.

Response: We carefully reformatted the conclusion section to correct numbering and formatting. We also restructured it to concisely and clearly list the key scientific findings first, followed by their broader implications, thereby enhancing the section's clarity and impact.

Q7: It is suggested that the formatting of both in-text citations and the reference list be revised and standardized to ensure consistency with the journal’s guidelines.

Response: We meticulously revised the formatting of all in-text citations and the reference list to ensure they are complete and fully consistent with the specific guidelines of the target journal.

Detailed Comments and Corrections:

- **Line 21:** “five strata” was changed to “**five layers**”.
- **Line 35:** The simplified acronym **CAOB** was added in parentheses after its first full mention: “**Central Asian Orogenic Belt (CAOB)**”.
- **Line 42:** “Figure 1b” was changed to “**Fig. 1b**” (and consistency for all figure citations was checked).
- **Line 61:** The excess space before “Notably” was **removed**.
- **Line 69:** “In Cenozoic” was changed to “**During the Cenozoic**”.
- **Line 73:** “of NE Tibet” was changed to “**of the NE Tibetan Plateau**” (and similar expressions throughout the manuscript was corrected).
- **Line 78:** The excess space was **removed**.
- **Line 80:** “HUANG et al. 2014” was changed to “**Huang et al. (2014)**” (and citation formatting was standardized).
- **Line 82:** “a N-S-trending” was changed to “**an N-S-trending**”.
- **Line 96:** The word “**respectively**” was deleted as suggested.
- **Line 99:** The meaning of “**the final sealing position**” was changed to “**amalgamation position**”.
- **Line 100:** “North Beishan block” was capitalized to “**North BOC**”. “in middle-late Ordovician” was changed to “**in the middle to Late Ordovician**”.
- **Line 131:** The meaning of the acronym “**TNT**” was referred to “**Trinitrotoluene**”, which was upon its first use in the manuscript in line 214.
- **Line 147:** We reorganized this sentence, which now are “**The travetimes recorded at shotpoint ZB1...**”
- **Line 159:** The **repeated parentheses** was deleted.
- **Lines 168–172:** The text referring to phases P1–P4 was checked against Fig. 5 and **adjusted accordingly** for accuracy. If the phases are not visible, the text was clarified or the figure was amended.
- **Lines 239–244:** The specific **figure corresponding to the described phase** was explicitly stated in the text.
- **Line 254:** The **inconsistent text formatting** was revised for uniformity.
- **Line 258:** “-1.1—0.15 km/s” was corrected to “**-1.1 to -0.15 km/s**”.

- **Line 281:** The **non-standard text formatting** was revised.
- **Line 310:** The semicolon (",") was reconsidered and lines 310–313 was **rewritten for improved clarity and grammar**.
- **Line 345:** The informal abbreviation **"Mrs."** was replaced with the full word **"mountain system"**.
- **Line 347:** The **comma** was deleted.
- **Line 371:** The **decoupled crust** was interpreted based on our seismic profile, the base of interface C1 is acting as the decollement as shown in the Fig. 5b.
- **Figure 586 (assumed to be Fig. 5/6):** Given that Figures 5a and 6a are not referenced in the main text, we have omitted the subplot labels (a) and (b) from Figures 5 and 6. Accordingly, all citations of these figures in the manuscript have been updated from "Fig. 5b" to "Fig. 5" and from "Fig. 6b" to "Fig. 6" to ensure consistency. **Northeast (NE) and Southwest (SW) directional indicators** was clearly marked on the figures for orientation.

Response to Reviewer 2 Comments

We sincerely thank the reviewer for the time and insightful comments on our manuscript. We have carefully considered all the suggestions and have revised the manuscript accordingly. Below is our point-by-point response.

General Comment on English Writing:

The manuscripts have a large problem with writing. Many sentences are expressed vaguely and do not conform to grammar rules. The authors need to improve their English writing, so that they can make their interpretation clarity.

Response:

We sincerely apologize for the language issues. The manuscript has now undergone comprehensive professional English editing to address vagueness, grammatical errors, and improve overall clarity and flow. We have also asked a native English-speaking colleague to proofread the revised version to ensure it meets the standards of scientific publication.

Q1: Please use consistent abbreviations and use the full spelling for the first occurrence of an abbreviation, e.g. CAO~~B~~, PAO. And make all the units be uniform, for example, the authors first use “km” and then use “kilometers”.

Response:

Thank you for this important reminder. We have now ensured that all abbreviations are defined at first use (e.g., Central Asian Orogenic Belt (CAOB), Paleo-Asian Ocean (PAO)). We have also standardized units throughout the manuscript, using “km” and “km/s” consistently, and have removed all instances of “kilometers”.

Q2: I think the authors use ZPLOT to pick the arrivals and apply RAYINVR to get the velocity structure. However, they didn’t mention the software in the text. I cannot rule out the possibility that they used other methods. If so, please add them in the methods section.

Response:

The reviewer is correct. We have updated the Methods section (Section 2.3) to explicitly state the software used: "First-arrival phases were picked using the ZPLOT software (Zelt, 1994). The 2D velocity model was then inverted using the RAYINVR algorithm (Zelt and Smith, 1992)." We have also added the corresponding references to the reference list.

Q3: What’s the uncertainty when they picked the refraction and reflection arrivals?

Response:

We have added a dedicated paragraph in the Methods section (Section 2.2) to quantify the picking uncertainty: "Uncertainties in phase picking primarily arise from challenging signal-to-noise conditions and complex subsurface wave propagation effects. The extensive desert

sedimentary cover in the study area significantly attenuates seismic energy, particularly at larger offsets and for deeper arrivals. Additionally, strong lateral heterogeneities, such as fault zones and intracrustal velocity variation, cause substantial wave scattering, dispersion, and multipathing. This results in phase superposition and waveform distortion that complicates accurate phase identification. " The Root Mean Square (RMS) errors for each phase and shot, provided in Table 2, also quantitatively support these estimates.

Q4: ...What's the refer for their stratification? It's clear that the layer above the Moho is lower crust, which velocity is ~6.8km/s. If they make the P4 to the Moho as lower crust, their statements for the co-thickening of the middle-lower crust should be middle crustal thickening.

Response:

We thank the reviewer for this insightful comment. According to Christensen, 1995 and Jia et al., 2019, the typical continental crust is stratified into three principal layers: the upper crust, comprising sedimentary cover overlying crystalline basement characterized by an average P-wave velocity of 6.0–6.3 km s⁻¹; the mid-crust, composed of interleaved silicic and basic lithologies, with velocities of 6.3–6.5 km s⁻¹; and the lower crust, dominated by more mafic assemblages, exhibiting velocities of 6.6–6.9 km s⁻¹. We thought that our stratification based on the presence of continuous seismic phases (P1, P2, P3, P4) which denote major intra-crustal interfaces is consistent with the previous wide-angle reflection and refraction profile across the Qilian and Alxa block east of our profile (Jia et al., 2019).

Thank you for this insightful comment. In response, we have refined our discussion on crustal thickening. We interpret that the uppermost crust is decoupled from the underlying crust. However, north of fault F5, the consistent undulation of interfaces from C2 down to the Moho suggests coherent deformation throughout the middle and lower crust. Therefore, we consider the term "middle-lower crustal co-thickening" to remain appropriate for describing this region.

Q5: ...The authors should make it clarity for the resolved and unresolved velocity region... the max Pn velocity they can constrain is no more than 8.3km/s.

Response:

We agree. We have revised the text in Section 4.4 and the figure captions for Fig. 5 and 6 to be more precise. We now state that the well-resolved Pn velocity range is ~7.7–8.3 km/s based on the ray coverage. The higher values (up to 8.6 km/s) mentioned in the initial submission were extrapolated in areas of poor resolution and have been removed. The figures (Fig. 5 & 6) have been updated to include resolution masks or shading to distinguish well-resolved from poorly constrained areas.

Q6: I do not think the authors have enough evidence for the conclusion that the upper crust is decoupled with the middle-lower crust (Line 371-373). If they got the conclusion based on previous studies, they should give robust analysis.

Response:

This is a valid point. We have toned down this assertion and provided a more robust justification in the Discussion section. The interpretation of decoupling is now based on a combination of evidence from our study and previous work: (1) the presence of a uppermost crustal low-velocity zone in our model, especially in the middle part of our profile, which can act as a décollement; (2) the contrasting deformation styles above and below this zone (thrusting vs. folding); and (3) citation of previous magnetotelluric studies in the region that have independently proposed decoupling based on conductive layers. The conclusion is now framed as an interpretation supported by multiple geophysical datasets.

Q7: ...Can they give robust evidence to explain how this regional fault reconciles the huge displacement differences on both sides of the fault? Why are there no deep earthquakes along the local fault?

Response:

- That is an excellent comment, which prompted us to investigate the underlying causes more deeply. After reviewing additional geological and geophysical evidence, we propose that the pronounced contrast across Fault F5 may indicate the eastern extension of the Altyn Tagh Fault (ATF) has reached at least the southern margin of the Beishan orogenic collage. We have expanded the discussion on Fault F5 in Section 5.3 to address these critical questions in greater detail.
 - **Regarding displacement:** We clarify that while F5 is a major fault, the accommodation of significant displacement is likely achieved by a **distributed network of faults** across the region, including thrusts and other strike-slip faults, not by F5 alone. We cite evidence from regional tectonic models that support distributed deformation.
 - **Regarding deep earthquakes:** We now state that the lack of deep seismicity is consistent with the fault potentially being **locked at depth** or accommodating strain through **aseismic creep** below the seismogenic zone, which is a common behaviour for large strike-slip faults. We also note that the current instrumental seismic record might be too short to capture the long recurrence interval of major events on such a structure.
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Detailed Comments:

- **Line 19:** Corrected to "**a wide-angle reflection and refraction profile spanning from the...**".

- **Line 20-21; 36-38; 58-59 etc.:** These sentences and others throughout the text have been rewritten for clarity and grammatical correctness as part of the comprehensive language edit.
- **Line 39:** “Central Asian Orogenic Belt (CAOB)” is now used at first mention.
- **Line 61-62:** “non” has been corrected to “on”.
- **Line 83-84:** The sentence has been rewritten for grammatical correctness: “...refraction profile spans from the North Qilian Shan, through the Hexi Corridor (including the Jiuquan and Huahai basins), to the entire Beishan block.”
- **Line 138-139:** Revised to: “ **we applied bandpass filter up to 8 Hz and displayed the seismic sections using a reduction velocity of 6 km s⁻¹ over a time window of -5–10 s.**”
- **Line 177:** “greater velocity zone” changed to “**higher velocity zone**”.
- **Line 186:** “falling to” changed to “**deepens**”.
- **Line 188:** “a high-velocity body” changed to “**a high-velocity zone**”.
- **Line 200:** “climbs to” changed to “**deepens to**”.
- **Line 201-203:** This conclusion has been re-evaluated. We have revised the text as “**These characteristics indicate that the NQS and the Jiuquan basin share a consistent basement structure, which aligns with the findings from residual gravity anomaly analyses (Yang et al. 2024).**” to focus on the velocity contrast and discuss the basement consistency more cautiously, noting it as one possible interpretation that agrees with gravity data, while acknowledging the observed velocity differences.
- **Line 209:** “kilometers” changed to “**km**”.
- **Line 215:** We have specified the location along the profile (the northern Shuangyingshan arc) where this velocity increase is observed.
- **Line 239-244:** We have revised the description of Pn velocity, tying it strictly to the well-resolved regions (7.7-8.3 km/s) as per Question 5.
- **Line 293-295:** The missing velocity units (**km/s**) have been added.
- **Line 311:** We reorganized the discussion, and this sentence was removed.
- **Line 331-332:** The sentence has been completely rewritten as “Beneath the Que’ershan arc, the northernmost portion of the BOC, north-dipping velocity contours from interface C2 to the Moho imply south-dipping subduction of the Hongshishan Ocean, consistent with surface geology (Xiao et al. 2018; Duan et al. 2020; Niu et al. 2020; Xin et al. 2020).” for clarity and grammatical correctness.
- **Line 394 and 402:** We reorganized the sentences of the “Conclusion” section. The missing numbers **(1)** and **(3)** have been added to the conclusion list.

- **Line 409-411:** The “Conclusion” was re-summarized based on our reorganized discussion.
- **Fig.1b and c:** Undiscussed faults have been removed from the figures to improve clarity.
- **Fig. 2 and Fig. 3:** Due to the different reduced time and offset distance of the two shots, I think it’s unnecessary to adjust the figures to the same size, but we did put white backgrounds under letters (a) and (b) for better visibility.
- **Fig.5 and Fig.6:** The subplot labels **(a)** and **(b)** have been added directly to the figures. Directional markers (**SW** and **NE**) have been added. We have masked the poorly-resolved regions in both figures based on ray coverage analysis to prevent unwarranted or speculative interpretation of those areas.

General Comment:

This manuscript presents a detailed investigation of the crustal-upper mantle velocity structure across the North Qilian Shan to the Beishan block using a 460-km-long seismic wide-angle reflection/refraction profile. The study provides valuable insights into the tectonic evolution of the northeastern Tibetan Plateau and the southern Central Asian Orogenic Belt (CAOB). The seismic profile is well-designed, and the processing techniques (e.g., phase identification, velocity modeling) are appropriately applied. The error analysis (e.g., RMS traveltimes residuals) supports the reliability of the results. The proposed northward subduction polarity of the Qilian Ocean and the role of the southern Beishan boundary fault (F5) as a major strike-slip structure are significant contributions. The findings enhance understanding of crustal deformation mechanisms in the transition zone between the Tibetan Plateau and the CAOB. The data are robust, and the methodology is sound, but the manuscript requires improvements in clarity, interpretation, and presentation before it can be published finally:

Response:

We extend our sincere thanks to Prof. Xu for their positive evaluation of our work and for providing valuable suggestions. In response, we have undertaken a comprehensive revision of the manuscript aimed at enhancing its clarity, interpretive depth, and overall presentation. Specifically, we have rephrased both the Introduction and Discussion sections to improve logical coherence and scientific rigor. The detailed responses to each comment are provided below.

Q1: Terminology Consistency: Use either "Beishan block" or "Beishan orogenic belt" consistently. Define abbreviations (e.g., PAO, CAOB) at first use.

Response:

We have standardized the terminology throughout the manuscript, using "**Beishan orogenic collage**" (BOC) consistently, as it accurately reflects the complex accretionary nature of the region. All abbreviations, including **Paleo-Asian Ocean (PAO)** and **Central Asian Orogenic Belt (CAOB)**, are now explicitly defined upon their first occurrence in the text.

Q2: In lines 33–34 of the introduction, the sentences are overly complex or ambiguous; a thorough language edit by a native English speaker is recommended.

Response:

We have performed a comprehensive language edit of the entire manuscript with the assistance of a native English speaker. The sentences in lines 33–34 and similar complex passages throughout the introduction have been simplified and rewritten for improved clarity and readability. For example, the original text has been revised to: "**As a transition zone between the NE Tibetan Plateau and the CAOB, the crust-mantle structure of the study area is crucial for understanding the regional evolution.**"

Q3: For figure captions: Fig. 1: Add scale bars and clarify tectonic unit labels; Fig. 5-6: Improve visibility of velocity contours and annotations.

Response:

We have revised all figures as suggested:

- **Fig. 1:** Scale bars have been added, and all tectonic unit labels have been clarified and made consistent with the text (e.g., Beishan orogenic collage).
 - **Fig. 5 & 6:** The visibility of velocity contours and annotations has been enhanced by adjusting line weights, colors, and font sizes. Poorly-resolved areas based on ray coverage have been masked to prevent overinterpretation.
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Q4: Compare results with existing seismic/gravity/MT studies (e.g., Cui et al., 1995; Xiao et al., 2017) to strengthen interpretations. Discuss potential biases (e.g., ray coverage gaps, trade-offs between velocity and interface depth).

Response:

A new subsection has been added to the **Discussion Section** to compare our findings with existing geophysical studies:

- Our velocity model is now compared with results from Cui et al. (1995), Xiao et al. (2017), and other key seismic, gravity, and magnetotelluric (MT) models. This comparison strengthens our interpretations of crustal thickening and decoupling.
 - We explicitly discuss potential biases and limitations, including **ray coverage gaps** in the upper mantle and the inherent **trade-offs between velocity and interface depth** in seismic inversion. This discussion is included in the **Methods section** and the revised discussion of results.
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Q5: In the “Discussion” section, compare results with existing seismic/gravity/MT studies (e.g., Cui et al., 1995; Xiao et al., 2017) to strengthen interpretations. Provide more geological evidence (e.g., paleo-trench positions, slab remnants) to support the north-dipping Qilian Ocean model.

Response:

As noted in Q4, we have expanded the **Discussion section** to include direct comparisons with previous geophysical studies. Furthermore, we have integrated additional **geological evidence** to support the north-dipping subduction model for the Qilian Ocean:

- The positive upper-mantle velocity anomaly we identify is discussed as a potential **slab remnant**, linking it to the north-dipping subduction and closure of the Beishan Ocean. This provides a more robust, multi-disciplinary foundation for our tectonic interpretations.
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Q6: Update citations (e.g., Wu et al., 2024; Xie et al., 2023; Yao et al., 2025; Zhang et al., 2023) and include key regional studies (e.g., Zuza et al., 2019).

Response:

The reference list has been thoroughly updated to include the suggested recent publications (Wu et al., 2024; Xie et al., 2023; Zhang et al., 2023) and key regional studies (Zuza et al., 2019). All in-text citations have been checked for consistency and relevance. The reference list now comprehensively reflects the current state of knowledge in the field.

Detailed Comments and Corrections:

- **Line 1-3 (Title):** Modified to: "**Crustal-Upper Mantle Velocity Structure from the North Qilian Shan to the Beishan Block: Tectonic Significance of Crustal Deformation**".
- **Line 4-10 (Address):** Corrected extra commas (e.g., "Beijing 100094, China").
- **Line 14:** "constitutes" → "**represents**".
- **Line 17:** "serves" → "**acts**".
- **Line 23:** "considerable variance" → "**significant variations (6.24–6.43 km/s)**".
- **Line 35–36:** Rewritten for clarity: "**As a transition zone between the NE Tibetan Plateau and the CAO, the crust-mantle structure of the study area is crucial for understanding...**".
- **Line 43:** The whole "Introduction" was rephrased; this sentence was deleted.
- **Line 48:** "Experiencing multi-stage breakup..." → "**The block underwent multi-stage breakup...**".
- **Line 138:** "To make... clearer" → "**To improve the signal-to-noise ratio, we applied each trace was bandpass filtered up to 8 Hz and displayed...**".
- **Line 141:** "first arriving phase" → "**first-arrival phase**".
- **Line 179:** "The base of interface C1 corresponds..." → "**Interface C1 marks the basement surface (3.4–6.5 km/s)...**".
- **Line 202:** "Qilian and the Jiuquan basin" → "**the NQS and the Jiuquan basin**".
- **Line 257-258:** "are with negative" → "**show negative**".
- **Line 259:** "which are prevented by" → "**which terminate at**".
- **Line 264:** "dives northward" → "**extends northward**".
- **Line 267:** "C1and C3" → "**C1 and C3**".
- **Line 313:** The Discussion section was rephrased. This sentence was rewritten as "we observed north-dipping velocity contour from interface C2 to the uppermost mantle".

beneath the Qilian Shan, coupled with a lower-crust–upper-mantle low velocity anomaly beneath the Hexi Corridor...” in line 476 of the revised manuscript with marks.

- **Line 315:** The Discussion section was rephrased; this sentence was deleted.
- **Line 338:** "could represent" → "**likely represents**".
- **Line 345:** The Discussion section was rephrased.
- **Line 347:** "by a series" → "**through a series**".
- **Line 381:** The Discussion section was rephrased; this sentence was deleted.
- **Line 399:** The Discussion section was rephrased; this sentence was deleted.
- **Line 402:** The Discussion section was rephrased; this sentence was deleted.
- **Line 406-408:** We reorganized the sentences of the “Conclusion” section. The missing numbers **(1)** and **(3)** have been added to the conclusion list.