## **Responses to the comments of Prof. Jinhai Yu:**

*I fully agree with Dr. Rey's comments on this manuscript. The core contribution of this paper is a detailed synthesis of the Hadean–Archean magmatic evolution of Eastern Hebei, North China. However, these conclusions are based on previous research findings, and this study has made little contribution. On the other hand, as stated in the manuscript, the 2.45 Ga magmatic activity is a continuation of the 2.55 Ga magmatic event, rather than the beginning of the TML. So, this study does not contribute much to the TML. Thus, there seems to be too much commentary on the TML in the introduction. I suggest that the paper focuses on the origin of the 2.45 Ga trondhjemite and its relationship with 2.55 Ga magmatic activity. Although the ~2.45 Ga trondhjemites have Hf-O isotope compositions similar to those 2.55 Ga TTG, suggesting similar source, the ~2.45 Ga trondhjemites show different compositions from the most 2.55 Ga TTG (Figs. 5, 9, 10 and 11), implying different melting conditions (melting degree) and magmatic differentiation process (fractional mineral assemblage and extent). Why are there these differences? What factors lead to these differences? The formation of the trondhjemites is consistent with an important metamorphic peak age (Fig. 8b), what is the inherent connection between them?*

*Thus, this manuscript is suggested to make major revision before it is considered to accept for publishing in this journal.*

**Response:** We sincerely thank the reviewer for these thorough and constructive comments. Following the reviewer's suggestions, we have substantially revised the manuscript, and the focus is now on the petrogenesis of the ca. 2.45 Ga trondhjemite and its relationship with the ca. 2.55 Ga TTG rocks in Eastern Hebei.

Our most recent work has divided the 2.55 Ga TTG rocks into two groups based on their geochemical and isotopic signatures (Jing et al., 2026). The first group is characterized by high $SiO_2$ and low MgO, Ni, and Cr contents, with positive zircon $\varepsilon_{Hf}(t)$ values and within or slightly higher zircon $\delta^{18}O$ values than mantle zircon, indicating a magma source of the juvenile thickened lower crust. Comparatively, the second group shows moderate to high $SiO_2$ and high MgO, Ni, and Cr contents, with a wide range of zircon $\varepsilon_{Hf}(t)$ and $\delta^{18}O$ values, suggesting that they were derived from partial melting of subducted oceanic crust, with some inputs of ancient crust material. In the **revised Figs. 5, 7, 9, and 10**, the 2.45 Ga trondhjemite shows similar whole-rock geochemical and zircon Hf-O isotopic characteristics to the first group of thickened lower crust derived TTG rocks, suggesting that were derived from the same magma source, i.e., the juvenile thickened lower crust formed at ca. 2.77–2.67 Ga (**see Lines 261-270**). The geochemical and zircon Hf-O isotopic characteristics differences between the ca. 2.45 Ga trondhjemite and the second group 2.55 Ga rocks primarily result from distinct magma sources (a mixed source of oceanic crust and ancient continental crust vs. thickened lower crust).

The crystallization age of the ca. 2.45 Ga trondhjemite is consistent with the 2.45 Ga metamorphic peak age in Eastern Hebei. We propose that the metamorphism likely induced partial melting of the thickened lower crust, generating the ca. 2.45 Ga trondhjemitic magma. The metamorphism provided the heat source, while the thickened crust supplied the source material. This interpretation is consistent with experimental petrology results showing that adakitic melts can be produced by partial melting of metabasaltic rocks under high-pressure (>1.5 GPa) and high-temperature (> 900°C) conditions.

We thank the reviewer again for these invaluable comments.

**Reference:**

Jing, J.H., Liu, Q., Han, Y.G., Yao, J.L., Zhang, D.H., Sun, C.Y., Wang, C., Zheng, J.K., Zhao, G.C., 2026. Petrogenesis of late Neoarchean tonalite-trondhjemite- granodiorite and dioritic gneisses in Eastern Hebei: Implications for coexisting vertical and horizontal geodynamic regime in the eastern North China Craton. Geoscience Frontiers, 17(4), 102305, https://doi.org/10.1016/j.gsf.2026.102305.

**Other specific comments:**

*1. Line 1, because this study focuses on the origin of trondhjemite, rather than their metamorphic process, it is best to directly use "trondhjemite" or "gneissic trondhjemite", instead of "trondhjemitic gneiss". The 2.45 Ga is the crystallization age of trondhjemite, not the metamorphic age of gneiss.*

**Response:** Many thanks for this careful and constructive comment. We fully agree with the referee's point that the term "trondhjemitic gneiss" is not suitable for a study focused on the origin of trondhjemite. Accordingly, we have revised the manuscript to use "gneissic trondhjemite" throughout. This change has been made in the revised manuscript (**see Lines 1, 12, 17, 19, 46, 47, 83, 89, 158, 185, 217, 223, 239, 248, 251-252, 261, 268**).

*2. Line 50, it is not advisable to attribute the lack of the early Paleoproterozoic magmatic records to preservation bias! because older rocks are widely preserved in the study area!*

**Response:** Many thanks for this comment. We have thoroughly revised the "Introduction" following the reviewer's suggestions. The updated "Introduction" no longer focuses on the tectono-magmatic lull (TML), and this sentence has been removed.

*3. Line 91, TTG belong to granitoid, and they are not in a parallel relationship.*

**Response:** We thank the reviewer for this correction. We agree that TTG is a subset of granitoid, and the original phrasing incorrectly implied a parallel relationship. Accordingly, we have revised the text to use "granitoid gneisses" to encompass all such rocks. This revision has been incorporated in the updated manuscript (**see Line 70**).

*4. Line 96, change "and" to "or".*

**Response:** We have changed "and" to "or" in the revised manuscript (**see Line 75)**.

*5. Line 100, metamorphic ages listed here are inconsistent with those in line 92.*

**Response:** We thank the reviewer for pointing out this discrepancy. The ages in Line

92 refer to the metamorphic ages of the granitoid gneisses in Eastern Hebei, whereas the ages in Line 100 are the metamorphic ages of the supracrustal rocks. These two rock units record different geological histories. In Eastern Hebei, the early Paleoproterozoic metamorphic event is only recorded in the supracrustal rocks, not in the granitoid gneisses. Therefore, the two sets of ages are intentionally different (**see Lines 70-71 and 75**).

6. Lines 155-168, 210-211 and figure 4b, the "inherited" and "magmatic" zircons have similar REE patterns (Fig. 4b), they are continuous changes on the Concordia diagram (Fig. 4a) and also cannot be easily separated in CL images (Fig. 4a). Therefore, this classification is artificial and lacks enough evidence (e.g., element and/or isotope compositions and inner structure) to support it. These "magmatic zircons" may be only outer layers of the zircon grains and have suffered slightly more Pb loss.

**Response:** Thanks for the reviewer's careful comment on the classification of "inherited" and "magmatic" zircons. We have carefully re-evaluated our zircon data and clarify the subdivision as follows. (1) **The two age populations are statistically distinct and regionally significant.** Although the 28 analyses seem to show a continuous range of $^{207}Pb/^{206}Pb$ ages from 2569 to 2389 Ma, they statistically define two weighted mean ages: 2549 ± 29 Ma (n=5, MSWD=0.3) and 2446 ± 15 Ma (n=23, MSWD=0.5). The probability of overlap between these two populations is extremely low (<5%). More importantly, both ca. 2.55 Ga magmatism and ca. 2.45 Ga metamorphism are well documented in Eastern Hebei. Thus, the two age populations are not statistical artifacts but correspond to the known regional magmatic episodes. (2) **The characteristics of Pb loss are not clearly observed in the studied magmatic zircons.** Pb loss causes data point to plot below the concordial line (discordance > 5%). All 23 analyses defining the 2446 Ma age are concordant within 5%, with most showing discordance < 3%. In addition, the magmatic zircons have high Th/U ratios (0.4–1.2) and retain sharp oscillatory zoning in CL images, both of which are inconsistent with significant Pb loss or fluid alteration.

7. Line 162-163, those two grains with discordance > 5% should be kept in supplementary Table S2 and S3 and plot in the Concordia diagram. Hf-O isotopic compositions of "inherited zircons" should be listed in Table S5.

**Response:** We thank the reviewer for this careful check. Following the suggestion, we have added the zircon U-Pb dating results and rare earth element (REE) concentrations of the two discordant analyses (**see revised Table S1 and S2**). They are also plotted in the concordial diagram (**see revised Fig. 4a**). Besides, the study did not perform Hf-O isotope analyses (Table S4) on the "inherited zircons".

*8. 173, delete "contents".*

**Response:** We have deleted "contents" as suggested (**see Line 151**).

*9. 187, change "slight" to "little".*

**Response:** We have changed "slight" to "little" in the revised manuscript (**see Line**

**165**).

10. 225-249, this part of discussion is too verbose, and not need to list the location of each rock.
**Response:** Following the reviewer's comment, we have deleted this part of the discussion in the revised version.

*11. 228, "Labahsan" to "Labashan".*
**Response:** Sorry for our negligence and thanks for reminder. The spelling of "Labahsan" has been corrected to "Labashan" in the revised manuscript (**see Line 73**).

*12. 232, "Zhao et al., 2025" to "Zhao et al., 2025b".*
**Response:** Thanks for pointing out the missing label. The citation has been corrected to "Zhao et al., 2025b" in the revised manuscript (**see Line 75**).

*13. 254-255, 259-261 and 266-267, delete these citations, they have been cited in the caption of this diagram (Fig. 8).*
**Response:** We thank the reviewer for this careful observation. These duplicate citations have been removed in the revised manuscript.

*14. 257, start a new line from "It".*
**Response:** Following the reviewer's main comment, we have deleted the section of the geochronological framework of Eastern Hebei.

15. 277, but low Th, U, Rb contents suggest that some trace elements of these samples may be affected by granulite-facies metamorphism.
**Response:** We thank the reviewer for this insightful comment. We agree that some trace elements, such as the Th, U, and Rb, might have been affected by granulite-facies metamorphism, and our original statement that the geochemical characteristics were "not significantly changed" was overly broad. However, the key elements used for petrogenetic interpretation, including the HFSEs and REEs, are generally considered less mobile during high-grade metamorphism. Additionally, we have revised the text to acknowledge the potential mobility of fluid-mobile elements while maintaining that the HFSEs and REEs are reliable for petrogenetic discussion. The revised sentences **see Lines 187-191.**

*16. 284-285, it is evidently illogical to combine samples with different ages and from different locations and plutons together to discuss their differentiation (Fig. 9)! In this diagram, the 2.45 Ga trondhjemites show little change！ Additionally, there are issues with the image itself. Different minerals have different partition coefficients for highly and moderately incompatible elements. The CH/CM of magma cannot remain constant during fractional crystallization!*
**Response:** We appreciate the reviewer's careful and constructive comments.

The ca. 2.55 Ga TTG and ca. 2.45 Ga trondhjemite are spatially associated in

Eastern Hebei and share similar geochemical and zircon Hf-O isotopic characteristics. We discuss their geochemical evolution for comparison. The limited variation of the 2.45 Ga trondhjemite in revised Fig. 8 is due to the small number of samples.

In revised Fig. 8, the concentrations and ratios of highly incompatible ($C_H$) and moderately incompatible ($C_M$) elements are used to distinguish partial melting and fractional crystallization (Schiano et al., 2010). During partial melting, $C_H$ are preferentially incorporated into the melt, whereas $C_M$ are comparatively retained in the residue, leading to a pronounced positive correlation as both the $C_H$ and $C_H/C_M$ ratio increase simultaneously. During fractional crystallization, although different minerals have different partition coefficients for CH and CM, the much lower distribution coefficients of CH compared to CM ($D_M \gg D_H$) mean that, following the Rayleigh distillation law, $CH/C_M$ remains nearly constant with increasing crystallization degree. This results in a horizontal trend, which is distinctly different from the steep trend of partial melting.

The studied samples display a clear positive correlation in Fig. 9, consistent with partial melting and distinct from the horizontal trend expected for fractional crystallization. This interpretation is further supported by the absence of coeval mafic rocks and cumulates in Eastern Hebei (**see revised Fig. 8**).

In addition, given the potential mobility of Rb and Sr during post-magmatic alteration, we have replaced the Rb/Sr vs. Rb diagram with the more robust Ce/Zr vs. Ce diagram. As relatively immobile HFSEs and LREEs, Ce and Zr are less affected by secondary processes and provide more reliable constraints on magmatic evolution (**see revised Fig. 8**).

**Reference:**

Schiano, P., Monzier, M., Eissen, J. P., Martin, H., and Koga, K. T.: Simple mixing as the major control of the evolution of volcanic suites in the Ecuadorian Andes, Contrib. Mineral. Petrol., 160, 297-312, 10.1007/s00410-009-0478-2, 2010.

*17. 286, change "gneiss" to "magma".*

**Response:** We have changed "gneiss" to "magma" in the revised text (**see Line 204**).

*18. 298, change "trondhjemitic gneiss" to "gneissic trondhjemite".*

**Response:** We thank the reviewer for this terminological refinement. We have changed "trondhjemitic gneiss" to "gneissic trondhjemite" (**see Line 216-217**).

*19. 299, delete "further", and add "source" behind "crust".*

**Response:** Many thanks for these two helpful suggestions. This sentence has been deleted in the revised manuscript.

20. 299-300, why can higher zircon $\delta^{18}O$ support a juvenile source? This is contradictory!

**Response:** We thank the reviewer for this insightful comment, which prompted us to reconsider the relationship between zircon $\delta^{18}O$ and magma source. The 2.45 Ga trondhjemite positive $\varepsilon_{Hf}(t)$ values (+3.3 to +4.9) and slightly higher zircon $\delta^{18}O$ values than mantle zircon (5.96–6.53 ‰), with corresponding $T_{DM2}$ ages varying from 2769 to 2671 Ma, indicating that they represent a crustal reworking of the juvenile crust produced by 2.67–2.77Ga (**see Lines 216-219**).

*21. 309, 318, delete "gneiss".*

**Response:** The term "trondhjemitic gneiss" has been revised to "gneiss trondhjemite" in the updated manuscript (**see Lines 223, 239**).

*22. 314-316, the "rutile vector" in Fig. 11b may be problematic! Because Ta is more compatible in rutile than Nb, and Nb is more compatible than La, more residual rutile in the source will lead to a decrease in both the Nb/Ta and Nb/La ratios of the magma, rather than the Nb/La ratio remaining unchanged as shown in the figure. On the other hand, the 2.45 Ga trondhjemites have low Nb/Ta, inconsistent with more rutile residual in the source.*

**Response:** We appreciate the reviewer's careful comment on the revised Fig.10b.

Extensive experimental studies have demonstrated that Ta is more compatible in rutile than Nb (Foley et al., 2002; Schmidt et al., 2004; Xiong et al., 2006, 2011; John et al., 2011). During partial melting with residual rutile in the source, Ta is preferentially retained in the residue relative to Nb, resulting in melts with elevated Nb/Ta ratios (**see revised Fig. 10b**).

As a representative element of LREEs, La is highly incompatible in rutile, with a distribution coefficient orders of magnitude lower than that of Nb (Klemme et al., 2005). When rutile is present as a residual phase, Nb is moderately retained in the residue, whereas La is almost completely incorporated into the melt, resulting in a significantly low Nb/La ratio in the melt. With increasing residual rutile, the Nb/La ratio shows little variation and remains roughly constant, consistent with the rutile vector in revised Fig. 10b.

Collectively, the 2.45 Ga trondhjemite displays low concentrations of Nb and Ta, coupled with their high Nb/Ta and low Nb/La ratios, indicating that the rutile was residual in the source (**see Lines 228-237**).

**Reference:**

(1) Foley, S., Tiepolo, M., and Vannucci, R.: Growth of early continental crust controlled by melting of amphibolite in subduction zones, Nature, 417, 837-840, 10.1038/nature00799, 2002.

(2) Schmidt, M. W., Dardon, A., Chazot, G., and Vannucci, R.: The dependence of Nb and Ta rutile–melt partitioning on melt composition and Nb/Ta fractionation during subduction processes, Earth Planet. Sc. Lett., 226, 415-432, https://doi.org/10.1016/j.epsl.2004.08.010, 2004.

(3) Xiong, X., Adam, J., Green, T. H., Niu, H., Wu, J., and Cai, Z.: Trace element characteristics of partial melts produced by melting of metabasalts at high pressures: Constraints on the formation condition of adakitic melts, Sci. China Earth Sci., 49, 915-925, 10.1007/s11430-006-0915-2, 2006.

(4) Xiong, X., Keppler, H., Audétat, A., Ni, H., Sun, W., and Li, Y.: Partitioning of Nb and Ta between rutile and felsic melt and the fractionation of Nb/Ta during partial

melting of hydrous metabasalt, Geochimica et Cosmochimica Acta, 75, 1673-1692, https://doi.org/10.1016/j.gca.2010.06.039, 2011.
(5) John, T., Klemd, R., Klemme, S., Pfänder, J. A., Elis Hoffmann, J., and Gao, J.: Nb–Ta fractionation by partial melting at the titanite–rutile transition, Contrib. Mineral. Petrol., 161, 35-45, 10.1007/s00410-010-0520-4, 2011.
(6) Klemme, S., Prowatke, S., Hametner, K., and Günther, D.: Partitioning of trace elements between rutile and silicate melts: Implications for subduction zones, Geochim. Cosmochim. Ac., 69, 2361-2371, https://doi.org/10.1016/j.gca.2004.11.015, 2005.

*23. 321-322, it is necessary to carefully distinguish whether the low Dy and Er contents of the 2.45 Ga trondhjemites are caused by the fractional crystallization of amphibole or by more amphibole residual in the source during the partial melting.*

**Response:** Many thanks to the reviewer for this constructive comment. The 2.45 Ga trondhjemites have low Y and Yb contents and high $(La/Yb)_N$ ratios, suggesting that garnet is the main residual mineral in the magma source. In addition, they show low concentrations of Ti, Nb, and Ta, coupled with their high Nb/Ta and low Nb/La ratios, indicating that the rutile was also residual. Notably, our samples show extremely high Sr/Y values (637–1248), combined with their flat patterns of MREEs/HREEs and positive Eu anomalies, supporting that they have undergone amphibole fractional crystallization during the magma evolution (Tiepolo et al., 2007).

To sum up, we interpret the low Dy and Er contents as primarily resulting from amphibole fractional crystallization rather than source residue (**see Lines 228-237, 243-245**).

**Reference:**

Tiepolo, M., Oberti, R., Zanetti, A., Vannucci, R., and Foley, S. F.: Trace-Element Partitioning Between Amphibole and Silicate Melt, Rev. Mineral. Geochem., 67, 417-452, 10.2138/rmg.2007.67.11, 2007.

*24. 327, change "the protolith of the 2.45 Ga trondhjemitic gneiss" into "the parental magma of the 2.45 Ga trondhjemites".*

**Response:** We have changed "the protolith of the 2.45 Ga trondhjemitic gneiss "to "the parental magma of the 2.45 Ga trondhjemite" as suggested (**see Lines 204**).

*25. 348-352, delete this sentence.*

**Response:** We have deleted the sentence as suggested.

*26. 352, in fact, some 3.07-3.51 Ga zircons have 4.4-4.0 Ga Hf-isotope model ages, suggesting their host rocks originated from the same old source as those 3.84-3.64 Ga magmatic rocks, supporting a deep-seated Hadean basement in the Eastern Hebei.*

**Response:** We thank the reviewer for this valuable addition. The Hf model ages (4.4–4.0 Ga) of the ca. 3.51–3.07 Ga zircons suggest that their host rocks were derived from an ancient source that formed in the Hadean. In addition, Hadean zircons have been identified in Eastern Hebei, supporting the existence of Hadean crustal materials in this region. However, the Paleoarchean crustal evolution is not the main focus of this study, and this sentence has been removed from the revised manuscript.

*27. Figure 12, add several Hf isotopic evolution lines with 176Lu/177Hf = 0.015 (average crust) or 0.022 (for mafic source);*

**Response:** We thank the reviewer for this suggestion. We have added the Hf isotopic evolution lines with $^{176}Lu/^{177}Hf$ = 0.015 (average crust) to **revised Figure 7a** as recommended.

*28. 354, 3.53-3.22 Ga? but there are not any 3.13-3.38 Ga rocks in Eastern Hebei (see Figure 12).*

**Response:** We thank the reviewer for this observation. We confirm that ca. 3.38–3.13 Ga rocks do exist in Eastern Hebei (Dong et al., 2025). However, these rocks lack corresponding Hf isotope data, and therefore they are not shown in Figure 12. Nevertheless, this issue is not the central focus of our paper, and the relevant discussion has been omitted from the revised manuscript. Nevertheless, the revised manuscript no longer contains the content on the Paleoarchean rocks of Eastern Hebei.

**Reference:** Dong, C., Li, P., Nutman, A. P., Xie, H., Liu, S., Li, Y., Liu, D., and Wan, Y.: New discovery of Paleoarchean-Mesoarchean magmatic rocks in eastern Hebei, North China Craton: Petrogenesis and tectonic environment, Precambrian Res., 427, 107870, https://doi.org/10.1016/j.precamres.2025.107870, 2025.

*29. 359, Why from the recycling of TTG rocks?*

**Response:** Many thanks to the reviewer for pointing this out. The inaccurate statement has been corrected by deleting it from the revised version.

*30. 360, change "a" to "more".*

**Response:** We have deleted this inappropriate statement from the revised manuscript.

*31. 377-379, delete these parenthetical citations. Many citations throughout the text are redundant.*

**Response:** We have removed the redundant citations. We also went through the rest of the manuscript and deleted other unnecessary duplicate citations.

*32. 380-382, this viewpoint is incorrect, because the formation ages of magmatic rocks are consistent with their Nd-Hf isotope model age, suggesting the juvenile crustal growth, rather than crustal reworking.*

**Response:** Many thanks to the reviewer. This valuable comment enhanced our understanding of the crustal growth and reworking. The magmatic rock with similar formation ages and Nd-Hf isotope model age might represent the juvenile crustal growth, rather than crustal reworking (**see Lines 272-274**).

*33. 399-400, this understanding is inaccurate. The occurrence of massive late Neoarchean felsic magmatic rocks, including TTG, suggesting strong crustal reworking. Crustal reworking may involve both juvenile crusts, generating high eHf(t) granitoids,*

*and ancient crust, producing low eHf(t) granitoids. So the proportion of crustal growth and reworking cannot be determined solely by Nd-Hf model age.*
**Response:** We thank the reviewer for this insightful comment, which help us clarify our thinking. Crustal reworking can involve both juvenile crust (generating high $\varepsilon_{Hf}(t)$ granitoids) and ancient crust (generating low $\varepsilon_{Hf}(t)$ granitoids), and therefore the proportions of crustal growth and reworking cannot be determined solely by Nd-Hf model ages. Following this comment, we have re-examined our data and conclude that the ca. 2.45 Ga trondhjemite in this study represents crustal reworking rather than crustal growth. The reworked source is likely to be the juvenile crust produced by 2.77–2.67Ga (**see Lines 216-219**).

*34. 401-405, the formation of 2.45 Ga trondhjemite indicate a crustal reworking event, and the reworked source is likely to be the juvenile crust produced by 2.67-2.77Ga, similar to those 2.55 Ga TTG. Also see above comment.*
**Response:** We fully agree with the reviewer. The ca. 2.45 Ga trondhjemite represents a crustal reworking event, and its source was the juvenile crust formed at ca. 2.67–2.77 Ga. This has been clarified in the revised manuscript (**see Lines 216-219**).

*35. 401, 405, 407, 414, change "2.45 Ga trondjemitic gneiss" to "2.45 Ga gneiss trondhjemite".*
**Response:** We appreciate the reviewer's careful reading. Following this suggestion, we have checked the entire manuscript and changed "2.45 Ga trondhjemitic gneiss" to "2.45 Ga gneiss trondhjemite" in the revised version (**see Lines 239, 248, 251-252, 261, 268, 288**).

*36. 415, that is reworking, but not the crustal growth!*
**Response:** We thank the reviewer for this correction. We have revised the manuscript, and the ca. 2.45 Ga magmatism is now interpreted as a crustal reworking event, not crustal growth (**see Lines 216-219, 285-286**).