Author's response:

Response to Review #1 (anonymous)

The authors try to use tectonic geomorphological techniques (e.g., hypsometric integral (HI), channel steepness (ksn), and local relief) to identify the impact of structural inheritance on the formation of the Shanxi Rift. The manuscript obtains new geomorphological parameters covering a large portion of the Shanxi Rift System, which is useful for understanding the tectonic characteristics of the rift. The manuscript also contains new ideas and interesting analyses regarding the tectonic evolution of the rift. Moreover, the manuscript is well prepared. Its structure is clear, and its language is easy to understand. Although I find one major issue and many minor ones (see below), I think this manuscript would be a good contribution to understanding the evolution of the Shanxi Rift System after revision.

> *We thank the reviewer. We have addressed the comments and have modified the manuscript accordingly. Below are the more detailed responses to the individual comments with references of the changed part (lines of the revised manuscript in brackets):*

Major Issue:

The manuscript tries to use tectonic geomorphological techniques (e.g., HI, ksn, and local relief) to study the impact of structural inheritance on the formation of the Shanxi Rift, but the manuscript does not show the relationship between observed geomorphological parameters and preexisting structures. There is even no discussion about the relationship between observed geomorphological parameters and the preexisting structures. The role of structural inheritance is mainly based on analyzing the relationship between the current rift structures and published geologic maps. Such discussion is somewhat similar to published works in recent years, but the authors do not mention them. Collectively, I feel there is a disconnection between the main research technique and the research target.

> *We agree that our phrasing here lacked clarity and was also noted by the other two reviewers. We agree there is no direct link between the geomorphological analysis we present, and the inferred structural inheritance based on previous studies, instead our geomorphological analysis is used to evaluate fault activity and has identified areas of increased tectonic deformation. Alongside this we present our investigation of the possible impact of inherited structures on these zones of more active deformation. Geomorphology can give us a better understanding of the evolution of the Shanxi Rift which can then be related to inherited structures to study their impact. The abstract text has been modified to clear this up.*
>
> ***"Here we use tectonic geomorphological techniques, e.g., hypsometric integral (HI), channel steepness (k_{sn}) and local relief to study the evolution of the Shanxi Rift and identify areas of higher tectonic activity. We found that HI was less sensitive to lithology and more valuable in evaluating the tectonic signal and found that activity is concentrated in two rift interaction zones (RIZ) formed between the basins. We then evaluate the relationship between the active faults and mapped pre-existing structures and found that many faults formed parallel to inherited structures but faults in the RIZs often crosscut these structures."*** *(17-22)*

Specific comments:

Line 81: I don't think you need to mention seismic data. There are many seismic reflection profiles in the Shanxi Rift. Previous isopach maps (e.g., Xu and Ma, 1992; Xu et al, 1992) already take full advantage of the seismic data.

> *While we appreciate the work in Shanxi that has been conducted using seismic reflection data, we think it is still appropriate to refer to a general lack of seismic reflection data coverage especially when compared to offshore areas like the North Sea, active rifts like East Africa or even adjacent onshore basins like the Bohai basin. These are covered by a greater range of 2D and 3D seismic which makes detailed studies of the rift evolution using seismic data possible. Shanxi, as a subaerially exposed rift, does not have this advantage but can instead be studied with geomorphological and remote sensing approaches which we wanted to highlight with this sentence.*

Lines 135-135: This is not correct. More and more studies found that the Eocene extension also occurred in western NCC, e.g., Wang et al (2013), Fan et al (2019), and Su et al (2021).

> *We have changed the text to indicate that the Western NCC has experienced limited extension in the Eocene. (145-146)*

Line 149-151: I think the authors want to describe the thickness of the syn-rift sediments since the late Miocene rather than the sedimentary rocks. The mentioned thickness values are not correct. Please refer to Xu et al (1992) for the syn-rift sediment thickness. For the Linfen Basin, you can refer to Su et al (2023) for the syn-rift sediment thickness.

> *We have changed the thickness values according to the referenced papers to 3800m of synrift fill in the Taiyuan basin and 2200m for the Linfen basin:* ***"Synrift thickness across the Shanxi Rift varies; While the Taiyuan basins has the thickest synrift sediment thickness of up to 3800m (Xu et al. 1992), the Xinding only contains up to a 1800m (Xu et al. 1992) and the Linfen basin contains up to 2200m of synrift fill (Su et al., 2023)."*** *(160-162)*

Lines 345-346: I think the precise description regarding the precipitation would be "...roughly little variation in precipitation...".

> *We have changed the text to* ***"broadly little variation in precipitation"****. (376)*

Lines 405-406: As the authors discussed regarding the limitations of HI in Lines 296-305, HI values may related to loess landscapes. The Lingshi RIZ is covered by widely distributed loess, which I think should also be considered when analyzing the observed high and varied HI values in the Lingshi RIZ.

> *We included in this section now that the presence of Loess in the Lingshi RIZ may have an impact on the high HI responses within the Lingshi RIZ. (456-459)*
>
> *However, when taking the per fault averaged HI values, as we have done for the violin plots (Fig. 7c) the basins analysed are solely basins in the footwall of the Huoshan fault. The Huoshan fault footwall mostly consists of Palaeoproterozoic basement therefore high responses here are not due to the presence of Loess. Therefore, our argument still stands that the Huoshan fault and therefore the Lingshi RIZ have seen increased activity, but we acknowledge that the high HI value basins in the hanging wall of the Huoshan fault may be due to the presence of Loess.*

Lines 397-98, 435: Please indicate the widths of the two swath profiles.

Both Swath profiles are 5km width, this has now been added to the figure caption.

Lines 419-422: I am not sure how you found this area experienced a "recent uplift". Also, can you specify the timescale of the "recent" you mean? For example, ... experienced uplift in ~10, 100 ka, 1, or 10 Ma.

We infer this region to have experienced recent uplift based on the abundance of high HI value basins, steep slopes and the presence of entrenched meanders show that this region must have been tectonically active recently and the footwall of the Shilingguan fault must have been uplifted recently which outpaced erosion creating the steep flanks of the river. The footwall geology here is low grade metasediments therefore the extreme geomorphic response can not be down to a lithology effect which makes the interpretation of intense tectonic activity even more likely. Based on the data of this study it is not possible to assign exact timings of this uplift, but it is most likely Quaternary. Further studies which quantify the river capture, or the fault slip data would be needed to make more absolute assessment of the uplift age.

Lines 452-453: This sentence needs a reference to support this idea.

This idea is a new proposal from the results of our work, however we added a reference to Middleton et al. (2017) which propose a stable extension field for the Shanxi Rift based on geodesy and seismicity. (518-519)

Lines 576-579 (Figure 11): The timing of the three evolution stages need references.

The time steps were mostly speculative based on previous studies (Shi et al. 2015), based on our study we cannot assess the absolute ages of when this reorganisation occurred, therefore we removed the mention of specific time steps. The relative sequence of rifting and reorganisation is the most important part of this figure.

Lines 589-591: The last sentence of this paragraph should be removed. Do not conduct a discussion in the Conclusion section. Also, the analysis regarding future major earthquakes is wrong. Any active faults including these basin border faults may host large earthquakes in the future.

We don't think this is new discussion in the Conclusions as it is covered extensively in section 5.2 where we discuss the seismic hazard implications of the study, and this sentence serves as a summary of this section. We agree that any fault hosts the potential for major earthquakes, and this is consistent with our model of a stable extension direction in which all of the faults are potentially active, however it is our suggestion here that activity may be concentrated in the RIZs. This is due to the increased tectonic activity due to strain localisation in these regions. This is also well documented by clusters of earthquakes in these regions (see Fig.2 of the revised manuscript with added ISC earthquakes).

However, we have reworded the sentence slightly:

***"This has major implications for seismic hazard assessments as it hints towards zones which show more complex and more active patterns of faulting due to the strain concentration in the RIZs, these may experience increased seismicity."** (674-676)*

Response to Review #2 (Anandita Samsu)

This contribution presents the use of geomorphic indices to assess fault activity in the Shanxi Rift (China). Fault orientations and activity are compared against pre-existing basement fabrics. The authors show that the overall geometry of the segmented Shanxi Rift, the geometries of the rift interaction zones (RIZs) between the main basins, and fault activity are influenced by pre-existing structures in the (upper) crust and anisotropies in the upper mantle; both of these types of pre-existing structures have been attributed to the amalgamation of the North China Craton and the formation and subsequent reworking of the Trans Northern China Orogen.

The manuscript fits the scope of the journal and special issue very well. The use of geomorphology to investigate the multi-faceted influence of structural inheritance is uncommon and therefore makes valuable addition to structural inheritance research. In general, the manuscript is well-structured. It would benefit from some thorough editing to enhance clarity and emphasize key messages. Below are some general and specific comments that I hope will contribute to the overall improvement of the manuscript. Congratulations to the authors for putting this interesting paper together.

> *We thank the reviewer for the positive and thorough review and their many constructive comments that will surely improve the overall quality of this contribution. Detailed responses to the general and individual comments are listed below (line references in brackets):*

General comments

This manuscript is missing a concise presentation of all the faults and their characteristics, including the lithology of the footwall, the main orientation of pre-existing basement fabrics, perhaps the strength of the geomorphic signal, and most importantly the inferred level/recentness of activity – this could be done as a summary table. The above information is all there already, but it is spread across several maps with different color schemes, which makes it difficult to follow the descriptions in the text and connect the different observations.

> *We agree that a summary of the faults and their geomorphological response, lithology and relation to inheritance would be helpful and make the argument of the manuscript stronger. We have added a table that summarises all this information (Table 1)*

A general comment that could apply to multiple parts of the manuscript: Sometimes I get lost in the details and explanations before understanding what the main statement of the paragraph/section is. It could help to flip the paragraph around, bringing the headline statement to the start of the paragraph, and then elaborating on the headline statement. One example of where this occurs is the first paragraph of the Conclusions.

> *We have done our best to implement this suggestion and overhauled some of the paragraphs to improve the overall readability and make the point of the paragraph clearer with a headline statement.*

Specific comments:

Lines 17-20: It would be more accurate to state that the tectonic geomorphological techniques were used evaluate fault activity. The interpretations of the role of inheritance comes later, but inheritance is not directly linked to geomorphological indices (at least not in this paper).

Yes, we agree that the wording in the manuscript suggesting a causative link between the inheritance and geomorphic analysis was imprecise and want to clarify we do not suggest a causative link between inheritance and geomorphology. We changed this part to ***"Here we use tectonic geomorphological techniques, e.g., hypsometric integral (HI), channel steepness (k_{sn}) and local relief to study the evolution of the Shanxi Rift and identify areas of higher tectonic activity. We found that HI was less sensitive to lithology and more valuable in evaluating the tectonic signal and found that activity is concentrated in two rift interaction zones (RIZ) formed between the basins. We then evaluate the relationship between the active faults and mapped pre-existing structures and found that many faults formed parallel to inherited structures but faults in the RIZs often crosscut these structures."*** *(17-22)*

Line 51: Line 60/61: Striking obliquely with respect to what? What is meant by "oblique striking"? Oblique with respect to what?

Oblique with respect to the main extension direction, we have modified the text to clarify that. Thanks for spotting that.

Line 75: What did these previous studies reveal? Are their outcomes helpful in understanding the Shanxi Rift?

Changed to ***"that show active normal faults often follow the trends of inherited structures (Su et al. 2021) and possibly detach into low angle shear zones at depth (Pavlides et al. 1999)"*** *(81-83)*

Lines 92-98: This is a great summary of the presented work and a strong conclusion to the introduction! It would be good to apply this style and clarity in the other sections.

Thanks and noted!

Line 94: Is it necessary to distinguish between basement heterogeneities and inherited structures? Please see the general comment about the need to clearly define basement structures, pre-existing structures, inherited structures, etc.

We have made clearer what we refer to when mentioning basement and inherited structures (I.e. Palaeoproterozoic structures) in the methods section.

"In this study we primarily focus on the influence of inherited structures in the Palaeoproterozoic basement on the evolution of the Shanxi Rift, therefore if not specified otherwise we refer to Palaeoproterozoic structures when discussing basement or inherited fabrics." *(181-183)*

Line 171: How is it determined that faults are active? What is your definition of an "active" fault?

Added the following definition and description to make clearer what we mean by active fault and how we identified them:

"We define active faults as linear, steep scarps (>20-30°) that offset Quaternary sediments, similar to the approach by Wedmore et al. (2022). Furthermore, we used topographic

profiles across faults and geomorphological features such as steepened river channels and triangular facets along the fault scarp as features guiding our identification of active normal faults." *(186-189)*

Lines 179-181: Is there literature supporting the statement that the three chosen geomorphic indices are the most robust for evaluating tectonic signals?

This statement is mostly based on our observations of using various geomorphic indices and these proved to be the best. The three chosen indices were used successfully in other studies – Erbello et al. (2022) employed Relief, ksn and HI; Gao et al. (2016) and Pérez-Peña et al. (2009) showed that HI is a robust index to evaluate tectonics; Obaid and Allen (2019) and Groves et al. (2020) furthermore showed the effectiveness of HI and ksn in evaluating active tectonics. We've added these references to the manuscript. (195-196)

Lines 218-220: Does a high k_{sn} also indicate a high uplift rate? If so, please specify this as you have done for the other two geomorphic indices.

Yes, high k_{sn}, denotes steeper channel and therefore higher uplift rates. We've added this along with references to the end of the sentence.

"Variations in ksn along channel segments may be related to changes of the uplift rate of that region (Snyder et al., 2000; Whipple, 2004) with higher ksn values often indicating higher uplift rates." *(244-246)*

Lines 229-330: You refer to Fig. 3 here, but the faults are not labelled in Fig. 3.

We've added labels to the faults on this map.

Lines 234-235: This statement is vague. How is the "general" NE-SW trend distinguished from the "local" ENE-WSW orientation? Where can we see this on the map (e.g., in Fig. 3)?

This change in trend is best observed on Fig.3 or on the stereonets on Fig. 5 which show the slight change in trend going northwards. We have reworded to: **"In the northern basement massifs (Hengshan and Wutai) there is a subtle change to WNW-ESE-trends"** *(Fig. 3). (264-265)*

Lines 279-281: Do you mean that the JC and TG faults have lower k_{sn} and R_i values compared to other faults in the region that are considered active? I think the sentence needs rewriting for clarity.

Yes, both faults generally have low R_l and k_{sn} values, we reworded this sentence to make this clearer.

"Low values of less than 50 are rarely associated with obvious faults with a surface trace. The Jiaocheng and the Taigu faults footwalls have drainage basins with ksn values between 50-85 which reflects the local relief response of these faults (Fig. 6a)." *(328-330)*

Section 4.5: Can this section be combined with the previous three sections? Otherwise, we are jumping back and forth between geomorphic indices.

We have combined sections 4.2/3/4 and 4.5 to improve readability.

Lines 307-308: I suggest moving this to the methods section.

We have added this part to the methods section. (196-200)

Line 347: Fig. 3 shows the ages of the units but not the lithologies.

We have fundamentally changed Figure 3 (in line with comments from other reviewers) to now include lithology as well.

Lines 348-351: Why not make it clear that the two groups you are referring to are crystalline rocks and low-grade metasediments? It would make the comparisons in the subsequent paragraphs easier to follow. Also, were the carbonates also subject to low-grade metamorphism? If so, wouldn't they technically also be considered metasediments?

We have changed this accordingly to reflect the two groups (crystalline rocks and low-grade metasediment) to improve readability. We include carbonates in the group of low-grade metasediments.

"The various lithologies can be divided into two main groups that differ in rock strength and erodibility. There are Precambrian crystalline rocks which include Archean Tonalite–trondhjemite–granodiorite complexes, high-grade metamorphic rocks and post-orogenic granites which are all part of the TNCO (Trap et al. 2012) and the low-grade metasediments units which include low grade clastic metasediments and carbonates from the Palaeozoic-Mesozoic (SBRGM, 1989)." *(379-384)*

Lines 357-363: What does HI tell us about tectonic activity? A short explanation of what HI means with respect to tectonics would be useful here.

Added two sentences to briefly highlight the tectonic implications of high HI values:

"High HI values are often correlated with high uplift rates, especially in regions with variable uplift rates; higher HI values are found in regions of higher uplift (Hurtrez et al. 1999). Therefore, the high HI values found in the footwalls of the Huoshan, Wutai, Xizhoushan and Shilingguan fault indicate that these footwalls have been uplifted the most rapidly." *(395-397)*

Lines 361-364: How do we reconcile this with the limitations of HI for tectonic interpretations (Section 4.4)?

We see high HI responses that are not related to active tectonics from 1) palaeorelief from previous tectonic events such as thrust faults and folds from the Mesozoic orogenies that shaped the Shanxi highlands prior to rifting. These are easily identified by comparing them to mapped structures. 2) The Loess plateau – just by the nature of how Loess forms and is shaped by surface processes it is prone to create ridges rather than sloping gentle landscapes. This is an impact of lithology on the HI response; however Loess is a rather extreme case and has very different properties to the main lithologies in the Shanxi Rift – Paleoproterozoic crystalline rocks and low-grade metasediments – therefore the main observation that HI is not as sensitive to differences in lithology still applies (apart from extreme cases such as Loess). However, this naturally has consequences for the interpretation as Loess needs to be accounted for when present.

We added a discussion part on the Loess plateau (and moved it from the results section)– ***To the western edge of the Shanxi Rift is a region of medium-high HI basins that to do not correlate with mapped active faults. This is likely due to the landscape that typifies the Loess Plateau west of the Shanxi Rift. Loess is unconsolidated wind-blown sediment that is prone to dramatic erosion that creates deep gullies and ridges which can lead to high HI values. The Loess Plateau formed in the Pleistocene and its linear ridges and gullies have***

been carved out by aeolian and fluvial forces (Kapp et al. 2015), therefore the high response of the Loess Plateau are related to young landscapes sculpted by surface processes rather than tectonic forces. This does not detract from the main statement that HI is less influenced by lithology, as loess is an extreme case of unconsolidated sediment as opposed to the main groups of low-grade metasediments and Palaeoproterozoic crystalline rocks. However, it does highlight that HI is sensitive to the presence of Loess, therefore when evaluating the tectonic response of an area this needs to be accounted for. *(399 - 408)*

Lines 366-367: What does "similar basement geology" mean? Would erodibility be influenced by factors other than lithology, e.g., the orientations and types of structures in these basement rocks?

We mean with similar basement geology the overall rock strength of that region, i.e. are these footwalls mainly composed of crystalline rocks or the low-grade metasediments which are the dominant groups in this study area.

Lines 368-373: These sentences seem to repeat what was already described in the previous paragraph.

We think, this short summary statement helps to highlight a key point, however we shortened it to:

"This enables us to compare the landscape response of these footwall uplifts to tectonics. In the Shanxi Rift for example, the Huoshan fault on average has higher values for geomorphic indices than other faults with Paleoproterozoic crystalline rocks in the footwall." *(412-414)*

Lines 375-377: It is difficult to follow which faults are being compared here.

Changed to:

"Here the difference in geomorphic response between the Shilingguan RIZ and the other faults with low-grade sedimentary rocks in their footwalls is even more pronounced than comparing faults with Paleoproterozoic crystalline rocks in the footwall where the difference between the Huoshan fault and for example the Hengshan or Wutai faults is less stark." *(416-419)*

Section 5.2: You could consider splitting up this section into two, with the second section focusing more on fault activity and implications for seismic hazard. Or you could include seismic hazard in the current heading.

Added seismic hazard to the current heading. (423)

Lines 386-388: Edit sentence for clarity. I recommend splitting it into two sentences. Also, in Line 388, replace "metrics" with "observations".

Edited the sentence and changed "metrics" to "observations." (433-435)

Lines 388-390: Do these two observations or categories only apply to breached RIZs? If so, please make this clearer. In Line 390, what does "They" refer to? Only breached RIZs or all RIZs? Perhaps it is worth summarizing how the temporal evolution of RIZs are assessed, and what observations are associated with unbreached, partially breached, recently breached, and breached RIZs (according to Kolawole et al., 2022).

We have changed this paragraph and have included a summary of the expected observations for the different evolution stages of RIZs:

> ***"Recently breached and breached RIZs have an established breaching fault and connect the drainage of two different rift segments, but breached RIZs show less topography due to increased subsidence during the longer time period since the RIZ was breached. Unbreached RIZs show no apparent structural connection and no drainage connection, while partially breached RIZs may have a breaching fault partially connecting the rift basins but the drainage integration has not occurred yet. The different RIZ stages come with distinct morphological responses and have relevance to the seismic hazard so in the following we classify the two RIZs based on the Kolawole et al. (2021) classification scheme and assess the response of the geomorphic indices."*** *(435-441)*

Lines 402-406: Here small-scale faults are described, but they are not shown on the maps in Fig. 7. Hence, it is difficult to observe the "complexity and distribution of faulting" in the Lingshi RIZ.

> *We marked the small-scale faults on the map in Fig. 8 (previously Fig. 7)*

Lines 410-411: Rewrite sentence for clarity.

> *Rewrote sentence and combined with previous sentence:*
> ***"Li et al. (1998) proposed that during the early evolution of the Shanxi Rift in the Miocene and Pliocene, the basins were filled by isolated lakes and later, during the mid-Pleistocene, a fluvial connection was established."*** *(461-463)*

Lines 413-414: Why is the Lingshi RIZ classified as "recently" breached? Because breaching is thought to have occurred in the Late Pleistocene? See previous suggestion about clarifying how RIZs are classified.

> *The RIZ has been classified as recently breached due to the presence of 1) a breaching fault that connects the two basins and 2) a physical connection of the depositional systems of the Taiyuan and Linfen basin in the form of the Fen River. This is apparent both in the topographical Swath profile (Fig. 8) and the longitudinal river profile that we added to Figure 8, which agrees with the classification scheme of Kolawole et al. (2021). Adding the timing of the breaching to have occurred in the Pleistocene is speculative based on literature on this area. However, the classification as "recently breached" is purely based on its morphology.*

Line 416: Is the Shilingguan Fault the breaching fault? If so, please make this clear. Also, the Jiaocheng Fault needs to be labelled on the map (Fig. 8a).

> *Yes, the Shilingguan Fault is the breaching fault of the Shilingguan RIZ – we have added this to the text (471-472) and have labelled the Jiaocheng Fault on Fig.9a*

Lines 421-422: "Recent uplift" was already mentioned earlier in the same paragraph. Combine the two for conciseness.

> *Rewrote this part to avoid using recent uplift twice in this proximity. (474-477)*

Lines 422-424: Refer to Fig. 2 here?]

> *Yes, good idea, included the reference to the figure here (477-479)*

Lines 441-442: What is the general extension direction? Or is this a general statement about oblique faults (not limited to the Shanxi Rift)?

In the case of the Shanxi Rift the general extension direction is NW-SE (151° - Middleton et al. 2016) so the N-S fault are forming oblique to it but the statement was intended to be more general to highlight other areas where similar observations were made.

Lines 454-455: Could you please rewrite this sentence for clarity?

Done. Reworded to: ***"RIZs often experience increased seismic activity due to increased strain along the tips of established basin bounding faults that progressively link across the RIZs."*** *(521-522)*

Line 461-465: Specify the length of the Huoshan Piedmont Fault here for comparison to the shorter faults in the Shilingguan RIZ. Also, this is a long sentence that should be split into at least 2 sentences.

Split the sentence into three and added the length of the Huoshan fault: ***"The faults in the Shilingguan RIZ are comparatively short and segmented (10-20km), this might limit their ability to generate large magnitude earthquakes. However, the Huoshan Piedmont Fault, the breaching fault of the Lingshi RIZ) is equally segmented (Fig. 7a) with segments 20-30km in length and has shown to be the site of major historic earthquakes. The historic Hongdong Earthquake (Mw 7.2-7.6) in 1303 CE was caused by slip on the Huoshan Piedmont fault (Xu et al. 2018) and had an estimated rupture length of 98km, which shows that multiple segments can link up during seismic slip to generate larger magnitude events."*** *(531-537)*

Lines 466-468: This sentence feels a bit out of place and could be connected to a previous statement about shorter RIZ faults.

Moved this sentence to an earlier position in the paragraph for a more logical progression. (523-526)

Line 473: Samsu et al. (2023) is now published.

Fixed that and included the correct reference.

Lines 478-480: Rewrite this sentence for clarity.

Reworded the sentence for clarity: ***"Some of the rift faults do not contain Precambrian crystalline rocks in the footwall, but for example the Jiaocheng and Taigu faults are in the direct vicinity of the crystalline Lüliangshan and Taihangshan massif (about 50km distance)."*** *(552-554)*

Lines 486-487: This headline statement could be moved further up to make the discussion easier to follow, e.g., to Line 477.

Moved this line to the start of the paragraph. (545-546)

Line 496: Upon observing Fig. 9, Hengshan Fault does not appear to follow the basement trend (at least not along its entire length), contrary to what is written in the text.

Agreed, it appears that the Hengshan fault only sometimes exploits the shallow basement fabrics, while other times cutting across it. We included two sentences to discuss this behavior which is similar to observations of the Bilila-Mtakataka Fault from Malawi (Hodge et al. 2018b) (565-568)

Lines 505-507: This is another headline statement that could be moved to the start of the paragraph.

Done. (560-561)

Lines 513-515: Zig-zag faults have been described in other studies (e.g., Lezzar et al., 2002; Corti, 2009; Hodge et al., 2018).

Added these further references to the paragraph, thanks for highlighting these. (587-588)

Lines 517-520: Here it would be good to mention the orientation of the regional strain (and cite the work that supports this, e.g., Middleton et al., 2017?). Also, have you considered whether (a) the geometry and relative timing of faults is influenced by the mechanical contrasts or weaknesses in the basement rocks, (b) rift-related faults that are still active and perturbing the stress or strain field as the RIZ faults form and grow, (c) we have a combination of a and b? Is there existing evidence of the main basin-bounding rift faults forming before the RIZ faults?

We propose that it is a combination of factors (c) – The main rift faults surrounding the RIZs perturbate the regional strain field in the RIZs, but the inherited structures of the basement rocks also influence the fault pattern, so instead of a regional strainfield that is orientated NW-SE (151 – Middleton et al. 2017) the local strain field (in the RIZs) is broadly E-W orientated. Some faults will follow the NE-SW trending basement structures, others will form perpendicular to the local strain field (N-S) – leading to the aforementioned zig-zag faults. The assumption that the main basin bounding faults formed before the RIZ faults is based purely on their morphology as they are larger, have accommodated more slip and often show more eroded fault scarps. Based on the work conducted in this study it is unfortunately not possible to make more concrete statements on the ages of these faults. It would also follow the pattern of RIZs in East Africa, where the basin bounding faults establish first and the breaching of the RIZs follows. We have edited the segment slightly to make this relationship clearer. (590-594)

Line 548: Molnar et al. (2020) presents analogue models, not numerical models.

Thanks for spotting the mistake, changed it to analogue models.

Lines 554-556: I appreciate that this is beyond the scope of this contribution, but I think it is useful to discuss in a bit more detail why the pre-existing lithospheric and crustal scale structures are not parallel, especially as you mention that this “could have either occurred during transpressional accretion of the Trans-North China Orogen or during later reworking by the polyorogenic event that formed the Trans-North China Orogen” (Lines 550-551) but do not explain this in more detail.

We tried not to go too far into this as at this point the paper already became quite lengthy, however we have added a bit more detail to this of one possibility. Kusky et al. (2007) propose one possible evolutionary model in which the TNCO (named Central Orogenic Belt (COB), the two are not technically the same as Kusky’s evolutionary model has different implications for timing of the orogenic events) formed initially as an Archean Orogen at about 2.5 Ga, later the NCC collided with Columbia (~1.8 Ga) which reworked the Archean COB, which may have contributed to the oblique relation of crustal and mantle structures of the Archean-Palaeoproterozoic rocks in Shanxi. Similarly, Santosh et al. (2010) proposes a double-sided subduction to be responsible for the amalgamation of the NCC, with the TNCO being formed primarily along a (present-day) N-S trend with later subduction of the Columbia supercontinent from the North, which may have reworked some of the crustal fabrics we see *today. Li et al. (2010) show a protracted evolutionary history of the TNCO from 2.5-1.8 Ga where closure of the ocean separating started along a broadly N-S trend and then later from about 1.85 Ga onwards the collision of the Eastern and Western block culminated in formation of NE-SW structures, this could also explain the obliquity of a N-S trending relict subduction zone in the upper mantle and NE-SW trending crustal structures that formed during later collision. These are just three possible scenarios, and this is by no way complete. The formation of the NCC and TNCO is still very contested, and we prefer to not get involved into reconstructions of the various subduction zones active at different times that may have formed the NCC/TNCO.*

We have added a bit more detail about these possible scenarios and the appropriate references:
"The difference in lithospheric and crustal structural trends could have either occurred during transpressional accretion of the TNCO, such as proposed by Li et al. (2010) where subduction occurred along a N-S trend while the later collision that formed the TNCO formed NE-SW trending fabrics. It may have also formed during later reworking by the polyorogenic event that formed the TNCO, where the N-S trending TNCO was partially reworked by a collision of the Columbia supercontinent in the Palaeoproterozoic which resulted in the formation of the E-W trending Inner Mongolia – North Hebei Orogen (Kusky & Li, 2003; Kusky et al. 2007; Santosh, 2010). However, the evolutionary history of the TNCO is debated and resolution of the exact timing of events is beyond the scope of this paper." *(623-629)*

Lines 558-559: Agostini et al. (2009) demonstrated this en-echelon arrangement of faults above a weak zone.

Added this to the sentence. (637-639)

Line 576: The last sentence is not a complete sentence.

Changed the sentence to make it into a complete sentence. (659)

Lines 584: Why is it a problem that lithology has a strong influence on the geomorphic signal? I think you could be more explicit that one of the aims is to see which geomorphic index is most useful for understanding the interaction between tectonics and landscapes – then this sentence would have a clearer meaning. I think you could also explicate this aim in the Discussion (Section 5.1).

If the differences between the faults were solely down to lithology that would severely affect the usefulness of geomorphic indices to evaluate the tectonic signal in the Shanxi Rift. If only faults with Palaeoproterozoic crystalline basement in the footwall would have high HI values while all faults with low grade metasediments in the footwall have low HI values the differences would probably be down to lithology. Yet, the fact that we have considerable spread within the two lithology groups (see Fig. 6) shows that tectonics most likely influenced the geomorphic signal of the various faults. This is best observed in HI on Fig. 6. While we think our results show that HI is the most robust of the three geomorphic indices, more detailed work would be needed to make a more concrete statement on this to eliminate other factors that might influence the geomorphic indices. We think this would be beyond the scope of this paper.

Figure 588-589: I don't recall where it was explained that linkage of sub-basins progressed towards the north.

> *Discussion on this has now been added following input from the third review by Folarin Kolawole. The evolution stages of the RIZs is less breached towards the North (Lingshi – recently breached; SLG – partially breached; Hengshan – unbreached) This may be related to their geometrical arrangement. Discussion on this has now been added to Section 4.2 (486-494; 675-677)*

Lines 589-591: This sentence should directly follow the first sentence of the paragraph.

> *Done (673-674)*

Figure 3: Label faults on this map. It would be good it the colors of the geological units here more closely matched the ones on Fig. 6.

> *Added labels to the faults and changed this figure significantly in response to comments from other reviewers*

Figure 6: The colors of the different faults are a bit distracting, as they appear arbitrary here and do not correspond with colors on any of the maps. On the other hand, the background colors that indicate Mesozoic-Paleozoic sedimentary rocks vs. Proterozoic basement is quite useful.

> *Agreed, changed the colour scheme of the figure.*

Figure 7: Label Taiyuan and Linfen basins and Fen River on map (e.g., Fig. 7a).

> *Done. (Fig.8a)*

Figure 8: Label basins in Fig. 8a and 8d. What are the blue arrows in Fig. 8a showing?

> *Blue arrows show the approximate drainage direction of the Fen river and the Hutuo river, added labels to make this clearer and labeled the basins on 9a/d*

Figure 9: Why does this figure appear so late in the text? I think this figure could really aid earlier explanations, including Section 5.1. Also, what do "high", "medium", and "low" geomorphic signals mean? Can these signals be quantified? Definitions of the abbreviations of fault names are missing in the caption.

> *High, medium and low geomorphic signals are based on the responses of the faults to the three analysed geomorphic indices. As a general principle we assume faults that are characterized by low responses to all three indices to have a "low" geomorphic signal, while high responses to all of these being "high". We are aware that this classification is somewhat arbitrary, but we think it is helpful in this figure to give an overall overview. Details of this are now presented in Table 1.*

Figure S3 (incorrectly labelled as S2): Why is this map in the supplementary information? It nicely shows the spatial relationship between earthquakes and faults (especially in the RIZs), which would be a useful visual aid for setting up the research problem (Introduction) and the discussion in Section 5.2. Is there a way to elegantly combine this map with Fig. 2?

> *Based on this being brought up by this and another review, we have decided to combine this with Figure 2, to show the recorded seismicity earlier in the text.*

Response to Review #3 (Folarin Kolawole)

The study by Froemchen et al. investigated the active tectonics of the Shanxi Rift System using geomorphic indices to 'to identify the impact of structural inheritance on the formation of the Shanxi Rift System'. The geomorphic indices highlight the focusing of active deformation in the rift interaction zones (RIZs) separating the active rift basins: Linfen and Taiyuan Basins are separated by the Lingshi RIZ, and the Taiyuan and Xinding Basin are separated by the Shilingguan RIZ. The Lingshi RIZ shows a through-going fault system, a through-going axial stream with unidirectional southward flow, and a southward down-stepping longitudinal surface relief shape that suggests a recently breached RIZ. The Shilinggian RIZ retains a high relief, lacks a through-going stream, but hosts evolving active faults that suggest a partially Breached RIZ morphology. The authors went further to assess the basement fabric trends across the region, and their relationship between faults bounding the rift basins and those extending into the RIZS, and found that the NE-trending basin-bounding faults follow the basement fabrics indicating structural inheritance control, whereas the RIZ faults form zigzag geometries suggesting strain re-orientation in the RIZs. The authors conclude that 'geomorphic indices might prove useful in the study of the evolution of structural inheritance in other active rifts'.

I think the topic of the paper is of broad interest to the continental rifting community and a good fit for EGU-Solid Earth's audience. However, while I enjoyed reading the manuscript, I have two major criticisms of the paper which I explain below and provide suggestions on how the issues can be fixed.

We thank the reviewer for their detailed review and the helpful comments and constructive suggestions. We have addressed the comments and have modified the manuscript accordingly. Below are the more detailed responses to the individual comments with references to the changed parts in brackets:

1) Drainage and topographic geomorphic indices cannot directly show the impact of structural inheritance on active rift tectonics. In other words, one cannot look at a map of hypsometric integral, local, relief, channel steepness index etc. and interpret that areas with high values are controlled by structural inheritance. Where there is a relationship, it is always indirect. The reason is simply because geomorphic indices of drainage systems are primarily sensitive to surface processes and controlling factors like vertical motions and variability in erodibility of rocks. Whereas structural inheritance is a mechanical process that is controlled by the interaction between the geometry and strength of inherited mechanical anisotropy and the tectonic stress field. Thus, while I think the tectonic geomorphology analysis and structural inheritance investigations in this study are great, the interpretation of a causative relationship between both is problematic. This implied causative relationship weakens the impact of the paper and should be avoided. The main point is that geomorphic indices can highlight the zones of intense active tectonic deformation which in the case of this study are the deforming RIZs within which active breach faulting is influenced by the inherited basement fabrics. However, I think it can be easily fixed by rewording key sections of the texts that alludes to an interpretation of direct causative relationship which includes the manuscript title, the abstract (lines 18-19, 24-25), introduction (lines 92-93), and many sections of the discussion (see my in-text suggested edits).

Yes, we agree that the wording in the manuscript suggesting a causative link between the inheritance and geomorphic analysis was imprecise and misleading. We will reword the outlined *sections in line with your comments those of the other reviewers to clarify that we do not imply a causative relationship between inheritance and geomorphic analysis but instead use geomorphic analysis to evaluate the tectonic evolution of the rift and compare this to the mapped inherited structures.*

*Line 18-19: **"Here we use tectonic geomorphological techniques, e.g., hypsometric integral (HI), channel steepness (ksn) and local relief to study the evolution of the Shanxi Rift and identify areas of higher tectonic activity. We found that HI was less sensitive to lithology and more valuable in evaluating the tectonic signal and found that activity is concentrated in two rift interaction zones (RIZ) formed between the basins. We then evaluate the relationship between the active faults and mapped pre-existing structures and found that many faults formed parallel to inherited structures."** (17-22)*

Line 24-25: removed.

*Line 92-93: **"By using geomorphic analysis to evaluate the tectonic evolution of the Shanxi Rift, highlighting areas of increased tectonic activity and comparing these with inherited structures, we provide new insights on the influence of inheritance on the evolution of the Shanxi Rift."** (99-101)*

2) On interpreting mantle anisotropy to represent inherited mantle fabric: Due to a lack of any age constraint on the timing of development of the anisotropy beneath this region, I do not think the interpretation of mantle shear wave anisotropy to be an inherited mantle fabric is appropriate. The mantle underlying active Continental rifts commonly develop anisotropic fabric due to mantle flow induced by the rifting, and this anisotropy is not always parallel to the rift axis (see East African Rift studies e.g., Tepp et al. 2018; doi.org/10.1029/2017JB015409). I don't think there is a need for this interpretation. The study has presented a strong case for the control of crustal inheritance. I think this is sufficient unless there is strong data on the age of the mantle anisotropy.

Thanks for bringing this to our attention. We understand that this discussion part is speculative and mainly based on the map shape of the TNCO and the shear wave anisotropy which as highlighted by you might be dubious evidence. We think that this is still a valuable thought experiment as multilayer inheritance is common in many rift basins and the response of rift evolution to obliquity of crustal and mantle inheritance has been modelled recently (Zwaan et al. 2022; Molnar et al., 2020). However, the evidence for this is thin and therefore perhaps more work needs to be done before highlighting this connection. We added the caveats and limitations to this interpretation highlighted above to make clear that this part of the discussion is speculative:

"However, we acknowledge that the observed mantle anisotropy may not be an inherited mantle fabric and could have formed during rifting (Gao et al., 1997; Kendall et al. 2006) and is aligned oblique to the rift (Tepp et al., 2018; Ebinger et al., 2024). Thus, the mantle fabric underlying Shanxi may be Cenozoic in age formed during extensional deformation of North China as has been proposed previously (Chang et al., 2012). We emphasise that our interpretation that the Shanxi Rift architecture is influenced by a crustal and mantle fabrics of the TNCO that are oblique to each other is speculative." *(639-643)*

In addition to these two criticisms, I have a lot of minor recommended edits which are mostly typographical errors in the text and missing references. I have attached my in-text comments to this review.

We went through the annotated pdf with the in-text comments and have done our best to address these and correct the errors and missing references. Thanks for highlighting these.

I would note two of the recommended edits:

1) Include some discussion text on the relatively different stages of development of the Lingshi and Shilingguan RIZs, which I think can be explained by their contrasting RIZ geometries. This is well supported by our recently accepted paper Kolawole et al. (2024, AGU Books, in print) where we find that RIZ geometries may influence the pace of breaching of active RIZs as they influence tectonic stress distribution across the interacting RIZ bounding faults. See the ESSOAr preprint:
https://www.researchgate.net/publication/370066205_Rapid_Versus_Delayed_Linkage_and_Coalescence_of_Propagating_Rift_Tips

Reference:

Kolawole, F., Xue, L., Dulanya, Z. Rapid Versus Delayed Linkage and Coalescence of Propagating Rift Tips. Accepted, in press at AGU Books: Extensional Tectonics: Continental Breakup to Formation of Oceanic Basins. Preprint: 10.22541/essoar.168167202.29986035/v2.

Thanks for highlighting this fascinating paper, we agree, that the differing geometries of the RIZs in Shanxi may indeed explain the different evolution stages of the RIZs. We included a short section of the discussion on this to refer to the apparent northward progression of the Shanxi Rift which may be connected to the different RIZ geometries.

"The different breaching stage of the Lingshi and Shilingguan RIZ may be related to their previously mentioned geometrical arrangement, which led to earlier breaching of the Lingshi RIZ (underlapping oblique convergent RIZ). The influence of initial geometry was shown by Kolawole et al. (2024) in a numerical model of the southern Malawi Rift, where the tip-to-tip arrangement of the Nsanje RIZ favoured rift coalescence compared to the overlapping divergent geometry of the Middle Shire RIZ. The convergent RIZ geometry of the Lingshi RIZ was beneficial for strain localisation and stress concentration at the fault tips of the surrounding basin bounding faults (Jiaocheng and Linfen) while the divergent geometry of the Shilingguan RIZ stalled rift coalescence. This in turn may also explain why the Hengshan RIZ is unbreached as it has an overlapping divergent geometry which is unfavourable to stress concentration and rift coalescence. Breaching status of the RIZs increases towards the south which may be controlled by the different RIZ geometries." *(486-494)*

2) Adding a panel to Figure 7 showing the longitudinal elevation profile of the Fen He River itself from the center of the Taiyuan Basin to the center of Linfen Basin. I did a quick plot of the profile, and it shows the very nice 'down-stepping' shape that is typical of 'recently breached RIZs'. I think a plot like this would make this figure stronger.

We have added a longitudinal elevation profile of the Fen He which shows that down-stepping profile typical of recently breached RIZ and have added this to the discussion to *strengthen the identification of the Lingshi RIZ as a recently breached RIZ. Thanks for the suggestion! (Fig. 8c)*