TEKTONIKA

Review Report

Reynolds et al., Kinematic Evolution of the Tangra Yumco Rift, South-Central Tibet. TEKTONIKA, 2024.

Table of Contents

1st Round of Revisions

Decision Letter

(6 June 2023)

Dear Ms. Reynolds,

We have now received comments from three reviewers on your submission to TEKTONIKA (see below). All three reviewers provided constructive and detailed comments on the text (although one reviewer was quite direct in their comments), and felt the manuscript is within the scope of Tektonika. However, they did also suggest varying levels of revisions to the text would be required prior to acceptance. In particular, note the connections between the age data and tectonics should be justified more carefully to ensure it is clear how the ages and structures relate to the various tectonic models considered. They also note that the geological background and discussion sections could be more concise and focus more directly on the topics most relevant for the study. Finally, the reviewers provide a number of more minor grammatical and spelling suggestions that may make the text more readable.

After reading both the text and reviews, we agree with the suggestions from the reviewers that major to moderate revision of the text will be necessary prior to accepting the article for publication. Please take into account all suggestions by the reviewers, either by implementing them or explaining why you do not in cases where you disagree with their comments.

As editors, we also recommend you consider proceeding as you intend for the data availability section by uploading your data to Zenodo (or another suitable repository) and creating a preliminary version of the citable data. If there are any changes to the data that occur during or after revision, a new version of the dataset could be produced and the link in the text could be updated. This would be nice to allow the reviewers and editors to see how the data have been made accessible and provide any feedback on that as well, if necessary. This is only a suggestion, and we understand if you have concerns about sharing the data prior to publication.

Submit your revised manuscript via the TEKTONIKA web site: under your manuscript's record you'll find a box named "revisions" with a way to upload your new files. Please also submit a detailed rebuttal letter explaining how you took into account reviewer's and editorial recommendations, and an additional manuscript version with the changes outlined.

Based on the scope of work suggested by the reviewers, we would hope that the revisions could be completed in approximately one to two months. If you have any concerns about this proposed timeline, or any other questions about how to proceed, you are most welcome to contact Executive Editor Robin Lacassin and Associate Editor David Whipp.

We will be anticipating the revised version of your paper and thank you for submitting to TEKTONIKA.

David Whipp, Associate Editor
Robin Lacassin, Executive Editor

Comments by Reviewer 1

(Konstanze Stübner)

The manuscript *"Kinematic Evolution of the Tangra Yumco Rift, South-Central Tibet"* by Reynolds at al. presents new zircon U-Th/He (ZHe) and U-Pb data from the Tangra Yumco (TYC) rift in southern Tibet, which they use to explore exhumation, rift kinematics and morphological development (development of the drainage divide) in this region. The data set is large and of high quality (49 ZHe samples, mostly 4-5 grains per samples, very few outliers; U-Pb ages are mostly Gangdese intrusive ages ~50 Ma but also include three Miocene dikes). Data tables and figures are carefully prepared and overall good. However, the manuscript includes very lengthy descriptions and discussions. It needs to be much more concise and will benefit from some major rewriting always keeping in mind the focus of the study. At the moment, the interpretation/discussion includes a lot of side tracks, the purpose of which is not clear and which lead to conclusions that are not supported by the data. I suggest to reject and encourage to resubmit. This is justified as follows:

The ZHe ages are nice and consistent and show a relatively simple pattern: south of 29.8°N, i.e. in the southern TYC rift and in three smaller rifts called GR1-3 ages are Oligocene/early Miocene; north of 29.8°N ages are variably late Miocene and unreset (~50 Ma). (I see no evidence for the claim that these ages are **partially** reset; also in Fig.9 there is a 13.9 Ma age that does not show up in Fig. 8b?). The interpretation could be straightforward but instead is overly complicated:

1. Fault propagation models: e.g. l 911: *"Based on kinematic observations from the field, normal fault patterns from geologic mapping, U-Pb weighted mean ages, and spatial trends in ZHe ages from this and previous studies, we interpret the best fit kinematic model to be the segment linkage model."* - Where are the individual "segments" with evidence of onset of faulting in each of their respective centres? What do all the 50 Ma U-Pb emplacement ages have to do with it? What are the kinematic observations and normal fault patterns that support this model? The spatial trend in ZHe ages (younging northward) would indicate "tectonically influenced tip propagation" if anything. Your only argument for segment linkage is that there are, indeed, individual fault segments. This has been shown in every previous study and does not rule out other models for fault growth. The discussion about fault propagation models is useless at best, personally I find it confusing and unsupported by the data.

2. Tibetan rifts vs. Gangdese rifts: The distinction seems a major part of the tectonic interpretation, yet I find it very confusing. This is in part due to terminology ("Gangdese latitudes"; "Gangdese rift 1 to 3"). It is also not clear to what extent this is background cited from other publications or outcome of this study. The TYC is >150 km, so by definition it's a "Tibetan" rift. I am missing the point.

3. Thermal modelling (HeFTy): The thermal models are based on three data points: a U-Pb age (with an arbitrary 900°C crystallisation age; not a thermochronometer), a ZHe age and an arbitrary 0°C at 0 Ma. What is the significance of the"best fit" path if all the "good fit" path basically tell you that **any** path is equally good. This is not the data set for thermal modelling. If anything I would use a simple thermokinematic model to try and constrain the depth of ZHe closure and estimate the amount of exhumation (although I suspect that these models, too, would be poorly constrained by the data). I do not see an *"initial phase of slower cooling followed by one or more phases of rapid* *cooling"* (l 817) in any of these models. The pattern of ages is simple, keep the interpretation simple.

4. Onset of rifting: A single 16 Ma (U-Pb) old dike does not constrain the onset of rifting and most certainly not a spatial pattern of rift initiation. *"We interpret Oligocene to early-Miocene ZHe ages from Gangdese latitudes as reflecting a distinct exhumation event prior to TYC rift initiation..."* - Where does this ad hoc interpretation come from? Just because cooling ages are older that a single dike?? All samples are from the footwall in close proximity to the normal faults, these data are simply not suitable to decide whether cooling is related to normal faulting. And why are the Palaeocene-Eocene ages interpreted as *partially* reset?

l. 994 *"We interpret E-W extension in the southern TYC rift to have initiated by ~16 Ma continuing until at least 4 Ma, whereas E-W extension across the Gangdese rifts appears to have begun by ~28 Ma and continue until ~16 Ma"* - This is the opposite of what you state in section 5.2.1, where 15-28 Ma cooling ages are interpreted as pre-rift, related to the Gangdese Thrust / Great Counter Thrust.

5. Tectonic interpretation (Fig 11): Hypothesis 3 "this study" is in direct conflict with the data and with the interpretation offered by the authors, e.g. "rifting started by 16 Ma" (l 885, 994) vs. "8-4 Ma" (Fig 11).

6. I fail to see how the data have any implcations on the development of the **drainage divide**: Exhumation through ZHe closure is not immediately linked to surface uplift.

Comments by Reviewer 2

(Reinhard Wolff)

The manuscript entitled “Kinematic Evolution of the Tangra Yumco Rift, South-Central Tibet” presents new zircon U-Pb and zircon (U-Th)/He ages from the central and southern Tangra Yumco rift on the Tibetan plateau. The zircon U-Pb ages range from 153 to 11 Ma and the zircon (U-Th)/He ages are between 59 and 5 Ma. From these data Reynolds and co-authors constrain the thermal history of the footwall rocks of the N-S trending rift and suggest that the rift formed due to fault-segment linkage. The 245 zircon (U-Th)/He ages together with the 18 zircon U-Pb ages are an important contribution to the recent discussion about rift propagation on the Tibetan plateau and a comprehensive data set. Overall, I find this paper suitable for publication in Tektonika, however, some work is needed to improve the presentation of the data.

General comment:

I highly recommend to add Table S1 to the manuscript and add the mean ZHe and U-Pb ages to this table. Additionally, the sample locations and sample names should be shown in a figure (e.g. Figure 2). By doing so, the reader can more easily find e.g. the position of sample 19AR11 on the map with the zircon U-Pb age of 16.1±0.1 Ma, which the authors interpret to reflect a minimum age for the onset of E-W extension of the Tangra Yumco graben while the table indicates the lithology of the sample: porphyritic andesite.

Specific comments are given line by line:

Line 24, line 702, and line 889: Figure 8 shows ZHe ages versus latitude but a correlation is only present for the ZHe ages of group 3 (4 mean ZHe ages) and when excluding sample 19AR23 as well as group 2. These exceptions should be mentioned more clearly in the text. What is the definition of a “strong” correlation in this context? Without statistical tests, I would suggest to omit “strong”.

Line 183: The references given here for rift initiation are from nearby study sites, only. Giving more references for ages on rift initiation across the entire Tibetan plateau (see Fig. 1) would highlight the significance of the present study for a broader audience (e.g. Armijo et al. 1986; Blisniuk et al. 2001; Williams et al. 2001; Murphy et al. 2010; Ratschbacher et al. 2011; Styron et al. 2011).

Line 195: Please add the age for rift initiation suggested by the model for the southern ZHe ages here, for the sake of completeness.

Line 308: Referring to the figures would help the reader to follow the text of sections 2.2.1 - 2.2.3.

Line 315: Abbreviation GRTB is not explained yet.

Line 385: Typo “grain”.

Line 387: This section could be shortened and condensed because it focusses on two other rifts on the Tibetan plateau, only. It is not clear to me why these two rifts are described in great detail, whereas other rifts are not described at all.

Line 450: What is the definition of Gangdese rifts? In the abstract they are defined by a length of less than 50 km, here a length of less than 150 km. Are there more reasons for discriminating these rifts from the larger rifts that underlines the importance to separate these grabens?

Line 524: ZHe closure temperatures might even be lower (e.g. Whipp et al. 2022) depending among other factors on the intensity of radiation damage.

Line 252: What are the assumptions that lead to the 2-10 km range given here?

Line 525-527: Please rephrase this section, the closure temperature does not depend on the geothermal gradient or the exhumation rate.

Line 549: 4He/3He were not reported herein.

Line 702 and 563: Is the eU calculated by 0.235 or 0.28xTh? See Guenthner et al. (2013) who suggest 0.235.

Line 700-701: In my opinion the manuscript would benefit by adding to the discussion a paragraph explaining why there is no correlation between ZHe ages and elevation, as mentioned in line 701. The horizontal distance between samples 19AR22, 19AR23, and 19AR24 is very small and they cover a vertical distance of 250m, however, the sample in the center is 15-20 Myr older than the lower and upper samples. The same pattern can be seen at many other sampling locations (e.g. 19AR15 on the western side of the TYC) where samples were taken close to each other (e.g. Fig. 8a).

Line 734: To be consistent with the number of significant digits of the ZHe ages, I would recommend to write 9.0 – 4.7 Ma.

Line 740 and line 958: At the Duozebu location, the ZHe ages are between 13.9 and 8.1 Ma and thus very close to the U-Pb ages (11.0 – 10.9 Ma). Can you exclude cooling after dyke emplacement for these samples (compare to Fig. S4 cooling path of sample 19AR25)?

Line 743: “Rapid cooling” is only true when sample 19AR23 is excluded from the data.

Line 798: Why was only one zircon grain used for thermal modeling? Adding e.g. crystals of different sizes could possibly improve the modeling results.

Line 814: What does “easiest” mean in this context?

Line 818-821: The authors state that HeFTy modeling results of the two samples 19AL06 and 19AR24 indicate that the onset of rapid cooling youngs towards the north. I suggest to indicate this finding in Figure 11 and therefore enlarge the line “rift acceleration” towards the positions of the two aforementioned samples.

Line 885-886: This is a very important finding of this study and could be more emphasized, e.g. in the abstract or conclusions. Maybe this constraint could be added to figure 11, too.

Line 892-897: What are the reasons for the interpretation that the Paleocene-Eocene ZHe ages are only partially reset and that the Oligocene-Early Miocene ages are cooling ages? Please add some information.

Line 913: This paragraph would benefit by giving more details on the structural observations from the field that lead to the conclusion that fault segments linked during normal faulting.

Line 930-933: The t-T paths of sample 19AL06 indicate rapid exhumation at 22-18 Ma as stated by the authors in line 819 and in Figure 10, and not at 13 Ma as written here. Please check the ages here. The older age for the onset of rapid exhumation (22-18 Ma) agrees well with the minimum age for extension given by the U-Pb age (16.1 Ma) on the dike in the southernmost part of the TYC.

Line 943-944: “all but one age”: There is only one ZHe age of 28 Ma at the Tangra Yumco graben, but there are three more 28 Ma ZHe ages in the Gangdese range farther east (Fig. 9). Maybe this is worth mentioning here.

Line 944-995: I agree that the ZHe ages of these samples are older and that they cooled earlier than the samples north of the Gangdese range. However, due to their position in the footwall of the Tangra Yumco normal fault, they have been exhumed due to normal faulting and erosion along the TYC, too. A combination of exhumation due to thrusting, erosion and subsequent normal faulting and erosion could possibly explain the large age-spread of the ZHe ages in the Gangdese range. Nevertheless, I would still expect the ZHe ages to increase with increasing elevation.

Line 996: The “28 Ma” in the sentence “E-W extension across the Gangdese rifts begun by 28 Ma” has not been mentioned in this context before. Please indicate what the onset age of 28 Ma is based on.

Line 996: It seems inconsistent that the ZHe age of sample 19AR21 (28 Ma) is interpret as “exhumation in the hanging wall of the north dipping GT” (line 948) while the ZHe ages of the samples in between the Tangra Yumco rift and the Gangdese rifts (two samples) yielding 28 Ma are interpret as initiation of rifting at the GR (line 995-996). Please clarify why there is a different interpretation of these ages.

Line 1042: The stated exhumation between 21.8-15.7 Ma for the Gangdese rift 2 is much younger than the onset of rifting suggested in line 996. Please clarify this discrepancy.

Line 1135: I would suggest to use the definition of England and Molnar (1990) for exhumation throughout the manuscript: exhumation equals rock uplift minus surface uplift. Using this definition, thermochronology constrains exhumation only, and does not give information on surface uplift directly.

Fig. 2 and 9: Adding transparency to the background increases the readability of the figures.

Fig. 8A: In my opinion, the figure showing the age-elevation relationship is not very helpful for illustrating the statements made in the text. Maybe showing two or three selected age-elevation profiles from the southern, central, and northern graben would be more helpful than mixing all data available in one figure.

Fig. 8B: To which of the three groups belong the ages at 30.15°N? The colored box is missing here.

Fig 9: Lat and Lon are missing in this figure.

Fig. S1: Please correct typos “Wolff et al., 2023” and 2019 in the legend of the figure.

Table S1: Four digits are sufficient for the latitude and longitude values when taken with a hand-held GPS.

Table S2-S3: The tables with the U-Pb and ZHe data are difficult to read in the PDF version and the mean values that are mentioned in the text are missing.

Comments by Reviewer 3

(Anne Replumaz)

This paper is dealing with a very interesting topic, the interactions between rifts and contractional structures to influence the evolution of topography during the collision between India and Asia. The paper is very well-written, with interesting new data on the Tangra Yumco Rift (TYR).
Nevertheless, the structure of the paper is a bit odd, in between a paper focus on the rifts kinematics and timing, and a review on South Tibet evolution not in link with the data presented here. Indeed, the new data on the TYR are pertinent to test the different kinematic models for normal fault growth (figure 3) and to discuss the link between rifts and contractional structures, as presented in the introduction. On the contrary, the sections “2.1 Rock units” and “2.2 Fault systems” are deeply detailed on the structure of the entire South Tibet, which is not illustrated on figures 1&2. These published data are used to discuss the evolution of the collision zone on a roughly NS cross-section, not in link with the rifts, which are NS structures not visible on such cross-sections.
I suggest to simplify the presentation of South Tibet data, and to better focus the discussion on what the study of the rifts could bring to the debate.
In particular, the Gangdese range as to be more clearly defined on figures 1&2. The classification between Tibetan and Gangdese rifts has to be clarified, as the Gangdese batholith is the southern part of the Lhasa block, and part of Tibet. Geological setting should be more focus on the description of the rifts, including rifts south of the Indus suture and north of the Bangong one, so that figure 2 should be enlarged. The contractional structures have also to be more clearly illustrated, by adding geological cross-sections. The description of the studied zone should be included in the geological setting, so that the link with a more regional context could be done based on these local results.
Anne Replumaz

Detailed comments:
72 We consider two classes of rifts in Tibet: (1) Tibetan rifts, which we define as rifts that are >150
73 km in length and crosscut the Lhasa Terrane, and (2) Gangdese rifts, which we define
74 as rifts generally <50 km in length that are isolated within the high topography of the
75 Gangdese Range of southern Tibet (Fig. 2; Burke et al., 2021).
This classification is not shown on figures 1&2. It has to be done. But, the Gangdese batholith is the southern part of the Lhasa block, so this classification has to be more precise.

198 A northward-younging trend in the timing of rift
199 acceleration has also been proposed for other Tibetan rifts where along-strike fault timing
200 is well constrained
Such

208 with its southern boundary and the modern-day
209 drainage divide marked by the crest of the Gangdese Range (Fig. 2).
Any name of river is shown on any figure. It has to be added, with a simplified drainage pattern.

227 Rocks exposed in the southern TYC geologic map area (Fig. 2) include Permian sedimentary
228 units of the Lhasa terrane, Late Cretaceous-Paleogene calc-alkaline intrusive rocks of the
229 Gangdese (Trans-Himalaya) magmatic arc (herein referred to as the Gangdese Range)
Figure 2 is not a geologic map, so that there is no figure corresponding to this very detailed section “2.1 Rock units”.

309 A contractional Cordilleran-style retroarc thrust belt north of the Gangdese Range in the
310 Lhasa terrane has been proposed based on the presence of an angular unconformity
311 separating highly shortened Permian-Cretaceous strata from overlying weakly deformed
312 Cretaceous-Tertiary rocks of the LVG
Such concept of contractional Cordilleran-style retroarc thrust belt north of the Gangdese Range in the Lhasa terrane is not understandable with the figures proposed in this paper. Similarly to previous comment, there is no figure corresponding to this very detailed section "2.2 Fault systems".
Furthermore, these sections are not specifically dealing with the rifts kinematics and timing, which is the main focus of this paper. I suggest to both simplify the text of the section 2 or to improve the figures, to show a more general geological map and cross-section.

315 GRTB
Not defined.

599 "4.1. Structural Results"
I agree that it is a result, but such mapping is also useful to present the region of study and should be in the "geological setup" section. A link with a more regional context could be done based on these local results.

842 we observe Xigaze forearc strata faulted onto the Kailas Formation,
843 and Kailas Formation strata faulted onto rocks of the Gangdese batholith along two
844 moderately south-dipping, top-to-the north reverse faults (Fig. 4).
The dipping is not visible on figure 4, it is lacking a geological cross-section. Furthermore, as the paper focus on the interactions between rifts and contractional structures, figure 4 should be enlarged to the south to better show this interaction. Field pictures of the contractional structures have to be shown.
As it is referred here to figure 4, this section has to go in the geological setting where this figure is presented. It should be used to make the link with published data for South Tibet.

850 satellite imagery of
851 unmapped and thus far inaccessible portions of central TYC appear to reveal footwall
852 mylonite fabrics, hanging wall scarps, and synthetic graben structures which may indicate
853 the presence of active low-angle faulting at depth.
According to me, it is not robust enough to base such interpretation on satellite imagery only, which appears more "model driven" than based on data.

911 Based on kinematic observations from the field, normal fault patterns from geologic
912 mapping, U-Pb weighted mean ages, and spatial trends in ZHe ages from this and previous
913 studies, we interpret the best fit kinematic model to be the segment linkage model. This
914model predicts similar patterns of fault displacement to what is observed in the TYC rift,
915 with complex distributions in the age of extension onset potentially related to variations in
916 the timing and rates of exhumation along different fault segments.
The results should be presented as in figure 3, to test these models.

945 The oldest
946 mean age in this study (28.04 ± 0.36 Ma) from sample 19AR21 was calculated from relatively
947 widespread single-grain ages from 22.57 ± 0.29 Ma to 38.74 ± 0.49 Ma. This age could reflect

948 exhumation in the hanging wall of the north dipping Gangdese Thrust (GT) which we infer
949 to be located at depth in this region, with previous timing estimates suggesting the
950 southernmost splay of the GT became active by ~27 Ma (Yin et al., 1994; Laskowski et al.,
951 2018). The widespread single-grain cooling ages within sample 19AR21 could potentially
952 reflect progressive cooling via exhumation along the GT in this region, and potentially even
953 an older splay of the GT, beginning as early as ca. 38 Ma and continuing to at least ca. 22 Ma.
Again, according to me, it is not robust enough to base such interpretation on one age.

1057 5.2.3. Implications for the Dynamics of East-West Extension in Southern Tibet
1058 Many models have been proposed to explain the dynamics or driving forces of extension
1059 in Tibet, with each model characterized by testable predictions for the spatial and temporal
1060 distributions of the age of extension onset, rates and magnitudes of extension, fault
1061 orientations, and relation to magmatism.
It is a bit strange to end this paper with a review of these different models, with no clear link with the EW rifts, and no clear conclusion from this study on which model is preferred based on the new data presented. Maybe it is worth to try to compare the different models in map ? see a recent paper that I published with a Chinese student, Shiguang Wang (Wang, S.G, A. Replumaz, M.-L. Chevalier, H. Li, Decoupling between upper crustal deformation of southern Tibet and underthrusting of Indian lithosphere, Terra Nova, doi: 10.1111/ter.12563, 2021).

Figure 1: insert showing a too wide zone, Tibetan and Gangdese rifts have to be differentiated on the figure. The drainage divide has to be shown at this scale. Lines showing the sutures are not thick enough. The color of the sutures names has to be related to the color of the lines.
Figure 2: divide of which river ? At least the Gangdese batholith as to be shown. Lines too thin.
Figure 3 is very clear.
Figure 4: geological cross-sections are lacking.
Figure 6. The U-Pb histogram is so clear that there is no need of the probability density plot or kernel density estimate.
Figure 8: a/ too many colors for latitude, use of the same code as the boxes ? b/ The 3 boxes should be shown as single big boxes on the graph. 2 oranges boxes larger than the data, why ?
Figure 9: this figure is not easily understandable. The results should be presented as in figure 3, to test these models.

Authors' Replies to Reviews

This document contains a detailed description of all changes made to the manuscript *Kinematic Evolution of the Tangra Yumco Rift, South-Central Tibet* including individual responses to each reviewer comment. The contents of the manuscript have greatly improved based on suggestions from the three reviewers and Tektonika editors, with notable incorporated changes including revision of figure 2 as a regional geologic map and a new schematic cross section, as well as a generally clearer overall focus on rifting rather than other related topics mentioned in the manuscript (e.g., discussions of contractional structures and drainage divides which are relevant but not directly studied in this manuscript have been reduced for conciseness). Responses to comments are organized by reviewer in the following sections.

Response to Reviewer 1: Konstanze Stübner

General Comments:

The manuscript "Kinematic Evolution of the Tangra Yumco Rift, South-Central Tibet" by Reynolds at al. presents new zircon U-Th/He (ZHe) and U-Pb data from the Tangra Yumco (TYC) rift in southern Tibet, which they use to explore exhumation, rift kinematics and morphological development (development of the drainage divide) in this region. The data set is large and of high quality (49 ZHe samples, mostly 4-5 grains per samples, very few outliers; U-Pb ages are mostly Gangdese intrusive ages ~50 Ma but also include three Miocene dikes). Data tables and figures are carefully prepared and overall good. However, the manuscript includes very lengthy descriptions and discussions. It needs to be much more concise and will benefit from some major rewriting always keeping in mind the focus of the study. At the moment, the interpretation/discussion includes a lot of side tracks, the purpose of which is not clear and which lead to conclusions that are not supported by the data. I suggest to reject and encourage to resubmit. This is justified as follows:
Response: The manuscript has been revised for clarity and conciseness throughout, with particular focus paid to rewriting the background and discussion sections to be more concise and focused on rift kinematics, as suggested by all three reviewers. All conclusions have been fully supported and/or are described as consistent with the data in this study, with other studies finding similar results cited in the text. One small note: only one sample in this study (19AR11) is from a Miocene dike though we discuss other studies with Miocene dike ages as well.

The ZHe ages are nice and consistent and show a relatively simple pattern: south of 29.8°N, i.e. in the southern TYC rift and in three smaller rifts called GR1-3 ages are Oligocene/early Miocene; north of 29.8°N ages are variably late Miocene and unreset (~50 Ma). (I see no evidence for the claim that these ages are partially reset; also in Fig.9 there is a 13.9 Ma age that does not show up in Fig. 8b?). The interpretation could be straightforward but instead is overly complicated:

Response: The evidence for partially reset ages is the large intra-sample age spread for these samples between ~65 Ma to 30 Ma in some cases. This spread of ages is much larger than normally expected for a simple one phase of cooling following emplacement, especially when compared to the well constrained young ages north of the Gangdese range. It seems likely the ages are partially reset due to some cause of continuing exhumation and cooling, which we can reasonably expect to be caused by continued rifting based on their location in the footwall and evidence of active faulting in the TYC rift. It seems unlikely that samples located in the footwall of a rift are completely unreset and have experienced no cooling due to continued rift exhumation, and to exclude this discussion from the manuscript would be an oversimplification of a protracted cooling history for these samples.

The 13.9 Ma age was a typo that has been corrected, the actual mean age for that sample (19AR26) is 8.13 ± 0.10 which was reflected correctly on figure 8b and has been corrected on figure 9.

1. Fault propagation models: e.g. l 911: "Based on kinematic observations from the field, normal fault patterns from geologic mapping, U-Pb weighted mean ages, and spatial trends in ZHe ages from this and previous studies, we interpret the best fit kinematic model to be the segment linkage model." - Where are the individual "segments" with evidence of onset of faulting in each of their respective centres? What do all the 50 Ma U-Pb emplacement ages have to do with it? What are the kinematic observations and normal fault patterns that support this model? The spatial trend in ZHe ages (younging northward) would indicate "tectonically influenced tip propagation" if anything. Your only argument for segment linkage is that there are, indeed, individual fault segments. This has been shown in every previous study and does not rule out other models for fault growth. The discussion about fault propagation models is useless at best, personally I find it confusing and unsupported by the data.

Response: firstly, I would like to mention there are numerous previous studies interested in testing fault growth models and mechanisms (e.g., Ellis, 2015; Curry et al., 2016; Jackson et al., 2017; Nicol et al., 2020; etc.), and it is both complimentary to our dataset and timely to incorporate a discussion of fault growth models into this study. There is currently very high interest in the rift research community regarding the early stages of continental rifting and the mechanism by which rifts initially operate, propagate, and grow through time (there will be a session at the AGU meeting this December dedicated specifically to this topic). Secondly, it is important to note that fault growth occurs on a spectrum, with tip propagation and constant fault length being two end members and segment linkage and tectonically influenced tip propagation models being variations of tip propagation. These distinctions can help us better understand the spatial and temporal patterns of rifting in Tibet and help provide important context for future publications interested in the dynamics of rifting in the complex tectonic setting of southern Tibet.

2. Tibetan rifts vs. Gangdese rifts: The distinction seems a major part of the tectonic interpretation, yet I find it very confusing. This is in part due to terminology ("Gangdese latitudes"; "Gangdese rift 1 to 3"). It is also not clear to what extent this is background cited from other publications or outcome of this study. The TYC is >150 km, so by definition it's a "Tibetan" rift. I am missing the point.

Response: Yes, the Tangra Yumco rift is a Tibetan rift, but we also have data from other smaller rifts nearby which we classify differently to compare the data more easily and because we suspected they may have a different cause for onset. Tibetan rifts are classified here as >150 km and crosscutting the Lhasa terrane. These are the classic rifts that most rift studies in Tibet have focused on investigating. However, there are also these shorter rifts (<150 km) that are isolated to crosscutting the Gangdese range, and these rifts have been far less studied – they are only mentioned in two prior studies to our knowledge. In Yin, 2000 they are described as follows: "two populations of rifts in this region can be clearly defined based on their spacing and along-strike length. The first are the well-known seven major rifts [Armijo et al., 1986]... which are several hundreds of kilometers long and are spaced at ~146+34 km. The second group consists of nine short rifts (<130 km long), all in south central Tibet and next to one another. They are spaced at 46+7 km. These short riffs bound a series of north-south trending, narrow lakes such as Dajia Co and Jiesha

Co." In Burke et al., 2021, the name "Gangdese rifts" and distinct classification from Tibetan rifts based on length (<150 km for Gangdese rifts and >150 km for Tibetan rifts) was used in describing new data from the Daijaimang Tso rift (relevant due to its location just west

of TYC). We adopt the terminology of Gangdese rifts to distinguish that some of our samples are collected from these shorter rifts in the region surrounding TYC, while other samples are from the TYC rift. Prior to this study (and Burke et al., 2021), there existed little age data or field observations from Gangdese rifts, thus a core goal of this study was to compare these two classes of rifts. To clarify, the two classes of rifts were first described by Yin, 2000 and the terminology distinguishing Gangdese rifts from Tibetan rifts was used in Burke et al., 2021, but all age comparisons between the TYC rift and Gangdese rifts (described as GR1, GR2, GR3 because they are previously unnamed rifts) are new to this study. Based on our results we noticed an unexpected distinction in ages not just between the TYC rift and Gangdese rifts, but more specifically, that the samples overlapping the Gangdese range from both the TYC rift and Gangdese rifts fell into one age group, thus the use of the terminology "Gangdese latitudes" which more accurately represents the results and facilitates comparisons of sample age based on latitude. It would be convenient and make the discussion simpler if all ages from the TYC rift were younger and all ages from the Gangdese rifts were older, but this is not what our results show. I hope this explanation helps to better explain the choice of wording used in the manuscript.

3. Thermal modelling (HeFTy): The thermal models are based on three data points: a U-Pb age (with an arbitrary 900°C crystallisation age; not a thermochronometer), a ZHe age and an arbitrary 0°C at 0 Ma. What is the significance of the"best fit" path if all the "good fit" path basically tell you that any path is equally good. This is not the data set for thermal modelling. If anything I would use a simple thermokinematic model to try and constrain the depth of ZHe closure and estimate the amount of exhumation (although I suspect that these models, too, would be poorly constrained by the data). I do not see an "initial phase of slower cooling followed by one or more phases of rapid cooling" (L 817) in any of these models. The pattern of ages is simple, keep the interpretation simple.

Response: thermal models for samples with U-Pb ages were constrained by the sample's age range at >900°C which is the equivalent temperature sensitivity for those samples. Models require an end constraint and were collected at the surface at present day, so I suggest the 0° at 0 Ma constraint is not simply arbitrary and is supported by geologic evidence of the samples being collected at surface temperatures. However, it is true that because the inverse model lacks additional thermochronologic data inputs or geologic information (narrower constraint boxes or restricted path behavior) at temperatures between the U-Pb age-temperature constraint and the ZHe age-temperature constraint, the model does not constrain the thermal history prior to the ZHe age very well for that sample. After the ZHe age-temperature constraint for a sample, the model inputs do require the paths to follow the diffusion parameters specific to the grain and offer potentially interesting cooling information to be interpreted. While the design of our constraint boxes based on available data is not optimized for exploring these specific histories, I believe it is beneficial to include this modeling in the manuscript as a visual representation of the dataset, particularly since the results are consistent with prior studies of Tibetan rifting. Finally, I'll note that it is probably much more likely for a sample collected from the footwall of a normal fault to have experienced two or more stages of cooling (primary cooling followed by cooling due to exhumation) as, from geologic evidence, the sample has clearly based on it's position been exhumed from multiple km depths in the footwall of rift bounding normal faults which is more than likely impossible to be accomplished without some level of additional cooling of the sample. If the magnitude of extension driving cooling is enough to rest the thermochronometer is a different discussion but is one which I believe is well covered in the discussion section describing ZHe results for different sample groups.

4. Onset of rifting: A single 16 Ma (U-Pb) old dike does not constrain the onset of rifting and most certainly not a spatial pattern of rift initiation. "We interpret Oligocene to early-Miocene ZHe ages from Gangdese latitudes as reflecting a distinct exhumation event prior to TYC rift initiation..." - Where does this ad hoc interpretation come from? Just because cooling ages are older that a single dike?? All samples are from the footwall in close proximity to the normal faults, these data are simply not suitable to decide whether cooling is related to normal faulting. And why are the Palaeocene-Eocene ages interpreted as partially reset?
Response: While I agree the age of rift intiation cannot be constrained by a single U-Pb age from one extensional dike, I will note that in the manuscript we do not solely use the age of one dike to make this interpretation. We suggest a minimum age for the onset of rifting in TYC of ~16 Ma which is consistent with and supported by:

(1) the age of the synextensional dike located in the SE footwall of the TYC rift (sample 19AR11 this study)
(2) Recently published geo- and thermochronology results from the Dajiamang Tso rift which suggest the age of extension onset to be between 16-8 Ma for south-central Tibet (Burke et al., 2021)

(3) 40Ar/39Ar results dating movement along the Lopu Kangri rift (Sanchez et al., 2013; Laskowski et al., 2017) and north striking mineralized fractures near the Thakkhola graben (Murphy et al., 2010) which yielded ages of ~15 and ~14 Ma, respectively
(4) the suggested onset of extension In TYC from a previous study in the south TYC rift (Wolff et al., 2023)

(5) results for extension timing from other rifts (Yin & Harrison, 2000; Williams et al., 2001;

McCallister et al., 2014; Sanchez et al., 2013; Laskowski et al., 2017).
From these points you can also see that the interpretation "We interpret Oligocene to early-Miocene ZHe ages from Gangdese latitudes as reflecting a distinct exhumation event prior to TYC rift initiation..." is not soley based on the ages being older than a single dike. This is based on a collection of data and interpretations from many prior studies of Tibetan rifting, with the oldest suggested age for rift initiation being around ~19Ma (well explained in the text). While the samples are all collected from the footwalls of normal faults, the samples overlapping the Gangdese range produced significantly older ages than those north of the Gangdese range, ages which are significantly older than any other prior study has suggested for the onset of rifting in southern Tibet. The interpretation that these samples are reflecting an older exhumation event should not be alarming in my opinion. Refer to Response 1 explaining why the Paleocene-Eocene ages are interpreted as partially reset rather than not reset. The spatial pattern of rift initiation (older in the south and younging towards the north) is interpreted from the variation of sample ages along strike of the TYC rift, is reflected in the age versus latitude comparisons and thermal models, and is supported by numerous previous studies in TYC (Wolff et al., 2019, 2023) and other Tibetan rifts (e.g., DeCelles et al., 2002; Kapp & Guynn, 2004; Styron et al., 2013, 2015; Sundell et al., 2013; Bian et al., 2022).

L. 994 "We interpret E-W extension in the southern TYC rift to have initiated by ~16 Ma continuing until at least 4 Ma, whereas E-W extension across the Gangdese rifts appears to have begun by ~28 Ma and continue until ~16 Ma" - This is the opposite of what you state in section 5.2.1, where 15-28 Ma cooling ages are interpreted as pre-rift, related to the Gangdese Thrust / Great Counter Thrust.

Response: Gangdese rifting is interpreted to be occurring simultaneously to balance uplift and exhumation along the GT/GCT... This does occur prior to the initiation of TYC and other Tibetan rifts, but I don't believe the terminology "pre-rift" was used as it would be confusing since we are also talking about the Gangdese rifts. In section 5.2.1. I am talking about the Gangdese rifts and the text states "These ages are older than reset rift footwall samples north of the Gangdese Range, suggesting a different structural mechanism for their cooling" which should clarify the apparent contradiction. I have also added the following text to this section to further clarify the timeline for samples overlapping the Gangdese range: "We note that samples positioned in the footwall of the TYC rift have likely also experienced exhumation due to normal faulting and erosion during the mid-Miocene-Pliocene. A combination of exhumation due to thrusting, erosion and normal faulting could possibly explain some of the widespread intra-sample ZHe ages between ~28 Ma – 12 Ma for TYC rift samples overlapping the Gangdese range."

5. Tectonic interpretation (Fig 11): Hypothesis 3 "this study" is in direct conflict with the data and with the interpretation offered by the authors, e.g. "rifting started by 16 Ma" (l 885, 994) vs. "8-4 Ma" (Fig 11).
Response: corrected conflict, the interpretation of rifting starting by 16 Ma in south TYC is now properly reflected in Figure 11 as well.

6. I fail to see how the data have any implications on the development of the drainage divide: Exhumation through ZHe closure is not immediately linked to surface uplift.
Response: I have included the definition (exhumation = rock uplift – surface uplift) and removed or reworded mentions of "surface uplift" in relation to thermochronology throughout for clarity. In the text it is stated that *If* the drainage divide is tectonically driven, we suggest the data presented in this study are relevant for discussion of its formation. We ask the question "how might rift processes relate to and interact with the Gangdese drainage divide?" and discuss this in the study. Here are some of the details also explained in section 1.3. which support the idea that these data are relevant for understanding the development of the drainage divide:

Landscape evolutionary models suggest that tectonically driven spatial and temporal variations in rates of rock uplift within active mountain belts has the potential to drive dynamic reorganization of fluvial networks and the drainage divides that bound individual network component (Willett et al., 2014). East- West extension and strike-slip faulting have been suggested as likely contributors to the diversion of river networks and relocation of lake centers in central Tibet since Miocene time (e.g., Han et al., 2019). Thus, it is reasonable to assume that the large-scale tectonic development of continental rifts has the potential for driving fluvial reorganizations related to changing drainage basin areas, stream power, and stream captures. We examine the tectonic development of the Gangdese drainage divide by evaluating low- temperature thermochronology results from north-trending rifts that crosscut or are localized within the high crest of the Gangdese Range, and then discuss how contraction beneath the Gangdese Range and rift exhumation relate to the timing of formation or potential change in location of the Gangdese drainage divide.

Response to Reviewer 3: Anne Replumaz

General Comments:

This paper is dealing with a very interesting topic, the interactions between rifts and contractional structures to influence the evolution of topography during the collision between India and Asia. The paper is very well-written, with interesting new data on the Tangra Yumco Rift (TYR). Nevertheless, the structure of the paper is a bit odd, in between a paper focus on the rifts kinematics and timing, and a review on South Tibet evolution not in link with the data presented here. Indeed, the new data on the TYR are pertinent to test the different kinematic models for normal fault growth (figure 3) and to discuss the link between rifts and contractional structures, as presented in the introduction. On the contrary, the sections "2.1 Rock units" and "2.2 Fault systems" are deeply detailed on the structure of the entire South Tibet, which is not illustrated on figures 1&2. These published data are used to discuss the evolution of the collision zone on a roughly NS cross-section, not in link with the rifts, which are NS structures not visible on such cross-sections.

I suggest to simplify the presentation of South Tibet data, and to better focus the discussion on what the study of the rifts could bring to the debate. In particular, the Gangdese range as to be more clearly defined on figures 1&2. The classification between Tibetan and Gangdese rifts has to be clarified, as the Gangdese batholith is the southern part of the Lhasa block, and part of Tibet. The Geological setting should be more focus on the description of the rifts, including rifts south of the Indus suture and north of the Bangong one, so that figure 2 should be enlarged. The contractional structures have also to be more clearly illustrated, by adding geological cross-sections. The description of the studied zone should be included in the geological setting, so that the link with a more regional context could be done based on these local results.

Response: The Gangdese Range and classification of Tibetan vs. Gangdese rifts are now more clearly defined by color on figures 1 & 2. The discussion of Tibetan rifts has been revise to include further information for other rifts in Tibet including those south of the IYS and north of the BNS. The discussion sections have also been revised to refocus the discussion onto rifting. Sections 2.1 and 2.2 have been revised to become more concise and Figure 2 revised to show a broader regional geologic map including the structures mentioned in section 2.2 (Figure 2A), as well as a schematic N-S cross section (Figure 2B) to illustrate these structures more clearly. Further description of the studied zone near TYC from previous work was included in the background section, but all results of this study were kept in the results section to keep clear the contributions of this study.

Line comments:

72 We consider two classes of rifts in Tibet: (1) Tibetan rifts, which we define as rifts that are >150
73 km in length and crosscut the Lhasa Terrane, and (2) Gangdese rifts, which we define
74 as rifts generally <50 km in length that are isolated within the high topography of the
75 Gangdese Range of southern Tibet (Fig. 2; Burke et al., 2021).

This classification is not shown on figures 1&2. It has to be done. But, the Gangdese batholith is the southern part of the Lhasa block, so this classification has to be more precise.
Response: Tibetan rifts and Gangdese rifts are now distinguished by color in figures 1 and 2 (Gangdese rifts shown in a bright pink rather than red), as well as the approximate extent of the Gangdese Range (dark pink transparent polygon or geologic unit) for clarity in the distinction of the

two classes of rifts. Additionally, the length of Gangdese rifts has been corrected to "<150 km" in the text for greater consistency of length estimates from previous studies (Yin, 2000; Burke et al., 2021).

208 with its southern boundary and the modern-day
209 drainage divide marked by the crest of the Gangdese Range (Fig. 2).
Any name of river is shown on any figure. It has to be added, with a simplified drainage pattern.
Response: Major river names (i.e., the Yarlung Tsangpo River) and smaller river and drainage traces were incorporated into figure 2.

227 Rocks exposed in the southern TYC geologic map area (Fig. 2) include Permian sedimentary
228 units of the Lhasa terrane, Late Cretaceous-Paleogene calc-alkaline intrusive rocks of the
229 Gangdese (Trans-Himalaya) magmatic arc (herein referred to as the Gangdese Range)
Figure 2 is not a geologic map, so that there is no figure corresponding to this very detailed section "2.1 Rock units".

Response: referenced the geologic map (Fig. 4) here and revised figure 2 to be a regional geologic map.

309 A contractional Cordilleran-style retroarc thrust belt north of the Gangdese Range in the 310 Lhasa terrane has been proposed based on the presence of an angular unconformity 311 separating highly shortened Permian-Cretaceous strata from overlying weakly deformed 312 Cretaceous-Tertiary rocks of the LVG

Such concept of contractional Cordilleran-style retroarc thrust belt north of the Gangdese Range in the Lhasa terrane is not understandable with the figures proposed in this paper. Similarly to previous comment, there is no figure corresponding to this very detailed section "2.2 Fault systems". Furthermore, these sections are not specifically dealing with the rifts kinematics and timing, which is the main focus of this paper. I suggest to both simplify the text of the section 2 and to improve the figures to show a more general geological map and cross-section.

Response: The text of section 2 was simplified and reduced to be more concise; Figure 2 was reworked as a geologic map covering a wider region (panel A) and a schematic geologic cross section oriented approximately N-S along strike of the TYC rift was created to better represent the contractional fault systems and tectonic/geologic units described in Section 2 (panel B).

315 GRTB
Not defined.
Response: GRTB now defined in text.

599 "4.1. Structural Results"
I agree that it is a result, but such mapping is also useful to present the region of study and should be in the "geological setup" section. A link with a more regional context could be done based on these local results.
Response: we are concerned it could be confusing to mix results and field observations from this study into the geologic setting or background sections, as it would become less clear to the reader which information is from previously published articles and which information is new and from this study. It is difficult to provide connection between local and regional results in this way when the only existing detailed observations from the field and structural measurements are from this study.

The revisions made to the text of the background section and distinctions between what was known in previous studies and results from this study may have helped to resolve this issue as well.

842 we observe Xigaze forearc strata faulted onto the Kailas Formation,
843 and Kailas Formation strata faulted onto rocks of the Gangdese batholith along two
844 moderately south-dipping, top-to-the north reverse faults (Fig. 4).

The dipping is not visible on figure 4, it is lacking a geological cross-section. Furthermore, as the paper focus on the interactions between rifts and contractional structures, figure 4 should be enlarged to the south to better show this interaction. Field pictures of the contractional structures have to be shown. As it is referred here to figure 4, this section has to go in the geological setting where this figure is presented. It should be used to make the link with published data for South Tibet.

Response: The enlargement of figure 4 to the south would not actually show any additional interactions between the rifts and contractional structures, as the rift truncates into the suture zone and the rocks exposed to the south of TYC are predominantly rocks of the Xigaze Forearc for a significant distance. Instead, Figure 2A has been expanded as was suggested in other comments to show a broader regional geologic map as well as including a new schematic cross section (Figure 2B) to provide better context for these structures. Unfortunately, I don't think we were ever able to obtain clear field pictures of the contractional structures as we spent only one day in this location and had to leave rapidly due to a monsoon thunderstorm. Information regarding the structure and morphology of the TYC rift from previous studies was included in the geologic background, while structural results and field observations from this study were kept in the results to clearly distinguish the contributions of this work from previous studies.

850 satellite imagery of
851 unmapped and thus far inaccessible portions of central TYC appear to reveal footwall
852 mylonite fabrics, hanging wall scarps, and synthetic graben structures which may indicate
853 the presence of active low-angle faulting at depth.

According to me, it is not robust enough to base such interpretation on satellite imagery only, which appears more "model driven" than based on data.

Response: This is a fair point, I have removed this sentence from the text.

945 The oldest
946 mean age in this study (28.04 ± 0.36 Ma) from sample 19AR21 was calculated from relatively
947 widespread single-grain ages from 22.57 ± 0.29 Ma to 38.74 ± 0.49 Ma. This age could reflect
948 exhumation in the hanging wall of the north dipping Gangdese Thrust (GT) which we infer
949 to be located at depth in this region, with previous timing estimates suggesting the
950 southernmost splay of the GT became active by ~27 Ma (Yin et al., 1994; Laskowski et al.,
951 2018). The widespread single-grain cooling ages within sample 19AR21 could potentially
952 reflect progressive cooling via exhumation along the GT in this region, and potentially even
953 an older splay of the GT, beginning as early as ca. 38 Ma and continuing to at least ca. 22 Ma.

Again, according to me, it is not robust enough to base such interpretation on one age.

Response: There are other samples that overlap the suggested timing of the GT in this area so I have noted that in the first part of this section, but I agree the mention of a possible older splay of the GT is not robust enough as it has no other supporting ages or field observations, so I have removed the last sentence from the text. Additional interpretations based on the GT have also been scaled back significantly in the text.

1057 5.2.3. Implications for the Dynamics of East-West Extension in Southern Tibet

1058 Many models have been proposed to explain the dynamics or driving forces of extension 1059 in Tibet, with each model characterized by testable predictions for the spatial and temporal 1060 distributions of the age of extension onset, rates and magnitudes of extension, fault
1061 orientations, and relation to magmatism.

It is a bit strange to end this paper with a review of these different models, with no clear link with the EW rifts, and no clear conclusion from this study on which model is preferred based on the new data presented. Maybe it is worth to try to compare the different models in map ? see a recent paper that I published with a Chinese student, Shiguang Wang (Wang, S.G, A. Replumaz, M.-L. Chevalier, H. Li, Decoupling between upper crustal deformation of southern Tibet and underthrusting of Indian lithosphere, Terra Nova, doi: 10.1111/ter.12563, 2021).

Response: this discussion section was revised for clarity, the dynamic model details were shortened and the focus shifted more onto the contributions and implications of the data produced in this study. The idea of comparing the different models in map view is an interesting one, and it was well executed in the paper you mentioned. It would likely be ineffective to replicate that method for this manuscript however, as the various subsurface interactions are essential to distinguishing each of the dynamic model predictions, and these concepts would be impossible to show distinctly from a map view.

Figure 1: insert showing a too wide zone, Tibetan and Gangdese rifts have to be differentiated on the figure. The drainage divide has to be shown at this scale. Lines showing the sutures are not thick enough. The color of the sutures names has to be related to the color of the lines.
Figure 2: divide of which river? At least the Gangdese batholith has to be shown. Lines too thin.
Figure 3 is very clear.
Figure 4: geological cross-sections are lacking.
Figure 6. The U-Pb histogram is so clear that there is no need of the probability density plot or kernel density estimate.
Figure 8: a/ too many colors for latitude, use of the same code as the boxes ? b/ The 3 boxes should be shown as single big boxes on the graph. 2 oranges boxes larger than the data, why ?
Figure 9: this figure is not easily understandable. The results should be presented as in figure 3, to test these models.

Response: All comments were helpful and appreciated, all suggested corrections were made to improve the corresponding figures, with any notes or exceptions addressed below.

Figure 2: “drainage divide” represents the Gangdese drainage divide which divides runoff to multiple different rivers rather than being a divide of one river.

Figure 6: it is the opinion of myself and co-authors that it is good practice to include the probability density plot and kernel density estimate plot in the manuscript, and as such we would like to keep this figure in the text if it can be agreeable to the reviewers.

Figure 8: After weighing this recommendation, we consider that re-coding the latitude plot to have less colors may not be the best choice as the plot was originally made incorporating an inclusive color gradient. Additionally, the initial choice of more colors for latitude was intentional to provide a smoother gradient for the plot and for consistency with the elevation gradient in plot 8b (only one more color was used in the gradient for 8a). Changing the colors of the plot to match the colors of

the age group boxes would also potentially make the figure more difficult to read and could be confusing for the reader for a

few reasons: (1) the age boxes will blend in with the colors of the data points and be harder to distinguish, (2) at present, the green color represents elevation and the red/orange/yellow are referencing age so it seems counter intuitive to make two variables the same color scheme, and (3) if for example red = higher elevations and yellow = lower elevations, one can see that groups 1, 2, and 3 will incorrectly appear to have more overlap in age and the distinction of the samples with larger intra- sample age variability from the well constrained will be diminished and may be confused (especially since the age boxes were changed to larger boxes rather than multiple small boxes as suggested).

Figure 9: We consider that it would likely be insufficient to show just the kinematic models as in figure 3 when discussing the three different tectonic hypotheses in the discussion section, because while these models are relevant for fault kinematics, they are also in large part based on rift dynamics too. If possible, we’d like to keep this figure as it is to allow for the clearer comparison of the three hypotheses and to provide broader context, considering much of the previous work in the region more heavily focused on rift dynamics rather than kinematics as well.

Response to Reviewer 2: Reinhardt Wolff

General Comments:

The manuscript entitled “Kinematic Evolution of the Tangra Yumco Rift, South-Central Tibet” presents new zircon U-Pb and zircon (U-Th)/He ages from the central and southern Tangra Yumco rift on the Tibetan plateau. The zircon U-Pb ages range from 153 to 11 Ma and the zircon (U-Th)/He ages are between 59 and 5 Ma. From these data Reynolds and co-authors constrain the thermal history of the footwall rocks of the N-S trending rift and suggest that the rift formed due to fault-segment linkage. The 245 zircon (U-Th)/He ages together with the 18 zircon U-Pb ages are an important contribution to the recent discussion about rift propagation on the Tibetan plateau and a comprehensive data set. Overall, I find this paper suitable for publication in Tektonika, however, some work is needed to improve the presentation of the data.

I highly recommend to add Table S1 to the manuscript and add the mean ZHe and U-Pb ages to this table. Additionally, the sample locations and sample names should be shown in a figure (e.g. Figure 2). By doing so, the reader can more easily find e.g. the position of sample 19AR11 on the map with the zircon U-Pb age of 16.1 0.1 Ma, which the authors interpret to reflect a minimum age for the onset of E- W extension of the Tangra Yumco graben while the table indicates the lithology of the sample: porphyritic andesite.

Response: Table S1 has been revised to include mean ZHe and U-Pb ages and has been added into the Results section of the text. Figure 2 has been revised as a geologic map over a broader region, and thus did not have the space to incorporate names and locations for each sample in a small portion of the figure - the geologic map in Figure 4 was revised to show sample names and locations.

Line comments:

Line 24, line 702, and line 889: Figure 8 shows ZHe ages versus latitude but a correlation is only present for the ZHe ages of group 3 (4 mean ZHe ages) and when excluding sample 19AR23 as well as group 2. These exceptions should be mentioned more clearly in the text. What is the definition of a “strong” correlation in this context? Without statistical tests, I would suggest to omit “strong”.

Response: clear distinctions for the correlations were mentioned in the text as sugested, and I have removed or rephrased all instances of “strong” used in this context.

Line 183: The references given here for rift initiation are from nearby study sites, only. Giving more references for ages on rift initiation across the entire Tibetan plateau (see Fig. 1) would highlight the significance of the present study for a broader audience (e.g. Armijo et al. 1986; Blisniuk et al. 2001; Williams et al. 2001; Murphy et al. 2010; Ratschbacher et al. 2011; Styron et al. 2011).

Response: I agree and have added the additional suggested references to the text.

Line 195: Please add the age for rift initiation suggested by the model for the southern ZHe ages here, for the sake of completeness.

Response: The Pecube modeling results suggesting the age of extension onset in the southern TYC rift were added to the text for completeness.

Line 308: Referring to the figures would help the reader to follow the text of sections 2.2.1 - 2.2.3.

Response: more figure references were added and the text was broken up into more paragraphs for clarity.

Line 315: Abbreviation GRTB is not explained yet.

Response: GRTB (Gangdese Retroarc Fold-Thrust Belt) was defined in the text here.

Line 385: Typo "grain".

Response: corrected and changed "structural grain" to "structural organization" for clarity.

Line 387: This section could be shortened and condensed because it focusses on two other rifts on the Tibetan plateau, only. It is not clear to me why these two rifts are described in great detail, whereas other rifts are not described at all.

Response: I agree, the sections of text focused on Lunggar and Yadong-Gulu were shortened to be more concise, as these two rifts were not a major focus of the results or discussion of this study. Inclusion of a discussion of other Tibetan rifts was suggested by another reviewer as well, so a short description of other Tibetan rifts south of the IYS and north of the BNS was included for completeness.

Line 450: What is the definition of Gangdese rifts? In the abstract they are defined by a length of less than 50 km, here a length of less than 150 km. Are there more reasons for discriminating these rifts from the larger rifts that underlines the importance to separate these grabens?

Response: I have corrected instances in the abstract and manuscript body which previously stated Gangdese rifts were <50 km (the definition of Gangdese rifts <150 km is more consistent with previous studies). In terms of the definition of the Gangdese rifts, the obvious differences between these two classes of rifts (prior to knowing any ages in this study) are their magnitudes/spatial extents and spacing between rifts (spacing information was added to the text) – the Gangdese rifts are documented as distinctly shorter than Tibetan rifts (defined in Burke et al., 2021 as >150 km for Tibetan rifts and <150 km for Gangdese rifts), are spaced closer together (), and are isolated within the Gangdese Range, whereas the classically studied Tibetan rifts crosscut the Lhasa terrane constituting a much broader region of the Tibetan Plateau. To make this distinction more obvious, I have distinguished the Gangdese rifts from Tibetan rifts on Figure 2 by color as well as marking the approximate spatial boundary of the Gangdese Range in Figure 2 for clarity. Prior to this study, the shorter Gangdese rifts had not been investigated in more than a handful of studies (two to our knowledge; Yin, 2000 and Burke et al., 2021) and had not been compared in detail with a major Tibetan rift, therefore their comparison was a major research interest and goal of this study. Based on our dating results, we interpret the Tibetan rifts and Gangdese rifts do in fact have distinct ZHe age differences which suggest an earlier onset of rifting for Gangdese rifts (prior to the typically accepted age of extension onset for Tibetan rifts) and therefore a distinct driving force for extension onset in the Gangdese rifts as they perhaps balance uplift of the Gangdese Range.

Line 524: ZHe closure temperatures might even be lower (e.g. Whipp et al. 2022) depending among other factors on the intensity of radiation damage.

Response: I have added some additional factors or parameters which affect the closure temperature to the text here for completeness. Added Whipp et al., 2022 to in-text citations and references cited.

Line 252: What are the assumptions that lead to the 2-10 km range given here?

Response: I added additional parameters which affect the closure temperature to the text here, and clarified this is a depth estimate is based on the variability of the closure temperature range.

Line 525-527: Please rephrase this section, the closure temperature does not depend on the geothermal gradient or the exhumation rate.

Response: I would think the depths associated with the ZHe closure temperature range (partial retention zone) is in part affected by the geothermal gradient of the region and the cooling rate (Reiners & Brandon, 2006) - a higher geothermal gradient in Tibet (e.g., 30°C/km rather than 25°C/km in other regions with average crustal thickness) means the ZHe PRZ may be shallower in Tibet. As for the cooling rate, since cooling during rifting is related to rift footwall exhumation: the rate of exhumation affects the rate of cooling and therefore affects the depths associated with the closure temperature range as well. Regardless, I have removed "exhumation rate" from the text for clarity, and have revised this section to distinguish cooling rate from other parameters that directly affect the closure temperature in individual crystals (e.g., grain size, radiation damage).

Line 549: 4He/3He were not reported herein.

Response: the text in this section reads "Detailed sample information and single grain ZHe analytical data are provided in supporting information Table S3" for clarity on where the reader can find this information.

Line 702 and 563: Is the eU calculated by 0.235 or 0.28xTh? See Guenthner et al. (2013) who suggest 0.235.

Response: I checked the calculations in the data again and they were in fact calculated using eU = [U] + 0.2358[Th]; this was corrected in the text to reflect the correct equation and I added the citation of Guenthner et al., 2013 where this equation is described. I also noticed and corrected two instances of "Guenthner, 2013" to "Guenthner et al., 2013" which is the correct citation.

Line 700-701: In my opinion the manuscript would benefit by adding to the discussion a paragraph explaining why there is no correlation between ZHe ages and elevation, as mentioned in line 701. The horizontal distance between samples 19AR22, 19AR23, and 19AR24 is very small and they cover a vertical distance of 250m, however, the sample in the center is 15-20 Myr older than the lower and upper samples. The same pattern can be seen at many other sampling locations (e.g. 19AR15 on the western side of the TYC) where samples were taken close to each other (e.g. Fig. 8a).

Response: the text was adapted to include additional discussion of the other factors potentially controlling ZHe age variability and how these factors may be more influential, as evidenced by the lack of age- elevation trends in our data. For example, for faster exhumation rates it would be more difficult to observe or evaluate any age-elevation trends, and if there are additional structural controls on location of certain samples this could also prevent a clear trend from emerging for some transects.

Line 734: To be consistent with the number of significant digits of the ZHe ages, I would recommend to write 9.0 – 4.7 Ma.

Response: text was corrected to follow this suggestion.

Line 740 and line 958: At the Duozebu location, the ZHe ages are between 13.9 and 8.1 Ma and thus very close to the U-Pb ages (11.0 – 10.9 Ma). Can you exclude cooling after dyke emplacement for these samples (compare to Fig. S4 cooling path of sample 19AR25)?

Response: It doesn't appear that this interpretation can be excluded, so I have noted this point in this portion of the text as well.

Line 743: "Rapid cooling" is only true when sample 19AR23 is excluded from the data.

Response: made note of this point in the text for completeness.

Line 798: Why was only one zircon grain used for thermal modeling? Adding e.g. crystals of different sizes could possibly improve the modeling results.

Response: only one grain was used for these models to allow modeling and comparison of all samples. Because many of the samples have large intra-sample age variabilities, the HeFTy models often could not find acceptable thermal histories to account for all grains from each sample, but we know they must have had the same thermal histories because they came from the same sample. If we had focused on modeling selected samples that had lesser spread in intra-sample ages (e.g., only the youngest population of samples) seemed it would bias the data and would not further contribute to the overall interest and purpose of this study, therefore we opted to compare single-grain models for each sample and look at spatial trends in ages across our large dataset rather than potentially over-interpreting a select few of the data points.

Line 814: What does "easiest" mean in this context?

Response: rephrased for clarity.

Line 818-821: The authors state that HeFTy modeling results of the two samples 19AL06 and 19AR24 indicate that the onset of rapid cooling youngs towards the north. I suggest to indicate this finding in Figure 11 and therefore enlarge the line "rift acceleration" towards the positions of the two aforementioned samples.

Response: revised figure 11 to show rift acceleration as suggested.

Line 885-886: This is a very important finding of this study and could be more emphasized, e.g. in the abstract or conclusions. Maybe this constraint could be added to figure 11, too.

Response: revised figure 11 to show extensional dike constraint as suggested and made note of this important age constraint again in the conclusions of this study.

Line 892-897: What are the reasons for the interpretation that the Paleocene-Eocene ZHe ages are only partially reset and that the Oligocene-Early Miocene ages are cooling ages? Please add some information.

Response: more information was added to this section to support this reasoning and strengthen this conclusion.

Line 913: This paragraph would benefit by giving more details on the structural observations from the field that lead to the conclusion that fault segments linked during normal faulting.

Response: additional field observations of fault geometry were added to this paragraph as suggested to strengthen this conclusion.

Line 930-933: The t-T paths of sample 19AL06 indicate rapid exhumation at 22-18 Ma as stated by the authors in line 819 and in Figure 10, and not at 13 Ma as written here. Please check the ages here. The older age for the onset of rapid exhumation (22-18 Ma) agrees well with the minimum age for extension given by the U-Pb age (16.1 Ma) on the dike in the southernmost part of the TYC.

Response: Corrected 13 Ma to 18 Ma to correctly reflect model interpretations and noted agreement with the extensional dike age in the text here as well.

Line 943-944: “all but one age”: There is only one ZHe age of 28 Ma at the Tangra Yumco graben, but there are three more 28 Ma ZHe ages in the Gangdese range farther east (Fig. 9). Maybe this is worth mentioning here.

Response: revised to report the actual number of samples from Gangdese rifts and the TYC rift (16) that fall into this age range rather than “all but one” from the TYC rift which was not as clear or descriptive.

Line 944-995: I agree that the ZHe ages of these samples are older and that they cooled earlier than the samples north of the Gangdese range. However, due to their position in the footwall of the Tangra Yumco normal fault, they have been exhumed due to normal faulting and erosion along the TYC, too. A combination of exhumation due to thrusting, erosion and subsequent normal faulting and erosion could possibly explain the large age-spread of the ZHe ages in the Gangdese range. Nevertheless, I would still expect the ZHe ages to increase with increasing elevation.

Response: This is a good point, I have noted this in the text to better reflect the impact of subsequent rifting on the sample ages as well and emphasize that the history of these samples is complex and exhumation likely involved a combination of causes through time.

Line 996: The “28 Ma” in the sentence “E-W extension across the Gangdese rifts begun by 28 Ma” has not been mentioned in this context before. Please indicate what the onset age of 28 Ma is based on.

Response: explained in the text that this onset age was based on ZHe ages from the Gangdese rifts.

Line 996: It seems inconsistent that the ZHe age of sample 19AR21 (28 Ma) is interpret as “exhumation in the hanging wall of the north dipping GT” (line 948) while the ZHe ages of the samples in between the Tangra Yumco rift and the Gangdese rifts (two samples) yielding 28 Ma are interpret as initiation of rifting at the GR (line 995-996). Please clarify why there is a different interpretation of these ages.

Response: this is because we interpret the Gangdese Rifts to have initiated to balance exhumation in the Gangdese range related to activity along the GT, therefore the fact that exhumation in the Gangdese Range is occurring at the same time as rifting in the Gangdese range makes sense. The distinction for sample 19AR21 is because it was not collected from a Gangdese rift, but instead was collected within the TYC rift where it overlaps the Gangdese range. I would argue that the age of 28 Ma is unlikely to reflect Tibetan rift initiation (pre-dates rift initiation in the TYC), thus the exhumation must be attributed to a different cause – exhumation of the Gangdese range along the GT? I have also rephrased this paragraph and removed the interpretation of an older splay of the GT in this region as this was based solely on sample 19AR21 and not a robust interpretation.

Line 1042: The stated exhumation between 21.8-15.7 Ma for the Gangdese rift 2 is much younger than the onset of rifting suggested in line 996. Please clarify this discrepancy.

Response: corrected this discrepancy by stating the age range more clearly in reference to Gangdese rifts.

Line 1135: I would suggest to use the definition of England and Molnar (1990) for exhumation throughout the manuscript: exhumation equals rock uplift minus surface uplift. Using this definition, thermochronology constrains exhumation only, and does not give information on surface uplift directly.

Response: I have included this definition (exhumation = rock uplift – surface uplift) and reworded mentions of exhumation and removed mentions of “surface uplift” in relation to thermochronology throughout for clarity.

Fig. 2 and 9: Adding transparency to the background increases the readability of the figures.

Fig. 8A: In my opinion, the figure showing the age-elevation relationship is not very helpful for illustrating the statements made in the text. Maybe showing two or three selected age-elevation profiles from the southern, central, and northern graben would be more helpful than mixing all data available in one figure.

Fig. 8B: To which of the three groups belong the ages at 30.15°N? The colored box is missing here.

Fig 9: Lat and Lon are missing in this figure.

Fig. S1: Please correct typos “Wolff et al., 2023” and 2019 in the legend of the figure.

Table S1: Four digits are sufficient for the latitude and longitude values when taken with a hand-held GPS.

Table S2-S3: The tables with the U-Pb and ZHe data are difficult to read in the PDF version and the mean values that are mentioned in the text are missing.

Response: All suggested corrections were made to the corresponding figures except as noted below:

Fig. 8A: I think the age-elevation plot showing all samples is very helpful for illustrating broader trends in the age-elevation for samples at different latitudes, such as the break between rapid extension (samples less than ~12 Ma) and protracted extension (Samples older than ~12 Ma) and would prefer to keep it in the text as is, if possible.

Table S2-S3: I agree the tables with the U-Pb and ZHe data are difficult to read in the PDF version – to correct this issue, all data tables have been uploaded to an open source data repository (Zenodo) to create a doi which has been cited in the text. This will permit access to high quality data tables which can be downloaded for review and even for use in future studies. The missing mean values that are mentioned in the text have also been added to the data tables.

2nd Round of Revisions

Decision Letter

(5 February 2024)

Dear A.Reynolds and co-authors,

We would like to thank you once again for your efforts in revising your manuscript that has been submitted to TEKTONIKA. Given the considerable changes to some parts of the text and the large number of reviewer comments you have addressed, we had decided to send the manuscript out for a second round of reviews. Two reviewers from the first round provided comments, with slightly differing perspectives. One reviewer feels you have adequately incorporated all of their comments and has only very minor suggested additional comments. The second reviewer would still like further clarification about the distinction between the Tibetan and Gangdese rifts in the text and questions the need to include the text addressing the interactions between contractional and extensional structures given the lack of new structural data. Reviewers comments are pasted below.

Given the reviewers' comments we suggest that the manuscript undergo minor to moderate revision to address the comments raised by both reviewers, whereafter we will consider the revised text for publication in TEKTONIKA. We feel the manuscript fits nicely within the scope of the journal, and thus look forward to receiving your revised text and rebuttal. Given the limited scope of the requested revision, we would like to received it within less than a month, thus before March 5th.

Thank you again for submitting your work to TEKTONIKA.

David Whipp, Associate Editor
Robin Lacassin, Executive Editor

Comments by Reviewer 2

(Reinhard Wolff)

The revised manuscript entitled “Kinematic Evolution of the Tangra Yumco Rift, South-Central Tibet” has been improved significantly. All changes have been done to my satisfaction and overall, I find this paper suitable for publication in Tektonika now. For two minor comments, see below.

Minor comments:

Table S1 has been added to the results section in the revised manuscript. I recommend to change the name of the table from S1 to Table 1.

The figure caption of the new Fig. 2B is missing and I am not sure if referencing a paper “*in review*” for Figure 1A is suitable for Tektonika (line 117 of the revised manuscript).

Comments by Reviewer 3

(Anne Replumaz)

I am a bit disappointed by the answers to my comments and to the comments of the other reviewers, and I think that the paper still needs some rewriting.

1/ In the revised version, the Tibetan and Gangdese rifts are now better defined. But, the results are not clearly presented to distinguish between the Tibetan and Gangdese rifts. On Figure 8, there is no distinction between these 2 rifts but between south and north rifts. “Samples collected at Gangdese latitudes (group 1) exhibit mean ages clustered between ~22-15 Ma, whereas samples north of the northern extent of the Gangdese Range (~29.8°N) exhibit both older Paleocene to Eocene (~59-45 Ma) ages (group 2) and younger late Miocene to Pliocene (~9-4 Ma) ages (group 3).” The discussion is not focusing on this first order result, as also noticed by Reviewer 1.

2/ The new data on the TYR are pertinent to test the different kinematic models for normal fault growth (figure 3), but the description of the models is not done in link with this topic of the paper. The model of Armijo et al (1986, 1989) has to be presented in section 1.1, because it is one model with a clear dissymmetry in the propagation. Furthermore, it is lacking another scenario, with two different rift “families” of different ages, as it seems to be the case in the results.

3/ The structure of the paper has been simplified a bit, but the presentation of South Tibet is still an important part of the paper, while no important new structural data are presented. In particular on the thrusts, the author answer that “Unfortunately, I don’t think we were ever able to obtain clear field pictures of the contractional structures as we spent only one day in this location and had to leave rapidly due to a monsoon thunderstorm.” So in that case, it is not pertinent to study the “interactions between contractional and extensional structures” and to do such a complete review, while not bringing any new argument, as for example on the GT. For the reader, it is harder to focus on the main results of the paper.

Anne Replumaz

Reviewer's detailed comments on specific parts of the text:

197 well-developed triangular facets in fault footwalls and offset Quaternary
198 alluvial fan deposits in the rift hanging wall (Wolff et al., 2019, 2023).

Armijo et al (1986, 1989) described than more than 30 years ago.

234 We investigate how contraction
235 beneath the Gangdese Range and rift exhumation relate to the timing of formation or
236 potential change in location of the Gangdese drainage divide.

It is not really the main topic of the paper, it could be removed.

264 arc magmatism related to northward subduction and/or breakoff of Neo-Tethyan
265 lithosphere in the Late Cretaceous-Paleogene (Schärer et al., 1984; Pan et al., 2004; Lee et al., 2007, 2009; Liu et al.,2018; Kapp & Decelles, 2019

See also Replumaz et al (2010), constraining such subduction events using tomographic images.

294 It is proposed that anchoring or rollback of the Indian slab at ca. 26 Ma may have reactivated
295 the IYS as a north-dipping normal fault to accommodate N-S extension and deposition in
296 the Kailas basin until ca. 21 Ma (DeCelles et al., 2011, 2016; Wang et al., 2013; Leary et al.,
297 2016; Laskowski et al., 2017, 2018; Kapp & Decelles, 2019).

Or deposited following a topography dynamic wave as the Indian .continent moved above the Indian slab (Husson et al, 2014).

298 Paleocene-Eocene porphyritic rhyolite intrusions (Eqλ, Fig. 4) related to the
299 Chagele deposits of the Gangdese Metallogenic Belt (~63-32 Ma, Hou et al., 2004; Gao et
300 al., 2021) and outcrop scale N-S trending dikes consistent with E-W extension observably
301 crosscut rock units of the southern TYC map area. North trending dikes from the Daggyai
302 Tso graben (recently referred to as the Dajiamang Tso rift; Burke et al., 2021) are located
303 ~50 km west of TYC and yield U-Pb ages of ca. 18-13 Ma consistent with studies suggesting
304 a minimum age of ~18 Ma for the onset of east-west extension in southern Tibet (Williams
305 et al., 2001; McCallister et al., 2014; Burke et al., 2021).

The time delay in between these 2 magmatic events is large, with no clear link.

338 Exposure of the GT near Zedong is more viable, marked by a >200-
339 m-thick mylonite shear zone that dips 25°-35° north, with abundant kinematic indicators
340 suggesting top-to-the-south shear (Yin et al., 1994). Minimum displacement and slip rate
341 estimates along the GT are 46 ± 9 km and 12 ± 6 km/Myr, respectively (Yin et al., 1994),

This fault has never been observed since 1994, so it is not well constrained by observation.

350 Evidence of the GT has not yet been
351 observed in the region of this study, but if the GT or equivalent structure were present at
352 the surface or at depth, it would likely have been active between ca. 23-13 Ma, overlapping
353 the estimated timing of Great Counter Thrust system activity and exhumation in southern
354 Tibet (Tremblay et al., 2015; Laskowski et al., 2018).

Maybe because it does not exist ? making an hypothesis on a none observation is a bit odd.

Rollback of the Indian slab at ca. 26 Ma is interpreted to have initiated N-S
364 oriented extension and deposition in the Kailas basin for ~5 Myr (Kapp & DeCelles, 2019),
365 but this interpretation remains controversial (see discussion section 5.2). Rollback, break
366 off or delamination of Indian mantle lithosphere at ca. 21 Ma could have caused N-S
367 extension and Kailas deposition to cease, triggering a return to N-S contraction, uplift of
368 the Kailas basin to ~4-6 km elevations between 20-16 Ma, and initiation of motion along
369 the GCT as early as 23 Ma with continued activity until ca. 18-13 Ma

According to me, this discussion is not valid because there is no new data or observation in this paper on any of the thrusts discussed, so that it is model driven, and not bringing new arguments. The paper should focus on the normal faults.

Here we report ZHe mean ages (Fig. 8, Fig. S3, Table S1, S3) for forty-nine samples including thirty-two samples from the southern TYC rift and seventeen samples from three Gangdese rifts (GR) located ~90 km (GR1, five samples), ~75 km (GR2, ten samples), and ~40 km (GR3, two samples) east of TYC.

Samples from TYR and GR are now well defined on the map, but not on the elevation/age or latitude/age graphs, so that it is not easy for the reader to link the presentation of the region made in the introduction and the presentation of the results.

Authors' answers to reviews

This document contains a detailed description of revisions addressing comments from the *second round of review* for the manuscript *Kinematic Evolution of the Tangra Yumco Rift, South-Central Tibet* including individual responses to each reviewer comment. The clarity of the manuscript has been further improved based on suggestions from two reviewers and Tektonika editors, with notable changes for round two including: correction to Table 1, revision of Figure 8 and addition of text in section 4.3 to more clearly distinguish results from Tibetan and Gangdese rifts, further reduction of the discussion of contractional structures and drainage divides for conciseness, and generally refining the focus of this manuscript towards rifting and the clarity of observations and interpretations from this study versus those from previous work. Text referring to the Gangdese Thrust in particular have been greatly reduced within the manuscript based on helpful reviewer suggestions, though we still mention the Gangdese Thrust in the background section of the manuscript (2.2.2.) for completeness and explain our thought process for doing so in detail below. Responses to comments are organized by reviewer in the following sections:

Response to Reviewer: Reinhardt Wolff

General Comments:

The revised manuscript entitled "Kinematic Evolution of the Tangra Yumco Rift, South-Central Tibet" has been improved significantly. All changes have been done to my satisfaction and overall, I find this paper suitable for publication in Tektonika now. For two minor comments, see below.

Minor comments:

Table S1 has been added to the results section in the revised manuscript. I recommend to change the name of the table from S1 to Table 1.

Response: The name of Table S1 has been corrected to "Table 1" in all occurrences within the text.

The figure caption of the new Fig. 2B is missing and I am not sure if referencing a paper "in review" for Figure 1A is suitable for Tektonika (line 117 of the revised manuscript).

Response: As this manuscript is still in review, we have removed this citation and added Spencer Dixon, its primary author, as an author on this manuscript. We have also added context to the map, specifying the sources for the geologic contacts and cross section interpretation (lines 116-118).

Response to Reviewer: Anne Replumaz

General Comments:

I am a bit disappointed by the answers to my comments and to the comments of the other reviewers, and I think that the paper still needs some rewriting.

1/ In the revised version, the Tibetan and Gangdese rifts are now better defined. But, the results are not clearly presented to distinguish between the Tibetan and Gangdese rifts. On Figure 8, there is no distinction between these 2 rifts but between south and north rifts. "Samples collected at Gangdese latitudes (group 1) exhibit mean ages clustered between ~22-15 Ma, whereas samples north of the northern extent of the Gangdese Range (~29.8°N) exhibit both older Paleocene to Eocene (~59-45

Ma) ages (group 2) and younger late Miocene to Pliocene (~9-4 Ma) ages (group 3).” The discussion is not focusing on this first order result, as also noticed by Reviewer 1.

Response: We previously described results for Tibetan rifts samples and Gangdese rift samples separately in section 4.3. and have now added additional text at the end of this section describing the first order observations between Tibetan and Gangdese rifts as suggested by the reviewers. We have revised Figure 8 to clearly distinguish between Tibetan (TYC) and Gangdese rifts to improve the clarity of the visual comparison between ages from the two types of rifts and better link the data results more clearly to the discussion of age trends with sample latitude.

2/ The new data on the TYR are pertinent to test the different kinematic models for normal fault growth (figure 3), but the description of the models is not done in link with this topic of the paper. The model of Armijo et al (1986, 1989) has to be presented in section 1.1, because it is one model with a clear dissymmetry in the propagation. Furthermore, it is lacking another scenario, with two different rift “families” of different ages, as it seems to be the case in the results.

Response: Thank you for the suggestion, as it is important to acknowledge this pioneering work on the rifts of southern and central Tibet. Per our understanding of the work of Armijo et al. (1986, 1989), they provided a compelling explanation for the switch in kinematics and structural style between three zones. Firstly, they highlighted the zone south of the Indus-Yarlung suture zone, arguing that the more subtle character of the rifts, typically expressed as half grabens with less displacement, relates to the young, hot, and weak rheologies in the region. The contrasted this with the zone north of the Indus- Yarlung suture, where the rifts are better developed and typically have a graben structural geometry (i.e. symmetric). Finally, the third zone they described is the zone of conjugate strike-slip faulting along the Bangong-Nujiang suture zone. As our work is completely contained within the middle zone, we do not adopt their arguments in contrasting the timing and/or kinematics of Gangdese and Tibetan Rifts, nor the differences between the rifts within and north of the Gangdese Range. We have added the text “Both of these classes are located south of the zone of conjugate strike-slip faulting along the Bangong-

Nujiang Suture Zone (i.e. the “chord” of Armjo et al., 1986), and north of the Indus-Yarlung suture zone within the Lhasa Terrane.” to section 1.1 for clarity.

3/ The structure of the paper has been simplified a bit, but the presentation of South Tibet is still an important part of the paper, while no important new structural data are presented. In particular on the thrusts, the author answer that “Unfortunately, I don’t think we were ever able to obtain clear field pictures of the contractional structures as we spent only one day in this location and had to leave rapidly due to a monsoon thunderstorm.” So in that case, it is not pertinent to study the “interactions between contractional and extensional structures” and to do such a complete review, while not bringing any new argument, as for example on the GT. For the reader, it is harder to focus on the main results of the paper.

Response: We thank the reviewer for the feedback on this aspect of the paper. For the discussion of the possible linkages between contractional and extensional structures, we rely on primary field observation from the field area, as well as the breadth of experience by the authors on this paper. Notably, Dr. Laskowski has published several papers focused on the Great Counter Thrust System at nearby locations, including a study where a structural interpretation linking the buried Gangdese Thrust with exposed backthrusts of the Great Counter Thrust system (Laskowski et al., 2018, GSAB). He also accompanied Dr. Reynolds in the field. We utilize some of the knowledge gained through these studies in our interpretation of the mechanism that might explain the timing of cooling, particularly in the Gangdese Range just to the north of the mapped Great Counter Thrust system (shown in Fig. 4). As the thermochronology samples are simultaneously in the footwalls of the rift segments and the footwalls of the GCT, it is important that we discuss these structures and analyze their potential contribution to the cooling history. While we feel we have the requisite data and observations to interpret both the extensional and contractional structures, there are places in the manuscript where it is not abundantly clear what arguments are based on new observations from this study versus previous work. We have made several modifications to the writing to clarify these differences (e.g., removal of text in sections 2.1., 2.2.2., and 2.2.3.).

Reviewer's detailed comments on specific parts of the text:

197 well-developed triangular facets in fault footwalls and offset Quaternary 198 alluvial fan deposits in the rift hanging wall (Wolff et al., 2019, 2023).

Armijo et al (1986, 1989) described than more than 30 years ago.

Response: We added a citation for Armijo et al., 1986 to these field observations.

Response: We removed this text.

234 We investigate how contraction
235 beneath the Gangdese Range and rift exhumation relate to the timing of formation or 236 potential change in location of the Gangdese drainage divide.

It is not really the main topic of the paper, it could be removed.

264 arc magmatism related to northward subduction and/or breakoff of Neo-Tethyan
265 lithosphere in the Late Cretaceous-Paleogene (Schärer et al., 1984; Pan et al., 2004; Lee et al., 2007, 2009; Liu et al.,2018; Kapp & Decelles, 2019

See also Replumaz et al (2010), constraining such subduction events using tomographic images.

Response: We added a citation for Replumaz et al. (2010), thank you for the suggestion.

Response: We added the following text: “Alternatively, the Kailas Basin may be the product of dynamic subsidence related to southward folding of the Indian Slab (Husson et al., 2014; Shen et al., 2020).“

294 It is proposed that anchoring or rollback of the Indian slab at ca. 26 Ma may have reactivated
295 the IYS as a north-dipping normal fault to accommodate N-S extension and deposition in
296 the Kailas basin until ca. 21 Ma (DeCelles et al., 2011, 2016; Wang et al., 2013; Leary et al.,
297 2016; Laskowski et al., 2017, 2018; Kapp & Decelles, 2019).

Or deposited following a topography dynamic wave as the Indian .continent moved above the Indian slab (Husson et al, 2014).

298 Paleocene-Eocene porphyritic rhyolite intrusions (Eqλ, Fig. 4) related to the
299 Chagele deposits of the Gangdese Metallogenic Belt (~63-32 Ma, Hou et al., 2004; Gao et 300 al., 2021) and outcrop scale N-S trending dikes consistent with E-W extension observably 301

crosscut rock units of the southern TYC map area. North trending dikes from the Daggyai 302 Tso graben (recently referred to as the Dajiamang Tso rift; Burke et al., 2021) are located 303 ~50 km west of TYC and yield U-Pb ages of ca. 18-13 Ma consistent with studies suggesting 304 a minimum age of ~18 Ma for the onset of east-west extension in southern Tibet (Williams 305 et al., 2001; McCallister et al., 2014; Burke et al., 2021).

The time delay in between these 2 magmatic events is large, with no clear link.

Response: Indeed. We did not directly implicate magmatism in our interpretations of the rift kinematics or dynamics. If we had, we would have focused more on this history. Other studies have argued that the magmatic gap reflects shallow underthrusting of India, with leucogranite intrusion related to later anatexis and/or Indian rollback (e.g. Replumaz et al., 2010).

Response: We removed most of the background on the Gangdese Thrust, shortening this paragraph to

Response: We have considered this point with care and have greatly reduced the text referring to the Gangdese Thrust and interpretations relating to it in this manuscript, yet we feel it is still important to include as a brief mention the previous work of An Yin and others, as well as studies in recent years, related to the Gangdese Thrust for completeness and potential relevance to the study area given that it

338 Exposure of the GT near Zedong is more viable, marked by a >200-
339 m-thick mylonite shear zone that dips 25°-35° north, with abundant kinematic indicators 340 suggesting top-to-the-south shear (Yin et al., 1994). Minimum displacement and slip rate 341 estimates along the GT are 46 ± 9 km and 12 ± 6 km/Myr, respectively (Yin et al., 1994),

This fault has never been observed since 1994, so it is not well constrained by observation.

350 Evidence of the GT has not yet been
351 observed in the region of this study, but if the GT or equivalent structure were present at 352 the surface or at depth, it would likely have been active between ca. 23-13 Ma, overlapping 353 the estimated timing of Great Counter Thrust system activity and exhumation in southern 354 Tibet (Tremblay et al., 2015; Laskowski et al., 2018).

Maybe because it does not exist ? making an hypothesis on a none observation is a bit odd.

overlaps the Gangdese Range and that this work incorporates a good amount of discussion of Gangdese Range uplift timing. We have rephrased the text to the following: The north-dipping Gangdese Thrust (GT) system was first interpreted by Yin et al. (1994) to place Cretaceous Xigaze Group forearc basin strata over Tethyan sedimentary rocks near the town of Xigaze (~250 km east of southern TYC), and Gangdese batholith rocks over Tethyan rocks to the east of Lhasa city near Zedong. Since then, many of the contacts near Xigaze have been revisited and interpreted to be predominantly related to the Great Counter Thrust system (e.g., Murphy et al., 2010; Leary et al., 2016; Laskowski et al., 2018). Evidence of the GT as defined in previous studies has not been observed in the study area, but if the GT or equivalent structure were present at the surface or at depth, it would likely have been active between ca. 23-13 Ma, overlapping the estimated timing of Great Counter Thrust system (Tremblay et al., 2015; Laskowski et al., 2018).

Rollback of the Indian slab at ca. 26 Ma is interpreted to have initiated N-S
364 oriented extension and deposition in the Kailas basin for ~5 Myr (Kapp & DeCelles, 2019), 365 but this interpretation remains controversial (see discussion section 5.2). Rollback, break 366 off or delamination of Indian mantle lithosphere at ca. 21 Ma could have caused N-S
367 extension and Kailas deposition to cease, triggering a return to N-S contraction, uplift of 368 the Kailas basin to ~4-6 km elevations between 20-16 Ma, and initiation of motion along 369 the GCT as early as 23 Ma with continued activity until ca. 18-13 Ma

According to me, this discussion is not valid because there is no new data or observation in this paper on any of the thrusts discussed, so that it is model driven, and not bringing new arguments. The paper should focus on the normal faults.

Response: We modified this discussion to remove lithospheric dynamics, instead focusing on clast compositions, crosscutting relationships, and paleocurrents in the Kailas Formation. We think that the timing of GCT structures is relevant to the interpretations of the thermochronology, as many of the samples are also in the footwall of the GCT.

Here we report ZHe mean ages (Fig. 8, Fig. S3, Table S1, S3) for forty-nine samples including
722 thirty-two samples from the southern TYC rift and seventeen samples from three Gangdese
723 rifts (GR) located ~90 km (GR1, five samples), ~75 km (GR2, ten samples), and ~40 km (GR3, 724 two samples) east of TYC.

Samples from TYR and GR are now well defined on the map, but not on the elevation/age or latitude/age graphs, so that it is not easy for the reader to link the presentation of the region made in the introduction and the presentation of the results.

Response: To improve the link between the introductory text, map figures, and the results in this study, we have revised the elevation/age and latitude/age plots in figure 8 to more clearly distinguish data from the Tangra Yumco (red) and Gangdese rifts (pink), matching the color coding used to define the rifts on maps in the introduction and as described within the text (an additional short paragraph was added to section 4.3. for clarity of results between the two types of rifts as well).

Final decision

(11 March 2024)

Dear Alistair Reynolds and co-authors,

Thanks for submitting your revised manuscript. We have now evaluated your revision and answers to the reviewers. Based on this evaluation, we are pleased to accept your manuscript for publication in Tektonika.

The manuscript will now move to the copy-editing and production stage. You will soon be contacted by our technical team.

Thanks again for submitting to Tektonika and supporting the community led DOA journals !

All the best,

Robin Lacassin, Tektonika Executive Editor
Dave Whipp, Tektonika Associate Editor