Comment on egusphere-2022-1203

Title manuscript

Tectonic interactions during rift linkage: Insights from analog and numerical experiments

Referee's comments in black
Authors answers in blue

Referee #2 Chris Morley

The paper by Schmid et al. presents analogue and numerical modelling of the rift segments, to investigate their propagation and interaction, and to understand how stress patterns are affected during propagation and interaction. The paper is well written and illustrated and will be a very good and useful addition to the literature on this subject. I have some minor comments, and one significant issue with the manuscript that are discussed in the attached word document. The significant issue is the way the deformation in Turkana is described - and in the attached document is describe the way I see the development of Turkana. Perhaps some examples form largely non-magmatic rifts outside of the EAR would be useful, since the authors note that the modelling does not consider the effects of magma on rift segment interaction.

I am not convinced Turkana is configured the way you indicate in Figures 1 or 9. Attached is my fault map from 2019, where you can see that northern Lake Turkana is one trend that continues onshore into the Turkana and Kero basins. This is the older trend and there is no evidence for propagation of this trend to the south (as you show in Fig. 9). Offshore the older history of this trend is difficult to discern, because there is a c. 5 Ma volcanic layer that absorbs a lot of seismic energy so imaging below that layer is poor. But onshore the older part is at least Miocene in age. So, it would be propagating to the north if anything. Then we jump to the southern part of the Lake, and that is complicated too. This does seem to be a younger trend in general and it trends a bit more NNE-SSW than the northern trend. In the Loriu and also in Mount Porr there are older (Oligocene(?), Miocene) rift deposits and faults too. But then this younger rift trend is superimposed on them. There does seem to be a NNE-SSW influence of basement trends to the orientation of the Pliocene rift trend. In the southern Loriu this inheritance is quite clear, because basement outcrops with a thin covering of Miocene and Pliocene lavas. What is important about this outcrop – and what is important for your story, is that here we get a rare view that gives us timing. The Miocene lavas are rotated into normal faults. They are unconformably covered by Pliocene lavas, and some faults offset and tilt those Pliocene lavas (Fig. 3). So, on these trends you have to very careful about your models and what relatively simple propagation and linkage history you are trying to describe and the actual history of the area. In that Suguta Valley trend, although it appears to be young, there are actually 3 phases of rifting revealed in the Loriu area – the one that provided the depocenter for arkosic, basement- derived grits (Oligocene or Early Miocene – probably). The one that tilted the Miocene volcanics, and the one that tilted the Pliocene volcanics. If we go to the Mt Porr area there is even an E-W fault trend in basement, whose timing is uncertain (part of the Anza Rift, or part of the EAR?).

The other aspect of the Turkana area that I would like to highlight is the major pre-existing fabric caused by the Cretaceous (reactivated in the Miocene) Anza Graben. It trends WNW-ESE and lies right at the south of the Chew Bahr Rift. I suspect it acted as a barrier to rift propagation. The Chew Bahr

Rift shows an unusual rectilinear boundary fault pattern, which is a foliation-fracture pattern in basement.

The Kino-Sogo belt fault pattern is completely different because it is younger than the Chew Bahr Rift, and so instead of the fault pattern being influenced by Precambrian Basement, it is a fault pattern developed on top of both the sediment fill of the Anza Graben, and also Pliocene volcanics that overlie the Anza Graben. So not only is there no basement influence on the fault pattern, there is also the possibility that volcanic processes (dyke intrusion, magma chambers) have influenced the fault pattern. It is not possible for me to categorically say whether the Kino Sogo belt is actually the southwards propagating Chew Bahr rift, or the northwards continuation of the Suguta Valley............but my prejudice (e.g., Morley et al., 1999) has been that it is part of the Suguta Valley trend (both are of similar age, both involve a volcanic influence. But there is that eastwards step at the north end of south Lake Turkana to explain. Another possibility is that it is its own independent system and that it propagated both northwards to the Chew Bahr Rift, and south to the Suguta Valley. That might actually make the most sense – that it nucleated around the volcanic center over the Anza Graben and propagated N and S from there.

Another tricky aspect of the Turkana area is that on the long-term time scale the rift has not propagated in a N-S direction it has actually migrated (apart from the reactivation of some faults in the Anza Graben) from the west side of the lake to the east-side (Morley et al., 1999, Morley, 2020, Figure 2 below). The oldest part of the rift on a regional scale has actually propagated both to the north and the south from Turkana. The younger part of the rift history that you are focused on in Lake Turkana catches part of the easterly migration – the northern part of the Late being part of the older Miocene trend, with the easterly shift being the Suguta-Kino-Sogo trend. But then as discussed above, even this trend is superimposed on remnants of older rift episodes. In Fig. 4 I made a suggested alternative scenario for Turkana, based on the discussion above.

Thank you very much for this detailed explanation which gives detailed insights into the evolution of the Turkana area. We agree that the Turkana Rift has undergone a much more complex evolution than how we described it. The present-day geometry of the Turkana Rift tempted us to use it as an example of rift deflection and rift cessation (with respect to the Kino Sogo Fault Belt) if two sub-parallel rift segments compete for linkage with an opposingly propagating segment. Therefore, we excluded the Turkana Rift in the revised manuscript as a natural example of a y-configuration. However, the revised manuscript still adheres to the original interpretation of our y-seed models, where influences from the i-seed, and v-seed configurations lead to two distinct phases of rift evolution (i.e., first symmetric phase, dominated by the competition of the sub-parallel rift segments, and a second phase after linkage where strain localizes along the linked segment and tectonic activity ceases along the remaining segment).

Minor points

Line 76. I suggest adding Morley et al. (2004) JSG. To the references – particularly with reference to lines 77-78 this paper discusses discrete pre-existing fabrics (such as shear zones or fault zones) vs pervasive fabrics, which is what I think you are describing in this passage.

Thank you for the additional study. Indeed, Morley et al. (2004) fits well here and is an important contribution regarding structural inheritance. We added the suggested reference at the suited line. Moreover, Morley et al. (2004) discusses the issue of local stress rotations which complicates the interpretation of regional tectonics. We also added this reference with respect to that matter in the conclusions.

Line 90. I do not understand this passage. Western rift basin? Do you mean western basin in the Turkana area? If so, this is wrong, because there are important older rift basins to the west of the rift trend in Northern Lake Turkana (Fig. 1 below). Also, the Turkana rift did not propagate northwards from the Kenya Rift. The Turkana area is the site of the oldest rift (Lokichar Basin) in the East African Rift system. The original work on the timing was done in Amoco (myself included), not by Bonini, Ebinger or Vetel and Le Gall.

In Morley et al., 1992 (GSL), 1999 (AAPG studies in Geology 44), Morley (2019, Geosphere), and Morley and Chantraprasert (2022, Ital. J. Geosci., Vol. 141, No. 3 (2022), pp. 295-333,) the models for the evolution of Turkana have changed a bit, but they consistently show the oldest, Paleogene, part of the rift system is in Turkana, possibly down to the Elgayo Escarpment area, and the rift propagated to the south. There is a change from the half graben stage, to the later volcanically dominated graben-in-graben stage (to use an old term), where the boundary fault style is replaced by smaller fault swarms, and the Suguta valley trend and Kino- Sogo Fault belt trend was established. In Turkana this is seen as a shift in fault activity to the east with time.

Line 93. As discussed below it is not cut and dried that the KSFB is part of the Chew Bahr Rift.

Line 98. As discussed below – there are some clear factors we do know are present that make a clear contrast between the Chew Bahr Rift, and the KSFB (timing of activity, influence of basement fabrics vs presence/absence of the Anza Graben and Pliocene volcanics).

Thank you for pointing this out that carefully. As stated above, we removed the Turkana Region as a natural analogue for our models from the revised manuscript and consequently removed this passage from the introduction.

Lines 114-115. You might also mention there are some studies where stress deflection has been identified in nature (modern stress from boreholes) deflected around faults (e.g., Tingay et al., 2010, JSG).

Thank you for pointing this out. We included the suggested reference as the North Malay Basin provides an excellent and well-studied example of stress deflection and re-orientation near pre-existing faults.

"… They suggested that pre-existing faults may disturb the local stress field and impede linkage of newly forming faults which also occurs in natural examples of multiphase extension (Duffy et al., 2015). Such stress deflections have been reported and studied in various natural settings such as the North Malay Basin, Thailand, due to the vicinity of pre-existing faults (Tingay et al., 2006; Tingay et al., 2010). …"

Line 498-499 – well visible sounds like a 'street' term. This is clearly visible, or well-display, or well-developed

We accept the suggested change and adjusted this passage.

511 the threshold for what? Failure?

This refers to the threshold of 10^{-16} s^{-1} that we set to distinguish between model locations of active (i.e., ≥ 10^{-16} s^{-1}) and tectonically inactive domains (i.e., < 10^{-16} s^{-1}). We adjusted this sentence for clarity.

Line 554. Isotropic areas, into which the rift segments have yet to propagate.

Thank you, we adjusted this sentence.

Line 558 into either

Thank you, we adjusted this part.

Line 686 approximately (replace somewhat).

Thank you, we adjusted this part.