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Interactive comment on "Influence of inherited structural domains and their particular strain distributions on the Roer Valley Graben evolution from inversion to extension" *by* Jef Deckers et al.

Jef Deckers et al.

jef.deckers@vito.be

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1. Rather than starting with the specifics of the study area, the Abstract might benefit from a more general sentence (or two) on the generic issues to be tackled in the paper (e.g. strain partitioning during inversion). By doing this, the paper may more immediately appeal to a broader, more general audience; e.g. the reader may not be particularly expert or interested in the Roer Valley, but may be concerned with the far wider, more general topic of basin inversion.

We have added several sentences to describe the more generic issues of our manuscript.

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2. I do not follow this section of text, especially the last sentence in the paragraph; i.e. how does the similar strain distributions show the importance of inherited structural domains? Please be more specific. Also, given the rifting width is narrow in the south than the north, and that the magnitude of extension and contraction was the same between the two domains, does this mean that there were: (i) fewer, larger displacement normal faults; and (ii) a greater amount of reverse reactivation per fault, in the south?

We have changed this sentence into the following: "The total normal and reverse throws in the two domains of the FFS were estimated to be similar during both tectonic phases. This shows that each domain accommodated a similar amount of compressional and extensional deformation, but persistently distributed it differently." Indeed, there are fewer, larger displacement faults in the southern domain and more in the northern domain. This is mentioned as follows: "A southern domain is characterized by narrow (< 3 km) localized faulting, while the northern is characterized by wide (>10 km) distributed faulting".

3. It is not clear why segmentation is mentioned at this point in the Abstract. It might work better earlier in the Abstract, when you describe the overall (present) structural style of the study, and before you discuss the kinematics (i.e. before the last few sentences in the first paragraph).

We have now mentioned segmentation at the first few sentences of the abstract.

4. The last sentence of the Abstract does not really make any clear statements about the inversion aspect of the study; instead, it principally focuses on rifting. This is surprisingly, given the Special Issue is about inversion tectonics.

The last sentence was removed since it is now already covered by the new first few sentences of the abstract.

5. Like the Abstract, the start of the Introduction is rather focused on NW Europe in general, and the Roer Valley in particular. It might help to make some broader,

more generic statements about the repeated reactivation (in extension and contraction) of basin-bounding faults. For example, the rationale-style statements in the last two sentences in the first paragraph of the Introduction might be brought to the start of this section.

We have now added several sentences to broaden the scope before focusing on the study area. “Rift basins are typically bounded by large fault systems. These border fault systems are generally segmented along strike. As they represent zones of pre-existing weaknesses, the large border fault systems are prone to reactivation under either extension or compression. The effects of pre-existing segmentation upon extensional or compressional strain distributions in reactivated rift border fault systems have thus far received little attention. One of the ideal areas to study these effects is at the border fault systems of the Roer Valley Graben (RVG). These systems developed in the middle Mesozoic, and were reversely reactivated under Late Cretaceous contraction and experienced normal reactivation again under Cenozoic extension (Demyttenaere, 1989; Geluk et al., 1994).”

6. On L59-61, where you mention “stratigraphic distributions”, it might also be worth mentioning “isopachs” (i.e. thickness maps), given this is, I think, what you are referring to.

Indeed, we have added the “thickness maps”.

7. L87-105 – Despite being syn-rift, the uppermost Oligocene to Recent strata appears to be rather widespread and tabular in the stratigraphic column presented in Fig. 2. Why are these units not more locally developed within the Roer Valley Graben, in a similar way to the Jurassic units? Or are these syn-rift units present on the basin flanks, but substantially thinner and/or punctuated by unconformities related to rift-flank uplift/non-deposition?

The syn-rift strata are much thinner on the graben flanks. This is mentioned in the sentence: “As a result of continuous rifting since the late Oligocene, the abovementioned stratigraphic units are relatively thick in the RVG (over 1000 m) compared to the flanking CB and Peel Blocks (generally below 500 m; Demyttenaere, 1989; Geluk, 1990; Fig. 3)." This is now also shown on the composite seismic figure 3 and on the cross-sections of figure 10.

8. L109 – you here mention the Paleogene-to-Neogene extension direction, but what was the shortening direction associated with the sub-Hercynian compressional phase? You do not mention this near L68-71 in the preceding paragraph. This is very important, given this will ultimately influence whether and how certain faults were reverse reactivated.

We have added the following sentence: "Inversion in the area probably took place under a N-S to NNW-SSE direction of maximum horizontal compression (de Jager, 2003) as the result of convergence between Africa and Europe (Kley and Voigt, 2008)."

9. L110-128 – This text would greatly benefit if some structure maps (e.g. Fig. 5) and/or cross-sections (Figs 7 and 8) were cited. It is presently very difficult to visualise the described relationships in the absence of any graphical support. I sense many such maps and sections have been generated as part of previous studies (e.g. Decker et al., 2019) and have been included in earlier publications, but some of them may benefit from being included again here. For example, a regional, NE-trending cross-section would a very useful accompaniment to Fig. 1.

We have added one composite seismic section on figure 3 that runs across the RVG (and the southern structural domain of the FFS). This figure shows the stratigraphic distributions and provides support for the 3D-models mentioned in the text. We have also added a composite seismic section as Figure 6 that runs across the northern structural domain of the FFS.

10. L158-169 - I think it is important to show at least some seismic profiles. If you do not, then the reader has to solely rely on the geoseismic (i.e. interpreted) sections presented in Fig. 7; in my view, this is not sufficient to really convince the reader of

your structural and stratigraphic (i.e. thickness) descriptions, and subsequent interpretations and conclusions. I again argue that, although some of these raw data may have been presented in earlier papers, they need showing again here, especially to help the reader visualise some of the interpretation challenges mentioned in, for example, L213-225.

We have added two composite seismic section as figures 3 & 6 in order to convince the reader of the differentiation between the northern and southern structural domains of this study.

11. L182-196 – Related to comment (10), this section would benefit from one or two simple stratigraphic correlations (e.g.one from the southern and one from the northern domain), perhaps presented next to or below spatially coincident seismic profiles, showing how the main syn-inversion and syn-rift strata change in thickness across some of the key structures. The gridded data in Fig. 6 are useful, as are the cross-sections in Fig. 7, but some hard-data, in the form of a correlation with stratigraphic/formation tops clearly indicated, would strongly support the inversion-to-extension argument being presented.

We have indeed added one composite seismic section across the northern domain and one across the southern domain (figures 3 & 6). Several of the used, deep boreholes are also indicated.

12. As a general aside, I recommend the authors read Freeman et al. (2010) - Using empirical geological rules to reduce structural uncertainty in seismic interpretation of faults. J. Struct. Geol. 32, 1668-1676. This is an excellent paper, showing how simple displacement-length (D-L) plots and displacement 'strike-projections' can be used to help reduce interpretation uncertainty in areas of modest-quality (and quantity) seismic reflection data. In any case, the authors are to be congratulated on a very open, honest discussion of the uncertainty in their structural model.

This is indeed a very interesting paper to handle uncertainties and improve fault interpretations on 2D seismic data. We will keep that in mind for the next modelling campagnes.

13. L248-251 – I think this text needs modifying, given that structure maps alone say nothing about kinematics; i.e. they tell you about present-day basin structure, but not about the motion history (i.e. kinematics) of those structures. Kinematics are best revealed by isopach maps, stratigraphic correlations (see comment (11)), cross-sections (e.g. Fig. 7), etc, both of which tell you about the timing of structural movement as recorded in the related uplift and subsidence.

We changed “kinematics” into “geometry”.

14. L263-269 (and elsewhere) – I suggest you use the cross-sections in Fig. 7 to help support your structural descriptions.

We have added some additional references to the figures.

15. As stated above, the cross-sections in Fig. 7 would greatly benefit from the addition of the location of boreholes. This would help make the interpretations more convincing; i.e. at the moment, the reader of this particular paper has to simply trust that the geometries, depths, etc, presented in Fig. 7 are true, without supporting data.

We now show some of the important, deep boreholes on the composite seismic sections of figures 3 and 6.

16. The title of sub-section 4.1 may benefit from modifying, given you provide a description of the present, rift-related structural style (e.g. fault throw, spacing, length, etc), but not the kinematics of rifting. 17

We agree and have changed the title into: “ Structural style of Cenozoic rifting”

17. L346 – change “doesn’t” to “does not”.

This sentence was modified accordingly.

18. L345-348 – The fact that strain is the same but more diffuse in the northern domain than the southern domain is a very important, which is currently described in a rather qualitative manner. One option would be to actually quantify this relationship by measuring and summing throws (or heaves) along a series of broadly fault-normal (i.e. NE-trending) profiles in the northern and southern domains (e.g. Wilson, P., Elliott, G.M., Gawthorpe, R.L., Jackson, C.A-L., Michelsen, L., & Sharp, I.R. (2013). Geometry and segmentation of an evaporite-detached normal fault array: 3D seismic analysis of the southern Bremstein Fault Complex, offshore mid-Norway. Journal of Structural Geology, 51, 74-91). This would be a powerful addition to the paper, and make the segmentation argument, which is currently only really supported by three cross-sections, even more compelling.

We agree and have added an additional figure 8 to the manuscript with the Cenozoic throw distribution along some of the major faults in the southern and northern domains.

19. L352-355 – What data indicate that the Chalk Group is missing in the axis of the Roer Valley Graben? It is shown as being absent in the cross-sections in Fig. 7, but is this directly constrained by deep boreholes in this location? For example, is the Cenozoic pre-rift early in demonstrably direct contact with Pre-Cretaceous strata in the rift axis? This query relates back to my earlier suggestion that far more stratigraphic and seismic data need to be shown to support Fig. 7.

The supporting evidence by deep boreholes is now shown on figure 3. The Molenbeersel borehole only penetrates the youngest sequences of the formal Chalk Group which are – for the purpose of this manuscript – not included in the Chalk Group (see chapter 2.1 of geological setting and stratigraphy).

20. L359-360 – A key issue relates to the argument that only few faults presently have reverse throws. From what I can see in Fig. 7, all faults are still in net-extension; even the Bree, Dilsen and Rotem faults, for example, all appear to be in net-extension, despite reverse slip vector arrows being drawn at deeper depths. So I again ask,

“what data are constraining the interpretations presented in Fig. 7?”. Furthermore, classic inversion-related structures, like so-called ‘harpoon structures’ (i.e. hangingwall anticlines) are absent. As it stands, I see little solid evidence for inversion in the data as it is currently presented.

The Bree and Dilsen faults were not normally reactivated and display net reverse throws on figure 10 (former figure 7). The net reverse throw of the Bree fault is supported by figure 3.

21. L378-382 – I do not follow the argument that the Bree and Dilsen faults formed only during the sub-Hercynian inversionn event, and are not pre-existing, rift-related normal faults that were subsequently inverted (although see my comment (20) regarding the present lack of evidence for inversion). Why do you think this is the case? It is completely implausible that they are Late Jurassic structures?

We cannot exclude earlier activity, but find it very unlikely. We therefore have rewritten this section as follows: “If they indeed represent footwall shortcut faults, the Bree and Dilsen faults would have originated during Late Cretaceous compression to accommodate inversion on the pre-existing Neeroeteren and Rotem faults. This hypothesis is supported by the fact that the base of the Lower to Middle Mesozoic strata shows a very similar amount of reverse vertical throw as the base of the Chalk Group along the Bree fault (Fig. 3). Nevertheless, earlier (Cimmerian) activity along the Bree and Dilsen fault cannot be excluded. Contrary to most other faults in the FFS, the Bree and Dilsen faults were not reactivated during Cenozoic extension and therefore now still have net reverse throws (Figs. 3, 10A and -B).”

22. L392-393 – I cannot see reverse throw of 200 m at the stratigraphic level of the Chalk Group in Fig. 7B. The GBF appears to be in net-extension along its entire dip extent. This comment also applies to the start of section 5 (Discussion and Conclusion), where you argue for the magnitude of reverse throw along the various faults in the northern and southern domains.

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We have now clarified this statement by rewriting it into: “The Chalk Group is about 200 m thick in the footwall of the GBF (the CB), but absent in its hangingwall (the northern domain of the FFS), which indicates that this fault had a reverse throw of at least 200 m (Fig. 10D)”.

23. L414-415 - Related to comment (22), this is a critical statement, which is presently not strongly supported by the presented data. I also strongly recommend the authors read Reilly et al. (2017) - https://sp.lyellcollection.org/content/439/1/447, who come to a similar conclusion, but via the presentation of much more quantitative data.

This statement is supported by the maps of figures 7 and 9, as well as the cross-sections of figure 10. Thanks for the article of Reilly et al. (2017)! It is indeed very relevant also for this manuscript, so we have added a reference to it in paragraph 5.1.

24. L415 – Mora et al. (2008) is not in the reference list. Please check all references.

We have corrected it to Mora et al. (2009) which is included in the reference.

25. L426-428 – Why would footwall shortcut faults be less prone to being reactivation (in extension) than other faults? Is it because they have gentler dips, thus are essentially ‘locked’ due to the normal stress exceeded the imposed (extensional) shear stress?

Good question. Since it is not the focus of our manuscript, we simply wrote in the text that we presume that the middle Mesozoic normal faults, rather than the Late Cretaceous footwall shortcut faults, were preferential sites for Cenozoic normal reactivation.

26. L447-454 – I agree there is a change in structural style between the two domains across the GBF, but why does this happen? More specifically, why are more fault required in the northern domain than the southern domain to accommodate the same extensional strain?

We consider underlying changes in lithospheric strength as likely triggers for the differences in strain distribution. This is now discussed in paragraph “5.2 Possible mechanisms behind the segmentation".

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