Reply to review by Frank Zwaan ([report #1])

We thank the reviewer Frank Zwaan for the additional review on our manuscript. We agree with all of his suggestions and changed the manuscript accordingly. In the 'track-changes' file of the manuscript all deleted text parts are colored in red and newly added parts are colored in blue. Our responses to each reviewer comment is given below (1. General comments). The reviewer uploaded a annotated .pdf file of the manuscript. We also replied to each comment given in the annotated pdf file below (2. Specific comments).

Kind regards

Michael Warsitzka on behalf of all co-authors

Suggestions for revision or reasons for rejection (will be published if the paper is accepted for final publication)

Review se-2021-17 (Warsitzka et al.)

1. General comments

• *Reply to review comments (seems incomplete)*

o I would like to thank the authors for their detailed reply to the general review comments from the first round. However, it seems that no replies to the various comments in the annotated PDF version of the previous manuscript I sent in are available. This is a pity, as it made it much harder to properly assess if all comments were considered, and what modifications were made, if any, and why. I strongly recommend addressing all review comments in future replies to authors.

>> We provided the replies to the annotated pdf version by the reviewer Frank Zwaan directly in the pdf file in which we wrote a reply to each comment instead of listing our replies in a separated word document. We thought that this is a better procedure, since our replies can be directly related to the passage in the manuscript. We then uploaded our annotated pdf along with our reply letters to the reviewer. Maybe the reviewer missed to find our replies in the pdf and we apologize if we didn't presented this clear enough.

• *References to appendices*

o I noticed that there are quite a number of references to the appendices. Perhaps it would be better to keep Table 1 in the main text. Concerning the scaling: see below.

>> We moved Tab. 1 into the main manuscript so that all related references are given in the main manuscript as well. Chapter A of the Appendix, which contained this table, was deleted, because the information in this text are also given in chapter "2 Geological prototype".

• *Set-up*

o There are now somehow 2 sections describing the set-up (see annotated PDF) → consider merging or renaming the sections.

>> We agree and removed the words "experimental setup" from the title of chapter 2. In fact, chapter "2 Geological prototype" does not contain statements about the experimental apparatus, but only about the boundary conditions derived from nature. The experimental setup is solely described section 3.1.

o Fig. 11 shows that the folding of the rift flanks is not as nicely parabolic as presented in the methods section. Would this not have affected the model results?

>> Fig. 11 shows cut cross section of Exp. ETS1. The base line of the silicone layer is slightly irregular, which is a consequence of cutting the silicone. For the cutting, we flipped the model upside down on an planar top plate and then detached the basal plates from the silicone. During detaching and cutting the silicone layer was slightly deformed. However, these irregularities were not present during the experimental run and, therefore did not affect the deformation structures. To improve the cross sections, we slightly flattened and smoothed the silicone layer, which did not changed the geometries of the syn-kinematic deformation structures in the sand layer.

• *Scaling:*

o The scaling in the main text is still rather long, but the whole scaling description is now split in a part that is now in the appendix and a part that is still in the main text. There are a lot of references to the appendices in the main text. This does not really read that well I think. I would therefore prefer to move the whole scaling part, including the various equations to the appendix, and only define the key things in the main text:

• Length scaling, time scaling and state that scaling behind it is worked out in detail, and more details are to be found in the appendix

>> We removed large parts of the scaling from the main text and only left a short text about the scaling in section 3.1. Furthermore, we moved Figure 3 (former version of the manuscript) into Appendix A as new Figure A1. We added some further explanation in the Appendix A: Scaling.

• *Results*

o Very nice, only a couple of comments → see below and annotated PDF

o Perhaps it would be good to address the boundary effects due to drag along the long sides of the models. This is something that is seen in various modelling studies.

>> We added sentences in section 4.1.1, in the caption of Figure 7 and in section "5.2 Limitations of the apparatus and the procedure" describing and discussing the influence of boundary effects on the displacement and strain pattern.

o Still an important point that I believe is not resolved I believe: how can the displacement of the model surface in the brittle-only experiments be so different from the applied displacement (See Figs. 4-6). The sand is directly coupled to the base and should move with the same velocity. Perhaps that the tilting of the plate affects things a bit, but this should not be the case in the one model without tilting (Eb in Fig. 4).

What does this mean for the other models with a viscous layer? Perhaps these results should be double-checked as well?

>> In Fig. 4g and 6g, the graphs indeed show that the average horizontal displacement of the model surface is smaller than the displacement of the outward moving flanks. This is simply because the blue and green curve show the *average* displacement of each half of the surface, which also includes the laterally stable graben centre. Since the horizontal displacement is 0 above the graben centre, the average hor. displacement is smaller than the lateral movement of the flanks. We added a sentence in the caption of both figures to clarify this.

• *Discussion*

o Something is missing here I think. Why not start discussing the most simple case (no viscous layer, so that the sand will directly follow whatever the base is doing?) → this should be mentioned first, before moving to the models with viscous layers. A useful reference could be Zwaan et al. 2019 in Solid Earth, who dedicate quite some attention to discussion coupling and the influence of (the absence of) a viscous layer during rifting (see also the other references in that paper). This discussion part does not need to be very long, but now it is not mentioned at all, which means that the discussion is not complete as these models are an important part of the results.

>> We added a paragraph at the beginning of the discussion describing the main differences between brittle-only and brittle-viscous experiments.

• *This comment also concerns the discussion; I think these models should be mentioned, even if it is very briefly.*

>> The reviewer probably means that we should briefly mention the brittle-only experiments in the *conclusions*. We added a sentence there.

o Please make sure to directly refer to the excellent Fig 12, so that the reader directly makes the link with what is written (I would also suggest adding a panel showing what generally happens when no viscous layer is present, to have a complete overview).

>> We added some more references to Fig. 11 (= Fig. 12 in the previous version of the manuscript) in section 5.1. According to the suggestion by the reviewer, we added an equivalent sketch of the simple strain patterns of exp. ETb in Fig. 11. However, no sketches of exp. Eb and Tb were included here, because strain patterns in Eb were equal to those in ETb or no strain occurred at all in Tb, respectively.

o Fig. 13: perhaps add headers to the different panel to help the reader? There should be sufficient space in the figure to do so and it would make things clearer.

>> We added headers above each subfigure.

• *Figures*

o The figures are very nice. But here and there, it could be possible to give the various panels a bit more white space (e.g. Fig. 1 is a bit crammed and there could easily be added some space between each panel. Perhaps the same could be done for the result figures, and Fig. 13.

>> We agree and increased the distance between the subfigures in each figure a little bit.

2. Specific comments in the annotated pdf file

Abstract:

- Line 9: “The” was added

1. Introduction:

- Line 33: Abbreviation “SBRB” was changed to SBRBs throughout the manuscript.
- Line 63: Word was changed

2. Geological setting and experimental setup

- Line 76: Yes, we agree that the title is misleading here and removed “experimental setup” from the title, since this chapter 2 actually does not contain specific information of our setup, but only of the natural prototype.
- Fig. 1a: We increased the vertical scale in Fig. 1a.

3. Method

3.2 Experimental materials

- Line 117: We added the type of the silicone and rephrased the sentences.
- Figure 3: We changed the graph of the shear strength to zero at the surface

3.3 Scaling

- Line 173: We removed large parts of this chapter, since the information are given in the appendix.

3.4 Experimental procedure:

- Line 219: Word were changed.
- Line 222: We further specified that graben was filled up to the edges of the graben flanks and that an additional 1mm thick layer of sand was added on the entire silicone basin. The thickness distribution of the syn-kinematic layer is also shown in Fig. 1a.

4. Results

- Line 247: Reviewer: “*The graphs in 4g and h show that the total displacement is still smaller than the applied extension. In Ev, that could perhaps be due to the viscous layer, but I don’t see how this can be the case in Eb… Here the sand moves directly with the base plate, so how is it possible that the displacement is not the same?”*

  >> The graphs in 4g and similar graphs in the other figure show the average x-displacement of the left and the right half of the experimental surface. Thus, it includes the outward moving flanks, but also the laterally stable graben centre. Since the horizontal displacment of the graben centre is 0, the average x-displacement is smaller than the horizontal displacement of the outward moving basal plate. To clarify this, we added a note in the caption of Figure 4.

- Reviewer: *"a further important thing to notice is that deformation continues during the post extension phase in Ev, whereas nothing happens in Eb. This should be mentioned."*

  >> We added a sentence explaining this.

- Line 251: Word was added.
- Line 252: Reviewer: *"perhaps add a remark that this si much less displacement than observed in Eb and Ev? This is not directly obvious from Figs. 4 and 5 due to the use of different scales."*

  >> A sentence was added

- Line 252: *"not sure if Fig. 5b really shows this? perhaps add some arrows or annotation there?"*

  >>We changed the location of the figure reference in text.

- Line 257: Figure reference was added
- Line 263: We specified this accordingly.
- Line 269: *"how is this dx(cum) specified? In Eb, the cover on the flanks is moving apart, where in Ev, the flanks are moving inward, so (large) displacements could be in every direction?. I assume what is meant is the relative displacement? (towards the center?) please specify this to avoid confusion."*

  >> d_{xcum} is the x-displacement extracted along the central profile and then summarized over time. To further clarify the meaning, we specified this in an additional phrase in section "4.1.1 Basal extension", because d_{xcum} was first mentioned there.

- Line 294: *"very much like typical salt tectonic models (e,g, the work by Ge et al.)"*

  >> Yes indeed. In the discussion, we compared our experiment ETv with analog models of passive margin salt basin and also cited the papers by Ge et al.

- Line 305: Figure reference was added
- Line 308: Figure reference was added
- Line 320: Word was changed

5. Discussion

- Line 330: Sentence was rephrased
- Line 334: Reference Zwaan et al., 2019 was added
- Line 340: Word was added
- Line 344: *"I believe, this is very similar to the classical salt tectonic system on passive margins, also presented in Fig. 1? (here we have basically 2 passive margins tilting towards the same rift center? Why not add some references to previous works here?"*

  >> We added a sentence citing references of salt-bearing passive margins

- Line 423: *"not sure, these structures develop after sufficient tilt is achieved? —> no real need for the graben to do anything than creating a regional sag?"*

  >> We are not sure what the reviewer means. We think that tilting of the graben flanks is created during the sag phase of rift, that means due to thermal subsidence and subsidence resulting from sedimentary loading of the crust. Thus, tilting should become effective some time after rift initiation and not already at the beginning of rifting. We rephrased the sentence to make this clearer.

- Line 439: Word was changed
- Line 443: Figure reference was added.
- Line 461: Figure reference were added

- Line 480: We slightly modified this sentence

6. Conclusion

- Line: 488: *"As with the discussion, I think the models without silicone/salt analogue should be mentioned as well (even if it is short), these models are an important part of the paper after all."*

  >> We added a sentence briefly describing the brittle-only experiments.

- Line 499: Words were changed

Appendix:

- Line 501: Chapter Appendix A was moved back to the main text and integrated into section 2
- Tab A1 was also moved back into the main text.
- Tab B1. Words were changed
- Tab B1. Reviewer: *"Same question as last time: did the applied extension rate differ between models? or is this the rate of deformation in the overburden?"*

  >> We already answered this in our annotated pdf that we uploaded after the first round of reviews. The values for extension rate given in the Table B1 are used for calculating the scaling parameters as it is stated in the caption of table B1. The extension and tilting rate applied in the presented experiments (1 mm/h) are listed in Table 2 and are mentioned in the main text in section 3.4. For that reason, we think it is clear for the reader that we applied only one constant extension rate in the models.

Fig. 11:

- Reviewer: *"the base of the model is not very nicely parabolic as was suggested in the methods. Is his an issue?"*

  >> As explained above, the irregularly drawn base of the silicone results from the cutting procedure. For cutting the model, we flip the model upside down and detached the sand and silicone form the basal plate. This cause slight deformation of the silicone base. During the experiments the basal plate was even and parabolic in shape and, thus, did not affected the deformation patterns.

  Since the distortion is only a result of the cutting and not of the deformation during the experiment, we smoothed the base of the silicone layer in Fig. 11.