

Review of “Inversion of transfer zones in salt-bearing extensional systems: insights from analogue modeling”

Authors: Elizabeth P. Wilson, Pablo Granado, Pablo Santolaria, Oriol Ferrer, and Josep Anton Muñoz

Frank Zwaan (editorial committee)

Response to comments in the annotated pdf -

Editor, Line 55: using “addressing how” would make the sentence flow a bit better

Authors: The text has been updated.

Editor, Line 64: “while” should be deleted it seems

Authors: The text has been updated

Editor, Line 69: by

Authors: Yes, the text has been updated.

Editor, Line 73: rifting stage/phase or so → a word is missing it seems

Authors: The text has been updated.

Editor, Line 74: is the basement not by definition part of the extensional system? please rephrase

Authors: Yes, we meant to reference the mantle exhumation. This has been modified in the text

Editor, Line 75: only one rifted margin was involved (there was a refitted margin on either side of the basin? I suggest using “rift basin” or so instead.

Authors: Here we use rifted margin, and prefer to use the term, because we are referencing the regional geologic history, not just the individual basins from the Pyrenean natural case study.

Editor, Line 75: the southern north sea and atlas were very small rift basins, so it should be stated that there are also variation in rift maturity.

Authors: The text has been modified to include variation in rift maturity of these other examples.

Editor, Line 80: analogue modelling

Authors: Yes, this has been modified in the text.

Editor, Line 84: I don't recall Brun & Beslier (1996) used seeds in their lithospheric-scale models? We did in Zwaan & Schreurs (2023, Tectonics), but perhaps a better citation is Le Calvez & Vendeville 2002 in J. Virtual Explorer. Many other examples of studies using seeds exist.

Authors: You are correct. We meant Brun and Nalpas, 1996. This has been changed (as well as in the reference list). We have also added the Le Calvez & Vendeville, 2002 article as you suggested

Editor, Line 87: consisting of

Authors: This has been updated in the text.

Editor, Line 88: in which extension is followed by contractional deformation

Authors: This has been updated in the text

Editor, Line 90: salt layer

Authors: This has been updated in the text.

Editor, Line 92: does

Authors: Yes, this has been changed in the text.

Editor, Line 97: there is a very nice review paper by Duffy et al. (2023) in the new journal of Tectonika, I suggest citing it here.

Authors: This reference has been added to the manuscript.

Editor, Line 98: use "for storing hydrogen gas (H₂)" → hydrogen can also refer to the single atom (H)

Authors: This has been updated in the text.

Editor, Line 98: natural gas (CH₄)

Authors: This has been changed in the text.

Editor, Line 108: this should be the Greek letter "mu"

Authors: This has been changed in the text.

Editor, Lines 119-120: what is missing is a statement how time is scaled, and what the deformation velocities in the models would represent in nature. This is important when using materials with a strain-rate dependent rheology (such as the silicone polymer) → it is important to provide the calculations and equations in the

text, so that the reader can check (and reuse) these. Part of this could potentially be moved to the appendix, but it is now lacking in the paper.

Authors: Table 2 has been updated to include the time and velocity scaling values and text has been added to the manuscript to explain the values.

Editor, Line 125: delete?

Authors: The word has been removed from the text.

Editor, Lines 127-128: the use of “wide” and “long” is a bit confusing, as “long” is normally used to indicate the longest side, which is not the case here. this seems to imply that the metal base is not large enough (35 cm, instead of the 50 cm model width). I understand that “long” is meant to be in the x-direction (in map view), but it may be better to remove “long” and “wide” in this sentence, to avoid any confusion.

Authors: The words have been removed from the text.

Editor, Lines 129-134: these sentences need a bit of rewording. It would be best to first state that extension is done by moving both backstops apart. Then, the mylar sheet is fixed to the base. Finally, one mobile wall moves inward (as I understand from the figure, the extension involves 2 moving walls, the inversion phase only 1 moving wall). The current way it is explained is a bit unclear.

Alternatively, as the whole procedure is explained a bit later on (so that there is some repetition): consider simply removing lines 131-133

Authors: We have opted to remove the repetitive text and leave the explanation in the following section.

Editor, Lines 137-138: highlighted text

Authors: The highlighted text has been corrected and the unintentional paragraph spacing has been removed.

Editor, Line 138: lateral = the long sides of the model?

Authors: No, we refer to the marginal area proximal to the moveable backstops. The text has been updated to clarify this.

Editor, Line 142: Such a

Authors: The text has been modified.

Editor, Lines 145-146: repeated statement, perhaps it is best to remove line 139-140.

Authors: Agreed. The first sentence has been removed.

Editor, Line 147: it is not 100% clear whether this highest part is the same in both models. It would be good to mention it somewhere. In Fig. 2a, it could be indicated with a dotted outline, to show it is the seed in the background (I hope that makes sense)

Authors: The text has been modified and 'along their highest part' has been removed. We do not think that it is necessary to modify Figure 2 based on our changes to the text.

Editor, Line 151: consists or consisted? Please check the text for consistency (either past or present tense, but not mixed)

Authors: The text has been updated.

Editor, Line 153: perhaps it is better to state that they are a means to localize listric faults (as is stated before)? Or that they represented the *impact* of pre-existing weaknesses (the triangular shape does not seem to be something that we would expect in nature)?

Authors: The text has been updated to better explain the purpose of the silicone seeds.

Editor, Line 160: see comment on scaling: what does this velocity translate to in nature?

Authors: The text has been updated.

Editor, Line 168: it seems that this sentence should be part of the preceding paragraph? Is it separated on purpose? —> why is 9 cm chosen? (is there a link with the Pyrenees that inspired this work?)

Authors: It should be part of the previous paragraph and has been moved. 9 cm was chosen because it was the amount of extension required to create sufficient topography across the basement and create early half-grabens above the silicone seeds. There is no link to the amount of extension experienced by the Pyrenean rift system.

Editor, Line 173: why slower? please explain shortly —> what is the link to the Pyrenees?

Authors: The rate of extension is slower to prevent the model salt from behaving brittlely under strain, allowing it to flow and migrate in response to the developing supra-salt syn-rift basin system. It has no relation to any interpreted changes in the rate of extension in the Pyrenean example. The text has been updated to explain this change.

Editor, Figure 3: the column in the figure shows a very nice definition of the various deposits. It would be good to use these definitions consistently in the text (especially in the discussion). —> see some comments down the line.

Authors: This has been updated.

Editor, Figure 3, Line 181: it would be good to specify which section this is exactly, and to refer to the figure with the respective model results.

Authors: These sections are used in the later figures. The caption has been updated to reference the corresponding section in figures 4, 7, and 10.

Editor, Line 187: consider “and to prevent model salt extrusion” → the sentence is a bit off

Authors: The text has been modified.

Editor, Line 192: delete

Authors: Done.

Editor, Line 193: this does not make sense: the layers are deposited at different times, one after the other.

Authors: The layers were added consecutively without pauses for periods of downbuilding. The text has been updated to better explain this.

Editor, Line 196: please provide a bit more motivation for including this tilt → mentioning the South-Central Pyrenees

Authors: Additional text has been added to explain its significance to the South Central Pyrenees (low angle unconformity).

Editor, Line 200: delete

Authors: The text has been updated.

Editor, Lines 201-202: again, what is the link to the natural example? (what was the displacement and displacement rate in nature?)

Authors: The text has been updated.

Editor, Line 206: how much would this be in nature? (m/Myr?) would be good to specify

Authors: The text has been updated with calculated values added to Table 2.

Editor, Line 214: I agree with reviewer 2 that it would be good to at least mention that an automated set-up is used for this (to make clear this is not simply done by hand, but by a more sophisticated method),

Authors: The text has been modified.

Editor, Line 222: 3D is used earlier on, may be best to choose one convention for the whole text

Authors: The text has been updated to only use 3D.

Editor, Lines 226-228: It would be good to describe some of the key observations we can see in map view in the main text. E.g. I see in the sections (a) and (c) that two grabens did develop. I assume this is because they propagated parallel to each other, in a kind of rift pass structure (see e.g. Zwaan & Schreurs 2020 in Journal of Structural Geology for references on such rift interaction structures). This does not have to be long, but it would greatly help the reader understand the 3D structures a bit better → I checked the video and it would just be nice to show the surface structures at the middle and end of the rifting phase in map view (as the upper row of Fig. 4, or Fig. 5).

Authors: A bit of text has been added to the first paragraph to briefly outline the 3D geometry of the system at the end of the model before moving on to the section interpretations.

Editor, Line 252: perhaps add in the caption that this is an extension-only model so that the reader knows directly what is shown. Similar details can be added to the other figures showing such model results.

It would also be good to make clear in the caption that this is the end of the model run (similar detail should be added to the captions of the other section figures).

Authors: Additional text has been added to the captions in Figures 2 and 4-12 to remind the readers which model they are looking at.

Editor, Line 258: it could be useful to make this the start of a sub-section within section 3.1 (including a header), as it is mostly about the evolution of the model, whereas the previous text is mostly about the final model structure. This could be helpful to the reader.

Authors: We would prefer not to add a sub-section here. The last three paragraphs of the section describe the final basement fault organization as well as the distribution of the model and salt and syn-rift succession and wouldn't fit into a sub-section about the model evolution. Additionally, as this was not suggested for models 2 and 3, it would be strange if all the model results did not follow the same format.

Editor, Line 279: see previous comment on showing the evolutions of the initial structures in map view.

Authors: We do not understand what you mean. There is a small inset top view image to show the location of the sections and the following 2 figures and text describe the evolution of the model and final structure and true stratigraphic thickness maps of the final configuration of the various units.

Editor, Line 283: due to the VD I assume?

Authors: Correct. Text has been added to reflect this.

Editor, Line 284: The term “transfer zone” is used in this paper. I would suggest using “accommodation zone” instead, as there is no “hard linkage” between both grabens (to me, a transfer zone is a linkn between two rift basins in the shape of through-going faults, which is not the case here). See for instance Zwaan et al. (2016) in *Tectonophysics*, and the references therein regarding the relevant terminology. A potential neutral option could be “rift linkage structures”

Authors: The text has been updated and all “transfer zone” terms have been replaced by “accommodation zone”, to the editor’s preference.

Editor, Line 303: what is indicated are not grabens, but normal faults?

Authors: The figure has been modified so that the arrows point to the space between the lines so that they fall within the grabens.

Editor, Line 306: for clarity: please specify that this is at the end of the model run/extension phase

Same for other map view imagery, where relevant

Authors: This has been updated on all figures.

Editor, Line 439: “despite being” might work better

Authors: The authors would prefer to stick with the current verbiage. The use of the word 'being' makes it sound as though the post-salt sequence is welded to the basement, but we have no way of knowing where the system was or was not welded prior to shortening.

Editor, Line 529: I believe it can (should?) be written together: “backthrust” —> consider doing so for the whole manuscript.

Authors: The text has been updated following the editor’s preference.

Editor, Line 548-550: I am not sure about this argument. As far as I understand, the mylar sheet is rigid, so I would the impact along the “mylar VD” not expect to be that different from that along the “metal VD”. Instead, I suspect it could have to do with the shape of the seeds —> the tip, i.e. that weakest spot in the model, is located towards the “metal VD” in both cases. So there is likely a difference in stresses on both sides, and deformation as such could be more focussed on the “metal VD” side.

Authors: Yes, your point makes sense as the three basal materials are rigid. However, the metal plate has a greater thickness than the comparatively paper-thin (only use qualitatively as a measurement comparison) mylar sheet. And this greater vertical offset between the metal plate

and rubber sheet, versus that of the mylar sheet to rubber sheet, is what helps make it a more effective VD. Additional text has been added to the discussion to address your point as well.

Editor, Line 553: akin to a rift pass structure —> see previous comment on this topic.

Authors: As stated previously, transfer zone has been replaced by accommodation zone throughout the text.

Editor, Line 573: “the dogma that states that the” —> given the wealth of knowledge on decoupling due to salt, is it really fair to present this dogma as a on-going issue? Perhaps it can be rephrased a bit.

Authors: The text has been modified and the term has been removed.

Editor, Line 593: concerns

Authors: This has been replaced

Editor, Line 605: 14a?

Authors: Correct. Thank you for catching this.

Editor, Lines 630-631: I suspect this effect may have been observed in previous models as well —> it would be nice to link it to a previous paper (I believe Jara et al. 2015 or 2018 could be of interest).

Authors: References have been added.

Editor, Line 638: this paragraph is rather long (a “wall of text”) so that it becomes a bit hard to follow. To improve readability, it would be better to split it up in 2 or three paragraphs.

Authors: Agreed. It has been split into 3 paragraphs.

Editor, Lines 661-662: here a citation is needed, and a specification of what is expected instead.

Authors: The text has been updated

Editor, Line 670: in

Authors: This has been corrected.

Editor, Lines 671-672: Is there no previous work that has looked a bit into this effect within the current context? I remember that Leonardo Pichel may have done some experiments with tilted basement and sedimentation loading (in salt-bearing systems?). If so, it should be cited.

In general, the stabilizing effects (more localized faulting) of a thicker salt overburden is in line with previous (modelling) works, and a short comment + some citations on this would be good to include here.

Authors: We have added citations for previous works that discuss this topic.

Editor, Lines 676-677: consider “of a salt-bearing system of which the overburden has been detached”

Authors: The text has been modified.

Editor, Line 676-677: not only rifted margins, but also for instance the Jura Mountains —> see for instance the work by Marc Schori (2019) in tectonophysics and in general the work done by the team of Jon Mosar in Fribourg (Switzerland). The transport of the overburden over many kilometers is of crucial importance for the interpretation of the system.

Authors: Additional text has been added to the end of the paragraph to make this point.

Editor, Line 682: as commented by reviewer 2, this should be “transfer” instead of “transference”, please check throughout the text. —> transference seems to be a term that is used to describe the transfer of knowledge or behaviour to other people

Authors: Transfer is typically the verb form of the word (while also used as the noun form) while transference is a noun form of the word as is ok. However, since only transfer is used in the rest of the text, the term has been exchanged here as well.

Editor, Line 716: these can be deleted I'd say?

Authors: The text has been updated.

Editor, Line 729: it seems that in the new interpretation, the top basement has a different geometry from the Alves et al. (2002) interpretation. Why is this? Is the basement not clearly defined on the seismic line to allow for this difference?

Authors: Yes. This has been explained in the text. But the text has been modified to highlight this.

Editor, Line 730: note the typo in the figure header (et a., 2002)

Authors: This has been corrected.

Editor, Line 743: basins?

Authors: No. But the text has been modified to 'syn-rift basin as a salt-detached ramp syncline basin' to prevent further confusion.

Editor, Line 759: delete?

Authors: It is not necessary to delete the 'the'

Editor, Line 775: please indicate the location of the basin on the map in Fig. 16 (and in the sections as well) —> is it all the post-rift? (yellow and pinkish colours?)

Authors: Thank you for catching this – the Cotiella basin is the large expanse of dark green on the western edge of the map. A label has been added to the map and clarified in the section.

Editor, Lines 786-789: that is, you propose that in the original situation, the basins were situated below the Las Aras and San Juan Basin, but that now all has been collectively transported some 10's of kilometers to the south? I think this needs to be specified a bit clearer as the current text seems to imply the original basins are below the current position of the LA and SJ basins.

Authors: We mean the supra-salt cover system comprised of the pre-kinematic-post-rift successions and syn-rift basins have been detached and translated to the south, separately from the basement rift system. The basement rift system is incorporated into the Axial Zone. The text has been updated to clarify this.

Editor, Line 791: that is, the transfer zone (or accommodation zone) between the thrust system? The original transfer zone should be situated far to the north?

Authors: No the pre-existing extensional transfer zone is positioned to the NW of the Las Aras basin between it and the San Juan basin. The text has been updated to clarify this.

Editor, Line 793: where is this basin? please indicate

Authors: The syn-contractual succession has been better defined in Figure 16 and the text has also been updated.

Editor, Line 793: can this be quantified? please add some citation as well

Authors: Instead of providing sedimentation rates, we have better described the differences in final syn-contractual sediment distribution to illustrate our point. The thrusts in the South-Central Pyrenees have been completely buried by the syn-contractual sedimentation, whereas in our Model 3, the sedimentation rate is not high enough to bury the thrust structures.

Editor, Line 796: it is not that clear what this means? sufficiently strong? thick? in what way does it support? do you mean "allow"?

Authors: We mean sufficiently thick and this has been added to the text.

Editor, Line 801: which thrust is that? please annotate in the figure. Otherwise, the text is rather difficult to follow —> I assume synorogenic is syn-contractional? I suggesting using a single term here.

Authors: Yes. Thank you for catching this. It should read syn-contractional and has been updated throughout the text. A label for the Las Aras thrust has been added to Figure 15.

Editor, Line 804: consider “have partially be the result of salt evacuation from a previously salt-inflated area”

NB: some words in the text should perhaps be hyphenated when they are used as adverbs (e.g. salt-inflated). I suggest checking the text for these instances

Authors: The text has been modified.

Editor, Line 807-809: I had some trouble following this. further to the north and south of what? —> of the footwall syncline?

This stems a bit from the fact that it is not that clear which structure in the figure is referred to (see comment on annotation).

In order to allow for easy comparison between Fig. 10a and Fig 16c, it may even be a good idea to include the model section in Fig. 16, directly below the seismic section interpretation

Authors: Yes, this is rather difficult to follow. The text has been modified more clearly state our point and compare the section to Model 3 results.

Editor, Line 810: this sentence is unclear, is this an interpretation made by others? if so, provide citations

Authors: The text has been updated to include a citation.

Editor, Line 810: remove “unlike out models”? this point is made in the next sentence, so this seems a bit repetitive

Authors: The text has been updated.

Editor, Line 812: how does it challenge this interpretation? please specify to hammer the message home: perhaps add something like: “instead, we propose that basement-involved shortening was coeval with the development of the cover thrust system”

NB: if this is a major point to be made, it should be mentioned in the introduction as well.

Authors: A sentence has been added to better state the message.

Editor, Line 817: please mention the transfer zone as well, as that is in the title, and thus a key part of the paper.

Authors: The text has been updated.

Editor, Line 843: why not mention the natural examples discussed in the text to make this point a bit more concrete?

Authors: The text has been updated.