Comments Handling topic editor

Yang Chu

Public justification (visible to the public if the article is accepted and published):

One previous reviewer has provided a positive comment on this revised manuscript. To fully evaluate it, I also read this revised version in detail. I agree that the authors have made a lot of effort to improve their work, and the text has been changed by following the comments. However, I still feel this manuscript probably needs more revision, not only on the structure and language, but also on the discussion which could largely highlight the importance of these analogue experiments. So, I think this manuscript should be returned to authors for further revision, mainly to make the manuscript more clear and straightforward to most readers.

Major comments:

1. In fact, the new title is more confusing. This ms deals with the fault growth under simple shear, when upper crust has lateral heterogeneity in strength. I do not think the cause is strike-slip faulting but is the stress field (simple shear). And the effect is internal deformation pattern in different vertical domains, not vertical domains themselves.

We have now changed the title into: "Influence of lateral heterogeneities on strike-slip faults behavior: Insights from analogue models".

2. Vertical domain is ambiguous, seemingly strength variation in vertical direction. The experiments focus on the modelling deformation within a laterally different upper crust. It worths reconsidering the title, of course, for better demonstrating the idea of the ms.

We appreciate the editor's suggestion for pointing out one question that has not been fully explained. We have now tried to be clearer throughout the manuscript and mention specifically that we focus on mechanical strength contrasts across lateral heterogeneities.

3. Brittle often refers to deformation. We do not use brittle to describe materials, because in different temperature or strain rates, same material can deform in either brittle or ductile ways.

In our experimental set-up and at the conditions in the lab, the quartz sand and microbeads deform in a brittle fashion.

4. The experiments are meaningful, but, as already suggested by reviewers, the text mostly stays in description of the results, even in the discussion, while interpretation for new understanding of these result still lacks. I do not find what I want when I finish reading it, at least some more geological implications. Mostly the explanation I can find is Mohr-Coulomb failure criterion, the improvement on current knowledge is not clear. This may reflect the unqualified role of introduction to summarize what we have known and what we want to know.

We appreciate the editor's suggestion. Following the general comments, we have partly rewritten the abstract, the introduction and the discussion, so that it is hopefully clearer what type of experiments we have done, and what is different with respect to previous studies.

Previous studies have investigated the influence of horizontal mechanical layering (for example horizontal sedimentary layers in the upper crust with different mechanical properties) on strike-slip faulting. In this manuscript, we present analogue model experiments to investigate how a lateral heterogeneous upper crust with vertical boundaries influences strike-slip faulting. To our knowledge the latter type of experiments have not been done, so we consider that the results are meaningful and could have geological implications.

We state those implications in the discussion, and summarize them in the conclusion, e.g. that the *presence* of domains with vertical boundaries and contrasting mechanical strengths has an influence on the strike-slip fault pattern (i.e. fault propagation, interaction, linkage – e.g. when comparing results in a homogeneous upper crust with results in a lateral heterogeneous upper crust), but that also the *orientation* of these domains with vertical boundaries and contrasting mechanical strengths has an influence.

We think that our results are useful for improving geological interpretations of strike-slip fault zones that are believed to have affected steeply dipping tectonic or lithologic units with lateral mechanical contrasts. As is generally the case with analogue model experiments, it is difficult to “perfectly” fit or link analogue model results with natural examples as our models are simplified and nature tends to be more complicated. In addition, we do not always have a good control on the 3D geometry of structures in nature, e.g. how do geological or tectonic boundaries that are (sub)vertical at the surface extrapolate to depth, and furthermore it is not always easy to reconstruct the direction of simple shear in nature. Nevertheless, our results can be used to generate ideas about tectonic scenarios and the presence or absence of potential vertical domain boundaries that might have influenced regional strike-slip fault patterns.

5. When comparing all the analogue models, I would like to see it presented in a more direct style. Figure 8 puts all final deformation conditions except the A1 and A2. I think the first two models should also been integrated in this figure. For better readability, I suggest moving all words to a table that can better compare similarities and differences.

We appreciate the editor's suggestion, but we do not fully agree. We believe it is more appropriate to discuss the models with a homogeneous upper crust, separately from the models with a laterally heterogenous upper crust. This way, we can focus first on the differences between homogeneous upper crustal models, i.e. between the quartz sand upper crustal model and the microbeads upper crustal model. Also, in our opinion, Figure 8 would get "too crowded" if we integrate models A1 and A2. We also believe it is more visual and easier for the reader to have the main summary points below each panel, instead of separately in a table.

6. In discussion, I prefer to use weak or strong crust instead of quartz sand or microbeads. Otherwise, it is too complicated to read the discussion, especially when I need to switch my mind between experiment materials and crustal rocks. This will be helpful for understanding the geological implications of the models.

We have now adhered to using the terms "strong crust" or "weak crust" throughout the discussion. However, in one paragraph of the first section of the discussion, we believe it is important to mention the specific material used, rather than making a generalization.

7. Both in the abstract and the final section of discussion, I am baffled with the comparison between modelling and field evidence. Why is this region chosen? Which model does the NW Iberian fault system belong to? If one model can be exemplified, what about the others? Can we have more tectonic implications on these analog modeling?

We now mention that the strike-slip fault zones in the NW Iberian Peninsula form the inspiration for our analogue modelling. And we highlight regions from within this huge fault system, that may show similarities with our models.

8. There are a lot of repetition in the text. The set-up of models is introduced in the section 2, but also repeated in each part in section 3, before describing the results. The discussion also replicate the results in each models, which make the text look redundant. The ms can be reduced at least to 450 lines.

We have now tried to avoid repetition, thus reducing the length of the manuscript. However, we were not able to reduce to 450 lines; we hope this is not a major issue.

Specific comments:

Line 17: Contrasting? Different.

We have rephrased the sentence.

Line 26: rotate around

We have changed the word

Line 28: Delete “width of the”. Which is the first case? Be specific.

We appreciate the editor's comment and we agree. Here we refer to the length of the domain and not the width. It was a mistake and now it has been specified in the text.

Line 29: Compartmentalized to segmented.

We appreciate the comment and we have modified that part of the abstract. We have changed to ”segmented”. We have clarified that there are cases in which the same fault is segmented as a consequence of the central domain, such as the faults in experiment B2; or new faults are formed that we cannot relate to each other on either side of the central domain (model C1).

Line 30: Delete brittle

We appreciate the comment and we have rephrased the sentence. We have removed brittle and rewritten those lines according to the previous comment. We have decided to put rheology because we want to refer to the properties of the central domain (brittle or strong).

Line 39: Give details on the style and factors. Rephrase: Structural styles and factors control the geometry of strike-slip faults.

We have fully rewritten the introduction sections following the major comments from above.

Line 48-50: Change the order of this sentence. Science first, and then economic use.

We have rephrased the paragraph.

Line 54: I need details on summarizing literatures. How does mechanical strength control fault activity and evolution? Is there any modelling work on steep or gentle boundaries? Without these information, the incentive of choosing steep boundary between different units remains unclear to me.

We give references related to studies investigating the influence of vertical changes in upper crustal strength (horizontal layers with different strength) on strike-slip faulting, and mention that no modelling studies have yet investigated the influence of lateral

heterogeneous crust with steep boundaries. This motivated us to do the experimental models presented in this paper.

Line 61: delete across.

The introduction has been reshuffled and rewritten, and we hope it is now clearer.

Line 64-66: Rephrase this sentence. Not clear to me.

We have rephrased the sentence.

Line 66: Delete crustal.

We have deleted crustal.

Line 67: but also occur->or

We modified the sentence

Line 71: delete such

We have deleted such.

Line 74: This sentence seems incomplete! Why do you compare the model with real example? For what reason?

We now mention that the strike-slip fault system in the NW part of the Iberian Peninsula formed the inspiration for our models.

Line 79: Past->above

We have changed the word

Line 80: I am not an expert, so I wonder why you choose 60 bars at the base? Do you use them to represent mantle rocks? Or just part of the apparatus?

The introduction of 60 plexiglass bars, is due to the dimensions of the model, which is 30 cm wide and could only fit 60 plexiglass bars.

Line 107: with only quartz sand or microbeads

We have changed the phrase

Line 108: in->of

We have changed the word

Line 109: Subsequent->other

We have changed the word

Line 110: Delete c

We have changed the word

Line 111: Delete brittle

We have deleted brittle

Line 112: Delete which changed from one series to the next.

We have deleted that part of the sentence.

Line 113-119: This part is less informative.

We appreciate the editor's comment, but we do not agree. The description of how the model was constructed is something that we put briefly in the first review and, after the first feedback, the reviewers indicated that this explanation should be extended because it could affect the results of the model. We have therefore decided to leave this explanation

Line 125: Used? Not finished? Besides, explain more in the figure captions. Figure caption can help understand the figure without texts.

We appreciate the editor's comment and we agree. We have expanded the explanation of the figure 2.

Line 159: MPA->MPa

We have corrected the word

Line 202: Physical world coordinates?

We appreciate the editor's comment, as it highlights aspects that were not clearly explained. The term 'physical world coordinates' refers to the calibration of the cameras, which is done once the model is complete. This allows us to obtain reference coordinates that are later used by the software to analyse the movement of the model. We have removed the word 'world,' as we believe it was causing confusion.

Line 205: Freckle pattern? Is this special term in analog modelling?

We appreciate the editor's comment and we agree that it could be confusing. We have changed the terminology by specifying that we are referring to sand grains.

Line 206: Small interrogation window? What is this? Do you mean grid?

In our manuscript, we define an interrogation window as a specific area of the image where cross-correlation analysis is conducted to measure displacements. These interrogation windows are indeed smaller segments of the overall grid used for analysis, allowing for a more localized and detailed examination of displacement fields within our analogue models.

The use of smaller interrogation windows is crucial for enhancing the spatial resolution of our displacement measurements. By analyzing smaller areas, we can capture finer details of the material flow and deformation patterns, which are essential for accurately interpreting tectonic processes. This approach is particularly important when tracking sub-pixel displacements, as fitting a Gaussian curve can restore accuracy in cases where the discrete correlation peak does not adequately represent the displacement (as discussed in the text).

Additionally, the DaVis StrainMaster module computes 3D displacement fields by employing a multi-pass algorithm. This method starts with a Fast Fourier Transform (FFT) on coarse interrogation windows, followed by successive applications of direct cross-correlation (DC) algorithms on smaller interrogation windows to refine the results. This stepwise refinement allows for a detailed assessment of the incremental displacement fields, which are calculated on a space-fixed Eulerian grid (i.e., an undeformed reference frame).

Line 207-210: This sentence is difficult for me.

This explanation was requested by previous reviewers who asked for a more detailed description of this part of the methodology. In this paragraph, we discuss the pixel size analyzed in the experimental images.

Particle Image Velocimetry (PIV), also known as Digital Image Correlation (DIC) in solid mechanics, utilizes random speckle patterns of solid particles on the model surface to track local patches (interrogation windows) of the image. This technique records continuous displacement fields on subsequent images, allowing for the quantitative capture of the entire displacement field, from which other quantities (e.g., strains) can be derived.

Line 212: Discarded vectors? Please demonstrate them in one of your figures.

We appreciate the editor's question regarding the discarded vectors in our analysis. Discarded vectors refer to those displacement measurements identified as outliers during the processing of the displacement data. This outlier detection is an essential step in ensuring the accuracy and reliability of our results.

The process of identifying and discarding these outliers occurs during the post-processing of the image data, specifically when analyzing the correlation results obtained from the interrogation windows. While we recognize the importance of visualizing these discarded vectors, it is challenging to represent them directly in the figures that showcase the model's overall displacement fields, as the discarded vectors do not contribute to the final analysis.

In our manuscript, we employ a systematic approach to outlier detection, as described in the literature (Westerweel and Scarano, 2005). After obtaining the displacement vectors from the cross-correlation process, the LaVisionDavis program filters out those that do not fit well within the expected correlation thresholds. This filtering process ensures that only reliable and accurate displacement vectors are included in our final displacement field calculations.

Line 214: local measure? Not clear. Mark XY-plane and Z axis in any figure.

We have added a sentence explaining the coordinates in our models. The X-axis corresponds to the long side of the rectangle; and the Y-axis corresponds to the short side of the model. The Z would be associated to the vertical displacement.

Line 217: Delete local.

We have deleted it

Line 219-220: Delete due to convention.

We have deleted it

Line 232-234: Repeated.

We have deleted it

Line 246: Delete only.

We have deleted the word

Line 254: Figure 3. Give captions for each figure, from a to j.

We appreciate your suggestion; however, we respectfully disagree with the need for individual captions for each subfigure (a to j). In the Results section, we provide detailed descriptions of the events occurring in each model at the specified time points. Adding more extensive figure captions would lead to unnecessary repetition, as the information is already clearly articulated in the text.

Additionally, the figures include small annotations that further clarify the significant features of each model. We believe this approach effectively conveys the necessary information without being redundant.

Line 268: Delete slightly.

We have deleted the word

Line 272: Here comes another domain, outer domain. Explain it.

We have already explained in the final section of Analogue model setup (Section 2.1), that we distinguish 3 domains:

"In models with a brittle strength contrast, we can distinguish two outer domains, a western and an eastern one, and a central domain (Fig. 2b-d)."

Nevertheless, in order to avoid confusion, we put western and eastern domains.

Line 277: a slight sigmoidal shape

We have added the word

Line 291-293: Repeated description of set-ups.

We appreciate editor's suggestions as clarify that the initial paragraph for each sections may be to repeated. We have deleted it.

Line 302: about->around

We have changed the word

Line 303: Delete as seen

We have deleted the word

Line 304: diminished->stopped

We have changed the word

Line 305: new fault segments parallel to earlier antithetic faults formed in the western and eastern domains

We have rephrased the sentence

Line 307: Delete both

We have changed the word

Line 320-322: Repeated.

We have changed the paragraph

Line 325: Delete orientation.

We appreciate the editor's suggestion and we agree, it was a typing error and now has been corrected.

Line 326: Mark these oblique-slip reverse faults on fig. 6.

We appreciate the suggestion made by the editor. The inverse fault was marked by a green line in the figure, but we did not add its meaning in the figure caption, it was an error. We have now modified the figure caption to specify that the green line is an oblique-slip reverse fault.

Line 330: weak central domain

We have added the word

Line 332: Delete somewhat

We have deleted the word

Line 341: In figure6, green lines are thrusts, right?

Yes, this is a reverse oblique-slip reverse fault. As mentioned in the above comment, an explanation of the meaning of the green line was missing. This error has been fixed and in the figure caption it is said that the green line is an oblique-slip reverse fault.

Line 350-353: Repeated.

We sincerely appreciate the editor's suggestion. In response to the comment, we have removed the introductory section from the discussion.

Line 357: homogeneous upper crust model

We appreciate the editor's comment. We have changed the beginning of this section based on the suggestion made

Line 360: see major comment 6.

We have considered comment major 6 and we have revised and modified the terminology used. However, we have specified the types of materials we are referring to, as their mechanical properties are an important part of our discussion. The terms "weak" or "strong" cannot be generalized, since they discuss their properties and depend on factors such as grain size, shape and cohesion. Therefore, in this section it has not been possible to extrapolate to the term brittle or ductile crust.

In this context, we have also added two additional references that address the implications of material properties on strike-slip faults to support our discussion.

Line 364: equal->uniform

We have changed the word

Line 365: is needed to localize the strain along ...

We have changed the sentence

Line 367: Are all synthetic faults sinistral? Why is sinistral used here?

Yes, all synthetic faults are sinistral in our study. We have used the term "sinistral" to provide clarity in our discussion. Moving forward, we will refer to these faults simply as "synthetic" to streamline the terminology and avoid confusion.

Line 368: See major comment 6.

We have modified that part of the text according to major comment 6. The properties of each material (internal friction angle, cohesion, grain size, and shape) influence whether it can potentially be considered "brittle" or "strong." For this reason, we have specified the type of material discussed (microbeads or quartz sand) and its internal coefficient value to clarify that the orientation of the faults in our models is defined by the materials used.

Line 370-374: This sentence is too complicate.

We appreciate the editor's comment, as it helps identify aspects of the text that were unclear. We have revised the sentence and referenced the figure that graphically illustrates the orientation of the fault in relation to the direction of the main principal stress.

Line 376: taken up->accommodated.

We have changed this.

Line 401: is a function of the orientation and strength of the domains. Delete the rest of the sentence.

We have made the proposed change.

Line 404-407: Again, not necessary.

Ok, we have removed most of the introductory statements.

Line 416: and finally reaches the strike of c. N08E.

Changed into: “reaching a strike of N°08E at the end of the experiment”

Line 420: Series D? Not B?

We have fully rewritten the discussion section 4.2, and this particular phrase no longer appears

Line 425: Less favorably oriented with respect to … Why? Not clear.

We have rewritten the discussion section, and this sentence has been removed for clarity. The term "favorably oriented" refers to the position of the contacts of the central domain concerning the direction of maximum stress and the ease of forming antithetic faults rather than synthetic ones.

Line 427-430: Repeated description.

We have rewritten the discussion in an attempt to be concise and avoid repetitive descriptions.

Line 440-444: Because the central domain is strong, there is not through-going fault. Make this sentence concise.

We have changed the sentence

Line 446: Why?

This has been explained before (first paragraph of section 4.2), and we don't want to repeat it here. The "ideal orientations" for the central domain boundaries to be reactivated are when they strike N11°E for microbeads and N18°E for quartz sand.

Line 452-455: This is only description of modeling result.

We appreciate your suggestion; however, we respectfully disagree here we discuss/explain why the strong-weak-strong model D2 shows a different behaviour than weak-strong-weak model D1.

Line 456-462: I can find similar sentence before, and I do not see any new information or interpretation.

We agree, and have left out most of line 456-462, accept the last sentence, which we believe is relevant and has been placed in section 4.3.

Line 479-483: Finally, some implications, but not new at all! Continental blocks can rotate, so faults rotate, obviously!

We have thoroughly revised the discussion section, aiming to highlight the potential implications of the model results. Additionally, we have discussed that fault strikes can change when upper crustal domains with vertical boundaries have rock types with contrasting mechanical strengths on either side of the contacts.

Further implications have been added, such as the idea that the presence of a laterally heterogeneous upper crust with steep boundaries—when suitably oriented for activation by antithetic faults—can prevent synthetic strike-slip faults from crossing certain domains. These are important concepts to consider when studying natural strike-slip fault systems.

Moreover, the rotation of fault blocks in large-scale strike-slip systems implies that the present-day orientation of antithetic faults cannot be used to infer the paleostress field, as faults rotate and are no longer in their initial conjugate position.

We have tried to frame the “potential implications” in a way that allows readers to understand how the models generate ideas about the evolution of strike-slip fault systems in a laterally heterogeneous upper crust.

Section 4.3-4.4, I am afraid I totally agree with reviewer 2’s opinion. This discussion does not touch the real meaning of the modeling.

We appreciate the editor's comment and we have made revisions to both sections. We believe Section 4.3 is important as it provides a detailed explanation of how fault linkage occurs. Similarly, Section 4.4 is crucial, as it represents the inspiration for the models setup. While no single model corresponds exactly to the fault pattern of the natural example, certain aspects do align, leading us to suggest that the crust in that area is more heterogeneous and complex than represented in our models.