Solid Earth Discuss., author comment AC1
https://doi.org/10.5194/se-2021-135-AC1, 2022

Reply on RC1

Sepideh Pajang et al.

Author comment on "The topographic signature of temperature-controlled rheological transitions in an accretionary prism" by Sepideh Pajang et al., Solid Earth Discuss., https://doi.org/10.5194/se-2021-135-AC1, 2022

Dear first Reviewer (se-2021-135)

Dear first reviewer thanks for your accuracy on our manuscript. Your comments were really valuable and we have corrected the manuscript in regard to your remarks. The manuscript improved by implementing your comments. Again, thanks for your guidance, and taking the time to read our manuscript.

General comments:

1.1 Reviewer's comment: I found the spatial distribution of viscous and brittle deformation in the brittle-viscous transition zone very interesting. I think that the Authors could provide some more clarity for their interpretations of the observed relationships. Specifically, most models show low strain islands of sand to deform viscously at temperatures between 300°C and 180°C. These islands of viscous deformation are bounded by faults characterised by brittle deformation. Moreover, deformation in the décollement remains brittle while part of the overlying sequence deforms viscously at lower temperatures. I am wondering how the Authors interpret these rheological relationships.

Authors' reply: This is due to large variation in strain rate, as well as brittle softening, low strain island deforms but at rates that are much smaller than brittle faults which are weaker. None the less as brittle soft faults rotate and become less well oriented and as the temperature rises making the low strain island weaker, viscous deformation occurs in between brittle faults.

1.2 Reviewer's comment: Is viscous deformation of quartz-dominated lithologies expected and what could cause the onset of viscous deformation at temperatures between 300°C and 180°C? If all sandstone in the sandstone sequences has the same mechanical properties, what causes the concurrent viscous and brittle deformation at a specific depth and temperature?

Authors' reply: Brittle softening in eq. 10.

After equation 10 which we added :

Friction and cohesion drop “permits to former faults to remain brittle where undeformed rocks creep viscously. The decollement is exempt of softening both to facilitate the comparison with CTT and because it is considered originally frictionally weak.”

- **Reviewer’s comment:** In D2 deformation phase occurring in the brittle-viscous transition zone, back-thrusts are attributed to the change in the material behaviour from brittle to viscous with depth (e.g., lines 333-334). In Figure 9a, however, the backthrusts are shown to be rooted within or at the top of the brittle décollement. The Authors could consider providing some clarity and additional explanation regarding the processes or conditions that favour the formation of back-thrusts at this part of the wedge.

Authors’ reply: Conjugate thrusts (fore- and back-thrusts) initially form at the transition of the brittle and viscous behavior to compensate different slip rates.

The backthrust is favored due to the large topographic slope behind: it is easier to scrape off the material at the front rather than to uplift a large wedge with a high topographic slope.

This is added to the text: " As temperature increases with burial, material behaviour in between faults which deforms with lower strain rates changes from brittle to ductile decreasing the effective friction coefficient of the bulk. This in turns causes the steepening of the slope which favors the activation of brittle backthrusts, that scrap off the frontal wedge rather than forethrusts that would have to uplift a lot of material."

- **Reviewer’s comment:** I found the titles of subsections 3.2 and 3.3 not very informative. I do not have any good suggestions of how the titles could be improved, but the Authors could rethink these titles.

Authors’ reply: They are changed to: "3.2 Time evolution of reference model

3.3 sensitivity to shear heating, erosion and thickness of incoming sediments"

- **Reviewer’s comment:** I found the colour schemes used in the models hard to follow and interpret. Less so in the “current state figure” of each model, where the type of deformation (brittle versus viscous), strain rate, and topographic slope are presented. In the “finite strain figure”, I found it hard to discriminate between the colouring describing the amount of brittle strain and the colouring for lithology / sedimentation time. For example, it hard to determine whether there is any brittle strain accumulated in the deposited sediments (i.e. deposited after 0 Ma). I am not sure how easy would be to fix this issue. I leave it to the discretion of the Authors to decide whether they wish to address this issue.

Authors’ reply: The reviewer is right that the color palette for brittle strain would not show well in the sediments, but we actually did not plot the brittle strain in the sediments for this reason. One can see, from the strain rate that sediments do deform, and the brittle/localized deformation in the sediments is outlined by the deformation of their bedding.

As we already tested different color codes, the one used in the manuscript was the best, we did not change the figure but we added this precision in the post processing part.

- **Reviewer's comment:** The use of the term "strain" is not clear. The text refers to finite strain (e.g., lines 145, 147), the figure legends suggest that it is the brittle strain mapped on the models. Observing the models, however, brittle strain appears in domains where the wedge deforms purely viscously. Also, from a rheological perspective, it might be interesting to show the spatial distribution of stress magnitude in the evolving wedge.

Authors' reply: we indeed map the brittle strain only on the figure, total strain can be deduced from the geometry of the incoming sediments. It is normal to have brittle strain in the viscously deforming area, because brittle strain is acquired during D1, but the brittle shear zone can be further deformed viscously during D3 if viscous creep is weaker mechanism than brittle yielding.

It is added to the text " For each simulation, we show the finite brittle strain in the rocks and the strain rate of the current state. The total strain (brittle and viscous) can be deduced from the geometry of the incoming sediments (grey and black originally horizontal)."

- **Reviewer's comment:** I am wondering if the Authors have explored the relationship between the slope of the isotherms and the topographic slope in their models.

Authors' reply: We did not, but they are in general almost parallel to the topography due to diffusion (poisson problem with dirchlet bc at top and Neumann at bottom) with some wiggles which corresponds to thrust activity (advection flux) and variations of diffusivity in the sediments. Dirichlet at top force the flux to be normal to the surface.

Specific comments:

1.Reviewer's comment: Line 11, Please explain what aspect of the brittle-ductile transition results in increase of the topographic slope (e.g., depth?).

Authors' reply: "by decreasing internal friction" is added to the text.

- **Reviewer's comment: Line 13,** Please change to: "Our models, therefore, imply ….".

Authors' reply: Thanks for your comment, it is done.

- **Reviewer's comment: Lines 37-38,** "…, which stability field is controlled mainly by temperature" – Please rephrase this part of the sentence. Something seems to be missing.

Authors' reply: True, modified as "Clay minerals are phyllosilicate-hydrated and their stability field is mainly controlled by temperature"

- **Reviewer's comment: Line 49,** Change "complex" to "complexes".

Authors' reply: Thanks for your comment, **done.**

- **Reviewer's comment: Line 50,** Please change "rich" to "reach".

Authors' reply: Thanks for your comment, **done.**

- **Reviewer's comment: Lines 58-66,** It is hard to follow the content of this sentence, primarily because of the large number of citations. Also, the "While" in the beginning of the sentence does not fit to how the sentence evolves. It seems that something is missing. I suggest rewriting the sentence.

Authors' reply: True**,** 'While' is omitted and number of citations reduced by using "e.g.,"

- **Reviewer's comment: Line 68,** "…how the introduction temperature evolution…" – Please check the sentence. Something seems to be missing.

Authors' reply: "of" was missing, now added in the text.

- **Reviewer's comment: Line 73-74,**"We briefly discuss internal deformation the morphology of the wedge and its potential seismic behavior." – Please check the sentence. It may need some rewording.

Authors' reply: We have improved the sentence as " We briefly discuss the internal deformation and the morphology of the wedge and also its potential seismic behavior"

- **Reviewer's comment: Line 127-128,** It is not clear to me to what "respectively" refers in this sentence. Does it refer to the two different initial thicknesses of the model? If so, please make it clearer.

Authors' reply: Thanks for this point, It is clearer now: " for 4 and 7.5 km thickness"

- **Reviewer's comment: Line 144,** Do you mean on the right of the panels?

Authors' reply: Thanks for your comment, done**.**

- **Reviewer's comment: Line 145,** Please explain what you mean by "current state". Also, in the text you mention "finite strain" while in the figures you report "brittle strain". Are these considered the same, in your descriptions? Please explain.

Authors' reply: For each simulation, we show the finite brittle strain and the strain rate of the current state. The total strain (brittle and viscous) can be deduced from the geometry of the incoming sediments. More explanation is available in comment 5 (General comments).

- **Reviewer's comment: Line 183,** Change "trust" to "thrust".

Authors' reply: Thanks for your comment, it is done.

- **Reviewer's comment: Line 193,** "…which corresponds to the brittle-ductile transition." – The brittle-ductile transition is present in almost the half length of the model. Do the Authors mean that the topographic slope corresponds to the slope of the 300°C isotherm, taken to correspond to the brittle-ductile transition? If not, please explain as this outcome is important but not clearly presented.

Authors' reply: No, higher topographic slope corresponds to the brittle-ductile transition which is a range between 180 to 450 °C isotherms**.**

We expended the sentence because it is very important point of the paper and it was also unclear to reviewer 2. "A mature brittle-ductile wedge forms three distinct segments that can be distinguished based on topographic slope. The back segment, close to the backstop where the decollement is viscous display a rather low but non zero topographic slope. The third segment, at the toe where the wedge is purely brittle, displays a CTT predicted slope. In between, where both brittle and ductile deformation co-exist within the wedge while the decollement is still brittle, a central segment displays a distinctively larger topographic slope than predicted by CTT. We refer to that segment as the brittle-ductile transition segment of the wedge."

- **Reviewer's comment: Line 200,** Do the Authors mean faults, instead of shear bands and shear zones? Deformation seems to be entirely brittle after 1 Myr.

Authors' reply: In numerical models, faults are brittle shear bands because they are not discrete. We added brittle to make it clear.

- **Reviewer's comment: Line 213:** Please elaborate on how strain rate shows information about the thickness of the wedge.

Authors' reply: Strain rate indeed does not inform on the thickness of the wedge but the text mentions the thickness of the shear zone not the thickness of the wedge. So, we did not change anything.

- **Reviewer's comment: Lines 223-224,** I would agree that the brittle-ductile transition in the wedge seems to reach some sort of steady state configuration, but in my view, this takes place between 15 and 20 Myr.

Authors' reply: Thanks for your comment, done**.**

- **Reviewer's comment: Lines 226-229,** The text does not flow very well in these lines. Please consider rewriting. For example:

"This phase corresponds to crossing the zone…." - It is not clear to which zone refers, and what crosses the zone.

"…whether they were incorporated in the ramp or not…" - It is not clear what is meant by "they".

"…before being exhumed for large temperature" – again, it is not clear to me what the Authors try to say here.

Authors' reply: we changed to:

"This phase of deformation corresponds to the moment at which the incoming sediments are incorporated to the second segment of the wedge where the topographic slope is larger than CTT predictions."

- **Reviewer's comment: Line 241,** Maybe "run" instead of "ran"?

Authors' reply: Thanks for your comment, **done.**

- **Reviewer's comment: Line 248-252,** This sentence is long and quite complicate. Also, the last part of the sentence does not flow well. The Authors could consider simplifying the sentence.

Authors' reply: The section is modified with your point.

"Actually, exhumation is reached under two conditions in our models, with large erosion coefficients, i.e. M4 and M6, and in presence of shear heating. The peak metamorphic temperature of rocks exhumed at the back-stop is compatible with thermochronometry studies in stationary accretionary prism like Taiwan (Suppe et al., 1981; Willett and Brandon, 2002). Its samples are exhumed to the surface by rock uplift to compensate for the mass lost via erosion (Fuller et al., 2006) and they have experienced temperatures in excess of 300–365oC but below 440oC e.g., (Lo and Onstott, 1995; Fuller et al., 2006)."

- **Reviewer's comment: Line 255,** Please provide the number of kilometres along the models in Figure 5, where the out-of-sequence thrusts appear.

Authors' reply: The distance in km added to the text.

- **Reviewer's comment: Lines 263-265,** This sentence needs to be simplified or broken in two, in my view. It is a long, dense sentence, and it does not read smoothly.

Authors' reply: They are broken and smoothed as "In absence of heat production and large vertical advective terms, the temperature is more or less proportional to the depth and thermal gradient in the models. Therefore, in experiments with thick sequences (M5 and M6 in Figure 5 and M7 and M8 in Figure 4) or in models with larger imposed basal gradient (M9, 10, 11, 12 in Figure 6), the brittle-ductile transition is reached earlier**."**

- **Reviewer's comment: Line 302,** "…by reducing both the size of the critical taper…" – Do the Authors mean the size of the critical taper angle? If so, it would be useful to provide the values for models M14 and M13.

Moreover, there are significant differences between models M14 and M13, potentially even more striking from the two mentioned in the text. The Authors could expand on this aspect.

Authors' reply: No, we meant the size of the brittle wedge with a basal friction of 5 degrees.

A sentence added at the end of the paragraph "As described above, without shear heating, the flat plateau above the viscous decollement hardly develops."

- **Reviewer's comment: Line 317-318,** in Figure 8a, the length of the frontal flat segment decreases between 3.8 and 6.3 Myr. After 6.3 Myr, I do not see any significant change in its length. Especially at 15 Myr, the length of the Frontal flat segment seems to me larger compared to 10 Myr. In case I am wrong, it might be preferable if the Authors describe quantitatively the change of length over time.
- **Reviewer's comment: Line 328,** Change "Comparision" to "Comparison".

Authors' reply: Thanks for your comment, **it is done.**

- **Reviewer's comment: Line 332,** "…which corresponds to the start development of…" – Please consider rephrasing.

Authors' reply: The section is modified as "The D1 is therefore overprinted by the phase D2, which is the start of a low-grade metamorphic foliation as a result of penetrative horizontal shortening.**"**

- **Reviewer's comment: Line 335,** "…or thick incoming sedimentary,…" – Something seems to be missing here.

Authors' reply: Changed to "thick incoming sediments".

- **Reviewer's comment: Line 338,** "…by a very vertical back-thrust." – Change to "a vertical back-thrust" or "a steeply-dipping back-thrust".

Authors' reply: Thanks for your comment, done**.**

- **Reviewer's comment: Line 343,** Change to "Forearc basins".

Authors' reply: Thanks for your comment, done**.**

- **Reviewer's comment: Line 356,** Something has gone wrong in this line. Does not make sense.

Authors' reply: Thanks for your comment, done**.**

- **Reviewer's comment: Line 362,**"…it corresponds more or less to the 450°C isotherm" – I think a more accurate description would be that the splay fault roots at the location of the 450°C isotherm along the décollement. Or something similar.

Authors' reply: Thanks for your comment, done**.**

- **Reviewer's comment: Lines 365-366,** Is it possible to provide examples of the velocities recorded at the base of the spay fault, by seismic studies of active margins? It would be useful for comparison with the velocities you report here.

Authors' reply: For Sumatra, Chauhan et al, 2010 (Sumatra) >=6; Kopp et al., 2013 (Chile) >5; Kopp et al., 2002 (Java) > 5.5.

"with Vp >= 5" added to the text.

- **Reviewer's comment: Lines 369-370,** For comparison reasons, the Authors may wish to add a figure callout to one of their models where the forearc basin forms on top of the viscous shear domain.

Authors' reply: *"(Fig. 9a)*" added.

- **Reviewer's comment: Line 381-383,** Please be more specific what is meant by "This" in the beginning of each sentence.

Authors' reply: This refers to " internal deformation**",** is added in the text.

- **Reviewer's comment: Fig. 9a,** An explanation for the isotherm lines is missing from the legend.

Authors' reply: True, because we mentioned the temperature beside each isotherm.