Reviewer Comments

Reviewer #1

For author and editor

This paper evaluates the possible mechanisms for systematic variations in the slip rate of seismogenic faults. This paper also provides a concise summary of the strengthening and weakening mechanisms in shear zones and thoughtfully explores how these mechanisms may interact to potentially explain slip rate variability. I found this paper to be informative, interesting and thorough in its approach. The authors do an excellent job of exploring shear zone mechanisms at all scales and linking these processes to affects on strengthening and weakening.

I have a few minor suggestions in the attached comments on the manuscript. In particular, I thought that aspects of Figs. 1 and 2 could potentially be improved to better illustrate what the text describes as characteristic features of the BDT. I think that the most exciting part of the description of the BDT is the mutually overprinting brittle and ductile structures, yet these sorts of relationships are not the focus of Figs. 1 and 2.

Also, I think that the two supplementary tables are very useful and I suggest that they are included in the main text rather than in the supplement.

Other than that, my feedback is minor and I think this paper will make an excellent contribution to the literature.

Reviewer #2

For author and editor

Dear Authors, dear Editor,

This manuscript presents a review of weakening and strengthening mechanisms considered to be common in natural faults and shear zones and evaluates which possible feedback effects among different mechanisms could account for cyclical seismic-aseismic fault-slip behaviour. The paper is motivated by the observation that faults within a fault system typically display alternating fast- and slow periods that span multiple seismic cycles and assumes that the underlying mechanisms steering such alternating behaviour and fault strength variations must operate at the brittle-ductile transition.

The main conclusion is that hydration-dehydration cycles and fabric development vs active shear folding are the mechanisms with the greatest potential to influence the cyclicity of fault-slip behaviour, which leads the Authors to propose a generalized conceptual model to explain periodic strengthening and weakening of shear zones.

This is an exciting paper, with a clear rationale and a thorough discussion and evaluation of literature data and of published models. Untangling the complex feedbacks between weakening and strengthening mechanisms is an ambitious goal, and assumptions and simplifications are inevitable. Yet, the assumptions made in this paper are all reasonable and do not weaken the overall reasoning and the final generalized model, although some clarifications are needed. The paper bridges the gap between the structural analysis and paleoseismic studies of large-scale (i.e., regional scale, plate boundary scale) fault systems, the mesoscale analysis of fault- and shear zone structure, and the grain-scale analysis of deformation mechanisms and fluid-rock interaction processes. As such, it is an excellent example of how different branches of tectonics can integrate and contribute to design useful and holistic conceptual models to help answer first-order research questions.

The manuscript is well written, I read it with great interest, and I look forward to seeing it published. I have made some suggestions to try to shorten it a bit, and to improve two figures. I do not have any major conceptual or methodological issue to raise, and I have only minor comments that I encourage the Authors to consider, keyed to line number.

Line 26: a justification of why the mechanisms responsible for the strength variation must affect rocks at the brittle-ductile transition would be welcome. Perhaps referring to earthquake distribution with depth would be useful here (e.g., see for example figure 1 in Passelegue et al. GRL 2021). It is also unclear at which depth is the fault rupturing, in the overall cyclical behaviour that the Authors are describing. Are they looking at transient seismic behaviour in the ductile crust? Or only to earthquake nucleation in the upper, brittle crust? Or a combination of both?

Line 107: replace “having” with “have”.

Lines 114-116: it is unclear why annealing should gradually weaken a shear zone, please clarify this. Annealing will increase the grain size. A shear zone might subsequently weaken again (for example dure to fluid infiltration, or to brittle grain size reduction and transition to grain size sensitive creep), but annealing in itself does not lead to weakening.

Line 141: I’d replace “brittle faults and cataclasites” with “brittle fault rocks” (also gouges and breccias can presumably record both seismic and aseismic deformation).

Line 174: the six images are not mentioned in the main text. Also, I am not sure that these images show typical characteristics of the BDT, as stated in the caption. For example, (D) shows a mylonitic gneiss that is typically found in the ductile crust below the BDT. I understand that the goal of this paper is to highlight how wekaneing and strengthing mechanisms in shear zones can inclufinece the overall fault-slip bahviour of crustal-scale faults, but the use of figure 1 should be clearer, at present it just reports a nice selection of structures that presumably formed at a rather broad range of depths. What do you exactly want to show here, the variability of fault rocks, and therefore of the associated weakening and strengthening processes, operative in the ductile crust?

Line 182: I suggest to rephrase as “… rate, shear zones at the BDT deform by viscous crystal-plastic mechanisms…”.

Line 232: same comment as for figure 1. For example (A) and (E) show mylonites that presumably formed below the BDT. I do not dispute that they might have undergone cyclical strengthening and weakening mechanisms as those discussed in this paper, but alternatively they might just have experienced steady-state viscous creep in the middle crust for their entire lifetime. Why are all these fault rocks representative of the BDT?

Line 265: this reference to phyllosilicate-rich rocks is probably unnecessary here. Reaction weakening occurs also in the middle and lower crust, where the (weak) reaction products are not necessarily phyllosilicate-rich (e.g., Marti et al. 2018). At the same time, earthquake nucleation in the middle and lower crust does require high stresses due to the higher confinement. Again, it would be useful if the Authors could clarify the depth range, in their conceptual model, at which seismogenic rupture nucleates.

Line 288: why would the rocks be otherwise non-deforming? There are many examples of fluid overpressure leading to transient brittle displacement in otherwise creeping shear zones (e.g., Menegon and Fagereng, 2021; but also many other examples describing sigmoidal veins in semi-brittle shear zones).

Line 294: please use normal stress instead of normal pressure.

Line 297: the actual weakening mechanism of W5 is unclear. Eventually also this mechanism requires the presence of grain boundary fluids that can facilitate either creep (dissolution-precipitation creep, hydrolytic weakening) or transient brittle failure due to fluid overpressure. I wonder if a separate W5 mechanism is really necessary, or if the weakening effects of grain boundary fluid can be cumulative discusses in W1-W4, also in an effort to make the manuscript a bit more concise.

Line 301: what are the actual constraints to state that fluid overpressure fluctuates on a very short timescale? I would argue that it fluctuates depending on the rate of pore fluid pressure buildup, which depends on many factors, such as fluid production due to devolatilization reactions, infiltration of external fluids, and development of synkinematic porosity in deforming rocks, to name a few.

Line 311: I suggest to rephrase as “smaller grain sizes enable deformation at lower stress at a given strain rate”. Higher stress deformation is tricky here, because high(er) stress deformation could bring the system into the dislocation glide regime, where smaller grains, initially deforming by diffusion creep, become stronger. See for example Kumamoto et al. (2017).

Line 319: the transient high stress necessary to generate earthquakes and pseudotachylytes in the middle and lower crust can also be generated in-situ within shear zone network (Hawemann et al., 2019; Campbell et al., 2020).

Lines 328: if I may, I suggest to refer to Campbell & Menegon (2019) here, as they specifically discussed the long-term weakening effect of pseudotachylytes in the lower crust during periods of fast slip.

Line 370: recovery typically leads to dynamic recrystallization, so that the actual difference between W8 and W14 are unclear. I suggest to group them, as they are genetically linked, again in an effort to make the manuscript more concise. The description of recovery itself could also be more concise and refer specifically to the replacement of highly strained grains with strain-free grains via the process of dynamic recrystallization driven by the reduction of internal strain energy (dislocation density).

Line 429: I am a bit confused by the description of S1 and S2 here. I do understand and agree that generally dehydration leads to hardening, and wet rocks (in the sense of rocks with free aqueous fluid at the grain boundaries) are weaker than dry rocks. However, fluid expulsion may lead to dehydration embrittlement or to transient hydrofracturing, which was mentioned as a weakening mechanism (W4) because it enables displacement.

Line 452-455: this is questionable, if the fine-grained rocks have a high degree of phase mixing that inhibits grain growth due to second phase pinning. Indeed, the polymineralic, fine-grained composition of ultramylonites and recrystallised pseudotachylytes is typically considered as the reason for their long-term weakening. What you're writing here does apply to monomineralic ultramylonites though (e.g., quartzite- or calcite ultramylonites in the upper and middle crust).

Line 461: I would delete "more massive", as it might indicate that the rocks loose their planar fabric.

Line 467: do you mean an externally derived fluid in disequilibrium with the bulk rock? The fluid will certainly have a different composition to the bulk rock.

Line 476: this S6 process also occurs in the middle and lower crust (e.g., Rogowitz and Huet 2021; Michalchuk et al. 2023).

Line 516: this is questionable, because recent experiments have demonstrated that water has no effect on the strength of minerals deforming by dislocation glide (Strozewski et al. 2021; Ceccato et al. 2022). Water may weaken the otherwise hardening rock, but via different mechanisms.

Line 573: I would also add enhanced grain boundary mobility (as indeed the paper by Mancktelow and Pennacchioni describes).

Line 581: I understand what you mean here, and I fully agree. But net-dehydration might be taken as indicative of devolatilization reactions, while here you are referring to fluid loss/fluid consumption, for example due to precipitation of new, hydrous phases, or to the formation of veins. Please clarify.

Line 608: yes, this has been recently shown in thermomechanical models by Moulas et al. 2022.

Line 678: one fluid flow mechanism that is not considered here is reactive fluid flow, which has been invoked as a fundamental process that influences rock rheology in broad depth range (e.g., Zertani et al. 2022), and which can occur over timescales comparable to seismic cycles (Beinlich et al. 2020; Kaatz et al., 2023).

Line 746: it also enhances the precipitation of new, hydrous material that is not necessarily weak (e.g., amphibole: Michalchuk et al., 2023), which also lead to fluid loss.

Line 768: strictly speaking, what you are discussing here is applicable only (or mostly) to monomineralic rocks, where the expelled fluid is not reactive and where the grains only deform by dislocation creep and recrystallize. If the expelled fluid is reactive, other processes will occur, but the net result might be similar to what you envisage (a hardening of the shear zone), if the fluid is anyway consumed in hydration reactions. See for example the discussion in Yardley et al. (2014).

Line 866: see my previous comment about annealing.

Line 901: which values? The timescale of buckle folds formation? Please clarify.

Line 912: one thing that is unclear of the conceptual model is the process by which displacement is transferred to another fault. Does this require networking or branching or faults? Could you please briefly elaborate on this?

Line 916-919: where do these relationships between time, slip and fold size come from? Have the Authors made calculations based on flow laws? Please clarify.

Best wishes, please contact me if you have any question about my review.

Luca Menegon, Oslo 21.02.2024.

Dear editor and reviewers,

Thank you for the thoughtful reviews; your suggestions were very helpful, and we feel they have significantly strengthened the manuscript.

Please see below for responses to each point made. In short, the main changes we have implemented are:

- **Figures**: We have replaced most of the content in Figures 1 and 2. Figure 1 now illustrates a simple fault compared to a branched fault system comprising two mechanically complementary branches, with both sketch maps and plots of idealized displacement versus time. Figure 2 now shows several photographs and photomicrographs that specifically highlight aspects of the brittle-ductile transition, like mutually overprinting brittle- and ductile structures, variably planar- and folded fault rocks from a single fault, and abundant hydrothermal veins and cementation.
- **Tables**: We have added simplified versions of both tables to the main text (Tables 1 and 2), and kept the full, detailed versions as supplements (Tables S1 and S2).

In addition, we have made several minor changes (fixing spelling errors, improving grammar or word choice, and replacing "in-preparation" and "in-review" references with the more up-to-date versions). All changes are shown in light blue in the attached pdf file.

Thank you for taking the time to review our manuscript.

Kind regards,
Tarryn Cawood and James Dolan

Point-by-point response:

Editor:

- Tables: very simplified versions in the main paper, that help the reader keep track of all the processes discussed, and then retain the current versions as a supplement.
    - We have added simplified versions of both tables to the main text (Tables 1 and 2), and kept the full, detailed versions as supplements (Tables S1 and S2).

Reviewer A:

- aspects of Figs. 1 and 2 could potentially be improved to better illustrate what the text describes as characteristic features of the BDT. I think that the most exciting part of the description of the BDT is the mutually overprinting brittle and ductile structures, yet these sorts of relationships are not the focus of Figs. 1 and 2.
    - We have replaced most of the content in Figures 1 and 2. Figure 1 now illustrates a simple fault compared to a branched fault system comprising two mechanically complementary branches, with both sketch maps and plots of idealized displacement versus time. Figure 2 now shows several photographs and photomicrographs that specifically highlight aspects of the brittle-ductile transition, like mutually

overprinting brittle- and ductile structures, variably planar- and folded fault rocks, and abundant hydrothermal veins and cementation.

- Also, I think that the two supplementary tables are very useful and I suggest that they are included in the main text rather than in the supplement.
  - We have added simplified versions of both tables to the main text (Tables 1 and 2), and kept the full, detailed versions as supplements (Tables S1 and S2).
- See annotated PDF
  - Most suggested changes have been made.
  - We have, however, retained the use of the terms W1-W19 and S1-S11 for the weakening and strengthening mechanisms respectively. We feel that this makes it easier to correlate the description of a specific mechanism in the text with its entry in the tables and supplementary tables, and removes potential confusion between different mechanisms with similar names.

Reviewer B:

- Line 26: a justification of why the mechanisms responsible for the strength variation must affect rocks at the brittle-ductile transition would be welcome. Perhaps referring to earthquake distribution with depth would be useful here (e.g., see for example figure 1 in Passelegue et al. GRL 2021).
  - The mechanisms responsible for strength variation must affect the strongest part of the fault, because this is where deformation will be slowest, making it the rate-limiting part of the fault that thus controls the overall slip rate of the fault. We have added a short phrase to the Abstract noting this, as well as a more detailed explanation in the Introduction (where we list the four criteria).
- It is also unclear at which depth is the fault rupturing, in the overall cyclical behaviour that the Authors are describing. Are they looking at transient seismic behaviour in the ductile crust? Or only to earthquake nucleation in the upper, brittle crust? Or a combination of both?
  - We are referring to earthquake nucleation in the upper, brittle crust, as this is where most earthquakes nucleate (with larger ruptures then extending downwards into the BDT, and triggering temporary embrittlement) – however, similar strengthening- and weakening processes will likely be at play at any depth in the crust that sees alternating brittle- and ductile deformation (such as in the hot, deep portions of dry, strong crust, e.g., Hawemann et al., 2018). We have modified parts of Section 2 to clarify this.
- Line 107: replace "having" with "have".
  - done
- Lines 114-116: it is unclear why annealing should gradually weaken a shear zone, please clarify this. Annealing will increase the grain size. A shear zone might subsequently weaken again (for example dure to fluid infiltration, or to brittle grain size reduction and transition to grain size sensitive creep), but annealing in itself does not lead to weakening.

    - The authors of the cited study used the term “anneal” to mean that the grains undergo recovery and the removal of intracrystalline dislocation tangles. We have modified this sentence to clarify this.
- Line 141: I’d replace “brittle faults and cataclasites” with “brittle fault rocks” (also gouges and breccias can presumably record both seismic and aseismic deformation).
    - done
- Line 174: the six images are not mentioned in the main text. Also, I am not sure that these images show typical characteristics of the BDT, as stated in the caption. For example, (D) shows a mylonitic gneiss that is typically found in the ductile crust below the BDT. I understand that the goal of this paper is to highlight how wekaneing and strengthing mechanisms in shear zones can inclufinece the overall fault-slip bahviour of crustal-scale faults, but the use of figure 1 should be clearer, at present it just reports a nice selection of structures that presumably formed at a rather broad range of depths. What do you exactly want to show here, the variability of fault rocks, and therefore of the associated weakening and strengthening processes, operative in the ductile crust?
    - We have replaced most of the content in Figures 1 and 2. Figure 1 now illustrates a simple fault compared to a branched fault system comprising two mechanically complementary branches. Figure 2 now shows several photographs and photomicrographs that specifically highlight aspects of the brittle-ductile transition, like mutually overprinting brittle- and ductile structures, variably planar- and folded fault rocks, and abundant hydrothermal veins and cementation.
- Line 182: I suggest to rephrase as “… rate, shear zones at the BDT deform by viscous crystal-plastic mechanisms…”.
    - done
- Line 232: same comment as for figure 1. For example (A) and (E) show mylonites that presumably formed below the BDT. I do not dispute that they might have undergone cyclical strengthening and weakening mechanisms as those discussed in this paper, but alternatively they might just have experienced steady-state viscous creep in the middle crust for their entire lifetime. Why are all these fault rocks representative of the BDT?
    - We have replaced most of the content in Figures 1 and 2.
- Line 265: this reference to phyllosilicate-rich rocks is probably unnecessary here. Reaction weakening occurs also in the middle and lower crust, where the (weak) reaction products are not necessarily phyllosilicate-rich (e.g., Marti et al. 2018). At the same time, earthquake nucleation in the middle and lower crust does require high stresses due to the higher confinement. Again, it would be useful if the Authors could clarify the depth range, in their conceptual model, at which seismogenic rupture nucleates.
    - We have removed the reference to phyllosilicate-rich rocks. Also, thank you for pointing us toward the Marti et al. paper – although we haven’t added it to this manuscript, it’s an interesting study.
- Line 288: why would the rocks be otherwise non-deforming? There are many examples of fluid overpressure leading to transient brittle displacement in otherwise creeping shear zones (e.g., Menegon and Fagereng, 2021; but also many other examples describing sigmoidal veins in semi-brittle shear zones).

  - Thank you for making this very valid point. We have modified the sentence.
- Line 294: please use normal stress instead of normal pressure.
  - done
- Line 297: the actual weakening mechanism of W5 is unclear. Eventually also this mechanism requires the presence of grain boundary fluids that can facilitate either creep (dissolution-precipitation creep, hydrolytic weakening) or transient brittle failure due to fluid overpressure. I wonder if a separate W5 mechanism is really necessary, or if the weakening effects of grain boundary fluid can be cumulative discusses in W1-W4, also in an effort to make the manuscript a bit more concise.
  - In the case of W5, the fluid is not necessarily chemically reactive or involved in any dissolution or diffusion (as in W2-4); instead, it could be a completely inert fluid, that nonetheless weakens the rock because it is (much) more easily deformed than the surrounding mineral grains. It is effectively behaving like very weak inclusions. We think this is stated fairly clearly in the manuscript ("This fluid-filled porosity acts as inclusions of a weak phase…"), and that it is distinct enough from W1-W4 to retain.
- Line 301: what are the actual constraints to state that fluid overpressure fluctuates on a very short timescale? I would argue that it fluctuates depending on the rate of pore fluid pressure buildup, which depends on many factors, such as fluid production due to devolatilization reactions, infiltration of external fluids, and development of synkinematic porosity in deforming rocks, to name a few.
  - Earlier in this section we describe how fluid overpressure is inherently cyclic and tied to the seismic cycle, because the resulting hydrofracturing results in a sudden decrease in fluid pressure, removing the mechanism of weakening. We have moved this sentence to the area of Line 301, to better remind readers of it.
- Line 311: I suggest to rephrase as "smaller grain sizes enable deformation at lower stress at a given strain rate". Higher stress deformation is tricky here, because high(er) stress deformation could bring the system into the dislocation glide regime, where smaller grains, initially deforming by diffusion creep, become stronger. See for example Kumamoto et al. (2017).
  - Thank you, this is a good point. We have made the suggested change.
- Line 319: the transient high stress necessary to generate earthquakes and pseudotachylytes in the middle and lower crust can also be generated in-situ within shear zone network (Hawemann et al., 2019; Campbell et al., 2020).
  - Very interesting! We have added a note about this.
- Lines 328: if I may, I suggest to refer to Campbell & Menegon (2019) here, as they specifically discussed the long-term weakening effect of pseudotachylytes in the lower crust during periods of fast slip.
  - This is a great reference, thank you. We have added it.
- Line 370: recovery typically leads to dynamic recrystallization, so that the actual difference between W8 and W14 are unclear. I suggest to group them, as they are genetically linked, again in an effort to make the manuscript more concise. The description of recovery itself could also be more concise and refer specifically to the replacement of highly strained

grains with strain-free grains via the process of dynamic recrystallization driven by the reduction of internal strain energy (dislocation density).

  - We have modified the text and tables to clarify the distinction: W8 refers specifically to *grainsize decrease* as a result of dynamic recrystallization; W14 refers to *the creation of weaker, less-strained grains* as a result of recovery and dynamic recrystallization.
  - We have also modified the description of recovery by dynamic recrystalliation.

- Line 429: I am a bit confused by the description of S1 and S2 here. I do understand and agree that generally dehydration leads to hardening, and wet rocks (in the sense of rocks with free aqueous fluid at the grain boundaries) are weaker than dry rocks. However, fluid expulsion may lead to dehydration embrittlement or to transient hydrofracturing, which was mentioned as a weakening mechanism (W4) because it enables displacement.
  - Yes, fluid expulsion may lead to both strengthening and weakening, because of the various effects fluids can have at different time- and spatial scales. In the case of transient hydrofracturing, it is only possible if there is fluid in the system, which is why it is grouped with other "fluid-present" (hydration) weakening mechanisms. In contrast, the strengthening mechanisms we discuss near Line 429 become active when there is less or no fluid in the system, and thus are grouped with "fluid-absent" (dehydration) mechanisms.
- Line 452-455: this is questionable, if the fine-grained rocks have a high degree of phase mixing that inhibits grain growth due to second phase pinning. Indeed, the polymineralic, fine-grained composition of ultramylonites and recrystallised pseudotachylytes is typically considered as the reason for their long-term weakening. What you're writing here does apply to monomineralic ultramylonites though (e.g., quartzite- or calcite ultramylonites in the upper and middle crust).
  - We have modified the text to note this.
- Line 461: I would delete "more massive", as it might indicate that the rocks loose their planar fabric.
  - This is precisely what we hope to convey (new hydrothermal minerals may completely replace pre-existing, foliated minerals, destroying the planar fabric; this is described later in the text). We have therefore retained the term.
- Line 467: do you mean an externally derived fluid in disequilibrium with the bulk rock? The fluid will certainly have a different composition to the bulk rock.
  - Thank you, yes! We have fixed this.
- Line 476: this S6 process also occurs in the middle and lower crust (e.g., Rogowitz and Huet 2021; Michalchuk et al. 2023).
  - Thank you for pointing these out.
- Line 516: this is questionable, because recent experiments have demonstrated that water has no effect on the strength of minerals deforming by dislocation glide (Strozewski et al. 2021; Ceccato et al. 2022). Water may weaken the otherwise hardening rock, but via different mechanisms.
  - We have removed this line, because in a later section (5.1) we discuss in detail how water may play a role in weakening strengthened grains.

- Line 573: I would also add enhanced grain boundary mobility (as indeed the paper by Mancktelow and Pennacchioni describes).
    - Added.
- Line 581: I understand what you mean here, and I fully agree. But net-dehydration might be taken as indicative of devolatilization reactions, while here you are referring to fluid loss/fluid consumption, for example due to precipitation of new, hydrous phases, or to the formation of veins. Please clarify.
    - Done.
- Line 608: yes, this has been recently shown in thermomechanical models by Moulas et al. 2022.
    - Thank you for bringing this paper to our attention.
- Line 678: one fluid flow mechanism that is not considered here is reactive fluid flow, which has been invoked as a fundamental process that influences rock rheology in broad depth range (e.g., Zertani et al. 2022), and which can occur over timescales comparable to seismic cycles (Beinlich et al. 2020; Kaatz et al., 2023).
    - We have added a note on transient reaction-induced permeability created by reactive fluid flow, and have included the estimated rates in Fig. 3.
- Line 746: it also enhances the precipitation of new, hydrous material that is not necessarily weak (e.g., amphibole: Michalchuk et al., 2023), which also lead to fluid loss.
    - True. Reaction hardening is already mentioned in Section 4.3, and we have added a note about the consumption of fluid by hydration reactions elsewhere.
- Line 768: strictly speaking, what you are discussing here is applicable only (or mostly) to monomineralic rocks, where the expelled fluid is not reactive and where the grains only deform by dislocation creep and recrystallize. If the expelled fluid is reactive, other processes will occur, but the net result might be similar to what you envisage (a hardening of the shear zone), if the fluid is anyway consumed in hydration reactions. See for example the discussion in Yardley et al. (2014).
    - We have added a note explaining this.
- Line 866: see my previous comment about annealing.
    - done
- Line 901: which values? The timescale of buckle folds formation? Please clarify.
    - We have modified this sentence to "These timescales of folding and strengthening are broadly consistent…"
- Line 912: one thing that is unclear of the conceptual model is the process by which displacement is transferred to another fault. Does this require networking or branching or faults? Could you please briefly elaborate on this?
    - When we talk about "mechanically complementary" faults, we mean faults that can accommodate the same overall plate motion. These may be broadly parallel faults, or faults that are actually branches or splays of the same fault system. We have attempted to illustrate this in the new Figure 1.
- Line 916-919: where do these relationships between time, slip and fold size come from? Have the Authors made calculations based on flow laws? Please clarify.

- We have modified the text to clarify this. The calculations are based on the amount of shear strain needed to rotate the axial plane of a fold from a high angle to the shear plane, into sub-parallelism with the shear plane.

Ian Honsberger (Geological Survey of Canada internal review):

- I think the Introduction is too long. Condensing it to the most critical elements would be beneficial. What areas could be condensed or removed?
  - It is difficult to condense it without losing important content – we have kept it as is.
- It is challenging to understand why the 4 criteria were chosen in the first place. The term reversible is a bit confusing in the context and may require some explanation.
  - We have modified the abstract and introduction to better explain why the four criteria were chosen, and why they must be active in the BDT.
- I think a Figure 1 that shows schematically the difference between a complex plate boundary fault system and a simple plate boundary fault system would be good.
  - This is a great idea, thank you – we have replaced Figure 1 with a schematic sketch as suggested.
- I think the section on fluids in the Discussion is a bit lengthy. Perhaps it can be condensed a bit.
  - It is difficult to condense it without losing important content – we have kept it as is.