Review Report

Ruh et al., Weakening effect of grain-size reduction in two-phase crustal and mantle lithospheric shear zones. TEKTONIKA, 2024.

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1st Round of Revisions

Decision Letter (20 Nov. 2023)

Dear J. Ruh and co-authors,

We have now received two reviews on your manuscript submitted to Tektonika. Reviewers and our associate editor agree on the quality and significance of your work. Some revision is however needed before we can accept it for publication.

You'll find below the evaluation letter by Dripta Dutta, associate editor, and the two reviews appended to this letter.

We hope you will be able to submit your revision before 2 January 2024. This is a non-strict deadline and we will not close the evaluation process at the due date. But we recommend not delaying the revision process. If needed, please keep us informed about your timetable.

When uploading your revision provide us with a full rebuttal addressing all reviewer's comments (see recommendations by associate editor) and also a second manuscript version with all changes clearly outlined.

Best regards

Robin Lacassin, Tektonika executive editor
Dripta Dutta, Tektonika associate editor

Associate Editor letter

Dear Dr. J. B. Ruh,

Your manuscript, "*Weakening effect of grain-size reduction in two-phase crustal and mantle lithospheric shear zones"* submitted for possible publication in Tektonika, has now been evaluated by two reviewers. Both reviewers agree on the high significance of this contribution to understanding strain localization in sheared crustal and mantle rocks. The comparison between the experimental results and natural observations is impressive, as are the high-quality figures and clear interpretation. However, the reviewers have raised some valid concerns, which must be addressed.

Reviewer #1 is mainly concerned with some of the experimental design choices and the lengths of Sections 4.1 and 4.2 compared to those of 4.3 and 4.4. We agree that under *'Discussions'*, the manuscript emphasizes comparing the experimental results with natural observations instead of focusing on the link between the results and the objectives laid out in the Introduction section. Reviewer #1 pointed out that the *'Abstract'* does not state the conclusions of the study clearly enough, and therefore, should be improved. The reviewer also recommends elaborating on the effects of the model limitations and including some additional models with different geometries and initial grain sizes. Reviewer #2 requests more details on the experimental design, such as a list of the mineral proportions used and whether or not they change over the course of deformation. A discussion on the role of biotite in localizing strain in the models is also recommended. Both reviewers suggest minor changes to the Title.

Based on the reviews, we conclude that the manuscript requires Moderate Revision. The detailed comments by the two reviewers and some additional comments by the AE are appended below this letter. Please use the Tektonika review form to address the concerns of Reviewer #1. You can prepare a traditional rebuttal to respond to the comments of Reviewer #2.

Please submit a revised manuscript that, insofar as possible, implements all reviewers' recommendations along with a copy of the manuscript with all the changes marked. You are requested to provide adequate justification(s) for disagreeing with and thus not incorporating any of the reviewers' recommendations. Tektonika values your contribution, and we look forward to receiving your revised manuscript by 02-Jan-2024. Please get in touch with us if you have any questions.

Best regards,
Dripta Dutta (Associate Editor)

<u>Additional comments by the AE</u>

1) Please incorporate the role of textural weakening in the case of the peridotitic rocks in the abstract.
2) Line 24 – I think 'weakly deformed' instead of 'undeformed' is more suitable for the host rocks surrounding the shear zones/bands.
3) Line 32 – It appears from the text that the coexistence of textural and grain size weakening has previously been reported from naturally deformed rocks. Please cite a few examples here.
4) Lines 78-80 – These lines are perhaps more suitable for Sec. 2. The advantages listed also require elaboration.
5) Figure 4 – Please consider commenting on
    a. what causes the curves to be squigglier at lower temperatures?
    b. why constant grain size values are achieved at lower strains for high-temperature deformation (at gamma ~5 for 750 deg C but ~10 for 350 deg C)
6) Line 304 – Please state the shear strain values separately for the three phases.
7) Line 328 – Please check if it should be 'as noted in' instead of 'as expected from'.
8) Figures 7 and 8 - What are the grey solid lines that connect the circles to the squares? Please also define the field-boundary lines in the caption.
9) Sec. 4.3 discusses textural as well as grain size weakening, but the title emphasizes the latter. Please consider modifying the title.
10) Fig. 10a – Please mark with arrows the directions of increasing grain size and stress values.

Comments by Reviewer 1 (Anonymous)

Section A: Overview of manuscript

A1) Overall evaluation, general comments & summary

A1.1) Reviewer's comments

A1.1.1) General evaluation and publication suggestion – Required:
Please use this space to describe, in your own words, the core subject of the submission and your overall assessment of its suitability for publication.

The authors present a selection of 36 2D numerical, visco-elasto-plastic, simple-shear models of a granitoid and peridotite hand sample at different temperatures and related pressures. They compare stress evolutions with and without grain size evolution to investigate the relative importance of textural and grain size weakening. They show that grain size weakening plays a secondary role (compared to shear banding of weak matrix) in granitoids and a primary role for peridotites between 700 and 1000 °C. Furthermore, they show differenes and similarities to 1D model results.

The manuscript has a high quality of English and is well written, albeit a bit lengthy and redundant in certain parts. The Figures are mostly of publication quality and all of them support the points that are being made well.

I think the manuscript provides valuable insight into the relative importance of shear banding and grain size reduction for typical crustal and mantle lithosphere compositions. Furthermore, it gives an idea of how much these mechanisms can weaken an intact rock once it starts deforming which is of interest to the geodynamic modelling community that needs to parameterize such effects. The comparison between 1D and 2D results is also useful for guiding future studies.

My main concern is the lack of discussion for some important design choices in the numerical model.
I) Temperature evolution through shear heating is an important mechanism contributing to strain localization and is neglected from the implementation without reasoning and discussion of its potential impact.
II) Applying the marker in cell approach and the grain size flow law on such a small scale brings up an important question. How appropriate is this approach when the size of a cell is much smaller than the grain size? This leads to a situation where there is a 1 cm large grain containing hundreds of markers, each of which may have a different grain size that can be smaller or larger than 1 cm. This issue is also not discussed.

In my opinion, there is also an imbalance in the discussion section where large parts deal with the comparison of the model results with field observations and piezometers which are not the objectives of the study according to title, abstract, introduction and conclusions. Shortening these sections would create space to discuss the design choices and robustness of the results. The comparison between 1D and 2D is very interesting in the context of the study but is mostly absent from conclusions and abstract.

Finally, there is also a lack of clarity in the methodology section regarding elasticity, brittle plasticity and grain size evolution.

I think if the above-mentioned issues are addressed, this work is suitable for publication.

A1.1.2) What does the submission need to be publishable? (select as needed; comment for all cases)

- ☐ No changes required
- ☐ Rewriting

- ☒ Reorganising
- ☐ More data/figures
- ☒ Condensing
- ☒ Reinterpretation
- ☐ Other

Comments:

Condensing: Parts of the manuscript feel lengthy and repetitive. It is not drastic, but I think the sections can benefit from some condensing. Examples:

- Line 70-72 and 76-78 are near identical.
- Instead of listing all of what can be seen in the Figures, it might be useful to make some summarizing statements. For example, lines 228 and 231 are more or less the same sentence about neighbouring subfigures.
- Lines 290 and 292 both mention Plagioclase forming rigid clasts in back-to-back sentences.
- Sections 4.1 and 4.2 are quite extensive without contributing much to the conclusions of the manuscript

Reinterpretation: Discussing the things mentioned in A1.1.1

Reorganising: Focussing the Discussion on the objectives

A1.1.3) Can the submission be improved by reducing/adding any of the following? (select as needed; comment for all cases)

- ☒ Text
- ☐ Table
- ☐ Figures
- ☐ Supplementary material

Comments:

See 1.1.2

A1.1.4) Please complete the following section if you recommend that the submission is NOT appropriate for publication (select as needed; comment if a box is selected)

- ☐ Quality is poor
- ☐ Research is not reproducible
- ☐ Other

Comments:

A1.2) Author(s) Responses:

A2) Summary of main merits and main points of improvement

A2.1) Reviewer’s comments

The main merits I have found are...

Putting a number on how much textural weakening can be expected in typical rocks in a small scale-high resolution experiment is useful for larger geodynamic models that cannot afford to resolve such small

features. This information can be reused as a parameterization of weakening and might be unobtainable from 1D models that are much more common. The comparison between 1D and 2D models is useful to judge whether 1D models are a good approximation or 2D models are necessary.
Quantifying the relative importance of textural weakening and grain size weakening for different rock types and conditions is also useful as it can guide other modelling studies on what mechanisms are important to cover and which ones may be negligible.

The main points of improvement I have found are...

The main improvement that can be done is discussing the design choices and their potential effects. Why is temperature evolution by shear heating neglected? What would be its effect? It uses more than 99% of viscous dissipation. Does this not have a large effect on temperature and rheology?
In the same vein, I think it is important to discuss the implications of having a resolution that is samller than the grain size. What does it mean when a single crystal contains hundreds of markers with potentially different grain sizes (Figure 3)? What does it mean when the grain size on markers is much larger than what the composition plot shows (Figure 5)? Are the flow laws even applicable in this case?
What effects would you expect the other simplifications mentioned in section 4.5 to have?

Clarify the interaction between plasticity and grain size evolution as well as elasticity and grain size evolution. More on that in section B3.

A few additional models (for the interesting temperature ranges) with different initial grain size and different initial geometry (can be as simple as rotating the setup by 90°) can demonstrate the robustness of the results. Without these variations it is difficult to say if the results given have quantitative or only qualitative meaning. I wonder how much of the grain size reduction effect in granitoids stems from the initial size being too large. Only a single quartz grain is on the scale of 2 cm. 5 or 10 mm seems more appropriate for the images in Figure 1.

Sections 4.1 and 4.2 are long, despite not contributing much to the objectives of the study. 4.4 is quite interesting and also adresses the objectives set in the introduction but is ignored in Conclusions and Abstract.

The readability and quality of the manuscript can be improved by condensing the information given in the text and reducing repetitive sentence structure and content. See 1.1.2.

A2.2) Author’s responses:

Section B: Detailed evaluation of manuscript

B1) Title and abstract

B1.1) Reviewer’s comments

*These statements are a **guide** to what good* Titles *and* Abstracts include*. Please select YES or NO to the statements below if you wish and detail in the free form box below your reasons for any box checked with NO, or to comment on any other matter.*

The *Title* describes the main topic of the manuscript **accurately** — no

The *Title* describes the main topic of the manuscript **succinctly** — yes

The *Title* includes **appropriate key terms** — yes

The *Abstract* includes a **clear aim and rationale** — yes

The *Abstract* supports the rationale with **sufficient background information** — yes

The *Abstract* includes a **well-balanced description of the methods** — yes

The *Abstract* describes the **main results sufficiently and adequately** — yes

The *Abstract* clearly describes the **importance/impact of the study** — yes

The *Abstract* clearly states the **conclusions of the study** — no

The *Abstract* is **clear** and **well structured** — yes

Comments:

The Title describes the main topic of the manuscript ***accurately: no***
I think textural weakening could be added to the title. Also "two-phase" could easily be confused with "two-phase-flow" and there are 3 phases in the granitoid model. I think "polyphase" as it is used in the abstract is better

The Abstract clearly states the conclusions of the study — no
The Abstract is good until until line 15 where it becomes quite vague. It talks about "revealing complexity not captured by 1D models" but to my understadning section 4.4 shows that 1D olivine is a good approximation for 2D peridotite and 1D quartz is not even compared to 2D granitoid. Instead of mentioning the term "quantitative constraints" without giving any, it could instead state them. For example the amount of maximum weakening provided by both mechanisms.

B1.2) Author's responses

B2) Introduction

B2.1) Reviewer's comments

These statements are a ***guide*** *to what good* Introductions *include. Please select YES or NO to the statements below if you wish and detail in the free form box below your reasons for any box checked with NO, or to comment on any other matter.*

The *Introduction* provides **sufficient background and context** for the study — yes

The *Introduction* describes the **aim/hypothesis/rationale** clearly, providing **sufficient context** — yes

The *objective/hypothesis/rationale* **flows logically from the background** information — yes

The *Introduction* describes the study's **objective and approach** (last paragraph) — yes

The *Introduction* contains **relevant, suitable citations** — yes

The *Introduction* is **organized effectively** — yes

Comments:

As somebody who was unfamiliar with the term "textural weakening", I was missing a real definition of it. Lines 28 and 31-32 do that to a degree but the message is not clear enough for one of the central topics of the study.

B2.2) Author's responses

B3) Data and methods

B3.1) Reviewer's comments

*These statements are a **guide** to what good* Method *sections include and good practices for* Dataset *accessibility. Please select YES or NO to the statements below if you wish and detail in the free form box below your reasons for any box checked with NO, or to comment on any other matter.*

The *Methods* are described **concisely and with enough detail** for reproducibility — no

Necessary information about **data sources/acquisition/processing** is included — yes

Data used are accessible via either supplementary files or links in the data availability statement — no

The *Dataset and/or Methods* are **organized effectively** — yes

Comments:

*The Methods are described **concisely and with enough detail** for reproducibility — no*
It is next to impossible to reproduce a numerical code from the method description of any paper. Still some things are more unclear than usual here:
Line 96: Shear modulus G is mentioned here but no value for it is ever provided.
Equations 2 and 3 use tau for deviatoric stress, but equations 4 and 8 use sigma when they should use deviatoric stress.
Line 98: Are you using the stress of the previous time step or the current one (with local iterations for the nonlinear dislocation creep)?
L. 99 & 107: the index "II" often refers to the square root of the 2^{nd} invariant. An equation could help clarify.
Line 107: Fluid pressure ratio is not given anywhere.
Line 108: The modification used in the references is not very complex. Why not just give the equation here?
Line 116-118: Can you clarify what this means? Does that mean that if 3% of all Plagioclase is yielding, that grain size evolution completely stops for all Plagioclase in the model? Or if 3% of the stress history of one marker is above the yield, that marker stops grain size reduction? And can it switch back on when under the yield stress? Is grain size reduction due to brittle plasticity neglected because there is no good formulation for it, not enough data, no consensus or to not overcomplicate the code?
Line 119: I assume stress and strain rate are tensors here. So what kind of product are you using? Dot product or tensor product?
Line 134: Activation volume is not given anywhere.
Line 137: Is grain size updated after the rheology is solved or updated during the iterations?

Not technically part of the methods but the sentence in line 427 is concerning to me. There should be no grain size reduction during elastic loading. If there is, is it a side effect of your elasticity implementation?

***Data used are accessible** via either supplementary files or links in the data availability statement — no*

The authors provide a link for the code but all options and parameters are from a different study. I don't know what tektonika requires here but an input script to reproduce at least one of the models would be nice.

B3.2) Author's responses

B4) Results

B4.1) Reviewer's comments

*These statements are a **guide** to what good* Result sections *include. Please select YES or NO to the statements below if you wish and detail in the free form box below your reasons for any box checked with NO, or to comment on any other matter.*

The *Results* findings are **supported by data** — yes

The *Results* findings are presented **clearly and succinctly** — no

The text in the *Result* section **cites tables and figures appropriately** — yes

The *Results* directly **relate to the study objectives** — yes

The *Results* present **data for all the approaches** described in the *Methods* section — yes

The *Results* **text belongs to the Results section**, not to *Introduction*, *Methods*, or *Discussion.* — yes

The *Results* section is **organised effectively** — yes

Comments:

The results are presented clear, but some shortening could help.

B4.2) Author's responses

B5) Discussion and conclusions

B5.1) Reviewer's comments

*These statements are a **guide** to what good* Discussions *and* Conclusions *include. Please select YES or NO to the statements below if you wish and detail in the free form box below your reasons for any box checked with NO, or to comment on any other matter.*

The *Discussion* is **focused on the objectives** of the study — no

The *Discussion* **addresses all major results** of this study, which are shown in *Results* — yes

The *Discussion* section makes **comparisons with other studies** that are relevant and informative — [YES] / [NO]

The *Discussion* section properly identifies all **speculative statements** — yes

The *Discussion* section presents the **implications of the study** persuasively — yes

The *Discussion* section **highlights novel contributions** appropriately — [YES] / [NO]

The *Discussion* section **addresses the limitations** of the study appropriately — no

The *Discussion* section is **organised effectively** — yes

The *Conclusions* are **consistent** with and **summarise** the rest of the manuscript — no

The *Conclusions* are **supported by the data** in *Results* and **follow logically** from the *Discussion* — yes

The *Conclusions* are **clear and concise** — yes

Comments:

*The Discussion is **focused on the objectives** of the study — no*
Section 4.1 and 4.2 are both concerned with comparing the model results with natural observations and grain size Piezometers. While this is a good way of checking the validity of the modelling results, it is quite extensive (110 lines and two Figures) and leads to no conclusions other than that the results are fine. Section 4.3 which deals with the main objectives of the study according to abstract and introduction is comparatively short (50 lines and 1 Figure).

The 1D models in section 4.4 come out of nowhere and are not mentioned in the Methods. Is the code for them also provided? A sentence or two could clarify this.

I disagree that a comparison of the 2D Quartz-Anorthite experiment to 1D Quartz is pointless. Since the 2D results seem to be governed by the link-up of weak Quartz matrix, they might be very similar to 1D Quartz, and if not, it would highlight the importance of 2D models.
Not sure I follow the statements in Lines 472 and 475. Are we comparing the dots in Figure 8 with their respective contours? In this case, some are above, some are below. They are also all below the Piezometer.

*The Conclusions are **consistent** with and **summarise** the rest of the manuscript — no*
The main message of section 4.4 (that 1D olivine models yield similar results to 2D olivine-pyroxene models) is neglected in the conclusions.

*The Discussion section **addresses the limitations** of the study appropriately — no*
Section 4.5 lists a lot of limitations but does not discuss their potential effects. Also, a major component in shear heating is missing.

B5.2) Author’s responses

B6) Figures, tables and citations

B6.1) Reviewer’s comments
*These statements are a **guide** to what good* Figures *and* Tables *include and how they are presented. Please select YES or NO to the statements below if you wish and detail in the free form box below your reasons for any box checked with NO, or to comment on any other matter.*

Tables and *Figures* are **ordered logically** and **numbered sequentially** — yes

Tables and *Figures* have **captions that explain** all their major features — yes

Tables and *Figures* have **captions that complement** the information in the main text — yes

Tables and *Figures* present data that **relate** to the study objective — yes

Tables and *Figures* present data that are **consistent** with and support the description of results — yes

Tables and *Figures* have **succinct and informative titles** — yes

Figures are **accessible** (elements are clearly labelled, accessible colour palettes, colour contrasts, font size legible, etc.…) — yes
Please, check our [Figure guidelines]

Figures with **maps or cross-sections** contain all **elements to be understood** (north arrow orientation, scale, visible coordinates, sufficient coordinate grid intercepts) — yes

Figures with **maps** have **sufficient location information** (in the map or caption) — yes

Cross-sections have clear labels for **scale and coordinates** at ends and within-section kinks — yes

All georeferenced elements are provided in common format (.shp, .geotiff, .kml) [in an open-access repository] — yes

Citations throughout are relevant, suitable, and comprehensive — yes

Comments:

Table 1 conveys all the information but looks lacklustre. At least the additional label in line 1 and the green corner of a selected cell in diffusion creep should go.
Figure 2 looks out of place compared to all other Figures. Please adapt it to the style of the other graphs.
Figure 10 has lower quality than the others.

B6.2) Author's responses

Section C: Additional comments

C1) Minor/line-numbered comments

C1.1) Reviewer's comments

Figure 1: e) and f) are called b) and c) in the caption. Legends for minerals would be nice in a) and d)
L. 150: Is Biotite restricted to dislocation creep because there is no available data for diffusion creep?
L. 219: You mean "temperatures are too low for viscous creep" here?
L. 224-233: Mention the similarity between GSE and constant GS here.
L. 308-317: This does not really relate to the results here and sounds more like motivation that belongs in the introduction. The part about brittle failure reducing grain size could go into the limitation section as this is not modelled here.
L. 347: "The stress-grain size data for the mean stresses and grain sizes" perfectly redundant. Probably a typo
L. 399-407: This is essentially a repetition of the introduction.
L. 420: I don't understand how the first half of the sentence relates to the second half.
Figure 10: The image quality is lower than all other Figures. Like they are screenshots.
10d: legend labels should be 10a,b,c?
L. 461&462: "two-phase" could be confused with "two-phase flow". "polyphase" is better here
L. 475: "deformation mechanism maps"?

C1.2) Author's responses

C2) Other remarks

C2.1) Reviewer's comments

C2.2) Author's responses

Comments by Reviewer 2 (Melanie Finch)

Review of Ruh et al 'Weakening effect of grain-size reduction in two-phase crustal and mantle lithospheric shear zones'.

This work investigates the relative effect of textural and grain-size-sensitive weakening on strain localization. The results of numerical experiments demonstrate the effect of each mechanism over increasing temperature with minerals in the models deforming according to established flow laws. This work is interesting and the models produced may have utility to the community beyond that discussed in this work, since models that develop over increasing strain can be compared to naturally-deformed rocks to provide insight into the evolution of the latter. My feedback is only minor, overall this work is great, the writing is excellent, the figures are high quality and clear, and the results and their interpretation are straightforward.

General comments:

1) I understand that every modelling method has unique capabilities, and I can see that this method has some benefits over other comparable numerical modelling techniques. However, I see no mention of mineral models and whether the CRSS of mineral slip systems has been considered in these models. This is important for all minerals, but a particularly critical aspect from a mechanical point of view is the weak biotite basal plane which controls the strength of biotite in rocks such as these. In a naturally deformed rock, the biotite basal plane would align to the shear direction early and localise most of the strain. You don't have much biotite in your granite model, but as little as 5% influences strain localization (e.g., Finch et al 2020). I can see that biotite concentrates into the high strain rate bands in some of your models, suggesting that it affects strain localization.

2) Why does it say 'two phase' in the article title when there are three phases in the granitoid model?

3) I may have missed it, but I couldn't find where the mineral proportions in each model are listed. This is important to allow comparison to other models, experimental work and to naturally deformed rocks. Do the mineral proportions change over the model duration? Some modelling techniques delete grains that get too small for the model to handle, which can mean that the proportion of a particular phase decreases over time.

4) L. 290-292 - Does biotite have any effect on the structural evolution? It should be the weakest phase in this model. While there is much less biotite than quartz in this model, at the temperatures studied even a small amount should have an effect on the structural evolution, as highlighted in the previous comment.

5) L. 298-300 – Why do your results differ from most natural peridotitic mylonites? This result requires explanation.

6) In modelling papers such as this one the 'movies' that show the evolution of the structure can be quite impactful on the broader community because they help others to apply your results to their work. Therefore, I suggest a number of changes to ensure that your movies are user friendly. The gif files provided in the supplementary material progress through the images very quickly. If the images were combined in a different format (e.g., .avi files) the viewer would be able to slow them down and watch more carefully. This will help others to compare their naturally deformed rocks or models to your models. I am also missing a caption that explains what is depicted in each of the 'movies' – that is, what do the values/colours in the legend for each figure mean? This is done well in the manuscript figures by annotating the colour bar with meaningful labels, so I suggest that is also implemented in the supplementary material.

Authors’ Reply to Reviewer 1

Section A: Overview of manuscript

A1) Overall evaluation, general comments & summary

A1.1) Reviewer’s comments

A1.1.1) General evaluation and publication suggestion – Required:
Please use this space to describe, in your own words, the core subject of the submission and your overall assessment of its suitability for publication.

The authors present a selection of 36 2D numerical, visco-elasto-plastic, simple-shear models of a granitoid and peridotite hand sample at different temperatures and related pressures. They compare stress evolutions with and without grain size evolution to investigate the relative importance of textural and grain size weakening. They show that grain size weakening plays a secondary role (compared to shear banding of weak matrix) in granitoids and a primary role for peridotites between 700 and 1000 °C. Furthermore, they show differenes and similarities to 1D model results.

The manuscript has a high quality of English and is well written, albeit a bit lengthy and redundant in certain parts. The Figures are mostly of publication quality and all of them support the points that are being made well.

I think the manuscript provides valuable insight into the relative importance of shear banding and grain size reduction for typical crustal and mantle lithosphere compositions. Furthermore, it gives an idea of how much these mechanisms can weaken an intact rock once it starts deforming which is of interest to the geodynamic modelling community that needs to parameterize such effects. The comparison between 1D and 2D results is also useful for guiding future studies.

My main concern is the lack of discussion for some important design choices in the numerical model.
I) Temperature evolution through shear heating is an important mechanism contributing to strain localization and is neglected from the implementation without reasoning and discussion of its potential impact.

> Thanks for raising this point, which is definitely interesting and important to discuss. In large-scale numerical geodynamic modelling, shear heating is considered to have an important effect on weakening and strain localization in ductile shear zones, as mentioned in the comment. Shear heating results from the energy of viscous deformation dissipating to heat. Grain size has a direct effect on shear heating as it affects the viscous strength in case diffusion creep is the dominant deformation mechanism. Thus, grain-size reduction (also the result of a fraction of dissipating viscous deformation energy) should reduce the amount of viscous shear heating.
> We decided to ignore shear heating in the model setup given the small width of the modelled shear zones (5 cm). All produced shear heating would be immediately diffused across the shear zone for the investigated shear zone width. However, we think the issue is interesting and added a section in the discussion comparing the accumulated temperature increase for peridotitic shear zones at temperatures where grain-size weakening is most intense (800–1000 °C), for constant grain sizes and activated grain-size evolution and given shear zone widths (including thermal diffusion).

II) Applying the marker in cell approach and the grain size flow law on such a small scale brings up an important question. How appropriate is this approach when the size of a cell is much smaller than the grain size? This leads to a situation where there is a 1 cm large grain containing hundreds of markers, each of which may have a different grain size that can be smaller or larger than 1 cm. This issue is also not discussed.

> It is correct that the numerical experiments do not model grains with boundaries that are individual entities, but, as mentioned by the reviewer, a field of markers that refer to a grain size based on local strain rate, stress, etc. We agree that discussing this implementation is important. We now specifically introduce this point in the methods section ("This implementation implies that each marker contains an individual value for grain size, independent of the mesoscopic textural context, but solely dependent on the local thermo-mechanical characteristics, in contrast to alternative studies investigating ductile shear zones (e.g., Finch et al., 2020)") and added a paragraph in the limitation section of the discussion: "Grain-size information is stored on Lagrangian markers without geometric implications related to the evolving microstructure of the deforming numerical shear experiment, but only depends on the local thermal and mechanical marker characteristics."

In my opinion, there is also an imbalance in the discussion section where large parts deal with the comparison of the model results with field observations and piezometers which are not the objectives of the study according to title, abstract, introduction and conclusions. Shortening these sections would create space to discuss the design choices and robustness of the results. The comparison between 1D and 2D is very interesting in the context of the study but is mostly absent from conclusions and abstract.

> Models as the one we present in this study mainly serve to better understand shear zones observed in nature, which are interpreted by means of piezometers to constrain their behavior. We believe that the mentioned sections are key to this study. We improved the abstract and conclusion that now integrate the outcomes related to these sections.
> Additional experiments with different initial conditions (see further below) are added to the supplementary material to underline the robustness of the results.

Finally, there is also a lack of clarity in the methodology section regarding elasticity, brittle plasticity and grain size evolution.

> We implemented changes to the Methods section according to more detailed comments above and further below.

I think if the above-mentioned issues are addressed, this work is suitable for publication.

A1.1.2) What does the submission need to be publishable? (select as needed; comment for all cases)

- ☐ No changes required
- ☐ Rewriting
- ☒ Reorganising
- ☐ More data/figures
- ☒ Condensing
- ☒ Reinterpretation
- ☐ Other

Comments:

Condensing: Parts of the manuscript feel lengthy and repetitive. It is not drastic, but I think the sections can benefit from some condensing. Examples:

- Line 70-72 and 76-78 are near identical.
  We deleted lines 76-78.

- Instead of listing all of what can be seen in the Figures, it might be useful to make some summarizing statements. For example, lines 228 and 231 are more or less the same sentence about neighbouring subfigures.
  We reorganized, rewrote these lines

- Lines 290 and 292 both mention Plagioclase forming rigid clasts in back-to-back sentences.

We agree completely and deleted one of the sentences.

- Sections 4.1 and 4.2 are quite extensive without contributing much to the conclusions of the manuscript
  See also comment above. We tried to incorporate these results better into the abstract and the conclusion.

Reinterpretation: Discussing the things mentioned in A1.1.1

Reorganising: Focussing the Discussion on the objectives

A1.1.3) Can the submission be improved by reducing/adding any of the following? (select as needed; comment for all cases)

☒ Text
☐ Table
☐ Figures
☐ Supplementary material

Comments:

See 1.1.2

A1.1.4) Please complete the following section if you recommend that the submission is NOT appropriate for publication (select as needed; comment if a box is selected)

☐ Quality is poor
☐ Research is not reproducible
☐ Other

Comments:

A1.2) Author(s) Responses:

We answered each comment individually above.

A2) Summary of main merits and main points of improvement

A2.1) Reviewer's comments

Please describe below in a few sentences (100 to 300 words) the main merits of the submission and suggestions for improvements.

The main merits I have found are...

Putting a number on how much textural weakening can be expected in typical rocks in a small scale-high resolution experiment is useful for larger geodynamic models that cannot afford to resolve such small features. This information can be reused as a parameterization of weakening and might be unobtainable from 1D models that are much more common. The comparison between 1D and 2D models is useful to judge whether 1D models are a good approximation or 2D models are necessary.
Quantifying the relative importance of textural weakening and grain size weakening for different rock types and conditions is also useful as it can guide other modelling studies on what mechanisms are important to cover and which ones may be negligible.

The main points of improvement I have found are...

The main improvement that can be done is discussing the design choices and their potential effects. Why is temperature evolution by shear heating neglected? What would be its effect? It uses more than 99% of viscous dissipation. Does this not have a large effect on temperature and rheology?

This is a very good point. It is true that shear heating can have an important effect on viscous weakening and since grain-size reduction reduces the strength of a shear zone, it also reduces work and therefore affects shear heating. The reason why shear heating was neglected was the geometric setup of the experiments with a shear zone width of 5 cm. For constant temperature boundaries, temperature would diffuse rapidly and shear heating could be neglected. Any other implementation would be speculative and unnecessarily complicate the model. We nevertheless agree that shear heating and its potential effect should be discussed. We therefore added a new section related to shear heating in which we provide temperature increases related to shear heating according to the dissipation energy produced by peridotite experiments. We provide values for the cases of no temperature diffusion and for a given shear zone with that demonstrate the effect of GSE on shear heating. See new section 4.5.

In the same vein, I think it is important to discuss the implications of having a resolution that is samller than the grain size. What does it mean when a single crystal contains hundreds of markers with potentially different grain sizes (Figure 3)? What does it mean when the grain size on markers is much larger than what the composition plot shows (Figure 5)? Are the flow laws even applicable in this case?
What effects would you expect the other simplifications mentioned in section 4.5 to have?

See answer in A.1.1.

Clarify the interaction between plasticity and grain size evolution as well as elasticity and grain size evolution. More on that in section B3.

We answered the points raised in section B3 to not be repetitive.

A few additional models (for the interesting temperature ranges) with different initial grain size and different initial geometry (can be as simple as rotating the setup by 90°) can demonstrate the robustness of the results. Without these variations it is difficult to say if the results given have quantitative or only qualitative meaning. I wonder how much of the grain size reduction effect in granitoids stems from the initial size being too large. Only a single quartz grain is on the scale of 2 cm. 5 or 10 mm seems more appropriate for the images in Figure 1.

We conducted granitoid experiments with initial grain size of 5 mm for temperatures of 500 and 700 °C, experiments without biotite and for a rotated initial setup for 400, 500, 600, and 700 °C, and added the results of grain-size evolution and stress in the newly compiled supplementary material.

Sections 4.1 and 4.2 are long, despite not contributing much to the objectives of the study. 4.4 is quite interesting and also adresses the objectives set in the introduction but is ignored in Conclusions and Abstract.

We tried to shorten these sections a bit, although we believe that they are quite important, and extended the related findings in the abstract and conclusion.

The readability and quality of the manuscript can be improved by condensing the information given in the text and reducing repetitive sentence structure and content. See 1.1.2.

We did our best to condense the text throughout the manuscript.

A2.2) Author's responses:

We answered each comment individually above.

Section B: Detailed evaluation of manuscript

B1) Title and abstract

B1.1) Reviewer's comments

*These statements are a **guide** to what good* Titles *and* Abstracts *include. Please select YES or NO to the statements below if you wish and detail in the free form box below your reasons for any box checked with NO, or to comment on any other matter.*

The *Title* describes the main topic of the manuscript **accurately** — no

The *Title* describes the main topic of the manuscript **succinctly** — yes

The *Title* includes **appropriate key terms** — yes

The *Abstract* includes a **clear aim and rationale** — yes

The *Abstract* supports the rationale with **sufficient background information** — yes

The *Abstract* includes a **well-balanced description of the methods** — yes

The *Abstract* describes the **main results sufficiently and adequately** — yes

The *Abstract* clearly describes the **importance/impact of the study** — yes

The *Abstract* clearly states the **conclusions of the study** — no

The *Abstract* is **clear** and **well structured** — yes

Comments:

*The Title describes the main topic of the manuscript **accurately: no***
I think textural weakening could be added to the title. Also "two-phase" could easily be confused with "two-phase-flow" and there are 3 phases in the granitoid model. I think "polyphase" as it is used in the abstract is better

> We changed the title to "Effect of grain-size and textural weakening in polyphase crustal and mantle lithospheric shear zones"

The Abstract clearly states the conclusions of the study — no
The Abstract is good until until line 15 where it becomes quite vague. It talks about "revealing complexity not captured by 1D models" but to my understadning section 4.4 shows that 1D olivine is a good approximation for 2D peridotite and 1D quartz is not even compared to 2D granitoid. Instead of mentioning the term "quantitative constraints" without giving any, it could instead state them. For example the amount of maximum weakening provided by both mechanisms.

> We rephrased the respective sentence in the abstract: "For peridotitic rocks, intense weakening is evident below temperatures of ~1000°C due to grain-size reduction, while textural weakening has a minor effect on weakening for experiments above 1000 °C. Two-dimensional experiments are compared to one-dimensional, single-phase models to reveal the effect of geometrical complexities in stress and grain-size evolution."
> In granitoid experiments, quartz is the weakest phase and thus undergoes the most intense deformation and grain-size reduction. However, there is no weakening effect related to grain-size reduction in quartz as it remains in the dislocation creep field for all temperatures (see Fig. 3 and 7a). Therefore, it is not compared to the 1D case. The fact that anorthite undergoes much slower strain rates than the bulk shear strain rate makes it difficult to compare to rapidly deforming anorthite in a 1D case. This reasoning is outlined in section 4.4.: "A comparison of granitoid shear experiments to one-dimensional models is not attempted because i) deformation of quartz is defined by dislocation creep and no grain-size-related weakening is expected (Fig. 7a), consistent with quartz single-phase deformation mechanism maps, and ii) plagioclase behaves mostly as rigid clasts in two-dimensional experiments (Fig. 3) and most plagioclase markers exhibit low strain ($\varepsilon < 3$) indicating out-of-equilibrium grain sizes (Fig. 7b)."

B1.2) Author's responses

We answered each comment individually above.

B2) Introduction

B2.1) Reviewer's comments

*These statements are a **guide** to what good* Introductions *include. Please select YES or NO to the statements below if you wish and detail in the free form box below your reasons for any box checked with NO, or to comment on any other matter.*

The *Introduction* provides **sufficient background and context** for the study — yes

The *Introduction* describes the **aim/hypothesis/rationale** clearly, providing **sufficient context** — yes

The *objective/hypothesis/rationale* **flows logically from the background** information — yes

The *Introduction* describes the study's **objective and approach** (last paragraph) — yes

The *Introduction* contains **relevant, suitable citations** — yes

The *Introduction* is **organized effectively** — yes

Comments:

As somebody who was unfamiliar with the term "textural weakening", I was missing a real definition of it. Lines 28 and 31-32 do that to a degree but the message is not clear enough for one of the central topics of the study.

We extended the sentence in the second paragraph of the introduction: "…, where texture defines the size, shape, and arrangement of mineral crystals in a rock."

B2.2) Author's responses

We answered each comment individually above.

B3) Data and methods

B3.1) Reviewer's comments

*These statements are a **guide** to what good* Method *sections include and good practices for* Dataset *accessibility. Please select YES or NO to the statements below if you wish and detail in the free form box below your reasons for any box checked with NO, or to comment on any other matter.*

The *Methods* are described **concisely and with enough detail** for reproducibility — no

Necessary information about **data sources/acquisition/processing** is included — yes

Data used are accessible via either supplementary files or links in the data availability statement — no

The *Dataset and/or Methods* are **organized effectively** — yes

Comments:

*The Methods are described **concisely and with enough detail** for reproducibility — no*

It is next to impossible to reproduce a numerical code from the method description of any paper. Still some things are more unclear than usual here:

Line 96: Shear modulus G is mentioned here but no value for it is ever provided.

We added the value, which is identical for all phases

Equations 2 and 3 use tau for deviatoric stress, but equations 4 and 8 use sigma when they should use deviatoric stress.

Equations 2 and 3 describe the governing equations, where tau are individual deviatoric stresses. Equation 4 describes the numerical implementation, where the second invariant of the stress tensor is used. We changed this one to tau_II. Equation 8 describes theoretical grain size reduction where sigma describes differential stress. We left it as sigma.

Line 98: Are you using the stress of the previous time step or the current one (with local iterations for the nonlinear dislocation creep)?

We apply the stress of the previous time step. We added this information in the respective place.

L. 99 & 107: the index "II" often refers to the square root of the 2nd invariant. An equation could help clarify.

We added equations for both cases.

Line 107: Fluid pressure ratio is not given anywhere.

We corrected the equation as fluid pressure is zero in our experiments.

Line 108: The modification used in the references is not very complex. Why not just give the equation here?

We added all necessary equations.

Line 116-118: Can you clarify what this means? Does that mean that if 3% of all Plagioclase is yielding, that grain size evolution completely stops for all Plagioclase in the model? Or if 3% of the stress history of one marker is above the yield, that marker stops grain size reduction? And can it switch back on when under the yield stress? Is grain size reduction due to brittle plasticity neglected because there is no good formulation for it, not enough data, no consensus or to not overcomplicate the code?

We modified the sentence: "For simplicity, grain-size reduction is switched off if the mineral phase deforms brittle/plastically (here, a phase is considered to deform brittle if >3 % of the mineral phase's markers exceed the plastic yield envelope, evaluated at every time step)." Brittle grain-size reduction is not implemented in our study, as there is no direct quantitative constrain available: "Grain-size reduction related to brittle deformation is ignored due to lack of quantitative constrain."

Line 119: I assume stress and strain rate are tensors here. So what kind of product are you using? Dot product or tensor product?

We use the dot product. We indicate that now in the equation.

Line 134: Activation volume is not given anywhere.

Activation volumes for the different phases are given in table 1 as part of Q_g. We corrected the equation and the text: "where A_g is the growth rate constant, f_{H2O} is water fugacity, Q_g is activation potential, P is pressure, T is temperature, R is the gas constant, d is grain size and p is the growth exponent (Table 1)."

Line 137: Is grain size updated after the rheology is solved or updated during the iterations?

We use the result of the mechanical solution to calculate the grain-size evolution: "Each time step a new grain size d_{new} is calculated on the Lagrangian markers combining the reduction and growth components after solving the rheological equations, …"

Not technically part of the methods but the sentence in line 427 is concerning to me. There should be no grain size reduction during elastic loading. If there is, is it a side effect of your elasticity implementation?

This sentence is not correct and we therefore deleted it. We revised all initial stress peaks and they are equal for GSE and constant GS experiments at the same temperature. As seens in Fig. 4 for example, it can be seen that the peak stress (~10 kyr, at bulk shear strain ~0.1), grain size hasn't reduced enough to produce a grain-size-sensitive weakening.

***Data used are accessible** via either supplementary files or links in the data availability statement — no*

The authors provide a link for the code but all options and parameters are from a different study. I don't know what tektonika requires here but an input script to reproduce at least one of the models would be nice.

We now provide one code example each for both peridotitic and granitoid experiments in the supplementary material.

B3.2) Author's responses

We answered each comment individually above.

B4) Results

B4.1) Reviewer's comments

*These statements are a **guide** to what good* Result sections *include. Please select YES or NO to the statements below if you wish and detail in the free form box below your reasons for any box checked with NO, or to comment on any other matter.*

The *Results* findings are **supported by data** — yes

The *Results* findings are presented **clearly and succinctly** — no

The text in the *Result* section **cites tables and figures appropriately** — yes

The *Results* directly **relate to the study objectives** — yes

The *Results* present **data for all the approaches** described in the *Methods* section — yes

The *Results* **text belongs to the Results section**, not to *Introduction*, *Methods*, or *Discussion.* — yes

The *Results* section is **organised effectively** — yes

Comments:

The results are presented clear, but some shortening could help.

We shortened the results here and there to make the text more concise.

B4.2) Author's responses

We answered each comment individually above.

B5) Discussion and conclusions

B5.1) Reviewer's comments

*These statements are a **guide** to what good* Discussions *and* Conclusions *include. Please select YES or NO to the statements below if you wish and detail in the free form box below your reasons for any box checked with NO, or to comment on any other matter.*

The *Discussion* is **focused on the objectives** of the study — no

The *Discussion* **addresses all major results** of this study, which are shown in *Results* — yes

The *Discussion* section makes **comparisons with other studies** that are relevant and informative — [YES] / [NO]

The *Discussion* section properly identifies all **speculative statements** — yes

The *Discussion* section presents the **implications of the study** persuasively — yes

The *Discussion* section **highlights novel contributions** appropriately — [YES] / [NO]

The *Discussion* section **addresses the limitations** of the study appropriately — no

The *Discussion* section is **organised effectively** — yes

The *Conclusions* are **consistent** with and **summarise** the rest of the manuscript — no

The *Conclusions* are **supported by the data** in *Results* and **follow logically** from the *Discussion* — yes

The *Conclusions* are **clear and concise** — yes

Comments:

*The Discussion is **focused on the objectives** of the study — no*
Section 4.1 and 4.2 are both concerned with comparing the model results with natural observations and grain size Piezometers. While this is a good way of checking the validity of the modelling results, it is quite extensive (110 lines and two Figures) and leads to no conclusions other than that the results are fine. Section 4.3 which deals with the main objectives of the study according to abstract and introduction is comparatively short (50 lines and 1 Figure).

> We consider both sections 4.1. and 4.2. as key sections of the study and we prefer them to remain extensive and informative. We tried to shorten the sections where feasible.

The 1D models in section 4.4 come out of nowhere and are not mentioned in the Methods. Is the code for them also provided? A sentence or two could clarify this.

> We now provide code examples for the 1d calculations in the supplementary material and mention it in the methods section. We mention the 1d approach in the introduction "Complex two-dimensional shear experiments are compared to the stress evolution of one-dimensional single-phase experiments." and refer to the supplementary material in the methods section: "Both one- and two-dimensional numerical codes rely on the same rheological and grain-size-evolution parameters and are provided in the supplementary data."

I disagree that a comparison of the 2D Quartz-Anorthite experiment to 1D Quartz is pointless. Since the 2D results seem to be governed by the link-up of weak Quartz matrix, they might be very similar to 1D Quartz, and if not, it would highlight the importance of 2D models.

> We didn't attempt the comparison of 2d experiments to 1d models for the granitoid assemblage due to the reasons outlined in the manuscript. Grain size of quartz will not reduce sufficiently for diffusion creep to become the dominant deformation mechanism and grain size is depending on strain rate that it elevated due to the localization of deformation within quartz. Anorthite behaves as rigid clasts and behaves therefore differently than as a potential single-phase model with much higher stresses etc.: "A comparison of granitoid shear experiments to one-dimensional models is not attempted because i) deformation of quartz is defined by dislocation creep and no grain-size-related weakening is expected (Fig. 7a), consistent with quartz single-phase deformation mechanism maps, and ii)

plagioclase behaves mostly as rigid clasts in two-dimensional experiments (Fig. 3) and most plagioclase markers exhibit low strain ($\varepsilon < 3$) indicating out-of-equilibrium grain sizes (Fig. 7b)."

Not sure I follow the statements in Lines 472 and 475. Are we comparing the dots in Figure 8 with their respective contours? In this case, some are above, some are below. They are also all below the Piezometer.

Only experiments at 700–900 °C are in the diffusion creep field, and the respective weakening (difference between circle, i.e. recrystallized, and square, i.e., not strained) is less than what would be expected from the sketch in Fig. 10a. We added information to the sentence and deleted one part to avoid confusion.

*The Conclusions are **consistent** with and **summarise** the rest of the manuscript — no*

The main message of section 4.4 (that 1D olivine models yield similar results to 2D olivine-pyroxene models) is neglected in the conclusions.

We added the relevant conclusions: "The amount of weakening in peridotitic rocks induced by grain-size reduction of olivine is shown to be well constrained by one-dimensional models, while for granitoitic assemblages, two-dimensional models are necessary to capture textural complexities and their effect on stress, strain rate, and grain size."

*The Discussion section **addresses the limitations** of the study appropriately — no*

Section 4.5 lists a lot of limitations but does not discuss their potential effects. Also, a major component in shear heating is missing.

We added a paragraph discussing the effect of shear heating and the insights presented in section 4.5.: "Viscous shear heating can become an important factor in the mechanical weakening of ductile shear zones (e.g., Thielmann et al., 2012; Hartz and Podladchikov, 2008).The present study ignores shear heating given the small scale of modelled shear zone width and the consequent effective thermal diffusion of additional heating. Section 4.5. provides first-order constraints on accumulated heat depending on shear zone width and their dependence on grain-size reduction."

B5.2) Author's responses

We answered each comment individually above.

B6) Figures, tables and citations

B6.1) Reviewer's comments

*These statements are a **guide** to what good* Figures *and* Tables *include and how they are presented. Please select YES or NO to the statements below if you wish and detail in the free form box below your reasons for any box checked with NO, or to comment on any other matter.*

Tables and *Figures* are **ordered logically** and **numbered sequentially** — yes

Tables and *Figures* have **captions that explain** all their major features — yes

Tables and *Figures* have **captions that complement** the information in the main text — yes

Tables and *Figures* present data that **relate** to the study objective — yes

Tables and *Figures* present data that are **consistent** with and support the description of results — yes

Tables and *Figures* have **succinct and informative titles** — yes

Figures are **accessible** (elements are clearly labelled, accessible colour palettes, colour contrasts, font size legible, etc.…) — yes
Please, check our [Figure guidelines]

Figures with **maps or cross-sections** contain all **elements to be understood** (north arrow orientation, scale, visible coordinates, sufficient coordinate grid intercepts) — yes

Figures with **maps** have **sufficient location information** (in the map or caption) — yes

Cross-sections have clear labels for **scale and coordinates** at ends and within-section kinks — yes

All georeferenced elements are provided in common format (.shp, .geotiff, .kml) [in an open-access repository] — yes

Citations throughout are relevant, suitable, and comprehensive — yes

Comments:

Table 1 conveys all the information but looks lacklustre. At least the additional label in line 1 and the green corner of a selected cell in diffusion creep should go.

We corrected the errors

Figure 2 looks out of place compared to all other Figures. Please adapt it to the style of the other graphs.

We modified figure 2 accordingly.

Figure 10 has lower quality than the others.

Thanks for pointing this error out. We produced a better quality image.

B6.2) Author's responses

We answered each comment individually above.

Section C: Additional comments

C1) Minor/line-numbered comments

C1.1) Reviewer's comments

Figure 1: e) and f) are called b) and c) in the caption. Legends for minerals would be nice in a) and d)

Done

L. 150: Is Biotite restricted to dislocation creep because there is no available data for diffusion creep?

Biotite deforms by dislocation glide, best represented by a dislocation creep type flow law. We added a reference and clarified.

L. 219: You mean "temperatures are too low for viscous creep" here?

Done

L. 224-233: Mention the similarity between GSE and constant GS here.

Done: "In both cases, stress evolution for low temperature experiments do not display significant stress loss, while experiments at intermediate temperatures (500–650 °C) experience the most weakening."

L. 308-317: This does not really relate to the results here and sounds more like motivation that belongs in the introduction. The part about brittle failure reducing grain size could go into the limitation section as this is not modelled here.

We believe that this part is important as it puts our findings in relation to natural observations of the implications of grain-size reduction in nature. The part about brittle failure is already listed in the limitations section.

L. 347: "The stress-grain size data for the mean stresses and grain sizes" perfectly redundant. Probably a typo

Done

L. 399-407: This is essentially a repetition of the introduction.

We deleted this part and reorganized the text.

L. 420: I don't understand how the first half of the sentence relates to the second half.

We deleted the last part of the sentence and corrected a spelling error that might have led to the confusion. The sentence is otherwise correct.

Figure 10: The image quality is lower than all other Figures. Like they are screenshots.

10d: legend labels should be 10a,b,c?

We regret this error. The figure is not at high quality. We corrected the labels in the caption.

L. 461&462: "two-phase" could be confused with "two-phase flow". "polyphase" is better here

Done

L. 475: "deformation mechanism maps"?

Done

C1.2) Author's responses

We answered each comment individually above.

C2) Other remarks

C2.1) Reviewer's comments

C2.2) Author's responses

Authors' Reply to Reviewer 2

Review of Ruh et al 'Weakening effect of grain-size reduction in two-phase crustal and mantle lithospheric shear zones'.

This work investigates the relative effect of textural and grain-size-sensitive weakening on strain localization. The results of numerical experiments demonstrate the effect of each mechanism over increasing temperature with minerals in the models deforming according to established flow laws. This work is interesting and the models produced may have utility to the community beyond that discussed in this work, since models that develop over increasing strain can be compared to naturally-deformed rocks to provide insight into the evolution of the latter. My feedback is only minor, overall this work is great, the writing is excellent, the figures are high quality and clear, and the results and their interpretation are straightforward.

General comments:

1) I understand that every modelling method has unique capabilities, and I can see that this method has some benefits over other comparable numerical modelling techniques. However, I see no mention of mineral models and whether the CRSS of mineral slip systems has been considered in these models. This is important for all minerals, but a particularly critical aspect from a mechanical point of view is the weak biotite basal plane which controls the strength of biotite in rocks such as these. In a naturally deformed rock, the biotite basal plane would align to the shear direction early and localise most of the strain. You don't have much biotite in your granite model, but as little as 5% influences strain localization (e.g., Finch et al 2020). I can see that biotite concentrates into the high strain rate bands in some of your models, suggesting that it affects strain localization.

> We realized additional experiments without biotite (biotite was replaced by quartz) and discuss them in the Supplementary Data (Fig. S2 and Movies Exp39–42). The absence of biotite has no effect on the stress evolution. This is due to its small amount and the stronger localization of quartz if biotite is absent, which at small grain sizes is equally weak (Fig. 1a).

2) Why does it say 'two phase' in the article title when there are three phases in the granitoid model?

> Correct. We changed the title according to several comments by the two reviewers to :
> "Effect of grain-size and textural weakening in polyphase crustal and mantle shear zones".

3) I may have missed it, but I couldn't find where the mineral proportions in each model are listed. This is important to allow comparison to other models, experimental work and to naturally deformed rocks. Do the mineral proportions change over the model duration? Some modelling techniques delete grains that get too small for the model to handle, which can mean that the proportion of a particular phase decreases over time.

> We now mention the percentages of each mineral phase for both granitoid and peridotite cases in the Methods section. Furthermore, we added a sentence in the Boundary Conditions subsection indicating the constant number of markers during model runs:
> "Lateral boundaries prescribe periodic conditions with vertical free slip, i.e. markers exiting the Eulerian domain on one side enter on the other, resulting in a constant number of Lagrangian markers during experiment evolution".

4) L. 290-292 - Does biotite have any effect on the structural evolution? It should be the weakest phase in this model. While there is much less biotite than quartz in this model, at the temperatures studied even a small amount should have an effect on the structural evolution, as highlighted in the previous comment.

See comment (1). Additional experiments show that the absence of biotite has no significant effect on the grain size and stress evolution. As displayed in Fig. 1, biotite can be the weakest phase, depending on the grain size of quartz and temperature. At temperatures >550 °C, botite becomes stronger than quartz in any case. Additional movies and figures in the supplementary data discuss the effect of biotite.

5) L. 298-300 – Why do your results differ from most natural peridotitic mylonites? This result requires explanation.

The sentence was erroneous as it implies that elongated clasts are rigid, which makes no sense. We moved the reference to the sentence before and deleted the sentence.

6) In modelling papers such as this one the 'movies' that show the evolution of the structure can be quite impactful on the broader community because they help others to apply your results to their work. Therefore, I suggest a number of changes to ensure that your movies are user friendly. The gif files provided in the supplementary material progress through the images very quickly. If the images were combined in a different format (e.g., .avi files) the viewer would be able to slow them down and watch more carefully. This will help others to compare their naturally deformed rocks or models to your models. I am also missing a caption that explains what is depicted in each of the 'movies' – that is, what do the values/colours in the legend for each figure mean? This is done well in the manuscript figures by annotating the colour bar with meaningful labels, so I suggest that is also implemented in the supplementary material.

We modified all movies to now have proper labelling and we changed all videos to .avi files and uploaded them to the supplementary material.

Authors' Reply to Associate Editor's comments:

Additional comments by the Associate Editor

1. Please incorporate the role of textural weakening in the case of the peridotitic rocks in the abstract.

   We introduced a sentence in the abstract: "For peridotitic rocks, intense weakening is evident below temperatures of ~1000°C due to grain-size reduction, while textural weakening has a minor effect on weakening for experiments above 1000 °C."

2. Line 24 – I think 'weakly deformed' instead of 'undeformed' is more suitable for the host rocks surrounding the shear zones/bands.

   Corrected

3. Line 32 – It appears from the text that the coexistence of textural and grain size weakening has previously been reported from naturally deformed rocks. Please cite a few examples here.

   We added relevant references after the sentence.

4. Lines 78-80 – These lines are perhaps more suitable for Sec. 2. The advantages listed also require elaboration.

   In our opinion, these lines (arguments of the usage of 2D models) belongs to the introduction, because it represents the motivation of why we apply 2D experiments over 1D ones. We prefer to keep it as is, clearly listing features of 2D models that cannot be achieved by 1D models.

5. Figure 4 – Please consider commenting on
   a. what causes the curves to be squigglier at lower temperatures?
   The squigglier lines at low temperatures arise from the relatively rigid plagioclase clasts choking against each other and narrowing quartz shear bands (for T <650 °C; see also Fig. 3). At section 3.1., we added: "Squiggly fluctuations in quartz grain size and stress evolution at temperatures up to 600 °C are related to constant rearrangement of rigid plagioclase clasts narrowing quartz shear bands and affecting bulk shear stresses (Fig. 3)."

   b. why constant grain size values are achieved at lower strains for high-temperature deformation (at gamma ~5 for 750 deg C but ~10 for 350 deg C)
   This is related to the localization of deformation within the shear zone. Due to rigid clasts of plagioclase at lower temperatures, there are zones of quartz that localize and others not. This implies that the overall decrease (dependent on stress and strain rate) is slowed down until a textural fabric is developed. We give this information now in the results: "Initial quartz grain sizes of 2 cm reduce to quasi-constant values of ~5 µm at 350 °C after a bulk shear strain of ~5 and to 400 µm at 750 °C after a bulk shear strain of ~5 (Fig. 4a)." and interpret it in the discussion: "For quartz, experiments at lower temperatures require larger bulk shear strain to achieve constant grain sizes due to the slower development of a foliated texture (Fig. 4a)."

6. Line 304 – Please state the shear strain values separately for the three phases.
   We now give separate values for quartz, and olivine and peridotite together.

7. Line 328 – Please check if it should be 'as noted in' instead of 'as expected from'.
   "as expected from" is correct. The deformation mechanism map illustrates the applied flow laws and at the given grain size and stresses, they predict dislocation creep.

8. Figures 7 and 8 - What are the grey solid lines that connect the circles to the squares? Please also define the field-boundary lines in the caption.
   The fine straight lines just indicate the same temperature for circles and squares, for easier readability. We introduce both now in the caption: "**Figure 7:** Deformation mechanism maps for quartz (a) and anorthite (b) for a strain rate of $10^{-12.5}$ s^{-1}. See Table 1 for rheological parameters. Horizontal dashed line: Brittle yield strength at 371 MPa confining pressure. <u>Field boundaries indicated by long dashed lines.</u> Squares indicate mean marker grain size and stress after bulk shear strain of $\gamma = 20$. Circles indicate mean marker grain size and stress for markers with accumulated strain $\varepsilon > 3$, the number indicates the percentage of markers that exceeds strain $\varepsilon > 3$. <u>Thin straight lines connecting circles and squared in (b) indicate same temperature experiments for better readability.</u> Red line in (a): Quartz piezometer (Stipp and Tullis, 2003). Blue line in (b): Feldspar piezometer (Speciale et al., 2022)."

9. Sec. 4.3 discusses textural as well as grain size weakening, but the title emphasizes the latter. Please consider modifying the title.
   Good point. We corrected the title accordingly: "Effect of grain-size and textural weakening in polyphase crustal and mantle lithospheric shear zones"

10. Fig. 10a – Please mark with arrows the directions of increasing grain size and stress values.
    Done

2nd Round of Revisions

Decision Letter (1 Feb. 2024)

Dear Jonas Ruh and co-authors,

Your revised manuscript has now been evaluated by our associate editor Dripta Dutta (see Dripta's recommendation below) and myself. We are pleased to be ready to accept it for publication in Tektonika. However before formally accepting it, we will ask you to make two very minor correction / update:
1. See Dripta's comment about the term 'textural weakening' and revise your text accordingly.
2. Your supplementary files (movies) are available from polybox at ethz. I infer it's a sort of dropbox, not a long-lived data repository. It is important for us to ensure the long-term availability of the data, which must also be correctly referenced, accompanied by a DOI and metadata. I will thus ask you to upload your files to a more formal repository (I will suggest using zenodo.org) and to update your data availability section with the new link and DOI.

As these requested revisions are very minor, we would like to receive your update within 2 weeks, if possible less.

Best regards

Robin Lacassin, executive editor Tektonika

------- Associate editor evaluation

Dear Jonas and co-authors,

Thank you very much for addressing all the comments raised by the reviewers.

We have carefully checked the revised manuscript and your responses to the comments made by the reviewers. We are satisfied by your responses and arguments. However, in Sec. B2.1 of the review report, we think Reviewer #1 perhaps requested a textbook definition of the term 'textural weakening', which is less commonly used in geosciences than the term 'grainsize weakening', for beginners. We note that you have explained 'texture' instead. Please consider defining 'textural weakening' more clearly. Pointing out its origin and usage in material sciences could also be helpful.

The rest of the revised manuscript looks suitable for publication and is therefore accepted.

Yours sincerely,

Dripta (AE)

Authors' answer to editorial comments (2nd round)

Dear Robin, dear Dripta

I uploaded onto the Tektonika online system a corrected version of the manuscript file, which includes:
- a corrected sentence related to the definition of textural weakening: "Several previous studies have examined the role of textural weakening in evolving ductile shear zones, where textural weakening refers to structural rearrangement and changes in size, shape, and crystallographic

orientation of mineral crystals in a rock." I didn't add a annotated version, as it is only one sentence. I hope that is ok.
- a new link to the repository.
- a new Acknowledgement section

Best wishes and many thanks for the editorial work on the manuscript
Jonas and co-authors

Final decision (5 Feb. 2024)

Dear Jonas Ruh and co-authors:

Thanks for submitting your revised manuscript. We are now pleased to accept it for publication in Tektonika. The manuscript will now move to the copy-editing and production stage. You will soon be contacted by our technical team.

Best regards, thanks for submitting to Tektonika

Dripta Dutta, Tektonika Associate Editor

Robin Lacassin, Tektonika Executive Editor