tektonika



# Review Report

**Evans et al. - Signatures of fluid-rock interactions in shallow parts of the San Andreas and San Gabriel Faults, southern California, TEKTONIKA, 2024.**

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# 1st Round of Revisions

## Decision letter and author response

17/07/2023

Dear Dr. Evans,

Thank you for submitting your manuscript, "Fluid-rock interactions, hydrothermal processes, and accommodation of slip in shallow parts of the San Andreas and San Gabriel Faults, southern California", to Tektonika. We have now received three reviews, which we have carefully appraised alongside the manuscript, and are recommending that revisions are required to the manuscript. Each reviewer acknowledged that the manuscript is interesting and would be suitable for Tektonika; we agree with these sentiments. The reviewers have all provided detailed reviews and we ask that you work through each of their recommendations before resubmission. In particular:

All reviewers expressed that the figures need to be improved with consistent formatting and additional annotations for clarity. The number of figures could also be reduced.

All reviewers found that the text organisation reduced the clarity of the content and suggested that it could be condensed and simplified. They have each provided excellent feedback to help with this process.

All reviewers found it difficult to assess how this manuscript fits in with the many others cited (Crouch et al., submitted; Studnicky et al., in prep; Williams et al., 2021). We appreciate this is difficult to convey when papers are note published yet, but we highly recommend stating their relationship explicitly where appropriate.

Tektonika does not impose a deadline for manuscript resubmission; however, we would suggest a three-month timeline should be achievable but please do let us know if extra time is required. Also, please let us know if you have any questions or need any clarification about the process. We look forward to receiving your revised manuscript.

All the best,

Noah Phillips – Associate Editor

Craig Magee – Executive Editor

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*Following the initial decision letter, there have been several e-mails between the Editors and authors regarding clarification of how the solicited reviews were addressed, partly related to a system error making two submitted review files unavailable to the authors; EE Magee acknowledges culpability for this. As such, the* *following e-mails document this exchange but only the final, complete response to reviewers is provided as it builds on all others.*

09/04/24

Dear JAMES EVANS, Kaitlyn Crouch, Caroline Studnicky, Sharon Bone, Nicholas Edwards, Samuel Webb:

Thank you for your submitted revisions and apologies it has taken us awhile to get round to considering them further - job interviews and the Easter holidays have gotten in the way of things a bit.

In a bid to make up for our tardiness, we have carefully read your revisions, review response, and letter to the editors, and I was hoping this would be sufficient for us to make a decision on the manuscript. However, we found it difficult to assess whether or how some of the reviewer comments raised were addressed. In particular, we found that the responses to comments provided for the one submitted review form were brief and directed us either to the marked-up document or the editors letter, and that the summary points raised in the editor letter, whilst detailed, were not clearly aligned with specific reviewer comments. Unfortunately, as is, we feel we cannot perform our due diligence regarding assessment of the response to reviews without a direct point-by-point response to the reviewers. As a guide, I have included some examples below where it is not clear how some comments have been addressed / considered:

1) Lydia Bailey - "I noticed that the discussion on slip deficit, energy adsorption, and frictional strength of the studied faults was only briefly mentioned in the conclusion, with minimal reference to these topics throughout the rest of the manuscript. It would be beneficial for the authors to either expand upon these concepts or remove them entirely. If they choose to delve deeper into this aspect, it would be valuable for them to explain in more detail how the observed fluid-rock interactions contribute to the distribution of seismic energy. The potential story of the weakening and strengthening of the fault zone through different phases of fluid-rock interactions is intriguing, and I believe the authors have sufficient data and textural evidence to explore this further."

2) Simone Masoch - "Description of specimen (section 3.1): Most observations are hardly observable in figure 3 and in many cases there no reference to the figure. For instance, at page 11 “These zones consist of chlorite ± calcite ± epidote ± clay shear zones, cataclasites, and regions of altered rocks that include calcite, zeolites, chlorite, and Fe-oxides. Sharp boundaries define fault slip zones, and clasts of earlier-formed cataclasite are present (Figure 3)”. Where are the chlorite ± calcite ± epidote ± clay shear zones in the samples? Where the cataclasites? Where do show the altered rocks including calcite-zeolite-chlorite and Fe-oxides? Then, what does the color legend refer to? Also it is not clear to me how you discriminated between the chlorite-rich shear zones and the foliated cataclasites. In general, describe

properly the fault architecture and the fault zone rocks forming the different units forming the fault core strands and the damage zones. Moreover, it is not really clear from where the samples shown in Fig. 3 come from within the logs."

I can see this section and figure have been improved, but the zones are still not clear to me (perhaps you could add interpreted maps of the cores?) and nor is the source of these samples apparent on Figure 2.

3) Simone Masoch - "For instance, at page 35 “Twinned calcite cement in pulverized rocks, in which intragranular fractured rocks recover some of the lost strength of the damaged grains via cementation, indicates that precipitation of calcite was followed by added loading in the fault zone. Calcite twins can occur at temperatures as low as ~20°C (De Bresser and Spiers, 1997; Ferrill et al., 2004). Twinned, i.e., aseismic, calcite veins were subsequently cut by brittle fractures filled with precipitated zeolite. The calcite grains with optically measurable twins indicate a temperature range of ⩾ 20°C to ⩽250°C with the high density and morphology of the twinning likely indicating temperatures closer to ~170°C - 200°” In which figure do you show the twinned calcite cement in the pulverized rocks? Could you add the analysis of the calcite twins you used to estimate the deformation temperatures?"

It seems this text has been removed, but it would be useful to provide a justification as to why and whether it affects the manuscript conclusions.

Overall, we understand differences of opinion may occur between reviewers and authors, and that not all reviewer suggestions need to be actioned, but in our assessment it is useful to know what has been changed and what has not, and why.

30/04/2024

JAMES EVANS, Kaitlyn Crouch, Caroline Studnicky, Sharon Bone, Nicholas Edwards, Samuel Webb:

We have reached a decision regarding your submission to τeκτonικa, "Fluid-rock interactions, hydrothermal processes, and accommodation of slip in shallow parts of the San Andreas and San Gabriel Faults, southern California".

Thank you for preparing a revised version of the manuscript and an updated response to reviewer comments. We have carefully read through both and, though I admit Noah and I are in some disagreement here, I would like to request some minor revisions be made to the manuscript. Part of our concern relates to the lack of detailed response to all Reviewer A comments (only their section A.1.1.1 is responded to), but from a couple of reads I think most comments have been addressed in the manuscript.

In terms of minor revisions:

1) I still feel there is a disconnect within and between the introduction and discussions sections. The introduction discusses shallow slip deficits and potential mechanisms for, then describes the importance of fluid interactions, before posting several questions of which only the latter two directly relate to fluid-rock rock interactions. The introduction also outlines that the study objectives are to examine the physio-chemical processes of the shallow fault zone. In contrast, the discussion identifies various fault rocks and structures and then documents how different parts have been altered, to varying degrees, by fluids at different times. From the conclusion it is evident that you consider cementation can strengthen faults rocks, whilst alteration weakens them. If I'm correct in my summary above, there is no clear return to the problem of shallow slip deficits raised in the introduction, nor is there clarification as to which of the five questions posed the work helps answer.

To help solve this disconnect, and the uncertainty it brings, I think that: (i) in the introduction there needs to be more of a bridge between how fluid interactions may contribute to proposed mechanisms for explaining shallow slip deficit (e.g. would weakening rocks by alteration mean bulk plastic yielding of fault rocks is more feasible, or that lower cohesion and frictional strength of off-fault rocks favour distributed deformation?), which could be framed as hypotheses to test; and (ii) the discussion needs to return to these and explain how the study findings fit within this broader fraemwork of understanding shallow slip deficits. I also note here that the conclusion should be a summary of the entire paper, so any concepts, etc... raised there should first have been mentioned and explored in the discussion section.

2) This comment relates to the previous in terms of expanding the discussion for clarity. In the final paragraph of the discussion you mention that your data "indicate that complex combinations of deformation and geochemical processes strongly influence seismogenic faults", but it is still not clear how the alteration you describe influences faults. Yes, you document different stages and types of alteration / cementation but what affect did these rocks / processes have on faulting? I see from the final two sentences that you discuss slip localization and the widespread nature of alteration, but they don't specify how you know that said alteration had an effect. Borrowing from the conclusion again it would be useful to elaborate on how you know alteration leads to fault weakening, and how you know cementation increases strength (e.g. there are many situations where stronger materials actually localise stress easier and so deform first). I think all this is in the text in various places, but for a reader its a bit difficult to disentangle pieces and rbing it all together currently.

3) In the final paragraph you also state "These results suggest a more complex combination of processes than earlier models may predict (Williams et al., 2021)." Perhaps it is a warped view on my part following some bad experiences I've faced as editor for the passed 8 years, but these sorts of sentences I've found have been the locus for some unpleasant interactions. Objectively they are often correct, but to some readers appear antagonistic. I do not question the intention of including this comment, but would ask that you consider its phrasing, or even remove it as I do not think it adds much to the discussion.

Finally, I would ask that you update the reviewer response to acknowledge all reviewer comments. All reviews and your responses will be published alongside the paper and given the effort reviewers put into reviews, I think it right that there is clarity that all comments have been considered.

Kind regards,

Craig Magee

***Response:***

20/05/24

Further responses to the reviewer and editor's comments regarding our Tektonika paper, now entitled:

**Signatures of fluid-rock interactions in shallow parts of the San Andreas and San Gabriel Faults, southern California**

By myself, Kaitlyn Crouch, Caroline Studnicy, Sharon Bone, Nicholas Edwards, and Sam Webb.

**Please note – I have (10-19 Apri, 2024) re-revisted the figures, their annotations, captions, and agreement with the text, following on the emails and messages from editors. Our replied below are in the larger font.**

## I. Editor summary comments

In particular:

- All reviewers expressed that the figures need to be improved with consistent formatting and additional annotations for clarity. The number of figures could also be reduced.

Most of the figures have been revised, clarified, and annotated. Figure captions have been rewritten accordingly. The number of figures has not been reduced. While we tried to achieve this, the overall comments asking for more detail, greater clarity, the requests for more evidence to support our work, and the delays in submitting our third paper (which is based on Studnicky's work on the San Andreas Fault) requires more figures, and splitting out some figures for clarity. We did eliminate parts of several figures, so the net figure space is about the same.

| Figure number | Actions / edits |
| --- | --- |
| 1 | Simplified with a single regional location map. B&W and gray scale. The small inset maps are eliminated, and the parochial nature o fthe figure and caption has been eliminated to make it |

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|---|---|
| | clearer to the non SoCal scientists. |
| 2 | This figure has been simplified into two basic sections, with the sample locations labelled. |
| 3 and 4 | These figures were grouped previously. The are separtated to enable the ties to text to be made clearer and for slightly expanded captions. |
| 5 and 6 | These are new figures. Reviewers indicated that greater context was needed for the work, samples, etc. Crouch and Evans (2023) provive much of the needed context for the SGF samples; Studnicky (2021), and Studnicky et al in prep provide context for the SAF work. We provide opticaly images of key aspects of these rocks, without shingling with other papers. |
| 7 | Figures 7-10 are rather "traditional" treatments of the whole-rock geochemistry of the fault-related rocks. We present these data to provide what a rather more standard treatment would consist of, AND to provide data for our semi-quantification of the results of the XRF mapping provided later. [1] |
| 8 and 9 | These cross plots show the relationships of the major cations as a function of Si content, for the groups of rock identified from core and optical-scale microscopy. In the previous figures, corrected here, I mistakenly misscaled the covariance ellipses, such that many of the ellipses encompassed few of the data. These ellipses are not calculated and scaled according to the scale of the abscissa and ordinate (which do not have the same scales). |
| 11 | Per reviewer suggestions, what was Figure 5 is moved to Fig 11. This helps address the issue of organization, as we now have Figures 11-19 presenting XRF map data. |
| 12-19 | These figures have been reorganized, annotated, rescaled, and reworked in terms of color balance, tone, and intensity, to emphasize the points we make in the text , |
| | |

- All reviewers found that the text organization reduced the clarity of the content and suggested that it could be condensed and simplified. They have each provided excellent feedback to help with this process.

The paper has been organized following these suggestions and we feel we have focused the text accordingly.

- All reviewers found it difficult to assess how this manuscript fits in with the many others cited (Crouch et al., submitted; Studnicky et al., in prep; Williams et al., 2021). We appreciate this is difficult to convey when papers are note published yet, but we highly recommend stating their relationship explicitly where appropriate.

We addressed this earlier in our letter of 23 Feb 2024. Crouch and Evans 2023 is now published; Studnicky et al. is still a work in progress. We have pulled in as much of

[1] As pointed out earlier, and perhaps below, one of the points of this paper is that while we could make various fluid-rock ratios, or enrichment-type estimates based on these data, the maps we present in Figures 11-19 indicate that the micron to mm scale variations of the major cations might make these quantifications less meaningful. We don't want to "bash' these sorts of analyses – indeed, we have made them previously; but we want to show how variable the compositions are in these rocks. perhaps, with a bit more beam time at SSRl, I might try to make such calculations at the very fine scale, - a topic for another paper.

Studnicky as we feel sets the context without risking overlap with that work to be submitted soon. I am well aware that theses are not mainstream citable literature – and we do not purport otherwise here. The point of this submission, Crouch and Evans (2023), and Studnicky et al. in prep, Studnicky (2021) is the core source of that paper. Studnicky (2021) thesis is easily retrievable via our electronic library – the reference cited in the paper; it has been downloaded 212 times, and the abstract of the thesis has been viewed 93 times. Studnicky's data sets (also cited) have been viewed 167 times, and there have been 56 downloads of the data. Crouch (2022) has been downloaded 116 times, with 70 abstract views; here, the data compilation abstract was viewed 88 times. Thus we feel that the raw data and first-pass analyses and interpretations have reached a reasonably broad audience. Where applicable, we also cite Williams et al. as context.

## Comments by Reviewer A (Lydia Bailey) and Author response

[Review included a Tektonika review form and commented manuscript]

Evans and colleagues have conducted a detailed examination of samples collected from boreholes along the San Andreas and San Gabriel faults in southern California. They have provided extensive mineralogical, geochemical, and textural observations to support their argument that the fault rocks underwent alteration during shallow-level deformation. They suggest that this alteration resulted in a reduction in frictional in these rocks. perhaps, with a bit more beam time at SSRl, I might try to make such calculations at the very fine scale, - a topic for another paper. strength, while the presence of cementation and vein precipitation increased the strength of the rocks. The dataset presented in the submission is comprehensive; however, I believe that some reorganization and condensation would greatly benefit the clarity of the paper.

In our new paper, we downplay or eliminate the mechanical interpretations. We try to demonstrate that our results might suggest a weakening and other mechanical effects, but we refrain from going further. That would require a much deeper understanding of our clay mineralogy, reviews of various estimates of frictional properties, etc.

In particular, I found that the figures, although occasionally helpful, lacked sufficient annotations and clarity, especially in regard to the elemental map figures. It was unclear what the main observations were in these figures and why each of them was necessary. I believe that with a reorganization of the manuscript, these figures can become more useful and informative.

We hope that readers will find the new figures, reformatted, with greater detail, scales, annotations, and figure captions, to have ameliorated this concern. As described above, the figures have been reformatted, annotatited, and we rewrote the figure captions and text to link these.

Additionally, I noticed that the discussion on slip deficit, energy adsorption, and frictional strength of the studied faults was only briefly mentioned in the conclusion, with minimal reference to these topics throughout the rest of the manuscript. It would be beneficial for the authors to either expand upon these concepts or remove them entirely. If they choose to delve deeper into this aspect, it would be valuable for them to explain in more detail how the observed fluid-rock interactions contribute to the distribution of seismic energy. The potential story of the weakening and strengthening of the fault zone through different phases of fluid-rock interactions is intriguing, and I believe the authors have sufficient data and textural evidence to explore this further.

As mentioned above, regarding frictional properties, we have eliminated mention of these issues. This is a topic for further discussion in another paper.

I appreciate the authors' efforts in conducting this study and presenting their findings. However, it is worth considering the contribution of this work to the existing body of knowledge, particularly considering Williams et al. 2021 and the other studies by the authors that are in preparation or in submission e.g., Studnicky et al. (submitted), Crouch et al (in revision) which may share similar data and conclusions. While all these studies provide valuable insights, it would be helpful for the authors to clearly articulate the unique aspects or advancements offered by their research that differentiate it from the previously published work. This will enhance the significance and novelty of their findings and reinforce the contribution of this study to the field.

We are well aware of Williams et al., 2021, and we cite it as needed throughout the paper. Williams et al., 2021, focus on one part of the fault zone, and we (this paper, Studnicky et al. in prep, and Studnicky, 2021) examine all parts of the inner part of the San Andreas Fault zone which go far beyond the range of analyses in Williams (C. Rowe, email comms., 2023, 2024). Studnicky worked at the same department in the autumn of 2019 with Dr. Williams and with Dr. Christie Rowe. Studnicky et al., is co-authored by Dr. Christie Rowe, also a co-author of Williams et al.

## Comments by Reviewer B (Tsuyoshi Ishikawa) and Author response

This paper provides interesting data on micro- to meso-scale geochemical signatures observed in shallow parts of the San Andreas and San Gabriel faults. The interpreted geochemical data combined with previously reported structural geological and mineralogical data are useful in understanding the physicochemical processes, including fluid-rock interactions, occurring at the seismic faults. In particular, SRS-XRF microanalysis is new in this field. I recommend that this paper will be suitable for publication in TEKTONIKA after appropriate revision.

In general, the data are good and of high quality. However, because the structure of the main text is not well organized, it is sometimes difficult to follow the interpretations and discussions of such extensive data. I suggest some reorganization of the main text as described in an attached file. I believe that this will increase the value of this paper.

*Please see points 1 and 2 of the overview of our revision summary.*

*1. We have thoroughly revised the paper, tried to write a clearer text that is reorganized along the lines of the reviewer suggestions. We used new grammar checking processes to create a clearer presentation of the paper. Several reviewers indicated that the paper needed to be better organized, and we have followed these suggestions.*

*2. The introductory materials, geologic setting, and detailed setting of the sample sections have been reorganized/edited along the lines of the reviewer's suggestions. We have a new, clearer regional geologic map of the area that is less parochial in its presentation of southern California geology, and we also revised the text to make it more readable by people not familiar with the geology here.*

The main points of improvement I would like to suggest are reorganization of the main text to improve the presentation of the geochemical data. Because the data presented are extensive but the structure of the main text is not always helpful to the readers, it is sometimes difficult to follow the authors' interpretations and discussions. For details, please refer Section B. I also point out that the text contains many references of "in revision", "submitted" or "in preparation", and some of such references seem important to understand the background of this paper. It is desirable that the authors add sufficient descriptions and explanations to know such background so that readers can understand this paper without currently unavailable references.

*Please see points 1, 2, and 4, regarding how we address these issues.*

*3. []Reviewers commented on several aspects of the geochemistry data.*

*a. At least one reviewer indicated that they thought this paper would have had more*

*quantitative analyses of geochemical data, and suggested changing the title of the paper (which we did) and we made some edits to try to emphasize the point that we* *are trying to make here – that we document the presence of syntectonic alteration, make some qualitative conclusions regarding this alteration, and introduce the XRF mapping to help identify the nature and location of alteration and mineralization textures.*

*b. We tried to simplify and clarify the presentation of the traditional geochemical data. In colloquial terms here – we provide traditional whole-rock data, describe what interpretations we might draw from these data, and then add the XRF mapping work to show how this effort adds to our ability to interpret the data. Happily, most reviewers seemed to get this. We describe the geochemical data in the context of the key elemental groups, (REE, major, minor, etc). We try to point to the limitations of what we have thought are 'high-resolution' 2 g-based analyses and that these analyses can be further interrogated with the XRF mapping.*

*c. We could have performed some more quantitative analyses of the geochemical data, to constrain fluid-rock interactions, evidence for volume loss, etc. (Indeed, we have contributed to these sorts of efforts – see for example, Evans and Chester, 1995; Goddard and Evans, 1995). I am much less confident that these methods are robust in brittle – semi-brittle shallowly deformed rocks due to the spatial heterogeneity of the alteration and mineralization. This is a point that we try to make with the XRF data (see a, above).*

*We could provide the geochemical analyses and their limitations based on our XRF maps, but that should be presented in another paper – some of the geochemical analyses (Gresen's method, etc.) and their interpretations will take quite a bit of text and would make this paper quite long and lose focus.*

From the current title "Fluid-rock interactions, hydrothermal processes, and accommodation of slip in shallow parts of the San Andreas and San Gabriel Faults, southern California", readers may expect quantitative discussions on fluid-rock interactions and hydrothermal processes (e.g., fluid chemistry, fluid- rock ratios, chemical reactions, reaction temperatures, and fluid transport mechanisms). The geological, petrological, and mineralogical data on the samples used in this study seem to have been published or submitted elsewhere, and the new geochemical data in this study are essentially used as qualitative proxies for fault and fluid processes rather than as tools for their quantitative estimation. Therefore, the current title may be somewhat misleading. For clarity, the authors may add more specific terms such as "micro- to mesoscale geochemical signature" to the title.

*All reviewers pointed to citations to submitted papers. Crouch and Evans (2023) is now published, and the work of Studnicky (2021) is openly available at the link provided. These papers are parallel constructed and present the core-scale and microstructures of deformed rocks sampled in the cores. These papers provide the critical setting and context for the present paper. We did add a new figure here to show some of the overall key microstructures, to make a clear transition from these microstructural observations to the new work presented here. The samples discussed in the new figure are samples* *that we examined in the XRF mapping. The first paper based on Studnicky's work (Studnicky et a;, in prep) is close to being submitted, but we are refining some final aspects of that paper and so we can't yet cite it.*

This part is generally well written. However, I feel that the authors could strengthen the descriptions of the usefulness of geochemical and mineralogical analyses of fault-related rocks so that the SRS-XRF mapping data presented in this paper are more emphasized.

Most of the content of the last paragraph of 2. Method (P. 10, L. 6-16) can be moved to the Introduction section and placed just before the last paragraph of the Introduction.

*Please see points 1, 2, and 3. In our summary of our edits.*

1) I think that the section 1.1 (Geologic Setting) should belong in a section such as "Geologic Setting and Samples" not as part of the Introduction.

2) Some of the important information on geologic settings and analytical methods is given by the "in revision", "submitted", or "in preparation" references, which are not currently available. The authors should

add some descriptions on these topics.

3) P. 6, L. 18-19 "Core-based studies of fault zones provide less altered rocks that have better-preserved alteration and deformation textures": The "less altered rocks" means "rocks that have undergone the least secondary weathering/alteration" and "alteration" means "the nature of primary hydrothermal alteration"?

4) P. 6, L. 25-26: It will be helpful to the reader to show the range of beam energies, spot sizes, and dwell times in the SRS-XRF analyses, even if the details are given in the Appendix.

*Please see points 1-4 for our efforts to address these comments*

1) Some of the important information on mesoscopic structures, microstructures, and alteration mineral assemblages is given by the "in revision", "submitted", or "in preparation" references, which are not currently available. The authors should add some descriptions on these topics.

2) 1st paragraph of 3.1 (P. 11): Some of the information on drilling, core logging and related lithological and structural descriptions can be moved to the section "Geologic Setting and Samples", as they seem to have been described in the previous studies.

3) It is desirable that brief lithologic, mineralogic, and meso/micro-structural descriptions of each sample appearing in Figures 3 and 4 are summarized at the beginning of Section 3.1. I think that this will makes it much easier to understand the correlation between microstructure, mineralogy, and geochemistry of each sample.

4) P. 12, L. 7-10 “Rocks from San Gabriel Fault ...”: These descriptions do not match those in Figure 3. I think that it will be better to show the photos of the San Andreas and the San Gabriel samples in separate figures.

5) P. 14, L. 1 to P. 15, L. 17 “The samples consist of .... fractured potassic feldspar zones”: The abrupt appearance of the SRS-XRF mapping-related descriptions is very confusing. It is desirable that these descriptions are moved to the Section 3.3.6) P. 15, L. 18-19: It seems that whether or not the pseudotachylyte is present in the sample is not important for the purposes of this paper. If the authors believe that the occurrence of frictional melting is relevant to the discussion of fluid-rock interactions, they should say so.

7) Last paragraph of 3.1 (P. 15, L. 19-26): These descriptions of alteration mineral assemblages can be moved to the beginning of Section 3.1.

8) P. 17, L. 14-15 “Relative to those additions ...”: The relative depletions of Si, K, and Na in the FDR and gouge samples cannot be seen in Figure 5.

9) P. 22, L. 13-26 “Trace and rare-earth element data .... Cs, Ta, and Th (Figures 8c and d)”: The reference protolith values should have some variation. Please show 1SD values of the protolith values (enrichment factor = 1) in Figure 8. Also, I think that the authors may make a more quantitative discussion, for example, by using an isocon plot.

10) Section 3.3: It is difficult to follow the descriptions and discussions in this section, because the descriptions of the SRS-XRF mapping data are rather vague, and not explained in terms of correlation with the microstructure and mineralogy of each sample. It is desirable that the SRS-XRF mapping data for each sample be described with reference to the microstructure and alteration mineralogy in the same sample. Perhaps, some of the content of the captions for Figures 9-16 should be shown in the main text so that readers can understand the micro-scale geochemical signatures that correlate with microstructures and alteration textures of each sample.

*We used these comments to guide our detailed rewrites that are all summarized in the overview of the edits we made, and see also the track changes version of the paper.*

Here I consider Section 4 “Analysis and Implications” to be the discussion section.

1) P. 34, L. 29-32 “The Nb, Hf, Ta, and Th signatures are ...”: If the increases in these fluid-immobile elements simply resulted from the alteration-induced volume reduction, why are the enrichment levels of these elements are different from each other?

2) P. 35, L. 21-24 “The cross-cutting relationships, ... mobilize the rare-earth and carbonate elements”: I think that this paper does not show clear evidence for fluid-induced REE mobilization.

3) P. 35, L. 25-26 “Our work documents the utility of integrated X-ray-based elemental mapping ...”: I strongly agree with the author’s opinion.

4) P. 36, L. 24-26 “hydrothermal alteration synchronous with brittle deformation”: I may be misunderstanding, but this point is not well discussed in this paper. The correlation between the geochemical and mineralogical signatures and deformation-induced microstructure does not always show that they are produced synchronously.

*Please see points 4 and 5, and the significant edits in the track changes version of the paper.*

1) Figure 1: The acronyms “LT”, “BT”, “Pmgn”, and “Kgrd” in the caption are missing from Figure 1.

2) Figure 3: It will be better to show the San Andreas and the San Gabriel samples in separate figures.

3) Figure 4: Figure 4d (“D”) is not denoted on the figure.

4) Figure 5: The graph formats should be consistent between Figure 5a and Figure 5b.5) Figure 6: “FDR” in the caption is shown as “DZ” on the figures.

6) Figure 7: It will be better to show abbreviated rock types as shown in Figure 6.

7) Figure 8: Figure 8c shows the San Gabriel data according to the description on the figure, but shows the San Andreas data according to the caption. Also, I do not see any depletion of Sm in these figures.

8) Reference to papers “in revision”, “submitted” or “in preparation” should be avoided, if possible.

1) P. 1, L. 24-25 “trace and transition elements”: Trace elements and transition elements are named based on different categories. The expression “Mobility of trace and transition elements in the deformed rocks” is misleading because it implies that trace elements such as Nb, Zr, Y, and REE are mobilized along with transition elements such as Cr and Fe.

2) P. 9, L. 1 (plus P. 22, L. 13; P. 34, L. 9-10; Caption for Figure 8) “trace-, and rare-earth element analyses”: Rare earth elements (REE) are a group of trace elements. In this paper, it seems that REE are not particularly important among the trace elements. Therefore, it is better to call them all “trace elements”.

3) P. 22, L. 10-11 “The volatile component”: For clarity “the LOI component” is better.

4) P. 35, L. 23-24 “rare-earth, trace, and carbonate elements”: See the Comment #2. Also, the term “carbonate elements” is not commonly used. Does it mean elements that are enriched in carbonate minerals?

*4. [Free form We changed several figures for the XRF mapping from the San Gabriel Fault – here we added SGF 65.1 and 71.1 to efficiently summarize key aspects of microtextures, alteration, and mineralization for two samples that show the range of* *alteration related to deformation.*

*5. We have rewritten the analyses, discussion, and conclusion sections to make the points outlined in point 4, above. This re-writing addressed our efforts to clarify the interpretation ofthe whole rock data and tie these data to the XRF mapping. We try to make the point that while traditional whole-rock data are important, for rocks of this structural level, compositional heterogeneities are revealed, and we need to use a range of methods to determine the nature of the alteration and mineralization.*

*6. One reviewer asked for more details regarding the XRF mapping. We are bumping up against length limits, so we added more detail to the Appendix that describes the methodologies used. We also add some references to the approach in the paper and the appendix. I hope that future papers that will go into much more detail of our XRF and spectroscopy work will provide more details on the approaches.*

*The other issues are addressed in the points summarized above.*

## Comments by Reviewer C (Simone Masoch) and Author response

**Review of manuscript entitled "Fluid-rock interactions, hydrothermal processes, and accommodation of slip in shallow parts of the San Andreas and San Gabriel Faults, southern California" by Evans et al.**

This study presents a characterization of samples retrieved from boreholes performed along the San Andreas Fault (Lake Elizabeth site) and the San Gabriel Fault (Tujunga field sites), Southern California. The characterization consists of meso- and micro-scale observations, through analysis of drilled-core specimen, optical microscopy, whole-rock X-ray fluorescence and synchrotron radiation scanning X-ray fluorescence, aiming at evaluating the fluid-rock interaction across the different damaged and strained fault zones of two fault zones. Although the several techniques applied by the authors and the high-resolution analysis performed on 22 selected samples (52 elemental maps were collected) to investigate these fault zone rocks, I found the material presented in this manuscript not organized at all and missing a careful and structured documentation of the mesoscale and microscale observations, which is required to evaluate the fluid-rock interaction in the studied samples. In particular, many observations described in the results sections are not reported in the figures or, if reported, I found very hard to read the figures, especially the graphs illustrated in figures 5-8 (see points below). As a consequence, as many observations are not presented and many key points are not properly documented I found very hard to evaluate positively the quality of this work and evaluate how what is presented in the manuscript could improve our comprehension of the processes governing fluid-rock interaction within fault zones at shallow crustal levels. In conclusion, the research presented in this manuscript requires more deep work and I consider it far to be considered suitable for publication. However, I think the authors have the material to come up with a nice piece of work, if presented in a more structured and careful way which in turn could help also to improve the quality of their interpretation. Hoping to help the authors to improve the quality of this work, I list some suggestions to clarify many points critical from my point of view.

Regional sections and mesoscale observations: the regional section is fine, however Figure 1 has to be redone. The zooms shown in b and c could be enlarged and shown clearer the relevant geological features. Moreover, it would be worth to add some more regional information presented in the text, which could help a reader not familiar with the geology of South California.

Please see above. Figure 1 redone, text rewritten.

Cross sections across the two studied faults: figure 2 is almost impossible to read and I wonder if all the information reported is really necessary. Cross section in a: add a legend of the several lithologies, add the orientation of the cross section, use better symbols to mark the samples analyzed and refer to them. The resistivity log is impossible to read. Caption of Fig. 2b: “Simplified lithology, fracture density, locations of core samples, geochemical data, and the locations of the fault zone from Crouch et al., submitted, and Crouch, 2022.” This is shown in 2c not in 2b. “ALT-B2 shows two principal slip zones, two damage zones, two highly fractured zones, and two zones of lower fracture intensity and plastic shear (blue arrows)”: all of this is not present in the figure 2b. The log shown in 2c is impossible to read.

Many thanks to this reviewer for pointing out what is required to document fluid-rock interactions and alteration in fault zones. As we try to make clear in the motivation/ introduction, and the mesoscopic observations, this paper builds on these very sets of observations – now published in Crouch and Evans 2023; in Studnicky, 2021; which we aim to submit as. Appear soon; and Williams et al., 2021. Adding significantly more mesoscopic and microscopic analyses here would further bloat this paper, and detract from the point we are trying to make with the results of elemental mapping. As to these issues, and the issues of organization, a point we try to make with the whole core elemental map is exactly what this reviewer seems – a macroscopic optical image of the deformed rock over a 60 cm length, and the elemental maps. We attempted, and failed, to try to weave this into the mesoscopic descriptions to make this very point – w but all reviewers did not appreciate that organization and thus we moved the XRF mapping to be all together. Figures cross section figures have been redone. I cannot imagine how these figures are unnecessary – they provide the fundamental location / structural context that reviewers expressed clearly to want. We keep these sections for this reason. The resistivity log is cut; reference to Crouch and Evans 2023 now cite a published a paper The cross sections figures can be made as large as you’d like. The location of the core, thin section, and XRF map samples are all inidicated on these sections.

In general, be consistent with the symbols in the two cross sections to help the reader. Description of specimen (section 3.1): Most observations are hardly observable in figure 3 and in many cases there no reference to the figure. For instance, at page 11 “These zones consist of chlorite ⍰} calcite ⍰} epidote ⍰} clay shear zones, cataclasites, and regions of altered rocks that include calcite, zeolites, chlorite, and Feoxides. Sharp boundaries define fault slip zones, and clasts of earlier-formed cataclasite are present (Figure 3)”. Where are the chlorite ⍰} calcite ⍰} epidote ⍰} clay shear zones in the samples? Where the cataclasites? Where do show the altered rocks including calcite-zeolite-chlorite and Fe-oxides? Then, what does the color legend refer to? Also it is not clear to me how you discriminated between the chlorite-rich shear zones and the foliated cataclasites. In general, describe properly the fault architecture and the fault zone rocks forming the different units forming the fault core strands and the damage zones. Moreover, it is not really clear from where the samples shown in Fig. 3 come from within the logs. Fig. 4: show clearly the fault zone rocks shown in the other maps. In the figure, the label D is missing (or not visible to me) in the figure. Consequently, it is impossible to follow the description and evaluate it. Then, I do not get how you determine the amorphous nature of some Fe-rich zones mentioned in the figure caption and in the text. Could you clarify this point?

Annotations and descriptions of Figures with core samples have been greatly improvised, as have the captions and the associated text. I feel these images are now well documented. I chose not to make maps, as they would further add to the length of the paper. We added new Figures 5 and 6 to summarize the nature of the mineral assembleges discussed here. So the Figures can be tracked from cross sections in Fig 2 score in Figs 3 and 5 to the XRF maps in 11-19.

"Samples from the San Gabriel Fault include similar structures, and both faults may also provide evidence for the presence of pseudotachylyte [Crouch, 2022; Crouch and Evans, in revision]. Opticalpetrography and X-Ray diffraction analyses show that the protolith gneiss is moderately to highly altered within the fault damage zones. In the San Andreas Fault, the common alteration assemblages are calcite, zeolites (primarily laumontite, wairakite, and heulandite), chlorite, smectite, hematite, and epidote. In the San Gabriel Fault, the host rock consists of quartz, albite, anorthite, and muscovite. In the damage zone, smectite, phlogopite, calcite, and undifferentiated zeolites are present. In the highly sheared rocks, Ti and Mn oxides, epidote, and clinochlore appear throughout the damage zone. These minerals are sheared,occupy fractures, and appear to replace feldspars, amphiboles, or biotite." (page 15) I suggest to show all these observations in the figures and refer to them in the text. I suggest to add a section describing the microstructure of the fault zone rocks before jumping to the geochemical analysis. This would clarify and structure your work.

Microstructural figures 5 and 6, and 12-19 have been edited, labeled, and additional text is provided in the figure captions , along with relevant text, to address this and to risk repetition, these are also discussed in Crouch and Evans, 2023, which was in press at the time we submitted this paper, and is cited here. Descriptions that we didn't explicitly show here but allude to are in Crouch and Evans, or Studnicky. We have taken these descriptions and any related images as far as is warranted without shingling the papers.

Geochemical analyses (section 3.2): what is presented in the text is not well illustrated in the figures. So from my point of view, it is hard to evaluate its goodness. Figure 5: as said above, it would be worth add a clear meso- and micro-scale fault zone rocks and it would help the interpretation of these data. B is impossible to read. In general, make the figure more readable. Question: till this point you never present any pulverized rocks form the San Andreas Fault at Elizabeth Lake site, why did you analyze them through XRF only? And not describe it also?

There is abundant work on the pulverized rocks – Dor et al., Aben et al., Weschler et al., etc., and the rocks are on the edge of the fault zone. Our emphasis is on the internal part of the fault zone, crossed by the core in all 7 cores; pulverized rocks were encountered in 1 or 2 at their ends.

Figures 6-7: which is the strength of your bootstrap analyses of the whole-rock data? As in many cases, most of your data are outside the 90% confidence uncertainty ellipses. I would care more about the data distribution on evaluating the variation trends among the fault zone rocks. I suggest to be consist with the symbols and refer correctly to the legend: for instance, in Fig. 7 the Grano DZ is marked by orange dots in a, instead by yellow dots in b-d.

Please see above. We present the data clearly, and changed the bootstrap analyses here. – We have changed this to somewhat more conventional statistical analyses with
covariance analysis to make our paper aligned with Williams et al; 2021) – a point that other reviewers wanted us to address. Figure 7-10 are intended to present the interpretations that we, and others, would likely make – correlating textural observations with geochemical data. As for 'how good the data ar' – that is quite the point here. We, and others, would use this approach to make calls regarding the nature of the rocks. As a result, most of us would arrive at some level of interpretation of alteration, etc. BUT without the RF work, we would NOT see the grain-scale nature of the alterations and mineralization. We have re-rewritten the text to make this clearer. I do not like to frame straw men arguments – so the geochemical data are constructed in a way to show what we would do and what conclusions we might draw from just those data.
In the discussion, we state that with the whole-rock, micro, etc., we would conclude that these rocks are indeed mineralized and altered, and what the elemental signals are. But we then add elemental mapping to show the grain scales how and in what detail this mineralization occurred.

Figure 8: in b and c the same data are shown. However, you report this in the caption: "B) Data for damage zone rocks from the San Gabriel Fault. Slight enrichments in Rb, Sr, Nb, and significant enrichments in V, Cs, and Th are observed. C) Data for the San Andreas Fault gouge samples. Slight enrichments in Rb, Sr, Nb, Hf, Ta, and significant enrichments in V, Cs, and Th are observed". Based on that, I do not comment this section and I really wonder on the quality and impact of this work.

These data have been replotted, and I fixed the error of plotting the same data. Apologies
for this error.

X-ray fluorescence maps (section 3.3): The section is somehow fine. However, many microstructural features described in the text are not indicated in the figures by labels or arrows, which could really help the reader. However, this section really suffers from the lack of a clear description of the architecture of the fault zones and of the different fault zone rocks (mesoscale, microscale, and geochemical), and moreover, it is really hard to understand from where the analyzed samples (and related maps) come from.

I don't know what "somehow fine" means. My apologies. Again, we revised these figures thoroughly and hope these changes have addressed these issues. This is part of the point of Figures 2 and 3—the cross sections, with fault zone components shown. Thus, this point is a bit confusing for me to address—we are asked to, and feel have, described the setting of the different samples, from macro to micro, and yet this reviewer wanted us to delete the content of Figures 2 and 3. Each sample is clearly denoted on the cross sections, and the structural location is mentioned in the figure captions. We added Figure 17E, which relates microprobe-based EDS element data to the XRF map results for this sample to provide a calibration of the maps and elemental concentrations.

Discussion: it is really poorly supported by observations and data as highlighted above. For instance, at page 35 "Twinned calcite cement in pulverized rocks, in which intragranular fractured rocks recover some of the lost strength of the damaged grains via cementation, indicates that precipitation of calcite was followed by added loading in the fault zone. Calcite twins can occur at temperatures as low as ~20°C (De Bresser and Spiers, 1997; Ferrill et al., 2004). Twinned, i.e., aseismic, calcite veins were subsequently cut by brittle fractures filled with precipitated zeolite. The calcite grains with optically measurable twins indicate a temperature range of ≥20°C to ≤250°C with the high density and morphology of the twinning likely indicating temperatures closer to ~170°C - 200°" In which figure do you show the twinned calcite cement in the pulverized rocks? Could you add the analysis of the calcite twins you used to estimate the deformation temperatures?

The twinned calcite discussing has be eliminated. It adds very little. The Discussion is completely rewritten, shortened, and focuses focused on the results, and with more clarity. At least I think so. In conclusion, I think the research can be of interest for the community but requires further deep work to improve the quality of the manuscript and a more structure organization in presenting the data to support the authors' discussion. I hope my comments will help the authors to improve the quality and impact of their work.

# Acceptance letter

JAMES EVANS, Kaitlyn Crouch, Caroline Studnicky, Sharon Bone, Nicholas Edwards, Samuel Webb:

We have reached a decision regarding your submission to τεκτonικa, "Fluid-rock interactions, hydrothermal processes, and accommodation of slip in shallow parts of the San Andreas and San Gabriel Faults, southern California".

Our decision is to: Accept Submission