Solid Earth Discussions

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Comment on se-2022-9

Anonymous Referee #1

Referee comment on "Tectonic evolution of the Indio Hills segment of the San Andreas fault in southern California, southwestern USA" by Jean-Baptiste P. Koehl et al., Solid Earth Discuss., https://doi.org/10.5194/se-2022-9-RC1, 2022

General Comments

I suggest that this paper be accepted/reconsidered after major revisions.

In general, I enjoyed this paper: it is a good, well-written paper with a structurally interesting dataset from a major transform plate boundary fault zone. The dataset is collected from a transpressional uplift within the San Andreas fault zone, then compared to other similar features along strike. As such, the paper stands to be a good contribution for those trying to understand the internal structure, along-strike complexity, and tectonic evolution of transform plate boundary fault zones, and more specifically the along-strike complexity of the southeastern terminus of the San Andreas transform plate boundary fault.

The overwhelming majority of my comments are minor, albeit numerous. However, there are a few major points concerning the figures that need to be addressed should the manuscript be accepted for publication. These few major points concerning the figures may take some time to complete, and are my only reason for listing the revision as major, not minor. These include:

- Figure 1 needs to be redone to include a regional map with all the features discussed in the text plotted on that map and, in general, showing the study area in the regional context (southern California, southwestern USA). An updated figure could take the form of a two-panel figure, where Fig. 1a is the regional map showing major features discussed in text, and Fig. 1b is the close-up map that is currently presented as the sole Fig. 1. At present, the reader has no regional context for the features discussed in-text, and some features and faults are not shown on any map, making their comparison and importance to the study area difficult and unclear.
- All maps in the figures (Figs. 2, 3, 5, and 6) should have coordinates of some sort, whether as points or a grid. Additionally, I suggest that un-interpreted images of all of the map areas should be added to the supplemental material (an un-interpreted Fig. 6

is already in the SM).
- Folds and faults mapped on Fig. 2 appear continuous across some parts of the Northwestern, Central, and Southeastern domains. However, in Figs. 3 and 6, the folds and faults appear short and discontinuous. These figures should be updated to reflect the full extent of the structure(s) within the figure's frame to be consistent with their geology on the ground and as shown on Fig. 2.

Should these changes be addressed, I think the paper will make a good contribution. Good luck, and I hope to see this in print in the near future.

Specific Comments –

Title: Should a broader geographic description be applied to the title, given this is European journal but the study area is in the USA? Perhaps "Tectonic evolution of the Indio Hills segment of the San Andreas fault in southern California, southwestern USA"

Line 46-47 - What about this continuation in to the ECSZ? The sentence needs more description about the significance of the Indio Hills fault with the ECSZ.

Line 68 - I am curious about the use of the term "culmination" - I am only familiar with this term in fold-thrust systems. As defined at https://link.springer.com/content/pdf/bbm%3A978-94-011-3066-0%2F1.pdf : "Culmination: An anticline or dome with four way closure generated by movement of the thrust sheet over underlying ramps." I understand you have transpressional folding/thrusting going on in your study area, so the term could be used, but does the Indio Hills exhibit folding over underlying thrust ramps? Or are you simply referring to a variety of distinct tectonic elements all observed together in one place? If the latter, I think a different term is warranted. If you choose to keep the term culmination, I think you need to explicitly define it, either here or in your Tectonic Culminations section below. Perhaps it is best to simply call it the Indio Hills uplift here on Line 68, as you do in the Fig. 1 caption, and leave the use of culmination (if you keep it) for the section below.

Line 69 - You state the Indio Hills are a transpressional uplift, but consider it analogous to a rift feature (which would suggest transtension)? See next comment.

Line 68-70 - I think what you mean is that the Indio Hills and Mecca Hills are analogous in that they are both inverted basins? If that is correct, be more explicit here. For example, you could say: "The Indio Hills uplift is an inverted Miocene–Pliocene sedimentary basin lying upon Mesozoic granitic basement rocks. Further to the southeast, the Mecca Hills are also shown to be an inverted Miocene–Pliocene sedimentary basin (Keller et al., 1982; Damte, 1997; McNabb et al., 2017; Bergh et al., 2019)."

Lines 84-86 – You state “We consider” but then list references. Are you interpreting that these units are The Mecca Formation, or did the cited authors interpret these units to be the Mecca Formation in the Indio Hills. The former is slightly problematic, as it is an interpretation before the data section (but understandably a necessary one to make for your study).

Line 103-104 - How would sediment accumulation rates define the age of a formation? More than likely, the dates of those stratigraphic members were used to calculate the sediment accumulation rates. Did the lower and upper members of the Palm Springs Formation show increased rates of sediment accumulation during these intervals? If so, specify that.

Lines 114-117 - See above comment on use of the term culmination. You only use the term four times in the paper, here three times and once in the former section. I suspect the term should be changed, given the formal definition I pasted in the Line 68 comment above, but if you choose to keep the term then define what you mean by “culmination” either here or at Line 68.

Line 119-124 - Your broad-scope description of tectonic elements here shows the necessity of adding a regional map to your Figure 1. At present, the reader has no context for the Eastern California shear zone (which is a much broader region than you show it in Fig. 1), the San Bernardino and San Jacinto faults, and San Gorgonio Pass. These features need added to a map with the location of the study area clearly shown so the reader can see their relationship and importance to the work presented here.

Line 155-156 – Delete the word “off-fault” – damage zones typically encompass principal slip surfaces but are technically part of the fault zone, too, so it seems kind of like a misnomer to say off-fault

Lines 160-163 – Is there a reference for this statement?

Line 219 - Are you saying that the open upright fold geometry is the result of (via) the kink/chevron styles? If so, no change is really necessary, but perhaps it could be described more clearly? If not, and instead you are describing a sequence of changing fold patterns, then I'd replace "via" with "to"

Line 241 – Here again with “via”. Do you mean the something is the result of the kink/chevron geometry, or are you saying it is spatially changing from symmetric style, to then changing to a kink/chevron style, to then changing to isoclinal? If so, I'd suggest replacing "via" with "to"

Line 273 – What do you mean by monocline-like? It seems the fold would either be a monocline or an anticline, not a mix of the two. According to your Fig. 3C the fold closest to the Indio Hills fault very much looks to be an asymmetric anticline, with 20NE dip on the northeast limb and 45SW dip on the southwest limb, in which case I would delete "monocline-like" from the sentence.

Line 299-305 – What kind of folds are these? Anticline? Syncline? Both? Note that hinge lines are not mapped on Figure 5 like they are on Figure 2.

Lines 307-319; Lines 310-311 – If you are discussing faults and fractures in the basement, then that is not a fold-related fault (unless the basement is folded). Perhaps the section should be renamed "Major and minor faults, fractures, and fold-related faults"

Line 388 – Cite Figure 2 stereonet at the end of the sentence. Also, these fracture sets look to be ~90° to one another; I'd expect conjugates to be ~60° (40-70°) to one another. It might be best to delete the "possibly representing conjugate sets" from the sentence, as I don't think these are conjugates. This shouldn't pose a problem, as you don't discuss these features any further in the manuscript.

Line 416 – "…indicates a younger phase of deformation." Saying younger slip event makes it sound like only one slip event caused the present-day observed deformation pattern.

Line 419 – You could delete "strain" after shortening; since shortening is a strain term it is a little redundant.

Lines 433-440 – I think it would help the reader here to remind them stratigraphically which unit overlies/underlies which unit, or which unit is older and which unit is younger. E.g., "the Mecca Formation and overlying Palm Springs Formation." or something to that effect.

Line 435 – would the fault be below the contact between the PS and MH formations, or would the fault be at/near the contact of the PS and MH formations?

Line 456-457 – dip-slip fault-parallel fold: wouldn't this just be a fault-propagation fold? I suppose it could also be a fault-bend fold by that description, but I get the impression it is fault-propagated.

Line 509 – stress, or strain?

Line 516 – I'd be more satisfied if these features were rigorously measured and restored back to a discrete bedding orientation through stereonet analysis. As presented in Supplement S6, you are "restoring" apparent dips at the outcrop face to an approximate horizontal based on the apparent dip of bedding in the picture/outcrop face. I absolutely agree with what you are saying and interpreting, but wonder if you should not refer to this as a restoration, per se, but rather that these features "appear to define a low-angle fold and thrust system (Supplement S6)."

Lines 558-559 – Concerning use of axial surfaces (i.e., axial planes), wouldn't a surface/plane be E–W-striking (not trending)? Perhaps it is better to just say E–W-trending folds.

Line 667 – Transpressional plate regime. Are you suggesting that the plate is entirely under transpression in this area (in which case, which plate – or both?), or are you saying San Andreas fault zone transpression? Depending which you mean could be important, as just to the east ~100 km some of us are arguing for late Miocene–Pliocene (and possibly ongoing) transtension in the lower Colorado River corridor. This is all the more complicated in that the ECSZ does seem to be overwhelmingly transpressive. Looking through your cited reference (Bergh et al., 2019), I think you mean San Andreas fault zone transpression – if so, please modify the "transpressional plate regime" part of the sentence to instead reflect SAFZ transpression. If you indeed mean transpression across the plate(s), I think you need to be more specific of the extent of this transpressional plate regime, and possibly even reconcile your claims by looking into recent literature for Pacific-North America plate boundary transtension inboard of the SAFZ just next door to the east (e.g., Singleton et al., 2019; Thacker et al., 2020; Dorsey et al., 2021), albeit ca. 3 to 1 Ma earlier than you propose the Indio Hills to have formed.

Lines 713-722; Point 4 in Conclusions (Lines 738-740) – I am a bit confused about how the Indio Hills and Durmid Hills are shown as initially different in Fig. 8a, but in this paragraph you suggest that the two areas might be similar in that the Indio Hills might be an early phase of a ladder structure like the Durmid Hills. In Fig. 8a you clearly show an inherent difference between the two areas: Indio Hills has E-W folds, Durmid Hills has NE-SW left-lateral faults - am I to assume the E-W folds had already formed, or did E-W folds not form, which would again suggest an inherent difference between the two areas? I am also confused how these two areas are potentially similar when the proposed timing of fault activation for the oblique dextral-reverse fault in both locations is opposite: The Indio Hills fault (what became the oblique dextral-reverse fault) formed before the Banning fault, while the Eastern Shoreline fault (what became the oblique dextral-reverse fault) formed after the main San Andreas fault, according to your figure.

Technical Corrections –
Line 33 – A geographic description is required. For example: "…San Andreas fault zone (SAFZ: Fig. 1; California, southwestern USA), …"

Line 34 – add "the" ("…deformation compared to the Mecca Hills…")

Lines 41-42 – Note that "Eastern California shear zone" is commonly written with "shear zone" not capitalized. Change here, and throughout the manuscript to be "Eastern California shear zone"

Line 60 – delete "transform" and remove "s" from movements so it reads "…North American plates and movement along the SAFZ…" Also, should it be North America plate or North American plate?

Line 65 (end of paragraph) – I think a final sentence is needed here that brings it all back into perspective. Perhaps something akin to: "This recent work provides the opportunity to explore the understudied Indio Hills segment in order to compare its structural development with other along-strike uplifted features on a major transform plate boundary fault zone."

Line 128 – Gorgonio is misspelled

Line 127-130 – Suggest breaking this one sentence into two different sentences.

Line 134 – Eastern California shear zone (decapitalize shear zone) – change here and throughout the manuscript and figure captions.

Line 137 – Delete "attitude and" so the sentence reads "Farther southeast, however, the geometry of the…"

Line 138 – Add an "s" to remains

Line 140-142 - Suggest separating these into two sentences: "The transpressional character of the Indio Hills uplift was suggested by Parrish (1983) and Sylvester and Smith (1987). Recent work, however, has not been conducted, and detailed structural analyses have not been published from this segment of the SAFZ."

Line 143 – perhaps change focusing to “that focused”

Line 149 – Be explicit here with who you are referring to. I think you mean Keller et al. (1982). If so, I suggest replacing "Their" with the reference.

Line 173 - I think you mean main San Andreas fault strand, based on the abbreviation, but that is not totally clear as written. Suggest saying "main San Andreas fault (mSAF) strand..."

Line 178 and throughout the manuscript and figures – Make sure to decapitalize "fault" after all formal names. E.g., East Shoreline fault, Banning fault, etc., even for San Andreas fault.

Lines 204-205 – I think this sentence needs reworked: "The study area comprises three major fold systems that are oblique to the SAFZ. These fold systems are E–W trending, moderately west-plunging, and contain multiple smaller-scale parasitic folds (Fig. 2)."

Lines 243–244 – This is more of an editorial preference by EGU, but I don't think forelimb and backlimb need dashed? If not, change throughout the manuscript. If so, ignore.

Line 267 – I think you mean southeastern here, not southwestern

Line 314 – Change offset to displacement.

Lines 327-329 – Add “for a damage zone of a”: “The granite there is highly fractured and cut by vein and joint networks (see description below), as is expected for a damage zone of a major brittle fault.”

Line 377 – minor-scale (needs a dash I think)

Line 386 – in other places I think you refer to it as a leucogranite. Be consistent, whether you choose simply granite or leucogranite.

Lines 396-397 – Suggested rewording: “The folds are arranged in a right-stepping pattern, and are increasingly asymmetric and sigmoidal (Z-shaped) to the northeast as they approach the Indio Hills fault.” Change as you see fit, but at present the sentence is difficult to understand.

Line 429 – as inferred for other parts of the SAFZ

Line 430 – remove en dash (–) in front of to

Line 506 – perhaps just say slip here, not “the last slip event”

Lines 560-562 – Your sentence is in present tense (“this is observed”) but you refer to the Banning fault as you interpret it to have been at a former time. Perhaps say “what was then a precursory Banning fault.”

Lines 601-602 – Should be Eastern California shear zone (says East, not Eastern, and shear zone needs decapitalized)

Lines 607-608 – These two faults do not appear to be on Figure 1

Line 610 – delete comma after “enhanced”

Lines 633-634 – Earlier in the paper (and in Fig. 8) you define main San Andreas fault as mSAF, whereas here you say main SAFZ. Is there a reason for the difference (e.g., one refers to a discrete/singular fault plane, whereas the other refers to the main fault zone)? Should mSAF just be changed to main SAFZ, or vice versa? Also do this at Lines 40, 117, 608, 637, 654, 690, 695, 698, and in various figures.

Line 639 – the Indio Hills fault (missing “the”)

Lines 634 and 649 – On line 634 you reference Fig. 8c before referencing 8a and 8b, and on line 649 you reference Fig. 8c before referencing Fig. 8b. You do reference Fig. 8 in its entirety at line 627 – this is more of an editorial decision by EGU if subfigures can be referenced out of sequence.

Line 652 – missing a reference

Line 680 – Eastern Shoreline fault (combine Shore and line)

Line 689 – Here I think you mean Eastern Shoreline fault

Line 692 – see comment above about main SAFZ and mSAF. Here you say main SAF, which you defined earlier in the paper as mSAF - should this one be mSAF or main SAFZ?

Line 695 and 697 – Eastern Shoreline fault

Line 736 – delete "in"

Detailed comments on figures –
Figure 1 –

Figure 1 needs a regional scope. At the very least, a regional map showing California and the study area should be squeezed onto to Figure 1. However, I'd suggest a more detailed regional map showing structural relationships in the area and the numerous features mentioned in the text that are not on any of the maps (e.g., San Gorgonio Pass). For example, from Figure 1, the reader at present would have no context to the extent of the Eastern California shear zone. This can be done as a two-panel figure, where Fig. 1a is a regional map showing major features discussed in the text and the field area, and Fig. 1b can be the present Fig. 1 map.

Line 982 – Brawley Seismic Zone needs defined as BSZ in the caption.

Lines 985-986 – As in the manuscript, decapitalize shear zone in "Eastern California shear zone" in this caption and in all figure captions. It is okay, of course, for the abbreviation to be ECSZ.

All fault names here, in all figure captions, and throughout the manuscript should not have

“fault” capitalized as part of the name. E.g., Banning Fault should be Banning fault, etc.

Figure 2 –

I hate to be a stickler here because these are GoogleEarth images, but all maps (Figs. 2, 3, 5, 6) should technically have at least a few coordinates, whether as a grid of lat/long or UTM, or a few lat/long coordinate points.

Note that your typed words have the spell check wiggle line underneath them. Make sure your final image does not have these.

On your stereonets labels, I suggest adding that the first two are bedding: “SAFZ-oblique bedding planes” and “SAFZ-parallel bedding planes”

In the text I think you say faults and fractures, but here you only say fractures. If both were measured, both should be specified here: “Sediments faults and fractures”; “Basement faults and fractures”

What program did you use to make the stereonets? Allmendinger’s? You should probably cite the program, unless it is a script you wrote.

Figures 2, 3, 5, and 6 –

In the supplemental file you have an un-interpreted figure 6; it would be good to also put un-interpreted images of figures 2, 3, and 5 in the supplemental file as well.

Figures 3, 5, and 6 –

Your mapped features (fold hinges and faults) commonly end before the end of the figure's frame, whereas on Figure 2 many of these same features are shown to be continuous across the frame of the figure. I would suggest mapping the features along their full extent and ending them at the end of the figure frame, instead of cutting them short within the figure frame. As currently drawn, it gives the impression to the reader that these folds and faults are short and discontinuous only within the frame of the figure, but Figure 2 shows clearly that many of these features are continuous from one domain into the other. For example, the southeastern corner of Fig. 3b is also the northwestern corner of Fig. 3c – from southwest to northeast there is an anticline then syncline then overturned anticline then overturned syncline/syncline – I think that these are the same folds in both figures, but as currently drawn Figs. 3b and 3c give the impression these are different folds.

Figure 3 –

What are the yellow dots? I think these are photograph locations; if so state this in the Figure 3 caption.

In each panel (a, b, and c), you could place the domain name right above the scale bar. For example: in Fig. 3a, label "Northwestern" above the scale bar, "Central" in 3b, and "Southeastern" in 3c. This would make it easier for the reader.

Figure 4 –

Line 1019 – The stereonet represents the cm-scale folds, correct? If so, add "cm-scale" to the caption so it is clear to the reader that these are the small cm-scale folds that cannot be seen in the photos.

Figure 5 –

Label “Banning fault” on the main figure.

The fold hinge should be mapped on this figure like it is in Fig. 2.

Figure 7 –

Line 1040 – You say Tentative model here; tentative on what? Perhaps just say “Model illustrating…”

Figure 8 –

I make this point at Lines 633-634, but in your figure, how does SAFZ differ from mSAF? Is one a discrete fault that is considered the main strand (mSAF) and the other is a zone of deformation (SAFZ)? Is using mSAF necessary?