

Dear Alex,

Thank you for the opportunity to revise our manuscript, "*Paleoseismic history of the causative faults of the 2019 Ridgecrest, California earthquake sequence*." We appreciate the time and care that you and the reviewers devoted to evaluating the paper, and we found the comments constructive and helpful. In response, we have revised the manuscript substantially. These revisions include improving organization and readability by converting much of the list-style text to paragraph form, adding a summary table and OxCal-based event constraints, moving technical OSL details to the supplement, and revising figures and captions for clarity. We also clarified the motivation and interpretation of the regional synthesis shown in Figure 7 and more clearly tied that analysis to the central questions of the study.

We also substantially strengthened the discussion and conclusions. In particular, we expanded the treatment of multifault and orthogonal rupture behavior, better connected our findings to broader Walker Lane/ECSZ and seismic hazard questions, and revised the slip-rate section to compare trench-site-based and rupture-based approaches while stating the assumptions and uncertainties more explicitly. In addition, we addressed numerous line-level comments regarding terminology, trench descriptions, event interpretation, and figure presentation. Below we provide a detailed, point-by-point response to each comment and indicate the corresponding changes made to the manuscript.

Sincerely,

Ian Pierce et al.

Dear Ian Pierce, Alana Williams, Rich Koehler, Ramon Arrowsmith, Kathleen Rodrigues:

I hope this email finds you well. I have reached a decision regarding your submission to Seismica, "Paleoseismic history of the causative faults of the 2019 Ridgecrest, California earthquake sequence". Thank you once again for submitting your work to Seismica.

Based on reviews I have received, your manuscript may be suitable for publication after some revisions. Both reviewers appreciated the trench interpretation, but have several suggestions for strengthening the presentation of the data, as well as a few technical points, that I recommend you take into strong consideration as you revise the manuscript.

I sincerely apologize for the elongated process to reach this decision. Thank you for your patience.

When you are ready to resubmit the revised version of your manuscript, please upload:

- A 'cleaned' version of the revised manuscript, without any markup/changes highlighted.
- A pdf version of the revised manuscript clearly highlighting changes/markup/edits.

- A 'response-to-reviewers' letter that shows your response to each of the reviewers' points, together with a summary of the resulting changes made to the manuscript.

Once I have read your revised manuscript and rebuttal, I will then decide whether the manuscript either needs to be sent to reviewers again, requires further minor changes, or can be accepted.

If you deem it appropriate, please check that the revised version of your manuscript recognises the work of the reviewers in the Acknowledgements section.

Please note that Seismica does not have any strict deadlines for submitting revisions, but naturally, it is likely to be in your best interest to submit these fairly promptly, and please let me know of any expected delays.

I wish you the best with working on the revisions. Please don't hesitate to contact me with any questions or comments about your submission, or if you have any feedback about your experience with Seismica.

Kind regards,

Alexandra Hatem
United States Geological Survey
alexandra.hatem@seismica.org

-Alex Hatem, Ph.D

Reviewer B:

Dear Seismica editor:

Thank you for the opportunity to review the Seismic manuscript "Paleoseismic history of the causative faults of the 2019 Ridgecrest, California earthquake sequence" by Pierce et al.

This manuscript addresses the question of whether the Paxton Ranch and Salt Wells Valley faults, which ruptured orthogonally in the 2019 Ridgecrest earthquake sequence, have paleoseismic evidence in support of previous synchronous/orthogonal ruptures. The authors excavated five trenches across these faults. Their interpretations and luminescence geochronology demonstrate repeated ruptures (approximately every 4–10 kyr) on the Paxton Ranch fault and infrequent ruptures (possibly every >15 ky) on the Salt Wells Valley fault since the latest Pleistocene. Slip rates approximated using 2019 displacement data are consistent with these results and show that the Paxton Ranch fault slip rate is about one to two orders of magnitude greater than that for the Salt Wells Valley fault. These data demonstrate that

near-synchronous orthogonal ruptures of these faults are infrequent, at a minimum, occurring with multi-decadal frequency (every >20 kyr).

Overall, I found the paper to be well written and nicely illustrated. The manuscript presents and discusses high-quality trench data that provide interesting insights into the rupture behavior of the 2019 Ridgecrest earthquake source faults. I've outlined several ways in which the manuscript could be strengthened; additional (minor) line comments are included below.

1. The text is formatted with several bullets/numbered sequences, incomplete sentences, figure call outs in headings, and short paragraphs. Much of this will likely be addressed in typesetting, but I recommend that the authors use bulleted lists only where necessary, converting most to paragraph form. Some lists (e.g., rupture times per trench/fault) could be presented in a table.

We have removed several of these bulleted lists, but where they remain we feel they are the clearest way to present repetitive unit descriptions.

2. The southern Walker Lane/ECSZ paleoearthquake plot (figure 7) is interesting but could use some additional introduction/description in the text. Is the point to evaluate whether the Paxton Ranch and Salt Wells Valley faults hosted ruptures within previous WL/ECSZ earthquake sequences? Some additional text relating this analysis to the current study is needed. ***New revised discussion focuses more detail on the observations that can be made from Fig. 7 and relating to bigger picture questions.***

3. The authors need to justify the basis for using average/max displacements from the 2019 surface ruptures to calculate slip rates. Why not use 2019 displacements measured at the trench sites instead of those averaged over the entire ruptures? This latter method assumes that the site-specific recurrence values are applicable to the entire 2019 ruptures and that previous ruptures had identical slip profiles to that in 2019. At the very least, I suggest that the authors measure the rates both ways and compare them. ***Revised slip rate section incorporates trench-site-specific rates and discusses with more detail on which may be appropriate.***

4. The discussion and conclusions sections could be bolstered. For example, what conditions led to the orthogonal rupture sequence in 2019? If the Paxton Ranch and Salt Wells Valley faults were at the ends of their seismic cycles in 2019, when could have such a scenario occurred in the past? I suppose >22 kyr. Are there other factors at play outside of just recurrence, such as dynamic triggering/stress changes that contribute to rupture? How do rupture length, displacement, and structural complexities along strike affect possible orthogonal rupture? I know the authors don't have answers to all of these questions, but it wouldn't hurt to discuss them briefly and set the stage for follow up research. Finally, it would be nice if the authors compared these results to other multi-fault/orthogonal ruptures (and related paleoseismic histories, if known), and expanded on the implications for rupture modeling.

We developed a significantly more robust discussion and conclusion section focused specifically on multifault behavior in this sequence, relating these results to broader

regional and plate-boundary scale patterns, and relating these observations directly to seismic hazard.

I recommend that this manuscript be accepted with minor revisions. The authors have submitted a manuscript with a solid foundation (well-presented trench data) and it should be fairly straightforward to improve the manuscript formatting/flow and add a paragraph or two of conjecture about multifault/orthogonal ruptures.

Sincerely,
Christopher B. DuRoss

Line comments

36 “have consistently ruptured together” You might add a little nuance here, as inherent uncertainties in dating paleoearthquakes prevents us from interpreting consistent multifault rupture. We can either rule it out or say it’s possible given overlapping earthquake time ranges.

39-46. These are good examples, but you might also add the opposite case, or an example of prehistoric multi-fault rupture interpreted from paleoseismic data. A recent paper on the Lost River fault zone (<https://doi.org/10.1130/B36144.1>) comes to mind 😊. ***Added sentence with this reference.***

56. “the present study evaluates...” Could simplify to “we study...” ***Simplified***

83. Insert “Ridgecrest earthquake” before “sequence” ***Inserted***

94. “subsequent large [insert: multifault?] events...” ***Added***

118. “Major Nearby Faults. Recommend removing the figure call out. Also, it’d be helpful to have a short intro paragraph describing why these faults are important. ***Removed callout. Added introductory sentences.***

119-156. Why a numbered list? It seems like this would work just fine as several paragraphs. ***Changed to paragraph formatting***

176. Please describe what you mean by “spillover events.” ***Added clarification***

185. The trench abbreviation SWV-T1/2 is slightly confusing. Consider “SWV-T1, T2” or similar. ***Changed to T1 and -T2 for both trench abbreviations.***

188. “pre-2019 tectonic geomorphology...” Flagging this since the reader will no doubt be interested in why you chose these sites. Recommend describing this in detail in the trench sections below. ***Added more detail to respective sections.***

198-207. I think this numbered list could be trimmed down to one or two sentences, rather than a numbered list. A lot of this is routine work that isn’t necessary to state here. ***Done***

208. It's nice to see a full OSL section but there are a lot of technical details included that may not be necessary in the main body of the paper. I recommend trimming this down a bit and sticking the extra details (e.g., the technical laboratory procedures or dimensions of the single-grain discs) in the table footnotes and/or supplement. **Moved to supplement.**

262. SWV trench locations are duplicated here (compare to Field Methods section). **Removed road references from this section.**

264. Can you describe the older surfaces and evidence of older ruptures in more detail? Surface extent and approximate age? How much cumulative lateral displacement? Same for the Paxton Ranch sites. **Added description of SWV. Added panel to Fig 5. showing lidar hillshade with potential 7-13 m right-lateral offset, and added description to PR.**

268. Please specify somewhere that this is 2019 displacement. **Done**

303. Is "SWT-T1 (Figure 3)" a heading or part of the sentence? Reads as the latter. **Reformatted**

305. The sentence starting with "Figure 3 shows..." doesn't seem necessary (just add a call-out to Figure 3 somewhere (but not in the subheading!)). **Done**

307. "intensely fractured bedrock" is repetitive with line 304. Recommend trimming this to just "weathered bedrock" at one of these locations. **Changed.**

308. Add "(Unit 6)" somewhere as it is called out in the next sentence. **Added**

309/315. Soils are described here but not apparently included in the trench figure. Consider adding them to the figures. **Top of unit 5 is indicated as a buried soil where that is present with hatching. For Unit 6, this is already shown by the highly wavy contact, the text is attempting to be descriptive of the nature of this contact. No change**

327. Add "weathered" before bedrock? **Added**

348. As above, the sentence "Figure 4..." reads like a figure caption and isn't needed. **Removed**

357. Is a bulleted list necessary? Seems like a paragraph would work fine. **Keeping bulleted lists for unit descriptions for clarity.**

371. "small splay fault" This looks like a fracture based on your trench mapping. Did it have minor faulting that isn't resolvable at the scale of the figure? **Changed text to 'fracture'. It was unclear how much displacement occurred on this strand but was quite evident in the field and full resolution orthophoto.**

381. You could add something like "which are inverted but overlap within their 1-sigma error bounds." **Added.**

391-393. Please revise this sentence to improve clarity (do you mean lacustrine sediments?) **Not sure exactly what sentence this is referring to as our line numbers don't match. If**

this is Fig 5 caption, we want to avoid using lacustrine sediments as those are also exposed on the stream cut. This is referring to the very thin layer of dried silt/clay deposited against the scarp.

404. Do you mean ponding “in front” of the scarp? You could revise to “on the down-thrown side” to make it clear. **Clarified this sentence- ponding on the “downthrown, upstream side of the scarp.”**

413. Recommend expanding these statements into paragraphs. **Keeping these as a bulleted list for clarity.**

433. “(possibly a result of faulting)” Seems like a stretch...especially given the dominantly strike slip tectonics in the region. Plus, I’d limit these to just observations. **We disagree that this is a stretch, the fault has a significant basin-up (downstream/towards depocenter of Searles Valley up) component at this site that is pinching all the stratigraphy across it and could certainly explain a ponded deposit behind a beach if an earthquake occurred during a high stand, which is consistent with the stratigraphy. This is consistent with the sudden change from a high energy beach (that is faulted) to a thin clay deposit (that is not faulted) Moving this possibility and expanding slightly to the description of E2.**

462. And unit 5, right? **Yes - clarified. Unit 5 is a coarser grained facies within the same package of backsets.**

467-468/472. These are incomplete sentences, please revise. **Revised**

471. “diagnostic features” This is vague. Please describe in more detail. **Changed to “due to the lack of additional evidence for intervening events such as the clear upward terminations and deformation associated with the other ruptures”**

479. “The following additional pieces of” This is somewhat wordy, you could just trim to “Evidence in support of E3...” **Trimmed.**

472. I agree that evidence in support of E3 is weak.

482. “cannot be traces across the fault zone” Could this also be related to the meters of lateral displacement that has occurred at the site? **Yes, but more likely in our view due to erosion of the uplifted side by the stream channel. Added text to clarify both possibilities.**

492. This would be a great place for a summary table including your earthquake times for the various (PR and SWV) trenches. **Added new Table 3.**

492. Did you consider building an OxCal model for this site? You could then use that to more quantitatively describe the earthquake times and inter-event recurrence times. **Added new Figure 7.**

502. A topic sentence like “Our trenches reveal infrequent surface ruptures on the Salt Wells Valley fault” would be a nice way to start this paragraph. **Added.**

515. “Fault terminations bracket...” Do you mean “Fault terminations and luminescence ages...”
Yes, done.

516. “A possible E3...” Consider inserting “older earthquake” before E3. **Done.**

520. “~6 ka” I think you could be more specific here. E.g., inter-event ranges are 4-8 kyr (E1–2019) to 5-10 kyr (E4–E3)...or list the midpoints of the inter-event ranges. **Added a sentence with inter-event intervals.**

526. I would start a paragraph with this sentence (“Our new record...”) **Done**

526. Why are you comparing the Paxton Ranch fault record to all of these broadly distributed faults? I feel like I’m missing something...or that a spatial component is missing. Consider adding a few sentences on why this comparison is important. **Addressed in new revised section**

535-547. I initially thought this was the figure 7 caption. Consider leaving all of the fault details to the actual caption and revise this to describe what is motivating this comparison and how it contributes to your study. **Addressed in the new revised section, but we are leaving in the list of faults missing data as we think that is useful.**

547-550. You might expand on the significance of this. **Addressed in new revised section**

569. Why are you using slip over 50 km of fault rupture rather than just the observed slip at the site? Some justification of your methods is necessary, especially as the previous Paxton Ranch ruptures may not have had the same rupture extent or displacement profile as that in 2019. **Addressed in the new revised section. Added this as one way to calculate rate.**

570. I think it’s important to qualify this somehow, maybe just by revising this to “may have accumulated...” **added “may”**

571. Is 1.2 mm/yr correct? ($14\text{m}/13\text{kyr} = 1.1 \text{ mm/yr}$) **the younger bracket of E2 is 12.16 $\pm$ 1.50; this actually can be as much as 1.3 mm/yr using the minimum interval & maximum displacement estimate.**

573-574. You state that the max slip might not be representative but then cite the same rate. You might revise the “reasonable” rate (which is fairly vague way of describing this) to be ~0.2 to <1 mm/yr. Or better yet, use twice the 2019 observed slip at the site (1.2 m) to derive the rate, which would be 0.2 mm/yr. **Addressed in new revised section. Added discussion that maximum rate may relate to other rates derived from large offsets of geomorphic features.**

Related: Can you rule out 9-14 m of total slip based on the site geomorphology? **Addressed in new revised section with detailed discussion on slip rate comparison**

594. “order of magnitude” 0.01 to 1.2 is two orders of magnitude. **Changed to “consistently higher”**

596. This would be a good place to discuss that this suggests that asynchronous rupture is the norm and that the recurrence of orthogonal/synchronous rupture on this fault pair is really controlled by the SWV fault. Such a rupture can only occur when that fault is ready to rupture (every 20 kyr?), unless of course, there are other processes at play related to stress triggering or rupture length/frequency along other parts of the faults not captured here. **Added discussion on this topic**

617. I'd turn this around and say that this study suggests separate/asynchronous rupture of these faults over the time period resolved in the trenches, but that you cannot rule out previous synchronous/orthogonal ruptures in the past. **Addressed in new revised discussion**

618. "distant past" is quite vague. **Removed**

617&618 rephrased "These findings suggest that these faults more frequently rupture separately over the ~25 k yr time period evidenced by the trenches. However, we cannot rule out a previous synchronous orthogonal rupture prior to ~25 ka."

620. "Future investigations..." This is true of any multifault network. Can you find a conclusion more specific to this region or orthogonal fault pairs? **New discussion is more specific on uncertainties inherent in paleoseismic studies, this should address this point.**

Figure 1. Recommend adding slip sense indicators to the lower panel. **These were on there, we have increased the line weight to improve visibility.**

Figure 2. Some of the text is hard to read. Also, the red rupture line is hard to see. You could make it bolder and add slip sense indicators. I'd also remove the lat longs from the figure and just include in the caption (same for PR figure). **All requested changes made.**

Figure 3. Soils mentioned in the text should be added to the trench interpretation and legend. **These soils are indicated on the current version with short lines and buried soil on the legend. No change.**

Figure 7. You could add vertical red bars representing your PR and SWV earthquake times to the lower panel to help tie this synthesis into your study. **Done.**

Figure 4. Check the F1 open fissure, which includes what looks like a contact and a fault across it. There is also a white polygon at the base of the flower structure – unit 5? You might add an arrow pointing out the "open fissures" to avoid confusion. Also, why does unit 2 thicken right at the graben (lateral variation in thickness, juxtaposed by faulting)? Is fault F3 a fault or fracture? **Figure is now modified. Text added to SWV-T2 description part of text explaining unit thickness (we agree, juxtaposition of units in a channel). F3 is a minor fault.**

Figure 5. Recommend adding flow direction to middle panel as well. Also, move lat longs to caption. **Both recommendations are included in revision.**

Recommendation: Revisions Required

Reviewer C:

This manuscript by Pierce et al. presents a fairly straightforward paleoseismic study with the usual mix of compelling and ambiguous earthquake evidence, which they have described well and appears consistent with what I can see in the trench mosaics and logs. Most of my comments below are seeking clarification on particular lines of text. I see the weakest part of this manuscript being portions of the discussion and the conclusion, but I think much of that can be managed with a bit of text reorganization, clarifying some statements, and making a more meaningful return to the bigger picture concepts that were invoked in the introduction.

OSL Measurement and Analysis

- I appreciate the discussion of the rationale for the use of different mixing models here - definitely more transparent than a number of studies with OSL dating that I've read.

Salt Wells Valley Fault Trenches

- In the caption for Figure 3, you describe the granitic bedrock as 'heavily fractured' and then in the next two paragraphs, Lines 303-308, you describe it as intensely fractured. But then you also describe faulting and fault gouge. Also, on your labels on Figure 3, you describe the bedrock as sheared. Taken as a whole it seems to be a reasonable description - but by describing it as faulted in one place, fractured in another, sheared on the figure, and fractured and faulted in another paragraph leads to unnecessary confusion/apparent inconsistency. Can you rephrase this to make this a little more straightforward? Maybe in your general statement in Line 304 you just describe it as a weathered granitic bedrock unit, and then in the following more detailed paragraph you introduce the details of fracturing and faulting - and then if necessary, update the caption and figure using the same language used in the text. ***We are keeping the figure as is. Changed figure caption to "sheared." Changed text in lines 303-308 to heavily sheared and weathered.***

Line 303: This structure: **"SWV-T1 (Figure 3):** was a 10-m-long" is a little weird. Is the bold and colon indicating a new subsection? But the words that follow act like a continuous sentence with the preceding. **Revised.**

I do find the use of past tense as stylistically debatable here - sure the trench is probably now filled in but the stratigraphy of the trench walls still exists. It could also be stated as 'was excavated as a . . .', but it could also be described with active voice 'the trench is a 10-m long. . .' since that is your data as you observed it. **Keeping as is.**

Line 318: What do you mean by 'erosional relationship'? Can you be a little more specific on what led to this observation/interpretation? **Language changed to be more precise -> nonconformable.**

Line 332: seems like if there's gouge, you could call this a fault rather than a more ambiguous 'fracture' **Changed to fault.**

Lines 335 and 339-341: Is it even possible to have 'at least one penultimate earthquake'? Penultimate is the *one* event that occurred before the most recent, right? If the point here is that you're unclear whether the faulting that terminates at the base of units 2, 3, and 4 is the result of one or multiple earthquakes, you should ditch the 'penultimate' term and describe it as something like 'one or more pre-2019 earthquakes'. **Changed reflecting suggestion.**

Lines 408-409: Would read better along the lines of: *The trench exposes fluvial deposits that cap late Pleistocene lacustrine sequences, and a prominent fault zone uplifts the downstream (northeast) reach.* Otherwise you're squeezing structure info into a sentence that's ostensibly about stratigraphy. **Revised as suggested.**

Line 420-421: Where you say "*but on the southeast wall it conformably caps Unit 8 on the northeast side of the fault zone.*" seems to overstate the extent of this relation. On your log, I see the contact of Unit 7 on Unit 8 as only occurring on a couple fault-bounded blocks within the fault zone, and that it is absent beyond the fault zone to the northeast. **We are leaving as is, the original text is correct and this unit pinches out likely due to the lateral variation in thickness of these deposits close to the channel margin. On the southeast wall (towards the center of the channel) channel deposits are thicker than close to the channel margin (northwest wall). This unit is clearly exposed on both sides of the primary F1 fault zone on the southeast wall and there is a clear difference between the two walls. The stratigraphy in these smaller fault blocks to the northeast of the fault zone are conformable and show the relation between Units 7 and 8 which is a key detail.**

Lines 472-485: It does feel like a stretch to pin E4 and E5 to a particular horizon based on your trench logs, and I think the text here finds a fair balance of describing potential evidence, but communicating the associated uncertainty.

Line 519: regular behavior?

Changed to “relatively periodic recurrence behavior”

Line 535-541: Starting with “Figure 7 presents. . .” is a weak way to start a paragraph. You’ve already invoked Figure 7 in the previous paragraph, so it’s unclear why you seem to take a step back and present it again. I think this section might work better if you began with introducing the rupture patterns of the ECSZ as illustrated in your figure 7, and then place your new findings into that context, covering the uncertainties and caveats as needed. ***Revised discussion should flow better for Figure 7.***

Lines 567-575: You don’t clearly state an important part of your assumption. You use the mean and max slip distributions from 2019, but you should also state that you assume that the slip measured in 2019 is the same amount that occurred in prior earthquakes, in order to calculate that accumulated slip amount. ***This is now clearly stated in the new revised discussion.***

→ I see a potential complication to making that assumption that may be worth noting: the 2019 rupture of the Paxton Ranch fault had contemporaneous rupture with the Salt Wells Valley fault, whereas the prior two earthquakes on the Paxton Ranch did not. Might this have resulted in a higher or lower slip in 2019? Given the range of the estimate, maybe the difference comes out in the wash - but I think it’s worth noting. ***This is directly stated in the revised discussion.***

Lines 585-586: Huh? “to resolve whether the Salt Wells Valley fault regularly accommodates slip in sub-millimeter-per-year increments or experiences more sporadic displacement episodes.”

This seems to ask whether this fault slips a tiny bit every year or has larger earthquakes (a sporadic displacement episode sounds like an earthquake). What are you actually trying to say here? Are you trying to get at temporal variability in slip rate? Ah, now that I see the disclaimer on use of GenAI, this does read like a sentence generated by genAI that wasn’t sufficiently reviewed. ***The original intent here was to incorporate the idea that slip rate may vary through time. This was not clearly written in the original submission and the revision more clearly states this intent.***

Conclusions:

- Thinking back to the broader scientific goals you described while motivating this study back in the Introduction - comments on multi-fault ruptures and earthquake sequence and the impact on seismic hazard models - it would enhance this manuscript to return to this topic in the conclusions or at the end of the discussion. Perhaps a more specific way to think about it is to try to address the claims that you make in lines 61-67.
- ***Added two new discussion sections & conclusions with a focus on these topics.***