Review Report

Rosell et al., Holocene Earthquakes on the Tambomachay Fault near Cusco, Central Andes, TEKTONIKA, 2023.

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1st Round of Revisions

Decision Letter

Dear Dr. Rosell,

We have now received comments from two reviewers on your submission to TEKTONIKA. Both reviewers provided constructive and detailed comments on the text, and felt it fell within the scope of Tektonika. However, they did also both suggest that revisions to the text would be required prior to acceptance, noting in particular a need to clarify how the fault offsets and throw were calculated, as well as other issues related to the moraine deposition, trench stratigraphy, and estimate for the moment magnitude. In addition to substance comments that will improve readers' abilities to fully understand how you have produced your results, the reviewers provide a number of more minor grammatical and spelling suggestions that may make the text more readable.

After reading both the text and reviews, we agree with the suggestions from the reviewers that moderate revisions to the text will be necessary prior to accepting the article for publication. Please take into account all suggestions by the reviewers, implementing them or, in case you disagree with, explaining why you don't.

As editors, we also recommend to reinforce the data availability section. You are using several high resolution DEMs (from Pleiades imagery and from drone photos). If there is no restrictive licence, you should indeed provide better shaded images as suggested by reviewer 2, but also the DEMs themselves. You may deposit the DEMs and the hr images on a data repository like zenodo.org or on the open topography portal https://opentopography.org. In that case explain it and give the links in the data availability section. If you cannot distribute a DEM because of the licence terms, you should explain why and how other researchers may access to the data.

Submit your revised manuscript via the TEKTONIKA web site: under your manuscript's record you'll find a box named "revisions" with a way to upload your new files. Please also submit a detailed rebuttal letter explaining how you took into account reviewer's and editorial recommendations, and an additional manuscript version with the changes outlined.

Based on the scope of work suggested by the reviewers, we would hope that the revisions could be completed in approximately three to four weeks. If you have any concerns about this proposed timeline, or any other questions about how to proceed, you are most welcome to contact Executive Editor Robin Lacassin and Associate Editor David Whipp.

Waiting for the revised version of your paper. Thanks for submitting to TEKTONIKA.

David Whipp, Associate Editor
Robin Lacassin, Executive Editor

Comments by Reviewer 1 (Maryline Le Beon)

General comments

Rosell et al present a neotectonic study of the Tambomachay normal fault, located very close to the city of Cusco, S. Peru, N. Altiplano, Andes. The authors map the active fault based on geomorphic scarps, determine a fault slip rate based on scarp heights across a moraine dated using 10Be exposure dating, constrain the Holocene earthquake history based on a paleoseismological trench and 14C dates, and discuss the possible earthquake magnitude and seismic hazard.
This work is a classical neotectonic study that required significant work in field data collection and sample analysis. It has implications for local seismic hazard assessment, which is a significant contribution. Broader implications regarding regional tectonics, fault seismic behavior or methodological developments, that could gather a broader audience seemed beyond the scope of this work.
Overall, the results shown by the authors are convincing and the manuscript is generally well written and well illustrated, but not always clearly explained. I recommend hereafter a few improvements regarding the throw calculation and uncertainty, the origins of the moraines, and the magnitude estimation.

Moderate comments

1. Abstract
- Abstracts should stand in their own. I started by reading the abstract and found that there was a lack of explanation regarding the gap between the description of historical earthquakes and the description of the paleo-seismological record. I was wondering if historical earthquakes not recorded in the trench could have occurred on other structures nearby. In the abstract alone, no background information is provided regarding the setting of the fault. An important point that I recommend including in a few words is the fact that the fault is not an isolated structure, but part of the network of normal faults.

2. Offset and fault throw determination based on topographic profiles
2.1. It seems that section 3.2 would require a reference to the supplementary material where the topographic profiles are shown together with offset estimation for each profile.
2.2. Dataset and calculations:
Section 3.2 / Paragraph 2: "The scarp heights in this sector vary between 2.2 ± 0.5 m to 8.4 ± 0.3 m, and the equivalent fault throw varies between 2.7 ± 0.6 m and 8.9 ± 0.7 m with a mean throw of 4.3 ± 0.4 m".
Because the slip rate is one of the key result of the paper, the way the offset, the throw and the uncertainty are calculated needs to appear more clearly.
I understood that the Sencca Hill offset is based on 10 topographic profiles. As indicated in the quoted sentence, the authors provide the range of offset, and then the conversion into fault throw. The average throw is stated to be 4.3 ± 0.4 m, with a lowest value of 2.7 m and a highest value of 8.9 m.
a. How was the throw calculated: Did I miss the information on the fault dip? How was the fault dip determined: was it inferred or observed?
b. Given the wide range of offsets, it is surprising that the uncertainty on the throw is so low. Even assuming that the throw population (throw values derived from each offset converted to throw using the fault dip) included the values 2.7 and 8.9, and 8 times the value 4.3 (to make it 10 values in total), then the standard deviation would be 1.6 m. The standard deviation is 4 times larger than the uncertainty provided by the authors, while their dataset could only be more scattered.

For readers to understand the calculations, the authors would need to clarify which profiles shown in the supplementary material are extracted from which site (i.e. what are the 10 values determined for this site?), and to clarify how the uncertainty have been calculated.

3. Moraines origin and their ages
Section 4.1 and 4.2
3.1. I haven't seen information on the lithology/ies of the boulders. Please specify.
3.2. Could the authors comment a bit more on the origin of the moraines? Where they formed by glaciers flowing down from the crest line located just North of the Tambomachay fault or could they come from further away? While I agree that the ages are all nicely self-consistent, further description of the background geomorphic setting may help understand why the ages are so clustered in this study.

4. Magnitude estimation (Section 5.3)
In the moment magnitude relation, the displacement refers to average displacement. Similarly, Wells and Coppersmith scaling laws applied to average displacement or maximum displacement. Also, these scaling laws have been improved based on a larger database by Leonard (2010; Bulletin of the Seismological Society of America, 100(5A), 1971–1988. https://doi.org/10.1785/0120090189; I'll let the authors check if there is an even more recent study).
The authors didn't discuss the assumptions that they make in their estimation of the magnitude, while they have observations at only one site. Did they consider that this slip values are a representative average? In contrast, after the authors mention a few times that the Senca Hill site is where the fault morphology is the most clear, should these values be considered as maximum? A conservative approach may be to consider several assumptions, which may not change the proposed magnitude range.

Minor comments:

There are several typos and minor grammar mistakes throughout the text.

Clarify the location for Tables 1 and 2: Will they appear in the main manuscript (as citation suggests / "Table 1" instead of Table S1) or in the supplementary data (as currently placed).

Figure 6:
- I recommend using colors that are easier to distinguish for units C2, U2, C3 and U3
- Move the label "U3" away from the upper termination of F2, so that the reader can clearly see where F2 termintates.

Introduction / Paragraphe 2: "particularly two events in 1650, 1950 and 1986" => looks like it should be 3 EQs.
If it is 2 EQs in 1650, 1 in 1950, and 1 in 1986, please rephrase accordingly.

Section 2 / paragraph 2:
- "3-20 m-high fault scarps cut glacial deposits" : I don't understand what the authors mean by "3-20". Please rephrase.
- "in the nearby Cordillera Vilcabamba": is this located on a map? If not, please specify the location, on a map or in the text.

Section 2 / paragraph 5:
- "was localized at Cusco" or was located?

- "The extreme values of fault throw are measured in the valleys...": I understand "extreme" as the lowest values and the highest values. / NB: Are these throw or vertical offset?
- "discontinuous scarps distributed in an area of 2 km² with a strike of ~105°" => discontinuous scarps with a strike of ~105° distributed in an area of 2 km²
- "Parina normal fault that ruptured in a Mw 6.1 earthquake 2016": Please provide the location on Earth in few words.

Section 4:
- Title: Since section 4 includes 1/ methodological aspect of the dating method, 2/ age results, and 3/ slip rate calculation, the title of section 4 should be modified to better match the content.
Section 4.3:
- "One previous estimate of the slip rate": the referenced study seems to have been conducted at exactly the same site. Please state it clearly.

Section 5.1.1 :
- "terminating": rephrase the sentence so that "terminating" clearly refers to units 2 and 3 (if I got it right) and not to the faults F2 and F3.
- "F2 and F3 are semi-parallel to the main fault plane": What does semi-parallel mean? Did authors mean sub-parallel?
- "3.5 m vertical offset was recorded by the moraine surface": add a reference to the specific topographic profile shown in the supplementary material.

Section 5.1.2:
- "A radiocarbon date from unit 4" + for unit C2 in the following paragraph and other cases in the following: please systematically specify the material that was dated (or provide the information in a table or on figure 6, in the main manuscript)
- "Unit C2 is a thin, dark brown, matrix-supported deposit with angular sandstone pebbles in a sandy siltstone matrix": "siltstone" or silt? Siltstone implies that indurated rock.
- in Paragraph 3: "thinning": rephrase so that "thinning" clearly refers to C2 (and not C1)
- in Paragraph 3: "The C2 unit tapers on both sides of the displacement": not clear what authors refer to by the "sides of the displacement". Writing probably needs to be improved here and I would recommend to make the description free from tectonic interpretation.
- Paragraph 4: "single" can be omitted here.
- Paragraph 4: "soft millimetre red clasts": improve writing
- Paragraph 5: "Unit C3 thins towards the bottom and has roots": 1) towards the bottom sounds awkward and unclear: vertically downward, towards the base of C3 or towards downstream, towards the N? Looks like both apply. 2) has roots => include roots.

Section 5.2 / Paragraph 3:
- While I agree that the ages do not seem problematic, I wish that the author comment on possible contamination of the organic matter in the sediment by more recent including modern humid acids carried via rainfall infiltration or groundwater transport.

Section 5.2 / Event 1:
- "The minimum displacement for this event is ~0.4m. ": Can the authors explain how they estimate this displacement? They write "minimum displacement". Why would this value be a minimum?
Section 5.2 / last paragraph.

- "vertical offset of the fault (3.5 m) calculated from the perpendicular profile on the moraine": if understand that the "vertical offset" referred to in this sentence is based on topography. Therefore, I would refer to it as the geomorphic offset across the fault scarp.
- "there is 3.15 m of vertical offset accumulated between the first and the second event": 1/ misleading writing that would suggest the occurrence of another event, between E1 and E2. Does the following fit more appropriately what the authors mean: there is 3.15 m of vertical offset accumulated during both the first and the second event. + I would add "POSSIBLY" accumulated because this is a possible scenario for which the authors have no evidence, as is an interpretation to divide these 3.15 m roughly equally between E1 and E2. Please highlight this as well.

Section 6 / Paragraph 3:

- Typo?: "the mb 5.3 1986 earthquake"

Comments by Reviewer 2 (Marthe Lefevre)

The present manuscript addresses the question of the fault activity in the Cusco area (Peru) which is more and more inhabited, using paleoseismological investigation. They focus in particular on the Tambomachay fault which is the one nearest to the city and is well-expressed in the landscape. The authors refine the fault map using high resolution imagery and produce a dataset of fault throw measurements. They also present a trench excavated in an offset moraine along the fault, showing traces of past surface ruptures that complete the earthquake catalog of the area, and allow them to propose some constraints on the seismic hazard. The article is well written but could benefit from some precisions in particular on the trench stratigraphy.

Main comments:

The article is relatively well written even if some unusual phrasing makes some sentences a bit hard to follow and could benefit from some rephrasing.

In general, the results and data could be more described to better support the interpretation of the authors, in particular for the trench stratigraphy.

The method of throw measurements could be more detailed at least in the supplementary material where the topographic profiles are displayed. Indeed, there are several assumptions in the method used by Benavente et al. 2022 to convert the vertical offset to throw and it would be helpful to include a brief summary of them. The supplementary material should be a bit reorganized. There is no legend for the graphic so we don't know what USS and LSS are. Moreover, you use swath-profiles to measure the offset, but on the graph we can see a doted gray line which seems to be the line you are looking to fit (example prof 6) but we don't know to what corresponds this line. In the same way you plot some Gaussian but as the method is not described we don't know what you are fitting.

It could also be nice to have a figure in the supplementary material showing zooms of the DEMs on which you made the profiles so we can better understand how the sections of the profiles used to compute the slopes are selected compared to the local morphology, because with only the profiles it is sometimes puzzling (ex profile 2).

It could be also an occasion to show your DEMs that seem to be really nice.

It is a bit frustrating to have so few offset measurements in the Pumamarca sector, was it not possible in other places? for example to complete the section close to the Sencca sector where you have a measure higher than the other. In this state we cannot determine if it is an "outlier" or if locally the offset is higher.

Showing parts of your DEM could also be used as a justification for the relatively low number of measurements if the morphology is clearly not preserved.

The fault mapping is not much detailed except for the Sencca sector, while following figure 3 there is more variation in the fault geometry in the other sectors. For the Pumamarca sector only the lithology of the offsets units are detailed, while it could be interesting to compare the lateral throw variations with the fault geometry, in particular in the bend at the north or in the relay in the southern part. In the same way the off-fault deformation is discussed for the Alto Qosqo area, but not in the Larapa sector, while we can see on figure 3 that there are a lot of minor faults in this

sector. It would be nice to mention them in a discussion about off-fault deformation and seismic hazard assessment.

The description of the trench stratigraphy is very succinct and does not reflect the log. Almost all the layers are described as “matrix-supported deposit with angular pebbles and cobbles” while we can see that there are granulometric changes between the different units. Describing the units in more detail and including some information about the possible mechanism of deposit will better support your conclusions about the deformation chronology.

When looking at the trench log I have a few questions concerning the relation of units 2, 3, 4 and C2.

Unit 3 is made of large angular clasts and a little matrix and on the photomosaic it looks a lot like the unit C1, so what make you consider that it is a filling unit and not a small colluvial wedge? In particular as you mentioned that it is erosive on unit 2.

The part of unit C2 against the main fault F1 is very similar to the unit C3, it has a triangular shape and looks like an infilled extension crack and it is not clear at all that it is connected to the deposit called C2 on southern part. And if we consider that it is not the same deposit it means that there might have been another small event. Maybe you can add a zoom of the photomosaic of this area to better illustrate your mapping.

In the same way, in this zone close to F1 the relation between “C2” and unit 3 is unclear is “C2” erosive on unit 3? It seems unlikely that there were no deposits of unit 3 (and possibly even of unit 4) against the main fault.

For a colluvial wedge associated to a major seismic event C2 has a fairly low granulometry especially when looking at unit 1 that forms the scarp, how do you explain it?

<u>Line by line comments:</u>

L.28: not “in major earthquakes” but “during/through major earthquakes”

L58: replace “mean” by “imply”

L61: replace “capable of rupturing in moderate…” by “able to produce moderate-magnitude…”

L69-70: you write that in “particular two events” were damaging and then you cite three dates, please rephrase for consistency

L93: replace “the seismic hazard in the city” by “the seismic hazard of the city”

L100: “a ~1800 km-long”

L102: rephrase “tectonic regime…oceanic plate” in “ tectonic regime associated with the subduction of the Nazca oceanic plate under the continental South American plate”

L107: replace ‘have been mapped “ by” has been mapped”

L118: in the sentence “the last Pleistocene-early Quaternary compressional and Late Cenozoic” you mixed three levels of classification of the stratigraphic chart, making it confusing. We even wonder if it is “last” or “late Pleistocene”

L121: maybe add the “Alto Qosqo” on figure 2

L124: typo (remove “Tambomachay fault”)

L126: in the Figure2 the deposits are just classified as Paleozoic, Mesozoic or Cenozoic rocks, while here you describing Cretaceous rocks over Eocene-Oligocene rocks, which is more detailed, maybe add a precision to link with the figure.

L139: “at least 8 ka old”

L140: maybe you can add the location of this dating (Wimpenny et al. 2020) on the map figure 2, as it is the only age constraint of the area

L144: replace “have had” by “have"
L160: rephrase “historical event…of M6” in “historical event with a probable magnitude of M6”

L174: add “suggest that it might”

Figure 1: the names of the faults are missing, i.e. the signification of the name abbreviations (CHF, SF, LF….)

L236: use “computed” instead of “calculated”

L240: “traced” maybe “mapped” is better

L242: section might be better than zones.

L247: It is unclear in this sentence where the connection with the bedrock-moraine contact is located.

L261: the values presented here are not exactly the same as in the table 1 in the supplementary materials.

In this part of the supplementary material even if all the locations are displayed it would be nice to have a map with the profile lines drawn and labeled, for example a figure with the detailed DEM zoomed on the area where the measurements have been done, so we can also appreciate the morphological situations of the profiles, i.e. on a crest, distance from stream, on alluvium or not… And it would also be an opportunity to show your DEM data that seems to be really nice.

In the figure 3.b/ on the main text you separate the samples that are measured on the bedrock, from the ones measured on alluvial deposits, it would be nice also to have this separation highlighted on the table 1 of the supplementary material (add a lithology column or use a different label)

L269: use “while” instead of “whilst”

L271-275: you can develop a bit more this section, you mention that part of the variability of the cumulative displacement is due to the fact that during one event only a part of the fault ruptures, but is there any link with the fault geometry? For example,

the place with the highest throw (n°11) is geographically separated from the others and just in the bend at the limit of the Sencca sector. To properly explore this matter, it would be nice to have more measurements around this area if the local morphology allows it.

L277:I don't really understand what you mean here because following the figure the fault is at the limit between the relief and the sedimentary basin, I don't really see the relief vanishing.

L284: in section 3.1, you mention that you compute a DEM from the aerial photographs from 1956, with a resolution of 1.26m/px. Does this DEM not allow to make any measurements of scarp height? On Figure 4a there are some places where with this kind of resolution we would expect that some measurements could be possible.

Figure 3: On 3.b. the difference between the blue square with light blue or grey borders is hard to make out.

It would be nice to have the extent of your different DEM datasets on this map.

L307: Off-fault deformation section: Based on the map in Figure 3a, it seems to exist other places with more distributed deformation like in the footwall of the Larapa sector, or in the eastern termination of the fault, but none of them are mentioned in the text. You might include them in this section and discuss their general distribution.

L313:Replace « sense » by « direction »

L321: It is not clear here whether you are refering to coseismic or cumulative scarp.

L344 : Table 1 is cited as if it was in the main text, but it is in the supplementary so we are looking for it, move it to the main text or change the citation.

L383: the ages described in the following section "exposure dating results" are not the same as in figure 5.c, which is currently the only place where we can see the samples ages. The ages in the text are all younger than on the figure and have smaller uncertainties, explain what is the difference between the two datasets and if you keep the table 1 in the supplementary material you should rather discuss the ages presented in the figure 5c.

L398: "tight" is not really used in such context

Figure 5: on the DEM in 5a there is no scale. On the picture 5b, the sampled boulder is rather small and partly hidden in the vegetation, you did not address in the text the possibility of a post-glacial cover of the boulder, is it the case? On figure 5c there is a problem with the ages that are not coherent with the text.

L433: use "more details on "

L438: maybe "across the fault scarp at Sencca Hills" instead of "in the footwall of the fault scarp"

L439: the end of the sentence is a bit unclear "the representative … Glacial Maximum" in this sector you made ten measurements, I assume you take the average but it is a bit weird to speak about representative value in this case.

L448: spelling: “the radiocarbon age of each sample”

L451: you could use log instead of sketch which is quite classic in paleoseismology.

L458: what the lithology of the pebbles and cobbles? As you mentioned some lithology for the clasts of the sediment in the hanging wall, so it could be interesting to have also the lithology of the footwall for comparison.

L465: in the figure 3 you write the throw value and not the one of the vertical offset, maybe adding the offset value on the figure, next to the throw.

Figure 6: The photomosaic does not have a good enough resolution to really look at the stratigraphy, I know that the constrains of having a complete figure in a reasonable space prevent to really improve this in the manuscript, but maybe you can add a higher resolution and larger version of this figure in the supplementary.

In 6.b the clast axes are represented by arrows and not dashed lines.

The insets 6b and 6c might be enlarged a bit to better apprehend the clasts rotation and the surrounding context (to achieve this I think that the inset 6.d can be reduced as there is not much information on in and the red clast can be shown in a smaller picture)

L492: remark the colluvial wedge C1 has a similar age to the colluvial wedge dated along the Qoricocha fault, suggesting the occurrence of events in a relatively similar period on both faults compared to the return time observed in the trench. I am not really familiar with the fault activity of the area but what do you think about a possible interaction between those faults?

L499: you mentioned pebbles and cobbles in the unit 2, while looking at the photomosaic it seems to be a unit with really fine clasts, we actually don’t really see them on the figure 6.

You also mentioned that those clasts are made of sandstone, does it match the lithology of other units?

L500: The unit 3 can be a bit more described, you don’t mention the clast rotation that are shown in figure 6.c. Moreover, the layer geometry is not described, this unit is way thinner on the southern side of F2. Based on the shape of the layer and its granulometry with large cobble and pebble we can wonder if it could not be a small colluvial wedge.

L503: based on the contact between unit 3 and 4 on both side of F2 and their internal deformation, we can actually wonder if unit 4 did not reach F1 at first before being eroded, the top of unit 3 in the area of the main fault seems erosional, which is not the case where the unit 4 is present. Maybe discuss more the erosional characteristic or not of the contact between unit 3, 4, C2, 5.

L506-508: the unit C2 is first a unit with “no cobbles or pebbles” and then became a “matrix-supported deposit with angular sandstone pebbles”

Moreover the unit C2 and C1 are described in the same way “ matrix-supported deposit with angular sandstone pebbles” only the color changes in the text, while we see clearly that the clast constant and the size of these clasts are very different between the two units.

L509: replace “sandy siltstone” by “a sandy-silt matrix “

L518: the fault F2 and F3 do not cut C2 on your trench log, suggesting an even older age for the last event on these structures.

L525: not “thins” but “gets thinner”

L527 “also” is not needed here

L528: use “when” instead of “where”

L529: use “are low” instead of “is lower” · this complete sentence need rewriting because it is unclear and have several mistakes

Figure 7: rewrite the sentence “stratigraphic units….age ranges”

L581: replace “1.5m of surface rupture” by “1.5m of slip”

L593: add the precision, here you are speaking of the fault throw “during one seismic event”

L600: rephrase: “the whole Tambomachay Fault and the whole seismogenic layer.”

L603: replace ‘has shown” with “have shown”

L608: based on the magnitude you propose for the historical earthquakes Mw7.2 in 1650 probably ruptured the surface according to the previous estimation you made on the magnitude

L617-618: here there are probably more than 300m of cumulated displacement as part of the fault plan is under the sedimentary cover of the Cusco basin and you can also expect a bit of erosion. The estimation of the initiation of the extensional faulting is probably underestimated.

L623: “into the seismic”

L647: “with offsets”

L648: rephrase “the Tambomachay identified ruptures”

L649: “or that they did not rupture”

Authors' Reply to Reviews

Dear Reviewers and Editor, please find below our responses, point by point, to the reviews. Initial reviews are given in black font. Our responses are given in green. Any quotes from the text in response to the reviews is given in italics. We provided a manuscript with the tracked changes and another manuscript with all the changes integrated. Line numbers from reviewer still refer to the lines of the original manuscript.

RESPONSE TO COMMENTS BY REVIEWER 1 (Maryline Le Beon)

General comments

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This work is a classical neotectonic study that required significant work in field data collection and sample analysis. It has implications for local seismic hazard assessment, which is a significant contribution. Broader implications regarding regional tectonics, fault seismic behavior or methodological developments, that could gather a broader audience seemed beyond the scope of this work.
Overall, the results shown by the authors are convincing and the manuscript is generally well written and well illustrated, but not always clearly explained. I recommend hereafter a few improvements regarding the throw calculation and uncertainty, the origins of the moraines, and the magnitude estimation.

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1. Abstract
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We modified the abstract and a sentence on this aspect.

In the abstract alone, no background information is provided regarding the setting of the fault. An important point that I recommend including in a few words is the fact that the fault is not an isolated structure, but part of the network of normal faults.

This was added and clarified at the beginning of the abstract.

2. Offset and fault throw determination based on topographic profiles
2.1. It seems that section 3.2 would require a reference to the supplementary material where the topographic profiles are shown together with offset estimation for each profile.

The reference to the Table S1 in supplementary material was added here.

2.2. Dataset and calculations:
Section 3.2 / Paragraph 2: "The scarp heights in this sector vary between 2.2 ± 0.5 m to 8.4 ± 0.3 m, and the equivalent fault throw varies between 2.7 ± 0.6 m and 8.9 ± 0.7 m with a mean throw of 4.3 ± 0.4 m".
Because the slip rate is one of the key result of the paper, the way the offset, the throw and the uncertainty are calculated needs to appear more clearly.

I understood that the Sencca Hill offset is based on 10 topographic profiles. As indicated in the quoted sentence, the authors provide the range of offset, and then the conversion into fault throw. The average throw is stated to be 4.3 ± 0.4 m, with a lowest value of 2.7 m and a highest value of 8.9 m.
a. How was the throw calculated: Did I miss the information on the fault dip? How was the fault dip determined: was it inferred or observed?

b. Given the wide range of offsets, it is surprising that the uncertainty on the throw is so low. Even assuming that the throw population (throw values derived from each offset converted to throw using the fault dip) included the values 2.7 and 8.9, and 8 times the value 4.3 (to make it 10 values in total), then the standard deviation would be 1.6 m. The standard deviation is 4 times larger than the uncertainty provided by the authors, while their dataset could only be more scattered.
For readers to understand the calculations, the authors would need to clarify which profiles shown in the supplementary material are extracted from which site (i.e. what are the 10 values determined for this site?), and to clarify how the uncertainty have been calculated.

We agree with this comment; some details were missing. We improved the presentation of the method and carefully check the correspondence between the text and the Tables. We now explain with higher level of details the calculation steps. Now it reads:

"*The DEMs allow us to not only map the locations of the fault scarps, but also to measure their offsets and associated uncertainties and to deduce the fault throw (fault vertical offset). For this, we followed the workflow detailed in* Benavente et al. (2021) and (2022) *that was based on the methodology proposed by* Mackenzie and Elliott (2017). *It consists in three steps: (1) we estimated the scarp offset using the established method of extracting profiles perpendicular to the fault scarp in areas where the surfaces in the hanging wall can be correlated with the surfaces in the footwall (e.g. moraines crests and flanks, linear and homogenous slopes). We fit lines to these surfaces and calculated the scarp offset between them at the foot of the scarp (see supplementary material Figure S1 for topographic profile locations and each individual topographic profile shown in Figure S2; (2) we converted the fault offset into a fault throw (see Table S1 in supplementary material) according to local measurements of the fault dip. Here we used fault dip ranging from 50 to 70° corresponding to the mean of several measurements performed around the paleoseismological trench; (3) we analysed the statistical distribution of the fault throws to deduce a weighted-mean value and its associated uncertainty along the fault segment. Finally a range of most probable mean slip fault value is calculated using the fault dip ranging from 50 to 70° and considering that the fault shows an almost purely normal component (rakes = ~90°).*"

A new figure (Figure S1) showing the exact location of each profile has been added to the supplementary (see also the Table S1 for the measured values).

As shown by the Table S1 (now actualized), the fault throw values at the Sencca sector varies from ~2.8 to ~9.0 m. However, discarding the value at 9.0 m that might be an outlier (see explanation in the text), the values become tightly grouped between 2.8 and 5.0 m, with a weighed-mean of 4.0 ± 0.3 m (error of the weighed-mean) and a standard deviation of 0.9 m.

We added this precision to the main text. The final conversion between the mean fault throw and the fault slip was done using classic geometric cosine conversion and using the range of fault dip from 50 to 70° (please see text for details).

3. Moraines origin and their ages
Section 4.1 and 4.2
3.1. I haven't seen information on the lithology/ies of the boulders. Please specify.

We now specify it in the "Sampling section". Boulders are from quartz-rich Paleogene sandstones.

3.2. Could the authors comment a bit more on the origin of the moraines? Where they formed by glaciers flowing down from the crest line located just North of the Tambomachay fault or could they come from further away?

While I agree that the ages are all nicely self-consistent, further description of the background geomorphic setting may help understand why the ages are so clustered in this study.

Thank you for your comment, this point was also raised by the second Reviewer. We added a description of the moraine origin. Yes, the head of glaciers was indeed located just north of the moraines, in the glacier cirques that we can weel see on the DEM. We added the contours of glacier cirques to the map Fig. 5c (dashed blue lines), as well as the interpreted glaciers flow direction.

Indeed, we were also nicely surprised with the fact the 10Be concentrations were so clustered here! As explained also here below, we have improved the statistical analysis of the ages. Now both internal and external uncertainties are reported (see Table S1) and we used the new P-CAAT software from Dortch et al. (2022) specially dedicated to moraine exposure dataset interpretation and analyses. Statistical age computation was performed considering internal uncertainty and, although ages remain well clustered, three outliers were identified at the margin of their normal distribution. Although it does not change the conclusions (weighted mean age of moraines is still around ca. 14 ka), the statistical analysis is now more robust.The Figure 5 has been updated as well as the supplementary materials.

4. Magnitude estimation (Section 5.3)
In the moment magnitude relation, the displacement refers to average displacement. Similarly, Wells and Coppersmith scaling laws applied to average displacement or maximum displacement. Also, these scaling laws have been improved based on a larger database by Leonard (2010; Bulletin of the Seismological Society of America, 100(5A), 1971–1988. https://doi.org/10.1785/0120090189; I'll let the authors check if there is an even more recent study).

Thank you for your comment. Indeed, numerous studies have proposed relations between fault parameters and possible moment magnitude that those faults may produce (ex: Leonard et al., 2010; Stirling et al., 2013; Thingbaijam et al., 2017; Stirling and Anderson, 2018, etc.). In these studies, different assumptions and distinction are made taking into account the geodynamic context of the faults (e.g. subduction, collision, plate boundary, intraplate, etc.) and they also propose various

method of calculus using one or several combinations of fault parameters such as fault length, width, area, displacement, etc. We tried to re-calculate applying the empirical equations reported by each of the above cited references, we obtained a similar result: moment magnitudes ranged from 6.2 to 7.6.

The authors didn't discuss the assumptions that they make in their estimation of the magnitude, while they have observations at only one site. Did they consider that this slip values are a representative average? In contrast, after the authors mention a few times that the Senca Hill site is where the fault morphology is the most clear, should these values be considered as maximum? A conservative approach may be to consider several assumptions, which may not change the proposed magnitude range.

Yes, in any case we agree that it exist several assumptions behind the moment magnitude estimation that we proposed. Nevertheless, one of the most basic way to estimate the moment magnitude is to use the fault length alone (Thingbaijam et al., 2017, for the most recent study, to our knowledge). For a 20-km-long fault, it returns a theoretical value of ~6.2 Mw, that would be a minimum bound in our case. Then, considering the fault slip measured in our paleosismic trench (0.5 to 2 m), the theoretical Mw would range from 6.7 to 7.6 (Thingbaijam et al., 2017).

To answer to the question above: yes, we had considered that this slip values are a representative average. But, it is not definitively sure that those values do represent the maximum slip for the whole fault segment. Exact location of paleo-epicenters will still remain unknown.

We have added the different scenarios to the text. We now explicitly mention the assumptions and the lower bound for the Mw estimation.

Minor comments:

There are several typos and minor grammar mistakes throughout the text.

We revised the text following suggestions and it was carefully checked before resubmission.

Clarify the location for Tables 1 and 2: Will they appear in the main manuscript (as citation suggests / "Table 1" instead of Table S1) or in the supplementary data (as currently placed).

Thank you for your comment. The tables will remain in the supplementary material and are cited in the manuscript as follows:
Table S1: summary table of locations and measured vertical offset and throw
Table S2: raw cosmogenic nuclide data (^{10}Be) and exposure ages computed with zero denudation
Table S3: exposure ages computed with denudation rate from Kelly et al.(2015)
Table S4 : summary table of the ^{14}C modeled ages in the Tambomachay trench

Figure 6:
- I recommend using colors that are easier to distinguish for units C2, U2, C3 and U3
- Move the label "U3" away from the upper termination of F2, so that the reader can clearly see where F2 termintates.

The changes were done according to the comments.

Introduction / Paragraphe 2: "particularly two events in 1650, 1950 and 1986" =>

looks like it should be 3 EQs.
If it is 2 EQs in 1650, 1 in 1950, and 1 in 1986, please rephrase accordingly.

Changed to: "*particularly three events in 1650, 1950 and 1986*"

Section 2 / paragraph 2:
- "3-20 m-high fault scarps cut glacial deposits" : I don't understand what the authors mean by "3-20". Please rephrase.

The sentence was changed by: *"a series of discontinuous fault scarps 3 to 20 m high are visible, cutting glacial deposits into the mountains."*

- "in the nearby Cordillera Vilcabamba": is this located on a map? If not, please specify the location, on a map or in the text.

The change was made, and the figure was specified as follows: "*…radiocarbon dating of peat underlying moraines in the nearby Eastern Vilcabamba (Figure 1)*",

Section 2 / paragraph 5:
- "was localized at Cusco" or was located?

Changed to: *"was located"*

- "The extreme values of fault throw are measured in the valleys...": I understand "extreme" as the lowest values and the highest values. / NB: Are these throw or vertical offset?
Changed to: "*The highest values of fault throw are measured in the valleys*"

- "discontinuous scarps distributed in an area of 2 km² with a strike of ~105°" => discontinuous scarps with a strike of ~105° distributed in an area of 2 km²

Changed to: "*…discontinuous scarps with a strike of ~105° distributed in an area of 2 km² "*

- "Parina normal fault that ruptured in a Mw 6.1 earthquake 2016": Please provide the location on Earth in few words.

We put the location of the Parina Fault in Figure 1b.
"The Parina Fault (PF) in red star with white border."

In addition, we specify each of the following abbreviations in Figure 1a as follows: *"From north to south the abbreviations: ZF-Zurite Fault, CHF-Chinchero Fault, TF-Tambomachay Fault, QF-Qoricocha Fault, CF-Cusco Fault, PF-Pachatusan Fault, UF-Urcos Fault, SF-Sangarara Fault and LF-Langui Fault."*

Section 4:
- Title: Since section 4 includes 1/ methodological aspect of the dating method, 2/ age results, and 3/ slip rate calculation, the title of section 4 should be modified to better match the content.

In agreement with the reviewer, the title was changed to:" *4. DATING OF THE TAMBOMACHAY MORAINES AND DETERMINATION OF HOLOCENE SLIP RATE."*

Section 4.3:
- "One previous estimate of the slip rate": the referenced study seems to have been conducted at exactly the same site. Please state it clearly.

We changed to: "*One previous estimate of the slip rate (0.1-0.3 mm/yr; Wimpenny et al., 2020) in the Alto Qosqo sector (Figure 3a) shows that it is slightly…"*

Section 5.1.1 :
- "terminating": rephrase the sentence so that "terminating" clearly refers to units 2 and 3 (if I got it right) and not to the faults F2 and F3.

We changed to: *"…that are in contact with the main fault F1, which in turn are displaced by the secondary faults F2 and F3."*

- "F2 and F3 are semi-parallel to the main fault plane": What does semi-parallel mean? Did authors mean sub-parallel?

All right, we made the change.

- "3.5 m vertical offset was recorded by the moraine surface": add a reference to the specific topographic profile shown in the supplementary material.

We reference Figure 3c, where the vertical offset can be observed.

Section 5.1.2:
- "A radiocarbon date from unit 4" + for unit C2 in the following paragraph and other cases in the following: please systematically specify the material that was dated (or provide the information in a table or on figure 6, in the main manuscript)
- "Unit C2 is a thin, dark brown, matrix-supported deposit with angular sandstone pebbles in a sandy siltstone matrix": "siltstone" or silt? Siltstone implies that indurated rock.

Agreed. We made the exchange for silt.

- in Paragraph 3: "thinning": rephrase so that "thinning" clearly refers to C2 (and not C1)

Done.

- in Paragraph 3: "The C2 unit tapers on both sides of the displacement": not clear what authors refer to by the "sides of the displacement". Writing probably needs to be improved here and I would recommend to make the description free from tectonic interpretation.

We agree. The description of the trench was completely re-write to take into account all the comments.

- Paragraph 4: "single" can be omitted here.

It was done

- Paragraph 4: "soft millimetre red clasts": improve writing

We changed to: *"red, soft and millimetric clasts"*

- Paragraph 5: "Unit C3 thins towards the bottom and has roots": 1) towards the bottom sounds awkward and unclear: vertically downward, towards the base of C3 or towards downstream, towards the N? Looks like both apply. 2) has roots => include roots.

We changed to: *"Unit C3 has a triangular shape and includes roots."*

Section 5.2 / Paragraph 3:
- While I agree that the ages do not seem problematic, I wish that the author comment on possible contamination of the organic matter in the sediment by more recent including modern humid acids carried via rainfall infiltration or groundwater transport.

Thank you for your comment. Even if such contamination is always possible for 14C dating applications, it is unlikely here. First all 14C ages are well consistent between each other's, following a logical stratigraphic distribution from the oldest ages at the bas of the trench, to the youngest at its top. Second, the samples were treated by Beta Analytic and followed common chemical pretreatment methods to remove this possible source of contamination. We did not find specific mention, nor discussion, about such specific type of contamination in the recent papers using 14C dating to constrains chronology of paleo seismic trench (e.g. Riesner et al., 2021; Lefevre et al., 2018).

Section 5.2 / Event 1:
- "The minimum displacement for this event is ~0.4m. ": Can the authors explain how they estimate this displacement?

It corresponds basically to the thickness of the layer C1. We add this in the text such as :

"Erosion of the resulting fault scarp formed the colluvial wedge 1 (C1) with a thickness of about 0.4m which give a rough estimation of the displacement for this event."

They write "minimum displacement". Why would this value be a minimum?

It is an estimation of the mean displacement.

Section 5.2 / last paragraph.
- "vertical offset of the fault (3.5 m) calculated from the perpendicular profile on the moraine": if understand that the "vertical offset" referred to in this sentence is based on topography. Therefore, I would refer to it as the geomorphic offset across the fault scarp.

This was modified.

- "there is 3.15 m of vertical offset accumulated between the first and the second event": 1/ misleading writing that would suggest the occurrence of another event, between E1 and E2. Does the following fit more appropriately what the authors mean:

there is 3.15 m of vertical offset accumulated during both the first and the second event. + I would add "POSSIBLY" accumulated because this is a possible scenario for which the authors have no evidence, as is an interpretation to divide these 3.15 m roughly equally between E1 and E2. Please highlight this as well.

We agree. The sentence was changed and we added the conservative mention.

Section 6 / Paragraph 3:
- Typo?: "the mb 5.3 1986 earthquake"

This was corrected (the Mw5.3 1986..)

RESPONSE TO COMMENTS BY REVIEWER 2 (Marthe Lefevre)

The present manuscript addresses the question of the fault activity in the Cusco area (Peru) which is more and more inhabited, using paleoseismological investigation. They focus in particular on the Tambomachay fault which is the one nearest to the city and is well-expressed in the landscape. The authors refine the fault map using high resolution imagery and produce a dataset of fault throw measurements. They also present a trench excavated in an offset moraine along the fault, showing traces of past surface ruptures that complete the earthquake catalog of the area, and allow them to propose some constraints on the seismic hazard. The article is well written but could benefit from some precisions in particular on the trench stratigraphy.

Main comments:

The article is relatively well written even if some unusual phrasing makes some sentences a bit hard to follow and could benefit from some rephrasing.

We corrected and rewrote the different parts as suggested by the 2 Reviewers.

In general, the results and data could be more described to better support the interpretation of the authors, in particular for the trench stratigraphy.

We rewrote and expand the whole paragraph 5.1.2 (trench description).

The method of throw measurements could be more detailed at least in the supplementary material where the topographic profiles are displayed. Indeed, there are several assumptions in the method used by Benavente et al. 2022 to convert the vertical offset to throw and it would be helpful to include a brief summary of them.

Thank you for your comment and suggestion. Similar criticism was raised by the Reviewer 1. We added details to better described the method of offset measurements and throw calulation to the text. We also add some additional figure to the supplementary material to located each profile and we completed the Table S1.

The supplementary material should be a bit reorganized. There is no legend for the graphic so we don't know what USS and LSS are. Moreover, you use swath-profiles to measure the offset, but on the graph we can see a doted gray line which seems to be the line you are looking to fit (example prof 6) but we don't know to what corresponds this line. In the same way you plot some Gaussian but as the method is not described we don't know what you are fitting.

The supplementary material was reorganized and improved. The figures have been improved and all items have now a legend. We also add new figure to explain the workflow and it description the figure caption.

It could also be nice to have a figure in the supplementary material showing zooms of the DEMs on which you made the profiles so we can better understand how the sections of the profiles used to compute the slopes are selected compared to the local morphology, because with only the profiles it is sometimes puzzling (ex profile 2).

It could be also an occasion to show your DEMs that seem to be really nice.

There is now a figure showing the location of the profiles. The row DEM is however very heavy. It will be uploaded to the OpenTopography web page.

It is a bit frustrating to have so few offset measurements in the Pumamarca sector, was it not possible in other places? for example to complete the section close to the Sencca sector where you have a measure higher than the other. In this state we cannot determine if it is an "outlier" or if locally the offset is higher.

Showing parts of your DEM could also be used as a justification for the relatively low number of measurements if the morphology is clearly not preserved.

The fault mapping is not much detailed except for the Sencca sector, while following figure 3 there is more variation in the fault geometry in the other sectors. For the Pumamarca sector only the lithology of the offsets units are detailed, while it could be interesting to compare the lateral throw variations with the fault geometry, in particular in the bend at the north or in the relay in the southern part. In the same way the off-fault deformation is discussed for the Alto Qosqo area, but not in the Larapa sector, while we can see on figure 3 that there are a lot of minor faults in this sector. It would be nice to mention them in a discussion about off-fault deformation and seismic hazard assessment.

We agree with this comment, more data and discussion about the off-fault deformation and related seismic hazard would be interesting. However we think it is not exactly the scope of the paper and it would significantly increase the length of the text (probably beyond the scope of a sole paper).

The description of the trench stratigraphy is very succinct and does not reflect the log. Almost all the layers are described as "matrix-supported deposit with angular pebbles and cobbles" while we can see that there are granulometric changes between the different units. Describing the units in more detail and including some information about the possible mechanism of deposit will better support your conclusions about the deformation chronology.

We improved the description and add much more details. We hope that it will now better convince the reviewers.

When looking at the trench log I have a few questions concerning the relation of units 2, 3, 4 and C2.

Unit 3 is made of large angular clasts and a little matrix and on the photomosaic it looks a lot like the unit C1, so what make you consider that it is a filling unit and not a small colluvial wedge? In particular as you mentioned that it is erosive on unit 2.

Thank you very much for your comment. It is true that it is very similar to unit C1, but we do not have the necessary arguments to affirm that it is another colluvial wedge, what we can confirm is that it is a colluvial deposit, derived from the erosion of the footwall.

The part of unit C2 against the main fault F1 is very similar to the unit C3, it has a triangular shape and looks like an infilled extension crack and it is not clear at all that it is connected to the deposit called C2 on southern part. And if we consider that it is not the same deposit it means that there might have been another small event. Maybe you can add a zoom of the photomosaic of this area to better illustrate your mapping.

It is true that the shape of C2 against the F1 fault plane is similar to C. According to field observations, the sediments in this area are similar to U4, a fine material,

however, importantly, the age does not correspond to that of the U4 unit, with that evidence we believe that this part of the C2 unit could correspond to C4 but with more recent sediments that would have infiltrated at the time of the seismic event, so we consider these sediments as part of the colluvial wedge C2.

In the same way, in this zone close to F1 the relation between "C2" and unit 3 is unclear is "C2" erosive on unit 3? It seems unlikely that there were no deposits of unit 3 (and possibly even of unit 4) against the main fault.
The top of unit U3 is erosional, however the contact between U4 and C2 is not erosional, so C2 could not have eroded U3, however we believe that the sediments of C2 against the F1 fault plane may contain interbedded sediments of U3 and U4, but it is not possible to distinguish them, therefore it is considered as C2.

For a colluvial wedge associated to a major seismic event C2 has a fairly low granulometry especially when looking at unit 1 that forms the scarp, how do you explain it?

The granulometry of the C2 deposit decreases towards the top, we observed in the field that there is a predominance of clasts towards the base, but nevertheless these are disappearing towards the top. If we look at the lower units we observe that U3 is a clastic supported deposit, and U4 is a finer material, so C2 may be a mixture of both. We guess that it also depends on the type of material that is available from the scarp (the moraine can have some variable granulometry).

Line by line comments:

L.28: not "in major earthquakes" but "during/through major earthquakes"

Done.

L58: replace "mean" by "imply"

Done.

L61: replace "capable of rupturing in moderate…" by "able to produce moderate-magnitude…"

Done.

L69-70: you write that in "particular two events" were damaging and then you cite three dates, please rephrase for consistency

Done.

L93: replace "the seismic hazard in the city" by "the seismic hazard of the city"

Done.

L100: "a ~1800 km-long"

Done.

L102: rephrase "tectonic regime…oceanic plate" in " tectonic regime associated with the subduction of the Nazca oceanic plate under the continental South American plate"

Done.

L107: replace 'have been mapped " by" has been mapped"

Done.

L118: in the sentence “the last Pleistocene-early Quaternary compressional and Late Cenozoic” you mixed three levels of classification of the stratigraphic chart, making it confusing. We even wonder if it is “last” or “late Pleistocene”

Sorry, there was a tipo here. We completely rewrote this paragraph.

L121: maybe add the “Alto Qosqo” on figure 2

Thank you, this was added.

L124: typo (remove “Tambomachay fault”)

Done.

L126: in the Figure2 the deposits are just classified as Paleozoic, Mesozoic or Cenozoic rocks, while here you describing Cretaceous rocks over Eocene-Oligocene rocks, which is more detailed, maybe add a precision to link with the figure.

This was improved. We modified the text and the figures so that they follow the same logic. We use the “System Period Levels” (e.g. Cretaceous, Paleogene, Neogene, Quaternary).

L139: “at least 8 ka old”

Done.

L140: maybe you can add the location of this dating (Wimpenny et al. 2020) on the map figure 2, as it is the only age constraint of the area

Done.

L144: replace “have had” by “have”

Done.

L160: rephrase “historical event…of M6” in “historical event with a probable magnitude of M6”

Modified.

L174: add “suggest that it might”

Added.

Figure 1: the names of the faults are missing, i.e. the signification of the name abbreviations (CHF, SF, LF….)

Fault names have been now added to the figure caption.

L236: use “computed” instead of “calculated”

Thank you. This was modified in all the text.

L240: “traced” maybe “mapped” is better

Modified.

L242: section might be better than zones.

Modified

L247: It is unclear in this sentence where the connection with the bedrock-moraine contact is located.

We removed this sentence.

L261: the values presented here are not exactly the same as in the table 1 in the supplementary materials.

We carrefully check so that the values in the text are the same as in the actualized Table S1.

In this part of the supplementary material even if all the locations are displayed it would be nice to have a map with the profile lines drawn and labeled, for example a figure with the detailed DEM zoomed on the area where the measurements have been done, so we can also appreciate the morphological situations of the profiles, i.e. on a crest, distance from stream, on alluvium or not… And it would also be an opportunity to show your DEM data that seems to be really nice.

Thank you for your comment. We have added the required informations and figures to the supplementary material.

In the figure 3.b/ on the main text you separate the samples that are measured on the bedrock, from the ones measured on alluvial deposits, it would be nice also to have this separation highlighted on the table 1 of the supplementary material (add a lithology column or use a different label)

Ok thank you, we added one column to the Table 1 with the corresponding lithology.

L269: use “while” instead of “whilst”

Done.

L271-275: you can develop a bit more this section, you mention that part of the variability of the cumulative displacement is due to the fact that during one event only a part of the fault ruptures, but is there any link with the fault geometry? For example, the place with the highest throw (n°11) is geographically separated from the others and just in the bend at the limit of the Sencca sector. To properly explore this matter, it would be nice to have more measurements around this area if the local morphology allows it.

We agree. We added a sentence to suggest a possible link with the fault geometry : “Finally, the variability of the cumulative displacement may be also linked to fault geometry changes along the fault segment but unfortunately, we do not have enough measurements to explore this hypothesis.”

L277: I don’t really understand what you mean here because following the figure the fault is at the limit between the relief and the sedimentary basin, I don’t really see the relief vanishing.

We agree, this was unclear. We had removed this part of the sentence.

L284: in section 3.1, you mention that you compute a DEM from the aerial photographs from 1956, with a resolution of 1.26m/px. Does this DEM not allow to make any measurements of scarp height? On Figure 4a there are some places where with this kind of resolution we would expect that some measurements could be possible.

Unfortunately, no. The DEM should have theoretically a good resolution, but in practice it suffers of a very high level of noise (due to vegetation and image correlation errors).

Figure 3: On 3.b. the difference between the blue square with light blue or grey borders is hard to make out.

We modified the figure so that it is now easier to identify both.

It would be nice to have the extent of your different DEM datasets on this map.

We agree but we are afraid it would be too much and saturating the Figure 3. We added this information in the supplementary material.

L307: Off-fault deformation section: Based on the map in Figure 3a, it seems to exist other places with more distributed deformation like in the footwall of the Larapa sector, or in the eastern termination of the fault, but none of them are mentioned in the text. You might include them in this section and discuss their general distribution.

Yes we agree, it would be very interesting. Actually, this will probably be the focus of another coming paper (we are waiting for more dating of moraines for the eastern continuation of this fault system).

L313:Replace « sense » by « direction »

Done.

L321: It is not clear here whether you are refering to coseismic or cumulative scarp.

We mean coseismic scarp. This was updated.

L344 : Table 1 is cited as if it was in the main text, but it is in the supplementary so we are looking for it, mov it to the main text or change the citation.

The citation has been changed.

L383: the ages described in the following section “exposure dating results” are not the same as in figure 5.c, which is currently the only place where we can see the samples ages. The ages in the text are all younger than on the figure and have smaller uncertainties, explain what is the difference between the two datasets and if you keep the table 1 in the supplementary material you should rather discuss the ages presented in the figure 5c.

Thank you for your remark. We apologize for this mistake. Exposure ages were calculated several times (with updated parameters) and unfortunately a wrong version has remained in the Figure 5c.

We have now double-checked the ages calculations and their reports. We also improved our statistical analyzes of ages. Now both internal and external uncertainties are reported (see Table S1). Then we used the new P-CAAT software from Dortch et al. (2022) specially dedicated to moraine exposure dataset interpretation and analyses. Statistical age computation was performed considering internal uncertainty and, although ages remain well clustered, three outliers were identified at the margin of their normal distribution. Although it does not change the conclusions (weighted mean age of moraines is still around ca. 14 ka), the statistical analysis is now more robust.

L398: “tight” is not really used in such context

This was changed by “well clustered”.

Figure 5: on the DEM in 5a there is no scale. On the picture 5b, the sampled boulder is rather small and partly hidden in the vegetation, you did not address in the text the possibility of a post-glacial cover of the boulder, is it the case? On figure 5c there is a problem with the ages that are not coherent with the text

A scale was added to the DEM.

Yes, the boulders were actually quite small along those moraines. This is probably due to the fact that the source material eroded by the glacier is sandstone, with strata

of 1m thickness at maximum. So, it did not produce big boulders such as in granitic context.

Nevertheless, we tried to sample the largest boulders available. Knowing that those boulders remained smaller than boulders routinely sampled for TCN dating in the literature, we adopt the following strategy to test for possible sources of uncertainties as suggested by the reviewer (partial shielding, erosion, etc.):

1-we sampled two replicates (T10A and T10B) located on two boulders distant from < 1m

2-we sampled a significant number of boulders in total (12 samples)

We were nicely surprised after the 10Be measurements that the concentrations were so clustered (including for the two replicates). To our opinion, such reproducibility of exposure ages allows to discard that any process would affect the boulders. This is now stated in the text.

L433: use “more details on ”

Thank you. This was updated.

L438: maybe “across the fault scarp at Sencca Hills” instead of “in the footwall of the fault scarp”

Done.

L439: the end of the sentence is a bit unclear “the representative … Glacial Maximum” in this sector you made ten measurements, I assume you take the average but it is a bit weird to speak about representative value in this case.

We agree. This was replaced by *“We selected this sector because of the preserved morphology of the fault scarps that allowed a good estimation of the accumulated displacement since the Last Glacial Maximum”*

L448: spelling: “the radiocarbon age of each sample”

This was corrected.

L451: you could use log instead of sketch which is quite classic in paleoseismology.

Thank you. This was replaced in all the text.

L458: what the lithology of the pebbles and cobbles? As you mentioned some lithology for the clasts of the sediment in the hanging wall, so it could be interesting to have also the lithology of the footwall for comparison.

These are from the Paleogene sandstones that are outcropping in the glacier cirque. This was added.

L465: in the figure 3 you write the throw value and not the one of the vertical offset, maybe adding the offset value on the figure, next to the throw.

This was added as well as the value of the offset on the Figure.

Figure 6: The photomosaic does not have a good enough resolution to really look at the stratigraphy, I know that the constrains of having a complete figure in a reasonable space prevent to really improve this in the manuscript, but maybe you can add a higher resolution and larger version of this figure in the supplementary.

Thank you for reporting, we added a high resolution raw photomosaic to the supplementary material, Figure S6, also now cited in the text.

In 6.b the clast axes are represented by arrows and not dashed lines.

We modified it.

The insets 6b and 6c might be enlarged a bit to better apprehend the clasts rotation and the surrounding context (to achieve this I think that the inset 6.d can be reduced as there is not much information on in and the red clast can be shown in a smaller picture)

We agree, this was modified.

L492: remark the colluvial wedge C1 has a similar age to the colluvial wedge dated along the Qoricocha fault, suggesting the occurrence of events in a relatively similar period on both faults compared to the return time observed in the trench. I am not really familiar with the fault activity of the area but what do you think about a possible interaction between those faults?

Thank you for your remark. Yes, we agree that it could be the same event. However, we are not completely sure that we have enough data to affirm it. We prefer not to speculate.

L499: you mentioned pebbles and cobbles in the unit 2, while looking at the photomosaic it seems to be a unit with really fine clasts, we actually don't really see them on the figure 6.

We agree. We modify the description accordingly such as "fine-grained material".

You also mentioned that those clasts are made of sandstone, does it match the lithology of other units?

Yes, the lithology of pebbles and cobbles is always the same. The source material are the Paleogene sandstone outcropping in the glacier cirques.

L500: The unit 3 can be a bit more described, you don't mention the clast rotation that are shown in figure 6.c. Moreover, the layer geometry is not described, this unit is way thinner on the southern side of F2. Based on the shape of the layer and its granulometry with large cobble and pebble we can wonder if it could not be a small colluvial wedge.

Thank you for your detailed comment. We considered all of this in the new description of the trench. However, uncertainty remains about the layer U3, we prefer to not over interpret it because (1) it is one on the smallest deposit, and (2) we have only one age here ; what does not allow us to ensure that it would correspond to a colluvial wedge.

L503: based on the contact between unit 3 and 4 on both side of F2 and their internal deformation, we can actually wonder if unit 4 did not reach F1 at first before being eroded, the top of unit 3 in the area of the main fault seems erosional, which is not the case where the unit 4 is present. Maybe discuss more the erosional characteristic or not of the contact between unit 3, 4, C2, 5.

We partly agree, it may be the case. However, we are afraid that it would be maybe too much interpretative (speculative) and we would prefer to keep a first order interpretation based on what we can be observed on the trench.

L506-508: the unit C2 is first a unit with "no cobbles or pebbles" and then became a "matrix-supported deposit with angular sandstone pebbles"

Thank you, sorry, it was an error. We remove this part as the unit C2 is further described in details just below.

Moreover the unit C2 and C1 are described in the same way " matrix-supported deposit with angular sandstone pebbles" only the color changes in the text, while we see clearly that the clast constant and the size of these clasts are very different between the two units.

Thank you, we improved the description with higher level of details here. Now C1 and C2 are specifically described.

L509: replace "sandy siltstone" by "a sandy-silt matrix "

Done.

L518: the fault F2 and F3 do not cut C2 on your trench log, suggesting an even older age for the last event on these structures.

Yes, it is precisely our interpretation. We use C2 age (4819-4449 cal. BP) as the probable age of the second event. Please see Figure 6 and section 5.2.

L525: not "thins" but "gets thinner"

Thank you. This was replaced.

L527 "also" is not needed here

Removed.

L528: use "when" instead of "where"

Done.

L529: use "are low" instead of "is lower" à this complete sentence need rewriting because it is unclear and have several mistakes

We agree. The sentence was rewrote. It now reads :

"This type of deposit geometry is associated with extensional crack infilling near the primary rupture zone. On the other hand, the vertical displacement is less than 0.3 m only, and it is too small to have formed a colluvial wedge (e.g. Aguirre et al. 2021). This suggests that the colluvial wedge may have formed after a recent earthquake that disturbed the Tambomachay fault surface before 1.2–0.9 ka cal BP."

Figure 7: rewritte the sentence "stratigraphic units….age ranges"

The sentence was improved.

L581: replace "1.5m of surface rupture" by "1.5m of slip"

Done

L593: add the precision, here you are speaking of the fault throw "during one seismic event"

This was added.

L600: rephrase: "the whole Tambomachay Fault and the whole seismogenic layer."

This was modified.

L603: replace 'has shown" with "have shown"

Done.

L608: based on the magnitude you propose for the historical earthquakes Mw7.2 in 1650 probably ruptured the surface according to the previous estimation you made on the magnitude

Yes, but as we mentioned it, the 1650 might be caused by the rupture of another fault.

L617-618: here there are probably more than 300m of cumulated displacement as part of the fault plan is under the sedimentary cover of the Cusco basin and you can also expect a bit of erosion. The estimation of the initiation of the extensional faulting is probably underestimated.

We agree. This is now mentioned in the text.

L623: “into the seismic”

Added.

L647: “with offsets”

Modified.

L648: rephrase “the Tambomachay identified ruptures”

Modified.

L649: “or that they did not rupture”

Done.

Final decision

Decision Letter

Dear Lorena Rosell and co-authors,

The revision of your manuscript, "Holocene earthquakes on the Tambomachay fault near Cusco, Central Andes" has now been carefully evaluated by our associate editor (Dave Whipp) and executive editor (Robin Lacassin). We are both in agreement that this round of revisions sufficiently addresses the core concerns that we and the reviewers had, and so we are pleased to accept your article for publication in Tektonika. Messages will follow in the coming days with regards to copy-editing and production.

However we have identified two points we ask you to implement in the manuscript files you will send to our copy-editing team: 1/ Dave Whipp has made some suggestions to correct some grammatical issues in you text (see the attached document); please take these comments into account. 2/ About your DEM, please upload it on a data repository (for example open-topography, or a more generic repository like Zenodo), and provide the link and DOI in the data availability section of your paper.

Best regards, thanks for submitting to Tektonika

Dave Whipp, Tektonika Associate Editor

Robin Lacassin, Tektonika Executive Editor

Authors' Final Answer

Thank you for your message, great news !

We send back in attachement the revised version of our manuscript after including all the suggestions made by Dave Whipp. Thank you very much Dave for your help. We took into account all our suggestions and we rephrased where it was required (among others : Mw and mm/yr has been homogenized ; we modified the sentence about the C14 ages from U5 because the age ranges are actually the same for the two samples when being rounded at one decimal of ka).

The DEM is now available online at https://doi.org/10.5281/zenodo.8147580. The link with doi was added to the manuscript too.

Best regards, and warm thanks again to the Maryline and Marthe for their helfull reviews, and to Robin and Dave for all their editorial work.

Lorena, Swann and co-authors.