



Dr. Nicolas Harrichhausen
Assistant Professor of Geology
Dept. Geological Sciences
njharrichhausen@alaska.edu

Dear Editor,

We thank the reviewer for taking their time to review our manuscript for a second time and provide thoughtful comments and suggestions for our paper "Distributed right-lateral strain at the northern boundary of the Quito-Latacunga microblock" that we submitted for publication in *Solid Earth*. This letter contains our responses to the comments and suggestions by the reviewer. We paraphrase the reviewer's comments in bold and follow with our responses and descriptions of relevant edits to a revised manuscript that has been resubmitted for review.

Main comments:

1. Slip Rate Calculations and Uncertainty: As you have chosen to retain the cosmogenic ages, it is crucial that the calculated slip rates accurately reflect these data. The current calculations appear arbitrary (e.g., assuming a 12 ka age). I strongly suggest recalculating the slip rates by properly propagating the uncertainties of your actual exposure ages and satellite interpretations. Please see my detailed line-by-line comments on this topic.

We thank the reviewer for pointing out that how our calculations have been done is not well explained and that they do contain some typos/errors. These calculations, however, were not based on arbitrary ages. The 12 ka age we use is based on the youngest cosmogenic age of the moraine (Model 3, ANG 50: 13.9 ka - 2.0 ka (2 sigma)), which we have rounded to 12 ka. This youngest age, along with the maximum offset gives us the maximum slip rate—3.1 mm/yr on both the northern and southern strands of the fault. Conversely, the minimum slip (5 m and 13 m on the northern and southern strands) over the maximum time frame (Model 2, ANG-51 = 16.8 + 3.6 = 20.4 ka) gives the minimum slip rate of 0.2 and 0.6 mm/yr.

Our slip rates (0.2 - 3.1 mm/yr on the northern strand and 0.6 - 3.1 mm/yr on the southern strand) encompass the rates the reviewer has calculated themselves. In fact, we show greater uncertainty, which we feel is more likely due to unaccounted-for epistemic uncertainty.

To make it clearer that the calculations do indeed propagate the uncertainty of both the ages and the offsets, we have edited the paragraph beginning on **line 456** to be more specific about where the chosen values originate. We have also chosen to not round 11.9 ka to 12 ka to make it clear that this number is not arbitrary.

"Based on our geomorphic mapping, a substantial portion of the geodetically modeled 3 mm/yr of right-lateral strain at the northern edge of the Quito-Latacunga microblock (Jarrin et al., 2023) is taken up by slip on the Reservoir fault. Considering the range of offsets of the glacial moraines and creeks (Fig. 5), the range of ages of

these features from our cosmogenic ^3He dating, and published ages we can estimate a slip rate on both the northern and southern strands of the fault. Assuming a maximum of 37 m of slip on both the northern and southern strands (26+11 m, 29+8 m, Fig. 5b), and a minimum age of 11.9 ka of the moraines (Table 1, Model 3, ANG-50), we calculate a maximum slip rate of 3.1 mm/yr on both of these strands or a combined rate of 6.2 mm/yr for both strands. Given a minimum offset of 5 m on the northern strand (16-11 m, Fig. 5b), 13 m on the southern strand (21-8 m, Fig. 5b), and a maximum deglaciation age of 20.4 ka (Table 1, Model 2, ANG-51), we estimate a minimum slip rate of 0.2 and 0.6 mm/yr on the northern and southern strands respectively. The combined minimum slip rate of both fault strands is 0.8 mm/yr. Using a mean offset of 23 m for both the northern and southern strands, and an ice-free age of 15 ka (Rodbell et al., 2009; Blard et al., 2013; Angel et al., 2017), we obtain slip rates of 1.5 mm/yr for both strands and 3 mm/yr for the combined faults. Given these rates, slip on just the Reservoir fault could account for between one third to over double the total 3 mm/yr strain rate observed in the block model (Jarrin et al., 2023). Because we observe active deformation on the July 25 fault, and most likely on the Polylepis fault, we argue that deformation is distributed across several faults and that slip on the Reservoir fault takes up substantially less than 100% of the right-lateral strain at the north edge of the Quito-Latacunga block. This argument entails that either the minimum combined slip rate of the Reservoir fault (0.8 mm/yr) is more accurate than the higher rates (>6 mm/yr), or that the geodetic instantaneous strain rate is lesser than the geologic slip rate."

2. Over-interpretation of Slip Rates: Regarding the interaction with the Chiles-Cerro Negro Volcano complex, some interpretations are not grounded in the presented data. For example, suggesting geologic slip rates could exceed geodetic slip rates is a significant issue—especially since this claim is repeated in the abstract, discussion, and conclusions—when the data supports a lower slip rate (see my calculations below). The reviewer has calculated even faster slip rates than what we use in our discussion, however, they have neglected to sum the north and south strand slip rates. This summation is necessary as the strands have offsets that overlap. Therefore, we believe our discussion and interpretation of our slip rates are solid and based on the presented data. See comments above on comment # 1 about our calculations and comments below on the "Note" on line 459-461 for more details.

3. Basement Faults and Regional Context: Discrepancies still exist regarding the interpretation of basement faults. The argument for their inactivity remains insufficient. Furthermore, while references to the Romeral Fault System were added, they feel isolated rather than integrated into the regional discussion. The argument currently revolves around faults south of the Chiles-Cerro Negro complex, neglecting the northern portion, which could also be part of the Quito-Latacunga microblock (as correctly depicted in Figure 9).

In the last revision we added a new paragraph that discusses the Romeral shear zone. Our discussion does focus more on faulting south Chiles-Cerro Negro as that is where the vast majority of our observations were made.

4. Terminology (Slip Rate vs. Strain Rate): The term "strain rate" is frequently misused throughout the document when referring to "slip rate." Please ensure the correct terminology is used. For example, the caption of Figure 1 mentions "strain rates" from Jarrin et al. (2023), but the GPS vectors are reported in units of mm/yr, which denotes slip/velocity.

We have changed all instances of "strain rate" to "deformation rate". We feel that using the term "slip rate" implies that strain is being accommodated as slip on faults. Deformation rate implies that while slip may be accommodating strain, other mechanisms such as plastic deformation, off-fault damage, etc... could account for some of the measured geodetic strain.

Line-by-line comments:

Line 52: Do you mean the city of Ibarra?

No, in the case of the earlier 1968 earthquake most of the damage was in El Angel.

Lines 459-461: For sample ANG-50, the weighted mean exposure age is 14.55 ± 0.65 ka (1σ), while sample ANG-51 is slightly older with a weighted mean of 15.20 ± 0.63 ka. If we assume a maximum displacement of 29 ± 8 m (taken from Figure 5), the mathematically propagated slip rate would be 1.99 ± 0.56 mm/yr (ANG-50) or 1.91 ± 0.53 mm/yr (ANG-51).

See reply to main comment 1.

Note: These calculated slip rates are roughly half of the proposed 3 mm/yr. Utilizing this statistically driven value would actually better fit your interpretation that the Reservoir Fault accommodates ~66% of the total slip rate proposed by Jarrin et al. (2023). Furthermore, a value of ~2 mm/yr is closer to the rates of the Buesaco and Aranda faults, strengthening your interpretation that the deformation zone could extend toward the northwest. You may keep your minimum and maximum estimates, but I highly recommend sticking to this statistically derived slip rate for your core concluding interpretations.

The reviewers calculated slip rates need to be summed (north and south strands, which overlap) to get a complete slip rate for the Reservoir fault. Their summed slip rate would be 3.9 ± 1.0 mm/yr, which is within error, and higher than our summed mean slip rate of 3 mm/yr. Our mean slip rate of ~3 mm/yr is statistically derived, and the basis of our core interpretations.

Line 467: Typo: "...the total 3 mm/yr strain strain rate observed..."

Thank you for catching this error. We have edited it.

Lines 500-502: Based on the uncertainty propagation mentioned above, the maximum slip rate on the Reservoir Fault is ~2 mm/yr. Without quantitative estimates for the slip rates on the other two structures, proposing that the combined slip rate is greater than 3 mm/yr is speculative and unsupported by the current data.

See comments above that show that the maximum combined slip rate on the two overlapping fault strands is over 6 mm/yr and the mean combined slip rate is 3 mm/yr. These are quantitative estimates directly based on our data collected in the field and previous research. The reviewer has not summed the slip rates up on the two overlapping faults and is basing their comments on this erroneous approach to estimating the slip rate across the entire fault.

Lines 509-511: "Therefore, the faults in our study area could have greater earthquake rates and slip rates over the Holocene, resulting in part from volcanic inflation, than the geodetic block model predicts." This claim overstates the results and is not directly supported by your data. I suggest revising this section to rely strictly on your InSAR analysis rather than speculating on Holocene earthquake rates.

See comments above.

Lines 517-518: The text states the Reservoir Fault is more aligned with certain faults, but it is unclear which ones. Polylepis? July 25? The subsequent mention of "bedrock faults" adds to the ambiguity. Please rewrite this and name the faults explicitly to avoid reader confusion.

There are several bedrock faults mapped in Figure 2b that we could not find names for. In our discussion we are referring to the structure that trends southwest--northeast immediately west of Cerro Negro. We have edited the text on **line 518** to make it clearer as to which fault we are referring to.

"The Reservoir fault, which trends northeast, however, may be more well aligned with some of these faults, for example the SW–NE trending structure immediately east of Cerro Negro."

Lines 520-52. I recommend removing or revising the interpretation that bedrock faults are inactive based on their absence in pre-existing geological maps. Older mapping efforts were generally not intended to identify neotectonic features or concealed active faults beneath recent deposits. Because of this limitation, the absence of these faults on older maps is not sufficient evidence to conclude they are inactive today.

The absence of faults on older maps is not our argument that they are inactive; our argument is that the mapped bedrock faults are not aligned with our mapped active faults. We have changed the text on **line 521** to make this clearer.

"But, based on the orientation of previously mapped bedrock geology maps and the orientation of most of our mapped active faults, bedrock structures south of Chiles-Cerro Negro are mostly not being reactivated and are therefore probably not favorably aligned with the crustal stress conditions."

Lines 526-528: Based on Figure 1, there is virtually no difference between the GPS vectors at the northern boundary of the QL block with respect to Pasto. Given this, how are you testing the hypothesis that local stress changes could be the reason behind the non- reactivation of bedrock faults?

We agree that this argument may be poorly worded. We are not arguing that the GPS vectors alone indicate a change in stress conditions (GPS vectors show strain, not stress). Instead, we suggest that the location of the northern edge of the microblock coinciding with the northern edge of a large left-step in the eastern boundary of the NAS may result in changing stress conditions. We have edited the text on **line 528** to make this clearer.

" At the larger scale, the northern edge of the block is aligned with the northern side of a large constraining step-over of the entire eastern boundary of the NAS (Fig. 2). This major change geometry may indicate that principal stress orientations are rotated and that the overall tectonic regime may also play a role in changing stress conditions at this location."

We thank both reviewers for their comments and suggestions, we believe they have greatly strengthened the manuscript.

Nicolas Harrichhausen et al.