Review for Petrie et al., submitted, Geologic characterization of nonconformities using outcrop and whole-rock core analogues: hydrologic implications for injection induced seismicity. Solid Earth

Reviewed by Owen Callahan, April 20, 2020

General Comments:

The authors present important and timely work about rock properties at the basement-basin interface and discuss potential implications for induced seismicity. However, the manuscript is missing a higher level synthesis needed to make the observations useful in a more practical, applied, or global sense. I encourage the authors to consider restructuring the paper so that their important observations are highlighted and lead to more transparent interpretations, with more explicit discussion of the impact of local geologic history or other possible controls on the properties of the non-conformity. I think these changes would make the paper much more impactful.

Specific Comments:

1. The manuscript is missing a higher level synthesis about what (predictable) factors control the various types of interfaces. In this regard, the manuscript feels more like a list of observations, without a real test of the hypothesis or further prediction. For instance, what is the impact of specific lithologies on fluid flow properties at the interface? Are fault damage zones different in the different basement lithologies? Is the weathering (paleosol) different depending on lithology, exhumation, or burial history? This important step would help identify other regions more or less prone to permeable basement interfaces based on knowable basement properties.

2. Paper organization: I think the paper would benefit from more informative headings. Methods could be more detailed. If modeling were its own section, not part of the discussion, then the model results could be used to support specific points in Discussion (referring to Fig 12). The Introduction is a bit jumbled. The manuscript is missing a section on local geology descriptions, which could be very informative when trying to generalize about geologic controls on the basement-basin interface. Instead these observations are lumped into results; this has the effect of making site selection seem opportunistic rather than designed to test specific differences in geology or geologic history, because the differences between sites or reason for picking them is not clear before the results are reviewed.

Line Item and Technical Comments:

20: Capitalize “Great Unconformity”

24: Perhaps just name the types here, rather than write around them?

26: Which one, and why? What contributes to allowing or inhibiting?

43: Missing second parenthesis.

45: This paragraph outlines the results from this study, but, due to its position in the introduction, makes it sound like a prior observation or known phenomena. I think it either needs more citations, or to be moved later into the intro as part of what you are describing as your work and the results of this study.

60: Whole-rock core here (and in the title) seems a bit redundant. Is this to differentiate between core and cuttings?

73: …observed/described rock AND fracture and fault features. Without introducing observations of fault/fractures earlier, the descriptions at each site seem to come out of the blue or to be irrelevant to the main hypothesis, even though faults and fractures in the basement are clearly very important.

77-84: This is a broad site description, not really methods. I would suggest including a more generic section on Geologic Setting (which could include much of what you describe in results), expanding the methods, and streamlining results so the reader can more easily map to your synthesis diagram in Fig. 12.

86-87: Analytical methods could be more detailed, or reference details in archived dataset. The specificity of the mineral identification from XRD is impressive, so it would be nice to know what kind of equipment, scan times, and analysis software was used.

125: Regarding granular flow, could use citation.

178: "altered and altered"

180: missing a period after (Anderson, 2012)

180-183: This statement would lead naturally to a **broader synthesis** discussion point about the nature of the nonconformity in mafic, rift-related portions of the midcontinent.

183: Looks like a missing space after "1995)."?

192: The paragraph break here is confusing for me, as the topic sentence is about the Mt. Simon, but the next few sentences are again referring to the altered upper portion of the basement, but that is not entirely clear until the reference to "50 m zone…"

199: Either new sentence or semi-colon at "contact, locally…"?

223: The observation that the altered shear zone can be fractured/reactivated would be another point to include in a **broader synthesis**: zones of prior deformation are more likely to be zones of subsequent deformation

229: Another good point to fold into a **broader synthesis**: phyllosilicates at the contact may inhibit cross-nonconformity fractures and flow, but maybe need to discuss their origin.

225-242: I find this section somewhat confusing. Doesn't the alteration and mineralization suggest fairly extensive fluid-rock interaction? I think the part that is missing is the point that *prior* fluid rock interaction and alteration has resulted in low permeability *now*, so perhaps clearing up the temporal aspects? However, mineralization (presumably strengthening) and alteration to phyllosilicates (presumably weakening) are both called upon to act as hydrologic and mechanical barriers, and as written it is hard to understand why. Consider, for instance, the impact of more brittle layers in fault systems (e.g. Schöpfer, M. P. J., Childs, C., & Walsh, J. J.

(2006). Localisation of normal faults in multilayer sequences. Journal of Structural Geology, 28(5), 816-833. 10.1016/j.jsg.2006.02.003)

259: "Our collective field and core observations document the occurrence of significant lateral variations in altered or mineralized zones that are associated with a relatively wide range of permeability values, and that alteration coupled with abundant structural discontinuities can result in relatively higher permeability that extends for 10's of m's both laterally and vertically into the crystalline basement rock below the nonconformity." Yes, but what controls the variations, and how might someone know from the surface, prior to siting an injection well, if basement faults in a region are more or less likely to be reactivated due to hydrologic properties at the non-conformity? This is the type of synthesis I would really like to see spelled out more explicitly, even if speculative, and there are sections where you already briefly bring up points that could feed into this broader synthesis (see above).

264: Modelling work could be a new method and result, then folded into discussion and used to support your summary diagram in Fig. 12, rather than added to the end. As it is, I find it hard to tell if this is new work, or prior work from J. Ortiz.

266-267: Note different style "x" shown for "times" in permeability values. Also, is the relative k_z/k_x and absolute k_z shown meant to be for the fault in basement or in the aquifer, because wouldn't at least one of those values need to be different for the two portions of the faults?

271: Ok, so in this model the low permeability zone formed after the fault? Or was it a weathered horizon that was incorporated into the fault? I wonder because that helps me think about the environment of formation of this zone, which could be very widespread at non-conformities (e.g. soil profiles like *Walter et al. (2018) Petrophysical and mineralogical evolution of weathered crystalline basement in western Uganda: Implications for fluid transfer and storage. AAPG Bulletin*).

283: I would like to see these geologic conditions spelled out more explicitly rather than leaving it to the reader to infer them.

284-286: In what scenario would they do both, either? This sentence could be more specific.

288: Do you mean Type 0 and Type 2? I thought Type I resulted in reduced fluid communication into the fault zone (line 274-275)?

295: Shameless plug about impact of fluid chemistry on deformation in mineralized fault rocks, but there are many others too: Callahan, O. A., Eichhubl, P., Olson, J. E., & Davatzes, N. C. (2020). Experimental investigation of chemically aided fracture growth in silicified fault rocks. Geothermics, 83. https://www.doi.org/10.1016/j.geothermics.2019.101724

359: Looks like a citation manager software glitch.

363, 364: Incomplete references? No pages or publisher? Might just be a reference style thing.

385/Figure 1. In legend, using a grey gradient box for 'craton' would be a bit clearer than the current black line, although this may be a reproduction issue.

390/Figure 2. Missing a description of inset "A". Not clear what diagonal lines are in B, Fault? Dike? Caption could be more informative, for instance noting evidence for fluid-rock interactions in "C". Some shorthand in captions is confusing, such as "min. congl". Mineralized? Minimal?

395/Figure 3. References to insets change from 1) , 2) to B), C), … “Colloform mineralization” image (“C”) is either missing or does not chow colloform habit very clearly. What are red lines near 4 and 5 on the “Lithology” log? Why does the thickness start with 0 below weathered basement and not at the non-conformity?

397/Figure 4. Could use more descriptive text, for instance, insets A, B, are not discussed. Red arrows in B, C are not described. Fault in C would be easier to see if white or other light color. B would benefit from a scale.

400/Figure 5. Choice of height scale at 1.2 m is a bit odd, and “Thickness” may be the wrong word to use here. Maybe depth relative to non-conformity and start with 0 there? Is Espirutu ~10 m thick, or 10.9-9.6 m thick? Because it shows very little, the “Elemental Analysis” column is a bit frustrating. Why not show XRD results as in Figures 3 and 7? Or better yet in all figures with similar columns show alteration/mineralization reactions and products, which could reflect either XRD or elemental work (e.g. + calcite, + albite, -quartz…) if you have a mixed bag of analyses. Note typo in 4a “phyllosicilate”. In caption: Espirutu or Espiritu?

408/Figure 6: This caption has a lot of passive voice. Unclear to me if the nonconformity is cut by “throughgoing veins” (check typo there) or the veins cut the shear zone, but those scenarios have pretty different implications.

414/Figure 7: Perhaps worth noting whether units are measured depth, relative to sea level, true vertical depth, etc. for clarity.

425/Figure 8. Typo: “Granitiod” in A. “Pink-coated” is not particularly helpful; perhaps ID the mineral, even if speculative, or just call them partially-mineralized, sealed, or stained fractures, etc. whatever the case may be.

430/Figure 9. Same comment about measured depth for clarity.

435/Figure 10. Cool plot. The “Depth” axis on the permeability column is perhaps redundant.

444/Figure 11. Photomicrograph 2. What does “intensely weathered ~60 m” mean? Consider argillic alteration or just argillization. Argillite is a rock type, not the product of argillic alteration. “Iron” capitalized in caption.

446/Figure 12…. “Phyllosilicate” (in figure) vs “weathering” in caption. What is the rationale for the circular flow path?

You made it this far! Good luck!