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Interactive comment on "Geologic characterization of nonconformities using outcrop and whole-rock core analogues: hydrologic implications for injection-induced seismicity" *by* Elizabeth S. Petrie et al.

Elizabeth S. Petrie et al.

epetrie@western.edu

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Line Item and Technical Comments: 20: Capitalize "Great Unconformity" – change made

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

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

43: Missing second parenthesis. – change made

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Discussion paper

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. – re-organized as per R1,R2,R3 comments (55)

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

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. – We have added details earlier in manuscript

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.

We have included a brief section (section 2) that describes the geologic setting of each site.

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. – Details included.

125: Regarding granular flow, could use citation. – change made

178: “altered and altered” – change made

180: missing a period after (Anderson, 2012) – change made

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. This statement has been incorporated into the geologic setting and used in synthesis within the discussion.

183: Looks like a missing space after “1995).”? – change made

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: : :” – added clarification

199: Either new sentence or semi-colon at “contact, locally: : :”? – change made

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 –

Noted. We have revised discussion to synthesize observations more clearly.

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.

Noted. We have revised discussion to synthesize observations more clearly in discussion

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)

Schopfer and other workers (Ferrill et al , Petrie et al, Larsen, Sibson, and others) show the change in failure mode across boundaries, our observation is that under the conditions in which the observed open-mode fractures formed they did not penetrate the nonconformity, reducing a potential future fluid flow pathway, and we expect the difference in relative permeability between the altered boundary and overlying sed. protolith injected fluids would move along the nonconformity. We have reworded this section to clarify.

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). We have provided clarification and edited the text; other reviewers have requested that we not speculate.

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

We have reorganized the inclusion of the modeling work, models were built based on observations presented in this manuscript and have been presented in part by previous work by Ortiz. The models serve to test the impact changing characteristics of the

nonconformity have on fluid pressure migration.

267: Note different style “x” shown for “times” in permeability values. Also, is the relative z/kx and absolute kz 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?

We fixed the x; and permeability values are different (kx = kz = 3×10-17 m2) in crystalline basement rock vs. conduit-barrier fault (kz/kx=105; kz = 3 × 10-10 m2

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).

The fault cuts low permeability zones creating a potential permeability pathway.

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

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

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)?

The faults cutting Type 1 appear to be potential permeability pathways.

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. - included

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.

We have modified the Basemap Figure (Figure 1) to support the newly added geologic setting details.

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? - change made

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?

We modified scale, added text to explain Fe mineralization.

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. – change made

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? –

We fixed spelling of Espiritu, changed scale on column, and added explanation of "thickness".

408/Figure 6: This cation 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. – changes made to clarify text

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

425/Figure 8. Typo: "Granitiod" in A. "Pinkcoated" 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. – change made

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

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

We have kept the depth axis for consistency between the two sub-figures.

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.

Correction to figure text and changes made to figure caption.

446/Figure 12: : :. "Phyllosilicate" (in figure) vs "weathering" in caption. What is the rationale for the circular flow path? – change made

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