

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.

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The Discussion presents some inferences about fluid circulation and the interpretations of structures and mineral deposits. As it stands some of this text seems speculative. The arguments should at least be bolstered by pointing to some of the extant structural diagenesis literature.

We have added citations to the fracture and diagenesis literature when discussing mineralogic changes.

C1

Where the text describes ‘fractures’ and fracture mineralization, the descriptions could be more complete (and meaningful). More information could be provided on whether the fractures are ‘opening mode’ or faults. The use of the term ‘vein’ is unhelpful, particularly with respect to structures in the cover above the nonconformities. Mineral fill in fractures is common throughout sedimentary sequences (e.g. Laubach et al. 2019, Reviews of Geophysics) and such mineral deposits could provide evidence of the post depositional structural and fluid history of these zones. So a more meaningful description of these features could be useful. Note also that there are a number of published studies of fracture systems in basal Cambrian and in Ordovician sandstones of the midcontinent and other Laurentia cover rocks, and the fracture sets have a range of ages and origins.

We have provided specific descriptions of fracture types throughout and made call outs where possible in figures to identify the features.

Some statement as to how representative these outcrops are of the midcontinent nonconformity zones would be helpful.

We have added a statement on the midcontinent nonconformity study locations and their use as analogs (section 2).

45 I think I follow what you are saying here about the definition of the ‘nonconformity zone’, but perhaps the definition could use sharpening. Are you talking about some volume of rock near the nonconformity that is somehow altered from what it would be if the same rock was not near the nonconformity? Do you only mean rocks in the basement or could this include rocks above the nonconformity? Can you try to make the definition more explicit?

The nonconformity zone is the volume of rock adjacent to the nonconformity, in most cases it is altered, we have clarified this definition (53).

60 Where you mention ‘the nonconformity’ it might help reader if you remind them here

C2

that you mean 'the nonconformity in the US midcontinent region'. – Change made

67 The Introduction would be improved by adding an explicit claim here that could start with the statement 'here we show that: : :'. Motivate the reader rather than just providing a list of what you did. – added

68 But are these overlying rocks mostly quartz-rich sandstones? Isn't the basal Cambrian sandstone pretty common? I see that you outline the geology you looked at in section 2.1. Do you discuss how representative these might be? –

We have added this information to Section 2 – Geologic setting.

70 Where in the Introduction do you alert the reader that you present modeling?

We have added reference to modeling into the introduction (77).

86 'detailed' is vague; can you replace this statement with a scale (or range of scales)? Or just omit, since the resolution level is implied by the instruments you used. – change made

90 Is there a reason for the order that you describe the localities? Same question for the listing in section 2.1. A representative selection?

Localities were grouped based on study and sampling sites being outcrop vs core. There is no specific order but the sites are a representative selection of the basement tectonic zones of US mid-continent. We have further addressed this in section 2.

95 How low is the porosity?

We have removed reference to porosity, as at this point in time it is only a qualitative observation from petrography.

100 if the fractures are bedding parallel as you say, it would be hard for them to extend into basement. Or do you mean the reduction spots are not in basement? – reworded sentence

C3

101 Are these slip surfaces in basement subparallel to the bedding parallel 'fractures' in the cover. Are the cover fractures faults?

There is no evidence of slip observed in the bleached fractures in the Jacobsville unit. Evidence of slip was observed in the basement and align with the near-vertical bleached fractures in the cover.

110 By 'span the contact' do you mean the faults extend into the cover? – yes – reworded (184)

115 Something is awkward in the phrasing here. – reworded typo

130 Are you saying fault rock is only found in faults? Clarify text. – change made (line214)

144 Quartz lined and quartz-filled fractures are common in quartzose sandstones even distant from nonconformities. The mineral deposits may not necessarily represent mineralization 'events' since the fractures themselves are reactive surfaces (e.g. Lander and Laubach 2015, GSA Bulletin). – reworded

155 and preceding text. What kind of 'fractures'; opening mode, or faults? Are there crosscutting relations here that provide evidence for the relative timing of these structures? Are you implying that the shear zone in the basement is somehow related to the fractures in the cover? (Wouldn't that be surprising?) – changes made (225>)

165 Is this the porosity range at the site you sampled? It seems a stretch to say that this is the range for the Mt Simon generally, since porosity ought to reflect thermal exposure/burial history and that could vary regionally. Clarify.- reworded

183 space – change made

186 'multi-layered veins and/or fracture mineralization'; are these different things? – reworded

192 'porous'; but can you specify how porous? –

C4

The porosity is qualitative based on petrographic observation at this time. No quantitative estimate of porosity was made and thus we have adjusted text.

197 'structural discontinuities' seems vague. We use this word because it encompasses all types of fractures, veins, faults across all study sites.

203 Is the thickness of the nonconformity zone specified at the outset of each description above? And how did you decide where the boundaries of the zones are? – added improved definition of the nonconformity zone

203 What is the opposite of 'in situ' mineral growth? – change made

206 Maybe put in a table? And refer to in description. – change made

201 The first paragraph of the Discussion seems vague and disorganized. Are these structures in the nonconformity zone' or in the basement or the cover? Are these only 'small faults' or are some of the fractures opening mode? - Discussion has been rewritten for clarity

209 The 'non fractured'; do you mean that these zones lack fractures in general, or that in areas where fractures happen to be absent, the host rock attributes might have these effects? – fractures are absent – reworded for clarity

210 'we note that: : :'; what is the basis for this inference? That there are porous rocks above the basement rocks? -removed statement

219-220 I don't see how it follows that the 'vein mineralogy' provides evidence for cross unconformity flow. Are you talking about mineral filled fractures in the basement or in the cover? Note that from mineral composition alone it can be challenging to find evidence for fluid flow (see for example, Denny et al.2020 GSA Bulletin). Maybe this point needs more development or the conclusion should be presented in a more nuanced way. – reworded

We see consistent mineralized fractures (vein) and cross-cutting relationships within

C5

the veins in the basement and sedimentary cover suggesting similar fluid rock interactions.

226 In the older rock mechanics literature there are examples of fracture systems in basement associated in typical midcontinent crystalline rocks that extend to depths of hundreds of meters and then abruptly stop; so zones of penetration of alteration could be much more than 5 m (and might be heterogeneous, if linked to deep seated fractures). See references by Aubertin. – reworded

The sentence was reworded to reflect our direct observations (5 m) and those of previous workers Duffin.

226 'that impacts' or 'that would be expected to impact'? – change made

236 But are these the 'bed parallel' fractures? –

These are fractures that cut across the nonconformity at an angle, so no, not bed-parallel

239 What do you mean by 'deep circulation'? The basement rocks are not all that far from porous sedimentary rocks, which likely contain fluids.

Change made to avoid confusion. We were referring to 'deep' as in basement involved and not limited to circulation within the sedimentary rocks.

241 Where did you mention what the mechanical properties of these rocks is? Did you measure them, or is that an inference from the rock types? An example of mechanical properties inhibiting fracture in the setting you are concerned with is in Ellis et al. 2012, J. Geol. Soc. London. –

No mechanical properties were measured in this work. We have added a citation to support importance of rheology/mechanical change across boundary.

255 do you mean 'faults'? Structural discontinuities in this paper could include veins, joints, faults, and cataclastite zones.

C6

259-264 Is this your claim? - reworded

265 Is this modeling work prefigured in the Introduction?

We have added reference to modeling work in introduction.

282 How representative are these various types you identify?

We provide a supplementary table with additional nonconformity sites (7 outcrop sites, 6 core total) at all sites the nonconformities fall into one of the three end-members. We have added text to the conclusion to reference supplementary table and representative nature of these end-members.

303 'Laubach' is the correct spelling. – change made

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