Solid Earth Discussions

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Comment on se-2021-23

Billy Andrews

Community comment on "Fault interpretation uncertainties using seismic data, and the effects on fault seal analysis: a case study from the Horda Platform, with implications for CO_2 storage" by Emma A. H. Michie et al., Solid Earth Discuss., https://doi.org/10.5194/se-2021-23-CC1, 2021

Dear Authors,

I read this contribution with great interest and hope my minor suggestions will improve what is already a very interesting and valuable contribution. The assessment of different seismic resolution, through the degradation of data, on fault growth and fault seal analysis is of upmost importance particularly when legacy areas are targeted for CCS schemes. Overall, I found the pre-print well structured, engaging and in general was impressed by the figures. A particular standout feature was the final paragraph of section 5 (L520-526), which I think will resonate with those interested in comparing different studies, and undertaking seismic interpretation themselves. My comments mostly pertain to where arguments could be strengthened, or where an alternative viewpoint may also provide a valid interpretation of the data.

I look forward to seeing the published manuscript and hope my comments are useful. If you have any questions please don't hesitate to get in contact,

Many thanks,

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Comment 1: Segmentation & fault corrugations

My 1st point is on the discussion of fault segmentation and fault surface geometry. From the data presented in the manuscript, i was not fully convinced by the 100 m line spacing representing the optimum spacing for the interpreted faults. More specifically, the simplification of fault geometry caused by this line spacing would miss several geological features (e.g., the majority of lenses, corrugations etc.) that are below the scale of 'segmentation', but can still play a large role in controlling fluid flow and fault stability. Additionally, segmentation and/or fault refraction can commonly occur in the down-dip component of the fault (D. Ferrill among others discuss this for faults cutting mechanically stratified layers), and at a scale that can be quite small. His could account for some of the variations in fault dip that you observe. A fantastic example of small scale changes in fault geometry can be found in Ross et al., 2020 (DOI: 10.1126/science.abb0779), where they assess the temporal evolution of micro-seismic events for an EQ swarm along a fault zone. Although there main focus of the work is the temporal evolution of events, the profiles for segmentation are very nice and show that small barriers can cause a barrier to flow, but also be breached. The recently published paper by Roche et al. (2021) would also be a good place to look in regards to how complicated the variability in strike and dip can be within a fault zone (DOI: https://doi.org/10.1016/j.earscirev.2021.103523)

Specifically, you mention that the variation in fault strike is often caused by fault segmentation, however, this does not have to be the case and faults may be corrugated without the need for fault linkage (asperities etc.). This is observed across a range of scales, and has been shown to change the slip behaviour and encourage areas of structural complexity to develop (which in turn can be linked to areas of fault leakage.. some good examples from along the Moab Fault in Utah). Additionally, corrugations can be scale dependent, which was beautifully outlined in some of A. Sagy's work. I have attached some potentially useful references on the attached PDF, however, please don't hesitate to contact me if you need any more as this is just the top of a very large iceberg.

From field studies, leakage of natural CO2 and/or hydrocarbons has been shown to occur at small ‘point-sources’ at a scale far below 100 m (relay zones, lenses, etc). I would be happy to discuss this further, however, I believe that some of the features observed at the 25 m line spacing which are attributed to picking strategy could easily be geological. Importantly, missing lenses could lead to the over-estimation of SGR/SSF and miss important leakage pathways for CO2. Overall, I agree with the 100 m suggestion for broad-scale fault interpretation, however, I think it is important that fault plane heterogeneities is considered as a viable control to fault geometry, with different scales picked up by different picking strategies.

Comment 2: Subjective bias between operators

Secondly, you make a nice comparison between two 'experienced' operators. Although this is a small dataset, and not across different scales, I found the similarity interesting. What was the relative training of both the operators? Regarding work into the human biases for seismic interpretation i think the work of Clair Bond and co-authors should be included. Of particular note is Schaaf and Bond 2019 who quantified differences in fault interpretation that students made from 3D seismic. To expand on this point, I recommend taking a look at the 2019 Special Issue of Solid Earth titled 'Understanding the Unknowns:..' (https://se.copernicus.org/articles/special_issue984.html).

You point about subjective bias being less for greater line spacing makes perfect sense, and is based on our geological training and experience of dealing with sparce datasets. We are trained to push our interpretations towards the simple, however, as discussed above this could also lead to the removal of key fault properties. Have you considered that different practitioners may have differing 'mental models' of faults, and that this may then mean they are more likely to interpret either complex or simple fault geometries. Whilst this may not be a factor between your two experienced interpreters, this may have a large effect in the wider community. This is something that I have seen for fracture analysis (in the SE SI) and is discussed in Shipton 2019 (doi: https://doi.org/10.1144/SP496-2018-161) for the effect on fault architecture (which will expand to fault geometry). Further, your point about the time invested in the interpretation improving the replicability of the results will be countered, and need to be balanced, by the need for pragmatism (limited time for the project, limited funds etc.).

Additionally, a couple of minor comments are provided below:

Section 1.3: I felt that this section was longer than what was required to introduce the key concepts of the manuscript and that some of the detail (e.g., equations etc.) could be removed, with interested readers directed to the key texts.

Line 205: Consider writing out the acronym in full, it is not used that often and would improve the readability of the text as well as enable people to dip into sections without reading from start to finish.

Line 215: How does the variability in gridding methodology compare to the variability you would expect between operators? Additionally, is there any variability within a single gridding method based on parameters used? (I am not a gridding expert, but alluding to the scale of this variability would be useful when assessing uncertainties within the workflow).

Line 238: The effect of drag and/or monocline development can have quite a large effect on fault geometry and cause certain parts of a fault to dip more shallowly than others.

Line 349: Will the change in SGR not equally, or even more so, be a function of juxtaposed lithology as opposed to fault geometry?

Line 360: I think it is important that you make it really clear that this is a site specific point within the results, and that it (at least in my opinion) cannot be easily transferred to other sites. (aka you don't want people citing you saying you said do 100 m, which is not what you are saying). .

Fig 7: It would be useful for the 25 m spacing to be added to this figure to show why 100 m is seen as optimum (i.e., to not just show where the smoothing has taken place, but show where the variability is high).

Fig 8: These are very nice, however, i suggest that you have a look at some of the corrugated fault surfaces in the references I suggested above, as there is a reasonable argument that the variability could be controlled by scale-dependent fault straightening effects. I think that was discussed mainly in one of Amir Sagy's papers (possibly the 2007 or 2009 one), also in several of Emily Brodsky's papers.

Please also note the supplement to this comment:
https://se.copernicus.org/preprints/se-2021-23/se-2021-23-CC1-supplement.pdf