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Interactive comment on "Near-surface Palaeocene fluid flow, mineralisation and faulting at Flamborough Head, UK: new field observations and U-Pb calcite dating constraints" *by* Nick M. W. Roberts et al.

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Summary of paper

This paper aims to understand the timing of faulting and fluid flow in the Flamborough Head Fault zone in NE England. The authors provide the first absolute timing constraints for carbonate crystallisation using U-Pb geochronology method. Different veins yield dates that span from ~63- 55 Ma. The authors interpret that veins and breccia fills formed largely associated with extensional faulting. It is interpreted that

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extensional faulting occurred synchronously with regional igneous dyke intrusions and is associated with the opening of the Atlantic.

General Comments:

This paper is a well-done geochronology study investigating regional timing of faulting and fluid flow. The U-Pb carbonate geochronology method is fast becoming a well-established method for directly dating faulting and fluid flow processes in the upper crust. This study uses this novel technique to provide the first absolute timing constraints in the region of interest. This is important because faulting in the Cretaceous chalks is an important process effecting reservoirs across much of Great Britain and the North Sea. This study therefore has the potential to provide a useful insight into the absolute timing and duration of fluid flow and faulting in the region with useful transferable applications to the petroleum and hydrogeology communities. This study is well conceived, uses appropriate methods, produces high-quality geochronology data that is well reported and documented. The interpretations are largely consistent with the data, although the structural history needs to be strengthened. It also would have been nice if the study was broader in scale and scope. Sample documentation could be better represented in the paper. The supplementary material is necessary and supports data in the main paper. Overall I think that this is a useful contribution to understanding the absolute timing of brittle faulting – a topic which is in its' infancy and with some additions (see below and in the annotated version of the manuscript), would make a nice regional geology study suitable for this journal.

Specific Comments:

1. Structural data.

I understand that the authors do not intend to make a detailed analysis of the structural evolution of the area (as stated in lines 158-160), however I think that it would make this paper much stronger if you did include some structural data. That would make the linkage between the dates presented here and the structural interpretation much

stronger and credible. It would also mean that you could interpret the ages relative to the structural setting with more confidence.

I therefore suggest that you add stereonets of the orientation of your samples, the local structures and the regional stress regime (hopefully this shouldn't be too much work as you should already have all the data!)

2. Geological setting

Throughout the writing could be more succinct and you could do a better job of describing the setting without interpreting- make more factual.

A cross section would be useful.

The structure is very linear, could you group together and discuss findings of authors rather than going through study by study.

It would be useful to have a sentence at the end framing your study- why it is interesting and important.

Section 5 might be better coming before section 4, or potentially merged with it. When I initially read section 4, I wanted a lot of the details that are in section 5, so I think restructuring or merging would be beneficial. Some sample numbers on the figures would also be immensely helpful (see my comments below).

3. Link between structural setting, sample description and ages.

Initially it is quite challenging to link together the different structures, photos and samples. I think you do a good job in the supplementary material but in the figures in the text it is less easy to follow. See my comments below on the figures, adding sample numbers, more annotations and a little more context of how the different photographs link together (similar to in the supp material) would be helpful.

4. Abstract – a little more information about the motivations of the study, why it is important and what the significance is would help to attract a broader audience.

5. Throughout make sure that you always keep description/ data reporting and interpretation separate.

6. Discussion

Could you provide a (visual?) summary of the relative timing, cross cutting relationships, structural orientation and terminology of vein types? That might help focus your discussion and if you made a figure would be a great visual aid for the reader.

The discussion is OK but you could be a little more definitive about interpreting the timing and sequence of compressional, extensional and strike-slip faults. You could think more about the limitations of your dataset- you have only analysed a few samples, if you broadened out the study it might be possible to fully interpret the timing of the different structures and understand how the regional stress regime has changed through time.

It would be interesting to make some comment about how these different structures might have formed and what overall stress regime you would need in order for the different structures to form.

Addition of some structural data might help you be a little more definitive.

What about pore fluid pressure and interaction between faulting and fluid flow?

How likely is it that there has been multiple periods of extensional faulting – during the Triassic- Cretaceous and then later in the Paleocene as recorded here. Likewise, do you think if you dated more veins that you would end up dating later Cenozoic (re)activation of compressional structures?

See additional comments on annotated PDF of manuscript

Comments on figures:

Figure 1

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Please add a key to geological units Consider adding a cross section.

Figure 2:

Please add some structural data (see comments above)- produce stereonets of the orientation of veins related to the major structures.

b) and c) could do with some additional annotation – show where veins are and clearly annotate sample locations

d) it is not clear why you have drawn the arrows on the vug- perhaps a slightly zoomed out image would be more useful for demonstrating that sense of motion.

Figure 3:

a) scale? What evidence is there for the sense of motion drawn in the images? c) Annotations are not clear of folded strata. d) would an additional image taken perpendicular to this one be useful to showing the fold? Throughout the veins could be better annotated and any analysed samples clearly marked.

Figure 4:

How does fig. 4 relate to fig. 3? How do a) and b) relate to each other? Close up of gouge would be useful in b) Clearly label sample labels on analysed samples- are d) e) and f) all the same sample?

Figure 5:

Link back to figure 2 to show where these samples are located Add sample numbers for analysed samples Some closer photographs of textures would be helpful.

Figure 6:

More annotations needed Show where these photographs are on previous photos Add sample numbers for analysed samples

Figure 7:

Add sample numbers More annotations needed F) missing scale.

Figure 8:

The geochronology data and TeraWasserburg plots are good quality- well done!

Ideas for additional figures:

1. Figure clearly showing stereonets with: a) Orientation of main faults b) Orientation of your slickenfibres and veins with respect to these faults. c) You could link to stress analysis done by previous workers (Sanderson and Peacock)?

2. Cross section

3. Better way of linking field photographs (more like you have done in the supplementary material), that is a much clearer way to show how the samples relate to the structures and how each photograph relates to one another.

4. Interpretational diagram synthesising the interpreted vein genesis based on previous work and your ages. This would be a useful visual sum-up of all your data.

Supplementary material

Excellent presentation of methods and data. The only addition could be Concordia plots of secondary standards (Duff Brown and Ash 15) and reproducibility quoted as a %.

Please also note the supplement to this comment:
https://www.solid-earth-discuss.net/se-2020-73/se-2020-73-RC2-supplement.pdf

Interactive comment on Solid Earth Discuss., https://doi.org/10.5194/se-2020-73, 2020.