Geochronology Discuss., author comment AC1
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Reply on RC2

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Author comment on "A revised alpha-ejection correction calculation for (U–Th)□/□He thermochronology dates of broken apatite crystals" by John J. Y. He and Peter W. Reiners, Geochronology Discuss., https://doi.org/10.5194/gchron-2022-11-AC1, 2022

We thank the referee for their thorough review. Our proposed revisions to address these comments and line-by-line suggestions are included below (original review in bold).

This manuscript presents a new fragmentation Ft calculation that improves (U-Th)/He date accuracy and precision for broken apatite crystals. They demonstrate this using a previously published synthetic dataset by using two fragmentation correction approaches – the "old" method and their "new" method – and then estimate the variation in their datasets. This is a relevant topic to the (U-Th)/He community, as apatite crystals often do not have terminations, either naturally from growth or from breaking during mineral separations. It is my opinion that this work is most appropriate as a Technical Note in Geochronology.

Although the approach seems straightforward, I found myself struggling to understand exactly what the authors did at certain steps. As such, I have several specific suggestions for places that the text and figures can be made clearer. I will list these below based on the location in the text.

We appreciate the constructive criticism and will revise the text and figures accordingly to try to clarify our approach (see specific comments below)

Line 64: "For apatite, these errors are usually minor (<1.5% for 80% of apatite crystals, and <9.5% for 95%), … Furthermore, the errors are usually symmetrically distributed, with apatite populations … (Ault and Flowers, 2011)." These lines state that apatite do not typically exhibit "extreme zonation" and that zonation is evenly distributed based on Ault and Flowers, 2011. Ault and Flowers, 2011 demonstrated this for a large number of apatite crystals from very old, cratonic crustal samples. Perhaps we do not know this statement to be true for all apatite across all rock types. For example, apatite from ore or metamorphic systems may exhibit different zonation distributions and concentrations. I suggest rewording this to not sound so definitive, unless there are other studies to cite to back it up.

We agree and will revise to qualify the statement to the following:

For apatite, these errors are usually minor (<1.5% for 80% of apatite crystals, and

<9.5% for 95%), because apatite crystals in most cases do not typically exhibit extreme zonation of parent nuclides (Ault and Flowers, 2011, in the case of old cratonic samples). The data from that study suggests that the errors are usually symmetrically distributed, with apatite populations not exhibiting bias towards either rim-enriched or rim-depleted grains, though this may not be the case for those from rocks that experienced metamorphism or hydrothermal alteration.

Line 160: Why are equations at Line 160 different from the equations in Figure 1? Should they be the same?

Equations at Line 160 are the same as the right hand side of the equations in Fig. 1 – with very slight rearranging of the terms. We will modify the equation in the text for consistency, so that the equation reads " 2R + …." Instead of " … + 2R".

Lines 170-174: Here you describe in words how your approach differs from Farley, 2002. To more effectively drive this important point home and to help those more inclined to visual understanding, I suggest you provide a schematic like Figure 1 (or modify Figure 1) that shows the different approaches, including the difference in the proportion of helium added based on the methods.

This is a good suggestion and we will revise Fig. 1 with a new column to show the difference between the old and new protocol, as well as a schematic illustration of the rationale from the point of view of the fraction of helium retained. (Suggested figure attached).

Figure 2/Section 3: The information provided in Section 3 and the caption of Figure 2 can be reorganized to more clearly outline the methods used. This should describe the synthetic dataset in more detail for the reader and the approach that was taken. How exactly were the 'old protocol' and 'new protocol' implemented? This information is introduced starting at Line 190, but should be introduced and explained more in depth before summarizing the results.

This is a good suggestion and we will re-organize and revise Section 3 to more clearly state the steps and assumptions of the method, before introducing the results.

Line 196: "crystals that are <20 µm from the tip,"/ Rephrase to "crystals broken <20µm from the tip"

Agreed.

Line 197: "apply both protocols to all fragments as we would in routine laboratory analyses."

This phrasing is tripping me up. I'm not sure what you are referencing with regard to routine laboratory analyses here. Are you talking about the assumptions you are using, or the way you are measuring the fragments? This paragraph could be clearer.

We are referring to the way we calculate FT corrected dates in routine laboratory analyses, not the measurement of the fragments. Will revise to clarify that:

We assume uniform spatial distribution of the parent nuclide, and apply both protocols to all fragments exactly as we would calculate F_T corrected dates in routine laboratory analyses: i.e. we assume no knowledge of the original length and thermal history of the crystals to compute the corrected age, and use only the raw date, length and width of the broken crystals, and the number of terminations present for the calculation.

Line 203: "In a more realistic scenario, when the two assumptions are relaxed, the proposed fragmentation correction results in a broader range of uncertainty (+0.7% ±205 4.2%), but it is nevertheless more accurate and more precise than the old protocol (+2.9% ± 5.0%)." What does "when these assumptions are relaxed" mean with regard to how you implemented it in your model? Exactly which 2 assumptions are you referring to? My reading is that Fig 2b doesn't exclude crystals broken <20µm from the tip? If that is correct, can it be more clearly worded in the text and labeled on the figure?

Will clarify text to emphasize what these 2 assumptions are, and will revise the caption to the figure to clarify what is included/excluded from Fig. 2b.

Line 206: "These results are based on the full fragment dataset from Brown et al., 2013, which includes a representative range of thermal histories that are more complicated than simple rapid cooling (i.e. slow, monotonic cooling; prolonged isothermal residence in the partial retention zone followed by rapid cooling; a mix of slow cooling and isothermal holding in the partial retention zone; and gradual reheating (e.g. burial) followed by rapid cooling; cf. Wolf et al. 1998)."Earlier you say you used 2 thermal histories – what thermal histories did you use, and what do you mean here when you say that "these results are based on…a representative range of thermal histories …" ? Are your results not comparable to the Brown results?

Will revise to clarify that Fig. 2a includes the two simple thermal histories (fast/slow monotonic cooling) and Fig. 2b includes in addition the complex thermal histories involving prolonged residence in the partial retention zone and/or reheating.

Figure 3: I find this figure confusing. Since L x 2 is the same for the old and new method, is it necessary to have it for both? Perhaps having a difference in the symbols between singly broken and doubly broken would be helpful to emphasize how they are generating different "answers". The red arrows are too difficult to see to realize they are arrows. Similarly, the dashed vs solid line arrows were only apparent when I zoomed in really close. The light gray bars saying "difference between corrections" is both hard to see, and unclear which points are being connected. Why do the black lines roll over at length = 20x width? Perhaps this would do better as two plots with single terminations and double terminations separated?

This is a good suggestion and we will make the stylistic revisions to the figure as recommended (for example, plotting singly and doubly broken grains as graphically representative symbols). We think it will be best to keep this as a single figure for ease of comparison. We also think it will be best to keep the two lines for both the old and new method to clarify that one represents the correction for singly broken grain and the other for doubly broken grains.

The FT value at 20x is approximately the same as the asymptotic value of infinity.

Line 258: "two ideal assumptions relaxed" Please state the 2 assumptions here so that there is no ambiguity.

Agreed.

Figure 7: The figure caption says this is schematic, but some of the curves are apparently based on real data too It is kind of hanging in the text and not so clear how it contributes to the rest of the paper (particularly D). The figure seems to show the "direction" and spread of error from different factors, all

scaled the same(?), but without any quantitative indication of the degree of the error introduced. The text says this shows the expected distribution based on different factors, but it's unclear what this expected distribution is based on (i.e., some constrained examples, or completely a cartoon?).

We agree with this comment and will revise the caption and text to more clearly indicate which curves are schematic and which curves are based on actual data, and to better integrate the figure into the text. The point of this figure is simply to show the potential of fully characterizing the uncertainties involved in apatite He dating, and how this and future work can help us interpret large intrasample date variations.

Line 347: – "and in certain cases up to 20%"

What cases had 20% older dates? Please be more specific.

These cases were drum-shaped fragments with no terminations that experienced gradual reheating. Will revise appropriately.

One other comment: There is no mention of zircon in the paper, but presumably a similar approach could be taken there? Can the authors add a brief discussion of whether this could be applied to zircon and what the expected outcome might be? I suggest this because I can imagine that labs that adopt this practice are likely to adopt it across any of the minerals they analyze, and it would be helpful to have a reference for why it would or would not be appropriate.

This approach would apply analogously to zircon, with exactly the same reasoning; however, it is much less common to see similarly fragmented zircon because it does not have the well-expressed basal cleavage that apatite does. For completeness, we will include an additional statement addressing zircon.