MS No.: egusphere-2026-889 - On some factors controlling fission-track etch rates in apatite - Author response to reviewer #1

Comment	Response
This manuscript investigates the etch rates of fission tracks and apatite crystals through laboratory experiments. The presentation of specific values for the track etch rate (VT) and the apatite etch rate (VR) is valuable. Furthermore, the experimental evaluation of the effects of track shortening and radiation damage on these rates is original. Since apatite fission-track analysis is one of the most commonly used methods in thermochronology, this manuscript has the potential to make a significant contribution to the field and is suitable for publication in GChron. However, there are some issues regarding the completeness of the manuscript, and there is considerable room for improvement in terms of readability for the audience. In addition, for some measurements and their interpretations, there is a risk of overinterpretation beyond the resolution limits of optical microscopy. These problems relate to the manuscript's structure, reasoning, and scientific soundness, and need to be corrected for it to be publishable. Considering these points, I recommend a major revision.	We are indebted to the reviewer for a most thoughtful review. Most of the specific comments are a matter of course and have been corrected as suggested; the exceptions are discussed below. There remain the issues of organization of the manuscript and over-interpretation.
A) This manuscript does not follow the conventional structure of an original research article: Introduction, Methods, Results, Discussion, and Conclusion. Deviating from the format that most researchers are accustomed to places a considerable burden on readers who are trying to follow the authors' reasoning. Adhering to a standard section structure is also beneficial for clearly distinguishing between facts and interpretations, and between the authors' work and that of others. To maximize the logical clarity, transparency, reproducibility, and readability of the research, a restructuring of the manuscript is strongly recommended. Even if the authors insist on retaining the current organization, each of Sections 2-4 should at least include subsections for an overview of experiments, procedures, results, and discussion. Moreover, the manuscript generally lacks sufficient explanation, so even if certain points seem obvious to the authors, it is desirable to provide careful explanations for readers who may not be familiar with them.	Our manuscript does not have a conventional content; it is in effect a set of three separate small experiments on a common subject. It is therefore impractical to force it into a conventional structure: Introduction (ex1, ex2, ex3), Methods (ex1, ex2, ex3), Results (ex1, ex2, ex3), … etc. No reader could keep track. The alternative is a threefold division with labelled subsections: Experiment 1 (Introduction, Methods, Results, Discussion, and Conclusion), Experiment 2 (idem), Experiment 3 (idem). This is doable, but the labelling is unattractive. Our manuscript is ~300 lines without Figure captions; to subdivide that into 3×5 headings and subheadings leaves an average length of 20 lines for each. Each of our sections is organized in the conventional manner; does the reader really need to be told what is the Introduction, Results, Discussion … etc? Unless otherwise advised, we believe that the current structure of our manuscript is well suited to its content.
B) The authors should provide their perspective on the measurement errors. The manuscript frequently reports measurements and errors on the sub-micrometer scale, yet the resolution of a typical optical microscope is limited by the wavelength of visible light (~0.38-0.78 μm), as described by Abbe's equation, and is typically on the order of a few tenths of a micrometer. Generally, measurement results below ~1 μm cannot be expected to have reliable accuracy. This is not intended to dismiss the authors' data or arguments entirely, but unless the authors clarify the expected magnitude of errors and the practical limits of their discussion, readers may find it difficult to judge how the results should be interpreted. Furthermore, as noted in some specific comments below, discussions that clearly exceed the optical resolution should be avoided.	Our errors are standard: all the tables report averages with errors 15-25× smaller than those of individual measurements (N >225). At the risk of being pedantic for a moment in order to correct a common misconception: the precision of a microscopic measurement is not limited by the Abbé rule. Diffraction smears out a dot into a disc. Adjacent discs can coalesce and become inseparable. The smallest separation that is still distinguishable is the optical resolution, determined by the Abbé rule. But that is not the limit of precision: nothing prevents a measurement from the midpoint of one disc to that of another. The track edge appears as a ~0.3 μm wide band in Figure 4a, but its centreline can be distinguished from its borders almost down to pixel-size, and in sophisticated applications sub-pixel size (Copeland et al., 2018). We explain our error perspective in specific cases. Copeland C.R., Geist J., McGray C.D., Aksyuk V.A., Liddle J.A., Ilic B.R., Stavis S.M. (2018)

	Sub-nanometre localization accuracy in widefield optical microscopy. Light: Science & Applications 7:31, 1-15.
C) Some instances of unit notation in the manuscript do not conform to standard conventions, and the notation is not used consistently throughout the text. For example, in L54, "MeV.amu^{-1}" would be more appropriately written as "MeV/amu" or "MeV·amu^{-1}," whereas L68 employs the "MeV/amu" format. Similar non-standard notations are also observed, to the best of my review, in L101, 108, 196, 197, 205, 217, 223, 224, 227, 236, 240, 272, 372 as well as in the labels of Table 3. I recommend that the authors carefully review the entire manuscript to ensure that unit notation is consistent and conforms to standard conventions throughout.	Corrected.
L26 : The temperature of subsurface rocks and minerals is controlled not directly by basin subsidence and uplift, but by the burial and erosion associated with these processes.	Agreed, but this is almost the first sentence of the introduction; we don't want to go off on a tangent about the thermal histories of basins here, and take "burial" and "erosion" as implied.
L30 : ...suitable for counting and measuring --> ...suitable for counting and measuring with an optical microscope	We mention "*examination with a microscope*" on L28.
L37 : Tt-modelling --> time-temperature modelling. The same applies to "Tt-conditions" in L231.	Corrected.
L42-44 : A brief explanation of the difference between V_R and V_B would be helpful. As currently presented, it is difficult for readers to understand the necessity of introducing V_R and the advantages it offers over the conventional V_B.	Lines 42-44 read: "*following established concepts of crystal dissolution (…), we redefined the apatite etch rate as the rate of displacement of a lattice plane (…) instead of that of each point on a surface (v_B)*." That is what the difference is; what it implies cannot be explained in an aside. We published several papers on the difference between v_R and v_B: Jonckheere et al. (2019; 2022; 2024), Aslanian et al. (2021; 2022); Trilsh et al. (2023), and Fu et al. (2024; see references in manuscript). We believe readers will be relieved if we do not attempt to summarize them here.
L46 : Insert a paragraph break before "Here we investigate...."	This would split two halves of an opposition in consecutive sentences: "*We investigated* ... " and "*Here, we investigate* ...", describing the connection between our earlier work and this.
Title of Section 2 : Variation of V_T --> Variation of V_T along tracks. As the authors discuss in lines 130-134, "variation of VT" could also arise from other factors such as chemical composition and orientation, so it should be clearly specified what the variation is referring to.	Corrected, although we write four lines higher: "*Section 2 focusses on the variation of v_T along tracks ...*".
L51 : Before proceeding to the experimental procedure, a brief explanation of the purpose and design of the experiment is necessary. Otherwise, readers will continue reading the following sections without a clear sense of direction, carrying many unresolved questions. For example, the rationale for using Durango, the reason for not performing	The explanation is disappointing: (1) Durango is the go-to apatite for all methodological investigations, (2) we had an unannealed prism section irradiated perpendicular to the ***c***-axis with Kr-ions. Some that intersected the crack at various depths offered an opportunity to use our etch model for direct v_T-measurements. The significance of

pre-annealing, the objective of employing step-etching, and the significance of measuring intersections with cracks are not self-evident to readers.	v_T is explained in the introduction: "*These factors* (v_T, v_R) *determine which grains are suitable for counting and dating and which tracks are suitable for measurement and Tt-modelling*".
L74 : "π/4" would be more appropriate than "1/4π." In addition, since the caption of Fig. 3 expresses the angle as 45° (L83, 89), please consider unifying the notation throughout the manuscript.	We corrected "45°" to "¼π".
L77-79 : The authors should provide the values of the errors for d_D and d_S measurements, or at least their perspective on error estimation and measurement limits. Considering the errors in Dpar shown in Tables 2 and 5, these values should also have an approximate standard deviation of ~10%. Furthermore, for the 20s data in particular, it is possible that some measurements are too small relative to the resolution of an optical microscope.	Not sure: d_S is the mean of 363-514 measurements of the same value (Dpar); if, like d_D (Figure 3), the measurements scatter 0.1-0.2 µm about the mean, then the errors on the means are <0.01 µm (≪1%); the errors on the intercepts (l_I) of the anchored geometric mean regression lines cannot be calculated analytically, but must be estimated by resampling. Given the sample size and scatter, they will be of the order of 1% or less. For more precise estimates we would need to write resampling code and insert a section explaining the approach. This is textbook statistics that has nothing to do with our subject. We cited the errors where possible, except where reliable values are too difficult to compute. Given that the errors on the means are ≪0.1 µm, and those on the derived quantities in the ~1%-range, we believe that more precise estimates are not needed for our work.
L84 : D_{PAR} --> Dpar	Corrected.
L87 : measured values --> measured values of l_M (Fig. 3b)	Corrected.
L87-89 : Add an explanation of the gray symbols. Also, clearly indicate in the figure that the numbers in Figures 3a and 3b correspond to lI and lM, respectively.	Corrected.
L88 : track rate --> track etch rate	Corrected.
L103-104 : Show the V_T values reported in Jonckheere et al. (2024).	Corrected; there is no numerical estimate; the comment refers to Figure 5c of the paper.
L104 : In the reference list, there are two entries for Jonckheere et al. (2024), labeled "a" and "b." Please specify which one is being cited here. The same applies to L132 and 289.	Corrected.
L112 : Figure 2 --> Figure 3	Corrected.
L114-115 : Explicitly present the equation used to calculate l_E. Since this paper contains various similar parameters that may be confusing, it might be helpful to include a new table summarizing the definitions, symbols, and equations of the frequently used key parameters.	That would be a trivial and useless equation that requires additional symbols, and an explanation that would wrongfoot the readers by focusing their attention in a dead-end direction. One can see in Figure 3a, and read in the caption how the l_E-values are calculated.

L115-117 : Considering the errors shown in Figure 3b, it cannot be said that the agreement is good. If there are other uncertainties being taken into account, please explicitly indicate them.	The differences l_M - l_E are -0.5 µm (30 s) and +0.4 µm (40 s); the differences L_I - l_M are -0.9 µm (30 s) and -3.0 µm (40 s). The agreement between L_M and l_E (average difference -0.05 µm) is much better than between L_I and l_M (average difference -1.95 µm). Add that the offset is in the expected direction, it is fair to conclude that the agreement between l_M and l_E (difference -0.05 µm) is "good". Must we do a one-sided comparison of means to determine the likelihood that the expected improvement is not due to chance? There is a point where statistics becomes statisticulation, in particular when one has an uncertain grip on the assumed uncertainties (see the discussion of the errors on l_I above).
L124 : Please check the publication year of Somogyi & Szalay (1973). In the reference list, it is given as 1974. The same applies to Trilsch et al. (2024) in L305.	Corrected.
L125 : Explain what dE/dx represents. Is this the stopping power, the energy a particle loses per unit distance traveled in a material?	Yes: [dE/dx] (dE.$(dx)^{-1}$?) is the conventional symbol for the stopping power of a detector for a given ion, depending on its composition and the ion mass, charge and velocity, as defined by the reviewer. It is as commonplace as writing ζ for a certain calibration factor, which few authors care to explain. We added "*stopping power*", but cannot load our manuscript with explanations of common terms for one group and others for another.
Title of Section 3,4 : Effect of ### --> Effect of ### on V_T and V_R	Corrected, although the full description of each section is given at the end of the introduction.
L142 : C° --> °C	Corrected.
L142-144 : Just to confirm, were all the measurements taken using TINT?	A handful of TinCle's could have been included, but less than 1/100 of confined tracks. However, we calculate their effective etch times from their widths, just like in the case of TinT's.
L144-146 : Please provide the explicit equations for these parameters. Requiring the reader to check the original references is inconvenient.	We have given those equations four times at least. Either one distrusts them, or is specifically interested, in which case checking them in the cited works is not inconvenient but essential. Or one is interested in the outcome of the calculation, and takes them on trust here. It would be a distraction to have to write/read them once again here, and bad for our structure. We aim for a clean storyline, without endless excursions left and right.
L154-155 : Do you mean "from host to the nearer track tip"?	Corrected: we do mean from the host-track-confined-track intersection to the nearest track tip.
L167 : Figure 5b --> Figure 6b	Corrected.
Table 2 : What does LSTD refer to? The same applies to Tables 3-4 and "DULU" in Tables 4-5. In addition, it would be helpful if the parameters in Tables 2 and 5 were listed	LSTD = length standard; DULU = Duluth intrusive complex, comprising both FC1 and AS3. Tables 2 and 5 now have the same structure; the captions list the parameters in

in the same order, as this would facilitate comparison between the two.	the right order.
L193-198 : In the caption, please describe the parameters in the same order as they appear in the table.	We will move the Dpar columns to the left; that will take care of this and the preceding issue.
L205 : If I understand correctly, since etching progresses from the intersection toward both tips, wouldn't the length difference generated over 2s actually be twice that, ~8 μm?	Yes and no: we have 2 s × 2 μm·s^{-1} = 4 μm. If the host track intersects a confined track in the middle, we indeed have 2 × 4 μm = 8 μm; if it intersects it at the tip and etches in one direction, we have 4 μm. If we average, we have ½ (4 + 8 μm) = 6 μm, which is about the mean-length difference between the unannealed and most annealed sample (~16 μm - ~10 μm). We should have applied weights: a confined track is more likely to be intersected near the middle; on the other hand, it has two tips. But that is taking the estimate too far.
L209-212 : This statement and the following discussions (L212-235) may be an over-interpretation. It is difficult to discuss this level of precision with the resolution of an optical microscope (generally >~0.2 μm). Even if we assume there is no issue with resolution, using mean values for comparison, the relative magnitudes do not show a distinct trend. Furthermore, the four Dpar values overlap within 1sd (Table 2), so the differences cannot be considered significant, whether using the mean or the median.	As discussed above, the microscope resolution is not the limit of precision of our measurements. The difference between the median Dpar of samples 21-2 (unannealed) and 21-3 (most annealed) is ~6%, a full six standard deviations (<1%). A one-sided t-test (Excel) indicates that the likelihood that this is due to chance is 0.03%. The reviewer is nevertheless right to be concerned, because the arithmetic means do not confirm the difference between the medians. However, Figure 6d shows that the offsets between the Dpar-distributions is small but consistent in the central part (0.2-0.8 quantiles), suggesting that the small differences between the arithmetic means are due to a few extreme values. In this case the medians are more robust central estimates than the means. We performed an error propagation calculation and cited the relevant results with their errors. All we want to suggest is that the annealing of fission tracks and other defects that affect the apatite etch rate both seem to occur under the conditions of the experiment, and in the expected order. We therefore wish to keep our back-of-the-envelope calculation, on condition that we add a proviso that the results are indicative rather than definite. They suggest that etch rate measurements could perhaps be used for estimating defect annealing kinetics.
L217 : meV --> MeV	Not in this case: milli-electron-Volt.
L218 : 1.22 10-3 --> 1.22×10-3. The same applies to L221 and 272.	Corrected.
L249 : This data is not included in Table 4. Instead, it is appropriate to refer to Figure S07.	Corrected.
L249-252, 257-258 : Given the limitations of measurement accuracy, this discussion might be overstretched.	It is worse: the problem is that the slopes of the regression-lines are small compared to the scatter about the line, so that simple confidence intervals cannot be calculated. The regression lines in Table 4 and Figures S07-09 are ordinary least squares (OSL). This means that the slopes are underestimated and the intercepts overestimated due to attenuation bias. It is no use in this case to substitute them with geometric mean regression (GMR) estimates, which, in contrast, overestimate the slopes and underestimate

	the intercepts. We therefore maintain our OSL-slopes and intercepts without misleading confidence intervals, while pointing out that the slopes must be understood as minima. We add that the magnitude of the underestimate depends on the variation of the independent variables (IP, t_E, v_T), and, e.g., that if half of their measured variation is true variation and the remainder is due to random measurement error, the true slopes would be twice the OSL-values. This somewhat weakens our conclusion that IP, t_E and v_T can be ignored for geological applications using similar etch and measurement protocols as in this work.
L260-262 : I did not quite understand what you're trying to claim here. I think you need to explain how parameters that do not affect the lengths of these tracks could influence the selection of tracks.	That is indeed unclear. We meant that, *within a sample* of confined tracks selected for measurement, (IP, t_E, v_T) have little effect on the length distribution, and can be ignored. This does not mean, however, that they have no effect on *the sampling itself*, i.e., on the distinction between tracks selected for measurement and those that are not. E.g., the effective etch time influences the widths of confined tracks, and so their qualification for measurement.
Table 4 : The data from "DULU" is not used in the main text. The corresponding data are presented in Figures S15-16; however, they do not seem to be cited or discussed in the main text.	That is an oversight. However, the DULU data in Table 4 just confirm that the preceding conclusions are applicable to both the fossil and induced confined tracks in geological samples. In this case too, we will discuss the regression estimates. This introduces no significant change.
L265 : Δ(.) --> Δ(...)	Corrected.
L267-269 : Since this experiment investigates the effect of aging, please provide the reference ages of these samples.	Corrected.
L272 : Are there data on the total alpha dose for AS-3? In order to compare the measurements of the two samples later and interpret their differences, the relative magnitude of radiation damage should be clearly established.	There are, to our knowledge, no published α-doses or Th-concentrations for the AS3 apatite. FT-dating indicates that it is ~10% older than FC1, and its U-concentration is somewhat lower. However, if new data are brought to our attention, we will of course include them. As we make no comparisons between them, we need only know that FC1 and AS3 have absorbed high α-doses, and likely retain a substantial fraction. Our work is concerned with radiation-damaged (fossil) vs. undamaged (induced) samples. For a comparison of FC1 and AS3, we would need to know the grain-to-grain variation within each sample.
L280-282 : You will probably need to cite Table 5 here.	We cite Table 5 on line 284.
L291, 298, 304, 315, 339 : Table 3 --> Table 5	Corrected.
Table 5 : Add the following to the caption: "For explanations of the parameters, see the caption of Table 2." In addition, while FT specialists may be able to infer this from the values, please clearly indicate which samples represent fossil-track and induced-track	Corrected.

measurements.	
L322-323 : If I understand correctly, the shorter length of host tracks may also act to shorten the access distance to the confined tracks, thereby similarly increasing the effective etch time of the confined tracks.	Yes. Ignoring their separation (see preceding lines), to a first order, shorter tracks mean shorter etchant trajectories and travel times before the etchant arrives at the track tips, and more time to etch them to the point that they are considered suitable for measurement.
L339 : Dpar's --> Dpar values	Corrected.
L341 : Replace 146Sm with 147Sm. Although 146Sm also undergoes α-decay like 147Sm, its natural abundance is nearly zero. Therefore, in methods such as U–Th–Sm/He dating, the contribution is mainly from 147Sm (e.g., Flowers et al., 2022).	Corrected.
L344 : I think it is necessary to explain the difference between Dper and Dpar.	Corrected; we added a few words although these terms are well known by researchers in this field.
L352 : It appears that only the word "been" is in a different font. If this was not intentional, please fix it.	Corrected.
References : The following references do not appear to be cited in the main text: Donelick (1991) in L412-413, Jonckheere et al. (2020) in L455-456, and Ketcham et al. (1999) in L465-466.	Corrected.
Supplementary files : Except for Figures S07-S09, the other supplementary figures are not mentioned at all in the main text, making it difficult to understand the purpose of the data. For example, Figures S01-S02 and S05-S06 could be cited in the caption of Table 2, or otherwise linked explicitly to the relevant data or discussion in the main text.	We consider these supplements as optional, i.e., for readers who desire a closer look. We therefore mentioned them, in toto, at the end of our introduction; we should however insert a reference to S15-16, which refer to data not plotted in a different form in the text.
I hope my suggestions contribute to enhancing the clarity and quality of the paper.	Yes, despite its cruel conclusion (major revision), we do recognize and value these detailed and thoughtful comments, and the commitment and understanding evident in this review. Like all authors, we have our own concept of our work, text and targeted readers. And each reviewer has one that differs from ours. We therefore ask for some understanding when, in matters of preference, we exhibit some inertia, so as not to be "torn between reviewers".

Sincerely,

R. Jonckheere
F. Trilsch
Jie Liu
Pengfei Zhai
T. Nagel