Manuscript gchron-2024-1 - Revision 2

The daughter-parent plot: a tool for analyzing thermochronological data

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Dear Editor,

We are pleased to receive the new comments by referee #2. The reviewer appreciates the improvements we have made in response to previous comments and contests neither the general usefulness of the D-P plot nor our practical advice for data analysis. We accept most of the reviewer's suggestions, which focus on the presentation of our data examples.

In response to these suggestions we modified our manuscript as follows: we reorganized the example figures and text in sections 2.2 and 2.3 to better separate the description of different data patterns. We also tried to better delineate the difference between the theoretical background in section 2 and the practical considerations in section 3.

In our opinion, these modifications enhance the readability of our manuscript, especially for readers inexperienced in thermochronological data analysis. We hope that the revised manuscript can be considered for publication in *Geochronology*. Please find below the replies to the reviewer comments.

Kind regards,

Birk Härtel for the co-authors

Referee #2 (anonymous)

We appreciate the suggestions by referee #2 concerning the presentation of our data examples and the need to better justify the use of the D-P plot.

Below we respond to each of these comments in detail. **R2** marks the reviewer comments and **A** the authors' replies.

R2: The revised manuscript by Härtel and Enkelmann is improved from the original submission, and I suggest minor revisions mostly regarding organization and figures. The introduction on the background, strengths, and specific differences between traditional isochron plots makes the apparent utility of D-P plots much more obvious than before (e.g., no error correlation between variables as in isochron plots). The paper still seems to tread on topics laid out in a previous publication and by their own admission represents a gray intermediary between traditionally utilized data plots and more detailed data interpretation methods. I think this point needs more development.

A: We understand that more justification for using the D-P plot over, e.g, the age-eU plot would make the manuscript more attractive. Some of these arguments are laid out in detail in Härtel et al. (2022). We added Figure 10 as an example to section 2.3, and provided a reference to the more detailed work on spurious associations in Härtel et al. (2022).

R2: The broader utility of the D-P plot remains elusive in my estimation, but I can see how it may be useful in very specific cases. The text does a better job of explaining utility (compared to the initial submission), but the figures do not support this improvement as clearly or efficiently. The figures should stand alone from the text, and in a paper specifically about plotting, the plots in the figures could better reflect the messaging of the paper.

The addition of D-P plots of previously published datasets from the literature is somewhat helpful in this regard but falls short due to the figures not distinctly showing the benefits of the D-P visualization. The figures often combine many different datasets and "trend styles" making the text and figure content hard to follow throughout (e.g., Sections 2.2 and 2.3 jump around a lot). This could all be simplified and thus the text made clearer in the process. If the focus of the paper is to justify usage of the D-P plot and advertise the advantages, then the figures should clearly reflect that goal. I recommend that the paper focus on a few very clear examples. This could alternatively be achieved by subheadings specifically breaking out each example from figure 1. This may sound tedious, but it makes it much more useful for the reader if Section X and Figure X are discussing one/the same topic.

A: We appreciate this criticism on our presentation of the data examples. We agree that the figures should be able to stand on their own and that the connection between the description in section 2.2 and each of the D-P relationships should be clearer. We therefore reduced the number of examples and split the figures by plotting the example for each relationship together with the conceptual plots from Figure 1, and associated each with a new subheading in section 2.2.
Concerning the utility of the plot, we split the previous Figure 5 to better reflect the arguments given in section 2.3. The two new figures now show: (1) the impact of systematic offset on the radial plot, the χ^2 statistic, and the central age, and (2) how the D-P plot is an improvement on the age-eU plot for detecting radiation-damage.

R2: For example, the D-P plot seems to be useful for identifying linear trends with either zero or non-zero intercepts, but WHY is that advantageous? The text goes into this a little, but the figures could better reflect the advantages.

A: We improved on the figures and text in section 2.3 to clarify to illustrate how overlooking systematic offsets compromises data interpretation.

R2: In Figure 2a, what is the accepted FCT age and how does the manner of plotting/pooled age calculation provide insight and/or better agreement with that age?

A: We added the reference age of FCT to the manuscript for comparison. In section 2.3 an in the conclusions we also emphasized the importance of recognizing the D-P relationship before choosing other data-analysis tools.

R2: Another recommendation would be to show very clear examples of when traditional date-eU or date-kinetic parameter plots diverge in behavior that can be explained or turned into some useful insight based on the D-P relationship. If the data are just being recast or undergoing a transformation just to be in D-P space for no other reason than the authors preference, then the reader will be unlikely to engage with the approach further.

A: We added a reference to Härtel et al. (2022) and a figure (Fig. 10) to section 2.3, showing that the age-eU plot displays an association for a true radiation-damage effect (True Positive), but also for scattered or systematically offset data (False Positive). In contrast, the D-P plot shows distinguishable patterns for each of these cases.

R2: For example, I expected this in Figure 5 with the Orme et al. data in panel A (confusing as presented). What should be taken away from panel A?

A: We reorganized Figure 5 (now Figure 9) to show (a) a D-P, (b) a radial, and (c) an age-eU plot to show how the systematic offset is only visible in (a) but leads to significant bias in (b) and a spurious (positive) association in (c).

R2: I would highly suggest combining figure 1 and the various other figures together to show one figure with, for instance, on the left side "hypothetical example" and right column "real example." This may be a better approach that would avoid jumping between early and late figure references. For example, a hypothetical "inverse" trend from Figure 1h and the Figure 4c Miltich data as the real example combined into one larger figure with clearly labelled columns/panels may be a better option? If the hypothetical and literature examples were combined in a single figure, then the text could easily discuss each in turn and reference the figure accordingly. This may help with organization and flow. Later figures may also delve into specific aspects of, say, details about why the D-P plot for published dataset X shows some pattern and how it could be interpreted.

A: We thank the reviewer for this useful suggestion. We applied it in the revised manuscript by pairing each of the relationships of the former Figure 1 with its respective counterpart(s) from Figs. 2-4.

Other comments:

R2: One phrase at line 78 is a bit confusing to me: "Summarizing thermochronological ages by a mean age without examining the daughter-parent relationship thus does injustice to the data and may neglect important information." What information is being wholly neglected outright (?) and we have already turned away from using mean ages for most thermochronological mineral systems where dates have a direct dependence or relationship with some kinetic variable.

Traditional plots utilizing eU (for U-Th/He), or elemental/compositional information in the case of AFT, are often examined in a similar manner with respect to "date(s)" but are not focused on the mean age—usually quite the opposite. For both zircon and apatite He data, mean ages are essentially useless due to radiation damage effects—a central tendency estimate for AFT data (either arithmetic mean or central age) is useful only when single-grain ages are kinetically homogenous and/or pass the chi-squared test (the latter being

somewhat problematic with high-n/high-precision single-grain data encountered with the ICPMS method). Figure 1 shows various data trend examples of similar "mean age" but again, all of these examples—clusters, non-linearity, multiple populations, scattered data, and inverse trends would all also be displayed in a date-eU or age-kinetic parameter plot for He or AFT data. This again comes back to a critique of the initially submitted manuscript.

A: We agree that the notion of a sample age becomes less and less important with our increasing understanding of thermochronological dating system, giving this statement an unclear direction. We meant to point out at the problem of deciding on an analysis tool (e.g., sample age, radial plot, isochron, age-eU, χ^2) before checking if such a tool is meaningful for a given data pattern (see section 2.3 on problems with systematic offsets). We decided to better clarify this point in sections 2.2 and 2.3 and deleted this phrase.

R2: In Figure 2a—is the "pooled age" unique to using the D-P information or is that just a pooled age is the classic sense using the single-grain data? I suspect the former based on the caption, but I see this as a useful metric and support for D-P plotting with an analytical age standard if specified.
A D-P plot with pooled age of 850 Ma carries what meaning?

A: Our pooled age is the classic pooled age as explained in Appendix C and thus has the same meaning (e.g., Galbraith (2005)). Plotting the pooled age as a line in the D-P plot allows us to evaluate if the single-grain data are in agreement with the pooled age as sample age, and if there is significant difference between a pooled and an isochron age (see section 3.4.1). We added these considerations to section 3.4.2.

R2: If multiple "trend types" are going to be shown in one figure (I'd advise against this), then they should be clearly labelled in the figure as "linear," "cluster", etc. Why is the data 'cluster' in figure 2b shown with the linear examples and what in the value of the D-P plot for such data?

A: We thank the reviewer for pointing out this confusion. In response, we split up the shown examples in section 2.2. The D-P plot for the clustered data is mainly a tool to identify the data as a cluster.

R2: Overall, the text in Section 2.2 seems rushed.

A: We reorganized section 2.2 with subheadings, individual figures, and a revised text to make it more readable.

R2: Figure 3ab zircon He examples again display a similar radiation damage relationship as observed in a date-eU plot. What do the date-eU plots look like? Are they similar?

A: They show an association in age-eU, but it is not distinguishable from spurious correlation. We added a figure (Fig. 10) to compare the differences between radiation-damage effects and other sources of age variation between the D-P and age-eU plot.

R2: Figure 3c nicely shows a multikinetic AFT relationship with two populations from Issler et al. 2005, but again this would also be apparent in an age vs. Cl plot as well...or would it? A direct comparison between such plots is necessary to justify usage of the D-P plot, at least to align with ideas presented in the text.

A: We agree that the age-Cl and the D-P plot should give the same result in such a case. We therefore do not suggest to use the D-P plot exclusively, but suggest its use together with the more traditional tools (section 3.4, Fig. 11). The D-P plot, however, is necessary as a first step (see section 2.3), because the single-grain ages or other plots could be biased. Starting out with an age-Cl or age-eU plot may therefore be misleading. In contrast, using the D-P plot first avoids these problems, and helps us to choose more specific plots (e.g., age-Cl) for subsequent data analysis. We added this explanation to section 2.3 together with a revised version of Figure 5 (Figs. 10 and 11) pointing out biases in some traditional data-analysis tools.

R2: Figure 4—wouldn't these data be scattered in a date-eU or MWAR-eU plot as well?

A: We added a figure to section 2.3 (Fig. 10) showing that the age-eU trend can be fairly systematic given a scattered D-P relationship, even if the age variation is due to different grain sizes (Fig. 10f). Again, we do not suggest to use the D-P plot exclusively, but warn against analyzing data without examining the D-P relationship.

R2: Section 3 seems out of place and some parts of it may not be necessary in the main text, as they distract a bit from the flow.

A: From our perspective, section 3 is the core of this article, providing practical guidance on how to analyze data in D-P space. We added an explicit statemtn to the introduction to clarify the contrast between section 3 and the more theoretical section 2.