Review of “A method for quantifying the time of cooling in thermochronometric inversions” by K. T. McDannell and C. B. Keller

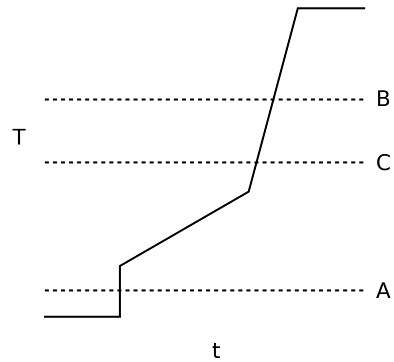
Pieter Vermeesch
University College London

June 4, 2024

I would like to apologise for the extremely slow review process. No fewer than 11 reviewers declined to review this manuscript, with only Dr. Murray kindly accepting the invitation. To get things moving, I have decided to write the second review myself.

The manuscript introduces a new method to summarise an entire thermal history using a single number (with uncertainty). This new method is called the ‘Full time-Distribution at Half-Maximum temperature’ or FDHM. In a sense, the new method generalises the concept of an ‘apparent age’ from a single fission track or helium age to a suite of multiple thermochronological age estimates. I can see the appeal of this. However, the examples provided in the manuscript reveal a number of awkward problems that cast doubt on the usefulness of the new approach.

FDHM is a ‘backronym’ that refers to the FWHM parameter in Raman spectroscopy. I personally think that the backronym is too far fetched to be useful. It is not clear to me what a ‘full time-distribution’ means, or what the ‘half-maximum temperature’ is. According to Figure 1 of the manuscript, the FDHM age should mark the half-way point between the onset and termination of rapid cooling. This is straightforward for simple step histories, but not for more complex cooling curves. Consider the following thermal history as a counter-example:



Which isotherm marks the FDHM? The fastest cooling occurs through isotherm A, with a slower but longer period of cooling going through isotherm B. Isotherm C marks the half-way point between the maximum and minimum temperature. It is not clear to me how this cooling history could be summarised with a single FDHM value. It could be reported as two or three FDHM values, but that would defeat the purpose of the method.

Further questions arise from the two synthetic examples that are discussed in the manuscript. Before I get to these examples, I would like to note that the synthetic data of Table 1 do not make much sense, with the ZHe data being younger than the AFT data and similar in age to the AHe data, even at low eU values. This seems quite unrealistic.

Unrealistic or not, the first example yields an FDHM age of $700 + 7.6/-6.0$ Ma for the slow cooling scenario. Inspection of the true thermal history (dashed line in Figure 2) reveals that nothing special happened at this time. The onset and termination of cooling correspond to geologically meaningful events. The middle of a cooling event does not. The scientific value of the credible interval for FDHM is also unclear. It reminds me of the story where a statistician took 100 depth measurements of a river; obtained a mean value of 1 m with a standard error of 10 cm; concluded that the river was safe to cross; and then drowned in it.

At various places throughout the manuscript, the FDHM value is claimed to constrain the time of "peak cooling" (Figure 1). However, the second example (U-Th-He dataset) shows that this is not true. For exactly the same history as the first example, it returns a different FDHM value of 634 ± 12 Ma, evaluated at a different isotherm (70°C instead of 140°C). It does not become clear how this closure isotherm is chosen until line 243 of the manuscript points out that 70° C marks the time of *maximum temperature sensitivity* for the AHe method. This is a very different concept than the time of peak cooling.

The concepts of an apparent age and closure/annealing temperature may be crude, but they have the advantage of reproducibility. In principle, two thermochronologists analysing the same rocks should obtain the same AFT central age or pooled helium age, say. I am worried that the same cannot be said about the FDHM method. Its definition is closely tied to the posterior likelihood space of the QTQt model. For small datasets, QTQt's RJMCMC model will produce simple models that can be easily summarised with an FDHM value (even if this value doesn't correspond to any geologically meaningful event). However, for large datasets, the solution space will include significantly more complex thermal histories, which will yield different FDHM values, or cannot be summarised with a single FDHM value at all.

This problem is aggravated by the fact that the RJMCMC algorithm can be tweaked in many ways. As mentioned on line 134 of the manuscript: "The time window, time interpolation step, and the histogram bin size (all in units of Myr) are variables that may require tuning based on the timescale of the specific problem under investigation". According to lines 178–179, " the option in QTQt to "reject more complex models that do not improve data fit" was not implemented since this explicit penalty is not a formal Bayesian Markov Chain Monte Carlo (MCMC) procedure and we were interested in examining the full suite of accepted histories". These many 'degrees of freedom' open a Pandora's box of 'designer ages'.

I summary, I am not convinced of the FDHM method's utility and fear that, instead of simplifying the interpretation of thermochronological data, the method will further complicate it.