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Interactive comment on "Beo v1.0: Numerical model of heat flow and low-temperature thermochronology in hydrothermal systems" *by* Elco Luijendijk

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article

Reply to review by Peter van der Beek

Authors' note: The reviewer comments are reproduced here. The replies can be found below each comment and are *italicized*.

Luijendijk presents an original modelling approach to assess the advective perturbation of the thermal field along a fault zone that acts as a fluid conduit, and the potential

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Discussion paper

effect on observed surface low-temperature thermochronometer (apatite (U-Th)/He, AHe) ages across the fault zone. The manuscript is concise and clear, the model is original, well documented and open-source, and the potential applications are clear. The author includes two (positive) model-validation tests. I therefore feel that this could make a good contribution to GMD after only modest revision, which could address the following points:

The author appears unaware of the modelling study by Whipp and Ehlers (2007), which, although addressing a slightly different problem (bulk fluid advection through a mountainous rock mass, if such a thing actually exists . . .), was the first to my knowledge to explicitly address the potential effects of fluid flow on thermochronometer ages, and should therefore, I think, be referenced.

Reply: Thanks for pointing out this reference. I have added a reference to Whipp and Ehlers (2007) to the revised manuscript.

Throughout the paper, the reference to "low-temperature thermochronology" is a bit vague – it would be better to state more specifically what you mean, i.e.:

-In the abstract, line 3: "... do not include low-temperature thermochronometer age predictions . . ."

-Page 2, line 1: ". . . effect of hydrothermal activity on thermochronometer ages/data ..."

-Page 2, line 11: ". . . to model heat flow and apatite (U-Th)/He ages . . ."

-etc.

Reply: Agreed. The references to low-temperature thermochronology have been replaced by more specific terms (low-temperature thermochonometer ages) where ap-

propriate.

Page 2, line 15: note that the latest version of HeFTy can simultaneously predict thermal histories of multiple (borehole) samples (Ketcham et al., 2018), and that the QTQt code (Gallagher, 2012) also has this capacity.

Reply: Agreed, I have adjusted this line to reflect the fact that HeFTy and QtQT can model the history of several samples. The revised version is: "In contrast to inverse thermal models such as HeFTy (Ketcham 2007) and QTQt (Gallagher 2012) which reconstruct thermal histories of one or more samples, Beo models 2D temperature fields over time, which can compared to multiple low-temperature thermochronology samples and which allows testing different hypothesis on hydrothermal activity."

Page 3, line 2: only two subscripts (b and f), but they refer to three things (the bulk material, the fluid and the solid matrix)?

Reply: Thanks for noticing this, only two of the subscript were used, this was corrected in the revised version

Section 2.5 on thermochronometer age predictions is relatively condensed. Some more detail could be provided here.

Agreed, this section has been expanded in the revised manuscript.

Page 12, line 5: what do you mean by “the strength of the thermochronological signal”? The amount of perturbation? How would you measure this? See also the next comment.

Reply: This line was adjusted to: "the strength of the hydrothermal perturbation of thermochronometer ages".

Figure 7 is a key figure as this shows the thermochronometer age predictions. It's a pity that the predicted age pattern is reproduced so small that it is difficult to read.

Reply: The figure has been revised to make the AHe age pattern easier to read.

I wondered how the background AHe age was set in these simulations? It seems strange that the background age is the same (30 Ma) for both the high and the low exhumation-rate cases. While this background age seems appropriate for the low exhumation-rate model, the model with high exhumation rate should have a background AHe age that is an order of magnitude smaller (i.e. 3 Ma). This is important because the relative perturbation of the age may be similar or even smaller in this case compared to the low exhumation-rate case. This also raises the question of whether such a perturbation could be resolved, either at the surface or within borehole samples. This may need some more consideration.

Reply: For this particular set of models the background AHe age for all the model experiments was the same, regardless of the exhumation rate. This was done to better compare the impact of hydrothermal activity between different model experiments. Visually comparing the size of the zone where AHe ages are partially or fully reset would be more difficult with two different background ages of 30 and 3 My. Note that it would be easier to reset a young AHe age, so i suspect the difference between the two age patterns would be more pronounced if different and admittedly more realistic background ages were used.

Linked to this, the model only explores the perturbation during a single interglacial cycle of 15 ky duration. This will only perturb thermochronological systems if very high temperatures (several 100 degr. C) are reached. Although it has indeed been argued that many hydrothermal systems in Alpine environments would have "switched off" during glacial times, there could still be the cumulative effects of multiple short-lived phases of activity throughout the Quaternary. It might be useful to explore such a scenario.

Reply: While it would be great to explore the effects of repeated hydrothermal activity, i feel that this would deserve a separate study/manuscript in itself. The case studies were meant to demonstrate the abilities of the model code, and adding results on episodic hydrothermal activity would be somewhat unsatisfactory without a thorough discussion, which would detract somewhat from the main objective of the manuscript. In addition, model runs with repeated hydrothermal activity and exhumation tend to require much more computational resources due to the long runtime and the high number of grid nodes required to discretize surface layers and simulate erosion over longer runtime. Such a model run would therefore no longer be in the realm of something that an average desktop computer can run within a reasonable timespan, and is therefore less suited as a demonstration example. Note that we did model the effects of episodic hydrothermal activity for a study in the Basin and Range province that is available on eartharxiv (Louis et al. 2018) and is currently in press in Geology (Louis et al. in press).

Linked to the previous two comments; Valla et al. (2016) have reported data from a drill-core close to a hydrothermal site in the Rhone Valley, Switzerland, and have argued that the hydrothermal system was too short-lived to significantly affect the thermochronological ages. They argued that besides limited shortening of fission-track lengths they did not see any effect of hydrothermal circulation on their samples. It could be interesting to use the model presented here to assess this inference more quantitatively.

Reply: Many thanks for the suggestion. The Valla et al study is an excellent demonstration case for the model code and provides an opportunity to compare models with published thermochronology data and also showcases the ability to model borehole temperatures and AHe data. This case study has been added to the revised manuscript, in section 5.2.

References

Louis, S., Luijendijk, E., Dunkl, I., & Person, M. (2018). Episodic fluid flow in an active fault. EarthArXiv. https://doi.org/10.31223/osf.io/cjvxk

Louis, S., Luijendijk, E., Dunkl, I., & Person, M. (in press). Episodic fluid flow in an active fault. Geology.