Review of Fox et al., "Origin of Great Unconformity Obscured by Thermochronometric Uncertainty"

In this manuscript, Fox and co-authors present a detailed and useful discussion regarding the effects of uncertainties related to the Zircon Radiation Damage and Annealing Model (ZRDAAM) on thermal history models based on zircon (U-Th)/He data. They go on to suggest that these effects complicate thermochronologic models that have been used to constrain plausible causes for the Great Unconformity at the end of the Precambrian.

After a brief review of the reasons why some sort of ZRDAAM-like model is necessary to reasonably interpret zircon (U-Th)/He data, the authors correctly note that the original ZRDAAM formulation of Guenthner and co-workers (Guenthner et al., 2013), based on helium diffusion experiments on variably damaged zircons, has shortcomings that make it difficult to realistically propagate uncertainties in two experimentally derived helium diffusion parameters – the pre-exponential constant D_o and activation energy E_a – into ZRDAAM models and onward into thermal history models. In order to do this more quantitatively, they first present a revised ZRDAAM formulation in Section 3 of the manuscript. They show that diffusion parameters derived from experimental data using the new formulation mostly agrees with the diffusion parameters adopted by Guenthner et al. for a highly damaged ("amorphous") crystal, but differ markedly for an "undamaged"crystal (Figures 1 and 2). They attribute this to difficulties in estimating D_o and E_a independently using the approach of Guenthner et al. Most importantly, however the authors show that the uncertainties on derived parameters are quite large, much larger than the thermochronology community generally assumes.

Using the revised ZRDAAM formulation, Fox et al. then proceed to explore how such large uncertainties in radiation damage and annealing model parameters might affect thermal history models calculated using the QTQt software package of Gallagher et al. (Gallagher, 2012). Unfortunately, direct propagation of such uncertainties into inverse modeling of thermal histories using QTQt is computationally impractical (lines 302-305), but the authors present the results of efforts using simplified models showing that uncertainties of up to several hundreds of million years in the estimated timing of a cooling event should not be unexpected (!). They go on to point out, specifically, that these results have dramatic implications for studies such as those being conducted by several groups on the Great Unconformity.

I enjoyed reading this well-written contribution and feel it is an important step toward developing a robust appreciation of how confident we should be in the results of thermal history modeling studies based on datasets for which either zircon or apatite (U-Th)/He radiation damage modeling is required. I found no fault in the mathematics presented here and I trust the authors to have done the modeling carefully. I hope, however, that these findings are not used by non-specialists to conclude that thermal history modeling using thermochronologic data is practically useless because the uncertainties are so large. Fox et al. have tried a bit to guard against that, but they might be more explicit about that in the Implications section. The principal lessons I think we should learn are: 1) we should not overinterpret every wiggle in a modeled time-temperature path as having geologic significance; 2) we should not overestimate the precision with which we know the timing of specific cooling (or reheating) events given the imprecision of derived diffusion and annealing parameters; and 3) we should all continue to work hard to improve our understanding of the impact of radiation damage on diffusion parameters through a combination of experimental *and empirical* studies. I was happy to see the nod toward also using natural laboratories to address these issues moving forward (lines 319-322). In fact, led by Alyssa Anderson, our research group at Arizona State performed such a study (Anderson et al., 2017), concluding that the Guenthner et al. formulation failed to predict ZHe closure behavior consistent with QTQt models of an independent multichronometer dataset for the McClure Mountain syenite of Colorado. However, Anderson and co-workers preferred to interepret this inconsistency as a consequence of variable and complex radiation damage zoning in individual McClure Mountain zircons rather than uncertainties in radiation damage. Certainly, however, uncertainties in the original ZRDAAM model might have played a role, as the Fox et al. work indicates. (It should be noted that, while the accuracy of the cooling history we derived has been disputed based on geological interpretations (Weisberg et al., 2018), the alternative proposed cooling history still remains inconsistent with the ZrnHe closure behavior predicted by the original ZRDAAM model (Anderson et al., 2018).) Our study and the current manuscript together remind us that the effects of radiation damage on ZHe closure behavior of ZHe is extremely complex and dependent on both the parameters we choose for modeling and the idiosyncracies of specific zircons. In such a climate of uncertainty, interpretive caution is advised.

– *Kip Hodges*

References

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