Earth Surf. Dynam. Discuss., 1, C150–C153, 2013
www.earth-surf-dynam-discuss.net/1/C150/2013/

Earth Surface Dynamics Discussions Open Access

Interactive comment on "A linear inversion method to infer exhumation rates in space and time from thermochronometric data" *by* M. Fox et al.

R. W. Brown (Referee)

roderick.brown@glasgow.ac.uk

Received and published: 14 September 2013

Over the last quarter century or so, since the publication of Dodson's seminal paper on the closure temperature concept for geochronologic systems, the field of thermochronometry has grown expansively, both in terms of techniques available and applications. Using the data to estimate exhumation rates has been central of most applications, and the development and advancement of low temperature techniques such as apatite fission track analysis and (U-Th)/He analysis has underpinned much of this work. The topic of this paper is therefore of broad interest, as it offers an efficient technique for deriving models of spatially and temporally variable exhumation rates from

regional (geographically dispersed) data.

However, in my view there is a potential dilemma with the rationale underpinning the technique and how the regional model is formulated. The first issue is that the closure temperature concept as defined by Dodson (1973), while elegant and simple to implement, is often not strictly appropriate, especially for the low temperature systems of apatite FT and (U-Th)/He. This concept of how thermochronometric systems behave relies on monotonic cooling and does not therefore allow for any history which is not monotonic. This introduces a dilemma because if you do not know what the thermal history of a sample is it is not possible to decide whether the closure temperature concept is appropriate for interpreting that sample or not. Although in some cases utilising multiple thermochronometers (with variable temperature sensitivities) may ameliorate this problem to some extent, I suggest it is not a pedantic point for the following reasons. The major advances in thermochronometry in the last few decades have arguably been in establishing the understanding of how various systems work in detail and thus being able to recognise and quantify the degree to which a measured "age" is partially reset or not. For low temperature systems/techniques that are the subject of this paper this is particularly true.

For example, in the fission track approach the distribution of track lengths within a sample provides the basis for constraining the temperature trajectory through the so called partial annealing zone and the 4He/3He step heating approach can be used in the same way to identify samples that have partially degassed (U-Th)/He "ages". This is important because the closure temperature concept, as described by Dodson (1973) and utilised in this paper, cannot be applied to samples that have partially reset ages. If the sample thermochronometric "age" is partially reset, by prolonged and non-monotonic residence within the partial annealing or retention zones respectively, then the age has no simple relationship with the depth to any isotherm and the rate/s of exhumation over that interval. This is precisely why most other inversion approaches for deriving exhumation histories from thermochronometric data ustilise not only the measured age, but also the information that most directly links to the rate and style of exhumation such as track length distributions or 4He/3He step heating profiles. Not including these measurements seriously limits the practical viability of the proposed approach to regional data. A simple hypothetical situation can be used to illustrate this dilemma. Consider a sample with an apatite FT age of say 12 Ma. This sample may have cooled effectively instantaneously (i.e. very rapid rate of exhumation) at circa 12 Ma or it may have experienced a protracted period of cooling (and possibly reheating) over a period of 100 Ma or more depending on the exact trajectory through the partial annealing zone. Assuming that the sample cooled monotonically after cooling below a notional closure temperature for the apatite FT system would possibly yield excellent fits to the measured ages but yield spurious T-t/exhumation solutions in the later case.

The approach as described here may however be more robust in the case of collocated sets of samples (at different depths/elevations), such as the Denali case history. Here, the additional information inherent in using multiple samples can overcome the ambiguity problem because the shape of the age vs elevation profile to some extent encodes the variability and style of exhumation. Even here though, there are cases where the age vs elevation gradient does not reflect the exhumation rate in any direct manner such as when the age gradient is set by a protracted period of no exhumation and partial annealing/degassing, or even slow burial.

Given the above discussion I feel some mention and discussion of the modern approaches to thermal history/exhumation inversion, developed over the last 25 years since Dodson's work, is warranted, in fact it is essential for a paper on this topic in my view, if only to clarify why the authors consider the Dodson concept to be routinely applicable and viable. Some additional experiments, conducted on synthetic data sets perhaps, to quantify and investigate the scale of any errors introduced for situations where samples have experienced protracted and complex exhumation histories would also significantly improve this paper, especially for data sets where multiple thermochronometry methods are not available. The synthetic data illustrated in Fig. 9

arguably is too simplistic as it does not include samples that have experienced non-monotonic trajectories through the respective temperature ranges for each system.

Roderick Brown

Interactive comment on Earth Surf. Dynam. Discuss., 1, 207, 2013.