Geophysical Research Abstracts
Vol. 13, EGU2011-8194-3, 2011
EGU General Assembly 2011

A new approach to deriving thermal history information from apatite (U-Th)/He analyses which exploits the natural dispersion of single crystal age determinations

Roderick Brown (1), Romain Beucher (1), Kerry Gallagher (2), Cristina Persano (1), Finlay Stuart (3), and Paul Fitzgerald (4)

(1) School of Geographical and Earth Sciences, University of Glasgow, Glasgow, United Kingdom (roderick.brown@glasgow.ac.uk, rbeucher@ges.gla.ac.uk, cristina.persano@glasgow.ac.uk), (2) Géosciences Rennes, Université de Rennes 1, Rennes, France (kerry.gallagher@univ-rennes1.fr), (3) Scottish Universities Environmental Research Centre, East Kilbride, United Kingdom (f.stuart@suerc.gla.ac.uk), (4) Department of Earth Sciences, Syracuse University, Syracuse, USA (pgfitzge@syr.edu)

Near surface tectonic and geomorphic processes typically involve erosion that leads to cooling of rocks through low temperatures characteristic of the upper few kilometers of the Earth's crust (circa 50-150 $^{\circ}$C). Over the last decade or so major progress has been made in developing both the theoretical and practical aspects of apatite (U-Th)/He thermochronometry (e.g. Farley, 2002) and the thermal sensitivity (40-70 $^{\circ}$C) of this technique has made it one of the most widely used methods of quantifying the low temperature thermal histories of rocks in geoscience investigations across an extremely wide range of geological settings. It is now standard practice, and generally seen as best practice (Farley *et al.,* 2010), to analyse single grains. These individual prismatic crystals (particularly of apatite and zircon) are usually broken, i.e. they are fragments of larger crystals that have broken parallel to the weak cleavage direction at right angles to the c-axis (for apatite) during mineral separation. This is clearly indicated by the common occurrence of only 1 or no clear crystal terminations present on separated apatite grains (e.g. Farley, 2002, Farley *et al.,* 2010).

Using a numerical model with a finite cylinder geometry to approximate ^{4}He diffusion in hexagonal apatite crystals we show that much of the natural dispersion typically seen for single crystal (U-Th)/He age measurements (i.e. the dispersion that exceeds that expected statistically from the analytical precision of measurements alone) is explained when broken grains are treated explicitly as fragments of larger grains. Our experiments indicate that natural dispersion is often of the order of 40-50% (and sometimes greater) for samples with well rounded diffusive profiles, and that the mean age of multiple fragment ages approaches the true whole crystal age for a sufficient number of analyses (circa 20-30). Where the majority of fragments analysed have no terminations then the sample age is always substantially overestimated for samples with highly rounded ^{4}He profiles. The results of our numerical experiments accords very well with degree and pattern of natural dispersion seen in several real data sets and reproduces the common observation that rapidly cooled samples with 'young' ages show least dispersion while 'older' samples with more complex T-t histories show large dispersion. This source of dispersion is a natural consequence of analysing broken crystals and the shape of the combined axial and radial diffusion profiles within prismatic crystals such as apatite and we believe it is a primary cause of much of the dispersion observed in (U-Th)/He data sets.

A key challenge to deriving T-t histories from these data, and therefore constraints on rates of erosion or relief development, is that there is usually no unique cooling path consistent with any given (U-Th)/He age determination. This is particularly demanding for samples that have experienced slow to moderate cooling or prolonged residence within the partial retention zone and therefore have strongly rounded ^{4}He distributions. Major progress has been made in this area with the development of the ^{4}He/^{3}He technique which uses a constant background ^{3}He distribution (induced by proton irradiation) coupled with a step heating protocol to obtain information about the diffusive ^{4}He profile within a single grain (Shuster and Farley, 2005).

We demonstrate a new approach to deriving T-t paths consistent with single grain apatite (U-Th)/He age measurements that explicitly uses the natural dispersion described above and exploits the valuable information about the spatial distribution of ^{4}He within the individual crystal fragments. The strategy involves finding a single common (to all fragments) T-t history that optimizes the fit to each fragment age (for which eU and radius are known) using a finite cylinder model geometry and with the initial crystal lengths (which are unknown) fitted as model parameters. The modelling approach yields similar information to the recently developed ^{4}He/^{3}He technique (Shuster and

Farley, 2005) with the advantage that it is inherently a multi grain method capable of jointly fitting a common T-t history to as many single grain analyses as are available from a single sample. Unlike the ^{4}He/^{3}He technique it is also clearly unaffected by analyses of broken fragments but rather explicitly accommodates and exploits the T-t information within these grains.

Our new modelling strategy explicitly exploits the information about the shape of the ^{4}He distributions inherent in the individual fragment ages, leading to improved constraints on viable thermal history models, especially those for samples that have experienced significant diffusive loss of ^{4}He. Some changes to criteria for selecting grains for analysis are indicated in order to maximize the effectiveness of this new approach. These include selecting a wide range of grain sizes (specifically prism lengths), perhaps even manually breaking grains to ensure that this is possible, and analyzing a larger number of single grains per sample (circa 15-20 grains per sample) than is usually the case where typically only 3-5 grains are analysed.

The advantage of this new approach is that it is essentially a generalisation of the current approach to modelling T-t histories from (U-Th)/He data with the assumption that single grain measurements are made on whole crystals being relaxed. It can therefore explicitly accommodate all the details of the current approach such as the effects of temporally variable diffusivity (e.g. radiation damage models), zonation of U and Th and arbitrary grain size variations and will work equally effectively for whole or broken crystals, or indeed the more likely situation where there is a mixture of both. But, just like the current T-t modelling approach, other causes of natural dispersion other than fragmentation need to be assessed and accounted for. However, we believe that much of the so called 'enigmatic' dispersion documented for single crystal apatite (U-Th)/He age determinations, especially for those samples that have had protracted T-t histories within the partial retention zone, is quantitatively explained by our explicit fragmentation model.

Farley, K.A., 2002, (U-Th)/He dating: techniques, calibrations and applications, *Reviews in Mineralogy and Geochemistry*, v. 47, p. 819-844.

Farley, K.A., Shuster, D.L., Watson, E.B., Wanser, K.H. and Balco, G., 2010, Numerical investigations of apatite ^{4}He/^{3}He thermochronometry, *Geochemistry Geophysics Geosystems*, v. 11, Q10001, 18 pp., doi:10.1029/2010GC003243.

Shuster, D.L. and Farley, K.A., 2005, ^{4}He/^{3}He thermochronometry: theory, practice and potential applications, *Reviews in Mineralogy and Geochemistry*, v. 58, p. 181-203.