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How to derive robust thermal histories from 'over-dispersed' single crystal apatite (U-Th)/He ages

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The (U-Th)/He thermochronometry technique has revolutionised our ability to investigate low temperature processes within the shallow crust (e.g. Farley, 2002). It is now standard practice to analyse single grains rather than multigrain aliquots for a variety of reasons, but in many instances the single grain ages from a given sample are severely dispersed, and often uncorrelated with either grain size or U or Th content. This suggests that there must be another common cause of dispersion other than absolute grain size or differences in 4He diffusivity caused by radiation damage accumulation.

Using a numerical model and a finite cylinder geometry to approximate 4He diffusion in apatite we show that much of the range of this 'over dispersion' is explained when broken grains are treated explicitly as fragments of larger grains. This situation is clearly indicated by the common occurrence of only 1 or no clear crystal terminations present on separated apatite grains.

Here we show that the shape of the 4He distribution within an individual crystal is indeed inherent in the pattern of dispersion of individual fragment ages, and we describe and demonstrate a new inversion approach that exploits this information by modelling the single grain ages explicitly as fragments of larger grains to obtain robust constraints on a sample's thermal history. Our new approach yields similar thermal history constraints to those obtained from the single crystal 4He/3He technique (e.g. Shuster et al., 2005) with the added advantage that it does not require the analysis to be performed on whole crystals.

The advantage of our new approach is that it can 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 it will work equally effectively for whole or broken crystals, or indeed the more likely situation where there is a mixture of both.

Our experiments also indicate that when a mixture of broken crystals with 1 and no terminations are analysed it is unreasonable to expect these analyses to replicate and to produce a single, discrete sample age. If broken grains with no terminations are analysed (i.e. none with 2 or 1 termination) then these crystal ages may indeed replicate, but would produce an erroneously 'old' sample age. We suggest that for routine single grain (U-Th)/He analyses on samples where whole grains are rare, or unavailable, then 15-20 single grain analyses is probably the minimum required to characterise the sample age. The experiments also suggest that picking very short crystal fragments as well as long fragments, or even deliberately breaking long crystals to maximise the age dispersion, would ensure the best constraints on the thermal history models.

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

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