Mapping He distribution in zircon by laser ablation noble gas mass-spectrometry: Implications for (U-Th)/He geochronology and thermochronology

Danišík, M.[1], McInnes, B.I.A.[1], Kirkland, C.L.[1,2], McDonald, B.J.[1], Evans, N.J.[1], Becker, T.[3]
1 Auscope AGOS GeoHistory Facility, John de Laeter Centre, TIGeR, Applied Geology/Applied Physics, Curtin University, Perth, Australia
2 Centre for Exploration Targeting – Curtin, Department of Applied Geology, Western Australian School of Mines, Curtin University, Australia
3 Nanochemistry Research Institute, Department of Chemistry, Curtin University, Perth, WA Australia
(m.danisik@curtin.edu.au)

Conventional (U-Th)/He dating of zircon is traditionally undertaken by measuring bulk He, U and Th abundances in single zircon crystals, and by applying an alpha ejection correction[1]. The homogeneity of U-Th in dated crystals is commonly assumed but is clearly not always valid[2-4], which may result in ages that are not concordant with the ages obtained from other techniques. It has been demonstrated that age discrepancies may arise from intra-grain variations in isotopic and/or structural composition in dated zircon crystals[2-7], however these are difficult to quantify given the lack of suitable analytical instrumentation.

In this paper we will present a new methodology, based on integrated *in situ* laser ablation micro-sampling and noble-gas mass-spectrometry, that allows the 2-dimensional visualization and quantification of He distribution in zircon (and possibly other minerals) at a micrometer scale. This approach provides the first opportunity to examine intra-grain distribution of He and allows us to investigate and visualize the impact of the several underlying reasons for problematic zircon (U-Th)/He ages. Using this methodology, we constructed high-resolution He “maps” for a set of zircon crystals in order to investigate the impact of U-Th zoning, radiation damage and inclusions on He distribution. The He maps, in combination with characterization information from other imaging techniques (i.e., cathodoluminescence, confocal Raman microscopy and LA-ICPMS elemental maps) allow us to visualize the impact of these commonly ignored grain features to the fundamental principles and assumptions of (U-Th)/He geochronology. Based on the outcomes of this work, we suggest refinements to analytical protocols currently used for conventional as well as *in situ* (U-Th)/He dating, $^4He/^3He$ thermochronometry and diffusion experiments. Finally, we will illustrate how He mapping may potentially provide a new means for thermal history reconstructions by allowing direct measurement of He diffusional profiles.

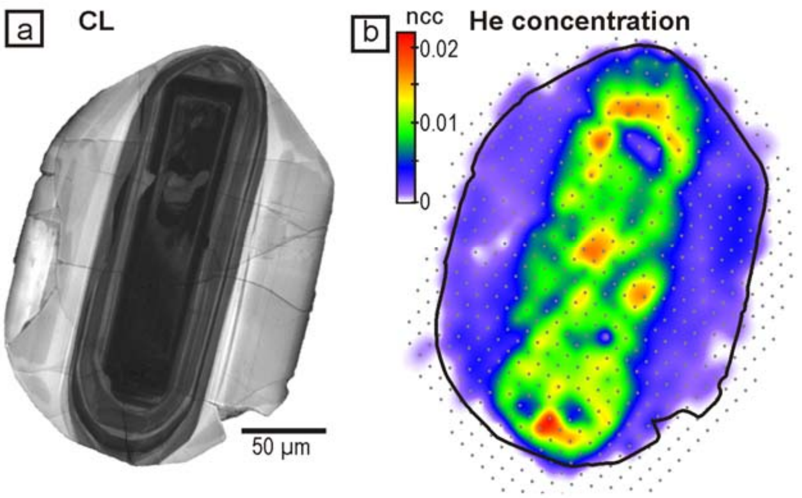

***Figure 1**. CL image (a) and He concentration map (b) of a zircon with U-rich core and U-depleted rims generated by SEM and RESOchron^{TM} instruments, respectively. Note that He distribution correlates well with CL intensity and therefore with U distribution. Understanding the intra-grain distribution of He, U and Th is essential for correct interpretation of (U-Th)/He results.*

References

1. Farley, K. A., Wolf, R. A. & Silver, L. T. The effects of long alpha-stopping distances on (U–Th)/He ages. Geochim. Cosmochim. Acta 60, 4223–4229 (1996).
2. Meesters, A. G. C. A. & Dunai, T. J. Solving the production–diffusion equation for finite diffusion domains of various shapes part 2, Application to cases with Alpha ejection and non-homogeneous distribution of the source. Chem. Geol. 186, 345–363 (2002b).
3. Dobson, K. H., Stuart, F. M., Dempster, T. J. & EIMF. U and Th zonation in Fish Canyon Tuff zircons: implications for a zircon (U–Th)/He standard. Geochim. Cosmochim. Acta 72, 4545–4755 (2008).
4. Hourigan, J. K., Reiners, P. W. & Brandon, M. T. U-Th zonation-dependent alpha-ejection in (U–Th)/He chronometry. Geochim. Cosmochim. Acta 69, 3349–3365 (2005).
5. Hurley, P. M. Alpha ionization damage as a cause of low He ratios. EOS Trans. Am. Geophys. Union 33, 174-183 (1952).
6. Shuster, D. L., Flowers, R. M. & Farley, K. A. The influence of natural radiation damage on helium diffusion kinetics in apatite. Earth Planet. Sci. Lett. 249, 148–161 (2006).
7. Stockli, D. F., Farley, K. A. & Dumitru, T. Calibration of the (U-Th)/He thermochronometer on an exhumed fault block, White Mountains, California. Geology 28, 983–986 (2000).