geoconvention
Calgary • Canada • May 11-13 2026

Laser Ablation zircon double dating: A tool for basin studies and exploration

Akeek, Maitra
Birk, P, Härtel
Eva, Enkelmann
Earth, Energy, and Environment, University of Calgary

Summary

Laser ablation U–Pb and (U–Th)/He zircon double dating is a novel analytical technique that enables us to simultaneously obtain U–Pb and (U–Th)/He ages as well as in-situ trace element chemistry from a single domain in a zircon grain. This analytical technique can provide a plethora of information on geochemical character, timing of intrusion and cooling history of crustal rocks all at once. The combined U–Pb, (U–Th)/He, and trace-element datasets available from a single zircon grain makes this technique a powerful tool that can be applied to sedimentary basins for source-area fingerprinting (provenance) and studying the thermal history of a basin – facilitating exploration. We tested the robustness of this technique by studying two plutons of the Canadian Cordillera in Southern British Columbia having well known geological history. In this study we further used the U-Pb and (U-Th)/He data to constrain a thermal history that the rocks underwent. The results of our study are in good agreement with the existing geological knowledge from the study region.

Theory/Method/Workflow

Zircon (U–Th)/He dating exploits the principle of production of radiogenic helium from the α-decay of U and Th and its diffusion in the zircon lattice providing a temperature sensitive (~130–200 °C) cooling and exhumation record of rocks (Farley, 2002; Reiners et al., 2004). Thus, Zircon (U–Th)/He dating estimates the time when a rock cooled to shallower crustal depth (about 5-6 km from the surface). Conventional zircon (U–Th)/He (ZHe) dating involves hand-picking individual zircon grains and degassing the entire crystal to measure radiogenic helium by noble gas mass spectrometry, and subsequently dissolving the grain to determine U and Th concentrations by solution ICP-MS. As helium retention is influenced by factors like zoning and inclusions, conventional whole-grain zircon He dating technique inherently averages domains and obscures complex albeit meaningful geological information within a zircon. The novel laser-ablation (LA)-ZHe technique overcomes this hurdle by allowing spatially resolved helium measurement of zircon grain by laser ablation. This technique reduces the time of sample preparation, increases analytical throughput and enables direct assessment of zoning dependent helium diffusion behaviour. Moreover, the same region of the zircon grain can subsequently be re-analyzed by LA-ICP-MS to obtain U–Pb crystallization ages and zircon trace-element compositions (e.g., Danišík et al., 2017; Evans et al., 2015; Horne et al., 2016).

We dated four samples by LA-ZHe technique, two samples from the Nelson batholith (Jurassic) and two samples Mount Skelly pluton (Cretaceous) – granite plutons of the Omineca Belt in the Southern Canadian Cordillera. Zircon crystals were concentrated from these samples using standard mineral separation procedures. Following mineral separation, the zircon grains were mounted on Teflon sheets and polished. About 50–55 zircon grains were analyzed by LA-ZHe technique. Helium was extracted by ablating each grain with a Resolution Excimer laser (193 nm) and measuring the extracted helium in an Alphachron mass spectrometer comprising an ultrahigh vacuum helium extraction line. Each zircon grain was subsequently re-ablated for U–Pb geochronology and for determining U, Th and other element concentration by LA-ICPMS by an Agilent 7700 quadrupole mass spectrometer.

Results, Observations, Conclusions

In Figure 1, we show the Geo- and thermochronology data from one of the four samples studied. This sample produced a zircon U–Pb age of 166.0 ± 1.1 Ma and (U–Th)/He age of 58 ± 6 Ma. Zircon rare earth element (REE) pattern of the analyzed zircons show enrichment of heavy REE relative to light REE typical of igneous zircon. Two zircon analyses with (U–Th)/He dates < 40 Ma in this sample (Fig. 1b) show elevated REE concentrations. These zircons can be potentially affected by high temperature metamorphism or hydrothermal alteration leading to enrichment of REE in the zircon.

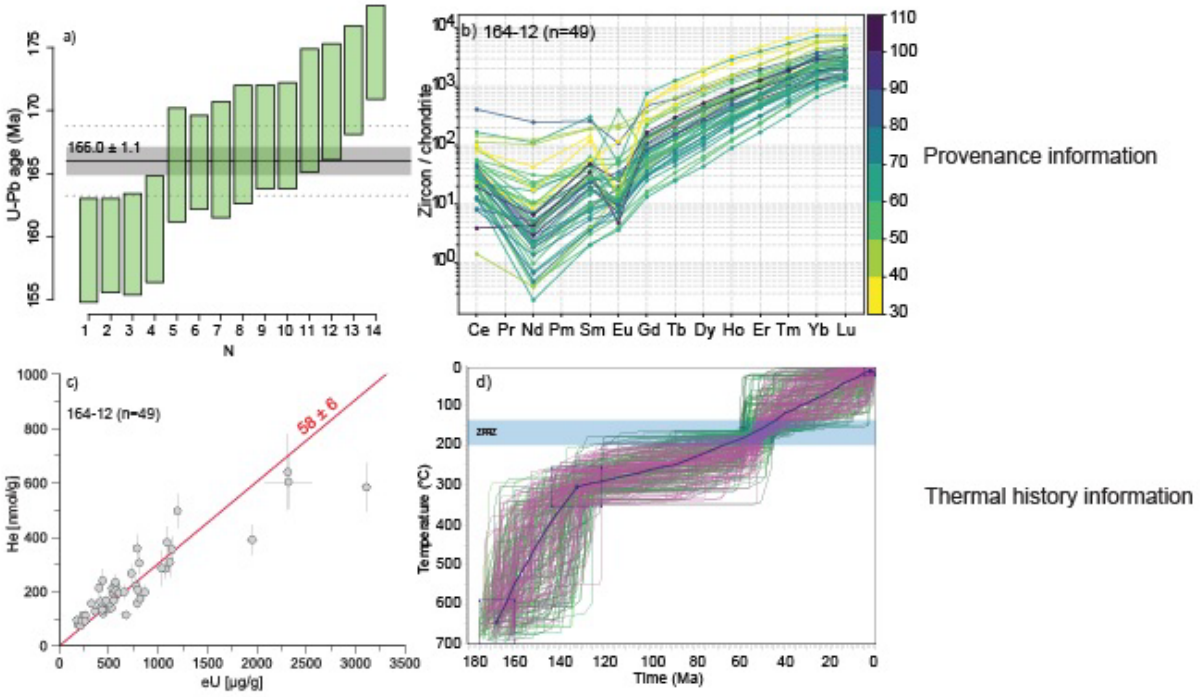


Figure 1. Geo- and thermochronology data available from laser ablation zircon double dating of single bedrock sample. a) U-Pb dates with weighted mean age b) Zircon REE pattern colour-coded by (U–Th)/He dates c) He-eU plot of LA-ZHe dates showing pooled (U–Th)/He sample age (Härtel and Enkelmann, 2024a). d) Inverse thermal history model of the sample based on U-Pb and (U-Th)/He age data.

Based on U-Pb and (U-Th)/He dates we constrained the cooling history (Fig. 1d) of the samples studied by inverse modeling in the HeFTy software (Ketcham 2005). The onset of cooling of the displayed sample is constrained by its U–Pb age of 166 Ma. The weighted mean temperature-time (T-t) path, shown in dark blue, depicts cooling from mid-crustal temperatures (~450–300 °C) between 150 and 110 Ma, followed by continued cooling into the zircon partial retention zone (ZPRZ; ~200–140 °C) ~ 80 Ma. The cooling from 140 °C to lower temperature took place around 55 Ma onwards.

In case of detrital samples, individual zircon grains record both, their source area and thermal history. In addition to this, each grain may experience variable degrees of heating during post-depositional burial in the basin. The laser ablation double dating technique becomes particularly useful for studying detrital samples where analyses of large numbers of grains are needed to extract meaningful geological information. At the Geo- and Thermochronology Laboratory of the University of Calgary, we have already applied this technique on detrital zircons from the Mackenzie Plains, region of hydrocarbon potential, for resolving provenance information and constraining basin thermal history (Härtel and Enkelmann, 2024b).

Acknowledgements

This research was funded by the Natural Sciences and Engineering Research council (NSERC) grant RGPIN-2024-03863 and by the donors of ACS Petroleum Research Fund under New Directions Grant PRF# 67107-ND8. EE served as Principal Investigator on PRF# 67107-ND8 that provided support for AM and BPH. BPH acknowledges a German Research Council (Deutsche Forschungsgemeinschaft) Walter-Benjamin fellowship (HA 9685/1-1).

References

Danišík, M., McInnes, B.I., Kirkland, C.L., McDonald, B.J., Evans, N.J., Becker, T., 2017. Seeing is believing: Visualization of He distribution in zircon and implications for thermal history reconstruction on single crystals. Science advances 3, e1601121.

Evans, N.J., McInnes, B., McDonald, B., Danišík, M., Becker, T., Vermeesch, P., Shelley, M., Marillo-Sialer, E., Patterson, D., 2015. An in-situ technique for (U–Th–Sm)/He and U–Pb double dating. Journal of Analytical Atomic Spectrometry 30, 1636–1645.

Farley, K.A., 2002. (U-Th)/He Dating: Techniques, Calibrations, and Applications. Reviews in Mineralogy and Geochemistry 47, 819–844.

Härtel, B., Enkelmann, E., 2024a. The daughter–parent plot: a tool for analyzing thermochronological data. Geochronology 6, 429–448.

Härtel, B., Enkelmann, E., 2024b. First results from U-Pb-He-Raman-triple dating of detrital zircon. Goldschmidt 2024 conference, Chicago, Illinois.

Horne, A.M., van Soest, M.C., Hodges, K.V., Tripathy-Lang, A., Hourigan, J.K., 2016. Integrated single crystal laser ablation U/Pb and (U–Th)/He dating of detrital accessory minerals–Proof-of-concept studies of titanites and zircons from the Fish Canyon tuff. Geochimica et Cosmochimica Acta 178, 106–123.

Ketcham, R.A., 2005. Forward and Inverse Modeling of Low-Temperature Thermochronometry Data. Reviews in Mineralogy and Geochemistry 58, 275–314.

Reiners, P.W., Spell, T.L., Nicolescu, S., Zanetti, K.A., 2004. Zircon (U-Th)/He thermochronometry: He diffusion and comparisons with 40Ar/39Ar dating. Geochimica et cosmochimica acta 68, 1857–1887.