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(U-Th)/He geochronology of kimberlite zircon megacrysts: a new chronometer for dating emplacement

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Motivation

Acquiring accurate emplacement ages for kimberlites is critical for understanding the geodynamics, triggers, and crustal conditions necessary for kimberlite eruptions, while also providing important context for diamond exploration strategies (e.g., Heaman et al., 2019). Zircon "megacrysts"—held to be part of the low-Cr megacryst suite—have been widely used to date kimberlites, especially in locations where weathering and kimberlite mineralogy precludes the application of other chronometers. However, there is increasing evidence that radiogenic Pb retention in these zircon can result in ages that are 10's of millions to billions of years older than that of the host kimberlite, owing to initial zircon growth in the mantle long before the eruption of the zircon megacrysts in a kimberlite. Consequently, significant caution is needed when interpreting U-Pb ages for zircon megacrysts where few other age constraints exist. In this work, we will present a novel application of (U-Th)/He chronology to zircon megacrysts to date kimberlite emplacement.

Zircon (U-Th)/He (ZHe) chronology is a commonly-applied method used to understand a variety of geologic processes that occur at upper crustal temperatures and depths (<260°C, upper ~10 km of the crust). ZHe chronology is based on the production and temperature-sensitive retention of radiogenic ^{4}He produced during the decay of U, Th, and Sm. In contrast to radiogenic Pb, ^{4}He is not retained within the zircon crystal lattice at temperatures above ~260°C, meaning that issues associated with pre-eruption crystallization of megacrystic zircon, whether in the crust or the mantle, do not exist.

Methods

Acquiring megacrystic ZHe dates is relatively straightforward. First, the outer ~16µm of the grain is removed via air abrasion in order to remove the "alpha-ejection rim" of the zircon, where ^{4}He particles produced during U, Th, and Sm decay can be ejected from the crystal due to the long stopping distance of ^{4}He. The removal of this rim eliminates the need for an alpha-ejection correction (Farley et al., 1996), and increases the precision and accuracy of ZHe dates. Crushed fragments of the interior of the megacryst are then packed in a Nb tube and loaded into a He extraction and measurement line in which the ^{4}He is degassed with a laser, spiked with ^{3}He, and measured using a quadrupole mass spectrometer. The zircon aliquots are then spiked with a mixed tracer, dissolved using a series of acids (HF, HCl, and HNO_3) at high temperatures, and the parent isotopes analyzed via ICP-MS (Flowers et al., 2022a). The relatively low concentrations of parent isotopes in zircon megacrysts (typically <100 ppm U) makes these grains retentive to helium at temperatures <260°C, such that their ZHe dates should faithfully record the time at which the kimberlite cooled below ~260°C, which for most kimberlites should be coincident with the eruption age.

We will present "proof of concept" ZHe data for two pairs of diamondiferous rocks with known eruption ages: the Voorspoed CROL (131.8 ± 1.7 Ma; phlogopite ^{40}Ar/^{39}Ar; Phillips et al., 1998) and Monastery kimberlite (90.1 ± 0.5 Ma; zircon megacryst U-Pb; Noyes et al., 2011) from the Kaapvaal craton, South Africa, and the Panda (53.3 ± 1 Ma; phlogopite Rb-Sr; Heaman et al., 2004) and Diavik (55-56 Ma; phlogopite Rb-Sr; Heaman et al., 2004) kimberlites from the Slave Craton, NT, Canada.

Results of pre-characterization by cathodoluminescence, trace elements, and U-Pb

Zircon megacrysts were characterized using cathodoluminescence images, trace element data, and U-Pb data to confirm a kimberlitic origin and suitability for ZHe. Cathodoluminescence images were acquired at the University of Colorado Boulder microprobe laboratory—all zircon megacrysts show little to no zonation. Trace element and U-Pb data were acquired via laser-ablation ICP-MS in the Thermochronology Research and Instrumentation Lab (TRaIL) at the University of Colorado Boulder. The measured trace element patterns and concentrations generally agree with the trends for megacrystic mantle zircon identified in Belosouva et al. (2002). U-Pb data reveal that the megacryst U-Pb dates faithfully record emplacement for Panda (58.18 ± 0.17 Ma) and Monastery (84.3 ± 3.8 Ma). In contrast, older U-Pb dates that significantly pre-date kimberlite eruption were obtained for the Diavik (~2.5 Ga) and Voorspoed (~2.6 Ga) zircon megacrysts.

ZHe dating of these megacrysts, regardless of antiquity of the U-Pb date, should record the kimberlite emplacement age. (U-Th)/He dating of zircon megacrysts represents a new chronometer with exciting potential to confirm or acquire emplacement ages on kimberlites that lack any other datable mineral phases, without the complications of anomalously old U-Pb ages. The ZHe approach also offers the potential to resolve emplacement age issues in kimberlites for which different methods have yielded differing results, or where a spread of ages is apparent for a single technique, if zircon are available. Where zircon megacrysts are available through mineral concentrates, (U-Th)/He chronology is a relatively rapid and cost-effective approach to dating kimberlites. These factors may make megacrystic zircon (U-Th)/He chronology a powerful new approach to evaluating kimberlite emplacement ages in the context of diamond exploration.

References

Belousova E, Griffin W, O'Reilly SY, Fisher N (2002) Igneous zircon: trace element composition as an indicator of source rock type. Contrib Mineral Petrol 143:602–622. https://doi.org/10.1007/s00410-002-0364-7

Farley KA, Wolf RA, Silver LT (1996) The effects of long alpha-stopping distances on (U/Th)/He ages. Geochimica et Cosmochimica Acta 60:4223–4229. https://doi.org/10.1016/S0016-7037(96)00193-7

Flowers RM, Zeitler PK, Danišík M, et al (2022) (U-Th)/He chronology: Part 1. Data, uncertainty, and reporting. GSA Bulletin 135:104–136. https://doi.org/10.1130/B36266.1

Heaman LM, Kjarsgaard BA, Creaser RA (2004) The temporal evolution of North American kimberlites. Lithos 76:377–397. https://doi.org/10.1016/j.lithos.2004.03.047

Heaman LM, Phillips D, Pearson G (2019) Dating Kimberlites: Methods and Emplacement Patterns Through Time. Elements 15:399–404. https://doi.org/10.2138/gselements.15.6.399

Noyes AK, Heaman LM, Creaser RA (2011) A Comparison of Chronometers Applied to Monastery Kimberlite and the Feasibility of U-Pb Ilmenite Geochronology. In: Dyke Swarms:Keys for Geodynamic Interpretation. Springer Berlin Heidelberg, Berlin, Heidelberg, pp 457–492

Phillips D, Machin KJ, Kiviets GB, et al (1998) A petrographic and 40Ar/39Ar geochronological study of the Voorspoed kimberlite, South Africa: Implications for the origin of Group II kimberlite magmatism. South African Journal of Geology 101:299–306. https://doi.org/10.10520/EJC-1ac875470b