

S1. Analytical procedures on Whole rock, Sm-Nd isotopes and LA-ICP-MS U-Pb data

S1.1 Whole rock geochemistry

Whole rock for major, minor and trace element analyses of thirty-two samples were carried out at the Activation Laboratories (ActLabs) (Ancaster, Ontario, Canada), and the results are given in Table S3. A batch system is used for preparation and samples analysis, each batch contains a method reagent blank, certified reference material and 17% replicates. The Alkali fusion method is used to digest samples with 5 g of material. The fusion of samples was done in an induction furnace, using Lithium metaborate/ tetraborate. The molten melt is then immediately placed into a 5% nitric acid solution with an internal standard, and it is continually stirred for about 30 minutes or until it is completely dissolved. The selected trace elements are on a combination simultaneous/sequential Thermo Jarrell-Ash ENVIRO II ICP or a Varian Vista 735 ICP. Calibration is performed using 7 prepared USGS and CANMET certified reference materials. The detection limits for the analytical procedure range from 0.01% for the majority of the major elements to 0.001% for TiO₂ and MnO.

S1.2 Whole rock Sm-Nd isotopic data

Sm-Nd isotopic analyses of seven representative samples from the Zgounder Mine Region were also performed at the Activation Laboratories (ActLabs) (Ancaster, Ontario, Canada), and the results are given as table 1 in the manuscript text. Rock powders were accurately weighed and totally spiked with a known amount of mixed ¹⁵⁰Nd- ¹⁴⁹Sm tracer solution - this tracer is calibrated directly against the Caltech mixed Sm/Nd normal described by Wasserburg et al. (1981). Dissolution occurs in mixed 24N HF + 16N HNO₃ media in sealed PFA Teflon vessels at 160 °C for 6 days. The fluoride residue is converted to chloride with HCl, and Nd and Sm are separated by conventional cation and HDEHP-based chromatography. Chemical processing blanks are < 200 picograms of either Sm or Nd, and are insignificant relative to the amount of Sm or Nd analyzed for any rock sample. Further details can be found in Creaser et al. (1997) and Unterschutz et al. (2002).

The isotopic composition of Nd is determined in static mode by Multi-Collector ICP- Mass Spectrometry (Schmidberger et al., 2007). All isotope ratios are normalized for variable mass fractionation to a value of ¹⁴⁶Nd / ¹⁴⁴Nd = 0.7219 using the exponential fractionation law. The ¹⁴³Nd / ¹⁴⁴Nd ratio of samples is presented here relative to a value of 0.511850 for the La Jolla Nd isotopic standard, monitored by use of an in-house Alfa Nd isotopic standard for each analytical session. Sm isotopic abundances are measured in static mode by Multi-Collector ICP-Mass Spectrometry, and are normalized for variable mass fractionation to a value of 1.17537 for ¹⁵²Sm / ¹⁵⁴Sm also using the exponential law. Using the same isotopic analysis and normalization procedures above. The Geological Survey of Japan Nd isotope standard “Shin Etsu: J-Ndi- 1” (Tanaka et al., 2000) is then analyzed, which has a ¹⁴³Nd / ¹⁴⁴Nd value of 0.512107 ± 7 relative to a LaJolla ¹⁴³Nd / ¹⁴⁴Nd value of 0.511850, when normalized to ¹⁴⁶Nd / ¹⁴⁴Nd = 0.7219. The value of ¹⁴³Nd / ¹⁴⁴Nd determined for the JNdi-1 standard conducted during the analysis of the samples reported here was 0.5121095 ± 7 (2SE). Using the mixed ¹⁵⁰Nd-¹⁴⁹Sm tracer, the measured ¹⁴⁷Sm / ¹⁴⁴Nd ratios for the international rock standard BCR-1 range from 0.1380 to 0.1382, suggesting reproducibility for ¹⁴⁷Sm / ¹⁴⁴Nd of ~ ± 0.1% for real rock powders. The value of ¹⁴⁷Sm / ¹⁴⁴Nd determined for BCR-1 is within the range of reported literature values by isotope dilution methods. Isotopic

ratios of Sm and Nd were measured on a subset of whole-rock powders. More information on the procedure, accuracy and precision of ACTLABS ICP-MS analysis for whole rock and Sm-Nd isotopic analyses can be found at www.actlabs.com.

S1.3 LA-ICP-MS U-Pb geochronology

Hand-picked zircons were annealed in a muffle furnace at 1000 degrees for 48 hours before being mounted in a 1 inch epoxy puck and polished to expose the center of the grains. Zircon grains have then been image on a imaged on a Hitachi S-3400 Variable Pressure SEM using a Centaurus cathodoluminescence (CL) detector at an accelerating voltage of 20 kV to guide the laser spot location. U-Pb analysis was conducted using a Nu Attom single collector mass spectrometer coupled with a Photon Machines G2 193nm excimer laser. The analytical procedures generally followed those outlined in Perrot et al. (2017), with some modifications. Notably, 3 ml/min of N₂ was introduced before the torch to reduce oxide formation in the plasma. Additionally, the mass spectrometer's sensitivity was optimized using U from a NIST610 glass, and gas flows were adjusted to achieve a U/Th ratio of 1 and a Th/ThO ratio of 1.10⁻³ for the NIST glass.

We used 91500 (Wiedenbeck et al., 1995) as the primary reference material for the correction of all the U-Pb ratios, while Plešovice (Sláma et al., 2008; Widmann et al., 2019), OG1 (Stern et al., 2009), R33 (Black et al., 2004) were analysed as a secondary reference material for quality control and validation purposes. Iolite 4 software was used to process the data and for down-hole fractionation correction. Measurements were conducted using a sample-reference material bracketing approach, with packages of 15 unknowns bracketed by 2 primary reference analysis and at least one analysis of the secondary reference grains. Analyses were conducted over 2 sessions, for each of the sessions, the repeated analyses of the secondary reference materials produced ages within 2 σ of their respective published ages. All data were processed in Iolite v4 using the laser log file and the U-Pb Geochronology data reduction scheme (DRS) (Paton et al., 2011; Petrus and Kamber, 2012) using an exponential equation to correct for downhole fractionation. Analyses containing detectable 204Pb were removed before data reduction, and no common Pb correction has been applied to the data. After processing the raw data in Iolite v4, Isoplot R (Vermeesch, 2018) was used. For filtering the data, we applied a distance-to-concordia filter, retaining only analyses with 95–105% concordance, prior to generating concordia diagrams. Weighted mean ages were obtained using the ‘exclude outliers’ function in Isoplot R. Ages calculated from the secondary reference material are summarized in Table S2.

Laboratory and Sample Preparation	
Laboratory name	Geotop, University of Quebec in Montreal
Sample type/mineral	Magmatic and detrital zircons
Sample preparation	Conventional mineral separation, 1 inch resin mount, 1 μ m polish to finish
Imaging	Centaurus, Hitachi S-3400N SEM
Laser ablation system	
Make, Model & type	Photon-machines G2
Ablation cell & volume	Helex, 2-volume cells
Laser wavelength (nm)	193 nm
Pulse width (ns)	4 ns
Fluence (J.cm ⁻²)	3.18 J.cm ⁻²
Repetition rate (Hz)	6 Hz

Ablation duration (secs)	30 secs
Ablation pit depth / ablation rate	Not available
Spot diameter (μm)	30 μm
Sampling mode / pattern	Static spot ablation n
Carrier gas	100% He in the cell
Cell carrier gas flow (l/min)	0.7 l/min He in the 1 st volume cell 0.5/min He in the 2 nd volume cell
ICP-MS Instrument	
Make, Model & type	ICP-MS (Attom, Nu Instruments)
Sample introduction	Ablation aerosol from laser to torch
RF power (W)	1300W
Make-up gas flow (l/min)	0.3 L/min Ar mixed along the sample transport line to the torch 3 ml/min N2 also added before torch
Detection system	single ion counter
Masses measured	202, 204, 206, 207, 208, 232, 235, 238.
Integration time per peak/dwell times (ms)	500ms for each isotope
Total integration time per output datapoint (secs)	~0.9secs
'Sensitivity' as useful yield (% , element)	0.4% U (NIST610 = 500ppm, #atoms sampled: 500ppm*85um*3Hz*3J/cm ² , #ions detected: >25 mcps)
IC Dead time (ns)	25 ns
Data Processing	
Gas blank	15 second on-peak zero subtracted
Calibration strategy	91500 used as primary reference material
Reference Material info	91500 (Wiedenbeck et al. 1995)
Data processing package used / Correction for LIEF	Iolite4 and IsoplotR softwares. laser-induced elemental fractionation correction assumes reference material and samples behave identically.
Mass discrimination	N/A - Down-hole effect with iolite.
Common-Pb correction, composition and uncertainty	No common-Pb correction applied to the data.
Uncertainty level & propagation	Ages are quoted at 1s absolute, propagation is by quadratic addition. Reproducibility and age uncertainty of reference material are propagated where appropriate.
Quality control / Validation	Plesovice, OG1, R33

Table S5 : Data reporting table for LA-ICP-MS U-Pb analyses

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