

Supplementary Information 5 – ANALYTICAL METHODS

Whole rock geochemistry (Data Table in Supplementary information Item 1)

Same as methods used for Morris et al. (2019).

Major and trace element compositions of 132 whole-rock samples were obtained via X-ray fluorescence spectrometry (XRF) and inductively coupled plasma mass spectrometry (ICP-MS) at the Washington State University (WSU) GeoAnalytical Laboratory. Sample preparation for major and trace element chemistry was conducted at Western Washington University (WWU) and WSU and UC Davis. Lithium tetraborate fused glass beads were prepared by powdering fresh rock chips following the methods of [Knaack et al. \(1994\)](#), [Johnson et al. \(1999\)](#), and [Steenberg et al. \(2017\)](#).

Analysis by XRF measured 10 major element oxides (SiO₂, TiO₂, Al₂O₃, FeO_{total}, MnO, MgO, CaO, Na₂O, K₂O, and P₂O₅) and 13 trace elements (Sc, V, Ni, Cr, Ba, Sr, Zr, Y, Rb, Nb, Ga, Cu, and Zn). Analysis by ICP-MS provided results for 14 rare earth elements (REE), as well as Ba, Th, Nb, Y, Hf, Ta, U, Pb, Rb, Cs, Sr, Sc, and Zr. Data accuracy was estimated by the GeoAnalytical Laboratory at WSU by analyzing repeat samples and certified reference materials (GeoPT certification samples for XRF, consensus GeoReM values for ICP-MS) that were run within the sample stream.

Maximum measured differences (in wt %) for accuracy between known values and WSU results for XRF-analyzed major elements are: <0.2% for SiO₂ and FeO_{total}; <0.07% for MgO, Al₂O₃, CaO, Na₂O, and K₂O; and <0.01% for TiO₂, MnO, and P₂O₅. Trace elements analyzed and reported by XRF include Zr and Rb, which are accurate to 3.0 and 1.1 ppm, respectively. Certified reference materials and GeoPT certification samples used to determine analytical accuracy (i.e. slopes of measured concentration versus certified concentration) produced linear regressions of >0.99 for all reported XRF analyses (major elements, Zr, and Rb). Maximum measured differences (in ppm) for accuracy between known values and WSU results for ICP-MS-analyzed trace elements are: <30ppm for Ba; ≤10ppm for Sr and Zr; ≤2ppm for Rb, Sc, and Y; ≤1ppm for Ce, Nd, and Dy; ≤0.5ppm for La, Pr, Sm, Eu, Gd, Tb, Ho, Er, Yb, Th, Nb, Hf, and Pb; and ≤0.1ppm for Tm, Lu, Ta, U, and Cs. Precision estimates measured between repeat samples at WSU were 2_5%.

Twenty-four samples, representative of each lithological unit, were analyzed for Sr, Nd, and Pb isotope ratios. Least altered samples were chosen based on thin section petrography. Approximately 0.5–0.7 g of rock powder was prepared at WWU and UCD using a silica mortar and pestle, which was decontaminated between samples. Powders were submitted to the University of Washington where column chemistry was completed on all the samples prior to analysis. Analyses were completed using a Nu multi-collector ICP-MS at the University of Washington as per analytical methods described by [Gaffney et al. \(2007\)](#), [Harkins et al. \(2008\)](#), and [Brach-Papa et al. \(2009\)](#). The following standards were used to normalize measured isotopic ratios: NBS 987 for ⁸⁷Sr/⁸⁶Sr (0.710240), La Jolla for ¹⁴³Nd/¹⁴⁴Nd (0.511843), and NIST-981 for ²⁰⁸Pb/²⁰⁴Pb (36.721), ²⁰⁷Pb/²⁰⁴Pb (15.491), and ²⁰⁶Pb/²⁰⁴Pb (16.937). The external reproducibility at ±2σ for samples analyzed are Nd = ±30ppm; Sr = ±40ppm; and Pb = ±125, 150, and 200 ppm for

$^{206}\text{Pb}/^{204}\text{Pb}$, $^{207}\text{Pb}/^{204}\text{Pb}$ and $^{208}\text{Pb}/^{204}\text{Pb}$, respectively.

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U-Pb zircon geochronology (Data Table in Supplementary information Item 2)

Lu-Hf Isotopic Analysis of Zircons - Laser Ablation ICPMS (University of Arizona)

Hf isotopic analyses were conducted on grains already dated by U-Pb at UCLA, using a Nu Instruments HR multi-collector ICPMS connected to a Photon Machines Analyte G2 excimer laser at the Arizona Laser Center at the University of Arizona, following established analytical protocols described in Gehrels and Pecha (2014). Instrument settings were optimized for laser ablation analysis, and in-run analyses of seven different natural zircon standards (Mud Tank, Temora, FC52, R33, Temora, Plesovice, and Sri Lanka) were analysed and monitored every 15–20 unknowns.

Ablation with a laser beam diameter of 40 μm targeted zircon domains directly over the earlier U–Pb analysis craters. All measurements were made in static mode using Faraday collectors equipped with $3 \times 10^{11} \Omega$ resistors. Each acquisition consisted of one 40-s integration for backgrounds (on peak with laser idle) followed by 60 one-s integrations

with the laser firing. A 30 s delay between laser analyses provided adequate time to ensure the previous sample was completely purged from the collector block. The laser was run in constant energy mode at with an output of 7.5 mJ (fluence ~ 8 J/cm²) and a pulse rate of 7 Hz. Isotope fractionation (β) was accounted for by incorporating the method of Woodhead et al. (2004) with β Hf determined from the measured $^{179}\text{Hf}/^{177}\text{Hf}$, and β Yb from the measured $^{173}\text{Yb}/^{171}\text{Yb}$ (except for very low Yb signals); β Lu is assumed to be the same as β Yb; and an exponential formula is used for fractionation correction. Yb and Lu interferences are corrected by measurement of $^{176}\text{Yb}/^{171}\text{Yb}$ and $^{176}\text{Lu}/^{175}\text{Lu}$ (respectively), as advocated by Woodhead et al. (2004). Isotope ratios of $^{179}\text{Hf}/^{177}\text{Hf} = 0.73250$ (Patchett and Tatsumoto, 1981); $^{173}\text{Yb}/^{171}\text{Yb} = 1.132338$ (Vervoort et al., 2004); $^{176}\text{Yb}/^{171}\text{Yb} = 0.901691$ (Vervoort et al., 2004); Amelin and Davis, 2005; $^{176}\text{Lu}/^{175}\text{Lu} = 0.02653$ (Patchett, 1983) were used and all corrections are done line-by-line. Data reduction protocols account for all standards and unknowns analysed during an entire session, and the β Hf and β Yb cut-offs were determined by monitoring the average offset of the standards from their known values resulting in a final standard offset of 0.0000001. $^{176}\text{Hf}/^{177}\text{Hf}$ uncertainty on the standard analyses for the entire session was determined to be 0.000037 (2σ).

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