

Supplementary information for:**EVIDENCE FOR PROTRACTED HALIP MAGMATISM IN THE CENTRAL SVERDRUP BASIN FROM STRATIGRAPHY, GEOCHRONOLOGY, AND PALEODEPTHS OF SAUCER-SHAPED SILLS**

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GEOCHEMISTRY**Analytical methods for mineral and glass analyses**

Minerals were analyzed using a 5 micron beam at 15kV and 20nA. A 20 s counting time was used for the peak, with 10 s for the background. For glass analyses, conditions were initially set as they were for the mineral analyses. However, count rates for Na₂O and K₂O dropped rapidly during analysis due to volatilization. Six glass analyses were redone using a lower setting of 10 nA and shorter count times of 10 sec to minimize this effect. The two sets of data were compared and regressed one against the other, and the initial set of glass analyses were corrected using this regression. Despite this correction, values of alkalis in glasses probably represent minima. Totals are typically low (82-96%), suggesting high volatile contents. Four types of glass were detected.

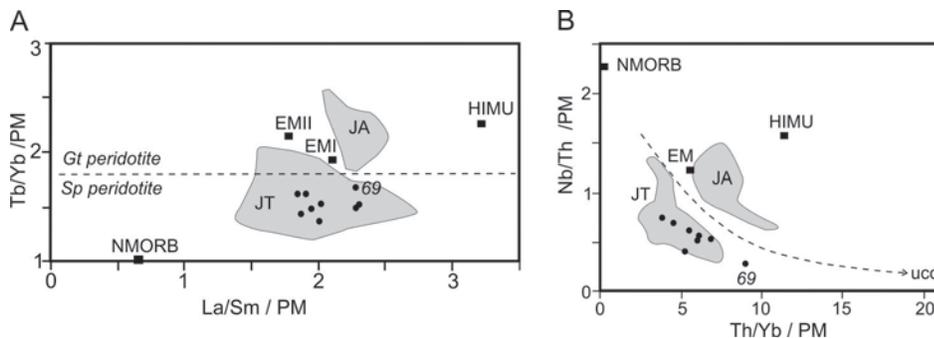


Figure DR1. (a) Tb/Yb vs La/Sm and (b) Nb/Th vs Th/Yb, all normalized to Primitive Mantle (PM) of Sun and McDonough (1989). Fields marked JA and JT are alkaline and tholeiitic HALIP data (respectively) from Jowitt et al. (2014). N-MORB and mantle components (black squares)

are also from Jowitt et al. (2014). Black dots are HALIP data from this study. 69 is sample 11EP069A1.

GEOCHRONOLOGY - U-PB ANALYTICAL TECHNIQUES

Analytical Methods - University of British Columbia

Chemical Abrasion Thermal Ionisation Mass spectrometry

CA-TIMS procedures described here are modified from Mundil et al. (2004), Mattinson (2005), and Scoates and Friedman (2008). After rock samples have undergone standard mineral separation procedures zircons are handpicked in alcohol. The clearest, crack- and inclusion-free grains are selected, photographed and then annealed in quartz glass crucibles at 900°C for 60 hours. Annealed grains are transferred into 3.5 mL PFA screwtop beakers, ultrapure HF (up to 50% strength, 500 µL) and HNO₃ (up to 14 N, 50 µL) are added and caps are closed finger tight. The beakers are placed in 125 mL PTFE liners (up to four per liner) and about 2 mL HF and 0.2 mL HNO₃ of the same strength as acid within beakers containing samples are added to the liners. The liners are then slid into stainless steel Parr™ high pressure dissolution devices, which are sealed and brought up to a maximum of 200°C for 8-16 hours (typically 175°C for 12 hours). Beakers are removed from liners and zircon is separated from leachate. Zircons are rinsed with >18 MΩ.cm water and subboiled acetone. Then 2 mL of subboiled 6N HCl is added and beakers are set on a hotplate at 80°-130°C for 30 minutes and again rinsed with water and acetone. Masses are estimated from the dimensions (volumes) of grains. Single grains are transferred into clean 300 µL PFA microcapsules (crucibles), and 50 µL 50% HF and 5 µL 14 N HNO₃ are added. Each is spiked with a ²³³⁻²³⁵U-²⁰⁵Pb tracer solution (EARTHTIME ET535), capped and again placed in a Parr liner (8-15 microcapsules per liner). HF and nitric acids in a 10:1 ratio, respectively, are added to the liner, which is then placed in a Parr high pressure device and dissolution is achieved at 240°C for 40 hours. The resulting solutions are dried on a hotplate at 130°C, 50 µL 6N HCl is added to microcapsules and fluorides are dissolved in high pressure Parr devices for 12 hours at 210°C. HCl solutions are transferred into clean 7 mL PFA beakers and dried with 2 µL of 0.5 N H₃PO₄. Samples are loaded onto degassed, zone-refined Re filaments in 2 µL of silicic acid emitter (Gerstenberger and Haase, 1997).

Isotopic ratios are measured using a modified single collector VG-54R or 354S (with Sector 54 electronics) thermal ionization mass spectrometer equipped with analogue Daly

photomultipliers. Measurements are done in peak-switching mode on the Daly detector. Analytical blanks are 0.2 pg for U and for Pb up to 2.0 pg. U fractionation was determined directly on individual runs using the $^{233-235}\text{U}$ tracer, and Pb isotopic ratios were corrected for fractionation of 0.23%/amu, based on replicate analyses of the NBS-982 Pb reference material and the values recommended by Thirlwall (2000). Data reduction employed the excel based program of Schmitz and Schoene (2007). Standard concordia diagrams were constructed and regression intercepts, weighted averages calculated with Isoplot (Ludwig, 2003). Unless otherwise noted, all errors are quoted at the 2 sigma or 95% level of confidence. Isotopic dates are calculated using the uranium decay constants $\lambda_{238}=1.55125 \times 10^{-10} \text{ y}^{-1}$ and $\lambda_{235}=9.8485 \times 10^{-10} \text{ y}^{-1}$ (Jaffey et al., 1971). EARTHTIME U-Pb synthetic solutions are analysed on an on-going basis to monitor the accuracy of results.

Analytical Methods – Geological Survey of Canada

Heavy mineral concentrates were prepared by standard techniques (crushing, grinding, WilfleyTM table, heavy liquids), and sorted by magnetic susceptibility using a FrantzTM isodynamic separator.

Thermal Ionisation Analyses

Isotopic and U-Pb compositional data were determined by isotope dilution thermal ionization mass spectrometry at the Geochronology laboratory, Geological Survey of Canada. Sample dissolution and chemical methods are described in Parrish et al. (1987). Individual crystals were selected under binocular microscope to avoid inclusions and other imperfections, annealed at 1000°C and leached in HF-HNO₃ following procedures modified from Mattinson (2005), spiked with a mixed ^{205}Pb - ^{233}U - ^{235}U tracer solution calibrated to $\pm 0.1\%$ against a gravimetric solution, and dissolved in high-pressure bombs in HF-HNO₃. Data reduction and error propagation follow methods outlined in Roddick (1987). U and Pb isotopic ratios were measured using a Triton mass spectrometer operated in either static multi-collection mode or using a secondary electron multiplier and ion counting system. The ^{205}Pb , ^{206}Pb , ^{207}Pb , and ^{208}Pb isotopes were measured simultaneously in Faraday collectors, with ^{204}Pb in an axial secondary electron multiplier. Faraday-multiplier gain was monitored and corrected by peak jumping ^{205}Pb into the axial cup. A Pb mass fractionation correction of $0.1 \pm 0.04\%$ /amu was applied as determined by replicate analyses of the NBS981 standard. U fractionation was corrected using the ^{233}U - ^{235}U double spike and was typically in the range of 0.12%/amu. Deadtime for the ion

counting system was determined by replicate analyses of the NBS982 solution. Accuracy and reproducibility were monitored by analyses of the GSC standard 6266 with a $^{206}\text{Pb}/^{238}\text{U}$ ratio of 0.0963.

SHRIMP Analyses

SHRIMP analytical procedures followed those described by Stern (1997). Briefly, zircons were cast in 2.5 cm diameter epoxy mounts along with fragments of the GSC laboratory standard zircon (z6266, with $^{206}\text{Pb}/^{238}\text{U}$ age = 559 Ma). The mid-sections of the zircons were exposed using 9, 6, and 1 μm diamond compound, and the internal features of the zircons (such as zoning, structures, alteration, etc.) were characterized in back-scattered electron mode (BSE) utilizing a Zeiss Evo 50 scanning electron microscope. Mount surfaces were evaporatively coated with 10 nm of high purity Au. Analyses were conducted using an $^{16}\text{O}^-$ primary beam, projected onto the zircons at 10 kV. The sputtered area used for analysis was ca. 25 μm in diameter with a beam current of ca. 8 nA. The count rates at ten masses including background were sequentially measured over 5 scans with a single electron multiplier and a pulse counting system with deadtime of 23 ns. Off-line data processing was accomplished using SQUID ver 2.2 and utilized the Temora 2 standard with an accepted age of 416.8 Ma (Black et al., 2004). The 1σ external errors of $^{206}\text{Pb}/^{238}\text{U}$ ratios reported in the data table incorporate a $\pm 1.3\%$ error in calibrating the standard zircon. No fractionation correction was applied to the Pb-isotope data; the common Pb correction utilized the Pb composition of the surface blank (Stern, 1997). U concentration was calculated based on a value of 910 ppm for the 6266 standard. Isoplot v. 3.00 (Ludwig, 2003) was used to generate concordia plots and calculate weighted means. The error ellipses on the concordia diagrams, and the weighted mean errors are reported at 2σ .

Analyses of a secondary internal zircon standard (z9910) were interspersed between the sample analyses to verify the accuracy of the U-Pb calibration. This zircon has a $^{206}\text{Pb}/^{238}\text{U}$ age of $441 \pm \text{Ma}$. Using the calibration defined by the Temora standard, the weighted mean $^{206}\text{Pb}/^{238}\text{U}$ age of thirteen SHRIMP analyses of 9910 zircon is $443.1 \pm 4.6 \text{ Ma}$ (MSWD = 1.4) within error of the accepted age.

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