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GSA Data Repository Item 2018273

ANALYTICAL METHODS

LA-ICPMS U-Pb Zircon Geochronology

U-Pb isotopic ratios for zircon from 13 samples in the northeast Brooks Range basinal succession of Alaska and Yukon were analyzed by laser ablation-inductively coupled mass spectrometry (LA-ICPMS) at the University of Arizona LaserChron Facility following methods outlined in Gehrels et al. (2006, 2008) and Gehrels and Pecha (2014). Zircon from our samples were ablated with a Photon Machines Analyte G2 excimer laser with a HelEx ablation cell using a spot diameter of 20 to 30 μm. Helium carrier gas carried ablated material into the plasma source of either an Element2 high resolution-ICPMS (HR-ICPMS) or a Nu Instruments HR-ICPMS, which sequences rapidly through U, Th, and Pb isotopes.

For samples analyzed with the Element2, signal intensities were measured with a secondary electron multiplier (SEM) that operates in pulse counting mode for signals less than 50K cps, in both pulse-counting and analog mode for signals between 50K and 4M cps, and in analog mode above 4M cps. The calibration between pulse-counting and analog signals was determined line-by-line for signals between 50K and 4M cps, and was applied to 4M cps signals. Four intensities were determined and averaged for each isotope, with dwell times of 0.0052 seconds for 202, 0.0075 seconds for 204, 0.0202 seconds for 206, 0.0284 seconds for 207, 0.0026 seconds for 208, 0.0026 seconds for 232, and 0.0104 seconds for 238. The ablation pit for

these analyses is ~12 μm in depth using an energy density of ~5 J/cm^2, repetition rate of 8 hz, and an ablation time of 10 seconds. Sensitivity with these settings is approximately ~5,000 cps/ppm. Each analysis includes counting for 5 seconds with the laser off for backgrounds and 10 seconds with the laser firing for peak intensities, which are followed by a 20 second delay to purge the previous sample and save files. For samples analyzed with the Nu HR-ICPMS, all of the measurements were made in static mode, using Faraday detectors with 3x10^{11} ohm resistors for ^{238}U, ^{232}Th, ^{208}Pb-^{206}Pb, and discrete dynode ion counters for ^{204}Pb and ^{202}Hg. Ion yields for this instrument are ~0.8 mv per ppm, and each analysis consisted of one 15-second integration on peaks with the laser off (for backgrounds), 15 one-second integrations with the laser firing, and a 30 second delay to purge the previous sample and prepare for the next analysis.

Unknown analyses in the northeast Brooks Range sample set were bracketed by the Sri Lanka (^{206}Pb/^{238}U age of 563.2 ± 4.8 Ma, 2σ, Gehrels et al., 2008), R33 (^{206}Pb/^{238}U age of 420.53 ± 0.16 Ma, 2σ, Mattinson, 2010), and FC1 (^{207}Pb/^{206}Pb age of 1099.0 ± 0.6 Ma, 2σ, Paces and Miller, 1993) standard zircons to assess reproducibility, U concentration and Pb/U fractioniation corrections. ^{204}Hg interference with ^{204}Pb was accounted for measurement of ^{202}Hg during laser ablation and subtraction of ^{204}Hg according to the natural ^{202}Hg/^{204}Hg of 4.35. This Hg is correction is not significant for most analyses because Hg backgrounds are low at the Laserchron facility (generally ~150 cps at mass 204). Common Pb corrections are accomplished by using the Hg-corrected ^{204}Pb and assuming an initial Pb composition from Stacey and Kramers (1975). Uncertainties of 1.5 for ^{206}Pb/^{204}Pb and 0.3 for ^{207}Pb/^{204}Pb are applied to these compositional values based on the variation in Pb isotopic composition in modern crystalline rocks. More detailed information related to instrument setup, tuning, run parameters, standard-unknown bracketing, and data reduction followed that of Gehrels et al. (2006, 2008) and Gehrels

and Pecha (2014). For each analysis, the errors in determining $^{206}Pb/^{238}U$ and $^{206}Pb/^{204}Pb$ result in a measurement error of ~1-2% (at 2σ level) in the $^{206}Pb/^{238}U$ age. The errors in measurement of $^{206}Pb/^{207}Pb$ and $^{206}Pb/^{204}Pb$ also result in ~1-2% (at 2σ level) uncertainty in age for grains that are >1000 Ma, but are substantially larger for younger grains due to the low intensity of the ^{207}Pb signal. All of these data are presented in Table DR4.

Zircon Lu-Hf Isotopic Analysis

A subset of the detrital zircons from the northeast Brooks Range basinal succession were analyzed for Lu-Hf isotopic compositions using a Nu Instruments HR-ICPMS connected to a Photon Machines Analyte G2 excimer laser equipped with a HelEX cell at the Arizona LaserChron Center. In each analysis, a 40 μm diameter ablation site is centered over the previously excavated U-Pb analysis pit. The analytical routine consists of a 40 second on-peak background measurement, a 60 second laser ablation measurement, and a 15 second washout time. Using a typical laser effluence of ~5 J/cm^2 and pulse rate of 7 Hz, the ablation rate is ~0.8 microns per second. Unknown analyses were bracketed by reference standards every 20 spots, including R33, SL2, Plesovice, Temora-2, FC-52, 91500, and Mud Tank (Woodhead and Hergt 2005; Sláma et al. 2008; Bahlburg et al. 2010; Vervoort 2010). These standards are included with unknowns on the same epoxy mounts. Instrument setup, tuning, run parameters, standard-unknown bracketing, and data reduction followed that of Gehrels and Pecha (2014). All of these data are presented in Table DR5.

Muscovite ^{40}Ar-^{39}Ar Isotopic Analysis

Two samples were submitted to the Geochronology Laboratory at University of Alaska Fairbanks for $^{40}Ar/^{39}Ar$ analysis. The standard mineral MMhb-1 (Samson and Alexander, 1987) with an age of 523.2 ± 0.9 Ma (Spell and McDougall, 2003) was used to monitor neutron flux and eventually calculate the irradiation parameter, J. The samples and standards were wrapped in aluminum foil and loaded into aluminum cans of 2.5 cm diameter and 6 cm height. The samples were irradiated in an uranium-enriched research reactor at McMaster University in Hamilton, Ontario, for 20 to 150 megawatt-hours. Upon return from the reactor, the samples and standards were loaded into 2 mm diameter holes in a copper tray that was then loaded in an ultra-high vacuum extraction line. The standards were fused and the samples were heated and/or fused, using a 6-watt argon-ion laser following techniques described in York et al. (1981), Benowitz et al. (2014), and Martin et al. (2015). Argon purification was achieved using a liquid nitrogen cold trap and a SAES Zr-Al getter at 400° C. The samples were then analyzed in a VG-3600 Isotopx mass spectrometer at the Geophysical Institute, University of Alaska Fairbanks.

Measured argon isotopes were corrected for system blank and mass discrimination, as well as calcium, potassium and chlorine interference reactions, following procedures outlined in McDougall and Harrison (1999). Typical full-system 8 min laser blank values (in moles) were generally 2×10^{-16} mol ^{40}Ar, 3 × 10218 mol ^{39}Ar, 9×10^{-18} mol ^{38}Ar and 2×10^{-18} mol ^{36}Ar, which are 10–50 times smaller than the sample/standard volume fractions. Correction factors for nucleogenic interferences during irradiation were determined from irradiated CaF_2 and K_2SO_4 as follows: $(^{39}Ar/^{37}Ar)$ Ca = 7.06×10^{-4}, $(^{36}Ar/^{37}Ar)$ Ca = 2.79×10^{-4} and $(^{40}Ar/^{39}Ar)$ K = 0.0297. Mass discrimination was monitored by running calibrated air shots, which was 0.8% per mass unit during these experiments. Calibration measurements were made on a weekly to monthly

basis to check for changes in mass discrimination with no significant variation during these intervals.

The stepwise $^{40}Ar/^{39}Ar$ results for each sample are presented in Table DR6 with all ages quoted to the ± 1 sigma level and calculated using the constants of Renne et al. (2010). The integrated age is the age given by the total gas measured and is equivalent to a potassium-argon (K-Ar) age. A plateau age is provided when three or more consecutive gas fractions represent at least 60% of the total gas release and are within two standard deviations of each other (Mean Square Weighted Deviation less than 2.5; see Ludwig, 2012). Both samples 15BJ10 and 15BJ11 were analyzed, in addition to the stepwise techniques, with single-grain fusion $^{40}Ar/^{39}Ar$ geochronology on 15 grains, respectively, to investigate intra-sample age variability. Argon was extracted by slowly increasing the power of a focused laser until total fusion of the target muscovite grain. These results are also reported in Table DR6.

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