Supplemental Item S6 – Analytical methods

$^{40}Ar/^{39}Ar$ Geochronology

Sand- and cobble-sized volcanic clasts were analyzed for $^{40}Ar/^{39}Ar$ ages at the University of Alaska Fairbanks Geochronology lab. Cobble clasts were crushed using a stainless-steel mortar and pestle, then sieved using 500- to 1000-micron sieves. Sand-sized volcanic-lithic grains were sieved to the 500- to 1000-micron fraction and separated by hand-picking grains under a light microscope. Special care was taken throughout sample processing to avoid biasing the final separate by size, shape, color, degree of rounding, etc. However, only relatively fresh, unaltered grains were chosen for analysis. Samples were then washed and sonically bathed in deionized water to remove and decant clay particles. Samples were then dried in an oven overnight at ~60°C and then grains were hand-picked under an optical microscope to select phenocryst-free homogenous groundmass chips and mineral separates of biotite, hornblende, and plagioclase. The monitor mineral TCR-2 with an age of 28.619 Ma (Renne et al., 2010) was used to monitor neutron flux and calculate the irradiation parameter (J) for all samples. The samples and standards were wrapped in aluminum foil and loaded into aluminum cans of 2.5 cm diameter and 6 cm height. Mineral separates were sent to the uranium enriched research reactor of McMaster University (Hamilton, Ontario, Canada) and irradiated for 20 megawatt-hours. After irradiation, samples were loaded into 2 mm diameter holes in a copper tray and loaded in an ultra-high vacuum extraction line. The monitors were fused, and samples heated, using a 6-watt argon-ion laser following the technique described in York et al. (1981), Layer et al. (1987), and Benowitz et al. (2014). Argon purification was achieved using a liquid nitrogen cold trap and a SAES Zr-19 Al getter at 400° C. The samples were analyzed in a VG-3600 mass spectrometer. The argon isotopes measured 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 x 10-18 mol ^{40}Ar, 3 × 10-18 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. The mass discrimination during these experiments was 0.8% per mass unit. The majority of samples were analyzed as single-grain or multi-grain fusion analysis approach. We developed a procedure to limit the effects of alteration by degassing each sample at 0.5 watts for 60 seconds, and the released gas was not measured and pumped off for time efficiency and increased throughput. The results have a single-grain and/or multi-grain precision of 1%. Two different batches were dated from the Cheslina River sand sample (and results were combined); 1000 to 1200 micron sized grains yielded better analytical returns than 500 to 1000 micron sized grains owing to the dominance of young (<1 Ma) volcanic bedrock with limited radiogenic ^{40}Ar in the watershed. Samples selected for further geochronology analysis were step-heated from relatively low temperatures until reaching fusion temperatures using the 6-watt argon-ion laser (Śliwiński et al., 2012; Benowitz et al., 2019). Refer to Repository Items DR7–11 for full $^{40}Ar/^{39}Ar$ analytical results.

U-Pb Zircon Geochronology

Detrital zircons were analyzed for U-Pb ages at the University of Arizona LaserChron Center. Zircon grains were separated from unconsolidated sand using standard mineral separation techniques. Special care was taken throughout sample processing to avoid biasing the final separate of zircon grains by size, shape, color, and degree of rounding. Grains were mounted in a 1" epoxy mount alongside fragments of standard zircons. Mounts were polished to a 1 μm finish, imaged using cathodoluminesence (CL) and/or backscatter electron (BSE) methods and cleaned with a 2% HNO_3 and 1% HCl solution prior to isotopic analysis. CL and BSE images were used to select analytical points, avoiding complex internal structures and fractures. U-Pb geochronologic analyses of zircon grains were conducted by laser ablation multicollector inductively coupled plasma mass spectrometry. Zircon crystals were randomly selected for analysis, irrespective of size, shape, color, and degree of rounding; grains with visible cracks or inclusions were avoided. After every fourth or fifth measurement of an unknown zircon, analyses were calibrated against a measurement of a zircon standard (Sri Lanka; 563 ± 3.2 Ma; Gehrels et al., 2008). $^{207}Pb/^{235}U$ and $^{206}Pb/^{238}U$ ratios and apparent ages were calculated using the Isoplot software program (Ludwig, 2003). The data were filtered according to precision (typically 10% cutoff) and discordance (typically 30%) and then plotted on Pb/U concordia diagrams. Refer to Supplemental Item DR12 for full U-Pb analytical results.

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