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Front cover:
Bedded rhyolite tuffs on Mount Savona, southeast of Savona BC. Location of Sample 20N-30.

Back cover:
Zoned sanidine phenocryst, in a felsic groundmass with microlites of feldspar, amphibole, and mica in devitrified ash. Sample 228N-59; cross polarized light; width of field of view is 1.0 mm.

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Abstract

Whole-rock major, trace, rare-earth element, and radiogenic isotope (Sr, Nd) geochemical data and high-precision geochronologic data support ongoing studies of volcanic rocks in southern British Columbia. These rocks represent part of a Late Paleocene to Early Eocene large igneous province. New geochemistry and isotope geochemistry data are from volcanic rocks of the Kamloops Group near Kamloops and from the Penticton Group near Rock Creek. Seven new U-Pb zircon results, obtained by the CA-ID-TIMS method, provide high-precision Eocene crystallization ages for felsic volcanic rocks. A volcanic rock collected from near the McAbee fossil beds east of Cache Creek, previously assumed to be Eocene, yielded a Triassic U-Pb zircon date, indicating that it is from the Nicola Group.

Keywords: Geochronology, geochemistry, Eocene, Kamloops Group, Penticton Group, CA-ID-TIMS, large igneous province

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1. Introduction

Eocene volcanic rocks in southern British Columbia form discontinuous belts of graben-fill volcanic and lesser sedimentary rocks. These rocks form part of a previously underappreciated Late Paleocene to Early Eocene large igneous province in the Cordilleran orogen of northwest North America (Fig. 1). Presented herein (Appendix 1 in BCGS_GF2026-10.zip) are new whole-rock major, trace, rare earth element, and radiogenic isotope (Sr, Nd) geochemical data from samples taken from the Kamloops Group (updated from Van Wagoner et al., 2021) and the Penticton Group (Kettle River and Marron formations; Höy et al., 2022). To better understand the timing of volcanism, we also present (Appendix 2) eight new high-precision U-Pb zircon ages determined using chemical abrasion isotope dilution thermal ionization mass spectrometry (CA-ID-TIMS) from samples collected between 2019 and 2021 by N. Van Wagoner, J. Thomson-Gladish, and L. Ootes (Fig. 2).

2. Whole rock geochemistry

2.1. Major and trace element geochemistry

Sample preparation and geochemical procedures follow those in Van Wagoner et al. (2021) and are summarized here. Samples were prepared as crush and pulps at the British Columbia Geological Survey; weathered surfaces were removed with a rock saw then crushed and split and unaltered pieces selected. About 100 grams of each crushed and split sample was submitted to Activation Laboratories (Actlabs; Ancaster, Ontario) for whole rock major and trace element analysis. At Actlabs the samples were further crushed to pass a 2 mm screen, mechanically split using a riffle splitter, and pulverized using a mild steel pulverizer to 95% passing 105 µm (code RX1). The pulp was dissolved and lithium metaborate/tetraborate fusion was performed to produce a molten bead, which was rapidly digested in a weak solution of nitric acid. Major elements were determined by inductively coupled plasma optical emission spectroscopy (ICP-OES), and trace element concentrations were measured using inductively coupled plasma mass spectroscopy (ICP-MS; Code 4Lithores). Measurement accuracy was determined using certified standards provided by Actlabs. In addition, blind in-house standards provided by the British

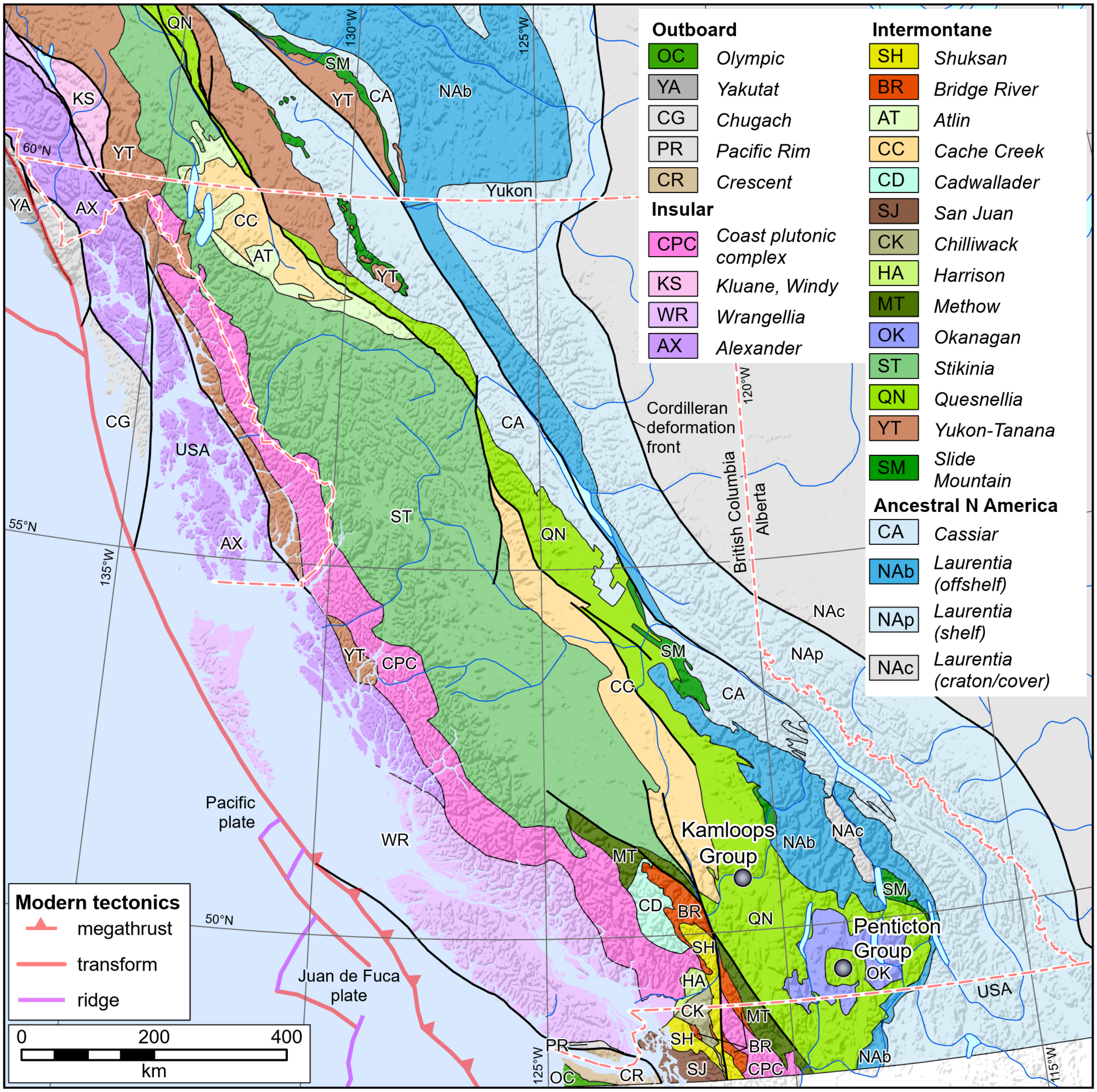
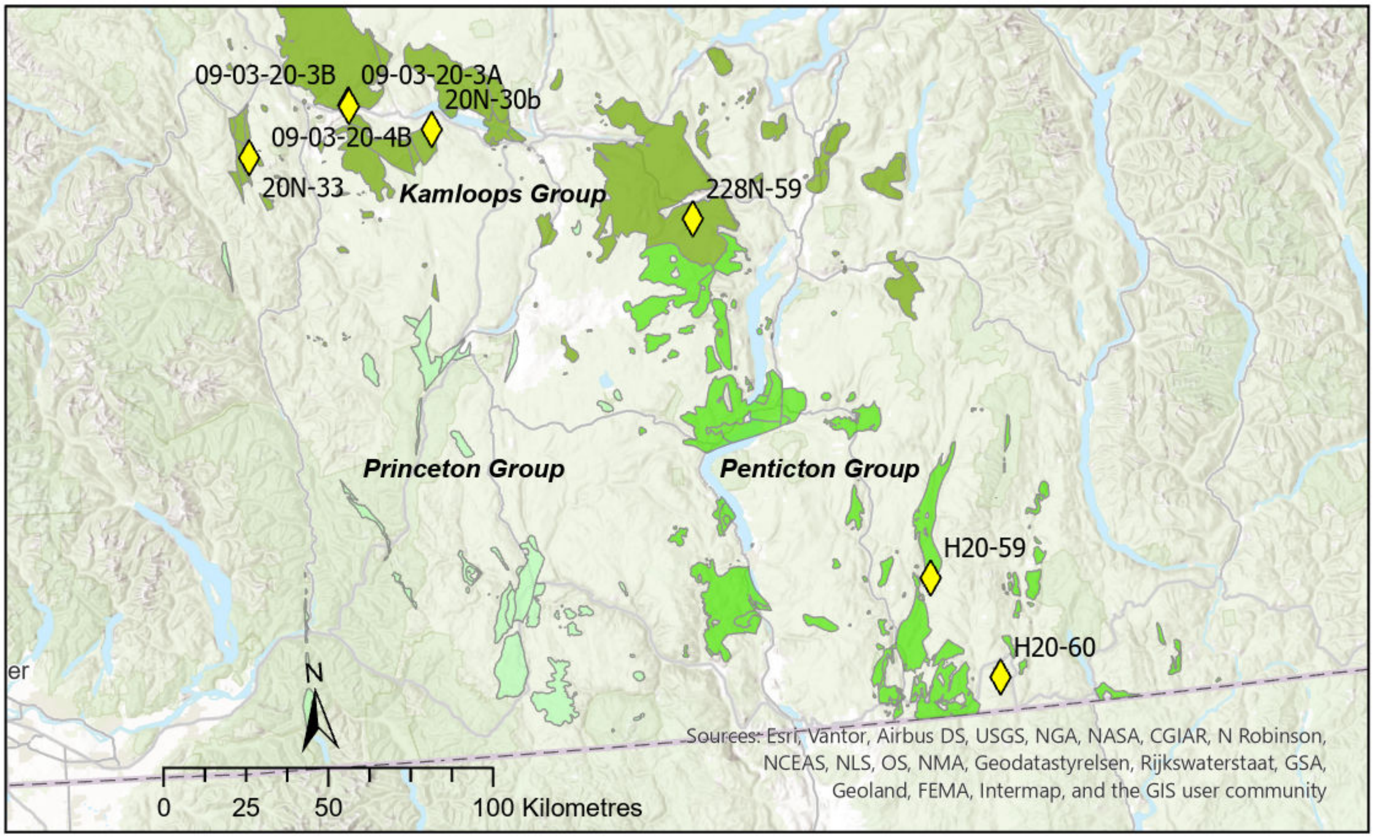


Fig. 1. Location of Eocene volcanic rocks discussed in this study. Terrane boundaries after Colpron (2020).

Columbia Geological Survey were analyzed with the unknowns (Van Wagoner et al., 2021). To quantify accuracy the percent relative difference between the measured value of the reference standards and the certified value were calculated. Major element accuracy is generally within 5% error, and typically less than 2%. Major elements MnO, K_2O and P_2O_5 have the greatest error (up to 10%) due to their low concentrations. The trace element and rare earth element (REE) accuracy is typically within 10% error with a few exceptions. Generally, where the error exceeds 10% the elements are in low concentrations (<10 ppm). To determine precision, the relative standard deviations (%RSD) were calculated using the duplicate reference material. Major element precision based on duplicate measurements was <7% RSD. Trace element measurements were within 11% RSD in most cases. Where it exceeds 11% the elements are in low concentrations.

Results of whole rock major and trace element geochemistry are included in Appendix 1.



Sources: Esri, Vantor, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap, and the GIS user community

Fig. 2. Location of Eocene volcanic rocks dated in this study by the CA-ID-TIMS U-Pb zircon method. Coloured polygons: dark green=Kamloops Group; light green=Penticton Group; medium green=Penticton Group

2.2. Whole rock radiogenic isotopic data

Eocene volcanic samples were selected for whole rock radiogenic isotope analysis (Nd, Sr). Nine geochemical pulps from the Kamloops Group and six from the Penticton Group were sent to the Isotope Geochronology and Geochemistry Research Centre (IGGRC), Carleton University, Ottawa, Ontario. There they were prepared in a clean lab and measured for the Sr and Nd isotope ratios using two Thermo-Finnigan mass spectrometers; a Neptune multi-collector inductively coupled plasma mass spectrometer (MC-ICP-MS) and a Triton thermal ionization mass spectrometer (TIMS). Sample powders between 50 and 150 milligrams were dissolved in the mixture of concentrated HF and HNO_3 on the hotplate at 130°C for 72 hours before were evaporated to dryness; the residues then were re-dissolved in 7M HNO_3 and 6M HCl. Strontium and Nd were sequentially separated following the ion exchange column procedures described in Cousens (1996), except that Nd was separated using the pre-slurry-packed 2ml LN-resin columns (Eichrom Technologies LLC, USA). In addition, a Sr-Spec resin (Eichrom Technologies, LLC, USA) column procedure was used to clean the Sr fractions of those samples for which the Sr isotopes were measured using the Neptune MC-ICP-MS.

Neodymium and Sr isotope ratios were measured using both MC-ICP-MS and TIMS. Sr and Nd isotopic ratios were normalized against $^{86}Sr/^{88}Sr=0.1194$ and $^{146}Nd/^{144}Nd=0.7219$, respectively. $^{143}Nd/^{144}Nd$ ratios measured by the Neptune MC-ICP-MS were further normalized for the offsets using the bracketing JNdi-1 average values against an IGGRC Triton TIMS JNdi-1 average value of 0.512100. For a period of 12 to 18 months, measurements of NBS987 and USGS standard BCR-2 with Neptune MC-ICP-MS and Triton TIMS yield average $^{87}Sr/^{86}Sr$ ratios, 0.710238±0.000024 (2SD, n=86) and 0.705009±0.000053 (2SD, n=7), and 0.710242±0.000020 (2SD, n=45) and 0.704998±0.000018 (2SD, n=6), respectively; measurements of JNdi-1(Tanaka et al, 2000) and BCR-2 give $^{143}Nd/^{144}Nd$ ratios 0.512084±0.000010 (2SD, n=138) and 0.512626±0.000006 (2SD, n=4) with Neptune and 0.512100±0.000008 (2SD, n=49) 0.512623±0.000011 (n=7, 2SD) with Triton. The total procedure blanks are <250pg and <50 pg for Sr and Nd, respectively.

Results of whole rock radiogenic isotope geochemistry are included in Appendix 1.

3. U-Pb zircon geochronology

Samples for zircon U-Pb geochronology were crushed and mineral separates prepared at the University of British Columbia, Pacific Centre for Isotopic and Geochemical Research (UBC-PCIGR) and at the GEOTOP laboratory at Université du Québec à Montréal. Zircon crystals between 20-150 microns long were separated from hand samples by conventional density and magnetic methods. Unless otherwise stated, zircon selected for thermal ionization mass spectrometry

(TIMS) were chosen based on their pristine appearance and lack of transport features, for example double terminations, lack of rounding, and absence of cores or inclusions. Grains with long aspect ratios and melt channels in their centers were preferentially targeted.

3.1. U-Pb zircon geochronology at UBC-PCIGR

To avoid analyzing inherited zircon by the the chemical abrasion isotope dilution thermal ionization mass spectrometry (CA-ID-TIMS) method, three samples (20N-33b, H20-59, and H20-60) were initially tested by laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS; Appendix 2). The zircon in sample 228N-59 were too fine to mount for LA analysis.

3.1.1. LA-ICP-MS U-Pb zircon geochronology

Samples were processed at the UBC-PCIGR where the entire picked zircon separate was placed in a muffle furnace at 900°C for 60 hours in quartz beakers to anneal minor radiation damage. Following annealing, individual grains from all samples were hand-picked based on morphology, clarity, and the absence of inclusions and mounted in epoxy for imaging. After this, mounted grains of zircon were imaged for internal structure at the Electron Microbeam/X-Ray Diffraction Facility (EMXDF) at University of British Columbia using a Philips Xl-30 scanning electron microscope (SEM). Zircon grains were imaged using a Robinson cathodoluminescence (CL) detector, using a Bruker Quanta 200 energy-dispersion X-ray microanalysis system with XFlash 6010 SDD detector at a voltage of 15 kV. Trace element concentrations were determined in zircon by LA-ICP-MS at PCIGR using a Resonetics (now ASI) RESOlution M-50-LR Class I laser ablation system coupled to an Agilent 7700x quadrupole ICP-MS. For U-Pb geochronology in zircon, 91500 was used as the calibration standard and reference materials PL and Temora2 were monitored as secondary references for quality assurance and control. For trace elements in zircon, NIST 612 was used as the calibration standard and the average Zr contents (by sample) determined by electron microprobe were employed as an internal standard value for the unknowns. For a full overview of LA-ICP-MS analytical technique applied here see Ootes and Wall (2024).

3.1.2. High-precision CA-ID-TIMS U-Pb zircon geochronology

Four samples were selected for high-precision U-Pb zircon dating by the CA-ID-TIMS (modified after Mattinson, 2005) method at the University of British Columbia, Pacific Centre for Isotopic and Geochemical Research. Dates were obtained from U-Pb analyses of single zircon grains. Two samples (H20-59 and H20-60) were previously dated by the U-Pb zircon LA-ICPMS technique and additional information for these samples (descriptions and outcrop photographs) are in Höy et al. (2022). Zircon from these samples were retrieved from the UBC-PCIGR mineral separation archive for CA-ID-TIMS. Two other samples (20N-30b and 228N-59) were collected as part of this study.

For sample 20N-30b, zircon were first analyzed by LA-ICP-MS technique (n=25). This was not conducted on sample 228N-59 because of the small zircon size. Zircon were transferred into 3 mL Teflon PFA beakers. The grains were then rinsed in 3.5 M HNO_3 several times before being transferred to 5 µL microcapsules. These microcapsules were placed in a large-capacity Parr vessel, and the zircon was partially dissolved in 120 µL of 29 M HF for 12 h at 200°C. The zircon was returned to 3 mL Teflon PFA beakers, the HF was removed, and the zircon was immersed in 6N HCl, ultrasonically cleaned for an hour, and fluxed on a hotplate at 80°C for an hour. The HCl was removed, and the zircon was rinsed twice in ultrapure H_2O before being reloaded into the 300 µL Teflon PFA microcapsules (rinsed and fluxed in 6 M HCl during sonication and washing of the zircon) and spiked with the EARTHTIME mixed ^{233}U–^{235}U–^{205}Pb tracer solution (ET535). Zircon was dissolved in Parr vessels in 120 µL of 29 M HF with a trace of 3.5 M HNO_3 at 220°C for 48 h, dried to fluorides, and re-dissolved in 6 M HCl at 180°C overnight. Solutions were subsequently dried down and redissolved in 60 µL of 3 M HCl to convert to $PbCl_3$-, UO_2Cl_3-, and UCl_6-ions. Uranium and Pb were separated from the zircon matrix using an HCl-based anion-exchange chromatographic procedure (Krogh, 1973). Lead was eluted with 200 µL of 6 M HCl and U with 250 µL of MQ-H2O into the same beaker and dried with 2 µL of 0.05 N H_3PO_4.

Lead and U were loaded on a single outgassed Re filament in 5 µL of a silica gel/phosphoric acid mixture (Gerstenberger and Haase, 1997), and U and Pb isotopic measurements were made on a Nu Instruments thermal ionization mass spectrometer equipped with an ion-counting Daly detector. Lead isotopes were measured by peak jumping all isotopes on the Daly detector for 100 to 160 cycles. Mass fractionation was determined using repeat measurements of standard material NBS-981 solution that has equal atom ^{208}Pb and ^{206}Pb and thus measures fractionation directly. It was either 0.16±0.03 %amu−1 or 0.18±0.03 %amu−1 (1σ) for the analytical sessions reported here. Transitory isobaric interferences due to high-molecular-weight organics, particularly on ^{204}Pb and ^{207}Pb, disappeared within approximately 60 cycles, while ionization efficiency averaged 104 cpspg−1 of each Pb isotope. Linearity (to cps) and the associated deadtime correction of the Daly detector were monitored by repeated analyses of NBS981. Uranium was analyzed as UO ions in static Faraday mode on 1012 Ω resistors for 300 cycles and corrected for isobaric interference of ^{233}U^{18}O^{16}O on ^{235}U^{16}O^{16}O with and ^{18}O/^{16}O ratio of 0.00206. Ionization efficiency averaged 20 mVng−1 of each U isotope. Uranium mass fractionation was corrected using the known ^{233}U/^{235}U ratio of the tracer solution.

Uranium–Pb dates and uncertainties were calculated using the algorithms of Schmitz and Schoene (2007); calibration of ET535 tracer solution (Condon et al., 2015) of ^{235}U/^{205}Pb = 100.233, ^{233}U/^{205}Pb = 0.99506, and ^{205}Pb/^{204}Pb = 11268; U decay constants recommended by Jaffey et al. (1971); and of ^{238}U/^{235}U = 137.818 (Hiess et al., 2012). The ^{206}Pb/^{238}U ratios and dates were corrected for initial ^{230}Th disequilibrium using $DT_{h/U}$ = 0.20±0.05 (1σ) and the algorithms of Crowley et al. (2007), resulting in an increase in the ^{206}Pb/^{238}U dates of ~ 0.09 Ma. All common Pb in analyses were attributed to laboratory blank and subtracted based on the measured laboratory Pb isotopic composition and associated uncertainty. Uranium blanks are estimated at 0.013 pg. Results of U-Pb zircon geochronology are included in Appendix 2.

3.2. High-precision CA-ID-TIMS U-Pb zircon geochronology at UQAM

Four sample were sent to the GEOTOP laboratory at UQAM where aliquots selected for U-Pb dating were processed for mineral separation. The bulk sample was crushed using a jaw crusher. After sieving and washing on a Jasper Canyon Research (JCR) table, zircon grains were separated by density and magnetic methods, using methylene iodide heavy liquids and a Frantz Isodynamic Separator operated with currents between 0.2 and 1.0 A. Zircon crystals with euhedral prismatic/elongated habit were hand-picked under a binocular microscope. The selected zircon grains were transferred into quartz crucibles and then annealed in a muffle furnace at 950°C for 48 h.

All selected grains were prepared for standardized zircon U-Pb CA-ID-TIMS methods (Mattinson, 2005) adapted to the GEOTOP facilities at UQAM (Boscaini et al., 2025; Dufour et al., 2023). Grains were transferred to 3 mL Savillex beakers and subjected to chemical abrasion by adding concentrated HF to remove domains affected by radiation damage and potential Pb loss. The beakers were loaded into Parr bombs and placed in an oven at 210°C for 12 h. After abrasion, HF was removed and replaced with 6 N HCl, and grains were fluxed on a hot plate at 80°C for 24 h. Zircon grains or fragments that were not fully dissolved during chemical abrasion (<10% of the total) were subsequently ultrasonically cleaned four times in clean HNO_3. Individual grains were then loaded into 200 µL microcapsules with ~45 µL of 29 N HF and trace HNO_3 and spiked with ~2.5 mg of EARTHTIME ^{205}Pb–^{233}U–^{235}U ET535 tracer solution (Condon et al., 2015; McLean et al., 2015). Microcapsules were loaded into Parr bombs and left in the oven for ~60 h at 210°C to ensure complete dissolution. Following dissolution, samples were dried down on a hot plate and converted to chloride form by adding ~45 µL of 6 N HCl and heating in the oven at 180°C for 12 h. After re-drying, samples were brought back into solution in 3.1 N HCl and loaded onto pre-cleaned anion-exchange columns containing AG1X8 resin (Krogh, 1973) for separation of U and Pb from the zircon matrix. Prior to sample loading, columns were rinsed with MilliQ water and 6 N HCl. The separated U and Pb fractions were recombined in pre-cleaned 7 mL Savillex beakers and dried down with one drop of 0.04 M H_3PO_4.

Isotopic measurements were performed at the Geotop Laboratories using a Triton Plus thermal ionization mass spectrometer (TIMS) equipped with a secondary electron multiplier (SEM) and faraday cups attached to 1013 Ω resistors. The linearity of the multiplier was calibrated using U500, Sr SRM987, and Pb SRM982 and SRM983 solutions. The deadtime was determined to be constant at 30.5ns for up to 1.3 Mcps. Isobaric interferences from $BaPO^{2+}$ and Tl^{+} were monitored on masses 201 and 203 and since no statistically significant signal was observed on the controlled masses no correction was applied. Lead isotopic fractionation was corrected based on a value of 0.18 ± 0.04 (2σ) abs/amu established as average of the long-term measurements of NBS981. The U mass fractionation for the same analyses was calculated using the ^{233}U-^{235}U ratio of the double-spike solution (0.99506 ± 0.01%, 1σ). Both lead and uranium were loaded with 1 µl of silica gel–phosphoric acid mixture (modified after Gerstenberger and Haase, 1997) on outgassed single Re-filaments. All lead isotopes ($^{204-208}$Pb) were measured in peak-hopping mode on the SEM detector. Uranium isotopes (measured as masses 265 representing $^{233}U^{16}O_2$, 267 representing $^{235}U^{16}O_2$, and mass 270 representing $^{238}U^{16}O_2$) were collected in dynamic mode on the SEM or in static mode on Faraday cups connected to 1013 Ω resistors. Isobaric interference of $^{233}U^{18}O^{16}O$ on $^{235}U^{16}O^{16}O$ was corrected using a ^{18}O/^{16}O ratio of 0.00205 ± 0.9%. The measured uranium isotopic ratios were corrected assuming a sample ^{238}U/^{235}U ratio of 137.818 ± 0.045 (2σ) (Hiess et al., 2012). Common Pb was assumed to be procedural blank and corrected using laboratory blank compositions of ^{206}Pb/^{204}Pb = 18.102 ± 0.23, ^{207}Pb/^{204}Pb = 15.35 ± 0.14, and ^{208}Pb/^{204}Pb = 38.01 ± 0.55. Uranium blanks were measured and a value of 0.01 pg +/- 50% was used in all data reductions.

U-Pb data reduction and uncertainty propagation were performed using Tripoli and U–Pb Redux software (McLean et al., 2011, 2015). Ages were corrected for initial ^{230}Th disequilibrium assuming a $D_{Th/U}$ = 0.20±0.05 (1σ). The accuracy of the measured data was assessed by repeated analysis of the 100 Ma synthetic solution (Condon et al., 2008), yielding an internal reproducibility in ^{206}Pb/^{238}U dates of better than ±0.05%. Results of CA-ID-TIMS U-Pb zircon geochronology are included in Appendix 2.

4. Geochronological sample description and U-Pb zircon results

Ages presented below are calculated ages ^{206}Pb/^{238}U ages from the data tables, unless otherwise stated. The notation ± X (Y)[Z] refers to: X is analytical error only; (Y) includes the tracer calibration uncertainties, and; [Z] includes both tracer calibration and decay constant uncertainties. All uncertainty is 2σ. For comparisons of analyses produced using the same isotopic tracers and techniques, only analytical errors are discussed since the same tracer solution was used for all CA-ID-TIMS analysis. MSWD=mean square of weighted deviation and n=number of zircon dates used to calculate the age. Analytical results are included in Appendix 2.

4.1. Sample 20N-33 – Hat Creek area – (50.67560°N, 121.57509°W)

In the Hat Creek area, east of the Upper Hat Creek road and south of Highway 99, is an outcrop of poorly exposed felsic to intermediate flows with sparse vesicles and trachytic texture defined by aligned plagioclase crystals. Three individual zircon crystals were analyzed and yield a weighted mean ^{206}Pb/^{238}U age of 51.851 ± 0.047 (0.052)[0.076] Ma (MSWD=2.8; n=3), interpreted as the time of crystallization.

4.2. Sample 09-03-20-3A – McAbee fossil beds (50.80145°N, 121.13469°W)

Sample 09-30-20-3A is from rare tuffaceous beds that occur within thinly bedded mudstones and siltstones of the McAbee fossil beds north of Highway 97, east of Cache Creek. This sample represents a 15 cm thick buff-coloured, vaguely laminated, very fine-ash tuff within the fossil beds.

Five individual zircon crystals were analyzed. One zircon yielded a 206Pb/238U age of 188.694 ± 0.088 Ma (z4), a second 58.6 ± 1 Ma (z5); this zircon is discordant and has high ^{207}Pb/^{235}U uncertainty (± 22%, 2σ). Two individual concordant results (z2, z3) yield overlapping ^{206}Pb/^{238}U ages, with a weighted mean of 51.805 ± 0.028 (0.036)[0.066] Ma (MSWD=3.5; n=2). A fifth result (z1) is slightly younger with at ^{206}Pb/^{238}U age of 51.16 ± 0.29 Ma but has high ^{207}Pb/^{235}U uncertainty (±9%, 2σ) and is not included in the weighted mean. The 51.805 ± 0.028 Ma result is interpreted as the best estimate for the time of crystallization of this tuff bed.

4.3. Sample 09-03-20-3B – McAbee fossil beds (50.80145°N, 121.13469°W)

This represents an outcrop of 15 cm ash tuff within sediment-hosted McAbee fossil beds, north of Highway 97, east of Cache Creek. It is a vaguely laminated white tuff that is very fine-grained, soft and friable. This tuff unit is about 1 m above sample A and is separated from it by a brown mudstone that intercalated with gypsum.

Only two zircon crystals were recovered and analyzed, yielding a ^{206}Pb/^{238}U weighted mean age of 51.54 ± 0.45 (0.45) [0.45] Ma (MSWD=0.9; n=2); however both of the zircon have high ^{207}Pb/^{235}U uncertainty (± 75% and ±14%, 2σ); therefore, the age determination is considered accurate, but not precise (i.e., ca. 51.5 Ma)

4.4. Sample 09-03-20-4B – McAbee fossil beds (50.79737°N, 121.13232°W)

Next to the dirt road within the McAbee fossil beds, is an isolated outcrop of massive ash tuff that is 4 m thick (minimum). Three concordant zircon crystals yielded a ^{206}Pb/^{238}Pb weighted mean age of 218.309 ± 0.053 (0.084)[0.25] Ma (MSWD=2.4; n=3). This is interpreted as the time of crystallization of this tuffaceous unit. This Triassic determination indicates that the unit, which was initially assumed to be Eocene, is part of the Nicola Group.

4.5. Sample 20N-30b – Savona Formation (50.71853°N, 120.78351°W)

Along the Tunkwa Lake road, southeast of Savona and Highway 97 is a welded, flow-banded crystal-vitric lithic felsic tuff that has been devitrified and altered. It is interpreted to be a pyroclastic flow or ignimbrite based on alignment of crystals elongation of fiamme and eutaxitic texture of the rock defining flow banding. This sample was first tested by LA-ICP-MS and the results indicate it contains inherited zircon with ages around 220, 160, and 90-80 Ma.

Zircon crystals for this sample were plucked from the LA grain mount. Four individual zircon were analyzed by the CA-ID-TIMS method and yield a weighted mean ^{206}Pb/^{238}U age of 51.971 ± 0.021 (0.03)[0.06] Ma (MSWD=0.94; n=4), interpreted as the time of crystallization.

4.6. Sample 228N-59 – Westwold area (50.418197°N, 119.698716°W)

Along the Ingram Creek road, southeast of Westwold and Okanagan Highway 97 is an outcrop of light-gray crystal-vitric tuff with layering defined by large, stretched fiamme (0.5 mm by 4-10 cm long) that comprise about 5% of the rock. The tuff contains microcrysts of feldspar (90%) of micocrysts and lesser hornblende in a groundmass of devitrified ash and glass with microlites of feldspar.

Eleven zircon crystals were analyzed and yield two distinct populations. The older population yielded a concordant weighted mean age of 162.260 ± 0.046 Ma (MSWD=1.4; n=6), interpreted as inherited zircon. The younger population yielded a ^{206}Pb/^{238}U age of 51.945 ± 0.018 (0.02)[0.06] Ma (MSWD=0.66; n=5), interpreted as the crystallization age of the volcanic rock.

4.7. Sample H20-59 – Kettle River Formation, Rock Creek (49.381386°N, 118.842229°W)

The sample location (Höy et al., 2022) is from the northwest slope of Lost Horse Creek, 2.5 km east of Kettle River and 35 km north of the town of Rock Creek. There, thick exposures of the Kettle River Formation, including conglomerate, siltstone, minor shale and massive to crudely layered crystal-lithic tuff unconformably overlie Late Paleozoic Wallace Formation. A sample of light grey, green tinged water-lain crystal-lithic tuff with vague layering was collected for U-Pb zircon geochronology. The separated zircon crystals yielded a LA-ICP-MS age determination of 51.50 ± 0.44 Ma, reported in Höy et al. (2022). This sample also contains inherited zircon with ages about ca. 190, 106, 75, and 65 Ma (Appendix 2).

Six individual zircon crystals from this sample were picked from the mineral separate and analyzed by the CA-ID-TIMS method. These yield a weighted mean ^{206}Pb/^{238}U age of 51.879 ± 0.019 (0.03)[0.06] Ma (MSWD=0.63; n=6), interpreted as the crystallization age of the crystal-lithic tuff.

4.8. Sample H20-60 – Kettle River Formation, Phoenix Pit (49.092758°N, 118.59472°W)

The sample location (Höy et al., 2022) is from exposures of Kettle River Formation in the Phoenix pit, a past-producing open pit mine east of the town of Greenwood. The unit includes crystal-lithic tuff, tuffaceous sandstone, and thin conglomerate beds. These exposures are conformably overlain by Marron Formation. A sample of light grey, slightly green tinged, medium grained, tuffaceous sandstone, crystal lapilli tuff was collected for U-Pb zircon geochronology. Zircon from the sample yielded a LA-ICP-MS age determination of 50.80 ± 0.49 Ma, reported in Höy et al. (2022). This sample also contains inherited zircon with ages about ca. 200, 190, 110-100, 85, and 75 Ma (Appendix 2).

Six individual zircon crystals from this sample were picked from the mineral separate and analyzed by the CA-ID-TIMS method. These yield a weighted mean ^{206}Pb/^{238}U age of 51.959 ± 0.021 (0.03)[0.07] Ma (MSWD=0.51; n=6), interpreted as the crystallization age of the tuff.

References cited

Allen, C.M., and Campbell, I.H., 2012. Identification and elimination of a matrix-induced systematic error in LA–ICP–MS 206Pb/238U dating of zircon. Chemical Geology 332-333, 157-165. https://doi:10.1016/j.chemgeo.2012.09.038

Boscaini, A., Davies, J.H.F.L., Perrot, M.G., Sassi, R., Mazzoli, C., De Min, A., Morelli, C., Kustatscher, E., Blanchet-Gavouyère, T., and Marzoli, A., 2025. Early Permian post-collisional magmatism induced by extensive removal of the Variscan lithospheric mantle. Contributions to Mineralogy and Petrology, 180. https://doi.org/10.1007/s00410-024-02196-z

Colpron, M., 2020. Yukon Terranes - A digital atlas of terranes for the northern Cordillera. Yukon Geological Survey. https://data.geology.gov.yk.ca/Compilation/2#InfoTab

Condon, D.J., McLean, N., Schoene, B., Bowring, S.A., Parrish, R.R., and Noble, S., 2008. Synthetic U-Pb 'standard' solutions for ID-TIMS geochronology. Geochimica et Cosmochimica Acta, 72, A175. https://doi:10.1016/j.gca.2008.05.006

Condon, D.J., Schoene, B., McLean, N.M., Bowring, S.A., and Parrish, R.R., 2015. Metrology and traceability of U-Pb isotope dilution geochronology (EARTHTIME Tracer Calibration Part I). Geochimica et Cosmochimica Acta, 164, 464-480. https://doi:10.1016/j.gca.2015.05.026

Cousens, B.L., 1996. Magmatic evolution of Quaternary mafic magmas at Long Valley Caldera and the Devils Postpile, California: Effects of crustal contamination on lithospheric mantle-derived magmas. Journal of Geophysical Research, 101, 27673-37689. https://doi.org/10.1029/96JB02093

Crowley, J. L., Schoene, B., and Bowring, S. A., 2007. U-Pb dating of zircon in the Bishop Tuff at the millennial scale. Geology, 35, 1123-1126. https://doi.org/10.1130/G24017A.1

Dufour, F., Davies, J.H.F.L., Greenman, J.W., Skulski, T., Halverson, G.P., and Stevenson, R., 2023. New U-Pb CA-ID TIMS zircon ages implicate the Franklin LIP as the proximal trigger for the Sturtian Snowball Earth event. Earth Planetary Science Letters, 618, 118259. https://doi.org/10.1016/j.epsl.2023.118259

Gerstenberger, H., and Haase, G.A., 1997. Highly effective emitter substance for mass spectrometric Pb isotope ratio determinations. Chemical Geology, 136, 309-312.

Hiess, J., Condon, D.J., McLean, N., and Noble, S.R., 2012. Systematics in terrestrial uranium-bearing minerals. Science, 335, 1610-1614.

Höy, T., Gabites, J., and Friedman, R., 2022. Summary Report on U-Pb and Ar-Ar age dating, Penticton map sheet (082E). Geoscience BC Report Number 2022-16, 60p.

Jaffey, A.H., Flynn, K.F., Glendenin, L.E., Bentley, W.C., and Essling, A.M., 1971. Precision measurements of half-lives and specific activities of 235U and 238U. Physical Review C, 4, 1889-1906.

Krogh, T.E., 1973. A low contamination method for hydrothermal decomposition of zircon and extraction of U and Pb for isotopic age determinations. Geochimica et Cosmochimica Acta, 37, 485-494.

Mattinson, J.M., 2005. Zircon U-Pb chemical abrasion ("CA-TIMS") method: combined annealing and multi-step partial dissolution analysis for improved precision and accuracy of zircon ages. Chemical Geology, 220, 47-66.

McLean, N.M., Bowring, J.F., and Bowring, S.A., 2011. An algorithm for U-Pb isotope dilution data reduction and uncertainty propagation: U-Pb ALGORITHM. Geochemistry, Geophysics, Geosystems, 12. https://doi.org/10.1029/2010GC003478

McLean, N.M., Condon, D.J., Schoene, B., and Bowring, S.A., 2015. Evaluating uncertainties in the calibration of isotopic reference materials and multi-element isotopic tracers (EARTHTIME Tracer Calibration Part II). Geochimica et Cosmochimica Acta 164, 481-501. https://doi.org/10.1016/j.gca.2015.02.040

Nasdala, L., Lengauer, C.L., Hanchar, J.M., Kronz, A., Wirth, R., Blanc, P., Kennedy, A.K., and Seydoux-Guillaume, A.M., 2002. Annealing radiation damage and the recovery of cathodoluminescence. Chemical Geology, 191, 121-140.

Ootes, L., and Wall, C., 2024. High-precision U-Pb zircon igneous crystallization and detrital zircon maximum depositional ages from the Toodoggone region, north-central British Columbia. British Columbia Ministry of Energy, Mines and Low Carbon Innovation, British Columbia Geological Survey Open File 2024-06, 10p.

Schoene, B., Crowley, J.L., Condon, D.J., Schmitz, M.D., and Bowring, S.A., 2006. Reassessing the uranium decay constants for geochronology using ID-TIMS U–Pb data. Geochimica et Cosmochimica Acta 70, 426-445. https://doi.org/10.1016/j.gca.2005.09.007

Tanaki, T., and 18 others, 2000. JNdi-1: a neodymium isotopic reference in consistency with LaJolla neodymium. Chemical Geology, 168, 279-281. https://doi.org/10.1016/S0009-2541(00)00198-4

Van Wagoner, N., Ootes, L., and Sutcliffe, B., 2021. Geochemical data from the Kamloops Group. British Columbia Ministry of Energy, Mines and Low Carbon Innovation, British Columbia Geological Survey GeoFile 2021-16, 2p.

Wendt, I., and Carl, C., 1991. The statistical distribution of the mean squared weighted deviation. Chemical Geology, 86, 275-285. https://doi.org/10.1016/0168-9622(91)90010-T xt

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