Supplementary data for British Columbia carbonatites revisited: New whole rock Sr-Pb-Nd isotopic insights and drainage prospectivity trends

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Front cover:
Sampling Howard Creek, Blue River area. **Photo by Alexei Rukhlov.**

Back cover:
Sampling Bigmouth Creek downstream of Trident Mountain alkaline complex. **Photo by Luke Ootes.**

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Supplementary data for British Columbia carbonatites revisited: New whole rock Sr-Pb-Nd isotopic insights and drainage prospectivity trends

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Abstract
This GeoFile serves as a data repository for Rukhlov et al. (2025b). It provides complete field and analytical data for whole-rock and stream-sediment samples downstream of known carbonatites and related alkaline rocks in southeastern British Columbia, including sample details; whole-rock lithochemistry and Sr-Pb-Nd isotopic data; a new Re-Os molybdenite date; stream-sediment lithochemistry; and a summary of analytical methods, quality control, and results.

Keywords: carbonatite, alkaline rocks, trace elements, Sr-Pb-Nd isotopes, Re-Os molybdenite model age, stream sediment geochemical survey, heavy mineral concentrate (HMC), rare metals, rare earth elements (REE)

1. Introduction

As part of province-wide geochemical re-analysis, the British Columbia Geological Survey (BCGS) is collecting hundreds of new whole rock radiogenic isotope (Sr-Pb-Nd-Hf) and trace-element data. Along with compiled analyses (Rukhlov et al., 2025a), these data constrain evolution of terranes and sources of mineralization and host rocks and supplement regional geochemical surveys to aid rare earth element (REE) and rare metal exploration (Rukhlov et al., 2024).

Here we contribute new whole rock data from carbonatites and related alkaline rocks, including the Mount Copeland historical molybdenum producer (Currie, 1976, Höy, 1988, Pell, 1994). In addition, new lithochemical data from modern drainages downstream of the known carbonatite and related-rock occurrences inform utility of the regional geochemical surveys. The full dataset (BCGS_GF2025-09.zip) contains eight spreadsheets: 1) details of rock samples with geographic coordinates, descriptions, and references; 2) whole rock major and trace-element results; 3) whole rock quality control; 4) whole rock Sr-Pb-Nd isotopic data, decay constants, and isotopic references; 5) a new Re-Os model age on molybdenite from the historical Mount Copeland mine; 6) details of stream-sediment samples, clast counts, fractions, and in situ water parameters; 7) stream sediment major and trace-element results; and 8) stream sediment quality control.

2. Stream sediment sampling and whole rock preparation

We collected two types of samples at each drainage site. First, sieved, <2 mm fraction of stream sediment (2.1 to 15 kg) was panned to recover heavy mineral concentrate (HMC; 185 to 704 g). The second sample included sieved (<2 mm), bulk stream sediment (0.3 to 2.5 kg). Both HMC and bulk stream sediment were dried in an oven at 36°C and sieved through stainless steel mesh into <0.18, 0.18 to 1.0, and 1 to 2 mm fractions. A Jones splitter was used for sub-sampling. Splits of <0.18 and 0.18 to 1.0 mm fractions of both HMC and bulk stream sediment and jaw-crushed whole rock fragments (2 to 4 mm) were pulverized to <75 µm powder for lithochemical and isotopic (Sr-Pb-Nd) analysis using Cr-steel ring and puck mill at the British Columbia Geological Survey (BCGS). Pure silica sand was pulverized, followed by thorough cleaning of the mill between samples to ensure negligible cross-contamination.

3. Analytical methods

3.1. In situ water parameters

Water temperature (°C) and pH were simultaneously measured using an Oakton® pH 450 portable meter connected to a sealed, 'all-in-one', single-junction pH electrode (WD-35808-71). The pH electrode was then swapped for a sealed, gel-filled, single-junction, Ag-AgCl combination reference electrode (WD-59001-75) and a BNC automatic temperature compensation (ATC) probe, and water oxidation-reduction potential (ORP; mV) was measured. Water electrical conductivity (EC;

$\mu S \cdot cm^{-1}$), total dissolved solids (TDS; mg/L), and salinity (‰) were measured using an Oakton® EC 100 portable meter connected to an Oakton®, epoxy-body, platinum band (K = 0.1), conductivity cell ATC probe (35606-53). Before taking the readings, all probes and a 100 mL clear plastic beaker were thoroughly rinsed with ultrapure water, then a few times with sample water. The pH and EC probes were calibrated daily using fresh, standard buffer solutions (3-point each). The ORP probe was also checked daily using 240 and 470 mV reference solutions. In addition, water total (phenolphthalein) alkalinity (mg/L as $CaCO_3$) determined colorimetrically with Hach® AquaChek Total Alkalinity Test Strips (0 to 240 mg/L as $CaCO_3$).

3.2. Major and trace elements

Whole rock samples (total 11, including 3 duplicates) were analyzed at ALS Canada Ltd. for a total of 73 analytes using sodium-peroxide and lithium-borate fusion techniques, combined with X-ray fluorescence (XRF) spectrometry and inductively coupled plasma mass spectrometry (ICP-MS); combustion infrared spectroscopy (total C and S); and gravimetric determination of loss on ignition (LOI) at 1000°C.

Sieved, <0.18 and 0.18 to 1.0 mm fractions of bulk stream-sediment and HMC samples (total 40, including 4 duplicates) were analyzed at Bureau Veritas Commodities Canada Ltd. for a total of 67 analytes. These include total determinations of major and trace-elements via lithium-borate fusion and a combination of inductively coupled plasma atomic emission spectroscopy (ICP-AES) and ICP-MS, KOH fusion with ion selective electrode (fluorine), combustion infrared spectroscopy (total C and S), and digestion in phosphoric acid with ICP-AES finish (overlimit niobium); multi-acid (HNO_3 + $HClO_4$ + HF + HCl) digestion with ICP-MS finish (In, Li, Re, Te); modified aqua regia (1:1:1 HNO_3:HCl:H_2O) digestion with ICP-MS finish (Ag, As, Au, Bi, Cd, Cu, Hg, Mo, Ni, Pb, Sb, Se, Tl, and Zn); and gravimetric determination of loss on ignition (LOI) at 1000 °C.

3.3. Whole rock radiogenic isotope data

Sr-Pb-Nd isotopic analysis on 7 whole-rock samples was performed in the Department of Earth and Atmospheric Sciences at the University of Alberta.

3.3.1. Sr isotopic composition

Rock powders were dissolved in HF + HNO_3 mixture at 160°C for 5 days, and chemical separation procedures for Sr followed the methods of Creaser et al. (2004) and Holmden et al. (1997). Isotopic analysis of Sr was performed using a multi-collector inductively coupled plasma mass spectrometer (MC-ICP-MS) operating in static mode. All analyses are presented relative to a value of $^{87}Sr/^{86}Sr = 0.710245$ for the NIST SRM 987 Sr isotopic standard. The value of the SRM 987 Sr isotopic standard measured during the analysis of these samples was 0.71029 ± 0.00002 (n = 4).

3.3.2. Nd isotopic composition

The isotopic composition of Nd was determined using a MC-ICP-MS in static mode (Schmidberger et al., 2007). All isotope ratios were normalized for variable mass fractionation to a value of $^{146}Nd/^{144}Nd = 0.7219$ using the exponential fractionation law. The $^{143}Nd/^{144}Nd$ ratio of samples is presented here relative to a value of 0.511850 for the La Jolla Nd isotopic standard, monitored by using an in-house Alfa Nd isotopic standard for each analytical session. Isotopic abundances of Sm were measured in static mode by MC-ICP-MS and were normalized for variable mass fractionation to a value of $^{152}Sm/^{154}Sm = 1.17537$ also using the exponential law. We analyzed the Geological Survey of Japan Nd isotope standard Shin Etsu JNdi-1 (Garçon et al., 2018) which has a value of $^{143}Nd/^{144}Nd = 0.512099$ relative to a LaJolla $^{143}Nd/^{144}Nd$ value of 0.511850, when normalized to $^{146}Nd/^{144}Nd = 0.7219$. The value of $^{143}Nd/^{144}Nd$ determined for the JNdi-1 standard conducted during the analysis of the samples reported here was 0.512090 ± 10 (2SE). Using the mixed ^{150}Nd-^{149}Sm tracer, the measured $^{147}Sm/^{144}Nd$ ratios for the USGS rock standard BCR-1 range from 0.1380 to 0.1382, suggesting reproducibility for $^{147}Sm/^{144}Nd$ of about ±0.1% for whole rock unknowns. The value of $^{147}Sm/^{144}Nd$ determined for BCR-1 is within the range of reported literature values by isotope dilution methods (e.g., Creaser et al., 1997; Unterschutz et al., 2002).

3.3.3. Pb isotopic composition

Rock powders were dissolved in ultrapure HF + HNO_3 mixture at 150°C for 2 days. Sample solutions were then evaporated under ULPA-filtered air, and converted to chlorides using 6N HCl, and bromides using 2N HBr. Lead was purified by standard anion exchange chromatography using HBr and HCl as eluents under ULPA-filtered conditions. The isotopic composition of Pb then measured by MC-ICP-MS in static analysis mode. The measured Pb isotope ratios were corrected for instrumental mass bias using the agreed value for $^{203}Tl/^{205}Tl$ ratio measured simultaneously with each Pb analysis (e.g., Belshaw et al., 1998). Based on repeated analysis of NIST SRM 981 Pb isotope standard for more than 6 years, the measured Pb isotopic ratios are reproducible at 1σ uncertainty level within ±0.016% for $^{206}Pb/^{204}Pb$ and ±0.018% for $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$. The most widely accepted values for this Pb isotope standard are those determined by Todt et al. (1996) using double-spiked TIMS analysis, which are: $^{206}Pb/^{204}Pb = 16.936$, $^{207}Pb/^{204}Pb = 15.489$, and $^{208}Pb/^{204}Pb = 36.701$. The absolute values of Pb isotope ratios for SRM 981 determined in this study are: $^{206}Pb/^{204}Pb = 16.934$, $^{207}Pb/^{204}Pb = 15.489$, and $^{208}Pb/^{204}Pb = 36.689$.

3.4. Molybdenite Re-Os model age

Molybdenite from the Mount Copeland mine, a historical molybdenum producer (Currie, 1976, Höy, 1988, Pell, 1994), was analyzed for Re-Os in the Department of Earth and Atmospheric Sciences at the University of Alberta. The sample (6550-E-3-2) was obtained from the BCGS rock archive and represents ore mineralization from the past-producing mine. Methods used for molybdenite analysis are described in detail by Selby and Creaser (2004). Areas of the sample with visible molybdenite were removed, and preparation of a molybdenite mineral separate was made by metal-free crushing and sieving followed by magnetic and gravity concentration methods. The ^{187}Re and ^{187}Os concentrations in molybdenite were determined by isotope dilution mass spectrometry using Carius-tube,

solvent extraction, anion chromatography, and negative thermal ionization mass spectrometry (NTIMS) techniques. For this work, a mixed double spike containing known amounts of isotopically enriched ^{185}Re, ^{190}Os, and ^{188}Os was used (Markey et al., 2007). Isotopic analysis used a ThermoScientific Triton mass spectrometer by Faraday collector. Total procedural blanks for Re and Os are less than <6 picograms and 1 picograms, respectively, which are insignificant in comparison to the Re and Os concentrations in molybdenite. The Reference Material 8599 Henderson molybdenite (Markey et al., 2007) is routinely analyzed as a standard, and in the past 2 years returned an average Re-Os age of 27.83 ± 0.08 Ma (n = 19), indistinguishable from the reference age value of 27.66 ± 0.10 Ma (Gonzales and Choquette, 2022). The ^{187}Re decay constant used is $1.666 \cdot 10^{-11}$ a^{-1} (Smoliar et al, 1996).

4. Quality control methods and results

4.1. Quality control

Randomly inserted, blind quality controls include preparation blanks, duplicate splits of pulverized material, and certified reference materials as standards.

4.1.1. Preparation blanks

Sigma-Aldrich sand (≥99.995 wt% SiO_2) was pulverized as a blank between samples. Based on one whole rock blank and two sediment blanks, most analytes were below the lower limit of the analytical methods. Only a few above this limit were detected (e.g., Fe_2O_3(T) up to 0.24 wt% due to using chromium steel mill) ruling out significant carry over contamination.

4.1.2. Precision

To monitor the analytical precision, we analyzed duplicate splits of pulverized material. Based on 3 whole rock duplicates, relative analytical precision in terms of the average coefficient of variation (Abzalov, 2008) was <10% for most elements; precision of near-detection level Cs, Ge, and Se was between 27% and 42%. Duplicates of stream sediment samples (n = 4) also show good precision of a few % for most analytes. Semi-quantitative precision of Au, Sn, and Ta reflects below the lower limit results.

4.1.3. Accuracy

Based on 4 different standards, calculated difference relative to certified values is within the uncertainties for all analytes, indicating accurate results by the analytical schemes.

4.2. Results

New whole rock data reveal crustal abundances of Sr and REE in the Mount Hunter 'extrusive carbonatite' (documented on Figure 6 in Thompson et al., 2006), which we thus re-classify as a marble. In contrast, Mount Copeland alkali-feldspar syenites and carbonatites, including Little Chicago, Felix, Three Valley Gap, Ren, and the new occurrence at Boulder Mountain, have much higher contents of these elements. Their sub-bulk Earth $^{87}Sr/^{86}Sr$ and super-chondritic $^{143}Nd/^{144}Nd$ ratios are consistent with those of most carbonatites elsewhere (Rukhlov et al., 2015). Ranges of initial $^{206}Pb/^{204}Pb$ (14.07-24.95), $^{207}Pb/^{204}Pb$ (15.210-15.956), and $^{208}Pb/^{204}Pb$ (36.94-40.51) ratios overlap those of other Cordilleran carbonatites (Rukhlov et al., 2025a).

New drainage lithochemical data downstream of known occurrences of carbonatites and alkaline rocks show elevated response of REE, Nb, Ta, and other rare metals. Panned HMC (<0.18 mm fraction) have up to 0.40 wt% Nb and 1.63% ∑REE (sum of lanthanides, yttrium, and scandium), which are an order of magnitude higher than those in bulk stream sediment (<0.18 mm fraction).

Molybdenite from Mount Copeland yielded a Re-Os model age of 55.94 ± 0.23 Ma (2σ) including a ~0.31% uncertainty in the decay constant of ^{187}Re.

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