A 'Critical Mineral Index': Geochemical signal of carbonatite-related critical metals in provincial drainage sediments
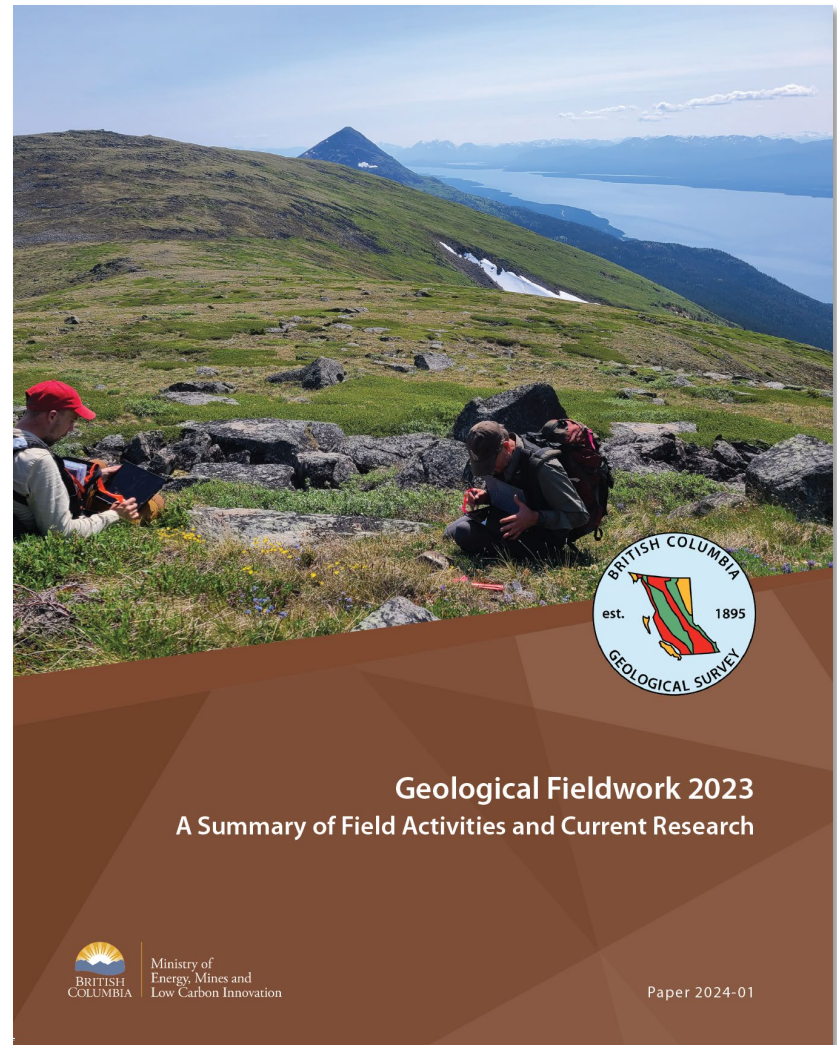
Alexei S. Rukhlov, Yao Cui, Quinn Cunningham, Gabe Fortin, and Cameron Anderson

British Columbia Geological Survey, Victoria, B.C., Canada

15-17 May 2024 | Spokane, Washington, USA
Cordilleran & Rocky Mountain Sections, GSA Joint Meeting

See Geological Fieldwork 2023 for more details:

Geological Fieldwork 2023
A Summary of Field Activities and Current Research

BRITISH COLUMBIA
Ministry of
Energy, Mines and
Low Carbon Innovation

Paper 2024-01

Talk overview

- Carbonatites, their significance, and British Columbia examples

- Provincial drainage data

- 'Critical Mineral Index' to assess prospectivity for carbonatite-hosted critical metals using multi-element drainage data

- Rare igneous rocks made up of at least 30% primary carbonates

- Typically found in intracontinental settings

- Important sources of Nb and rare earth elements (REE)
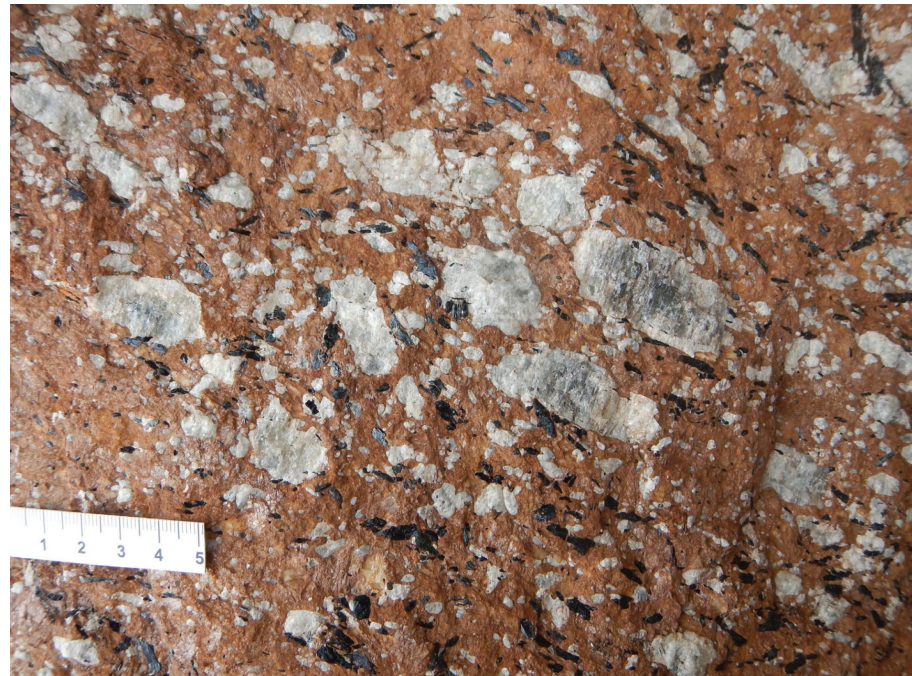

Carbonatite with light-toned apatite and dark-toned amphibole set in a ferroan dolomite matrix that readily oxidizes brown-red; Upper Fir Ta-Nb deposit.

Geochemical characteristics

Carbonatites are strongly enriched in rare metals, REE, P, Sr, and Ba relative to most other rocks, including sedimentary carbonates
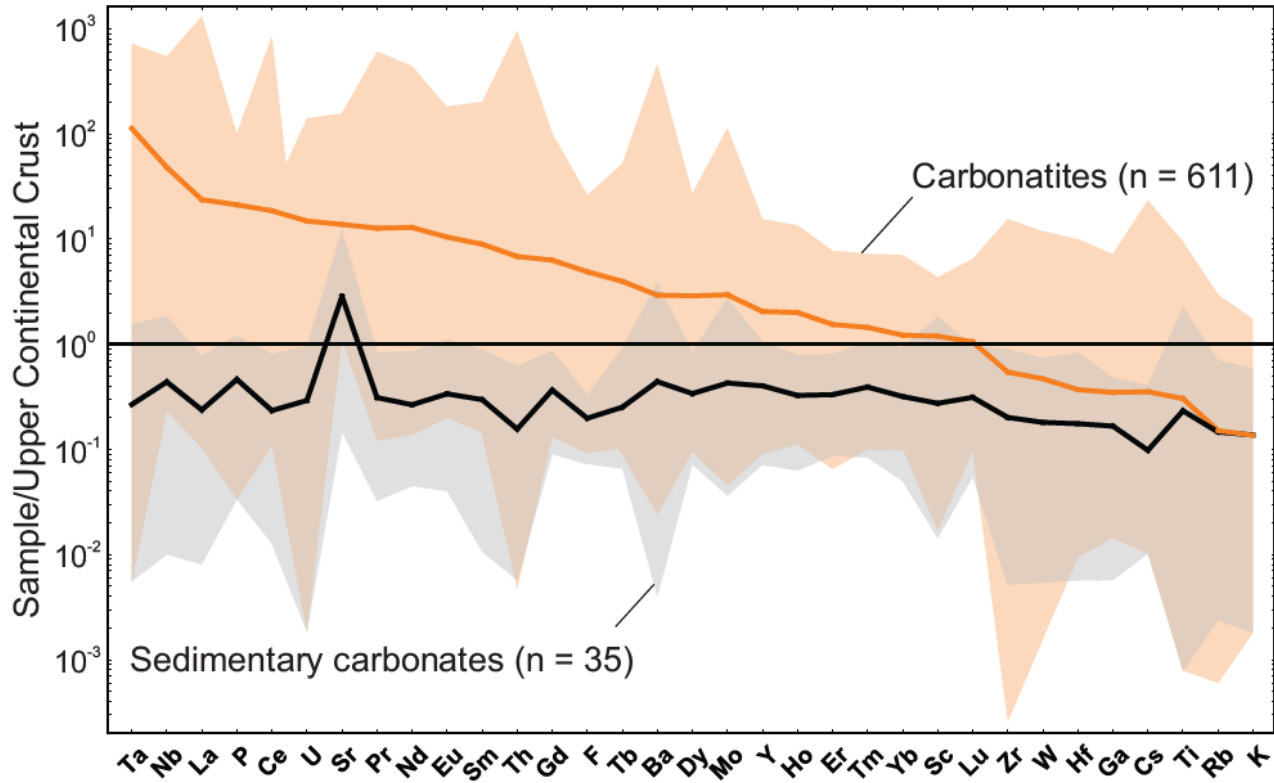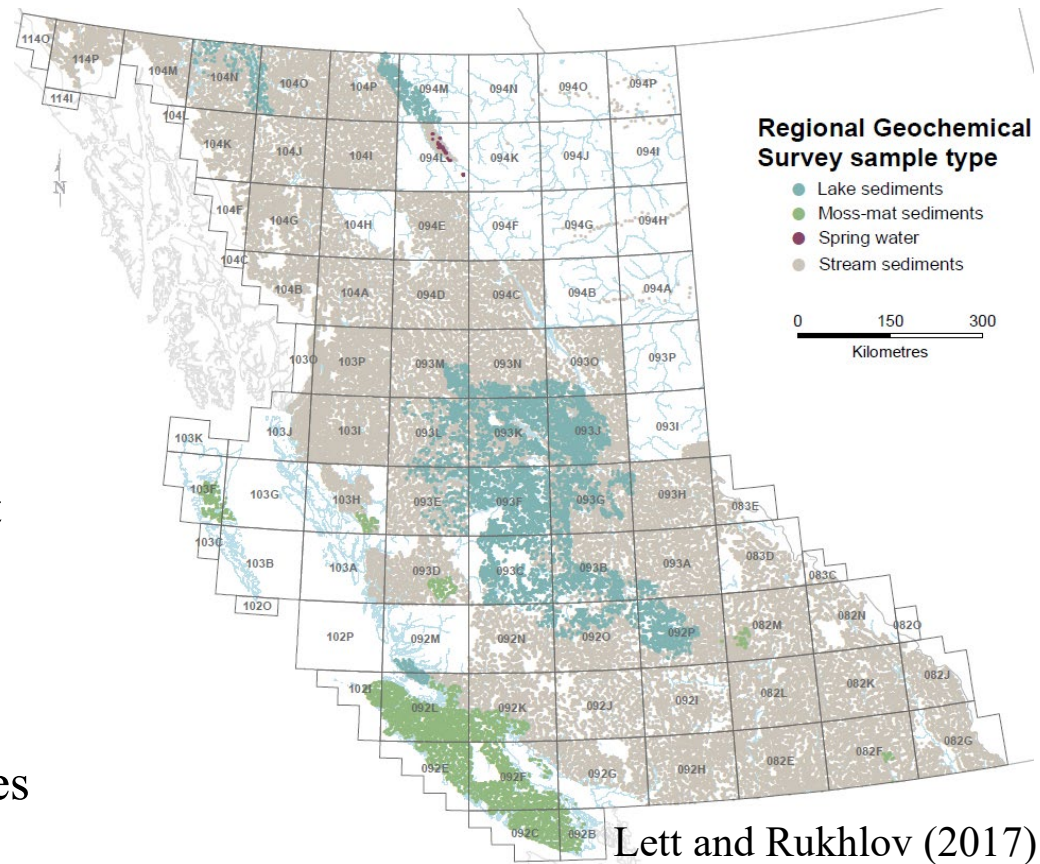
British Columbia examples

- Orogen-parallel belt of carbonatites and related rocks

- Hosted by parautochthonous rocks of the Omineca and Foreland belts

- Neoproterozoic, Cambrian, and late Paleozoic pulses
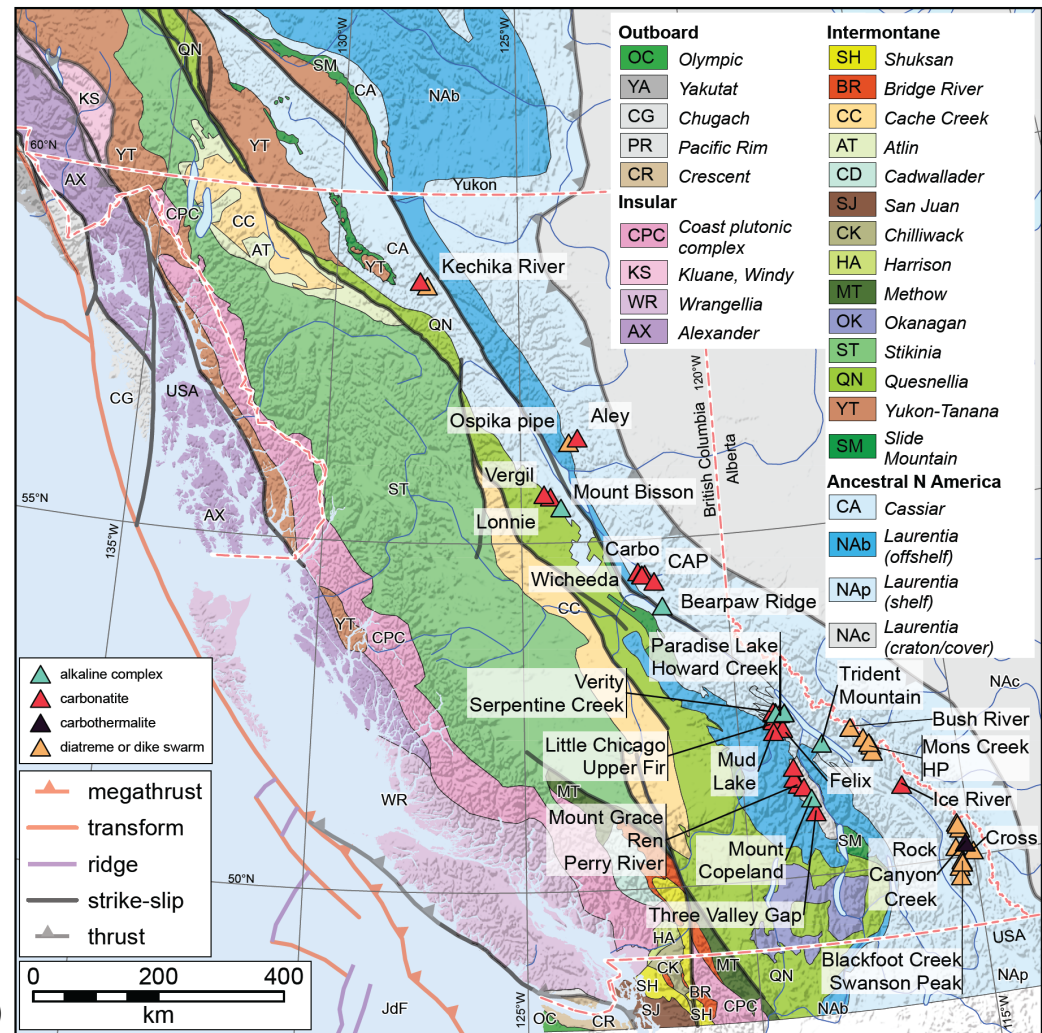
Terranes after Colpron (2020)

Provincial drainage data

- Government-managed Regional Geochemical Survey (RGS) program since 1976

- 65,000+ samples cover ~80% of the province at an average density of one sample per 10 km^2

- Lake- and stream-bottom or moss-mat sediment and water

- Multi-element determinations using AAS, INAA, and a combination of ICP-AES and ICP-MS for 60+ analytes

Regional Geochemical Survey sample type
- Lake sediments
- Moss-mat sediments
- Spring water
- Stream sediments

0   150   300
Kilometres

Lett and Rukhlov (2017)

Drainage geochemistry

- Rapid and efficient for prospecting

- Evaluates mineral potential of watershed or catchment basin upstream of sampling site

- Enables estimating predicted geochemical resources based on productivities of elements downstream of mineralization


RGS Catchment Basin
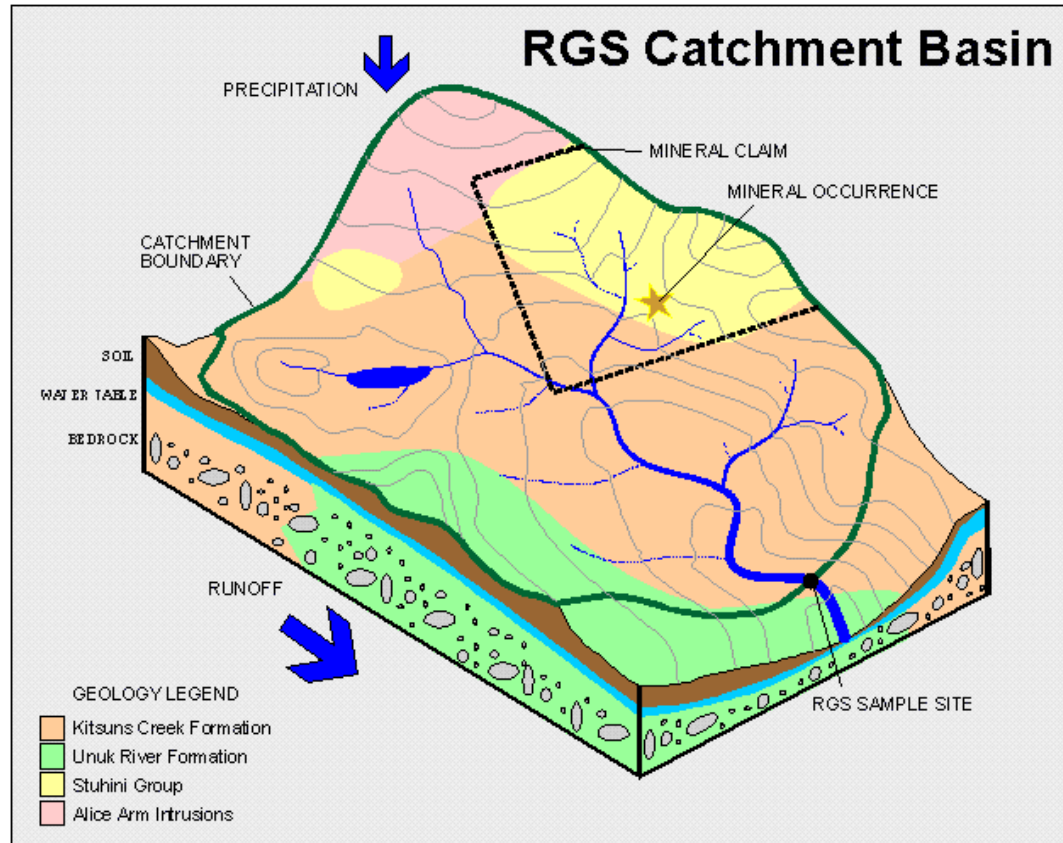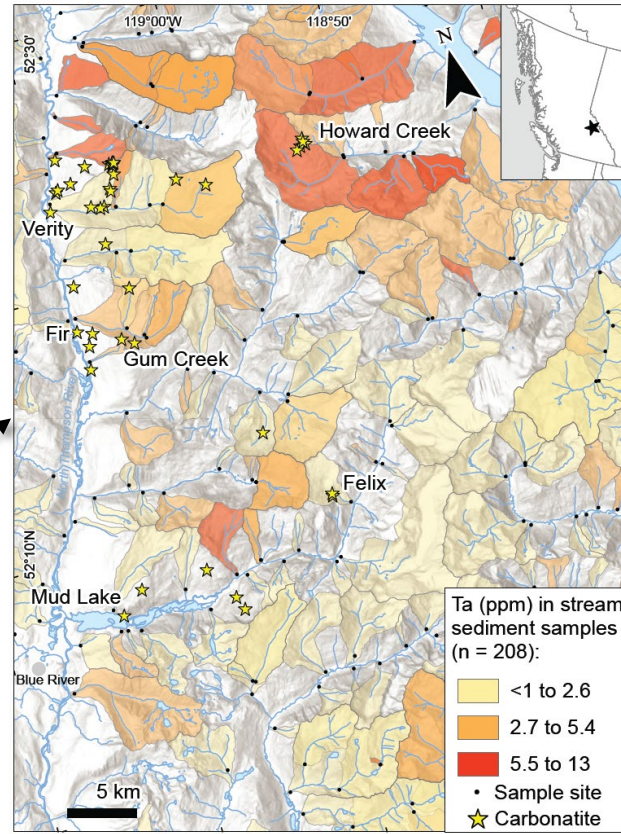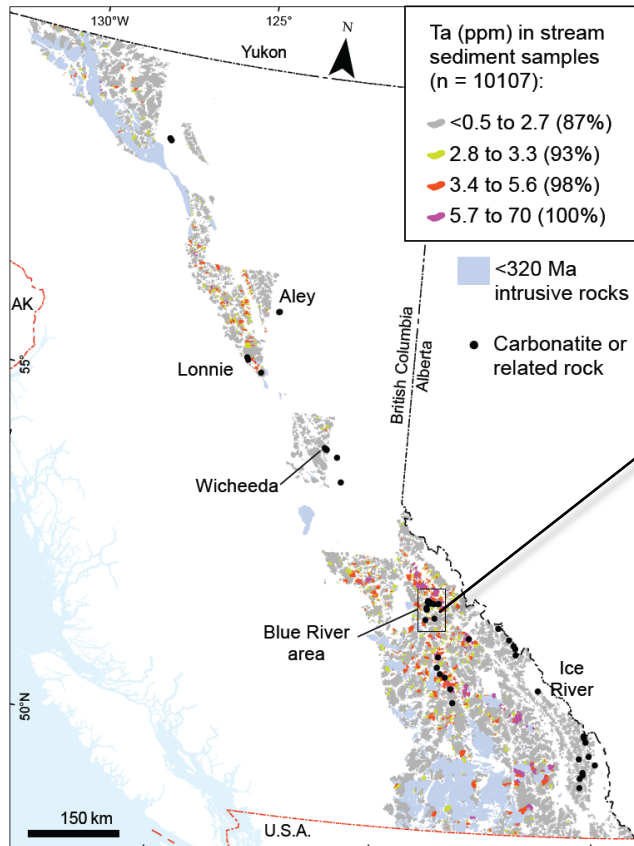
Concentrations of indicator elements in stream sediments reflect local background variations, including at known carbonatite occurrences

Multivariate approach

- Involves discriminant analysis to identify carbonatite-related critical minerals signal using multi-element stream-sediment data

- User-defined groups of the data:

  Group 1: downstream of known carbonatite or related rock (n = 53)

  Group 2: stream basin underlain mainly by sedimentary carbonate rocks (n = 90)

  Group 3: a random 20% sub-sample of stream-sediment data (n = 1943)

Regional Geochemical Survey stream-sediment data selected for discriminant analysis:
- Downstream of known carbonatite or related rock (n = 53)
- Catchment basin underlain mostly by sedimentary carbonate rocks (n = 90)
- Random 20% sub-sample of stream-sediment data in the study area (n = 1943)
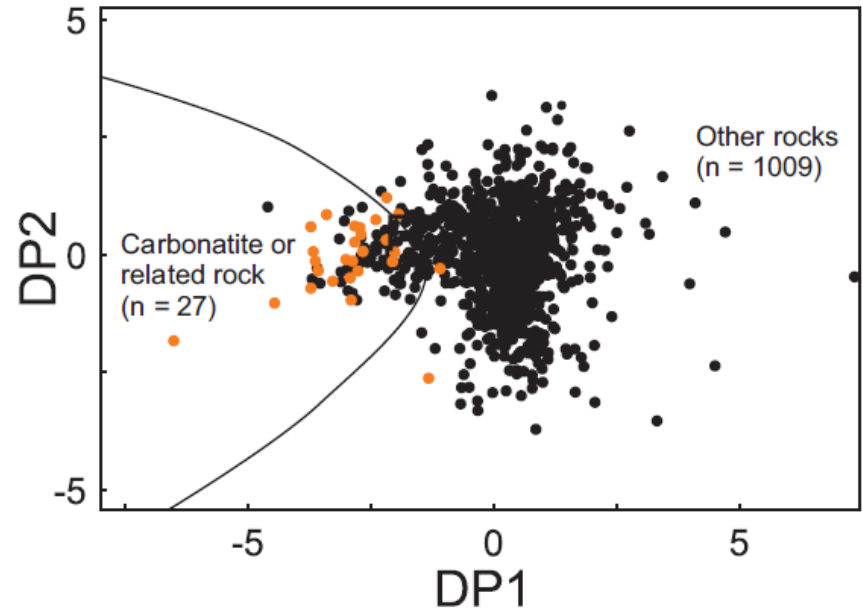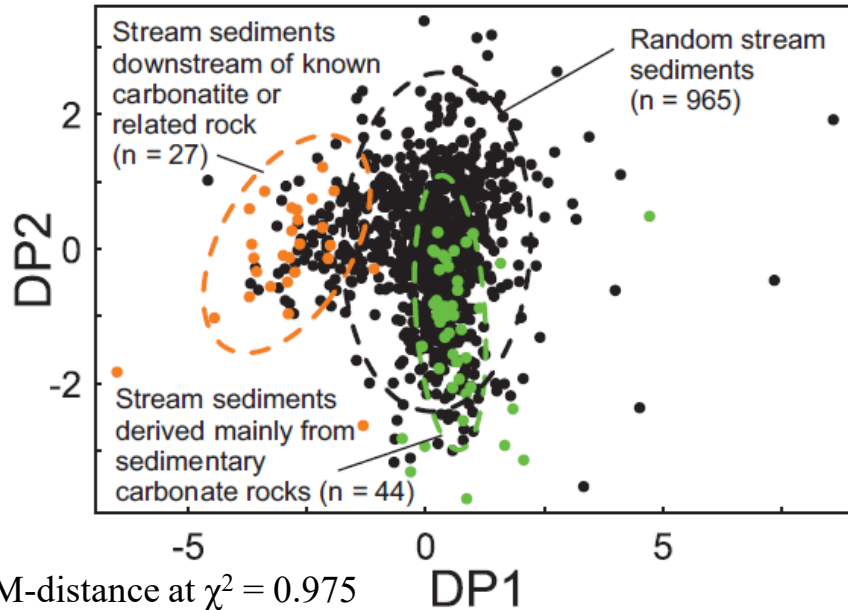- Carbonatite or related rock
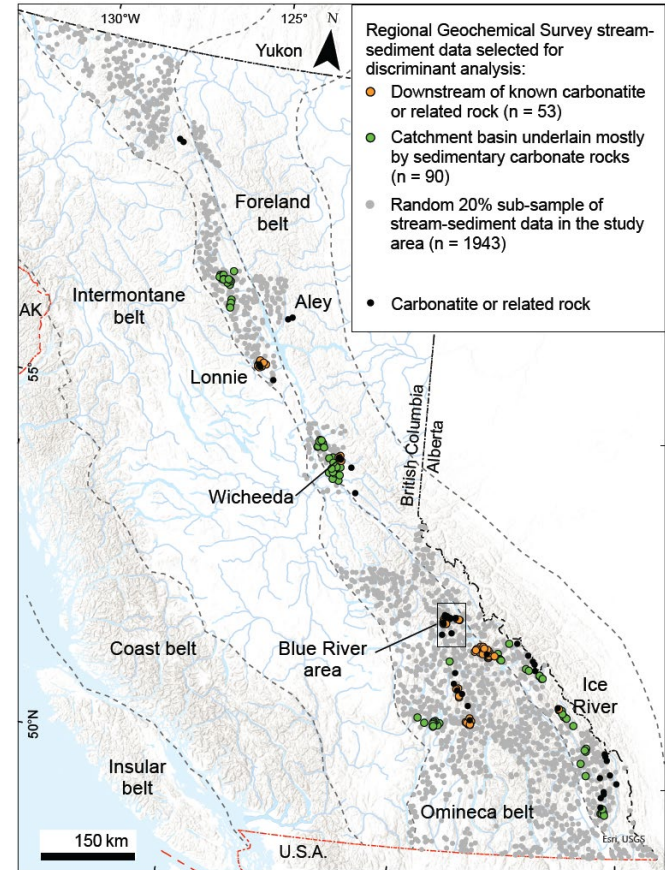
Discrimination diagram

Based on 20 variables and a random 50% training sub-set of the group 1 to 3 data, discrimination diagram DP1 versus DP2 optimally separates the stream-sediment data downstream of known carbonatites from other data
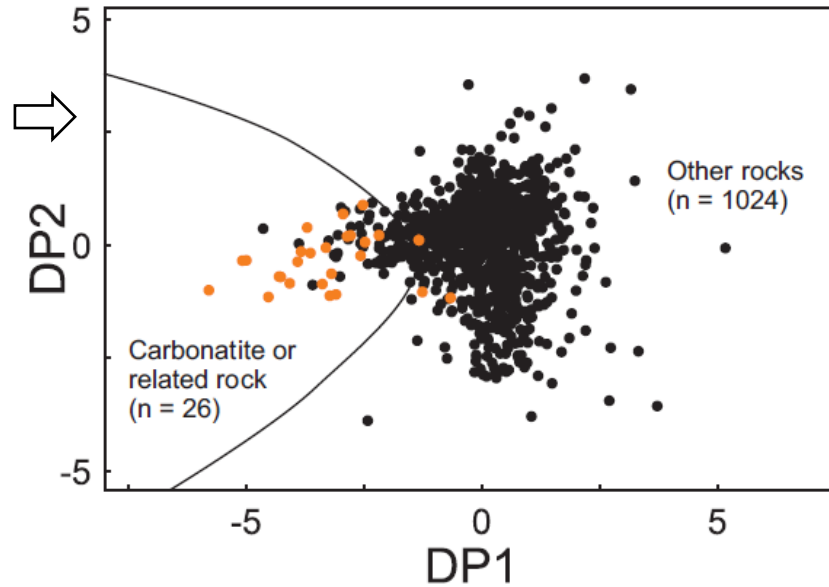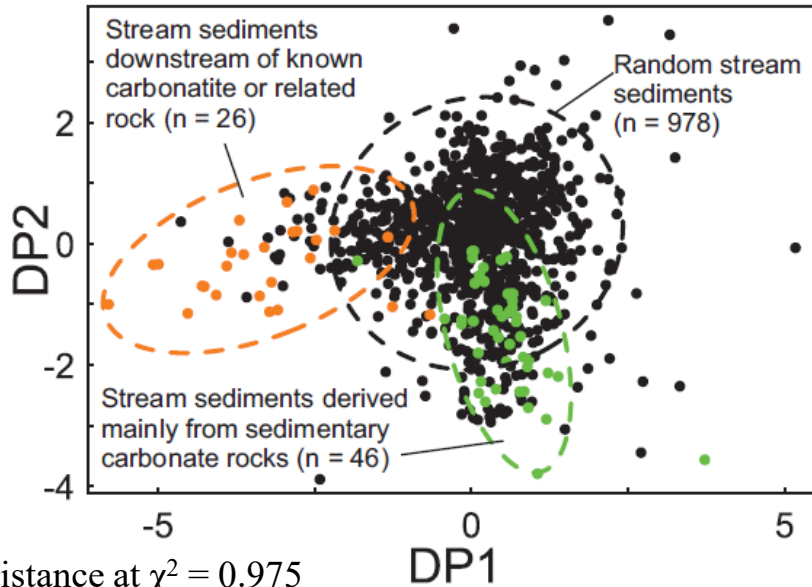

M-distance at $\chi^2 = 0.975$

Not used in the discriminant analysis, a random 50% test sub-set of the stream-sediment data validates the discrimination diagram DP1 versus DP2 with a boundary separating carbonatite or related-rock and other rock sources

M-distance at $\chi^2 = 0.975$

Applied to all RGS data

- Discrimination diagram identified 721 stream basins (~6% of all data) showing carbonatite or related rock signal

- We refer to this signal as the 'carbonatite index', which is the value of DP1 score multiplied by minus one
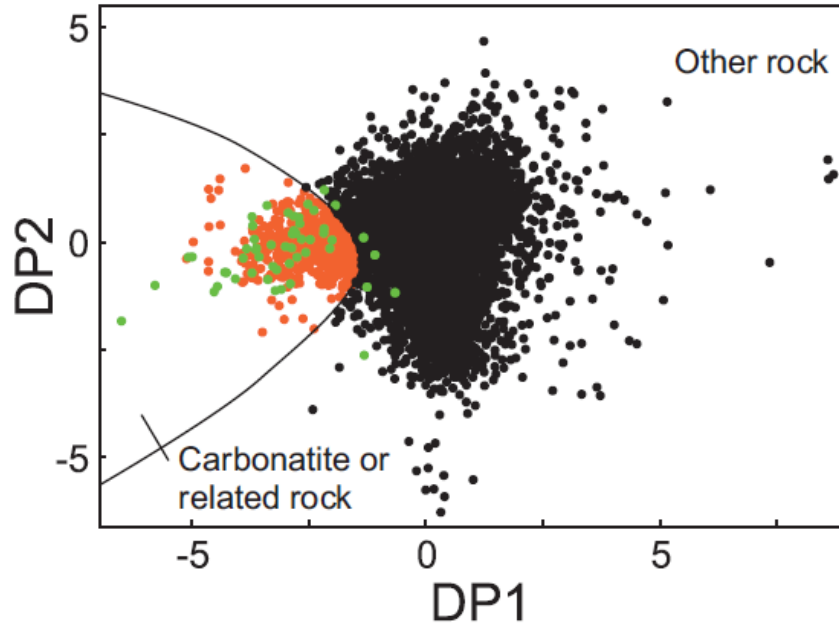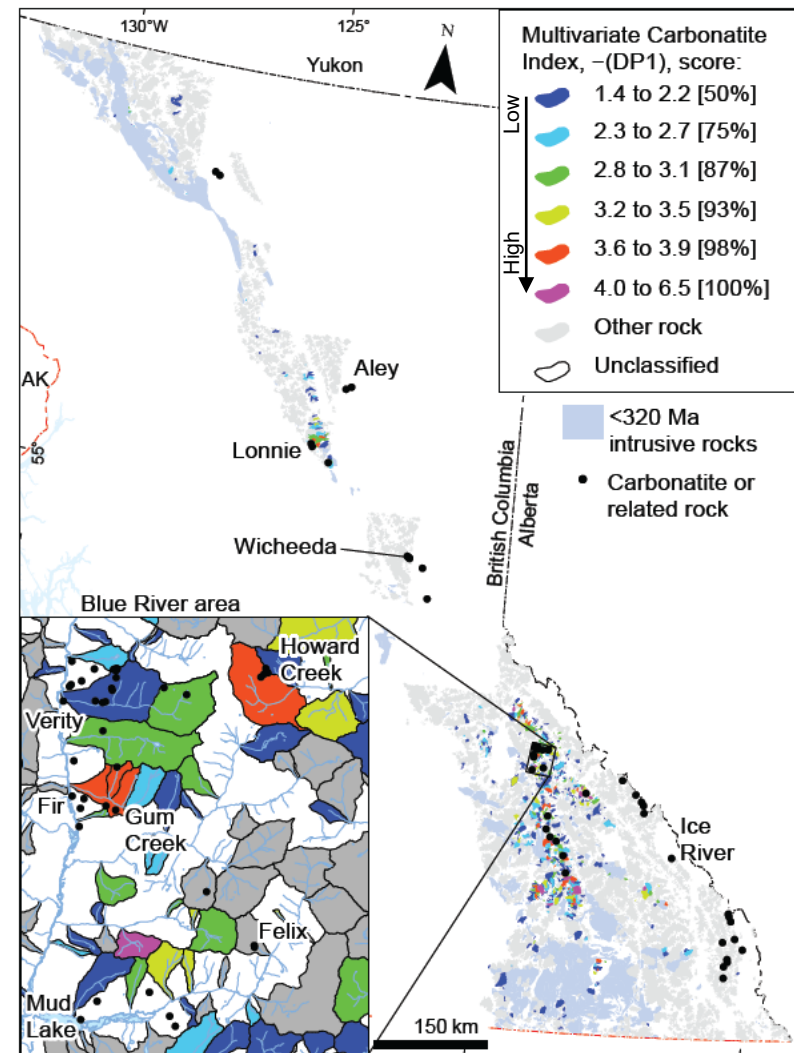

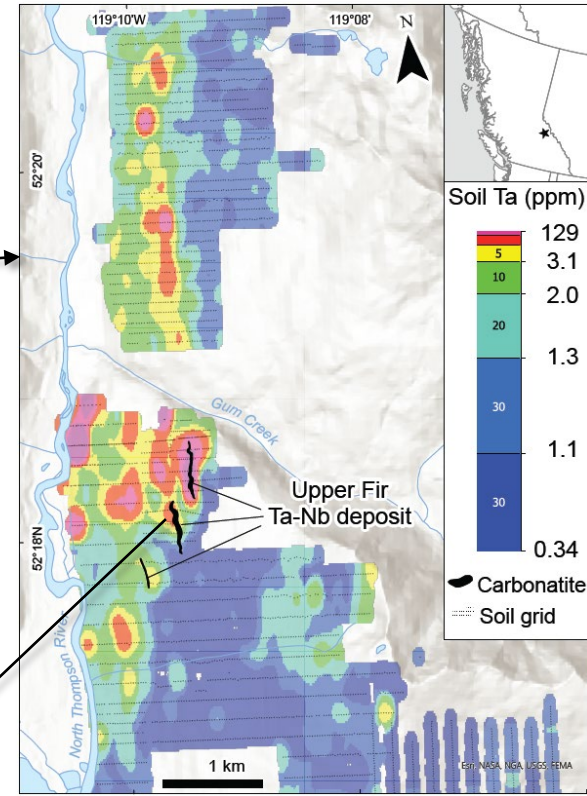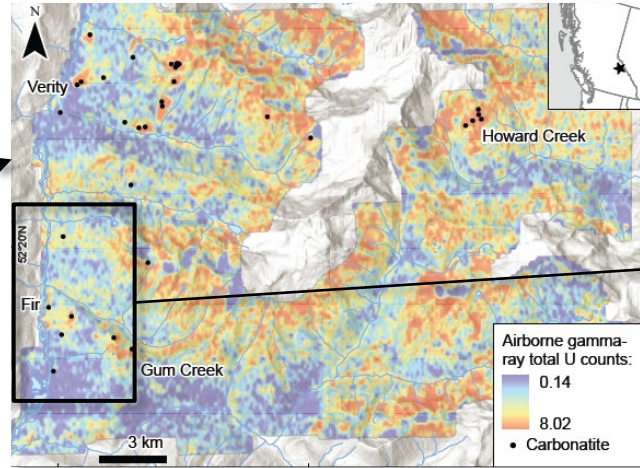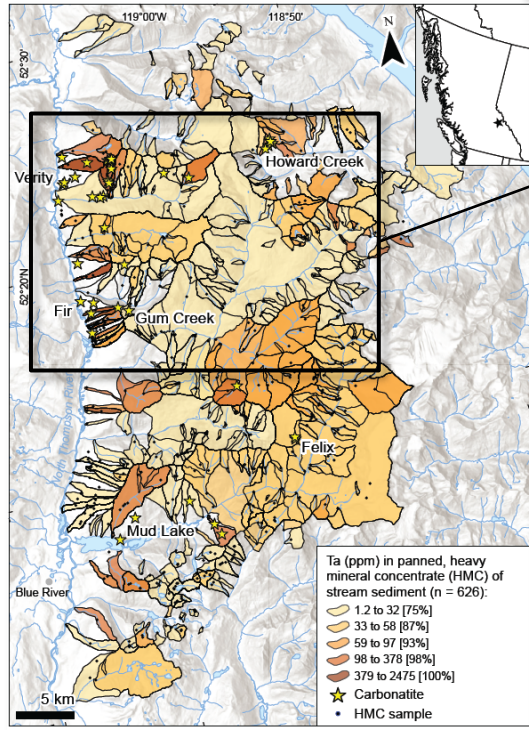Regional geochemical survey (RGS) stream-sediment data in the study area:

- 🟢 Downstream of known carbonatite or related rock (n = 53)

- 🟠 Carbonatite-like source upstream (n = 721)

- ⚫ Derived from other rocks (n = 9067)

Non-multivariate samples (n = 1660) are unclassified

Carbonatite index-themed catchments

- Highlight prospective stream basins for critical metals

- Reveal elevated contents of REE, Nb, Ta, Ti, Zr, Hf, Th, U, P, K, and Na

- Estimated geochemical resources suggest significant potential for REE and other carbonatite-hosted metals

1. Stream anomaly ⇨ 2. High-resolution airborne response ⇨ 3. Soil anomaly

Ta (ppm) in panned, heavy mineral concentrate (HMC) of stream sediment (n = 626):
- 1.2 to 32 [75%]
- 33 to 58 [87%]
- 59 to 97 [93%]
- 98 to 378 [98%]
- 379 to 2475 [100%]
- ★ Carbonatite
- • HMC sample

Airborne gamma-ray total U counts:
0.14
8.02
• Carbonatite

Soil Ta (ppm)
129
5   3.1
10   2.0
20
1.3
30
1.1
30
0.34
Carbonatite
Soil grid

Upper Fir Ta-Nb deposit

4. Critical metals resources

Thank you!

British Columbia Geological Survey