An assessment of the carbon mineralization potential of ultramafic rocks in British Columbia

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Abstract:

Ultramafic rocks and their altered serpentinite products are variably reactive with carbon dioxide at surface conditions and may, therefore, be used to mineralize and sequester carbon dioxide and to mitigate greenhouse gas (GHG) emissions. British Columbia contains extensive volumes of serpentinized ultramafic rock; however, they are poorly characterized. Serpentinization (hydration) results in distinct changes in the magnetic and density properties of ultramafic rocks such that they should be identifiable from airborne geophysical surveys. The Carbon Mineralization Potential Project for British Columbia (CaMP-BC) assesses the abundance, location, shape, and areal extent of serpentinized ultramafic rocks in B.C. using existing geological, geochemical, and geophysical data and recent advances in geophysical inversion techniques. Here, we present: 1) the general workflow used to identify and quantify the volume of highly-reactive ultramafic rocks in BC; 2) two case studies (the Decar and Turnagain nickel deposits) that were used to test our integrated approach; and 3) total volumetric estimates of reactive ultramafic rocks in BC made on the basis of geophysical inversions along with their estimated sequestration capacity. British Columbia serpentinites have a total sequestration capacity exceeding 800 years of provincial GHG emissions at current rates and the use of reactive serpentinite tailings from nickel deposits represents an opportunity to develop a carbon-neutral nickel-mining industry. Given the importance of nickel for developing environmentally-sustainable energy and transport sectors, the carbon mineralization of serpentinites may be critical to the decarbonization of supply chains for renewable energy.

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1 - INTRODUCTION

Ultramafic rocks and their serpentinite products are variably reactive with carbon dioxide at surface conditions and may, therefore, be used to mineralize and sequester carbon dioxide and to mitigate greenhouse gas (GHG) emissions. British Columbia contains extensive volumes of serpentinized ultramafic rock; however, they are poorly characterized. Serpentinization (hydration) results in distinct changes in the magnetic and density properties of ultramafic rocks such that they should be identifiable from airborne geophysical surveys. The Carbon Mineralization Potential Project for British Columbia (CaMP-BC) assesses the abundance, location, shape, and areal extent of serpentinized ultramafic rocks in B.C. using existing geological, geochemical, and geophysical data and recent advances in geophysical inversion techniques. Here, we present: 1) the general workflow used to identify and quantify the volume of highly-reactive ultramafic rocks in BC; 2) two case studies that were used to test our integrated approach; and 3) total volumetric estimates of reactive ultramafic rocks in BC made on the basis of geophysical inversions along with their estimated sequestration capacity.

2 - GEOLOGICAL FRAMEWORK AND STUDY SITES

Serpentinization: net volume-increasing reaction and involves the production of **serpentine and magnetite**.

R1: olivine + orthopyroxene + H_2O ⟶ serpentine + brucite + magnetite +/- awaruite

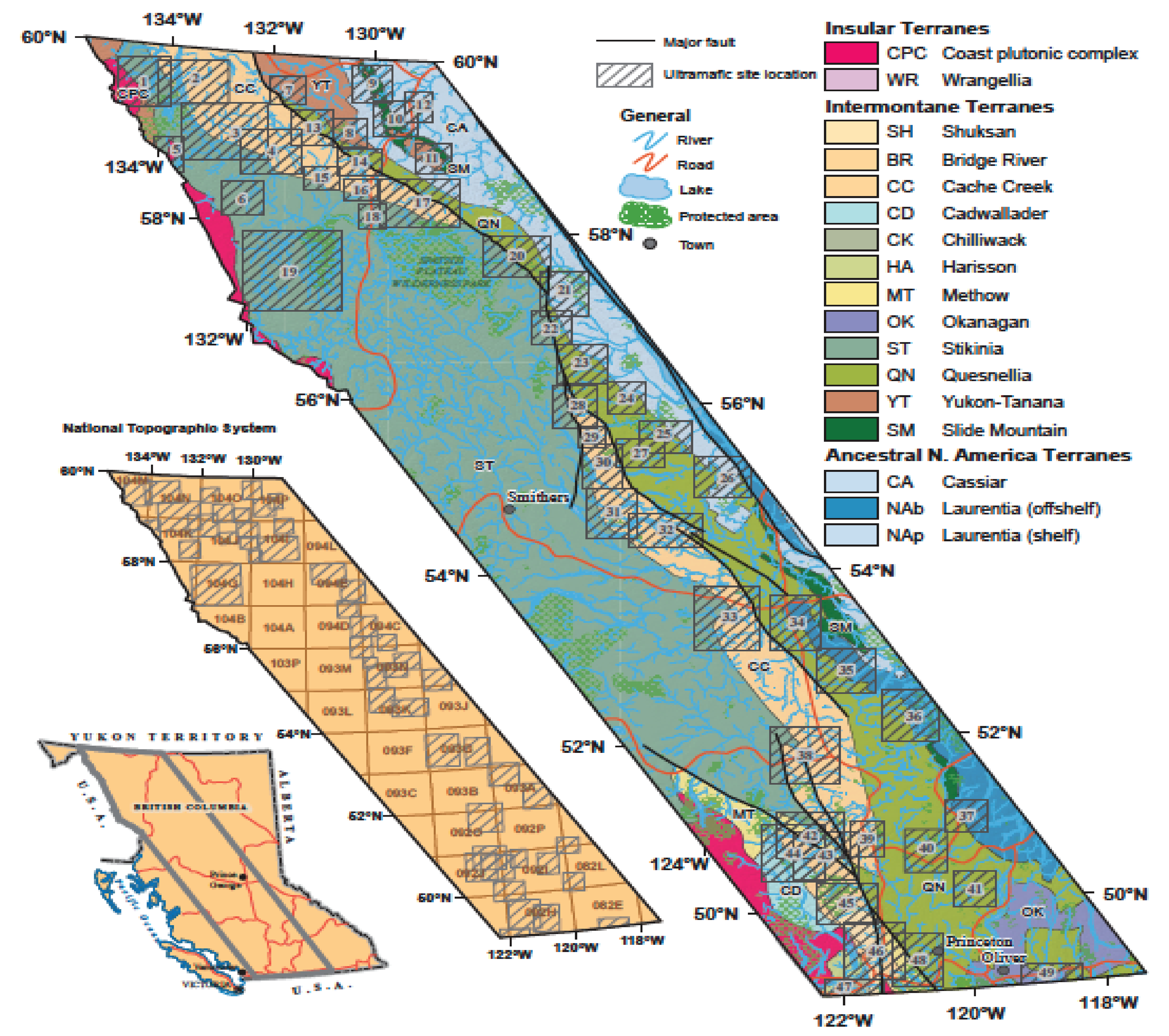
Carbonation: Consumes **magnetite, brucite, and serpentine** to form rocks dominated by **magnesite.**

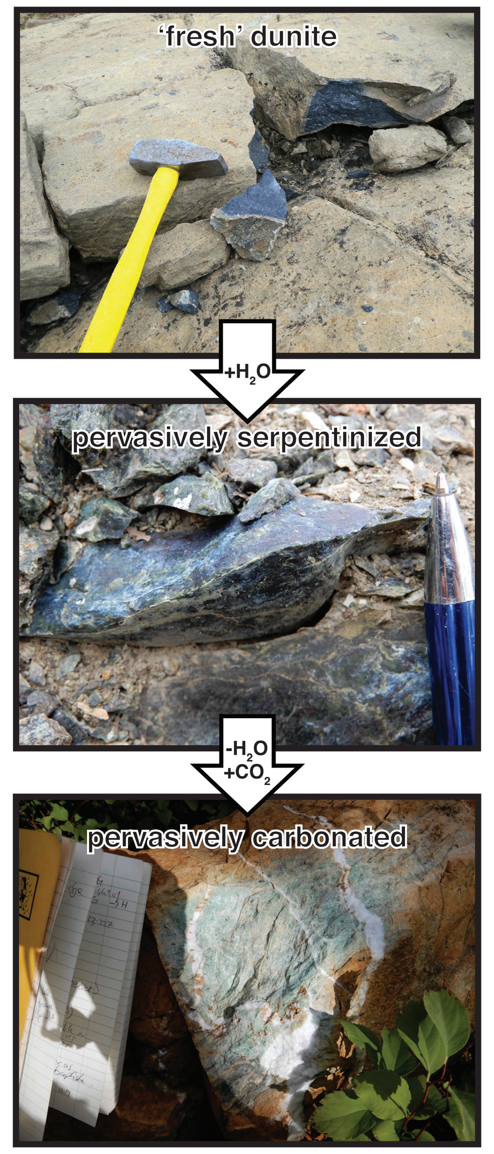
R2: olivine + brucite + CO_2 ⟶ serpentine + (ferro-)magnesite + H_2O

R3: serpentine + magnetite + CO_2 ⟶ (ferro-)magnesite + talc/minnesotaite + H_2O

R4: talc/minnesotaite + CO_2 ⟶ (ferro-)magnesite + quartz

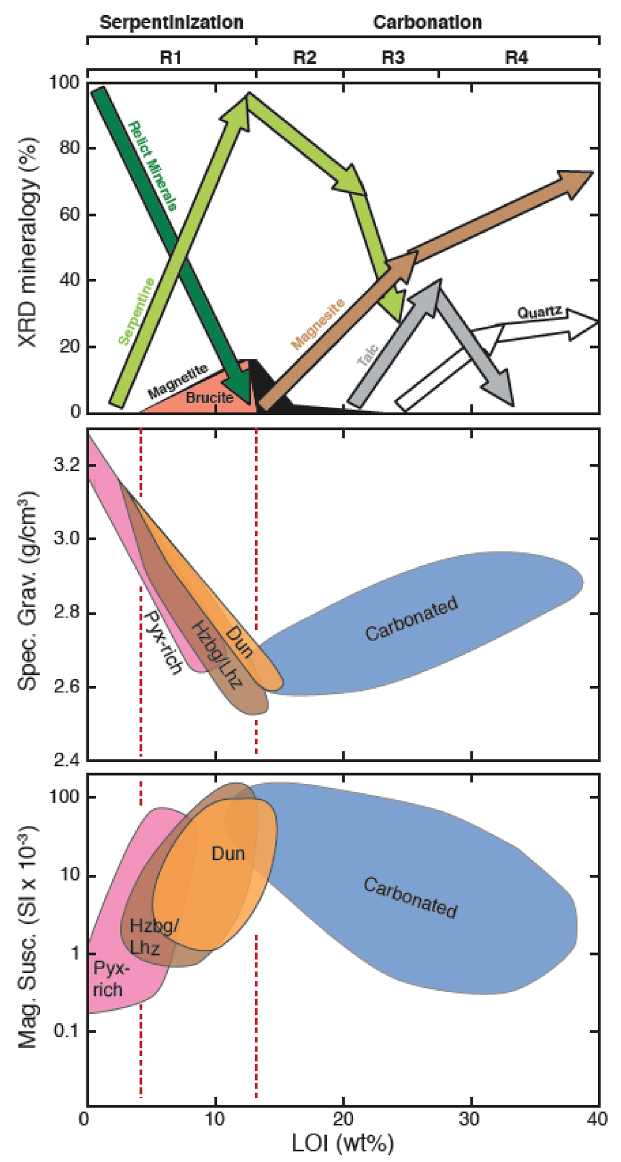
The formation of magnesite during carbonation is analagous to reactions that would occur during carbon sequestration

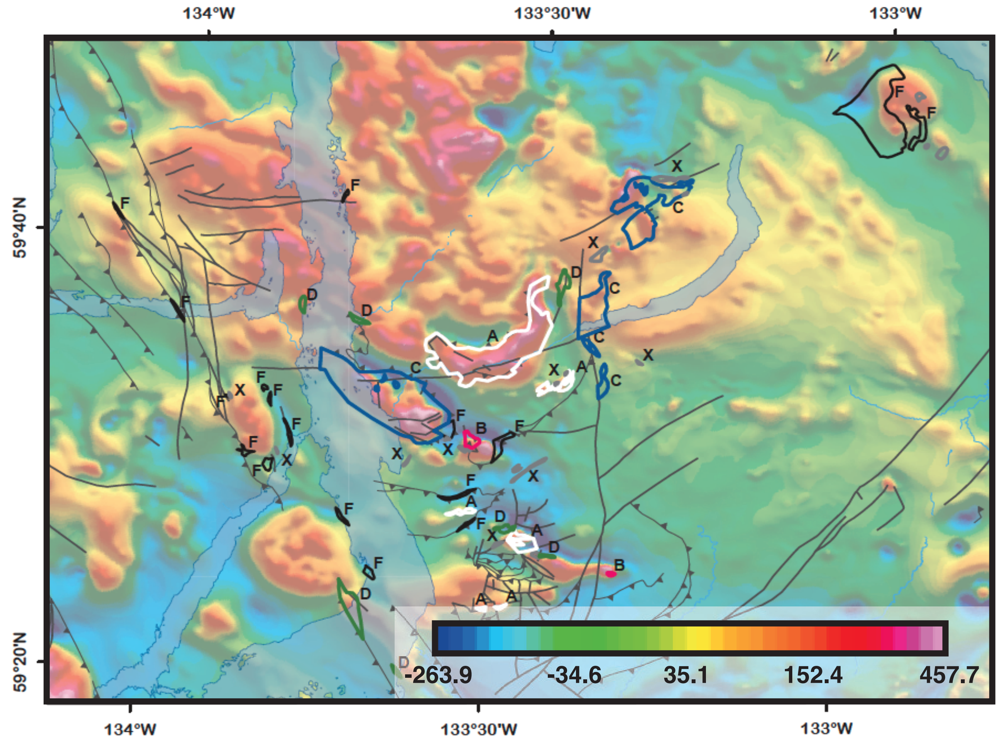




(left) There are >800 mapped occurrences of ultramafic rocks in British Columbia; these were grouped based on geographic occurrence and geological context (e.g., ophiolite vs. intrusive rock).

3 - PHYSICAL PROPERTIES OF ALTERED ULTRAMAFIC ROCKS



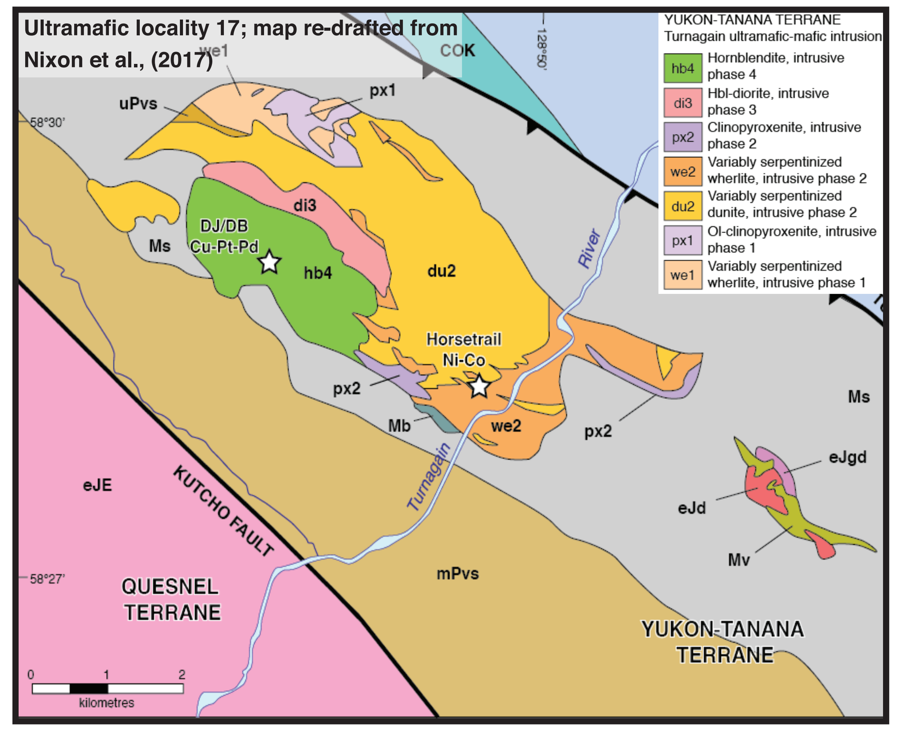


Class	Description	Confidence anomaly related to unit	# of polygons
A	Positive anomaly correlates well with mapped unit	High	78
B	Positive anomaly extends beyond mapped unit	High	105
C	Irregular or patchy positive anomaly within mapped unit	High	158
D	Polygon with offset anomaly	Low	39
E	Can't isolate a magnetic signal from surrounding material	Low	38
F	Weak to no anomaly correlated to polygon	None	95
X	Small polygon of varied response; insignificant contribution to total ultramafic volume	None	210
ND	No data	None	23
	Total		**746**

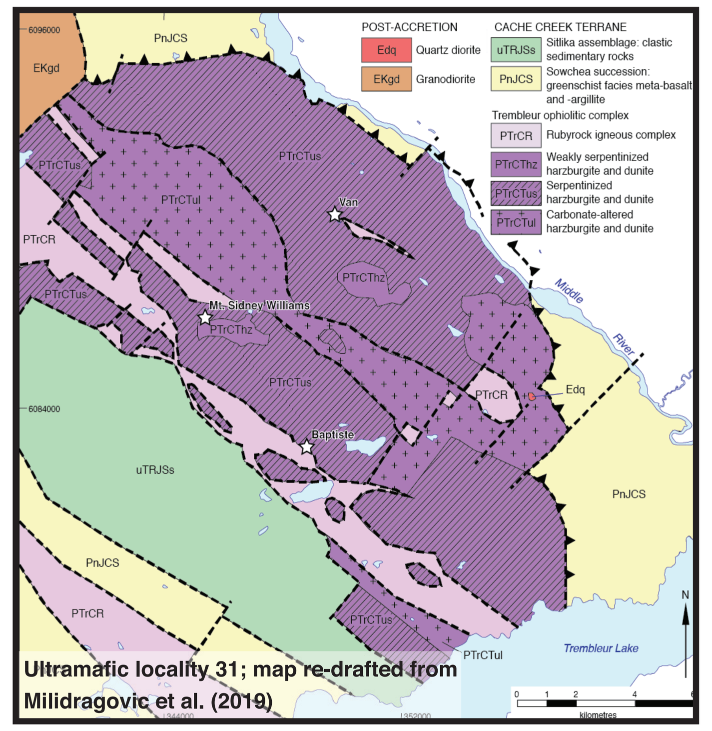
The mineralogy and physical properties of >500 samples of ultramafic rock (left) demonstrate that pervasively-serpentinized rocks that contain abundant brucite--a highly-reactive mineral with CO2--have lower density and higher magnetic susceptibility than their fresh and carbonated equivalents.

High-resolution density surveys are not common in BC; we instead rely on regional magnetic data (e.g., top-right: an example output for the Atlin area: locality #2). Ultramafic rock occurrences were classified according to the coincidence between positive magnetic anomalies and mapped ultramafic rocks. (classification shown in bottom- right).

4A - CASE STUDIES: TURNAGAIN AND DECAR GEOLOGY



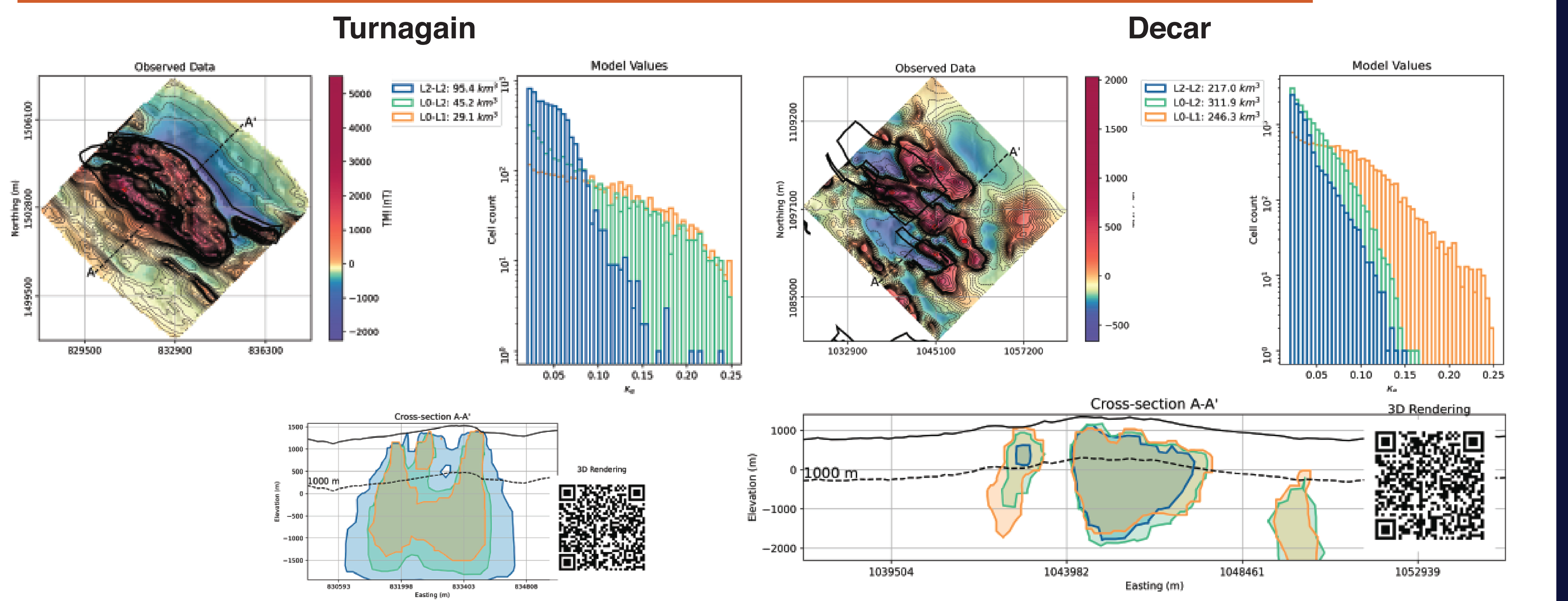
Ultramafic locality 17; map re-drafted from Nixon et al., (2017)



Ultramafic locality 31; map re-drafted from Milidragovic et al. (2019)

The Turnagain intrusion (left) and Decar nickel district (right) are two key case studies used to test the workflow due to the abundance of lithological, geochemical, and geophysical data. Turnagain hosts Ni-Co sulphide mineralization in variably-serpentinized dunitic and wehrlitic rocks, whereas in the Decar nickel district, nickel is hosted in Ni-Fe alloys that typically occur in highly-serpentinized harzburgites (See Steinthorsdottir et al. poster for more details).

4B - GEOPHYSICAL INVERSIONS OF CASE STUDY AREAS



Inversions of high-resolution aeromagnetic data from the Turnagain intrusion (left) and Decar nickel district (right). Inversions were done using different constraints (lp norms) applied to the model values and spatial gradients; the choice of lp norm determines the level of blockiness or smoothness and the volume of the calculated 3D physical property model. See Naylor et al. poster for more details on geophysical inversions. For both localities:

- Top-left: observed magnetic data
- Top-right: the effective susceptibility ranges for the three main model results
- Bottom: vertical cross-section along A-A' showing outlines of high effective susceptibility volumes using 20 SI x 10^{-3} as a lower cut-off for the physical properties of pervasively-serpentinized rocks.

Volumes of serpentinized ultramafic rocks determined from six localities containing the largest A, B, and C classified polygons (~50 % of the total in BC) and the extrapolated total for the province

Locality Name	Locality #	Volume assuming 0.5 km thickness (km^3)	Upper 0.5 km of high susc volume (km^3)	Upper 1.0 km of high susc volume (km^3)	Upper 2.0 km of high susc volume (km^3)	Upper 4.0 km of high susc volume (km^3)	Full high susc volume (km3)
Atlin	2	30	6	21	50	56	56
Sylvester Allochthon	9 - 10	31	1	13	51	70	70
Dease Lake	17	207	4	88	596	1375	1414
W. Hogem Batholith	28 - 30	134	38	131	410	888	888
Trembleur/Decar	31	124	37	153	449	826	840
Bridge River	42	150	17	58	199	493	501
Total		676	103	464	1755	3708	3769
Extrapolated Total		1438	219	988	3738	7898	8028

Carbon dioxide sequestration capacity for all of B.C. based on various depth intervals and methods

Depth Interval (km)	Serpentinite Volume (km^3)	Sequestration Capacity (Gt CO_2)	Method
0 to 1	988	56	*ex-situ* carbonation
0 to 2	3,738	210	*ex-situ* carbonation
2 to 4	4,160	5,139	*in-situ* carbonation
2 to full depth	4,290	5,300	*in-situ* carbonation

5 - KEY TAKEAWAY POINTS

1. Development of physical property model for ultramafic rocks combined with refined inversion techniques demonstrate large volumes of reactive material in BC
2. Inversions can approximate the size and shape of ultramafic bodies but artificially push volumes to depth (they are known to occur at surface) partly due to compilation and gridding of legacy data. This will be addressed in future work.
3. Using a 1 km-depth cut-off, if the volumes of reactive ultramafic rock are mined and exposed to the atmosphere, 800 years of B.C.'s greenhouse gas emissions could be mineralized and stored (based on 2018 emissions).

Read more about it in our pre-liminary Geoscience BC report!

We gratefully acknowledge FPX Nickel Corp., and Giga Metals Corp. for access to samples from the Decar ophiolite and Turnagain intrusion and A. Zagorevski from the Geological Survey of Canada–Central Division for providing access to samples from the northern BC ophiolites, which were collected as part of the Geo-mapping for Energy and Minerals-2 research program. The researchers in CarbMin Lab are also thanked for the continuing discussions on carbon sequestration.

References: Nixon et al. (2017). BC Geological Survey Geoscience Map 2017-1; Milidragovic (2018). BC Geological Survey OF 2019-06.