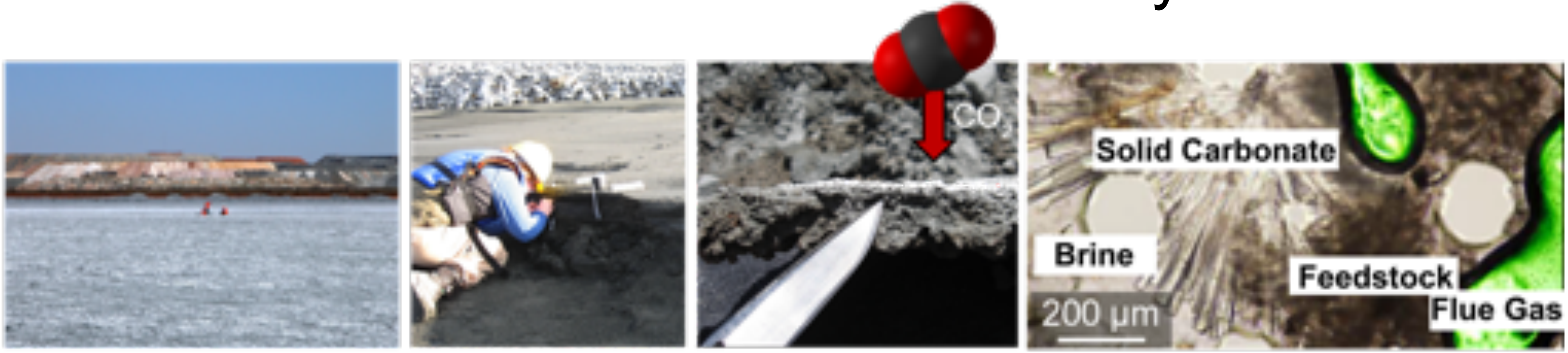
The Carbon Mineralization Potential of Ultramafic Rocks in British Columbia: A Preliminary Assessment



Dianne Mitchinson, Jamie Cutts, Dominique Fournier, Annika Naylor, Greg Dipple, Craig Hart, Connor Turvey, Mana Rahimi, Dejan Milidragovic

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MINERAL DEPOSIT RESEARCH UNIT
BRITISH COLUMBIA GEOLOGICAL SURVEY
CarbMinLab

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Carbon Mineralization Research Project

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The Carbon Mineralization research project seeks to develop practical, long-term, and safe carbon sequestration strategies through three research streams:

SCO_2UT (Sequestration of CO_2 in Ultramafic Tailings)

SCOUT aims to determine the rate-limiting constraints on carbon mineralization, prioritize strategies for accelerating carbon mineralization, engage the mining industry in carbon sequestration strategies, and demonstrate low-cost carbon sequestration technology.

CaMP (Carbon Mineralization Potential)

CaMP identifies the locations, distribution, abundances, geometries, and qualities of ultramafic rock bodies that are suitable for carbon mineralization. Once these are mapped and characterized, then the amount of CO_2 that can potentially be mineralized through reaction with these bodies can be quantified.

CarMA (Carbon Mineralization Analogues)

Natural analogue sites allow for the study of the geochemical and biological transformation of CO_2 at the field-scale in different reaction environments, ranging from weathering at the Earth's surface to hydrothermal alteration within the Earth's crust. Investigations into natural systems further our understanding of the conditions required for efficient carbonation and conditions for long-term stability of CO2 as carbonate minerals.

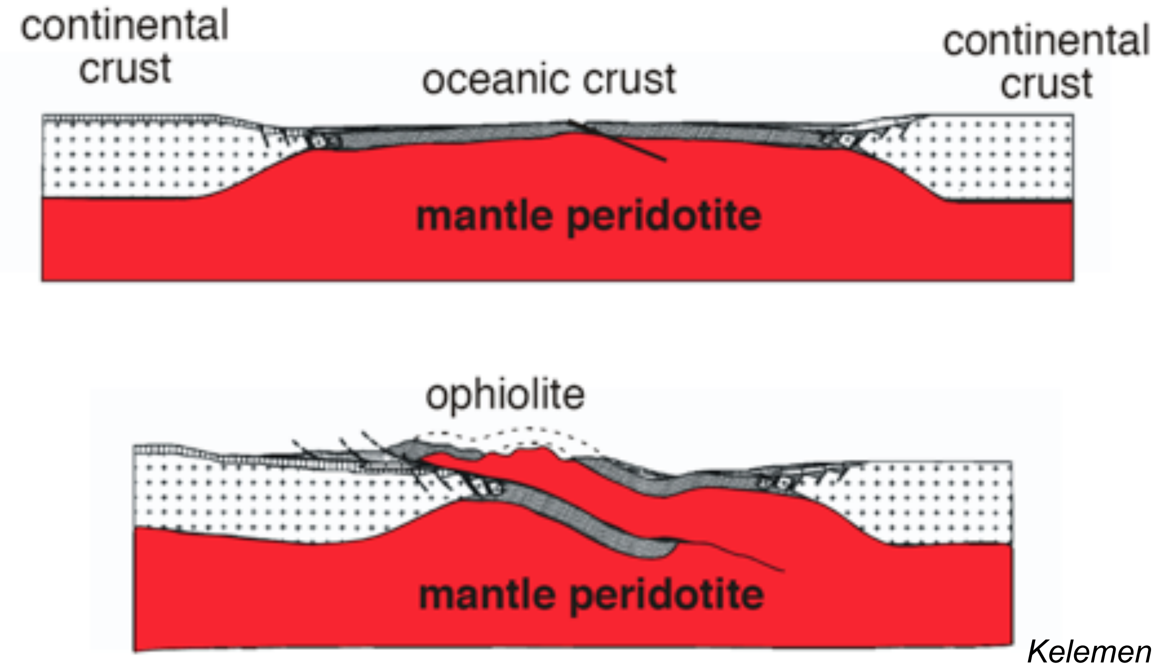
FPX Nickel Corp. TSX-V:FPX | GIGAMETALS CORPORATION | De Beers Group of Companies | Natural Resources Canada | British Columbia | Yukon Geological Survey | Northwest Territories | The University of Queensland Australia | University of Alberta | Trent University School of the Environment | INRS Institut national de la recherche scientifique

Carbon Mineralization in Ultramafic Rocks

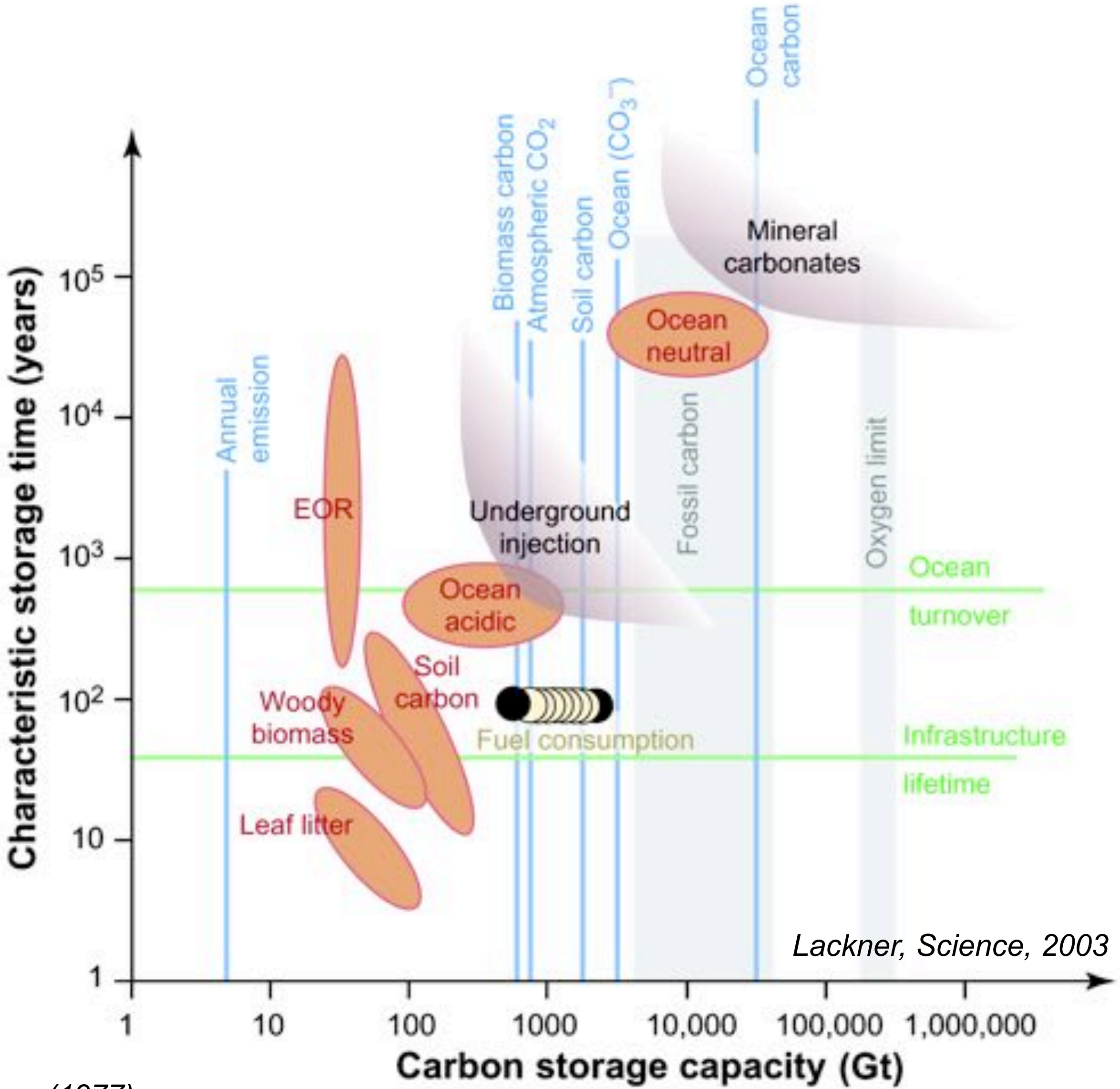
Carbon mineralization offers advantages over gas/liquid storage:

- stable over millennia
- dense
- virtually unlimited capacity (Petatonnes)
- geologic setting differs from “conventional” CCS

But slow to form in nature.



Kelemen after Coleman (1977)



Lackner, Science, 2003

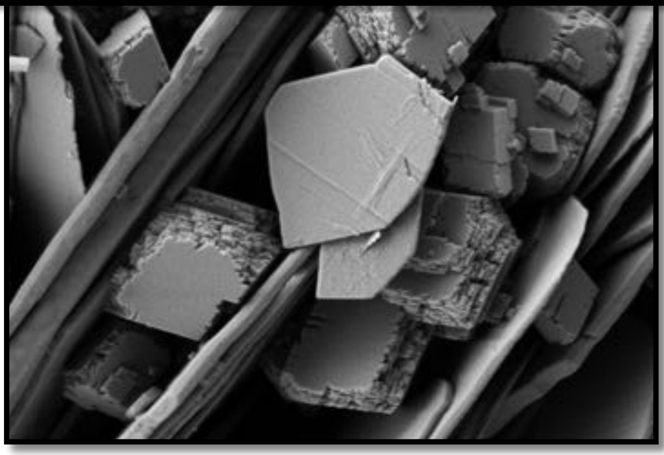
Geochemical Framework

Mineral dissolution

Cation source (Mg^{2+}) and pH buffer

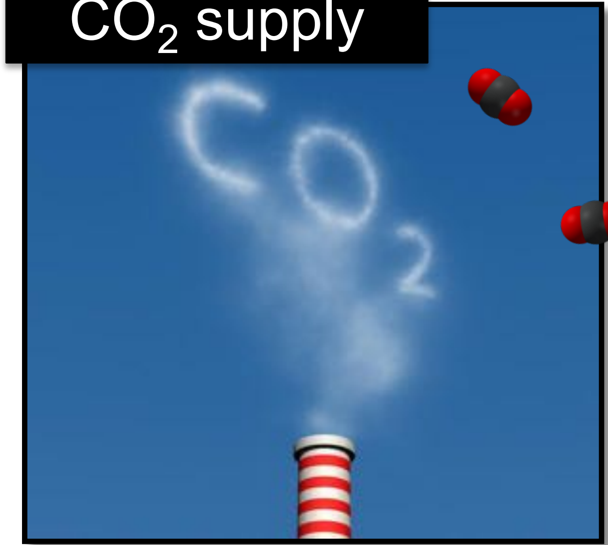
Mg^{2+} Mg^{2+} Mg^{2+}

Mineral Carbonate Precip'n



Permanent CO_2 Storage

CO_2 supply



Source of CO_2 (air or point source)

Carbon mineralization at operating mines

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Cementation of tailings originally deposited as water-sand slurry
Mt Keith Nickel Mine, WA, Australia

Mineralization of flue gas CO_2 concentrations in real time using mine tailings

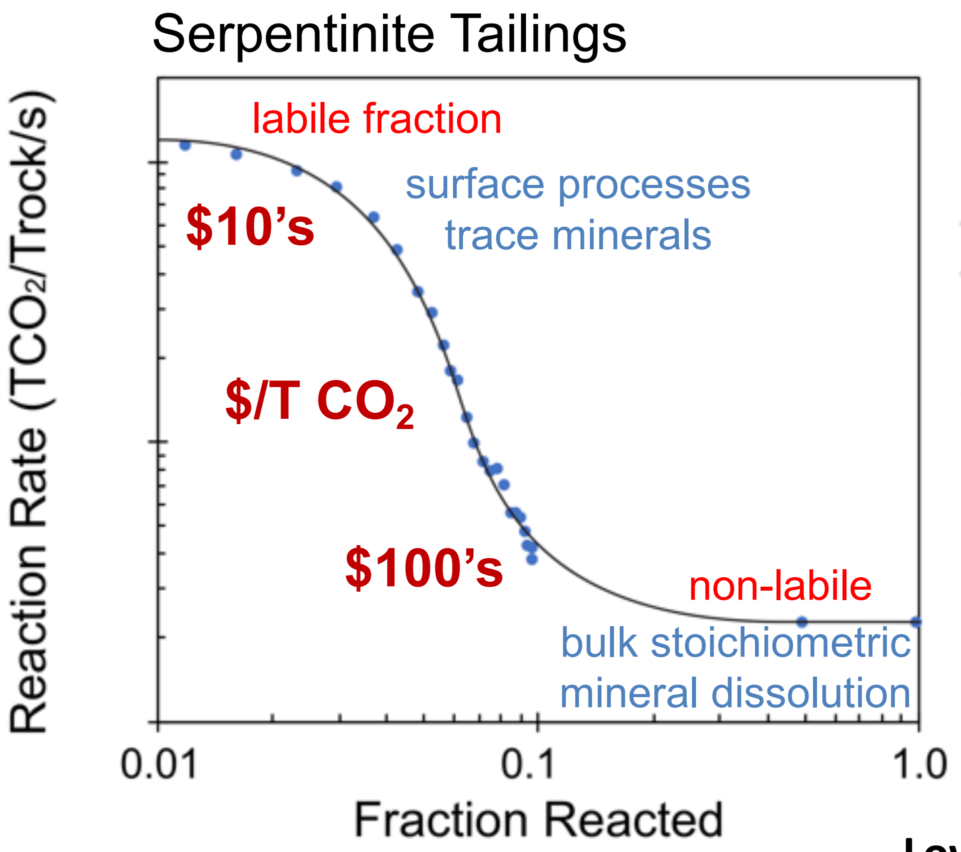
40,000 t/year CO_2
2.4 kg CO_2 / m^2 / year
Mt Keith Nickel Mine, WA, Australia

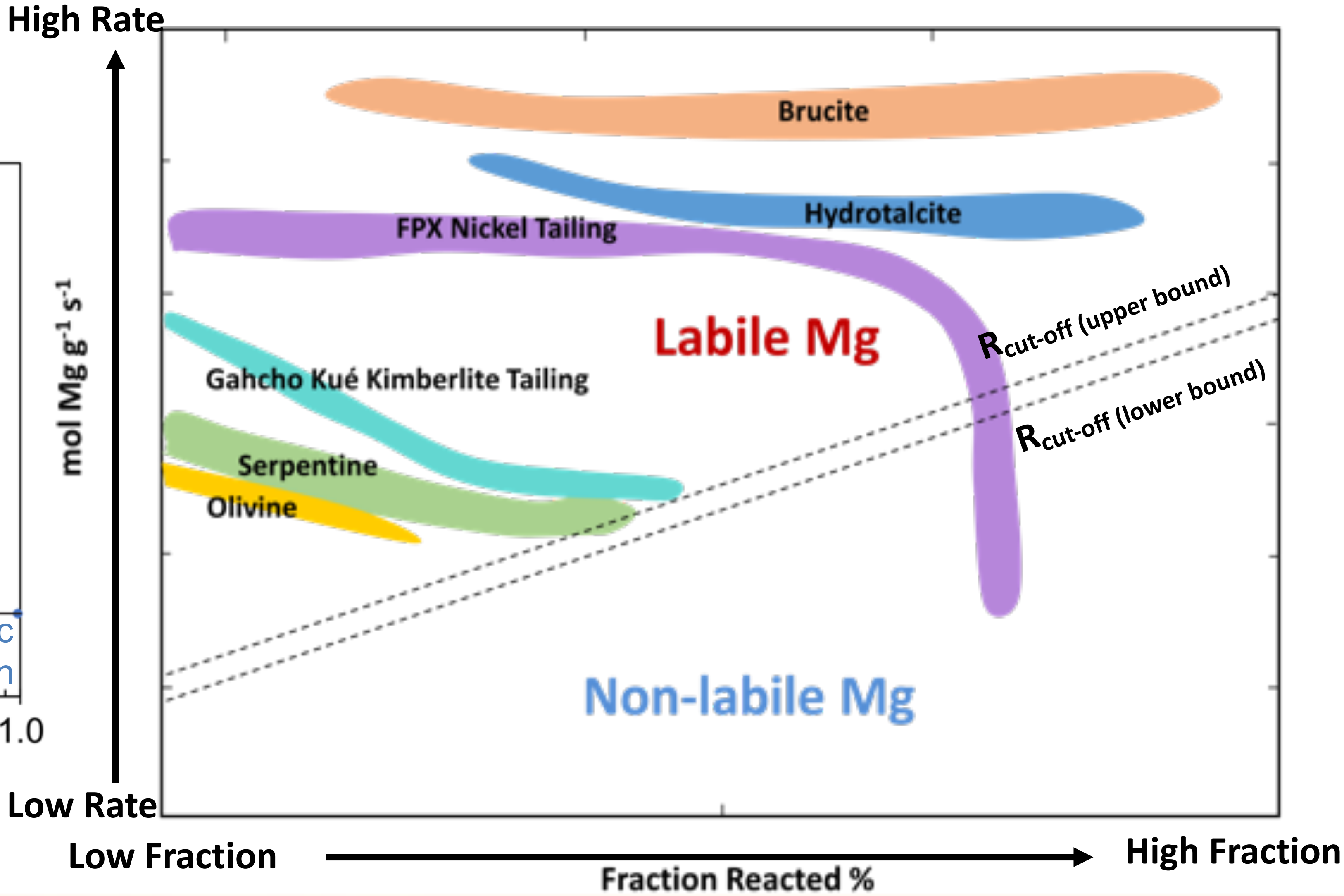
11 Mt tailings/yr

CO_2 direct air capture measured with soil gas chambers
3 kg CO_2 / m^2 / year

Labile Magnesium for Carbon Capture

Serpentinites have capacity to react with CO_2 in air.





(Lu, 2020)

Rock Physical Props Track Alteration

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Magnetic susceptibility is a proxy for serpentinization and carbonate alteration

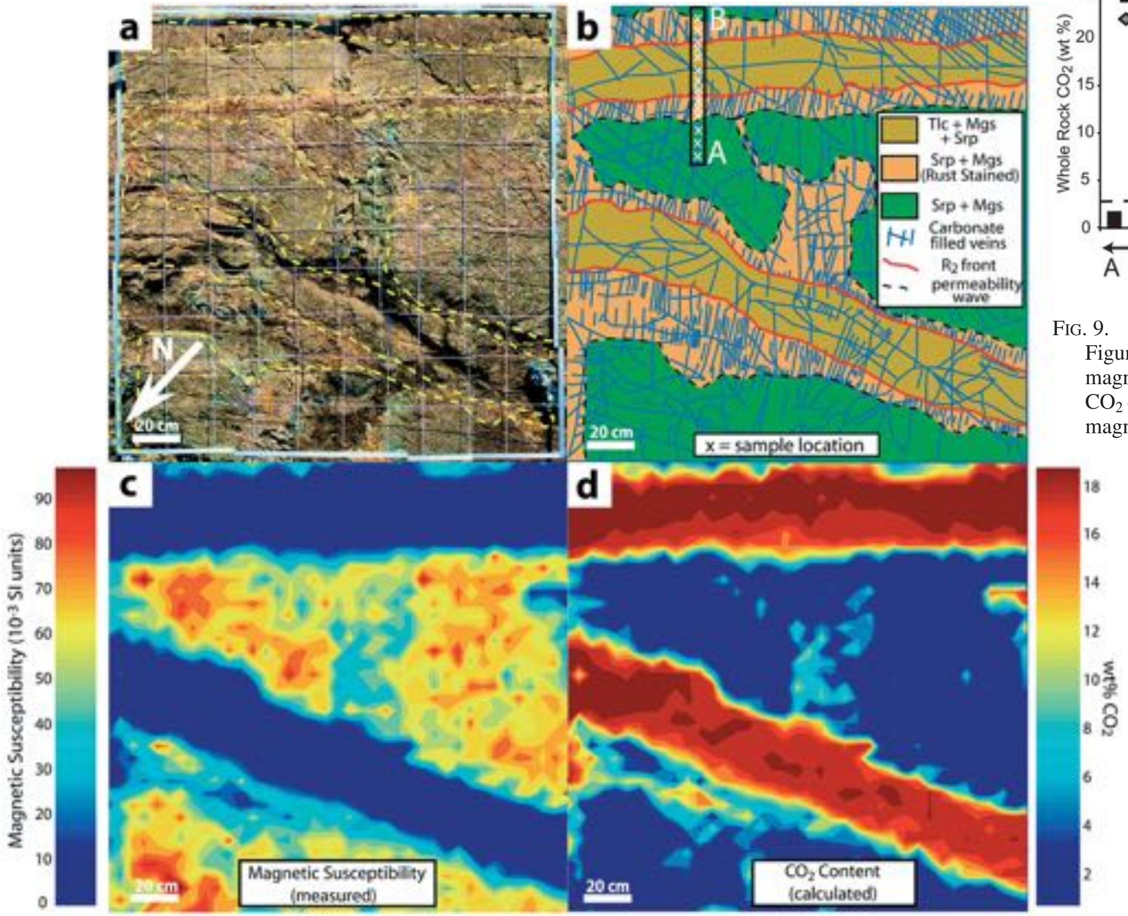


FIG. 8. a) Composite photograph of a 2 by 2 meter pavement-type outcrop on the western slope of Monarch Mountain (E 575887, N 6602098, WGS 84). b) Detailed geological map of the listwanite zone mapped at 1:20 scale. Sample locations and section A–B correspond to those of Figure 9. c) Magnetic susceptibility map, made from *ca.* 1550 measurements, showing the correlation of magnetic susceptibility with mineral content. d) Whole-rock wt% CO_2 map calculated using Eq_1.

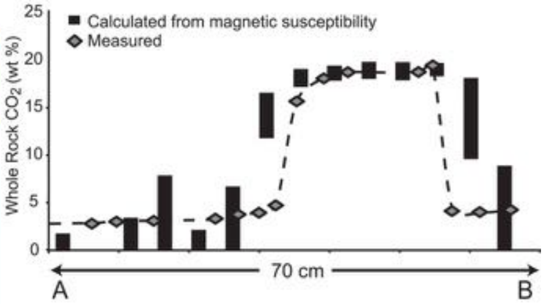
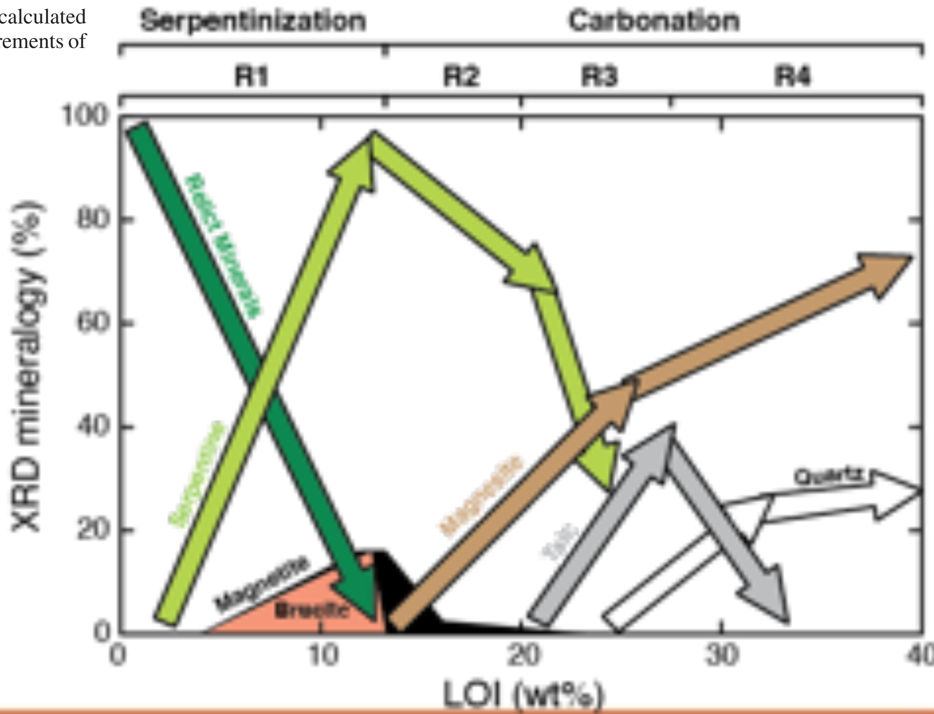


FIG. 9. Measured and calculated wt% CO_2 across A–B from Figure 8b. Wt% CO_2 is calculated using Eq_1 and data on magnetic susceptibility (Fig. 8c). The range in calculated CO_2 content reflects the full range of four measurements of magnetic susceptibility at each location.



(Hansen et al., 2005; This study)

Physical Properties Model

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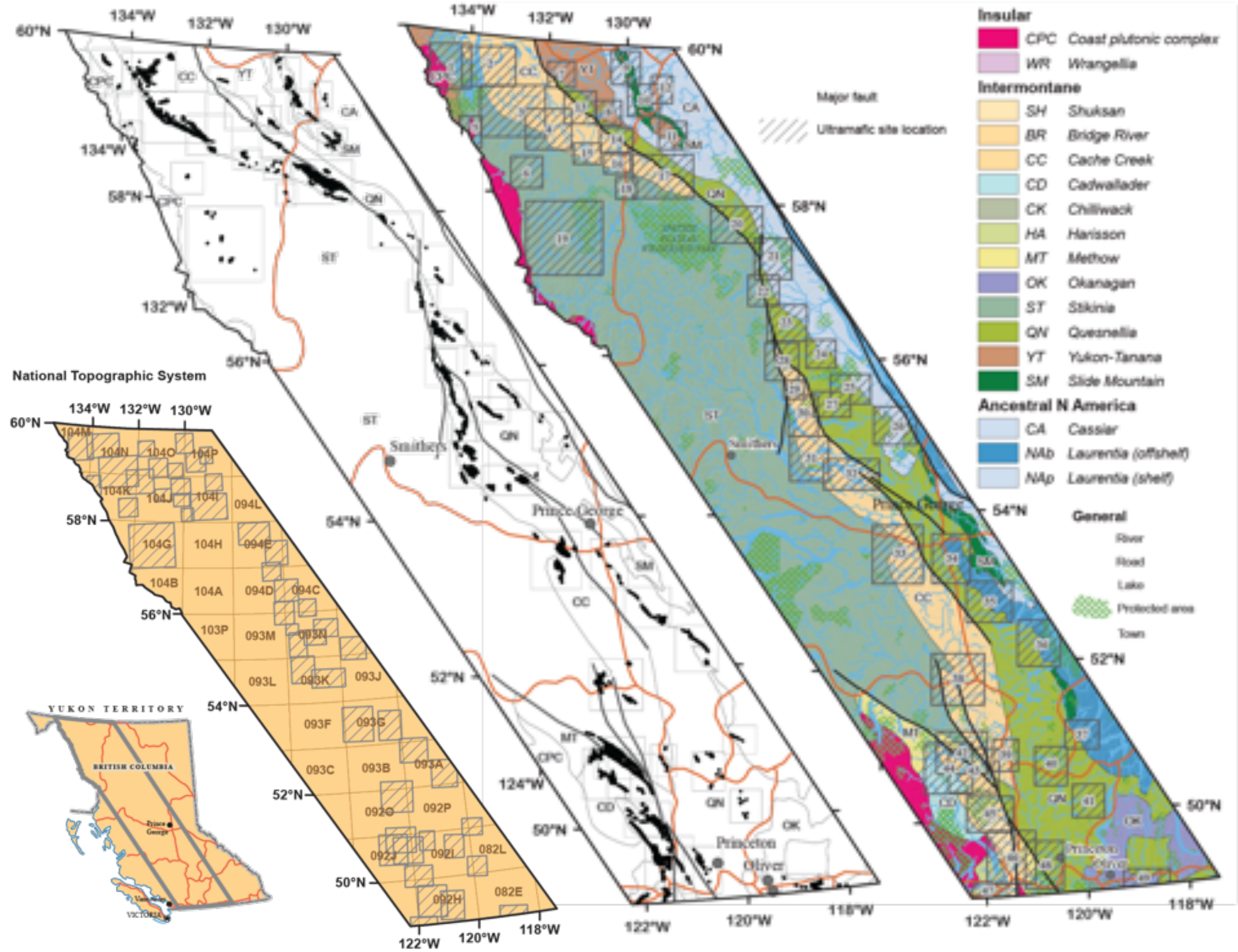

UMR Locality (Fig. 1)	Locality (general)	Locality (detail)	Total samples	Phys. Prop (UBC)	Phys. Prop (GSC)	qXRD
Ophiolitic Rocks						
2	Atlin	City proper	49	43	15	23
2		Monarch Mtn.	137	95	30	119
2		Union Mtn.	5	5	3	0
2		Sentinel Peak	1	1	0	1
2		Mt. Barham	5	5	2	0
2		Marble Dome	3	3	0	1
3	Nahlin	Hardluck Peak	3	3	2	0
3		Menatutuline Range	45	45	17	6
3		Mt. Nimbus	1	1	0	0
3		O'Keefe-Focus	3	3	2	0
3		Nahlin Mtn.	1	1	0	0
3		Peridotite Peak	2	2	2	2
3		Hatin Lake	4	4	0	0
3		Sunday Peak	2	2	0	0
N/A	S. Yukon	Jake's Corner/Squanga Lake	16	16	0	2
31	Decar	Baptiste	62	60	8	33
31		Van	15	15	5	8
31		Mt. S-W	23	23	10	17
31		Other	37	36	13	26
28		Hogem	20	19	4	0
17	King Mtn.	King Mtn.	20	20	10	6
		Sub-Total	454	402	123	244
Intrusive Rocks						
17	Turnagain	DJ/DB	36	36	0	11
17		Horsetrail	53	53	0	9
17		Cliff	4	4	0	1
17		Highland	5	5	0	0
23	Polaris	Polaris	95	95	0	0
		Sub-Total	193	193	0	21
		Total	**647**	**595**	**123**	**265**

Physical Properties Model

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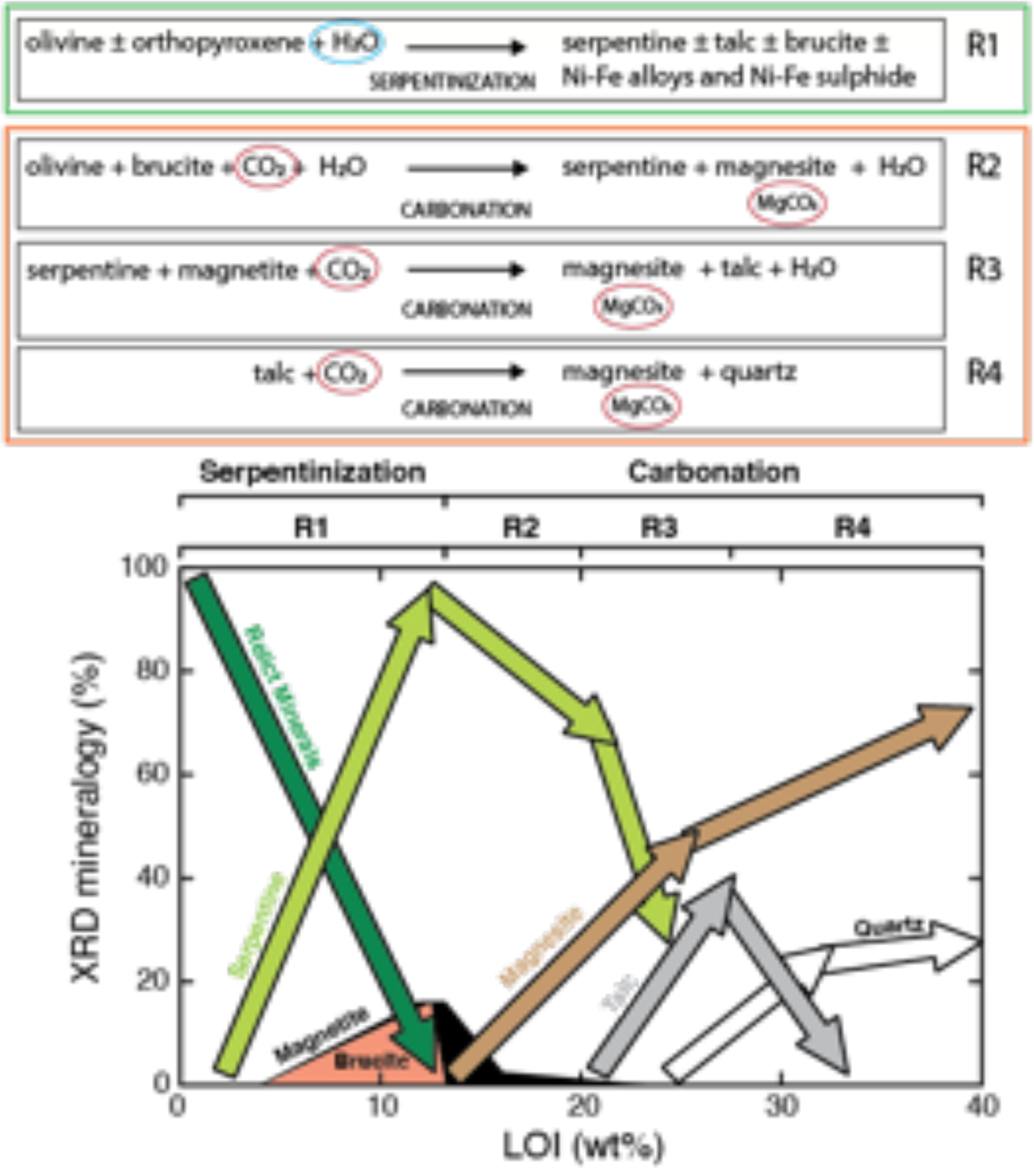
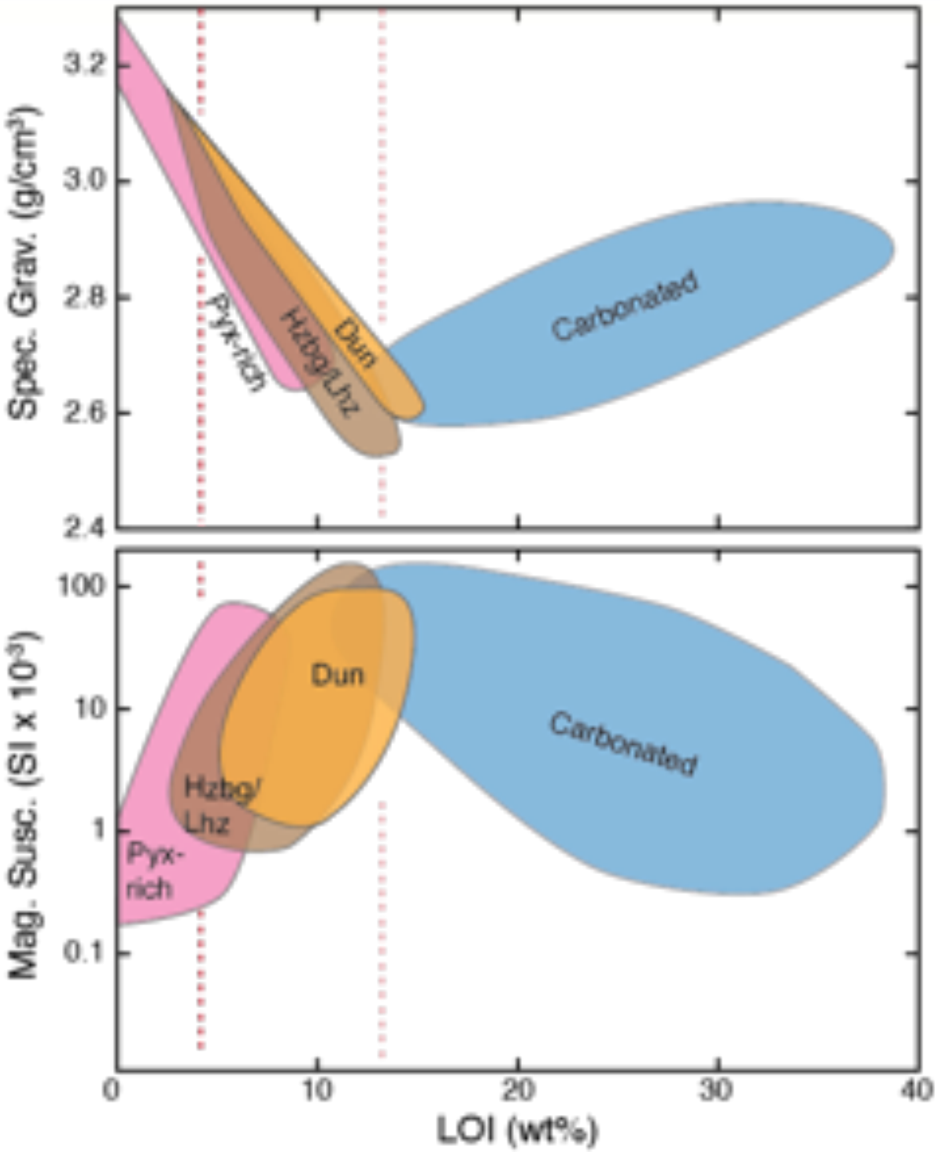
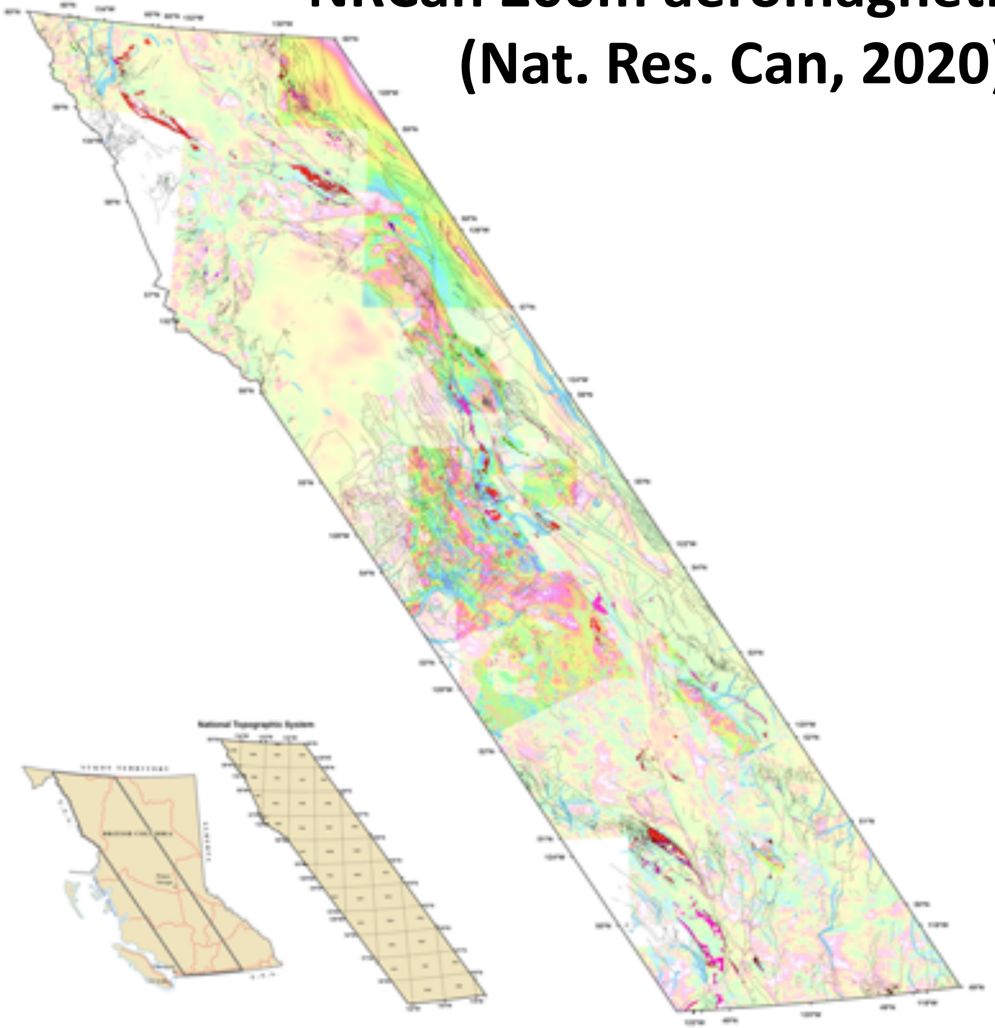
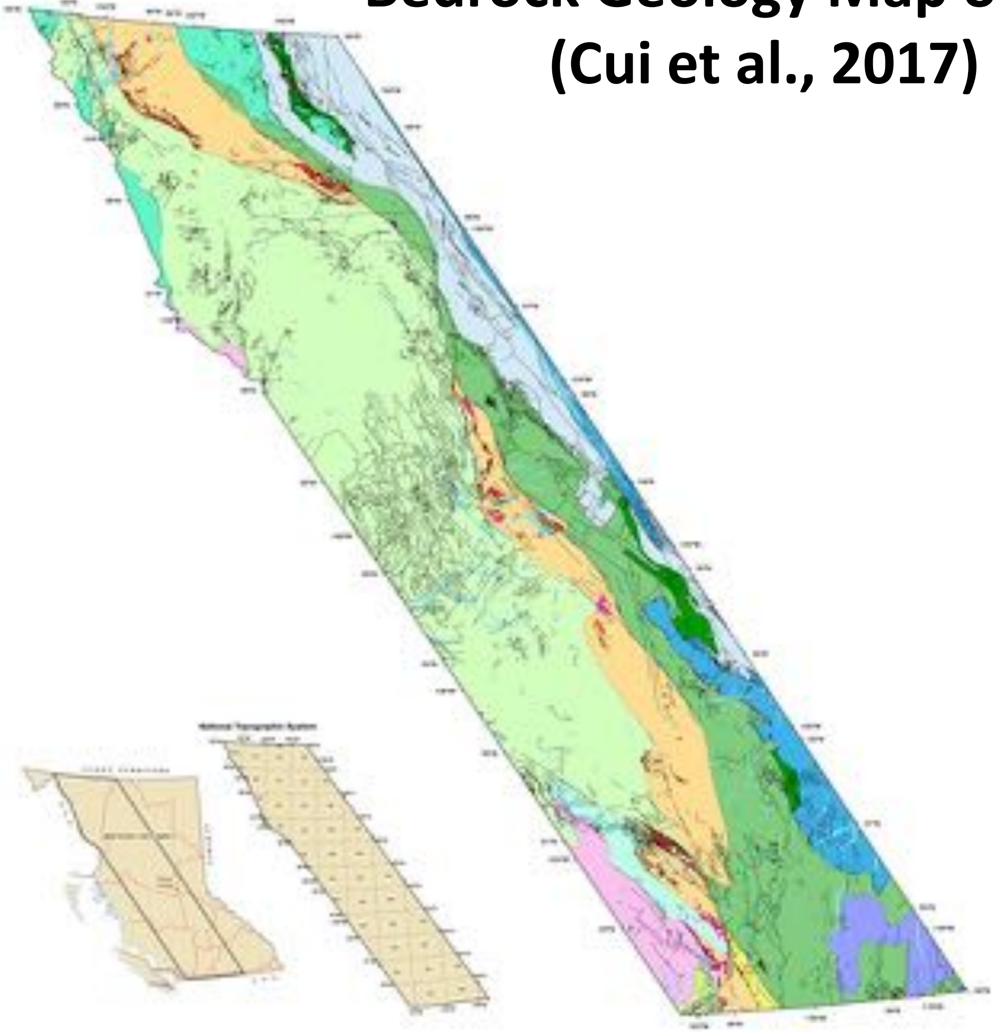




Integrating Two Datasets



NRCan 200m aeromagnetic data (Nat. Res. Can, 2020)



Bedrock Geology Map of B.C. (Cui et al., 2017)

Classification of Ultramafic Occurrences

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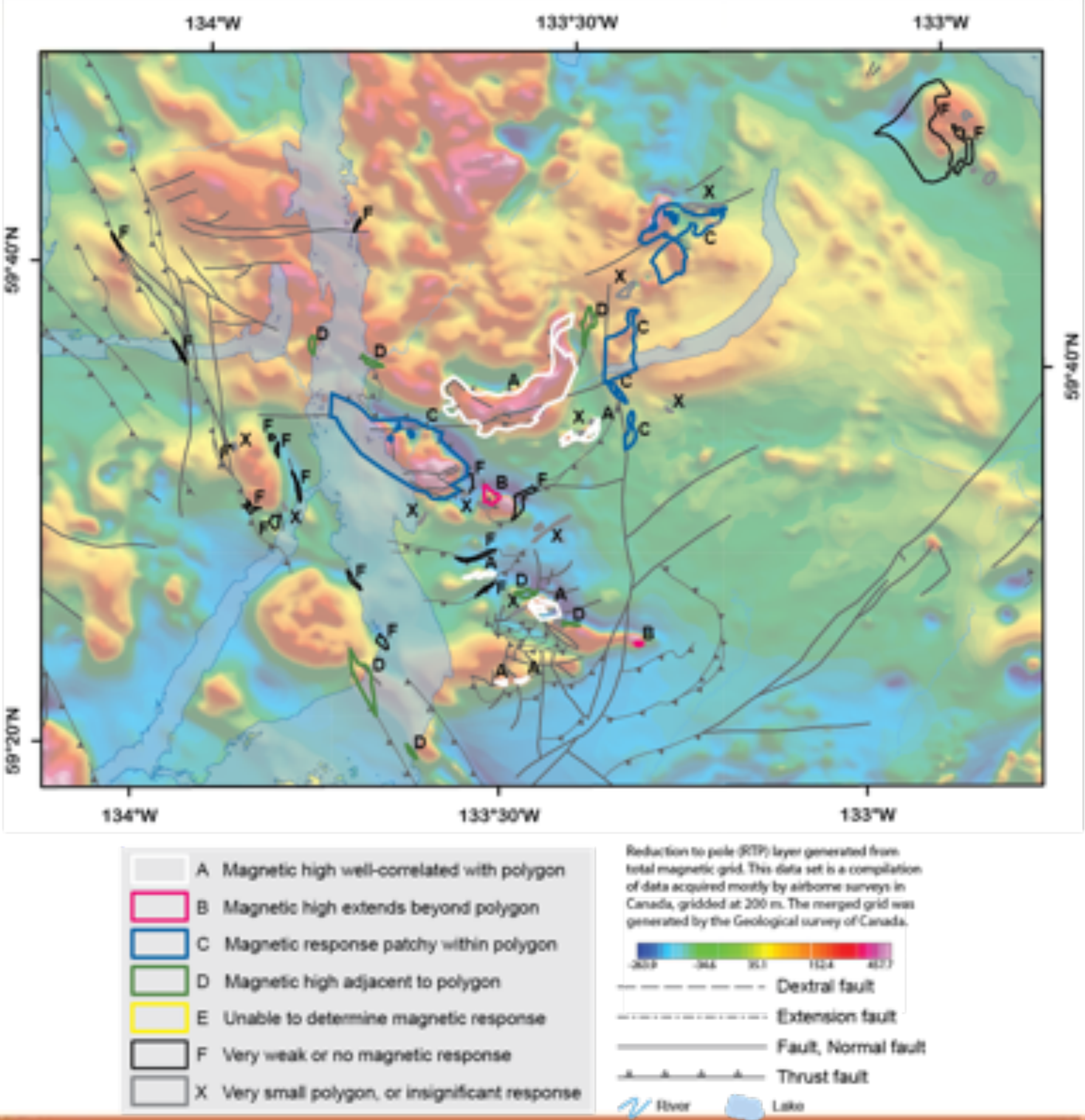
Classification	Description	Confidence that magnetic anomaly is related to mapped ultramafic unit	Number of polygons represented	Total Area (km^2) of mapped polygons within class
A	Positive magnetic anomaly well-correlated spatially to mapped ultramafic polygon	High	78	1681
B	Positive magnetic anomaly extends beyond mapped ultramafic polygon	High	105	232
C	Irregular or patchy positive magnetic anomaly contained within a mapped ultramafic polygon	High	158	958
D	Polygon with offset positive magnetic anomaly (may be due to the ultramafic or adjacent unit)	Low	39	119
E	Can't isolate/differentiate a distinct magnatic signal from surrounding magnetic material	Low	38	39
F	Very weak to no magnetic signal correlated to the mapped ultramafic polygon	None	95	733
X	Generally small polygon of varied magnetic response, overall insignificant contribution to ultramafic rock volume	None	210	56
ND	No magnetic data coverage	None	23	9
		Total	**746**	**3827**



Distribution and Abundance of Serpentinite

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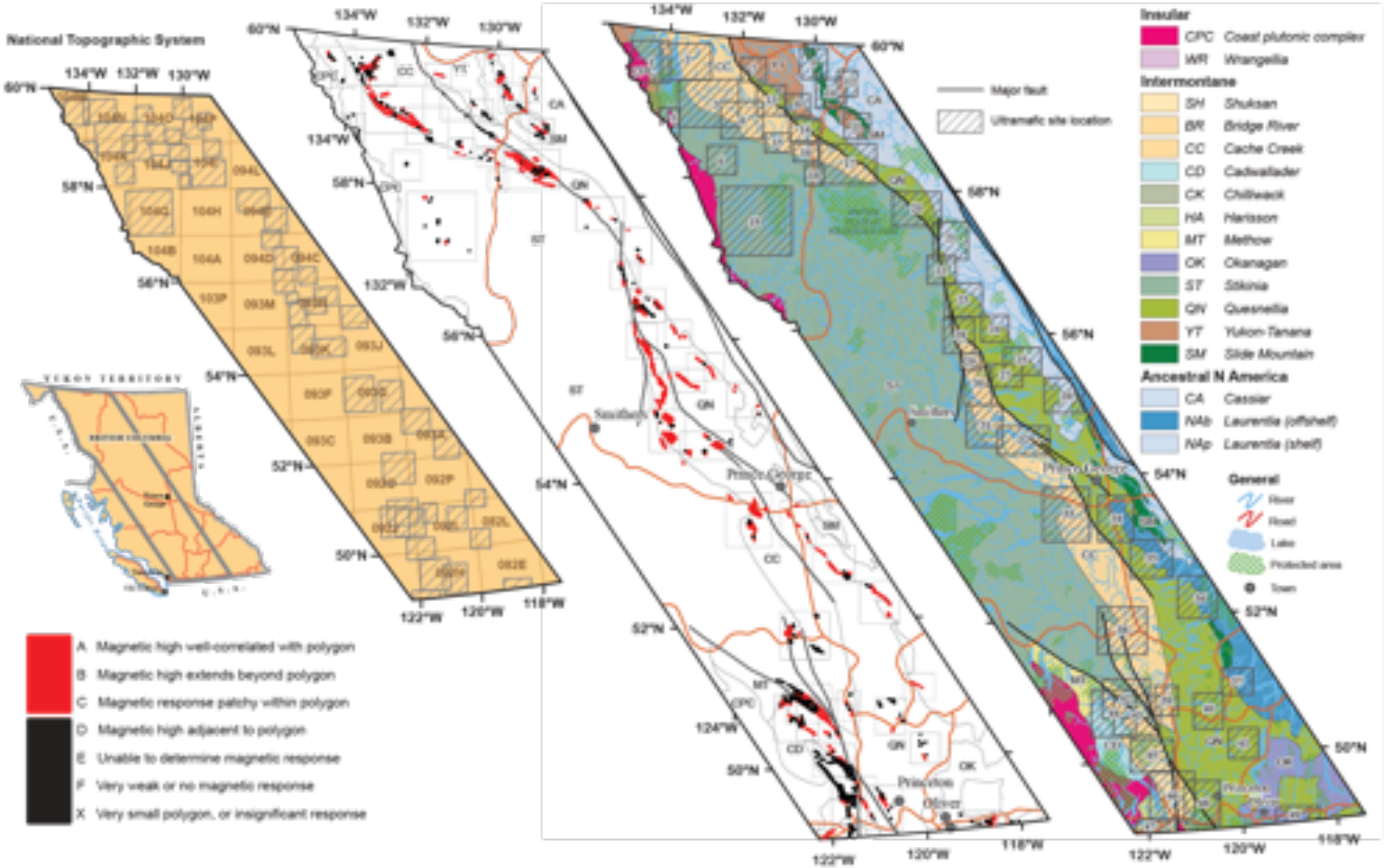
Forty-six percent of mapped ultramafic bodies are associated with magnetic anomalies indicating substantial serpentinization.



Inverse Modeling of Serpentinite Bodies

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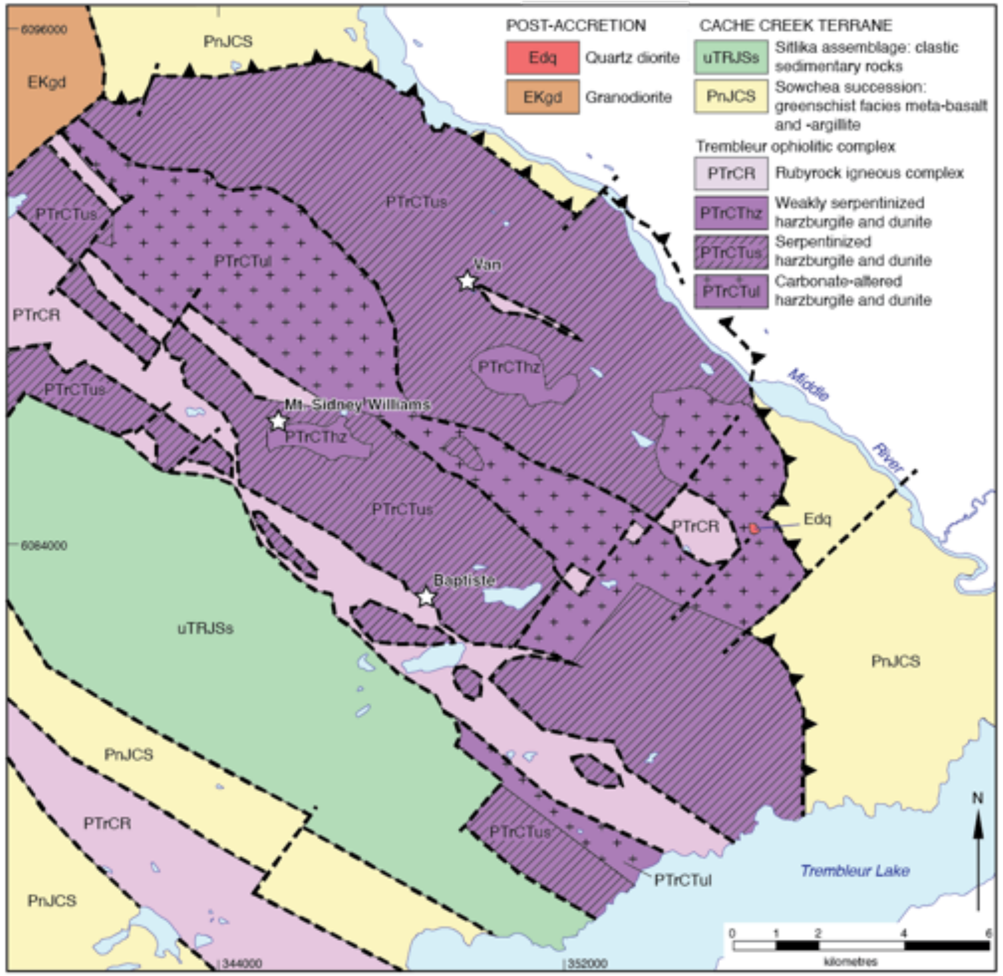
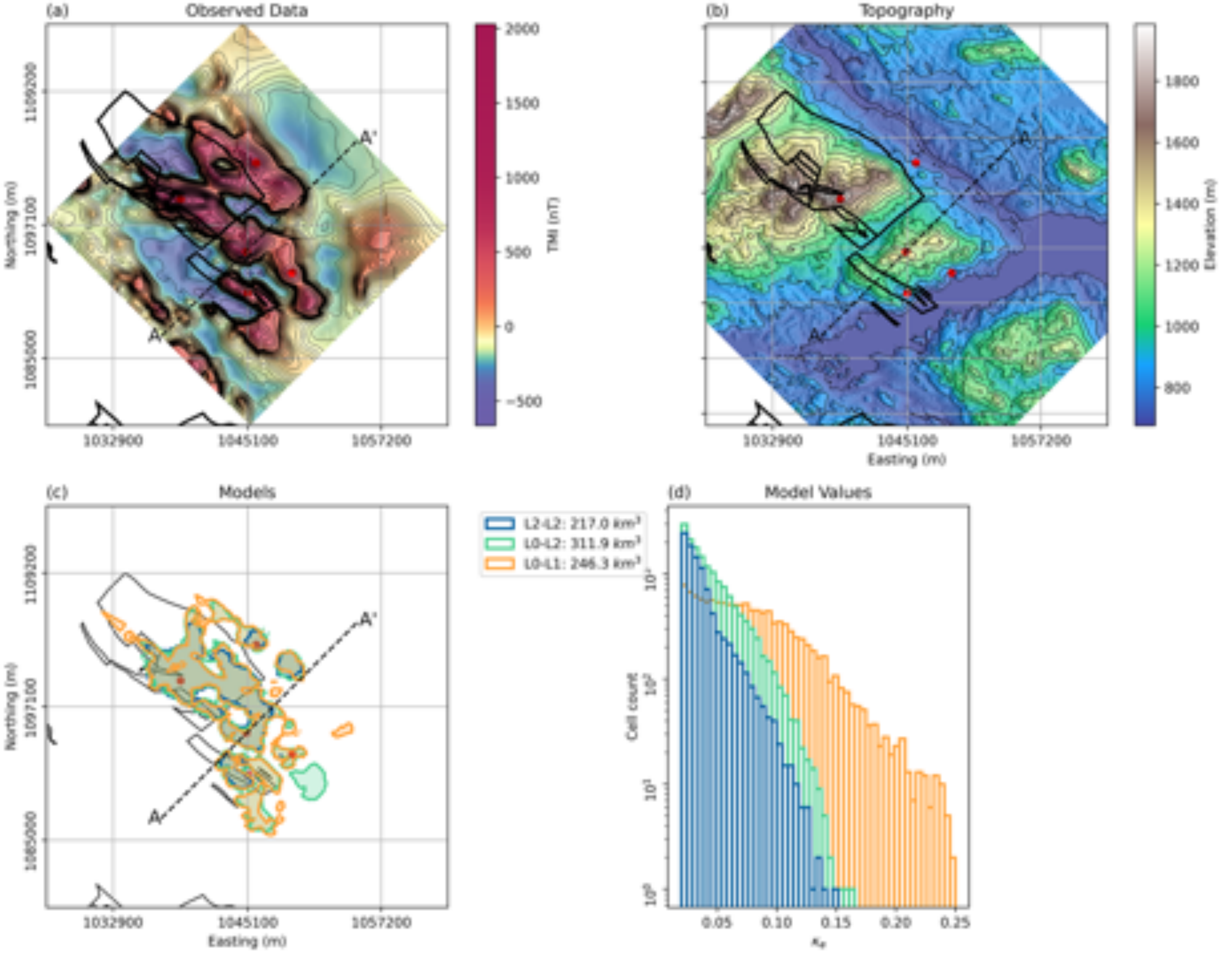
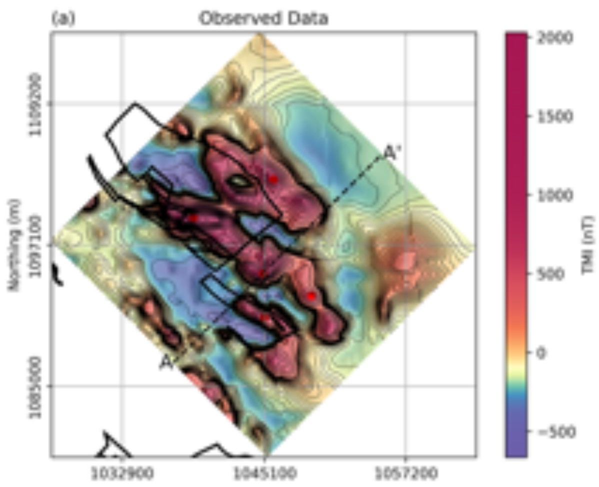
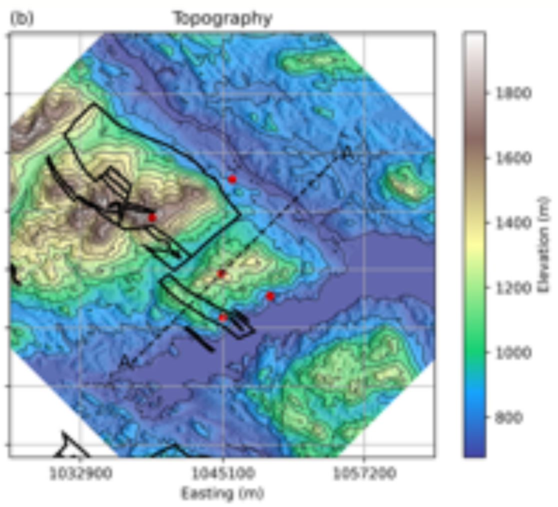
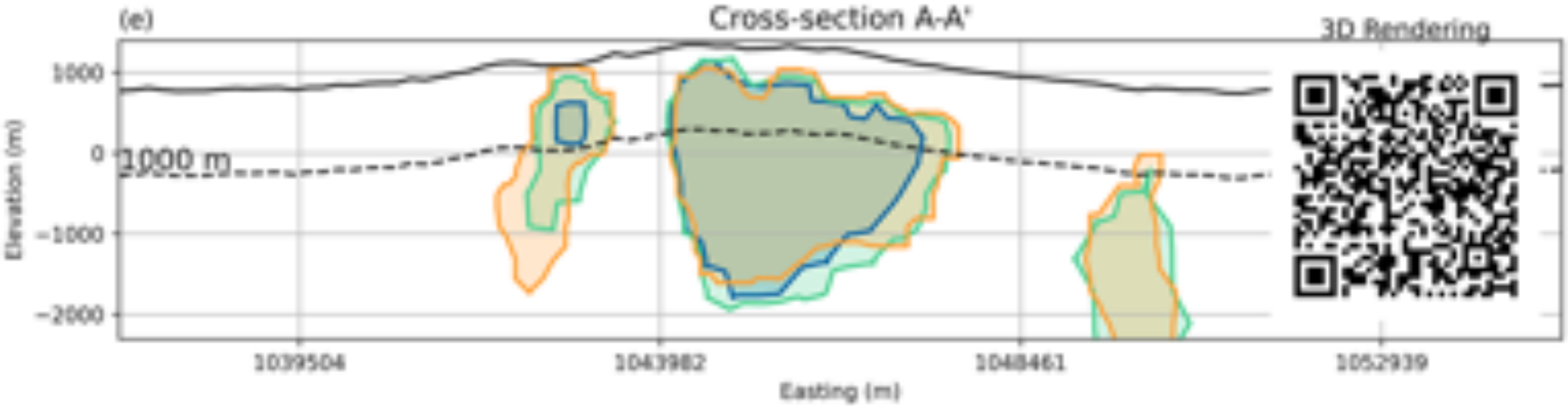




Inverse Modeling of Serpentinite Bodies







Areas and Volumes of Serpentinite in B.C.

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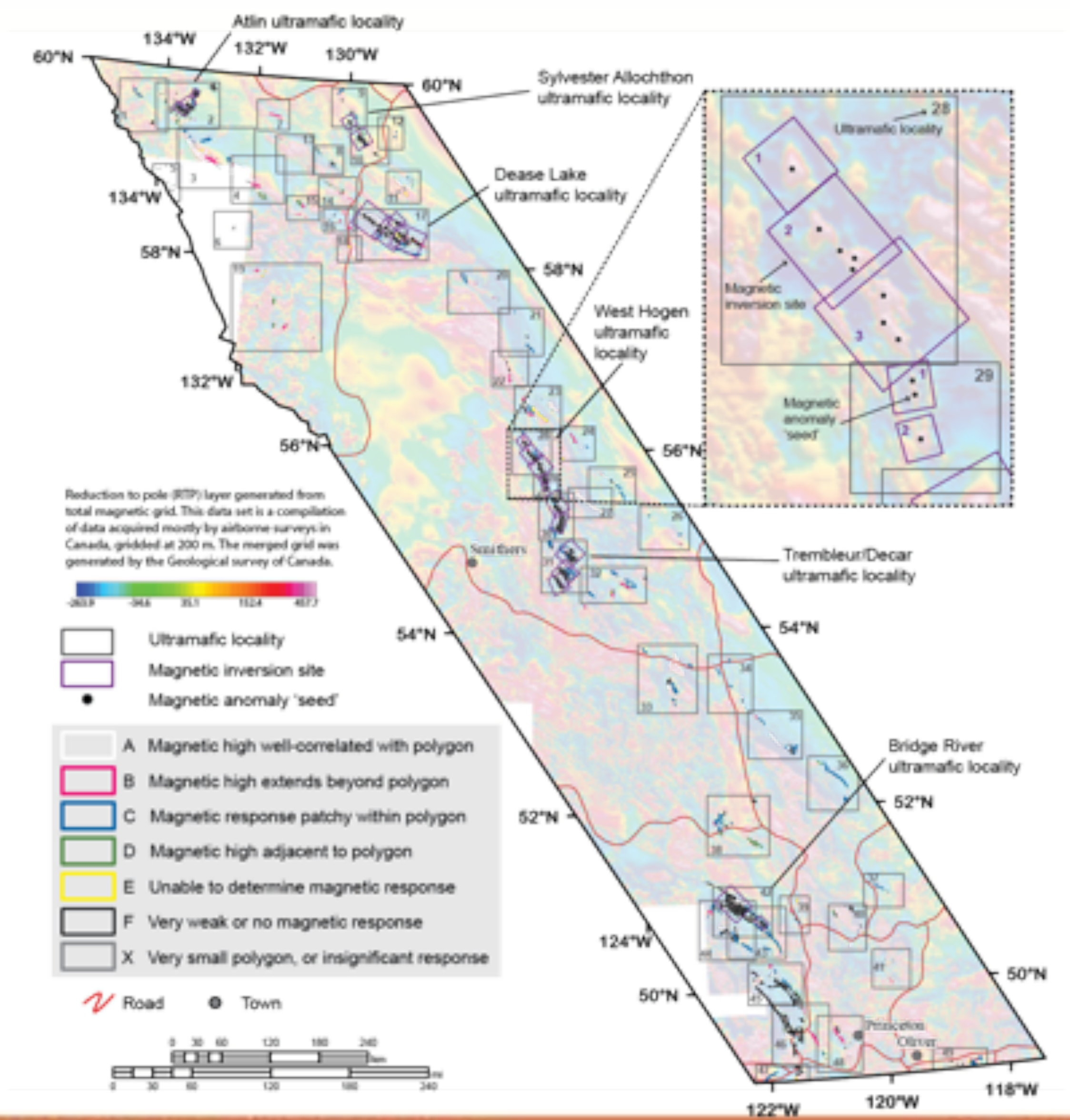
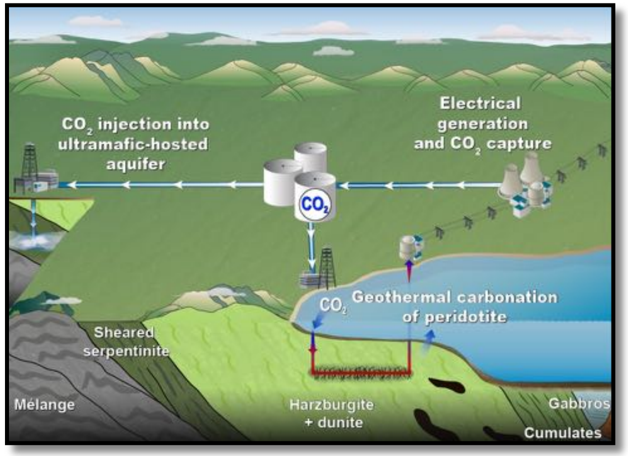


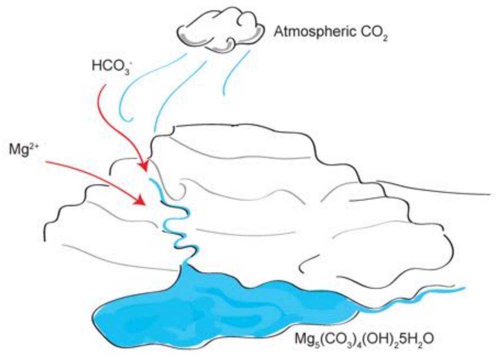
Locality Name	Ultramafic Locality	Polygon area captured by inversion sites - A, B, C only	Volume related to polygons (assuming 0.5 km thick)	High sus volume from inversions (top 0.5 km - median)	High sus volume from inversions (top 1 km - median)	High sus volume from inversions (top 2 km - median)	High sus volume from inversions (top 4 km - median)	High sus volume from inversions (full depth median)
Unit		km^2	km^3	km^3	km^3	km^3	km^3	km^3
Atlin	2	60	30	6	21	50	56	56
Sylvester Allochthon	9	8	4	0	2	8	13	13
Sylvester Allochthon	10	54	27	1	11	43	57	57
Dease Lake	17	413	207	4	88	596	1375	1414
West Hogem Batholith	28/29	168	84	26	89	267	534	534
West Hogem Batholith	30	100	50	12	42	143	354	354
Trembleur/Decar	31	248	124	37	153	449	826	840
Bridge River	42	299	150	17	58	199	493	501
Totals		1351	675	102	464	1754	3708	3769
Factor of 2.13 to give total A, B, C polygons for BC		**2878 km^2**	**1438 km^3**	**218 km^3**	**988 km^3**	**3736 km^3**	**7898 km^3**	**8028 km^3**

In-situ targets all Mg



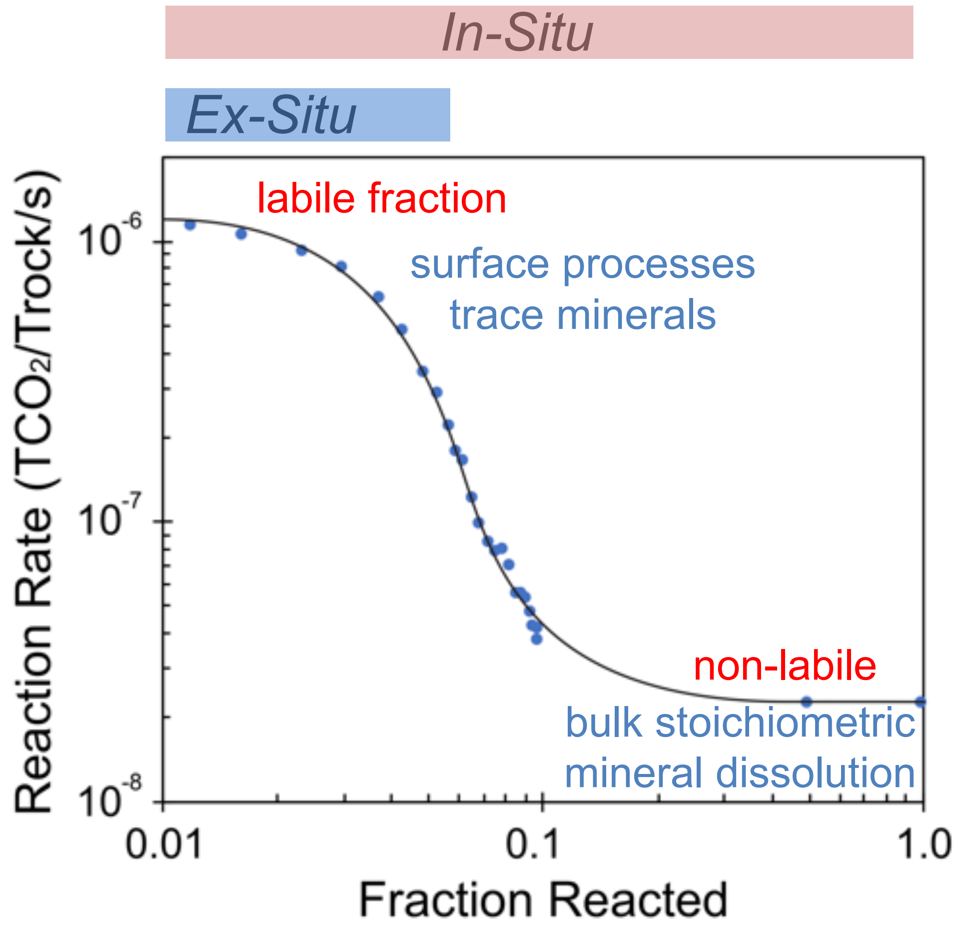
Power et al 2013 after Kelemen and Matter, 2008

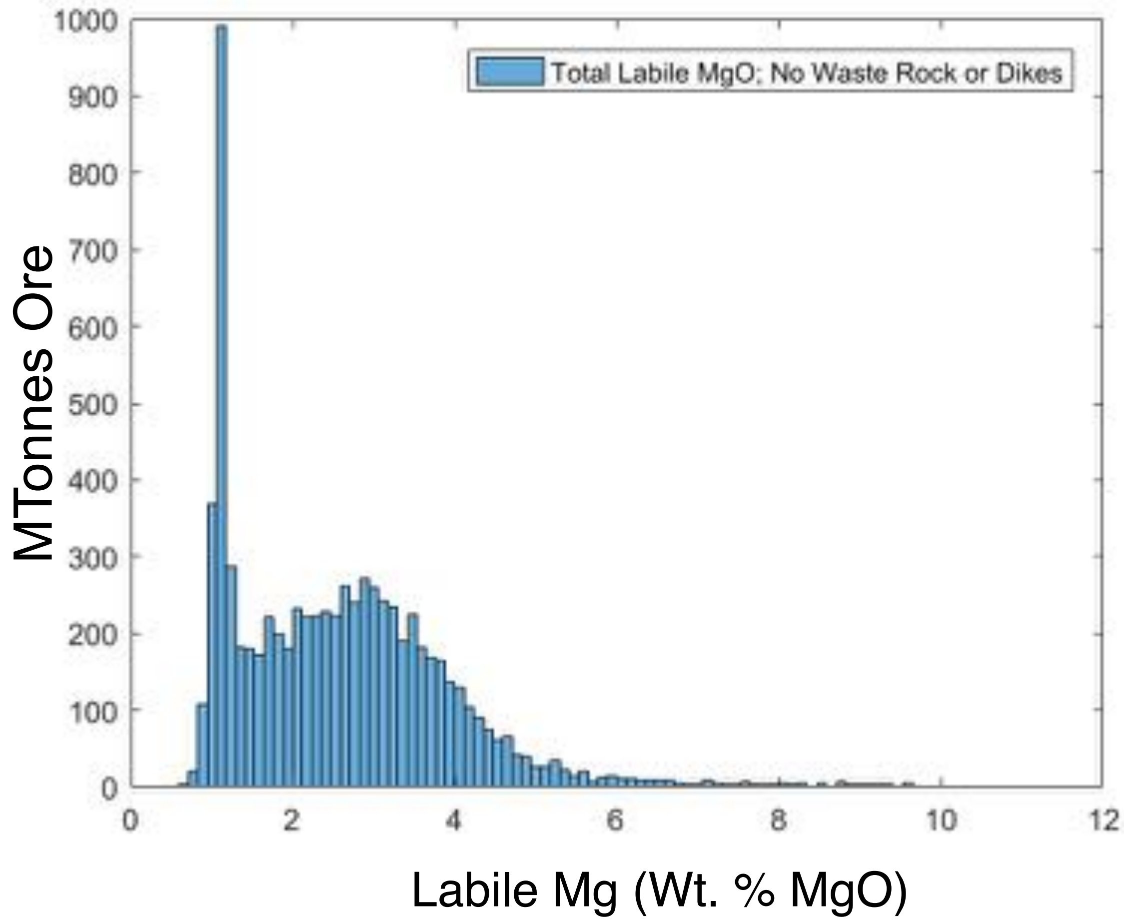
Ex-situ uses labile Mg



Labile Mg Content of Serpentinite

Labile Mg content variability within the Baptiste Deposit, Decar Ni District, Central B.C.





(Vanderzee et al., 2019)

Carbon Mineralization Capacity

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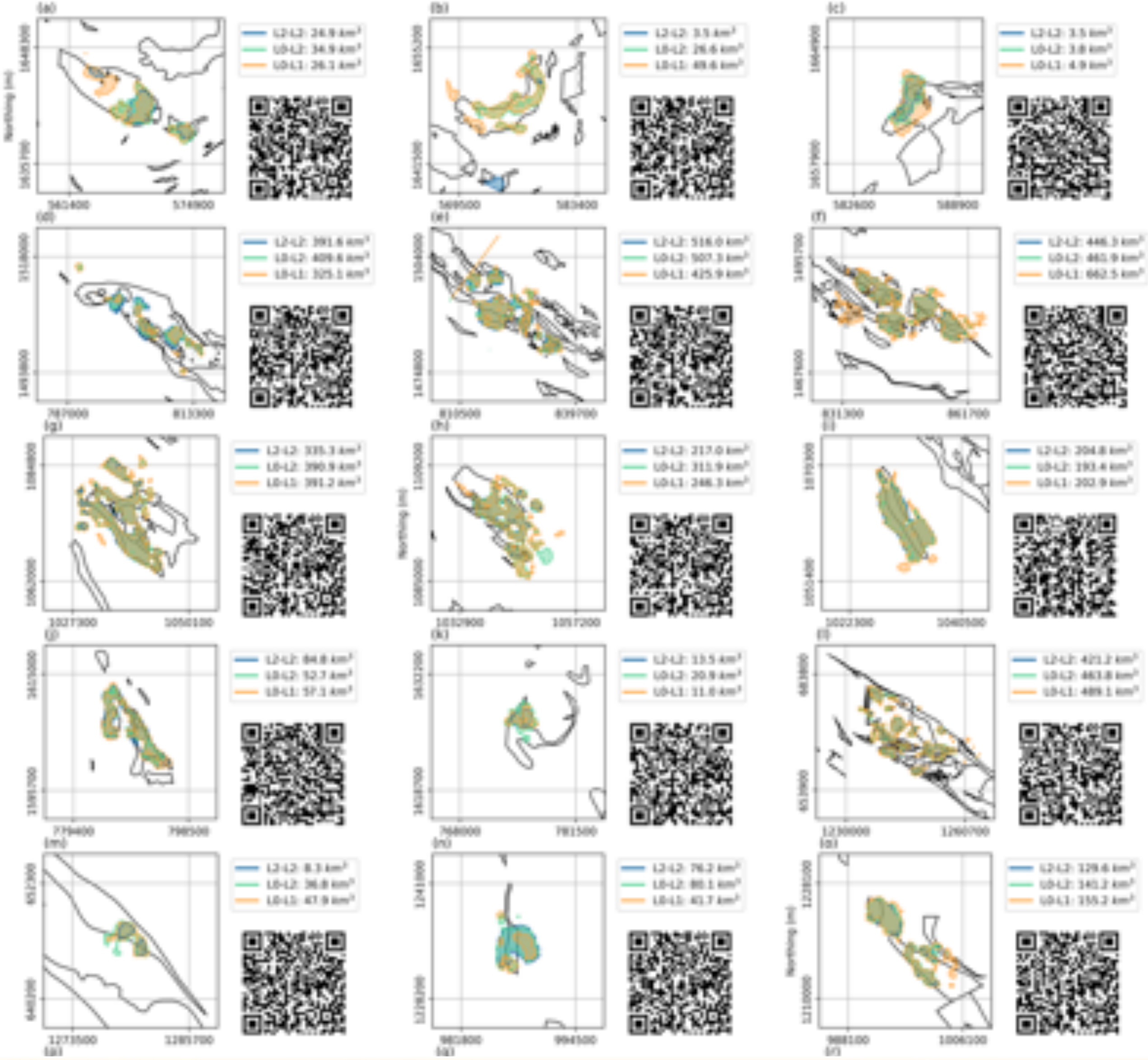

Depth Interval (km)	Serpentinite Volume (km^3)	Sequestration Capacity (Gt CO^2)	Method
0 to 1	988	56	*ex-situ*
0 to 2	3,689	210	*ex-situ*
2 to 4	4,162	5,139	*in-situ*
2 to full depth	4,292	5,300	*in-situ*

Ex-Situ Carbon Mineralization

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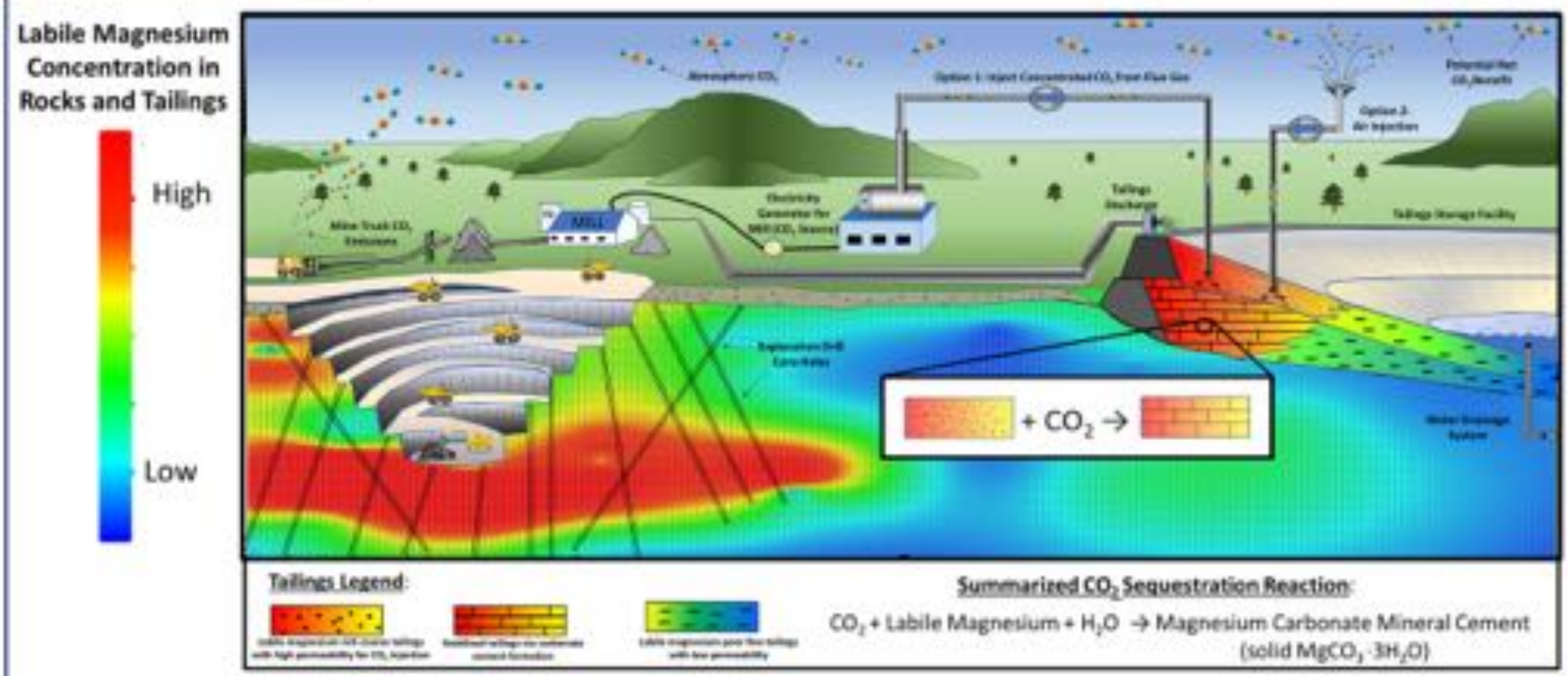

(Vanderzee et al., 2019)

Decarbonize Ni Supply Chain

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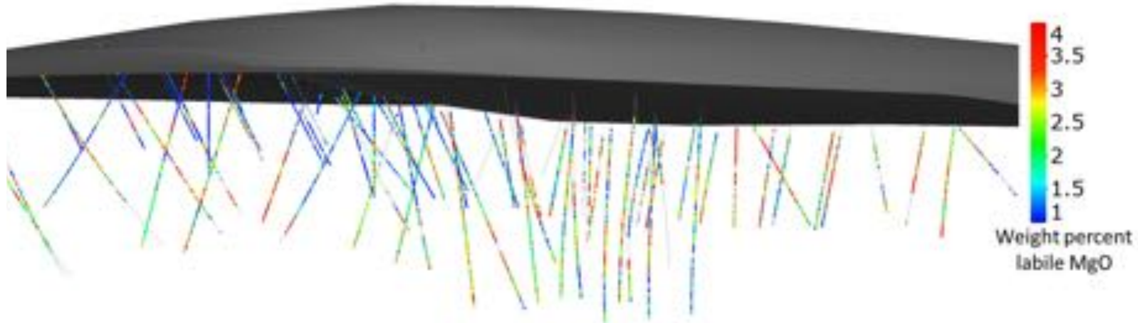
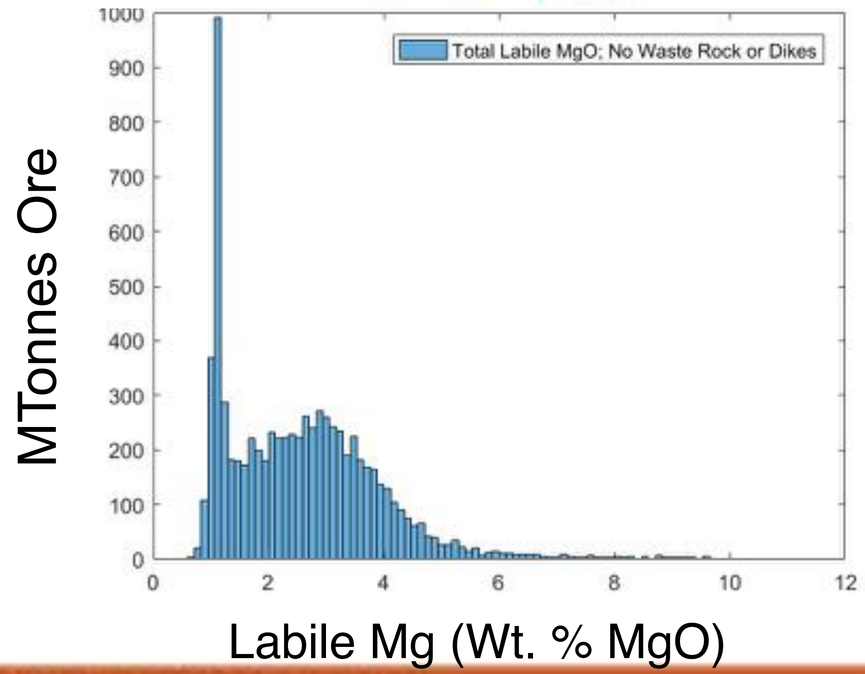
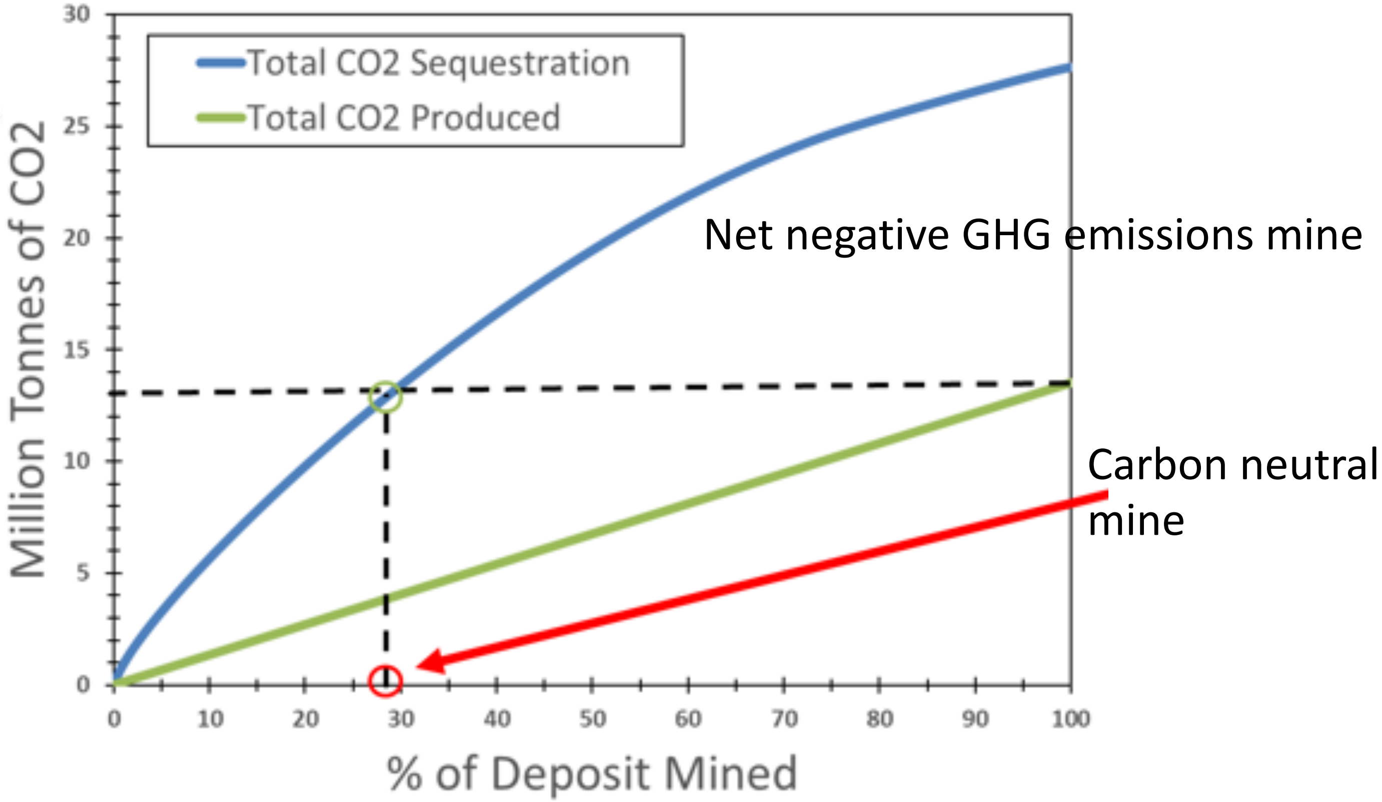
FPX Nickel Corp.
TSX-V:FPX

Reaction of labile Mg in 30% of tailings will offset mine GHG emissions
Reaction of more than 30% could contribute to net carbon removal







For 1.8 Gt indicated reserve

(Vanderzee et al., 2019)

Results

- Serpentinized ultramafic rocks can be highly reactive to CO_2 in air at ambient conditions.
- Creates an opportunity to use mine tailings to capture and store CO_2, reducing or eliminating GHG emissions of mine operations.
- The amount of CO_2 storage is governed by labile Mg content which is controlled by mineral content.
- Key changes in mineral content change bulk rock physical properties which allows magnetic and gravity survey data to serve as proxies for carbon storage prospectivity.
- A comprehensive physical properties model based on B.C. occurrences of ophiolitic rocks is complete and underway for intrusive ultramafics.
- B.C. ultramafic occurrences are ranked based on geophysical response.
- Forty-six percent of mapped ultramafic bodies have significant zones of serpentinization.
- Inverse modeling of serpentinite body magnetic data offers insights into size, geometry and location but also provides challenges.
- Preliminary conservative estimate is that shallow serpentinite bodies have labile Mg content sufficient to sequester 56 Gt of CO_2 – 800 years of B.C. emissions.

Improve Inverse Modeling

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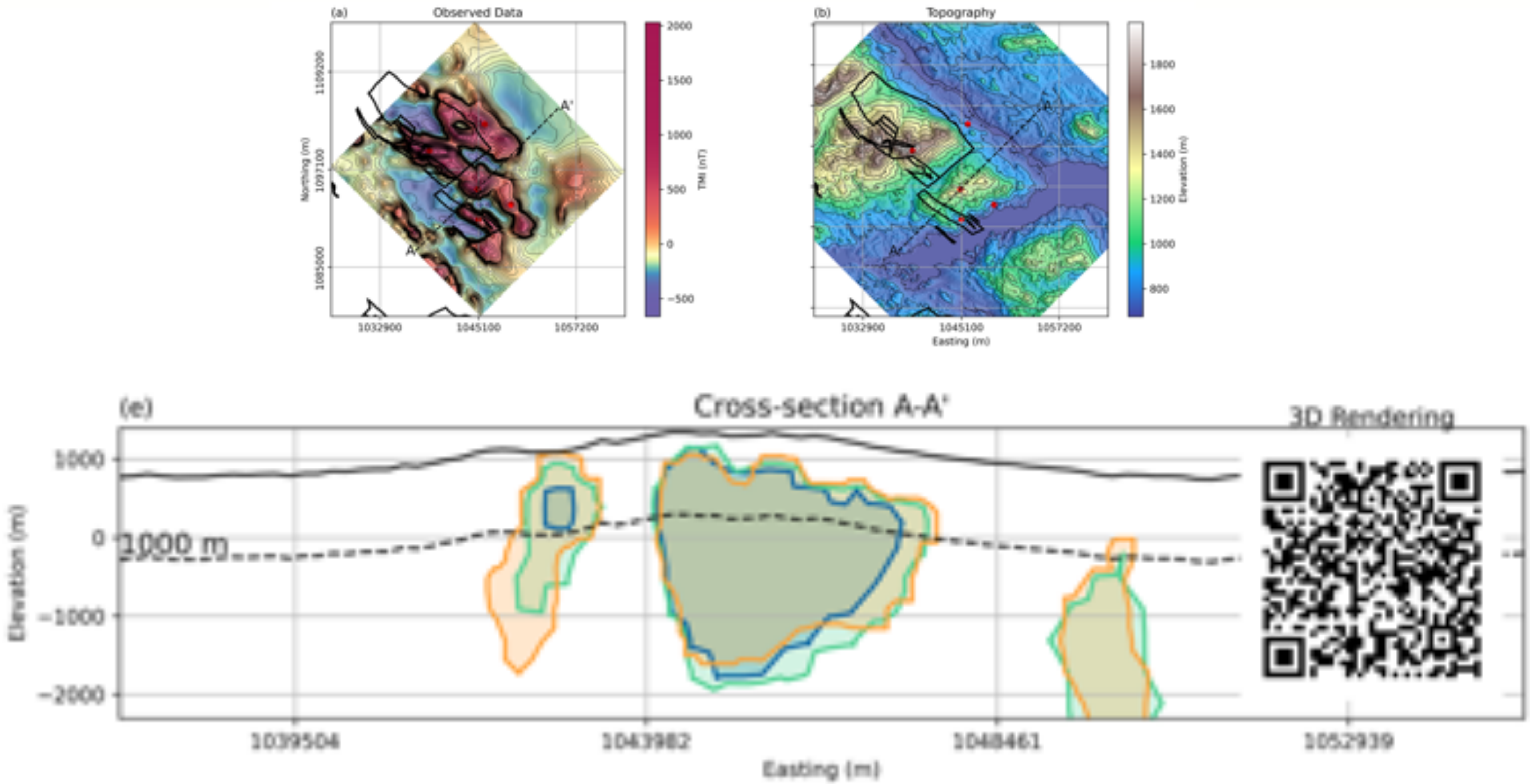

3D Rendering

Carbon Mineralization Potential Atlas

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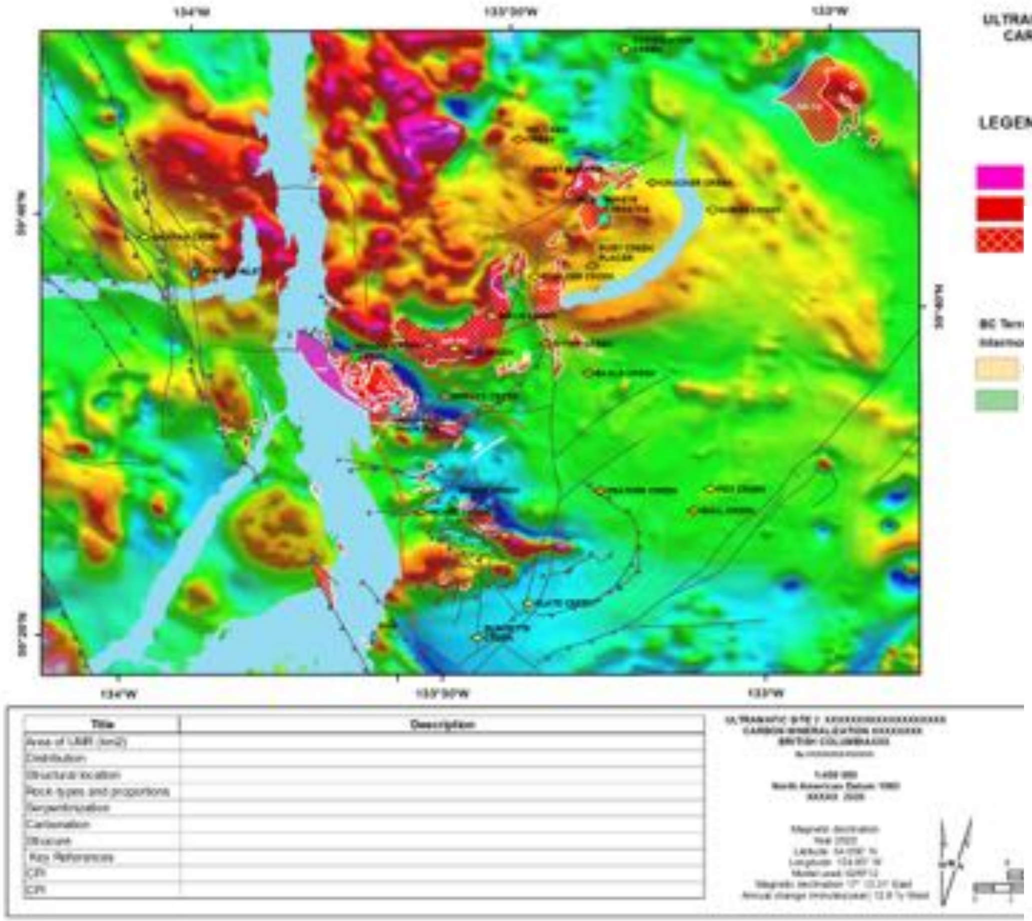

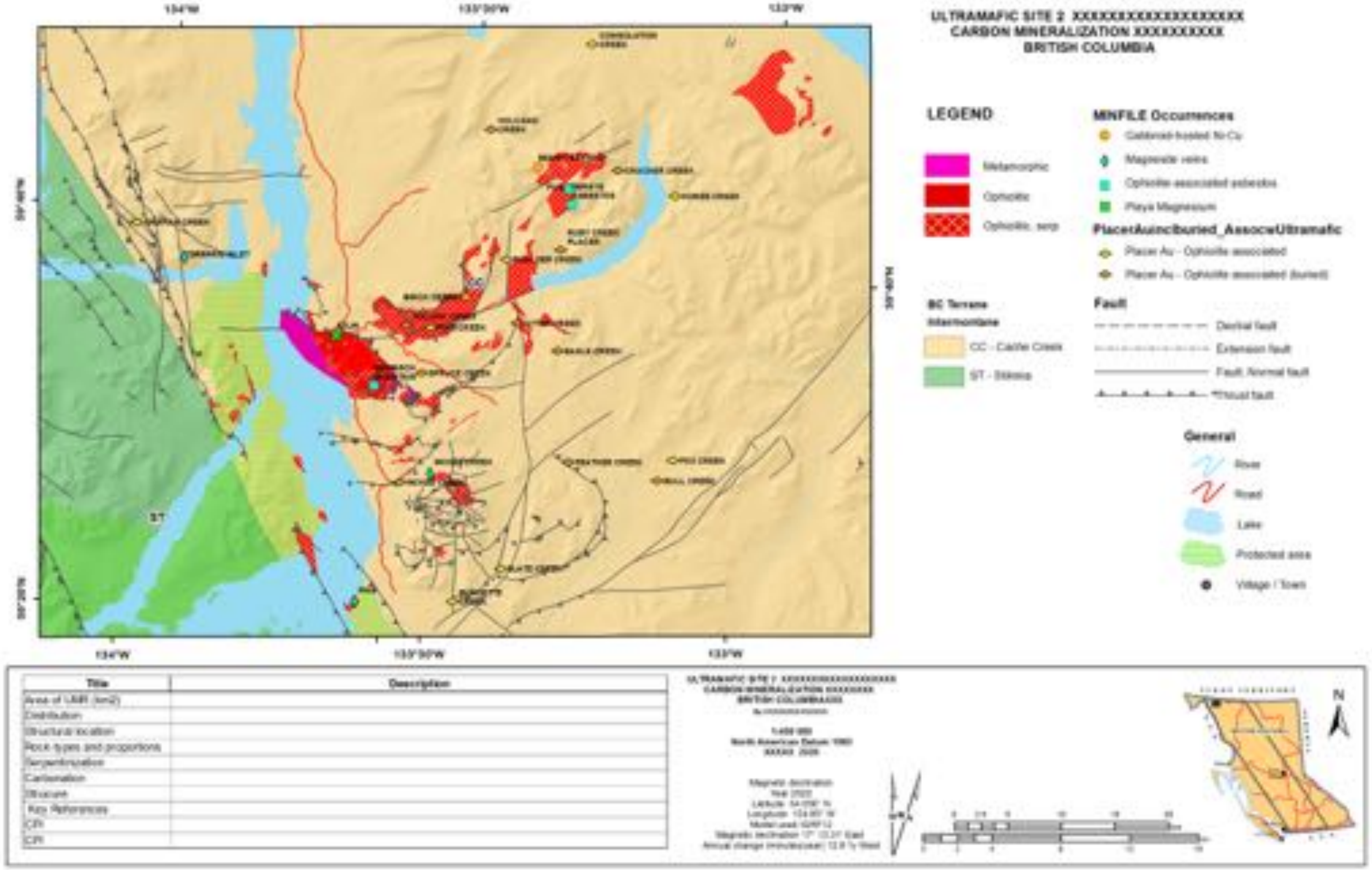

Carbon Mineralization Potential Map

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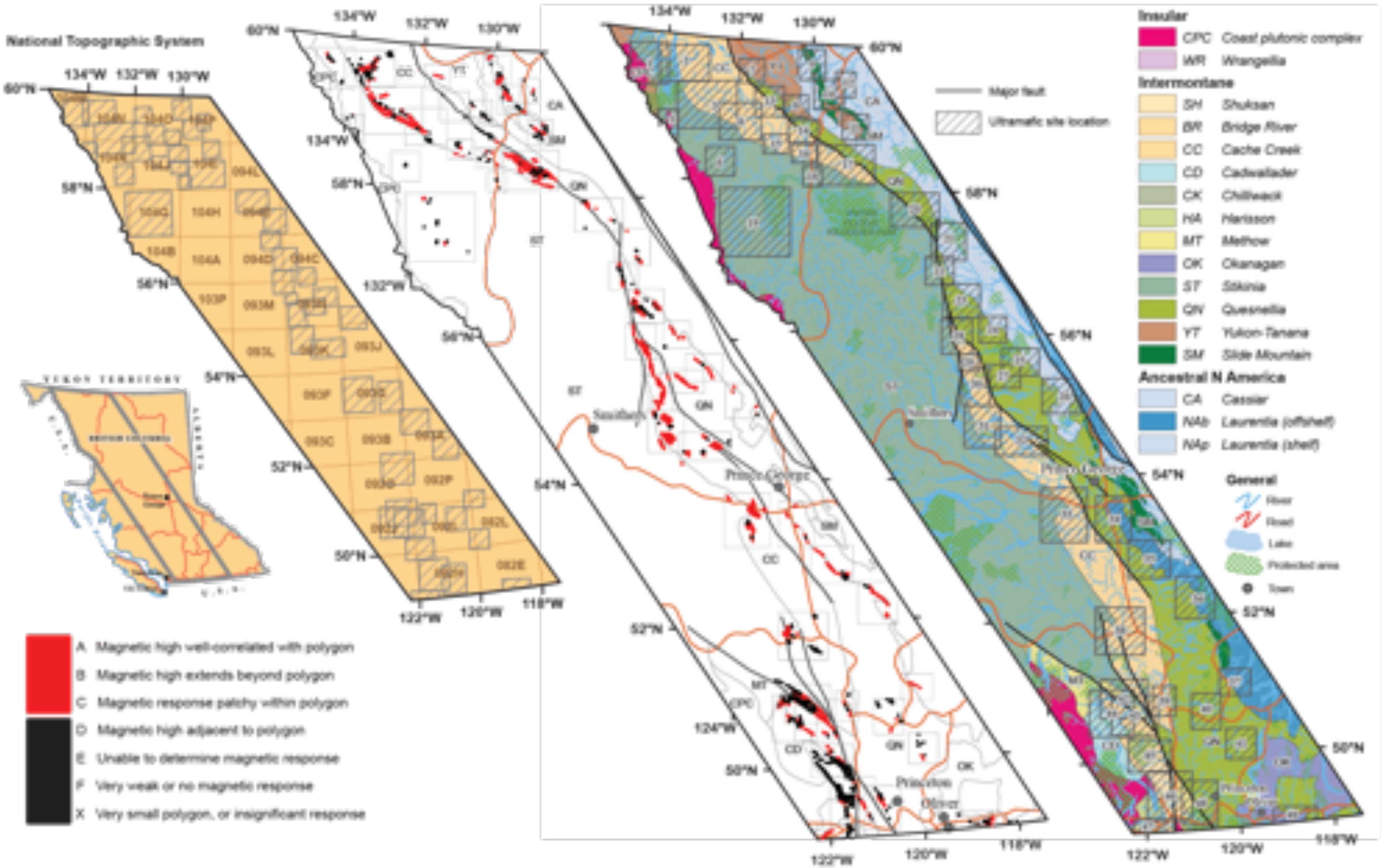

Questions?