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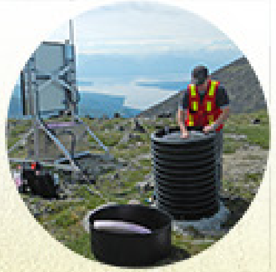

Geological Survey of Canada
Scientific Presentation 162

Public presentations May 16th and May 30th, 2023: Environmental Geoscience Program, current status of research projects for the 2019–2024 program cycle

J. Mochizuki, J. Jautzy, C. Rivard, H. Kao, S. Larmagnat, G. Lintern, D. White, A.J. Desbarats, J.M. Galloway, P.R. Gammon, J.M.E. Ahad, M. Bringué, and P.M. Outridge

2025

Canada

Presented at: Public presentations May 16th and May 30th, 2023: Environmental Geoscience Program, current status of research projects for the 2019-2024 program cycle

Date presented: May 2023

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Environmental Geoscience Program (EGP).
Presentation of current research status for projects in 2022-2023.

The goal of the EGP is to provide innovative scientific information that makes it possible to distinguish between the environmental effects of natural resource development and those produced by natural processes. As part of this mandate, developing new approaches in geoscience supports the responsible use and development of Canada's natural resources through informed decision-making.

The ultimate outcome of the EGP is to increase the effectiveness and efficiency of Canadian environmental regulation and oversight. In developing innovative geoscience for environmental stewardship, as well as increasing public and private sector access to research findings, decision makers have a greater capacity to carry out and review environmental assessments.

The advancement of EGP projects is documented herein and via the EGP YouTube account. The talks on this work were recorded during the public online presentations held on May 16th and 30th, 2023, and are also available via the following link: https://www.youtube.com/channel/UCWiCrKnTeF-j_La6_Wc5NMA/playlists

Key words: *Clumped isotope, induced seismicity, impacts on aquifers, diluted bitumen, modelling in oil sands region, marine oil spill, Mackenzie River Basin, climate change, global mercury assessment, geological storage of carbon, cumulative effects, permafrost degradation, permafrost geochemistry, dredge disposal at sea, environmental regional assessment, baseline characterization, environmental geoscience, impact assessment.*

Programme de géosciences environnementales (PGE).
Présentation de l'état d'avancement des recherches en 2022-2023.

L'objectif du PGE est de fournir des informations scientifiques novatrices qui permettent de distinguer les effets environnementaux de l'exploitation des ressources naturelles de ceux produits par les processus naturels. Dans le cadre de ce mandat, le développement de nouvelles approches en géosciences soutient l'utilisation et le développement responsable des ressources naturelles du Canada par une prise de décision éclairée.

Le résultat ultime du PGE est d'accroître l'efficacité et le rendement de la réglementation et de la surveillance environnementale au Canada. En développant de la géoscience novatrice pour la gestion de l'environnement, ainsi qu'en augmentant l'accès des secteurs public et privé aux résultats de la recherche, les décideurs ont une plus grande capacité à effectuer et à examiner les évaluations environnementales.

L'avancement des projets du PGE est documenté dans le présent document ainsi que sur le compte YouTube du PGE. Les exposés sur ces travaux ont été enregistrés lors des présentations publiques tenues les 16 et 30 mai 2023 et sont disponibles via le lien suivant : https://www.youtube.com/channel/UCWiCrKnTeF-j_La6_Wc5NMA/playlists

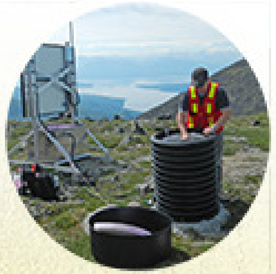
Mots-clés : *Isotopes agglomérés, sismicité induite, impacts sur les aquifères, bitumen dilué, modélisation dans la region des sables bitumineux, déversements pétroliers marins, bassin du fleuve Mackenzie, changements climatiques, évaluation mondiale du mercure, stockage géologique du carbone, effets cumulatifs, dégradation du pergélisol, géochimie du pergélisol, dépôts de dragage en mer, évaluation environnementale régionale, caractérisation de niveaux de base, géosciences environnementales, évaluation d'impacts.*

Environmental Geoscience Program (EGP)

Environmental Geoscience Program (EGP)

The following deck represents the advancement of a research project under the Environmental Geoscience Program but was not presented during the May 2023 public presentations.




Cercle de Feu: Test d’approche de géochimie environmentale sur sites analogues en support aux évaluations régionales

Ring of Fire: Testing environmental geochemical approaches on analog sites to support regional assessement

2023

Abstract

Ring of Fire (RoF) = large mineral deposits of Ni/Cu/Zn/Cr and PGM

- Located in one of the world's largest peatland system;
- Sensitive to climate change (Hadley et al., 2019) and anthropogenic stresses (Leclair et al., 2015)

Additional knowledge on environmental conditions required:

Pre-mining:

- Natural presence/behavior of metal(loid)s needs to be carefully assessed
- Baseline conditions response to climate change + remote anthropogenic stresses

Post-mining initiation:

- Changes to groundwater flow dynamic, geochemical fate of metal(loid)s in surface storage of tailings and waste rocks over time.

Explore and develop environmental indicators adapted to the monitoring of RoF environment.

Project Members

J. Jautzy[1], N. Benoit[1], J. Marion[1], M. Parsons[1], Paul Gammon[1], Pierre Pelchat[1], A. Desbarats[1], A. Nguyen[3], J. Galloway[1], N. Sanderson[4], Tim Patterson[3], S. Hepditch[5], G. Légaré-Couture[2], P. Bergeron[1], M. Parent[1], V. Tremblay[1], J. Ahad[1], É. Girard[1], E. Berryman[6], M. Garneau[4]

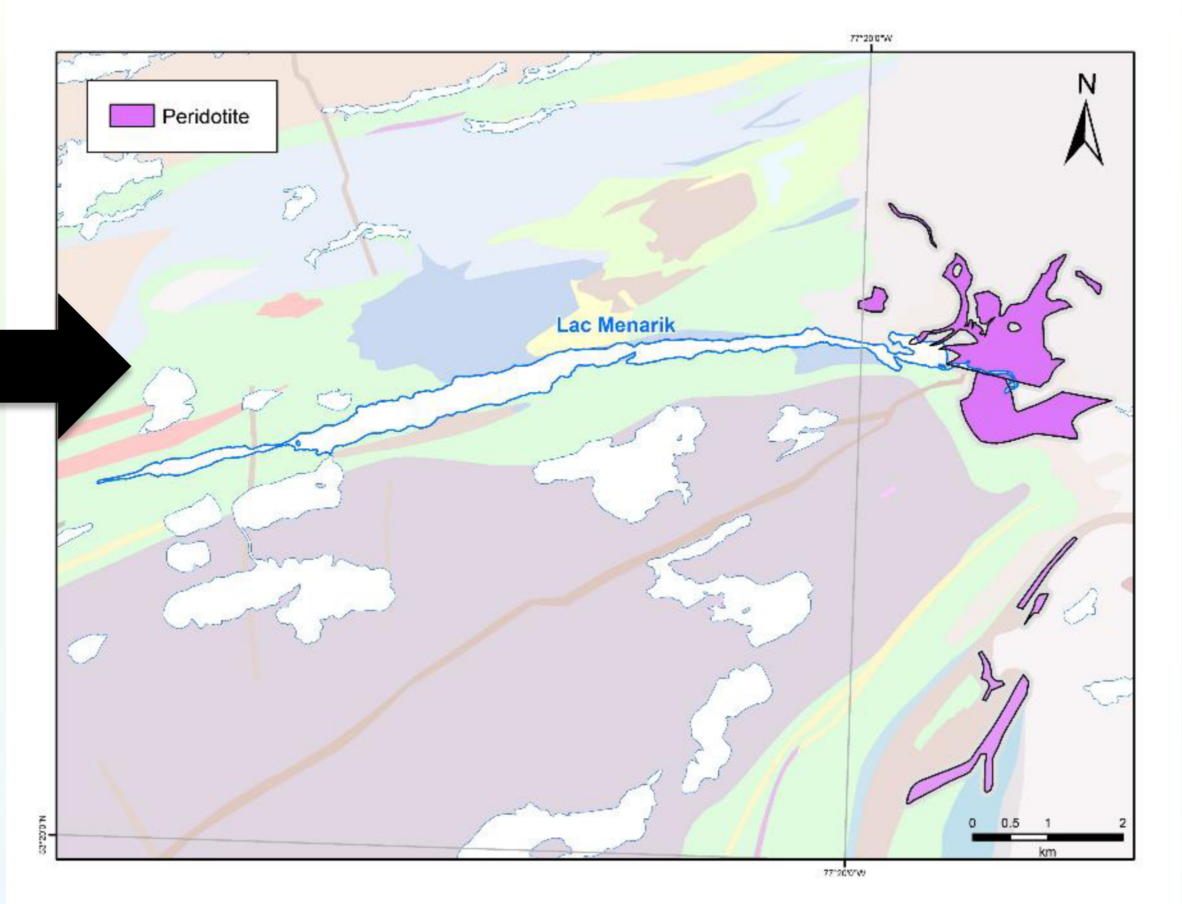
[1]*Geological Survey of Canada, Natural Resources Canada (NRCan)*
[2]*Canada Centre for Mapping and Earth Observation, Natural Resources Canada (NRCan)*
[3]*Carleton University*
[4]*Université du Québec à Montréal*
[5]*Institut national de la recherche scientifique*
[6]*CanmetMINING, Natural Resources Canada (NRCan)*

Activities

- Environnemental archives study on a pre-mining analog context of chromite deposit – Menarik lake (Qc): Metal(loid)s in lake sediments and rock samples / isotopic investigation of the tree and peat archives.
- Hydrogeochemical study on a post-mining analog context of chromite deposits – Chaudière-Appalaches (Qc): Metal(loid)s in lake sediments, waste rock and tailings.
- Analytical development of Chromium speciation analyses in water, laboratory and real field development.

Pre-mining context

- Analog Cr-deposit context – Cr-mineralized outcrops in a boreal environment.



Pre-mining context

Colocalized archives with ≠ complementary chronological scales.
Past climatic anomalies as analog to current climate change.

1000s yrs

200-1000 yrs

50-200 yrs

Climate proxy

Link?

Record of Cr loading?

Test and development of new indicators:

- forest fire intensity

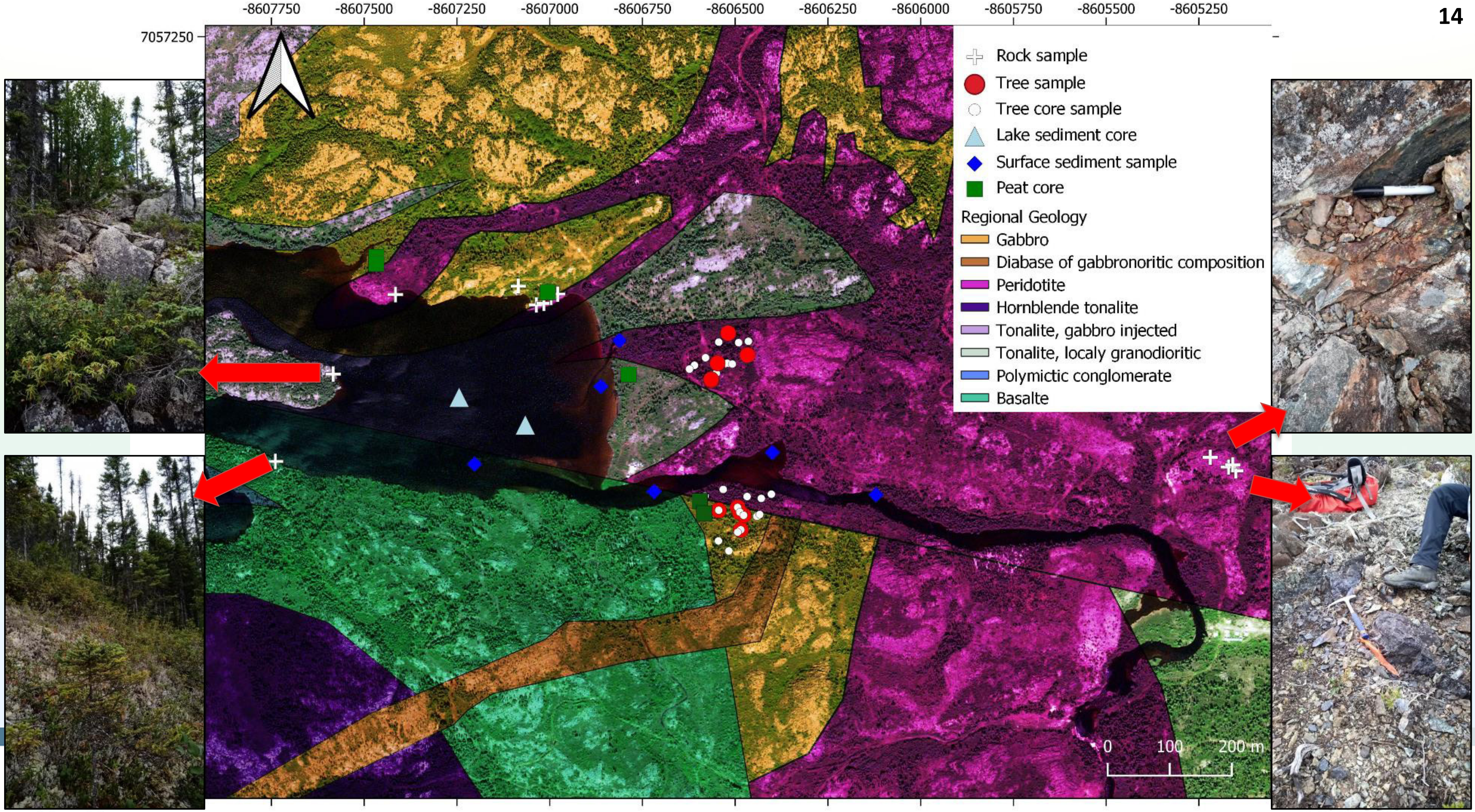
Pre-mining analog of chromite deposit

Coring platform

Minerotrophic peat sample

Blake Spruce sample

Sediment Cores



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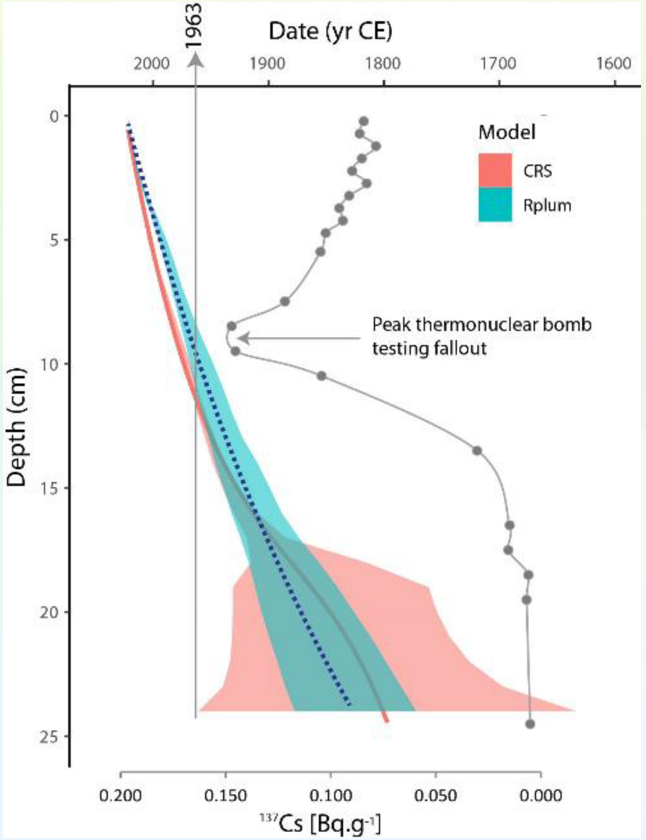
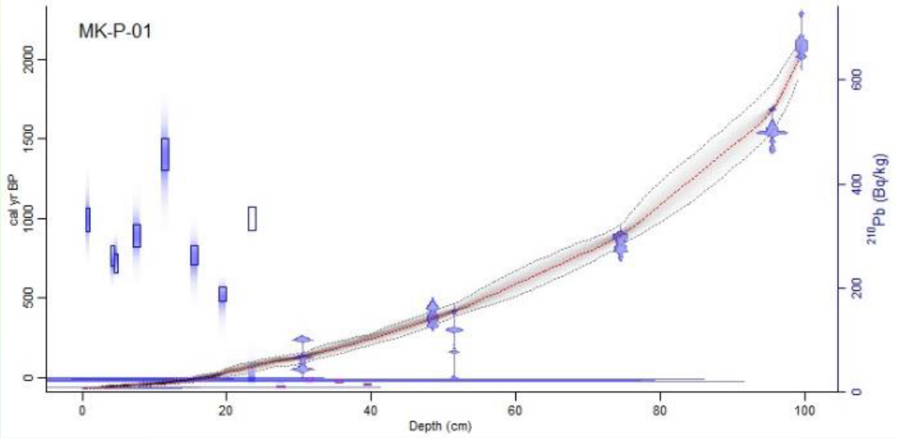
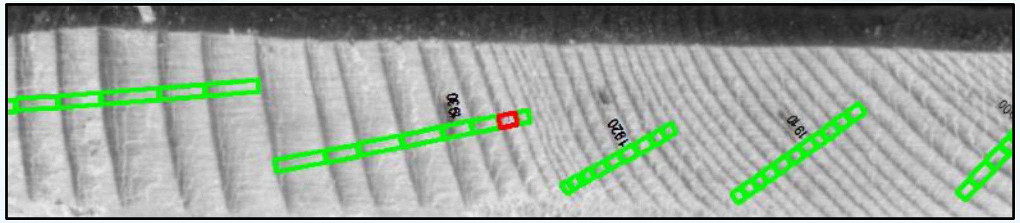
-8606250
-8606000
-8605750
-8605500
-8605250
7057250
Rock sample
Tree sample
Tree core sample
Lake sediment core
Surface sediment sample
Peat core
Regional Geology
Gabbro
Diabase of gabbronoritic composition
Peridotite
Hornblende tonalite
Tonalite, gabbro injected
Tonalite, localy granodioritic
Polymictic conglomerate
Basalte
0
100
200 m

Chronologies

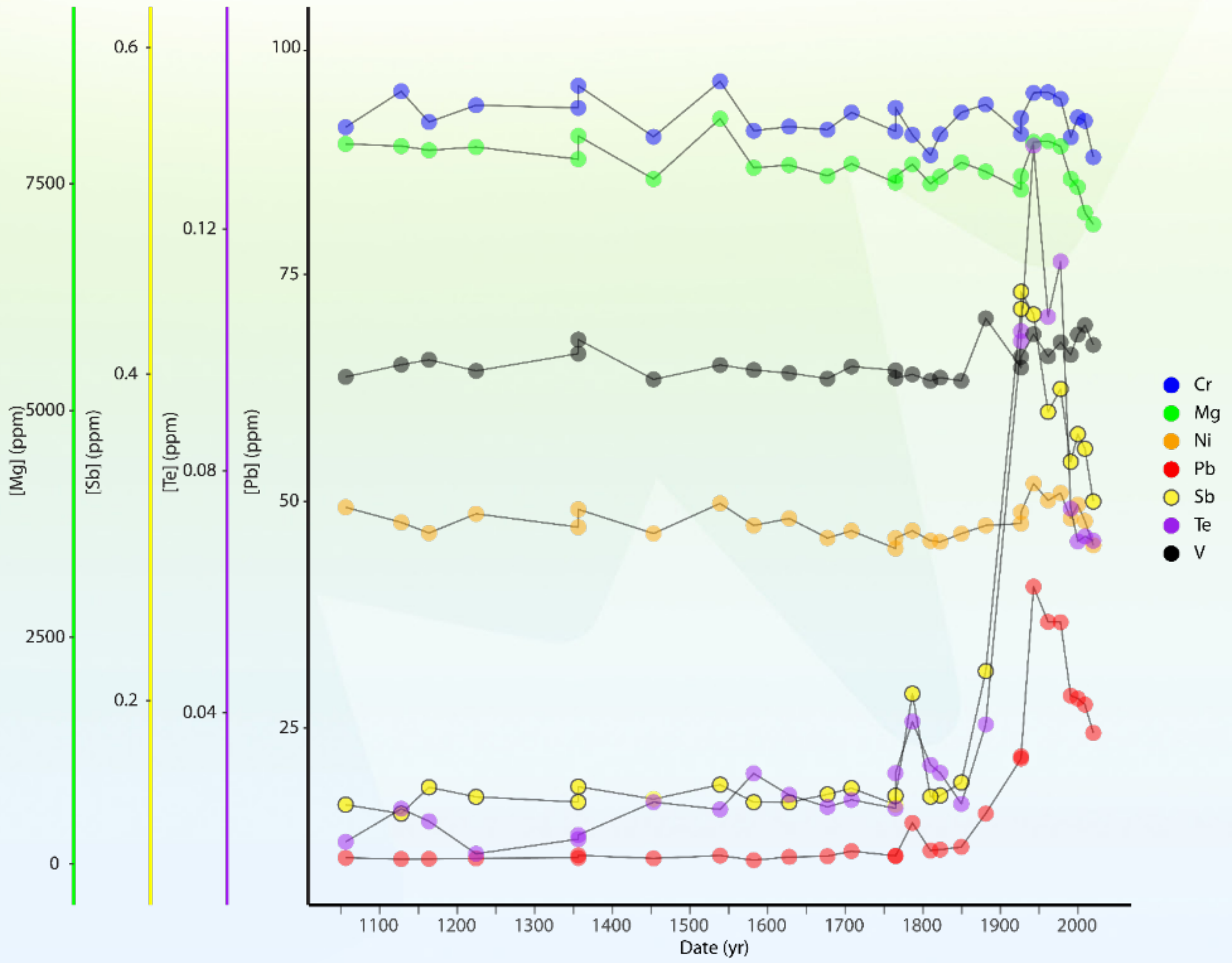






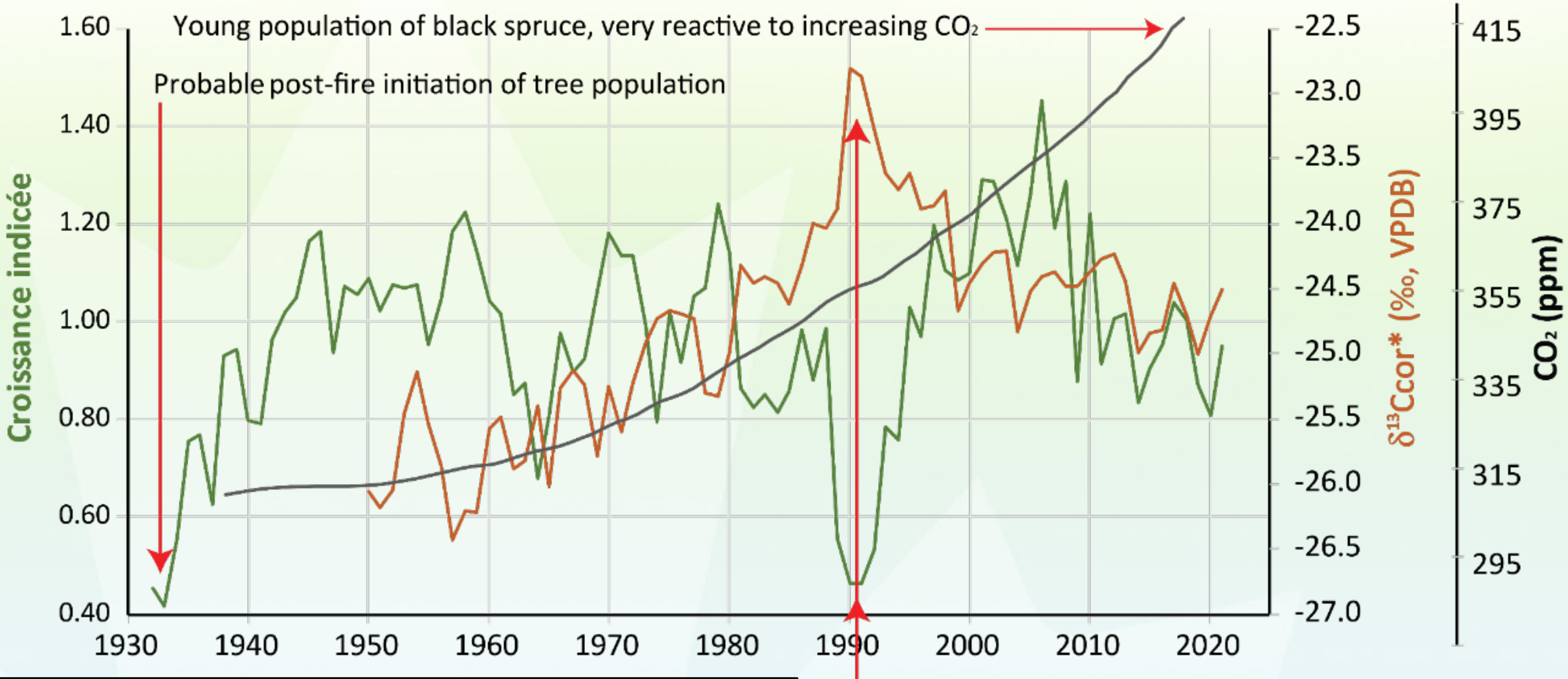
- ^{210}Pb ^{137}Cs, ^{226}Ra, ^{241}Am and ^{14}C for lake sediment cores and peat cores
- Bayesian vs linear age
- Tree ring counting for absolute datation in black spruce population sampled

[Metal(loid)s] – Lake sediment

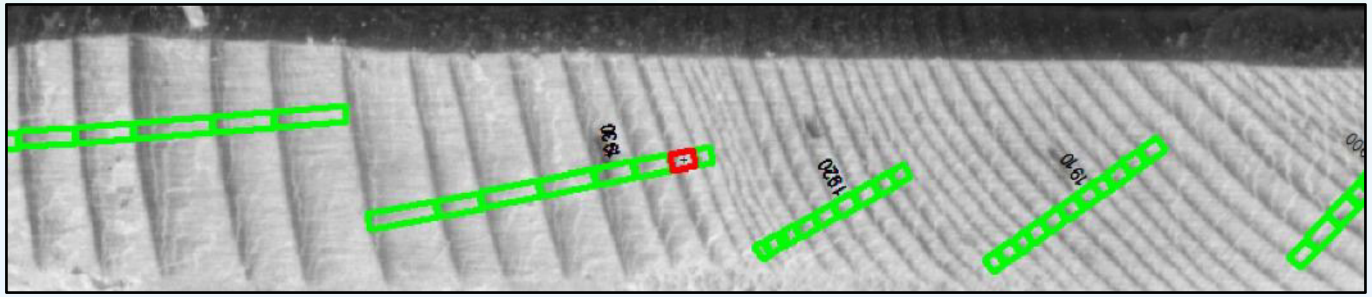


- Link with forest fire, forest fire molecular ^{14}C indicator to come
- Link with bedrock mineralogy
- Careful with diagenetic influence on profiles
- Next: to compare with dendro and peat record
- Cr naturally above CCME guidelines, Pb above at peak in the 60s.
- Likely influence of long range transport of fossil fuel combustion

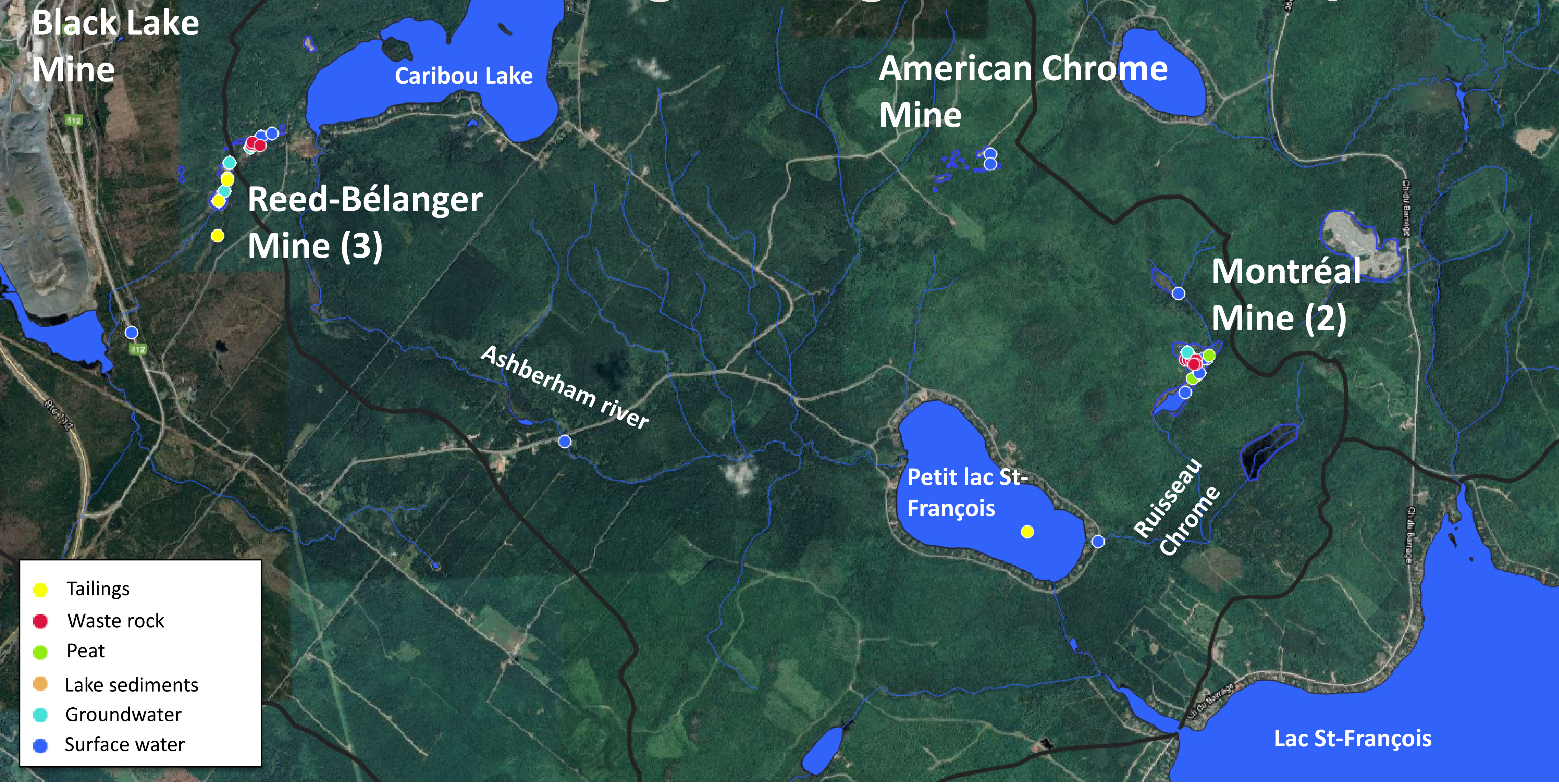
Results - Tree



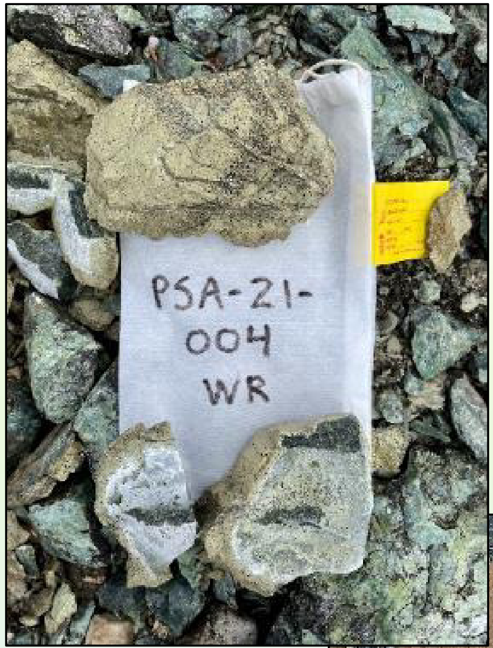
Severe forest fire in summer 1989 followed by growth reduction of impacted tree that survived. ^{13}C-enrichment anomaly could be related to loss of photosynthetic efficiency (*i.e.* foliage reduction).



Post-mining analog of chromite deposit



Waste Rock & Tailings



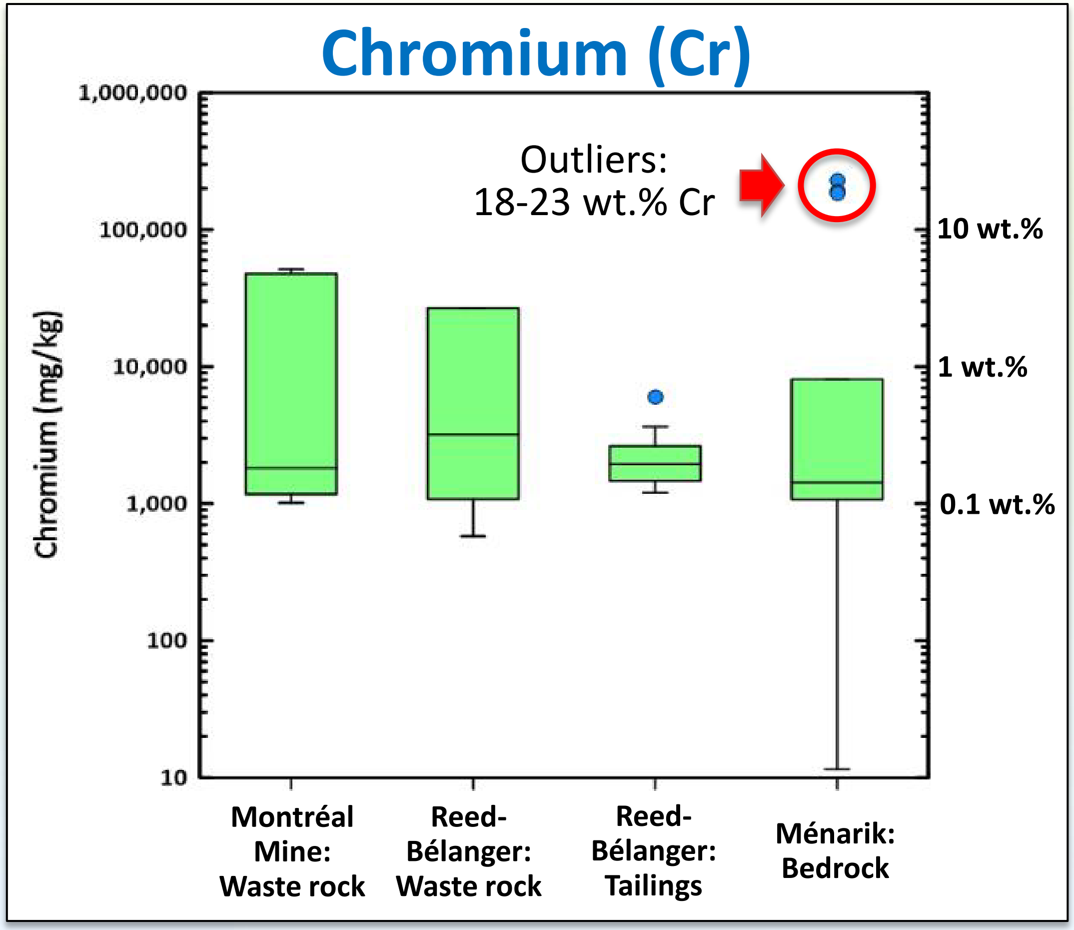
Dunite waste rock with weathering rind and disseminated chromite

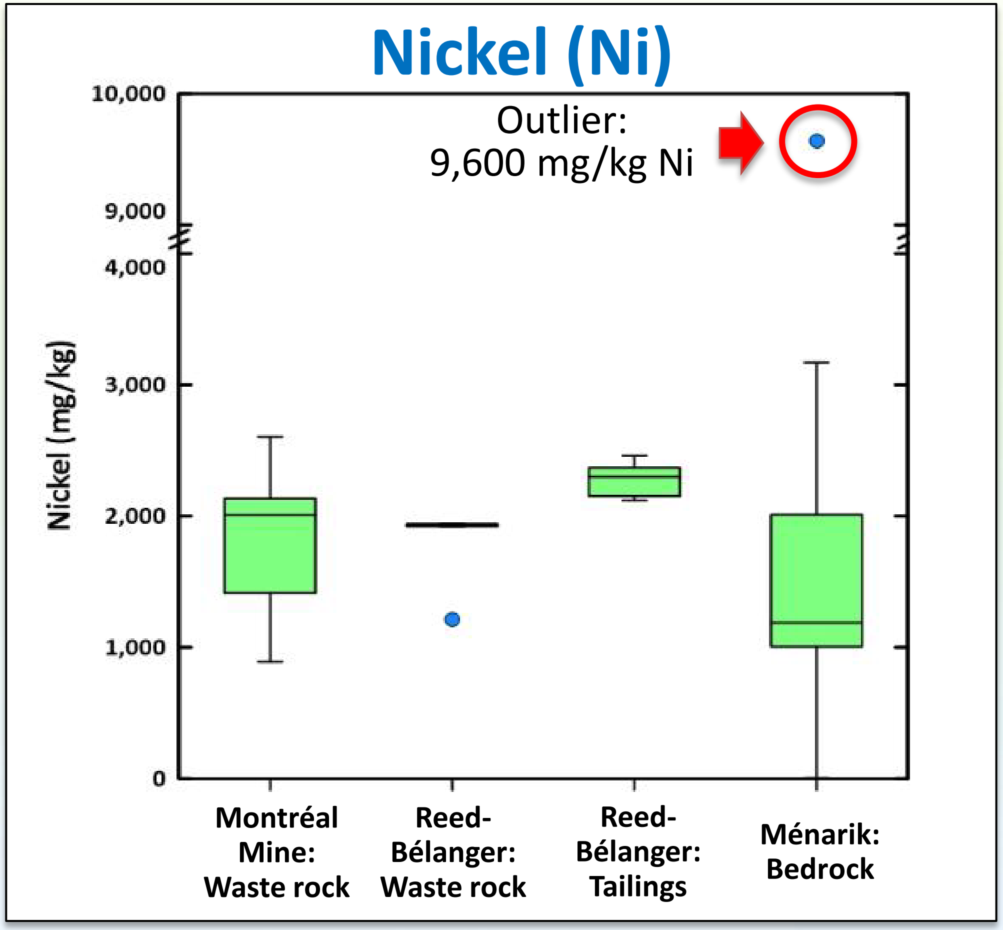
Chromite layers (black) in dunite waste rock

Tailings with hardpan layers

Overgrown tailings downstream of Reed-Bélanger mill

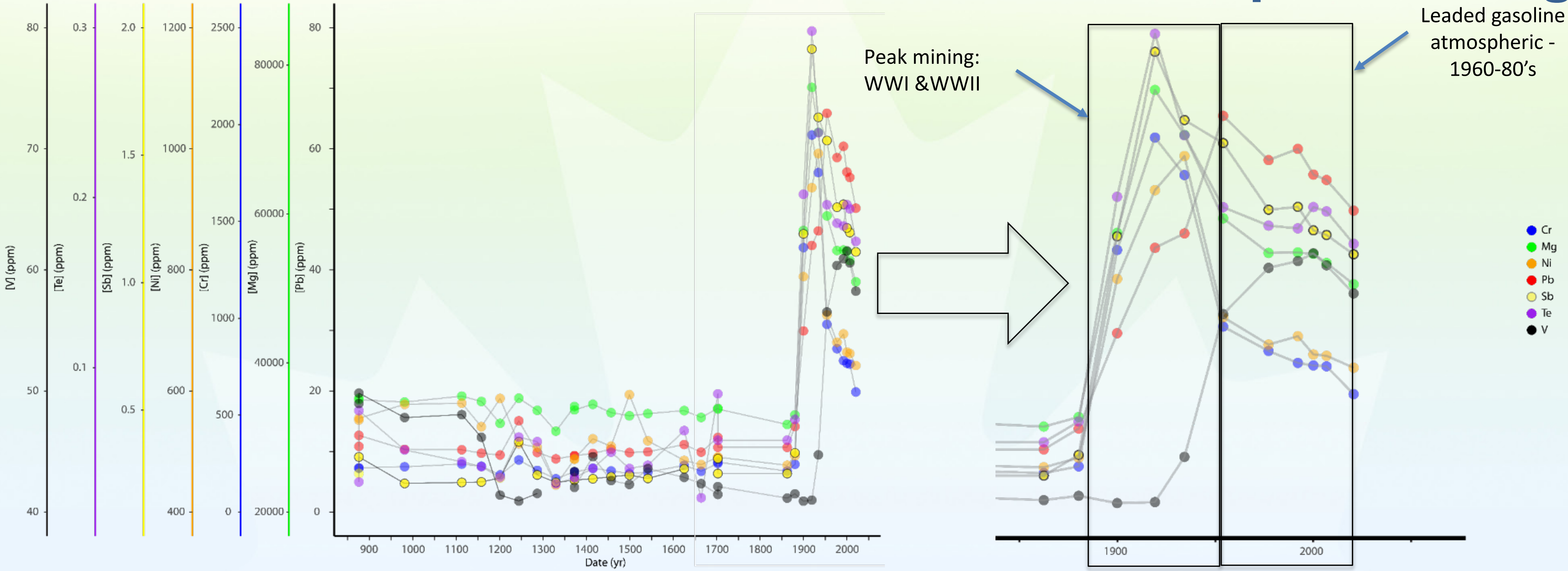
Waste Rock & Tailings – Bulk Metal Content





Cr and Ni concentrations measured using ICP-ES/MS following a 3-acid (HNO_3-$HCLO_4$-HF) digestion

Lake sediment archives post-mining



Source?

Conclusion

Groundwater Geoscience program reporting

2020 presentation – post-mining
https://www.youtube.com/watch?v=Di3G6FBplpg&list=PLdapv5BeduhXDE4XnjWz6EZjeOEA3DbA3&index=1&t=8s

2021 presentation – post-mining
https://www.youtube.com/watch?v=QiJPd-plw4Y&list=PLdapv5BeduhX3m6Mknl67esKsiQRr6wH1&index=5

Contact Information

- Josué J. Jautzy
  581-305-8437
  josue.jautzy@nrcan-rncan.gc.ca

- nicolas.benoit@nrcan-rncan.gc.ca

Thank you / Merci!

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Évaluation des impacts potentiels liés aux activités pétrolières et gazières sur les aquifères peu profonds dans la région de Fox Creek (AB) – mise à jour de mai 2023

Assessment of potential impacts of oil and gas development activities on shallow aquifers in the Fox Creek area (AB) – May 2023 update

Christine Rivard

Canada

ABSTRACT

A multidisciplinary and multi-institutional project was initiated in the Fox Creek area (west-central Alberta) in April 2019 to study environmental impacts of hydrocarbon development activities. The initial objective was to specifically study potential impacts on shallow groundwater. However, different Sectors within NRCan later identified the Fox Creek area as a region of interest for developing regional cumulative effects evaluation methods in support of new impact assessment legislation. As a result, the scope is now much broader and the project includes studies of vegetation, forest, snow cover, landscape evolution over time, and contributes to a woodland caribou habitat study. The project involves many collaborators from the federal and provincial governments, as well as from the academic community.This project is supported by the GGP and EGP programs and the Initiative on Cumulative Effects.

Project members 2022-2023
(including EGP, GGP and cumulative effects)

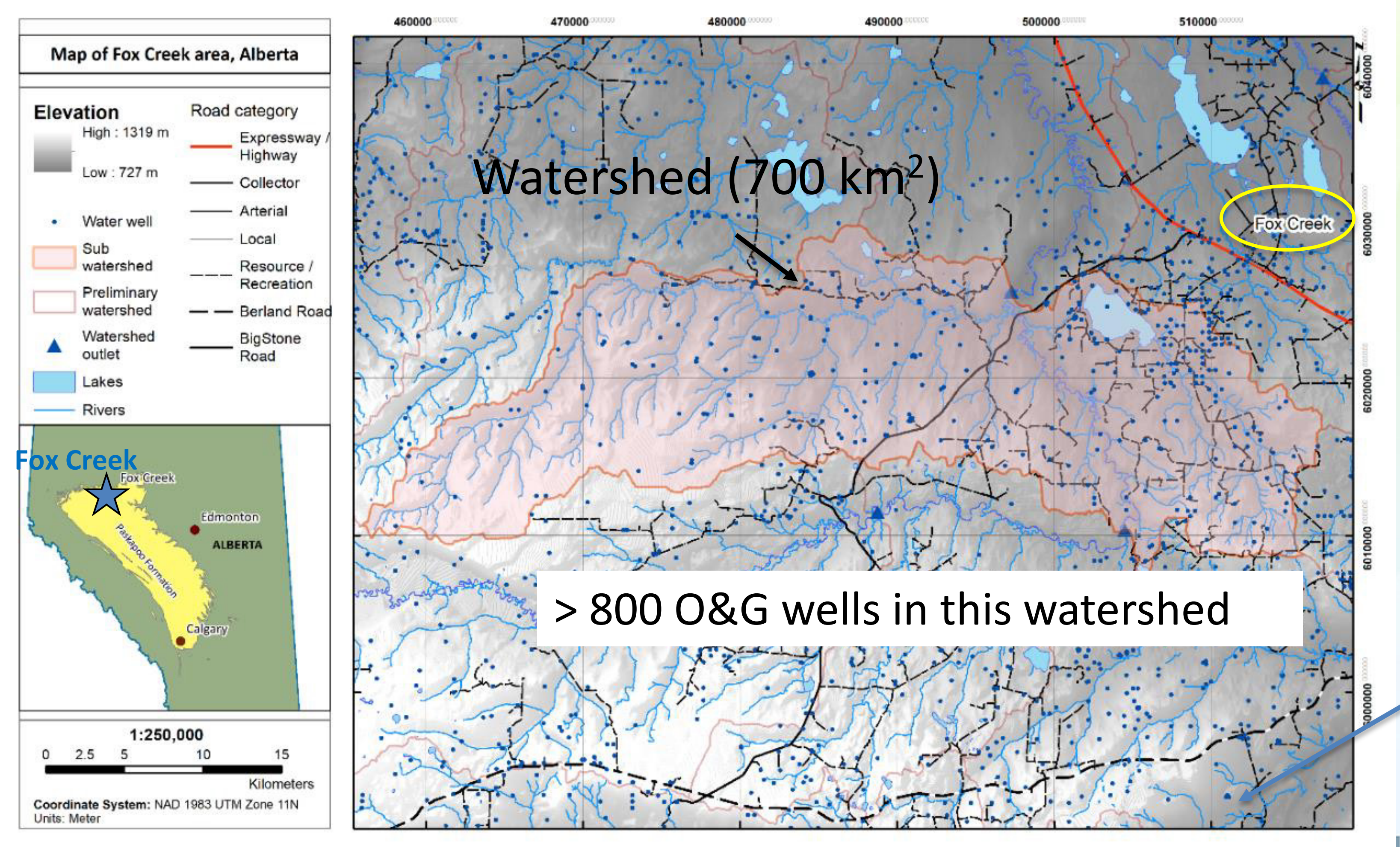
C. Rivard[1], C. Paniconi [2], G. Bordeleau[2], H. Crow[1], B.J. Meneses-Vega[1,2], D. Kononovs[1,6,3], P. Leblanc-Rochette[1,4], H. Cole[1,5,8], M. Sayag[2], D. Degenhardt[6], D. Alessi[3], B. Xu.[7], D. Lavoie[1], E. Konstantinovskaya[3], O. Haeri Ardakani[1], R. Lavoie[4], D. Palombi[8], J. Lovitt[9], W. Chen[9], S. Heckbert[8], I. Aubin[6], C. Mcclain[10]

[1] *Geological Survey of Canada, Natural Resources Canada, Québec, QC; Ottawa, ON; Calgary, AB;*
[2] *Institut national de la recherche scientifique – Eau Terre Environnement (INRS-ETE), Québec, QC*
[3] *University of Alberta, Department of Earth and Atmospheric Sciences, Edmonton, AB*
[4] *Université Laval, École supérieure d'aménagement du territoire et de développement régional, Québec, QC*
[5] *University of Alberta, Faculty of Agricultural, Life and Environmental Sci - Renewable Resources Dept, Augustina Campus*
[6] *Canadian Forest Service, Natural Resources Canada, Edmonton, AB; Sault-Saint-Marie, ON*
[7] *Northern Alberta Institute of Technology (NAIT), Edmonton, AB*
[8] *Alberta Energy Regulator and Alberta Geological Survey, Edmonton, AB*
[9] *CCMEO, Natural Resources Canada, Ottawa, ON*
[10] *Alberta Biodiversity Monitoring Institute (ABMI), Edmonton, AB*

2 MSc students
2 PhD students

Description of the study area

Fox Creek, west-central Alberta: one of the most active regions for O&G production in the last 50 years



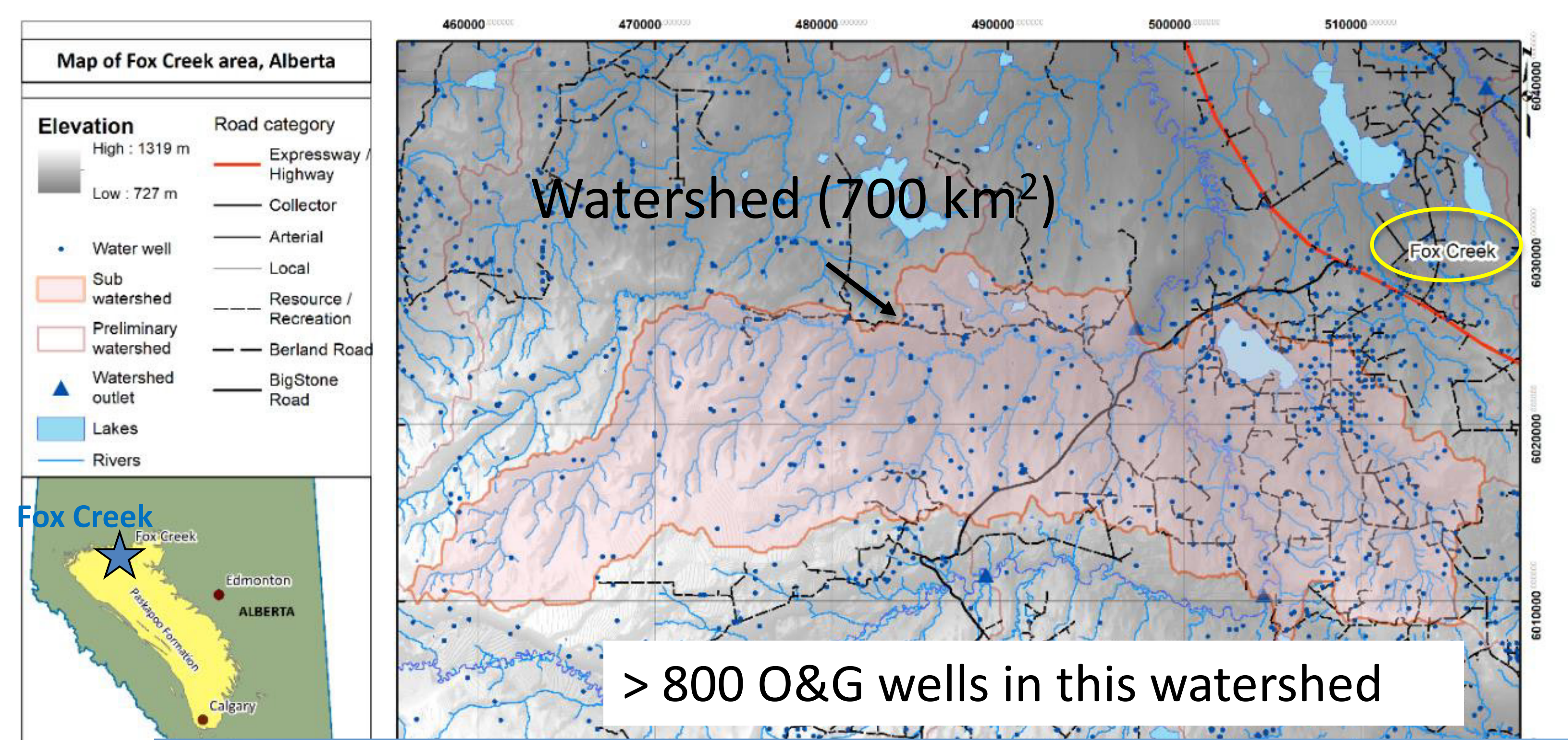
The study area is mainly forested and unpopulated

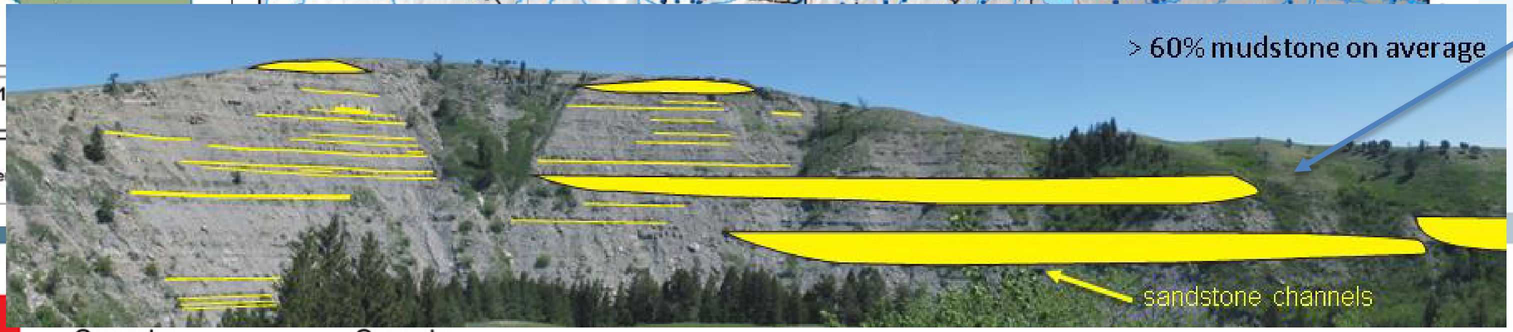
Elevations range from 785 to 1180 m

The regional aquifer is located in the Paskapoo Fm.: a complex succession of interbedded mudstone and siltstone with sandstone channels

Description of the study area

Fox Creek, west-central Alberta: one of the most active regions for O&G production in the last 50 years





The study area is mainly forested and unpopulated

Elevations range from 785 to 1180 m

The regional aquifer is located in the Paskapoo Fm.: a complex succession of interbedded mudstone and siltstone with sandstone channels

Project objectives

1) Characterize the regional shallow aquifer (GGP)
2) Study the intermediate zone integrity (EGP)

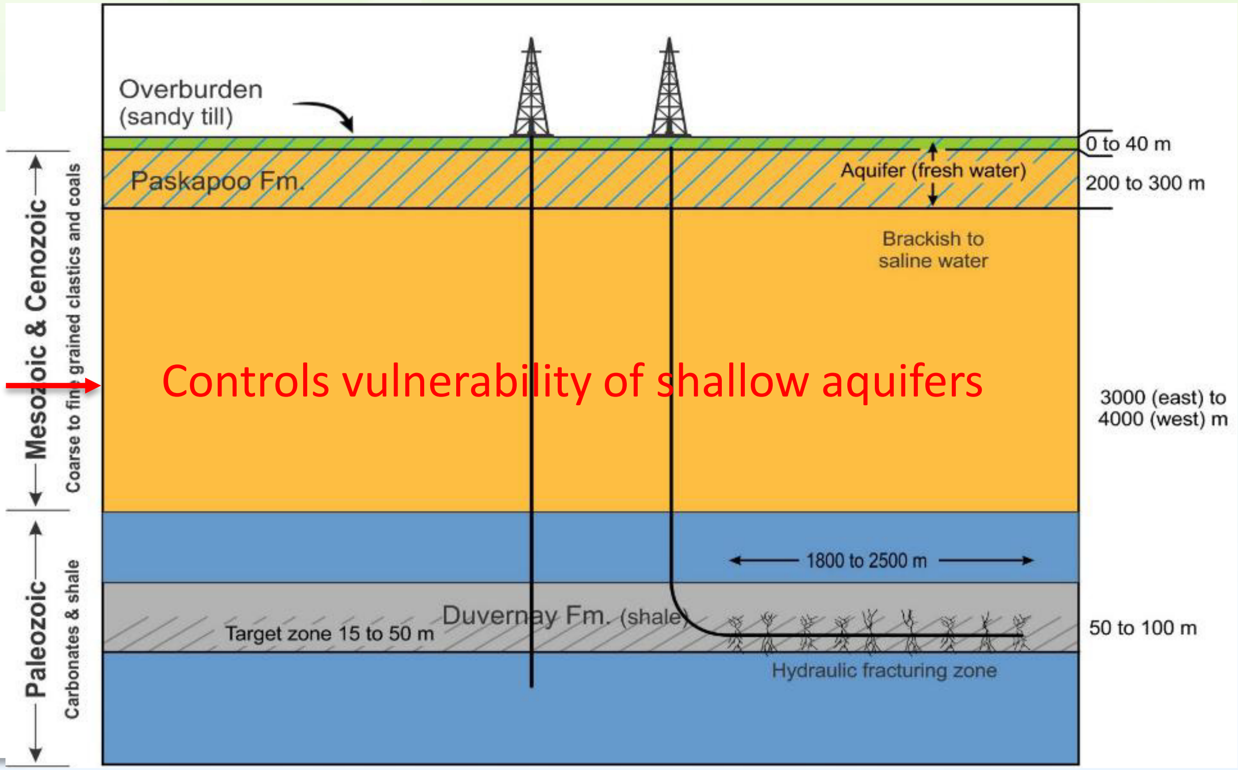
Mean water-well depth in the Paskapoo Fm: ≈50 m

Mean O&G well depth: 3000-3500 m

Surficial aquifers

Intermediate zone

Zone targeted by the industry



3) Assess cumulative effects (CE)

GGP: Groundwater Geoscience Program
EGP: Geoscience Environmental Program
CE: Cumulative Effects Initiative

Fieldwork 2022-2023

1) July 2022: Sampling campaign of the 9 monitoring wells and surface water, installation of 2 wellpoints in Tony Creek bed

2) October 2022: drilling of 3 additional monitoring wells:
   - Boreholes (cores): 2 x 32 m and 1 x 100 m
   - Wells: 3 x 32 m

Coal

Sandstone

3) January 2023: Groundwater sampling

4) Initial identification of vegetation on former well pads

5) Collection of data or samples from lysimeters, soil moisture sensors, rain gauges, rain collectors and weather stations at 5 sites in undisturbed and disturbed areas; Snow density and thickness

monthly sampling

Results

(some are preliminary)

Cause of unconsolidated sandstone intervals

Cores from the 3 wells drilled in Fall 2022

Well-compacted and cemented

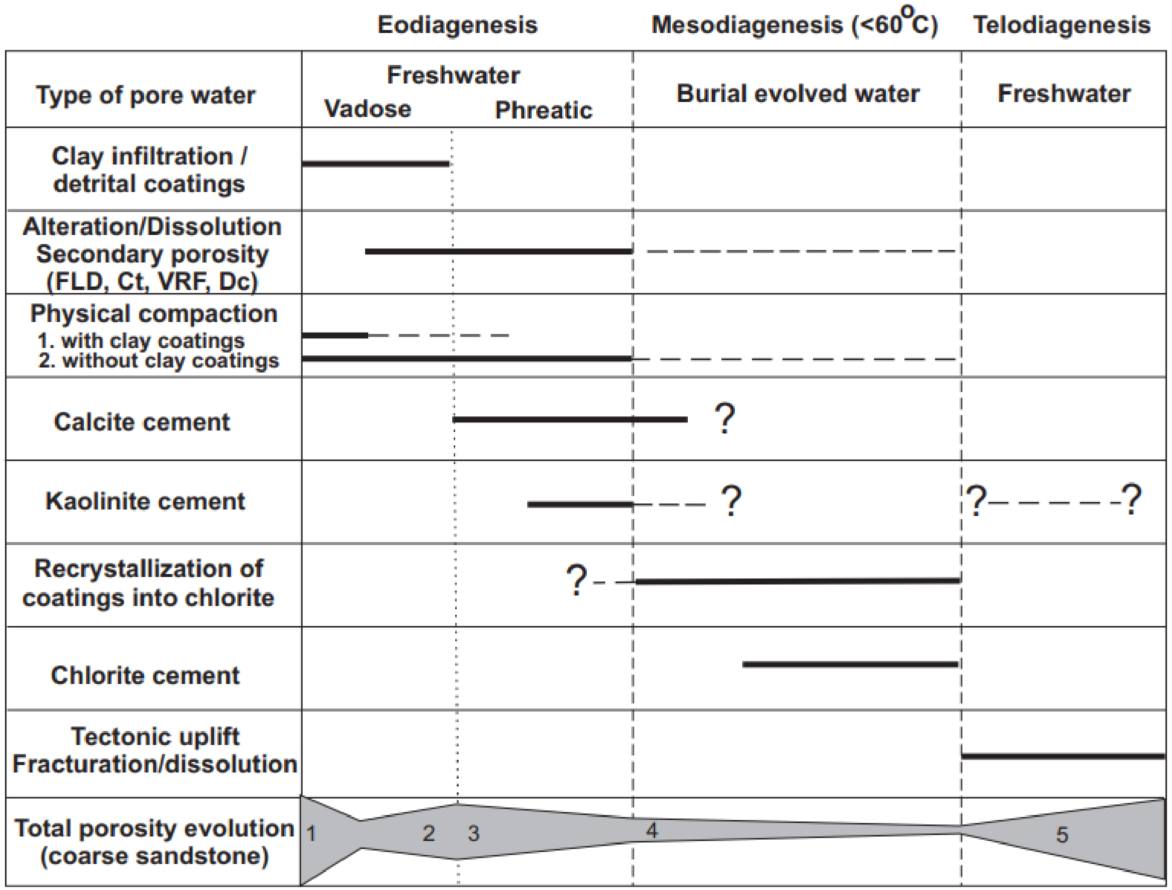
Friable

Unconsolidated

Thin section

Paleocene (60 Ma)

Eocene (45 Ma)



FLD: Feldspar
Ct: Chert
VRF: Volcanic rock fragment
Dc: Detrital calcite

By D. Lavoie

Canada

Cause of unconsolidated sandstone intervals

Cores from the 3 wells drilled in Fall 2022

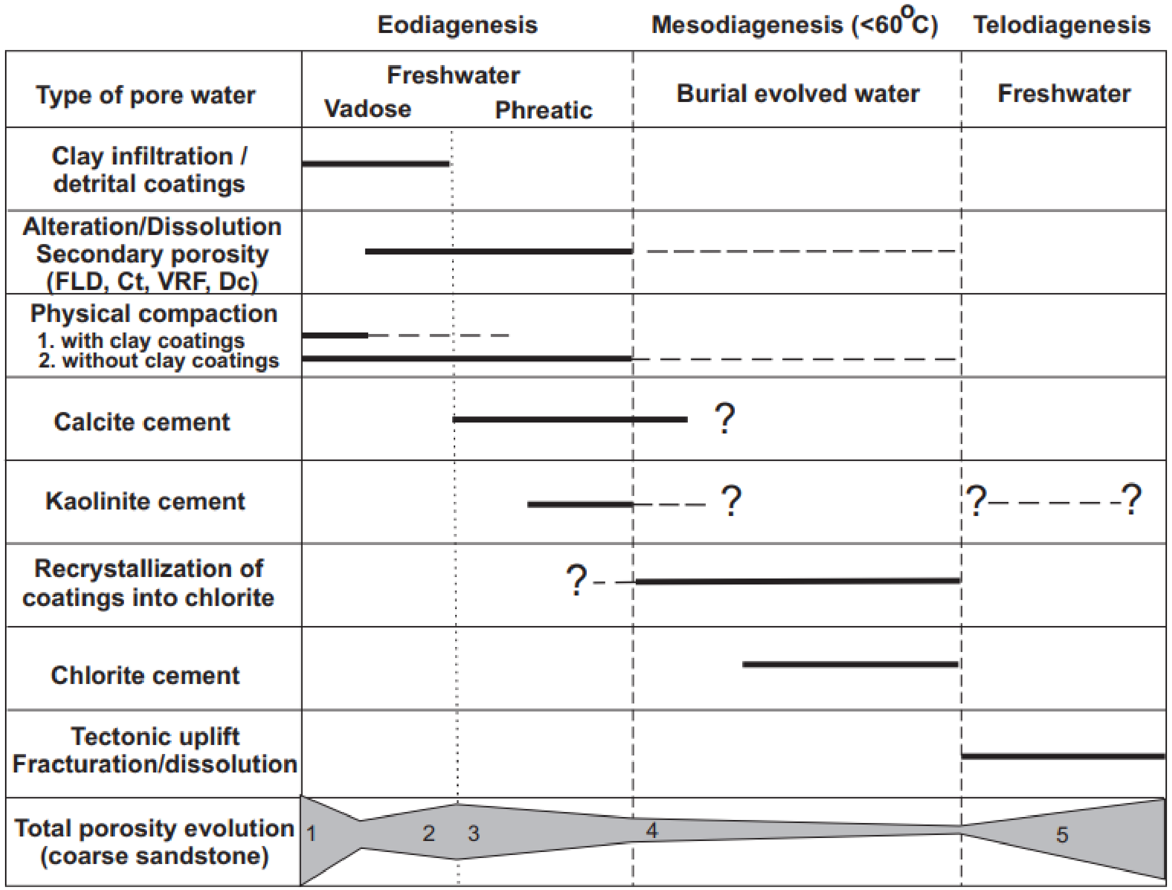
Well-compacted and cemented

Friable

Unconsolidated

Paleocene (60 Ma)

Eocene (45 Ma)



- framework integrity has been preserved through early clay coatings and early (limited) cementation events;
- dissolution of chemically unstable minerals has played a significant role in creating secondary porosity;
- Exhumation resulted in major freshwater circulation;

late dissolution of minerals and cements producing the friable to unconsolidated framework

FLD: Feldspar
Ct: Chert
VRF: Volcanic rock fragment
Dc: Detrital calcite

By D. Lavoie

Canada

Numerical modeling – 1D recharge

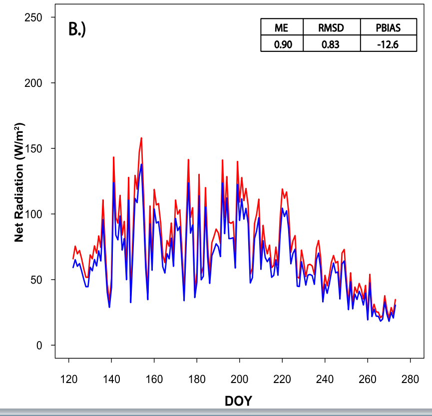
1D SHAW (Simultaneous Heat and Water) model

Simulates heat and water movement through plant cover, snow and soil

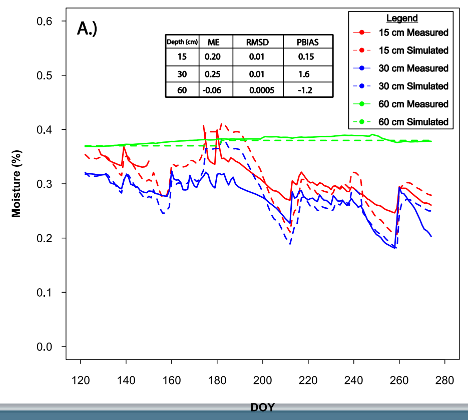
takes into account soil freezing and thawing to estimate runoff, evaporation, transpiration and percolation

Examples for the undisturbed upland site:

Net solar radiation



Soil moisture content

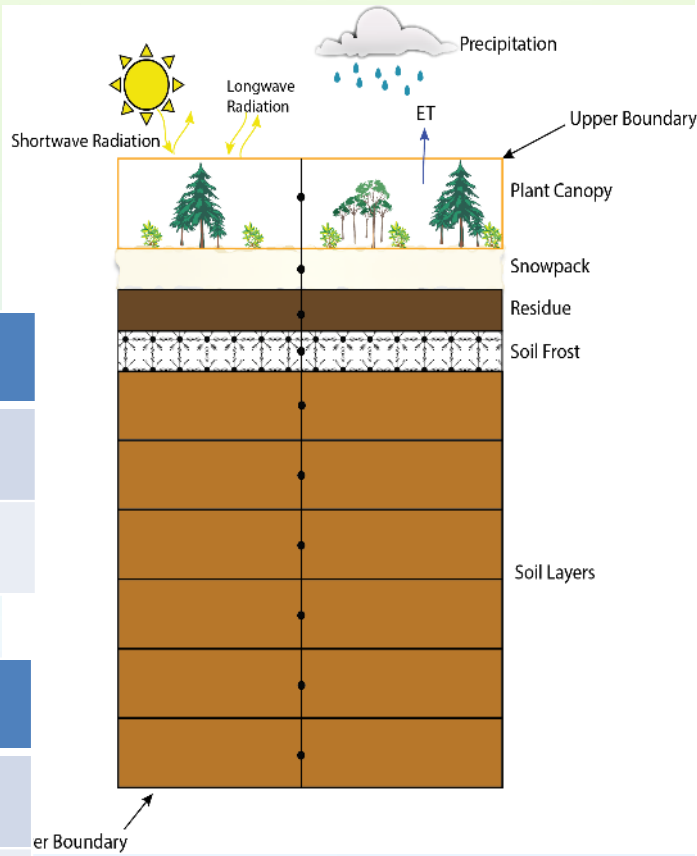


Upland site:

Site	Precipitation (mm)	ET (mm)	ET:P
Undisturbed Forestland	307.7	448.4	1.46
Disturbed Forestland	307.7	317.3	1.03

Lowland site:

Site	Precipitation (mm)	ET (mm)	ET:P
Undisturbed Wetland	468.2	433.8	0.93
Disturbed Wetland	468.2	217.7	0.38



By D. Kononovs, MSc student

Geochemistry and Groundwater flow

Map of water types

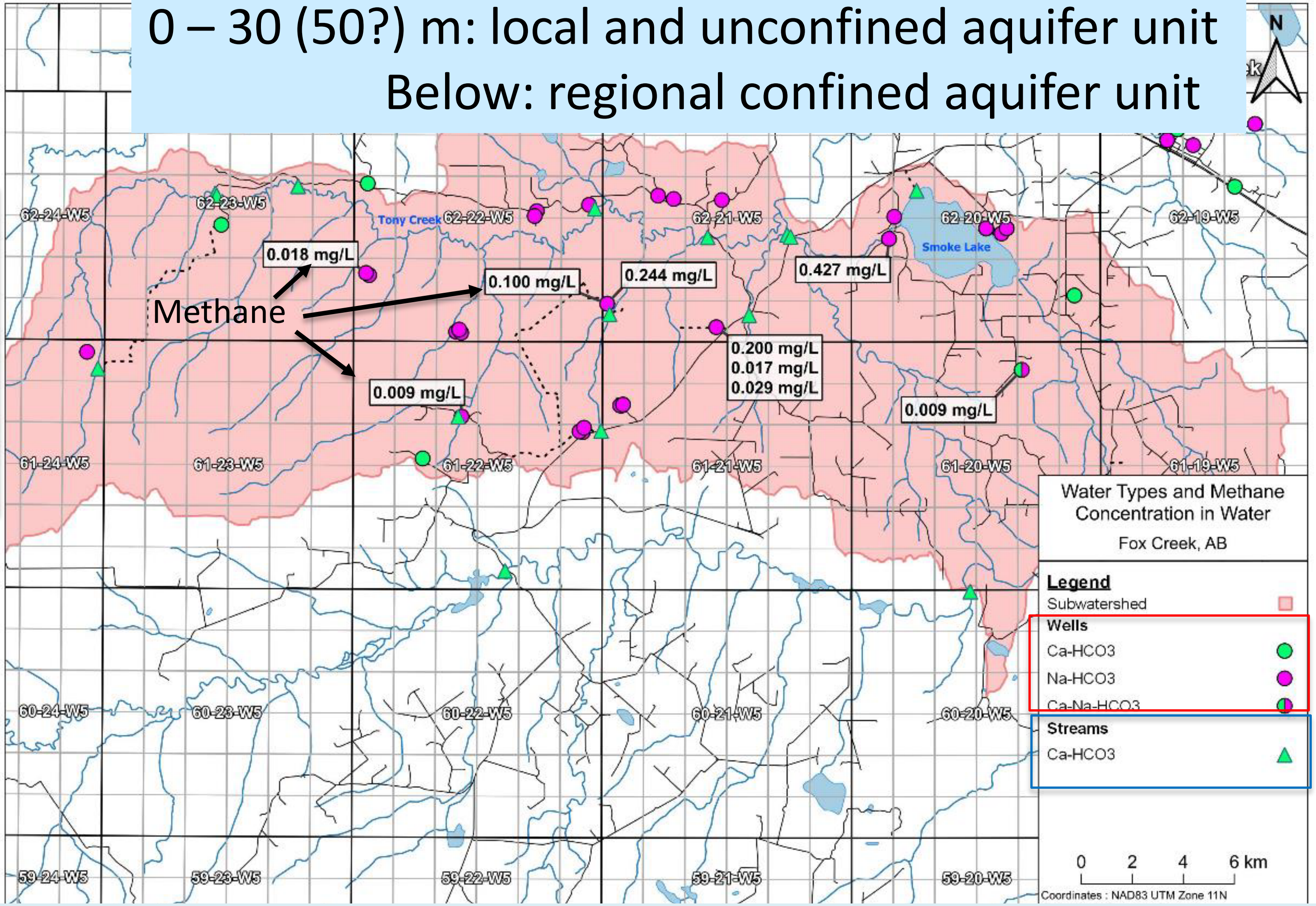
For GW: mostly **$NaHCO_3$**

moderately evolved

For SW: **$CaHCO_3$**

little evolved

0 – 30 (50?) m: local and unconfined aquifer unit
Below: regional confined aquifer unit



Samples from:

- monitoring wells (12)
- private wells (12)
- surface water (10)

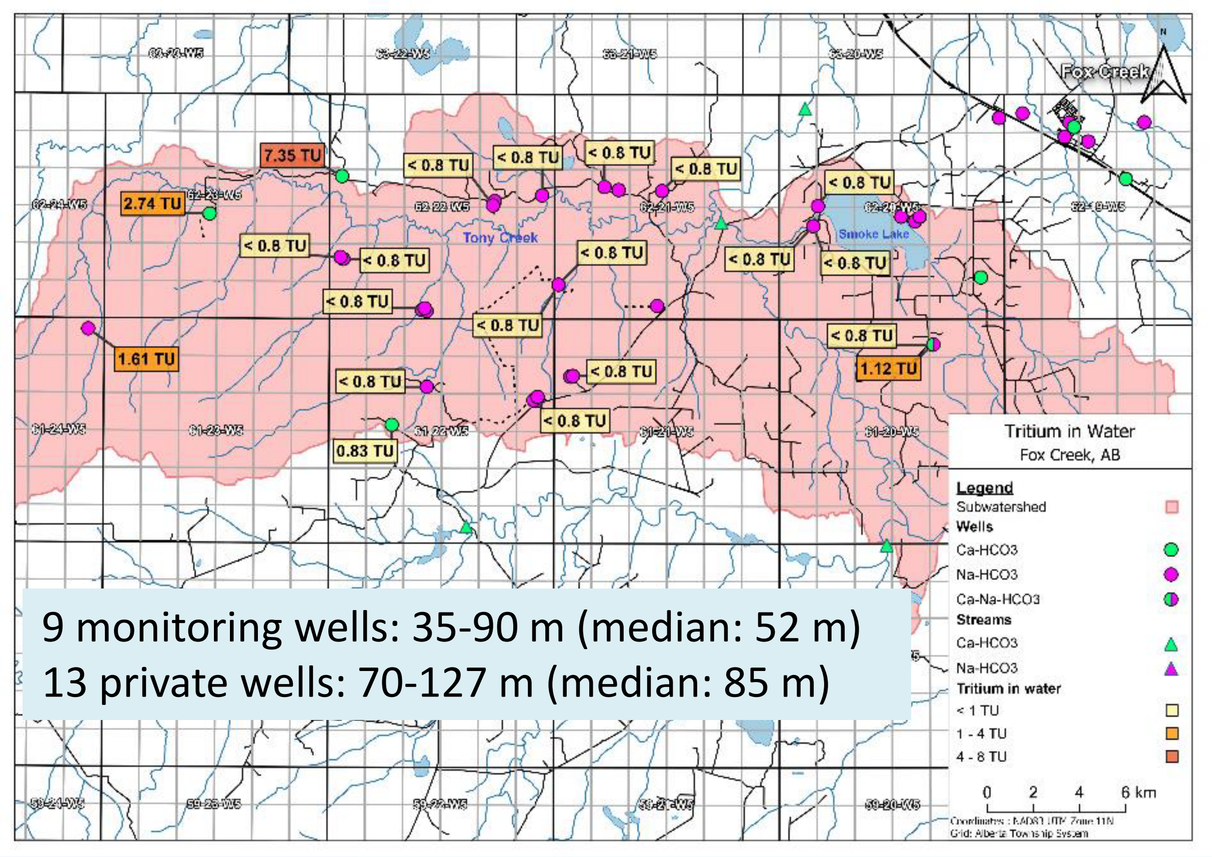
Well depth (m)	Mean SWL (m)	Mean Elev. (m)
0 - 30	10.5	936.7
0 - 50	20.3	913.7
50 - 100	33.5	857.6
100 - 150	67.3	827.7

Only 7 wells contained small concentrations of dissolved methane. All of **microbial** origin.

By G. Bordeleau

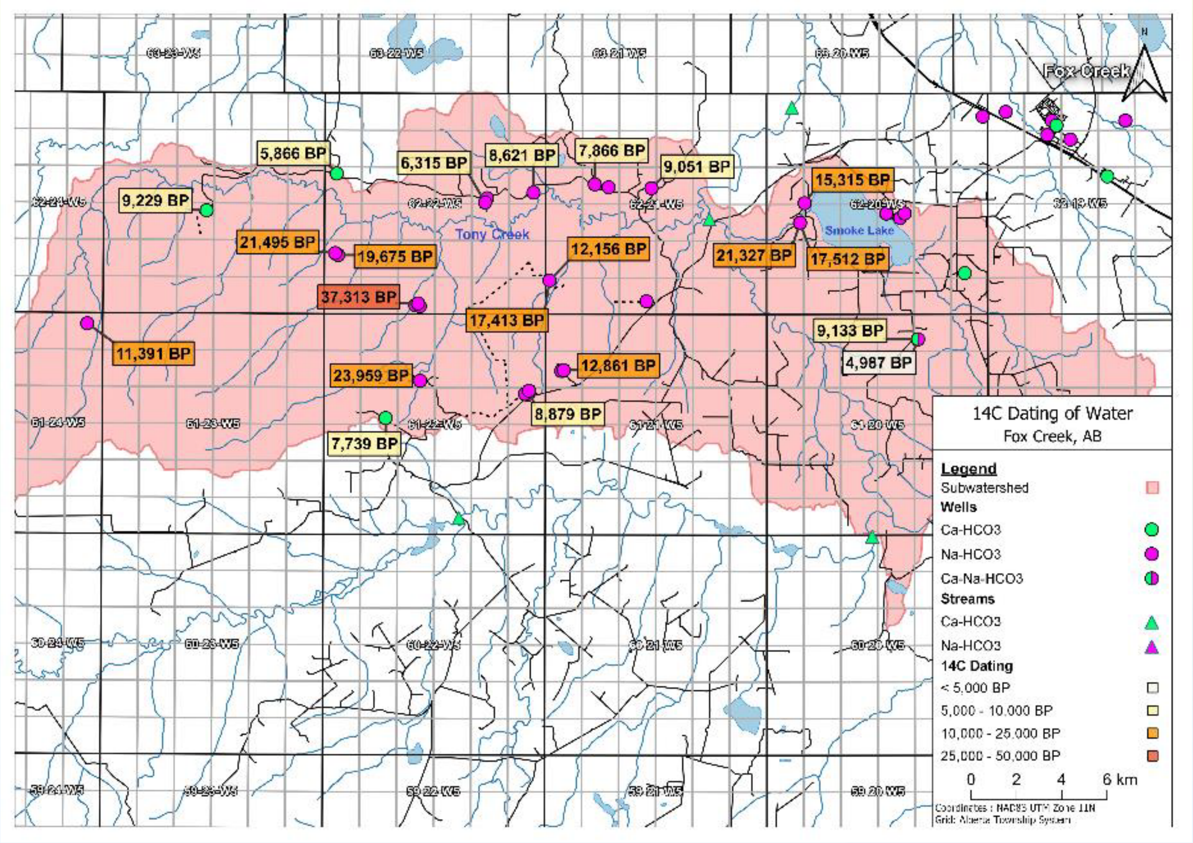
Geochemistry and Groundwater flow

Tritium

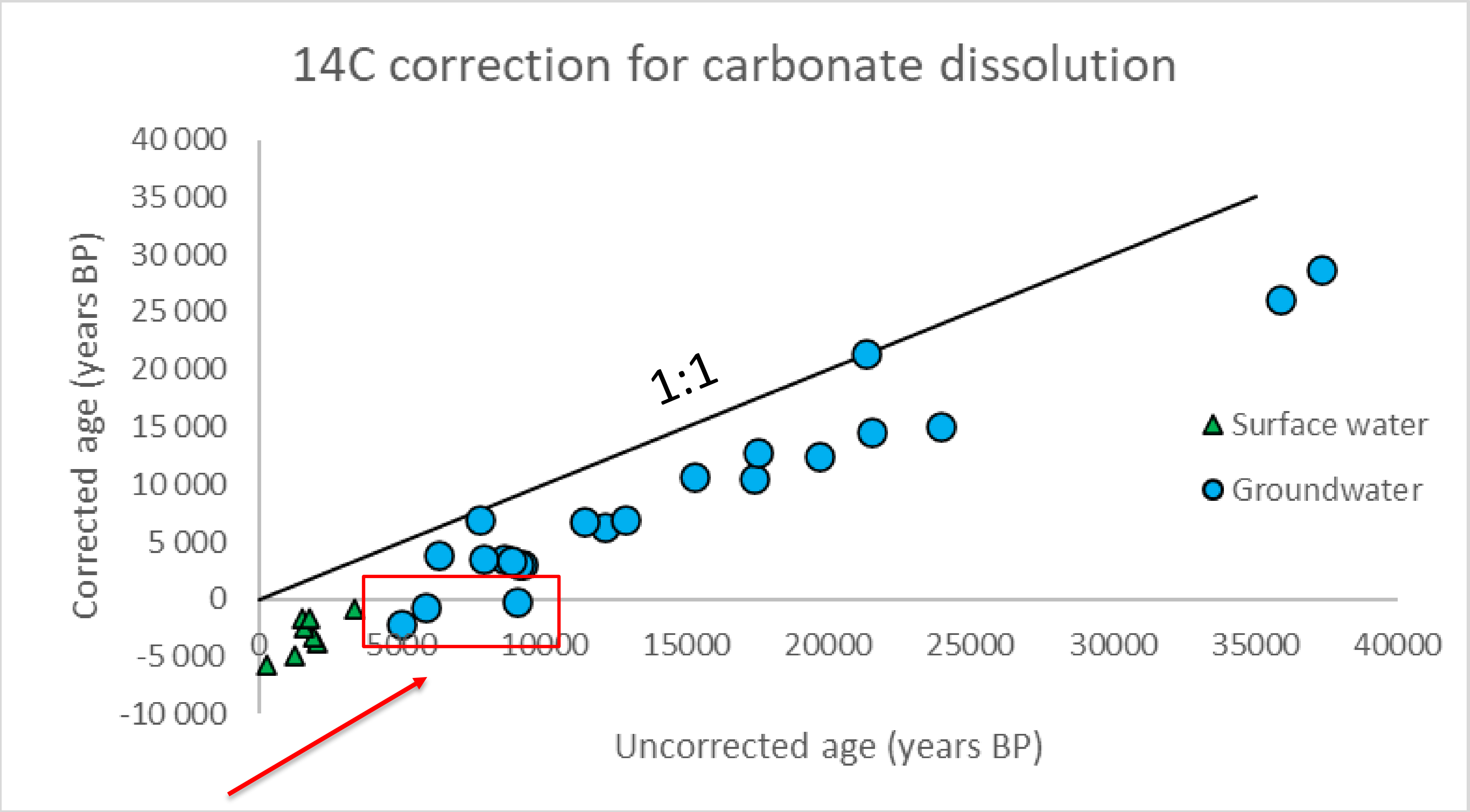


9 monitoring wells: 35-90 m (median: 52 m)
13 private wells: 70-127 m (median: 85 m)

Uncorrected radiocarbon age (from the lab)



Geochemistry and Groundwater flow



Reduction by 20 to 70%

Negative values: water is too young to be estimated using ^{14}C

Geochemistry and Groundwater flow

In the Paskapoo Fm.:

1) high yields are available
2) vertical recharge is low (0 – 70 mm/y)
3) some sandstone intervals are barely consolidated
4) GW shows relatively large radiocarbon age values (> 5,000 y)

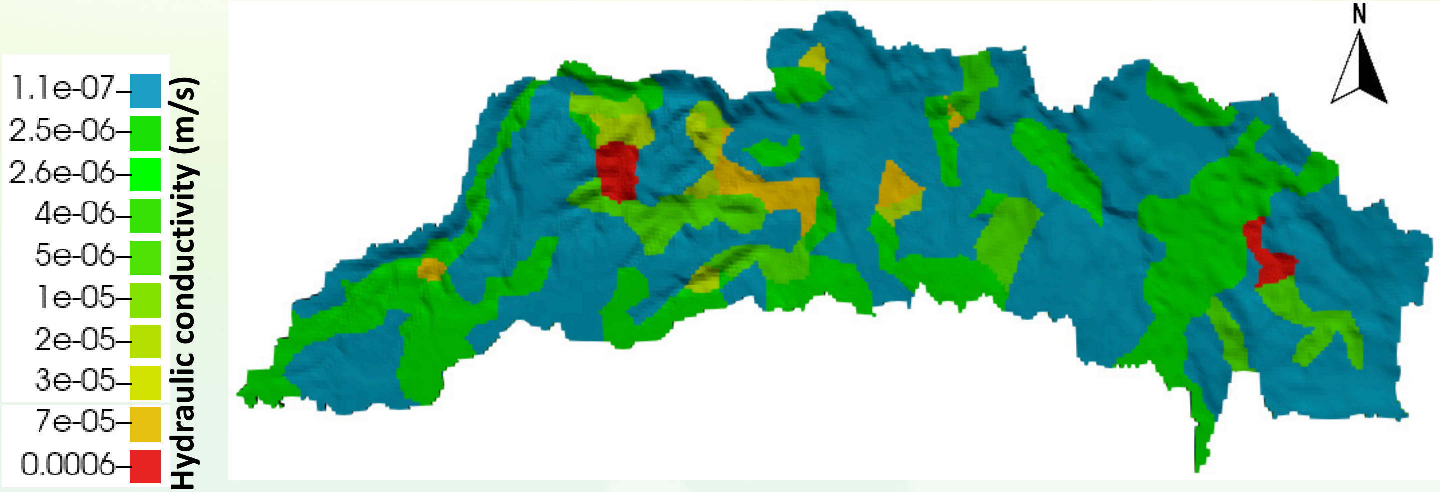
↓

significant contribution of water likely comes from the Rocky Mountain foothills

SW – GW interactions with CATHY

(CATchment HYdrology)

Goal: Study SW/GW interactions

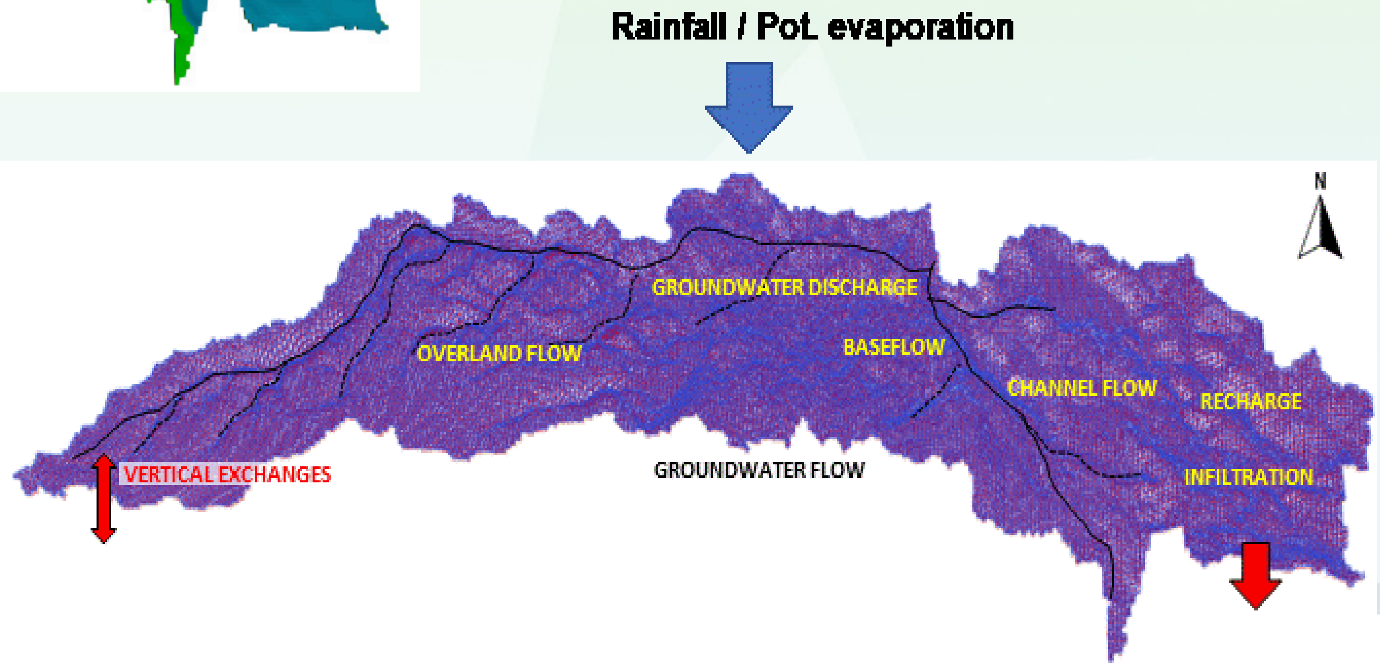


The CATHY model includes:

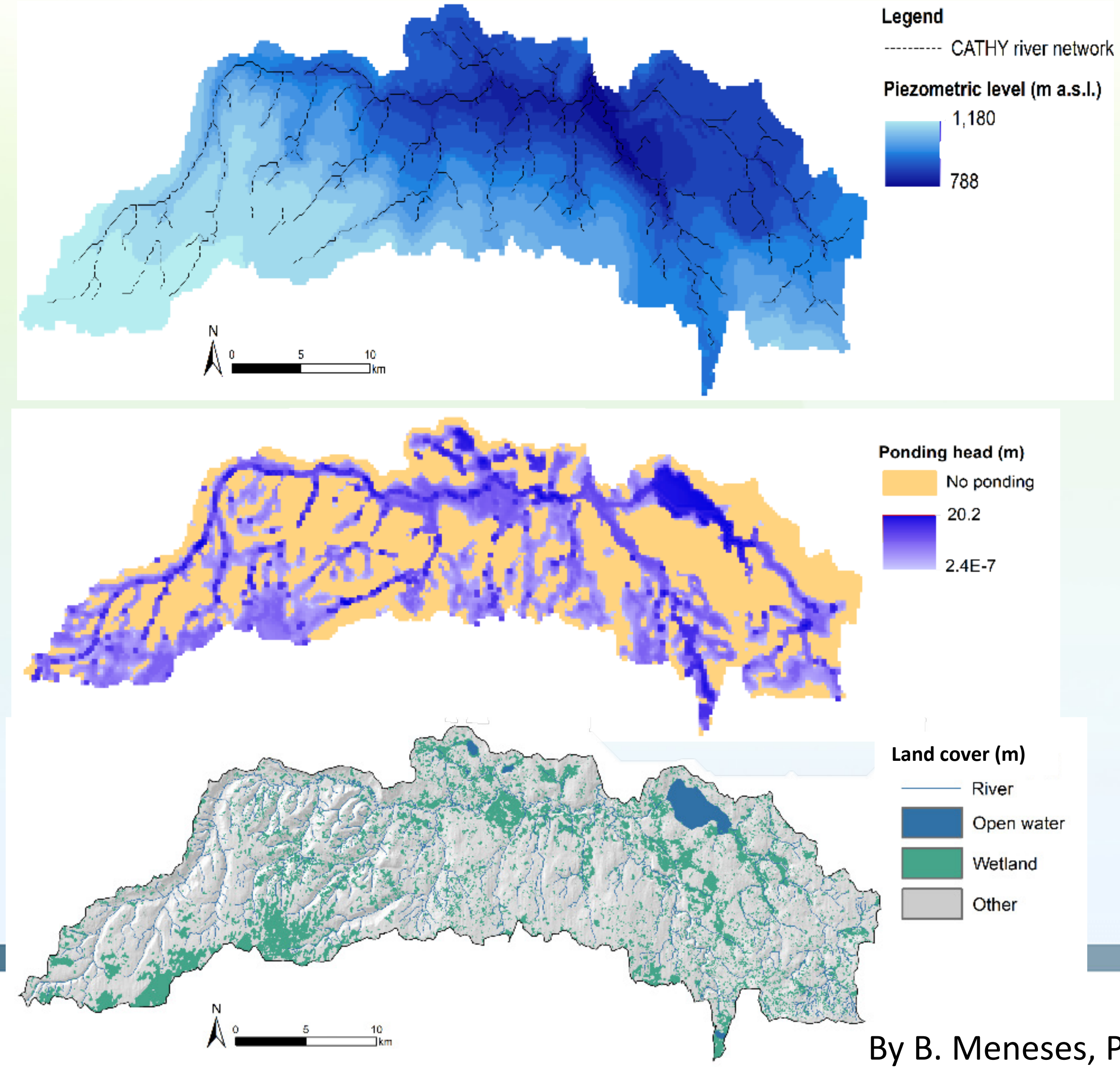
- Upper Paskapoo Fm. and surficial units defined from the provincial geological models
- Depitted DEM (200 m resolution)

Model spatial discretization:

- ✓ 14 layer (15 slices) ;
- ✓ 274 005 nodes ;
- ✓ Total model depth: 45 m.

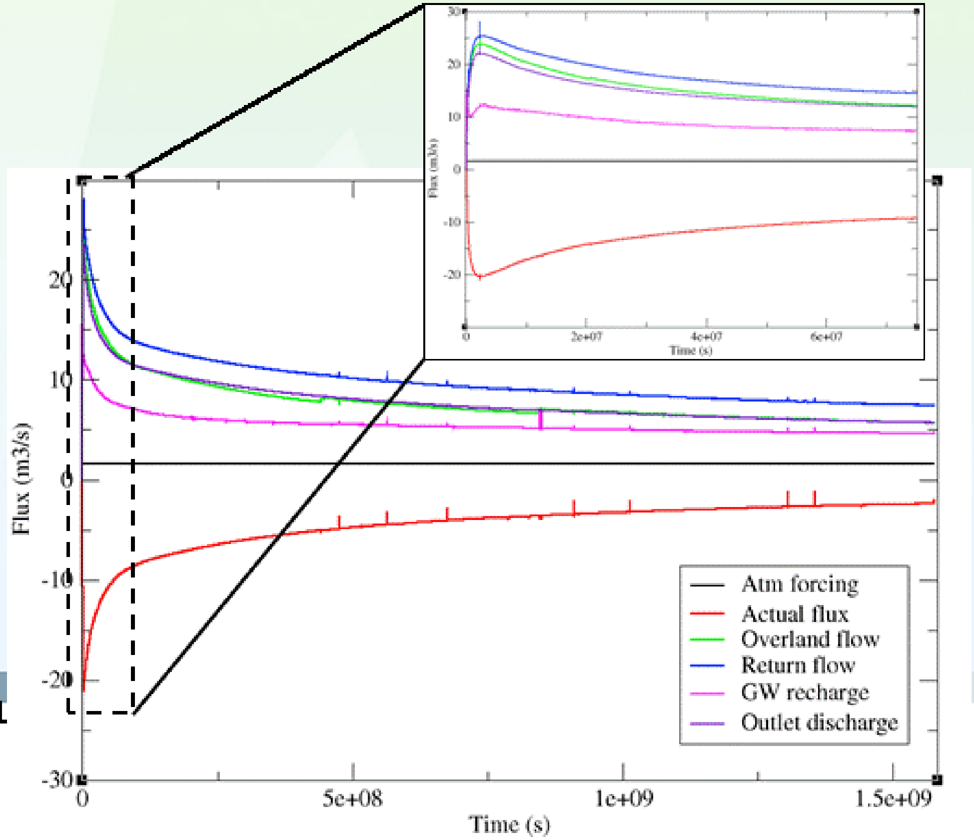


SW – GW interactions with CATHY



Simulation:

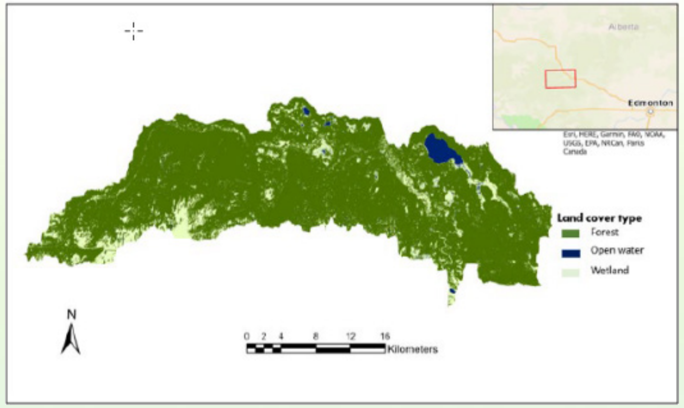
- 50 years
- Initial water table depth: 1.0 m
- Atmospheric forcing: 70 mm/y
- No-flux boundary condition along the lateral and bottom boundaries of the model

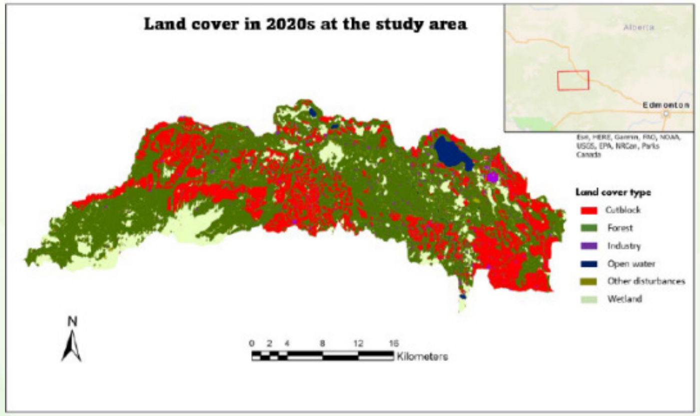


By B. Meneses, PhD student

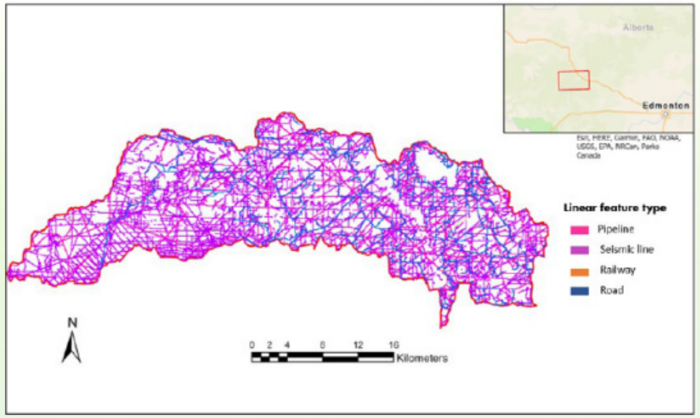
Evolution of landscape over time (1950-2020)

Land cover in the 1950s at the study watershed



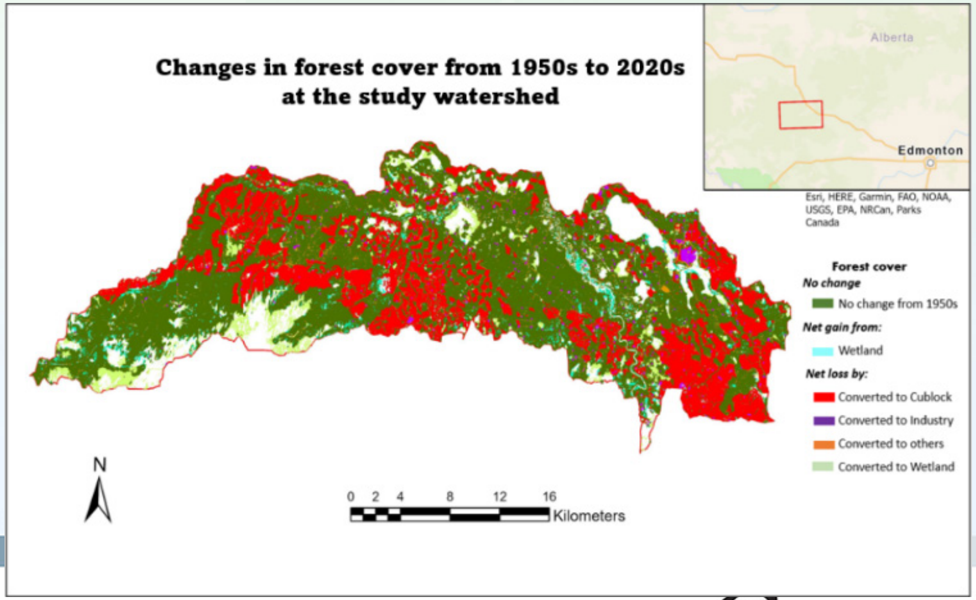


Linear features in 2020s at study watershed



Class	Study area (km²)			
	1950s	2020s	Change km²	Change %
Cutblock	-	184.05	184.05	83.70*
Forest	617.07	397.19	-219.88	-35.63
Industry	-	10.41	10.41	4.73*
Open water	11.33	11.85	0.52	0.24*
Other disturbances	-	22.89	22.89	10.41*
Wetland	89.23	91.76	2.53	1.15*
Total	706.3	706.3		

Example for the loss of forest (in red):



Vegetation recovery

Functional, structural, and taxonomic recovery of plant communities on reclaimed well pads over time

Project goal: quantify vegetation recovery over time on reclaimed well pads in the Fox Creek area.

Fieldwork next summer to collect data on:

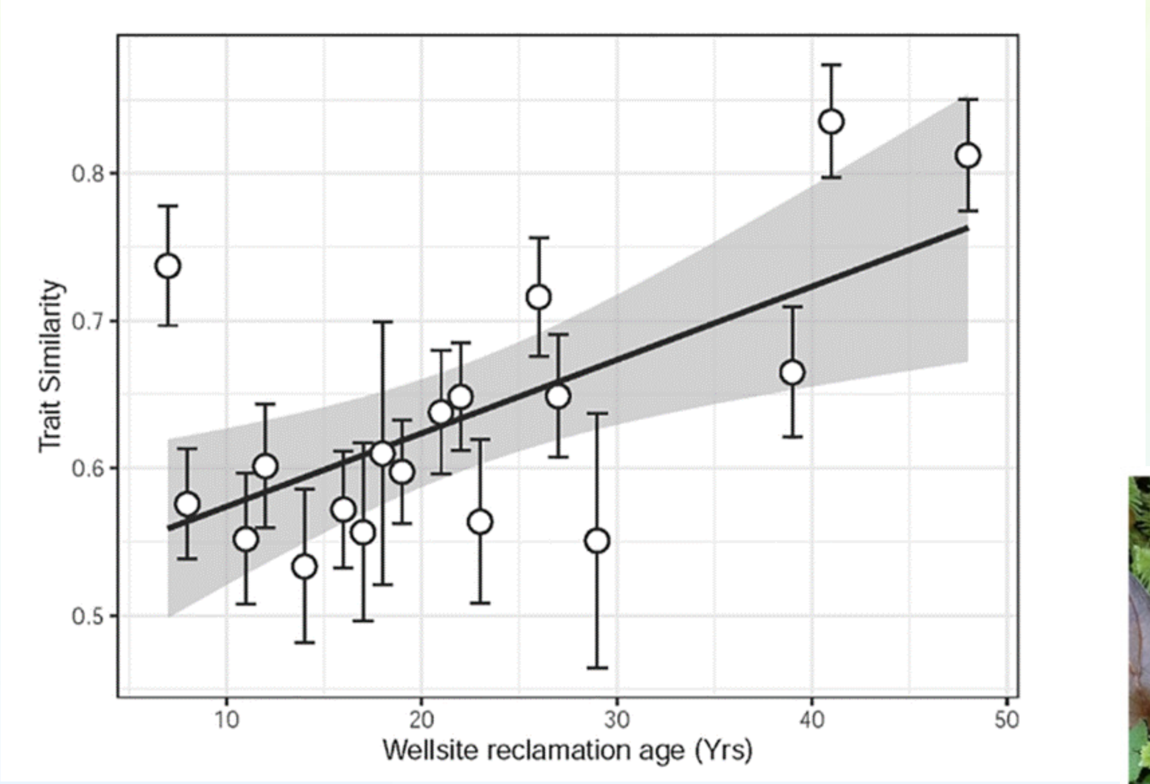
- Sites (soil measurements)
- Community composition
- Vertical and horizontal structure
- Functional traits

↓

Trait database and field measurement values

Vegetation recovery

Future application and analysis



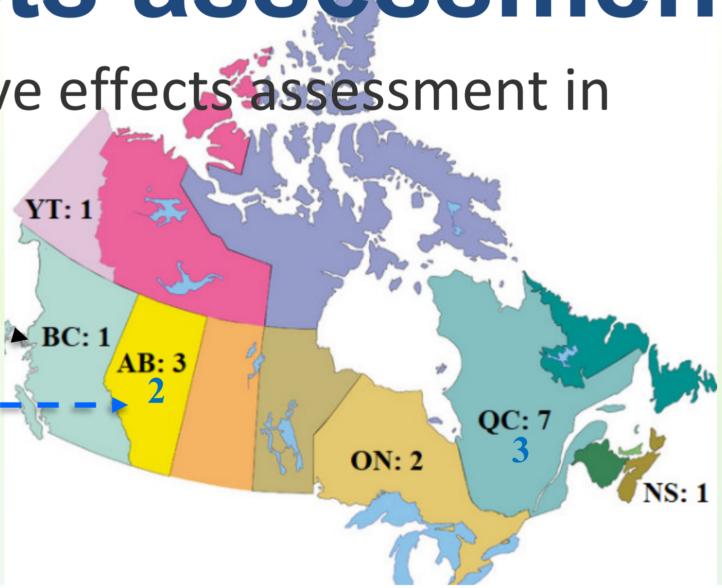
Azeria et al. (2020)

- Inform forest management and reclamation practices
- Improve understanding of ecological processes post-disturbance

Study on cumulative effects assessment

Objective: to identify challenges and obstacles to cumulative effects assessment in Canada and make recommendations to address them.

- 15 semi-structured interviews with consultants and federal government employees
- 5 focus groups



10 Recommendations, including:

1) Acquire more data, notably through the development of strategic and regional assessments which would be government-funded, especially on the VC conditions;
2) All collected data should be shared and stored into publicly available databases;
3) Provide clearer, more specific guidelines to proponents, with achievable anticipated outcomes;
4) Increase and improve collaboration among stakeholders during the CEA process;
5) Recognize the importance and value of Indigenous Knowledge and include it in CEAs and decision-making processes;
6) Centralize requests to Indigenous communities for all development projects, to avoid unreasonable workloads and duplication of work;

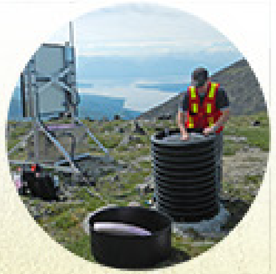
by P. Leblanc-Rochette, MSc student

CONTACT INFORMATION

- Christine Rivard
- Work phone number: 418-654-3173
  Christine.Rivard@nrcan-rncan.gc.ca

THANK YOU!




Geological Survey of Canada
Scientific Presentation, Environmental Geoscience Program

Induced Seismicity Research Project:
Highlights of Accomplishments in 2022-2023

Projet de recherche sur la sismicité induite :
Faits saillants des réalisations en 2022-2023

H. Kao

May 16, 2023

ABSTRACT

The Induced Seismicity Research (ISR) project has a national scope with team members from NRCan offices in Sidney, Ottawa, and Quebec City. The Project establishes close collaboration with both public and private sectors, including provincial and local governments, crown corporations, professional organizations, and academia, to address critical knowledge gaps in the source process of induced earthquakes and to provide observation-based science to improve regulations on the development of unconventional hydrocarbon resources.

Key accomplishments during 2022-2023 include:

- Enhanced monitoring of injection-induced earthquakes (IIE) for west Canada;
- Development of innovative AI-based methodologies for automatic detection and location of IIE;
- Delineation of physical factors controlling hydraulic fracturing-induced seismicity with AI;
- Publications of research results on source characteristics of significant IIE events in Canada;
- Media interviews, including live programs by CBC and local radio stations, on significant IIE events and IIE research;
- Invited by the American Rock Mechanics Association (ARMA) to give an international webinar (recorded and available at ARMA's YouTube channel).

KEY PROJECT MEMBERS

- GSC Research Scientists and Supporting Staff
  - Sidney: Honn Kao (Project Leader), John Cassidy, Ramin M.H. Dokht; Nina Parry (admin support)
  - Ottawa: Don White
  - Quebec: Joby Aubut Bernard, Christine Laberge, and Juliette Mochizuki (admin support)

- Research Associates and Volunteers
  - Ryan Visser (analyst funded by Geoscience BC; left in March 2023)
  - Bei Wang (UVic PDF funded by Geoscience BC; left in Nov 2022)
  - Hongyu Yu (GSC casual employee; left in Nov 2022)
  - Fengzhou Tan and Chet Goerzen (UVic graduate students)
  - Ayodeji Kuponiyi, Ene Johnson, Mankirat Singh, Kai Jobin, and Kashike Umemura (contractors and co-op students)

Collaboration Highlights

- External Research Resources
  - $90,000 from BC Oil and Gas Research Innovation Society (BCOGRIS) in support of targeted research of IIE in NE BC.
  - $185K contributed by the BC Seismic Research Consortium in support of IIE monitoring in the WCSB.

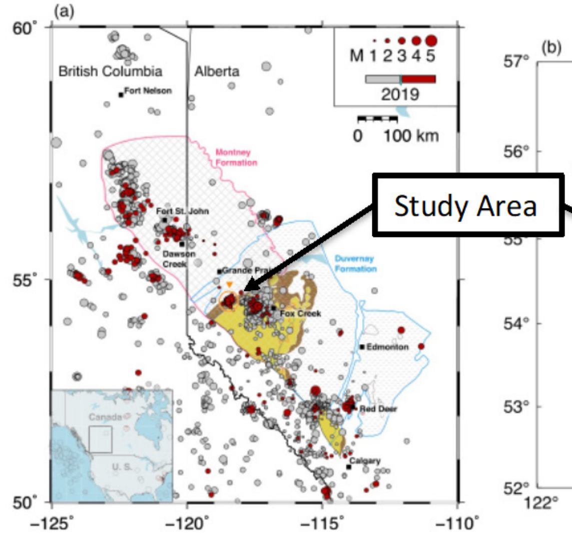
- Enhanced Local and Regional Seismograph Coverage in Western Canada
  - McGill University, University of Victoria, University of Calgary, Geoscience BC, BC Energy Regulator (BCER, formally known as BC Oil and Gas Commission), Alberta Energy Regulator (AER) and Canadian Association of Petroleum Producers (CAPP)

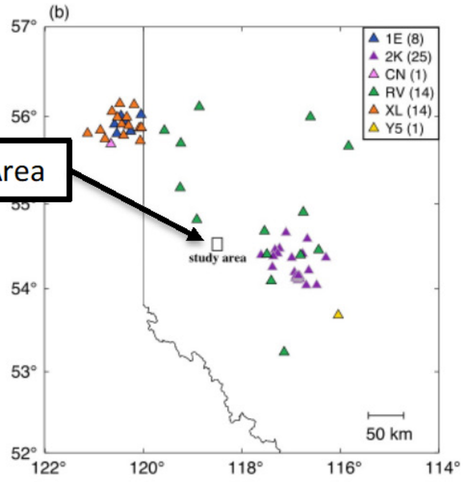
- Joint IIE Research and Publications
  - McGill University, University of Victoria, University of Calgary, Ruhr University Bochum (RUB, Germany), Geoscience BC, and BCER

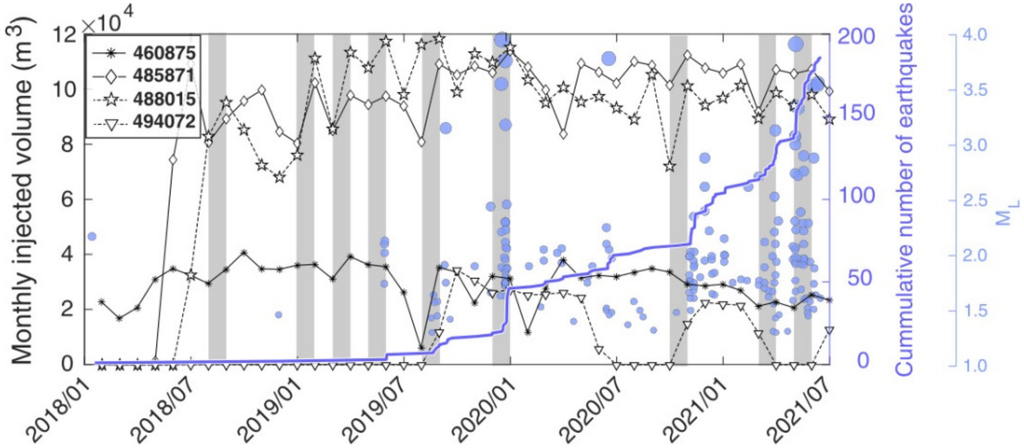
Scientific Highlight #1:

Decades of fluid injection can turn seismic quiescence into surged activity

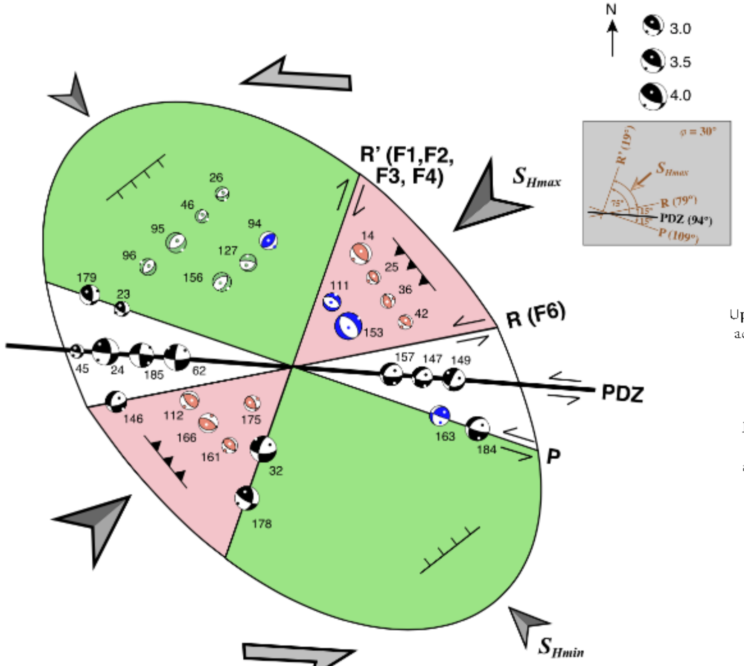
Observations

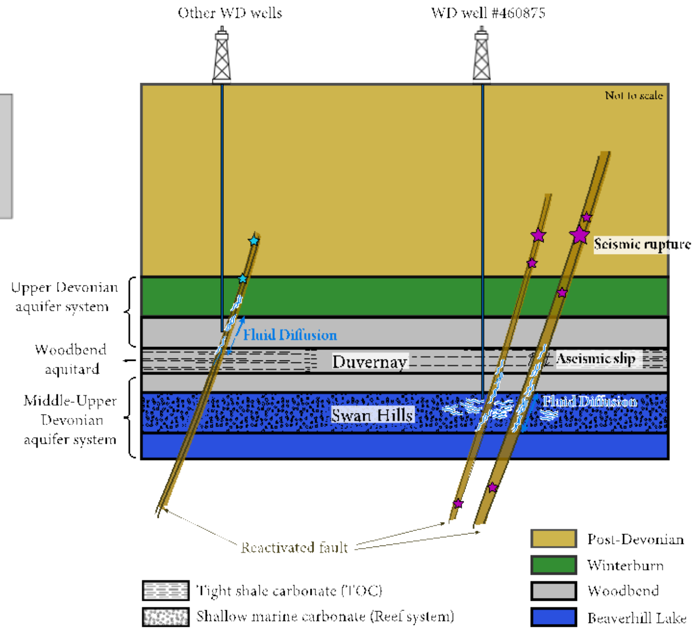






Interpretations





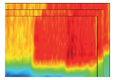
- Focal mechanisms and fault orientations are consistent with RSS in a stress regime of S_{Hmax} = N38°E (from breakout measurements, *Shen et al.,* 2019)
- Key message: Long-term WD injection leads to the development of RSS consisting of reactivated crustal faults extending to both shallow and deep depths.

Yu et al. (2021, GRL; 2022 JGR-SE)

Scientific Highlight #2:

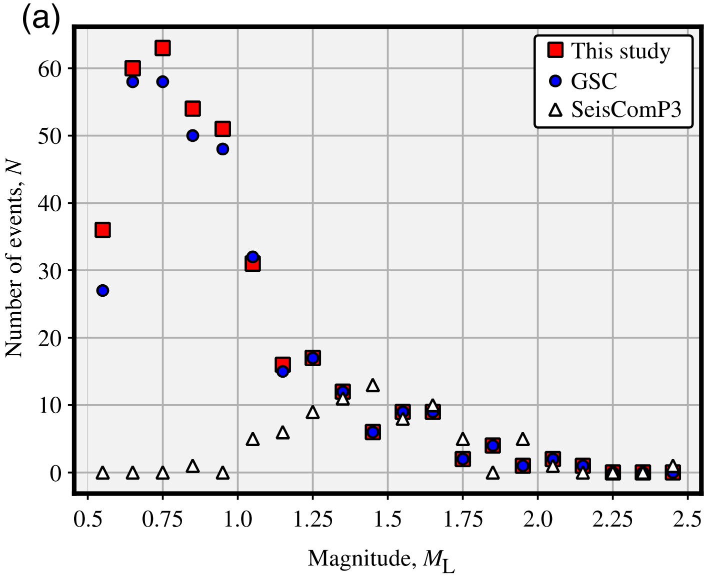
Locating IIE more efficiently AND accurately with innovative AI-based methods

1. Convert seismograms to spectrograms

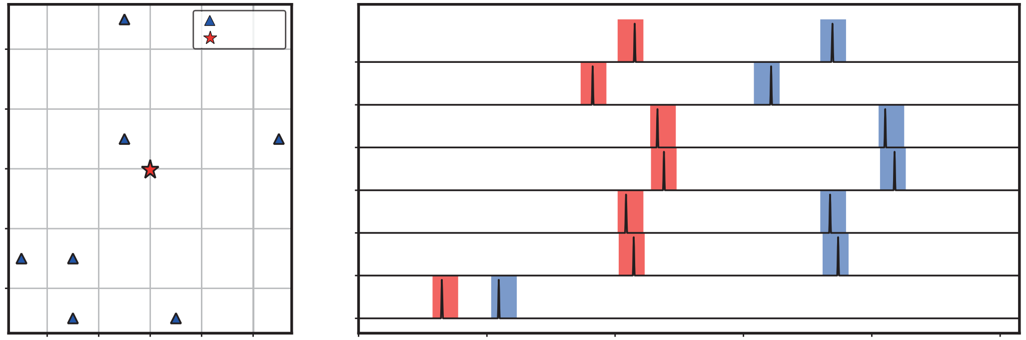


3. Use the Source-Scanning Algorithm to obtain the final solution

Performance Evaluation



2. Apply a fully convolutional U-Net to obtain phase arrival times



Key messages:

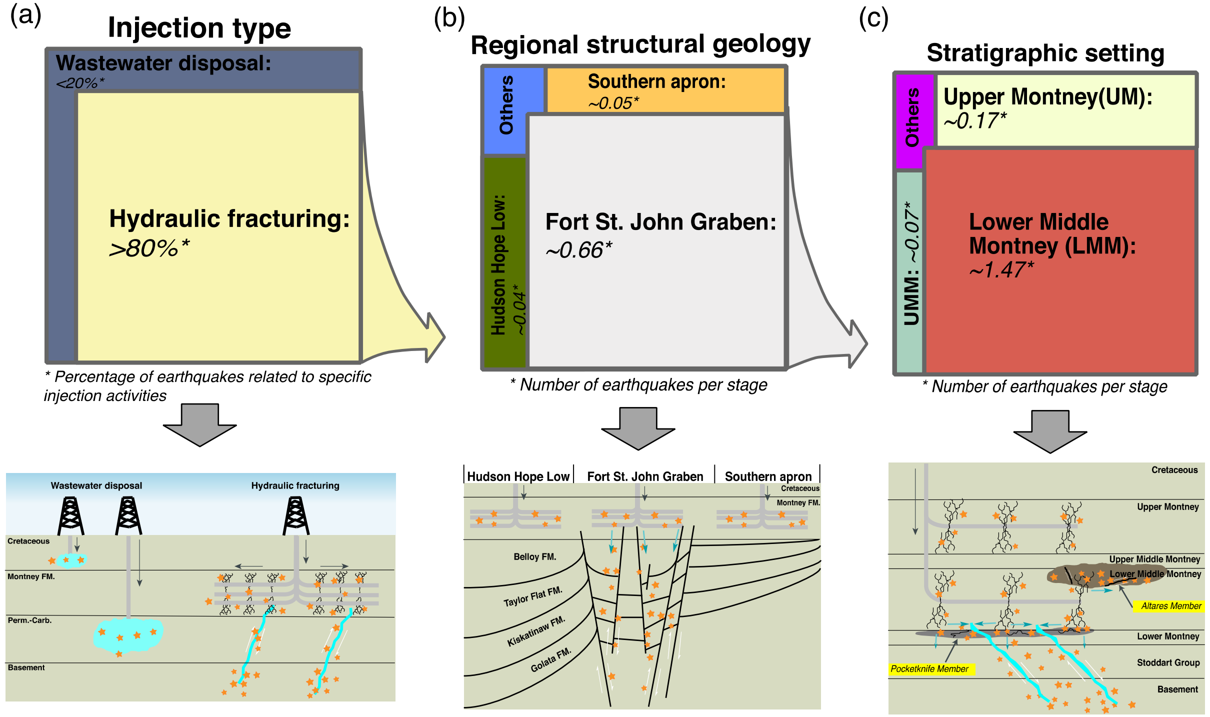
- The accuracy of AI-based methods is comparable to that of a skillful analyst but can operate automatically with high efficiency.
- AI-based method can outperform traditional automatic location methods in detecting small events, thus is particularly suitable for IIE study.

Dokht et al. (2022, BSSA)

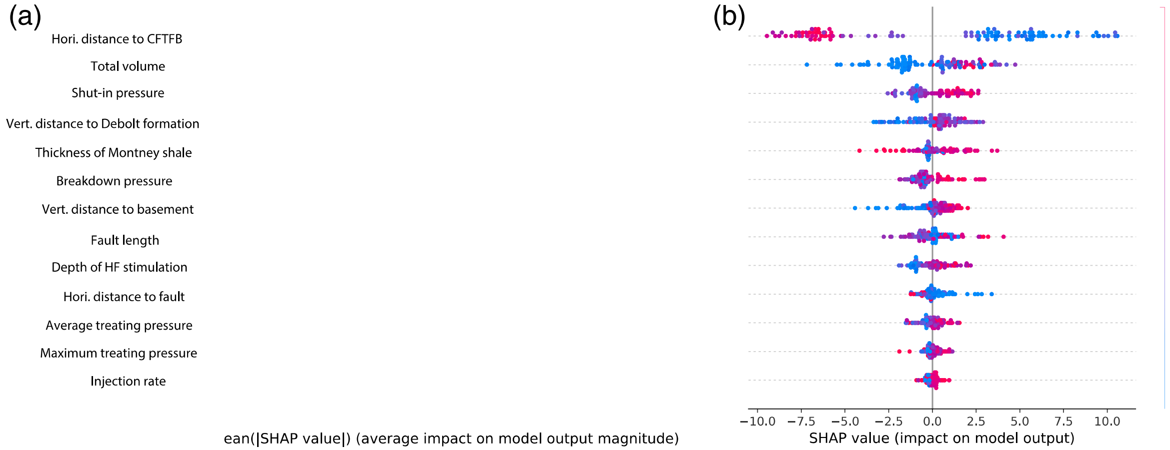
Scientific Highlight #3:

Delineate physical factors controlling the seismogenesis of IIE with AI

For IIE in Southern Montney



For IIE in Northern Montney



Key messages:

- Most IIE in Montney are related to HF.
- Regional structural geology and stratigraphic setting are important in controlling IIE's occurrence.
- AI-based analysis suggests both operational and natural factors can be important, but their relative significance may vary from one region to another.

Wang et al. (2022, EPSL; 2022 SRL; 2023 EPSL)

CONTACT INFORMATION

- Project leader: Dr. Honn Kao
- Webpage on Science.gc.ca: https://profils-profiles.science.gc.ca/en/profile/honn-kao-phd
- Email address: Honn.Kao@nrcan-rncan.gc.ca

THANK YOU!

Ressources naturelles Canada | Natural Resources Canada

Dynamic reservoir assessment to support CO2 sequestration in carbonate reservoirs / Évaluation dynamique des propriétés réservoir des carbonates pour la séquestration de CO2




Stéphanie Larmagnat

INRS
Institut national de la recherche scientifique

May 16, 2023

Canada

ABSTRACT

This project uses carbonate rock samples from quarry exposures in Quebec to appraise CO_2 sequestration potential in carbonate reservoirs, a type of reservoir widespread across Canada. It will deliver a novel multi-parameter reservoir assessment approach applicable to on-site sequestration for CO_2 producers in Canadian sedimentary basins.

The project combines clumped isotopes and U/Pb dating of calcite to document the porosity evolution, dry/saturated petrophysical measurements to derive the effective porosity, geophysical and geochemical monitoring of mineral carbonation experiments using medical Computed-Tomography (medCT) and micro-CT under varying reservoir conditions (temperature, pressure, saturation). Clumped isotopes and U/Pb dating will deliver a refined diagenetic history of the carbonates. The combination of medCT and micro-CT will allow determining the scale of spatial heterogeneities that influence the effective porosity, a key parameter for CO_2 storage. The suite of geochemical, geophysical and CT tools will enable to track mineral precipitation, diagenesis and CO_2 distribution.

This innovative reservoir characterization approach will benefit to government initiatives aiming to reach net zero CO_2 emission and limit future climate change.

PROJECT MEMBERS

GSC – Québec division

Stéphanie Larmagnat, Sedimentary Geology
Mathieu J. Duchesne, Geophysics
Nicolas Pinet, Structural Geology
Josué Jautzy, Geochemistry

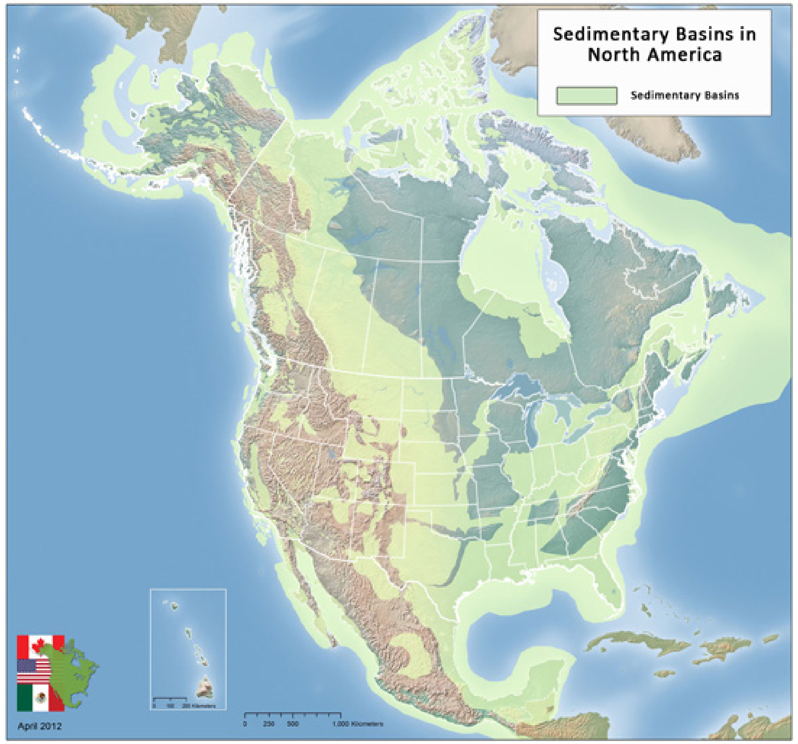
INRS – Centre Eau Terre Environnement

Louis-Cesar Pasquier, Geochemistry and CO_2 Capture & Storage
Bernard Giroux, Geophysics
Pierre Francus, Sedimentology
Mathieu Des Roches, CT-scanning
Ehsan Vosoughi, PhD student, Geophysics
Arnault Baldassari, PhD student, Geochemistry
Jasmin Raymond, Geothermal Energy
Michel Malo, Emeritus, Structural Geology and CO_2 Storage

- **12 persons**
- **6 disciplines**
- **2 PhD students**

Context

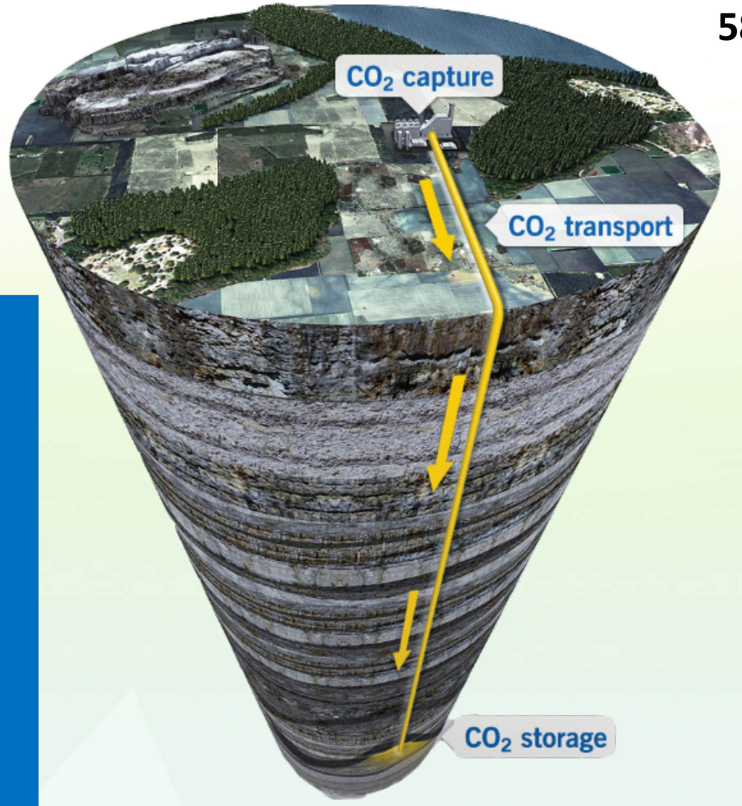
Preparing the canadian CCUS picture in 2050 ?



https://www.nrcan.gc.ca/energy/publications/16226

3 keys components to geological storage

- **capacity**
- **integrity**
- **injectivity**



https://www.globalccsinstitute.com/resources/ccs-image-library/

Importance of exploring a wider range of geologic storage options within canadian sedimentary basins (e.g. low porosity, low permeability carbonates)

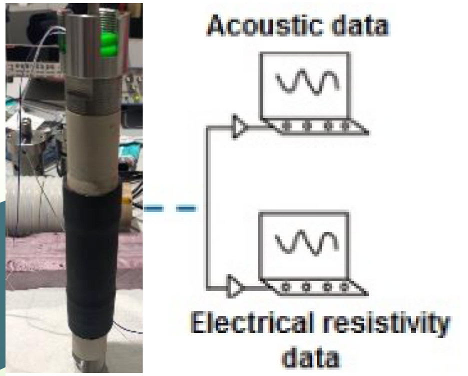
Three main objectives

- Objective 1 & 2 uses reference rock samples to develop new, lab-scale **methodologies to better characterize the reservoir sequestration potential of sedimentary units at depth**
  - **(1) CO_2 injections tests and geochemical assessments reactivity**
  - **(2) Testing geophysical tools to monitor CO_2 injection**

- *Objective 3 focuses on a **surface analog in eastern Québec** to develop **new tools to reconstruct porosity history in carbonates***

Not presented today

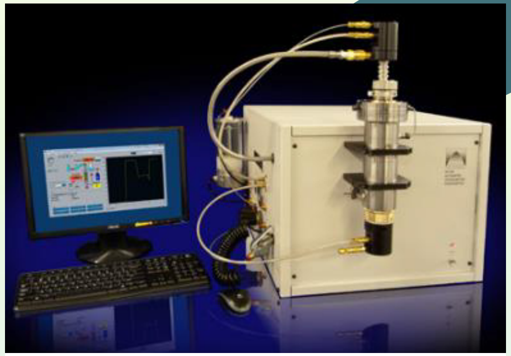
Methods

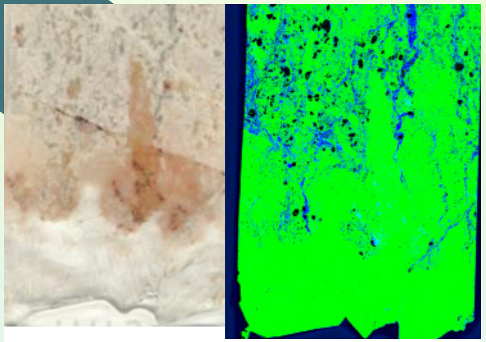


Geophysics


ICP AES


HPLC, TOC


Petrophysics


Petrography + µXRF

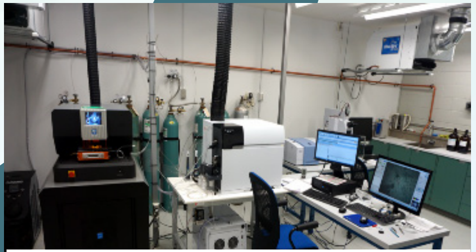
- **Pluridisciplinary**
- **Multi-scale**
- ***In situ***
- **Real-time** (whenever possible)

Micro-CT


Med-CT


MEB


Clumped isotopes


LA-ICPMS
U/Th dating

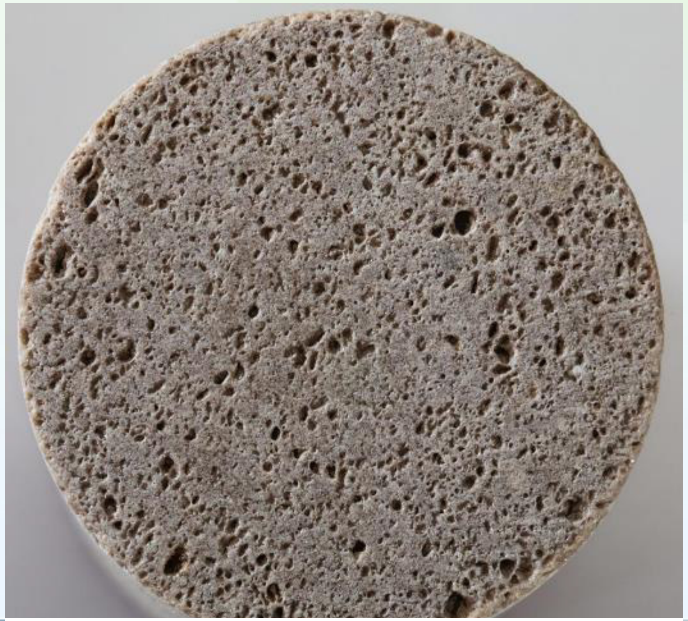
Reference rock material

Sedimentary rocks common within sedimentary basins in North America

Exp #	Sample	V_{pore} (cc)	Porosity (%)	Perm. (mD)
1	IN-15-1	10.3	12.4	5.1
2	SI-15-1	11.4	13.9	0.9
3	BE-15-1	15.8	19.0	175.0
4	WI-15-1	7.5	9.3	9.0
5	CA-15-1	0.2	1.1	0.009

Ex. Indiana Limestone ($CaCO_3$)

Ex. Berea Sandstone (SiO_2)



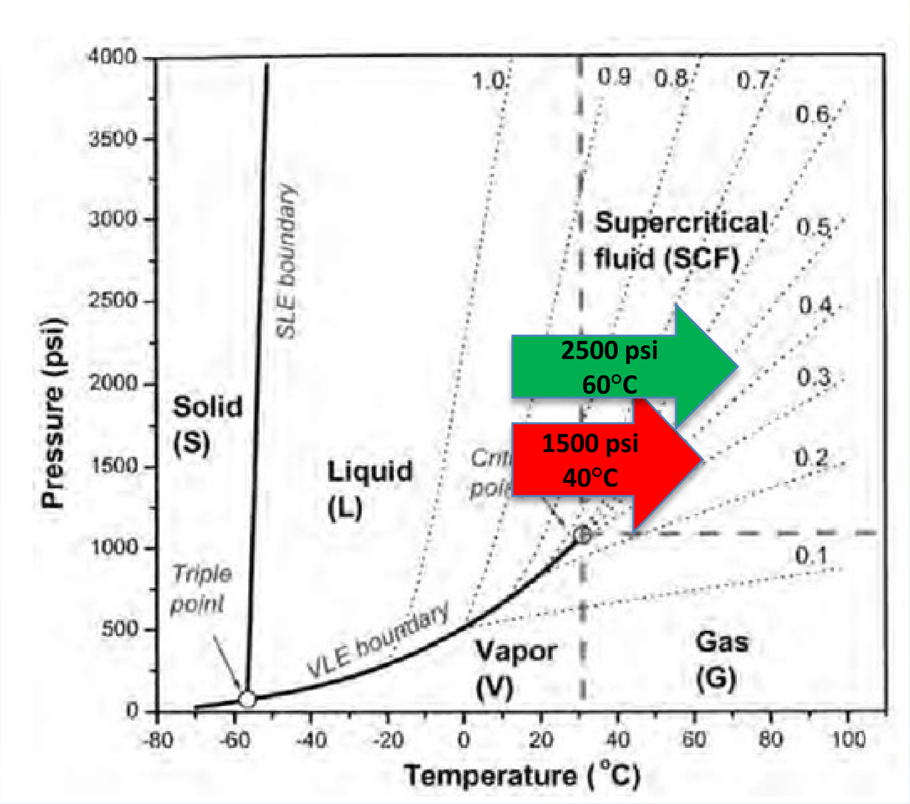
Ex. Silurian Dolomite ($CaMg(CO_3)_2$)

https://kocurekindustries.com/

Objective 1 - CO_2 injections tests and geochemical reactivity

Goals and challenges

- **Protocol applied to 5 selected lithologies**
- Samples **saturated with brines** (recipes from literature)
- **Carbonation reactor** = pressurized and controlled temperature vessel
- **CO_2 in supercritical conditions** (>1500 psi; 40 °)

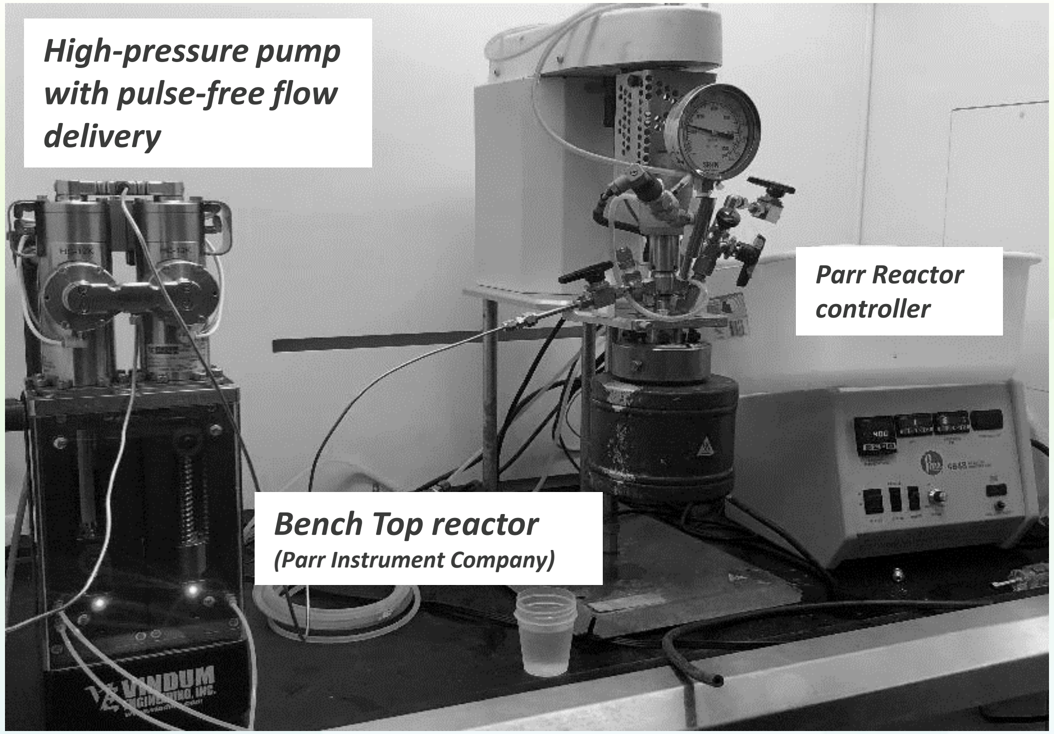


https://www.itec-es.co.jp/English/co2/co2_00.html
Note *1 Mpa = 145 psi*

Brines	NaCl (mg/L)	KCl (mg/L)	$CaCl_2.2H_2O$ (mg/L)	$MgCl_2.6H_2O$ (mg/L)
Indiana/Carthage	30 175	493	8 644	-
Wisconsin	30 249	501	8 660	341
Guelph Dolomite	30 258	499	8 667	2 430
Berea	-	980	-	-

Brines prepared with chemical compositions in equilibrium with the corresponding reservoir rock

Objective 1 - CO_2 injections tests and geochemical reactivity

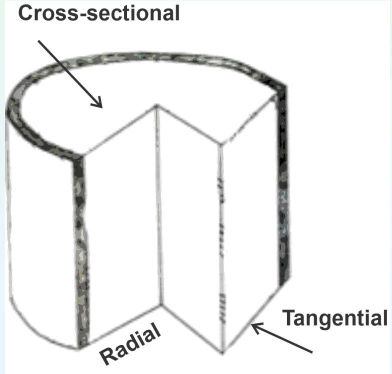


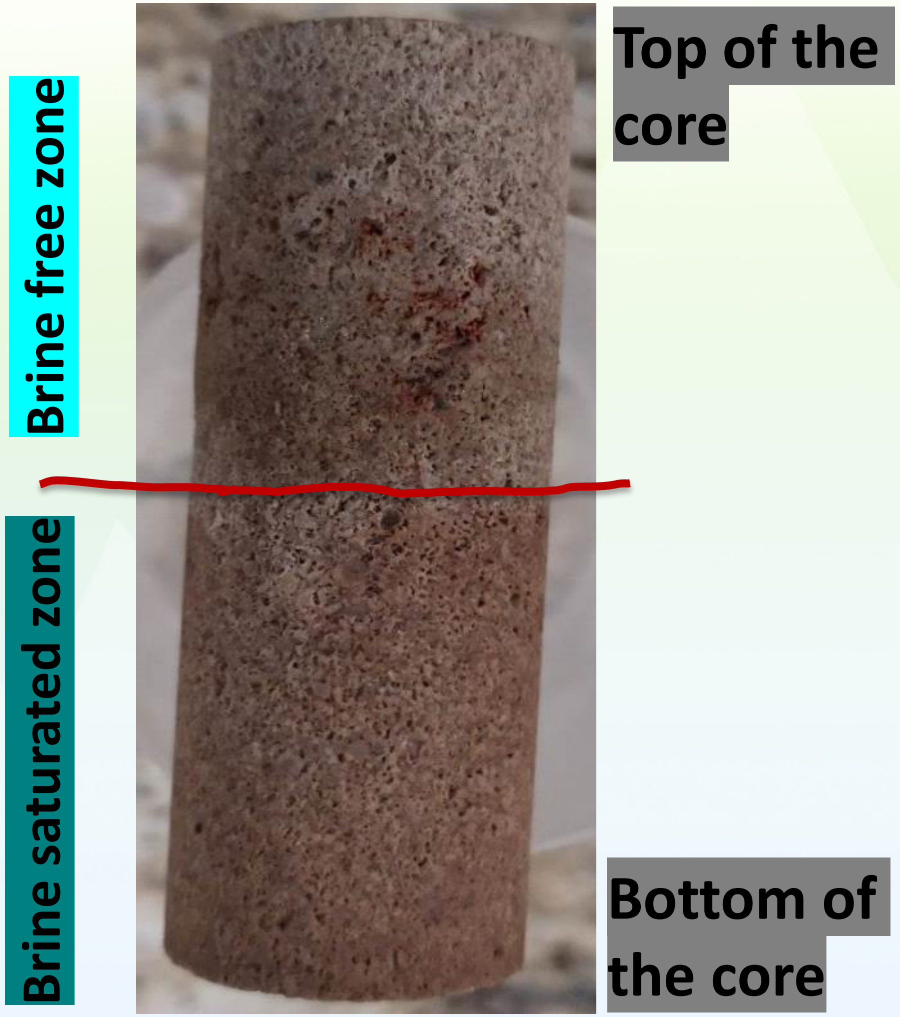
Results

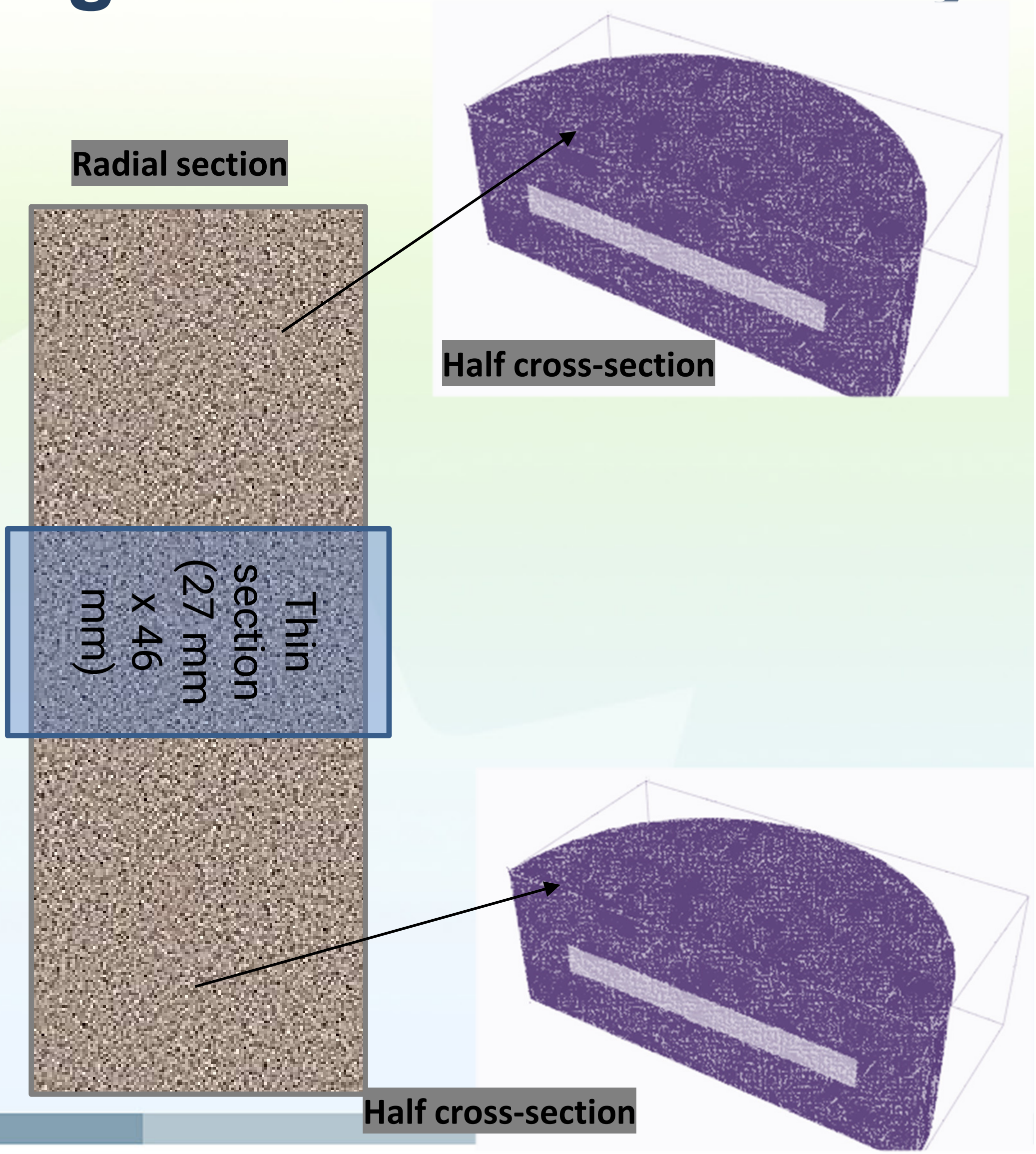
- 5 sucessfull experiments (1/lithology)
- Pre/post μ-CT imaging
- Brine collected and filtered after CO2 reaction
- Pre/post poroperm measurements
- Set of geochemical analyses on rocks, brines and precipitates *(ongoing)*

Objective 1 - CO_2 injections tests and geochemical reactivity

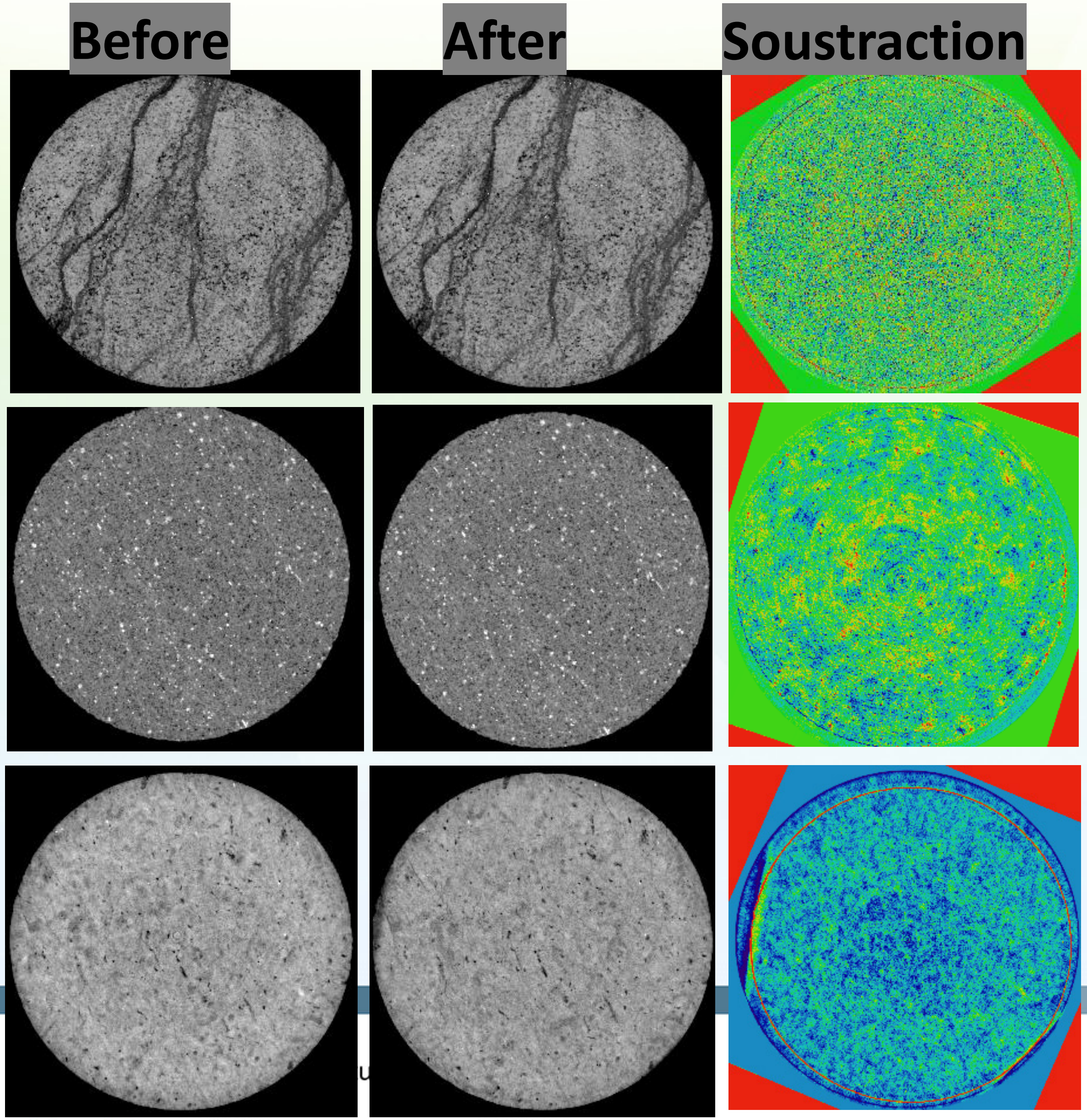
Sampling strategy for petrographic observations







Objective 1 - CO_2 injections tests and geochemical reactivity



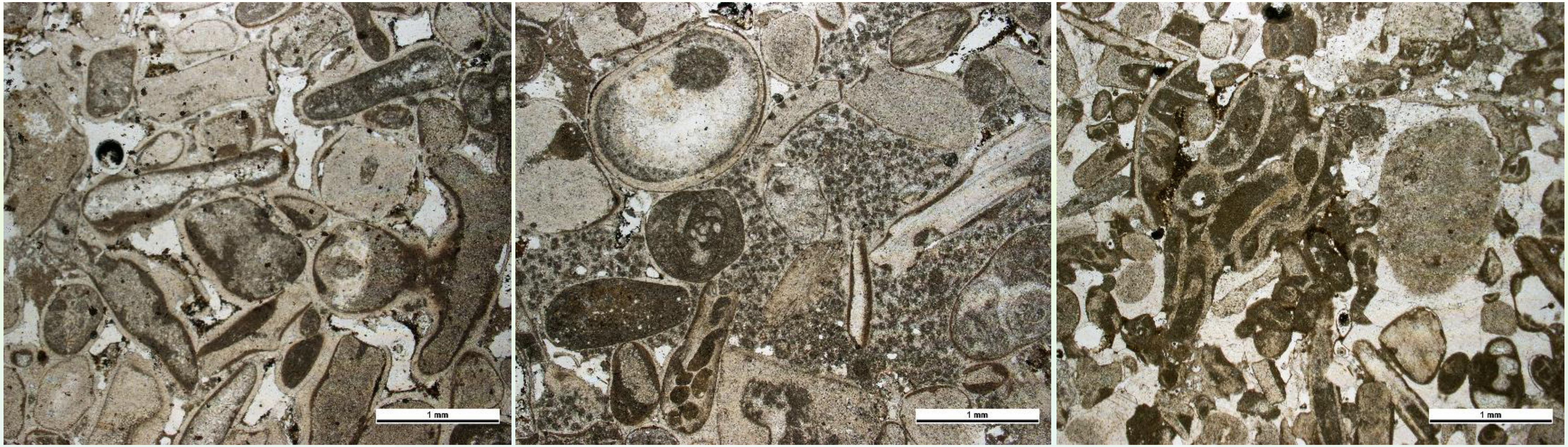
Wisconsin limestone

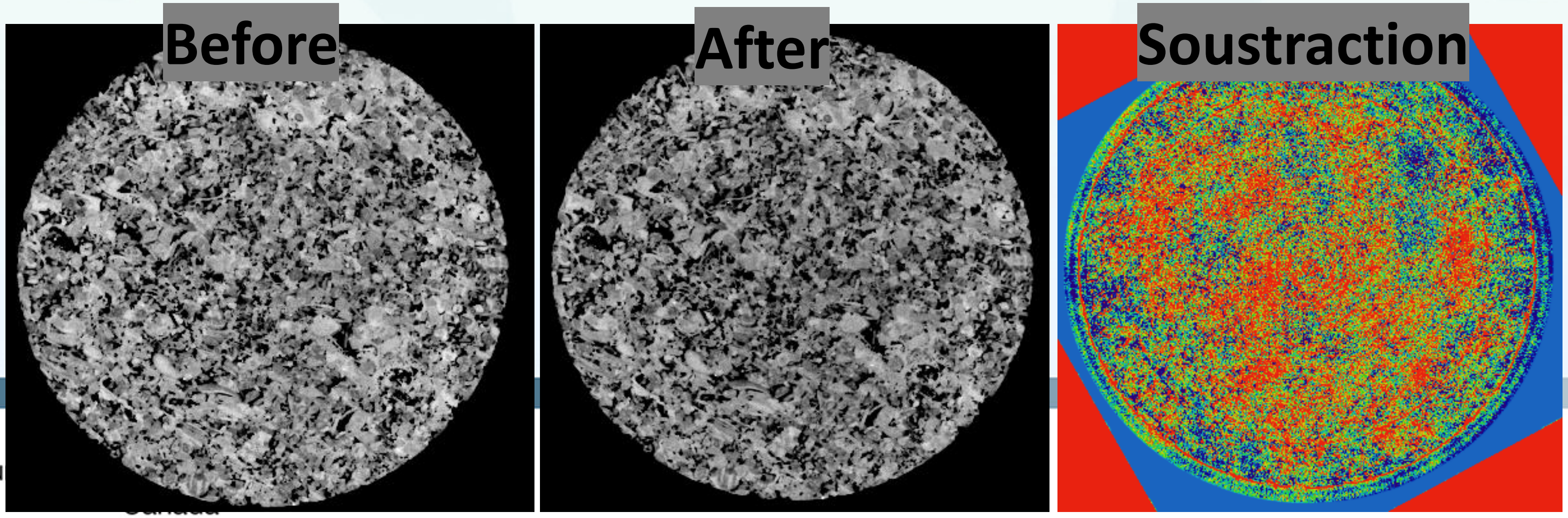
Berea sandstone

Carthage limestone (Burlington)

Objective 1 - CO_2 injections tests and geochemical reactivity

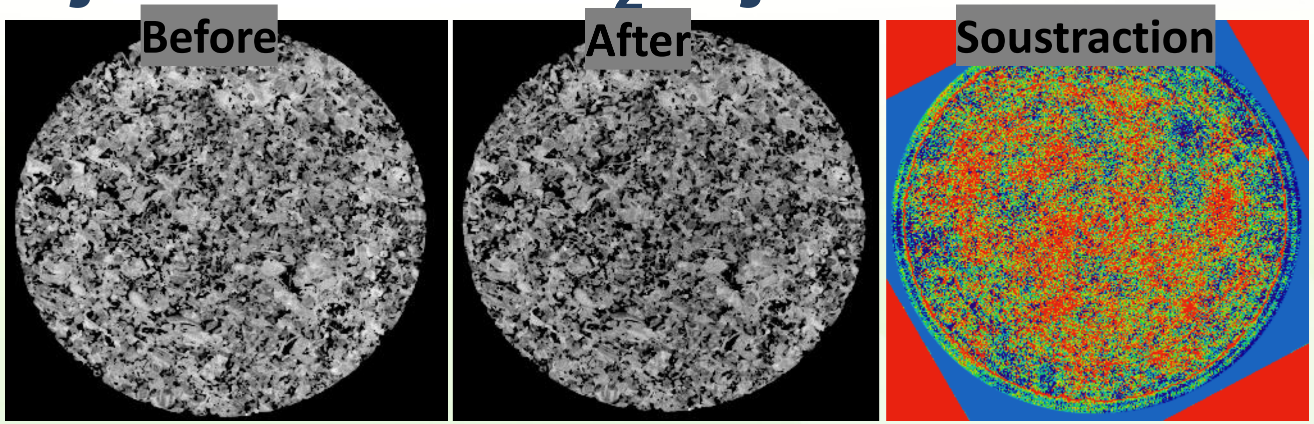
Indiana limestone

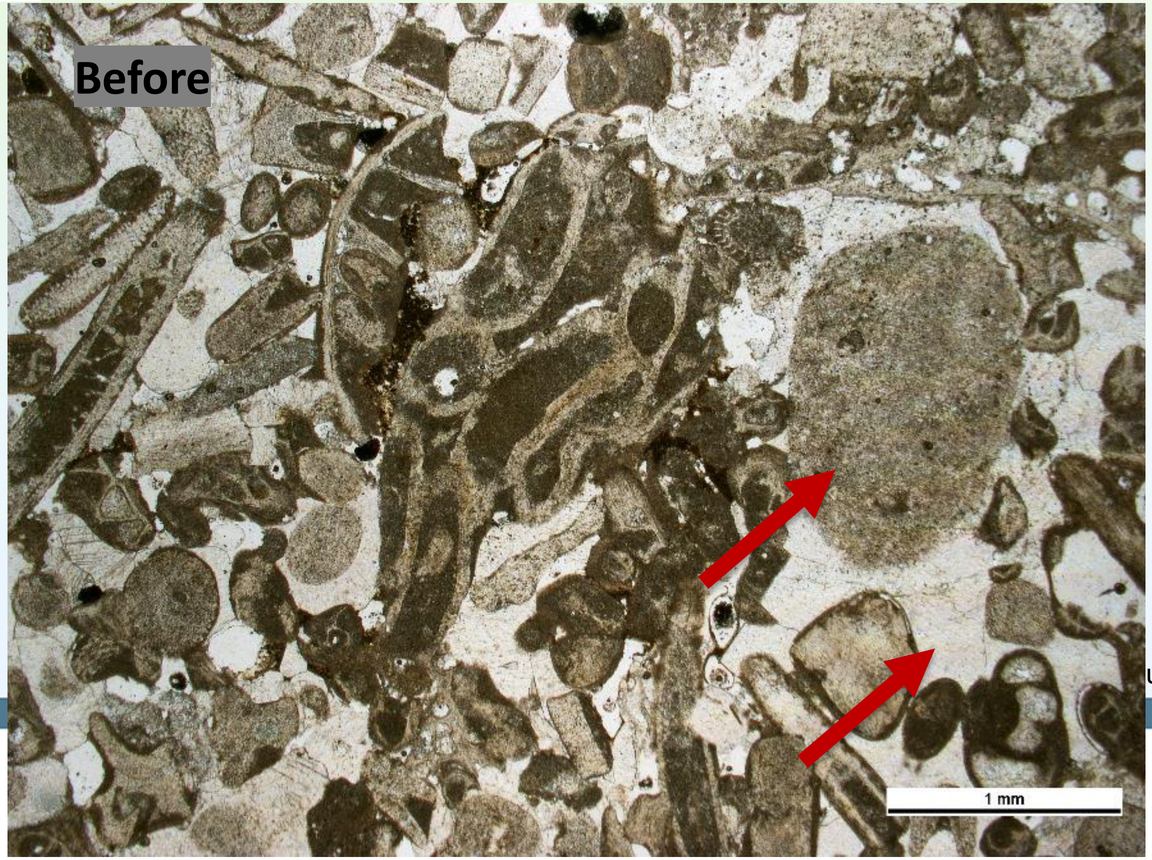


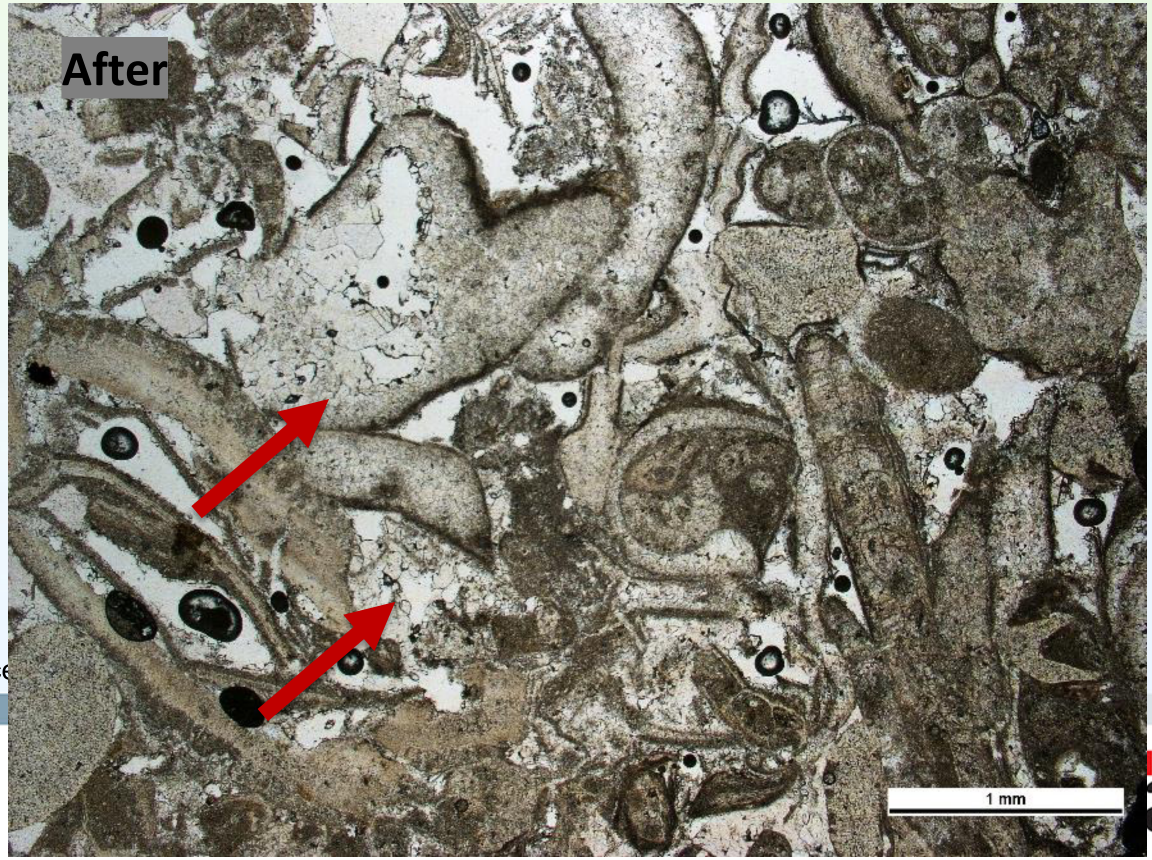


Objective 1 - CO_2 injections tests and geochemical reactivity

Indiana limestone

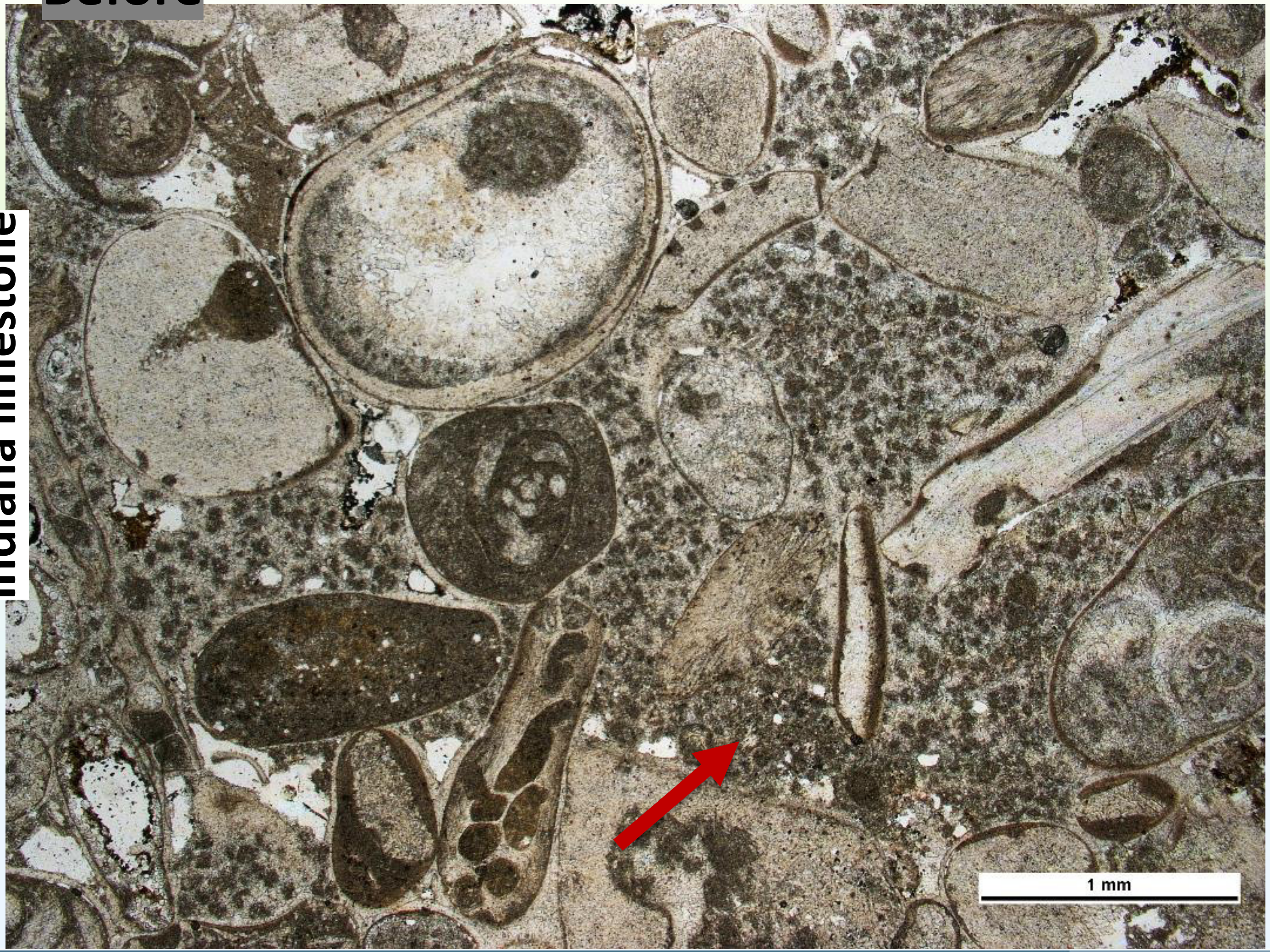




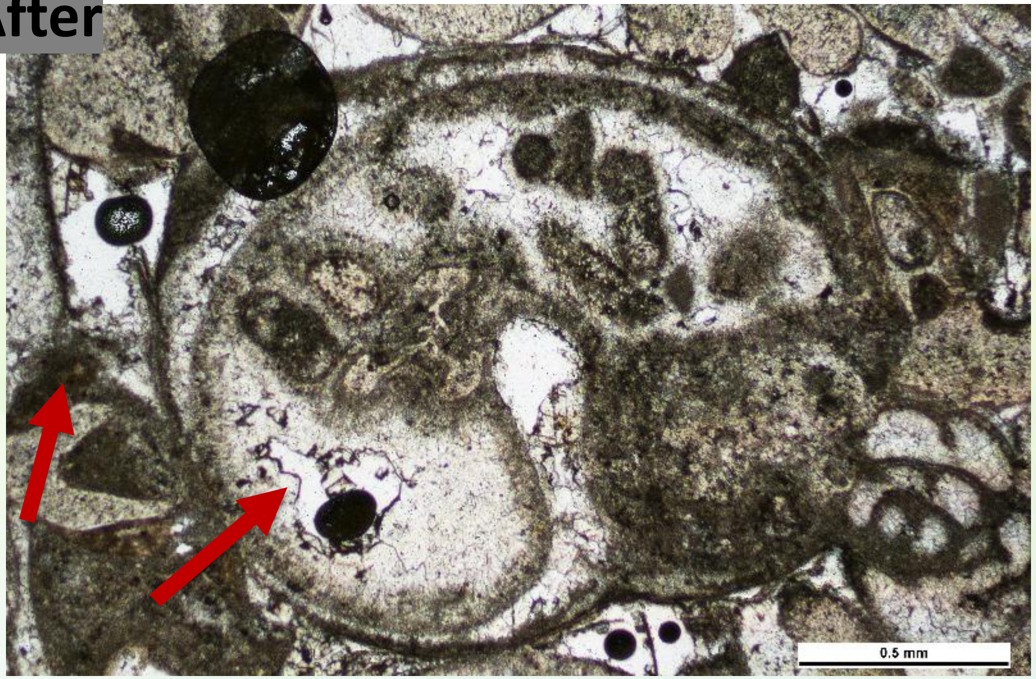


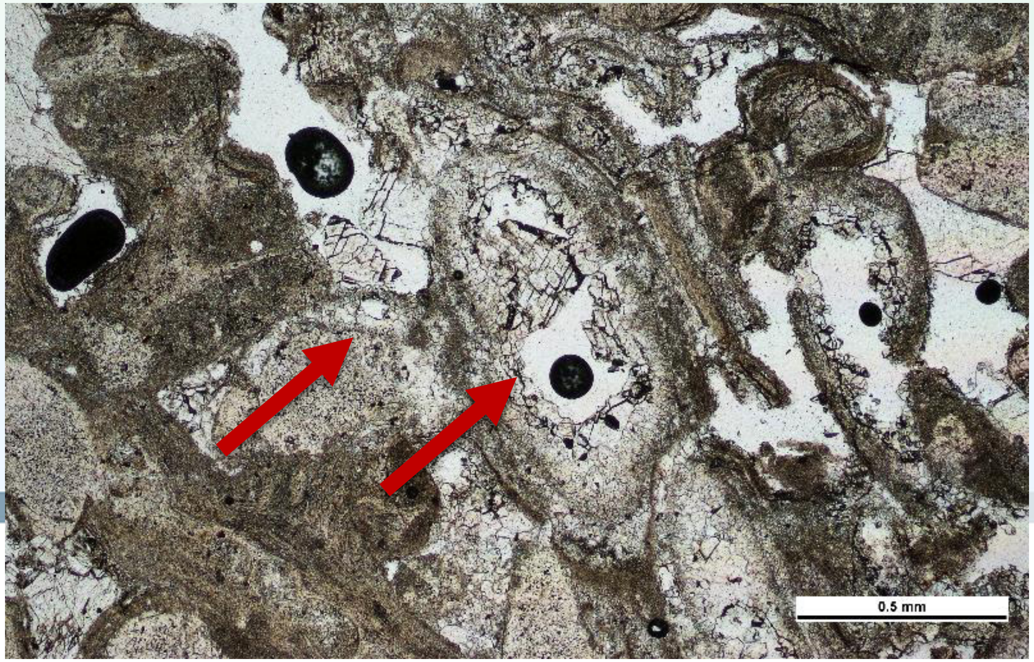
Indiana limestone

Before



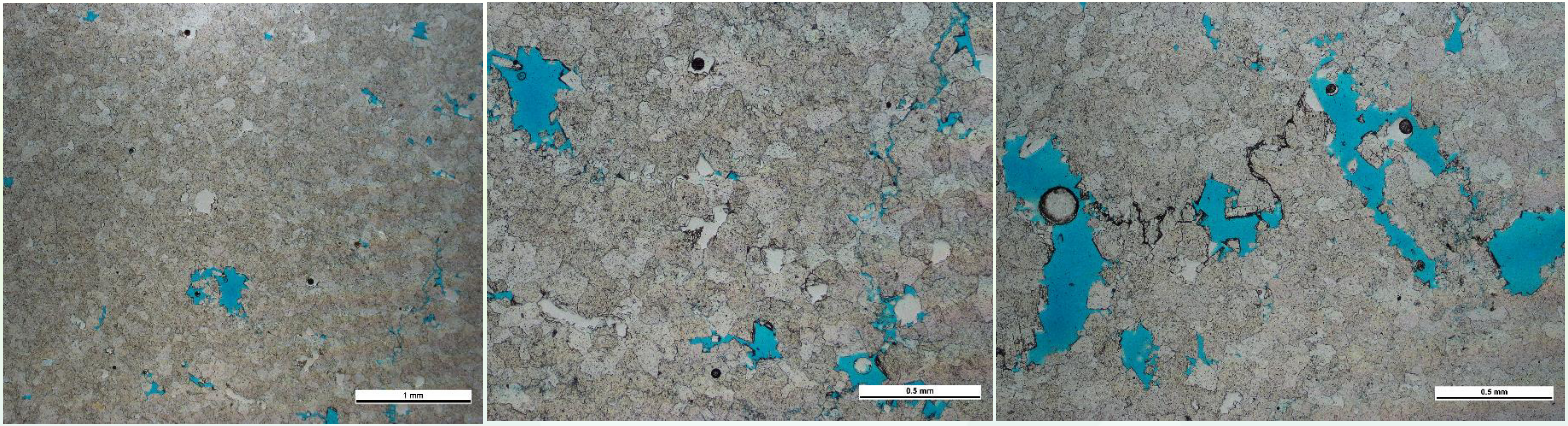
After

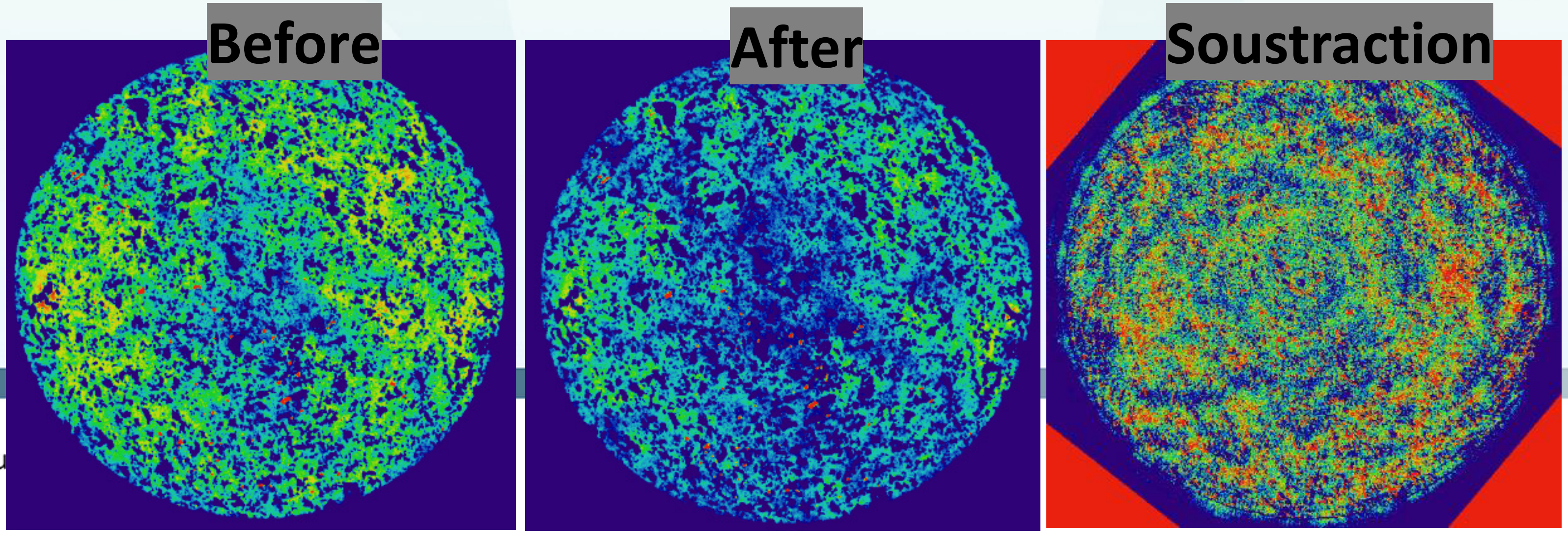




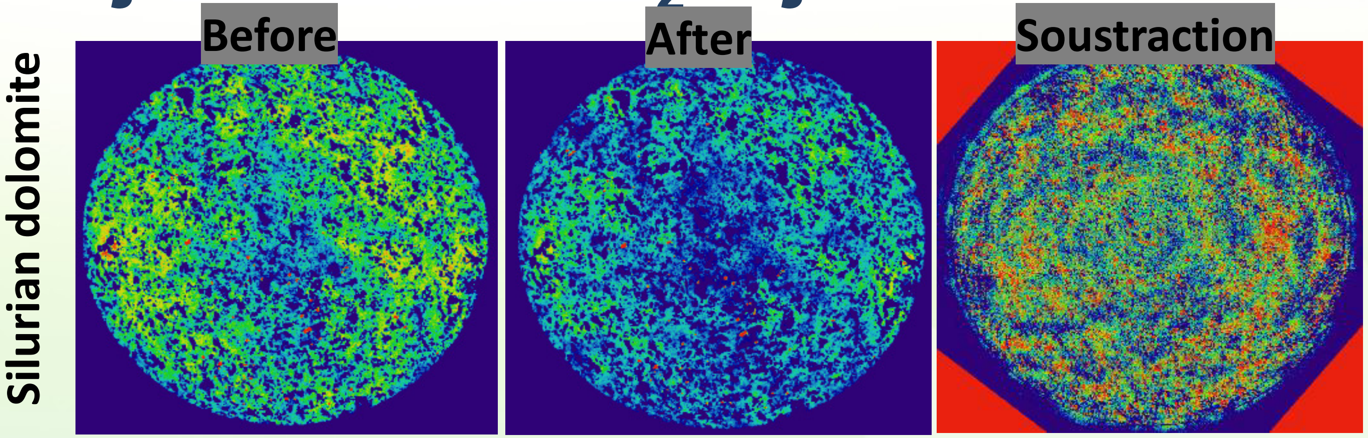
Objective 1 - CO_2 injections tests and geochemical reactivity

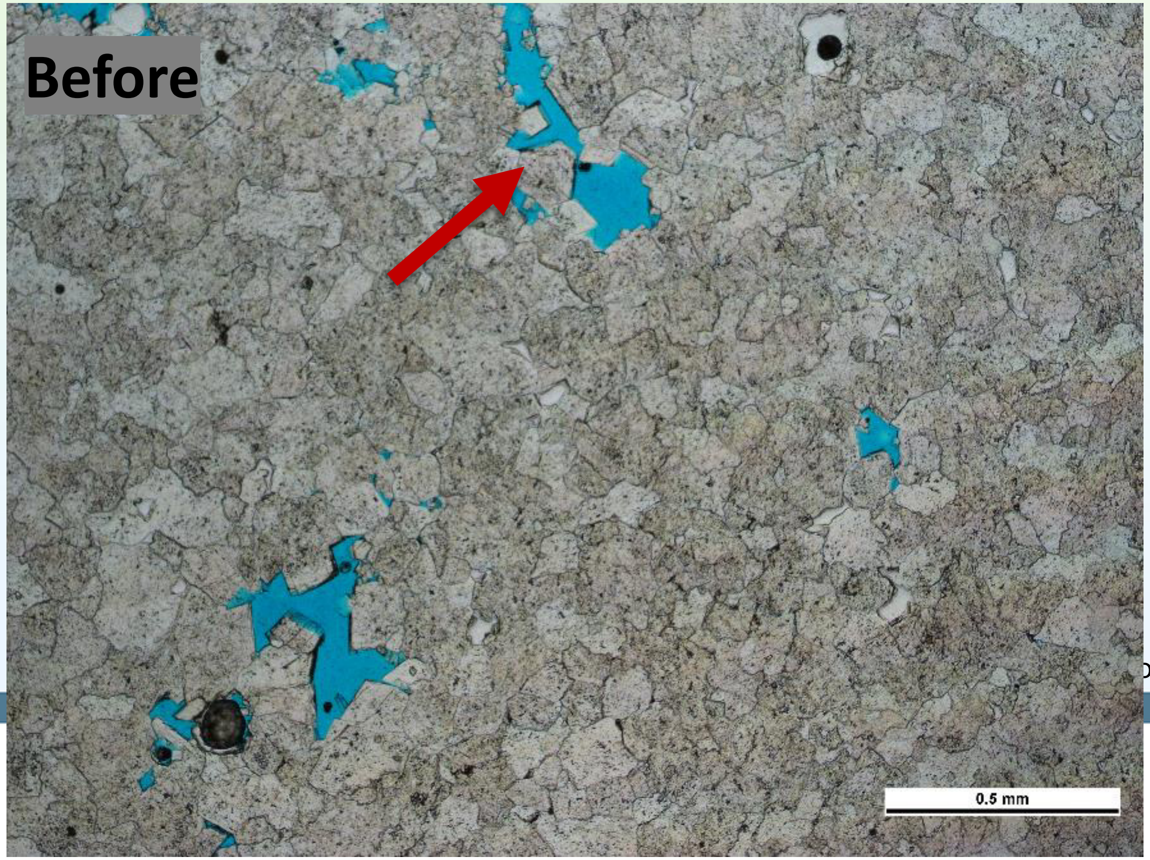
Silurian dolomite

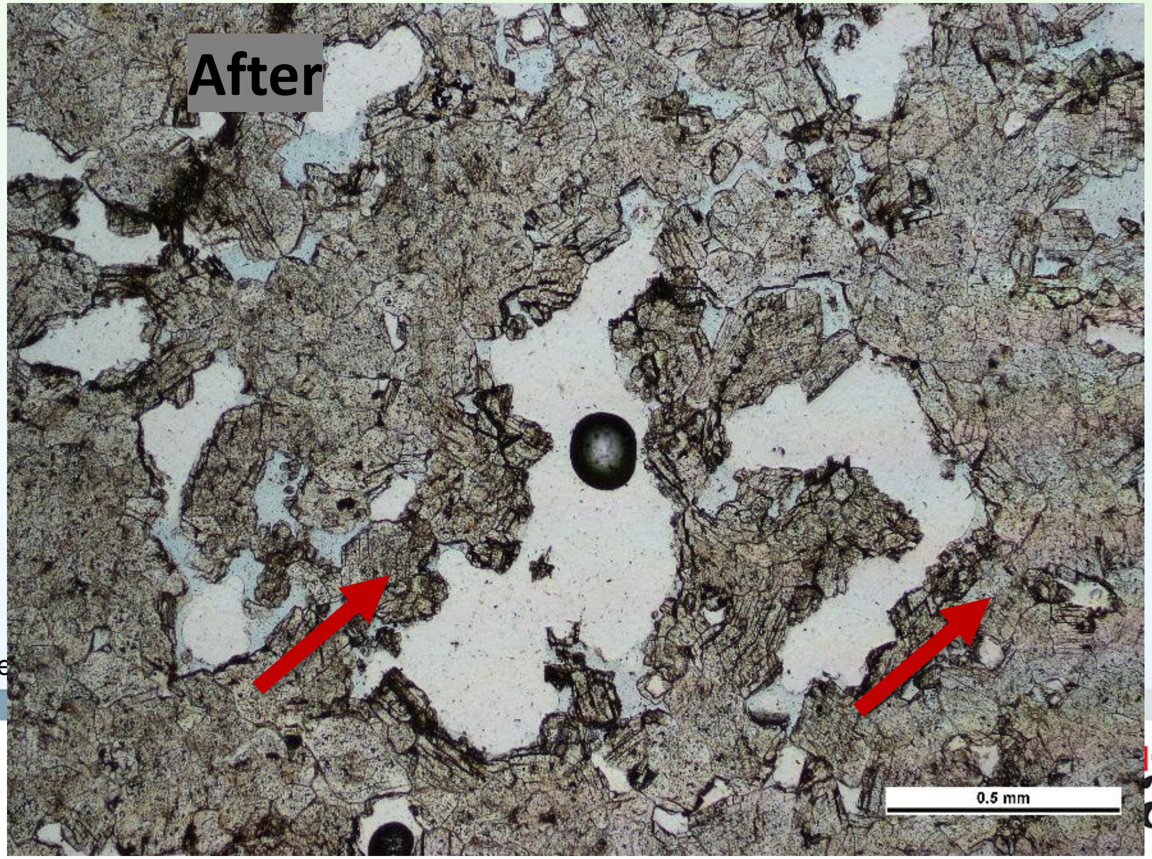


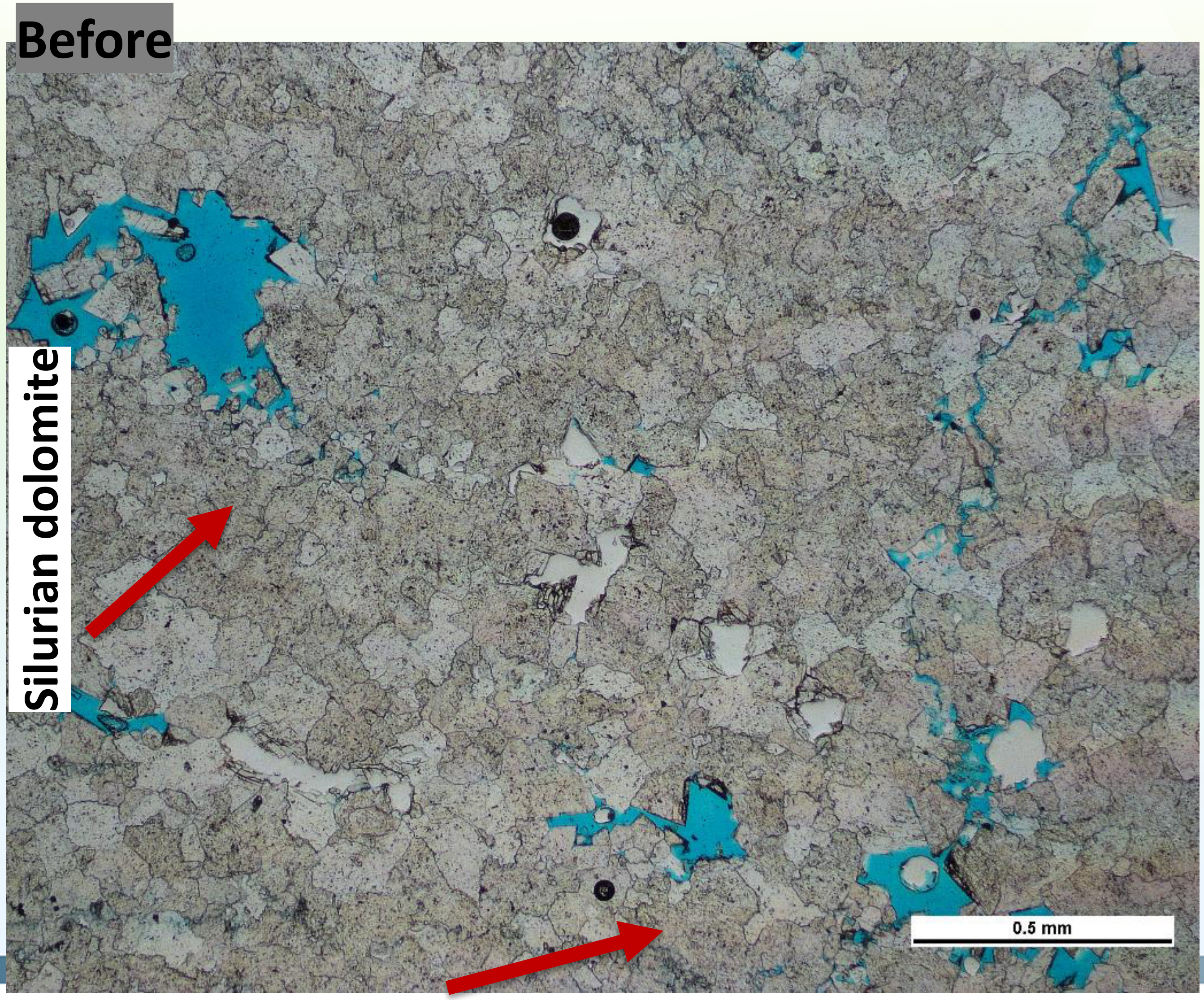


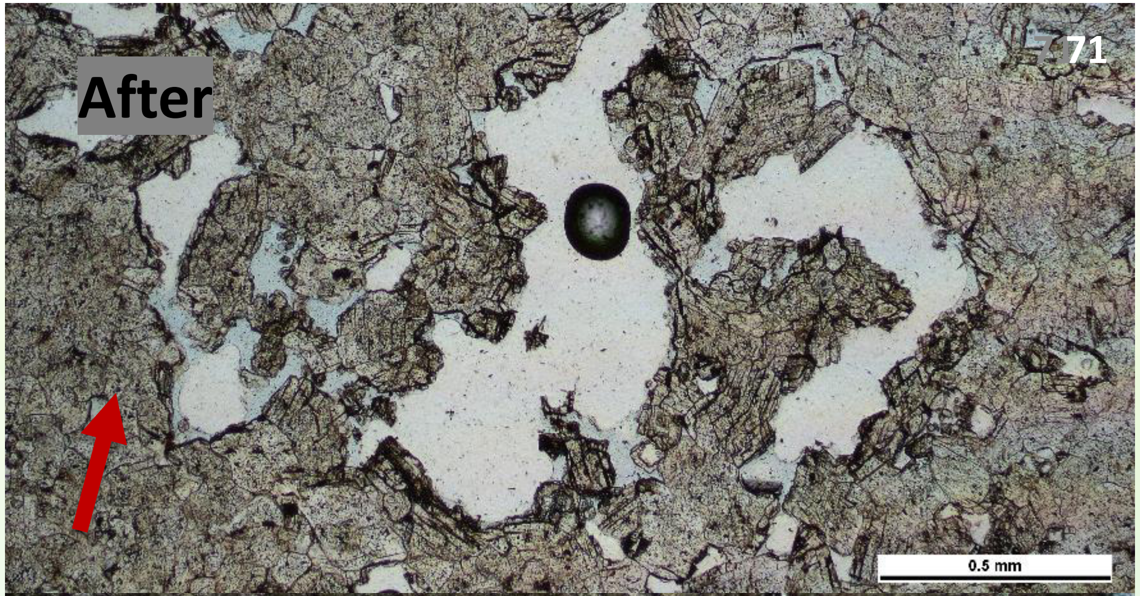
Objective 1 - CO_2 injections tests and geochemical reactivity

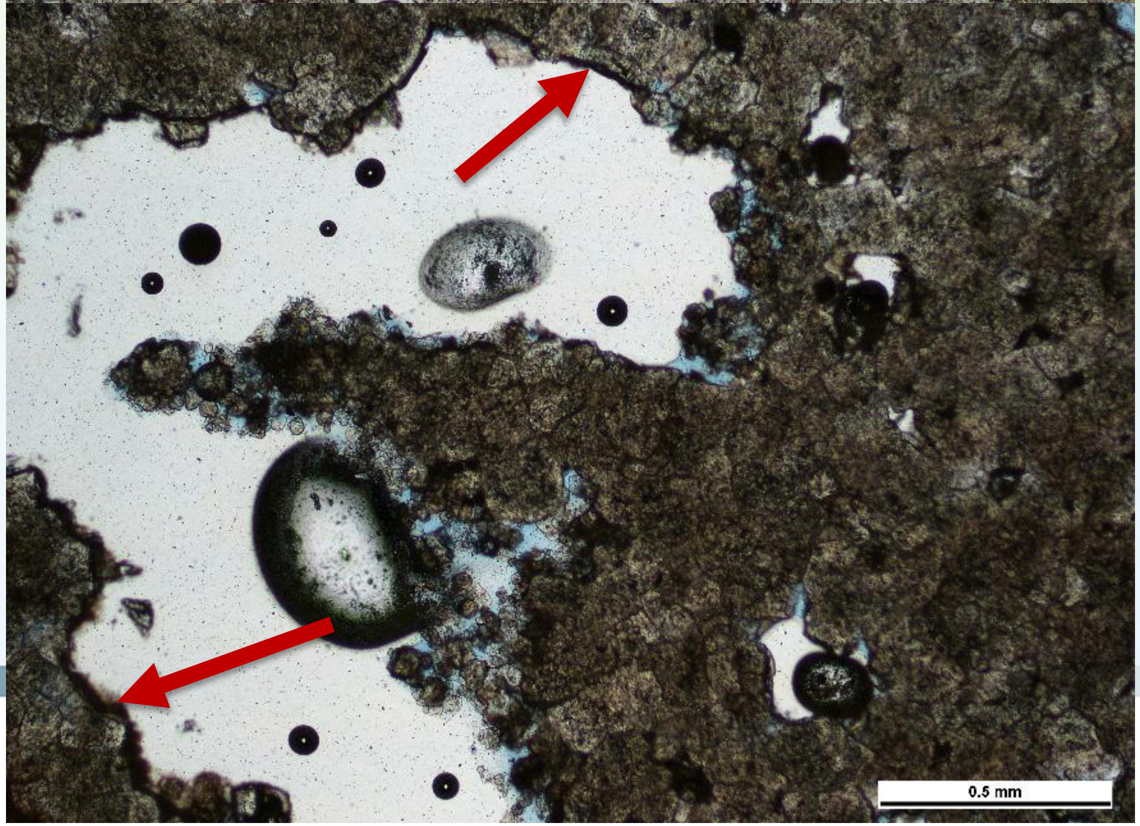




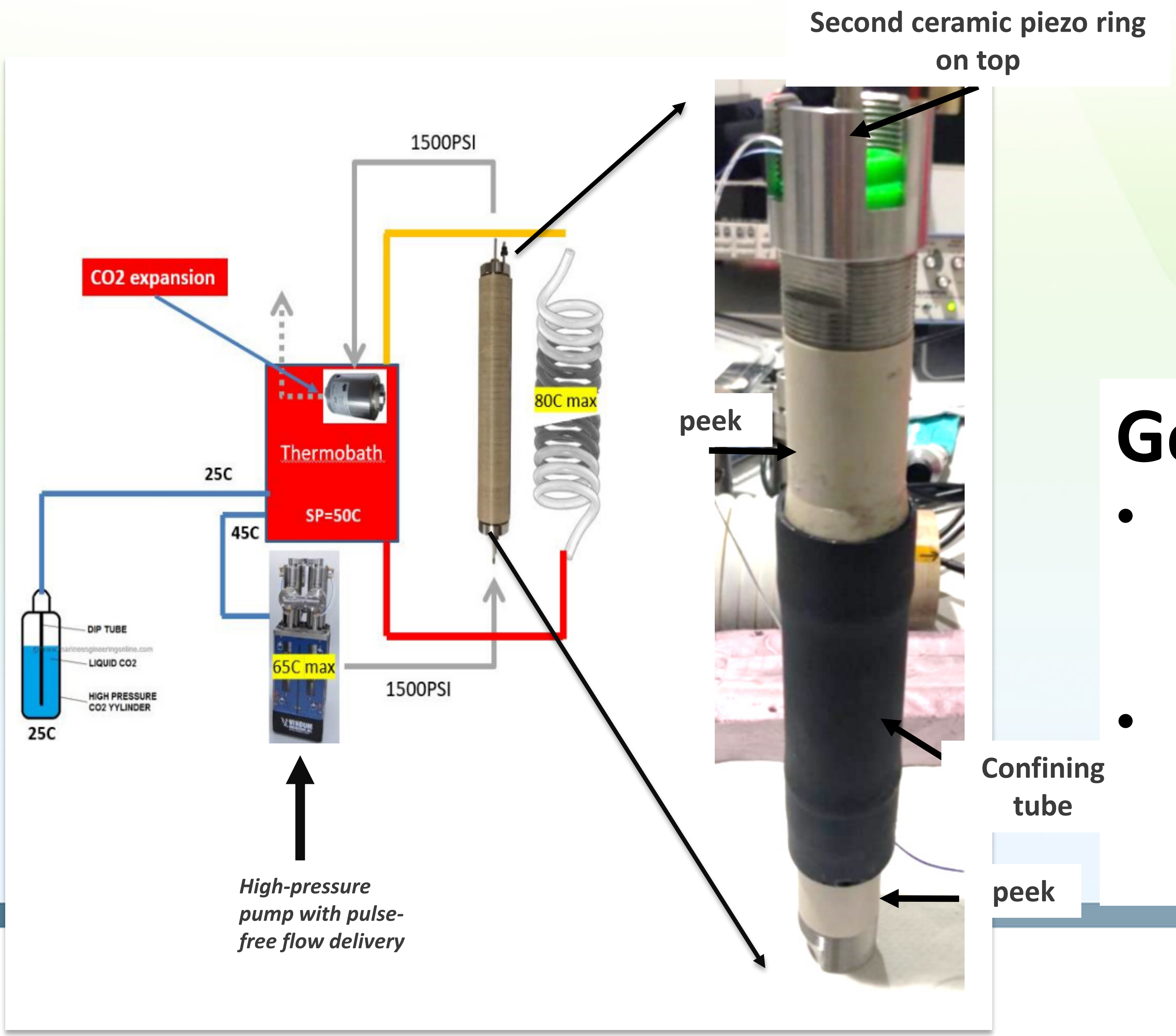



Before
Silurian dolomite
0.5 mm


After
0.5 mm


0.5 mm

Objective 2- Geophysical tools to monitor CO_2 injections

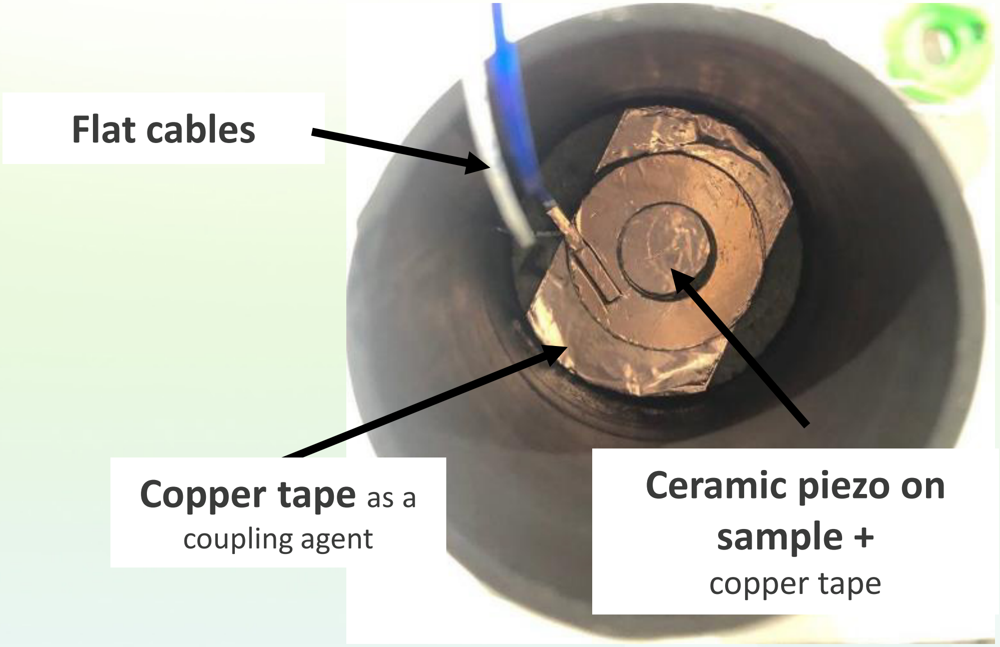


Joint interpretation of elastic-electrical data combined with micro-CT images has the potential to reveal new aspects of fluid-rock interaction

Goals and challenges

- Ultrasonic Acoustic and Electrical measurements both monitored during the micro-CT acquisitions
- Both working at pressure and temperature consistent with reservoir conditions

Objective 2- Geophysical tools to monitor CO_2 injections



- Initial Trials and errors phase for custom made setup
- **But** during injection, confining fluid leaks occured !

→ Upgrade core-holder setup to avoid leakages under confining conditions

Next steps

Objective 1 - CO_2 injections tests and geochemical reactivity

- Complete geochemical analyses on thin sections and core plugs (μXRF; SEM)
- Focus on **most reactive** lithologies for **clumped isotopes**
- **Optimize μ-CT** images for enhanced evaluation of reactivity in 3D
- Optional - Reproduce CO_2 injections in reactor for additional lithologies and test higher reservoir pressure and temperature (2500 psi; 60 C)

Objective 2 - Geophysical tools to monitor CO_2 injections

- Run CO_2 injection experiments comparable to those of objective 1 with *in situ* electric and acoustic monitoring and imaging under micro-CT

CONTACT INFORMATION

- **Stéphanie Larmagnat, PhD**
- Phone number (418) 654-1463
- Email stephanie.larmagnat@NRCan-RNCan.gc.ca

THANK YOU!

Ressources naturelles Canada | Natural Resources Canada

Developing National Guidelines and Site Assessment for Disposal at sea

Élaboration de lignes directrices nationales et évaluation du site pour immersion en mer

Results shown by: Gwyn Lintern (NRCan), Roanna Leung (ECCC), Pauline Martens (NWH Consultants), Philip Hill (NRCan).

May 16th, 2023

Canada

ABSTRACT

Coastal energy infrastructure and other port projects require dredging to make the sites suitable for shipping. On the west coast of Canada, dredging has been required at many recently proposed port sites. Environment and Climate Change Canada (ECCC) licences disposal of material at several large disposal-at-sea (DoS) sites on the coast. Proponents may also propose a new or temporary DoS site nearer to their development to save shipping time and costs. Depending on the level of contamination of the sediment to be disposed, and the methods used, the regulation may require sediment to be disposed at either a dispersive or non-dispersive site. In the past several years, "guidelines for determining dispersivity" have been proposed by NRCan (Lintern)/EC scientists and stipulated to proponents. The validity of the methodology is being tested. NRCan is tasked with determining dispersivity at existing sites and with conducting sensitivity analysis of the variables used in the existing guidelines. This requires oceanographic mooring instrumentation, data analysis and modeling. The innovative approach and results are reported to the London convention on dumping at Sea.

Project members

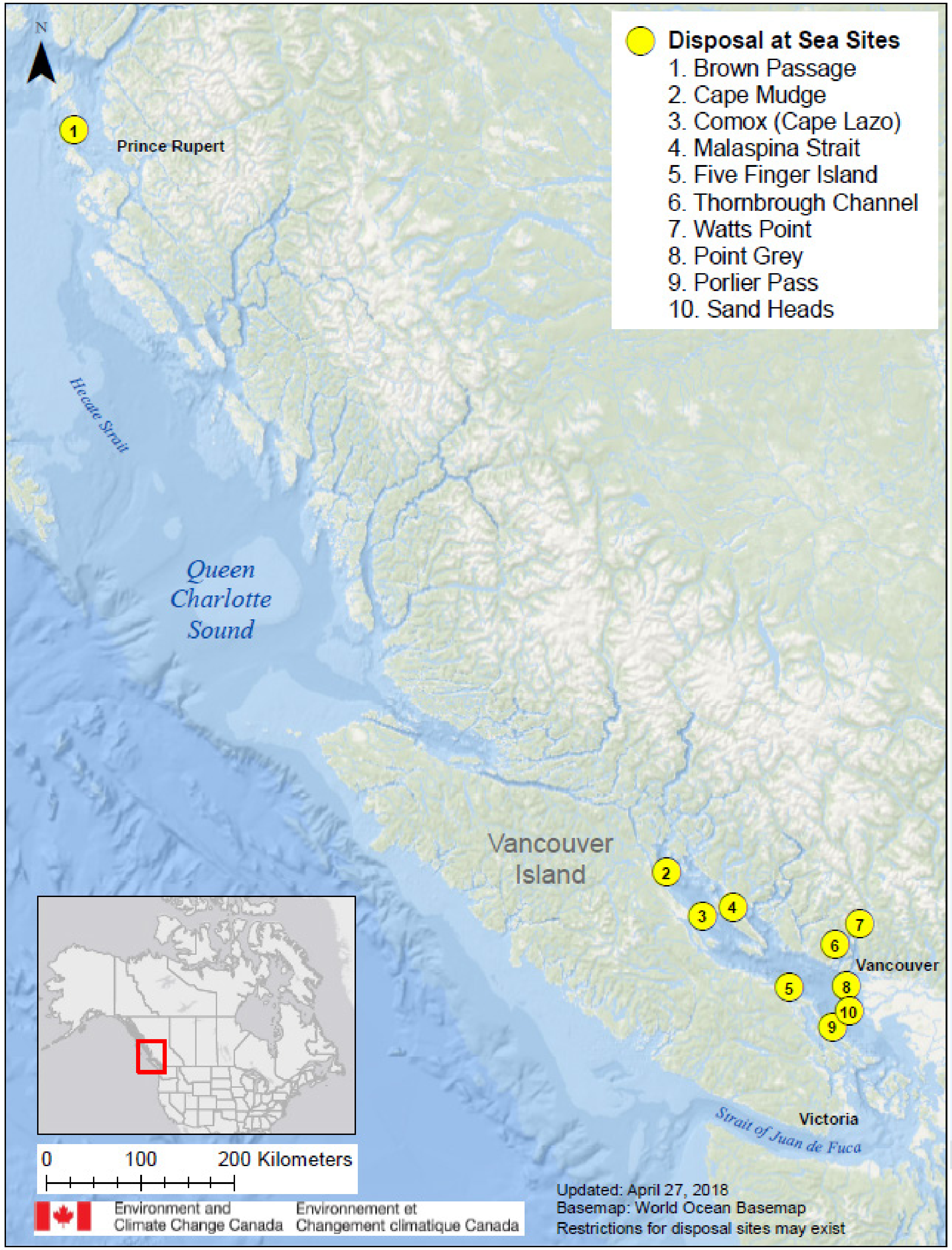
- Gwyn Lintern (NRCan)
- Roanna Leung (ECCC)
- Pauline Martens (NWH Consultants)
- Philip Hill (NRCan)

Background

- Canada regulates Disposal at Sea (DAS) through a permit system
- Canada releases data to fulfill its international obligation under the 1972 London Convention and its 1996 Protocol.
- A permit should require site characteristics to be determined quantitatively, which would then set the criteria for what types of material can be dumped
- A permit should determine whether the proposed disposal site can be considered non-dispersive

Issue

- Disposal sites few and far between.
- Transport is expensive.
- Proponents are requesting new disposal sites.
- License requests (in EA's) vary in quality.
- Guidelines are required.



2020-22 Monitoring Program
Point Grey Disposal at Sea site, Vancouver

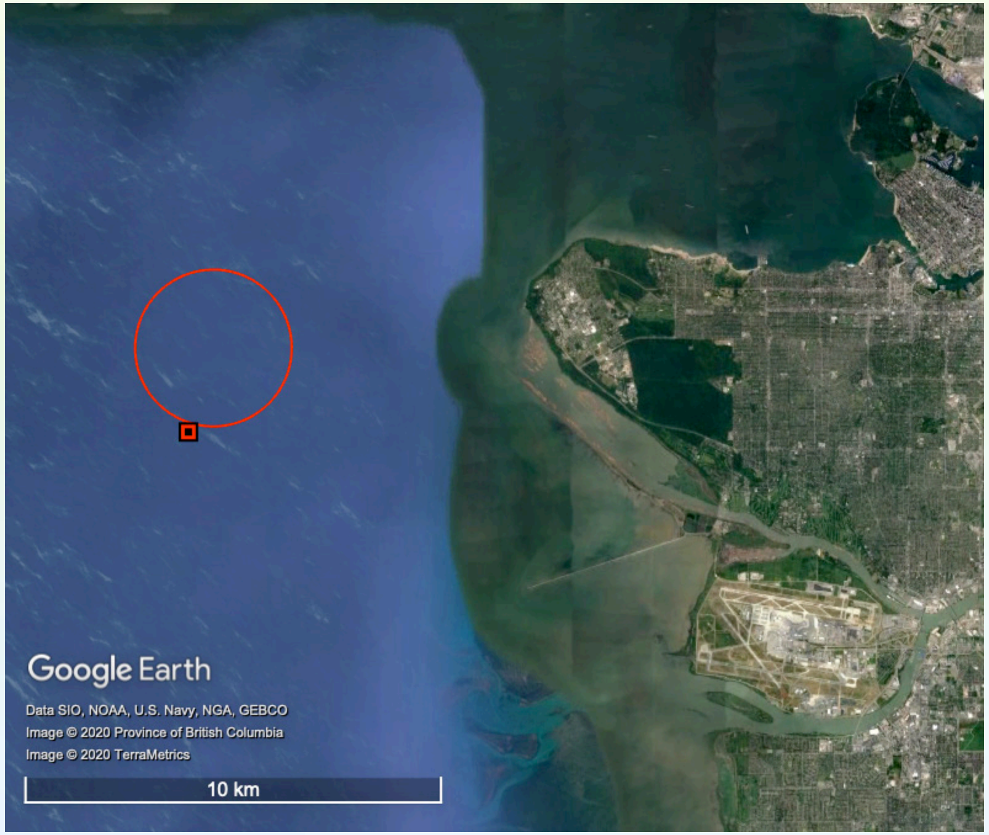


Figure 2. Map of the location of the Point Grey mooring[L[1] .

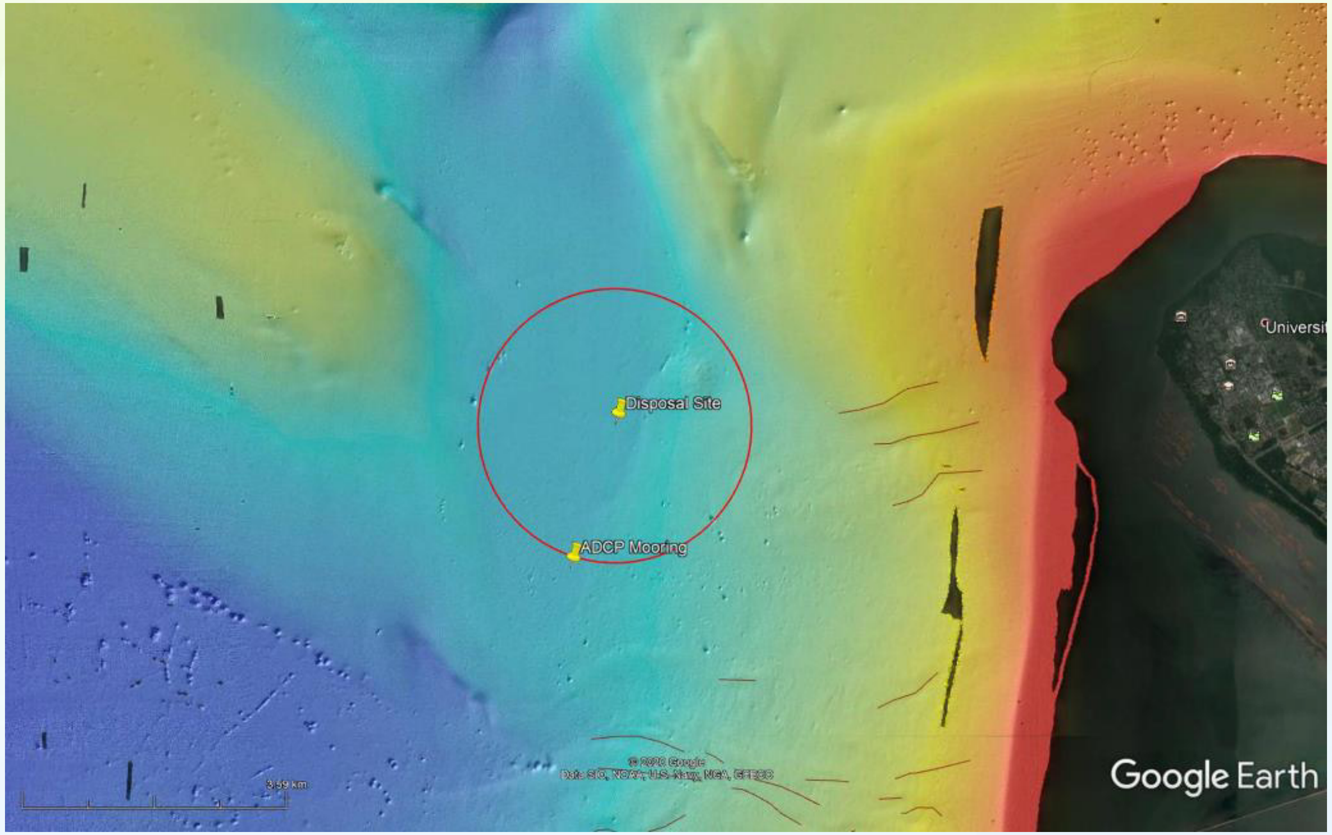
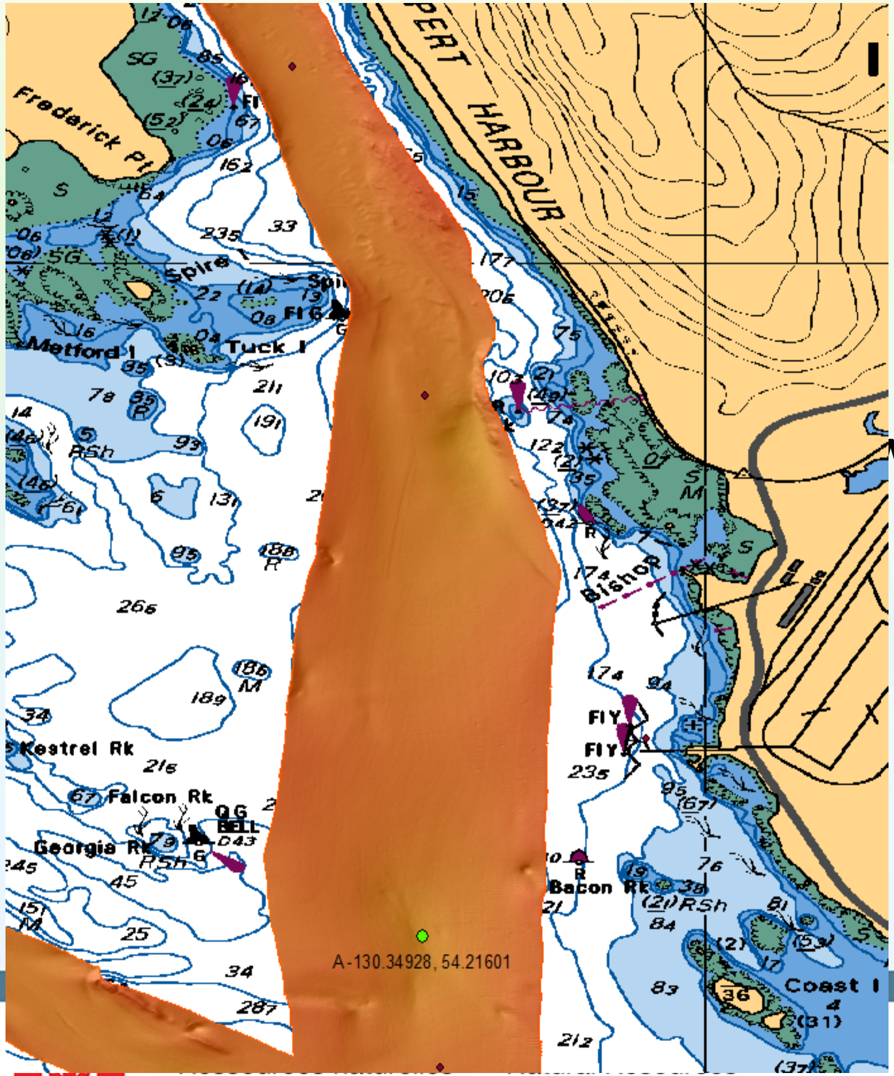


Figure 3. Map with Multibeam of the Point Grey disposal site and surrounding area[L[2] .

Dispersive or non-dispersive?

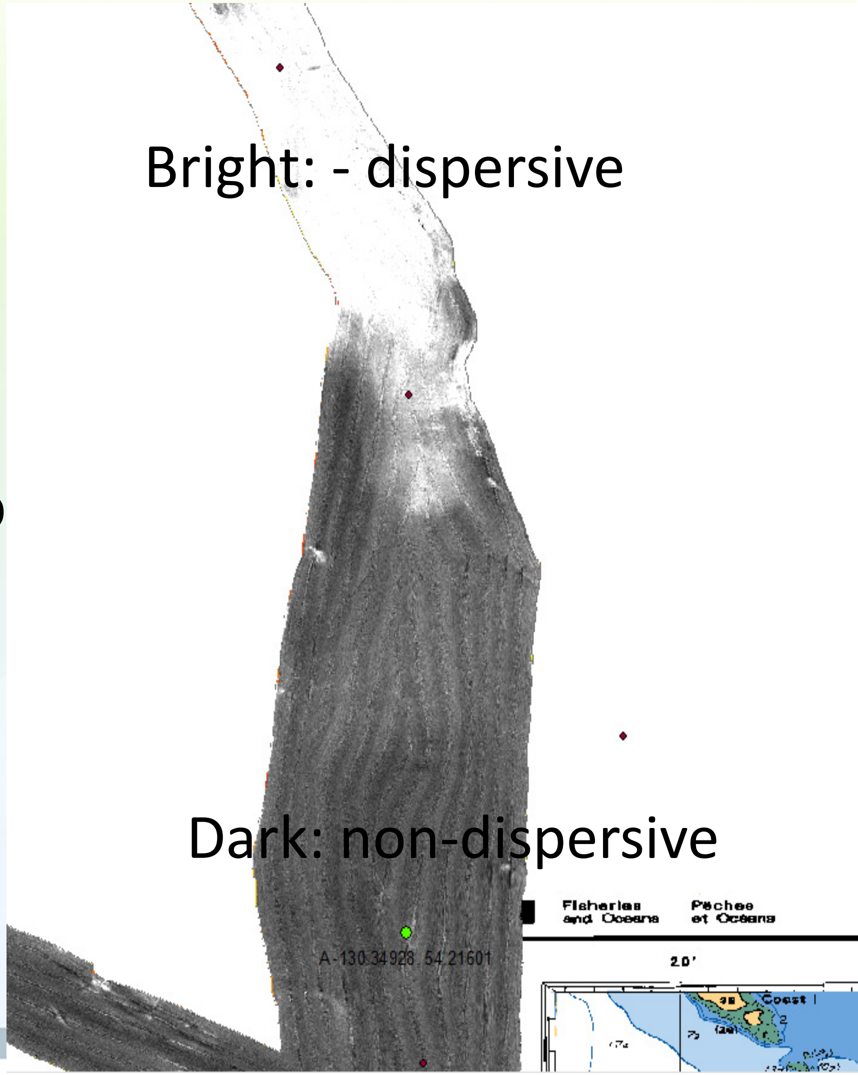
Multibeam backscatter example from a previous site



← Bathymetry

Backscatter →

Darker = finer grained, which usually translates to non-dispersive



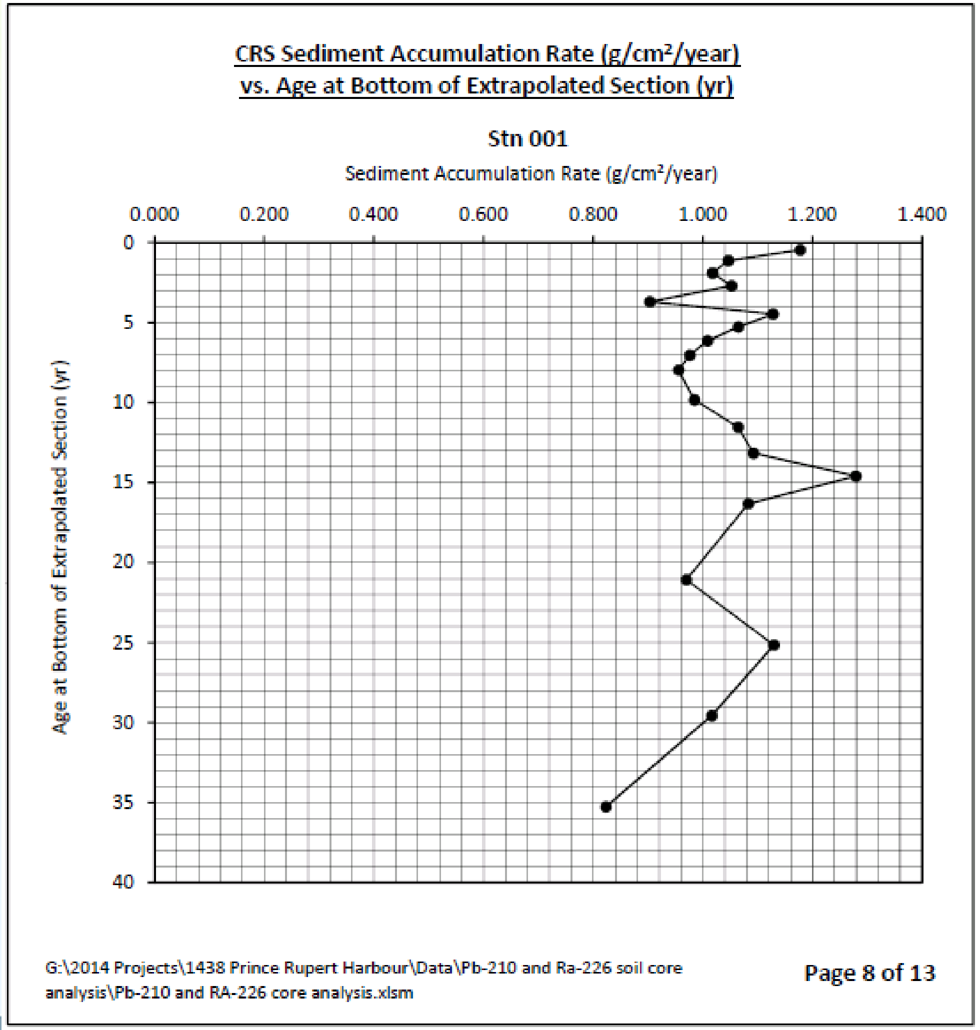
Bright: - dispersive

Dark: non-dispersive

Dispersive vs non-dispersive?

Coring and dating example from a previous site

Coring and Pb210 and Ra226 isotope analysis



Dispersive or non-dispersive?

Modelling example from a previous site

In this case the model:

- overestimated the average flows
- Underestimated some peak flows
- Did not capture currents in a westward direction
- Only 1 summer month of data was available

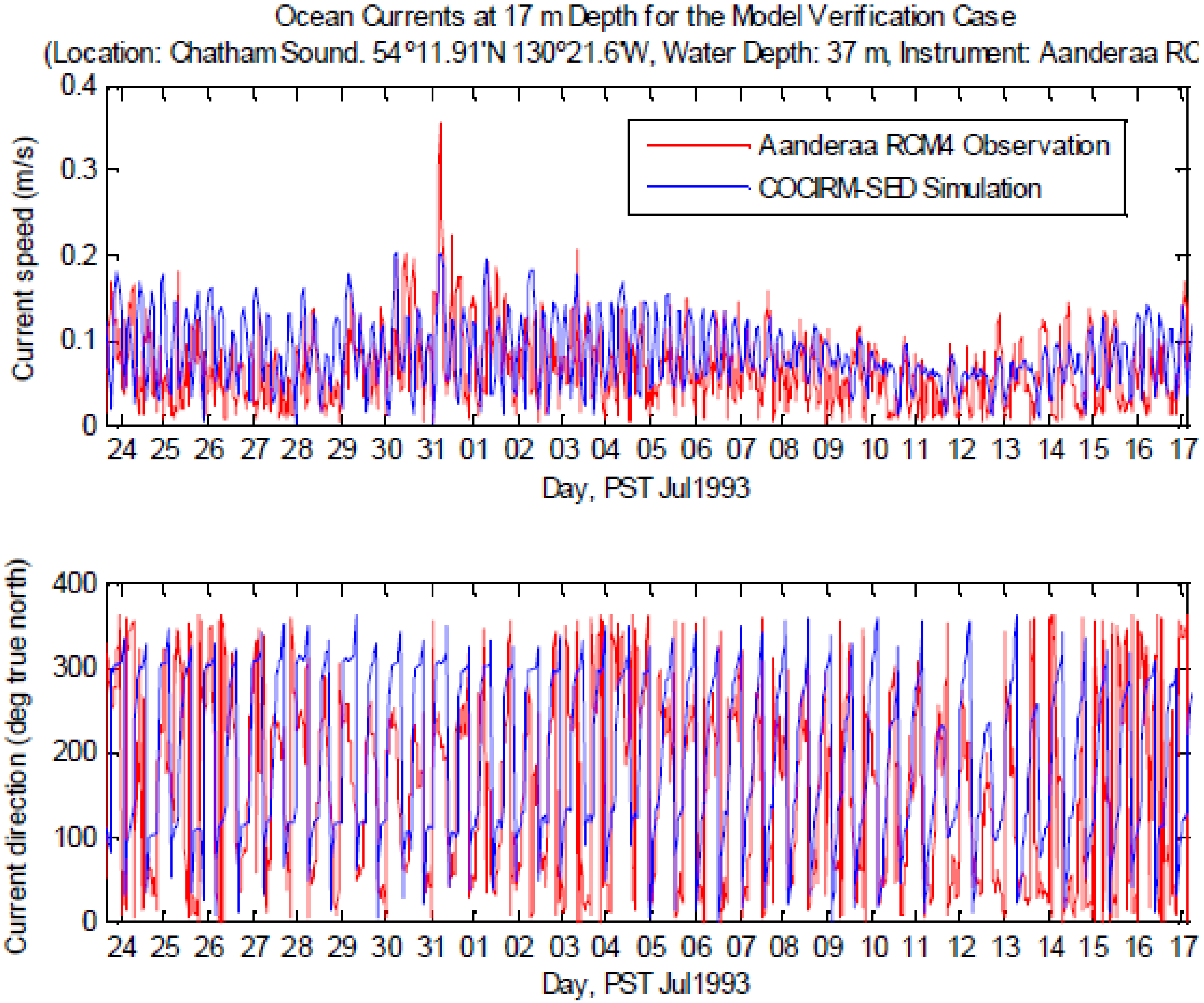


Figure 5: Verification modeled and measured ocean currents at 17 m depth near disposal site 1.

Dispersive or non-dispersive?

The goal: Design experiments which give actual measurements of currents and sediment transport, but which are easy for proponents to implement

- Must be robust and designed using best techniques
- Must be transferrable to a proponent in an inexpensive form (no oceanographic research vessel)
- Test the 25 cm/s rule (is this really when sediment are resuspended?)

not

Test: Can simple instrument replace all of this to determine dispersivity?

Simple instrument (inside)

Answer:
Not completely

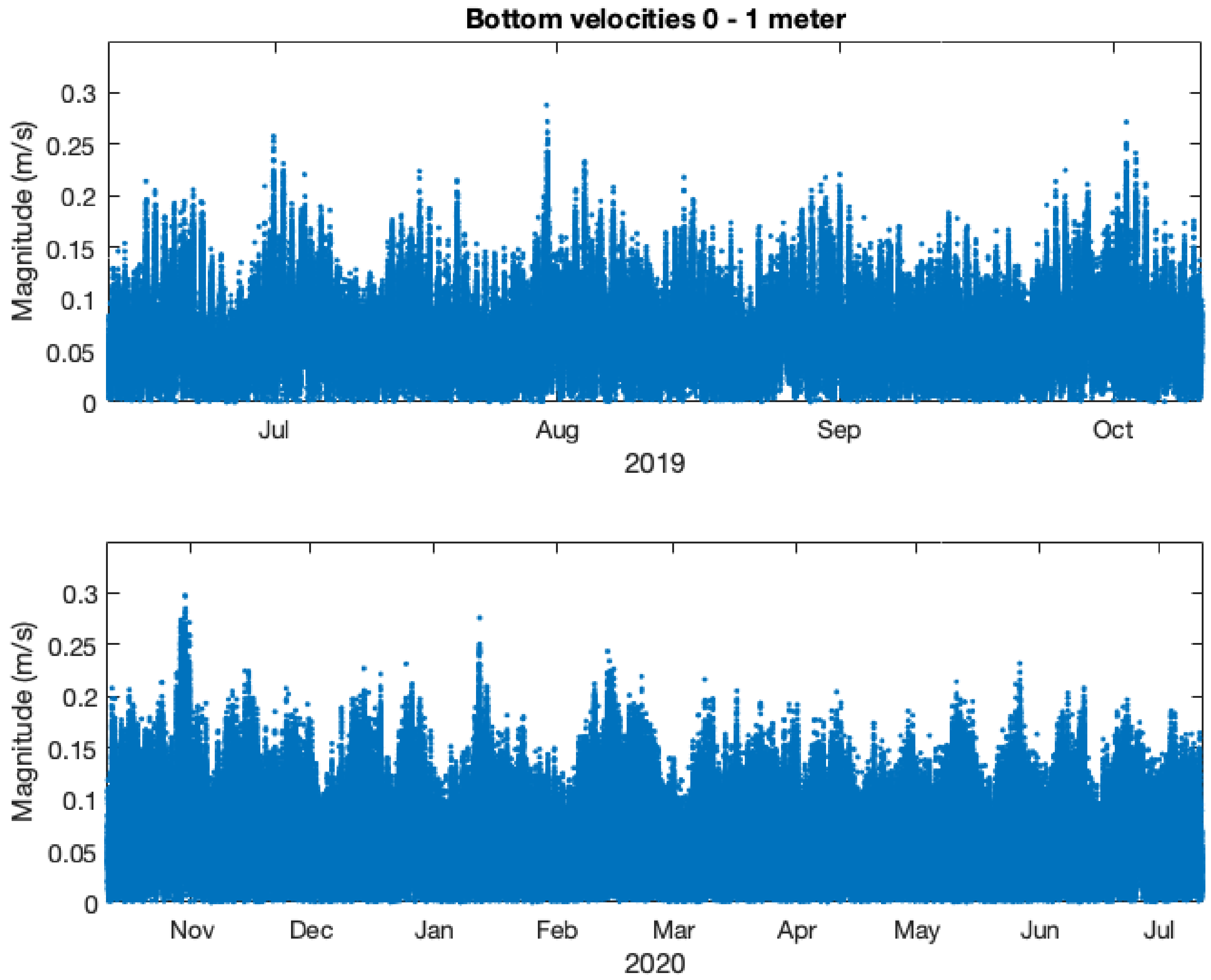
Mooring deployment
Point Grey, Vancouver

Canada

Dispersive or non-dispersive?

Testing:

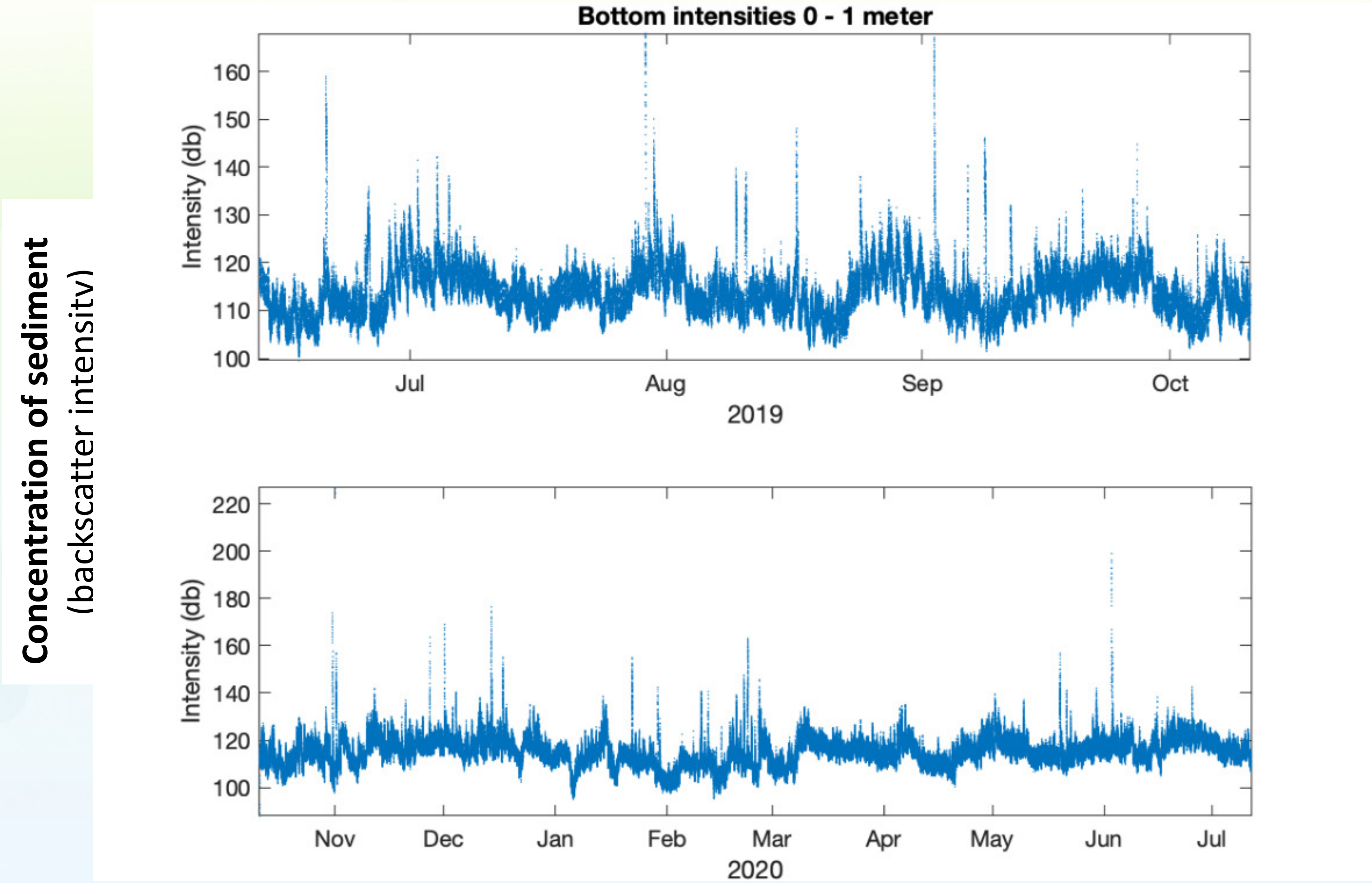
Peak 1% bottom current speed measurements less than 25 cm/s. Therefore Point Grey is considered to be non-dispersive by the definition we chose.



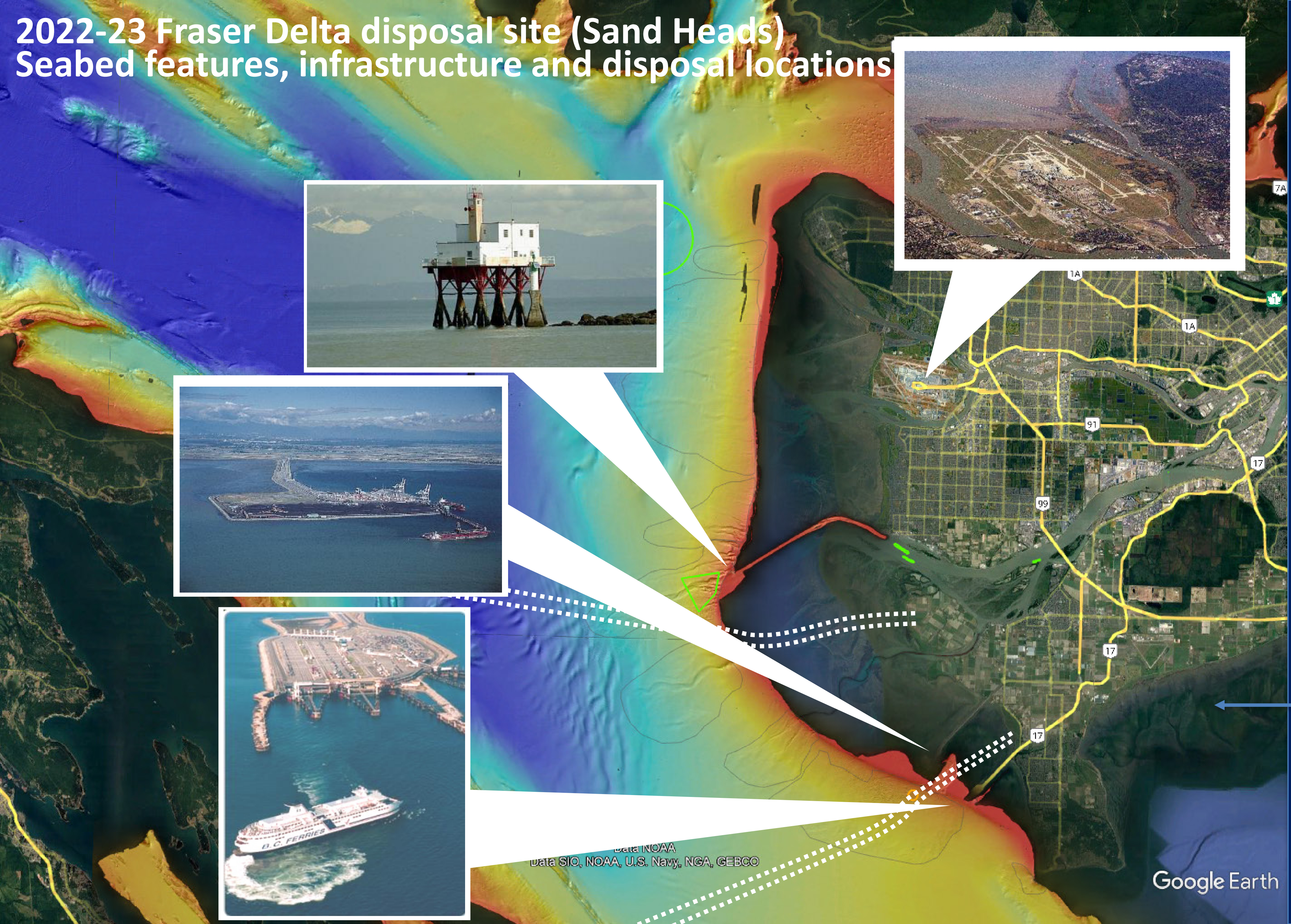
Dispersive or non-dispersive?

Although non-dispersive by definition, there are times when there are higher concentrations of sediment near the seabed

The 2021-22 report examines what is causing these



2022-23 Fraser Delta disposal site (Sand Heads)
Seabed features, infrastructure and disposal locations



— disposal locations

Nature Based
Coastal Protection
“Living Dyke”
(Beneficial use)

Dispersive or non-dispersive? Fraser Delta (Sand Heads)

Exceedance analysis – Site is dispersive

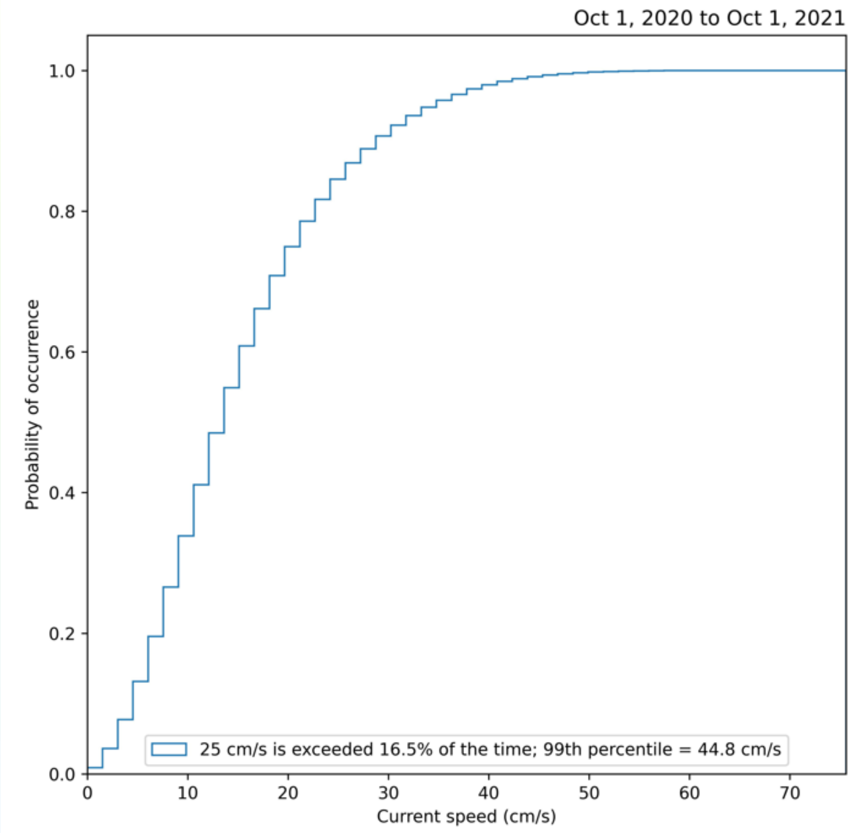


Figure 12 For the entire deployment period the 99th percentile is 44.8 cm/s, thus the peak 1% of measurements is above this. By the definition used, Sandheads disposal at sea site is dispersive.

Sediment concentration analysis – Huge variability driven by Fraser River Plume

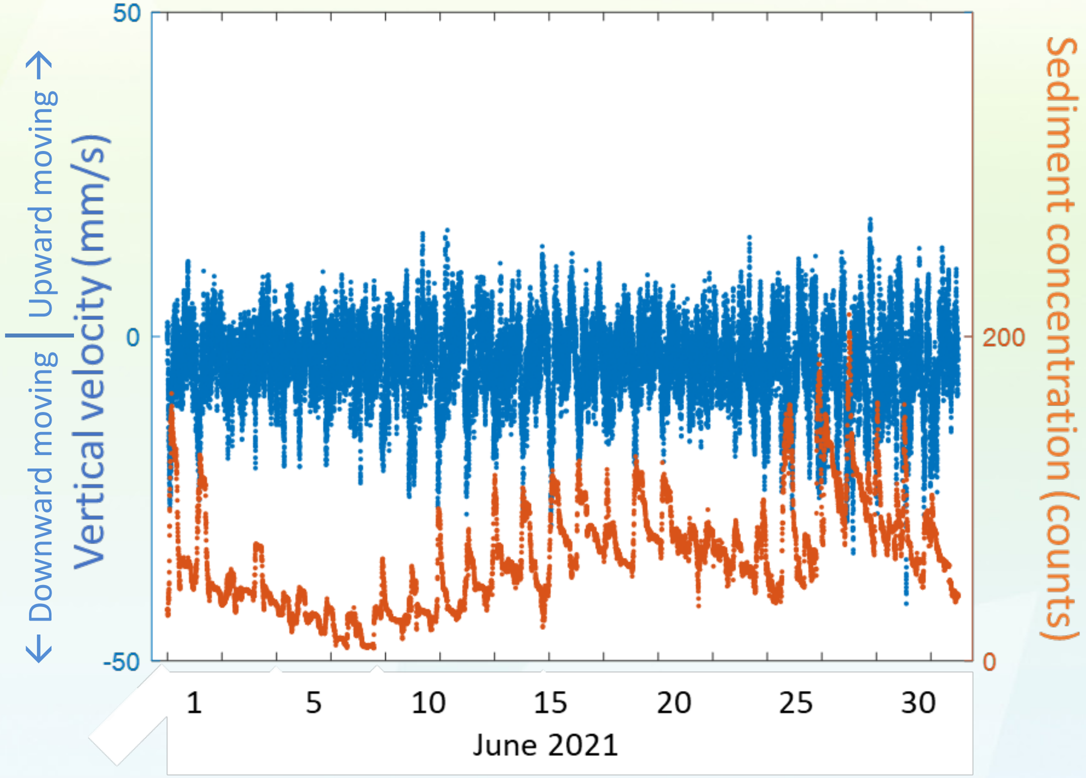


Figure 13 Vertical velocities of the particles in the water 1 m above the bed plotted alongside sediment concentrations at the same depth during freshet. High sediment concentrations are strongly linked with a downward settling sediment plume from the Fraser River.

Dispersive or non-dispersive?

Fraser Delta Landslide 2022-23

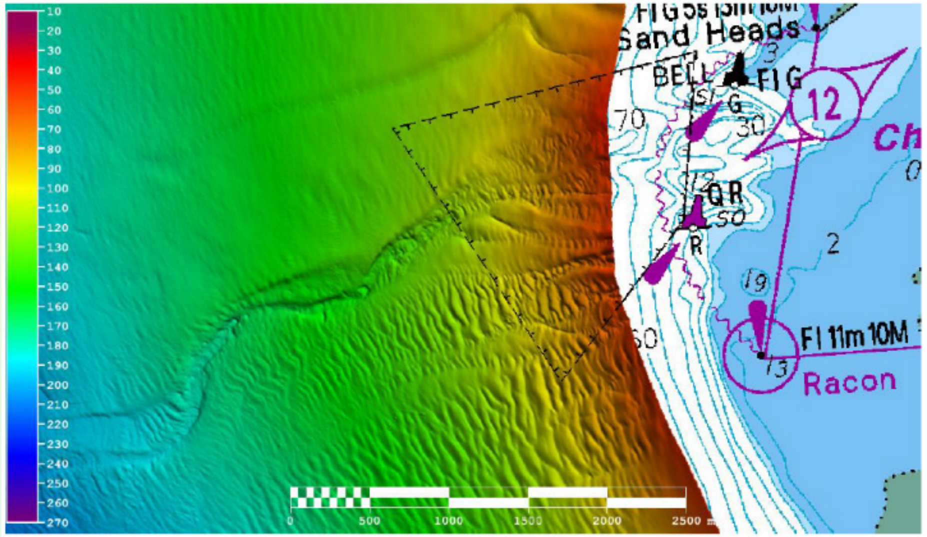


Figure 7. 2020 Sand Heads Bathymetry

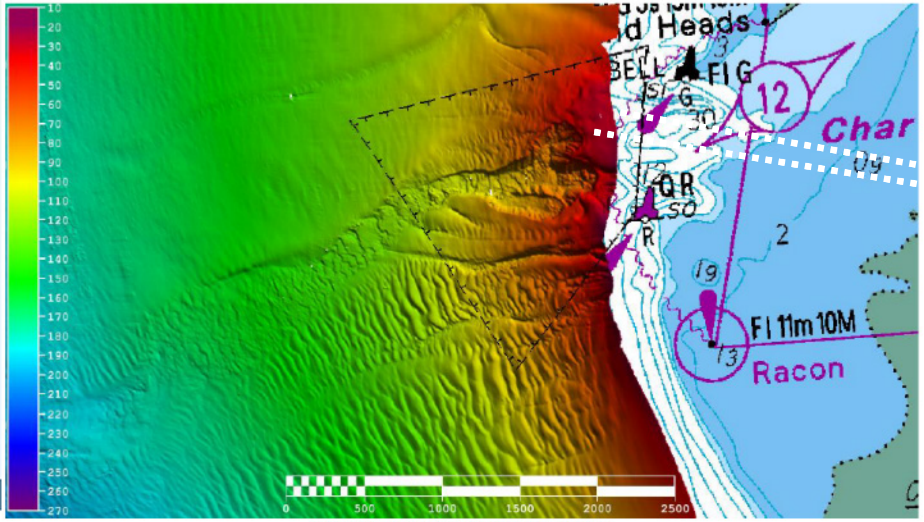
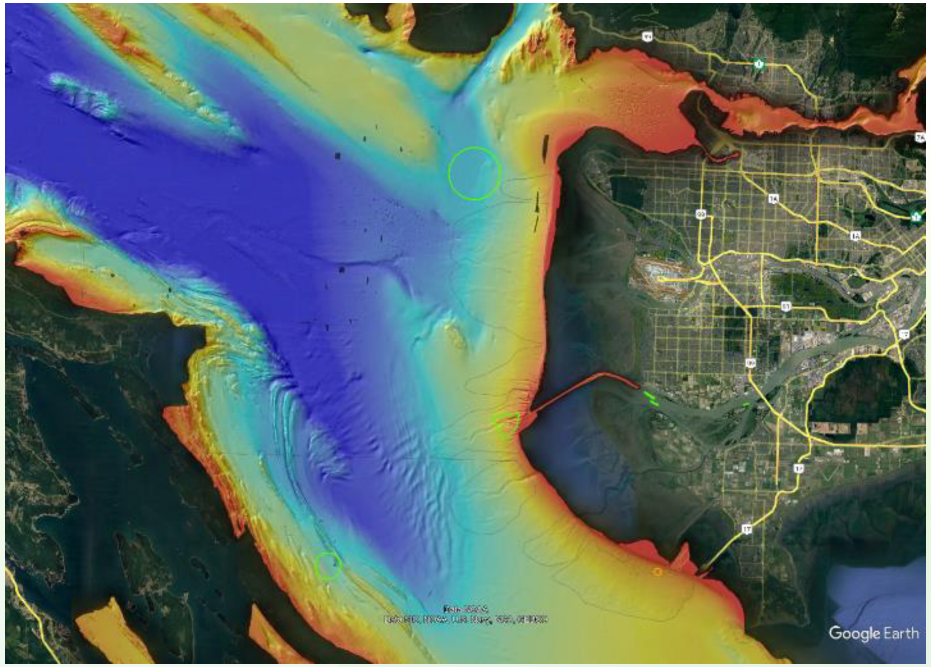


Figure 8. 2022 Sand Heads Bathymetry



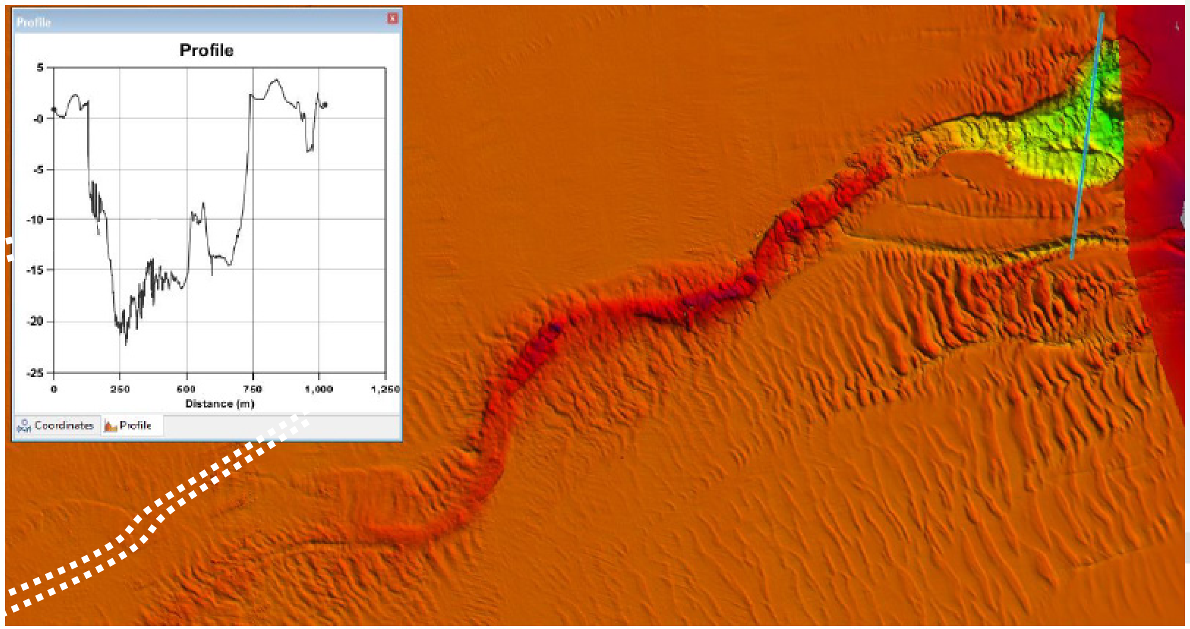


Figure 10. 2022-2020 difference surface profile, material collapse

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Natural Resources Canada

Publications and future

E

INTERNATIONAL MARITIME ORGANIZATION

SCIENTIFIC GROUP OF THE LONDON CONVENTION – 46th Meeting; and SCIENTIFIC GROUP OF THE LONDON PROTOCOL – 17th Meeting
13 to 17 March 2023
Agenda item 7

LC/SG 46/7/1
9 January 2023
ENGLISH ONLY
Pre-session public release: ☒

MONITORING AND ASSESSMENT OF THE MARINE ENVIRONMENT

Results of Canada's 2021 disposal site monitoring programme

Submitted by Canada

SUMMARY

Executive summary:	This document summarizes the disposal site field monitoring carried out in Canada in 2021. Representative sites were monitored off the Pacific, Atlantic and Arctic coasts. The studies highlighted in this document all used physical monitoring techniques, specifically hydrographic surveys, optical (video) surveys and ocean bottom current monitoring. These techniques are beneficial to the Canadian disposal at sea monitoring programme as they provide cost-effective, repeatable methods that increase our understanding of sediment dynamics, dispersivity, compliance and navigational safety at disposal sites on all three coasts.
Action to be taken:	Paragraph 21
Related document:	LC/SG 45/INF.3

This work has resulted in:

- Public Annual reports with characteristics of an individual sites
- Guidance on monitoring for proponents of new disposal at sea sites.
- Forms part of Canada's submission to London Convention and Protocol

Future Directions

- ECCC would like sediment transport modelling
- New capital (received 2023 by GSCP) will allow better definition of sediment transport
- Beneficial use of sediment (port expansion, Coastal protection, slope stability)
- Guidance for seabed mining (sediment detection and transport)

CONTACT INFORMATION

Dr Gwyn Lintern

250-889-9887

gwyn.lintern@canada.ca

THANK YOU!

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CCS: Benchmarking CO_2 Storage Capacity with Real-World Measurements

CSC: évaluation de la capacité de stockage du CO_2 à l'aide de mesures réelles

Don White

May 16th, 2023

ABSTRACT

CCS research conducted this last year focused on geophysical imaging of CO_2 saturation within a deep CO_2 plume at the Aquistore CO_2 storage site. The objectives of this work are to directly measure CO_2 storage efficiency factors, constrain practical estimates of storage capacity, and calibrate remote methods for plume imaging. The expected outcomes are to provide a basis for more robust storage capacity estimation and to inform regulations and international CCS standards. Progress this year included processing of the crosswell seismic data that were acquired at the Aquistore site. Initial crosswell reflection images of the reservoir interval have been attained and are being compared with comparable pre-injection images from 2012 to determine the effects of CO_2 injection. New electromagnetic field measurements were made at the Aquistore site in 2022. This new survey occupied the same measurement site as were used in 2013-2015 when long-offset controlled-source electromagnetic surveys were conducted. Comparison of the two surveys will examine the ability of surface electromagnetic methods to monitor the CO_2 plume as it modifies the electrical properties of the subsurface.

PROJECT MEMBERS

- Don White, Jim Craven, Vicki Tschirhart (**GSC**)
- Mike Craymer (**CGS**)
- Riley Chesterton (**SaskPower**)
- Erik Nickel, Zeinab Movahedzadeh (**Petroleum Technology Research Centre**)
- Alireza Rangriz Shokri, Rick Chalaturnyk (**University of Alberta**)
- Chris Hawkes (**University of Saskatchewan**)
- Ian Ferguson (**University of Manitoba**)
- Bernard Giroux (**INRS**)
- Anna Stork (**Silixa/Techne-Physis**)
- Masaru Ichikawa, Yuta Kitawaki (**Japan Oil, Gas Metal NC**)
- Biondo Biondi (**Stanford University**)

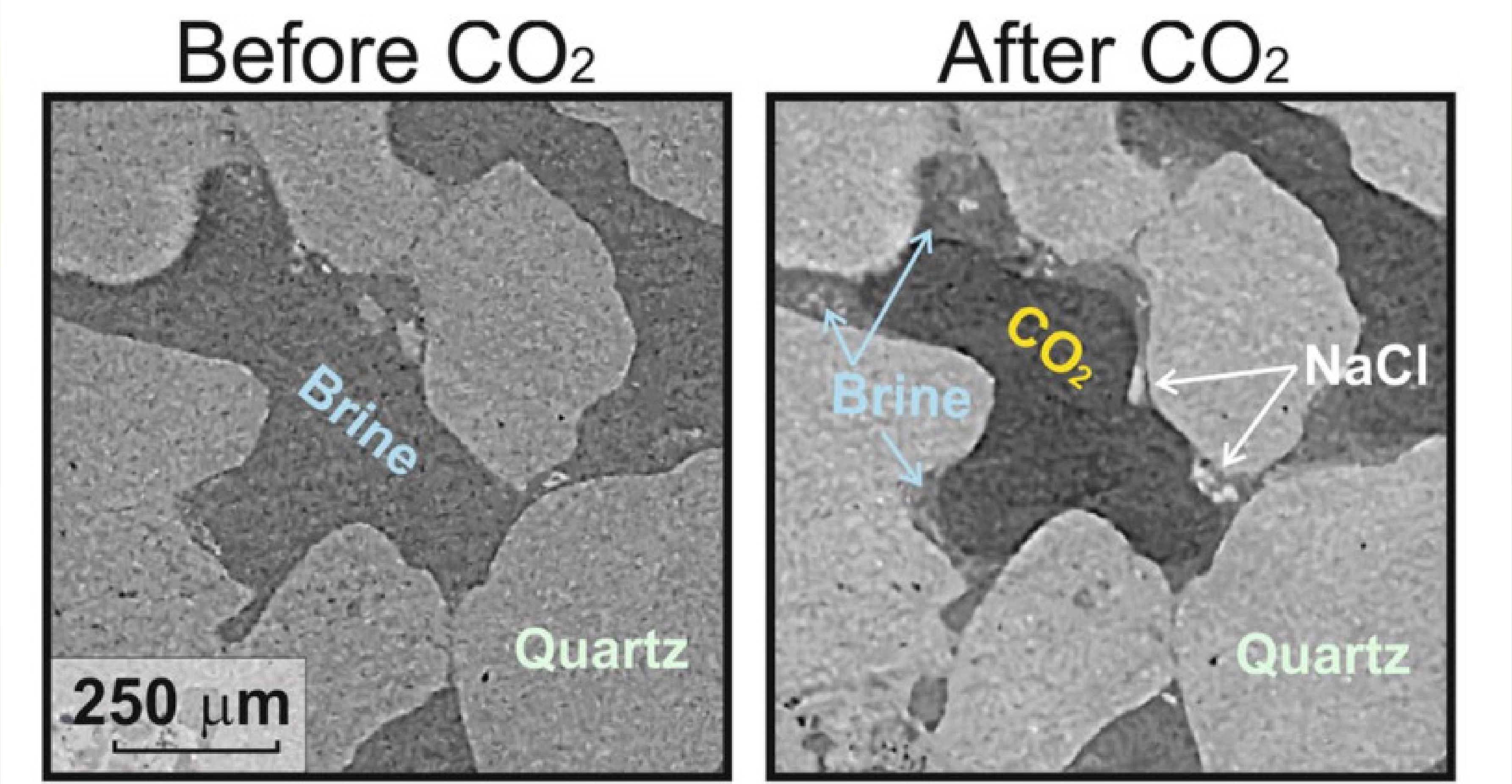
CO_2 Storage Resource

Computing CO_2 Resource Estimate – Saline Formations. The volumetric equation for CO_2 storage resource estimate potential in saline formations is as follows:

$$G_{CO2} = A_t h_g f_{tot} \rho E_{saline} \quad \text{[Eq. 2]}$$

The total area (A_t), gross formation thickness (h_g), and total porosity (f_{tot}) terms account for the total volume of pore space available. The CO_2 density (ρ) term transforms pore volume into the CO_2 mass that can fit into the formation volume at in-situ conditions of temperature and pressure. The storage efficiency factor (E_{saline}) reflects the fraction of the total pore

How efficient is CO_2 storage?



Falcon-Suarez et al., Nature, 2020

GSC Research Objectives

- Image CO_2 saturation within a deep CO_2 plume at the Aquistore site using geophysical methods:
  - Directly measure CO_2 storage efficiency factors
  - Constrain practical estimates of storage capacity
  - Calibrate remote methods for plume imaging.

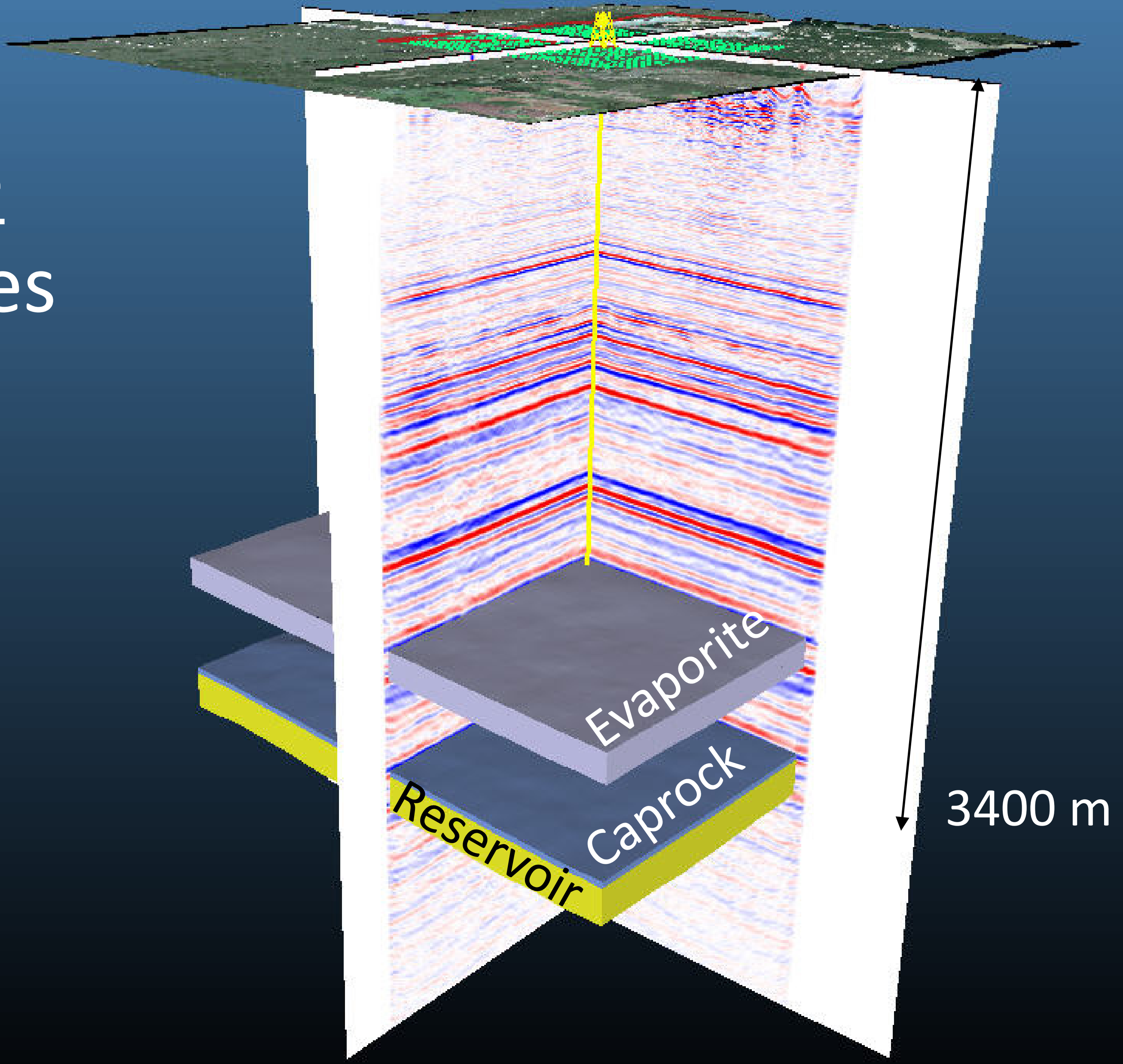
Outcomes

- More robust storage capacity estimation
- Inform regulations and international CCS standards

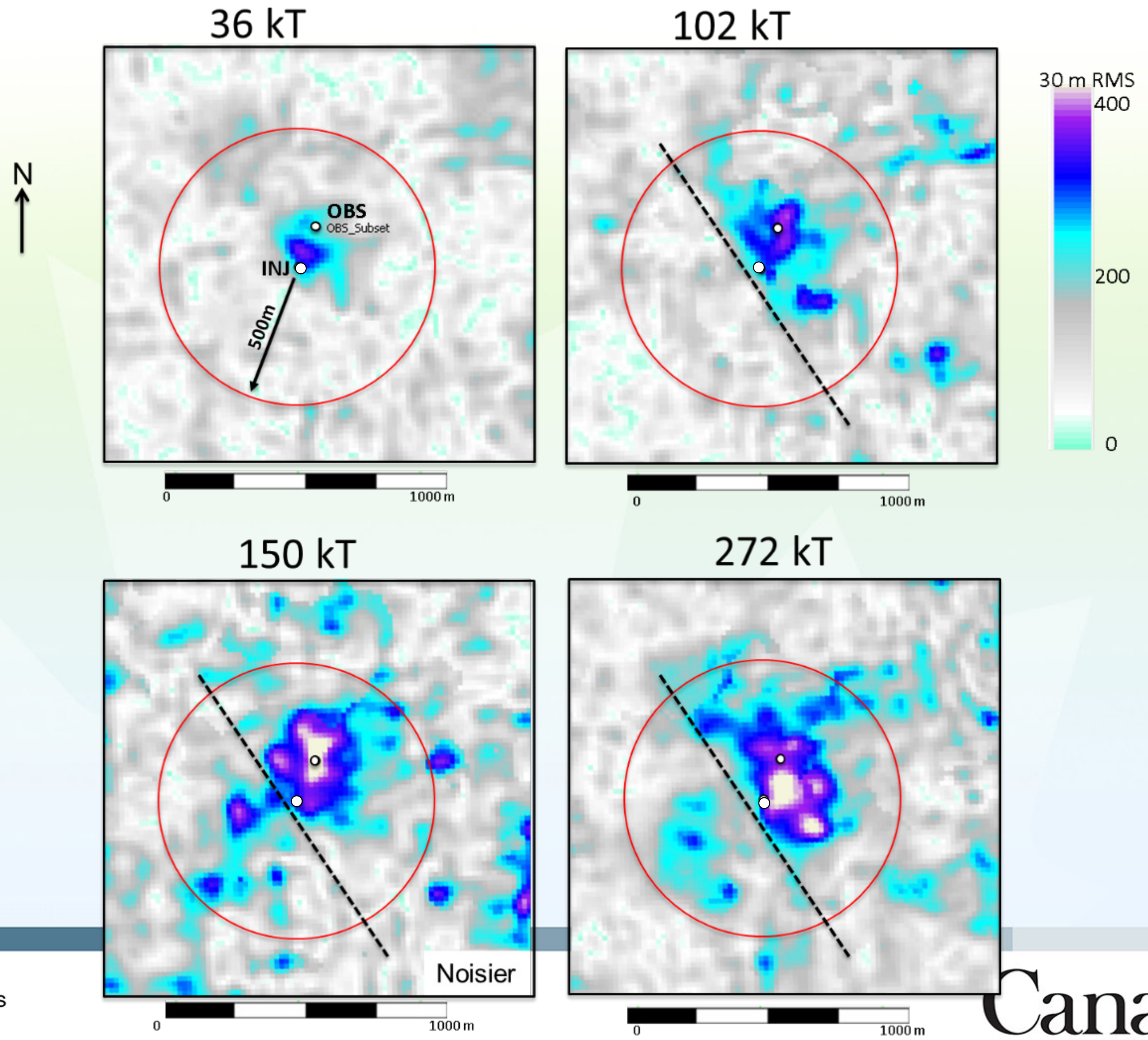
Aquistore Site

530,000 tonnes

CO_2 injected



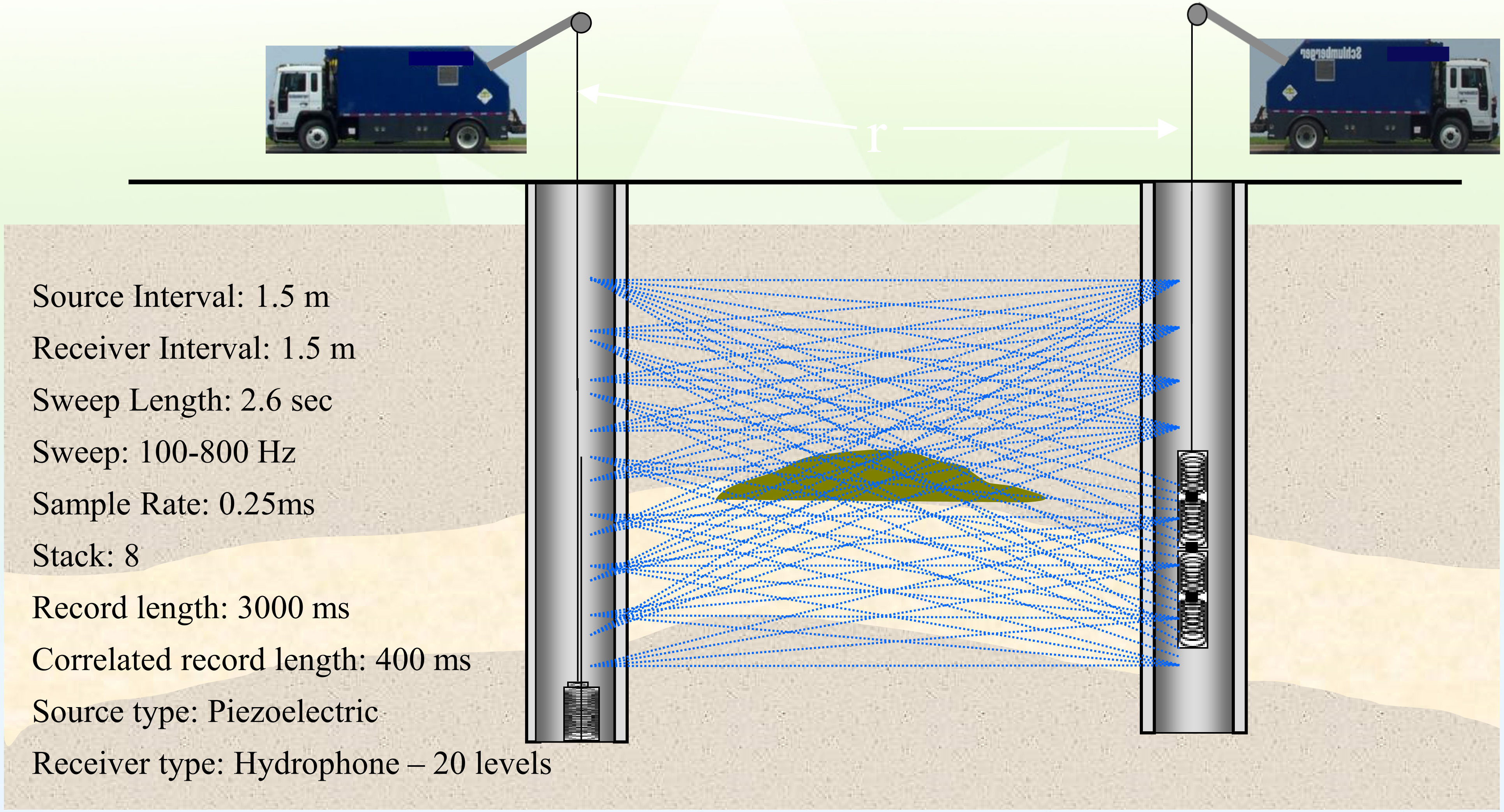
UPPER DEADWOOD: 4D RMS Amplitude Difference



Methodology

- Time-lapse imaging:
  - High-resolution crosswell seismic
  - Surface-based electromagnetic measurements

Data Acquisition



Source Interval: 1.5 m

Receiver Interval: 1.5 m

Sweep Length: 2.6 sec

Sweep: 100-800 Hz

Sample Rate: 0.25ms

Stack: 8

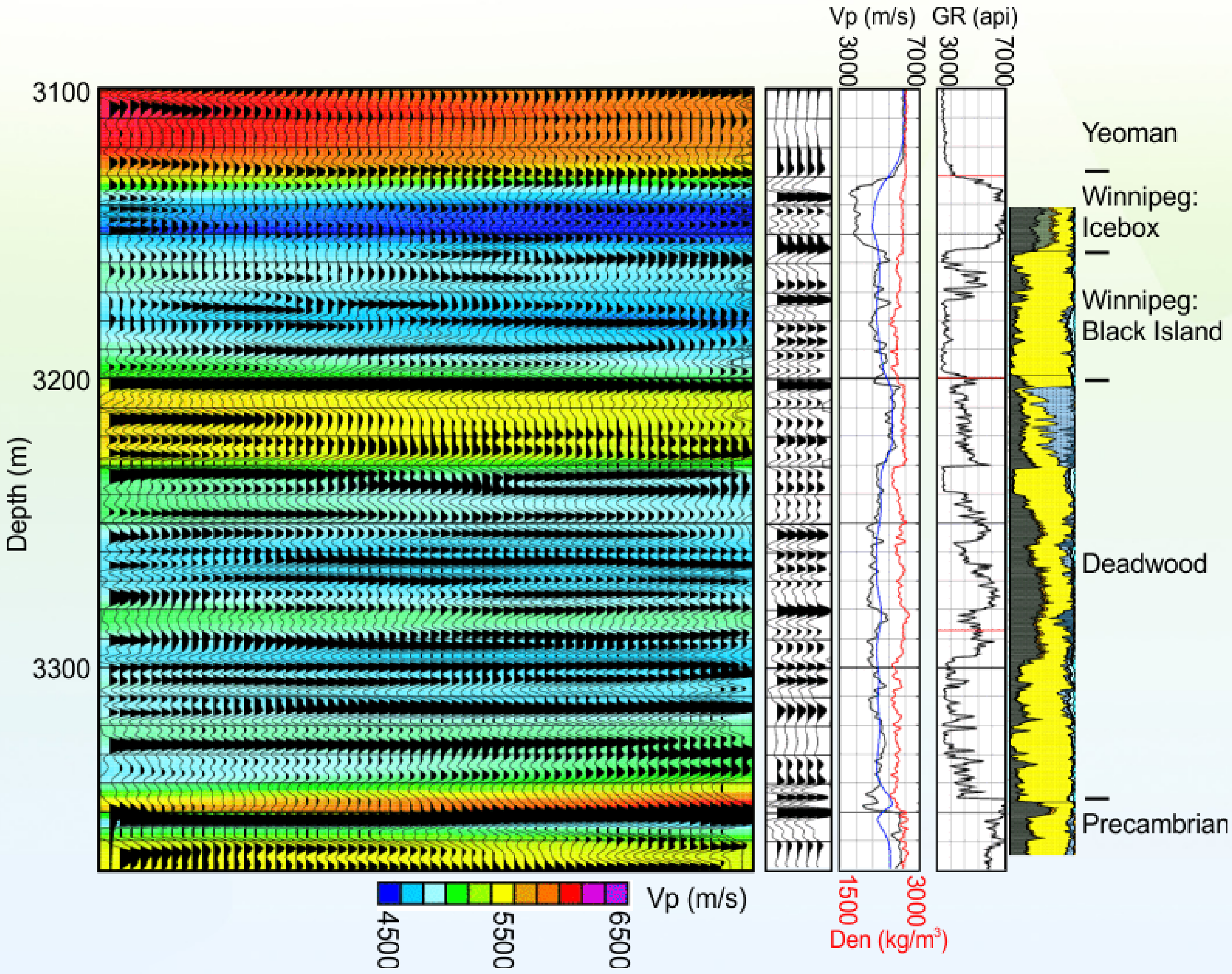
Record length: 3000 ms

Correlated record length: 400 ms

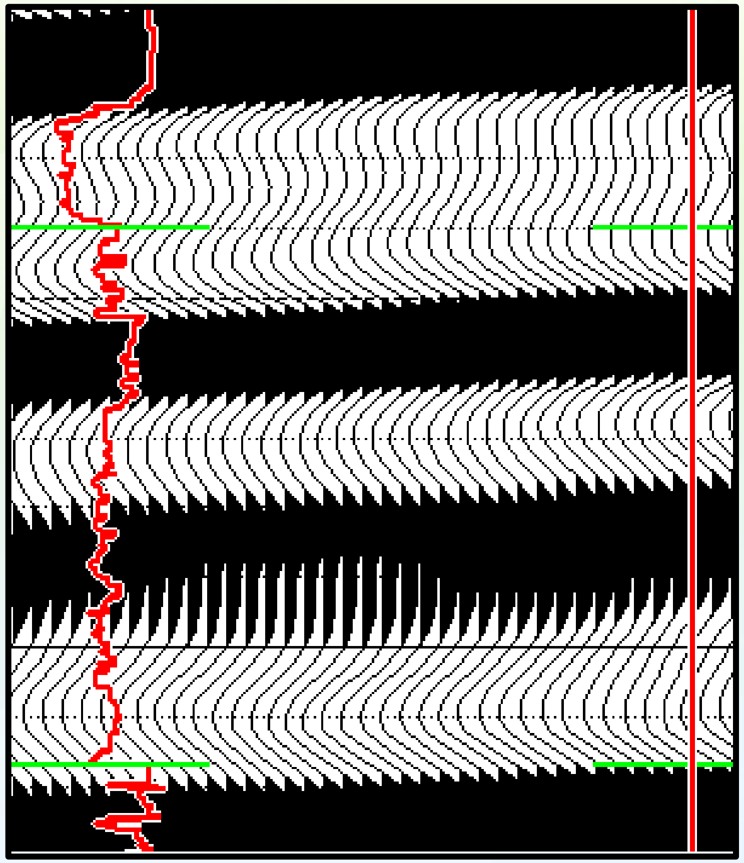
Source type: Piezoelectric

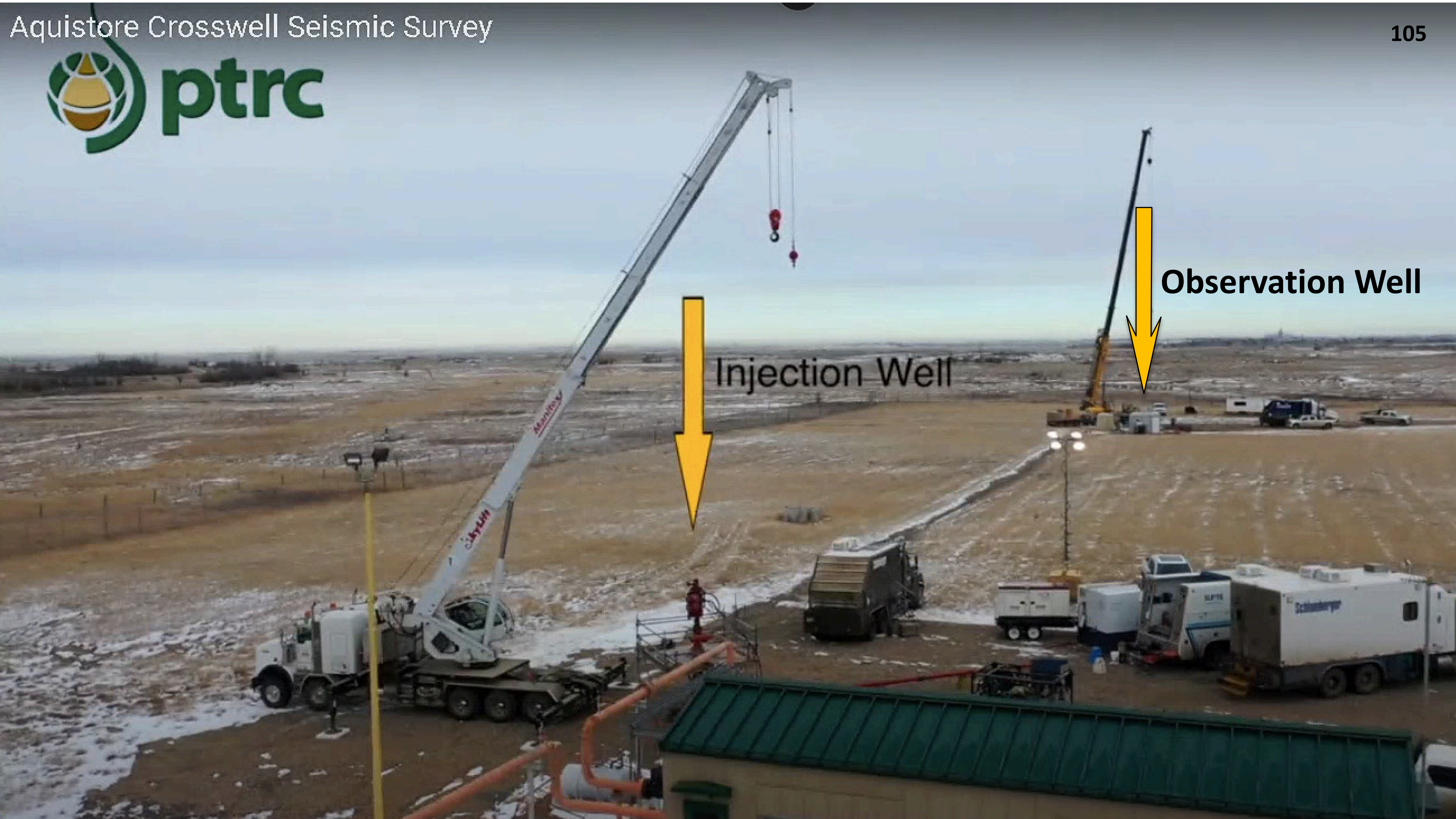
Receiver type: Hydrophone – 20 levels

Crosswell Seismic



Surface Seismic

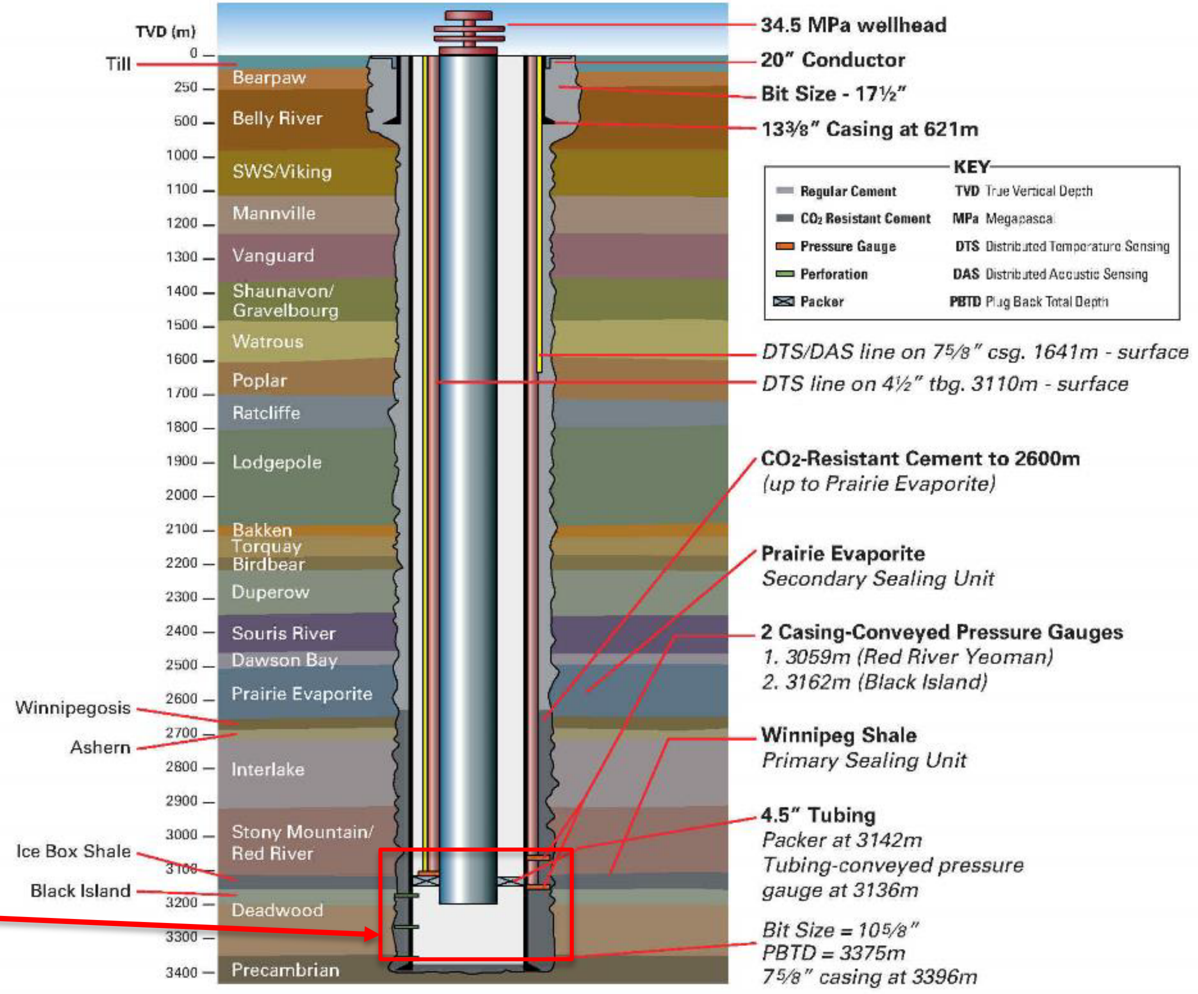


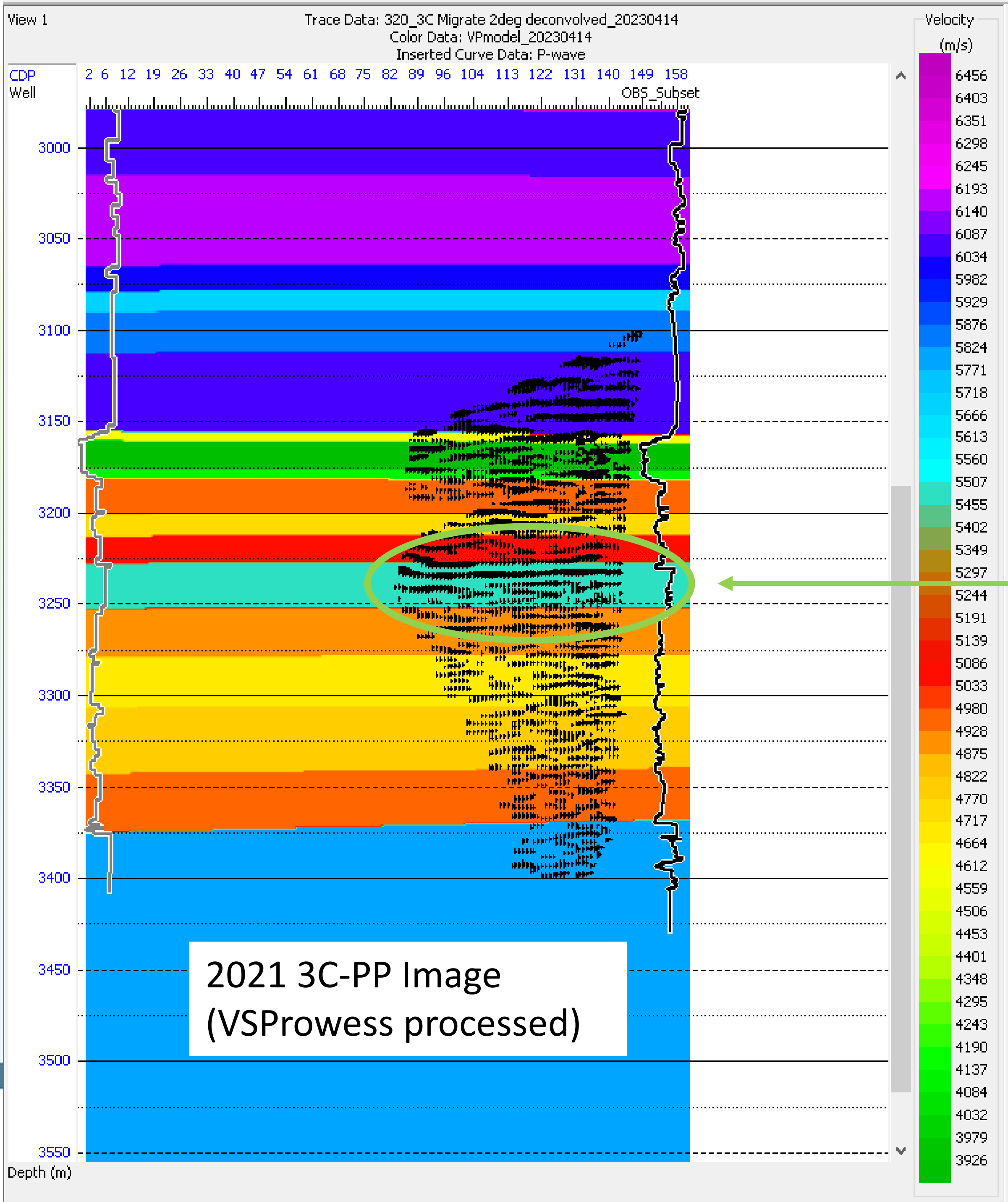

Aquistore Crosswell Seismic Survey
ptrc
Injection Well
Observation Well

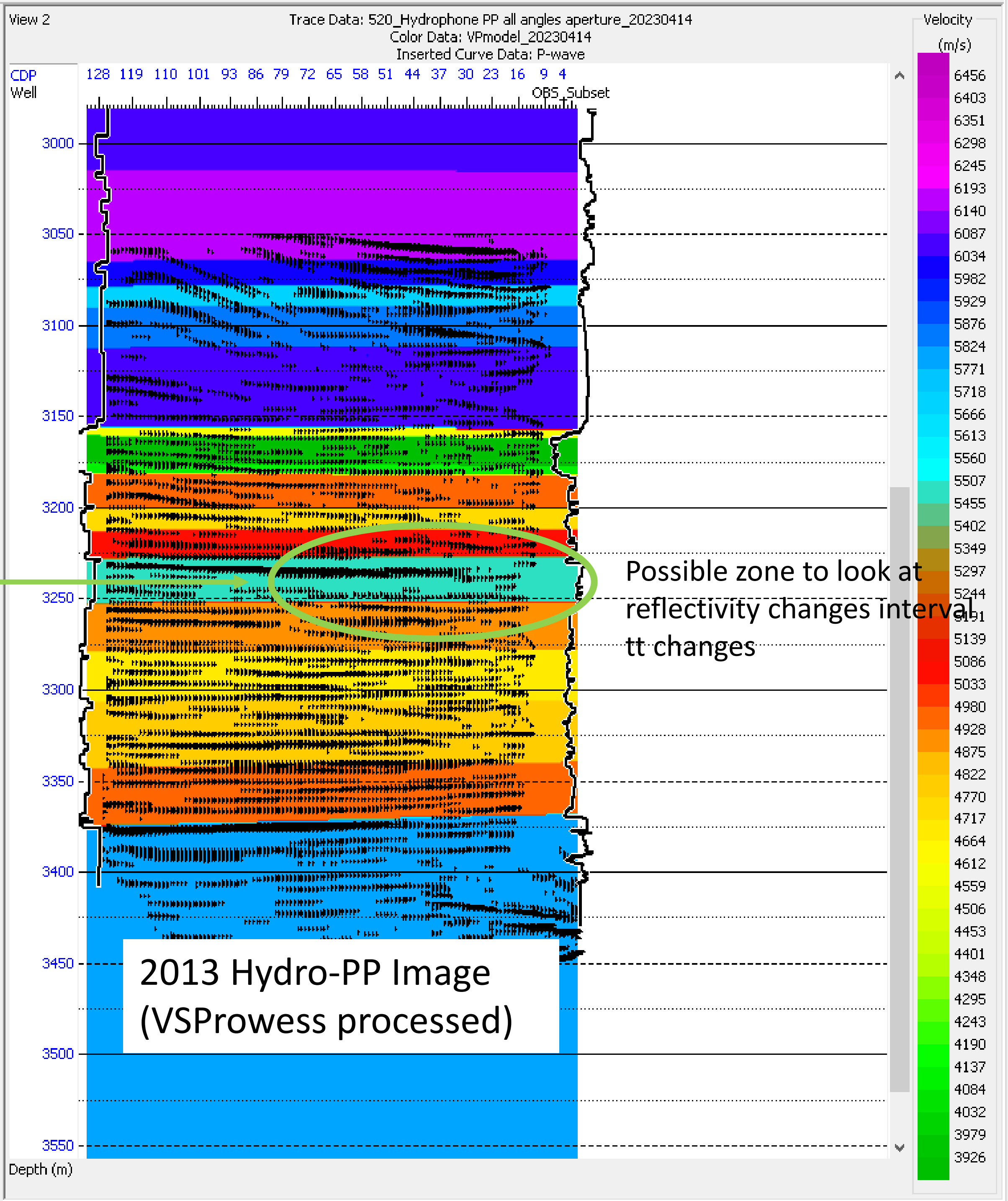
Challenges for Time-lapse Crosswell Seismic in 2021

- Injection well under pressure
- Use of a lubricator (pressure control) limits tool length (< 10 m)
- Original hydrophone array to be replaced by geophones (reduced repeatability)
- Borehole conditions have changed since baseline:
  - partial constriction in OBS well milled prior to survey
  - super-critical CO_2 has replaced brine in INJ (expect weak seismic response and possible ringing)
  - Precipitation of salt in INJ restricts access in lower Deadwood formation
  - Constriction at bottom of tubing in INJ limits access to reservoir for the source
  - Mitigate by part 2 acquisition using source in OBS and DAS in INJ
  - CO_2-resistant cable of required gauge to run the source wasn't available, resulting in reduced power.

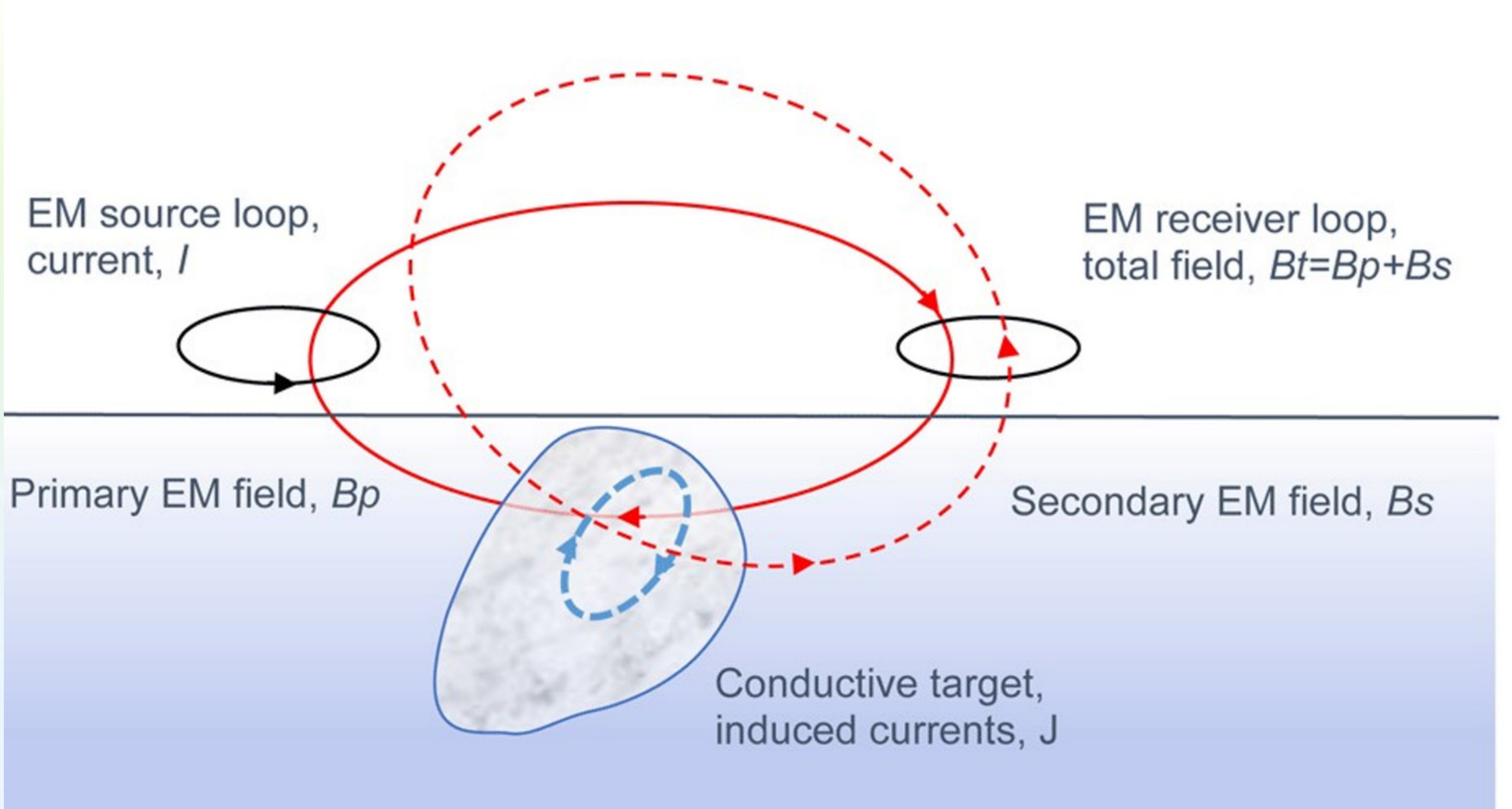
Injector: Precipitated salt (Lower Deadwood)




View 1
Trace Data: 320_3C Migrate 2deg deconvolved_20230414
Color Data: VPmodel_20230414
Inserted Curve Data: P-wave
Velocity (m/s)
CDP
Well
OBS_Subset
Depth (m)
2021 3C-PP Image
(VSProwess processed)


View 2
Trace Data: 520_Hydrophone PP all angles aperture_20230414
Color Data: VPmodel_20230414
Inserted Curve Data: P-wave
Velocity (m/s)
CDP
Well
OBS_Subset
Depth (m)
Possible zone to look at reflectivity changes interval tt changes
2013 Hydro-PP Image
(VSProwess processed)

Electromagnetic Imaging

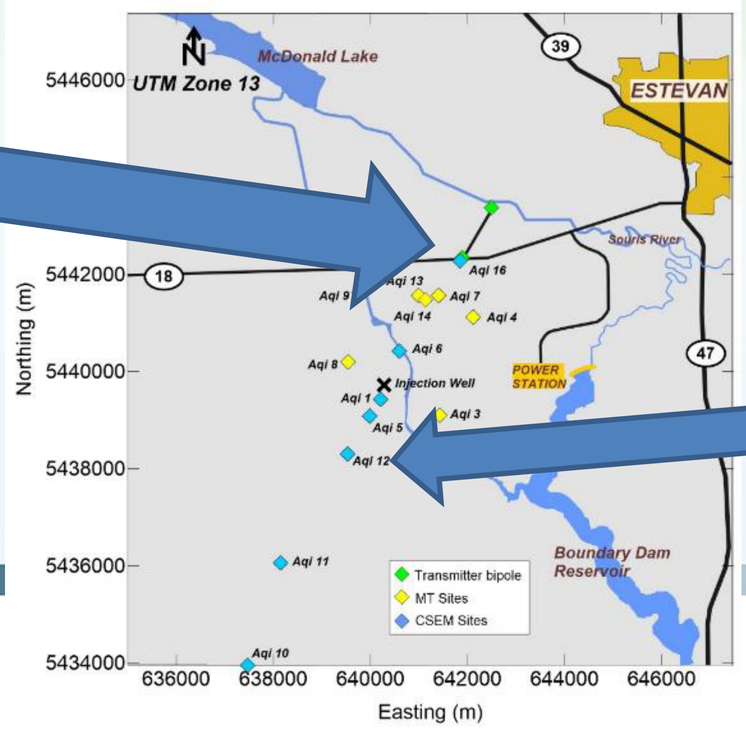


Examine the ability of surface electromagnetic (EM) methods to monitor CO_2 plume as it modifies the electrical properties of the subsurface.

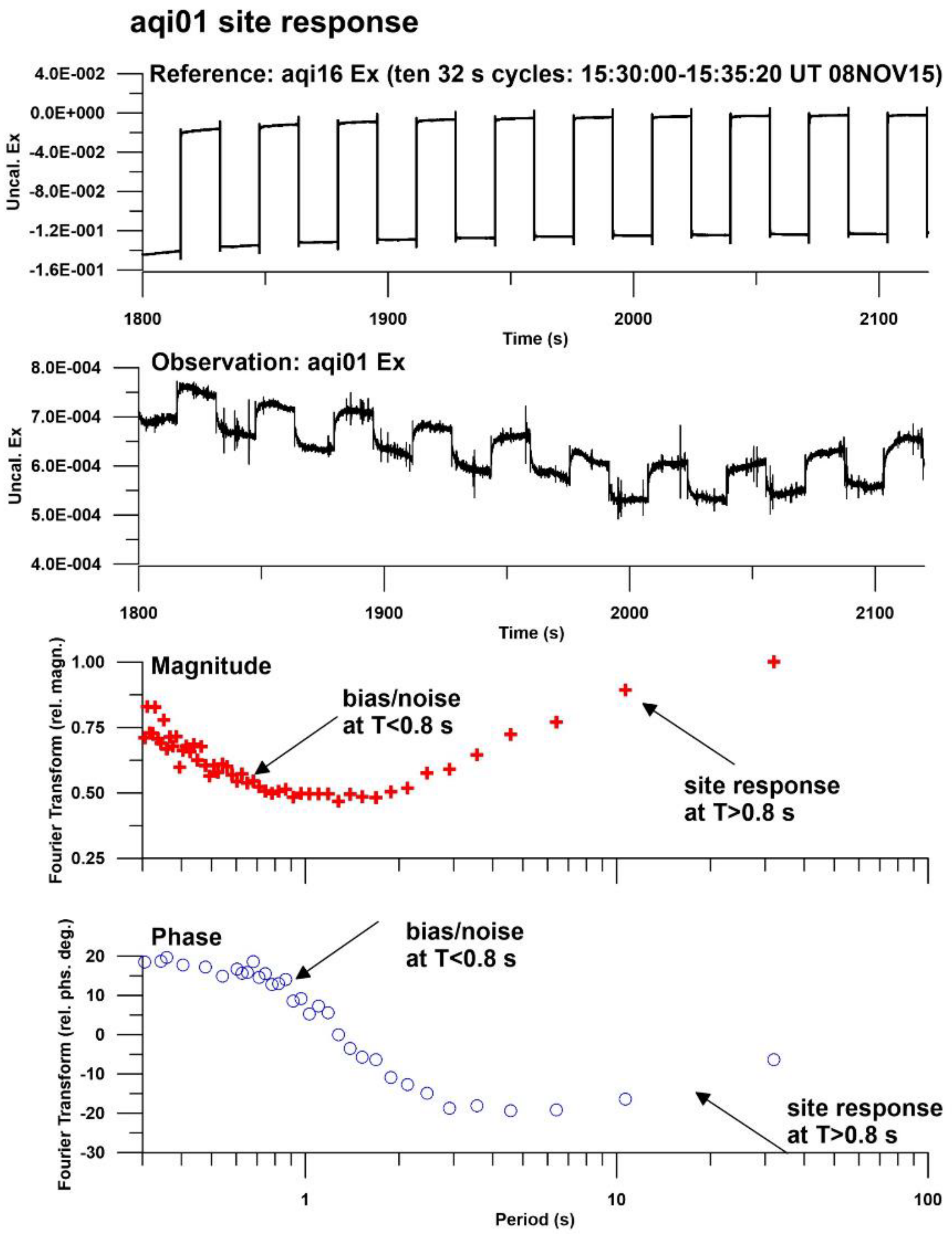
Long-offset controlled-source EM surveys completed in 2013–2015, focused on a 2.5 km × 8.5 km area around the injection well to define the pre-injection EM responses and resistivity structure.

A large bipole transmitter was used, designed to measure the electric field at receiver site locations at offsets of 3 km to 10 km.

The 2022 survey occupied the same sites to look for changes after seven years of injection.



Receiver Sites



Source signal

Receiver site response

<u>Frequency response</u>

Magnitude

Phase

- Modelling of the time-lapse responses will allow mapping of reservoir properties such as porosity and the temporal changes in CO_2 saturation.
- The broad frequency spectrum allows discrimination of CO_2 within the reservoir from CO_2 that may reside above the reservoir or changes to groundwater conditions.

CONTACT INFORMATION

- Don White
- don.white@nrcan-rncan.gc.ca

- Jim Craven
- jim.craven@nrcan-rncan.gc.ca

- Aquistore crosswell seismic survey
- Aquistore 4D seismic imaging
- CBC/Radio Canada: 'Enfourir le CO_2'

Ressources naturelles Canada | Natural Resources Canada

Cumulative Effects of Resource Development on Mining-Impacted Watersheds

Effets Cumulatifs du Développement Minier dans les Basins Versants Contaminés

Alexandre Desbarats

May 30, 2023

Canada

ABSTRACT

Renewed exploration or development in historical mining districts, such as Cobalt, presents unique challenges for proponents and government regulators because of the cumulative nature of environmental impacts. To increase capacity to carry out or review environmental assessments, this project will develop geoscience methods for distinguishing environmental effects of new mining activity from complex existing background conditions in affected watersheds. Specifically, the project will develop means of unraveling the history of accumulated polymetallic contamination from multiple sources over multiple periods. This information and new data from mine wastes and mine drainage will be synthesized in the first geoenvironmental model for Ag-Ni-Co-As vein type deposits. Project results will be disseminated to key end users in order to improve the environmental assessment process and to ensure that decision makers have a better understanding of the cumulative nature of environmental impacts for sustainable mineral resource development.

Project Members and Collaborators

- Alexandre Desbarats (GSC-NC, leader)
- Michael Parsons (GSC-ATL)
- Jeanne Percival (GSC-NC)
- Jennifer Galloway (GSC-Cal)
- Alexandre Normandeau (GSC-ATL)
- Josué Jautzy (GSC-QC)
- Tom Al (University of Ottawa)
- Heather Jamieson (Queen’s University)
- Richard Goulet, Sean Langley, Asma Asemaninejad (CanmetMINING)

Beaver-Temiskaming tailings

Cumulative Effects Assessment in a Historical Mining Camp undergoing a new Exploration Boom: Scientific Questions

- How to assess environmental impacts of new resource development against a brownfield legacy of pervasive contamination due to 90 years of un-regulated mining activity?
- What was the pre-mining (bio)geochemical baseline of the soils, sediments, vegetation, and waters of the mineralized watersheds?
- Has the existing environment reached a new geochemical equilibrium after historical resource development activities?
- Are there geochemical thresholds (tipping points) that need to be considered in assessing cumulative effects?
- Can lake sediment cores provide a reliable chronology of different phases of resource development in a mining-impacted watershed?
- With reference to climate change, what effects will the environment have on past, current, and future resource development projects?

Task 1: Metal(loid) loading in groundwater discharge to surface waters (Desbarats, lead)

Task 1.2: Discharge of metal(loid)-impacted groundwater from mine openings: Locating and characterizing anthropogenic seeps of mine-impacted groundwater

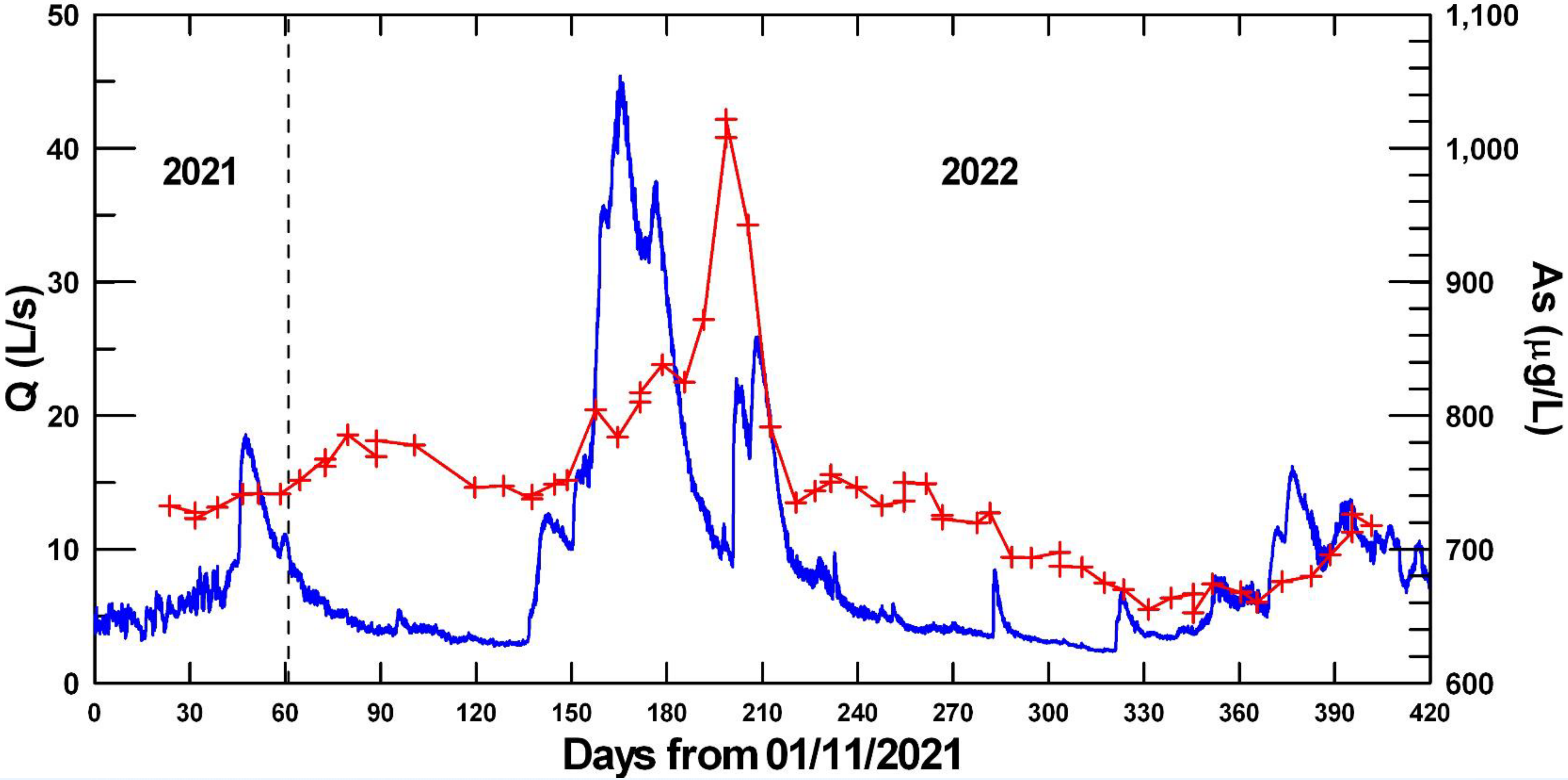
Research question: Concentration-discharge relationships for point sources of mine drainage - How will metal(loid) mobilization be affected by extreme flow events related to climate change?

FY 2022-2023 Achievements (Year end):

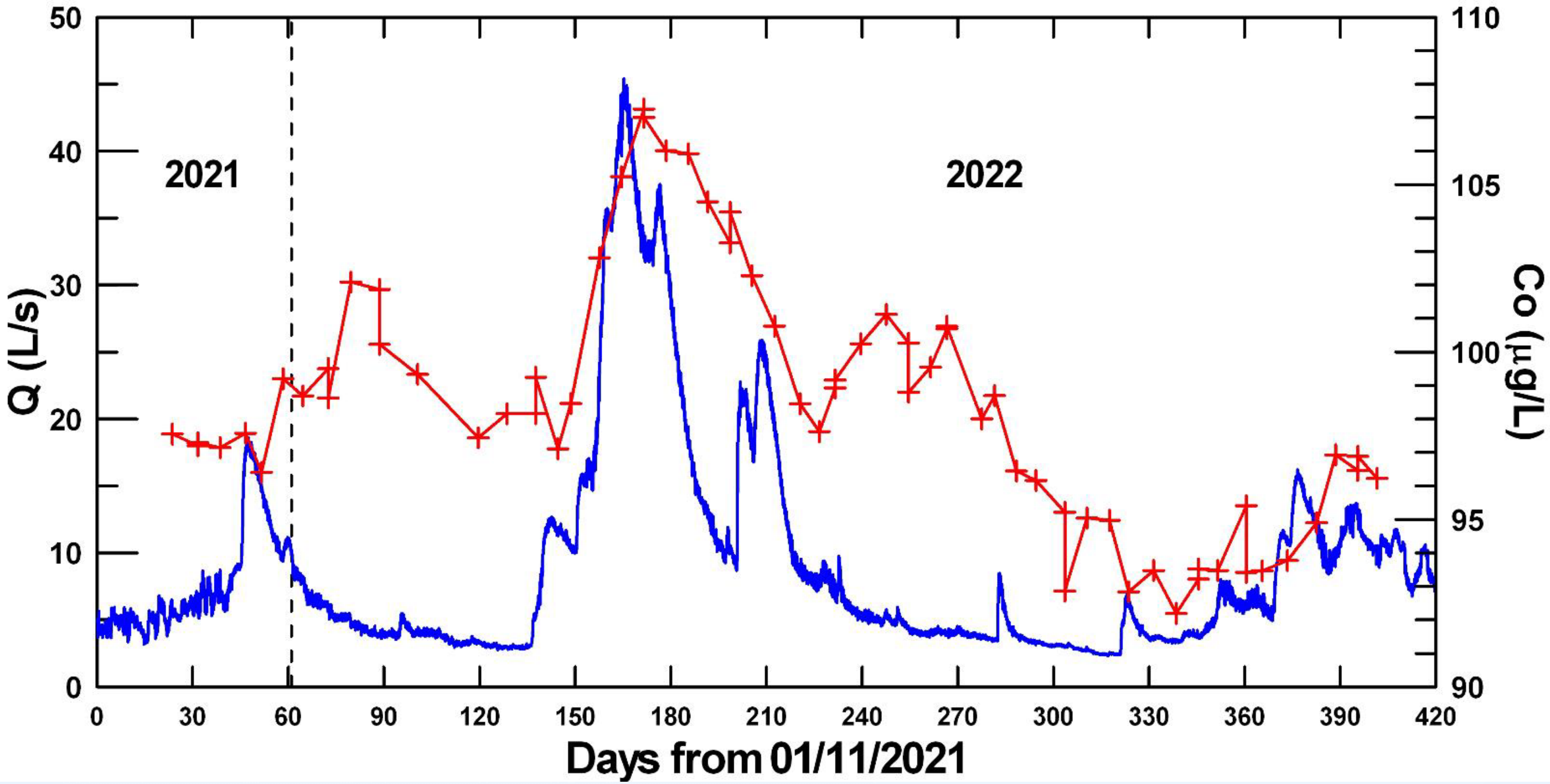
- High-frequency monitoring of flow and chemistry of contaminated mine waters discharging from Shaft #98 in the Cobalt camp – sampling and analyses completed

H-Flume at Shaft #98

Task 1.2: Discharge of metal(loid)-impacted groundwater from mine openings



Task 1.2: Discharge of metal(loid)-impacted groundwater from mine openings



Task 2: Stability of legacy contaminants in wetlands and lake environments (Parsons, lead)

Task 2.1: Sample mine wastes, sediments, and surface waters upstream and downstream of mining-impacted areas to evaluate the concentration and speciation of Ag, As, Co, Hg, Ni, and Sb in pre-mining and near-surface sediments and pore water.

Sediment coring on Lake Timiskaming, ON, downstream of the Cobalt Mining Camp, March 7-11, 2022

Task 2.1 : Stability of legacy contaminants in wetlands and lake environments (continued)

FY 2022-2023 Achievements (Year end):

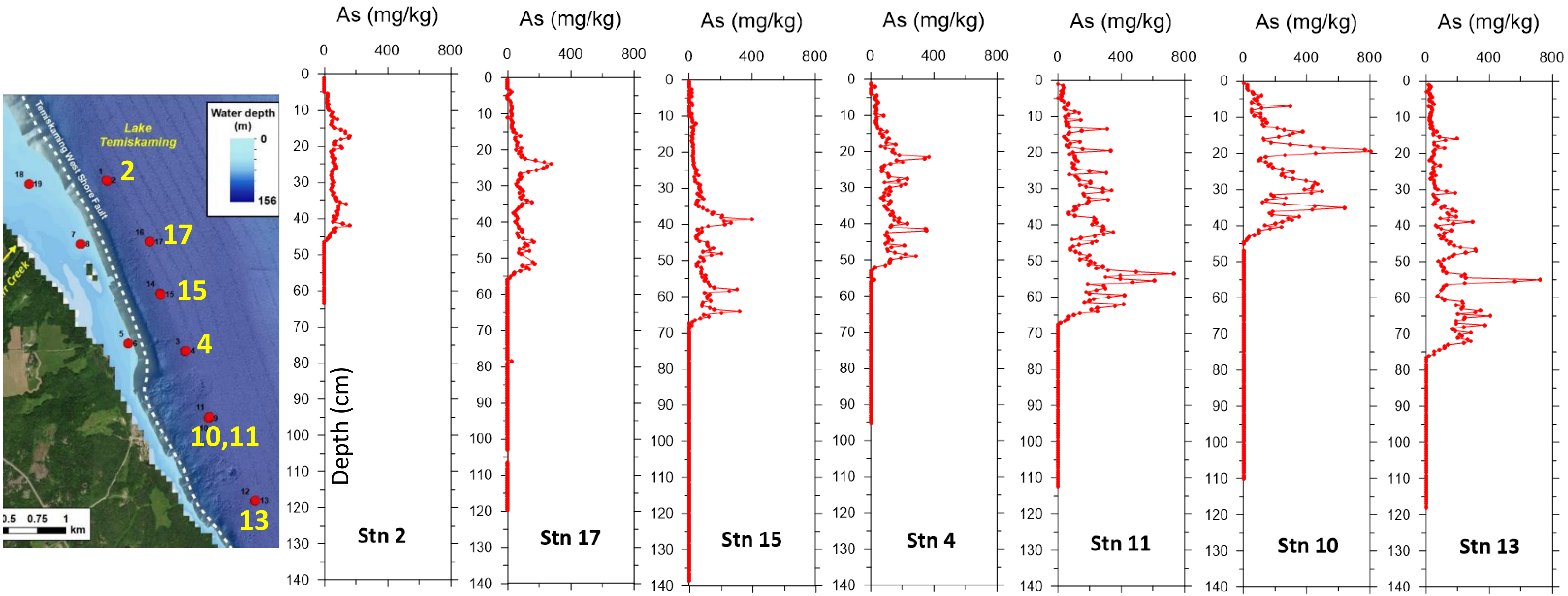
- Geochemical and geochronological analyses completed on cores collected from Lake Timiskaming in March 2022:
  - Nine sediment cores logged at GSC-A and characterized using X-ray Computed Tomography (XCT), high-res photography, spectrophotometry, Multi-Sensor Core Logging (MSCL), and track-mounted portable X-ray fluorescence analysis (pXRF)
  - 400 sediment subsamples dried and submitted to Actlabs for elemental analyses via ICP-MS following aqua regia digestions
  - Subsamples from three cores submitted to INRS for radiometric dating via $^{210}Pb/^{137}Cs$
- Results will be used to assess the pre-mining baseline concentrations of key elements of concern (e.g. arsenic, cobalt) in this part of the lake, the influence of past mining activities, and the extent of post-mining recovery (including the effect of ongoing reclamation activities).

Sediment core logging @ GSC-A

X-ray Computed Tomography analyses of sediment cores @ GSC-A

Arsenic concentrations (via pXRF) in deep-water sediments, Lake Timiskaming, ON

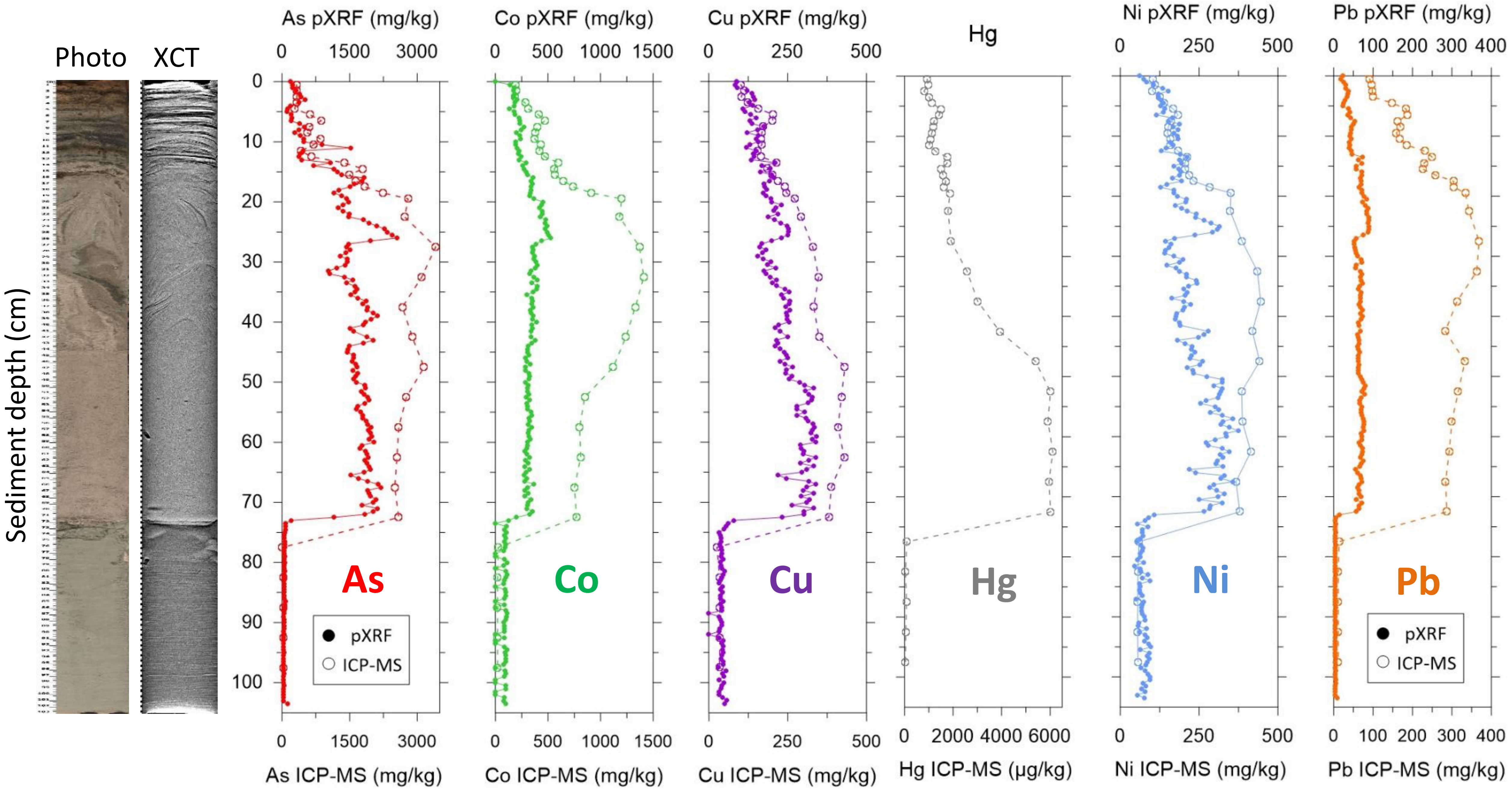
Arsenic profiles in sediment cores show that historical mining impacts extend at least 3 km south from mouth of Farr Creek



Distance from mouth of Farr Creek: 0.94 km | 1.1 km | 1.2 km | 1.7 km | 2.2 km | 2.2 km | 3.0 km

North → **South**

Metal(loid) concentrations in sediments, Station 7/8, Lake Timiskaming, ON



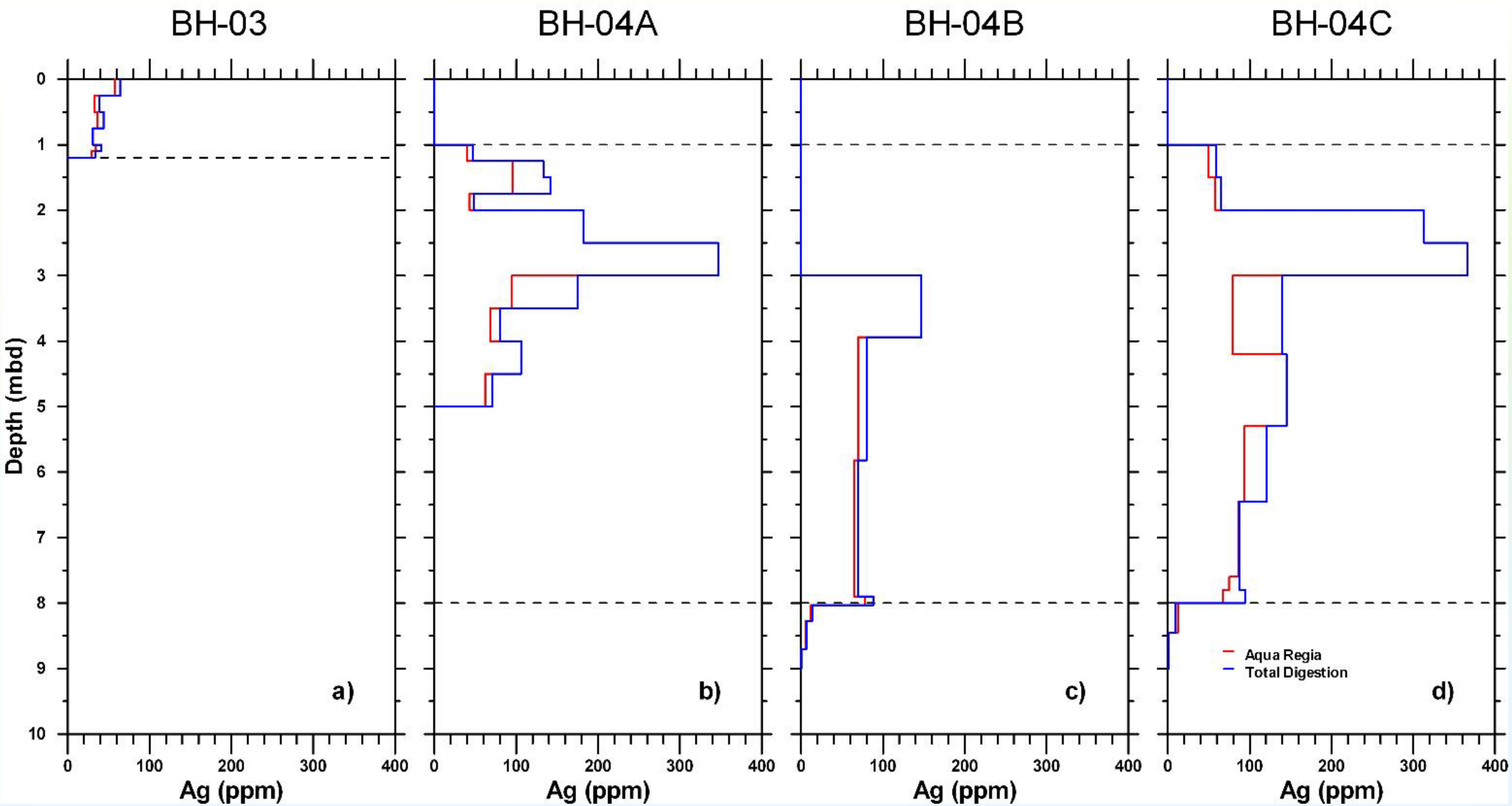
Task 3: Mineralogical characterization of mine wastes and other solid phases (Percival, lead)

Task 3.1: Review and re-analysis of selected archived samples from earlier studies as a platform to define the mineralogical signature for the geoenvironmental ore deposit model.

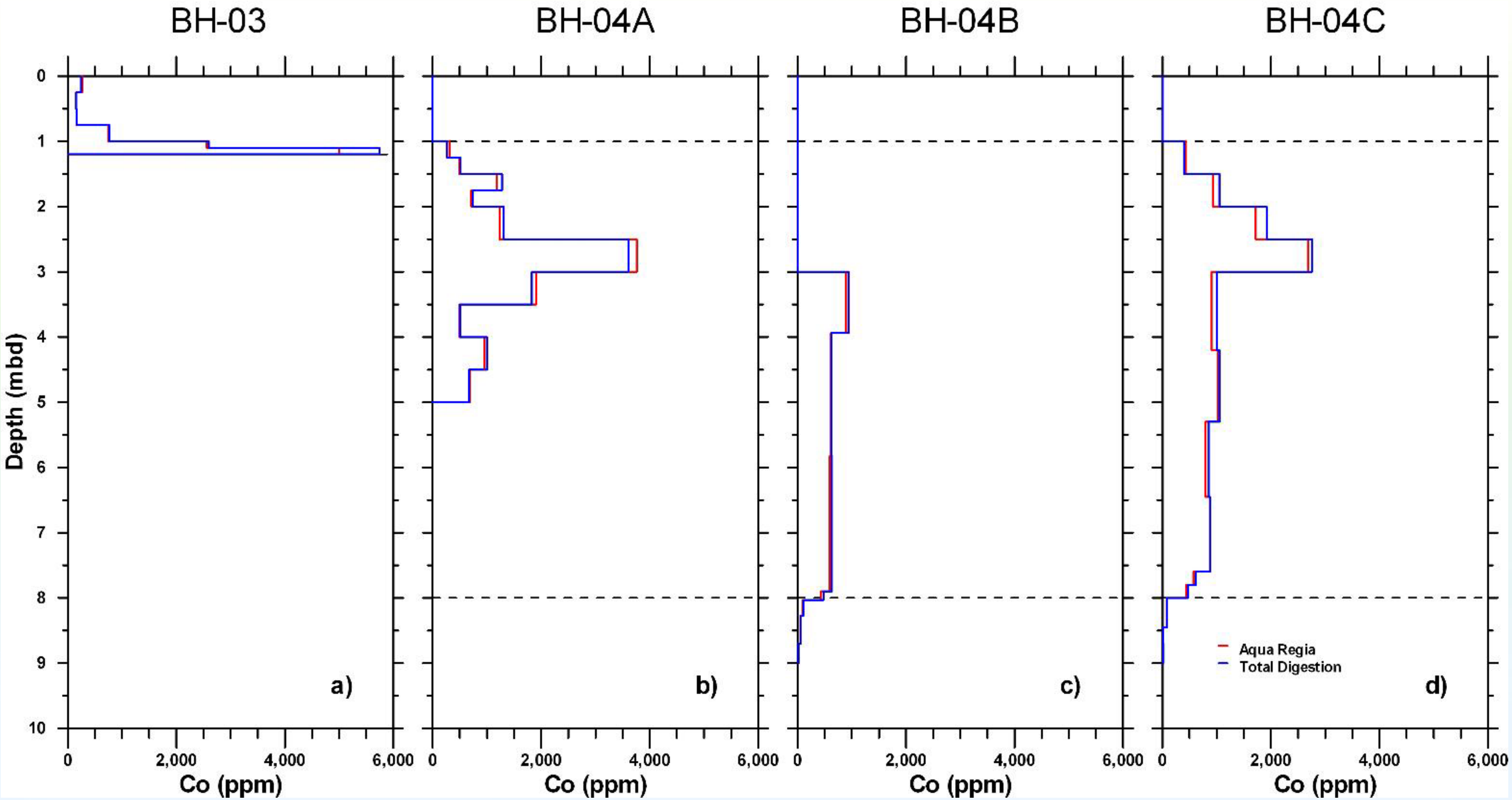
FY 2022-2023 Achievements (Year end):

- Geochemical analyses of Crosswise Lake tailings core samples using Aqua Regia and Total digestions (completed)
- Interpretation of mineralogy (bulk and clay-size fraction) for tailings from Crosswise Lake, Cobalt (in progress)
- TIMA (SEM) study of heavy mineral separates from archived Cobalt Lake cores (in progress)

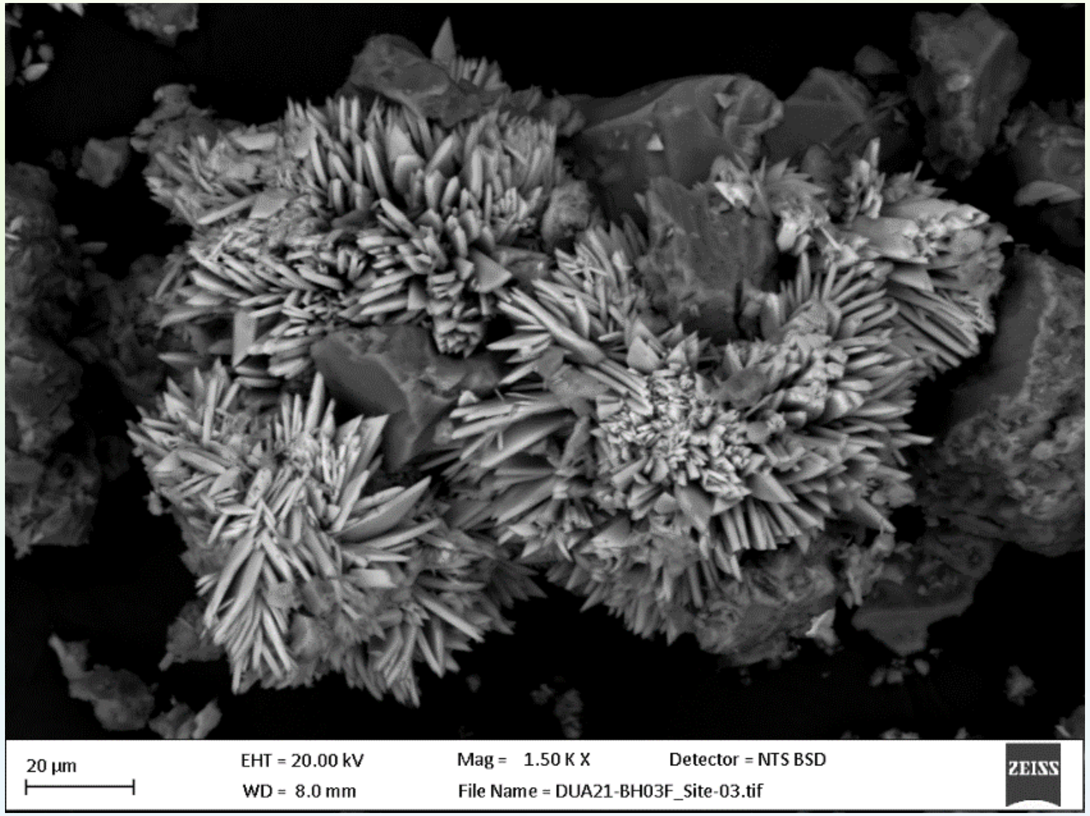
Task 3.1: Geochemical Analyses of Crosswise Lake tailings



Task 3.1: Geochemical Analyses of Crosswise Lake tailings



Task 3.1: Geochemical Analyses of Crosswise Lake tailings



Physical property measurements completed including moisture content and total grain size.

Quantitative and semi-quantitative mineralogical analyses on bulk and clay-size fractions, respectively, in progress in the GSC Mineralogy Lab (MPP).

Example of erythrite (plus plagioclase feldspar) found as a trace phase in the Crosswise Lake core (BH03 - F).

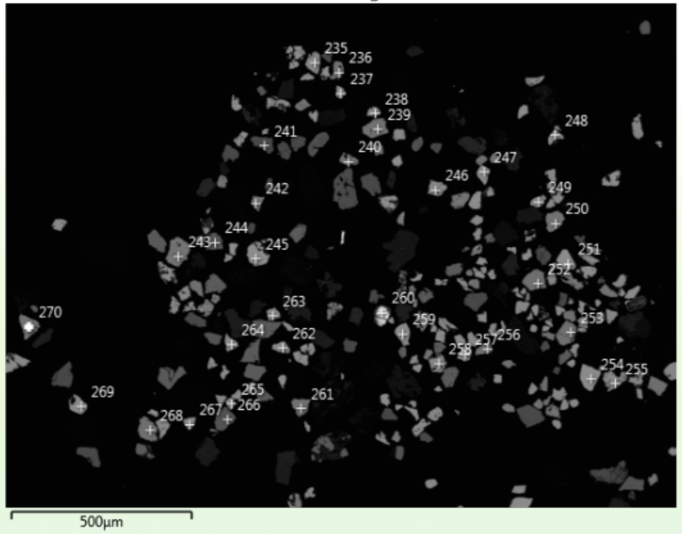
Task 3.1: Mineralogical Analyses of archived core samples
Heavy Mineral Separates

Material collected in 1995 from shallow core (95-C4) from Cobalt Lake, directly west of the high-grade drainage (Nippising Hill). Total depth of core = 4.5 m.

Material was sent to Overburden Drilling Management (Ottawa) to prepare heavy minerals separates to examine the trace mineral content.

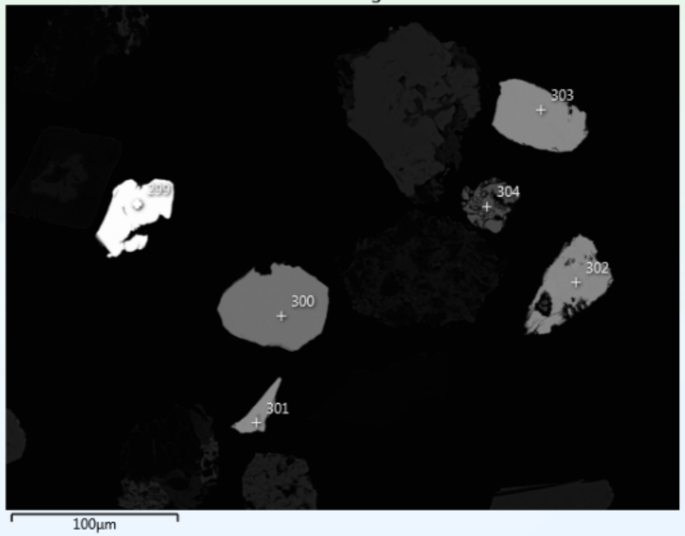
Original mineralogy by XRD for the bulk sample shows:
-abundant chlorite
-abundant to minor plagioclase feldspar
-minor quartz, calcite and erthyrite
-minor to trace illite
-trace amphibole.

Electron Image 17



Numbers represent EDS analyses, FE-SEM.

Electron Image 19



Comprised of native bismuth (bright grain), arsenopyrite (med. grey), erythyrite (with Ni; light grey), pyrite (dark grey) (very dark grey grain not analysed).

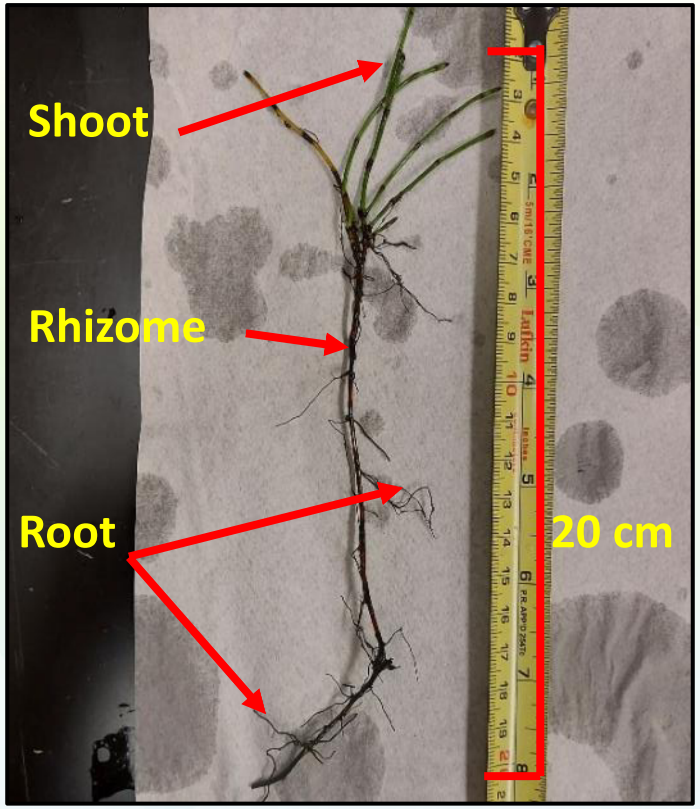
Task 3: Mineralogical characterization of mine wastes and other solid phases (continued)

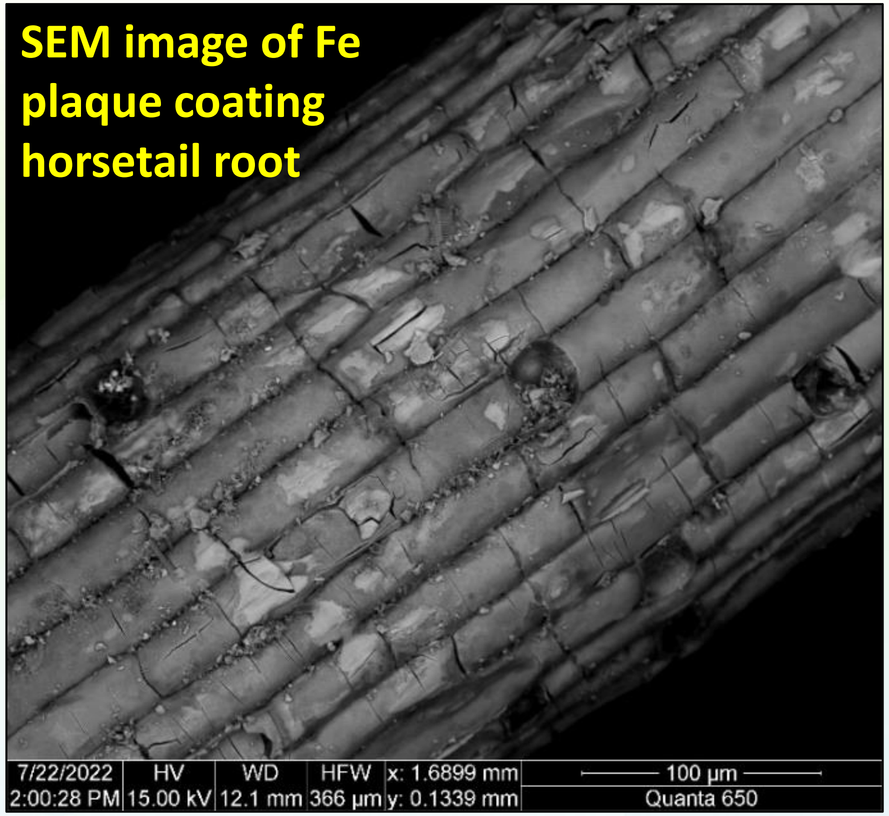
Task 3.3: Micro-mineralogy of primary and secondary As, Co, Ni and Sb phases in high-grade tailings and mill waste to evaluate the solid-phase speciation of these elements and their long-term stability under weathering conditions and remediation scenarios.

FY 2022-2023 Achievements (Year end):

- Queen's University M.Sc. student, Melissa Turcotte (co-supervised by Jamieson and Parsons) successfully defended her M.Sc. thesis on Nov. 9: *Characterization of tailings, sediments, and vegetation and their impact on metal(loid) mobility in the Cobalt Mining Camp, Ontario*, Department of Geological Sciences and Geological Engineering, Queens University, Kingston, ON (available online at http://hdl.handle.net/1974/31326).
- Presentation at the GAC-MAC 2022 conference in Halifax (Turcotte et al.)

Task 3.3: Mineralogical characterization of mine wastes and other solid phases (cont'd)





M.Sc. Study by Queen's M.Sc. Student, Melissa Turcotte, shows that metal(loid) cycling is influenced by horsetails growing in the tailings around Cobalt. Metal(loid)s are concentrated in the roots of horsetails (mainly on oxidized iron plaques) relative to the shoots, making horsetails potentially suitable for phytostabilization of mine wastes.

Task 5: Weathering processes in Cobalt-type Ag-Ni-Co arsenide tailings (T. Al, University of Ottawa, lead)

Task 5.2: Detailed mineralogical investigations of weathering products and laboratory studies of metal(loid) mobilization

FY 2022-2023 Achievements (Year end):

- Completed M.Sc. thesis (Cole Fischer): "Mineralogical and Hydrogeochemical Characterization of Legacy Mine Wastes near Cobalt, ON"
- Conference presentation: "Geochemical and mineralogical investigations of tailings and smelter waste from abandoned gold, silver and niobium mines in Ontario and Quebec" GAC-MAC-IAH-CNC-CSPG Annual Meeting, Halifax, NS, May 15-18, 2022; Al, T., Balkwill-Tweedie, H., Sapkota, B., Fisher, C., Desbarats, A., Percival, J., Fortin, D.

Cart Lake tailings

CONTACT INFORMATION

- Project leader: Alexandre Desbarats
- 343-548-5571
- alexandre.desbarats@nrcan-rncan.gc.ca

THANK YOU!

Ressources naturelles Canada | Natural Resources Canada




Long-term hydrological dynamics of Canada's largest watershed: The Mackenzie River Basin

Dynamique hydrologique à long terme du plus grand basin versant du Canada: le basin du fleuve Mackenzie

Canada gwizhìt chuu tł'it gwiinchii goo'aii gwats'àt chuu niinlaii nits'òo gwizhìt goo'aii k'iighè' nikhwinagoo'ee yeendoo nits'òo gwihee'ah: Nagwichoo Njik Gwizhìt Khehłat Niinlaii

Jennifer Galloway and team

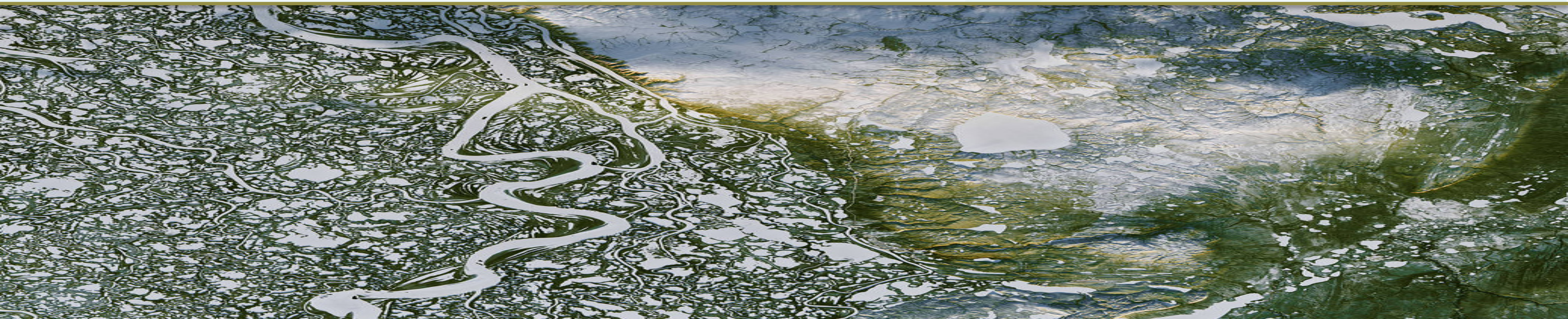
May 2023

Canada

ABSTRACT

- The Mackenzie River (*Deh-Cho, Kuukpak, Fleuve de Mackenzie*) Basin (MRB) is one of the World's largest (4200 km long) and most important freshwater ecosystems
- Climate change is disproportionately affecting high northern latitudes
- How will climate change affect water quantity in the MRB?
- This project will examine long-term trends and cycles to develop predictive ecohydrological models

NASA Earth Observatory Joshua Stevens. LandSAT82 2016 data from USGS



PROJECT MEMBERS

Galloway, Jennifer (GSC-C) (lead, ArcticNet PI)
Lord, Sarah (Gwich'in Renewable Resources Board, now DFO)
Snowshoe, Sharon (Gwich'in Tribal Council, Dept. of Cultural Heritage)
Lantz, Trevor (University of Victoria) (ArcticNet NI)
Shotyk, William (University of Alberta) (ArcticNet NI)
Patterson, R. Tim (Carleton University) (ArcticNet NI)
Andrii Oleksandrenko (PhD) (U of Alberta) (Shotyk)
Anne Nguyen (PhD) (Carleton U) (Patterson, Galloway)
Hadlari, Thomas (GSC-C)
Ardakani, Omid (GSC-C)
Morse, Peter (GSC-N)
Parsons, Michael (GSC-A)
Colmenares, Jaime Rafael Cesar (GSC-C)
Falck, Hendrik (GNWT)
Swindles, Graeme (Queen's University, Belfast)
Gałka, Mariusz (University of Łodz)
Clarke, Leon (Manchester Metropolitan University) (NERC PI)

Funding: GSC's Environmental Geoscience Project, ArcticNet (Project #51) (FY 19-20 to 22-23; Galloway), NERC (Clarke), Gwich'in Renewable Resources Board (Lord) and Gwich'in Tribal Council, Department of Cultural Heritage (Snowshoe)

This research occurs under NWT Science License #16737

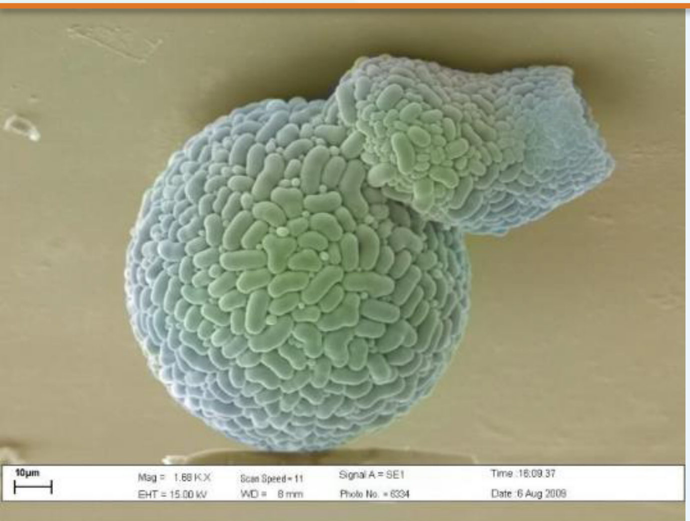
PROGRESS TO DATE

- 11 peat cores collected and sub-sampled for various analyses
- 100 vegetation samples and depth to water table measurements from 8 sites within and outside of the Gwich'in Settlement Area (Nguyen et al., 2023)
- Analysis of samples for sequential pyrolysis, Hg, inorganic geochemistry, age dating, stable isotopes, and paleontology (testate amoebae, charcoal, plant remains)
- Traditional Knowledge study based on synthesis of previously documented knowledge related to water levels in the Gwich'in Settlement Area (synthesized semi-structured interviews exploring hydrological dynamics in the Gwich'in Settlement Area; compilation of the Department of Cultural Heritage's archives for information on changing water level and the cultural significance of regional waterways) (lead Snowshoe & Lantz)

TO

- Reconstruct depth-to-water table (quantitative), fire and vegetation history, chemical change, hydrological change, and synoptic-scale climate patterns (e.g., Pacific Decadal Oscillation) over millennia, that may drive future water quantity and quality change in the MRB

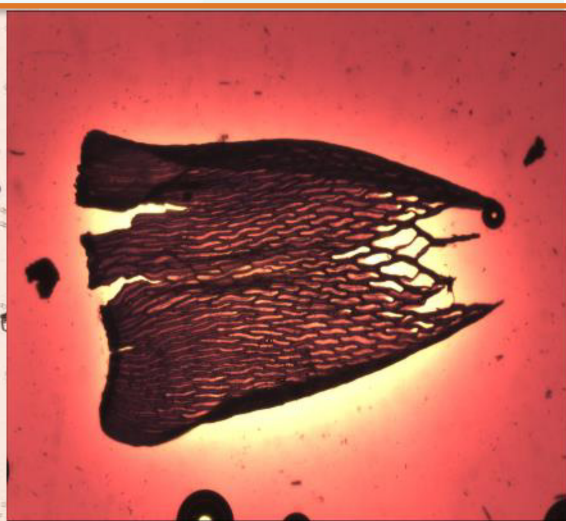
Lesquereusia epistomium survives peat fires (credit: Yuri Mazei)



Picea (spruce) pollen (~125 µm) (credit: Neotoma database)

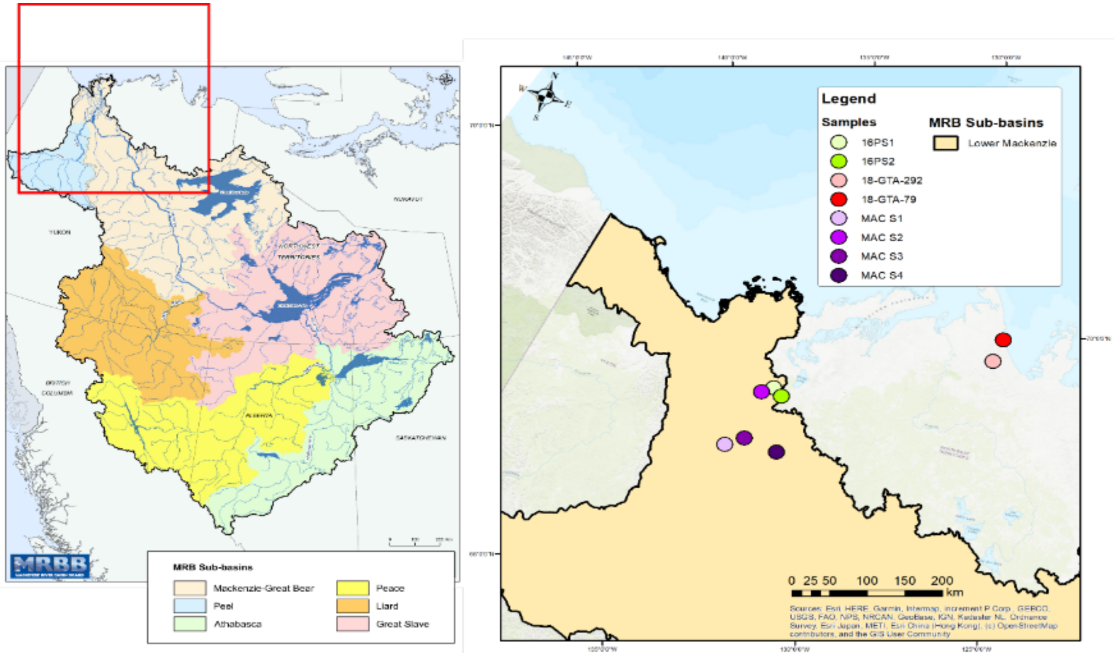
Microscopic charcoal (credit: Mathewes et al. 2019 Vegetation History and Archaeobotany)

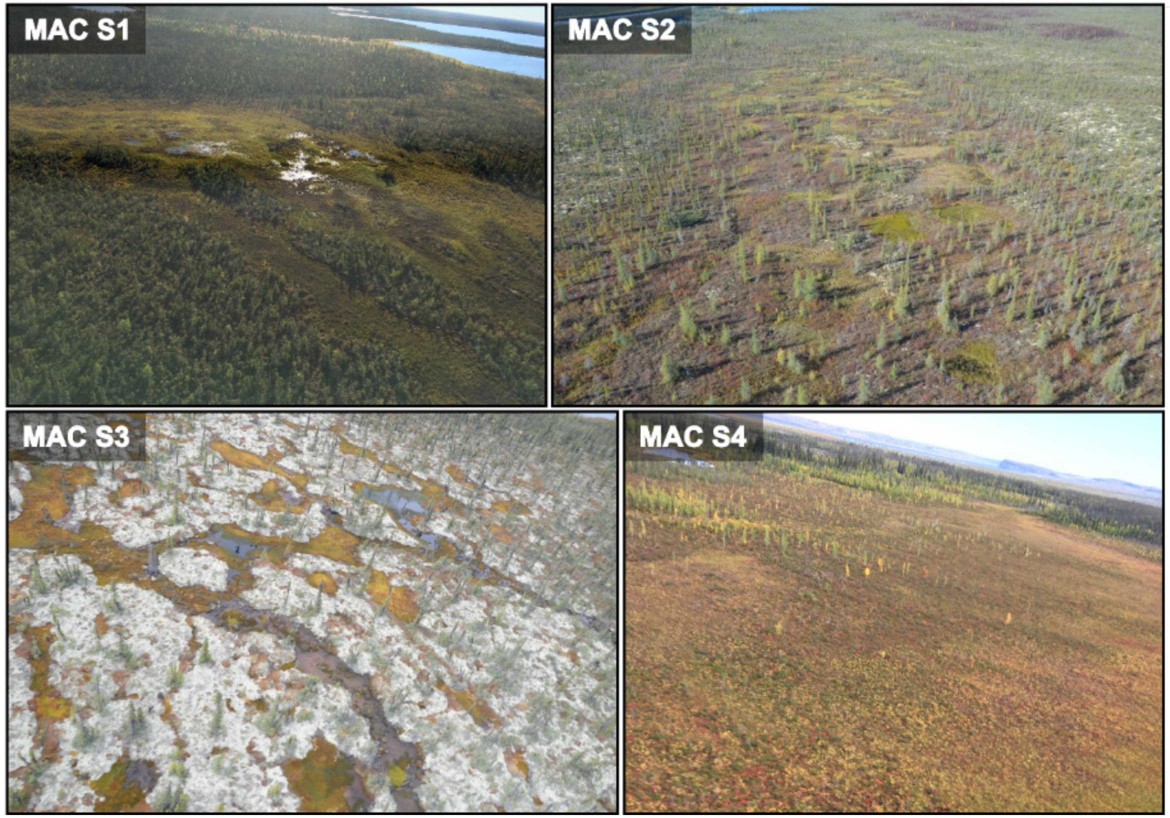
Sphagnum riparium (credit: Mariusz Gałka)



Peat cores

11 peat cores collected from within (*n*=6) and outside (*n*=2) of the Gwich'in Settlement Area (GSA); 8 are being used for the study; and of these, 4 "MAC" cores collected with purpose-built titanium coring device by the Gwich'in Renewable Resources Board are being used for detailed study. This presentation will focus on results from the MAC cores.



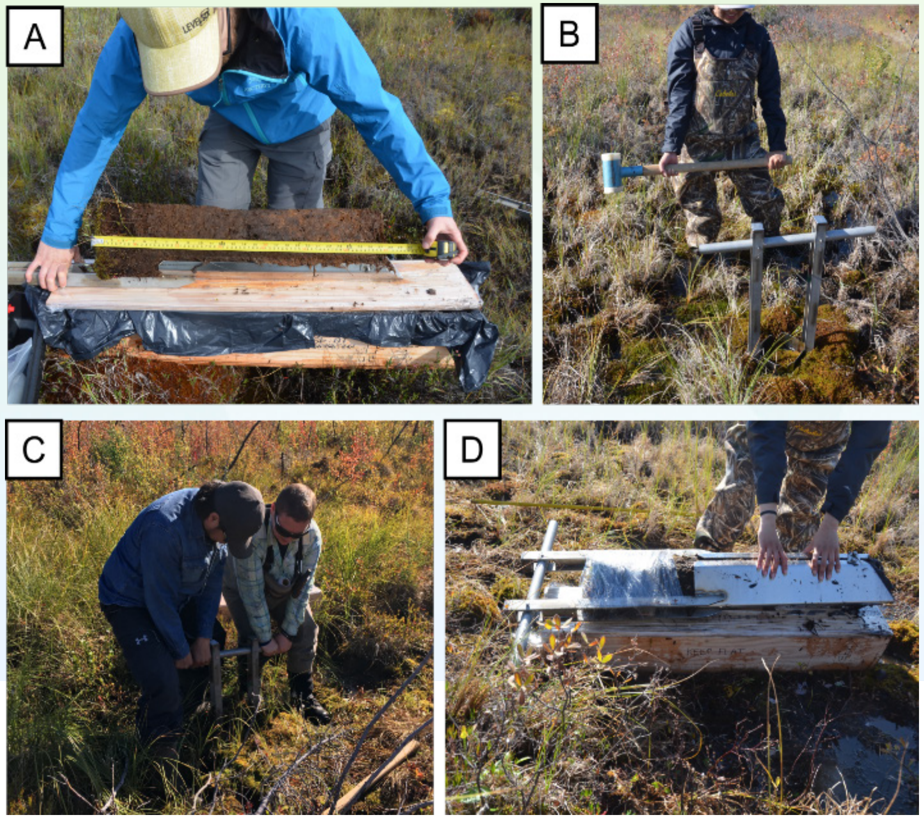


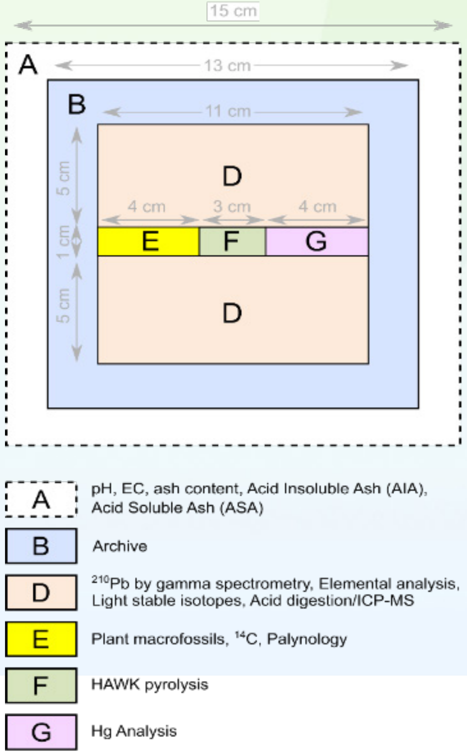
(L) Map of the MRB and peat core locations. The red box outlines the map boundary on the right. Modified from MRBB and EETSD, 2017. (R) site photos of MAC S1 – Mackenzie Site 1; MAC S2 – Mackenzie Site 2; MAC S3 – Mackenzie Site 3; MAC S4 – Mackenzie Site 4; photo credits S. Lord (2020)

Peat cores

(R) Site photos from the collection of the MAC cores by the Gwich'in Renewable Resources Board team in 2020. A) Steve Anderson measuring Site 1 Core 1, B) Julienne Chipesia using the titanium corer, C) Sarah Lord and Jason Blake McLeod using the titanium corer, D) Julienne Chipesia extracting Site 2 Core 1. Photo credits: S. Lord, 2020.

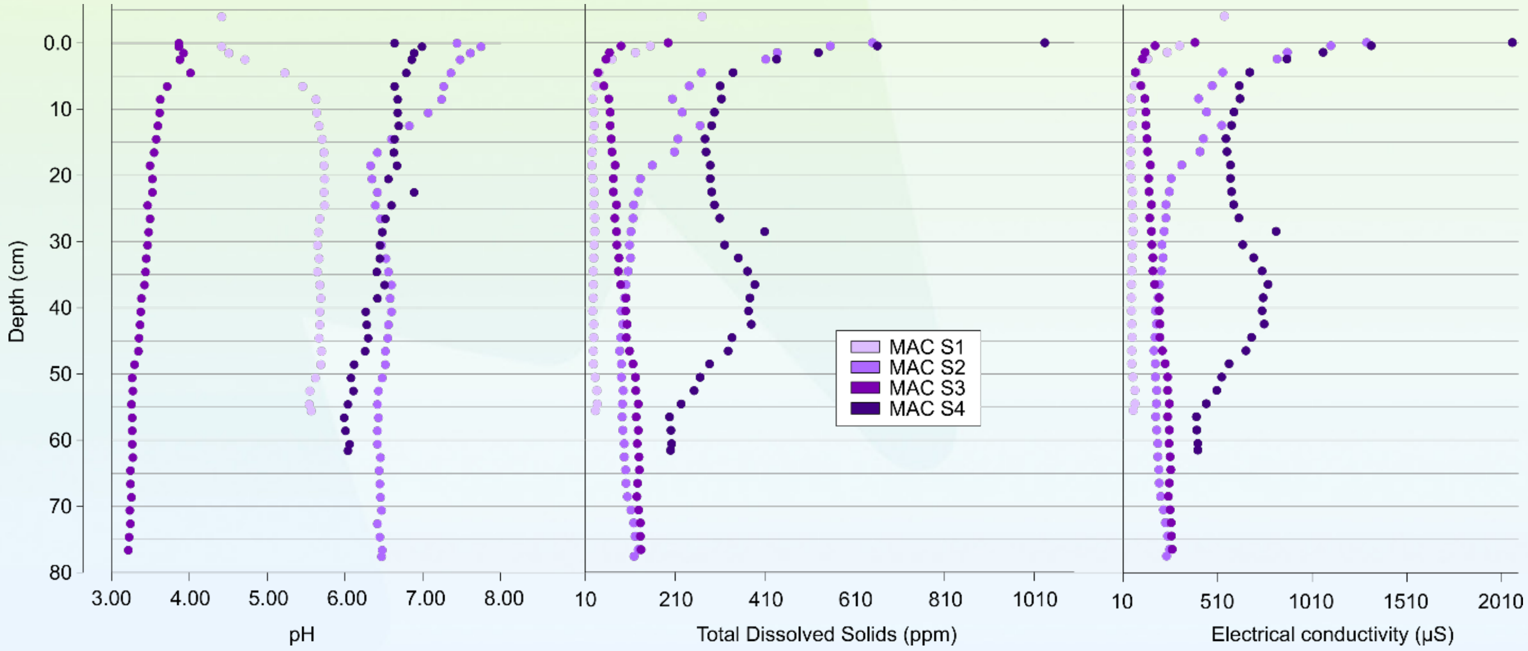
(L) Slicing and sub-sampling protocol devised by the SWAMP laboratory, University of Alberta for MAC cores sliced at 1-cm intervals and showing division of living layer from peat. Photo credit: A. Oleksandrenko, 2020, University of Alberta.



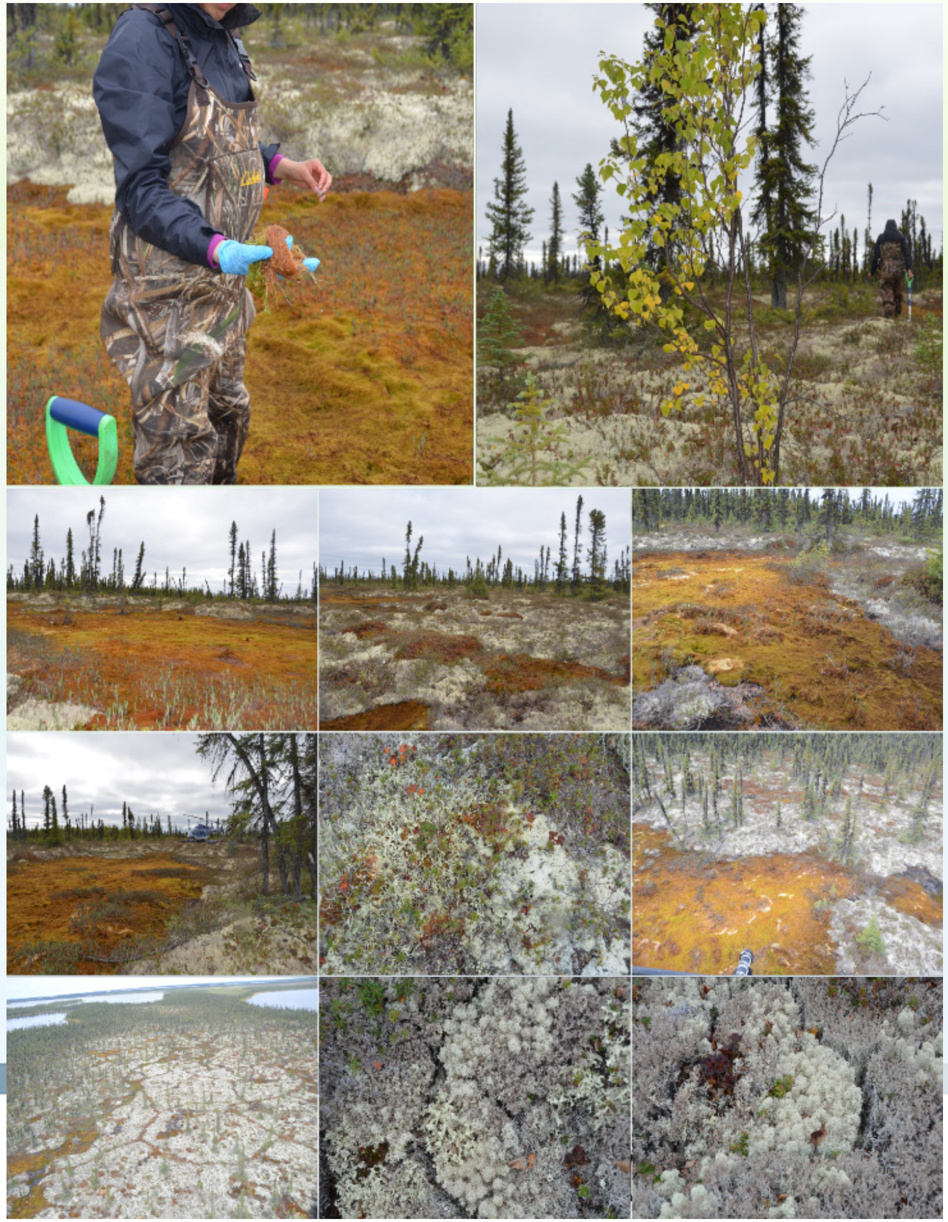


Peat cores

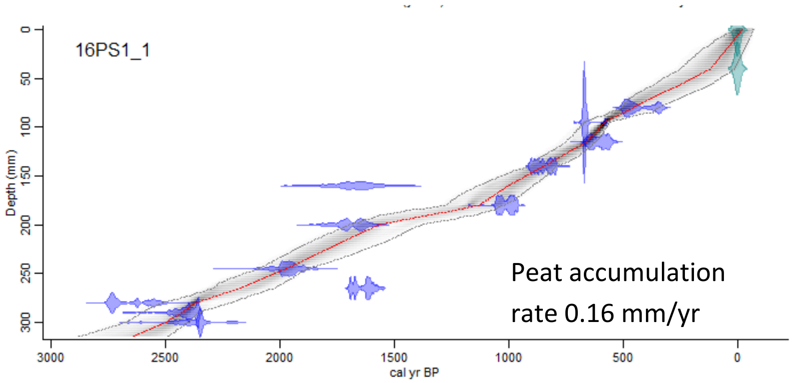
The MAC S3 peatland is ombrotrophic (pH < 4). This environment is ideal for reconstruction of atmospheric metal accumulation; other sites received input from connected surface waters and/or groundwater.

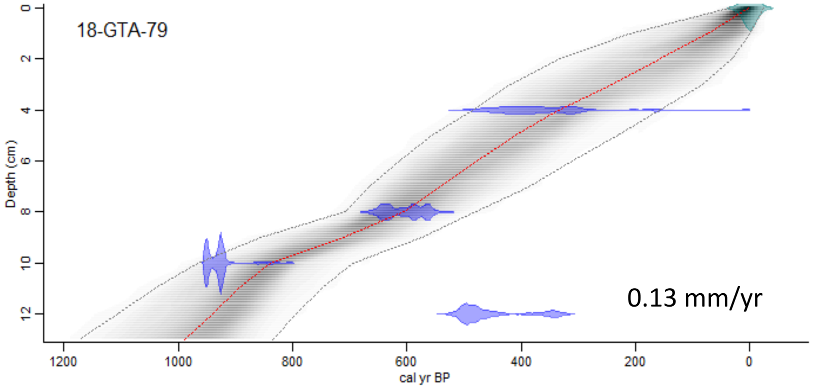


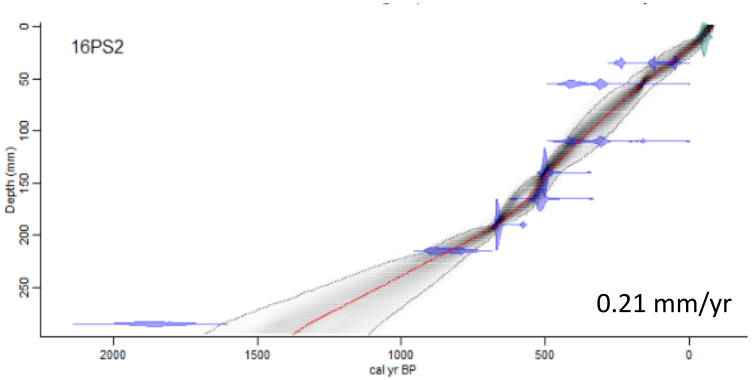
MAC S3 surface moss, vegetation, and depth to water table measurements. Photo credits: S. Lord, Gwich'in Renewable Resources Board, 2020. From Nguyen et al. (2023)

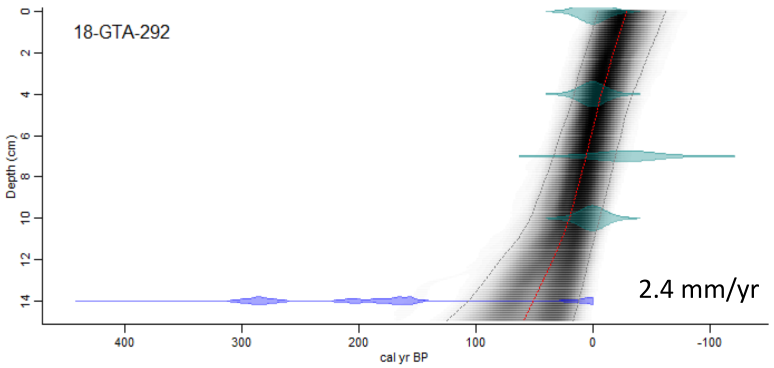


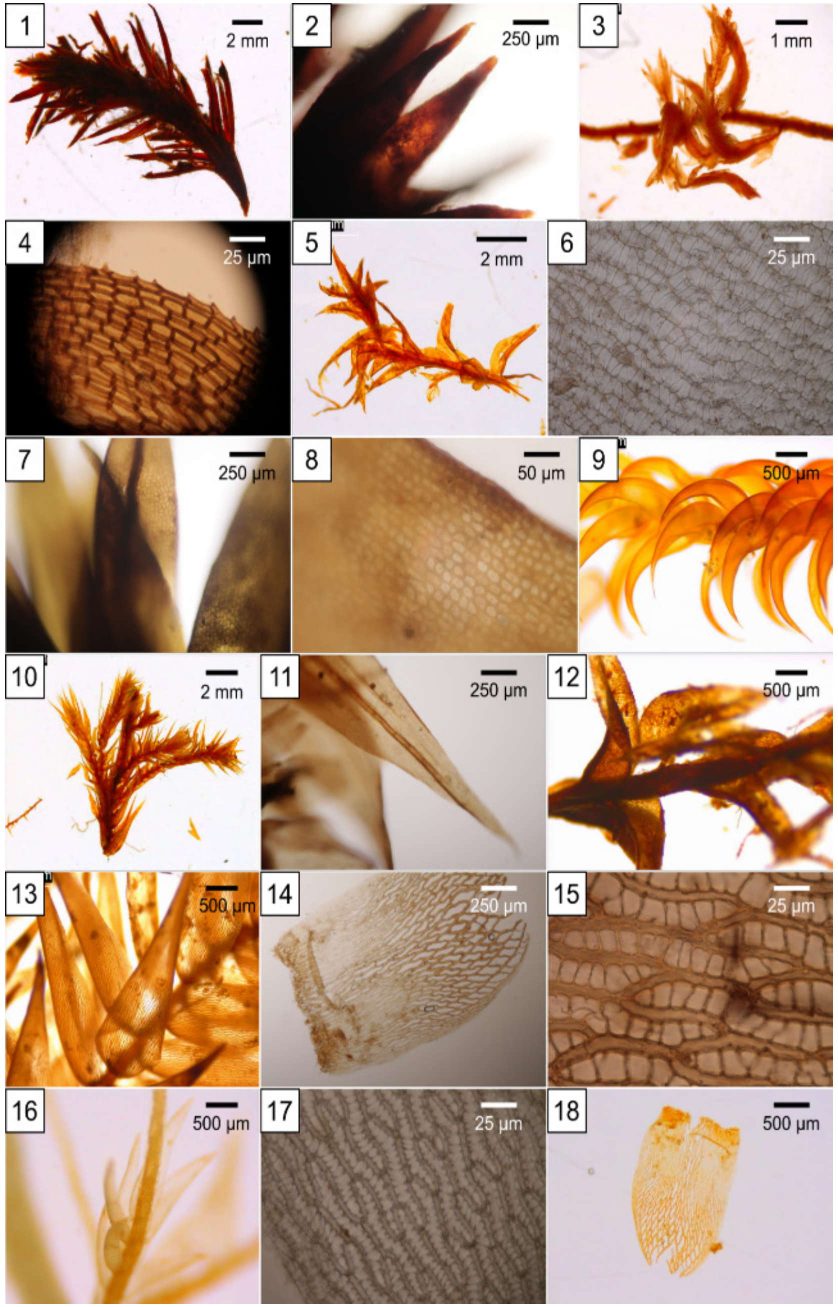
Chronologies





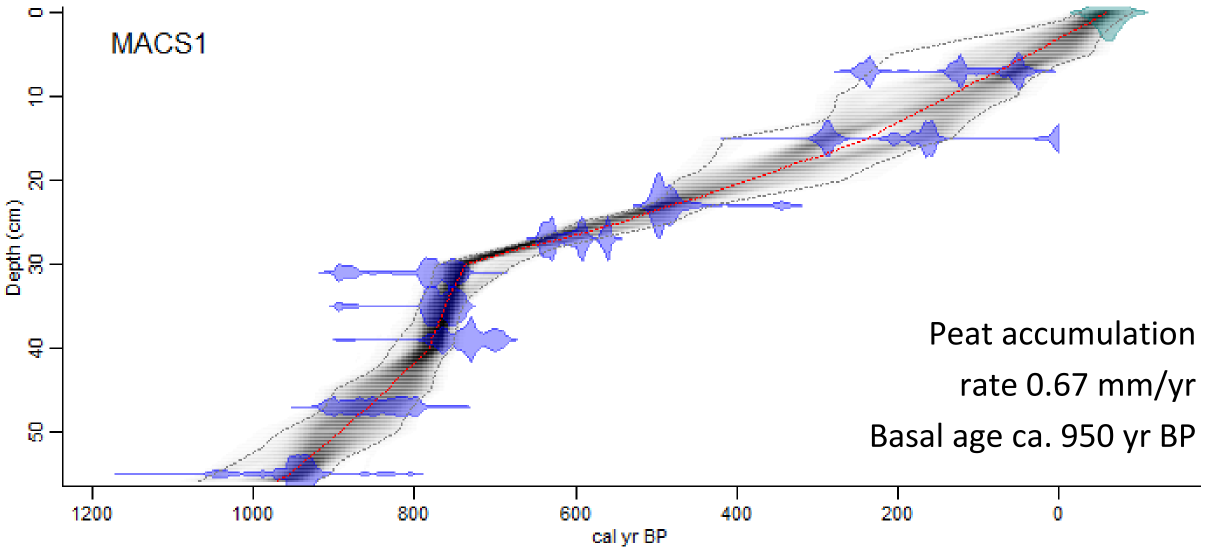


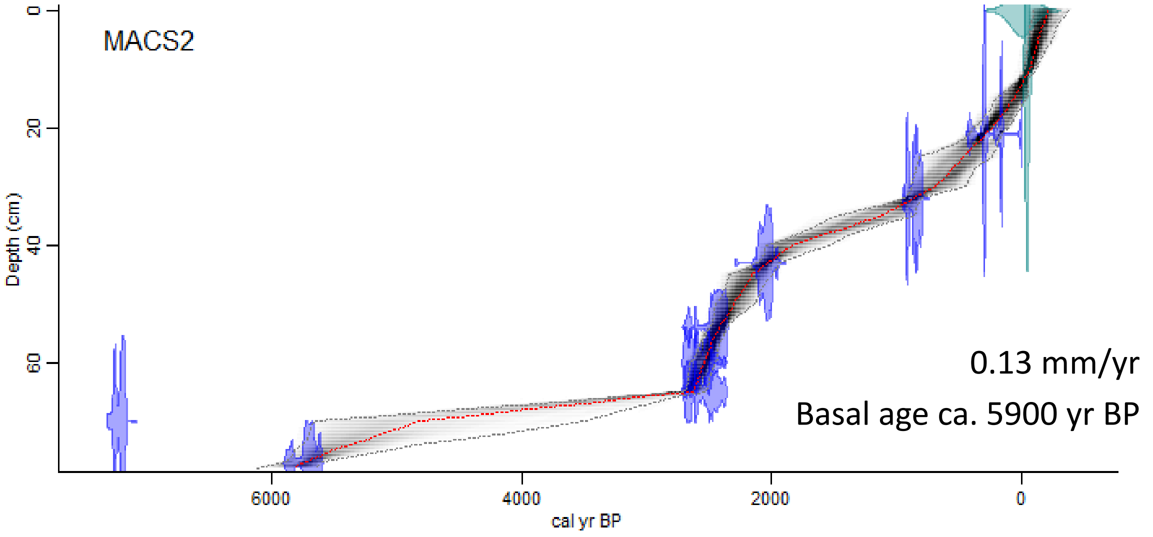


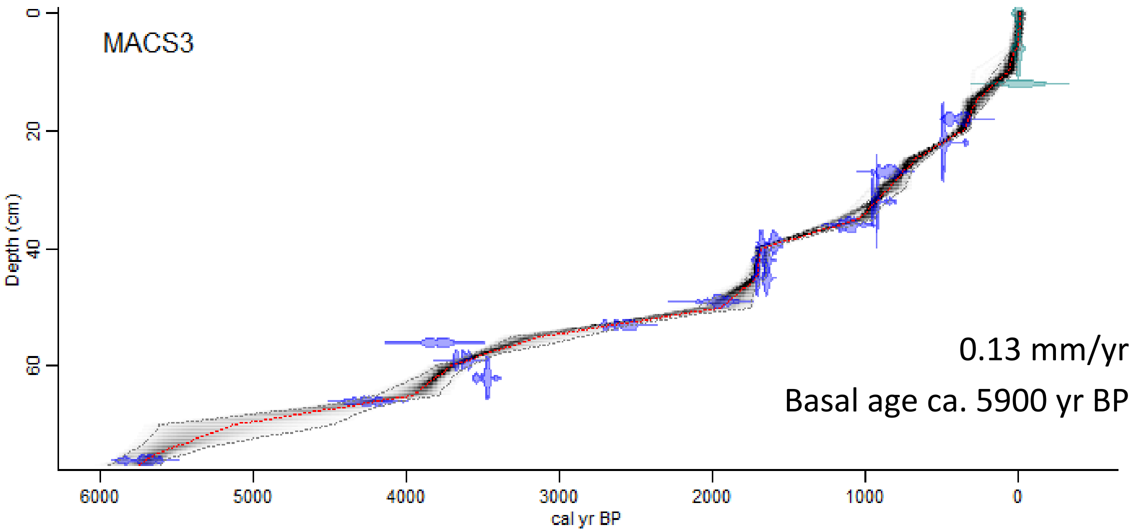


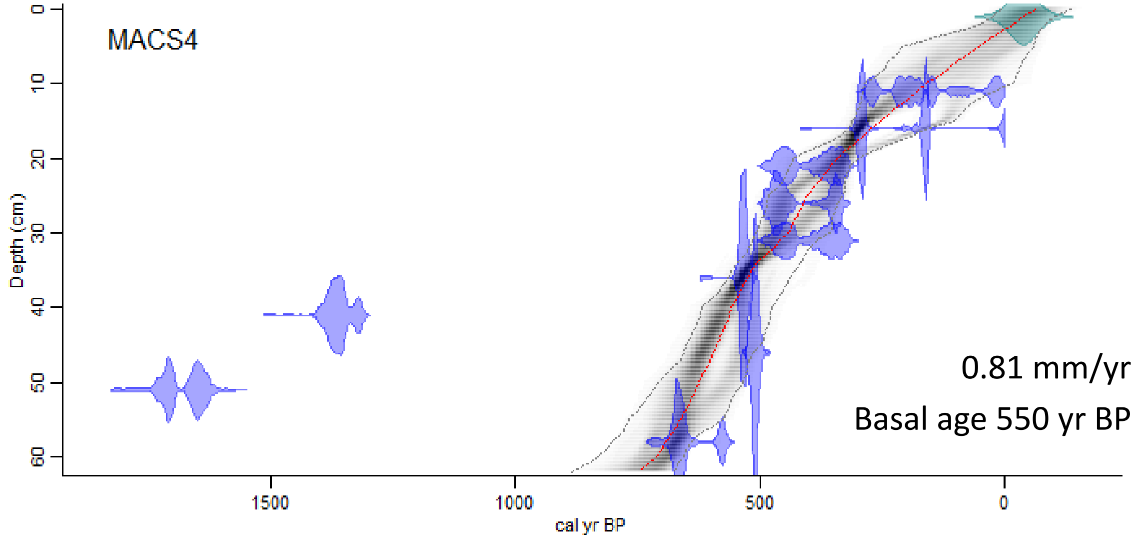
Representative plant macrofossils from each peat core/monolith that were selected for AMS ^{14}C dating. 1) 16PS1 0-5 mm – *Dicranum*? sp.; 2) 16PS1 80-85 mm – *Dicranum*? sp.; 3) 16PS2 55-60 mm – *Sphagnum* sect. *Acutifolia*; 4) 18-GTA-79 4-5cm – *Meesia triquetra*; 5) 18-GTA-79 4-5 cm – *Meesia triquetra*; 6) 16PS2 285-290 mm – leaf cells of *Sphagnum* sect. *Acutifolia*; 7) 18-GTA-79 12-13 cm – *Aulacomnium palustre*; 8) 18-GTA-79 12-13 cm – characteristic leaf cells of *Aulacomnium palustre*; 9) MAC S3 2E 0-1 cm – *Scorpidium* sp.; 10) 18-GTA-292 0-1 cm – *Tomentypnum nitens*; 11) 18-GTA-292 0-1cm – *Tomentypnum nitens*; 12) MAC S4 3E 1-2 cm – *Meesia triquetra*; 13) MAC S1 57E 55-56 cm – *Sphagnum lindbergii*; 14) MAC S1 57E 55-56 cm – stem leaf of *Sphagnum lindbergii*; 15) MAC S1 57E 55-56 cm – leaf cells of *Sphagnum lindbergii*; 16) MAC S3 2E 0-1 cm – *Sphagnum balticum*; 17) MAC S3 2E 0-1 cm – leaf cells of *Sphagnum balticum*; 18) MAC S3 8E 6-7 cm – stem leaf of *Sphagnum riparium*.

MAC core chronologies









Geochemistry – Sr, Y, Pb

Sr –soluble, so the groundwater is “full of” Sr, particularly in areas with carbonate bedrock

Used as an indicator of a groundwater input

Y – conservative lithophile element, relatively insoluable after weathering, commonly forms new minerals

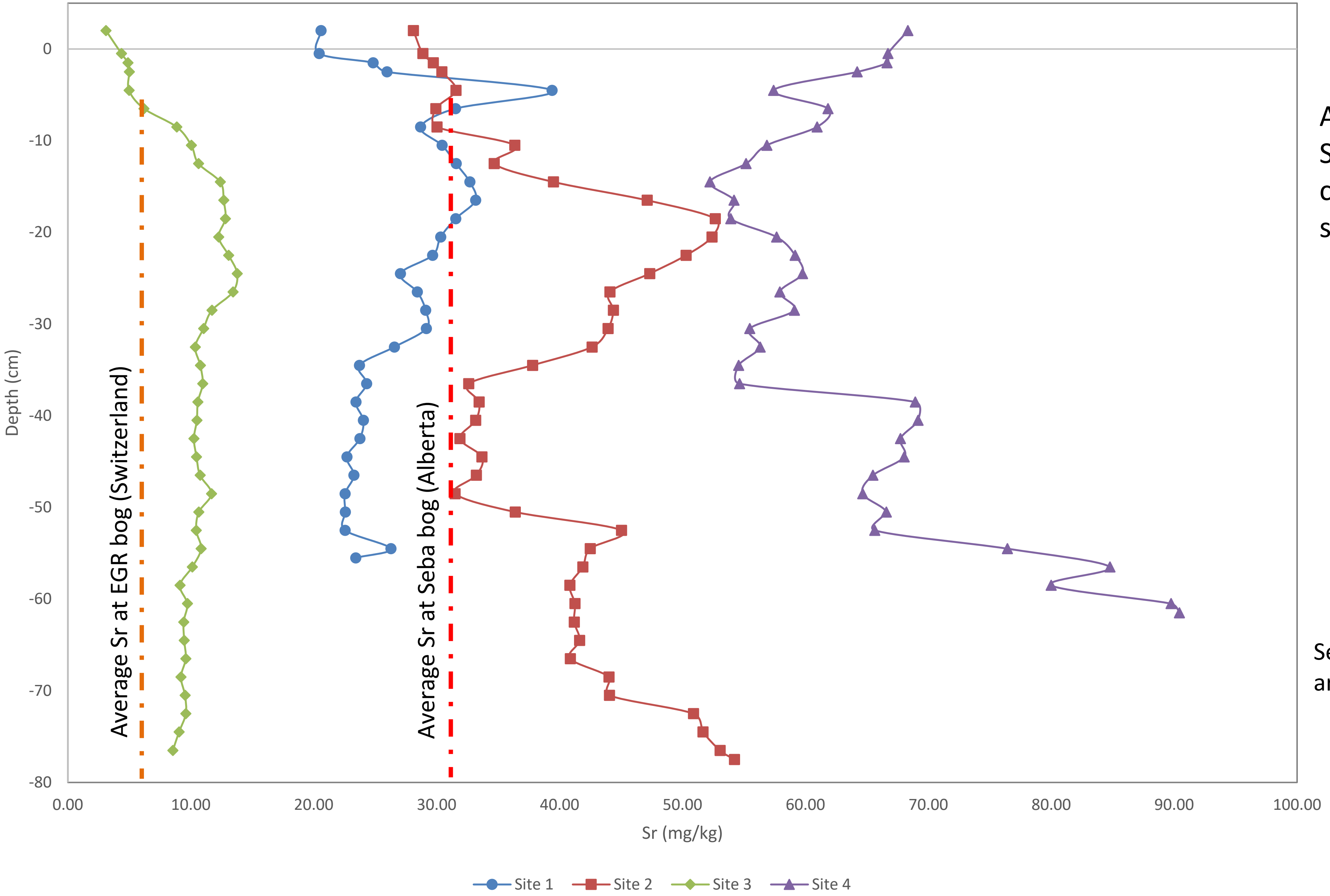
Used as an indicator of a mineral matter input (dust)

Sr/Y ratio used as an indicator of groundwater vs. dust input

Pb – in this study is considered as an anthropogenic trace element

Used as an indicator of atmospheric anthropogenic input (especially in the case of MACS3, the ombrotrophic bog)

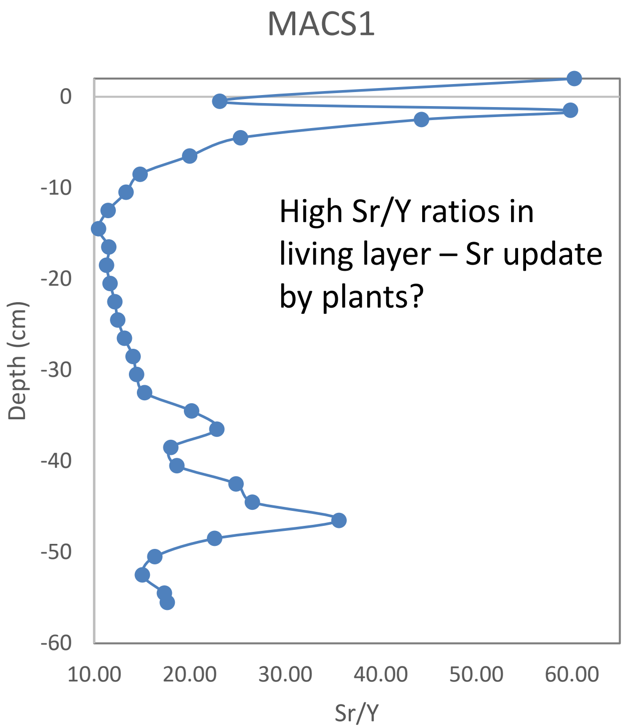
Strontium (groundwater)

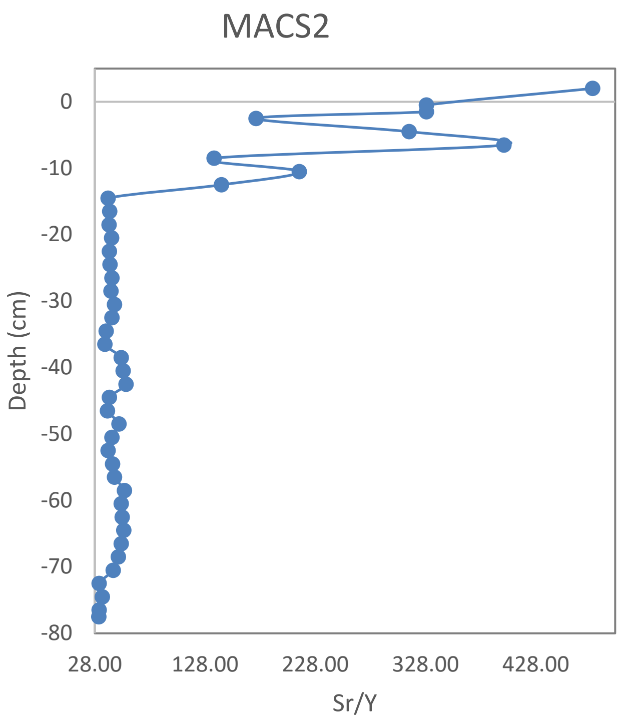


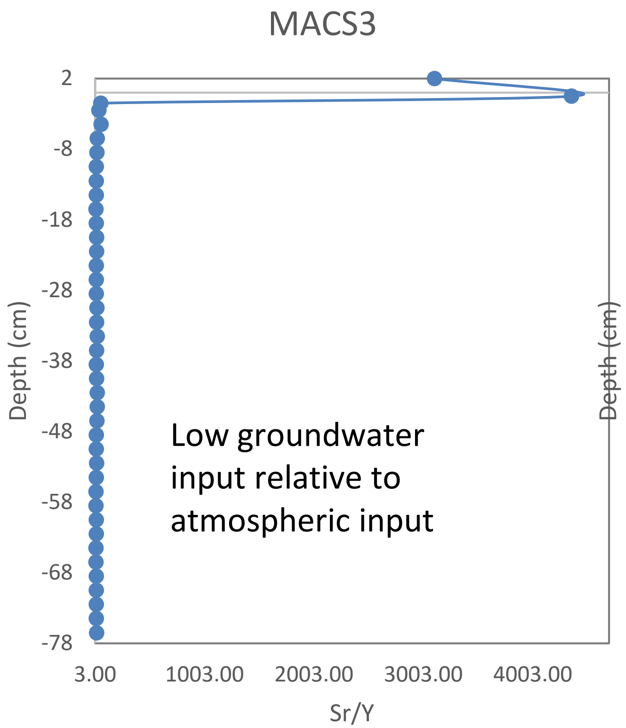
As expected, ombrotrophic MAC S3 shows lower Sr concentrations than the other sites

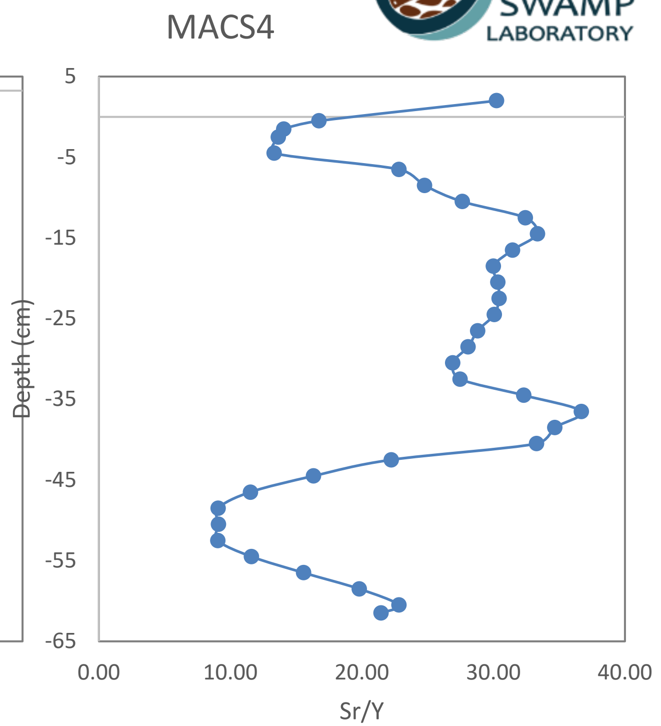
Seba Bog and EGR (Etane de la Gruère) Bog are two “reference” sites (Shotyk 2020)

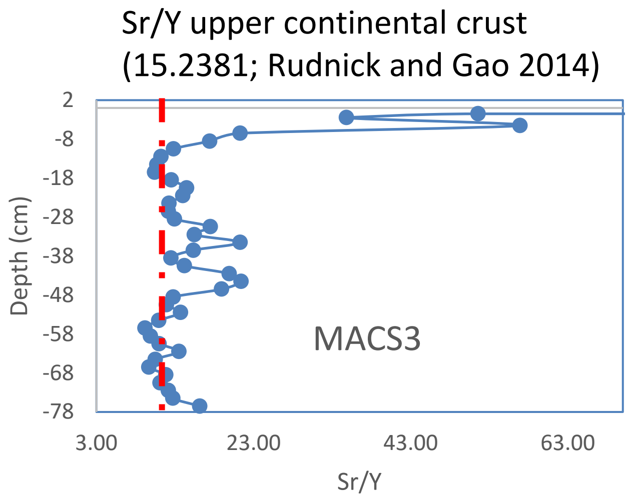
Sr/Y ratios (groundwater vs. atmospheric dust)



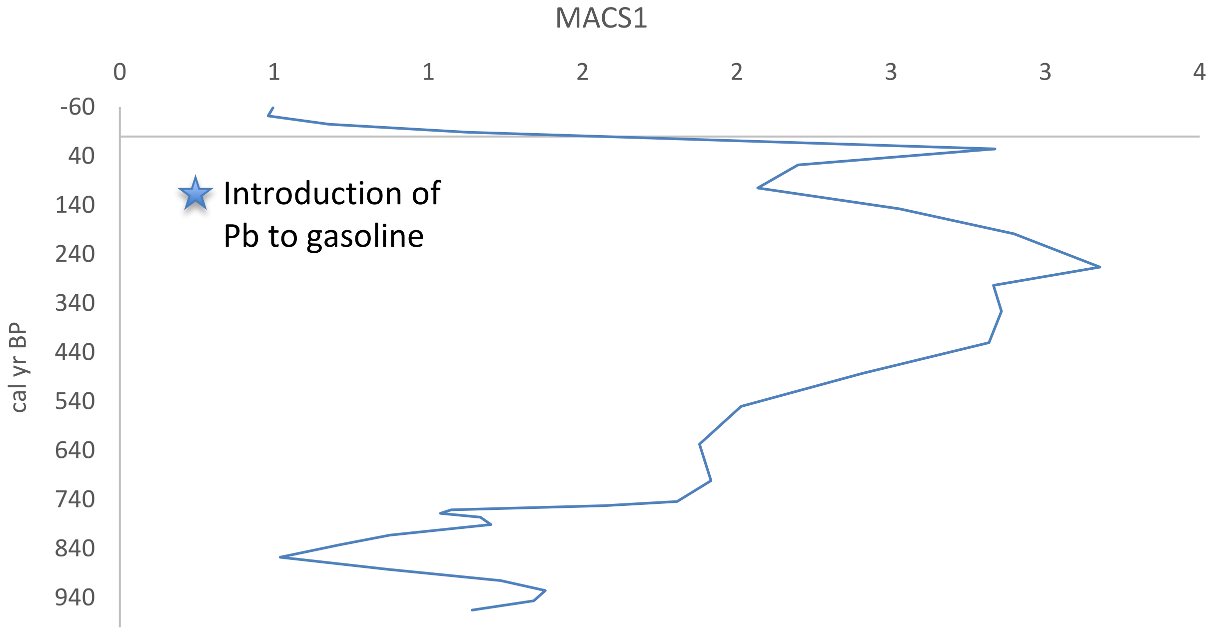


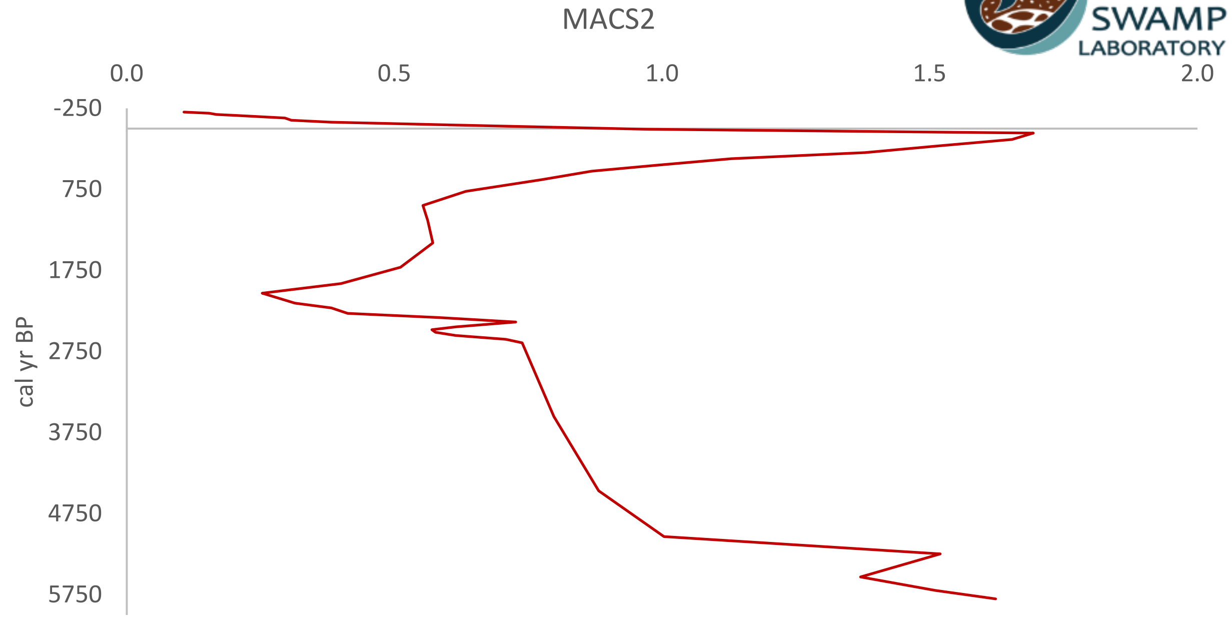


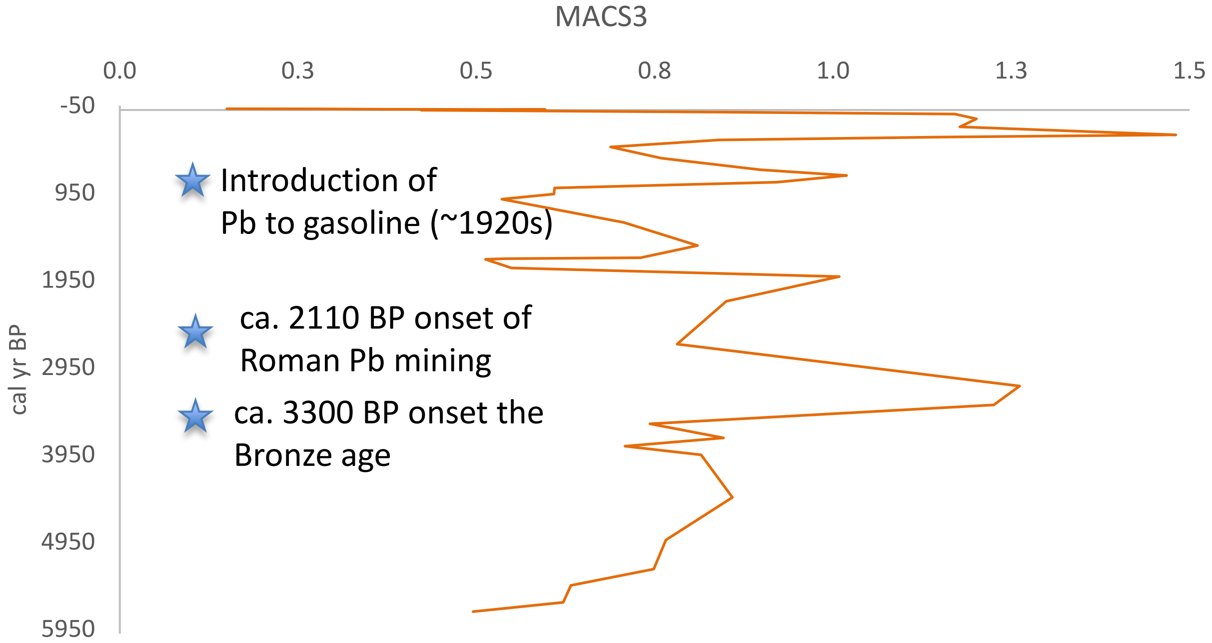


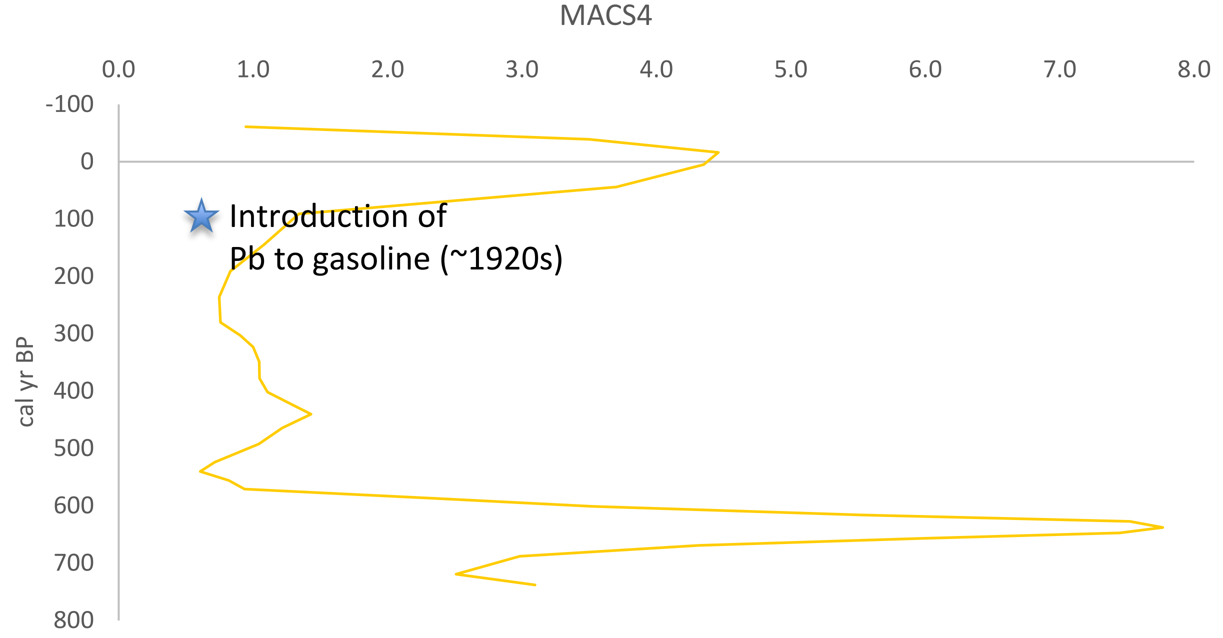


Lead (atmospheric)









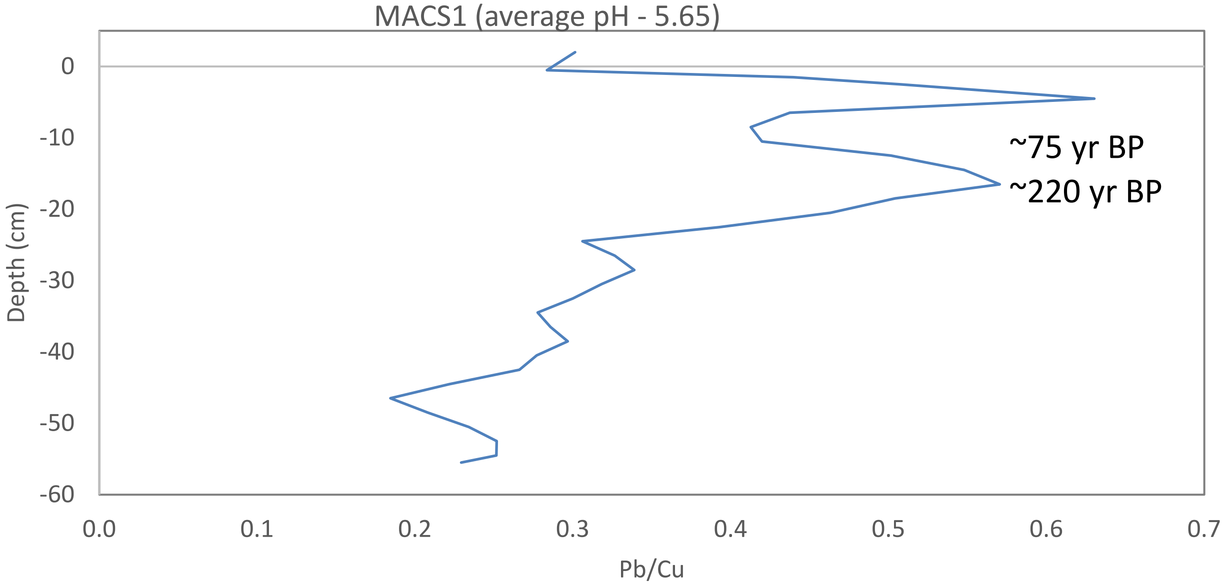
Lead/Copper ratios

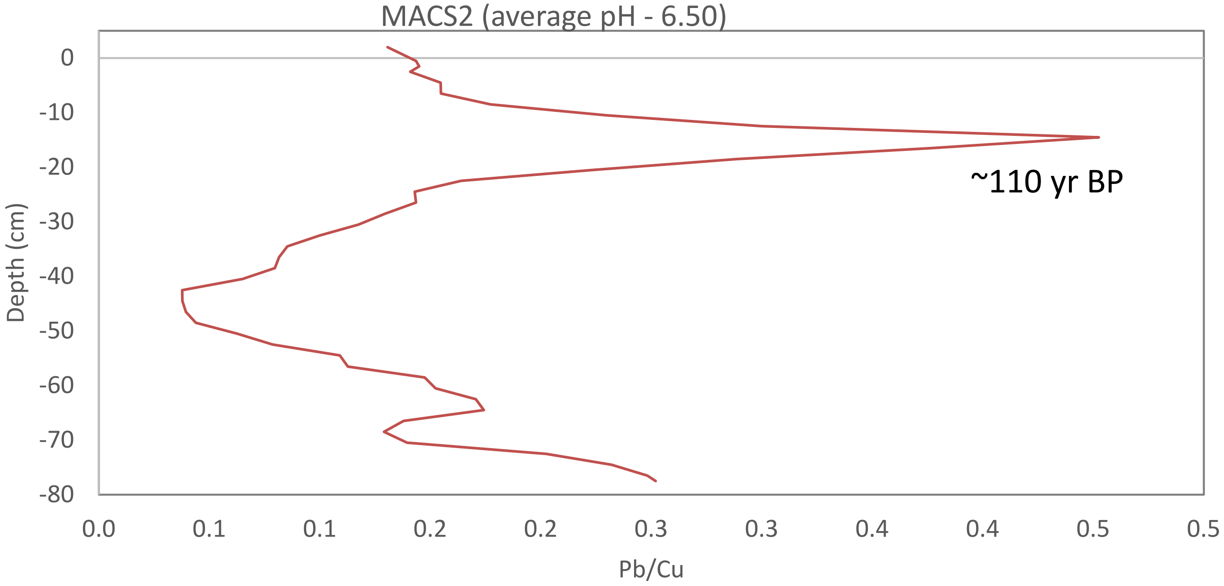
Pb/Cu ratio is calculated to provide an estimation of the source of Pb. As Pb and Cu have different melting points (Pb = 327.5 °C; Cu= 1085 °C), we can roughly estimate that if Pb/Cu is high, the Pb is probably from burning (e.g.: coal burning, smelting, etc.) and not from dust.

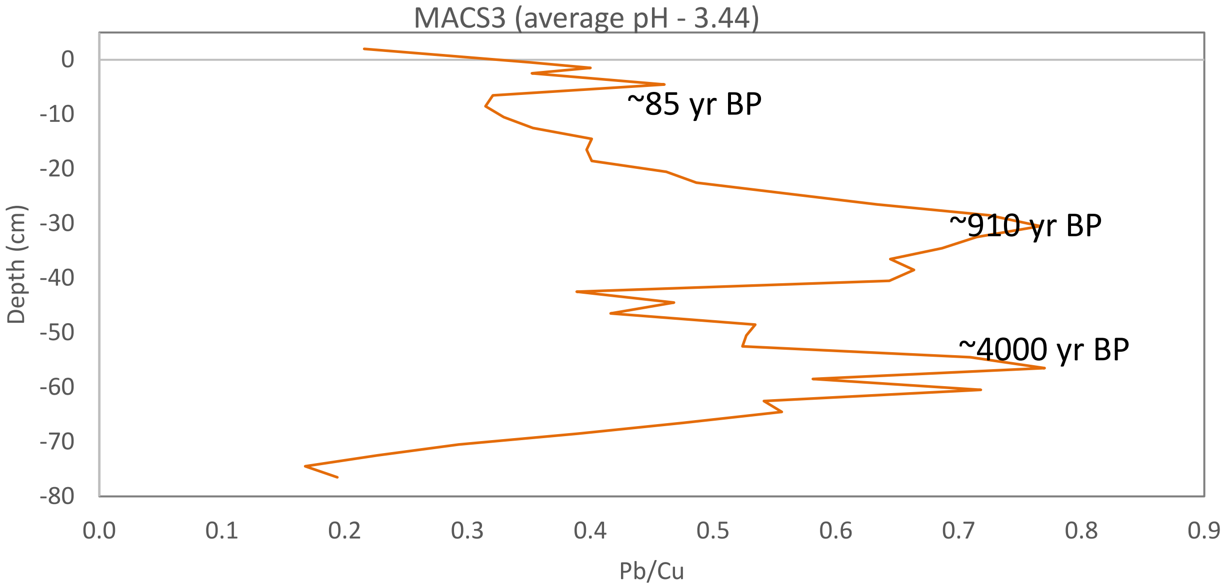
"…during high-temperature processing, whether base smelting and refining or coal combustion, Pb should be preferentially emitted to the atmosphere over Cu…" (Shotyk, 2020).

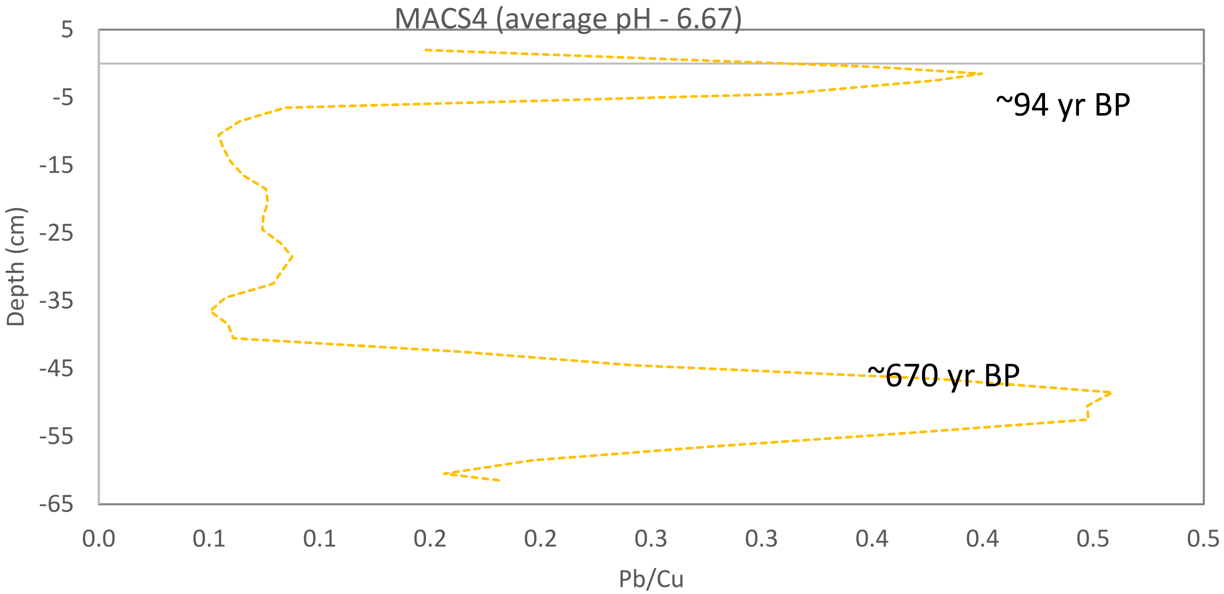
Shotyk W. (2020). Natural and anthropogenic sources of copper to organic soils: a global, geochemical perspective. Canadian Journal of Soil Science. https://doi.org/10.1139/cjss-2019-0161

Pb/Cu ratios

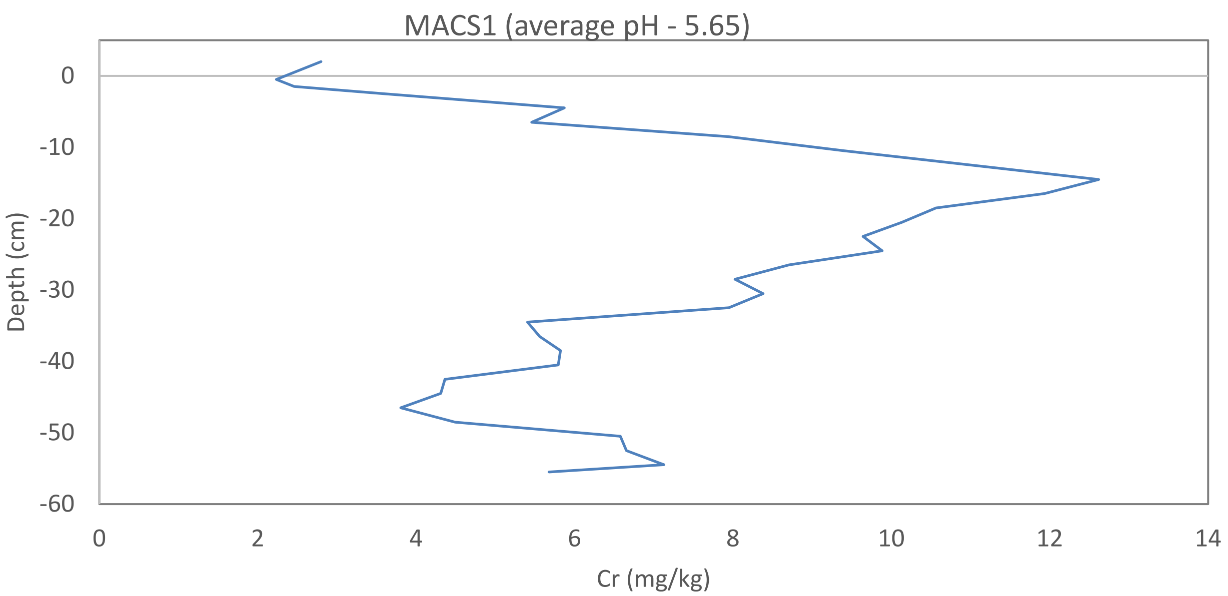

MACS1 (average pH - 5.65)
~75 yr BP
~220 yr BP
Depth (cm)
Pb/Cu

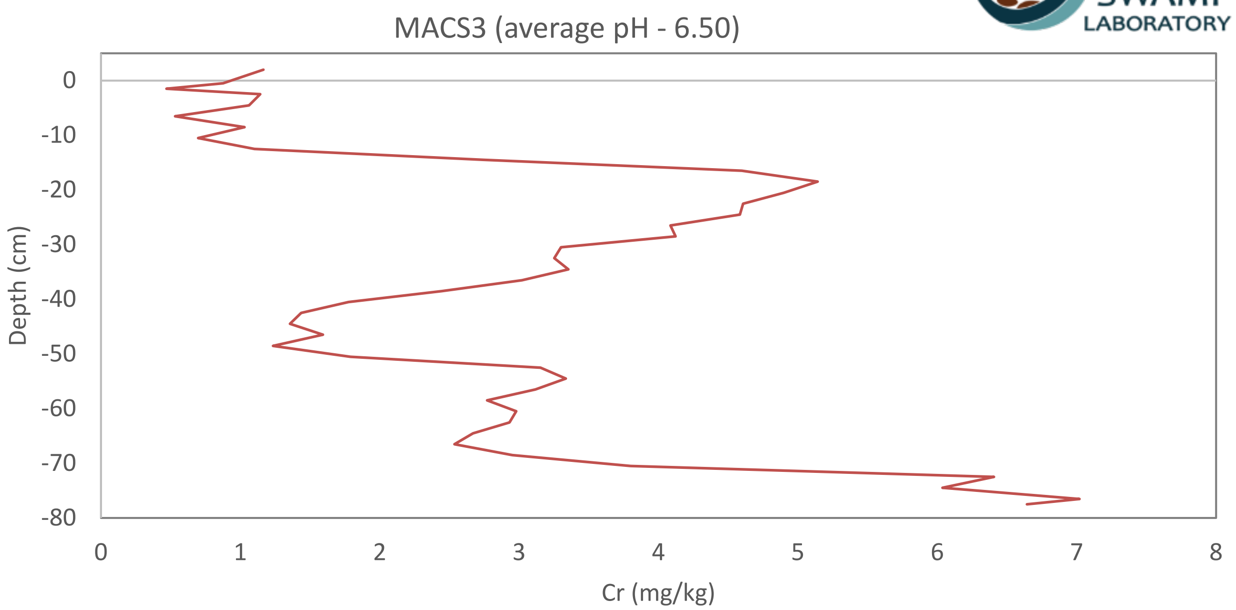

MACS2 (average pH - 6.50)
~110 yr BP
Depth (cm)
Pb/Cu

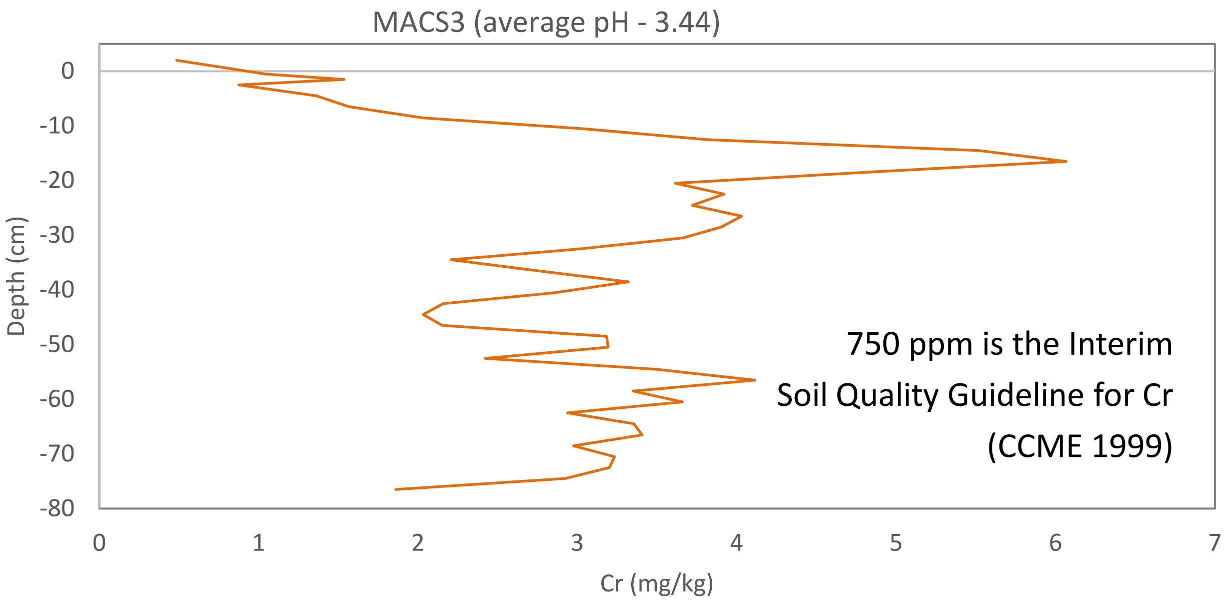

MACS3 (average pH - 3.44)
~85 yr BP
~910 yr BP
~4000 yr BP
Depth (cm)
Pb/Cu

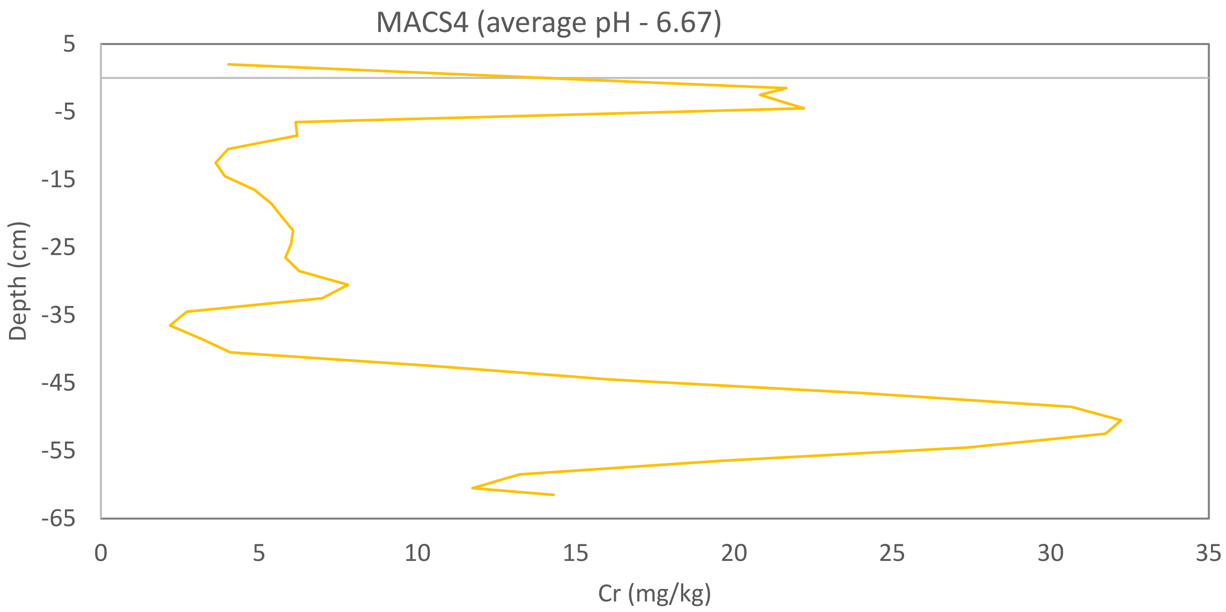

MACS4 (average pH - 6.67)
~94 yr BP
~670 yr BP
Depth (cm)
Pb/Cu

Trace elements profiles: Cr

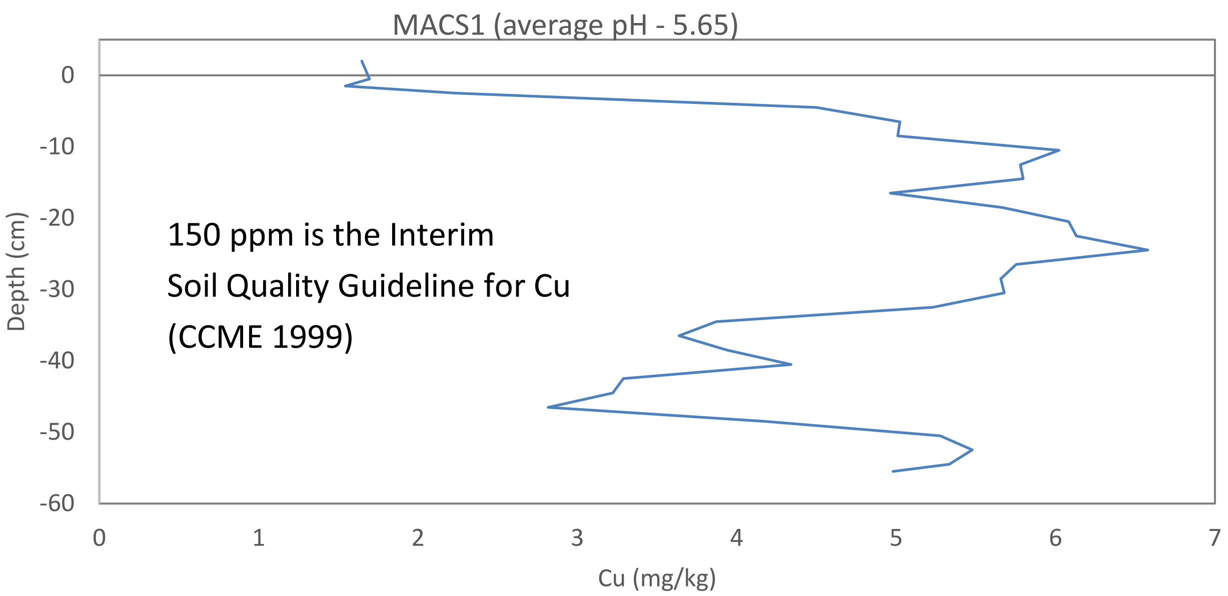


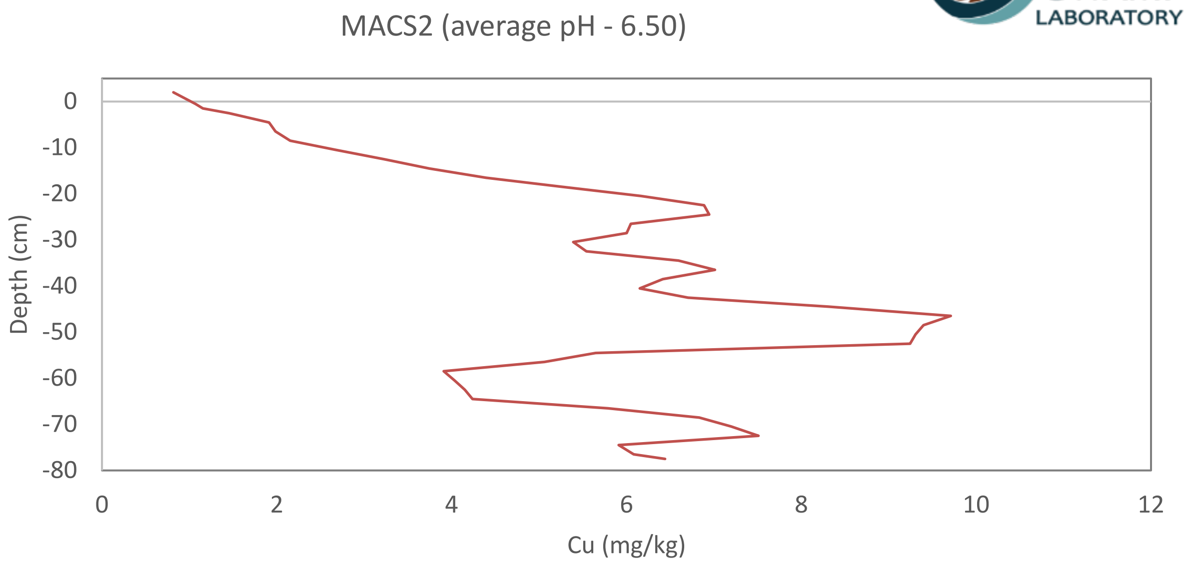


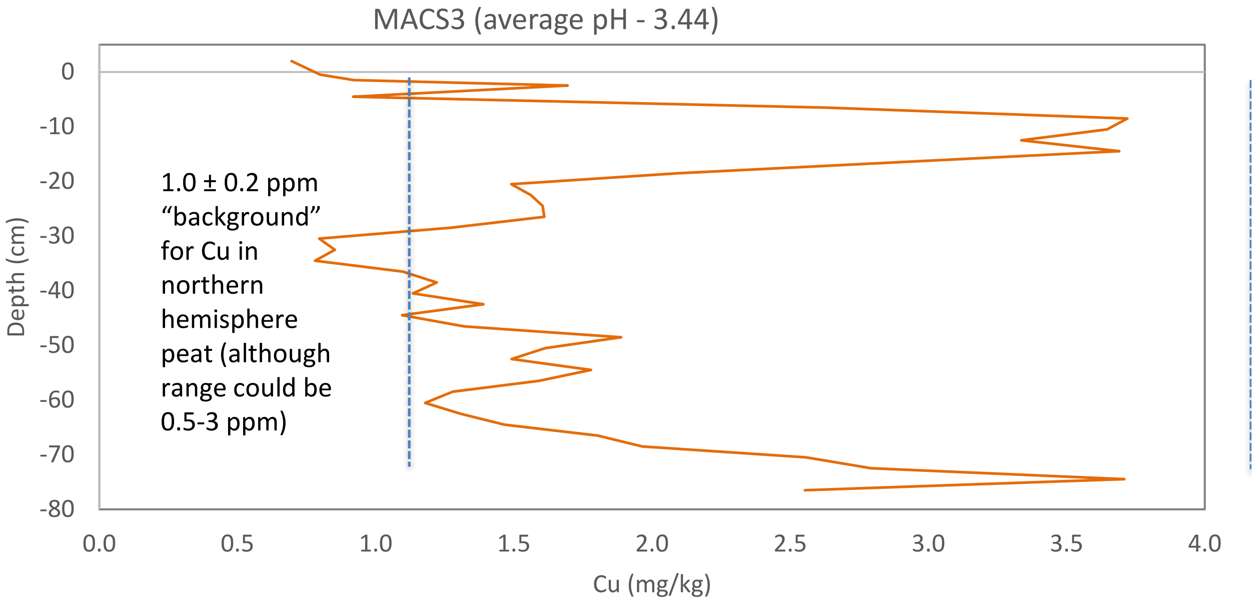


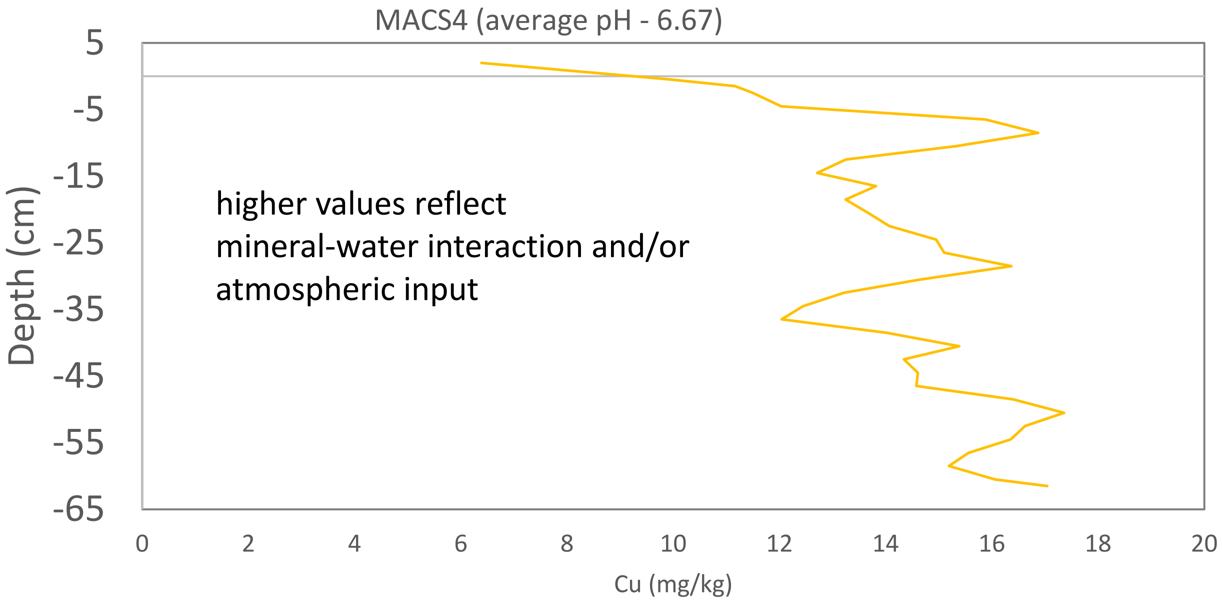


Trace elements profiles: Cu

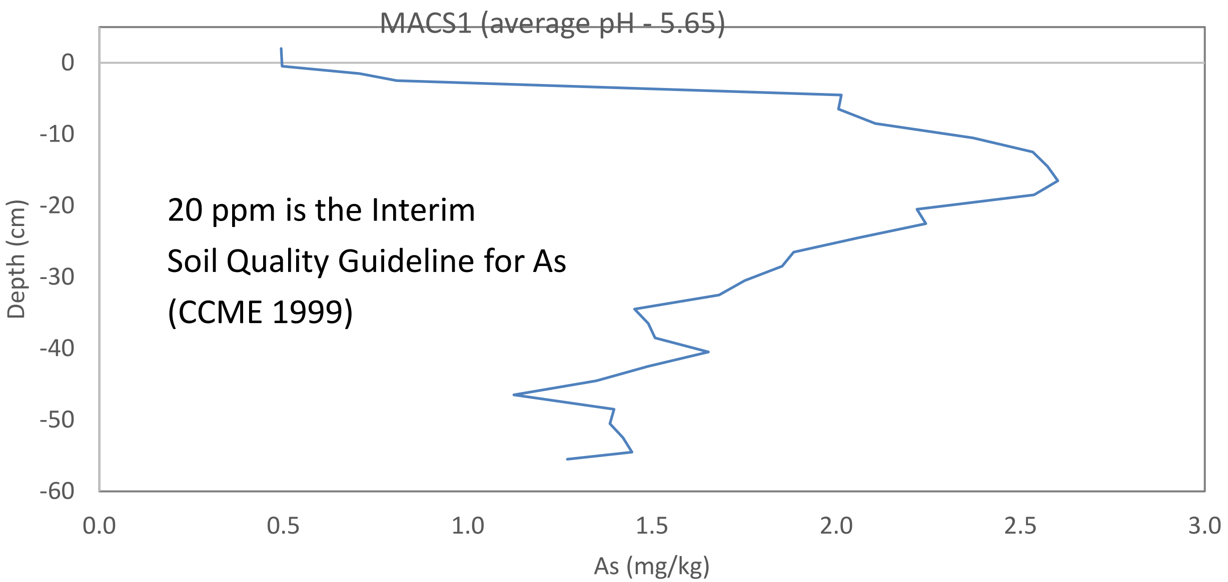


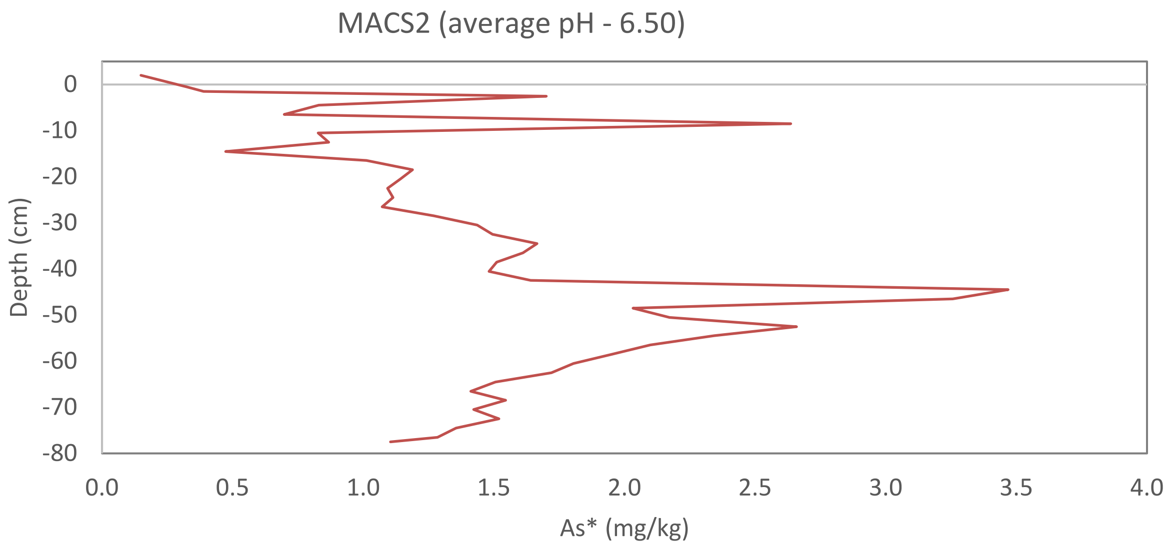


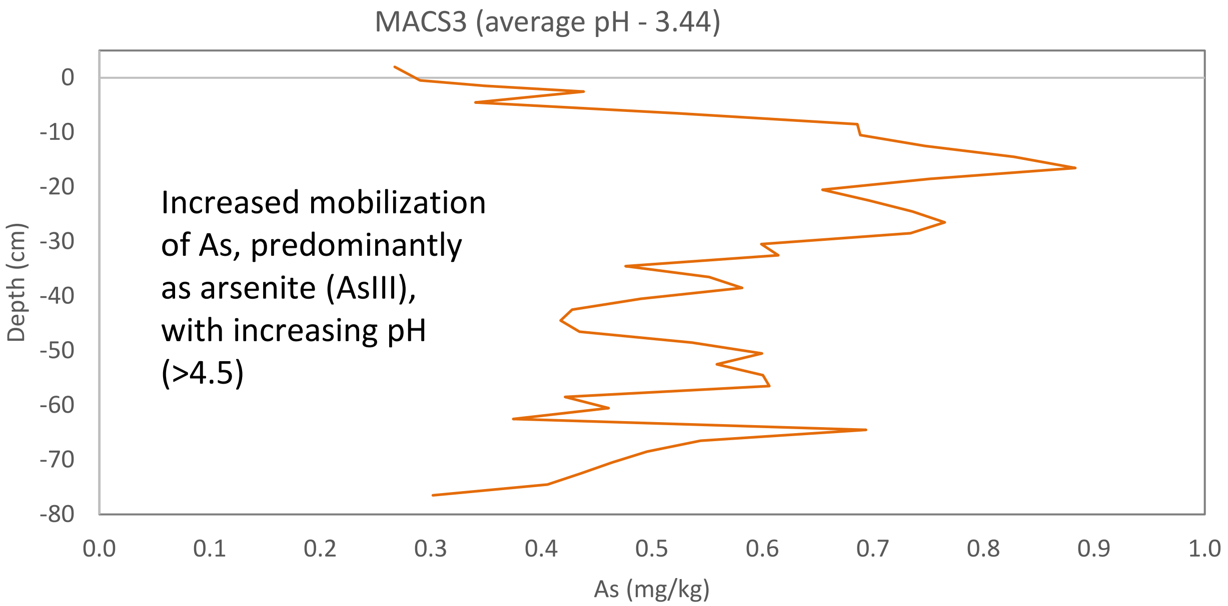


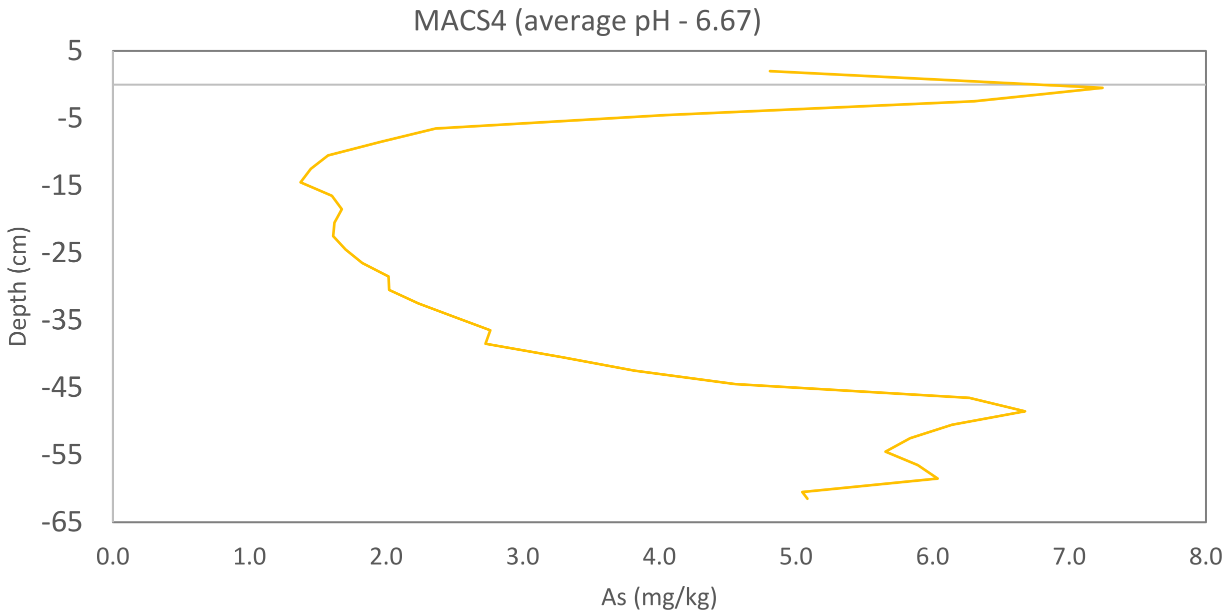


Trace elements profiles: As

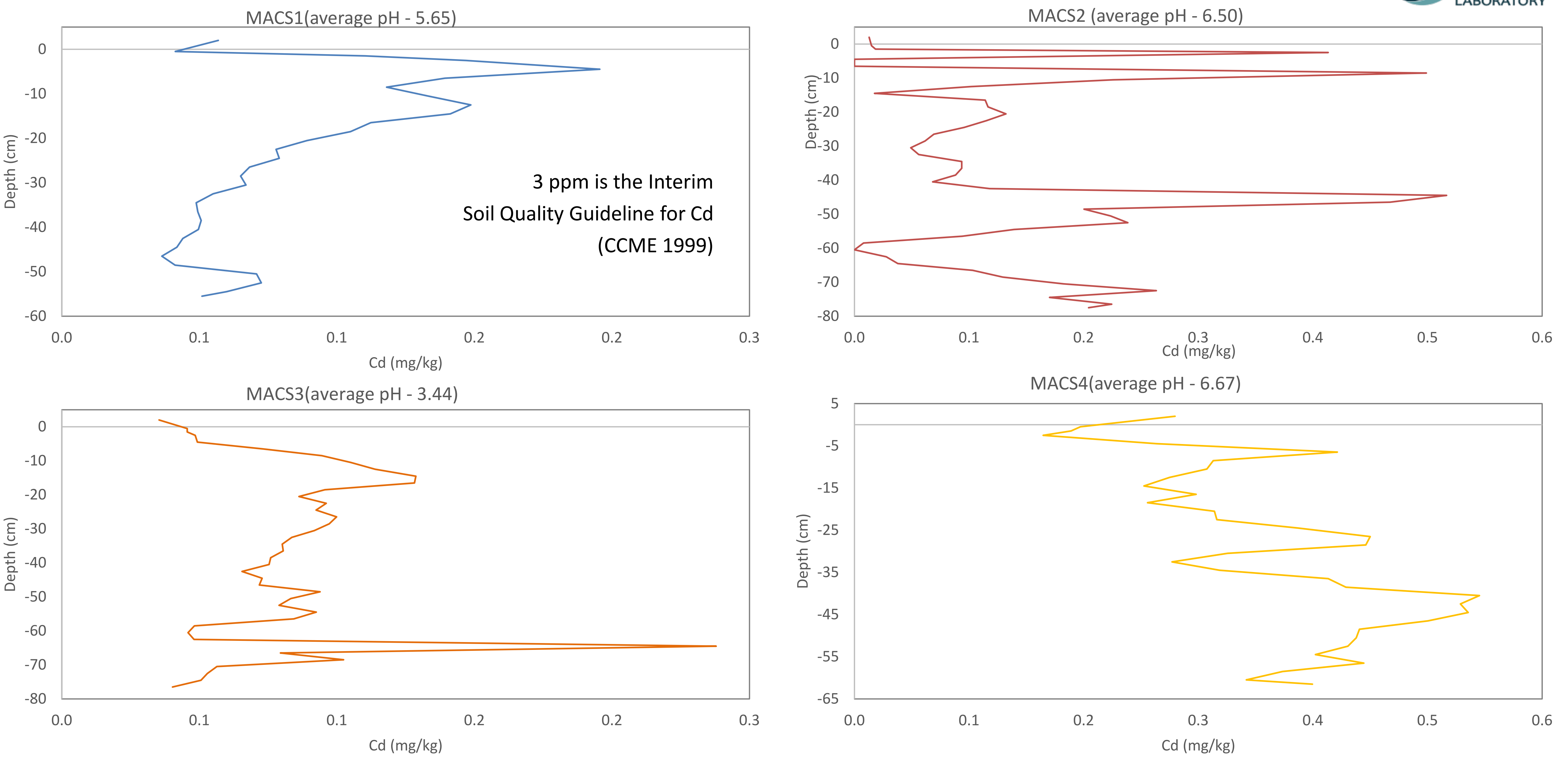




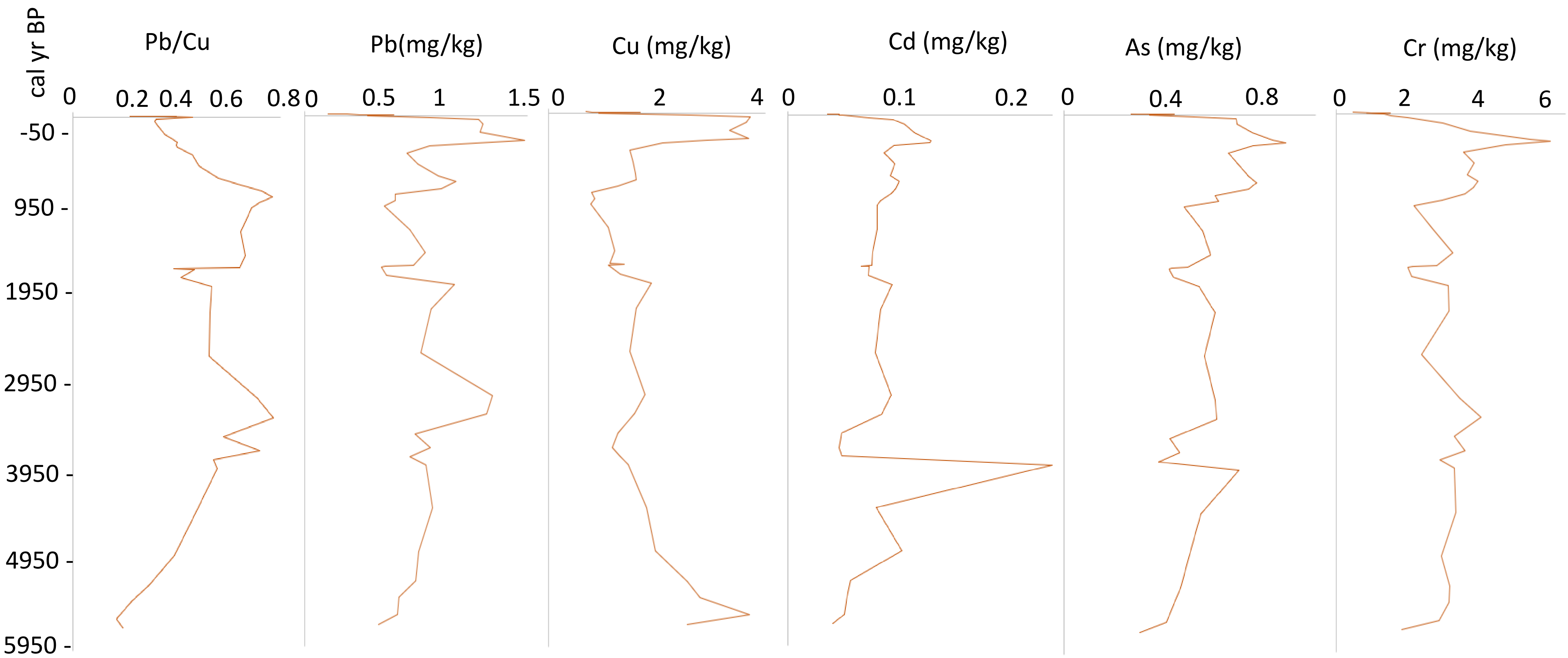




Trace elements profiles: Cd

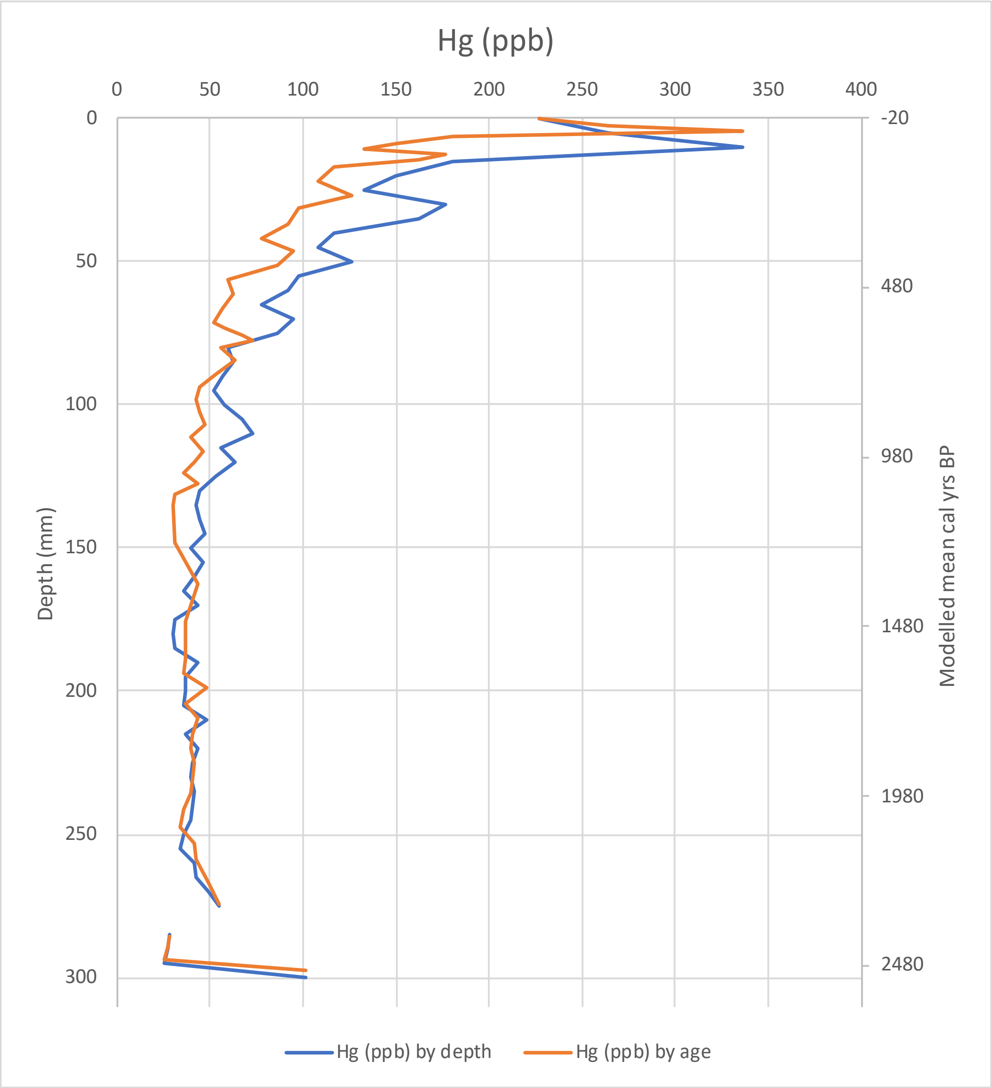


Example: MACS3

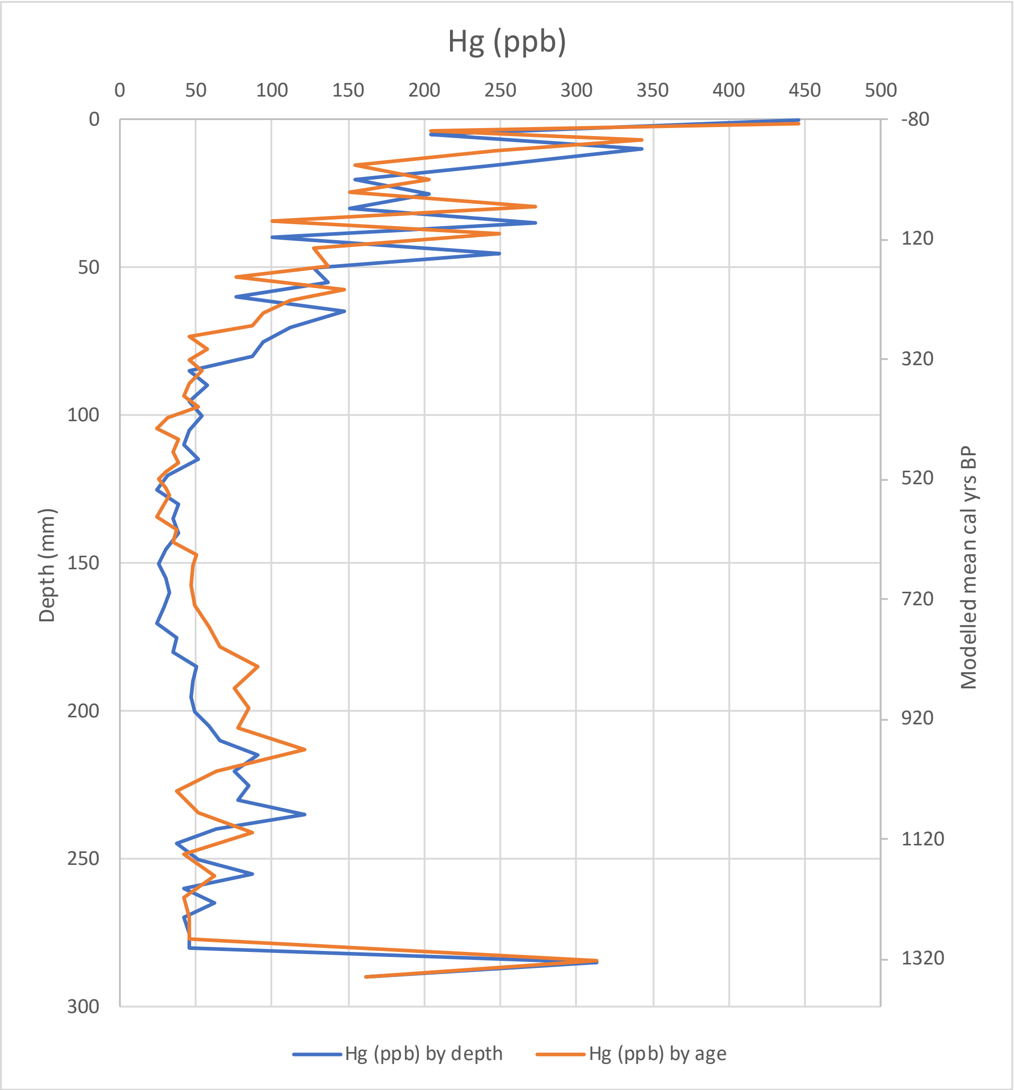


Trace elements profiles: Hg

16PS1

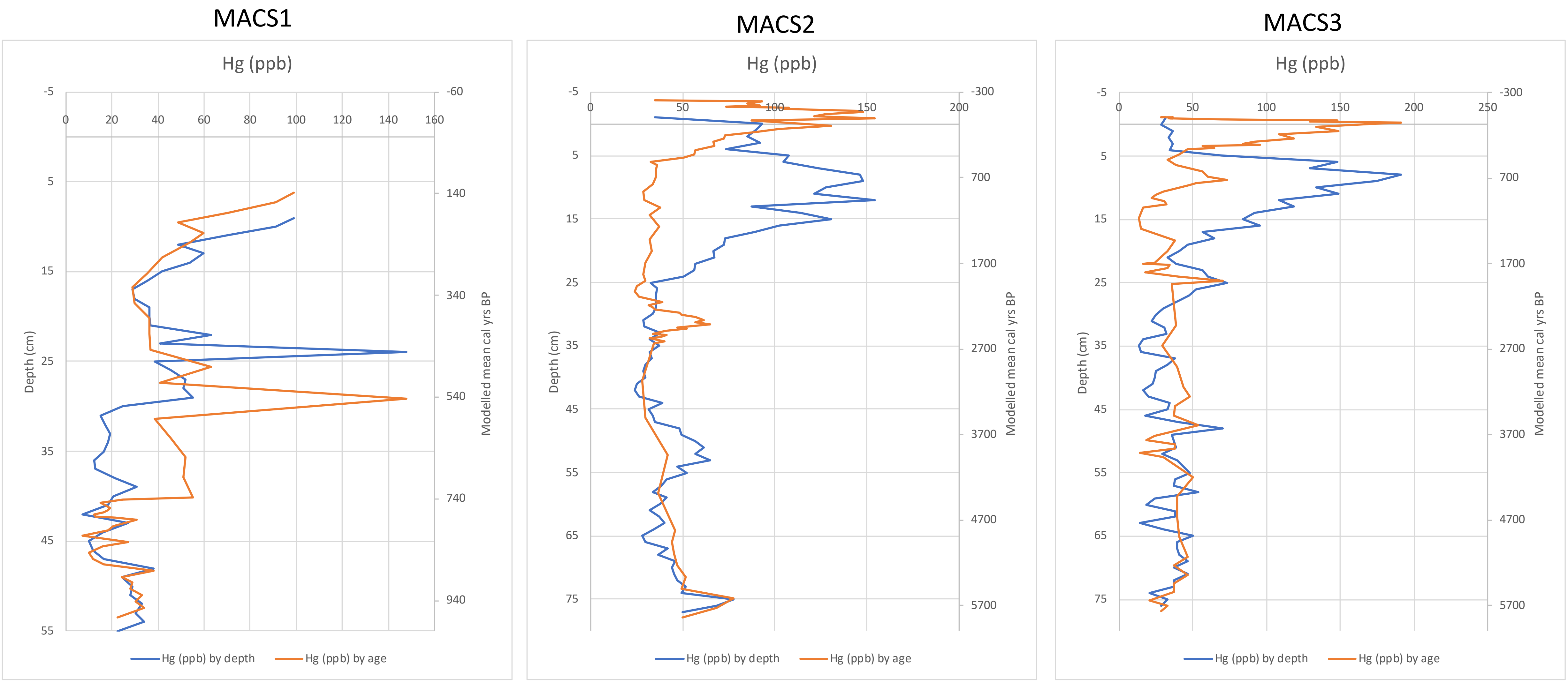


16PS2



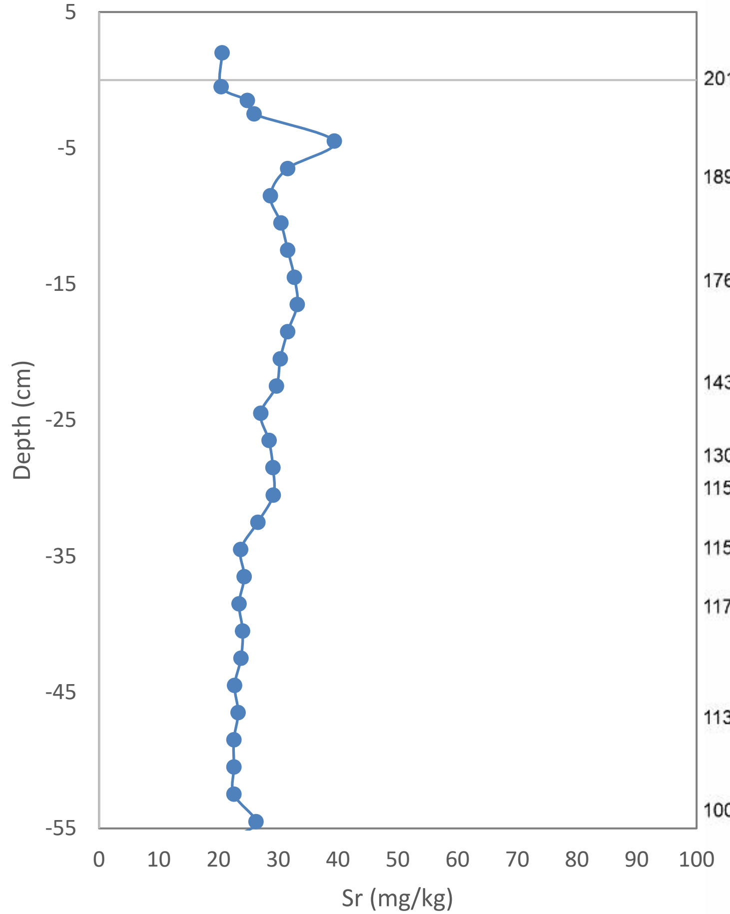
800 ppb is the Interim Soil Quality Guideline for inorganic Hg (CCME 1999)

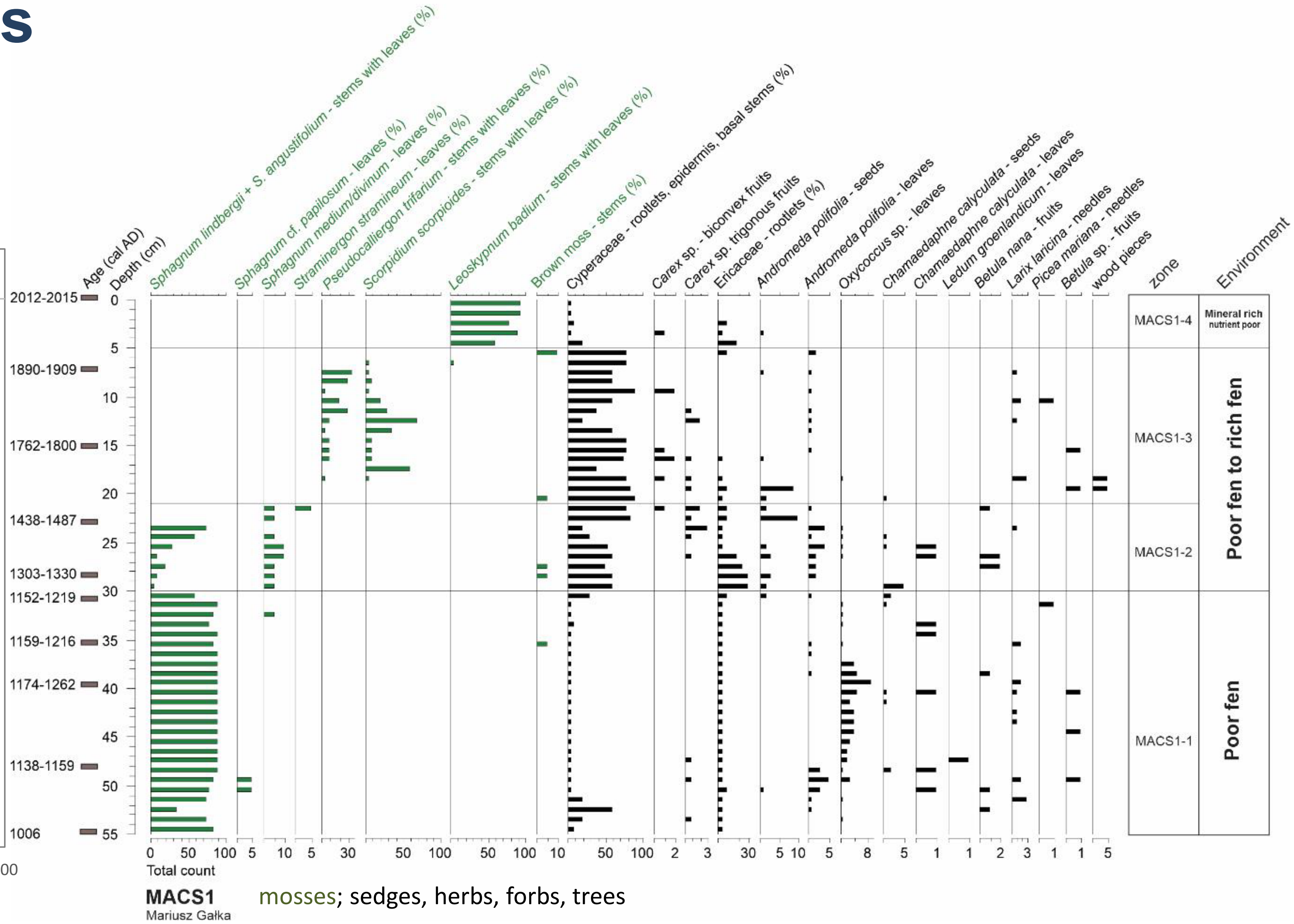
Trace elements profiles: Hg



800 ppb is the Interim Soil Quality Guideline for inorganic Hg (CCME 1999)

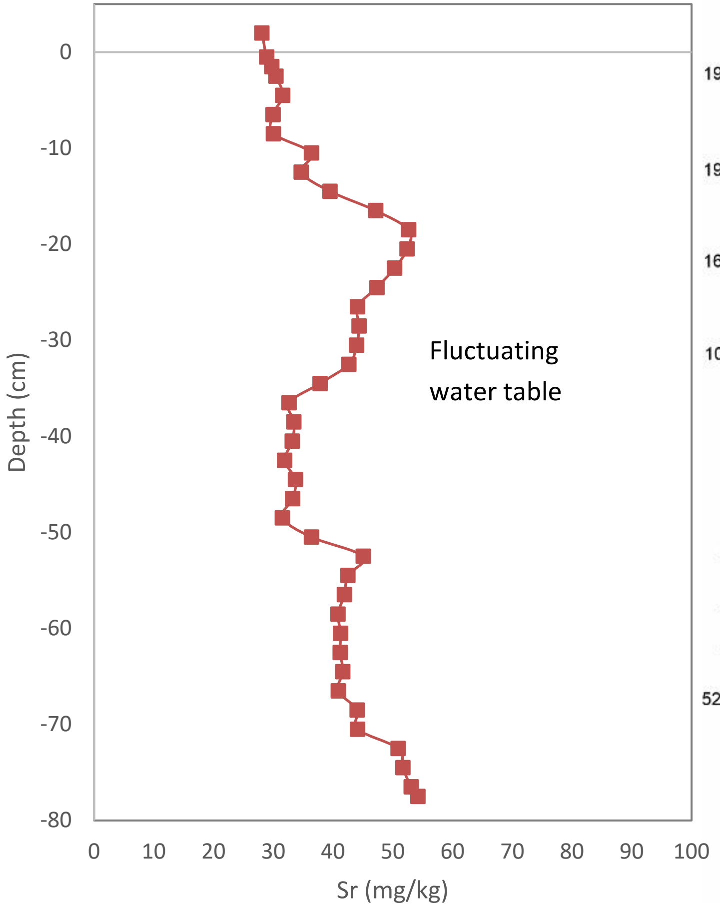
ECOHYDROLOGICAL DEVELOPMENT: Plant macrofossils

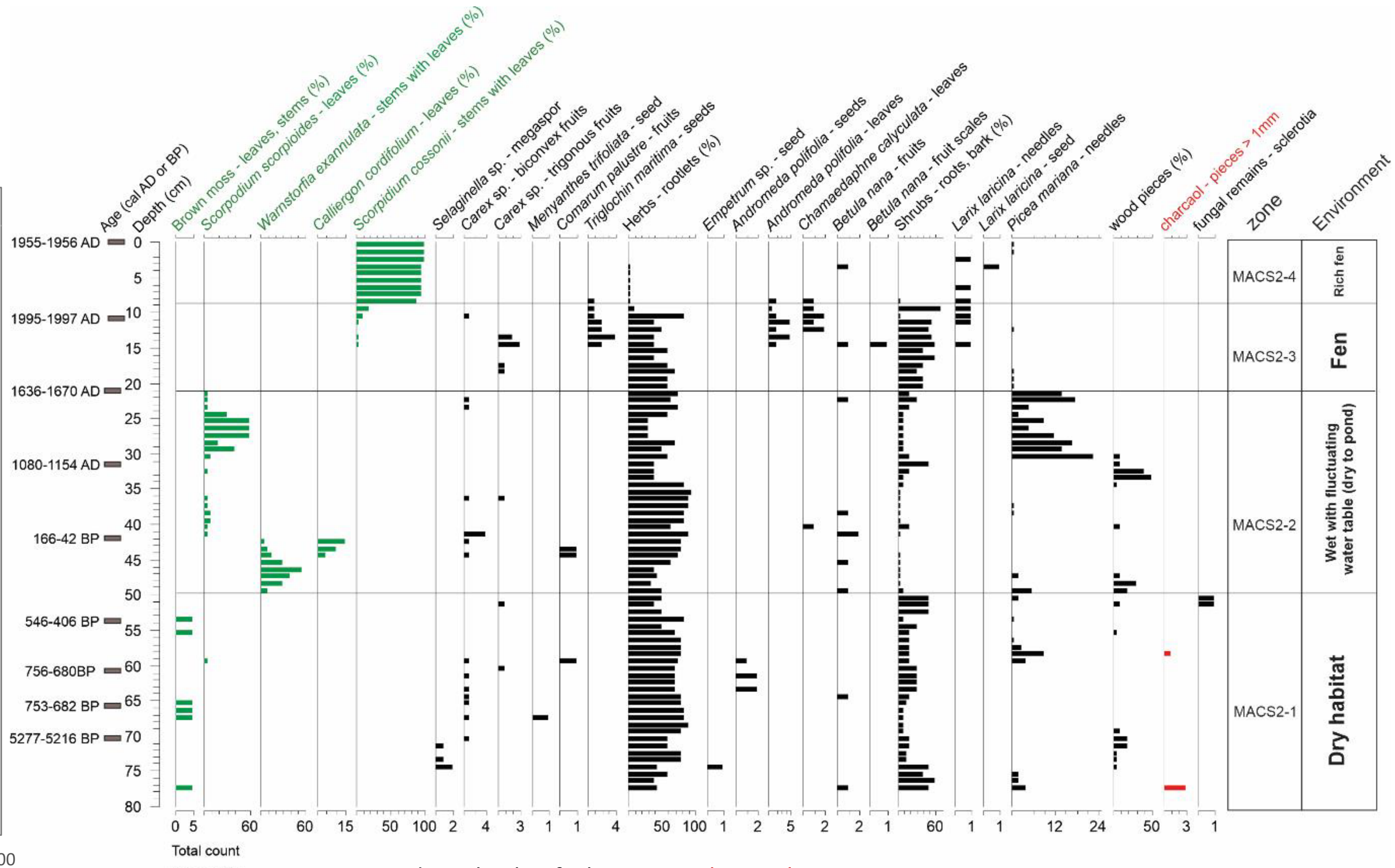




mosses; sedges, herbs, forbs, trees

ECOHYDROLOGICAL DEVELOPMENT: Plant macrofossils

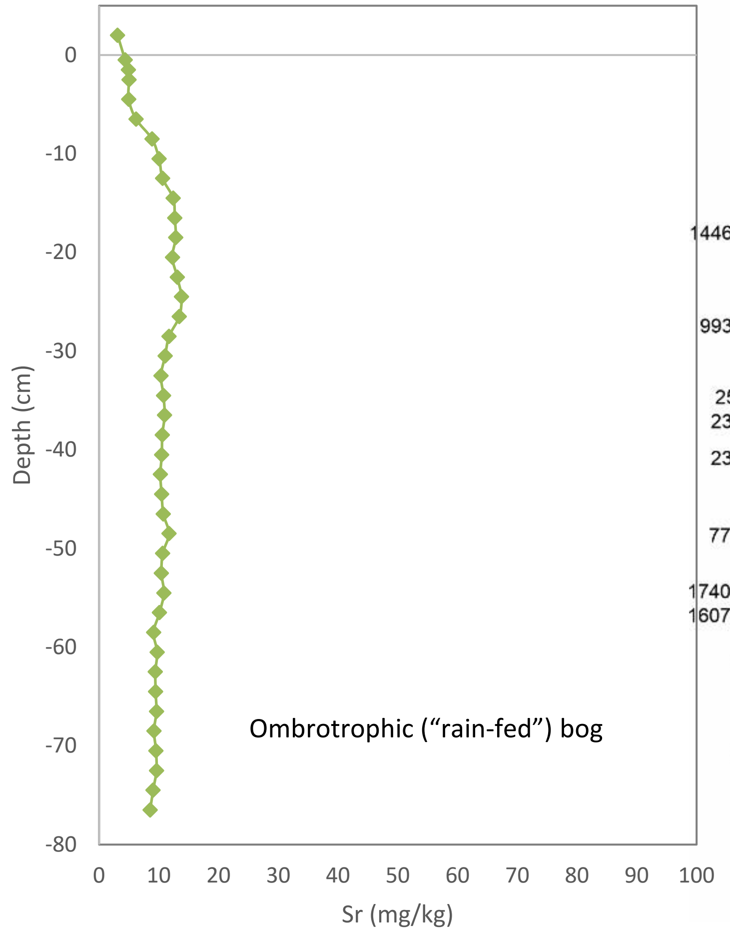


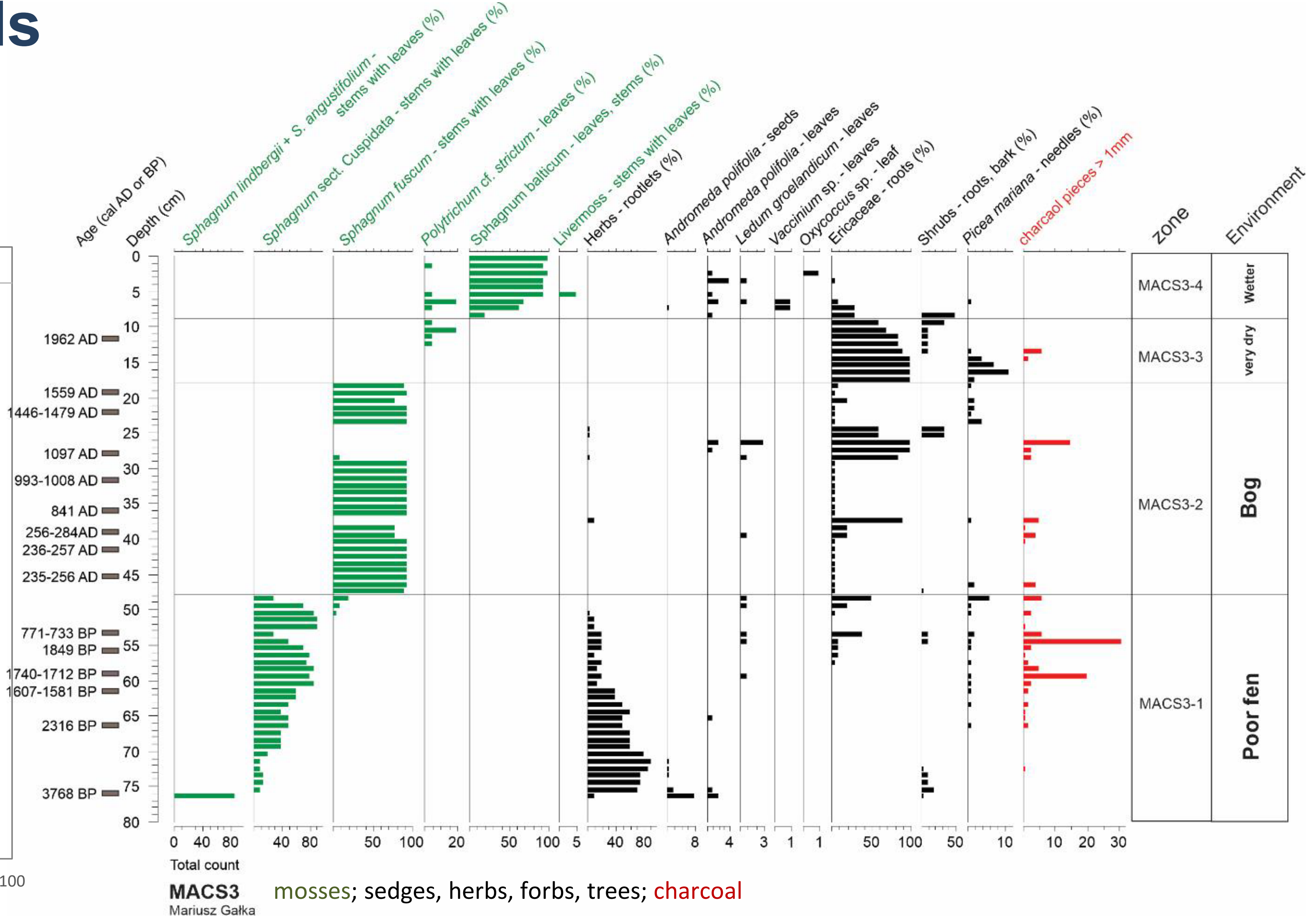


MACS2
Mariusz Gałka

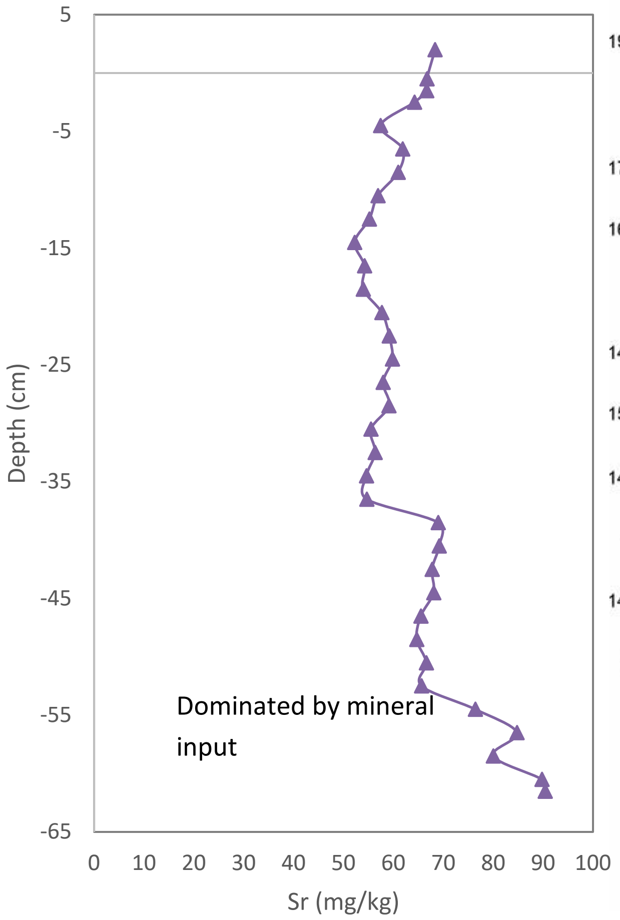
mosses; sedges, herbs, forbs, trees; charcoal

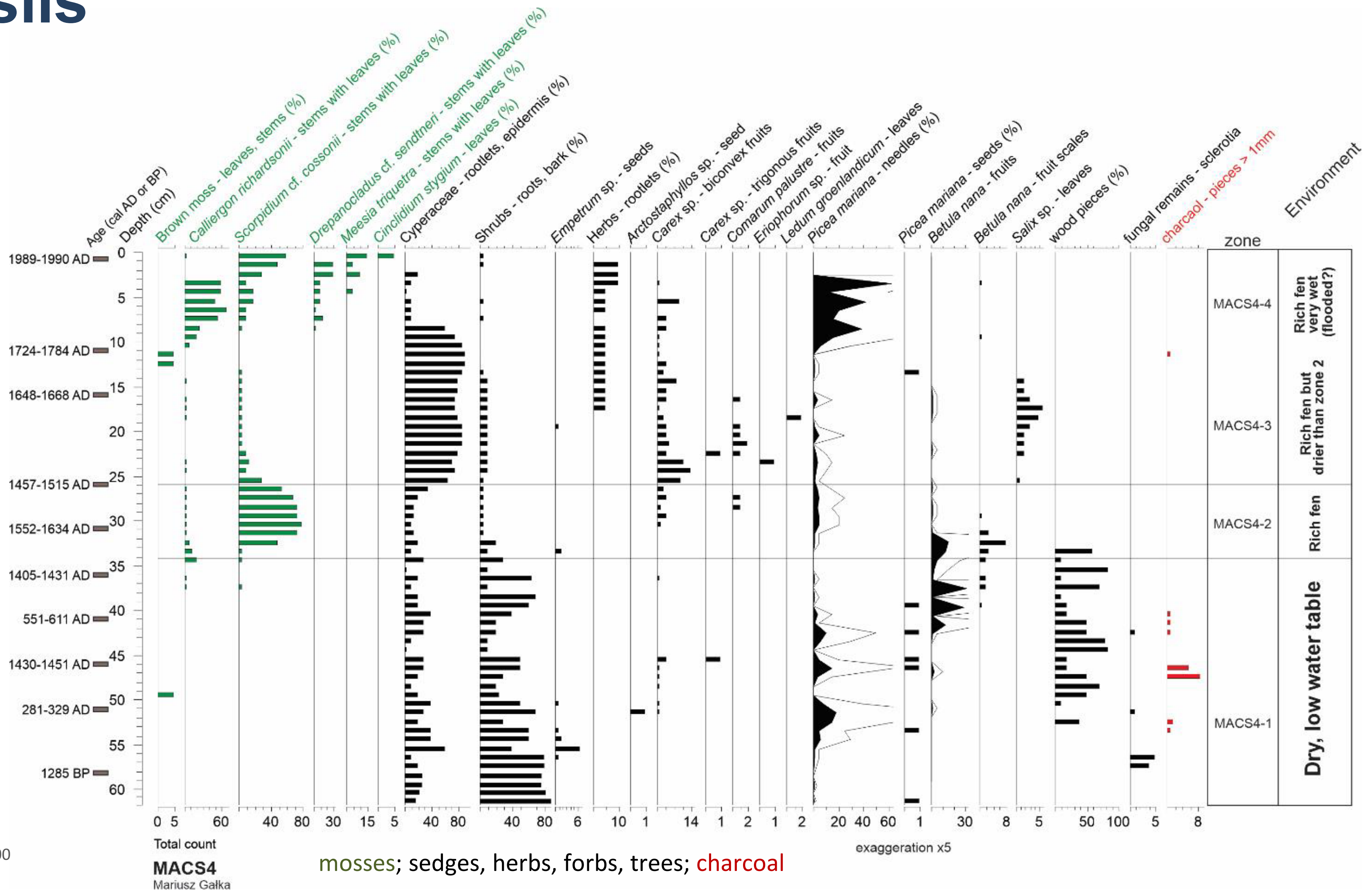
ECOHYDROLOGICAL DEVELOPMENT: Plant macrofossils





ECOHYDROLOGICAL DEVELOPMENT: Plant macrofossils





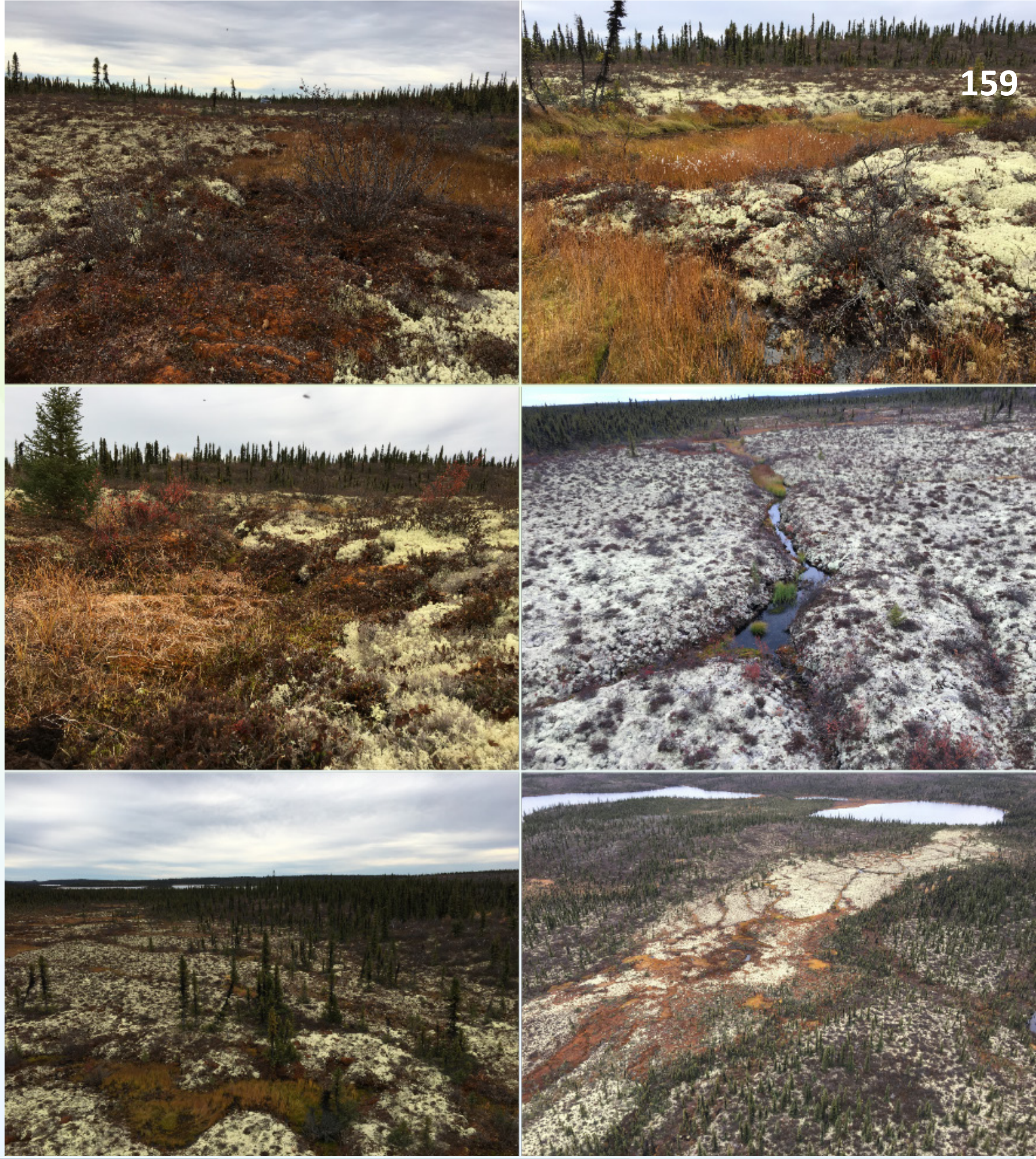
HIGHLIGHTS

- Plain language summary, abstract, and conclusions of a GSC Open File (Nguyen et al., 2023) translated into Gwich'in

- Project has supported 1 PDF (completed), 2 PhDs (in progress), 2 MScs (1 graduated, 1 in progress), local Gwich'in youth and community members, and a staff member at the Gwich'in Tribal Council, Department of Cultural Heritage

- Next steps – complete remaining analyses (Hg of MACS4, testate amoebae and quantitative water table depth measurements, ecohydrological modelling), meta-analysis of data

Nguyen, A.V., Oleksandrenko, A., Lord, S., Clarke, L., Gałka, M., Patterson, R.T., Shotyk, W., Swindles, G., Galloway, J.M., 2022. Project summary of samples collected in support of the Climate Controls on Long-term Hydrological Change in the Mackenzie River Basin project, Yukon and Northwest Territories, Environmental Geoscience Program and ArcticNet Project 51; Geological Survey of Canada, Open File 8919, 85 p. https://doi.org/10.4095/330928



CONTACT INFORMATION

Jennifer Galloway

https://www.researchgate.net/profile/Jennifer_Galloway2;
https://scholar.google.ca/citations?user=x6SQcrsAAAAJ&hl=en

Jennifer.Galloway@nrcan-rncan.gc.ca

SWAMP LABORATORY

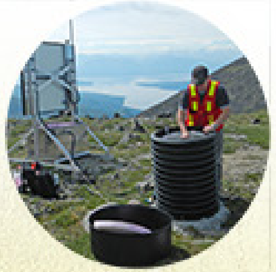
Carleton University

ArcticNet

Natural Environment Research Council

Natural Resources Canada | Ressources naturelles Canada




Infrastructure Impacts on Permafrost Geochemistry

May 30, 2023

ABSTRACT

The geochemistry of groundwaters and groundwater-surface water interactions resulting from permafrost freeze-thaw processes are poorly understood. This EGP activity aims to refine our current understanding of these processes, and how they are impacted by infrastructure development. The initial research site was Pit I401A, which was dug during construction of the Inuvik to Tuktoyaktuk Highway (ITH) and has since generated high-solute ground- and surface waters that pose an environmental risk to surrounding areas. The environmental risk is intimately related to the unknown hydrogeochemical regime within active layer groundwater aquifers – this study aims to define the aquifer systematics, and this presentation focusses on the performance and information of novel arctic-compatible sensor systems used to measure the annual seasonal hydrogeochemical cycle. The four main sensors used all worked well: Pore water pressure, permittivity, temperature, electrical conductivity sensors detected groundwater flow throughout non-frozen times, which continued at least partially in winter. However, later in winter (March-April) the aquifer appeared to become compartmentalized which likely inhibited flow until early July. This implies 8 months of flow and advective latent heat transport rather than the assumed 3-4 months – resulting in substantively more permafrost-related thaw than anticipated – which generates substantially more high solute ground- and surface waters than would otherwise be predicted.

PROJECT MEMBERS

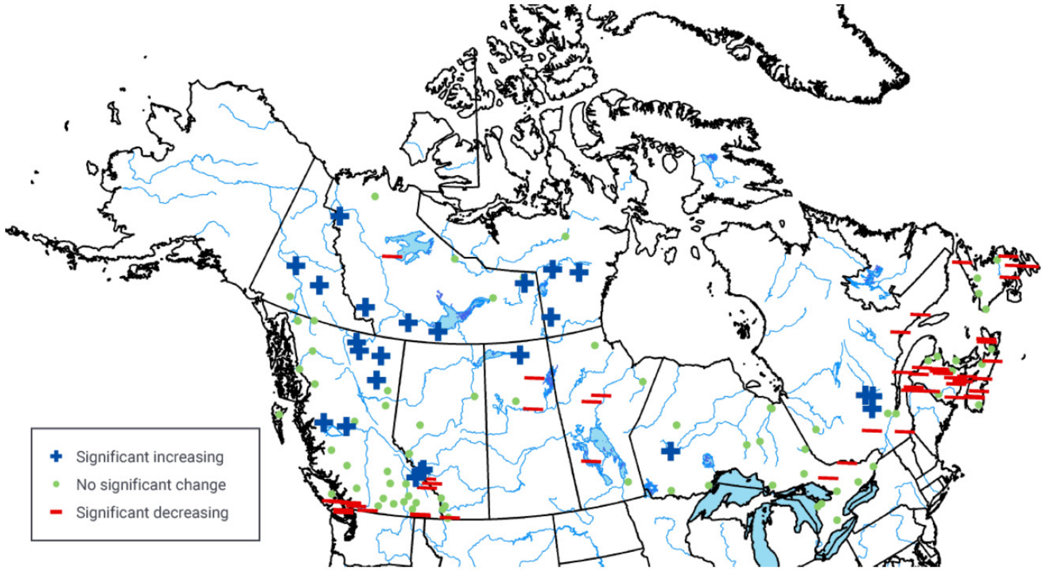
- Paul Gammon
- James Zheng
- Melissa Bunn
- Jason Ahad
- Lilianne Pagé
- Pierre Pelchat
- John Sekerka

Indigenous Stakeholders

- Aurora Research Institute
- Inuvialuit Land Administration
- Inuvik Hunters and Trappers

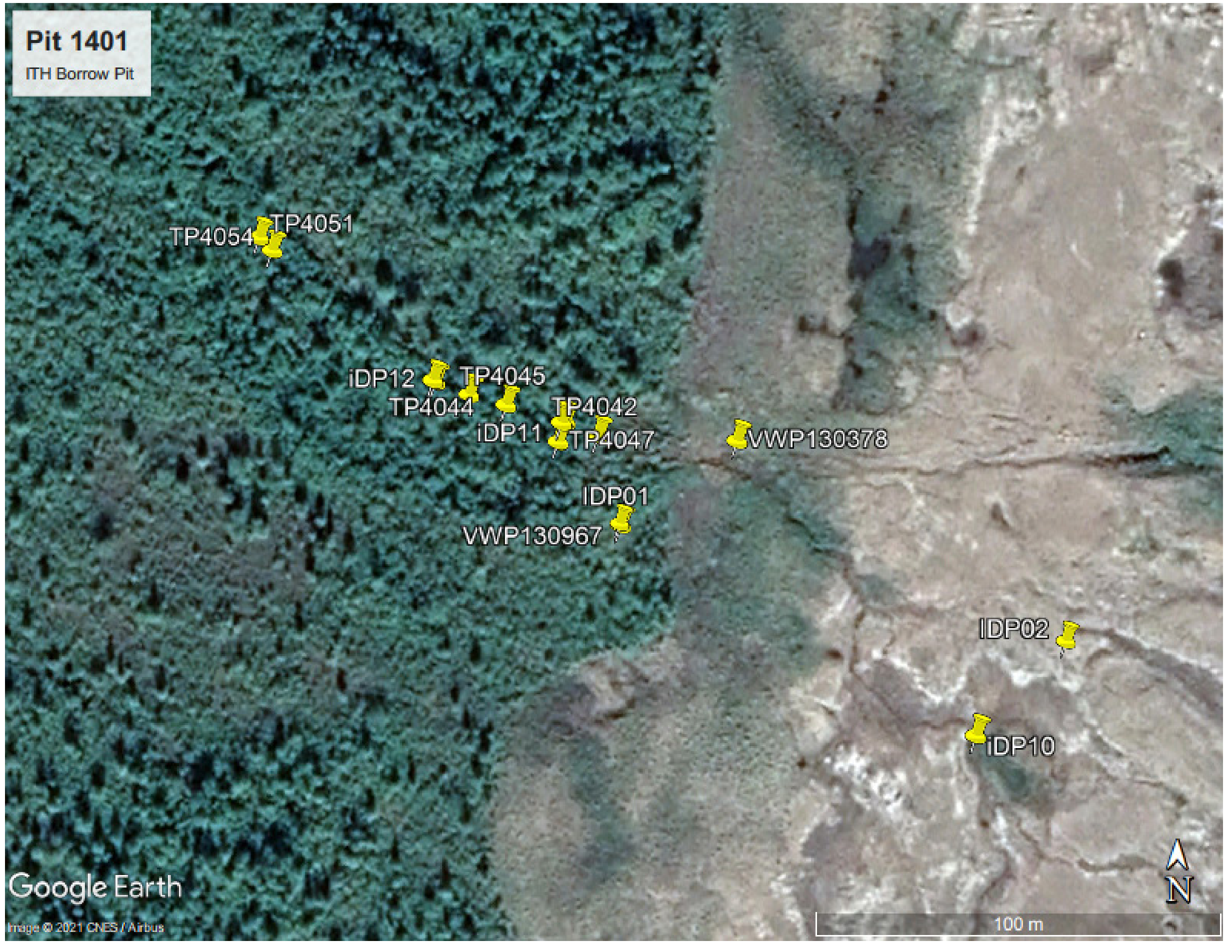
Background

- Climate change induced warming temperatures and snowpack dynamics are contributing to permafrost degradation and increases in active layer thickness
- Groundwater flow and ground- and surface-water interactions within permafrost active layer systems are poorly understood, and climate warming will make these more dominant contributors to arctic hydrogeochemical systems.
- These issues have implications for permafrost and infrastructure stability, water quantity and quality, and sustainable development in northern permafrost lands.



Trends in minimum (winter in the north) river flows (from: Changes in Freshwater Availability Across Canada, Canada's Changing Climate Report)

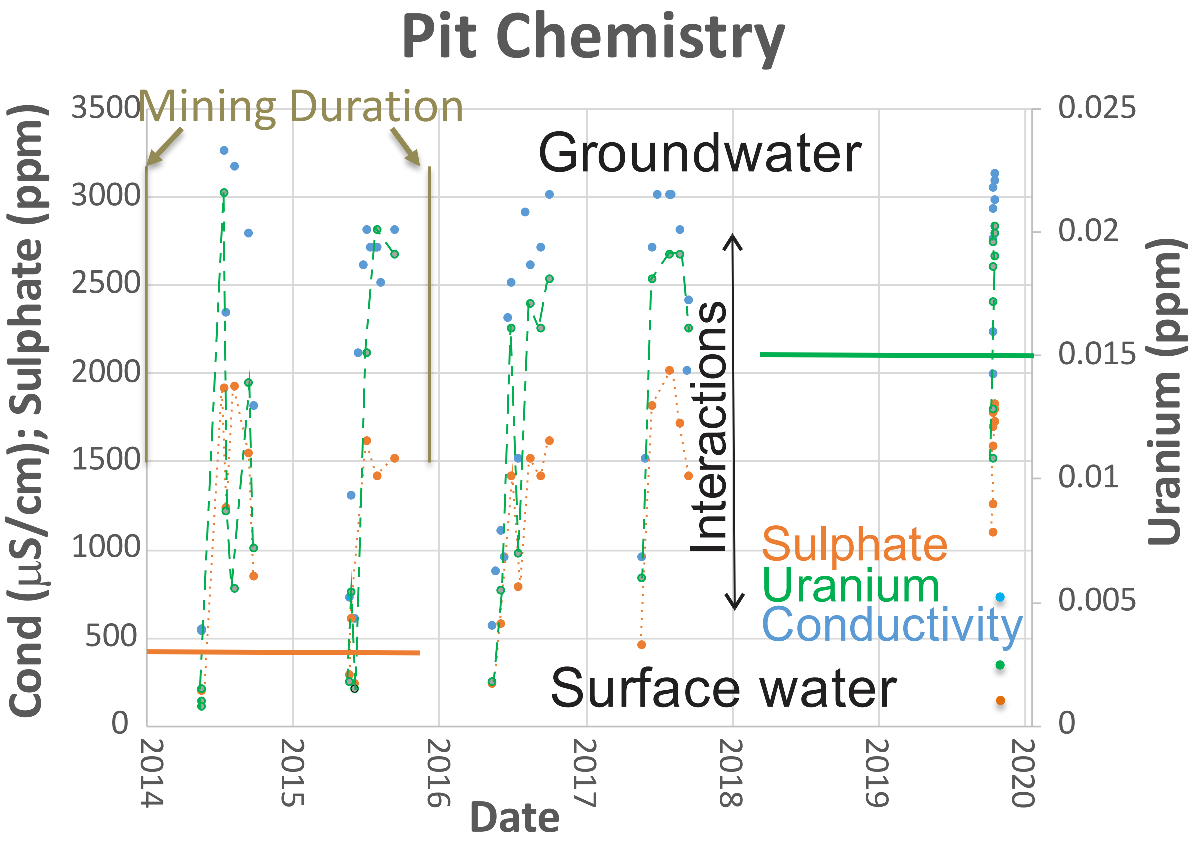
The research site: Borrow pit dug for road material for ITH



Inuvik to Tuktoyaktuk Highway:

- Completed 2017
- Borrow pits actively degrading
- Rapid permafrost thaw yields waters with high solute chemistries.

The research site: Hydrochemical starting point.



High solute concentrations.

Pit water chemistry unchanged since mining ceased.

Groundwater chemistry dominates except for a short spring run-off period.

Groundwater chemistry indicates a permafrost origin.

Why/how is this groundwater so high in solutes?

Hydrogeological context

Aquifers and aquitards:

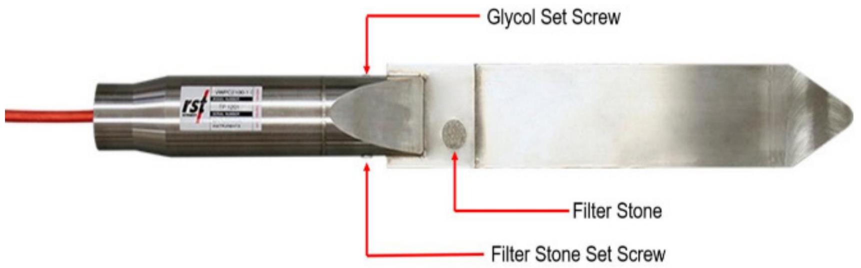
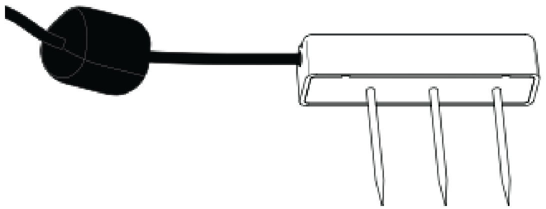
- Pit is predominantly silty clay with minor pebbles (till)
- Lenticular pebbly, variably muddy, gravels form complexly interconnected aquifer(s)

Active layer aquifers define aligned depressions and reflect:

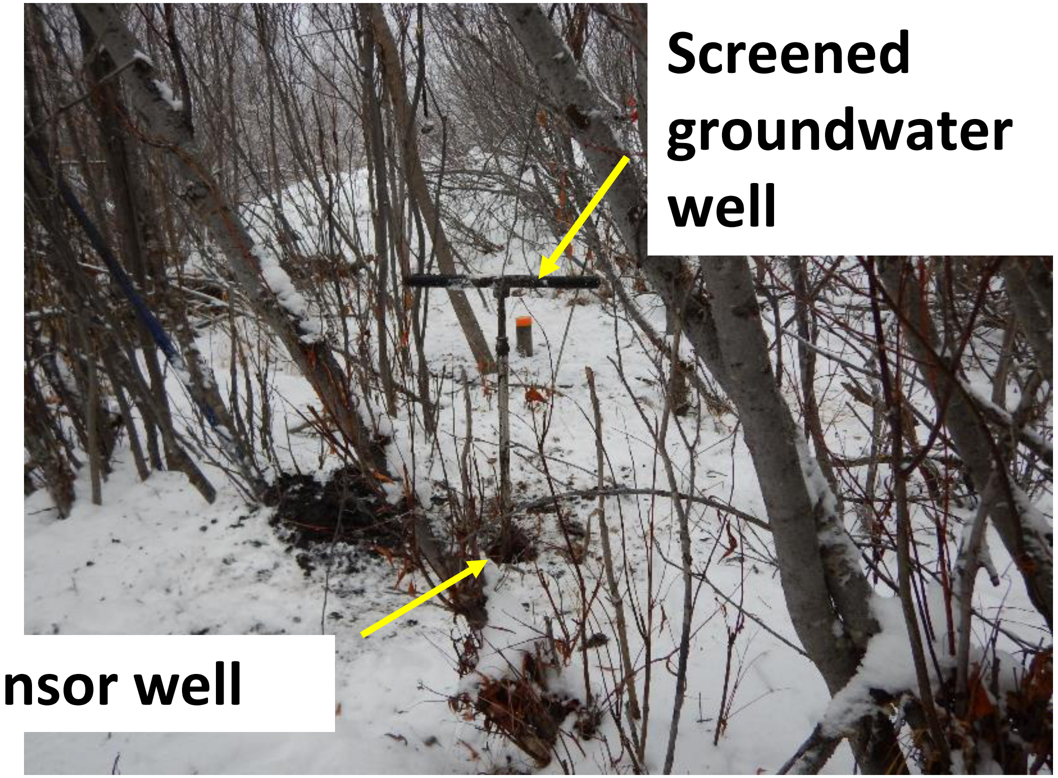
- Preferential permafrost thaw and subsidence along gravel aquifers
- Groundwater flow + advective heat beneath depressions

NB. Surface flow intermittent (and relatively minor)

Monitoring Approach

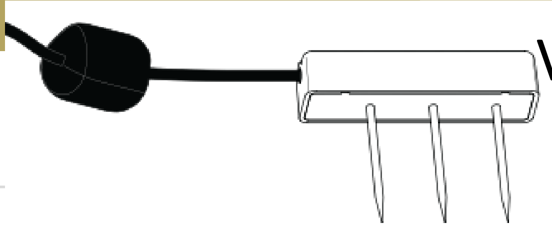
Push-In Pressure Cell	Vibrating Wire Piezometer	Time-Domain Reflectometry
		
• Measures pore water pressure, water temperature and total earth pressure • Pore water pressure indicates groundwater flow and pressure • Formation pressure reflects soil lithostatic pressure • Changing pore water or formation pressures indicate changing systematics	• Measures pore water pressure, water temperature • Pressures reflects groundwater pressure and flow • Changing pressure reflects changes to groundwater systematics	• Measures bulk volume dielectric permittivity (ε ~ volumetric water content), temperature and electrical conductivity • ε decreases significantly as water freezes - a direct indicator of state • Electrical conductivity and temperature indicate formation of brines and freezing point depression

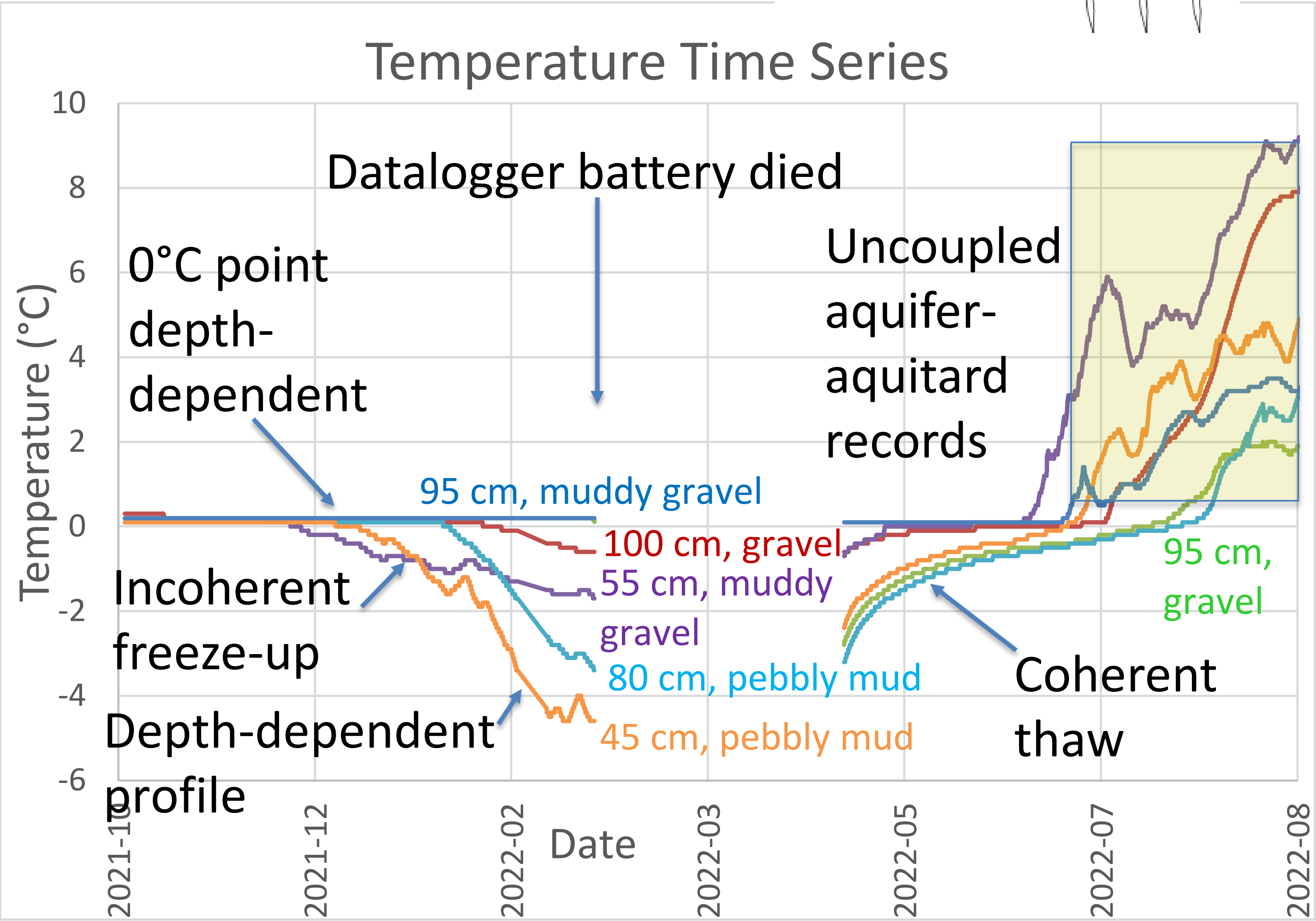
The research site: Hydrogeological investigations



- Active layer 0.4 – 1.8 m thick - Greatest thickness where gravel/water present.
- Aquifer is ?connected gravel lenses
- Pressure and water parameter sensors attached to dataloggers.
- Sampled groundwaters from wells

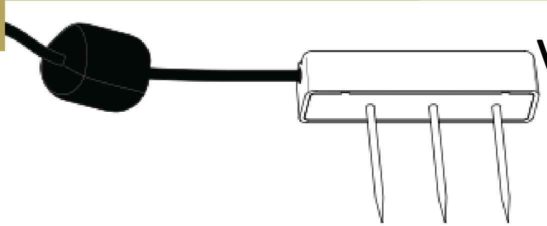
ε, EC, T Sensor Data



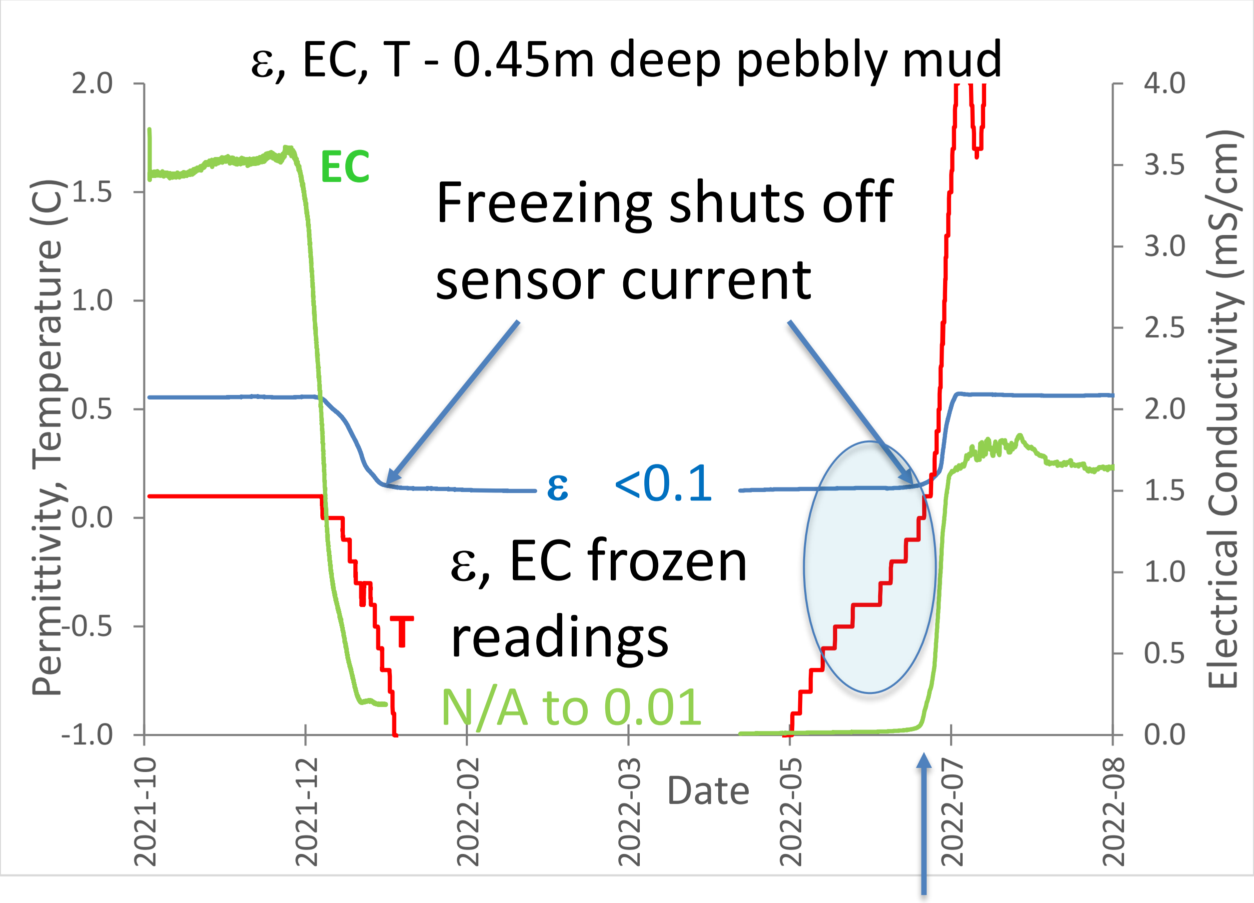


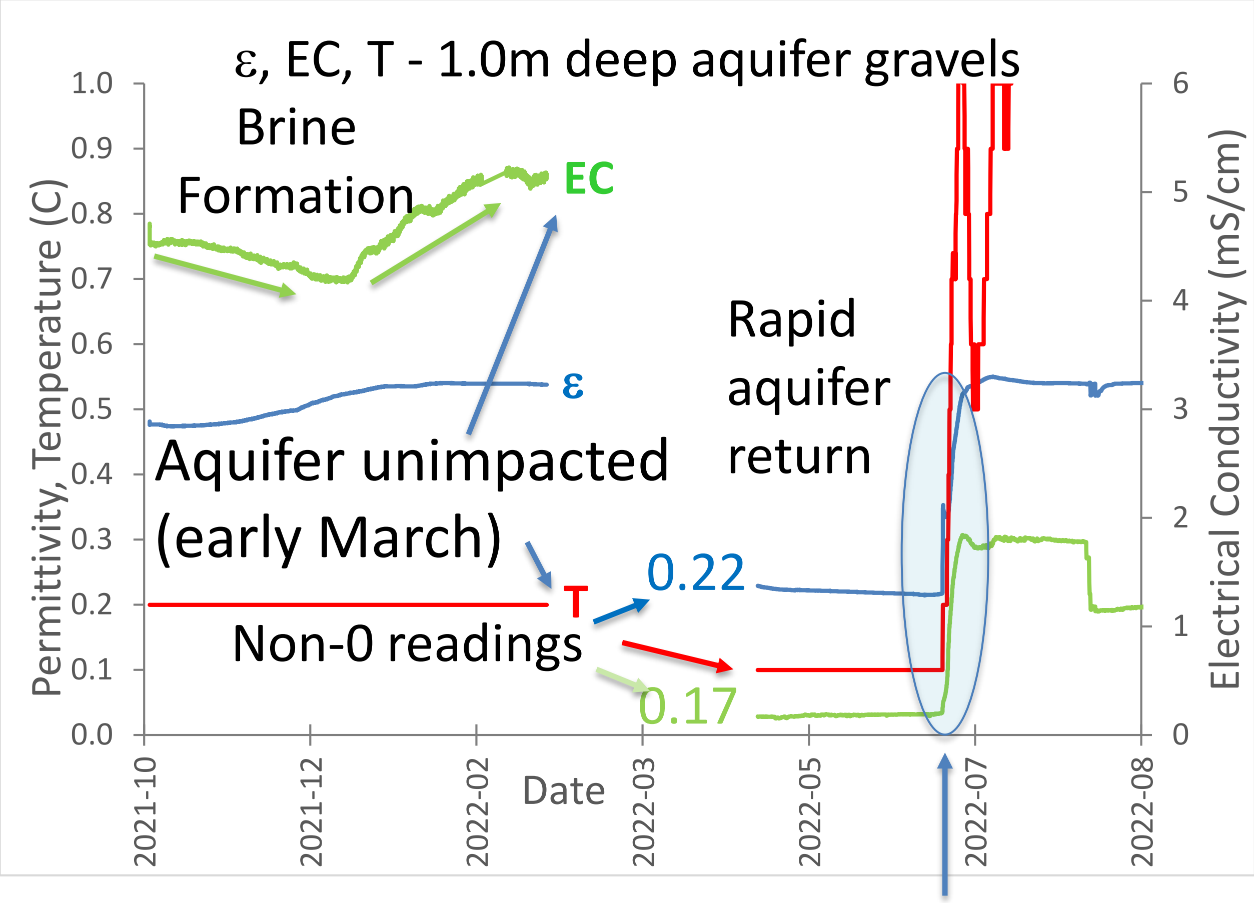
- Datalogger died in March.
- Depth-dependent profiles for freeze-up but not thaw
- Shallow sites “noisy” (insulation)
- Coherent thaw (mostly).
- Incoherent freeze-up – related to aquifer-aquitard lithologies. Directly implicates advective groundwater heat (=flow) in early winter
- T, EC, ε and pore pressure records during summer/fall indicate groundwater flow throughout summer.

ε, EC, T Sensor Data



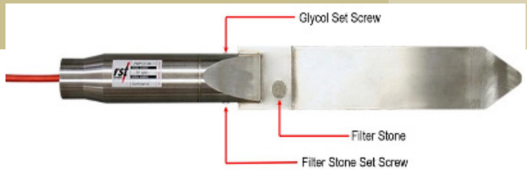
Voltammetric



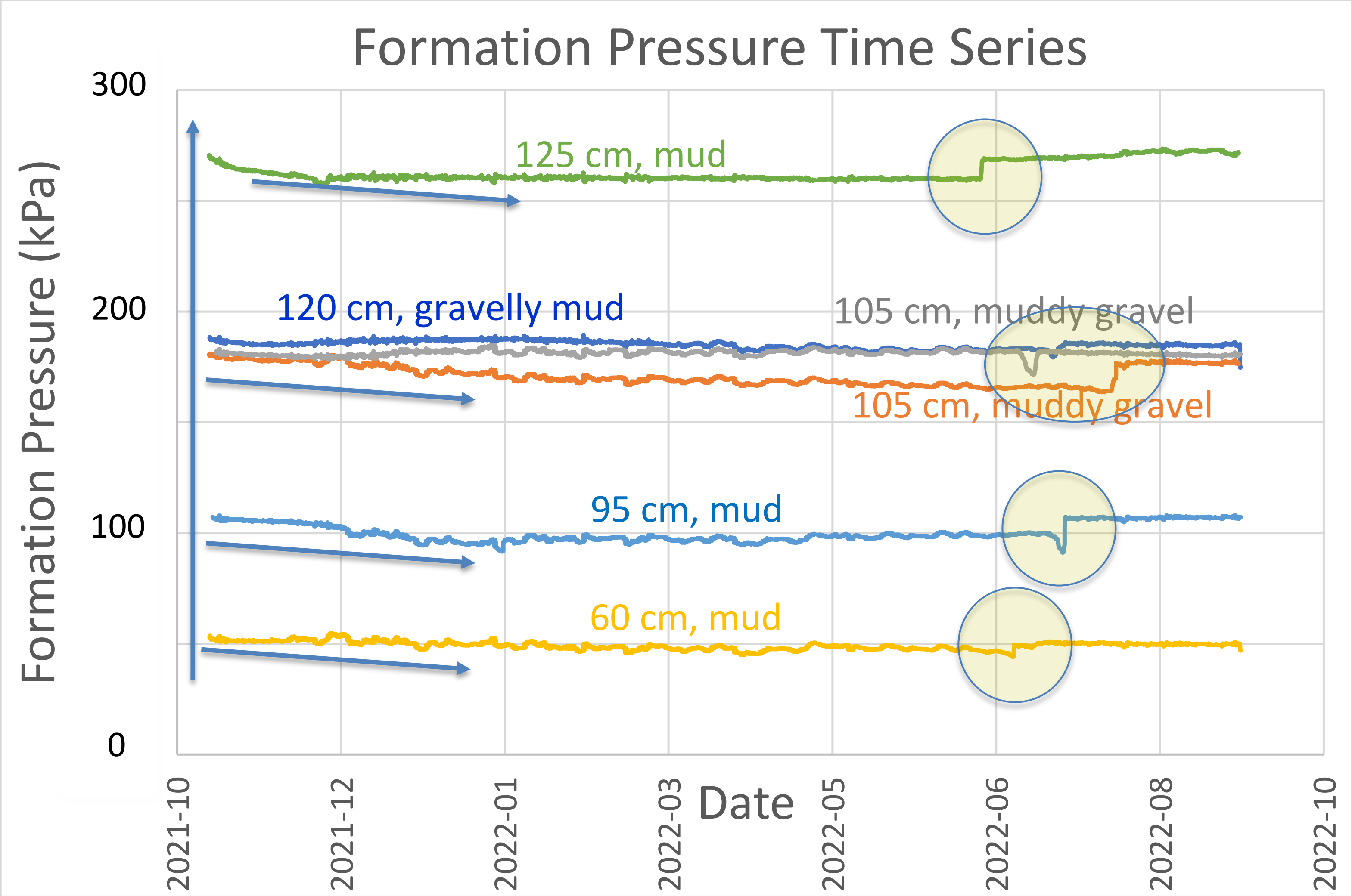


01/07/22 ← Advective heating → 28/06/22

Formation Pressure Sensor Data

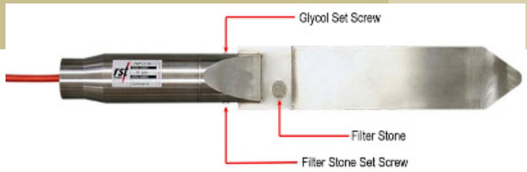


Vibrating wire

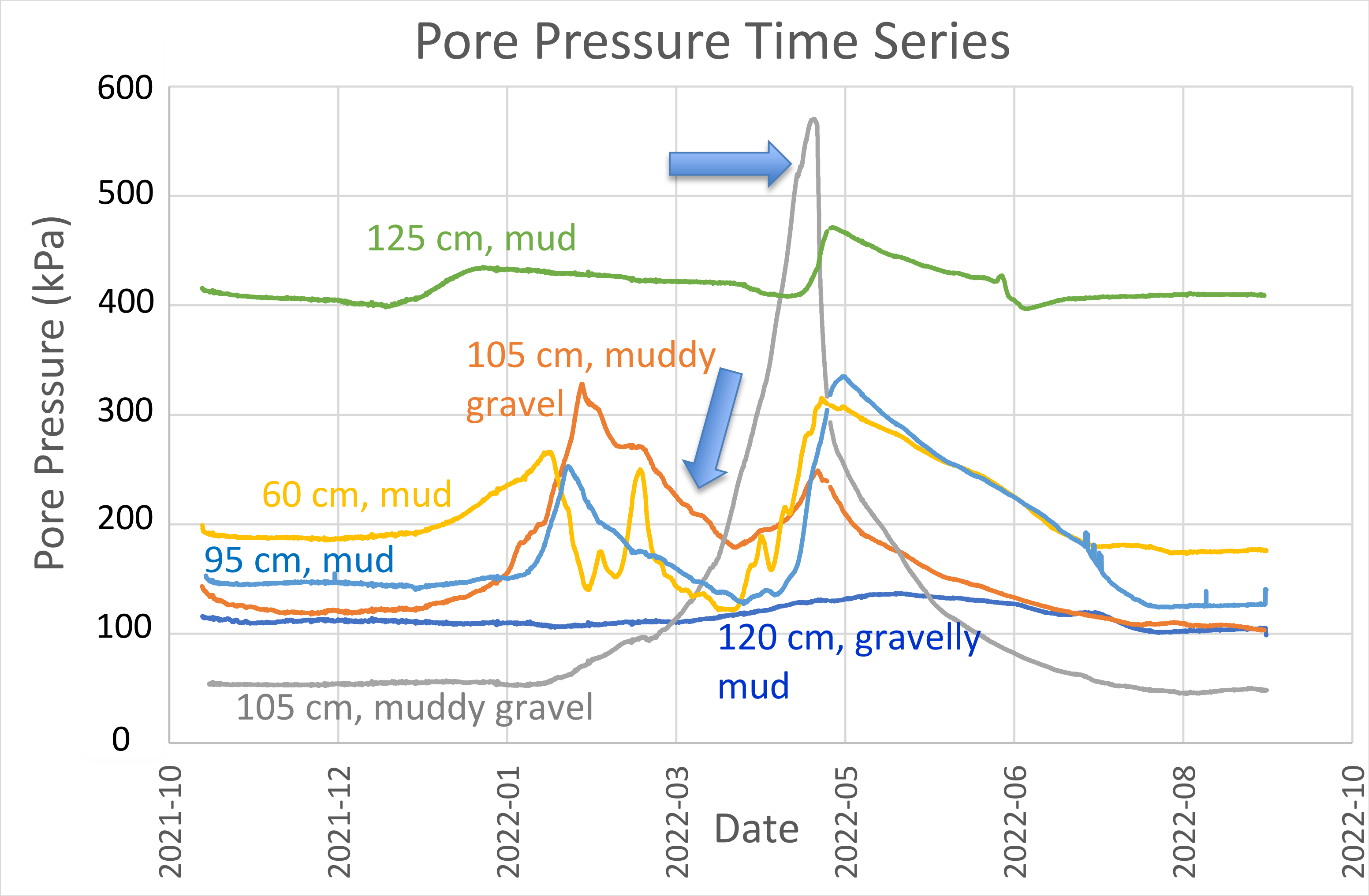


- Formation Pressure is depth-dependent
- Slight decrease with freezing
- Rapid return to non-frozen pressures

Pore Pressure Sensor Data

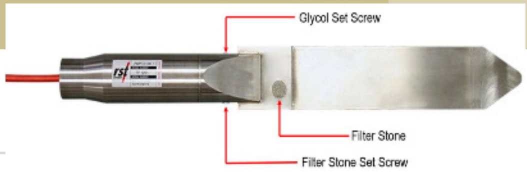


Membrane - Vibrating wire

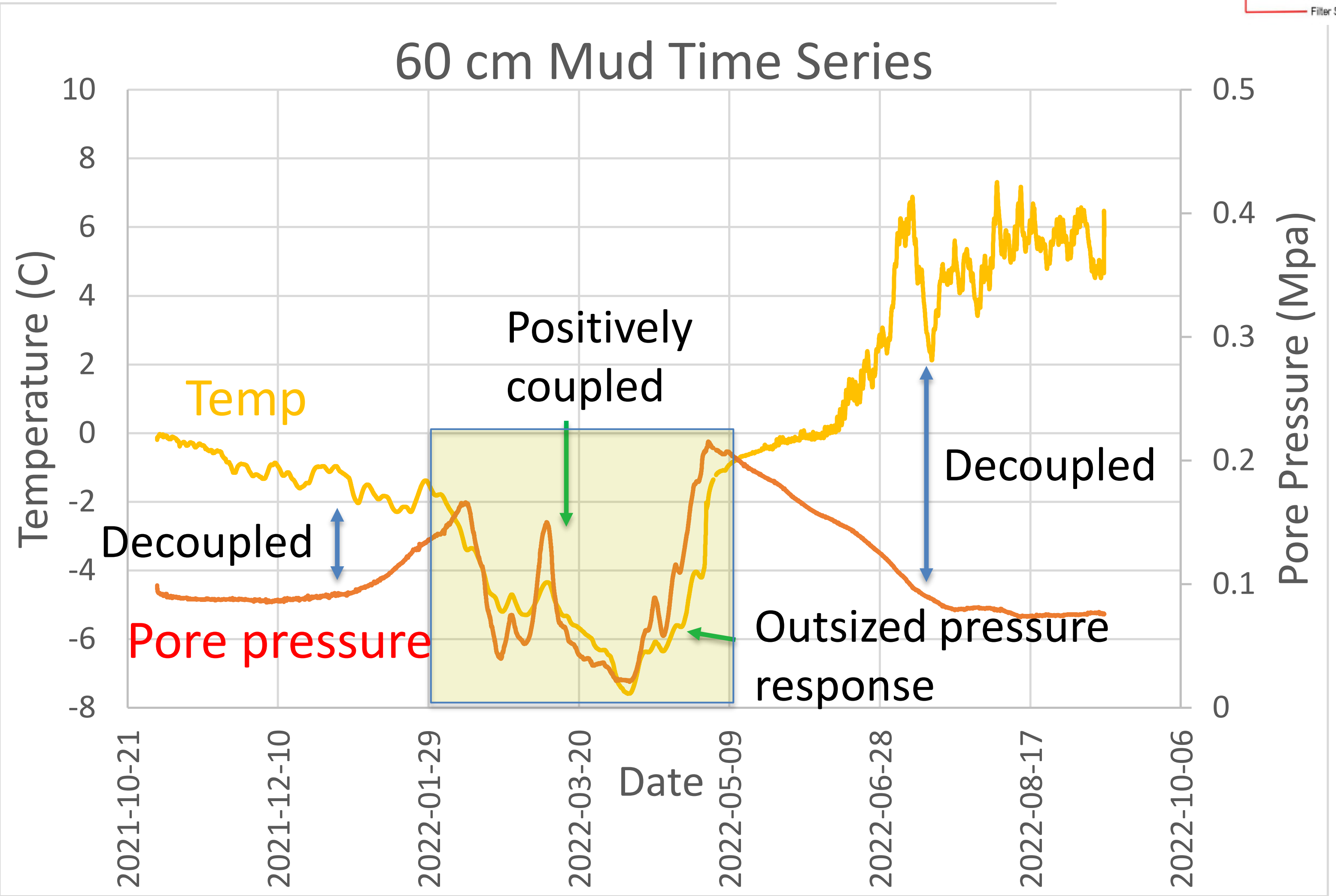


- 2 main response types

Pore Pressure Sensor Data

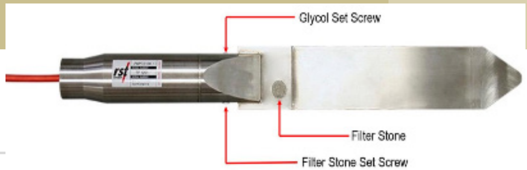


Membrane - Vibrating wire

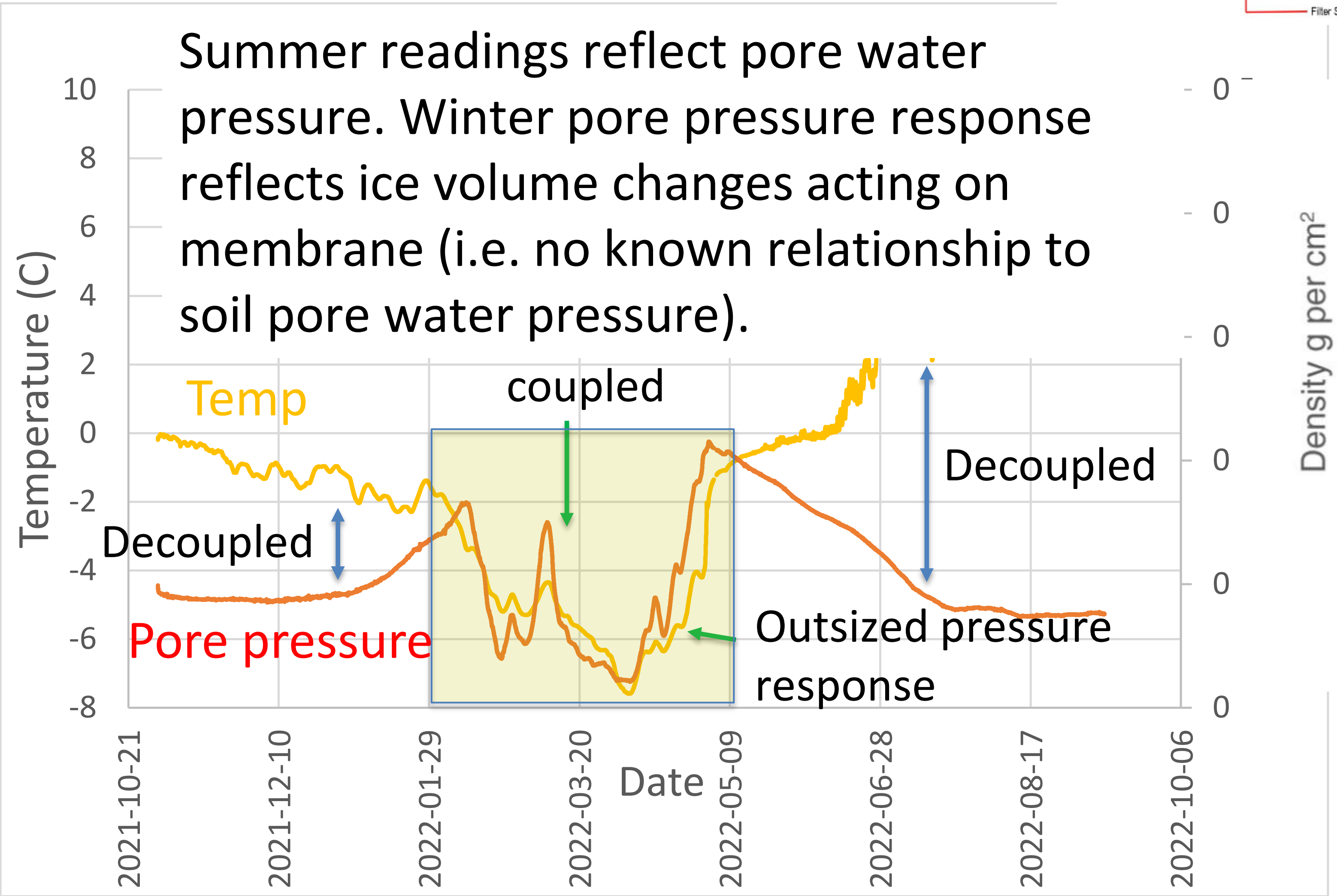


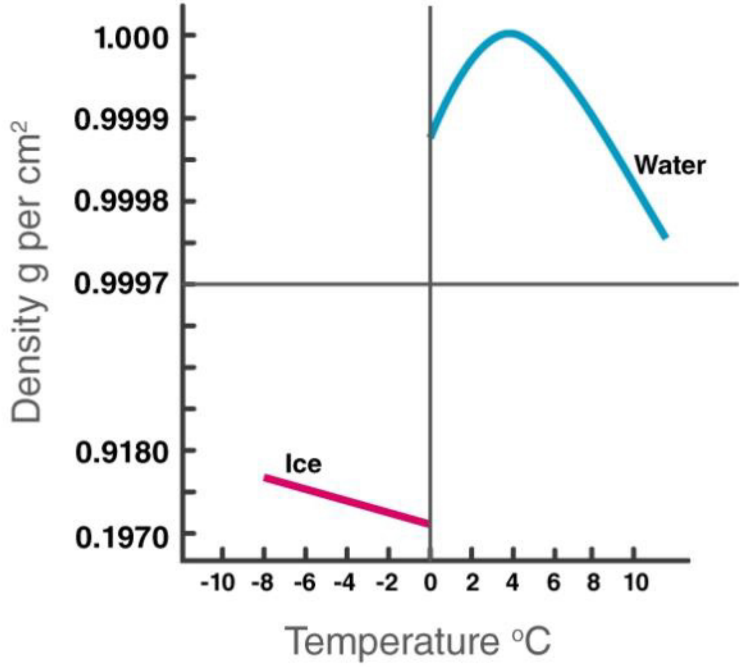
- T and pore pressure decoupled when active layer unfrozen
- T and pore pressure coupled when active layer frozen
- Large pore pressure change for small T implies small volume effect.

Pore Pressure Sensor Data

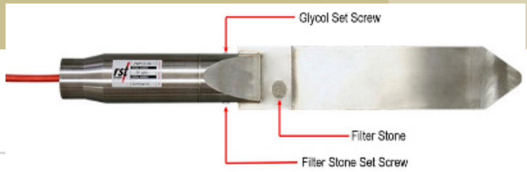


Membrane - Vibrating wire

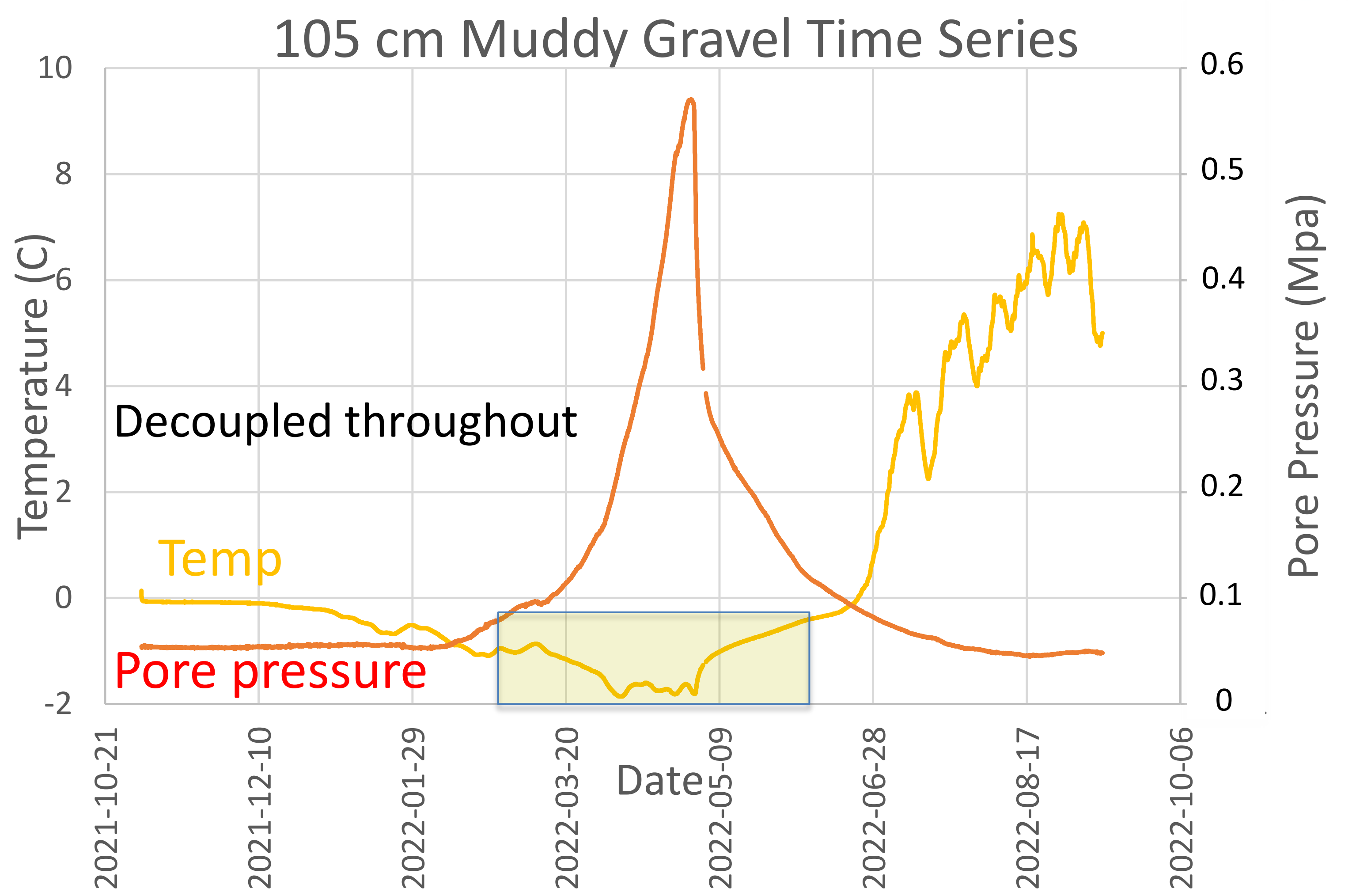




Pore Pressure Sensor Data

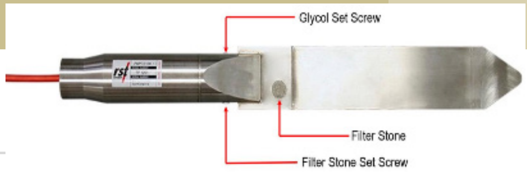


Membrane - Vibrating wire

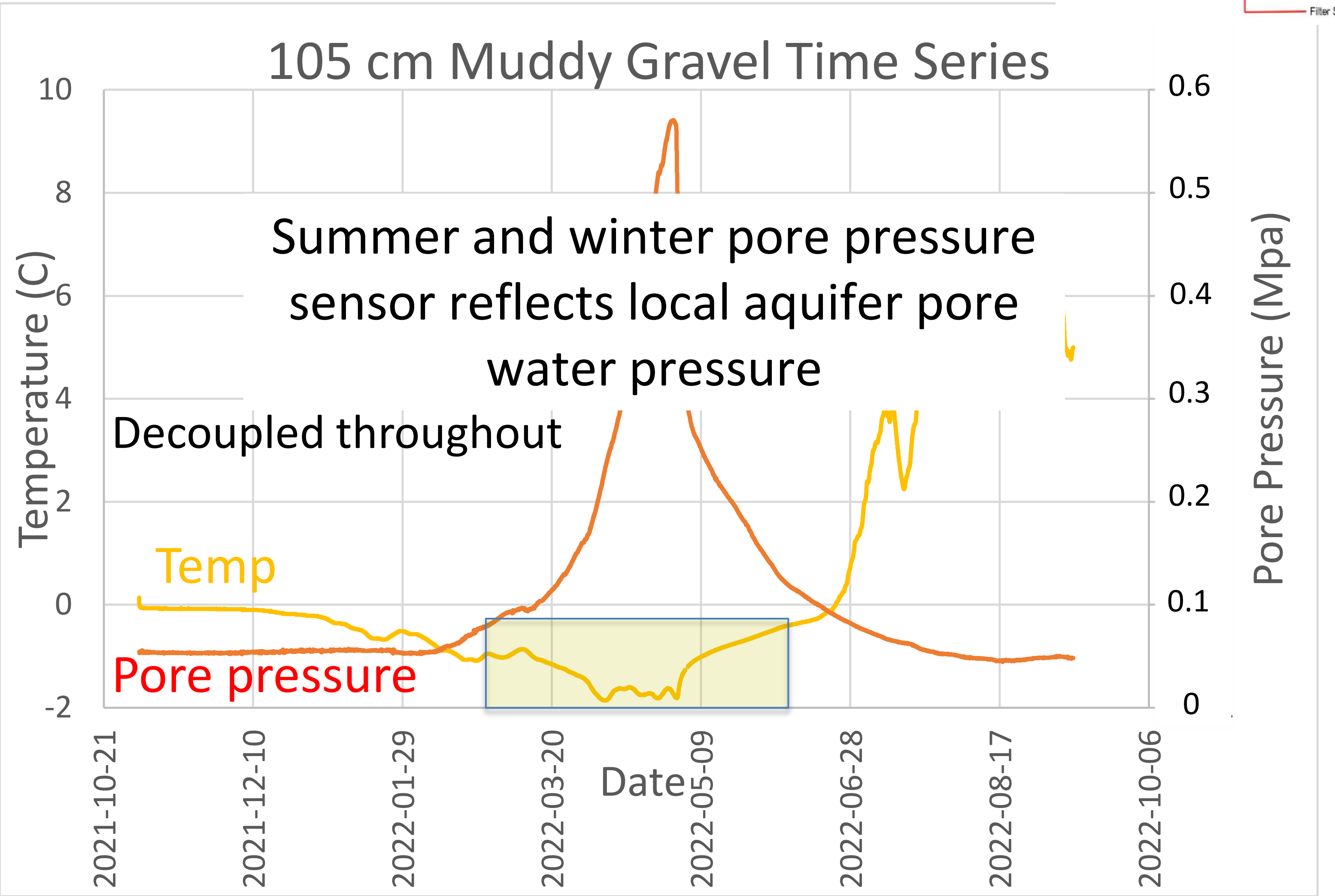


- T and pore pressure decoupled throughout
- T always above -2C
- Aquifer was confirmed as unfrozen when drilled in earliest May 2022.

Pore Pressure Sensor Data



Membrane - Vibrating wire



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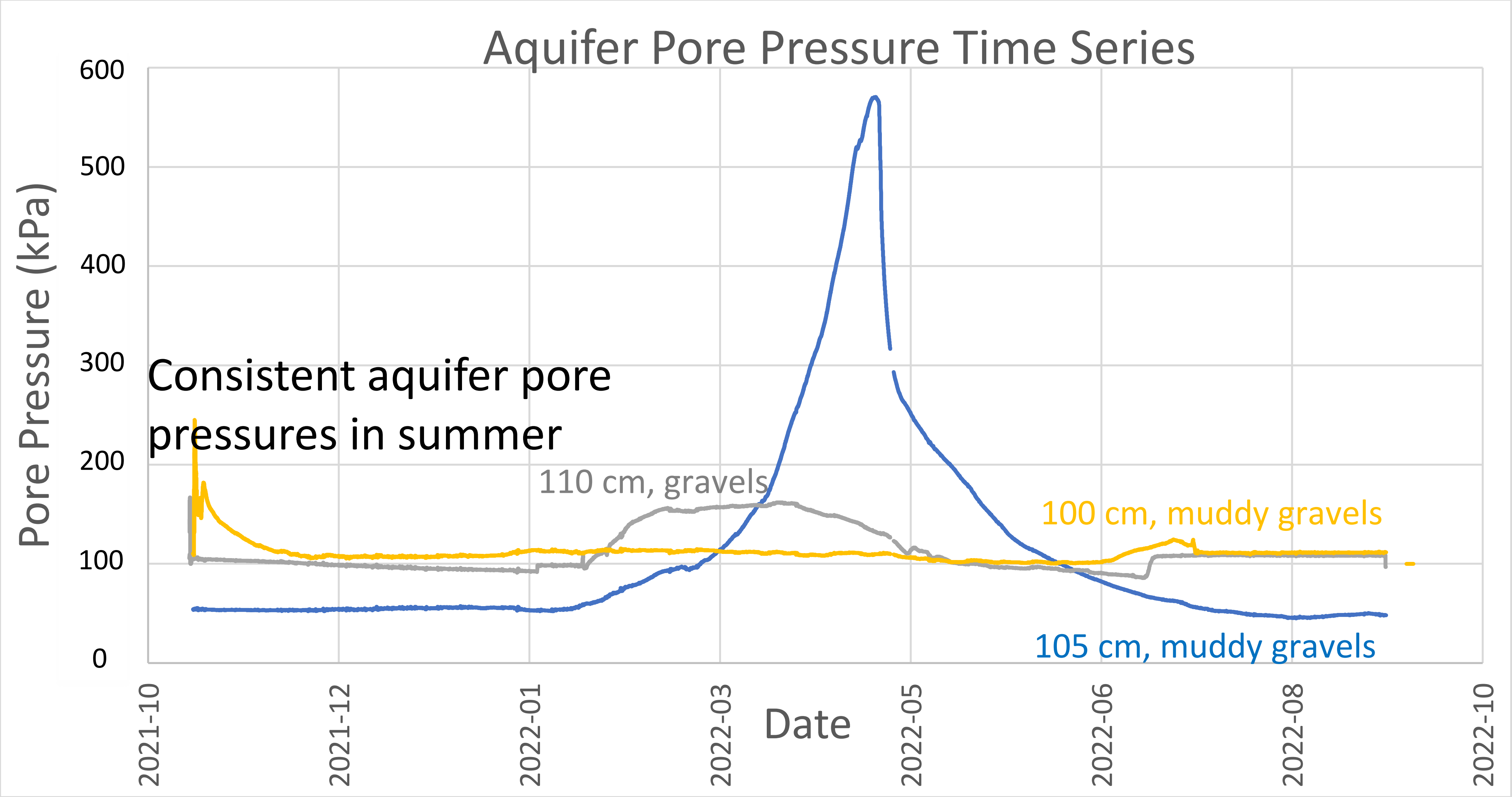
- T always above -2C
- Aquifer was confirmed as unfrozen when drilled in earliest May 2022.

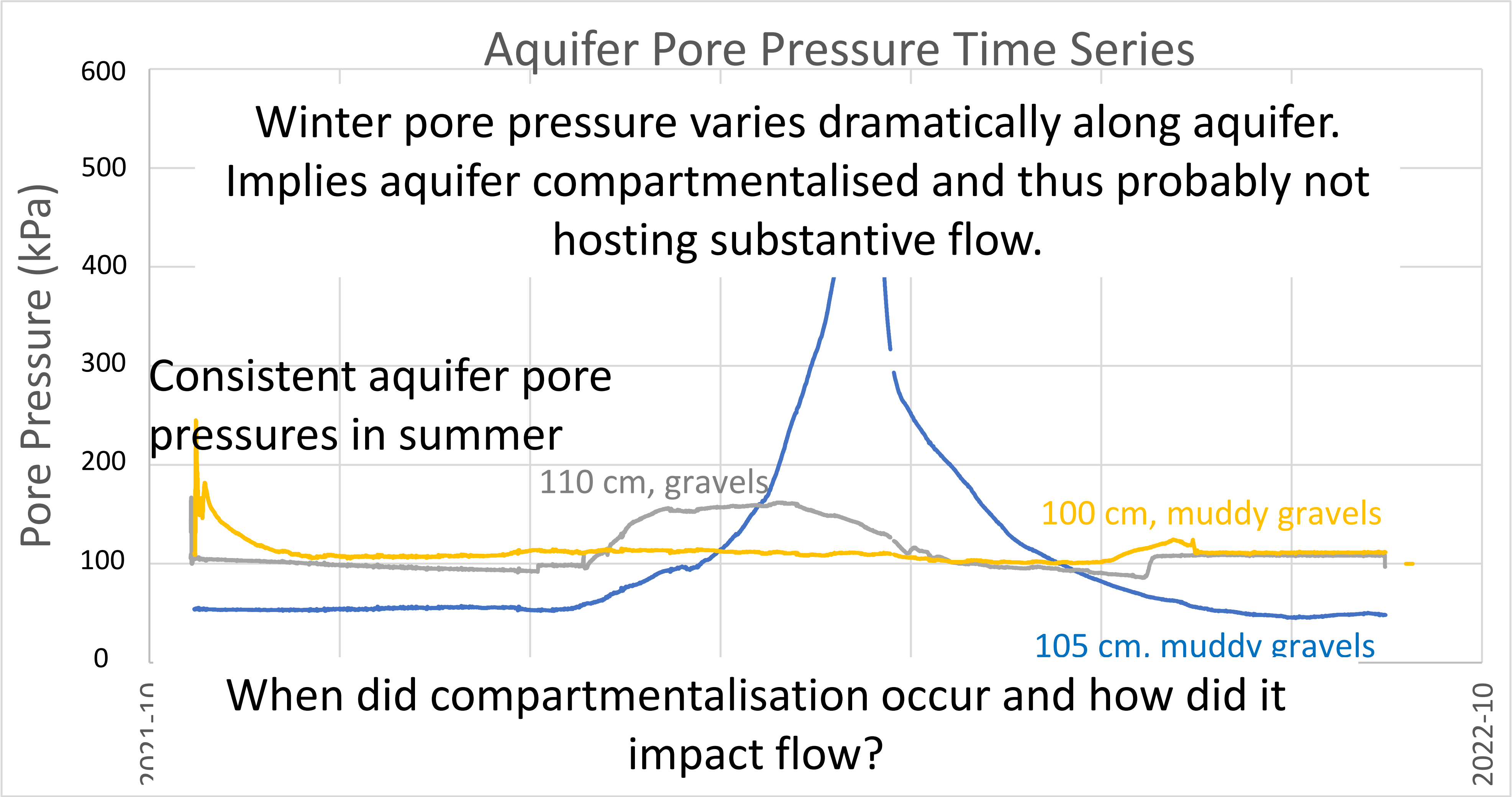
Pore Pressure Sensor Data

Membrane - Vibrating wire

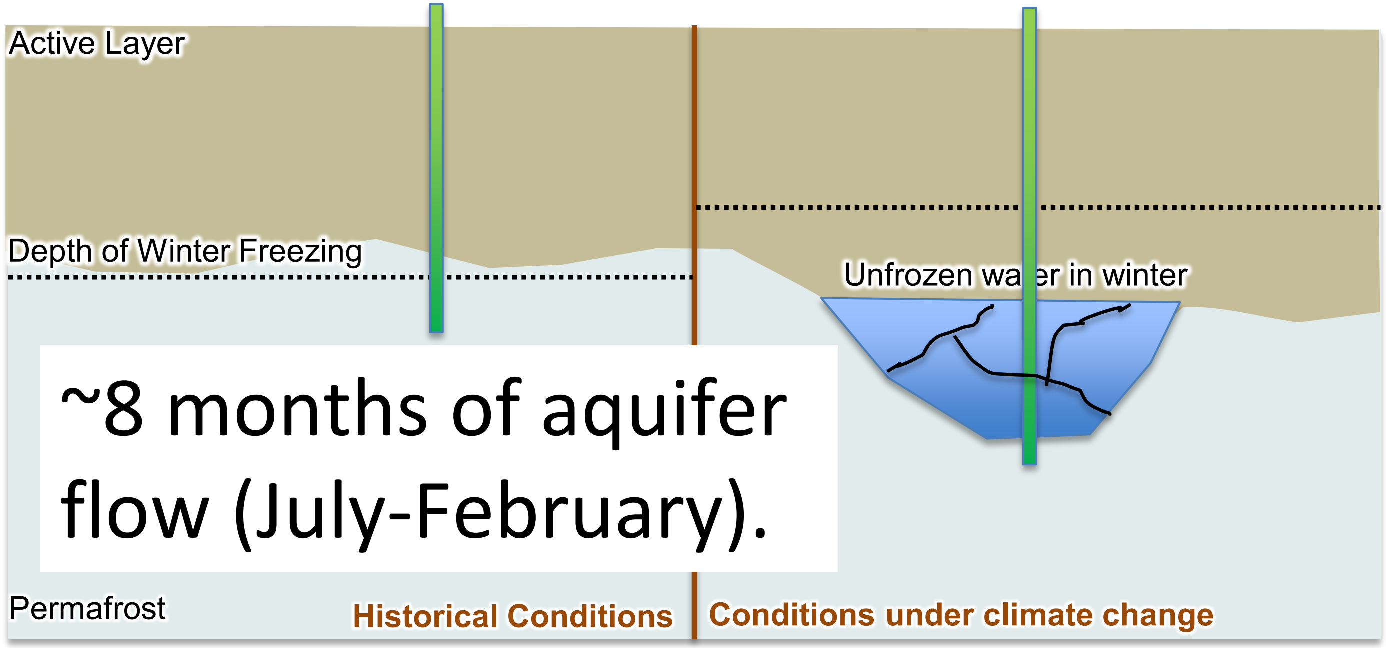


Pore Pressure Sensor Data

Membrane - Vibrating wire



Conclusions: Hydrogeologic context derived from sensor data



Successful sensor deployment has established the seasonal hydrogeochemical regime (pressure, permittivity, electrical conductivity, aquifer flow timing) for this aquifer and surrounds.

Unfrozen water in aquifer throughout winter – but winter compartmentalises aquifer (with unresolved impacts on flow).

CONTACT INFORMATION

- Paul Gammon
- 613-371-1972
- paul.gammon@nrcan-rncan.ca

Thank you!

Ressources naturelles Canada Natural Resources Canada

Environmental impact of diluted bitumen
Impact environnemental du bitume dilué

Jason M. E. Ahad[1*], Scott L. Hepditch[2], Richard Martel[2], Valerie S. Langlois[2], Leah Mindorff[1,3] and Nagissa Mahmoudi[3]

[1] Geological Survey of Canada, Natural Resources Canada, Québec, QC, G1K 9A9, Canada,
[2] Eau Terre Environnement, Institut national de la recherche scientifique (INRS), Québec, QC, G1K 9A9, Canada
[3] Department of Earth and Planetary Sciences, McGill University, Montréal, QC, H3A 0E8, Canada

NRCan's Environmental Geoscience Program 2023 Annual Presentations, 30 May

* jason.ahad@nrcan-rncan.gc.ca

Ressources naturelles Canada Natural Resources Canada

Canada

ABSTRACT

In 2019, crude bitumen production from Alberta's oil sands region totalled around 3 million barrels per day, compared to 0.5 million barrels per day for conventional crude. To transport bitumen via pipeline, it is blended with lighter hydrocarbons, yielding a less viscous, diluted bitumen referred to as 'dilbit'. Although pipelines are generally considered safer than other means of transport, major ruptures have occurred (e.g., the Kalamazoo River spill in 2010). Dilbit spills may behave differently than conventional crude oil spills, yet our understanding of the environmental impact of dilbit in freshwater systems (particularly groundwater) is limited. To address this research gap, this project is carrying out a range of activities to better understand the relationships between geochemistry, hydrology, microbiology and toxicology during natural attenuation of dilbit using controlled spill experiments. This presentation focuses on experiments conducted for 3.5 months using large unsaturated soil columns amended with Cold Lake Blend dilbit and a comparative conventional heavy crude blend. Significantly greater prevalence of malformations and induction of cyp1a were observed in hatched larvae within 34-days post-spill for both dilbit and conventional heavy crude leachate, with no discernible differences in toxicity between oil types. Noticeable temporal increases in the relative abundances of O_x and O_xS_x species were observed within the acid extractable organics fraction, but contaminants responsible for toxic effects were not evident.

[1] *https://www.capp.ca*

Background

- In 2019, crude bitumen production from Alberta's oil sands region totalled ~ 3 million barrels per day, compared to ~ 0.5 million barrels per day for conventional crude[1]
- To transport bitumen via pipeline, it is blended with lighter hydrocarbons, yielding a less viscous, diluted bitumen ('**dilbit**')
- Although pipelines are generally considered safer than other means of transport, major ruptures have occurred (e.g., Kalamazoo R., 2010)
- Dilbit spills may behave differently than conventional crude oil spills, yet our understanding of the environmental impact of dilbit in freshwater systems (***particularly groundwater***) is limited…

[1] *https://www.capp.ca*

Activities

To better understand the relationships between ***geochemistry***, ***hydrology, microbiology*** and ***toxicology*** during natural attenuation of dilbit using controlled spill experiments (lab and field):

1. **Shallow groundwater systems:**
   i. *Large column experiments (INRS Labos Lourds)*
   ii. *Large tank experiments (INRS Labos Lourds)*
   iii. *Glass tanks (CanmetENERGY)*

2. **Riverine and lacustrine systems:**
   i. *Wave-action weathering (CanmetENERGY)*
   ii. *Microbial uptake of spilled dilbit in lake sediments (Experimental Lakes Area – ELA , Northwest Ontario)*

Large Columns: Unsaturated Zone Spill

2 kg Diluted Bitumen

2 kg Conventional Heavy Crude

Control

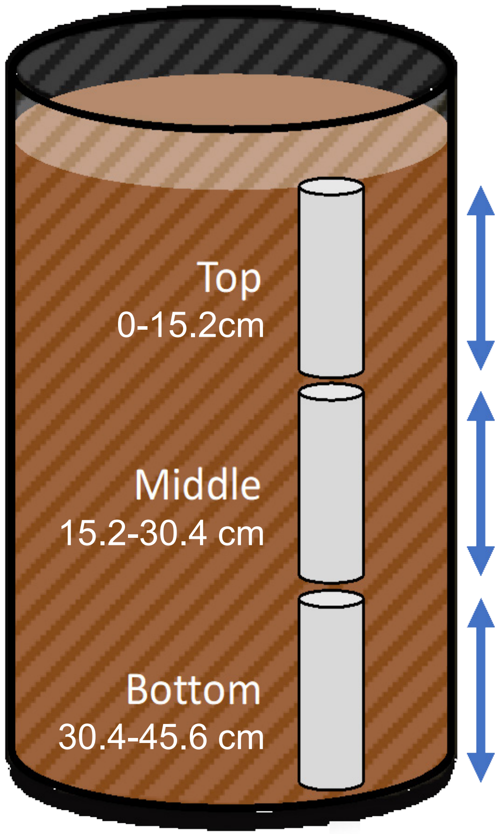
6.25 L water added each week

- 15 weeks (Aug to Nov 2019)
- Spring/autumn recharge (9 ^oC)
- pH = 4.80

Leachate (analyses carried out):

- ✓ Total organic/inorganic carbon (TOC/TIC)
- ✓ BTEX (benzene, toluene, ethylbenzene, xylenes)
- ✓ PAHs (polycyclic aromatic hydrocarbons)
- ✓ Acid extractable organics (naphthenic acids)
- ✓ Major elements & metals
- ✓ Fathead minnow (*Pimephales promelas*) toxicity assays

10 Soil Cores Collected Over 15 Weeks



Soil (analyses carried out):

- ✓ Total petroleum hydrocarbons (concentrations)
- ✓ Phospholipid fatty acids (PLFAs)
- ✓ Compound-specific $\delta^{13}C$ analysis of PLFAs
- ✓ Compound-specific $\Delta^{14}C$ analysis of PLFAs
- ✓ Microbial community analyses (16S rRNA amplicon sequencing)
- ✓ PAHs (concentrations)

Soil (analyses ongoing):

- Compound-specific ($\delta^{13}C$, $\delta^{2}H$) PAH analysis

Contents lists available at ScienceDirect

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journal homepage: www.elsevier.com/locate/envpol

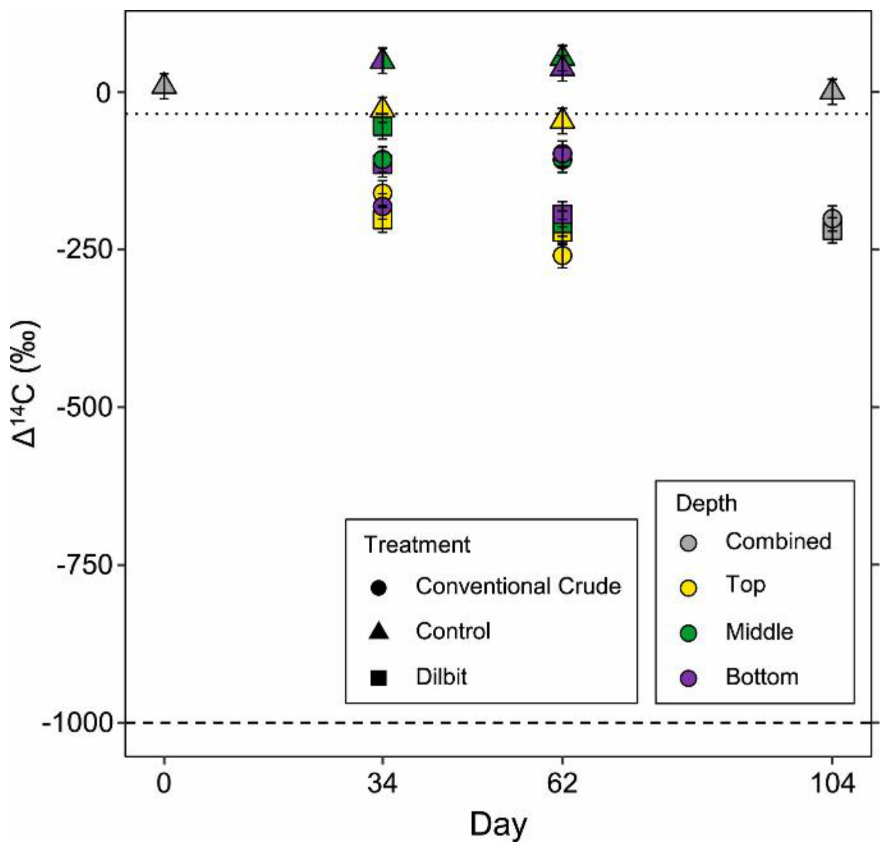
ELSEVIER

Available online 7 February 2023

Isotopic and microbial evidence for biodegradation of diluted bitumen in the unsaturated zone☆

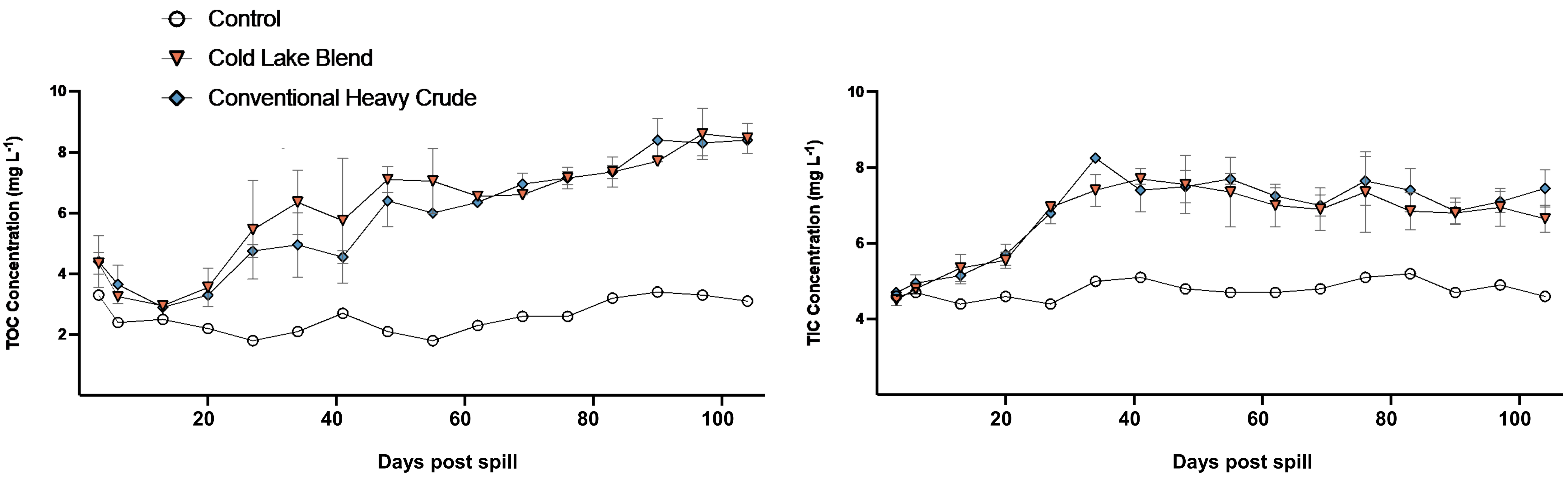
Leah M. Mindorff[a,b], Nagissa Mahmoudi[a], Scott L.J. Hepditch[c], Valerie S. Langlois[c], Samrat Alam[b], Richard Martel[c], Jason M.E. Ahad[b,*]

[a] Department of Earth and Planetary Sciences, McGill University, Montréal, QC, H3A 0E8, Canada
[b] Geological Survey of Canada, Natural Resources Canada, Québec, QC, G1K 9A9, Canada
[c] Institut National de la Recherche Scientifique (INRS), Centre Eau Terre Environnement, Québec, QC, G1K 9A9, Canada



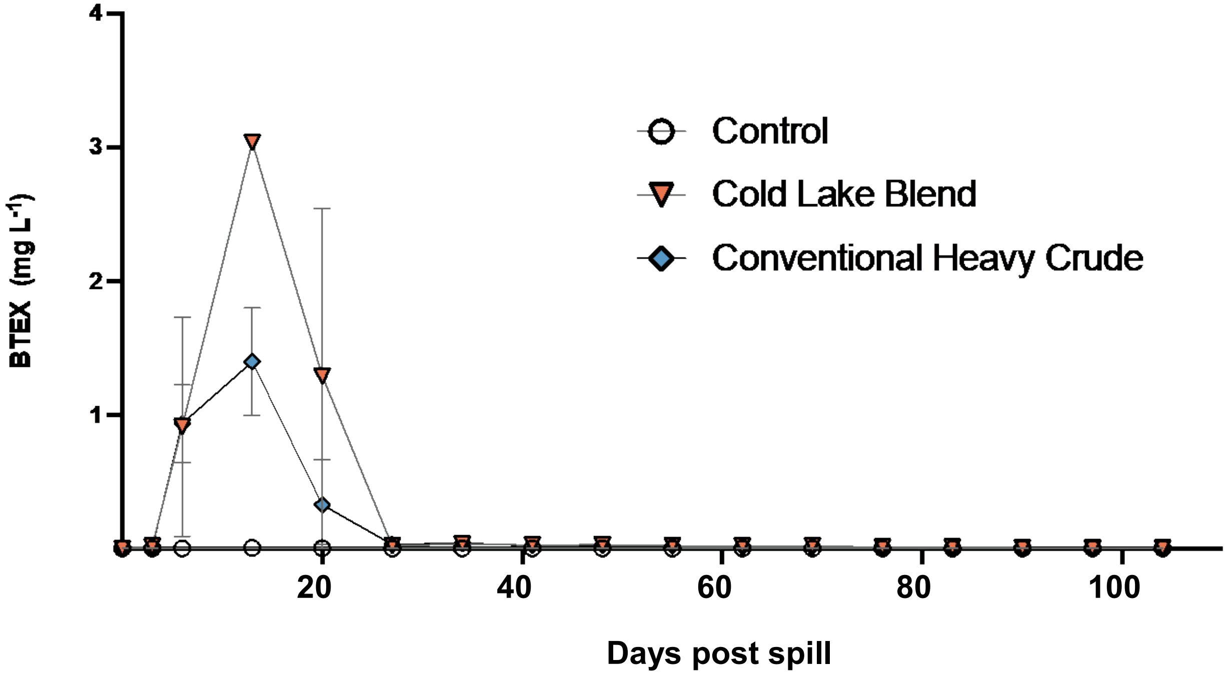
- Dilbit (DB) & conventional heavy crude (CC) showed similar biodegradation over 104 days
- Up to ~20% of carbon in microbial phospholipid fatty acids derived from CC or DB
- Abundances of *Polaromonas*, a known hydrocarbon-degrader, increased over time
- Natural attenuation potential for DB similar to CC following a vadose zone spill

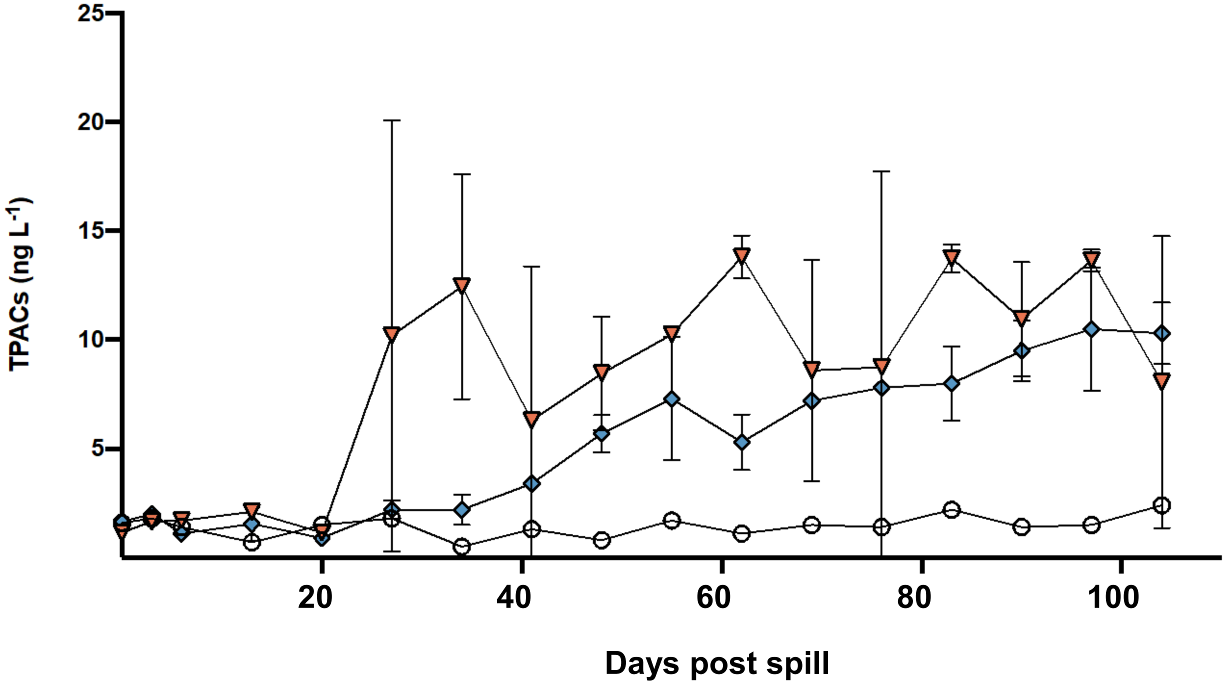
Total organic & inorganic carbon (TOC, TIC)



Column leachate

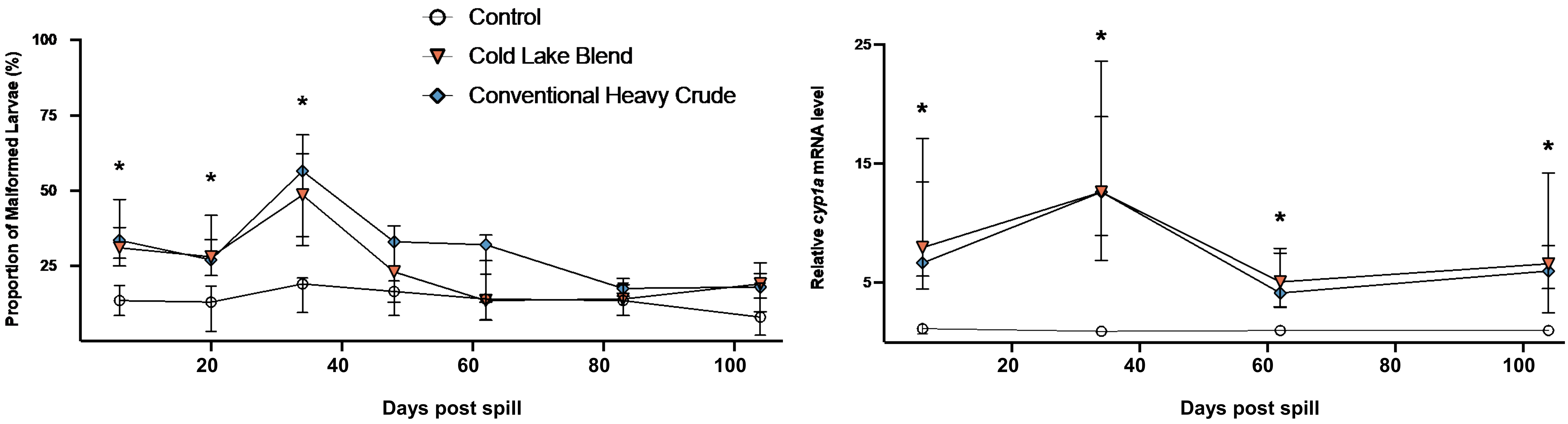
BTEX & polycyclic aromatic compounds (PACs)





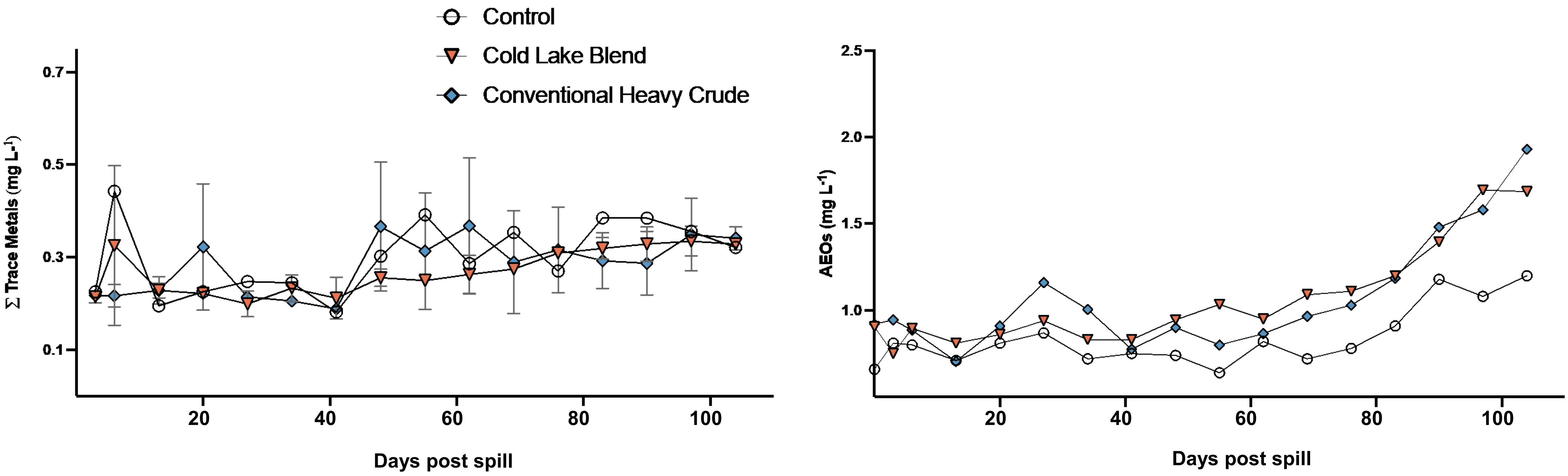
Column leachate

Toxicity and gene expression (fathead minnow)



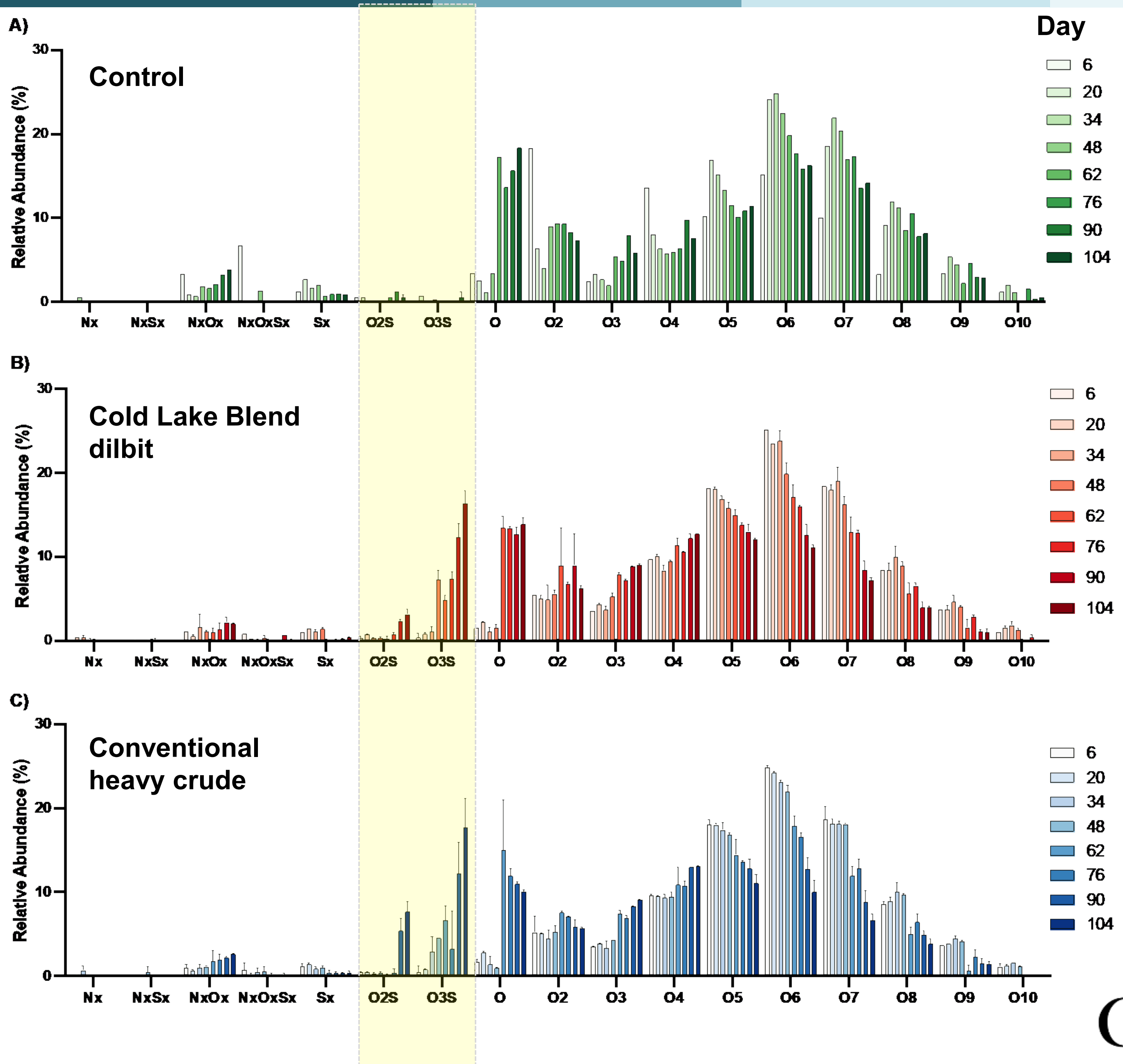
Column leachate

Trace metals & acid extractable organics (AEOs)



Column leachate

Relative abundances of species classes in AEOs



Merci!

- Delta-lab: Anna Smirnoff, Marc Luzincourt, Jade Bergeron, Samrat Alam
- ECCC: John Headley, Ian Vander Meulen
- Collaborators and In-kind Support:

CAPP INRS Institut national de la recherche scientifique
IISD Experimental Lakes Area
WARWICK THE UNIVERSITY OF WARWICK
uOttawa
Environment and Climate Change Canada Environnement et Changement climatique Canada
McGill

Ressources naturelles Canada | Natural Resources Canada

Project MOSS: Marine Oil Spill Studies

Projet EDPM: Études sur les déversements pétroliers marins

MANUEL BRINGUÉ

May 2023

Canada

ABSTRACT

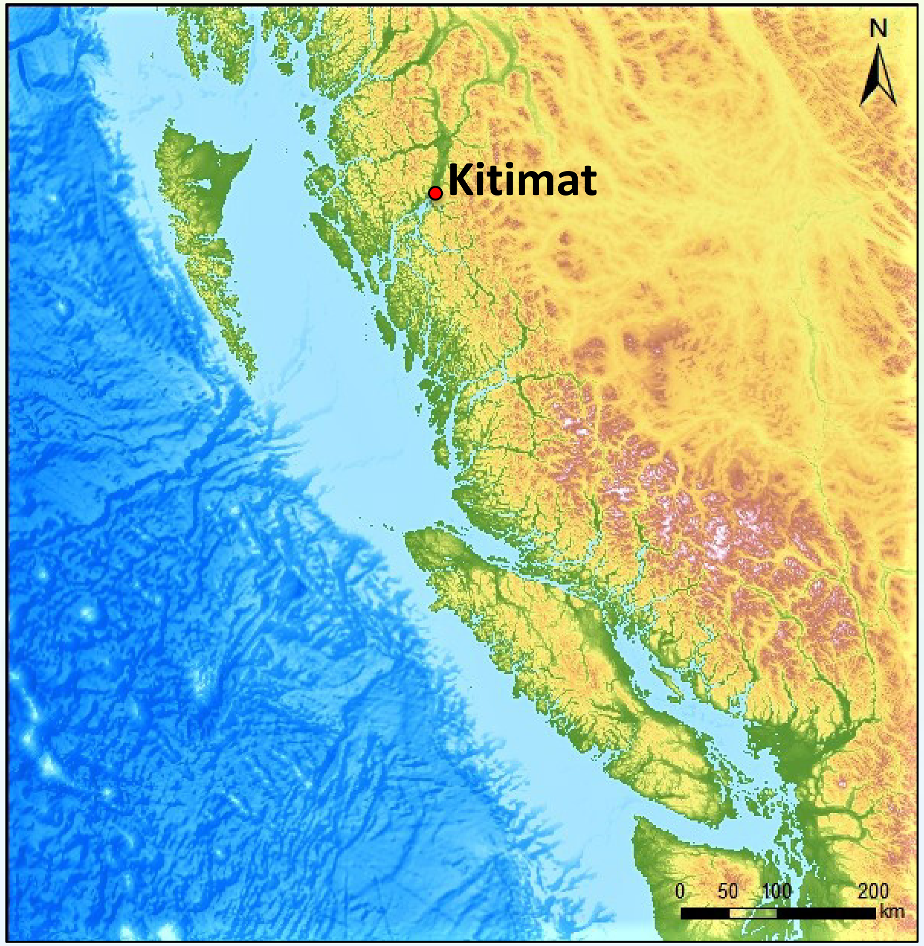
Context

Active port of **Kitimat** (BC's North Coast) is a gateway for the export of Canada's **energy** resources (LNG etc.) to international markets. Current and future projects translate into dramatically **increased tanker traffic** in Douglas Channel for decades to come.

Objectives are to determine:

- a baseline of **natural variability** (e.g., temperature, productivity) and **human impacts** in KFS on seasonal to millennial time scales;

- the capacity of in-situ microbial communities to mitigate accidentally-released petroleum products **under reduced O_2 conditions**.



PROJECT MEMBERS

- Manuel Bringué (PL), Jennifer Galloway, Omid Ardakani, Andy Mort, Rachel Robinson (GSC-Calgary)
- Jason Ahad (GSC-Québec)
- Michael Parsons (GSC-Atlantic)
- Paul Gammon (GSC-Ottawa)
- Gwyn Lintern, Cooper Stacey (GSC-Pacific)
- Heather Dettman, Nayereh Saborimanesh, Christine Ridenour (CanmetENERGY-Devon)

- Sophia Johannessen (DFO, IOS Sidney)
- Kenneth Lee (DFO, BIO Dartmouth)
- Charles Greer (NRC, Montréal)
- Vera Pospelova (U. of Minnesota)
- Casey Hubert, Jianwei Chen, Oye Adebayo – UofC

Acknowledgements

Gitga'at Nation (Hartley Bay) – Chris Picard

Haisla Nation (Kitamaat Village)

PROJECT OVERVIEW

1. Surface sediment and sediment trap component – *CALIBRATION*

To assess **spatial distribution** and **seasonal variability** in phytoplankton communities and geochemical indicators. Assess **human impacts**.

2. Sediment cores component – *RECONSTRUCTIONS*

- Short (box) cores: to **reconstruct past environmental variability** and trace possible **human impacts** over the last ~ 120 yrs

- Long (piston) cores: to reconstruct **natural variability** over the Holocene (last ~ 11,000 years), for context

3. Microcosm experiments – *LAB TESTS*

Lab-based experiments testing the capacity of in-situ microbial communities (water + sediment) to degrade petroleum products **under a range of O_2 conditions**.

2.

1.

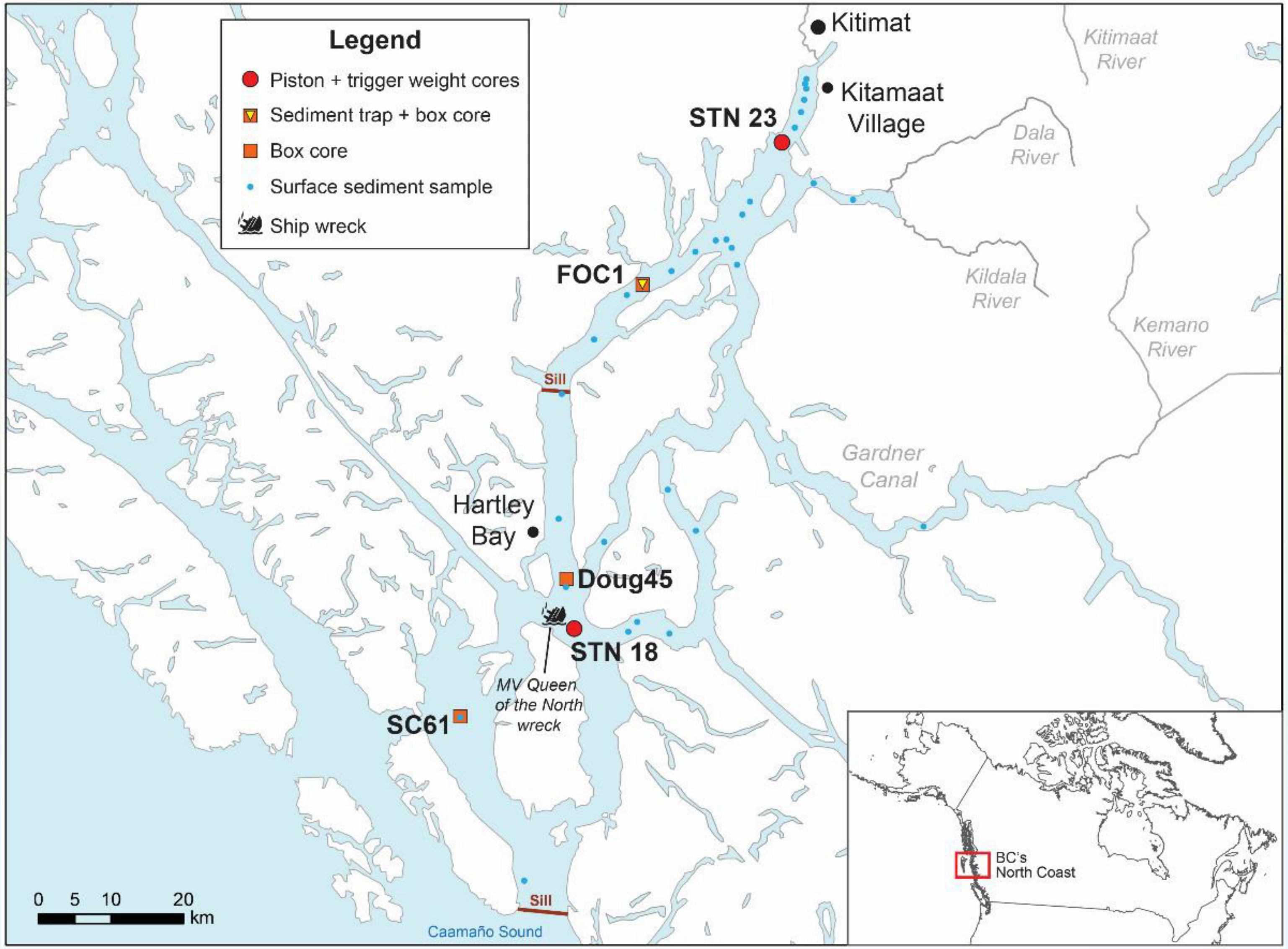
3.

Kitimat Fjord System

- Complex fjord system on N. BC coast
- Hydrological "head" is Gardner Canal
- Seasonally hypoxic
  - (~ 2.5 mL/L) at depth
  - 37 samples

- Sediment samples*
  - Sediment trap (FOC1) (~ 3 yrs)
  - Surface sediment (n = 37)
  - Box cores (n = 3)
  - Piston cores (n = 2)

* All material provided by PGC & DFO



Preliminary results: Surface sediment

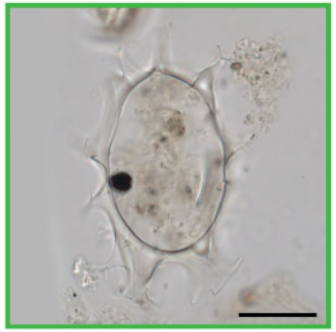
<u>Palynology:</u> Dinoflagellate cysts and other organic-walled microfossils as (paleo)environmental indicators

Alexandrium spp.

Operculodinium centrocarpum (WD'66)

Spiniferites ramosus

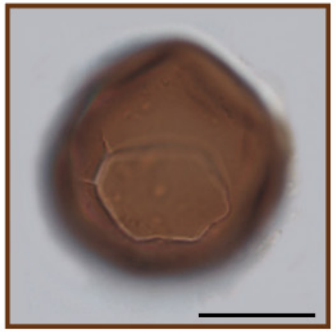
Spiniferites bentori



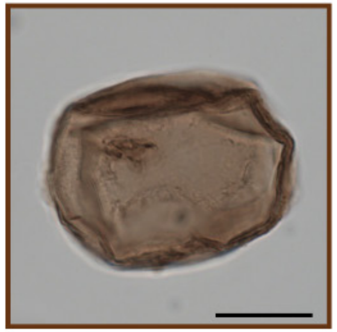
Spiniferites elongatus

Cyst of *Penta-pharsodinium dalei*

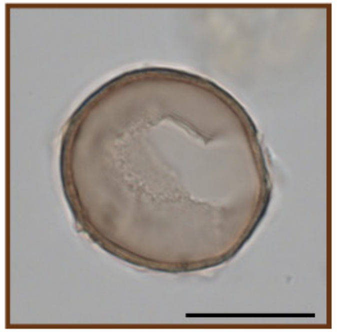
All scale bars are **20 µm**



Brigantedinium spp.



Dubridinium spp.



Cyst of *Protoperidinium americanum*

Taxa reported from the first 7 samples

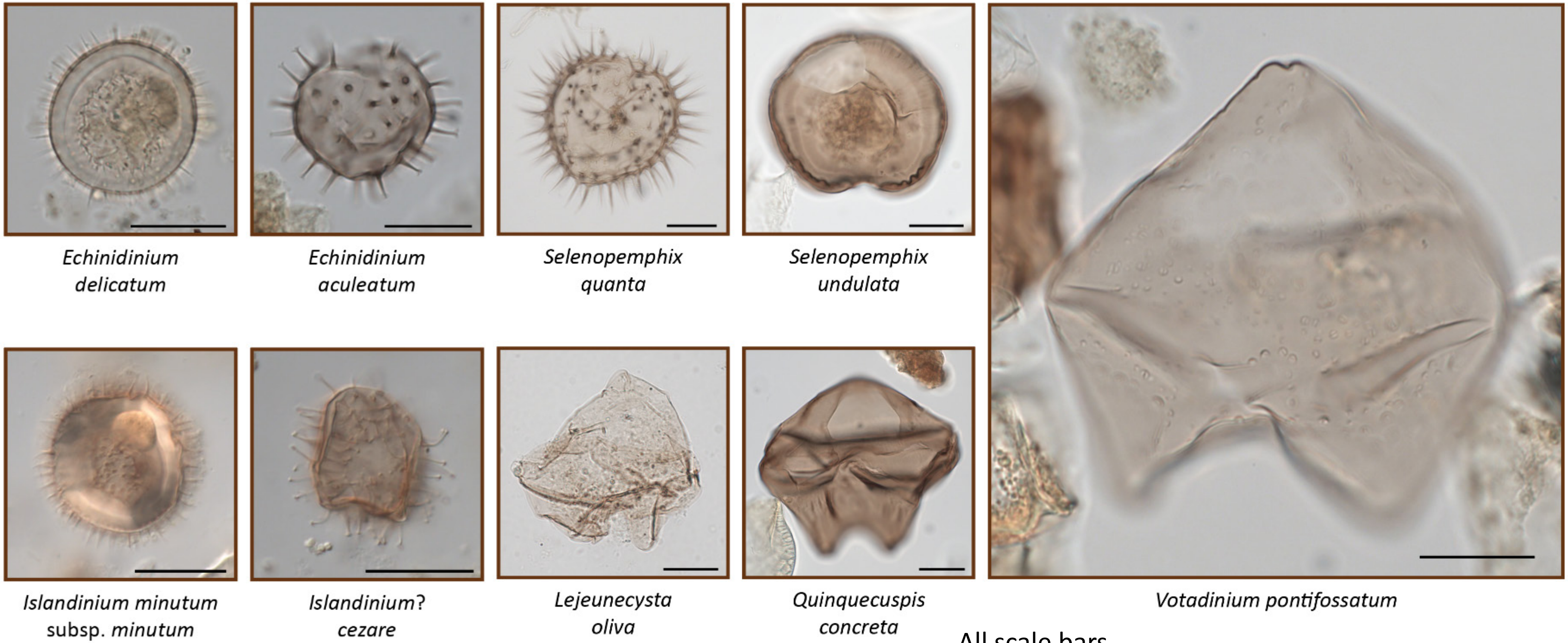
45 cyst taxa, incl. 6 informal types

Average relative abundances:

Brigantedinium spp.	35.8%
Islandinium minutum subsp. *minutum*	8.6%
Cyst of *Archaeperidinium minutum*	6.3%
Cyst of *Protoperidinium americanum*	6.1%
Quinquecuspis concreta	5.8%
Dubridinium spp.	5.8%
Echinidinium delicatum	3.7%
Islandinium pacificum	3.2%
Spiniferites ramosus	3.1%
Operculodinium centrocarpum s.l.	2.9%
Cyst of *Archaeperidinium saanichi*	2.8%
Echinidinium aculeatum	2.5%
All others	<2%

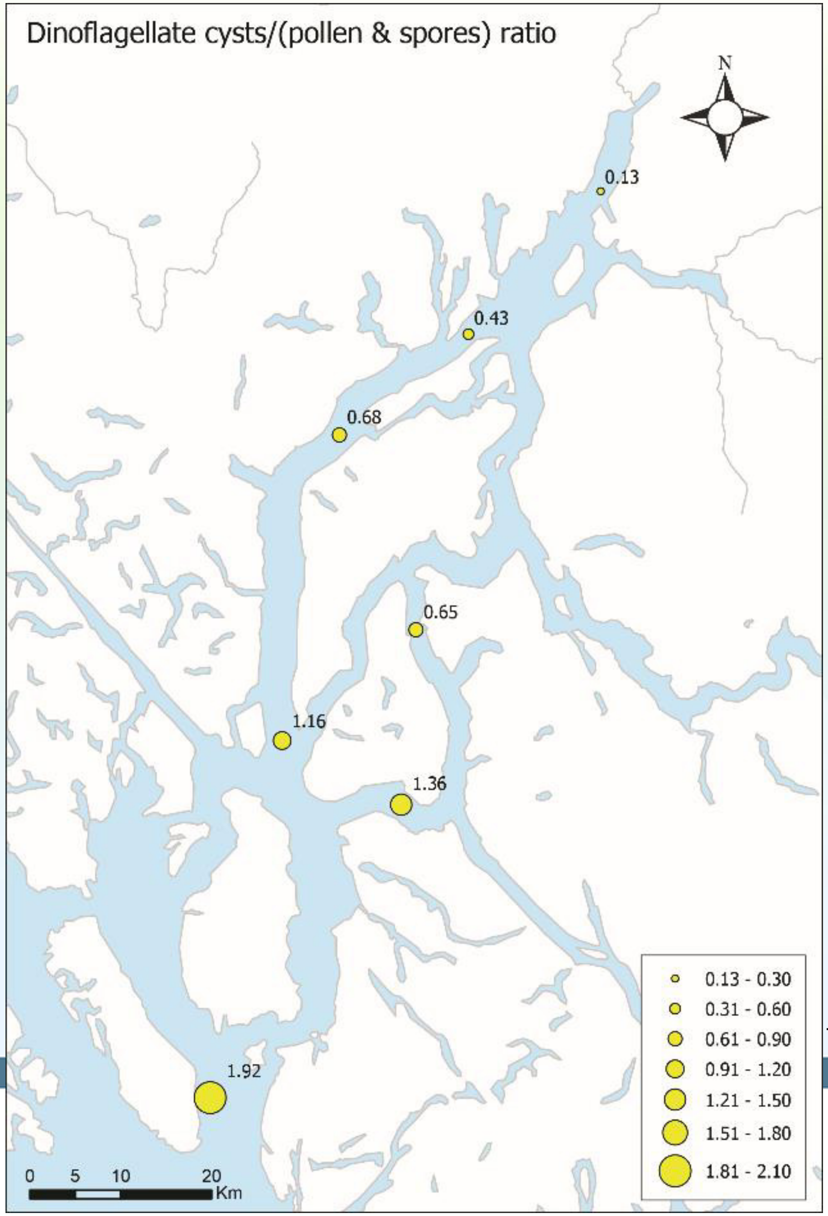
Preliminary results: Surface sediment

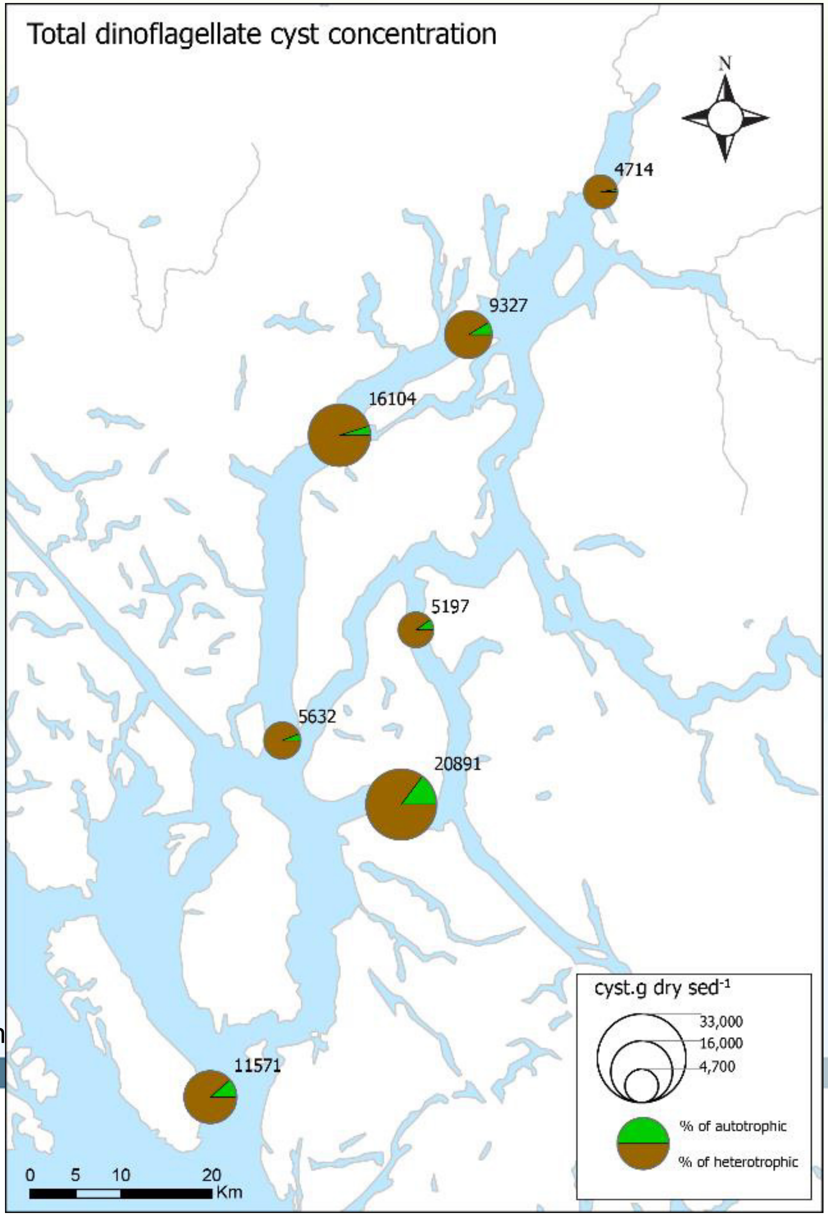
<u>Palynology:</u> Dinoflagellate cysts and other organic-walled microfossils as (paleo)environmental indicators

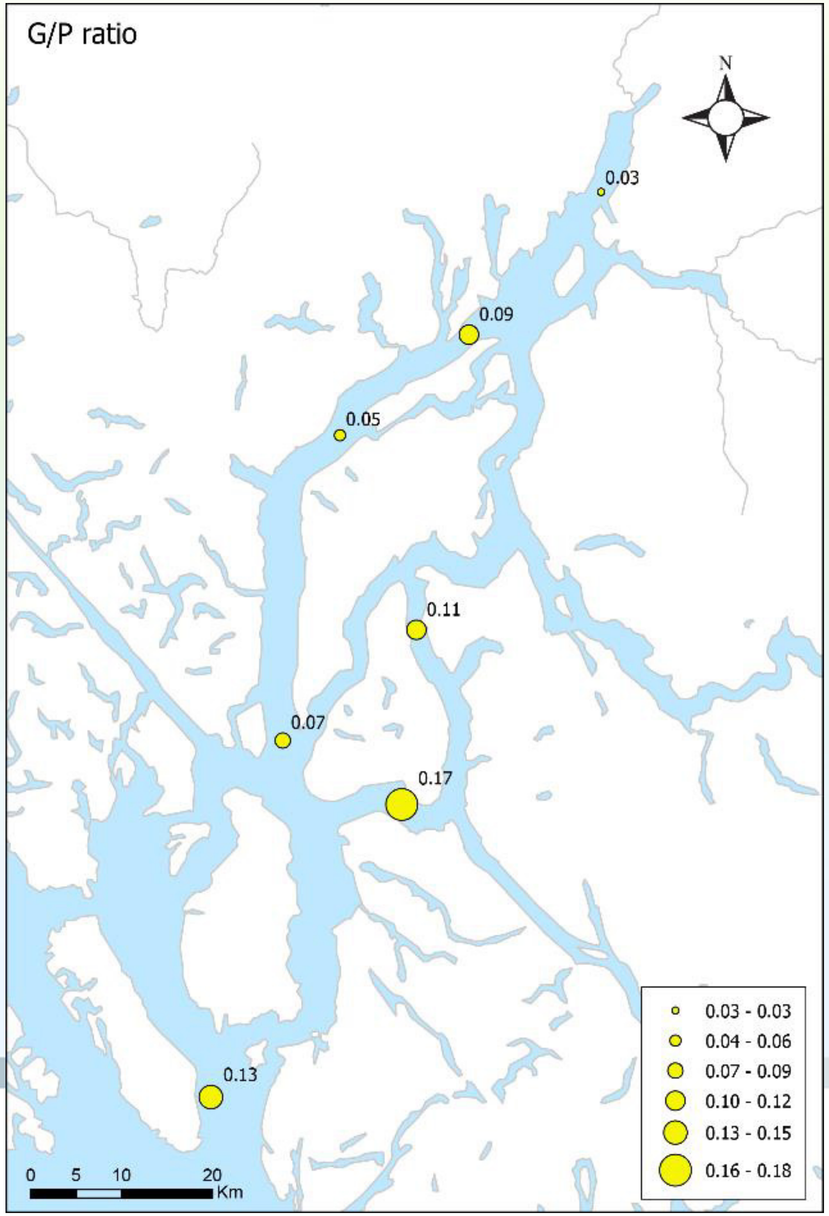


All scale bars are **20 µm**

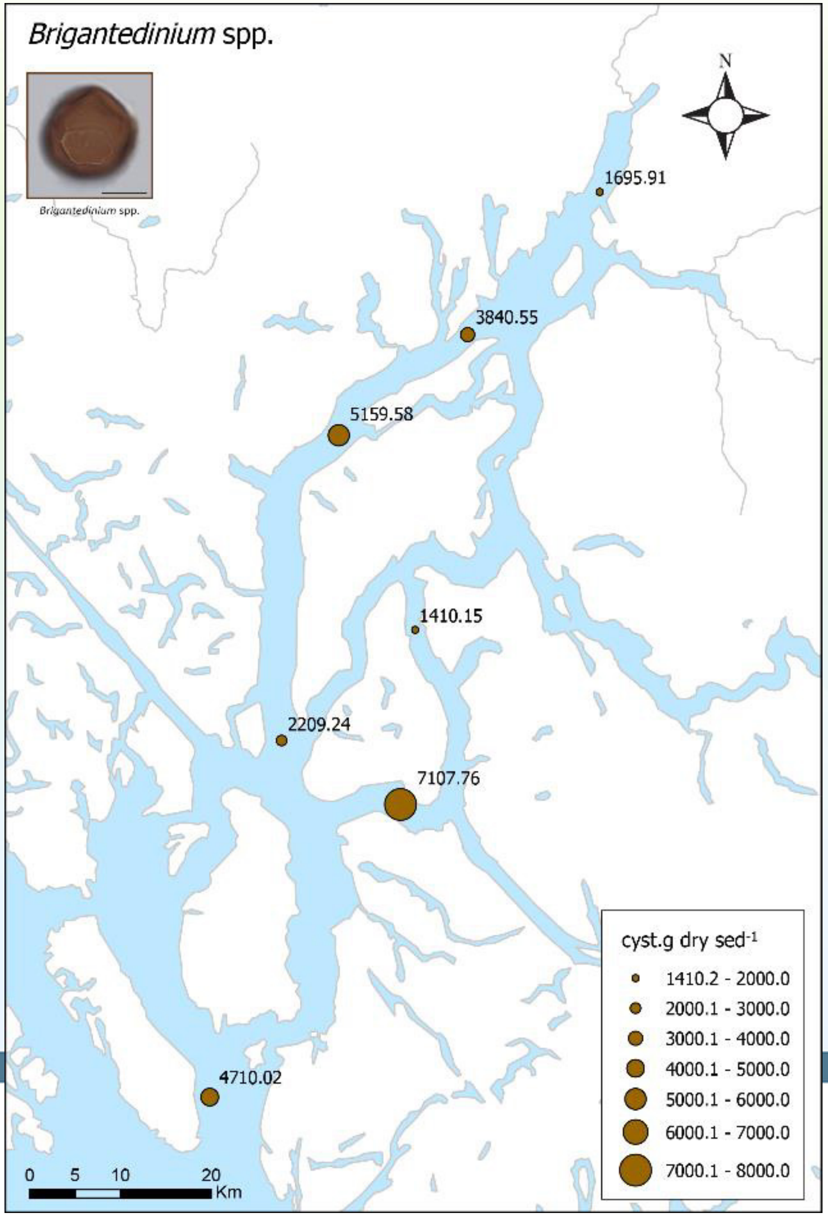
Preliminary results: Surface sediment







Preliminary results: Surface sediment



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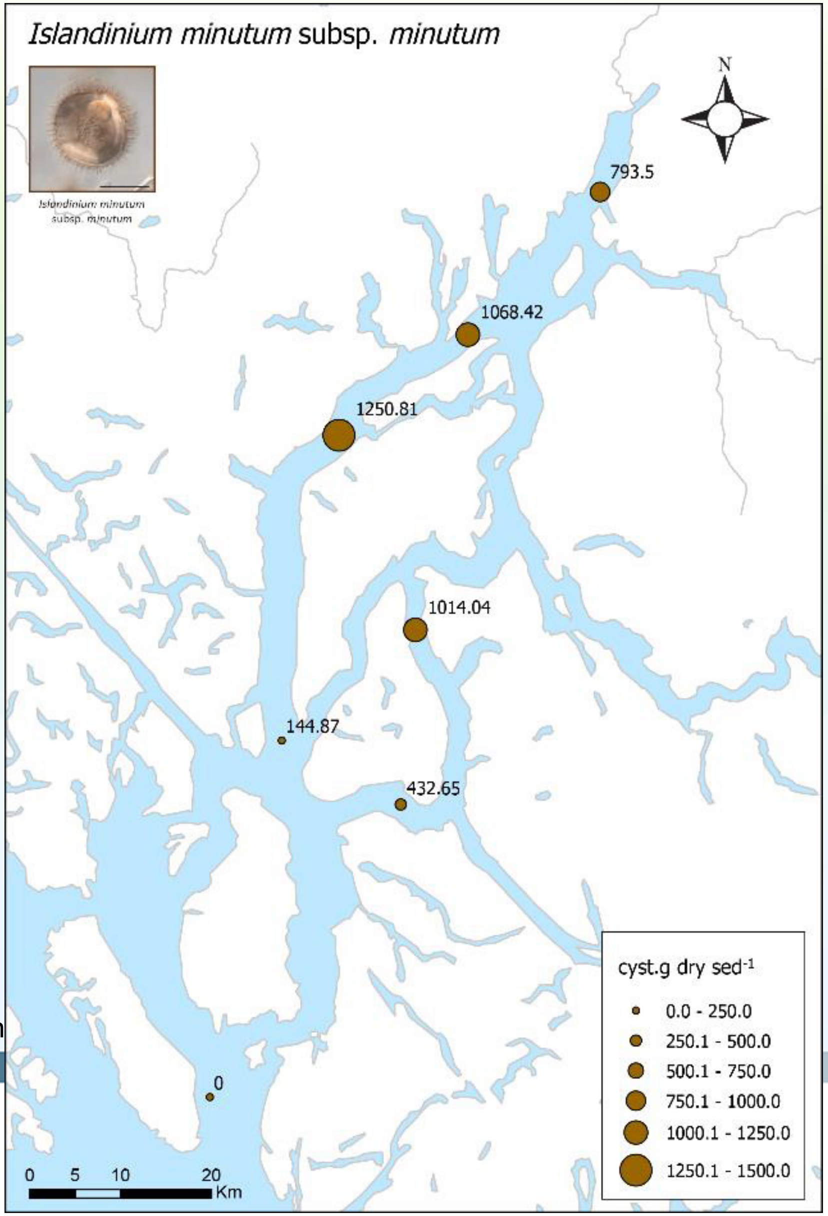
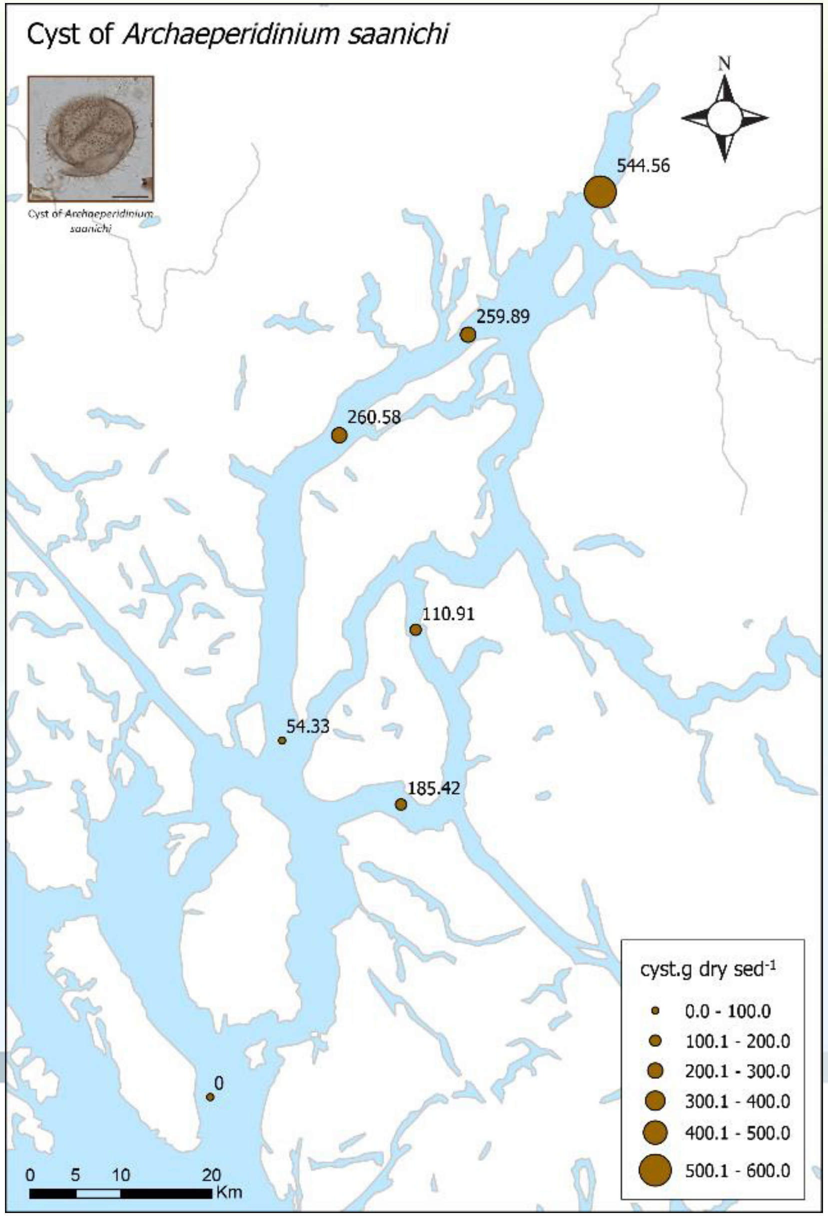
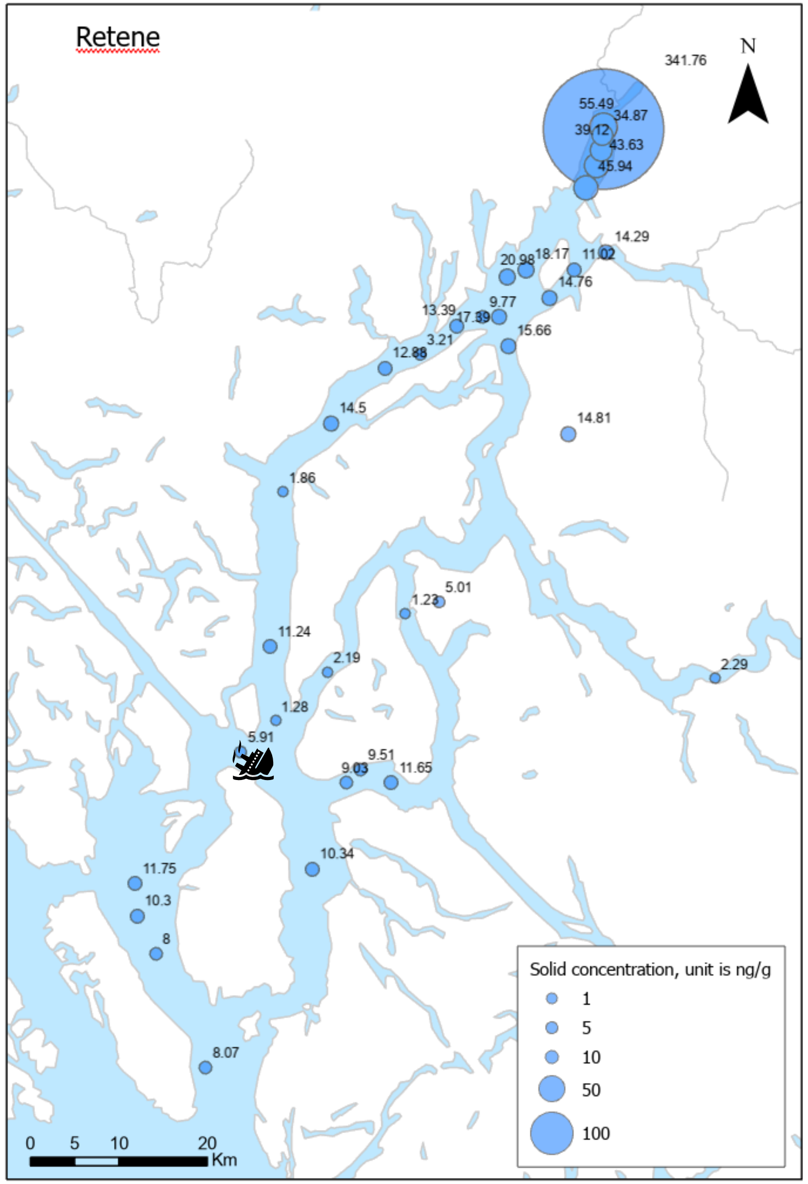




Preliminary results: Surface sediment



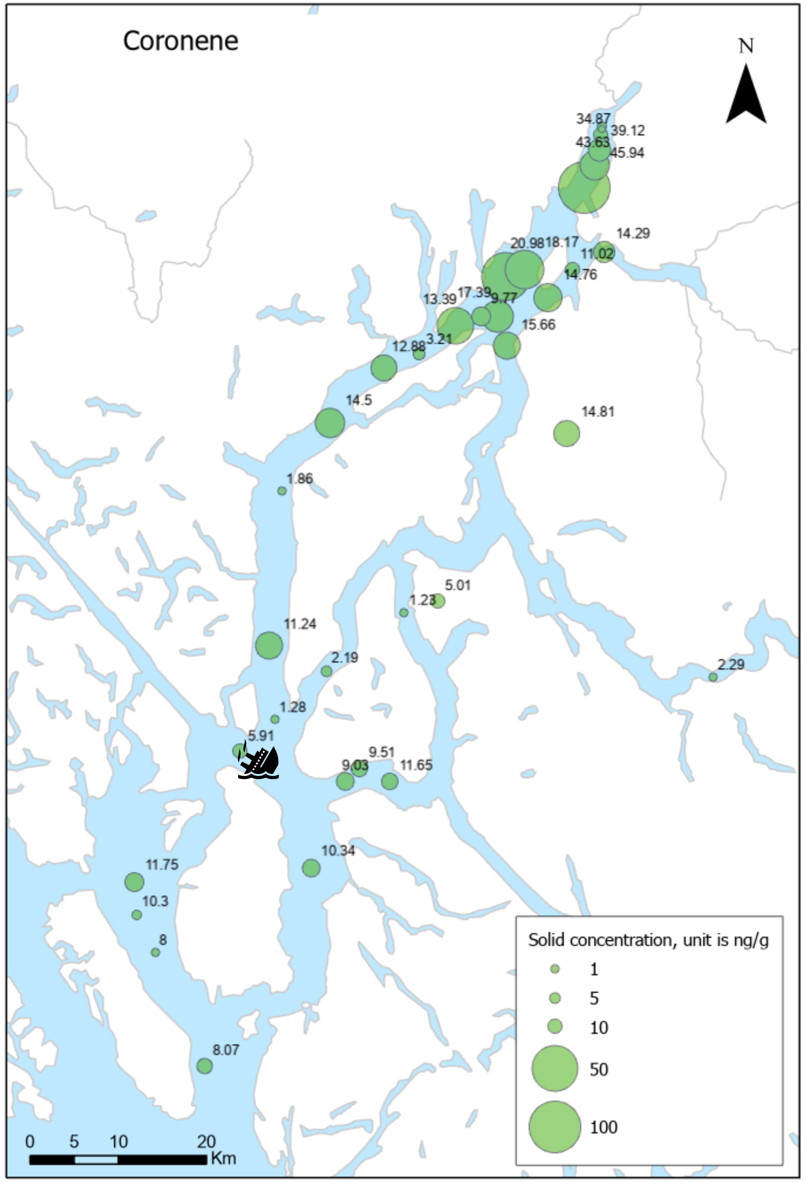
PAHs

(J. Ahad – GSC-Q)

Retene: marker for conifer combustion

Coronene: marker for fossil fuel combustion

PAHs: polycyclic aromatic hydrocarbons



Preliminary results: Microcosm experiments

Objective: To test the effect of **O_2 limitation** on **natural oil degradation rates** at the sediment/water interface

- Material
  - Both seawater and surface sediment from 3 stations representing "oxic", "hypoxic" and "anoxic" conditions
  - Weathered Very Low Sulphur Fuel Oil (VLSFO)

- Methods
  - Bottles in incubator (8°C)
  - O_2 supply controlled from gases in the headspace
  - Headspace gases measured by GC
  - Microbial communities assessed with 16S rRNA
  - Oil degradation tracked with GC-MS
  - C uptake tracked with ^{14}C-PLFAs

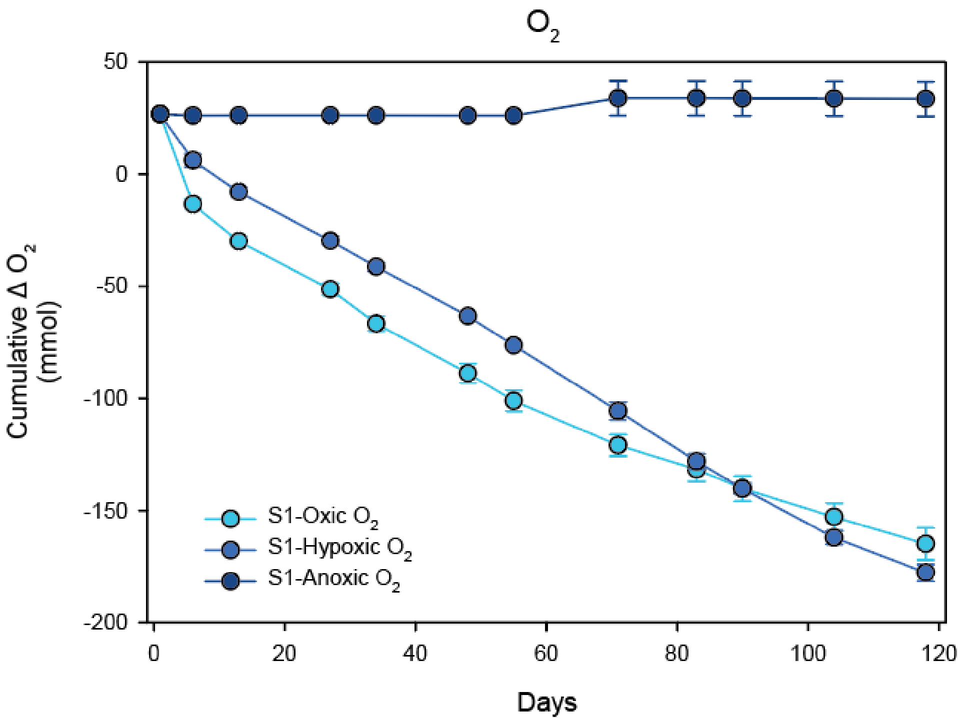
"Oxic" *"Hypoxic"* *"Anoxic"*

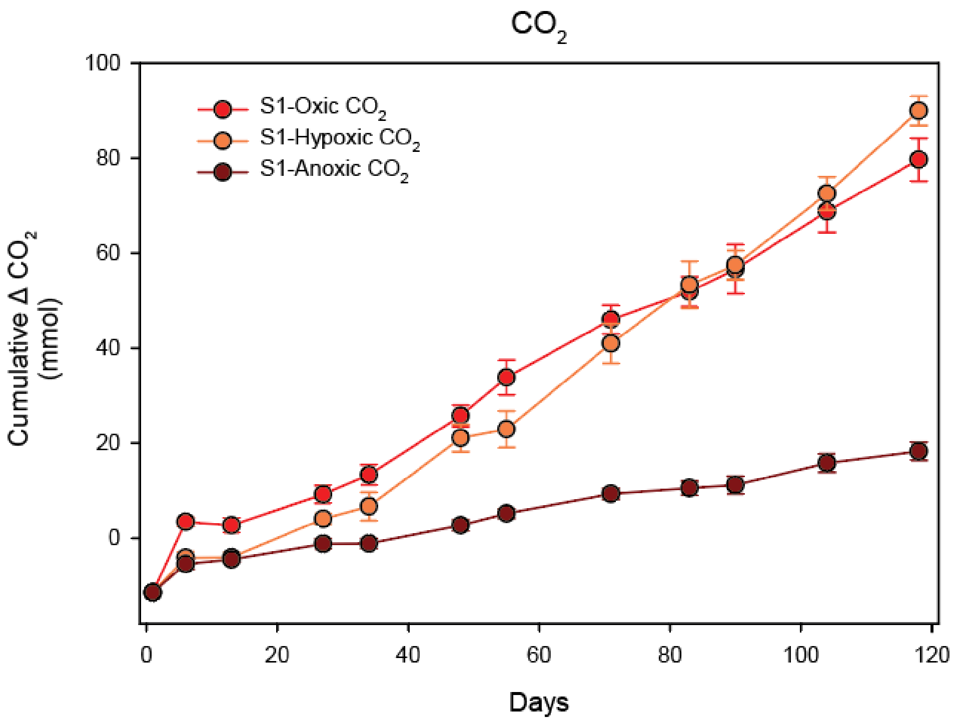
- 3 experimental setups:
  - S1: Sediment + water + fuel
  - S2: Sediment + water *[no fuel control]*
  - S3: Autoclaved (sediment + water + fuel) *[kill culture control]*

Preliminary results: Microcosm experiments

Headspace gas composition

Cumulative O_2 consumption / CO_2 production in Setup 1 (sediment + water + fuel) microcosms



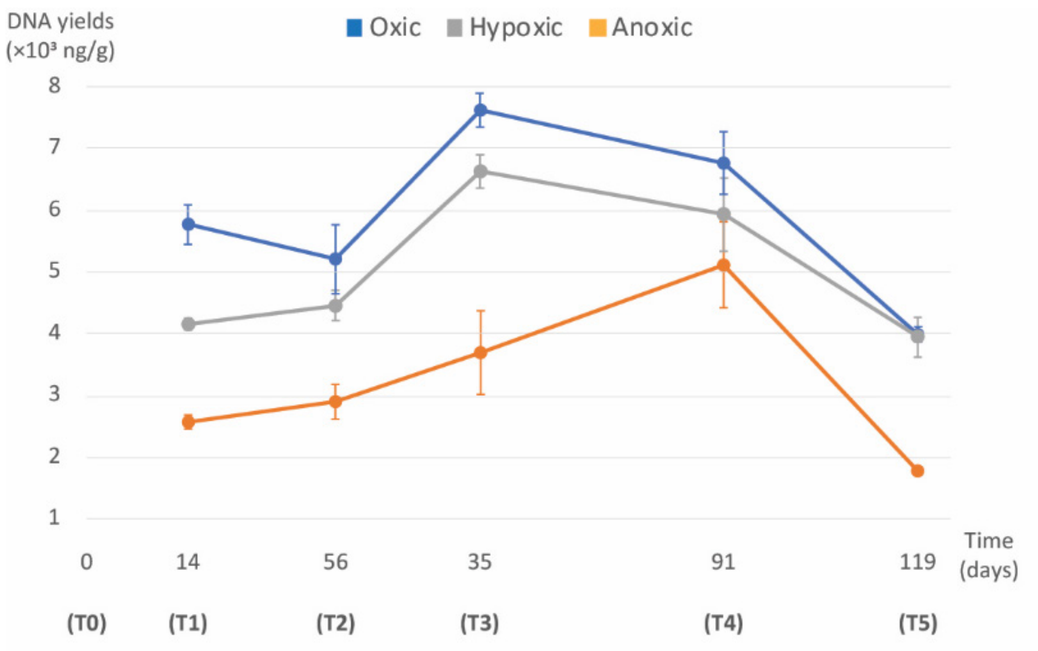


- Anoxic cultures barely active
- Comparable activity under oxic and hypoxic settings
- Oxic cultures show fastest rates at the start, but hypoxic cultures are more active in the end

Preliminary results: Microcosm experiments

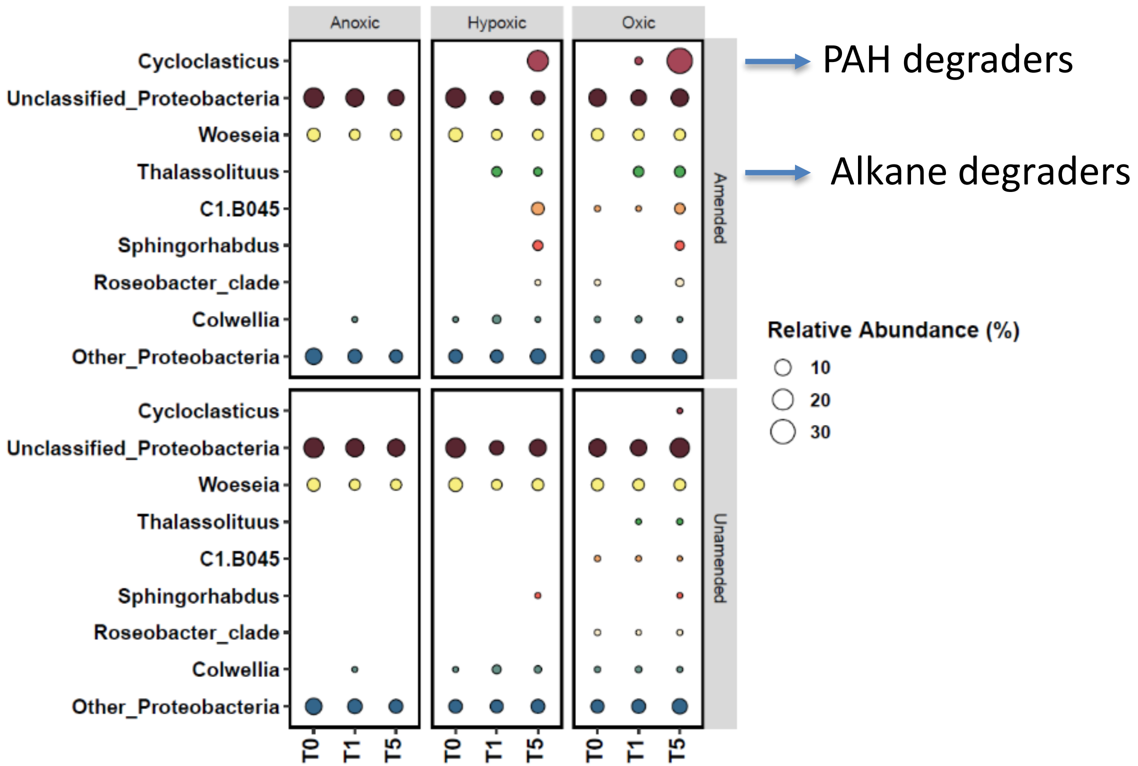
Genomics (J. Chen, O. Adebayo, C. Hubert – UofC)

DNA yields



16S rRNA sequencing

Trends in Phylum Proteobacteria

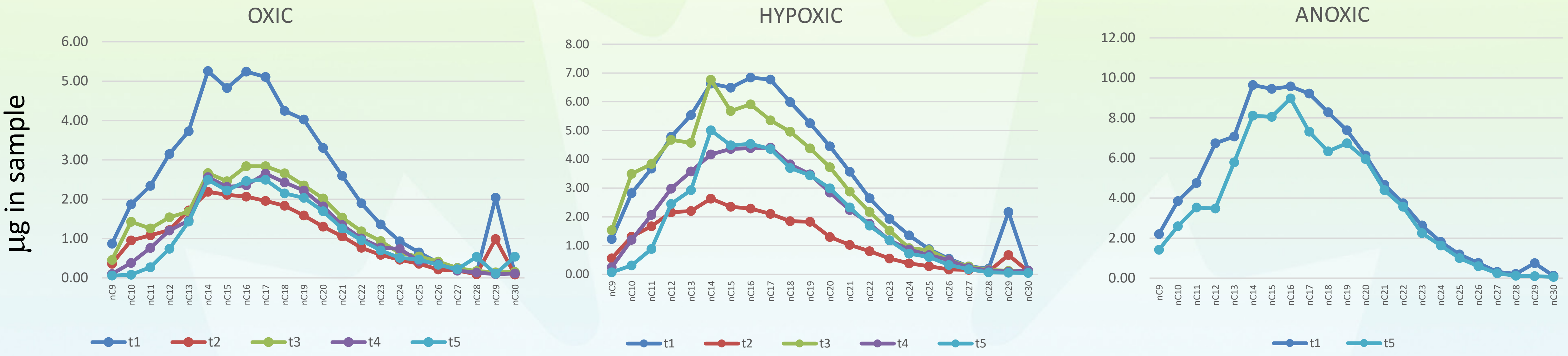


Preliminary results: Microcosm experiments

Petroleomics (A. Mort, R. Robinson – GSC-C)

GC-ToF-MS

N-alkanes



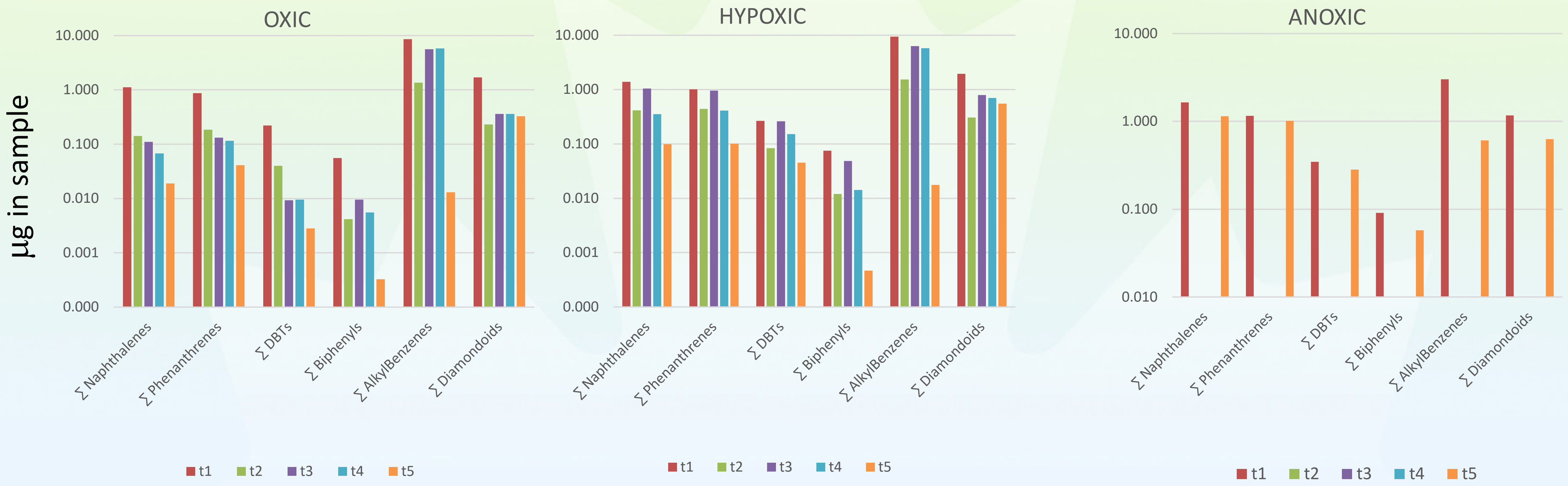
- Oxic: alkanes degraded early and to the greatest extent
- Hypoxic: more gradual consumption of alkanes
- Anoxic: little difference between T1 and T5

Preliminary results: Microcosm experiments

Petroleomics (A. Mort, R. Robinson – GSC-C)

PAHs

GC-ToF-MS



PAHs: polycyclic aromatic hydrocarbons

Conclusions

- **Natural variability and human impacts:**
  - Clear environmental signals recorded by dinoflagellate cysts
  - Geochemical tracers of human activities

- **Effect of oxygen limitation on natural oil degradation rates:**

Oil degradation is:

- **fastest** and **more complete** under **oxic** conditions
- **slower** but **ultimately comparable** to oxic setting under **hypoxic** conditions
- **slowest** and **incomplete** under **anoxic** conditions

Stay tuned for more results!

CONTACT INFORMATION

- Manuel Bringué
- (403) 471-1727
- manuel.bringue@nrcan-rncan.gc.ca

Also:

- Jason Ahad (PL of over-arching 'oil spill' project)
- (418) 654-2615
- jason.ahad@nrcan-rncan.gc.ca

THANK YOU!

Natural Resources Canada | Ressources naturelles Canada

Fingerprinting sources of polycyclic aromatic compounds (PACs) in the Athabasca oil sands region using compound-specific isotope analysis

Identification de sources de composés aromatiques polycycliques (CAP) dans la région des sables bitumineux de l'Athabasca à l'aide d'analyses isotopiques sur molécules spécifiques

Jason M. E. Ahad[1*], Samrat Alam[1], Colin Cooke[2]

[1] Geological Survey of Canada, Natural Resources Canada, Québec, QC, G1K 9A9, Canada,
[2] Alberta Environment & Parks, Edmonton, AB, T6G 2E3, Canada

NRCan's Environmental Geoscience Program 2023 Annual Presentations, 30 May

* jason.ahad@nrcan-rncan.gc.ca

Canada

ABSTRACT

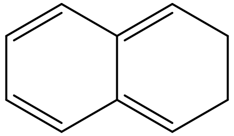
The emission of contaminants such as polycyclic aromatic compounds (PACs) from surface mining and upgrading activities in Canada's Athabasca oil sands region (AOSR) has raised concerns about their impact on the surrounding environment. PACs, which are found naturally in crude oil, are also generated by the incomplete combustion of organic matter, and thus have a variety of possible sources. Effective environmental management requires techniques that can accurately identify and potentially quantify the relative proportions of different sources of PACs in environmental samples. Previous work carried out at GSC-Québec's Delta-Lab demonstrated the value of dual carbon and hydrogen compound-specific isotope analysis (CSIA) to discriminate sources of PACs in the AOSR. Here, we build upon this work to identify and quantify the sources of PACs in surface sediments along the main stem of the Athabasca River at sites upstream, nearby and downstream of bitumen surface mining operations. Previous work showed that petroleum coke (petcoke) – the carbonaceous by-product of bitumen upgrading – was the principal source of mining-related PACs deposited to lake sediments in the Peace-Athabasca Delta and AOSR lake snowpack, with minor inputs from gasoline or diesel soot. In contrast, preliminary carbon-CSIA data from Athabasca River sediments indicates that in addition to petcoke, gasoline/diesel soot is an important PAC source. Unprocessed oil sand and wildfires also contribute to the isotopic signal.

Polycyclic aromatic compounds (PACs)

- PACs are a large group of ubiquitous organic contaminants containing thousands of individual compounds
- Include (but not limited to):
  - polycyclic aromatic hydrocarbons (PAHs)
  - alkylated PAH derivatives (alk-PAHs)
  - heterocyclic compounds with one or more N, S or O atoms in the aromatic ring
  - oxygenated (oxy-) and nitrogenated (nitro-) PAHs
- Found naturally in *petrogenic* sources such as crude oil and coal
- Also formed from incomplete combustion of organic matter (i.e., *pyrogenic*) and through *diagenetic* processes

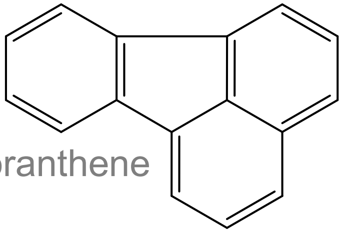
PAHs

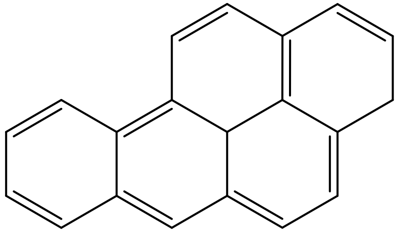
Naphthalene



Phenanthrene

Fluoranthene

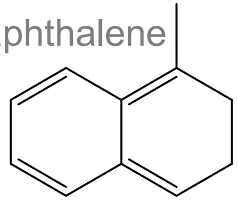




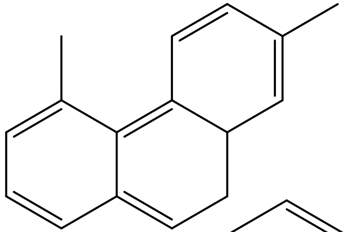
Benzo[*a*]pyrene

Alk-PAHs

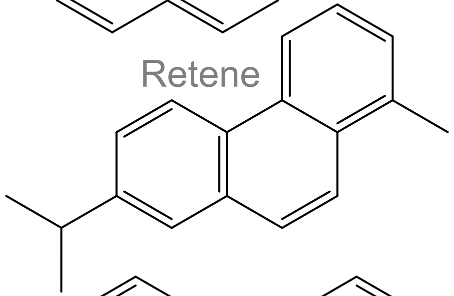
C1-Naphthalene

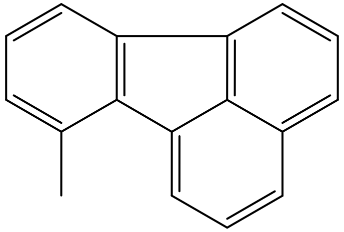


C2-Phenanthrene



Retene

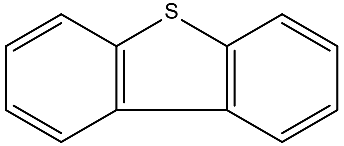




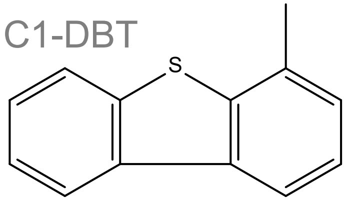
C1-Fluoranthene

S-PACs

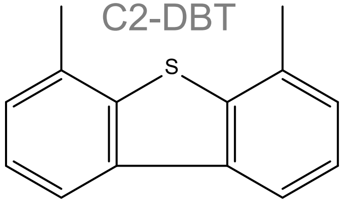
Dibenzothiophene (DBT)

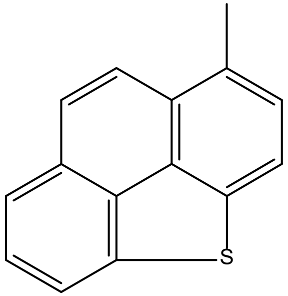


C1-DBT



C2-DBT

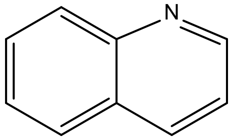




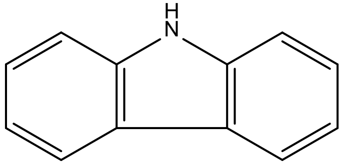
C1-Phenanthrothiophene

N-PACs

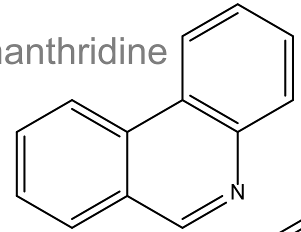
Quinoline



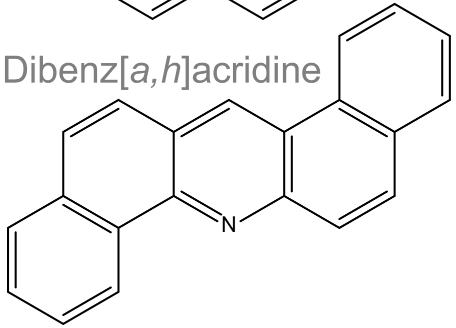
Carbazole



Phenanthridine

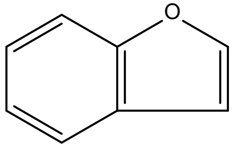


Dibenz[*a*,*h*]acridine

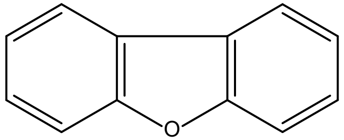


O-PACs

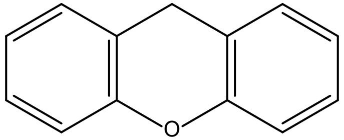
Benzofuran

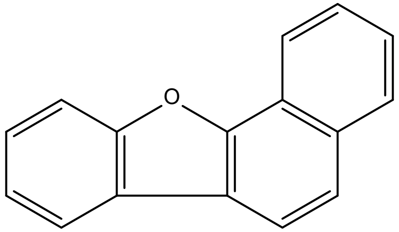


Dibenzofuran



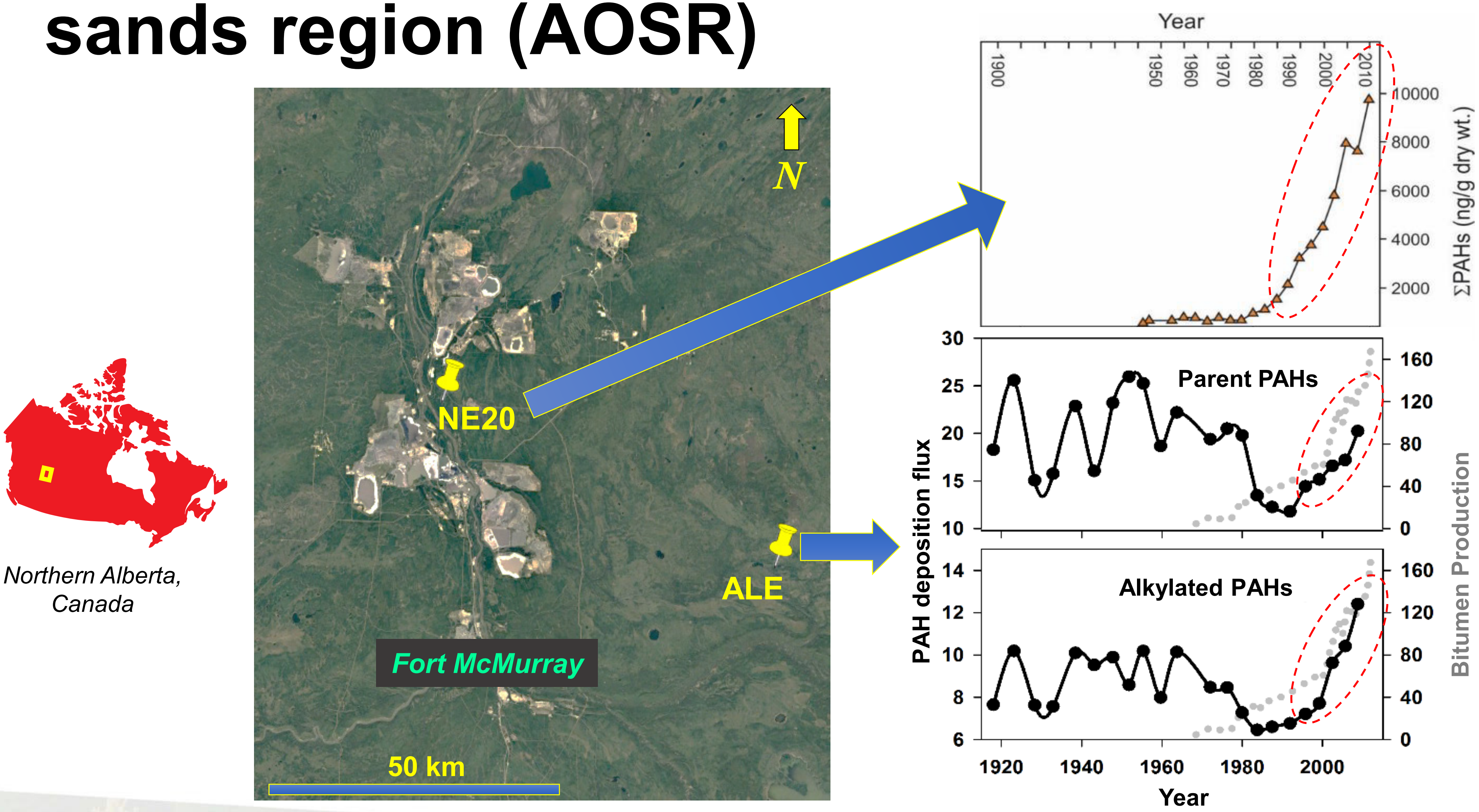
Xanthene





Benzo[*b*]naphtho[2,1-*d*]furan

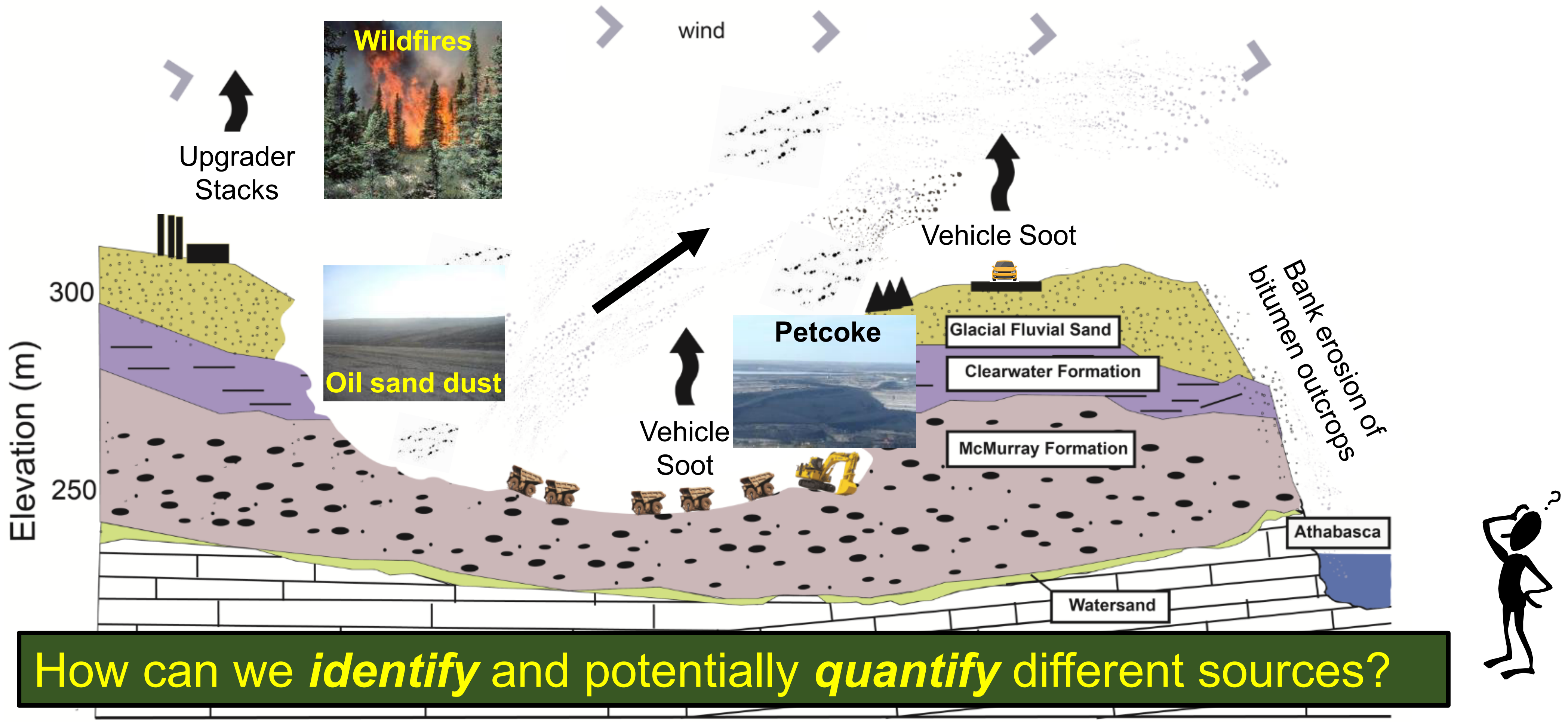
Increase in PACs to lakes in the Athabasca oil sands region (AOSR)



Kurek et al. 2013, *PNAS*

Jautzy et al. 2013, *Environ. Sci. Technol.*

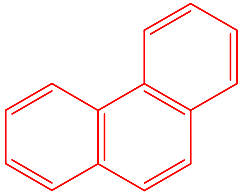
Potential sources of PACs in the AOSR

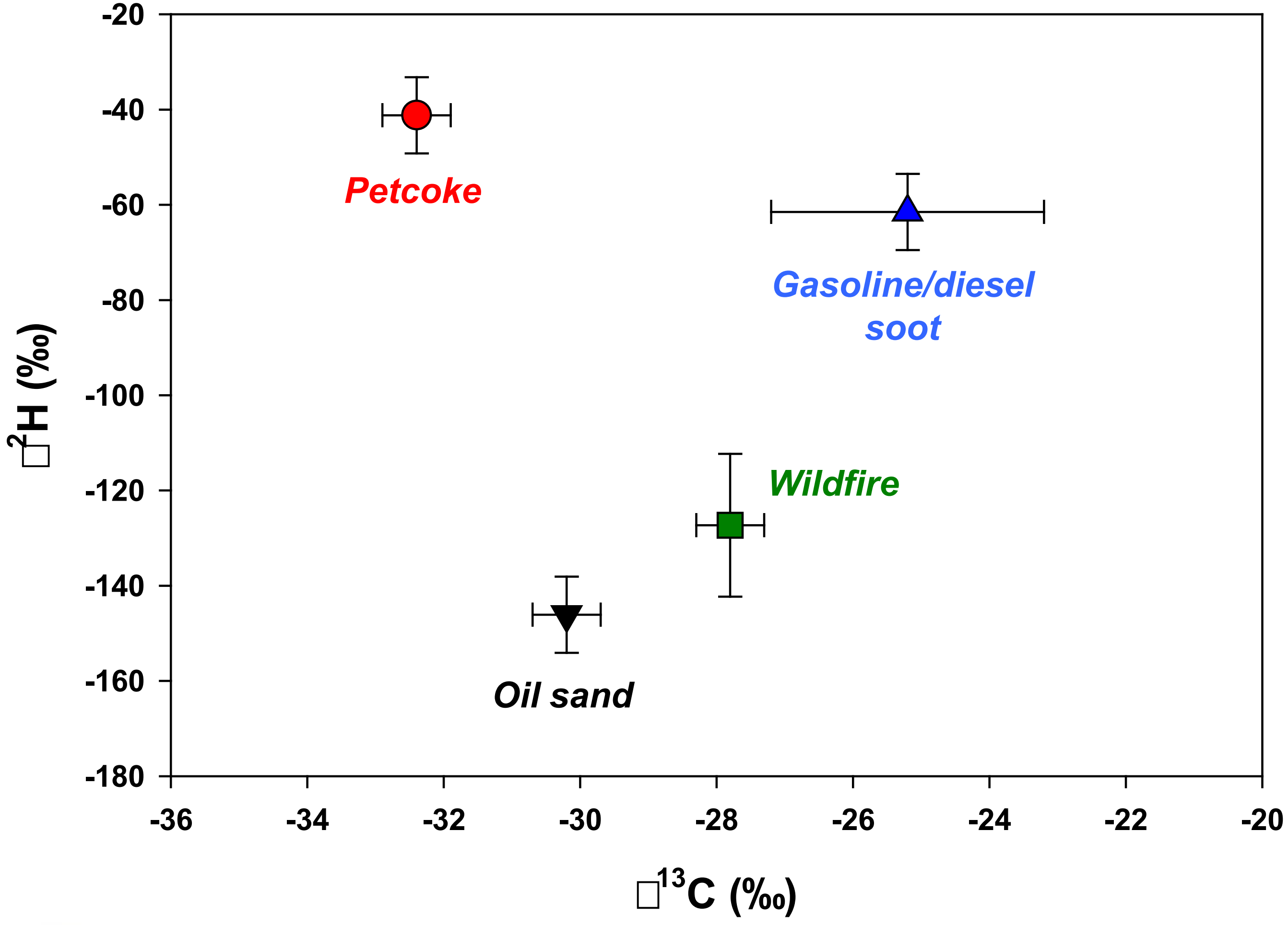


How can we ***identify*** and potentially ***quantify*** different sources?

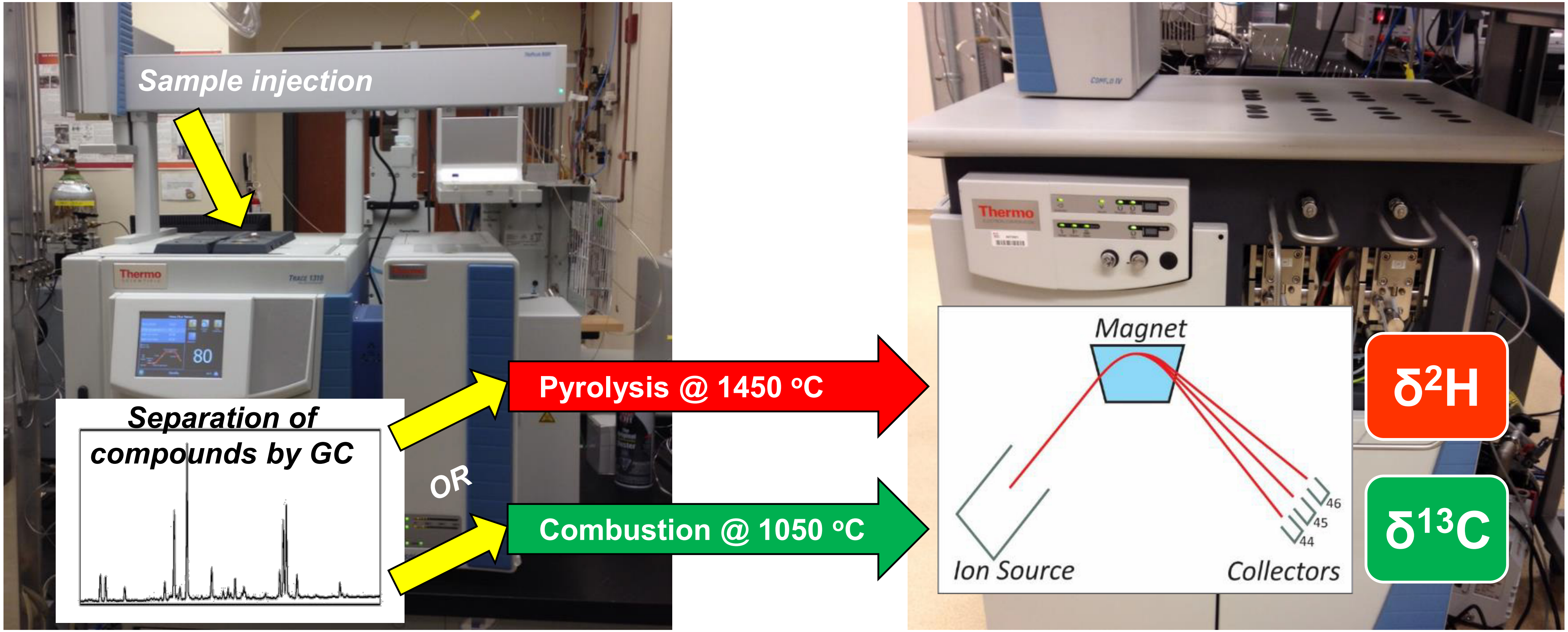
Compound-specific isotopic analyses (^{13}C, ^{2}H)

e.g., Phenanthrene

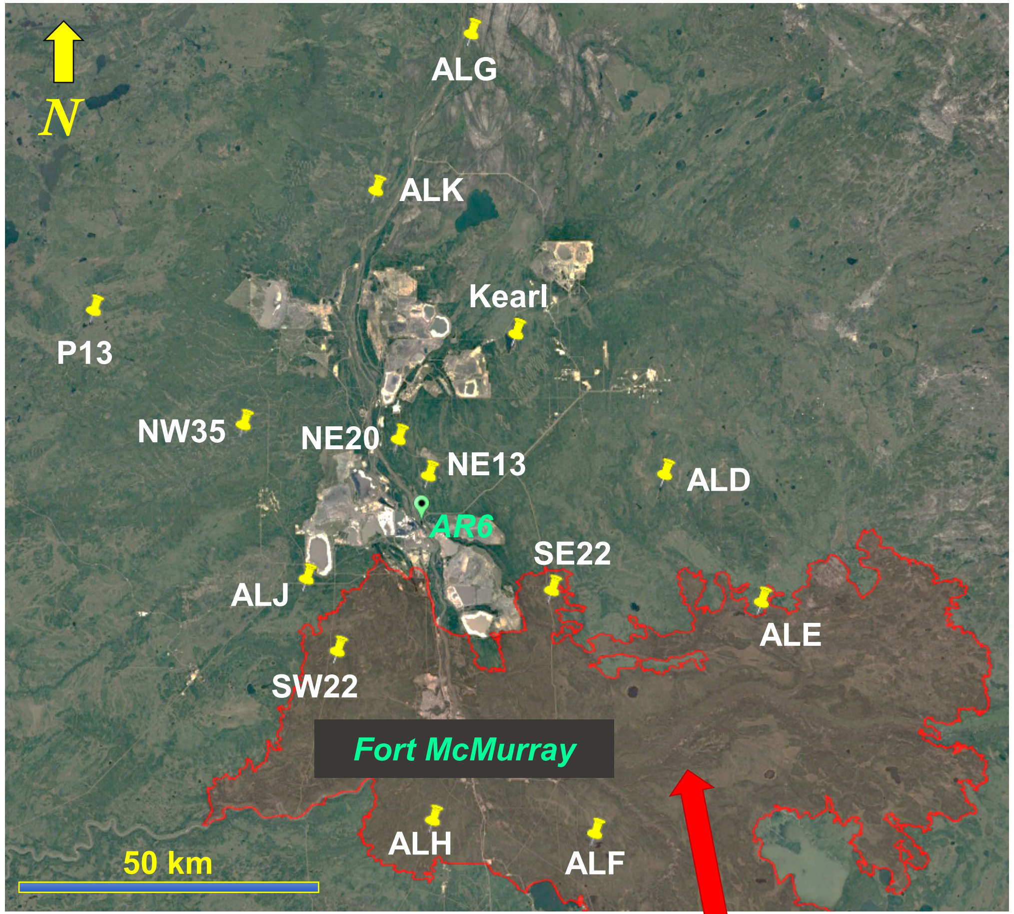




Gas chromatography – isotope ratio mass spectrometry (GC-IRMS)

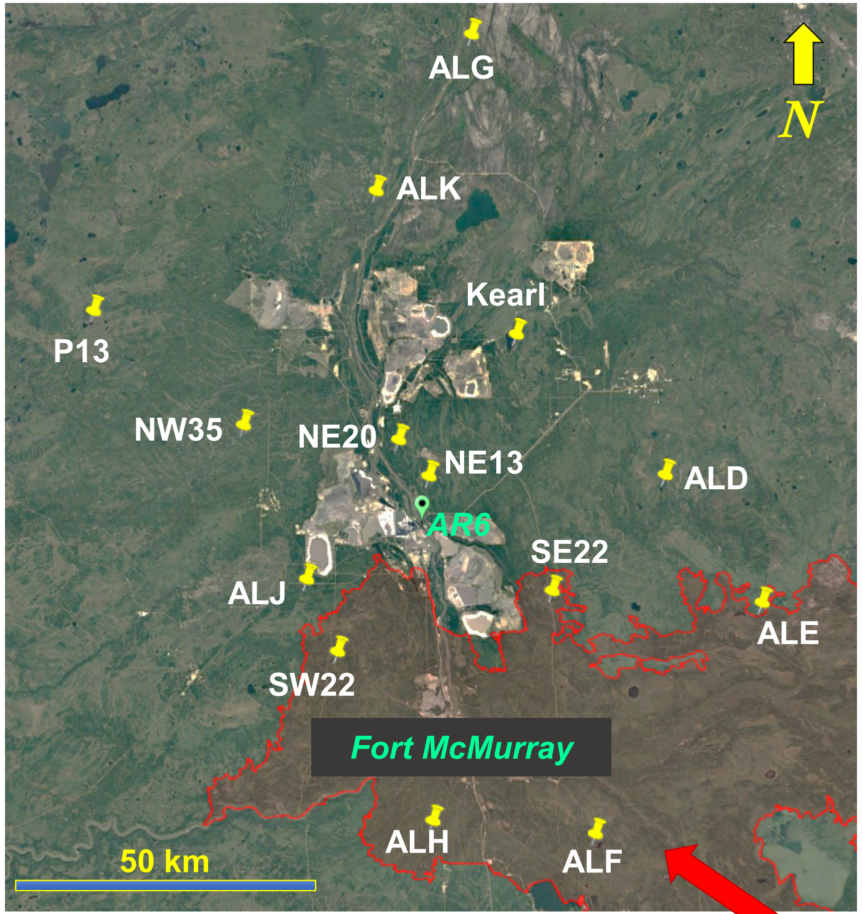


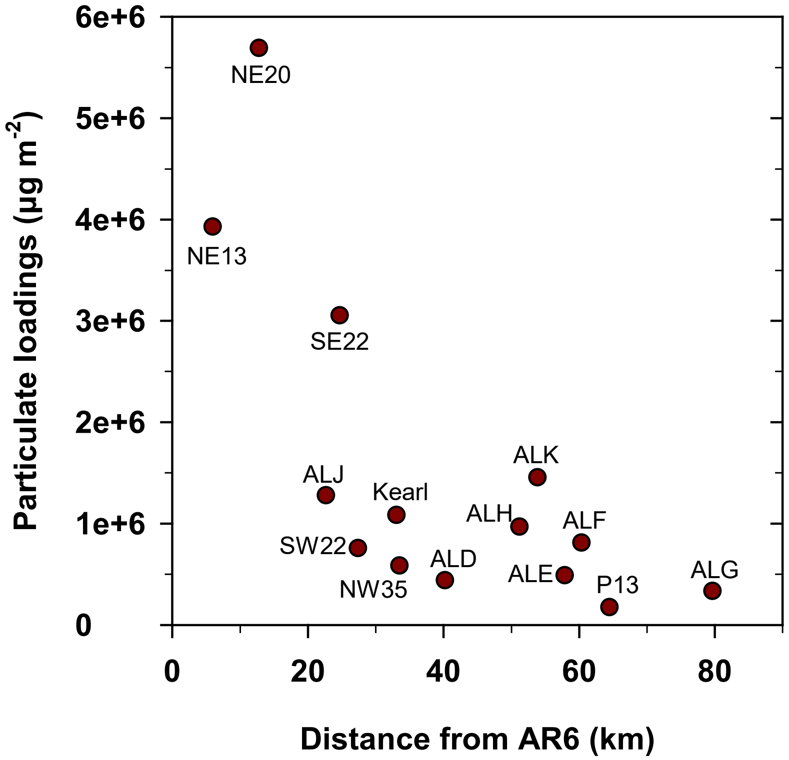
Snow sampling from frozen surfaces of AOSR lakes (Feb 2017)

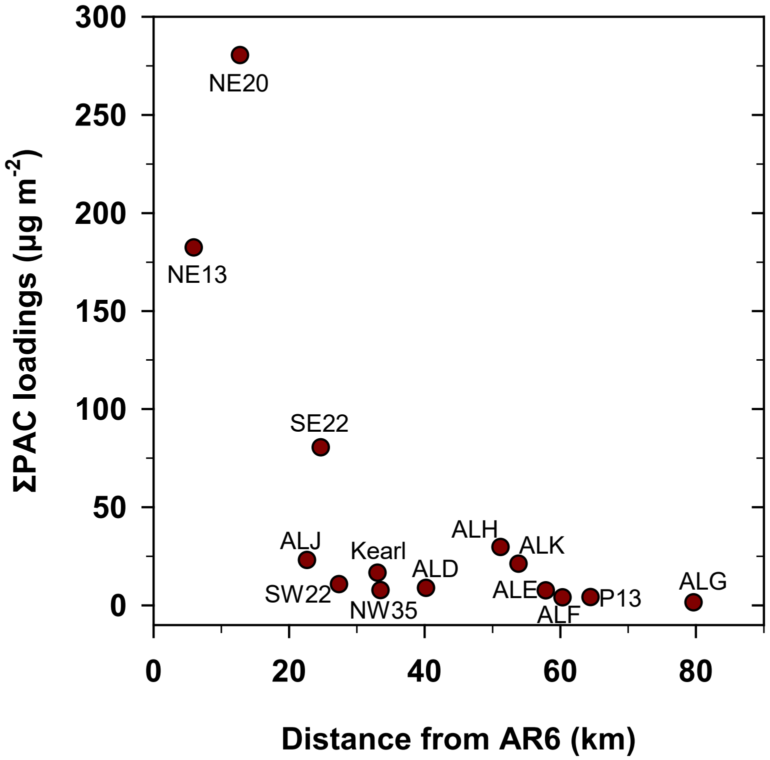


2016 Fort McMurray wildfire

Particulate and ΣPAC loadings (μg m^{-2}) to snowpack



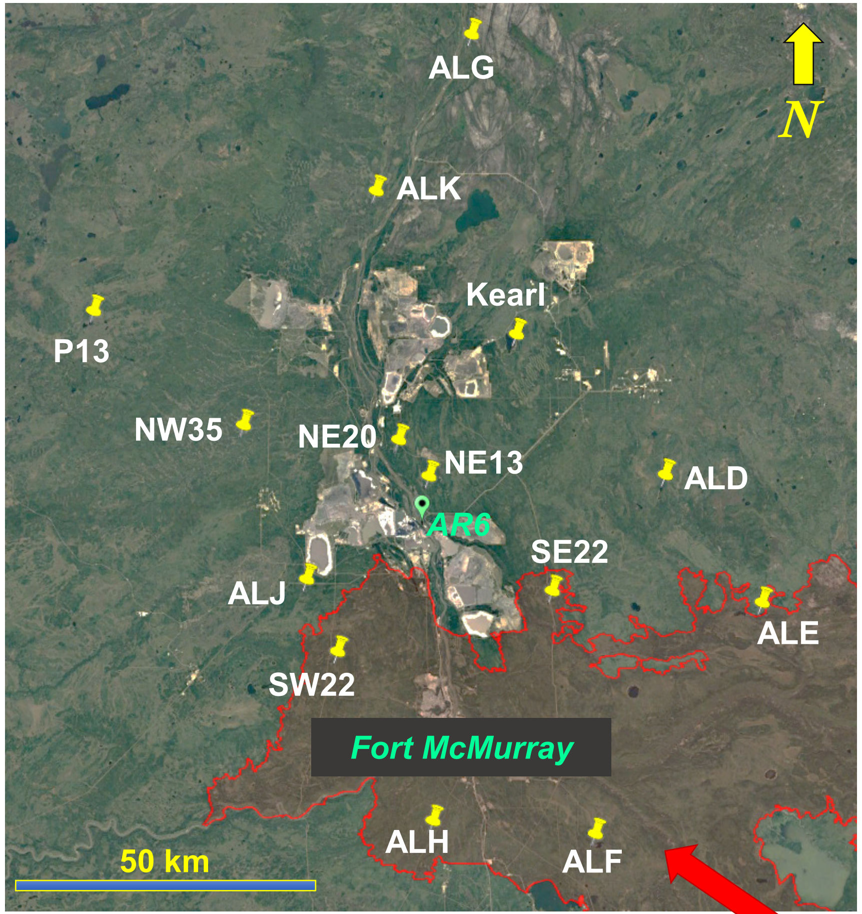


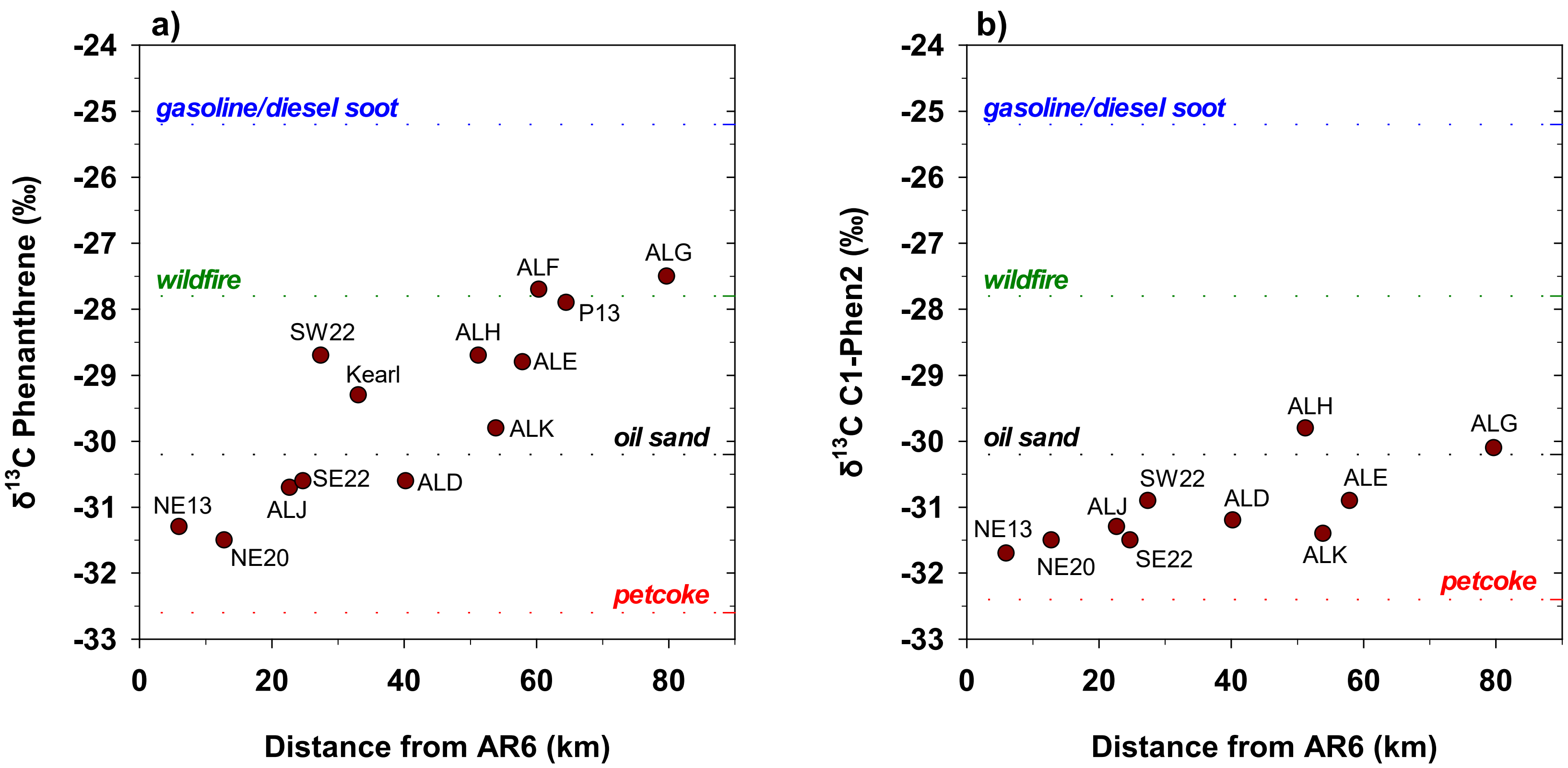


2016 Fort McMurray wildfire

Ahad et al., 2021, *Environ. Sci. & Technol.*

δ¹³C values for phenanthrene and an alkylated phenanthrene in snow particulates

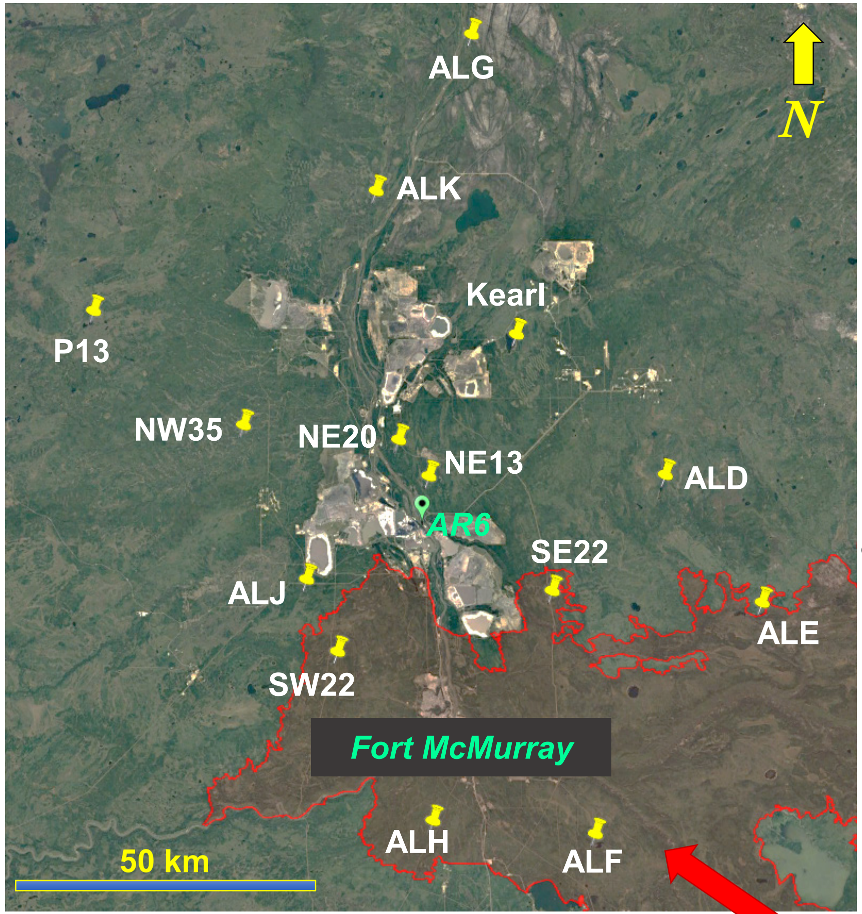


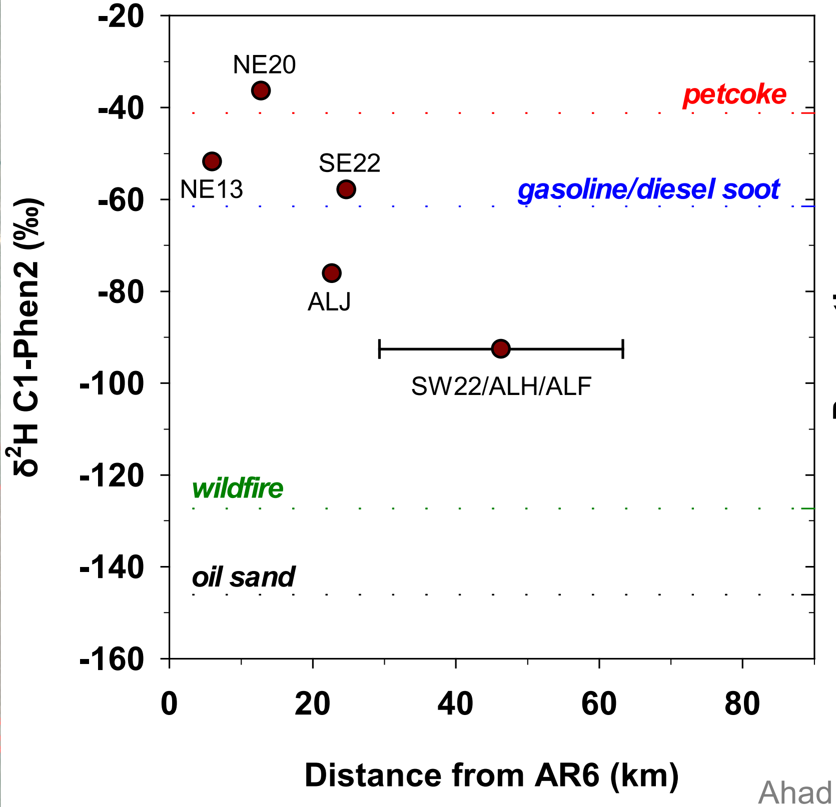


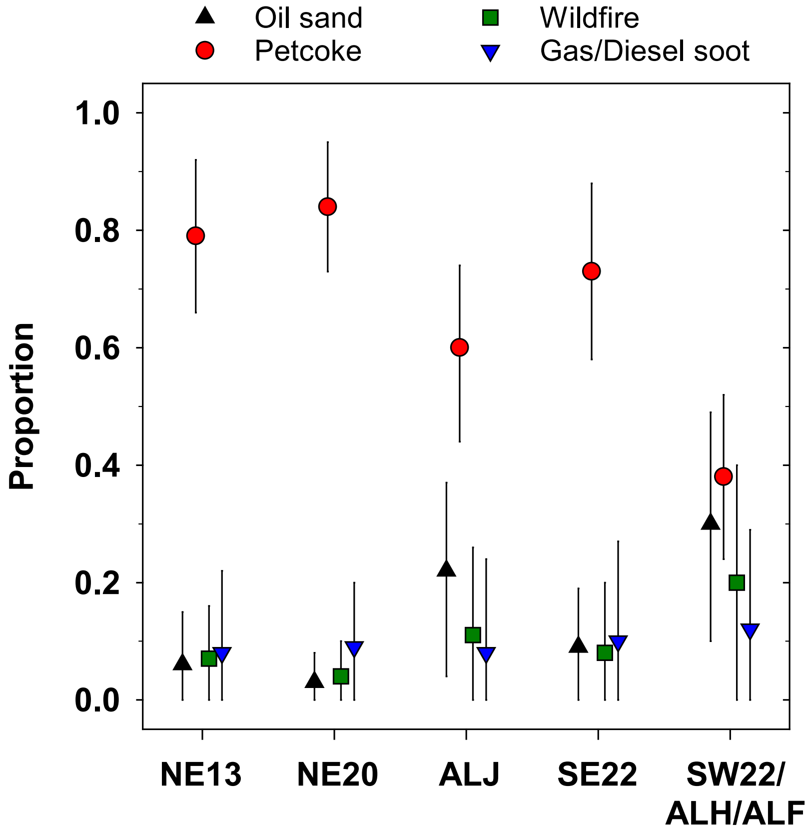
Ahad et al., 2021, *Environ. Sci. & Technol.*

2016 Fort McMurray wildfire

Isotopic mixing model using δ^{13}C values and δ^{2}H values of an alkylated phenanthrene



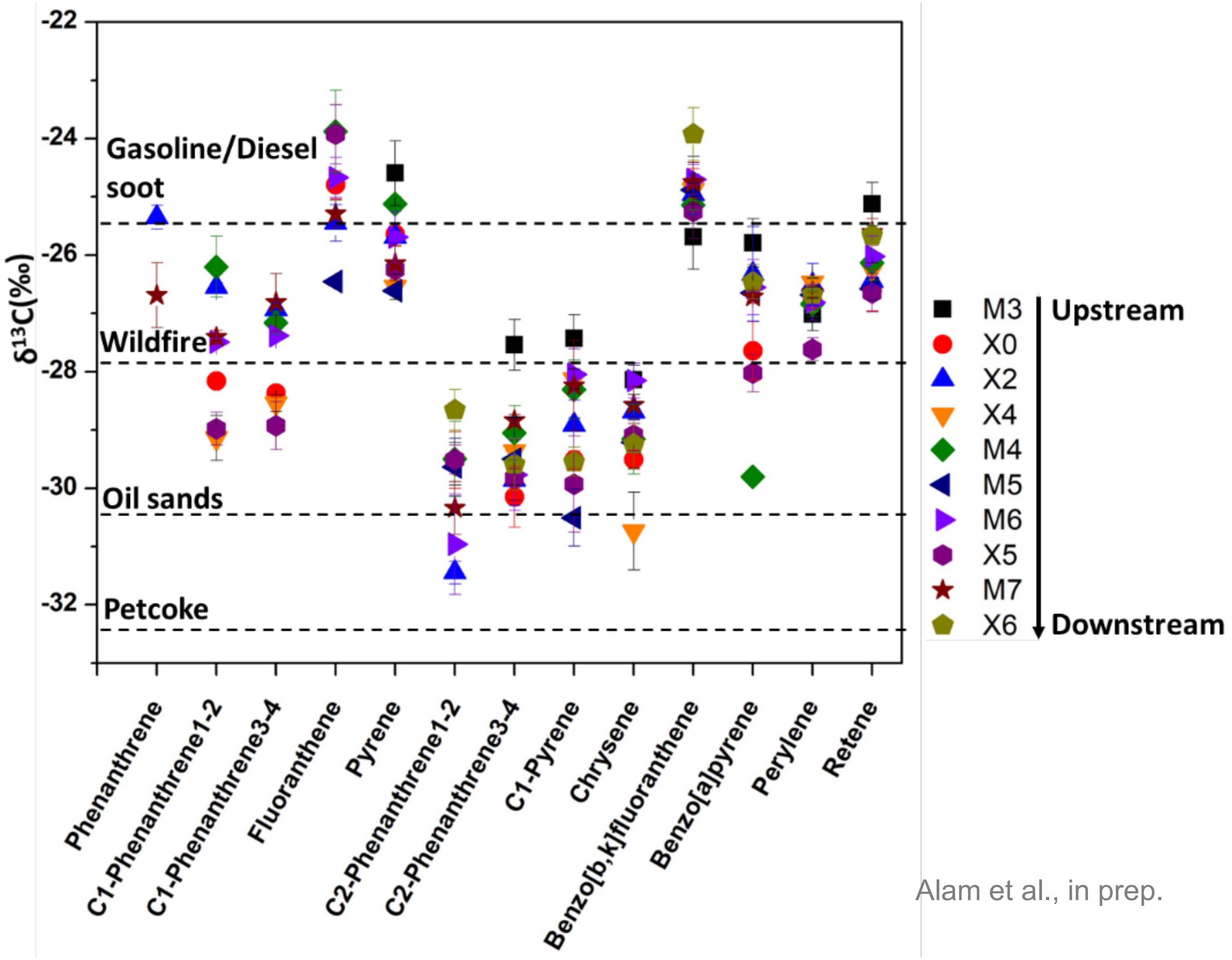




2016 Fort McMurray wildfire

Ahad et al., 2021, ***Environ. Sci. & Technol.***

Sources of PACs in the Athabasca River



Alam et al., in prep.

Thanks!

- Josué Jautzy, Paul Gammon, Martine Savard, Hooshang Pakdel, Leah Mindorff, Anna Smirnoff, Marc Luzincourt, Jade Bergeron, Momotaj Begum, Thibault Labarre, Richard Huang, François Létourneau, Canadian Oil Sands Innovation Alliance (COSIA), several oil sands mining companies
- **Environmental Geoscience Program** (2001-341308-NAF1)
- **Alberta Environment & Parks** (SPA: 7017-R00351-NAF1)
- **NRCan**'s Program of Energy Research and Development (**PERD**) Project 1C03.001A ("Quantifying sources of PAHs in Canada's oil sands region")

INRS Institut national de la recherche scientifique

Alberta Environment and Parks

UNIVERSITY OF ALBERTA

Ressources naturelles Canada | Natural Resources Canada

Filling Knowledge Gaps in Global Mercury Science - Research in Support of the UNEP Global Mercury Assessment

Combler les lacunes scientifiques sur le mercure mondial - Recherche à l'appui de l'évaluation mondiale du mercure du PNUE

Peter Outridge, GSC Northern Div.

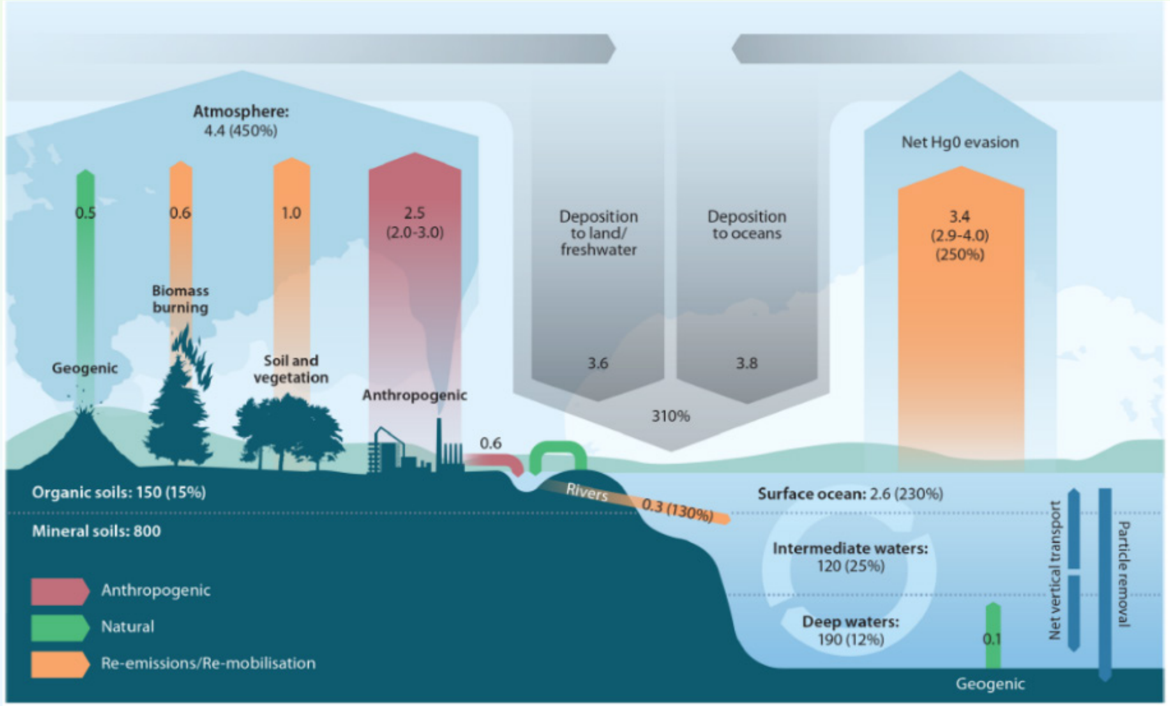
Canada

Activities (Status at Apr. 2023)

- 1. Volcanic mercury emissions (on-going)
- 2. Deep-ocean trench mercury (completed in 2022)
- 3. Publications from AMAP 2021 Arctic Mercury Assessment (completed in 2022)

Project Context – Activities 1 & 2

- Importance of natural processes & sources in the global Hg story.
- Total geogenic Hg emissions to air poorly constrained (<1 – ~30% of anthropogenic emissions, i.e. <10 – 900 tonnes/yr).
- Iceland Hg studies 1970s support very high natural emission estimate
  - many 10,000s ng Hg/m^3.
- Oceans as largest final repository for Hg in environment. Rate poorly constrained by sampling (none until our study).



AMAP/UNEP (2018) Global Mercury Budget

ABSTRACT – 1. Volcanic Mercury Emissions

- Goal: Help fill key knowledge gap in natural Hg cycle (volcanic systems' emissions), a weakness in global Hg budget supporting Minamata Convention on Mercury, 2017.
- Focus on Icelandic volcanic systems (possible high Hg emitters).
- Progress on schedule.


Brock Edwards sampling gaseous Hg at Fagradalsfjall fissure eruption, Aug 2021

PROJECT MEMBERS – 1. Volcanic Mercury Emissions

- Peter Outridge, GSC P.L.
- Brock Edwards (NRCan RAP-PhD student)
- Feiyue Wang, U. Manitoba
- Melissa Pfeffer & Michelle Parks, Icelandic Met. Office
- Hamed Sanei, Aarhus U., Denmark
- Bruce Kjarsgaard, GSC

Progress (Apr '21- Mar '22)

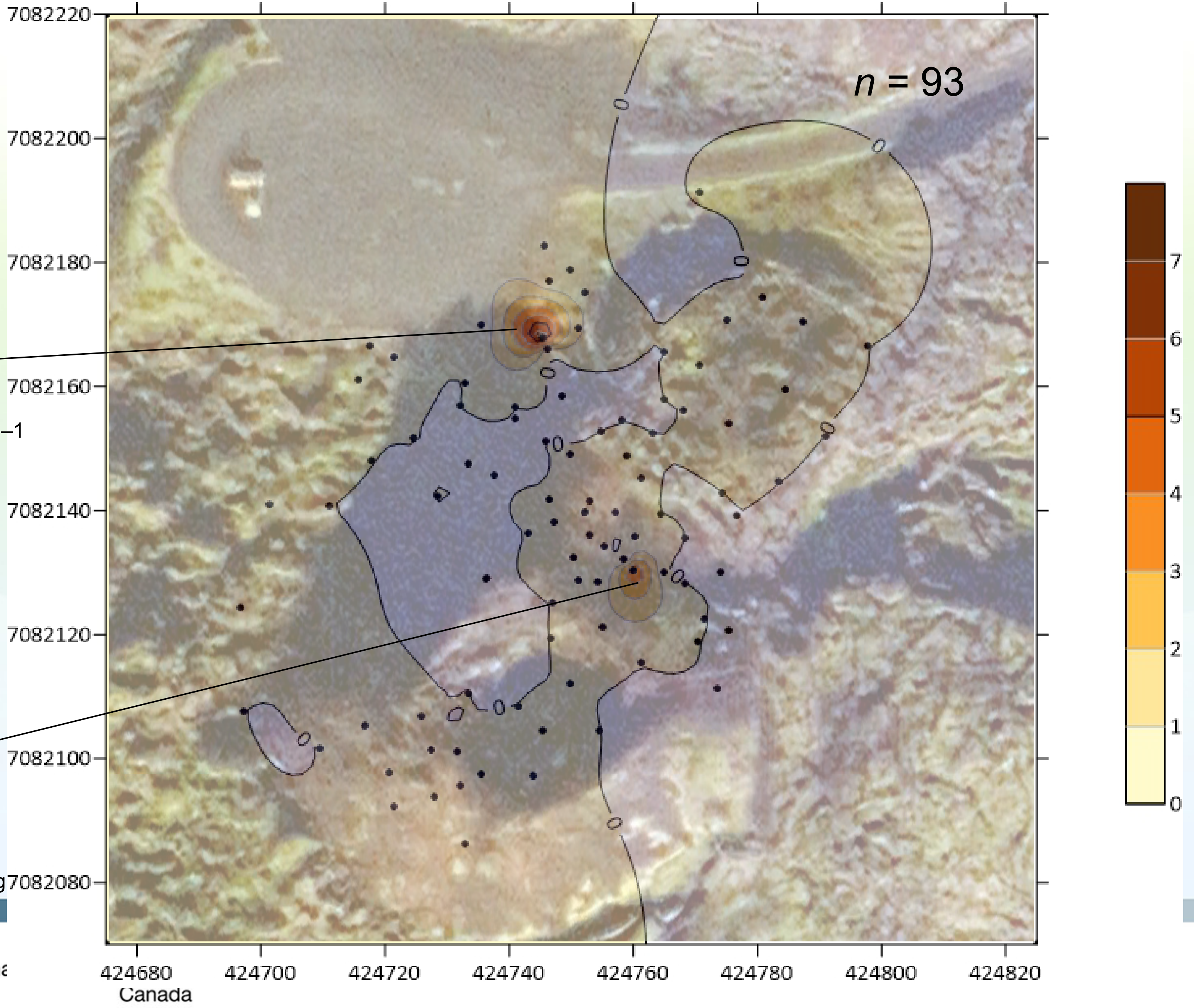
- Brock's PhD course work completed;
- 3rd Icelandic field trip (August 2021);
- passive & active sampling of gaseous Hg from erupting Fagradalsfjall fissure;
- Spatially intensive soil gas Hg measurements show previously unrecognized high subsoil Hg levels that may drive high fluxes into air;
- Sampling methods inter-comparison of gas Hg concentrations (new flux measurement method for soil Hg emissions adapted from volatile organics; active & passive samplers; real-time Lumex measurements vs samplers).

Eldvörp

ELD-59
ΔC = 2450 ng m^{-3}
Soil Hg content:
19,298 ± 2,618 ng g^{-1}

(Eldvörp median
1,071 ng g^{-1})

ELD-88
ΔC = 8655 ng m^{-3}
Soil Hg content:
7,056 ± 209.5 ng g^{-1}



GEM flux
(g/m^2/d x 10^{-6})

Area average
0.21 x 10^{-6} g/m^2/d

Novel drone-based airborne sampling of volcanic plumes

Active sampling of particulate Hg (& other metals) directly within volcanic plumes

Brock Edwards & Evgenia Ilyinskaya (U. of Leeds, UK) preparing drone for sampling the Fagradalsfjall eruption plume, August 2021.

Progress (Apr '22- Mar '23)

- Additional Iceland field trip to expand & intensify soil subsurface Hg flux measurements (Aug. 2022; B. Edwards & Dr. P. Outridge);
- Additional drone-based sampling of Fagradalsfjall fissure eruption gases (Aug. 2022);
- Inter-method Hg comparability paper accepted in *Applied Geochemistry*;
- Analytical work ongoing on samples collected, with aim to complete Edwards Ph.D. thesis in fall 2023.

Brock sampling soil Hg gases, Geysir geothermal area, Iceland, 2022

Peter at Seltun geothermal area, Iceland, 2022

Activity 2. Deep-ocean trench mercury (Completed)
Team members

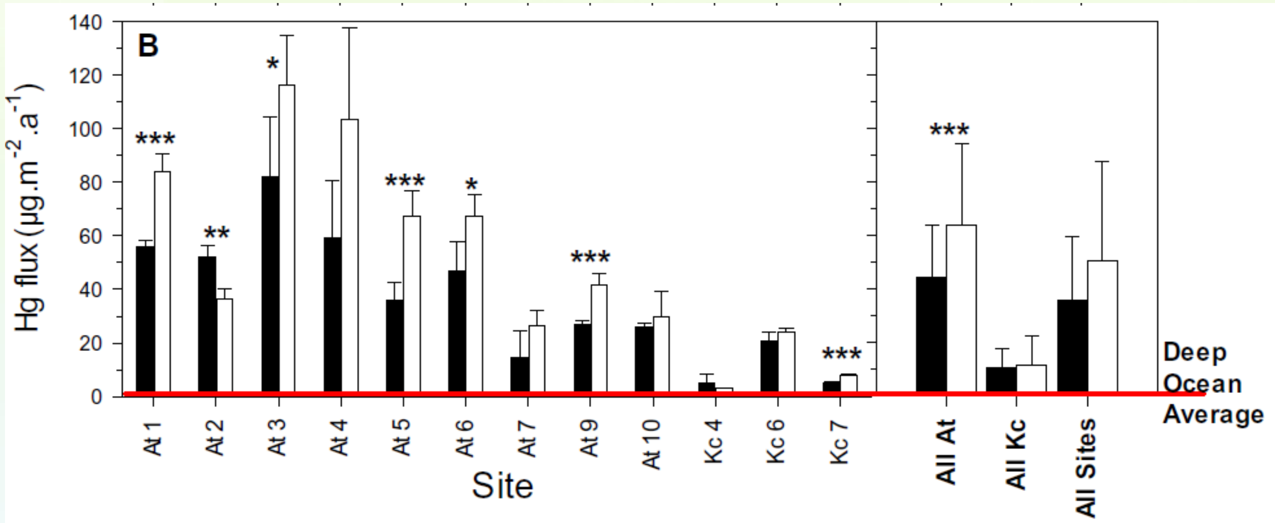
- Hamed Sanei, Aarhus U., Denmark
- Peter Outridge, GSC
- Feiyue Wang, U. Manitoba
- Ronnie Glud, U. Southern Denmark (Hadal Research Group)

Deep-ocean sediment core retrieval, Atacama Trench, Pacific Ocean, on board *Polarstern.*

- Sanei H, Outridge PM, Oguri K, Stern GA, Thamdrup B, Wenzhöfer F, Wang F, and Glud RN. 2021. High mercury accumulation in deep-ocean hadal sediments. **Scientific Reports** 11: 10970. doi: 0.1038/s41598-021-90459-1.

Deep-ocean (>6 km) sediment Hg fluxes may be many times higher than ocean models predict.

➡ Reliability of the ocean models??



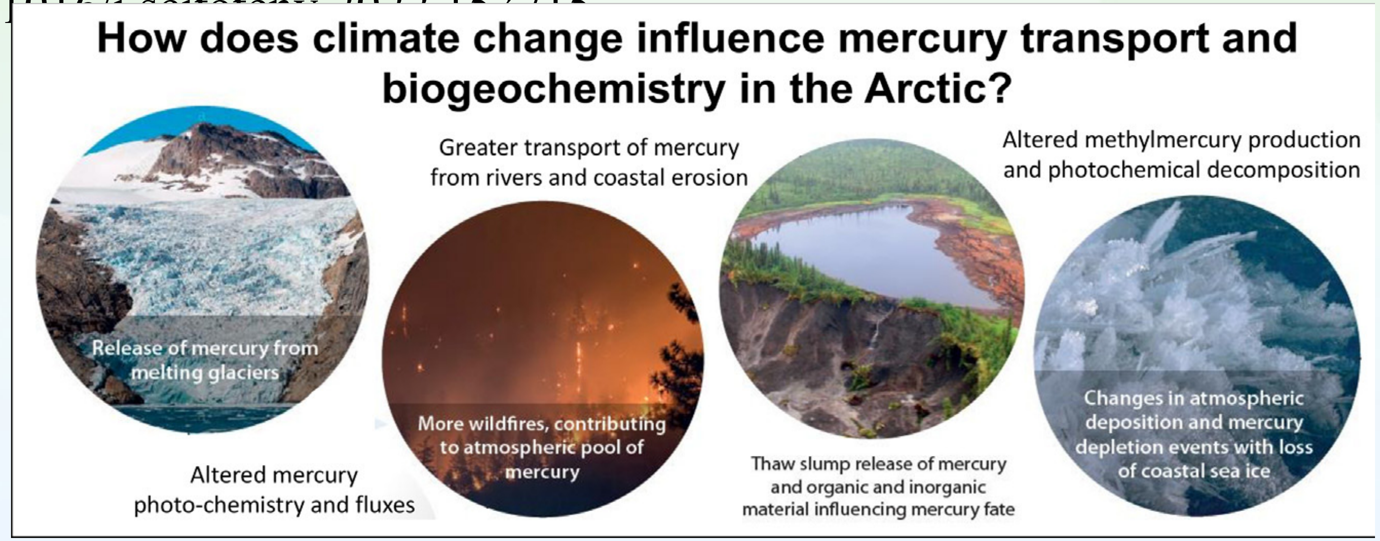
- 2,903 downloads since publication

- 98th percentile all natural science papers published since May 2021.

Activity 3. Publications from AMAP 2021 (Completed)

Dastoor A, Angot H, Bieser J, Christensen JH, Douglas TA, Heimbürger-Boavida L-E, Jiskra M, Mason RP, McLagan DS, Obrist D, Outridge PM, Petrova MV, Ryjkov A, St. Pierre KA, Schartup AT, Soerensen AL, Toyota K, Travnikov O, Wilson J, and Zdanowicz C. 2022. Arctic mercury cycling. **Nature Reviews Earth & Environment** doi.org/10.1038/s43017-022-00269-w.

Chételat J, McKinney MA, Amyot M, Dastoor A , Douglas TA, Heimbürger-Boavida L-E, Kirk J, Kahilainen KK, Outridge PM, Pelletier N, Skov H, St. Pierre K, Vuorenmaa J, and Wang F. 2022. Climate change and mercury in the Arctic: Abiotic interactions. **Science of the Total Environment** doi.org/10.1016/j.scitotenv.2022.153715



Publications 2017-2023

PEER-REVIEWED JOURNAL ARTICLES

- Edwards BA, Pfeffer MA, Jóhannsson Þ, **Outridge PM**, and Wang F. (in press). An inter-method comparison of mercury measurements in Icelandic volcanic gases. **Applied Geochemistry.**
- Chételat J, McKinney MA, Amyot M, Dastoor A , Douglas TA, Heimbürger-Boavida L-E, Kirk J, Kahilainen KK, **Outridge PM**, Pelletier N, Skov H, St. Pierre K, Vuorenmaa J, and Wang F. 2022. Climate change and mercury in the Arctic: Abiotic interactions. **Science of the Total Environment**. doi.org/10.1016/j.scitotenv.2022.153715.
- Desforges J-P, **Outridge P**, Hobson KA, Heide-Jørgensen MP, and Dietz R. 2022. Anthropogenic and climatic drivers of long-term changes of mercury and feeding ecology in arctic beluga (*Delphinapterus leucas*) populations. **Environmental Science & Technology** 56: 271-281.
- Dastoor A, Angot H, Bieser J, Christensen JH, Douglas TA, Heimbürger-Boavida L-E, Jiskra M, Mason RP, McLagan DS, Obrist D, **Outridge PM**, Petrova MV, Ryjkov A, St. Pierre KA, Schartup AT, Soerensen AL, Toyota K, Travnikov O, Wilson J, and Zdanowicz C. 2022. Arctic mercury cycling. **Nature Reviews Earth & Environment** 3: 270–286.
- Sanei H, **Outridge PM**, Oguri K, Stern GA, Thamdrup B, Wenzhöfer F, Wang F, and Glud RN. 2021. High mercury accumulation in deep-ocean hadal sediments. **Scientific Reports** 11: 10970. doi: 0.1038/s41598-021-90459-1.
- Edwards BA, Kushner DS, **Outridge PM**, and Wang F. 2021. Fifty years of volcanic mercury emission research: Knowledge gaps and future directions. **Science of the Total Environment** 757: 143800.
- Lindström S, Sanei H, van de Schootbrugge B, Pedersen GK, Lesher CE, Tegner C, Heunisch C, Dybkjær K, and **Outridge PM**. 2019. Volcanic mercury and mutagenesis in land plants during the end-Triassic mass extinction. **Science Advances** 5: eaaw4018. doi: 10.1126/sciadv.aaw4018.
- Wang F, **Outridge PM**, Feng X, Meng B, Heimbürger-Boavida L-E, and Mason RP. 2019. How closely do mercury trends in fish and other aquatic wildlife track those in the atmosphere? – Implications for evaluating the effectiveness of the Minamata Convention. **Science of the Total Environment**. 674: 58-70. doi: 10.1016/j.scitotenv.2019.04.101.
- **Outridge PM**, Stern GA, Hamilton PB, and Sanei H. 2019. Algal scavenging of mercury in preindustrial Arctic lakes. **Limnology and Oceanography** doi: 10.1002/lno.11135.
- **Outridge PM**, Mason R, Wang F, Guerrero S, and Heimbürger-Boavida L-E. 2018. Updated global and oceanic mercury budgets for the 2018 United Nations Global Mercury Assessment. **Environmental Science & Technology** 52: 11466–11477.
- Zdanowicz C, Zheng J, Klimenko E, and **Outridge PM**. 2017. Mercury and other trace metals in the seasonal snowpack across the subarctic taiga-tundra ecotone, Northwest Territories, Canada. **Applied Geochemistry** 82: 63-78.
- **Outridge PM**, Sanei H, Courtney Mustaphi CJ, and Gajewski K. 2017. Holocene climate change influences on trace metal and organic matter geochemistry in the sediments of an Arctic lake over 7,000 years. **Applied Geochemistry** 78: 35-48.
- Kocman D, Wilson SJ, Amos HA, Telmer KH, Steenhuisen F, Sunderland EM, Mason RP, **Outridge P**, and Horvat M. 2017. Toward an assessment of the global inventory of present-day mercury releases to freshwater environments. **International Journal of Environmental Research and Public Health** 14: doi:10.3390/ijerph14020138.

Publications 2017-2023 cont'd

TECHICAL REPORTS AND ASSESSMENTS

- Dastoor A, Angot H, Dibble T, Douglas TA, Jiskra M, Kirk J, Mao H, Mason R, Obrist D, **Outridge PM**, et al. 2021. Changes in Arctic mercury levels: emissions sources, pathways and accumulation. Chapter 3 in, AMAP (2021) Arctic Mercury Science Assessment 2021. Arctic Monitoring and Assessment Programme, Tromso, Norway. pp. 63-122. https://www.amap.no/documents/doc/amap-assessment-2021-mercury-in-the-arctic/3581
- Nerentorp M, Wang F, Jonsson S, Cairns WRL, Chételat J, Jonsson S, Lescord G, Nerentorp M, Ukonmaanaho L, **Outridge PM**, et al. 2021. Changes in Arctic mercury levels – Processes affecting Hg transformations and biotic uptake. Chapter 4 in, AMAP (2021) Arctic Mercury Science Assessment 2021. Arctic Monitoring and Assessment Programme, Tromso, Norway. pp. 123-144. https://www.amap.no/documents/doc/ amap-assessment-2021-mercury-in-the-arctic/3581
- McKinney M, Chételat J, Amyot M, Burke SM, Dastoor A, Douglas TA, Elliott K, Fernie K, Heimbürger-Boavida L-E, Houde M, Kirk J, Muir D, Kahilainen K, Letcher RJ, Morris A, **Outridge PM**, et al. 2021. How does climate change influence mercury in the Arctic environment and in biota? Chapter 5 in, AMAP (2021) Arctic Mercury Science Assessment 2021. Arctic Monitoring and Assessment Programme, Tromso, Norway. pp. 145-172. https://www.amap.no/documents/doc/amap-assessment-2021-mercury-in-the-arctic/3581
- **Outridge PM**, Mason RP, Wang F, Heimbürger-Boavida LE and Feng X. 2018. Recent Advances in Understanding of Global Mercury Cycling. Chapter 2, In Arctic Monitoring and Assessment Programme/United Nations Environment Program, Global Technical Assessment for Mercury in the Environment. AMAP/UNEP, Geneva. 16 p. https://www.unep.org/resources/publication/global-mercury-assessment-2018
- Wang F, **Outridge PM**, Mason RP, Heimbürger-Boavida LE, and Feng X. 2018. Relationship between changes in mercury levels in the atmosphere and in fish and wildlife – Implications for implementation of the Minamata Convention on Mercury. Chapter 9, In Arctic Monitoring and Assessment Programme/United Nations Environment Program, Global Technical Assessment for Mercury in the Environment. AMAP/UNEP, Geneva. 22 p. https://www.unep.org/resources/publication/global-mercury-assessment-2018

Publications 2017-2023 cont'd

CONFERENCE PRESENTATIONS

- **P.M. Outridge**, R. Mason, F. Wang, S. Guerrero and L.-E. Heimburger. 2018. Updated global and oceanic mercury budgets for the 2018 United Nations Global Mercury Assessment. European Geosciences Union General Assembly, April 2018, Vienna. Abstract available at Geophysical Research Abstracts Vol. 20, EGU2018-8630.
- Brock A. Edwards, **Peter M. Outridge**, and Feiyue Wang. 2019. Uncertainties in measuring mercury outgassing from volcanic and geothermal systems: implications for understanding the global mercury budget. Oral Presentation, American Geophysical Union (AGU) Fall Meeting, 9–13 December 2019, San Francisco, CA, USA.
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Environmental Geoscience Program (EGP)

For more information on the EGP, please contact:
Director: rejean.couture@canada.ca
Manager: gilles.cotteret@canada.ca
Geoscience planning officer: juliette.mochizuki@canada.ca

For more information on a specific project, please contact:
Regional assessment: josue.jautzy@canada.ca
Aquifers in Fox Creek: christine.rivard@canada.ca
Induced seismicity: honn.kao@canada.ca
CO_2 sequestration: stephanie.larmagnat@canada.ca
Dredge disposal at sea: gwyn.lintern@canada.ca
Geological storage of carbon: don.white@canada.ca
Mining impacted watershed: alexandre.desbarats@canada.ca
Hydrological dynamics of the Mackenzie River Basin: jennifer.galloway@canada.ca
Permafrost geochemistry: paul.gammon@canada.ca
Diluted bitumen impacts: jason.ahad@canada.ca
Marine oil spill: manuel.bringue@canada.ca
Oil sands: jason.ahad@canada.ca
Global mercury budget: gilles.cotteret@canada.ca