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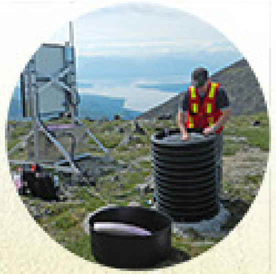

Geological Survey of Canada
Scientific Presentation 163

Public presentations (126th) of May 17th, 2022: Environmental Geoscience Program, current status of research projects for the 2019–2024 program cycle

J. Aubut Bernard, P. Gammon, M.J. Duchesne, J. Jautzy, J. Ahad,
M. Bringué, L. Gwyn, and D. White

2025

Presented at: Public presentations (126th) of May 17th, 2022: Environmental Geoscience Program, current status of research projects for the 2019–2024 program cycle

Date presented: May 2022

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Environmental Geoscience Program (EGP): Presentation of research status for 8 out of 15 projects

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.

Due to the pandemic, research advancement occasionally faced delay due to laboratory closure and lack of fieldwork access. Nevertheless, the advancement of projects is documented herein and via the EGP YouTube account. The talks on this work were recorded during the public presentations via Zoom on May 10 and 17, 2022 are available via the following link: https://www.youtube.com/channel/UCWiCrKnTeF-j_La6_Wc5NMA/playlists

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

Programme de géosciences environnementales (PGE): Présentation de l'état d'avancement des recherches pour 8 des 15 projets

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.

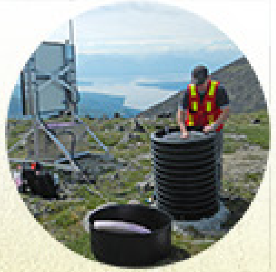
Le résultat ultime du PGE est d'accroître l'efficacité et le rendement de la réglementation et de la surveillance environnementale au Canada. En développant de la géoscience novatrice pour la gestion de l'environnement, ainsi qu'en augmentant l'accès des secteurs public et privé aux résultats de la recherche,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

En raison de la pandémie, l'avancement des recherches a parfois été retardé par la fermeture des laboratoires et le manque d'accès au travail sur le terrain. Néanmoins, l'avancement des projets est documenté dans le présent document et sur le compte YouTube du PGE. Les exposés sur ces travaux ont été enregistrés lors des présentations publiques via Zoom les 10 et 17 mai, 2022 et sont disponibles via le lien suivant: https://www.youtube.com/channel/UCWiCrKnTeF-j_La6_Wc5NMA/playlists

Mots-clés : *Clumped isotope geothermometry, induced seismicity, impacts on aquifers, diluted bitumen, modelling in oil sands region, marine oil spill, Mackenzie River Basin, climate change, UNEP global mercury assessment, geological storage of carbon, cumulative effects, permafrost degradation, permafrost geochemistry, dredge disposal at sea and regional assessment.*

DAY 2 : May 17, 2022 // JOUR 2 : 17 mai, 2022




Infrastructure Impacts on Permafrost Geochemistry

Paul Gammon

May 17, 2022

ABSTRACT

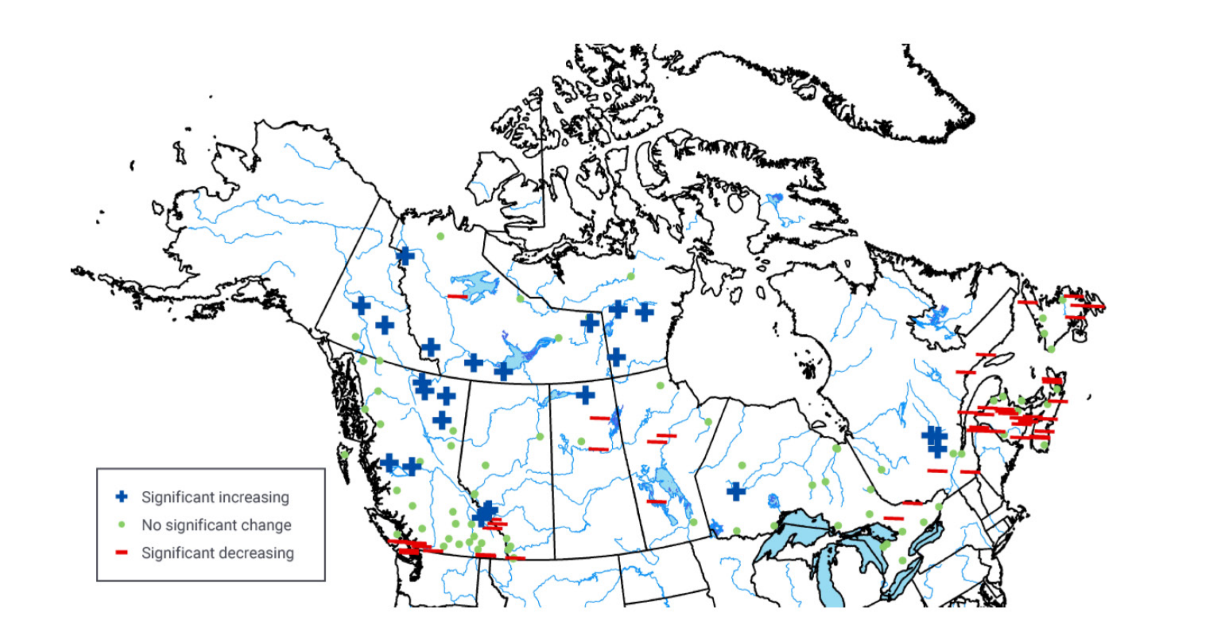
The geochemistry resulting from permafrost freeze-thaw processes are poorly understood. This EGP activity aims to refine our current understanding of these processes, and how they are impacted by infrastructure development. It will do this via sensor monitoring and sampling of a borrow pit used for the construction of the Inuvik to Tuktoyaktuk Highway (ITH). Construction generated high-solute groundwaters within some of the borrow pits. Pit I401a was chosen as the test site with sampling (solids and waters) and sensor installation conducted in Fall 2021. Inuvik workers downloaded the dataloggers episodically during the winter to monitor their performance. Overall the sensors worked well and the pressure and water monitoring data generated suggest groundwater movement occurred throughout the winter. Sensor data suggests brine formation is likely the source of the high solute concentrations and that latent heat transport is a critical component of active layer hydrology. Overall the data has provided new insights into active layer processes, and modest changes to sensor design can successfully generate standard monitoring data in these harsh environments.

PROJECT MEMBERS

- Paul Gammon
- James Zheng
- Melissa Bunn
- Lilianne Pagé
- Pierre Pelchat
- John Sekerka
- Aurora Research Institute
- Inuvik Hunters and Trappers

Background

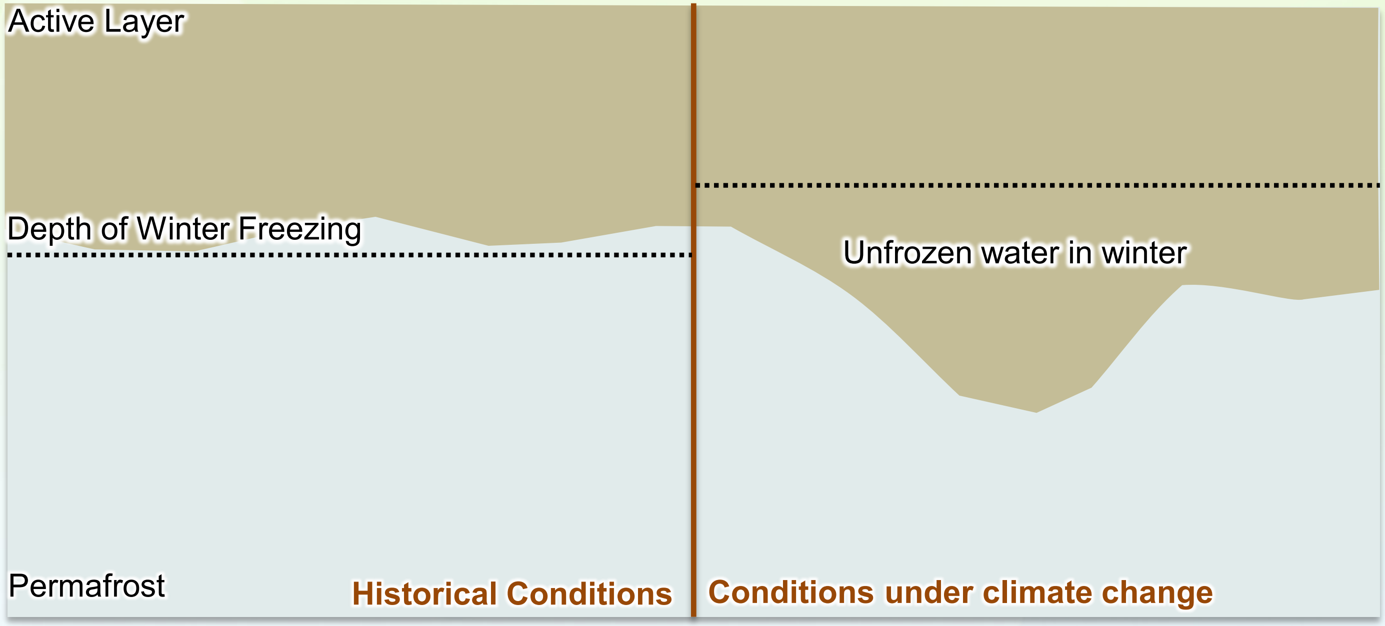
- Climate change induced warming temperatures and snowpack dynamics are contributing to permafrost degradation and increases in active layer thickness
- Groundwater flow will become a more dominant contributor to the arctic hydrologic systems.
- These changes have implications for water quality as solutes formerly sequestered in frozen ground are released and transported to surface water via groundwater



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

Challenges

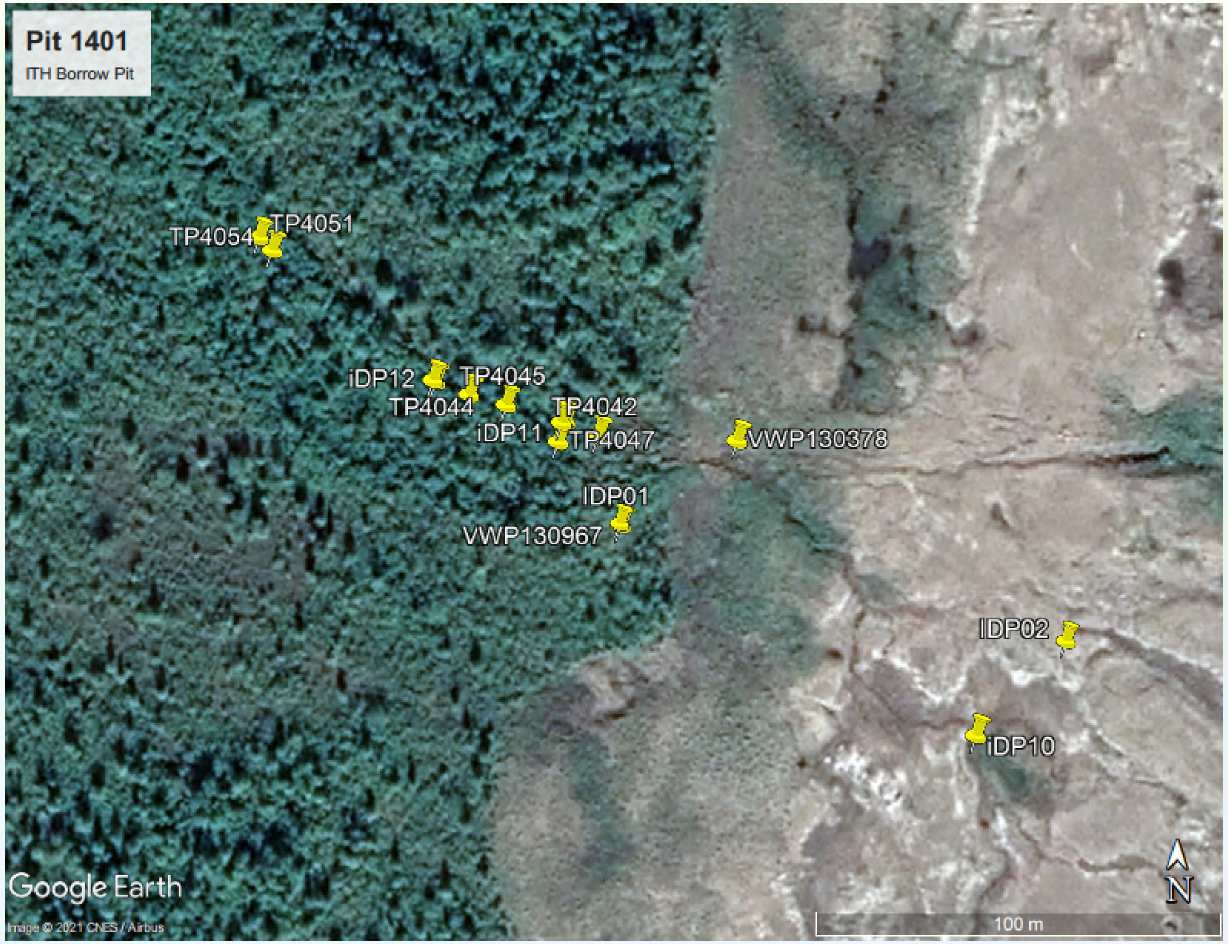
- Complex physical processes
  - spatially variable,
  - Seasonal (temporally variable),
  - unique to these environments.
- Long-term monitoring data is essential for modelling and forecasting, but scant and difficult to obtain (especially winter monitoring).
- Hydrogeological monitoring limited due to the active layer freezing. **This data is an essential starting point.**



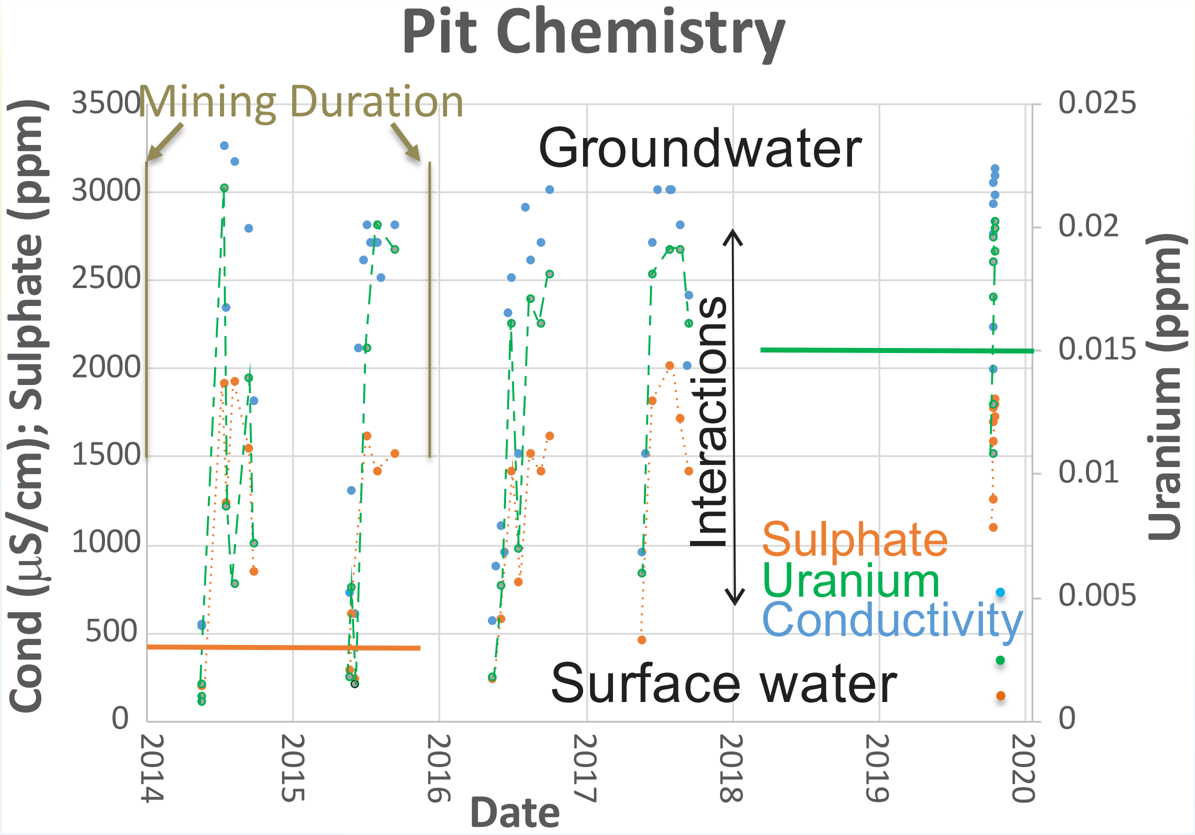
The research site: Borrow pit dug for road material for ITH

Inuvik to Tuktoyaktuk Highway:

- Completed 2017
- Borrow pits actively degrading
- Rapid permafrost thaw



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 melt origin.

Why is this permafrost so high in solutes?

The research site: Hydrogeological context

Geophysics!

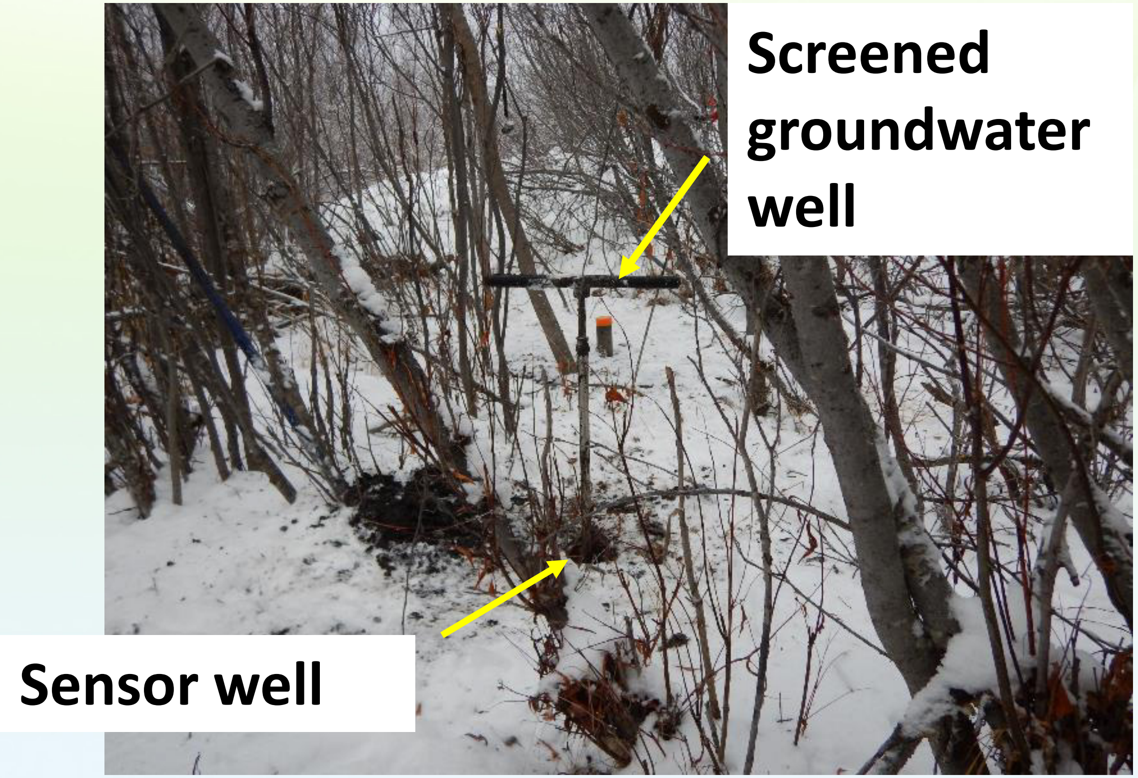
Aquifers and aquitards:

- Pit is predominantly clayey silt with minor pebbles (till)
- Lenticular pebbly silty gravels throughout
- Gravels form complexly interconnected aquifers (old outflow streams?)
- Conglomerates define drainage pattern

Drainages are aligned depressions:

- Depressions formed via subsidence (thaw)
- Groundwater flow occurs beneath depressions
- Surface flow intermittent (likely relatively minor)

The research site: Hydrogeological context



Outside of pit (natural areas):

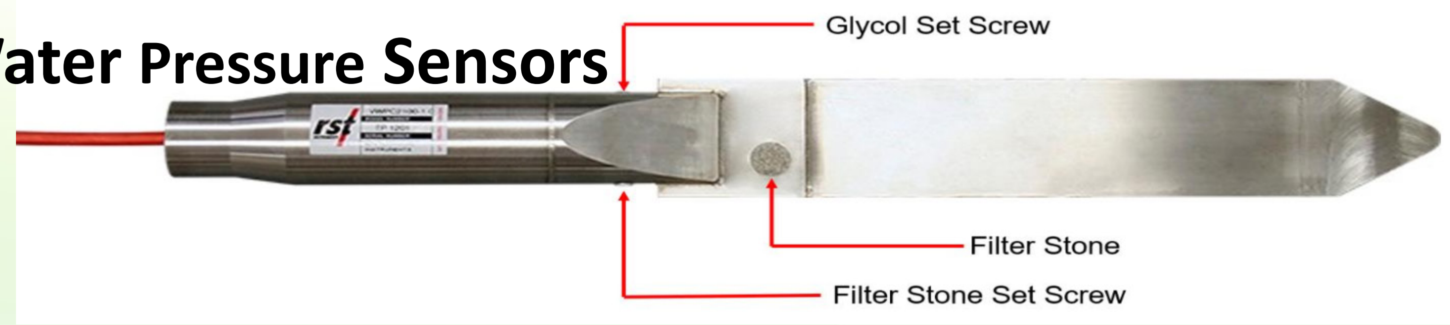
- Active layer 0.4 – 1.8 m thick (probe and auger)
- Greatest thickness below drainages where gravels present.
- Gravels not intersected outside of drainages

Sensing of active layer groundwater during freeze-thaw

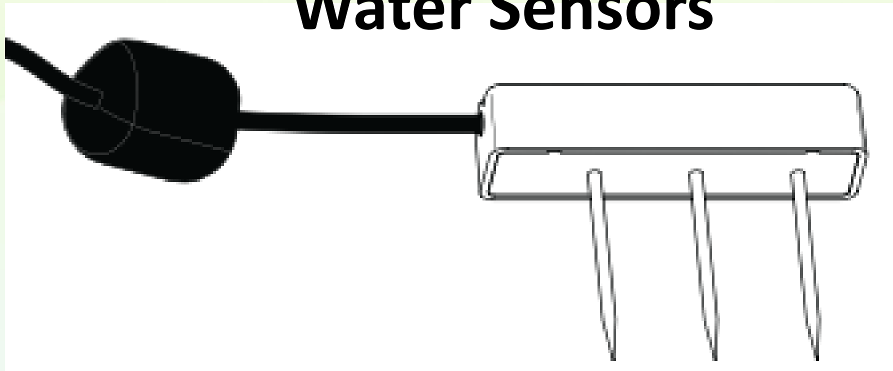
- Traditional soil pore water and formation pressure sensors unable to withstand the volumetric expansion of freezing water.
- Methods that limit freezing (e.g. grouting) difficult to execute in unconsolidated materials
- Goal is to develop and test monitoring systems that are robust and can be easily deployed and interpreted.

Sensing of active layer groundwater during freeze-thaw

RST Formation and Water Pressure Sensors



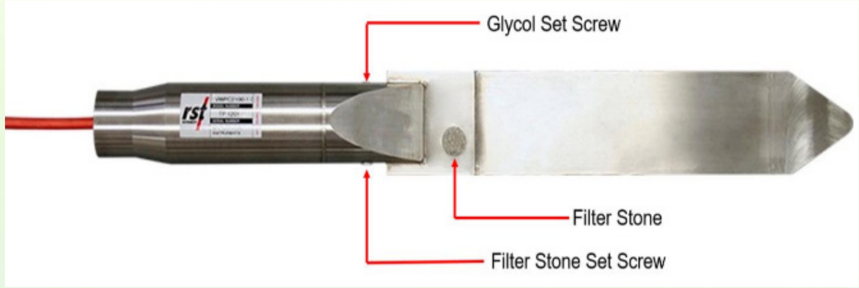
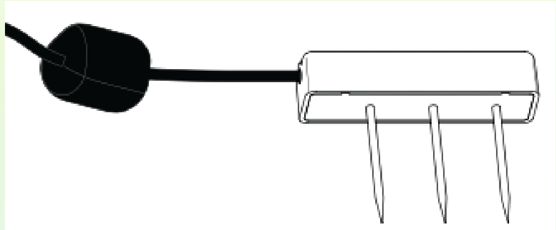
METER Soil Water Sensors



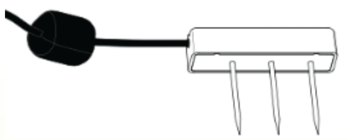
Pressure sensors:
Does groundwater flow occur in winter?
What is the subsurface active layer pressure regime during winter freezing?

Groundwater soil sensors:
What happens to active layer soil water during winter?
Do electrical conductivities indicate brine formation or movement during freezing?

Monitoring Approach

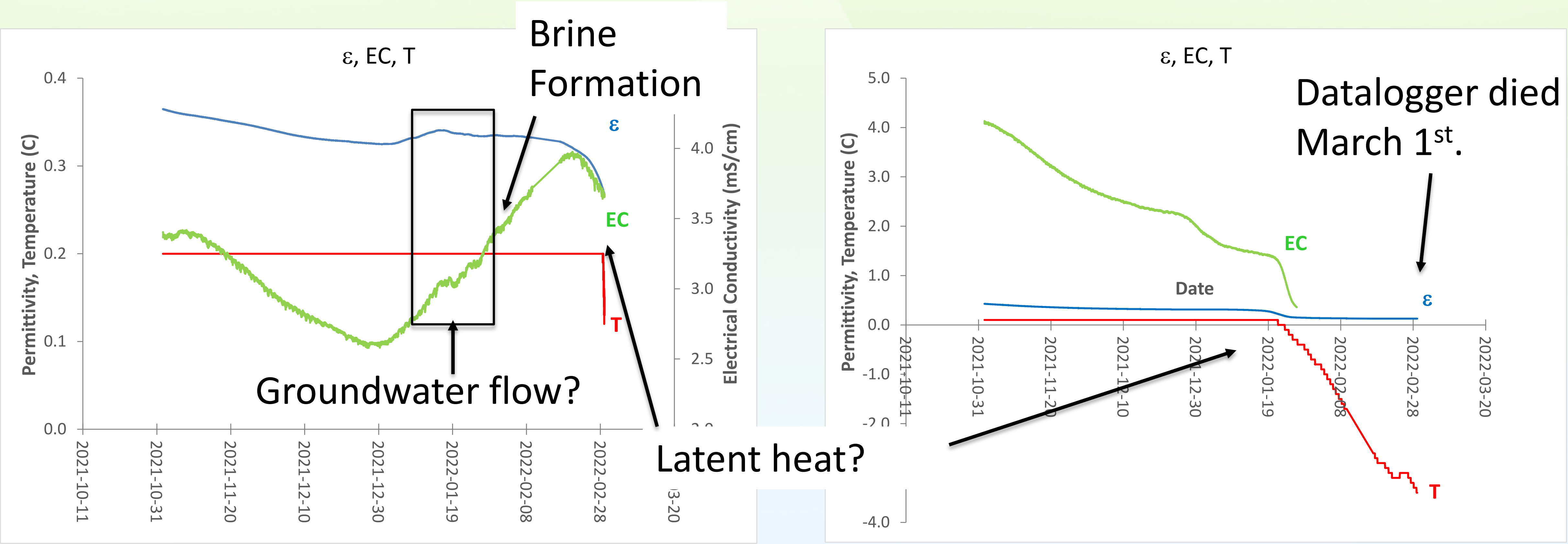
Push-In Pressure Cell	Vibrating Wire Piezometer	Time-Domain Reflectometry
		
• Measures water pressure, water temperature and total earth pressure • Indication of groundwater flow and pressure increase due to soil freezing	• Measures water pressure, water temperature and total earth pressure • Indication of groundwater flow	• Measures bulk volume dielectric permittivity (ε), temperature and electrical conductivity • ε decreases significantly as water freezes and indicates state • Electrical conductivity and temperature indicate formation of brines and freezing point depression

How did the sensors do over winter 2021-22? - METER

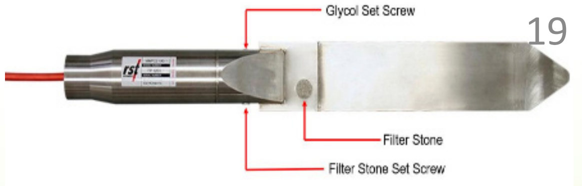


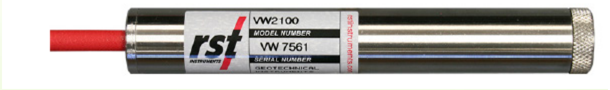
Sensor: 0.9m deep in gravel

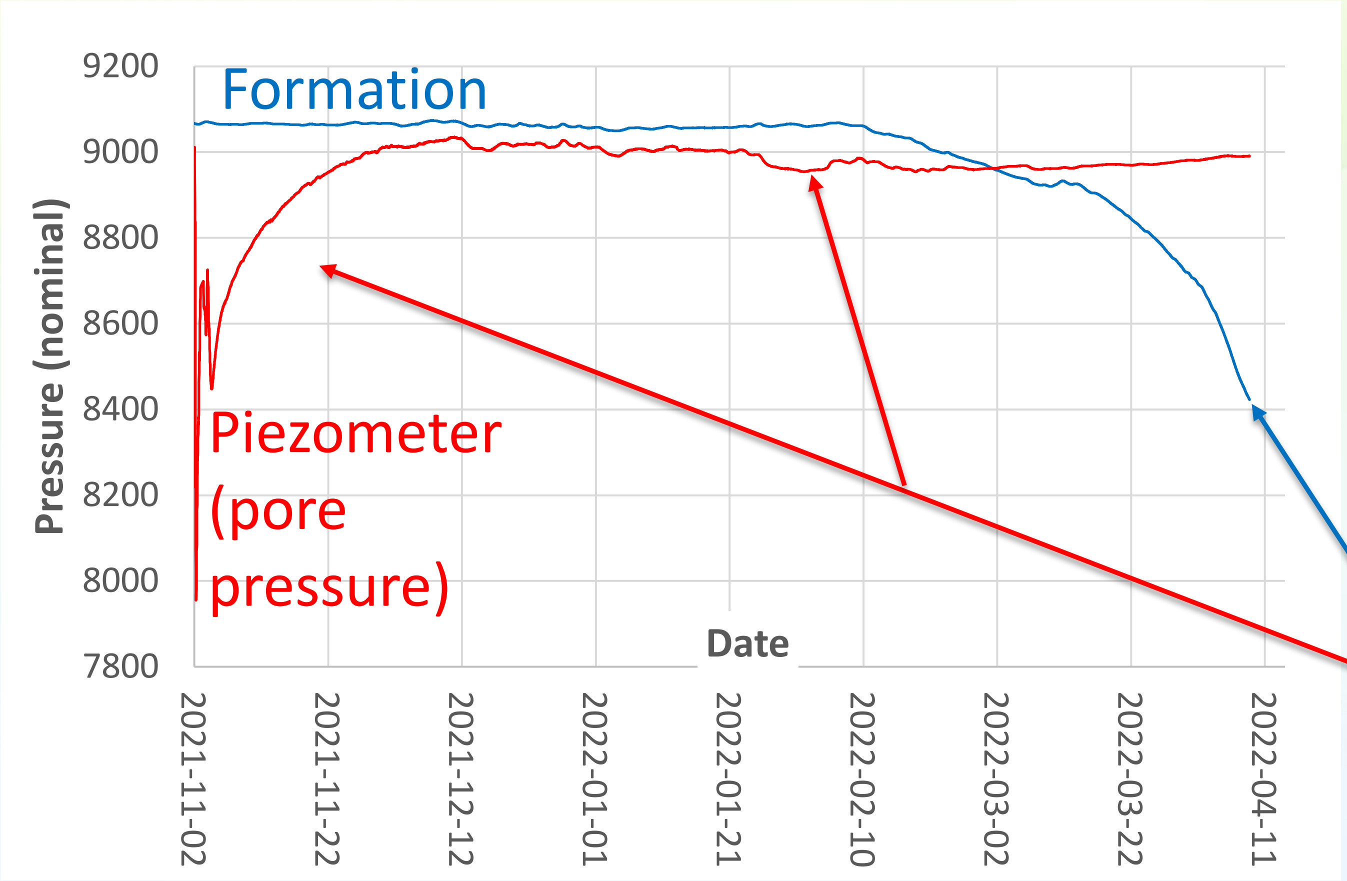
Sensor: 0.8m deep in mud



How did the sensors do over winter 2021-22? - RST







Piezometer and Formation sensors @ 1m depth in gravel

Dataloggers and sensors worked well all winter!

Sensors require relaxation time after installation

Both pressure increases and decreases seen over winter, particularly pore water (?= water movement?).

Summary

Pit I401a is hydrogeologically complex:

- Pit comprised of tills hosting minor to moderate gravel lenses
- Groundwater flow concentrated along gravel lenses
    - Aquifer geometry complex – Geophysics!
- Rapid subsidence controlled by latent heat flow along gravel aquifers

Pit I401a sensor monitoring:

- Monitor sensors worked well
    - batteries failed in 1 Meter datalogger
- Groundwater becomes concentrated during freeze-up (brine formation)
    - Likely source of elevated solute concentrations
- Groundwater flow and pressure regimes can be monitored over winter with these systems!
    - Needs greater sensor sensitivity

CONTACT INFORMATION

- Paul Gammon
- 613-995-4909
- Paul.gammon@nrcan-rncan.ca

Thank you!

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Natural Resources Canada

Environmental impacts of permafrost degradation

Impacts environnementaux de la dégradation du pergélisol

Mathieu J. Duchesne. May 17, 2022

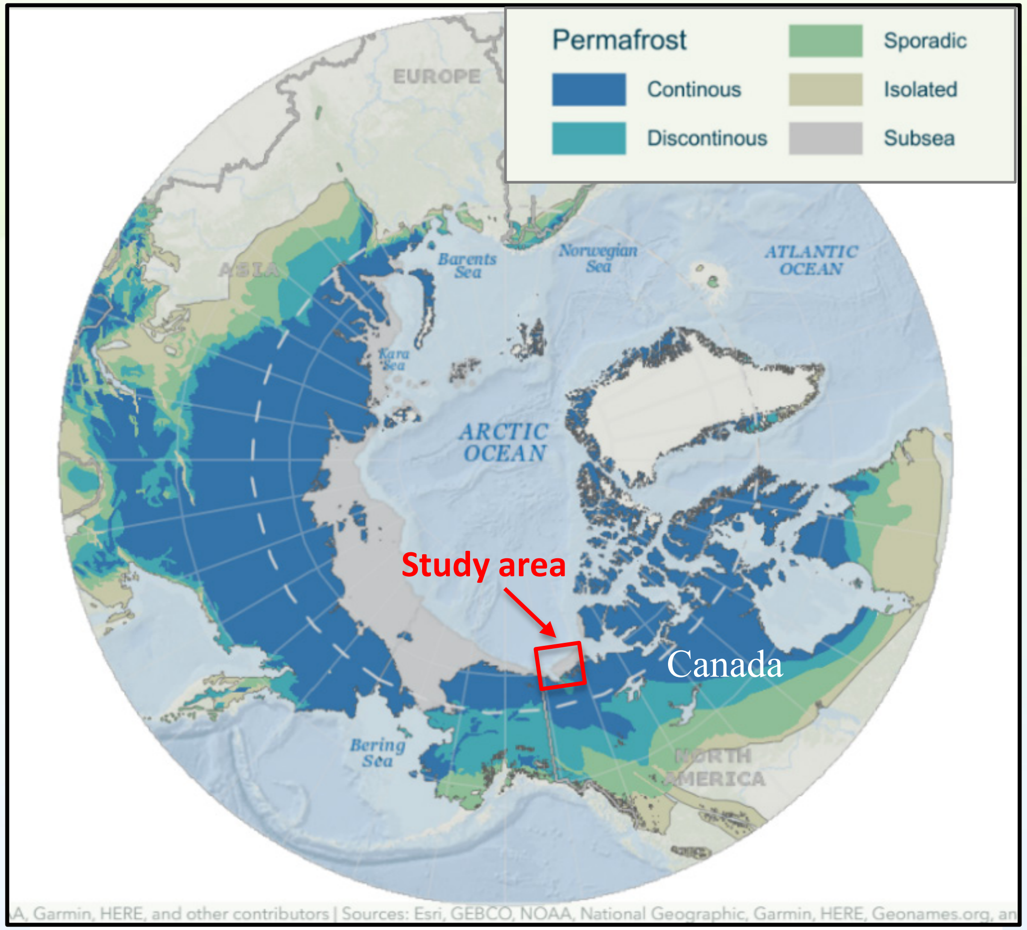
Canada

Abstract

- Permafrost underlies ~50% of the Canadian landmass.

- Permafrost degradation: natural release of contaminants (e.g. heavy metals), trapped greenhouse gases and saline pore fluids into the environment.

- Project objectives:
  1. assess the environmental implications of permafrost degradation
  2. provide a baseline to better appraise the environmental consequences of resource development.



ESRI, GEBCO, NOAA, National Geographic, Garmin

(May 2021 - October 2022)

Project members

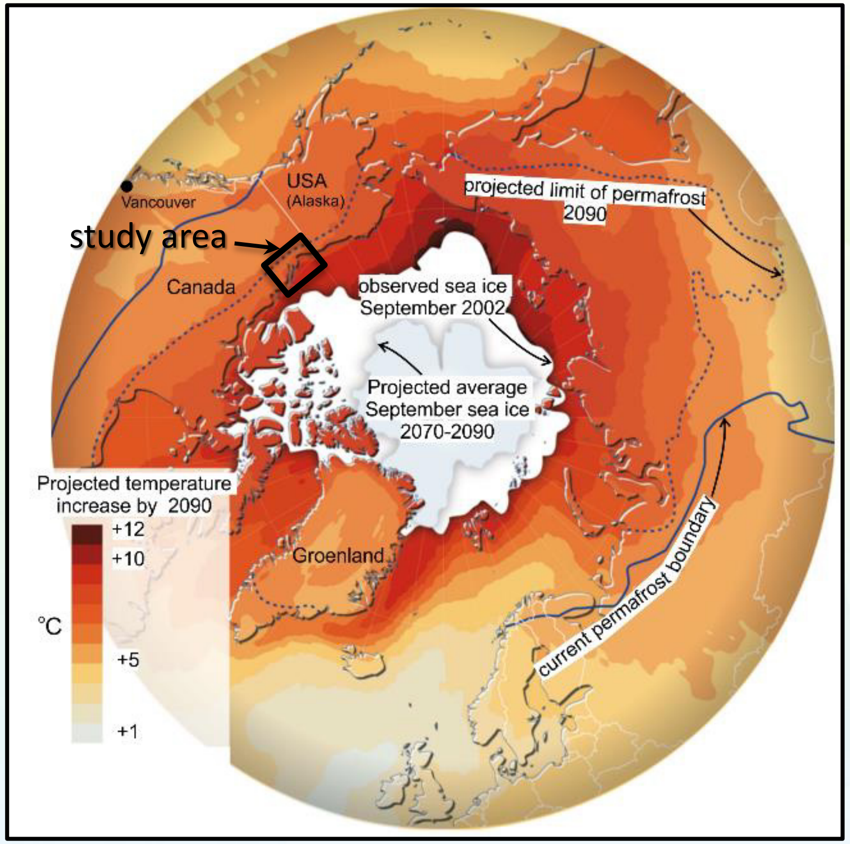
- **GSC**:

  Brake, V. I., Duchesne, M.J., Pinet, N., Côté, M., Dallimore, S.R, King, E., MacLeod, R., Morse, P., Wolfe, S., Jautzy, J.

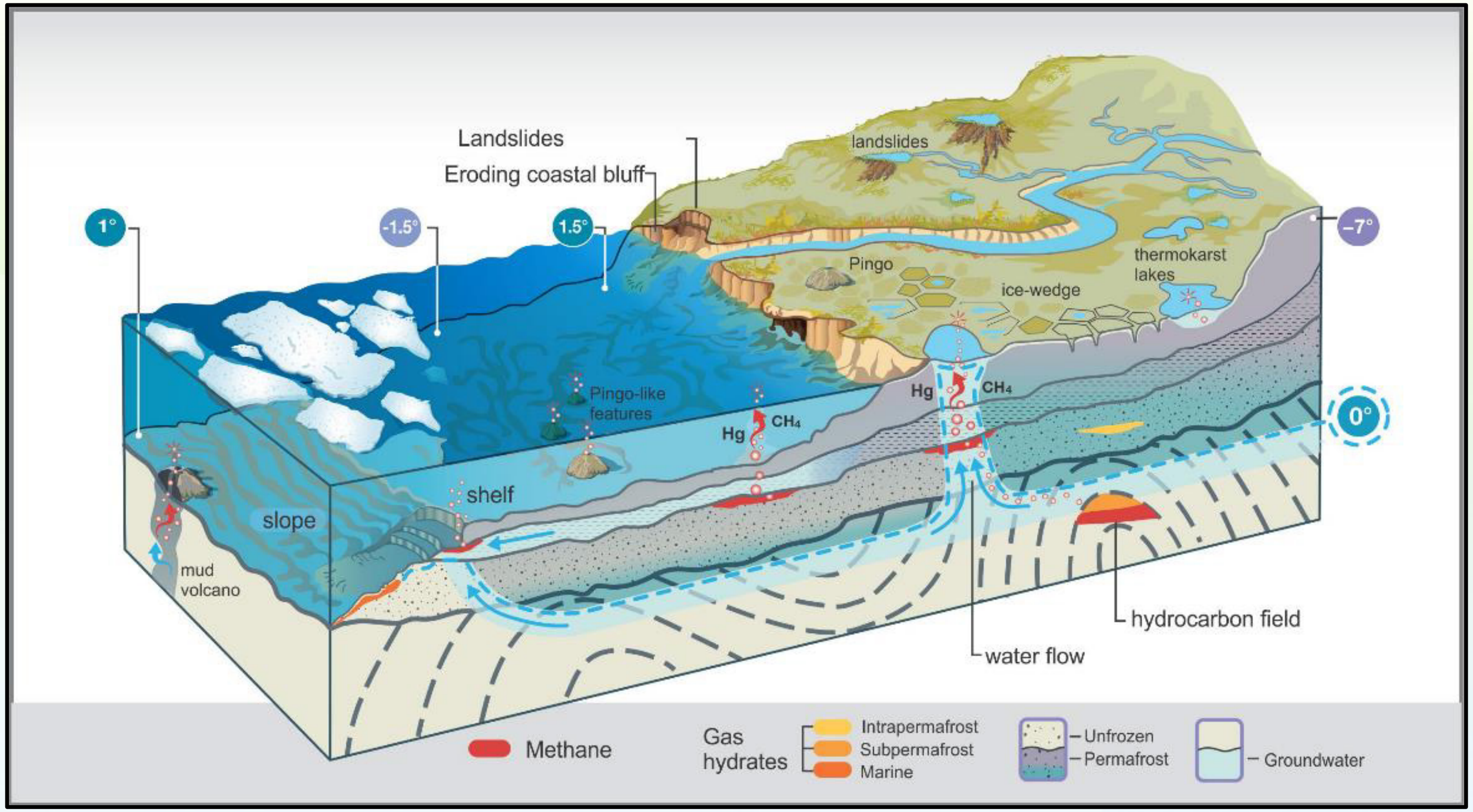
- **External collaborators**:

  Fabien-Ouellet, G. (Polytechnique Montreal), Giroux, B. (INRS), Raymond, J. (INRS), Dupuis, J. C. (Laval University), Risk, D. (St. Francis Xavier University), Greinert, J. (GEOMAR), Riedel, M. (GEOMAR), Gwiazda, R. (MBARI), Paull, C.K. (MBARI), Jin, Y. K. (KOPRI), Hong, J.K. (KOPRI), Rhee, T. S. (KOPRI), Kang, S.-G. (KOPRI), Lapham, L. (U. of Maryland), Orcutt, B. (Bigelow Lab.), Overduin, P. (AWI), Wheat, G. (U. of Alaska), Woods, W. (NRL), Obelcz, J. (NRL), Goordial, J. (U. of Guelph), Sachs, T. (GFZ), Miller, C. (NASA), Fix, A. (DLR), Melling, H. (DFO), Applejohn, A. (GNWT), Seccombe-Hett, P. (ARI), Giordano, N. (Geotherma)

Project Context



National Center for Atmospheric Research, 2008



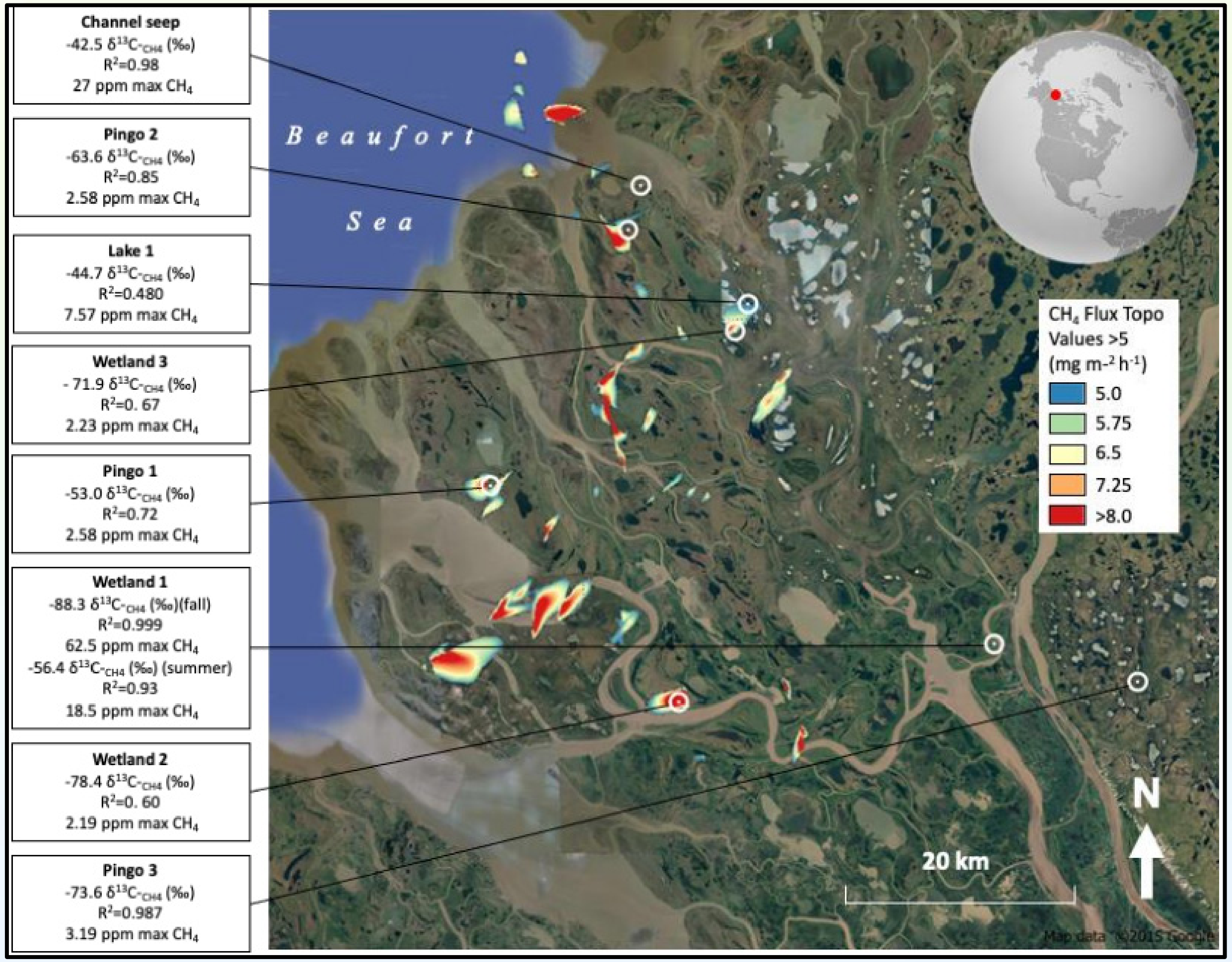
UNEP -Rapid Response Assessment-: Offshore and Coastal permafrost

The abrupt temperature increases across the Arctic circumpolar triggers a wide range of geological processes associated with permafrost degradation. Some of them, such as the release of greenhouse gases, have profound impacts on the environment.

Terrestrial permafrost degradation

Assessing hotpots of atmospheric CH_4 release

- St. Francis Xavier University, GSC

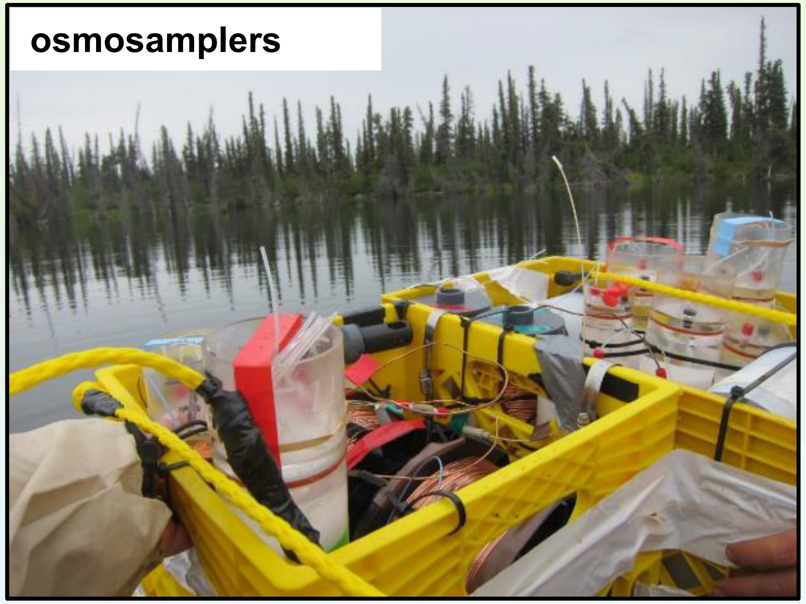


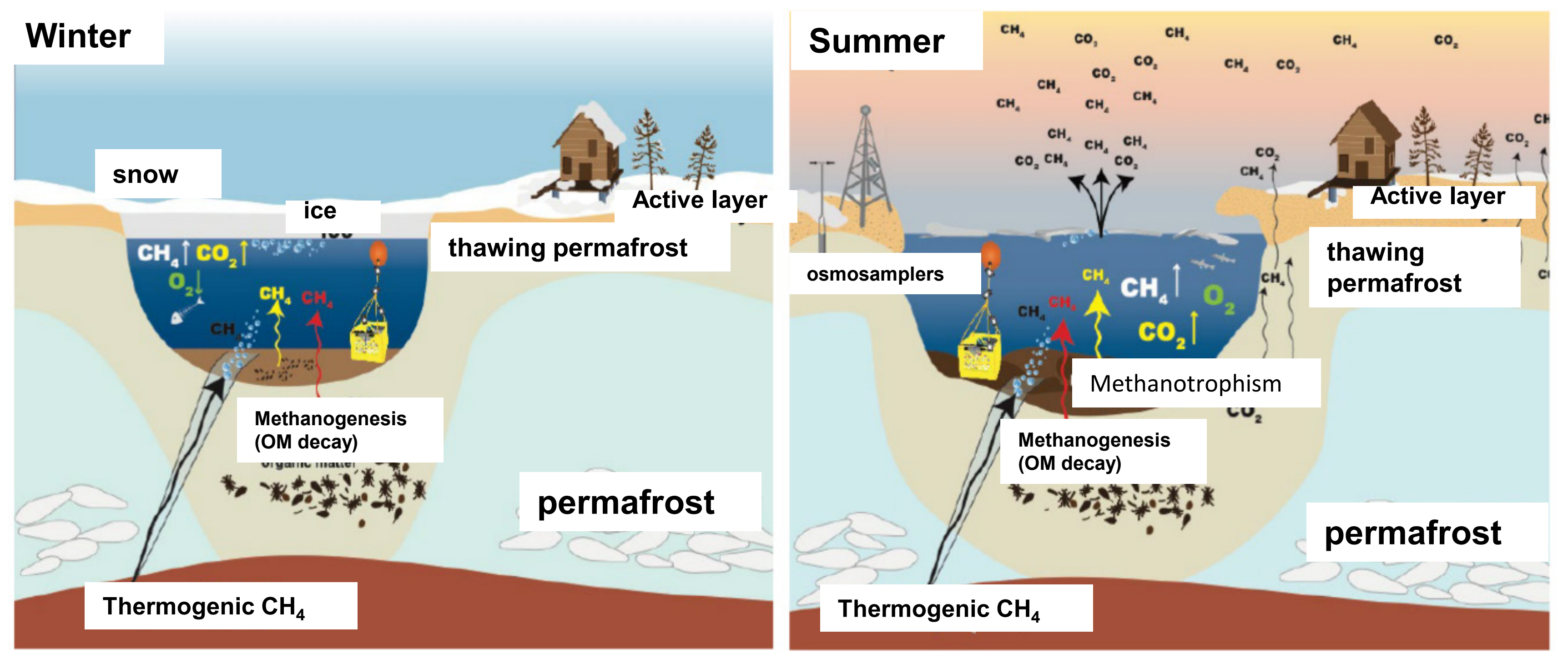
- Aerial surveys of CH_4 flux have identified hot spots in the Mackenzie River Delta but their origin was unknown
    - ground sampling and characterization of hotspots
- Considerable regional variability with distinct indicating thermogenic, biogenic and mixed CH_4 sources

Terrestrial permafrost degradation

Continuous measurements of CH_4 release in lakes

-UMaryland



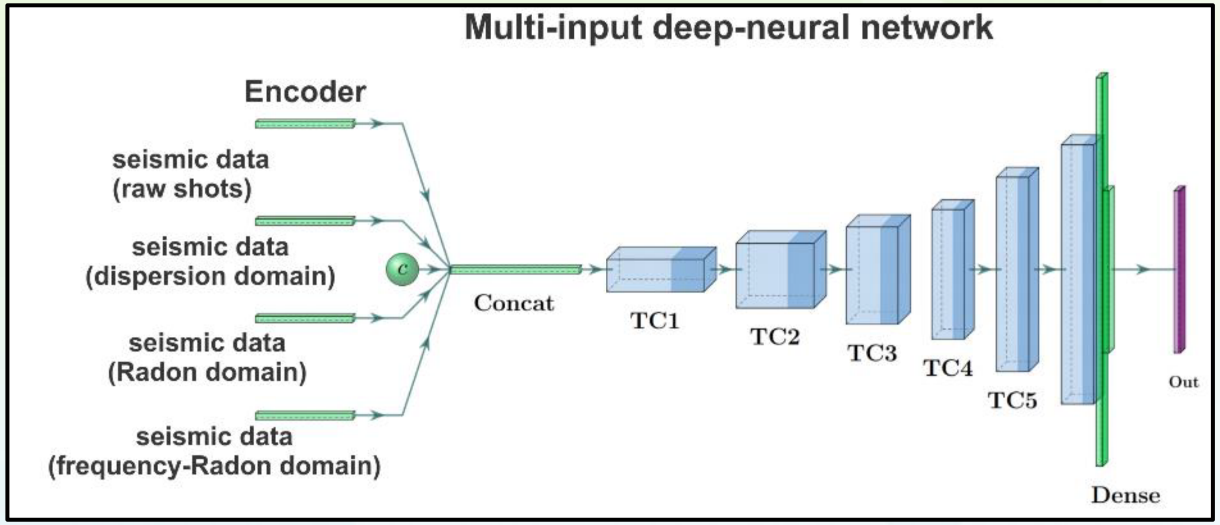


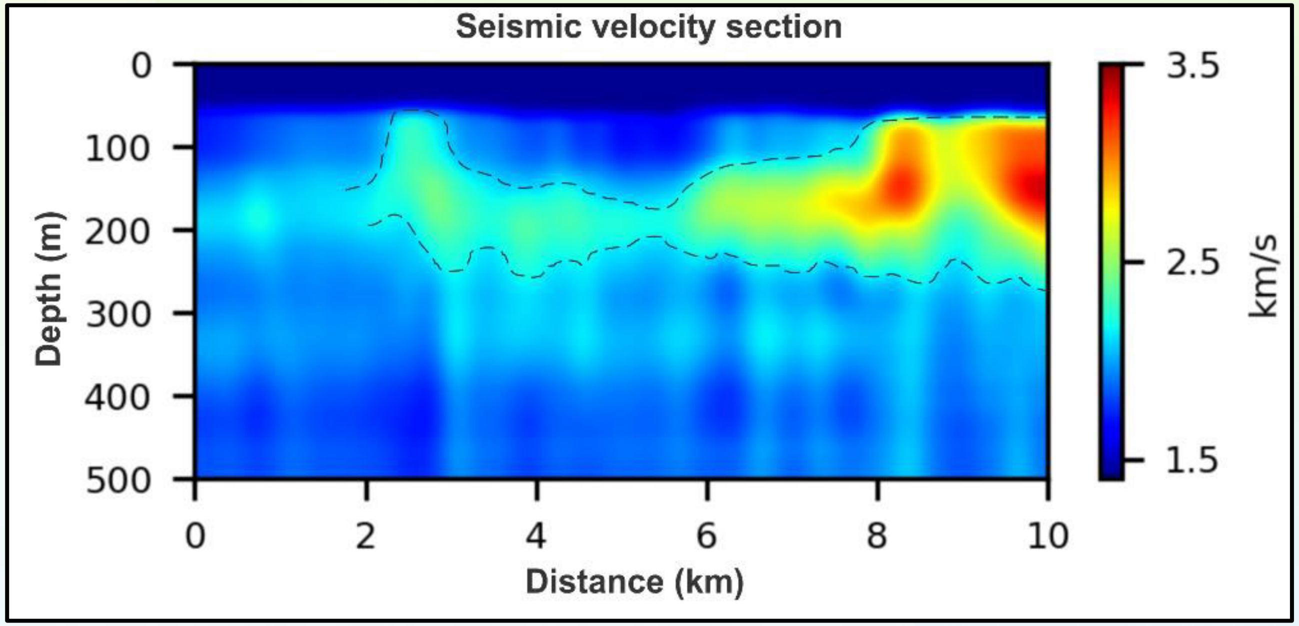
(May 2021 - October 2022)

Subsea permafrost degradation

Seismic velocity estimation in changing permafrost conditions

-Polytechnique Montreal, GSC



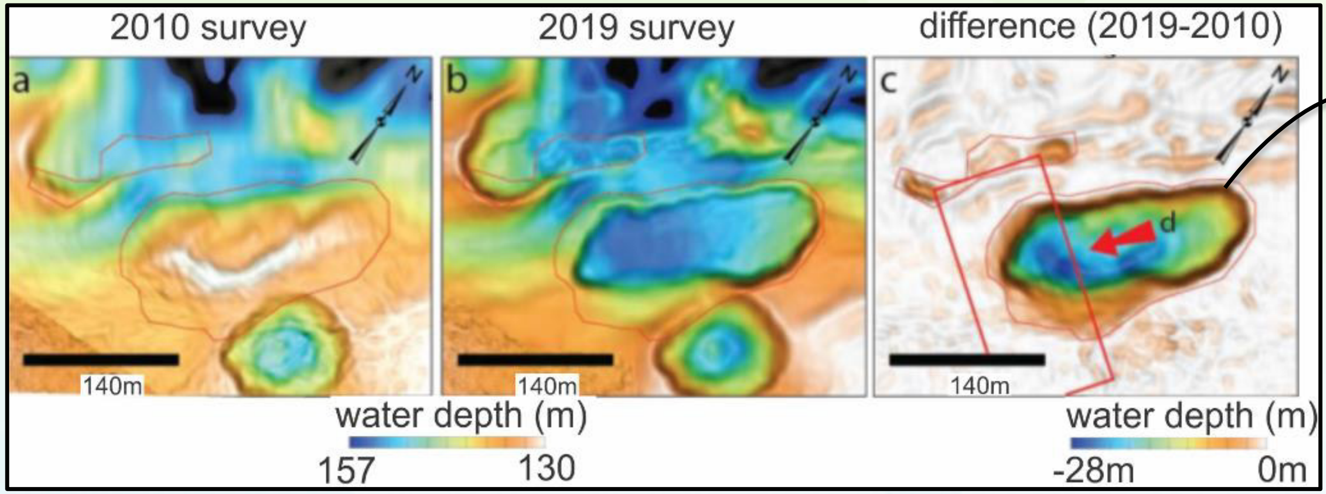


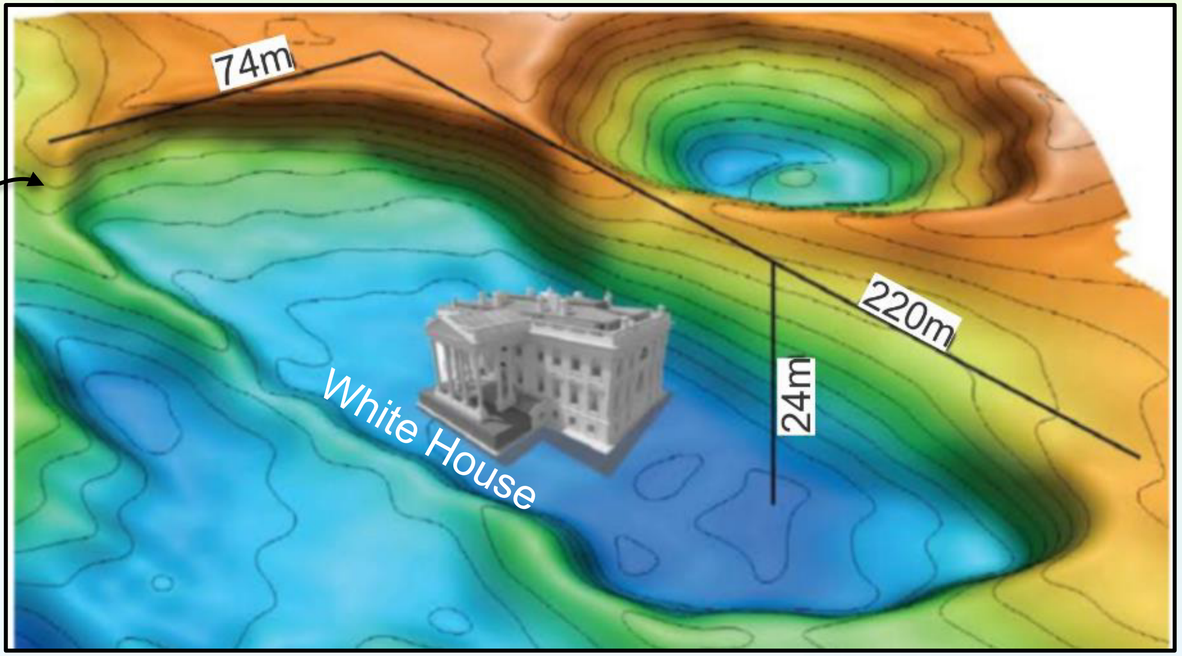
Bustamante et al. (2022)

Subsea permafrost degradation

Rapid seafloor changes associated with subsea permafrost degradation

-MBARI, KOPRI, DFO, GSC



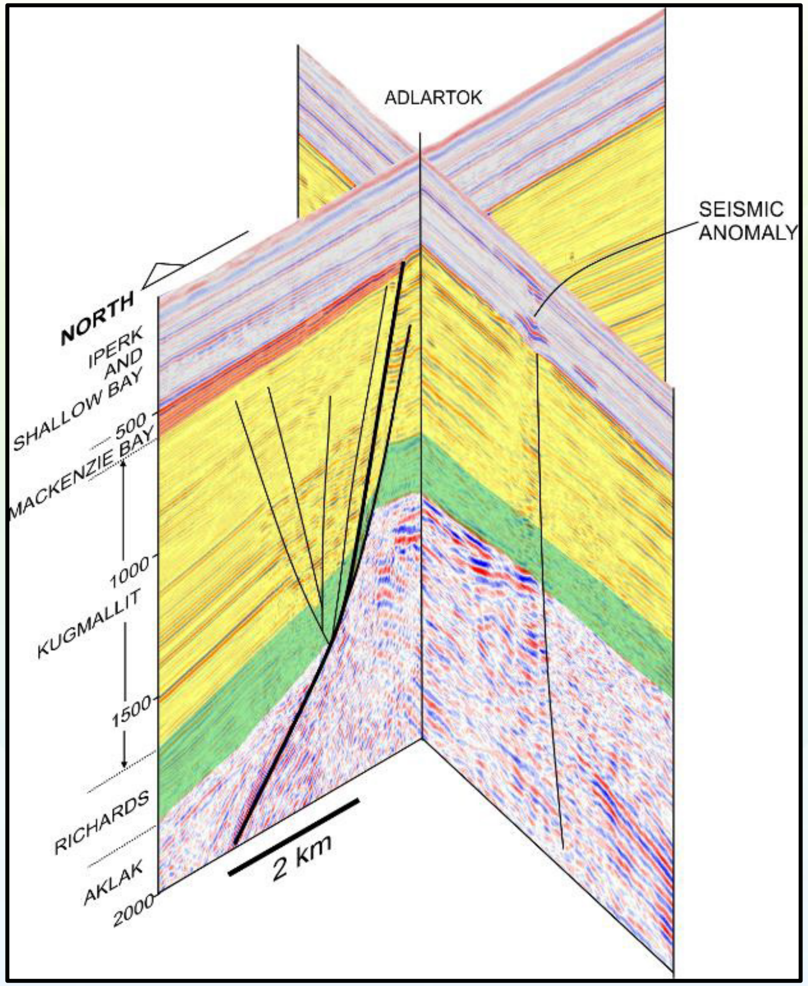


Paull et al. (2022)

(May 2021 - October 2022)

Subsea permafrost degradation

The influence of Cenozoic normal faults on fluid leakage *-GSC*

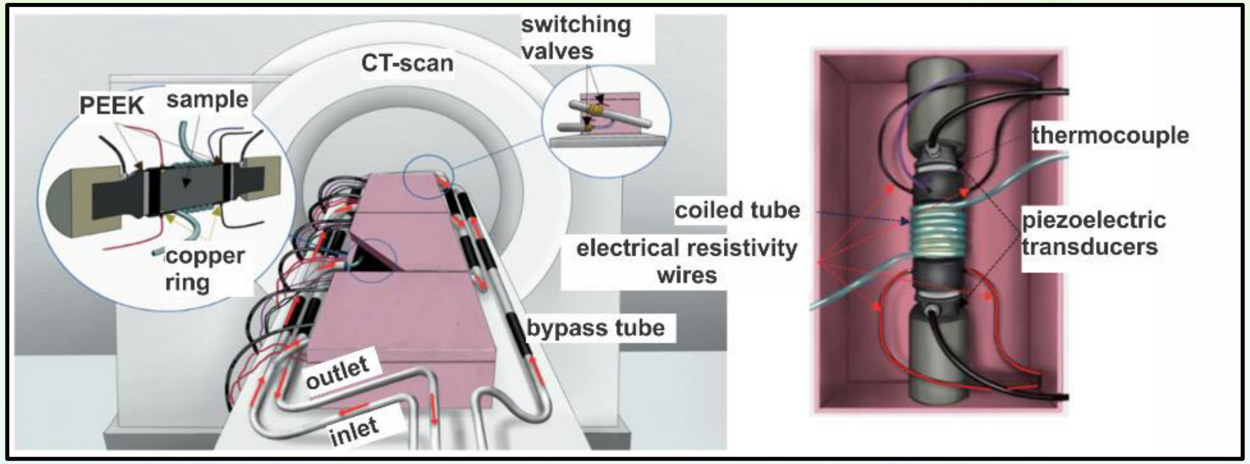


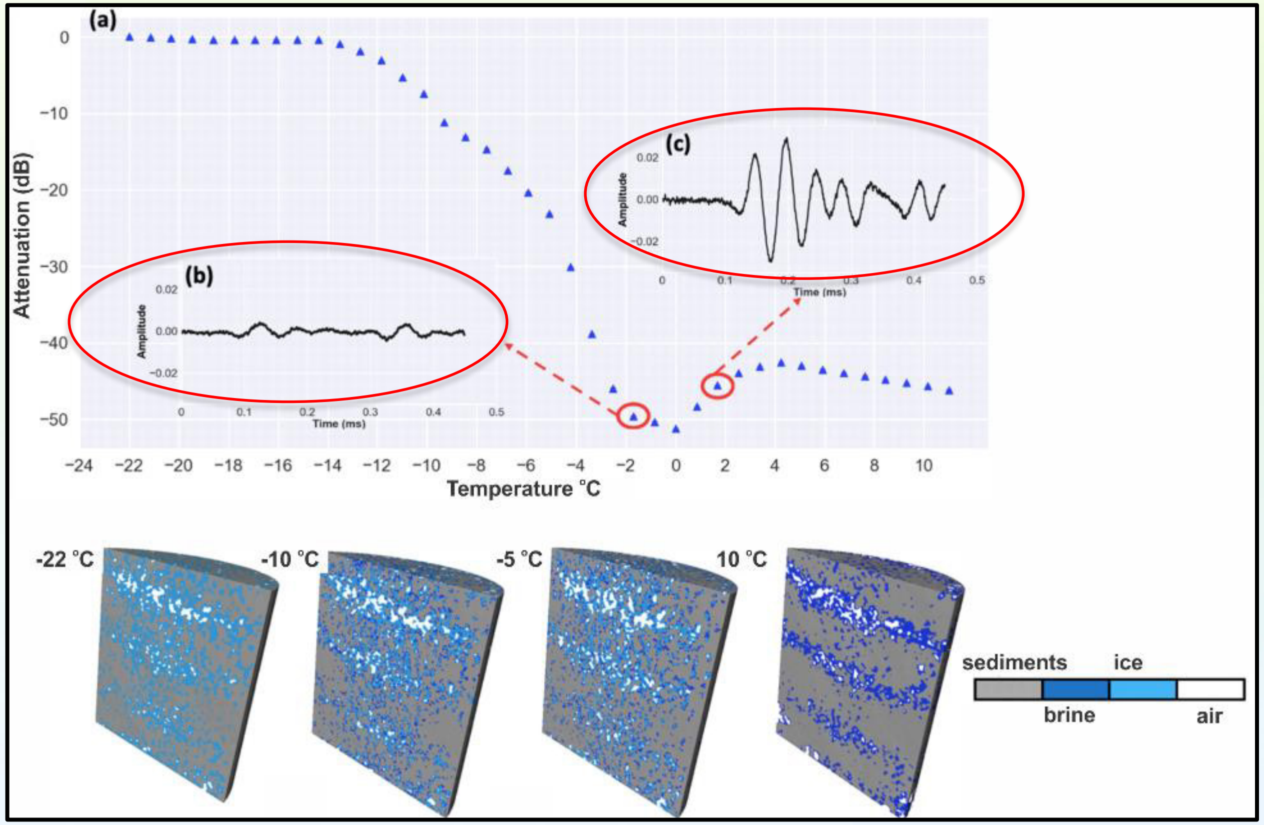
Pinet et al. (in prep)

Laboratory experiments on permafrost degradation

Real-time, simultaneous electrical, acoustic and CT-scan measurements

-INRS, ULaval, GSC



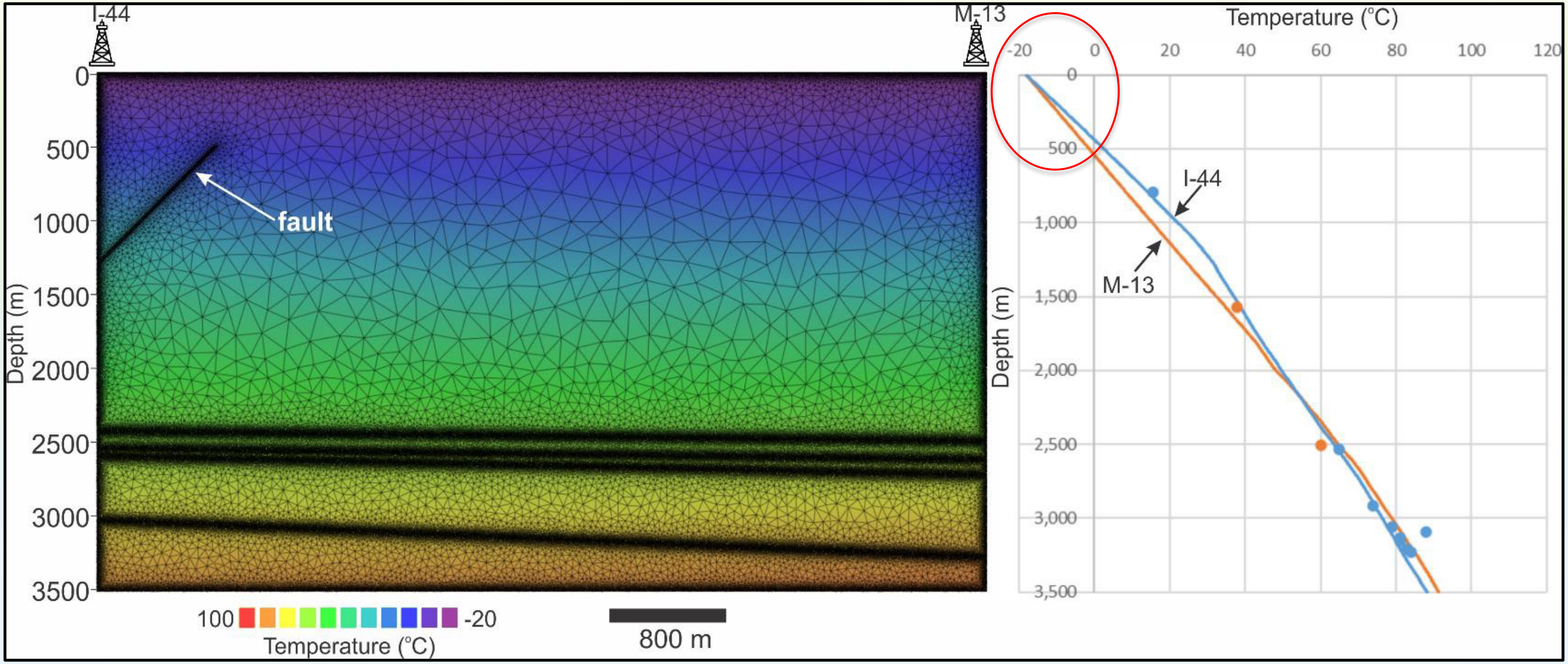


Vosoughi et al. (2022)

(May 2021 - October 2022)

Numerical experiments on permafrost degradation

Numerical simulation of heat transfer and implication on permafrost degradation -*INRS, Geotherma, GSC*



Giordano et al. (2022)

CONTACT INFORMATION

- Mathieu J. Duchesne
- tel: 418.654.2647
- mathieuj.duchesne@nrcan-nrcan.gc.ca

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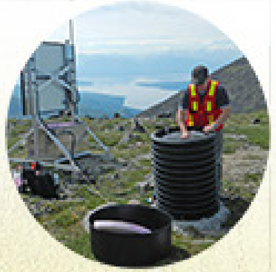



SOURCES 2022.

Paul Gammon, Jason Ahad

May 17, 2022

Canada

ABSTRACT

Data collection and interpretation continues to generate important new insights into the environmental processes and chemistry at the research site new Fort McMurray. Interpretation and modelling of inorganic geochemical data from the site demonstrates that the plumes' boron (B) distribution is consistent with an equilibrium sorption model. B distribution is in the process of being coupled to the flow model for the numerical Reactive Transport Model. The very rapid (<20 m) attenuation of the OSPW signature continues to provide insights into the organic components of the plume. Statistical analysis of detailed microbial eDNA data indicates that Firmicutes microbes are closely linked to plume attenuation. In other hydrocarbon spill localities Firmicutes microbes have been linked to hydrocarbon degradation. Chloroflexia bacteria also seem to be linked to plume components, although they are not considered hydrocarbon degraders. Conversely, Proteobacteria, another group that elsewhere has been linked to hydrocarbon degradation, do not appear to be closely linked to plume organics degradation at this site. Important differences exist within the microbial complement of existing industrial experimental wetlands, particularly Firmicutes (abundant at test site, mostly absent in industrial experimental wetlands) versus Actinobacteriota, Acidobacteriota (abundant in industrial experimental wetlands, modest presence at test site). Given the strong links between Firmicutes and OSPW attenuation at the research test site, the observed microbial complement might be important for informing industrial wetland reclamation and pathways for mitigating OSPW toxicity in the event of a spill.

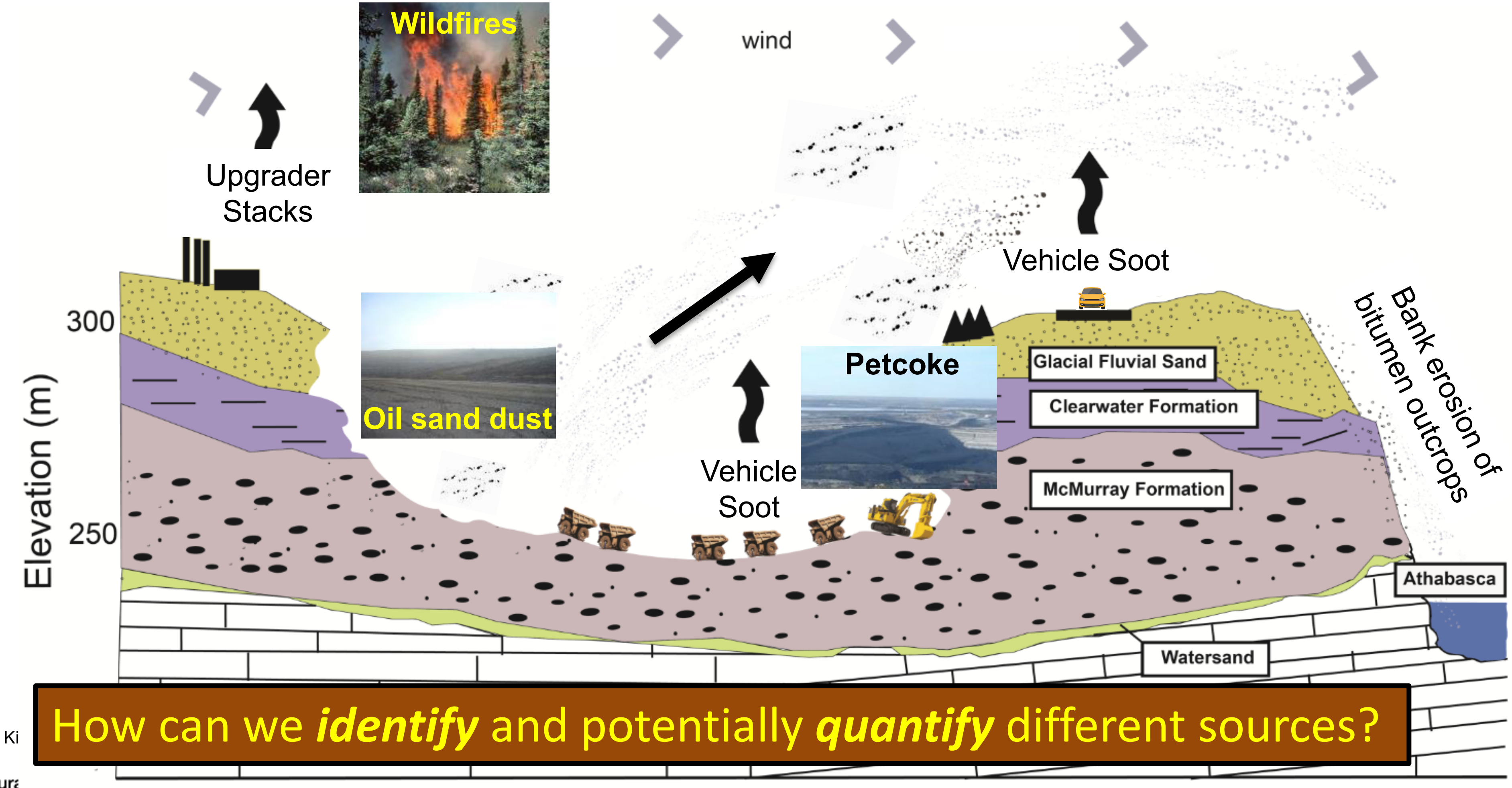
PROJECT

Paul Gammon, Jason Ahad, Richard Amos, Samrat Alam, James Zheng, John Headley, Samuel Morton, Stephanie Roussel, Martine Savard, Hooshang Pakdel, Charles Gobeil, Anna Smirnoff, Marc Luzincourt, Jade Bergeron, Marie-Christine Simard, Richard Huang, Colin Cooke, Kim Kasperski, COSIA, + AOS companies

Activity 1: A Reactive Transport Model of an oil sands production water plume

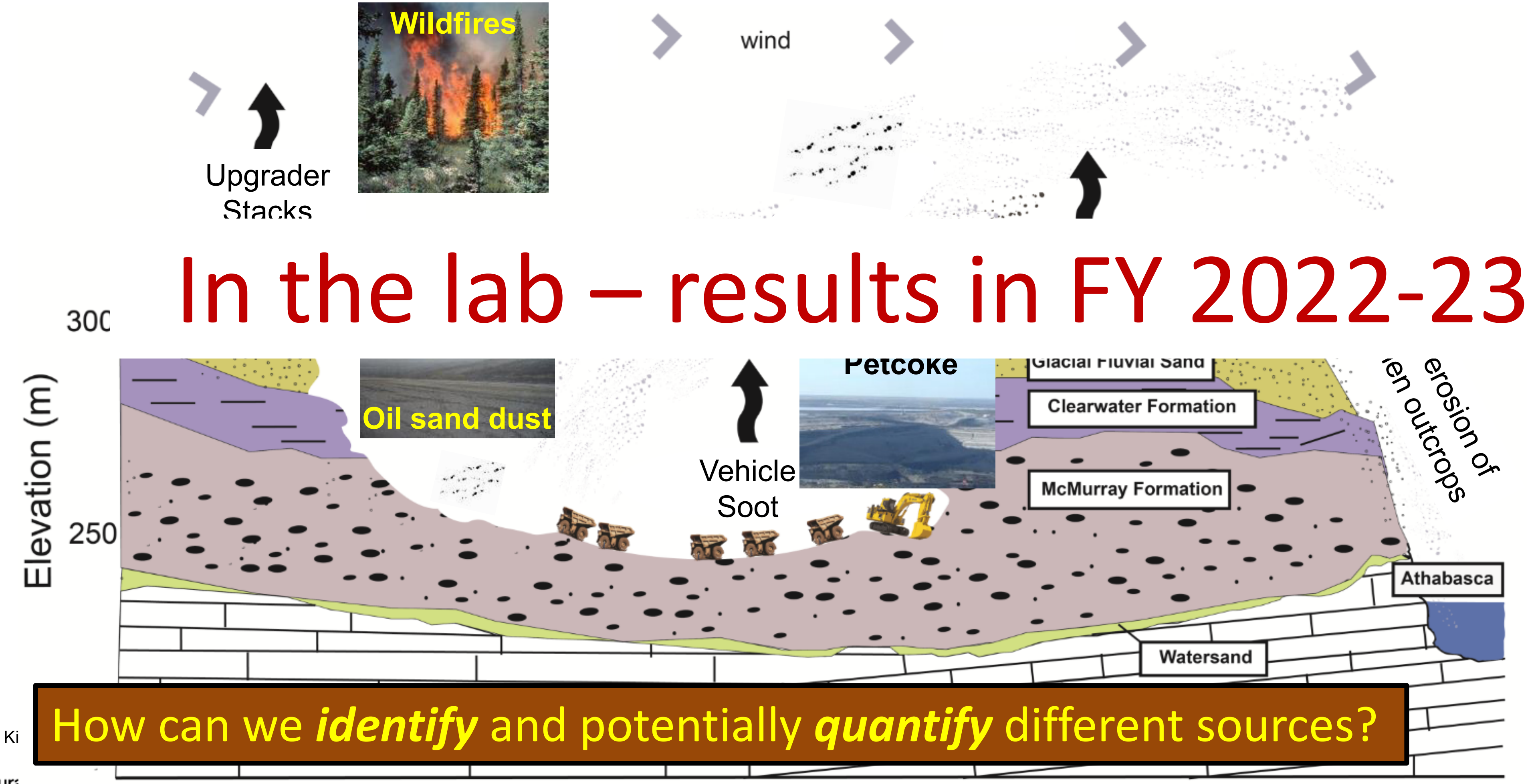
Activity 2: Identification of Polycyclic Aromatic Compound (PAC) sources in the AOSR.

Potential sources of Polycyclic Aromatic Compounds in the Athabasca oil sands region (AOSR)



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

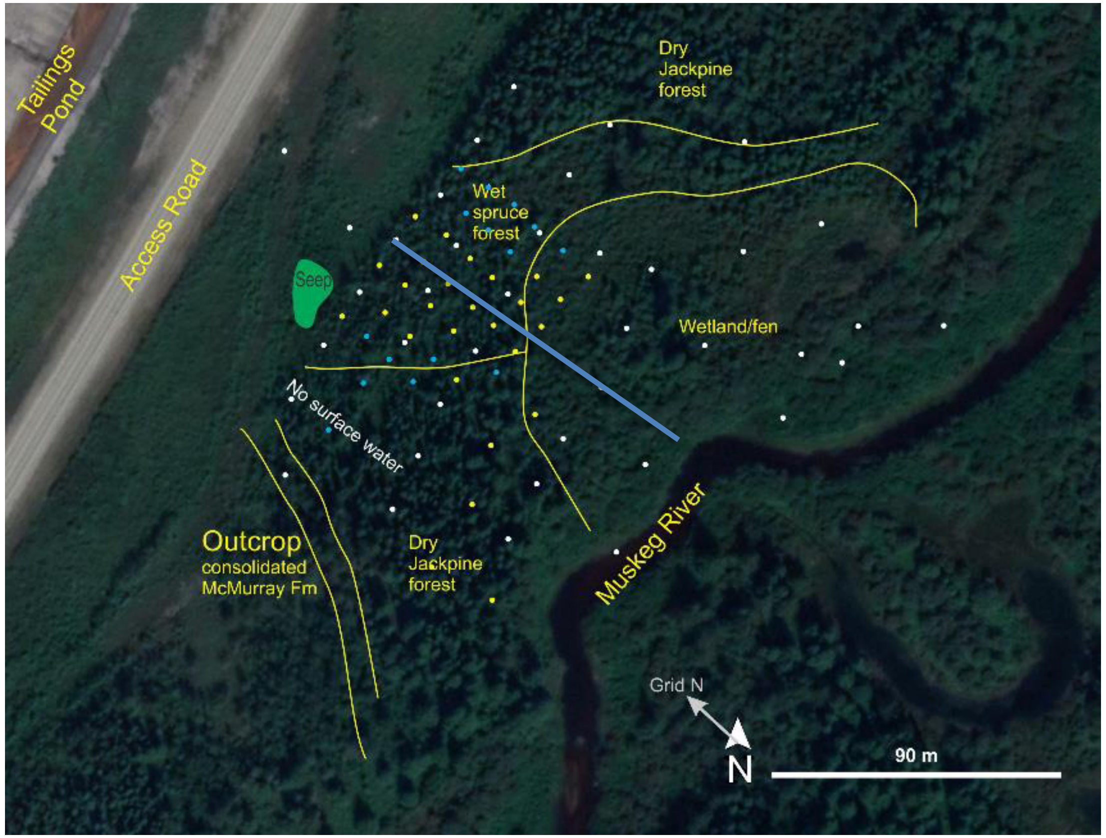
Potential sources of Polycyclic Aromatic Compounds in the Athabasca oil sands region (AOSR)



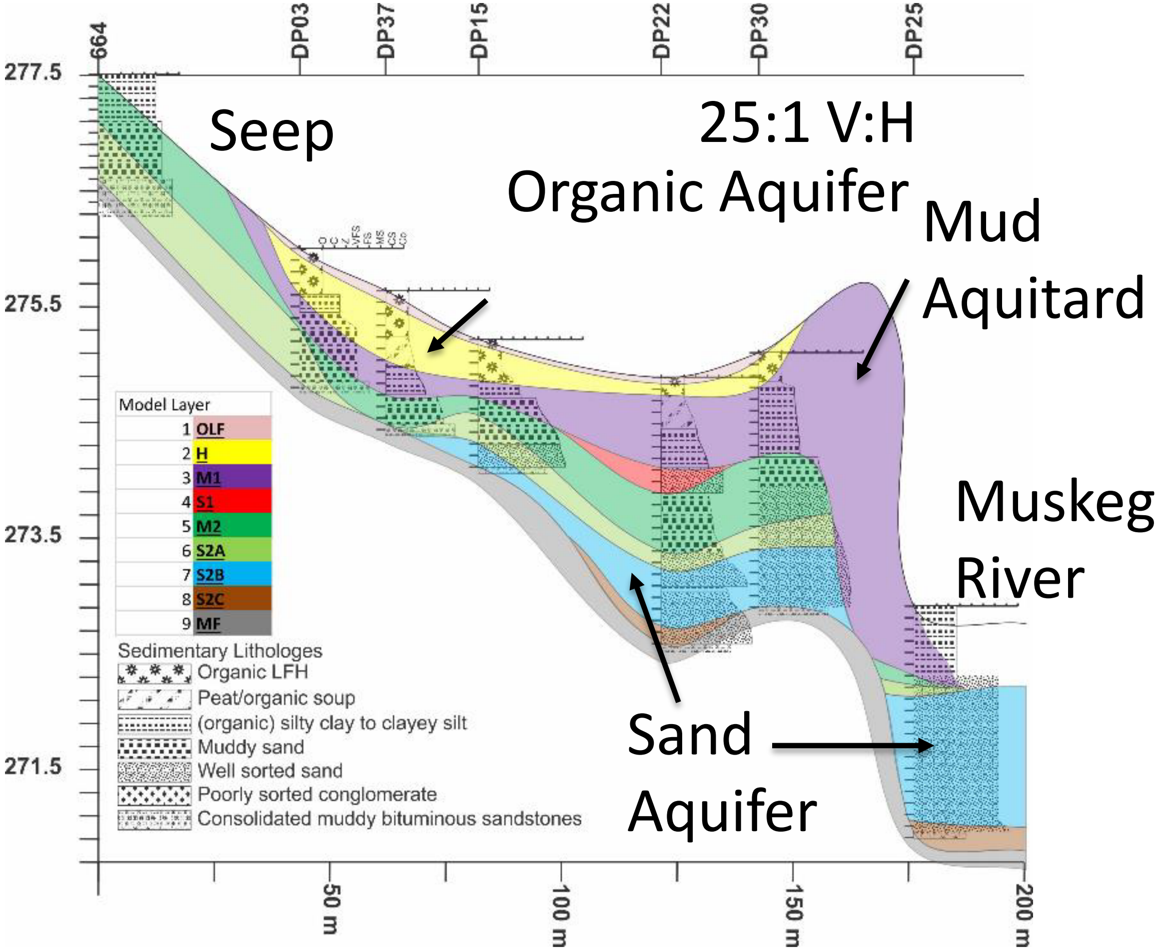
In the lab – results in FY 2022-23

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

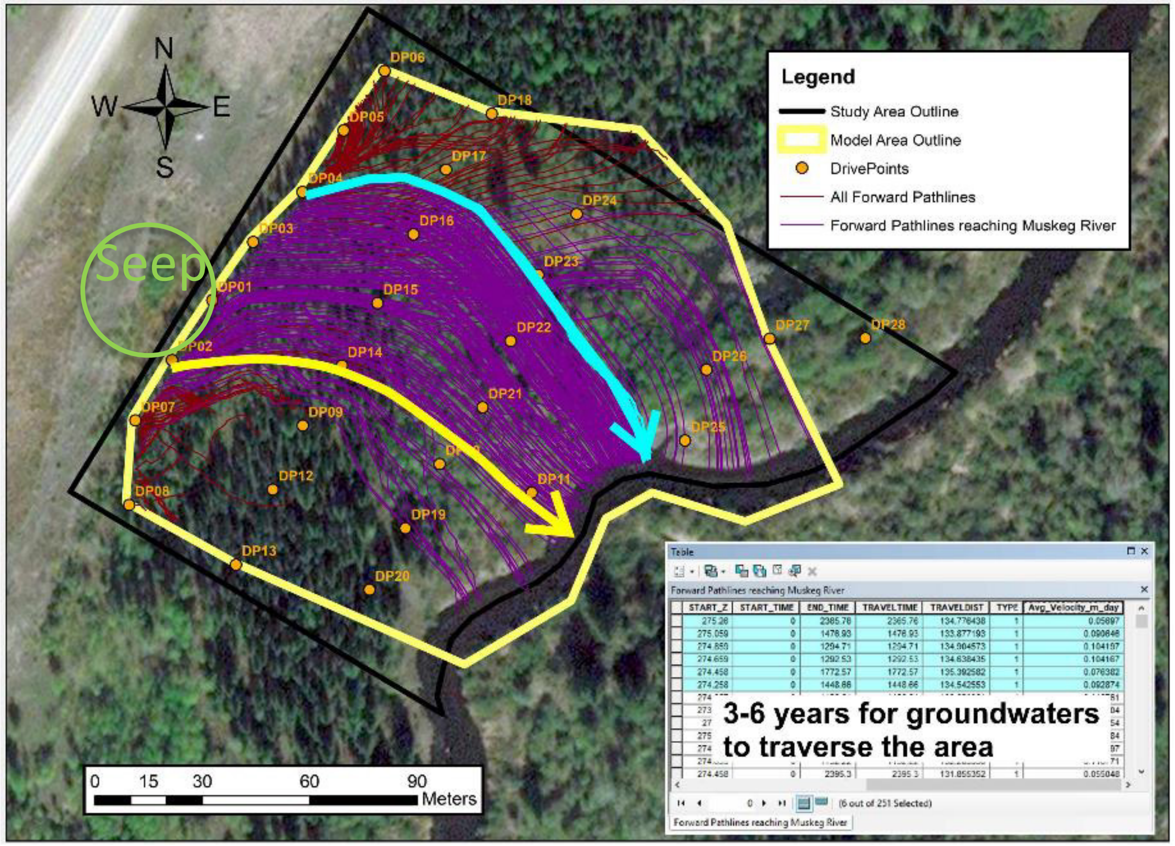
Site Physiography



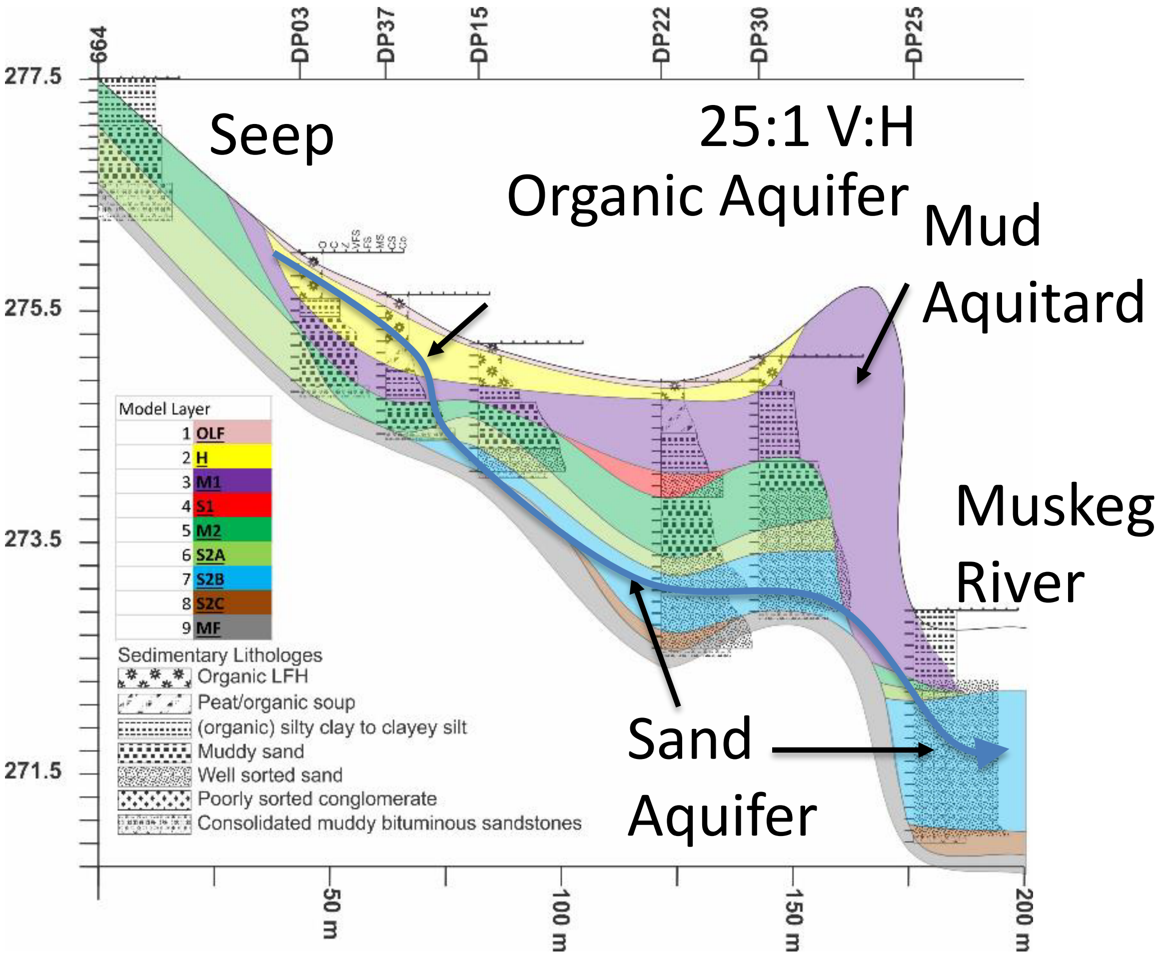
Hydrostratigraphic Model



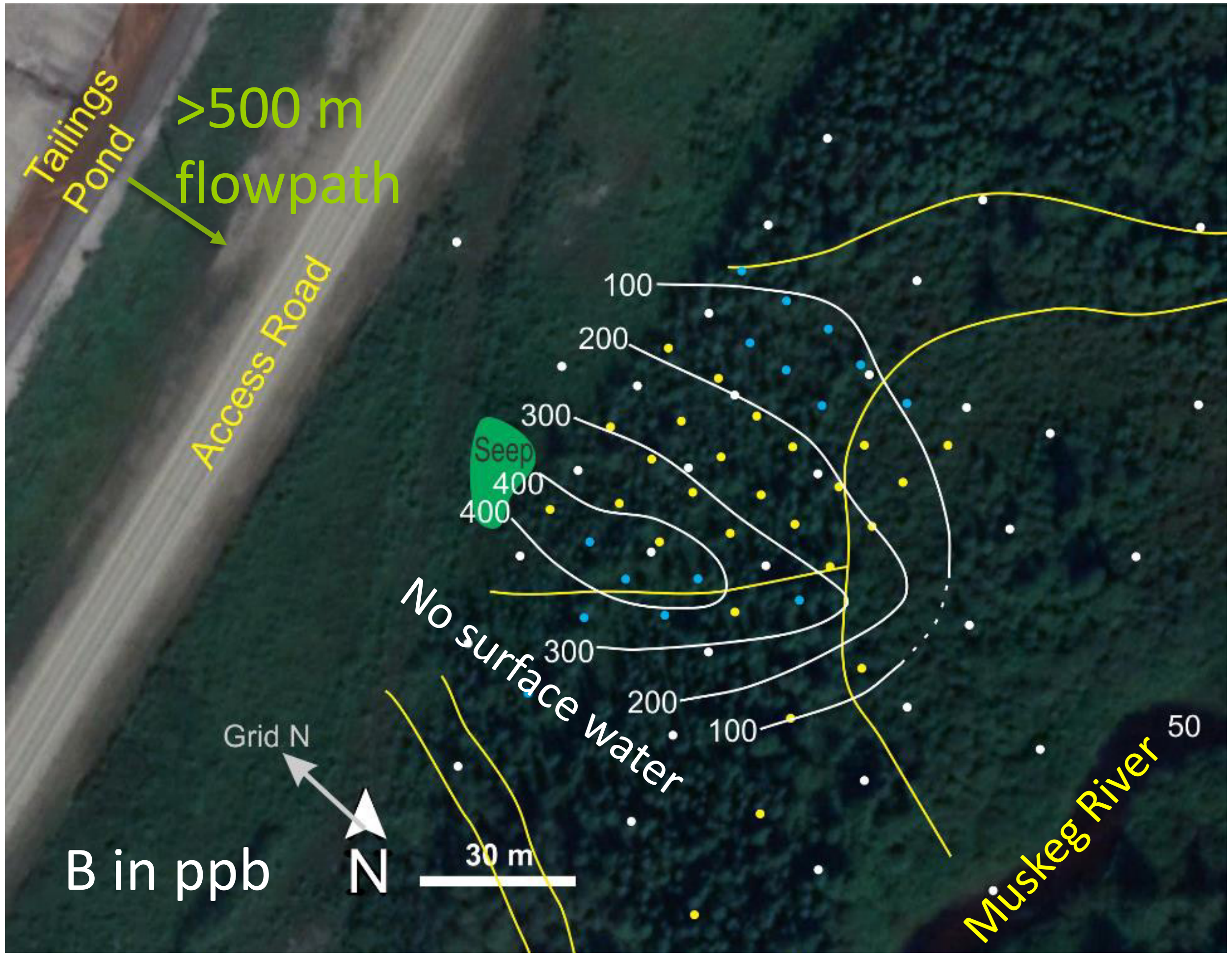
Site Physiography



Hydrostratigraphic Model



Surface waters B contours - bullseye



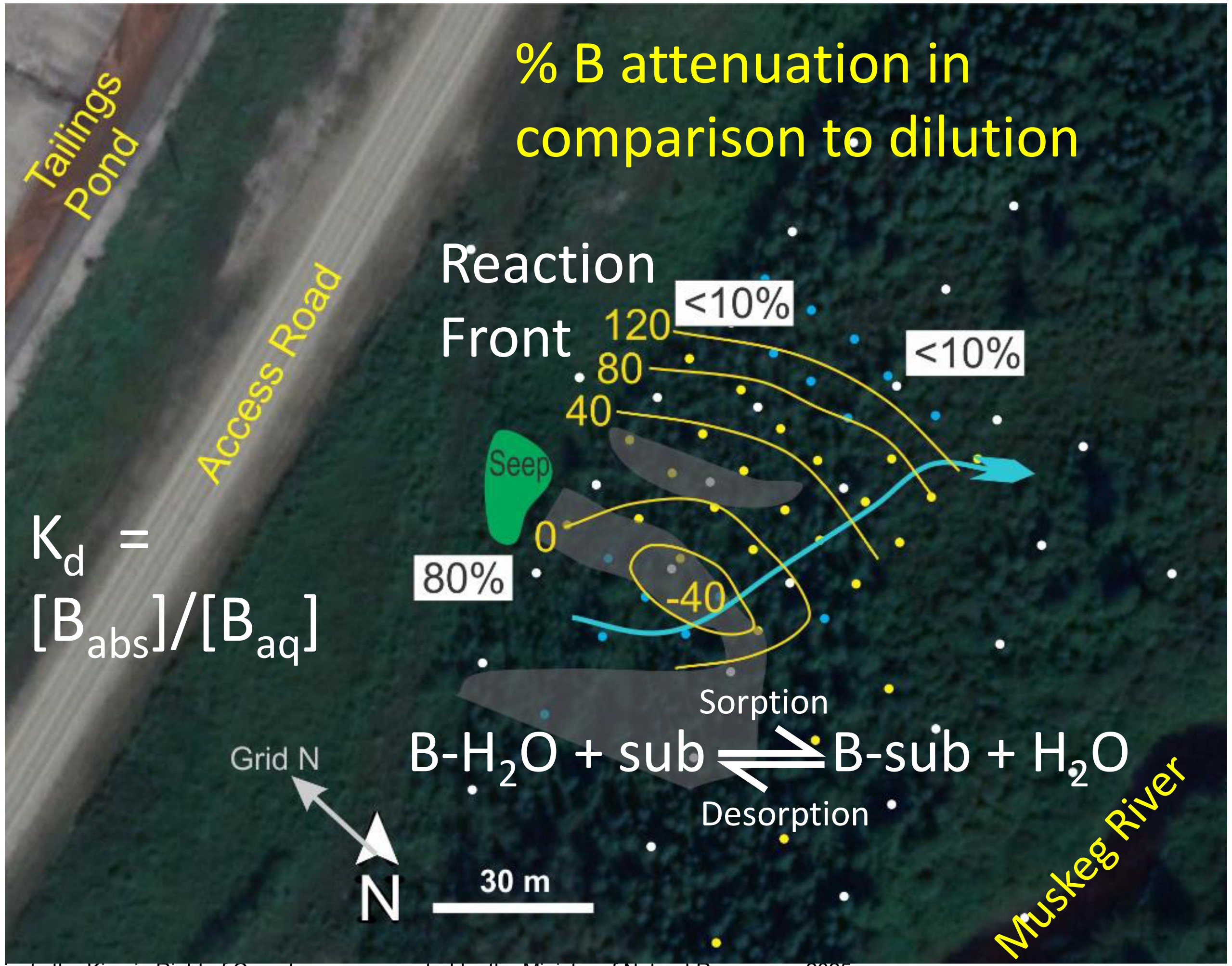
Detailed 10 m X 10 m grid fully captures surface water plume extent

Plume defined by textbook bullseye contour pattern.

Attenuation is very rapid (~60 m).

Ongoing organic, isotopic, eDNA and toxicity analyses…

Surface B sorption model: equilibrium sorption with a reaction front

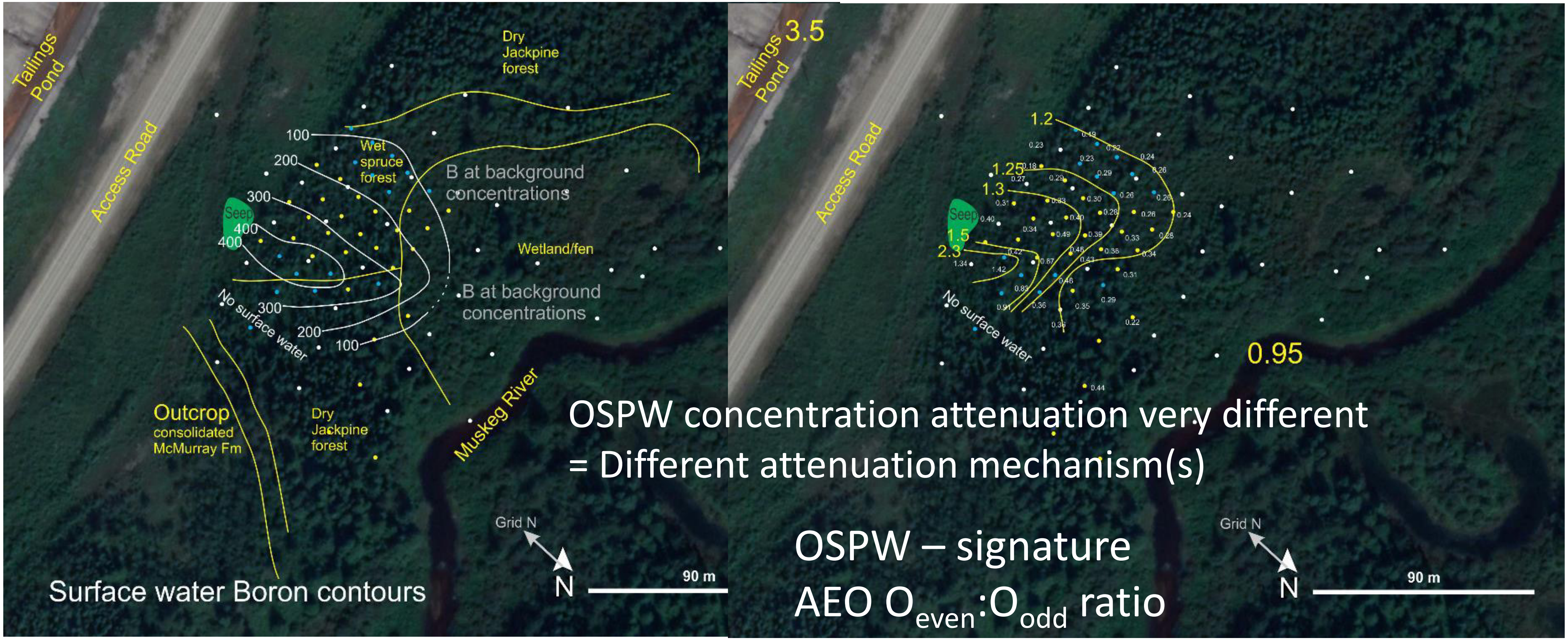


Sorption dynamics can wholly explain the B distribution, with equilibrium sorption dynamics operating within the plume area, and a strong reaction front.

Coupling the B reactive chemistry to the hydrogeology underway:

= Numerical Reactive Transport Model

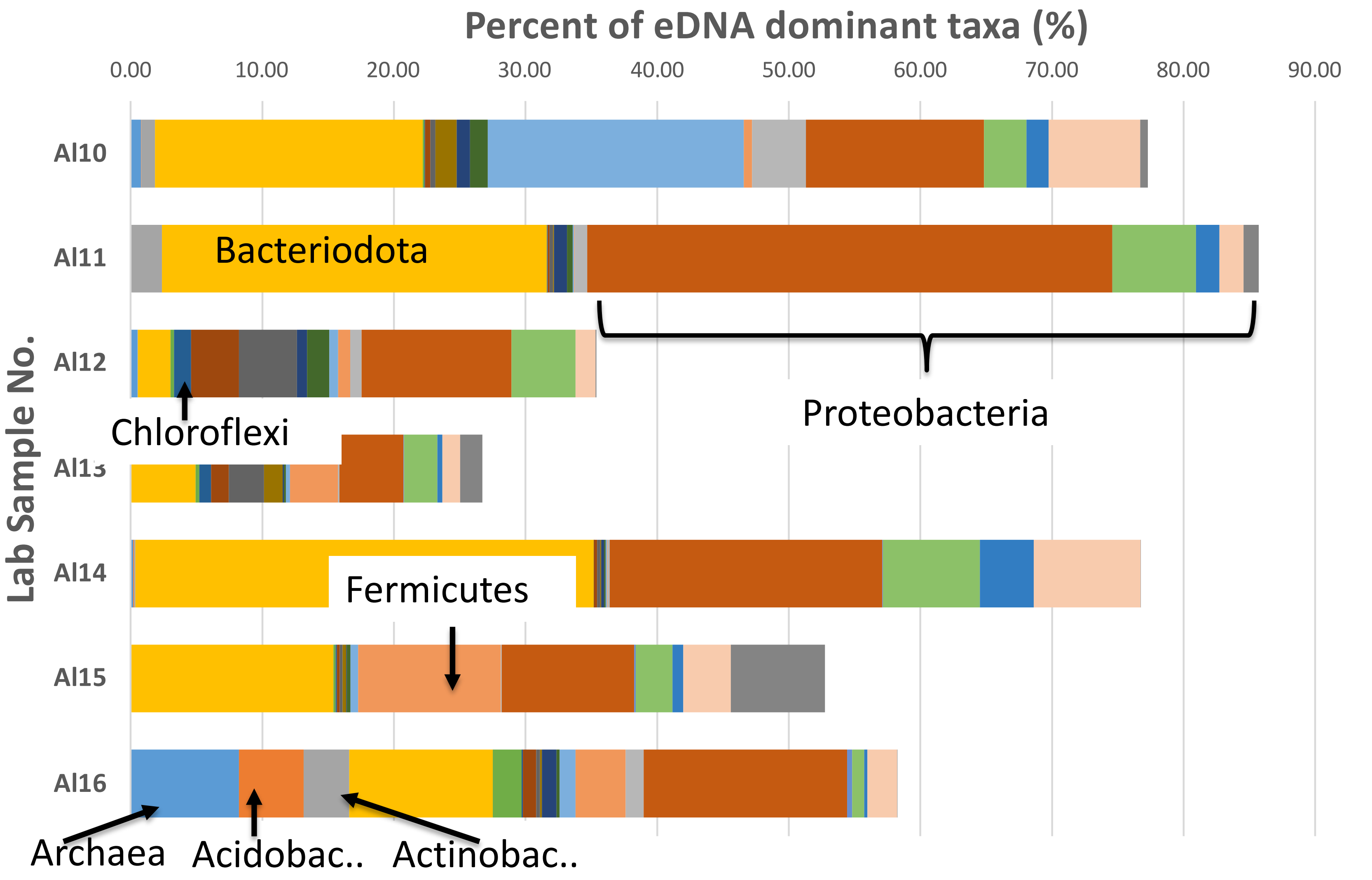
Surface waters B vs OSPW contours



OSPW concentration attenuation very different
= Different attenuation mechanism(s)

Site is relatively small and relatively simple! Plume defined by “textbook” bullseye contour pattern.
Plume attenuation is very rapid (~60 m).

eDNA Analysis: Bacterial Community



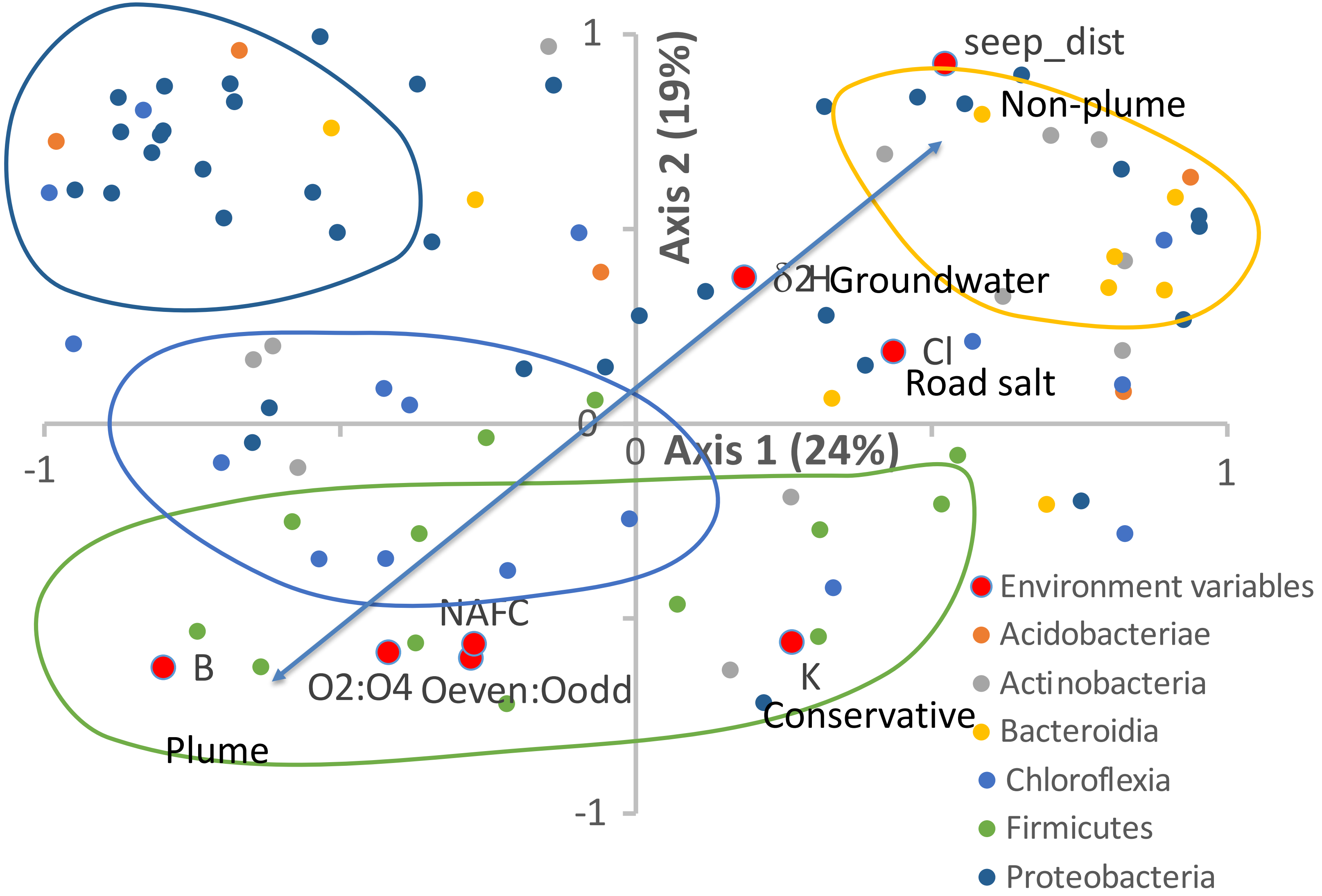
eDNA analysis via qPCR amplification of 16S rRNA

Diverse: >1000 microbial genera identified.

Dominant microbial phyla (86% of identified reads):

- Archaea (6%)
- Acidobacteriota (3.4%)
- Actinobacteriota (4.7%)
- Bacteriodota (14.8%)
- Chloroflexi (6.3%)
- Firmicutes (15.6%)
- Proteobacteria (35.6%)

eDNA Analysis: rPCA statistics



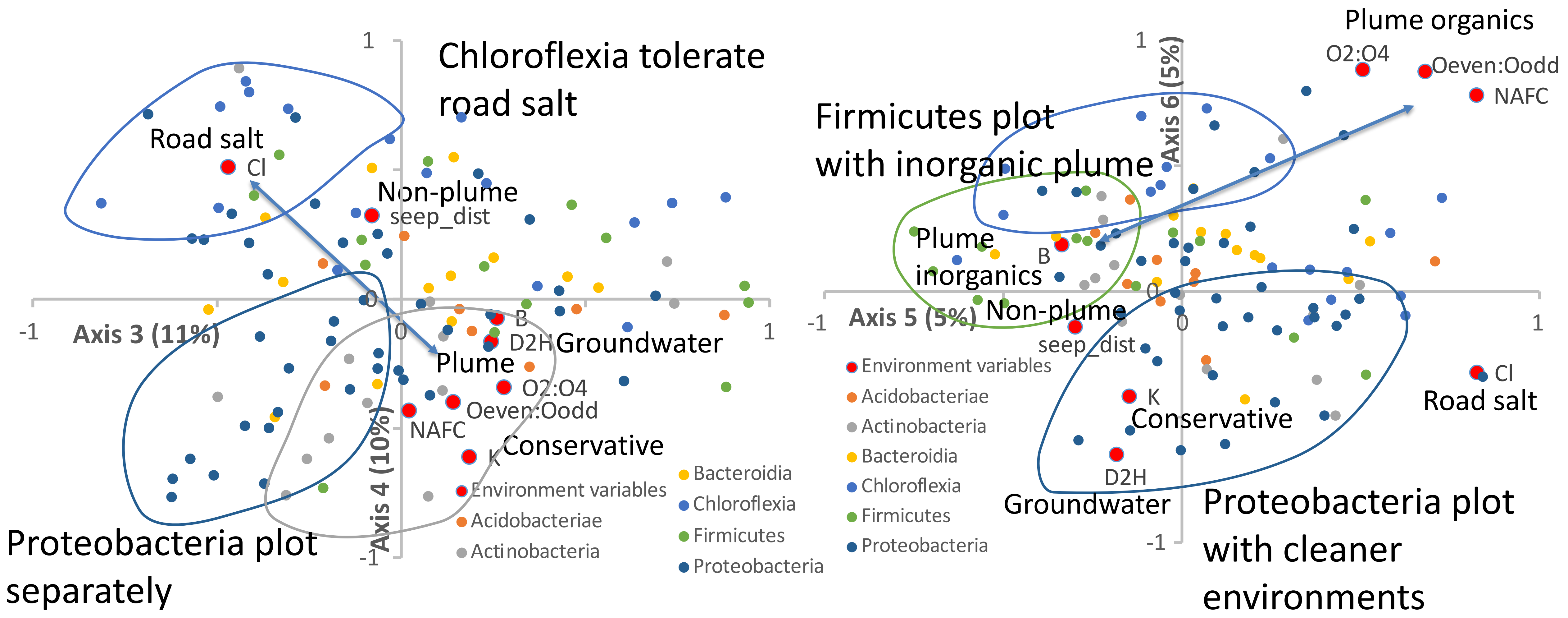
Environmental variables reflect major environmental stressors within the test site

Data demonstrates diversity of environmental influence

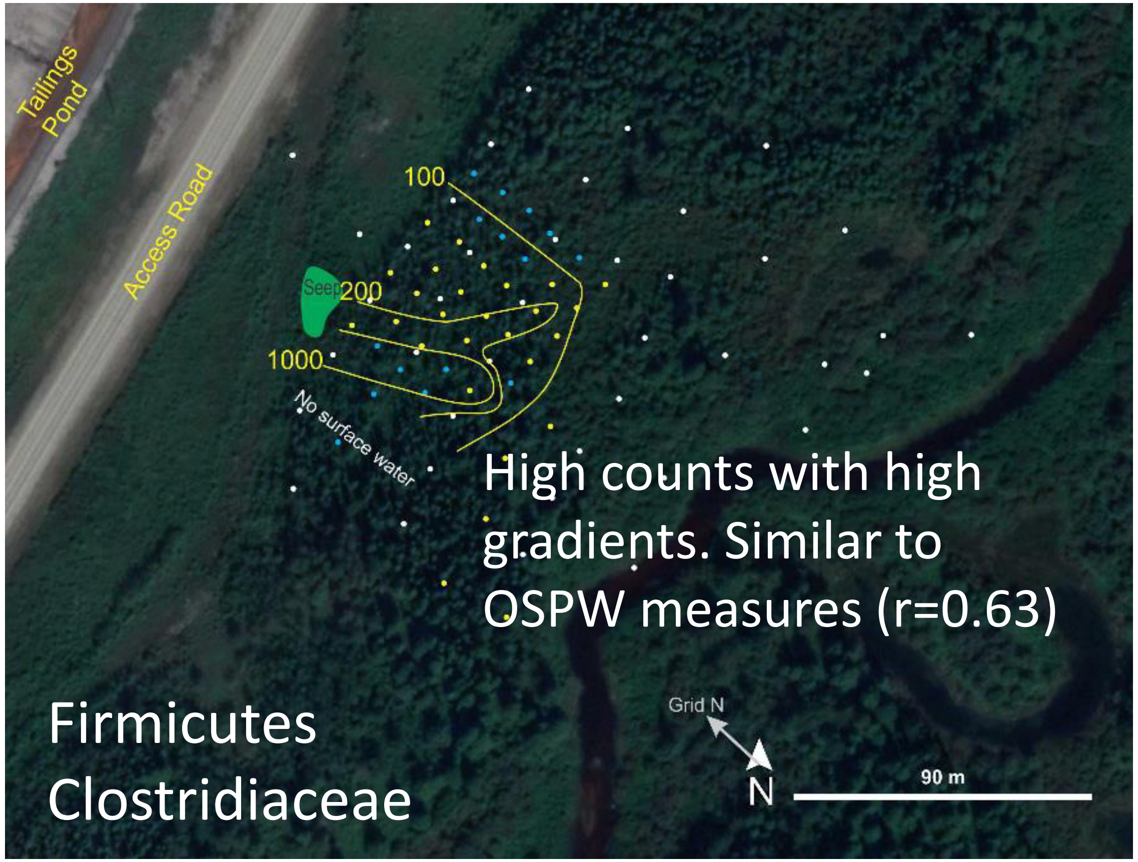
Bacteroidia and some Proteobacteria like cleaner localities

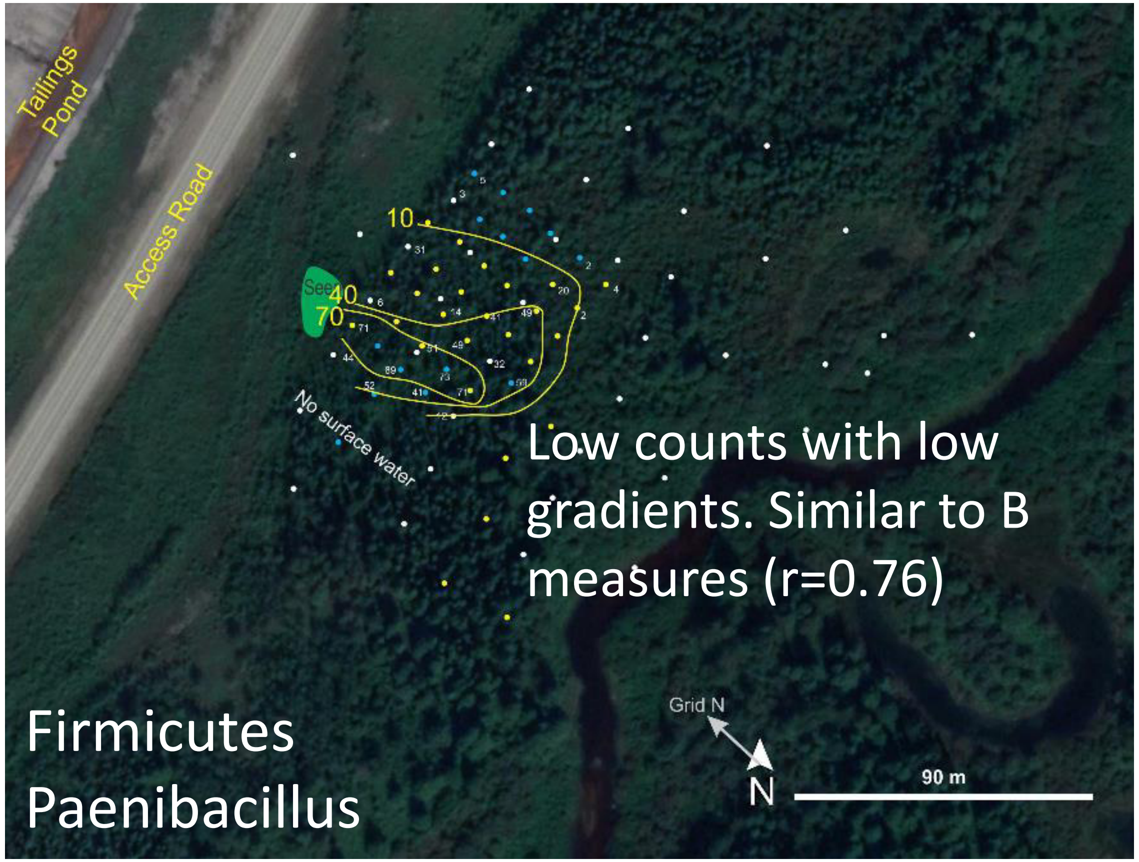
Firmicutes and some Chloroflexia tolerant of OSPW.

eDNA Analysis: rPCA statistics



Firmicutes distributions





Why is the microbial composition important?

Firmicutes: implicated in petroleum hydrocarbon degradation
implicated in OSPW hydrocarbon attenuation at test site.
rare in tailings pond waters or solid microbiomes.
Uncommon in industry-built experimental wetlands.

Proteobacteria: implicated in hydrocarbon degradation.
are not implicated as degraders at the test site.
demonstrated active hydrocarbon degraders in tailings ponds and experimental wetlands

Chloroflexia: not considered hydrocarbon degraders.
potentially implicated at the test site.
common in tailings ponds/experimental wetlands (considered reducers/fermenters)

Natural site is highly differentiated to the industrial sites (tailings pond and experimental wetlands)

Potential to help modify/improve hydrocarbon bioremediation in AOSR

Starting point for OSPW spill bioremediation

Summary

B sorption model is currently being coupled to hydrologic model to generate a numerical Reactive Transport Model

- requires a student for more rapid advance.

OSPW plume organics rapidly attenuate

- not compatible with sorption model
- Microbial eDNA analyses implicate microbial degradation of OSPW hydrocarbons
    - Firmicutes strongly implicated
    - Chloroflexia potentially implicated
    - Proteobacteria not implicated
- Microbiome structure and petroleum degraders differs substantially from those in Athabasca oil sands tailings pond and experimental wetlands
- Additional bioremediation potential for OSPW

Outputs

Ahad, J.M.E., Pakdel H., Labarre T., Cooke C.A., Gammon P.R., and Savard M.M. 2021. Isotopic Analyses Fingerprint Sources of Polycyclic Aromatic Compound-Bearing Dust in Athabasca Oil Sands Region Snowpack. Environmental Science and Technology 55, 9, 5887–5897. https://doi.org/10.1021/acs.est.0c08339

Ahad, J.M.E., Pakdel, H., Labarre, T., Cooke, C.A., Gammon, P.R., Savard, M.M., 2021. Quantitative source apportionment of polycyclic aromatic compounds (PACs) in Athabasca oil sands region snowpack using compound-specific carbon and hydrogen isotope analysis. Goldschmidt 2021, Virtual, 4-9 July.

Gammon, P., 2021. Two peas in a pod: discriminating between natural and industrial sources of contaminants to environments surrounding the Athabasca Oil Sands? Cumulative Effects workshop, April 23, 2021, Ottawa.

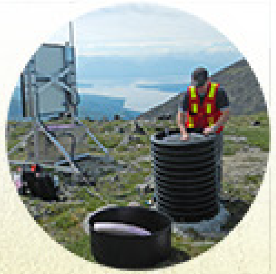
CONTACT INFORMATION

- Paul Gammon
- 613-995-4909
- paul.gammon@nrcan-rncan.ca

Thank you!

Ressources naturelles Canada
Natural Resources Canada



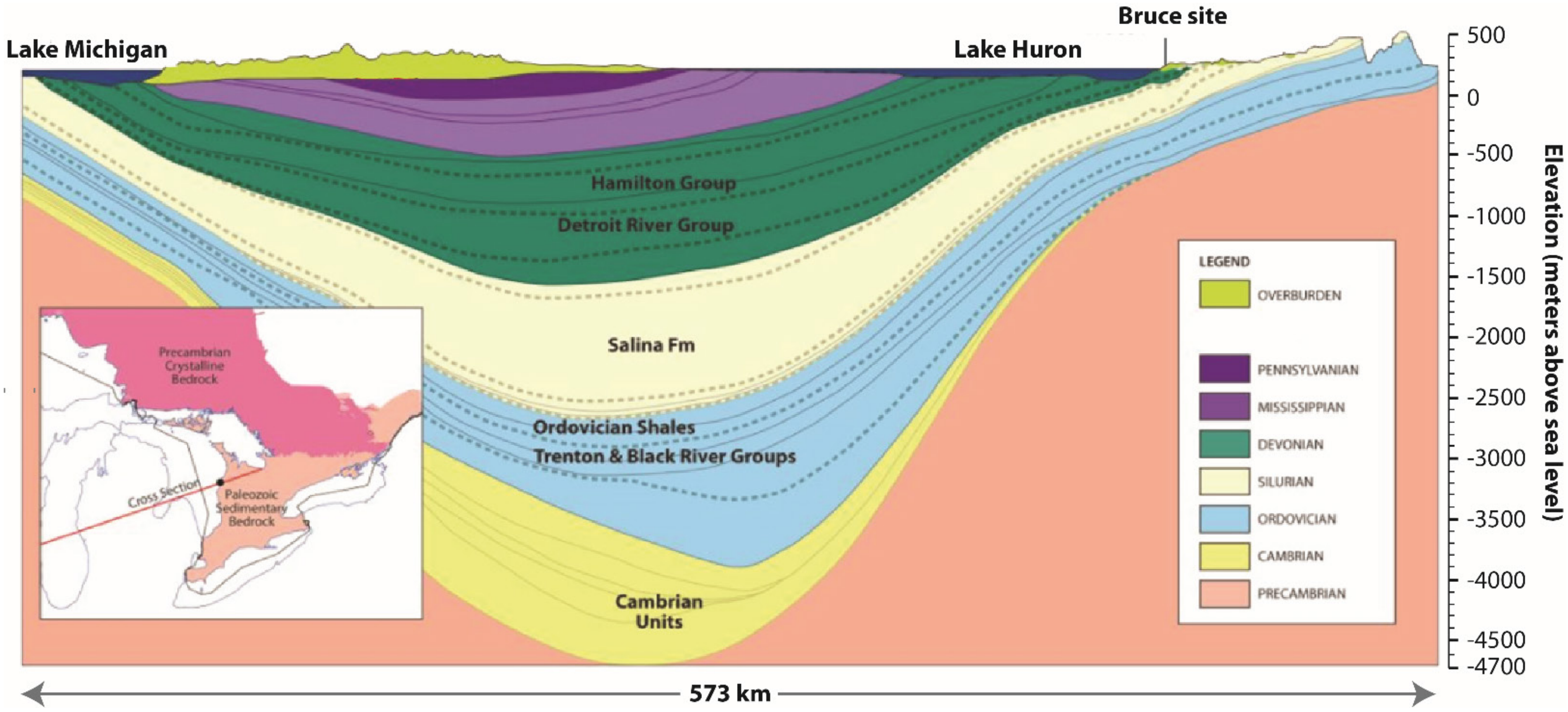

Development of automatized clumped isotope measurements on dolomite for improved characterization of paleofluids in sedimentary rocks

J.J. Jautzy, B. Fosu, T. Al[1], I. Clark[1]

[1] University of Ottawa

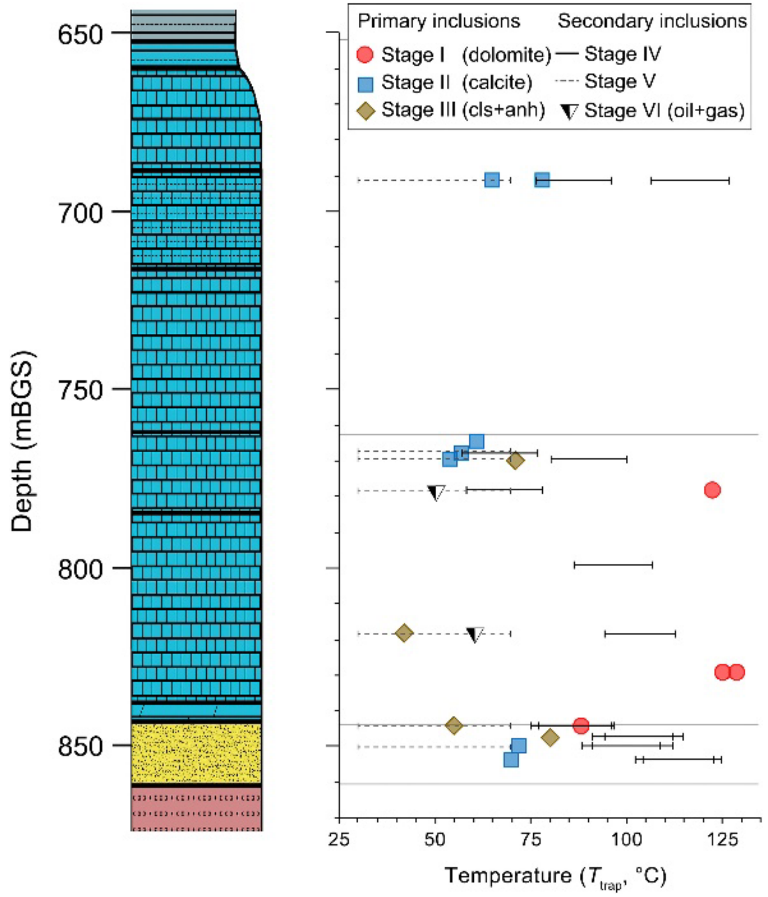
2022

Context



(Intera Engineering Ltd. 2011)

Previous Work



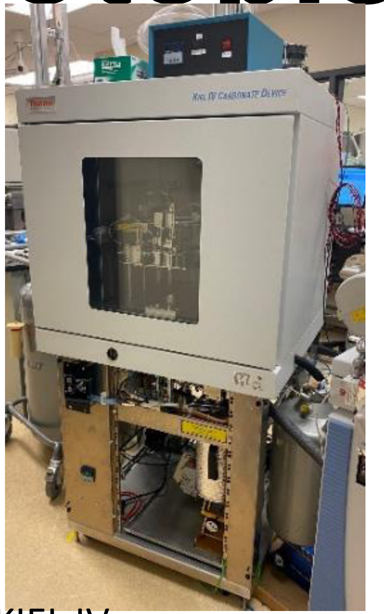
Petts *et al.* (*2017*)

Mainly 2 systems:

- Extremely tight aquiclude confined for at least 260 m.y.
- Lower system with a complex paleofluid history.

Isotopic Clumping on Carbonates: Δ_{47}

Acid digestion of carbonate

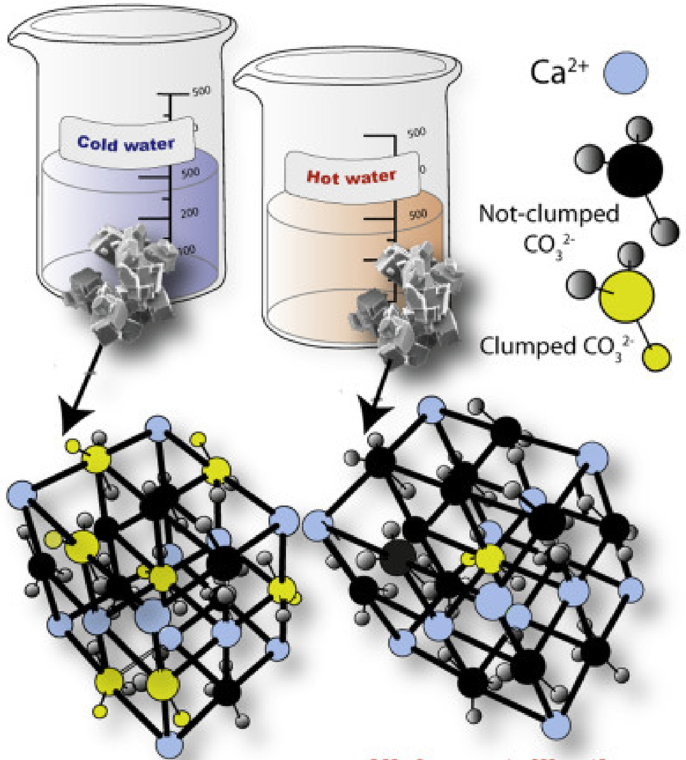


KIEL IV

Counting ultra rare isotopologues

MAT253+ IRMS

Performances	
Sample mass requirement	0.6-1.6mg (*n*=10-20)
Analytical throughput	138 replicates/week
Long term stability/precision	SD=32ppb SE=2.0ppb (*n*=200)
Temperature uncertainty	Low T (0°C) ±2°C High T (200°C) ±8°C



Mangenot *et al.* (2017)

A single phase geothermometer

Activities

- Upgrade of the Kiel IV Carb device for high temperature applications
- Laboratory precipitation of dolomite at different temperatures
- Calibrating the clumped isotope thermometer for dolomites

From Kiel IV to FrankenKiel

Modifications of the system to increase temperature of acid digestion from 70 to 90°C.

✓Decrease reaction time (20 to 10 min) → Increase sample throughput
✓Processing of resistant minerals (dolomite, siderite)

Replacements/modifications of:

- acid delivery tubings with SS material with protective inner coating
- compressed air tubings with high-T resistant PPL tubings
- cable ties with high-T resistant type
- acid barrels
- electronic components (cables and proximity switchs)

FrankenKiel online since November and no failure to date!

From Kiel IV to FrankenKiel

Modifications of the sys stion from 70 to 90°C.

✓De mple throughput
iderite)

Replacements/modificat

- acid delivery tubings with SS ma
- compressed air tubings with high
- cable ties with high-T resistant ty
- acid barrels
- electronic components (cables ar

FrankenKiel online since November and no failure to date!

Synthetic Dolomite

Precipitation of (proto)dolomite for use as anchors for temperature calibration

- ✓ Experimental T range: 40-200°C
- ✓ Conversion of **Mg-rich amorphous carbonate (Mg-ACC)** to dolomite

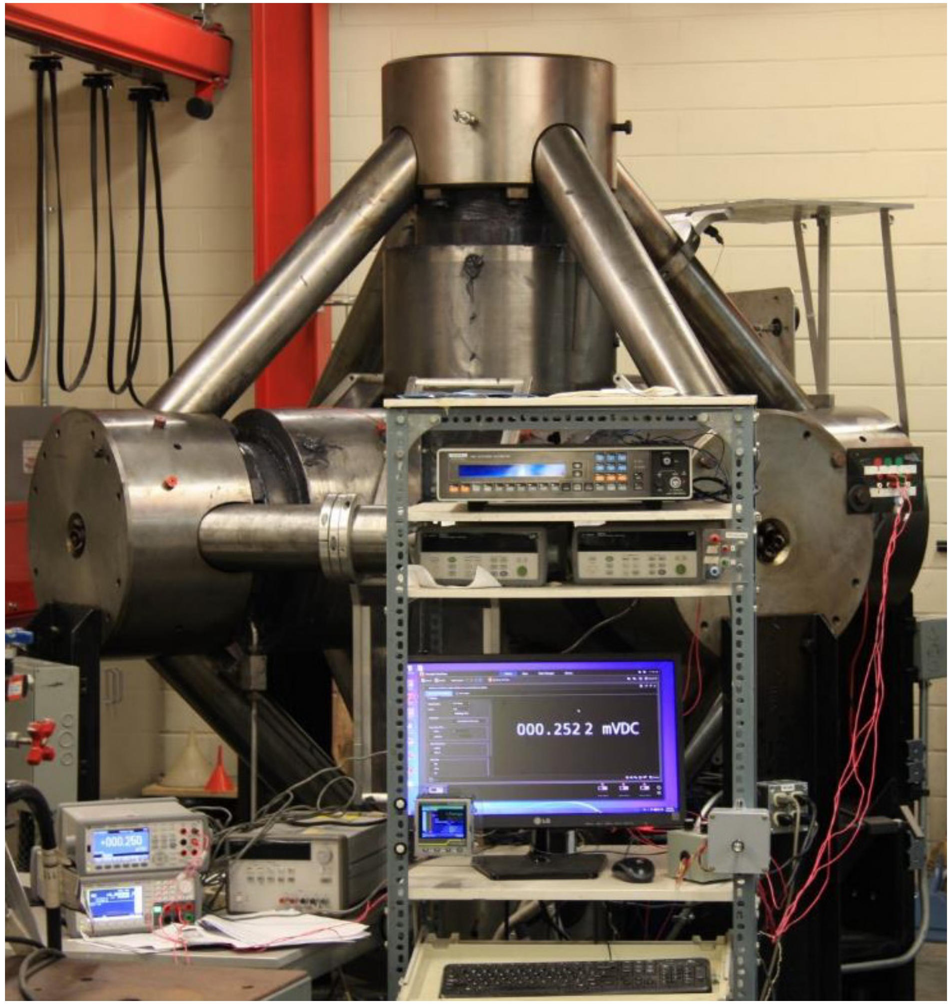
- Mixed equimolar (1M, 2.5M) solutions of Na_2CO_3, $CaCl_2$ and $MgCl_2$ in 2:1:1 proportions
- Heated gel inside enclosed vessels at desired T for weeks to form mineral precipitates
- Sample precipitates at the following temperatures: 40, 60, 70, 80, 150 and 200°C

↓

- Optimum $MgCO_3$ content (39.7 – 45.8%)
- Weakly to moderately ordered dolomite
- Ordering increases with T as expected

- ✓ Characterised precipitated material as ***(proto)dolomite*** by X-Ray Diffraction

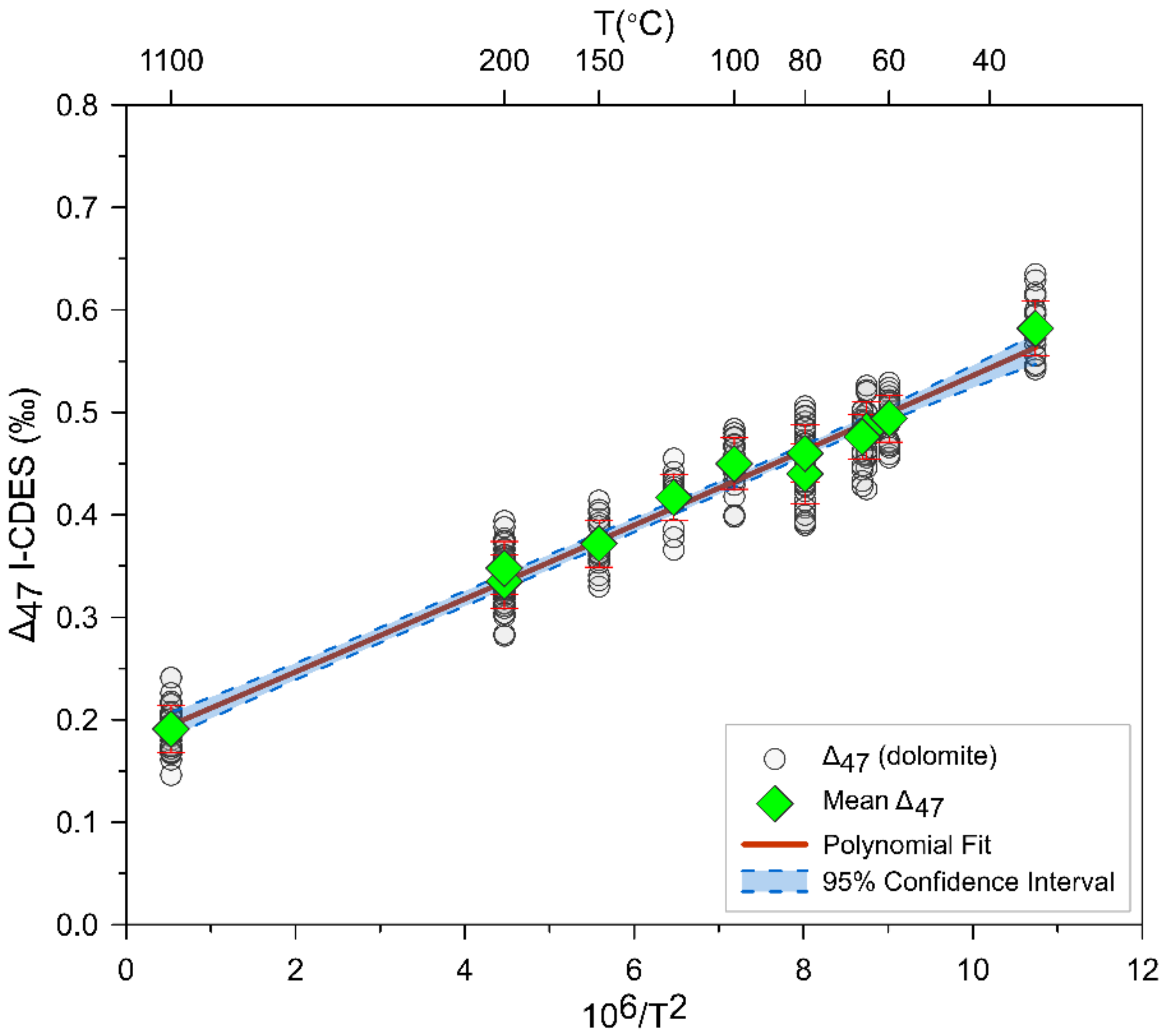
High T Anchors



Full solid state re-ordering experiment using an Anvil press:

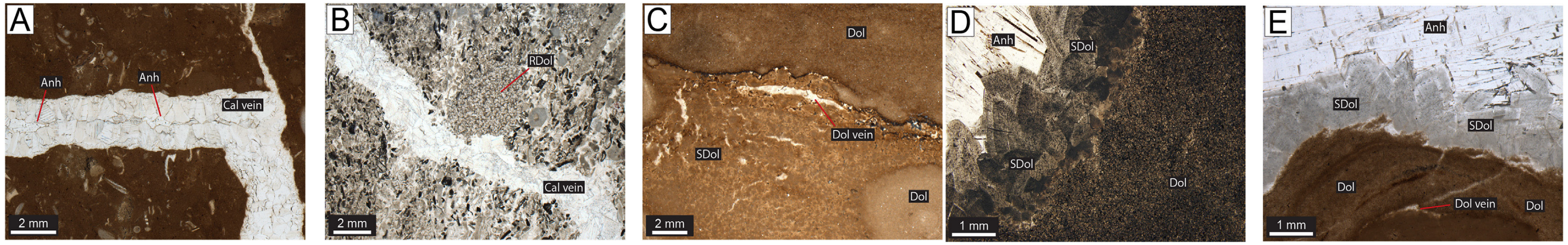
- Heated at 1100°C at 2GPa for 4 hours at UWO
- Mineralogy is conserved → confirmed through XRD
- Δ_{47} analyses ongoing but preliminary results confirm full reordering!

State of Dolomite Calibration at the δ-lab



Fosu *et al.* (*In prep*)

Next Step: The Michigan Basin



Petts *et al.* (*2017*)

Δ_{47} on co-existing dolomite and calcite phases to provide:

(1) additional information on the temperature history of the sedimentary package;

(2) information on the paleo-temperature where fluid inclusions are absent;

(3) further investigation of the effect and extent of the suggested conductive heating (i.e. attributed to the reactivation of the mid-continent rift) on the sedimentary rocks in southern Ontario.

Contact Information

Josué Jautzy
418-654-3866
josue.jautzy@canada.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 2022 meeting (virtual), 17 May 2022

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

Natural Resources Canada   Ressources naturelles Canada

Canada

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**')
- Dilbit is generally considered safer than other means of transport, although major pipeline ruptures have occurred (e.g., Kalamazoo R.)
- Dilbit spills may behave differently than conventional crude oil spills, yet our ***understanding of the environmental impact of dilbit in freshwater environments 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 and tank experiments (INRS Labos Lourds)*
   ii. *Glass tanks (CanmetENERGY)*

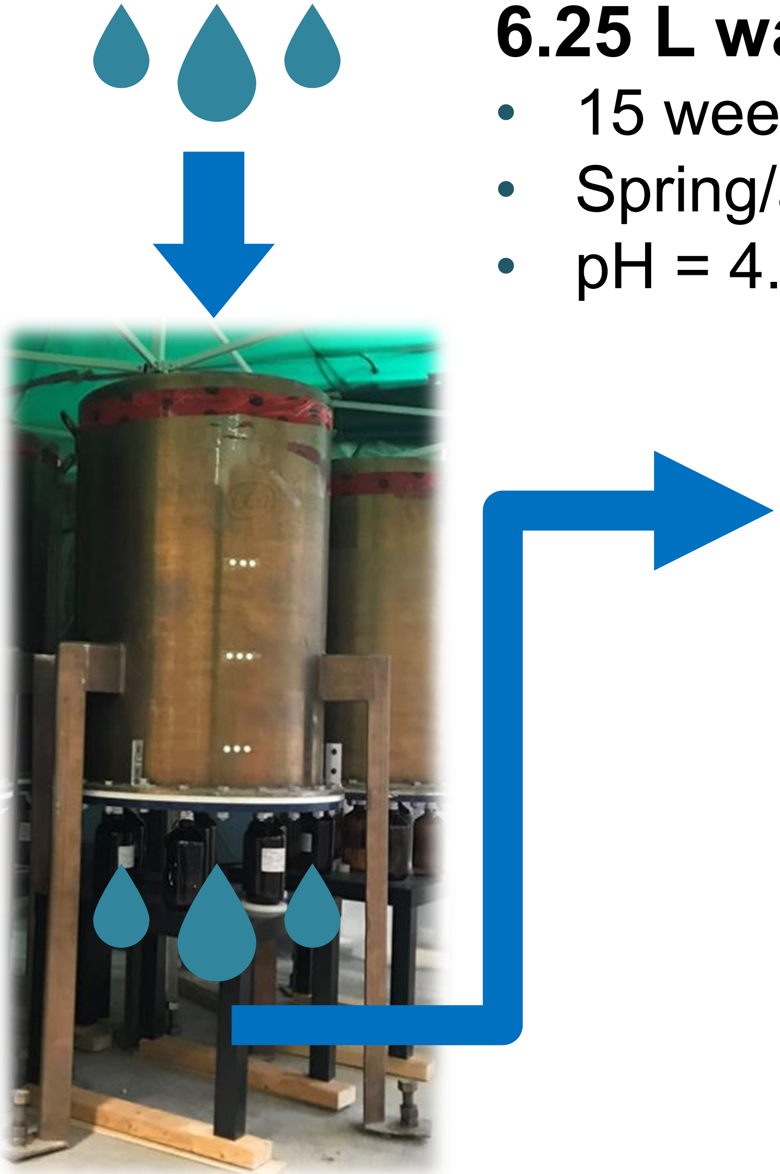
2. **Riverine and lacustrine systems:**
   i. *Wave-action weathering (CanmetENERGY)*
   ii. *Microbial uptake of spilled dilbit in lake sediments (Experimental Lakes Area – ELA , Northwest Ontario)*

Large Columns: Unsaturated Zone Spill

2 kg Diluted Bitumen

2 kg Heavy Conventional Crude

Control



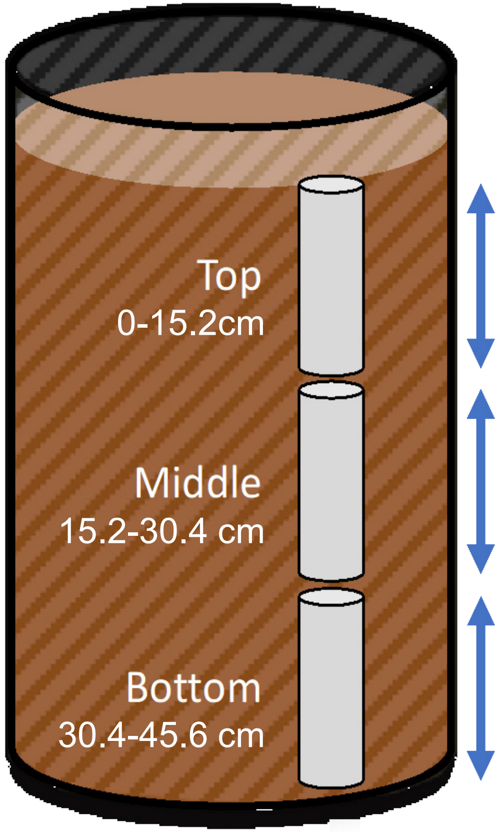
6.25 L water added each week

- 15 weeks (Aug to Nov 2019)
- Spring/autumn recharge (9 ^{o}C)
- 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



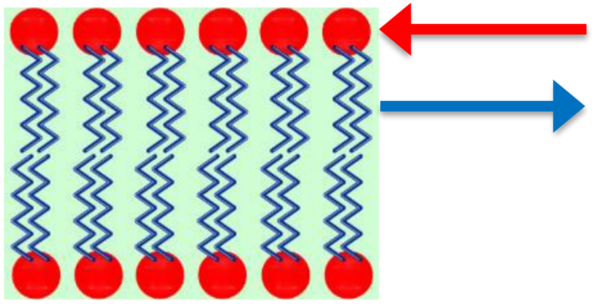
Soil (analyses carried out):

- ✓ 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)

Soil (analyses ongoing):

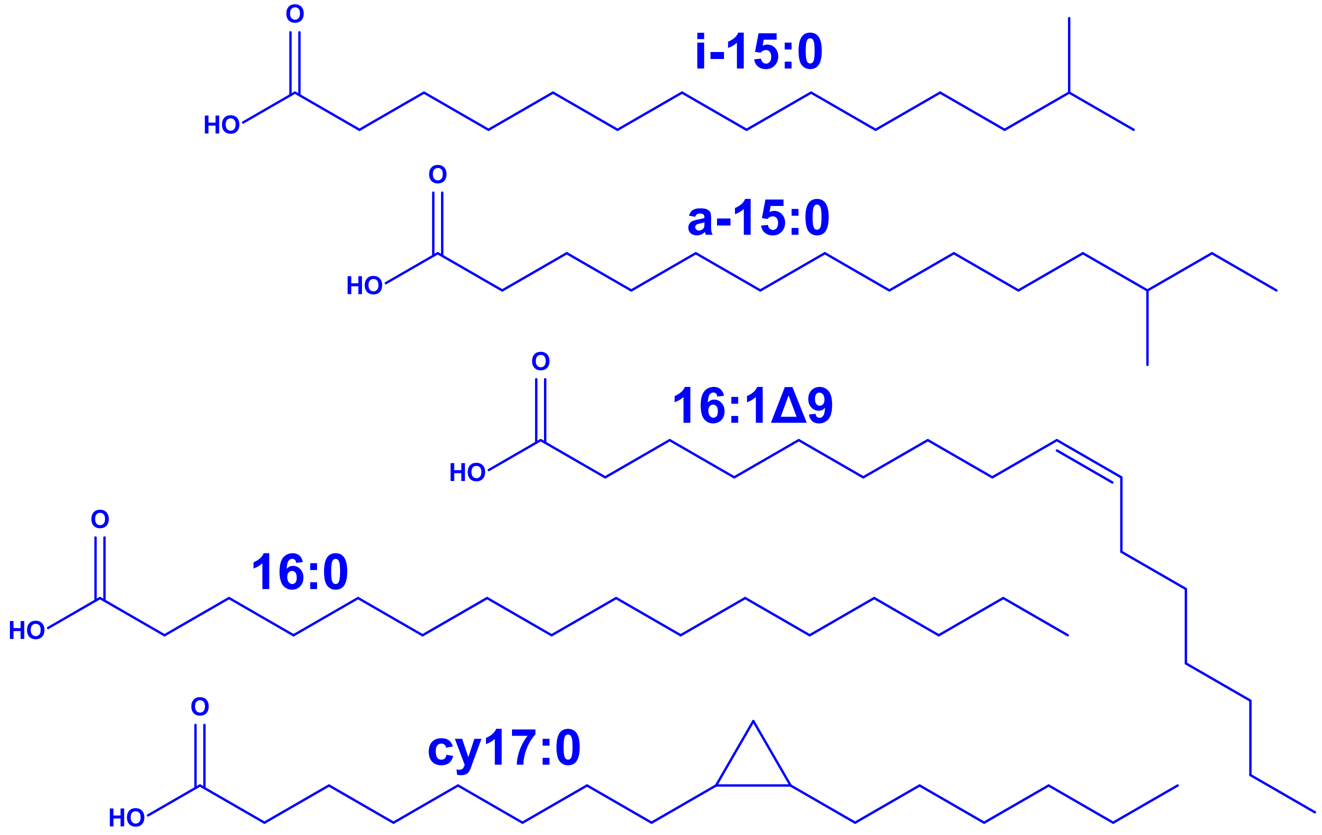
- PAHs (concentrations)
- Compound-specific ($\delta^{13}C$, $\delta^{2}H$) PAH analysis

$\delta^{13}C$ and $\Delta^{14}C$ Analysis of PLFAs

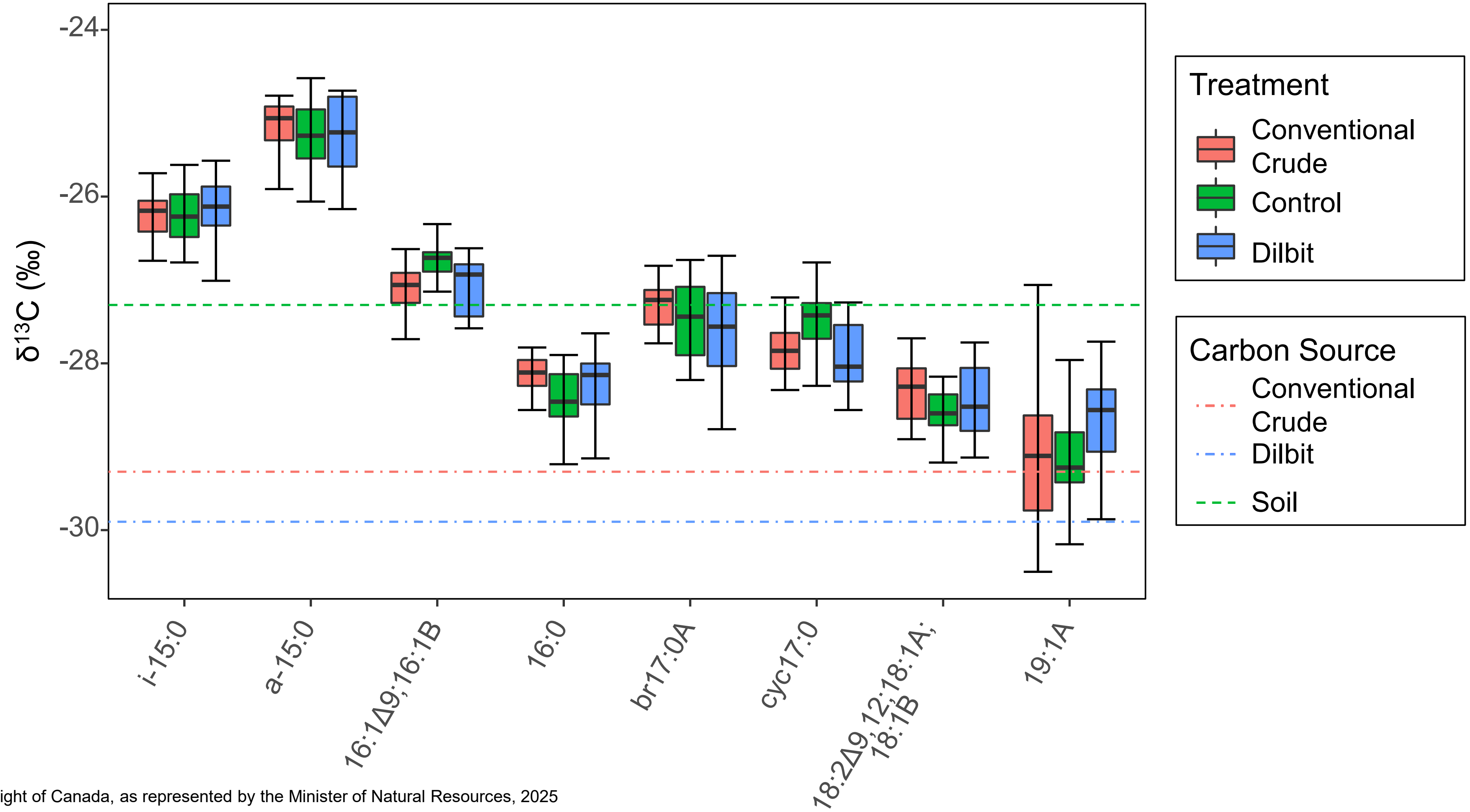


PLFAs: *Biomarkers for the* ***active*** *microbial community*

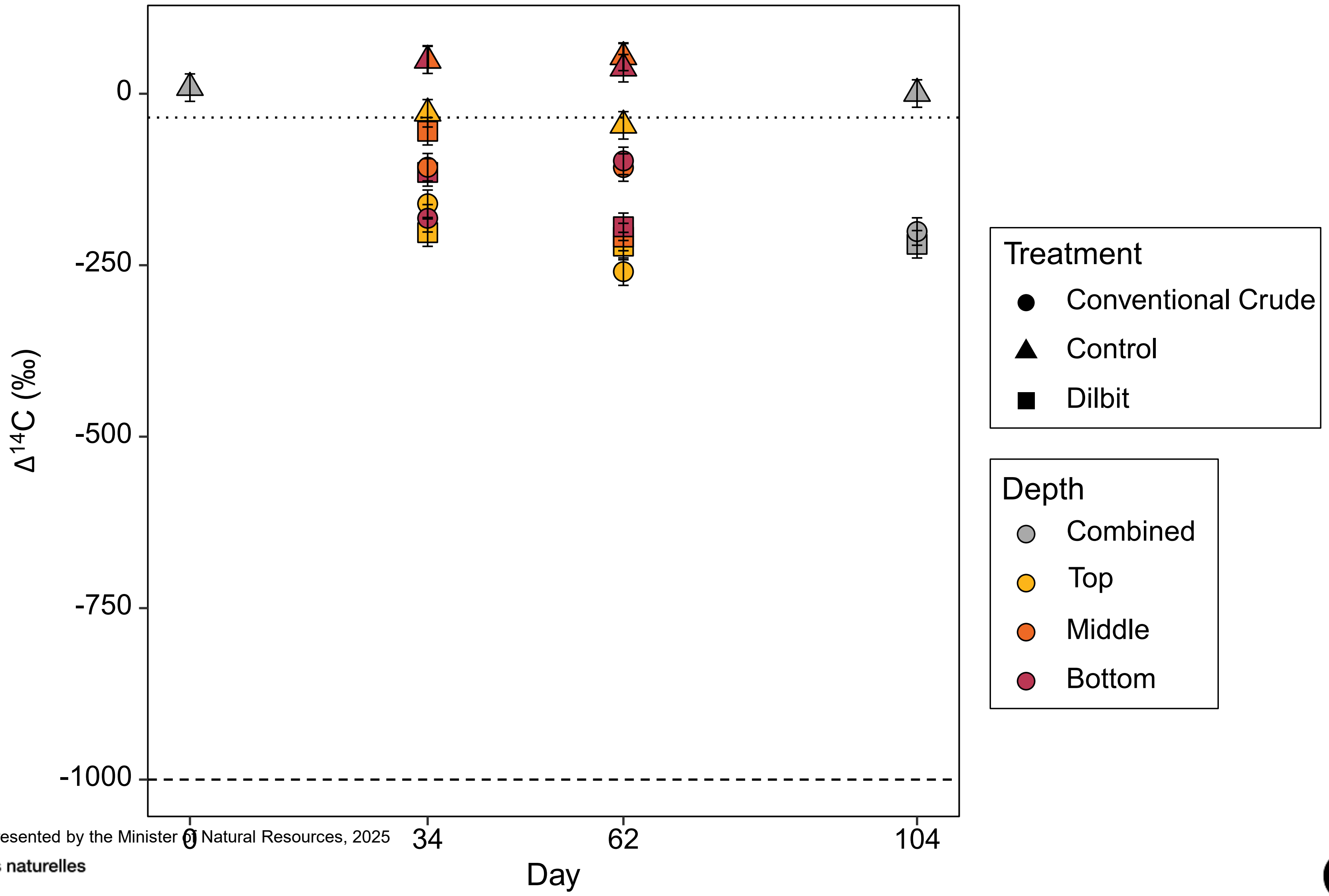
$\delta^{13}C$/ $\Delta^{14}C$ analysis: provides insight into microbial ***carbon sources***



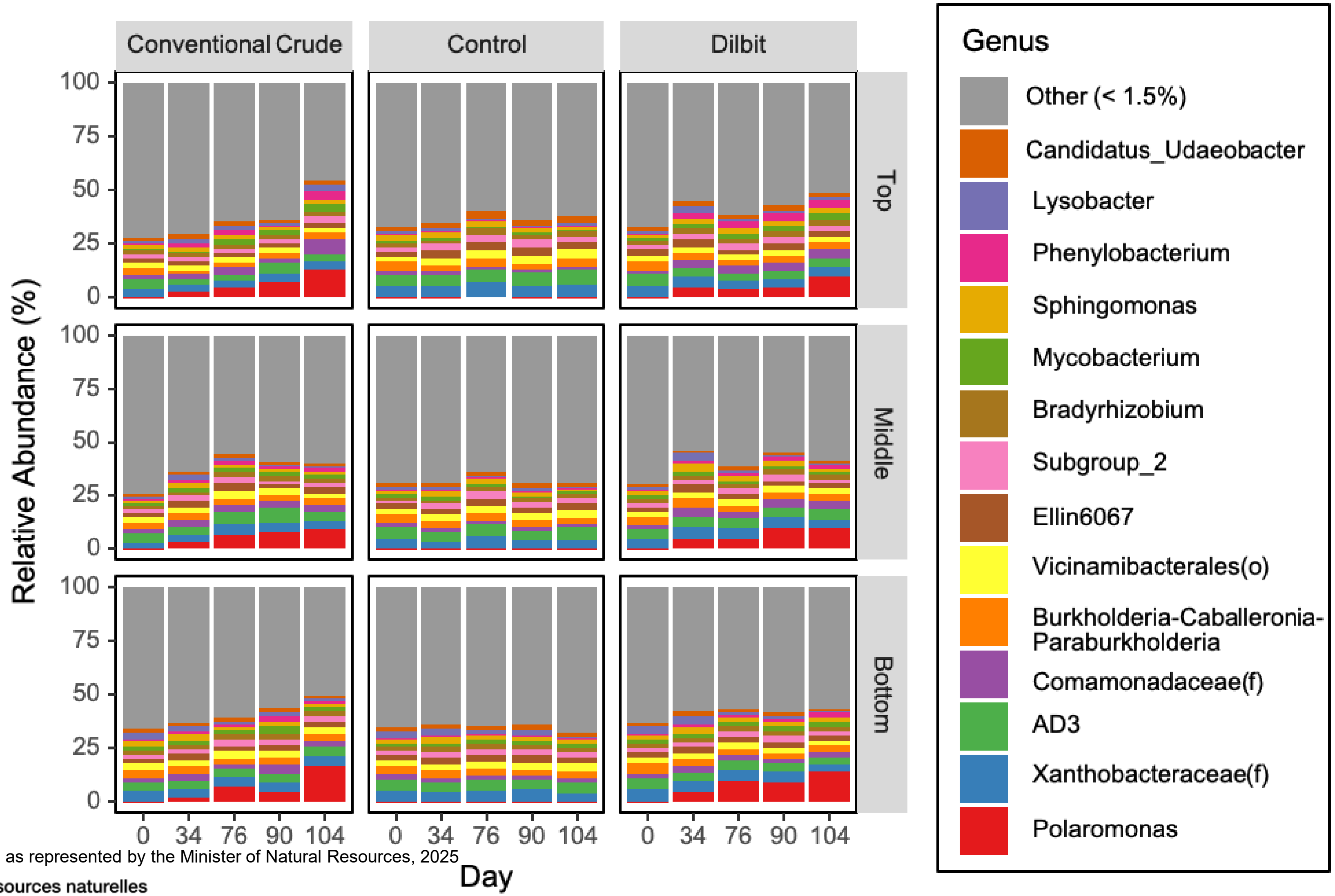
δ13C Values of PLFAs in Soil Cores



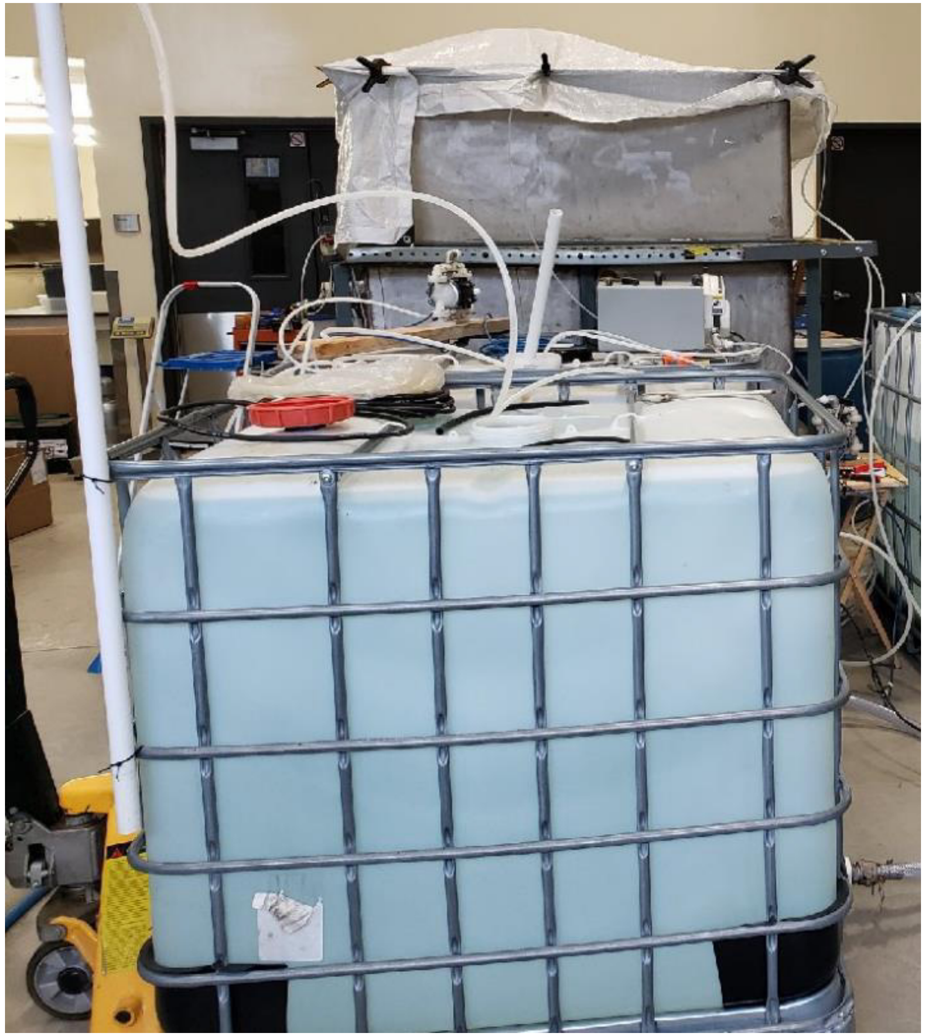
$\Delta^{14}C$ Values of PLFAs in Soil Cores

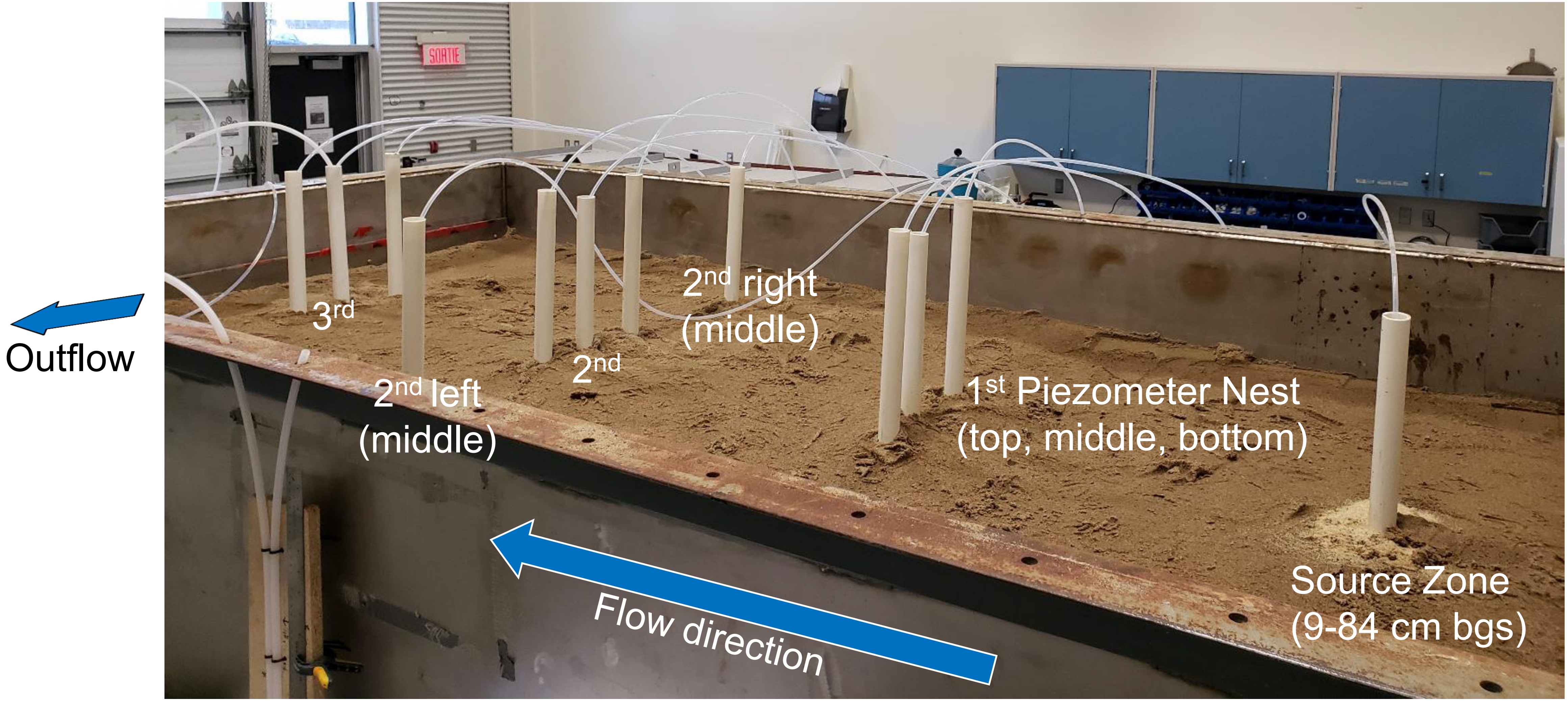


Microbial Community (Genus Level)



Large Tank Experiment: Saturated zone spill





Outflow
3rd
2nd left
(middle)
2nd
2nd right
(middle)
1st Piezometer Nest
(top, middle, bottom)
Source Zone
(9-84 cm bgs)
Flow direction
SORTIE

Merci!

- Delta-lab: Anna Smirnoff, Marc Luzincourt, Jade Bergeron, Samrat Alam
- ECCC: John Headley, Kerry Peru, 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

Project MOSS: Marine Oil Spill Studies

Projet EDPM: Études sur les déversements pétroliers marins

MANUEL BRINGUÉ

May 2022

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 (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 – UofC

Acknowledgements

Gitga'at Nation (Hartley Bay) – Chris Picard

Haisla Nation (Kitamaat Village)

ABSTRACT

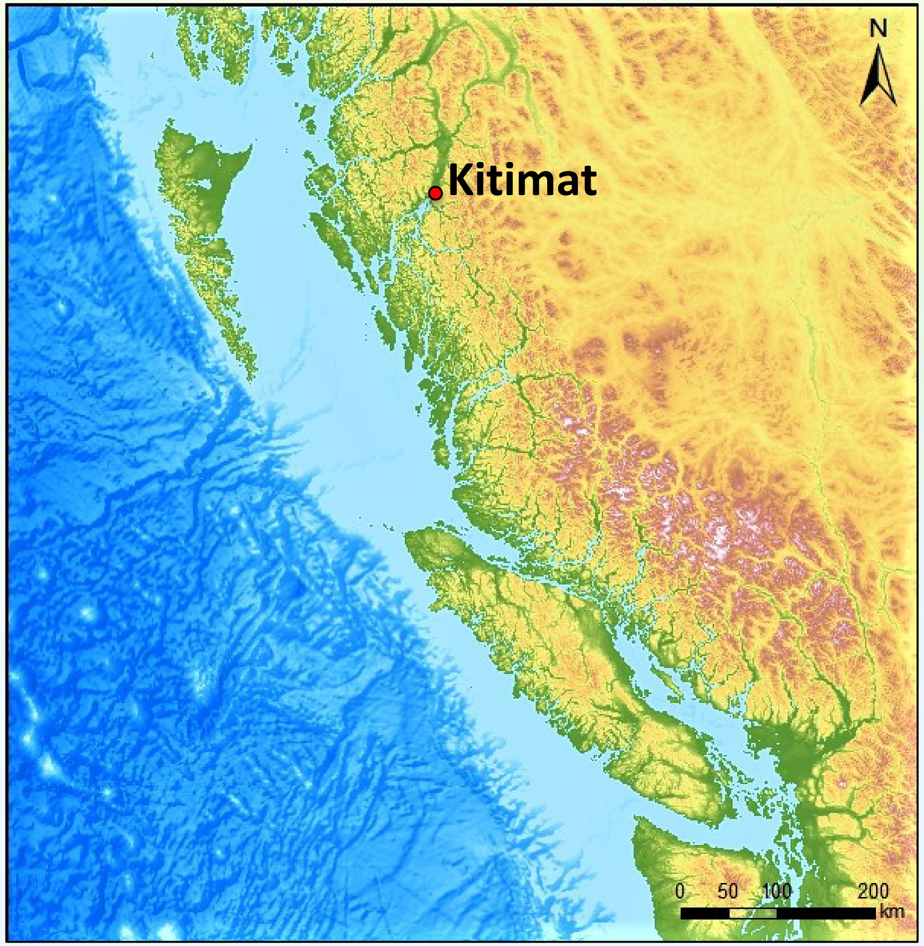
Context

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** in Douglas Channel (e.g., temperature, productivity) on seasonal to millennial time scales;

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



PROJECT OVERVIEW

1. <u>**Surface sediment** and **sediment trap** component – *CALIBRATION*</u>

To assess **spatial distribution** and **seasonal variability** in phytoplankton communities and geochemical indicators

2. <u>**Sediment cores** component – *RECONSTRUCTIONS*</u>

- 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. <u>**Microcosm** experiments – *LAB TESTS*</u>

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

2.

1.

3.

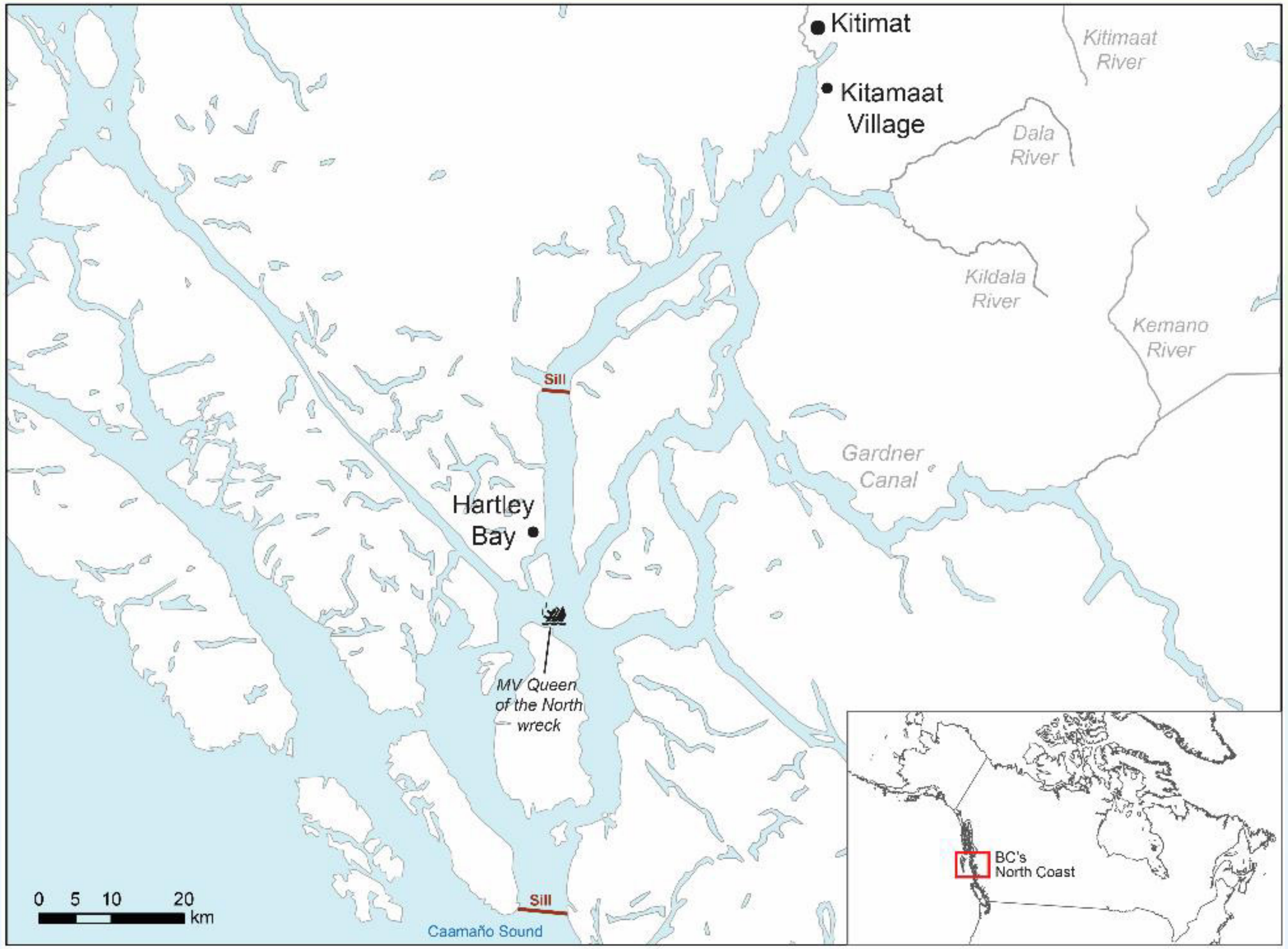
Environmental setting

Kitimat Fjord System

- Complex fjord system on northern BC coast
- Opens to Pacific Ocean through Hecate Strait

Hydrology

- Small rivers but abundant precipitations
- Hydrological "head" is Gardner Canal
- 4-5 layer estuarine circulation
- Surface temperature: ~ 7°C – 15°C
- System seasonally hypoxic (~ 2.5 mL/L) at depth
- Particle flux driven primarily by freshet, rainfall

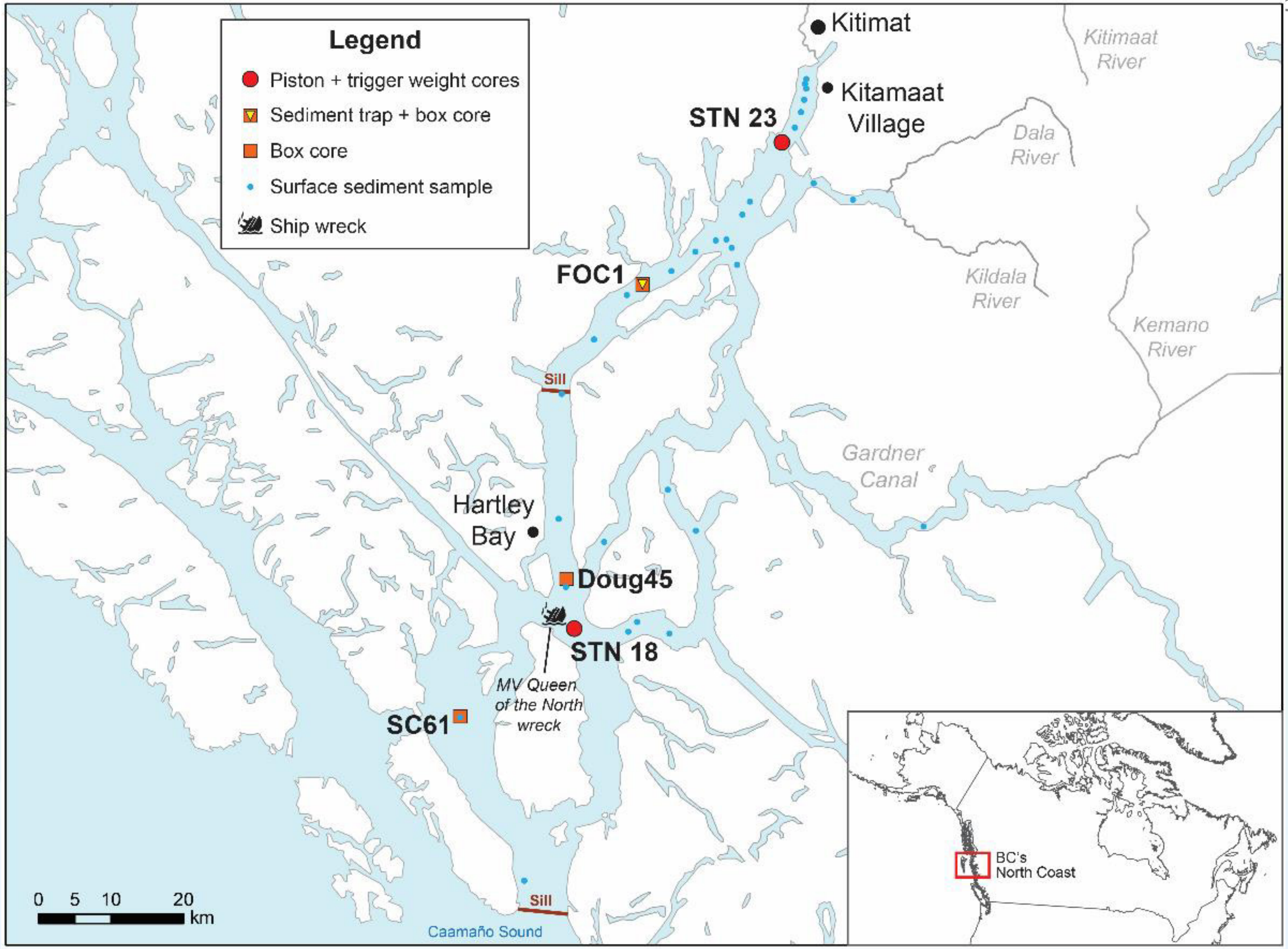


(Macdonald, 1983; Wan et al., 2017; Johannessen et al., 2019)

Sediment samples

- Surface sediment
  - 37 samples
- Sediment trap
  - ~ 3 yrs of data
- 3 box cores
  - ~ 120 yrs
- 2 piston cores
  - Holocene (~ 11 kyr)

All material provided by PGC & DFO



Microcosm experiments

Round 1: Effect of O_2 limitation on natural oil degradation rates

- 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

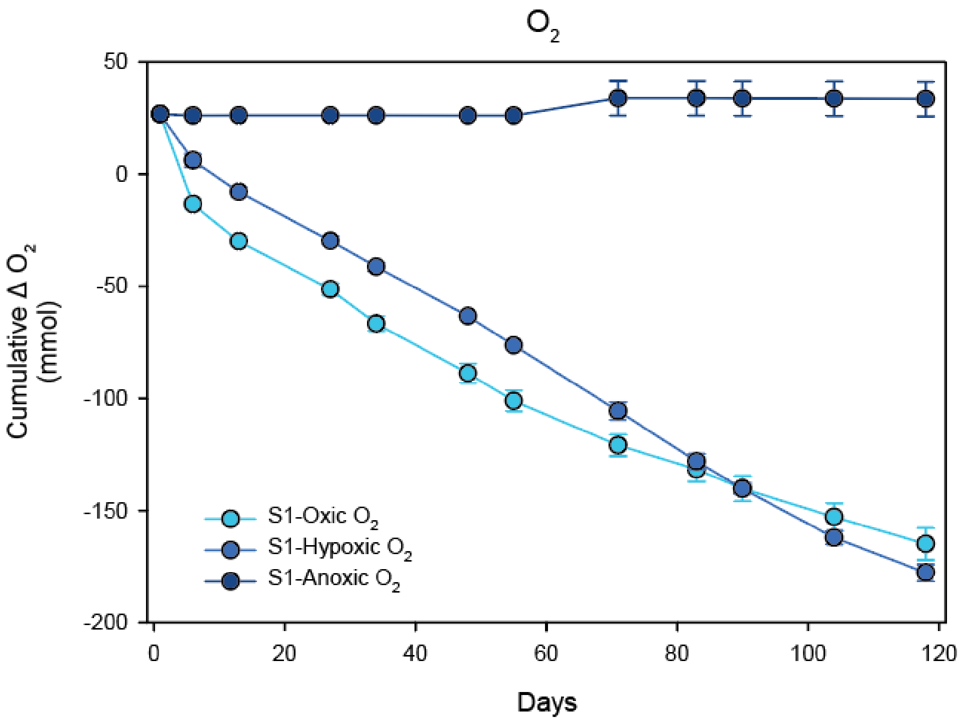
"Oxic" *"Hypoxic"* *"Anoxic"*

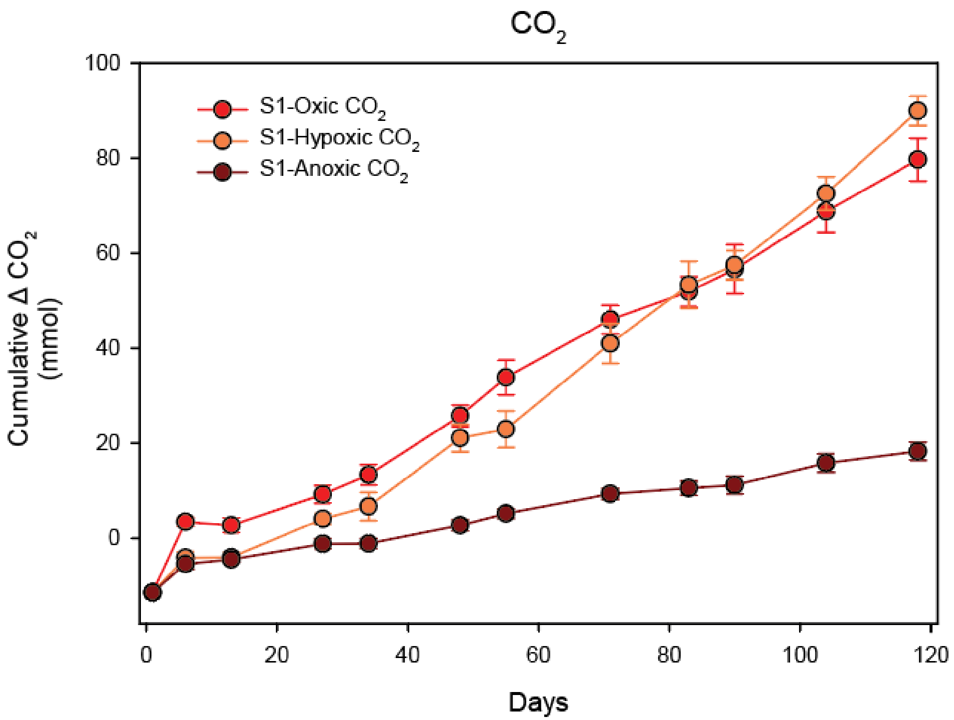
- 3 experimental setups:
  - S1: Sediment + water + fuel
  - S2: Sediment + water *[no fuel control]*
  - S3: Autoclaved (sediment + water + fuel) *[kill culture control]*

Microcosm experiments

Round 1: Effect of O_2 limitation on natural oil degradation rates: GC data

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

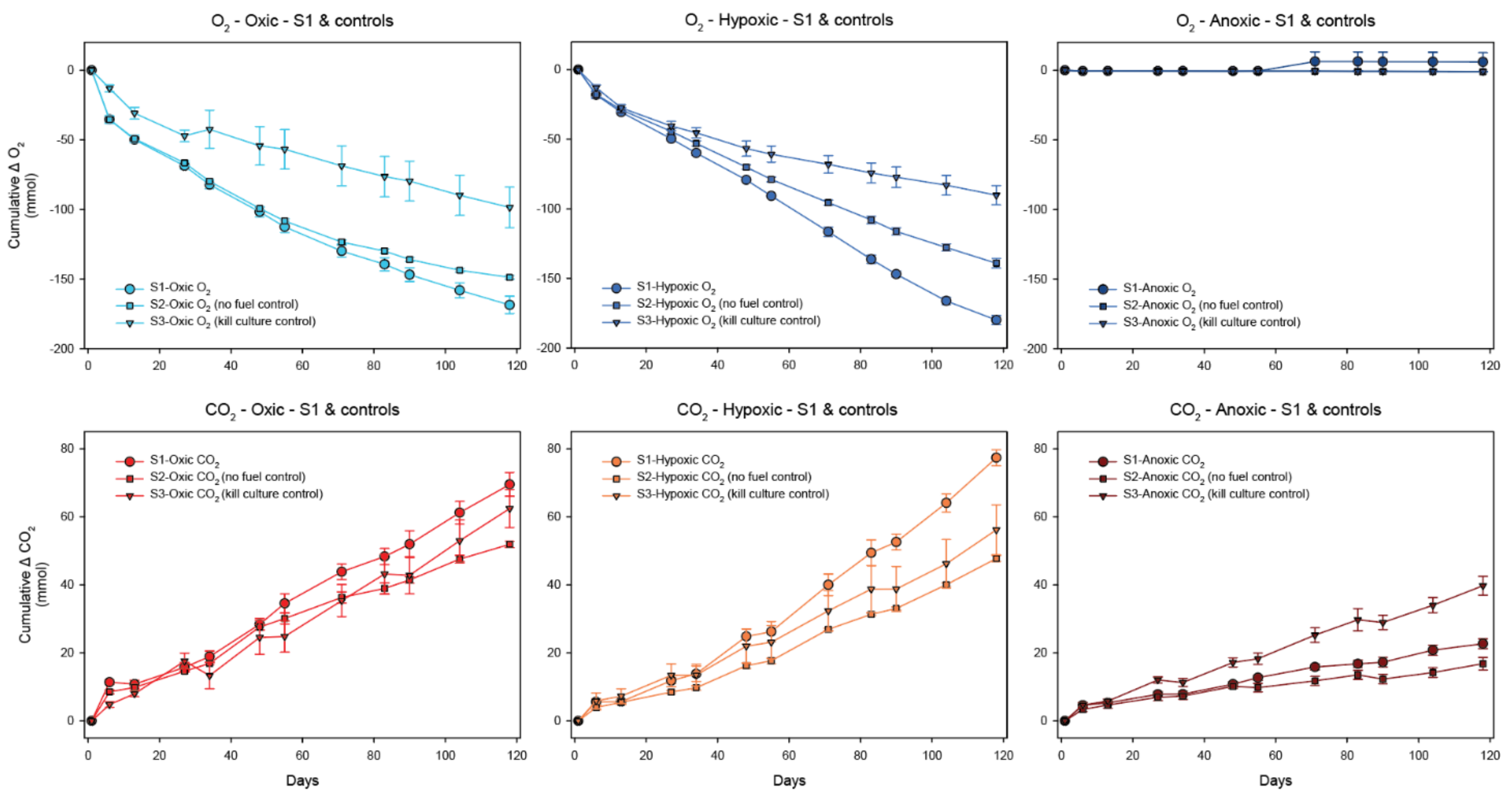




- Anoxic cultures barely active
- Comparable activity under oxic and hypoxic settings
- Oxic cultures show fastest rates at the start, but hypoxic cultures are more active in the end

Microcosm experiments

Setup 1 (sediment + water + fuel) *versus* controls



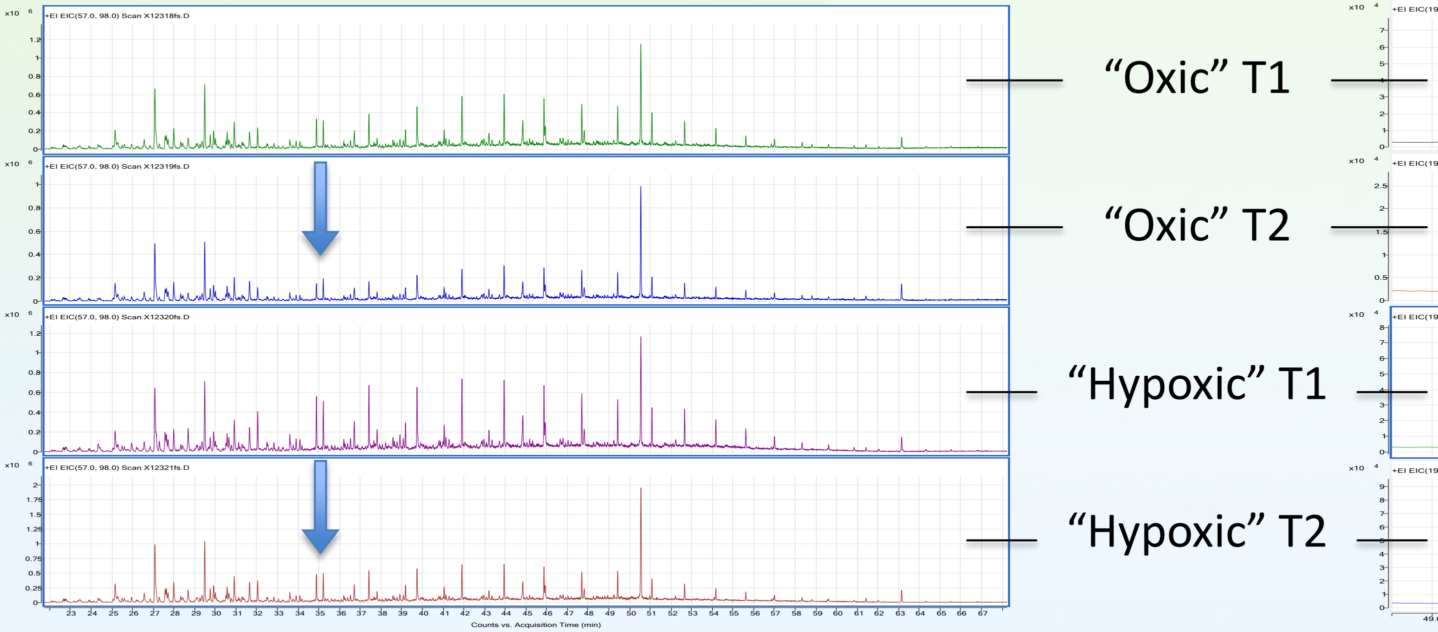
- "Background" activity not negligible
- S1 *vs* S2: Activity always higher with oil, across all oxygen settings
  → oil stimulates microbial activity
- S1 *vs* S3: minimal O_2 uptake in kill cultures, but lots of CO_2 released
  → abiotic process

Microcosm experiments

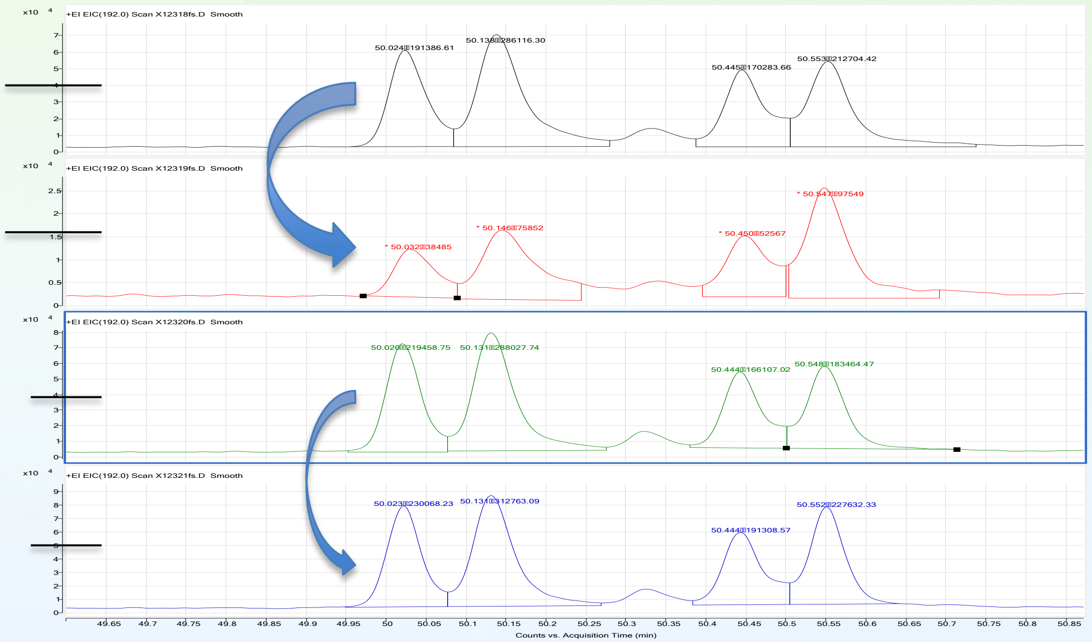
Round 1: Effect of O_2 limitation on natural oil degradation rates: GC-MS data

Difference in oil degradation: oxic *vs* hypoxic conditions

Alkanes:
similar degradation



Aromatics:
more efficient degradation under oxic conditions



Methyl phenanthrenes

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!

Ressources naturelles Canada | Natural Resources Canada

Developing National Guidelines for Dredge disposal at sea

Élaboration de lignes directrices nationales pour les dépôts de dragage en mer

Gwyn Lintern

May 17th, 2022

Canada

ABSTRACT

Coastal energy infrastructure and other port projects require dredging to make the sites suitable for construction. 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 enormous 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 two proponents. The validity of the methodology is being tested. NRCan is part of a triparty Regional Ocean Disposal Advisory Committee that will investigate several aspects of dredge disposal on the coast, one of which is dispersivity of existing sites. 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 modelling.

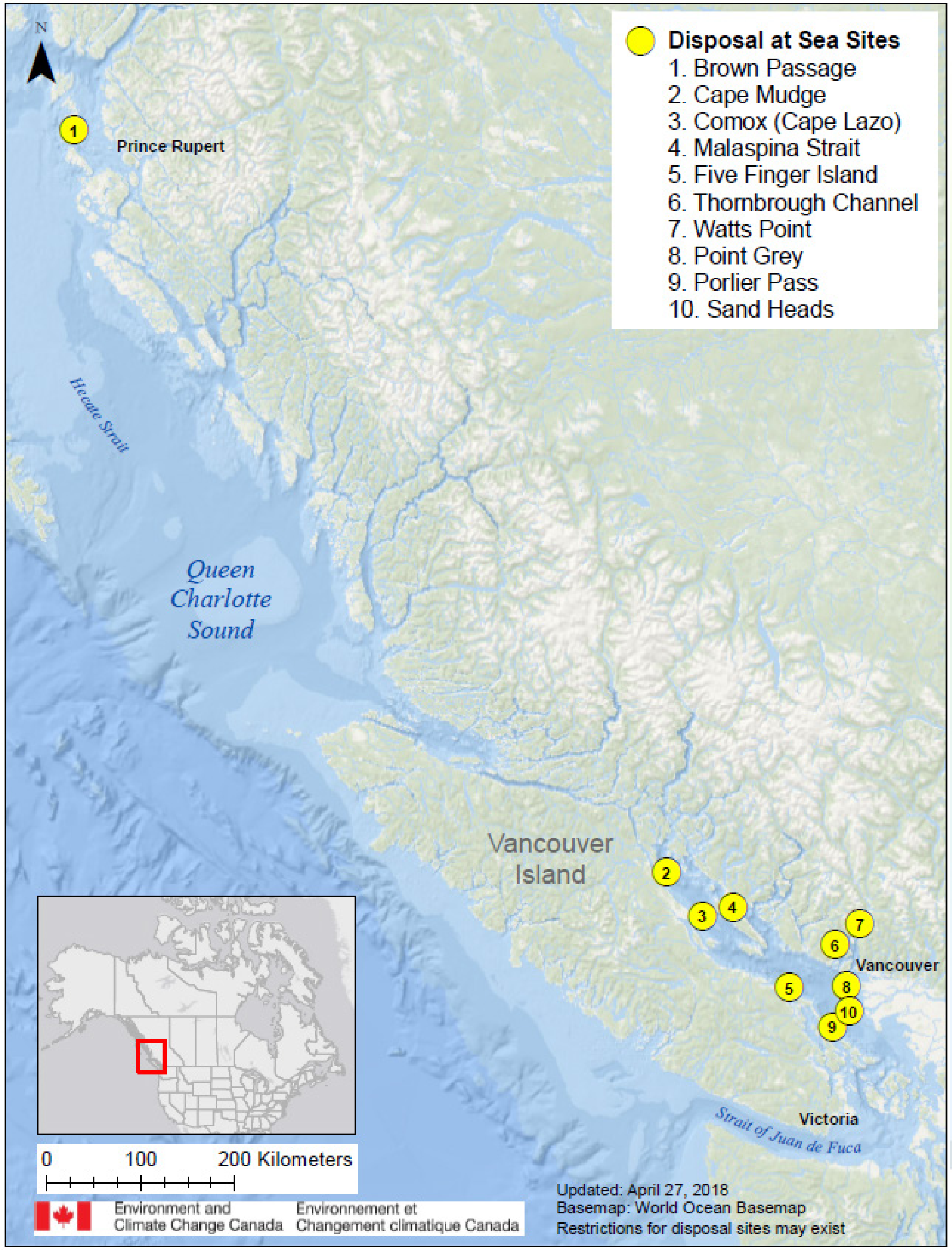
PROJECT LEADS

- Gwyn Lintern, Geological Survey of Canada
- Roanna Leung, Environment and Climate Change Canada

We share ships, equipment, staff, and funds

Issue

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



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 (using peak 1% bottom current speed <25 cm/s)

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

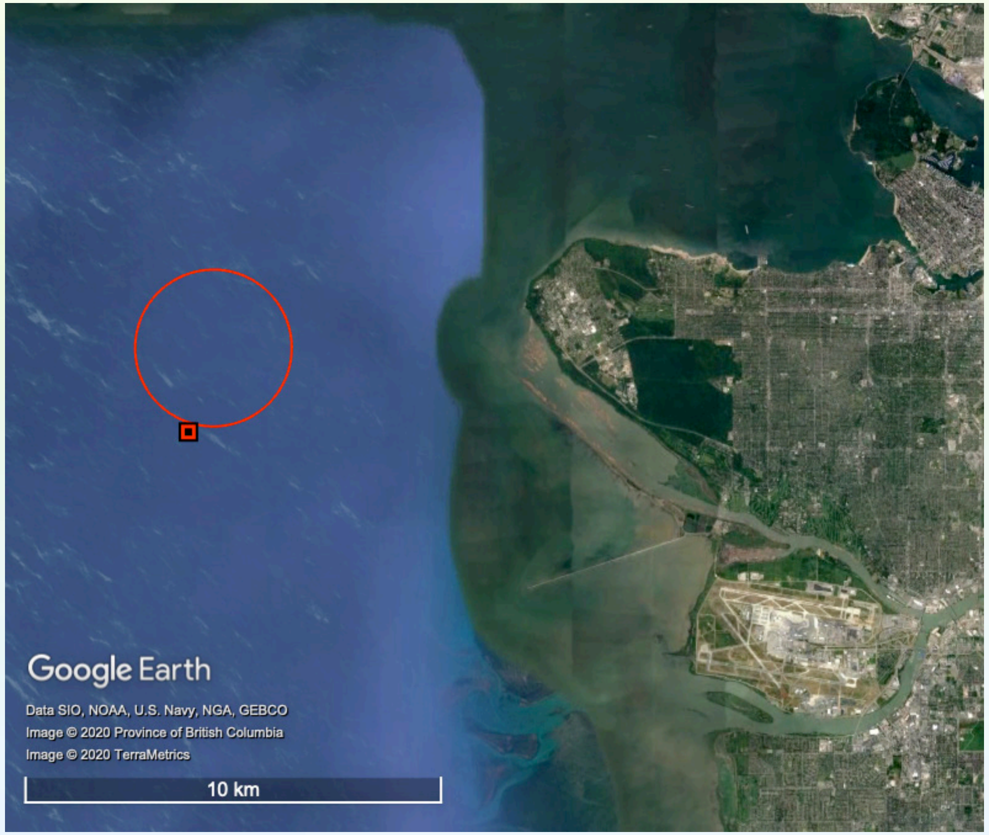


Figure 2. Map of the location of the Point Grey mooring[L[1] .

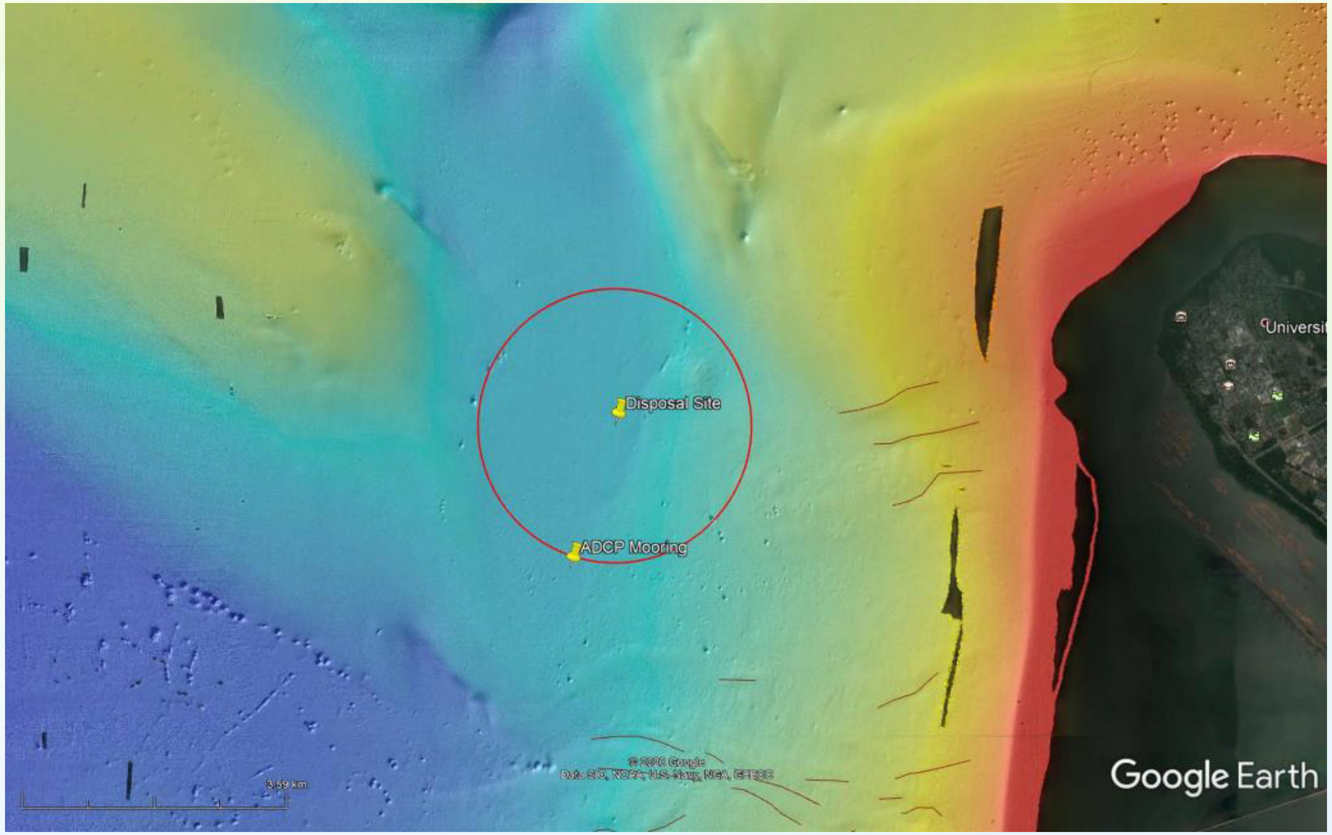
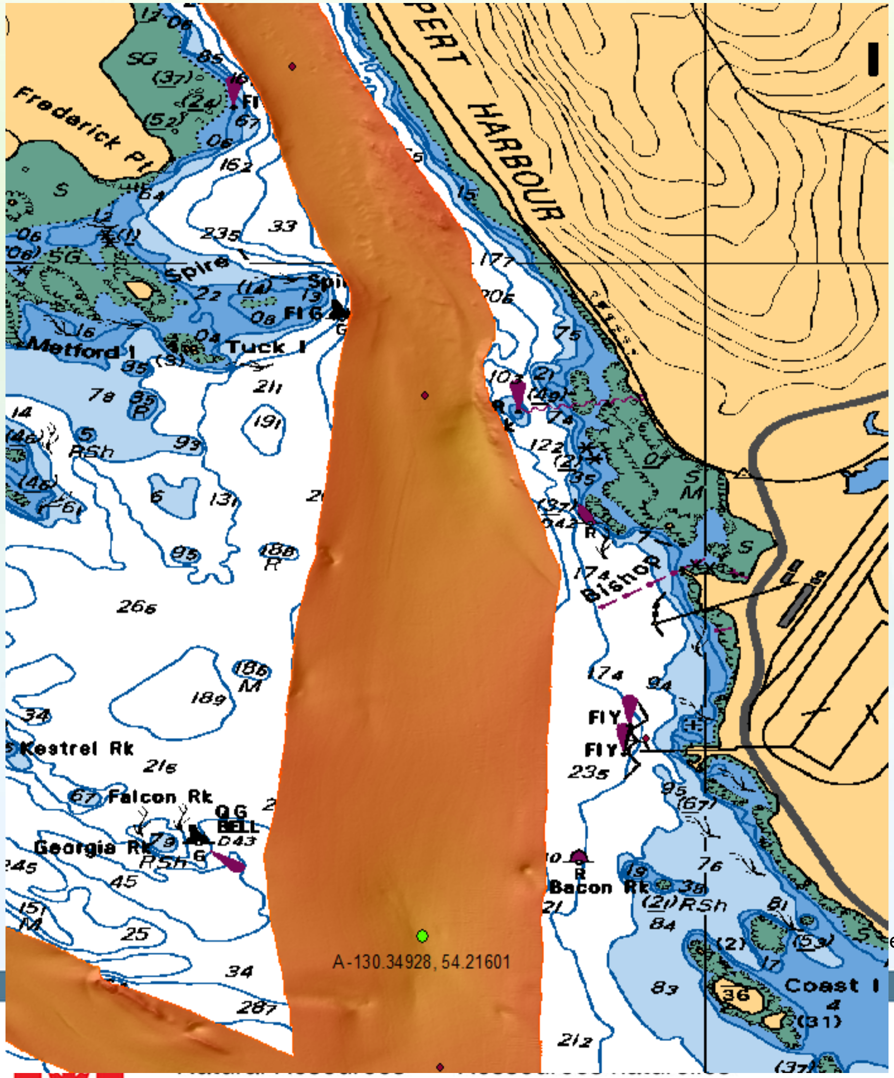


Figure 3. Map with Multibeam of the Point Grey disposal site and surrounding area[L[2] .

Dispersive or non-dispersive?

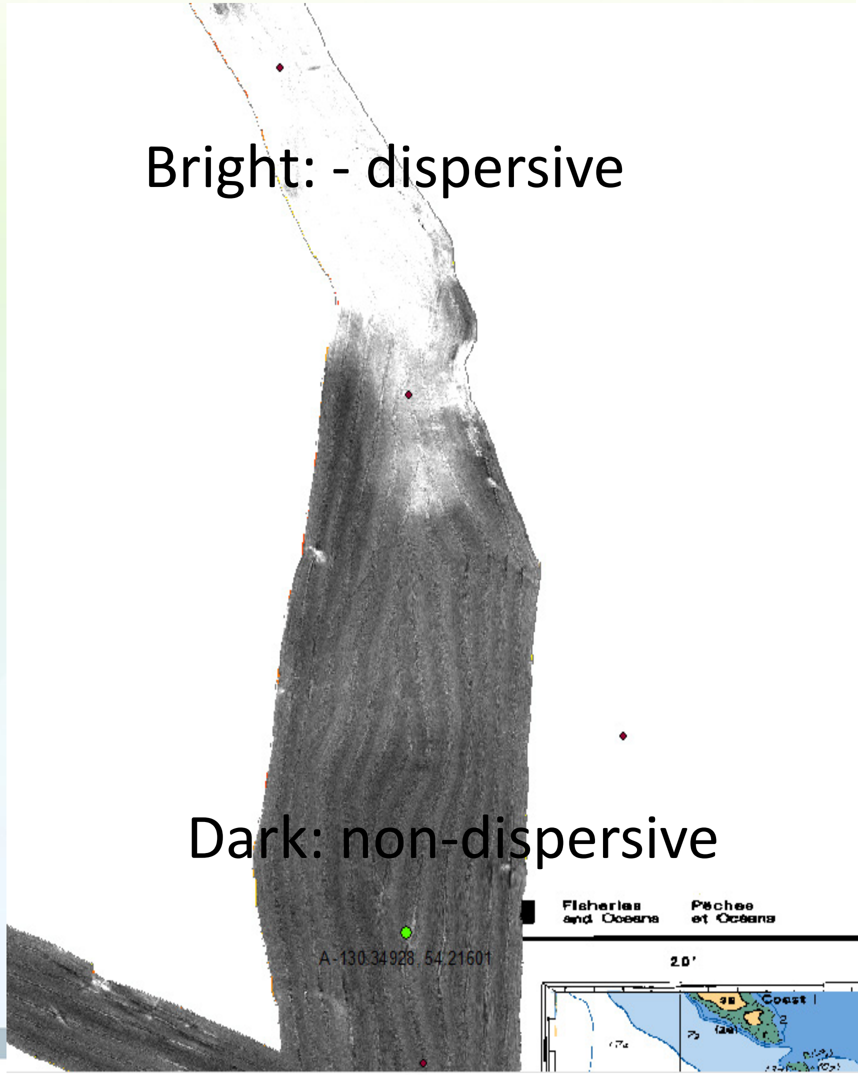
Multibeam backscatter example from a previous site



← Bathymetry

Backscatter →

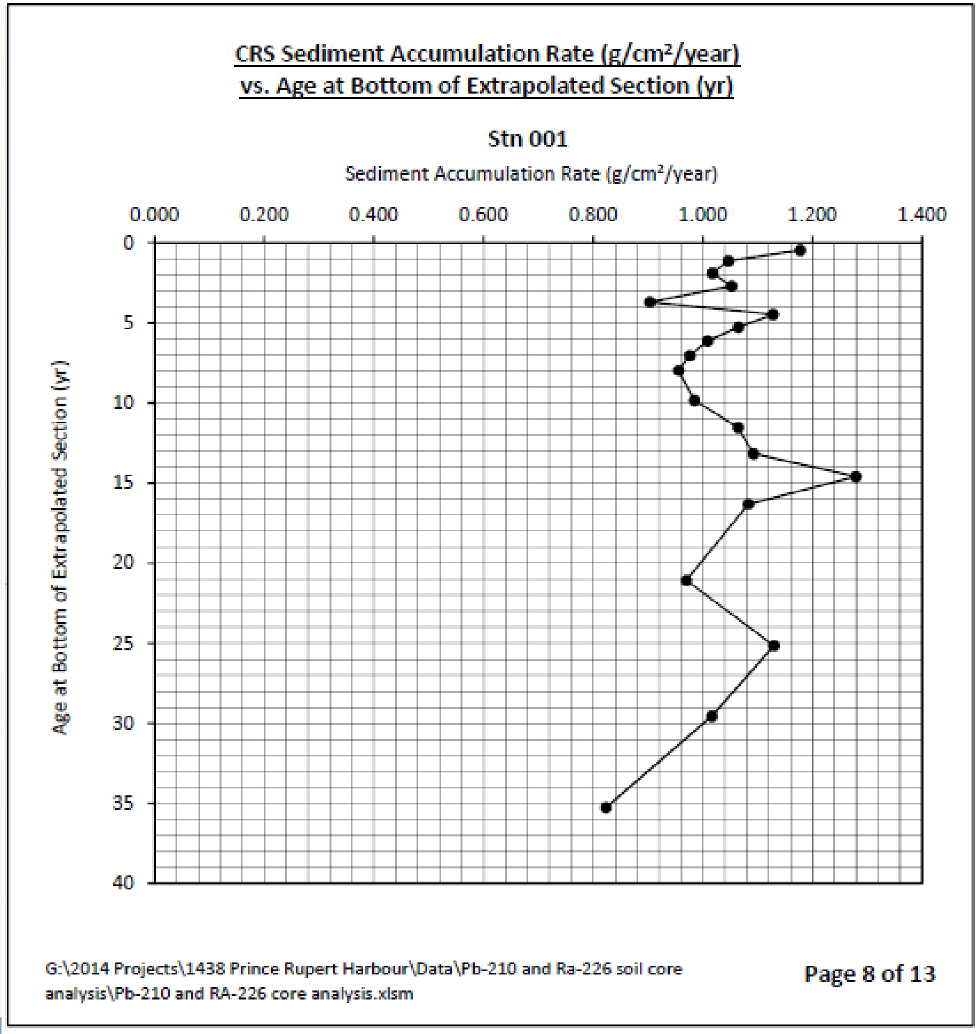
Darker = finer grained, which usually translates to non-dispersive



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

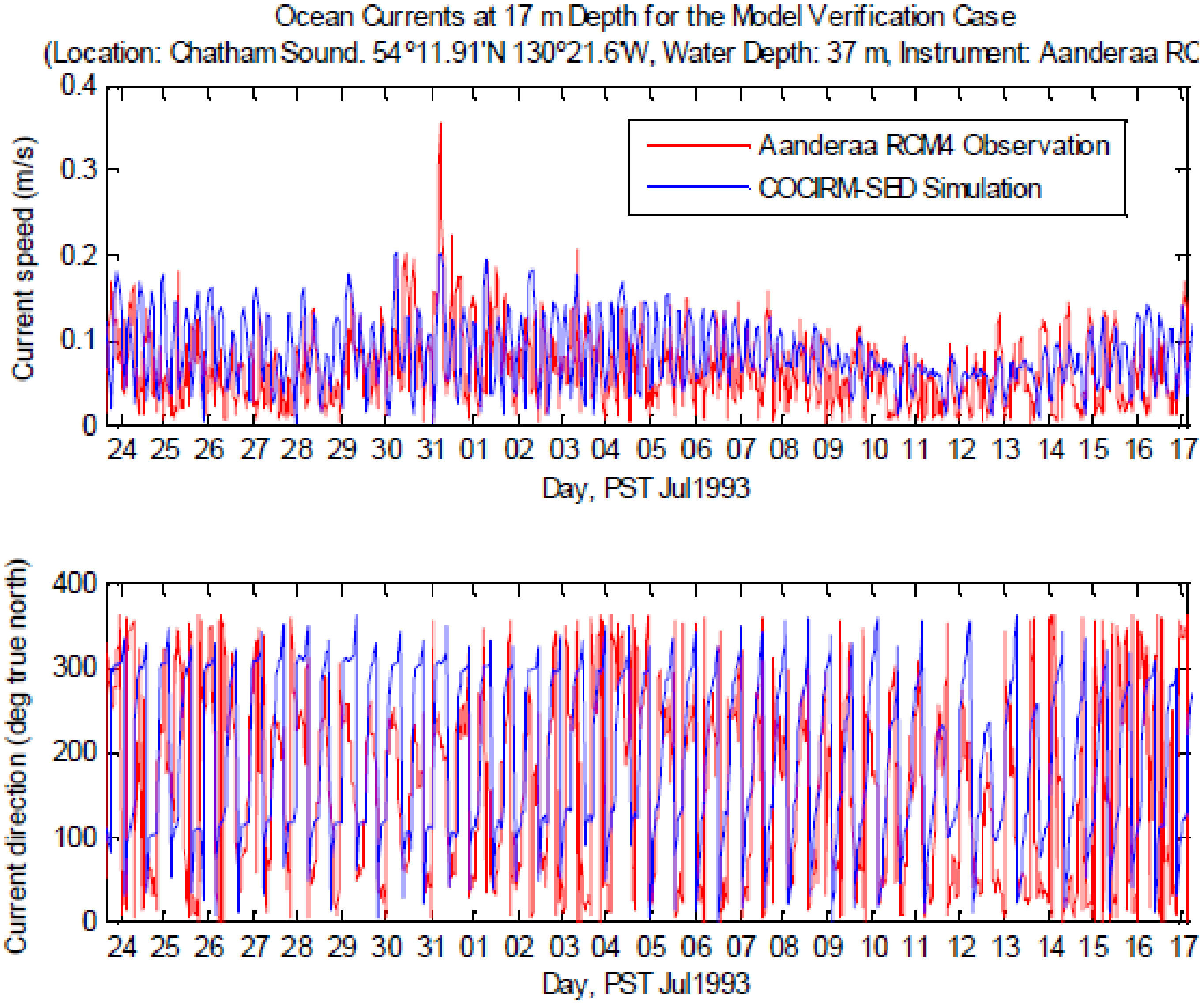


Figure 5: Verification modeled and measured ocean currents at 17 m depth near disposal site 1.

Dispersive or non-dispersive?

The goal: Design experiments which give actual measurements of currents and sediment transport

- Must be robust and designed using best techniques
- Must be for all seasons
- 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)

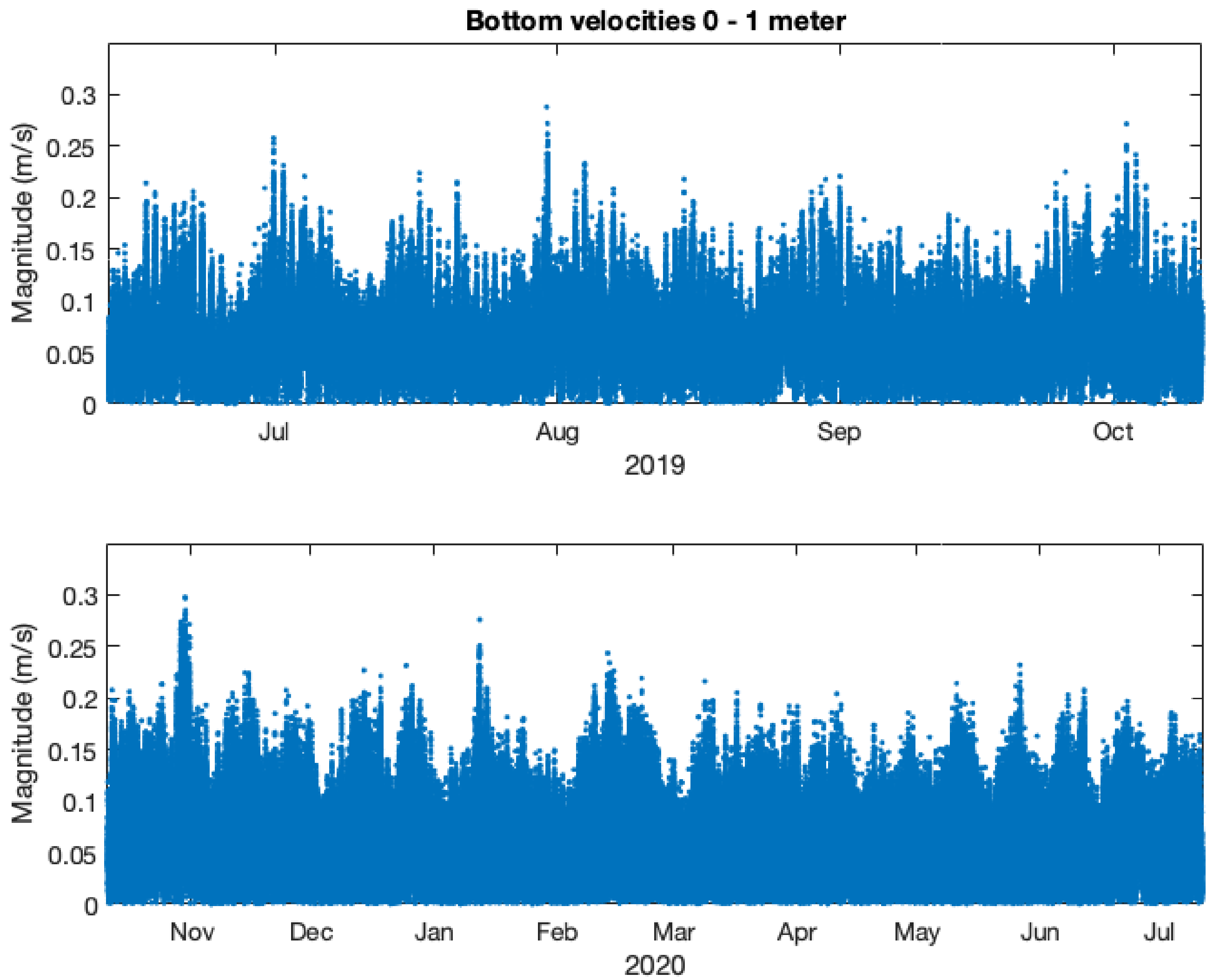
Mooring deployment
Point Grey, Vancouver
October 31, 2020

Dispersive or non-dispersive?

Testing:

Peak 1% bottom current speed < 0.25 m/s

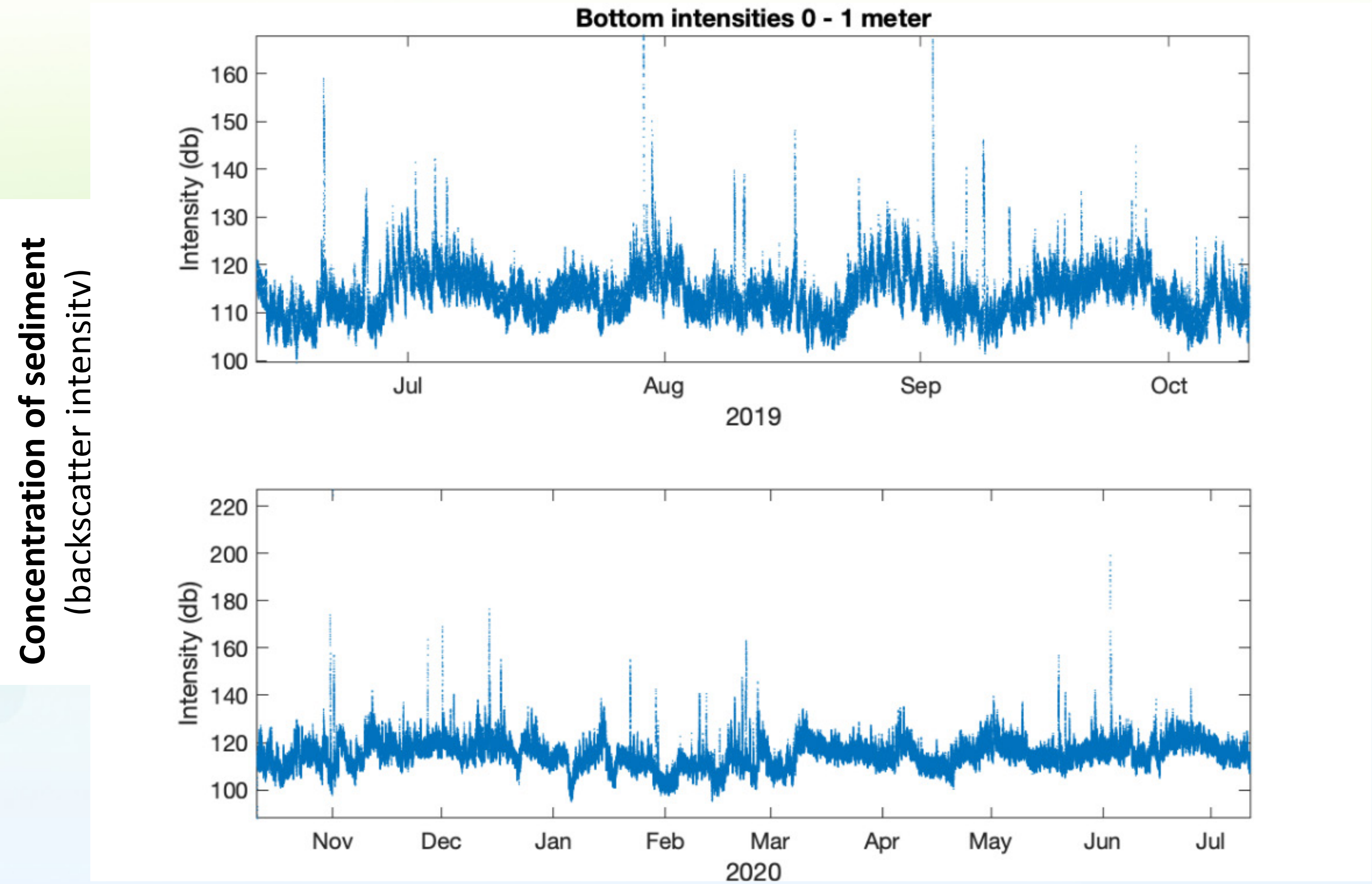
Point Grey is considered to be non-dispersive by this definition



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



Publications

IMO INTERNATIONAL MARITIME ORGANIZATION

E

SCIENTIFIC GROUP OF THE LONDON CONVENTION – 45th Meeting; and

SCIENTIFIC GROUP OF THE LONDON PROTOCOL – 16th Meeting
12 - 16 April 2021
Agenda item 7

LC/SG 44/INF.5
19 February 2021
ENGLISH ONLY
Pre-session public release: ☐

MONITORING AND ASSESSMENT OF THE MARINE ENVIRONMENT

Results of Canada's 2020 disposal site monitoring program

Submitted by Canada

SUMMARY	
Executive summary:	This document presents a summary of the disposal site field monitoring carried out in Canada in 2020. Representative sites were monitored off the Pacific and Atlantic coastlines. Mainly physical methods were used and previous inconsistencies at sites in the Gaspé region of the Gulf of St. Lawrence were investigated. Canada also embarked on a research project to deploy an instrument on the seafloor on the Pacific coast to characterize the movement of sediment at our largest disposal site over a one year period.
Action to be taken:	Paragraph 21
Related documents:	

- Annual reports with dispersivity and other characteristics of an individual disposal site
- Guidance on monitoring for proponents of new disposal at sea sites.
- London Convention and Protocols, 2021

CONTACT INFORMATION

- Gwyn Lintern
- 250-889-9887
- gwyn.lintern@canada.ca

THANK YOU!

Ressources naturelles Canada
Natural Resources Canada

Measuring, monitoring and verification of geological carbon storage

Mesure, surveillance et vérification de la séquestration géologique du carbone

Don White

May 17th, 2022




Canada

ABSTRACT

Aquistore CO_2 storage site: 7 years of monitoring

- Monitoring updates:
    - CO_2 plume tracking
    - Induced seismicity
- Next generation monitoring: DAS configuration tests
- Storage efficiency factors: Crosswell seismic imaging

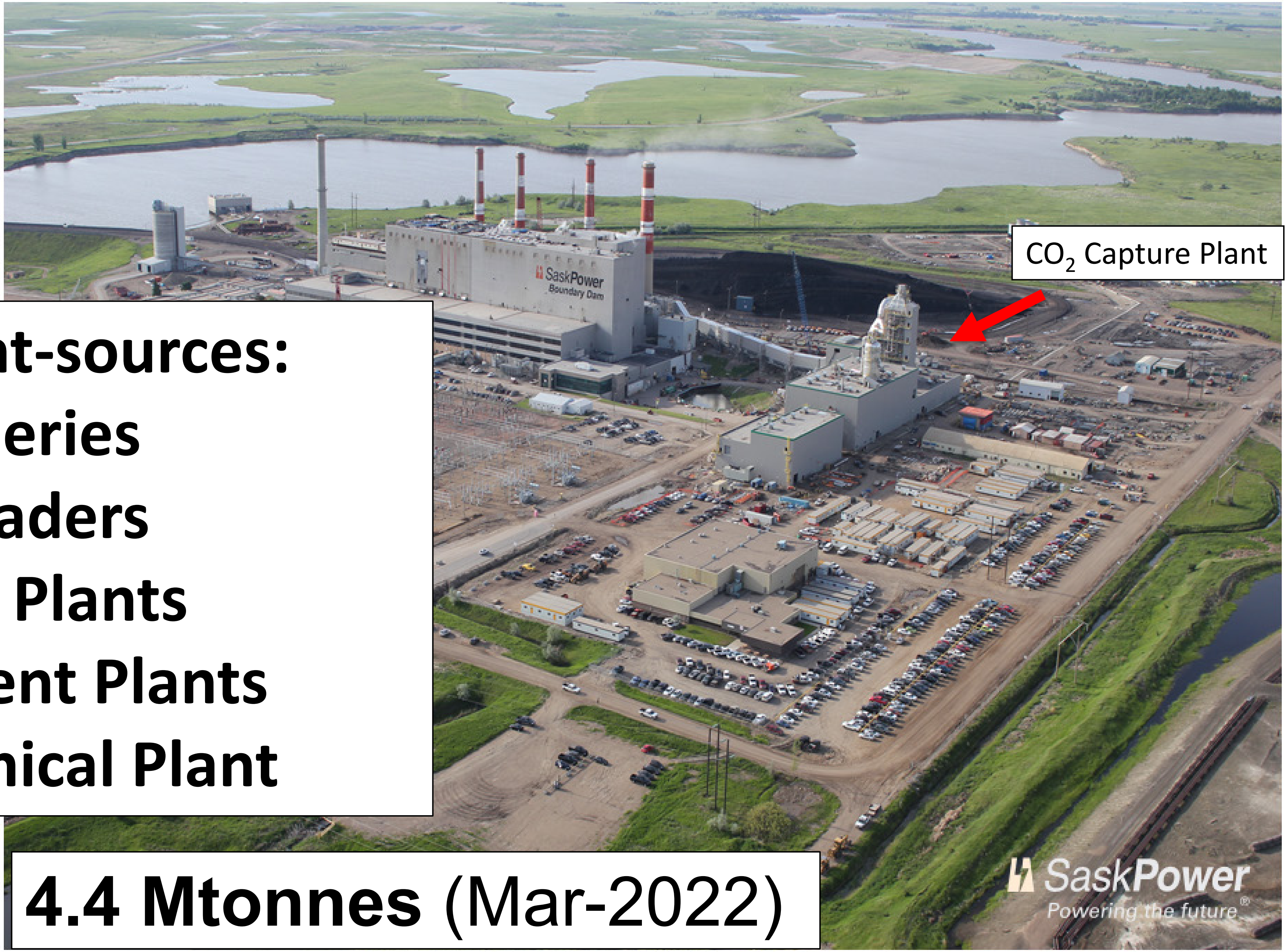
PROJECT MEMBERS

- Don White, Gilles Bellefleur (**GSC**)
- Mike Craymer, Jason Silliker (**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**)
- Anna Stork (**Bristol University**)
- Masaru Ichikawa, Yuta Kitawaki (**Japan Oil, Gas Metal NC**)
- Kevin Dodds (**Australian National Low Emissions Coal Research & Development**)


SaskPower
Boundary Dam
CO_2 Capture Plant
4.4 Mtonnes (Mar-2022)
SaskPower
Powering the future

CO_2 point-sources:

- Refineries
- Upgraders
- Steel Plants
- Cement Plants
- Chemical Plant



4.4 Mtonnes (Mar-2022)

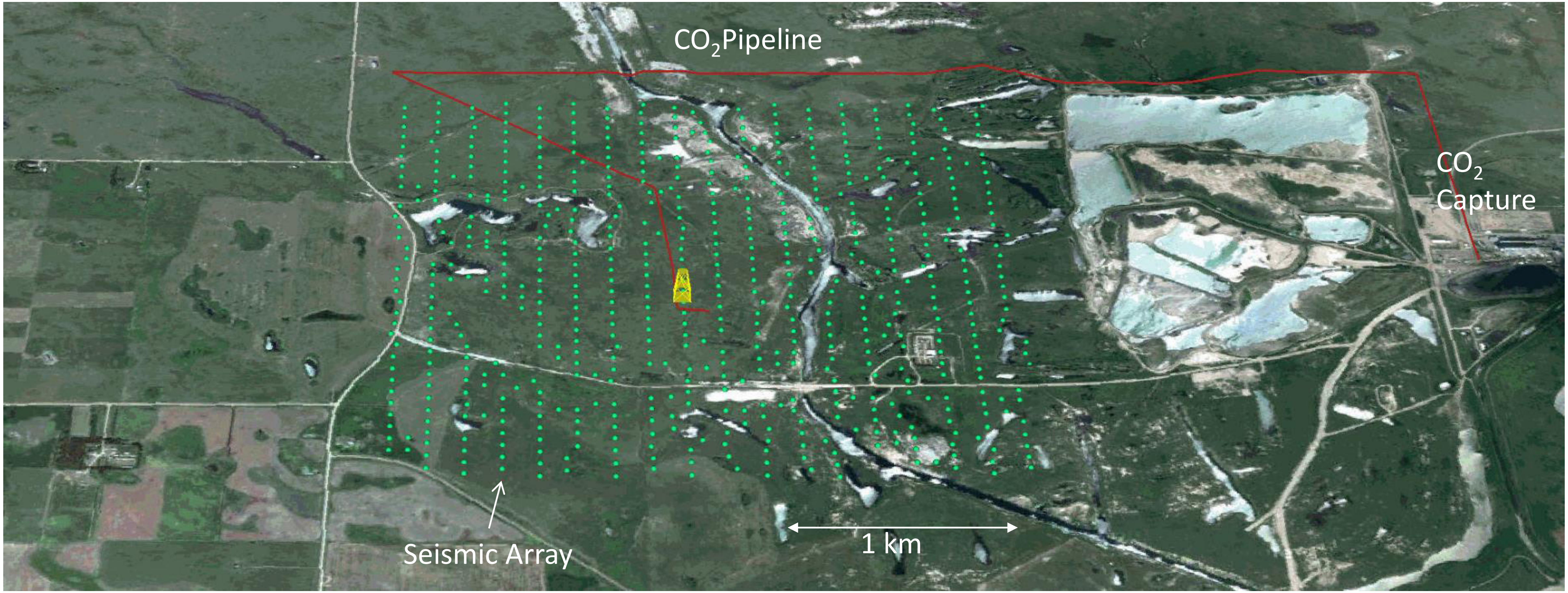
GSC Research Objectives

- Methods for monitoring CO_2 containment
- Induced seismicity
- <u>CO_2 storage efficiency factors</u>

Outcomes

- Informs regulations and international standards under development
- Effective but efficient CO_2 monitoring

Aquistore CO_2 Storage Project

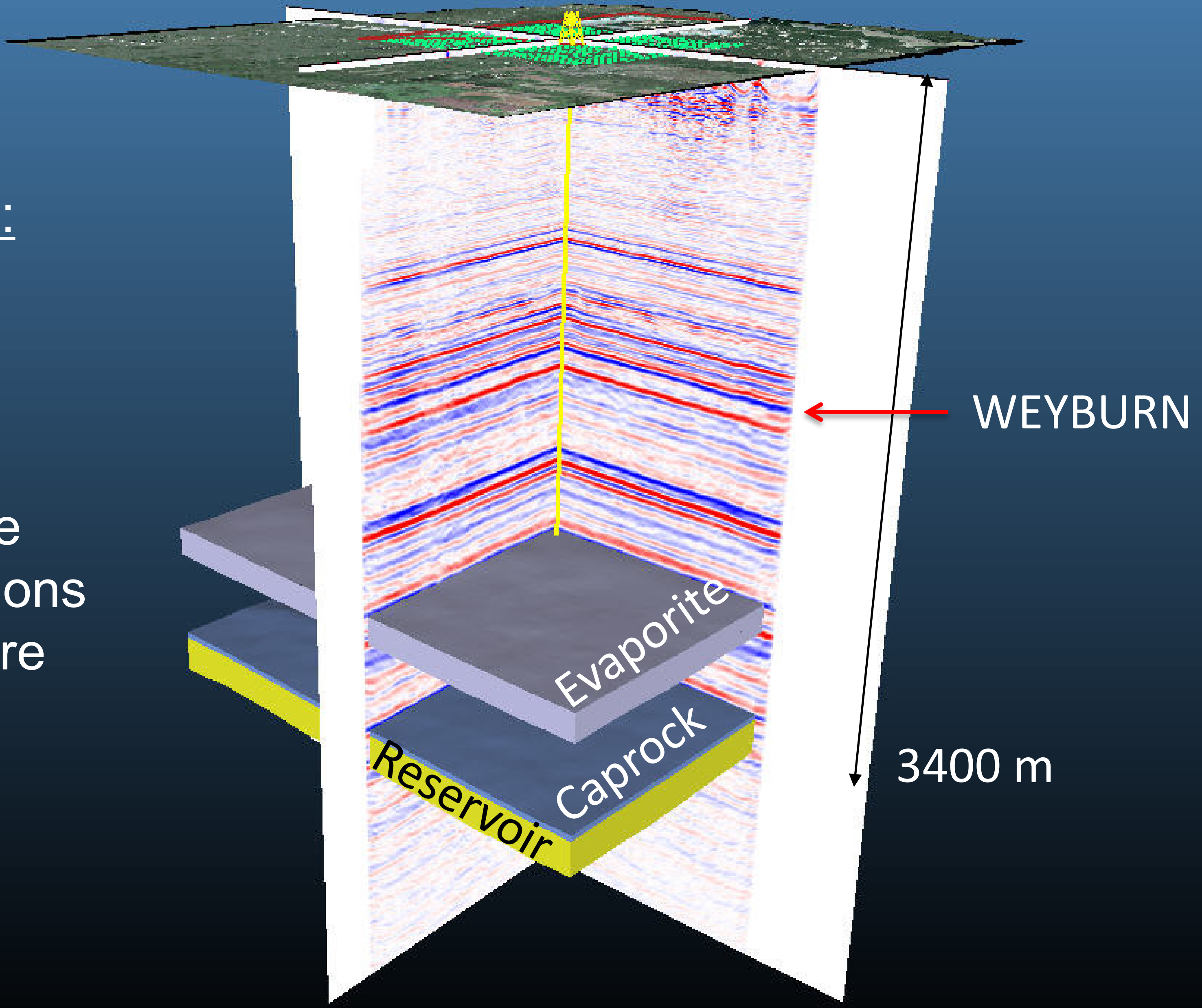


Monitoring Challenges:

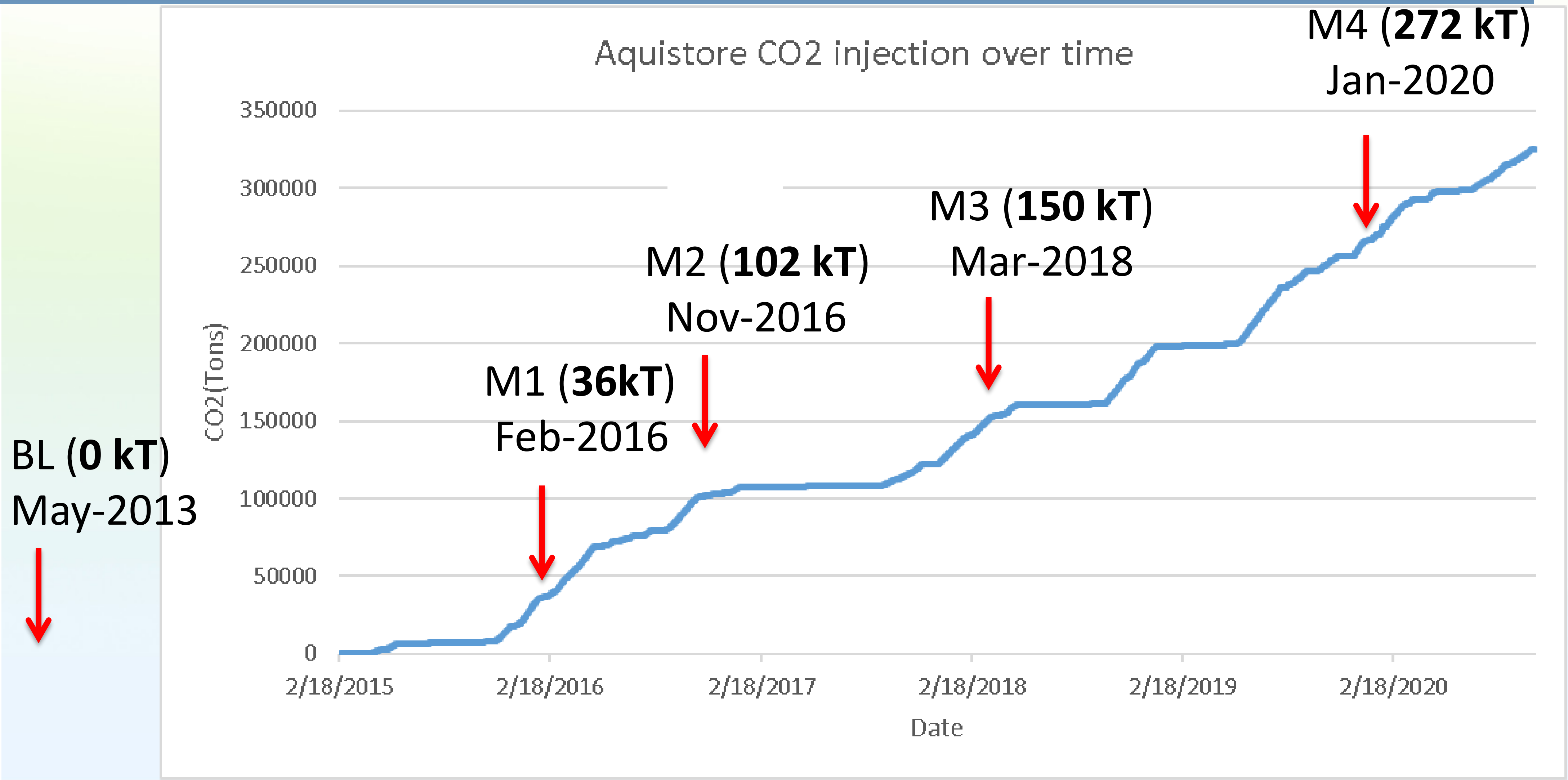
- Deep reservoir
- Low injection rate

Advantages:

- Weyburn experience
- Permanent installations
- Minimal infrastructure
- Limited land use

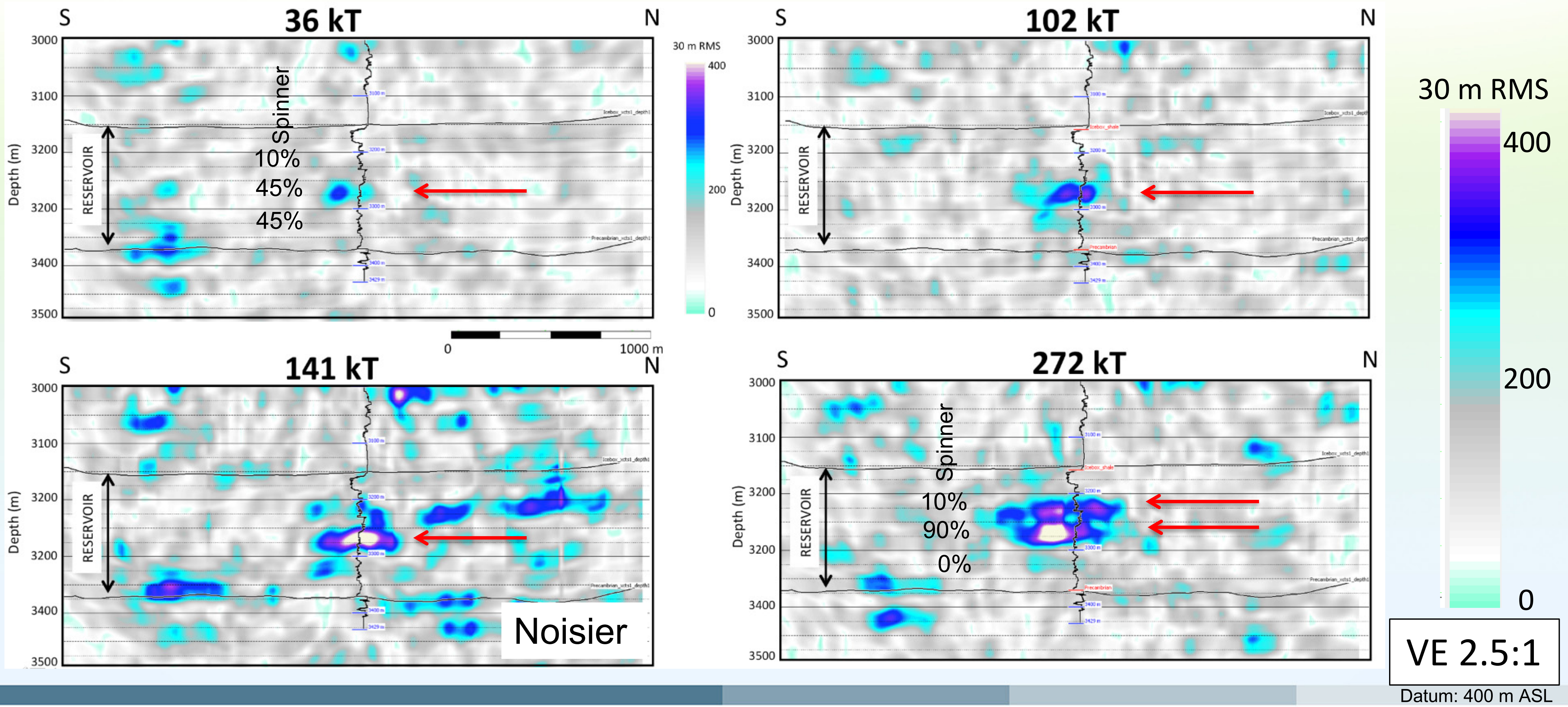


Monitoring CO_2 Injection



Currently:
428 kT

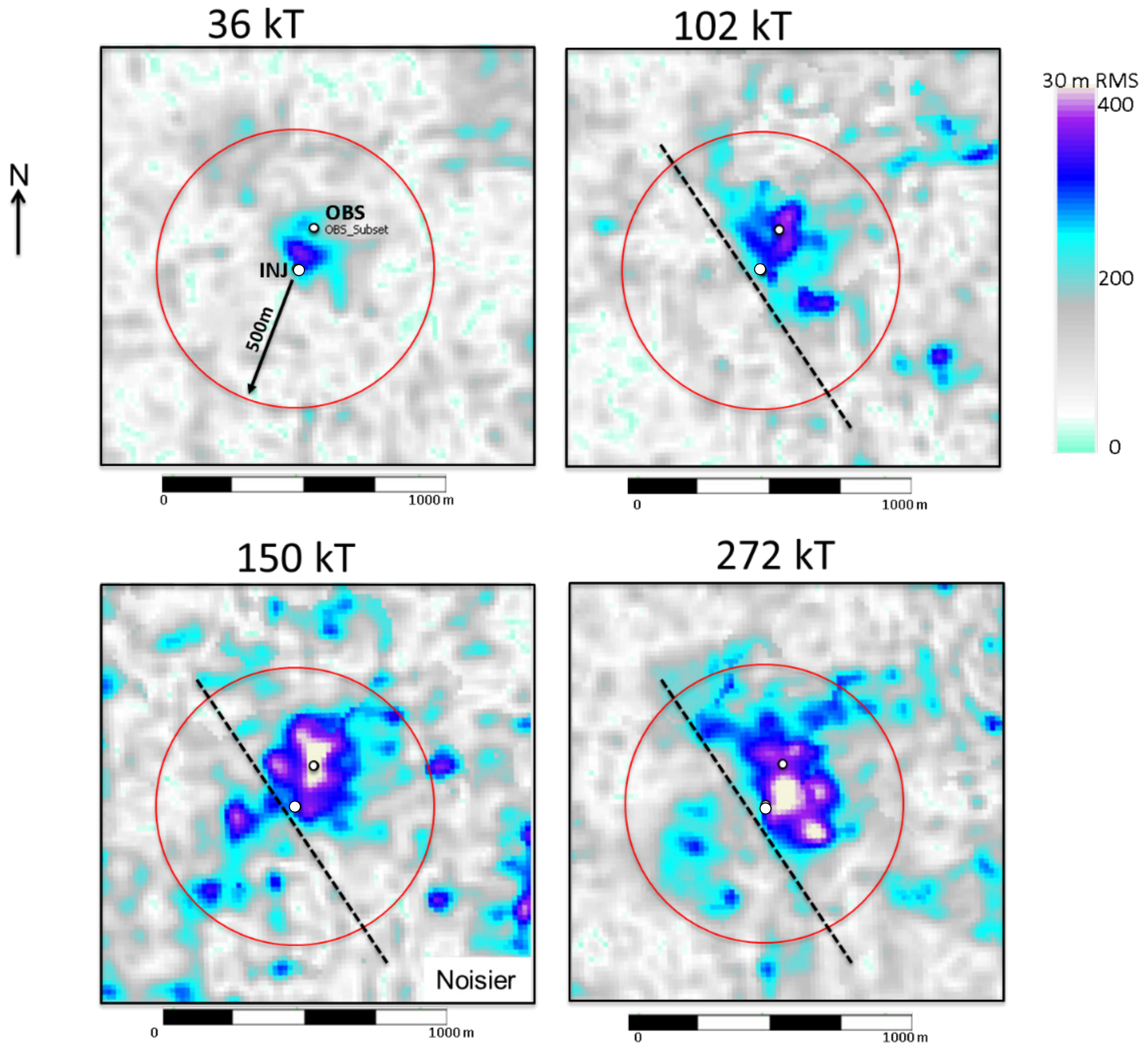
OBS WELL: 4D RMS AMPLITUDE DIFFERENCE

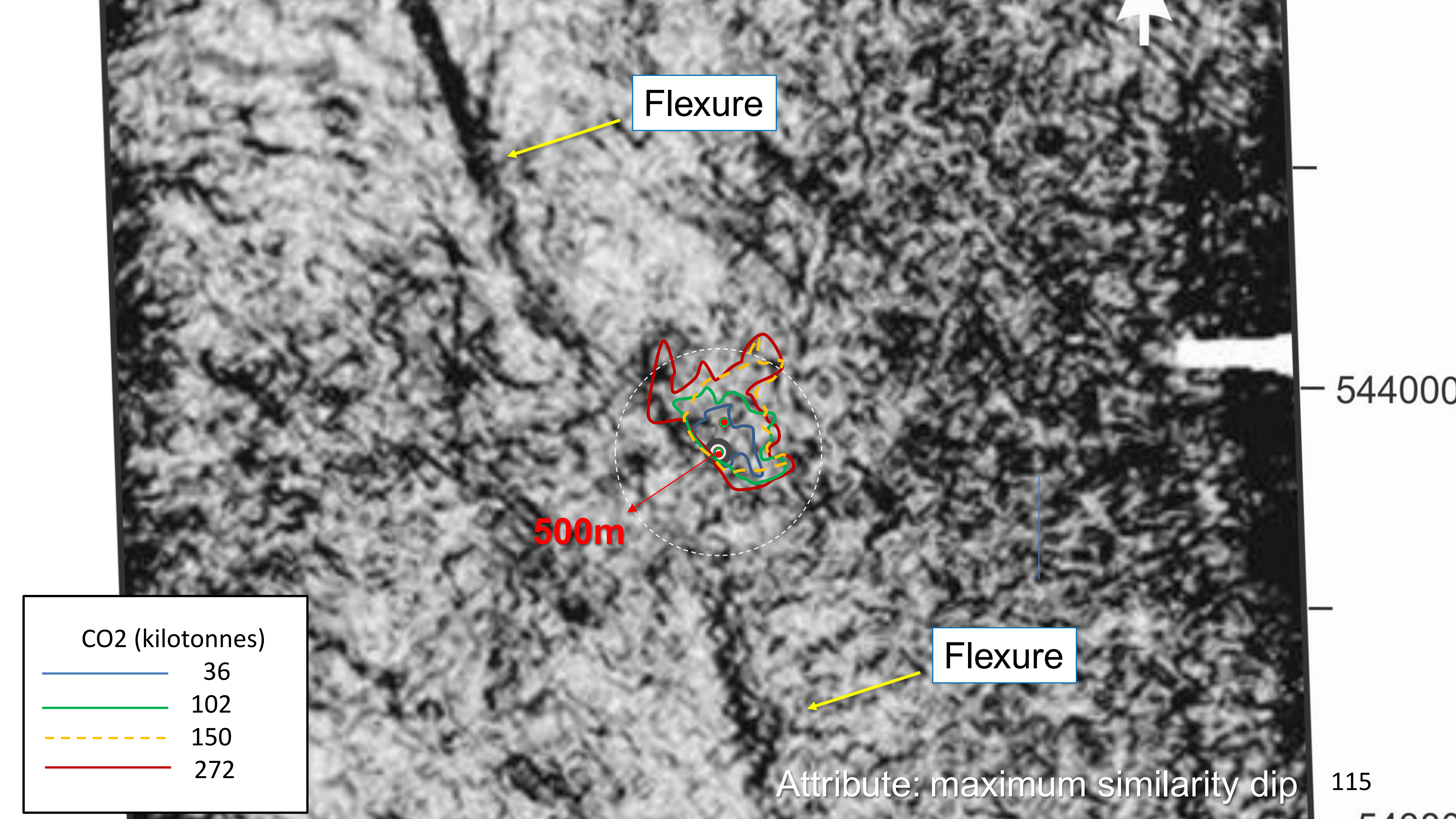


Natural Resources Canada

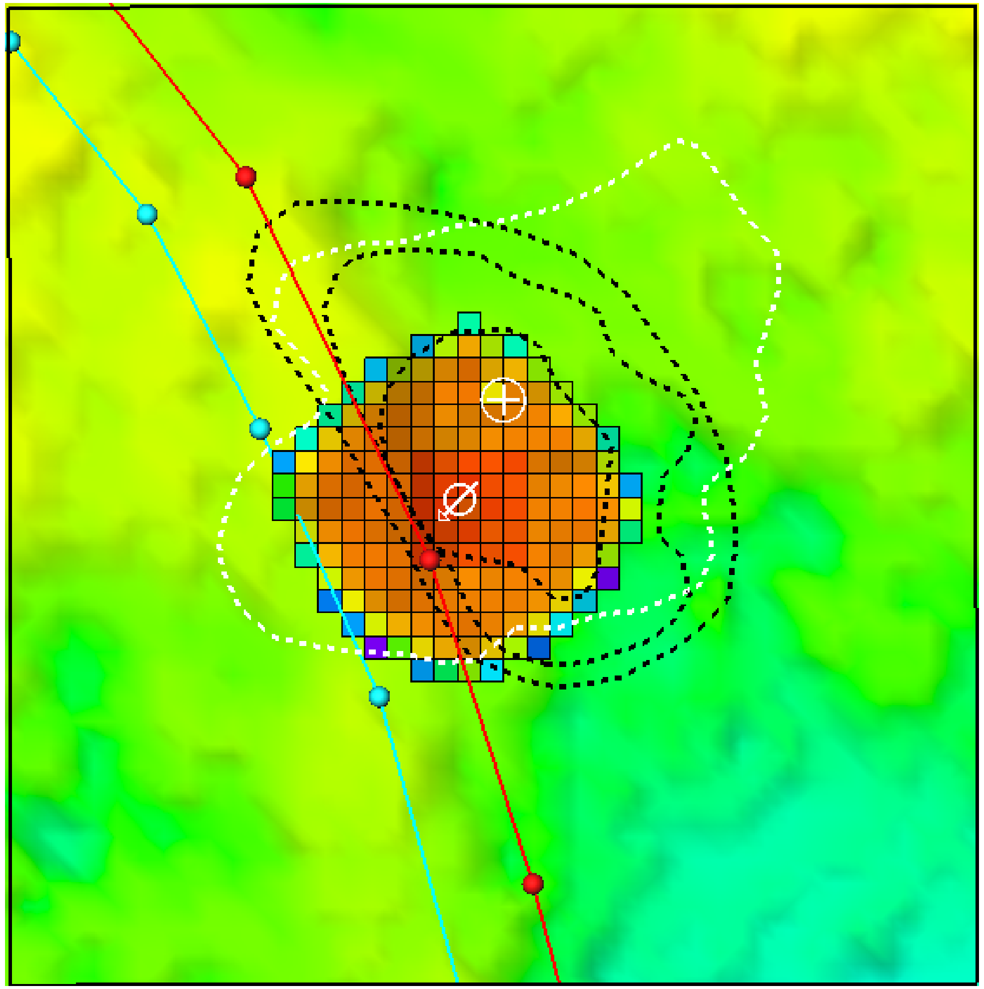
Ressources naturelles Canada

UPPER DEADWOOD: 4D RMS Amplitude Difference



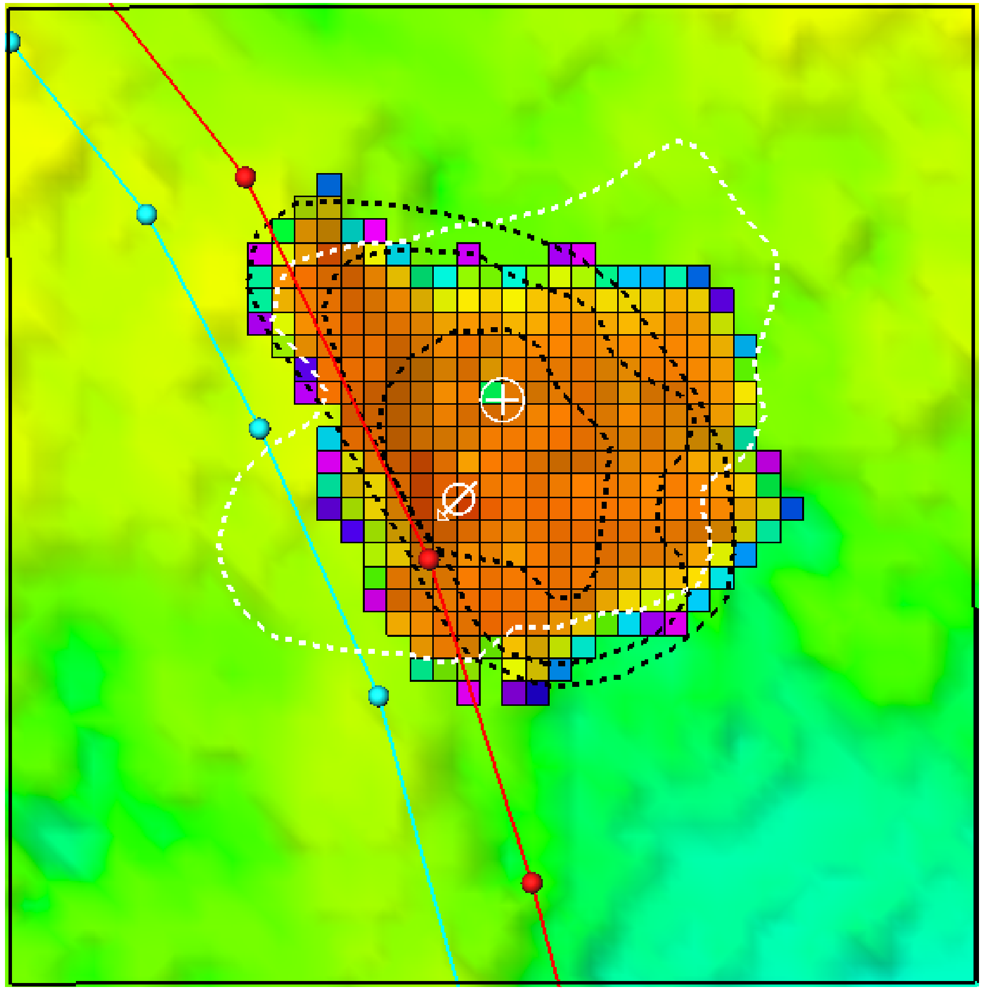

Flexure
Flexure
500m
544000
CO2 (kilotonnes)
36
102
150
272
Attribute: maximum similarity dip

Different History Matched Realizations of CO2 Plume



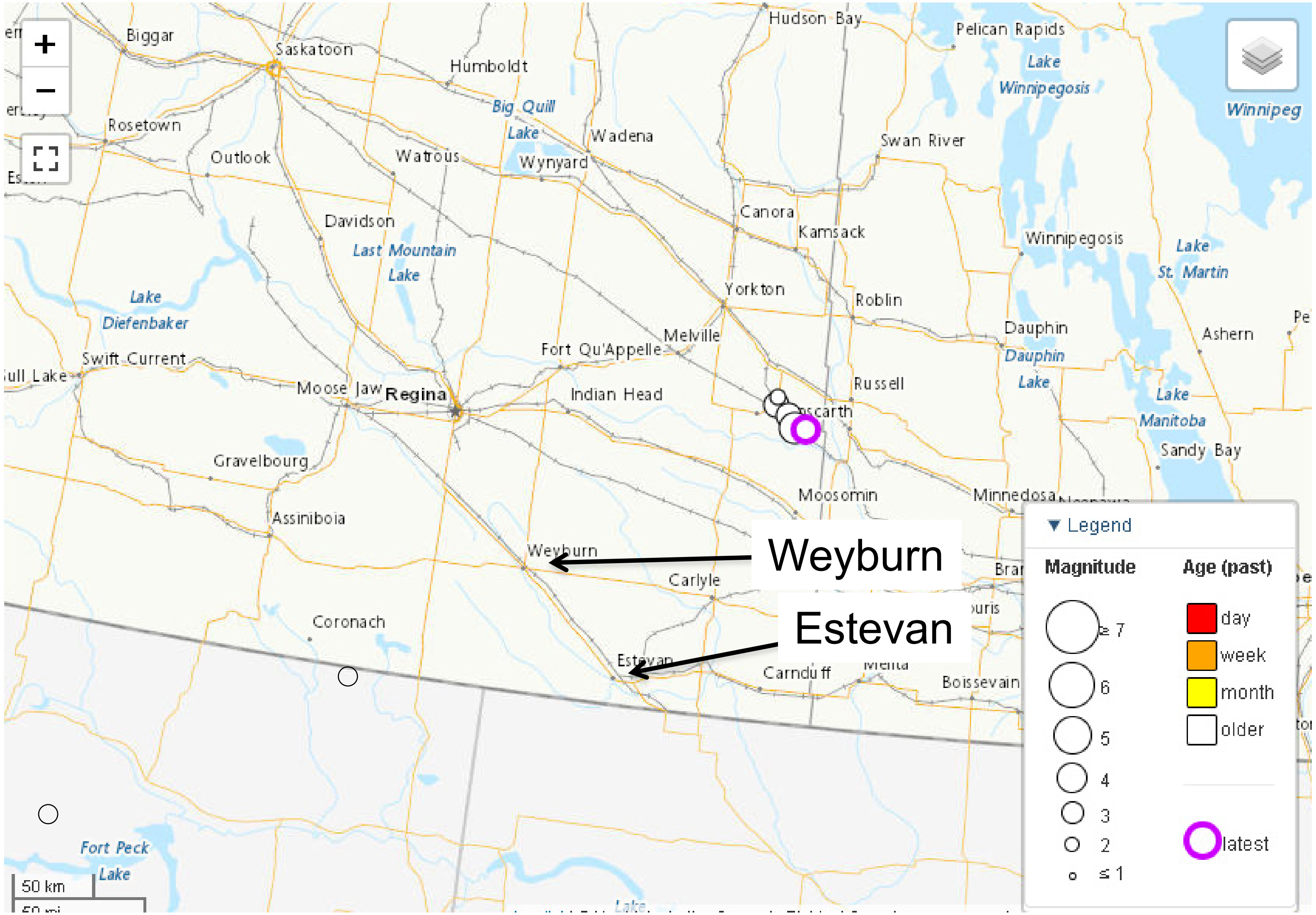
Rangriz Shokri (2021)

Different History Matched Realizations of CO2 Plume



Rangriz Shokri (2021)

Seismicity 2015-2021



Induced Seismicity

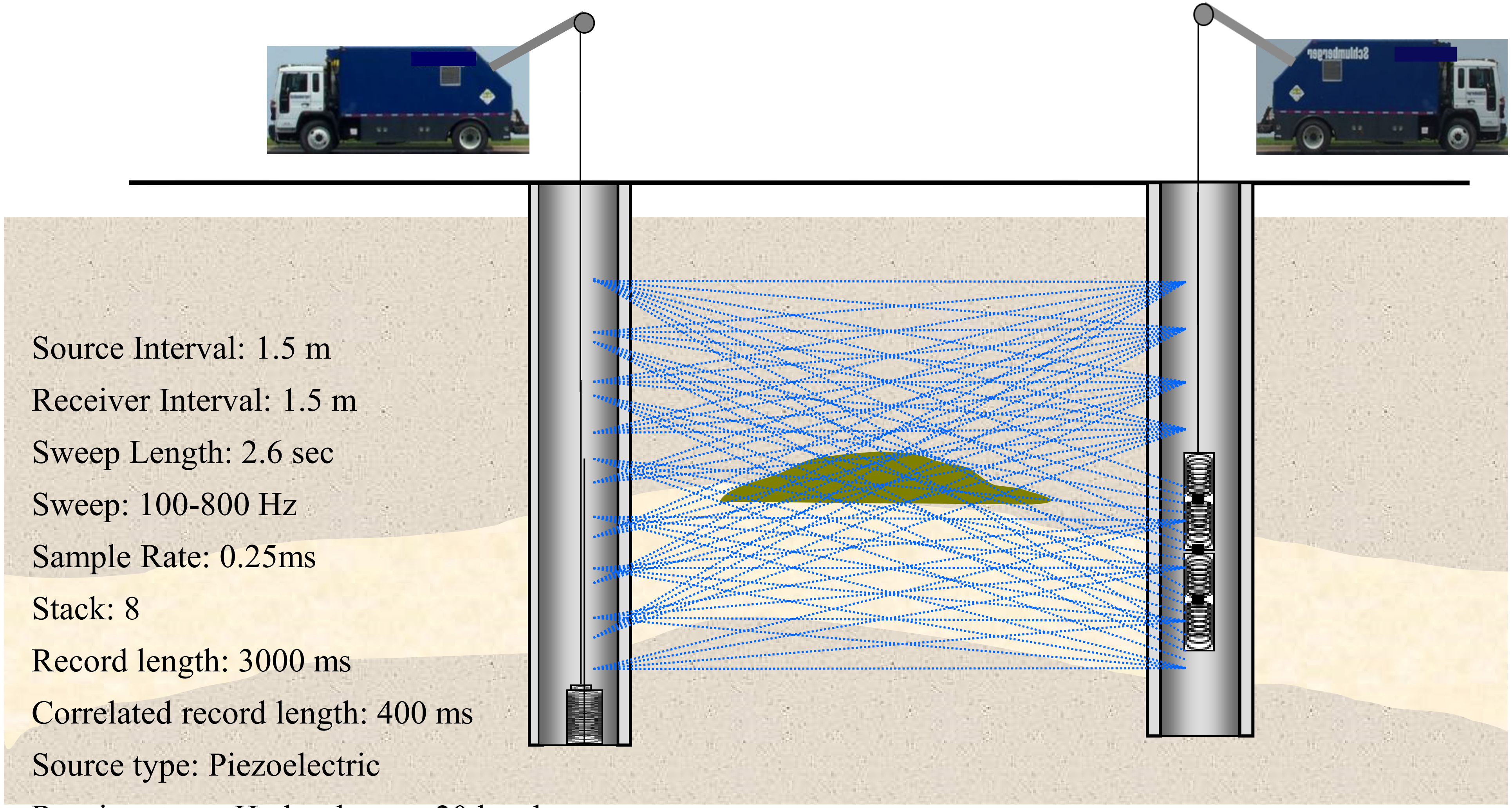
- No induced seismicity during 7 years of injection
- Minimum detectable magnitude for 3.2 km depth:
  - BB: M_L= -0.8
  - Array: M_L= -1.6 to -0.6
- Magnitude of completeness (STA/LTA):
  - BB: M_W = 1.3
  - Array: M_W = 0.6

(Stork et al., 2018)

Improved Storage Capacity Estimation

- Storage capacity estimates still remain largely unproven
- Storage efficiency factors are key but uncertain
- ‘Real World’ measurements from active sites are required for calibration.

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

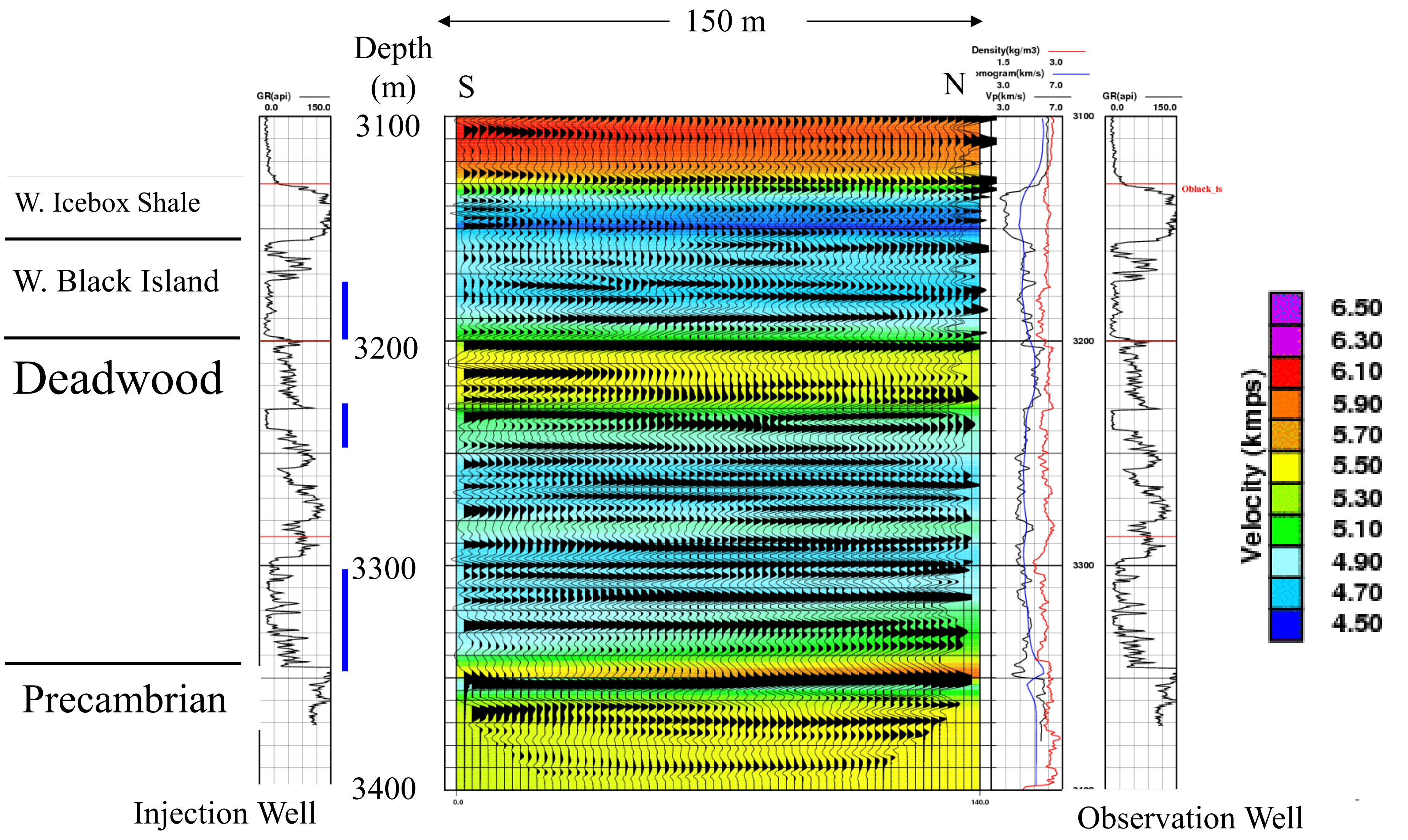
Record length: 3000 ms

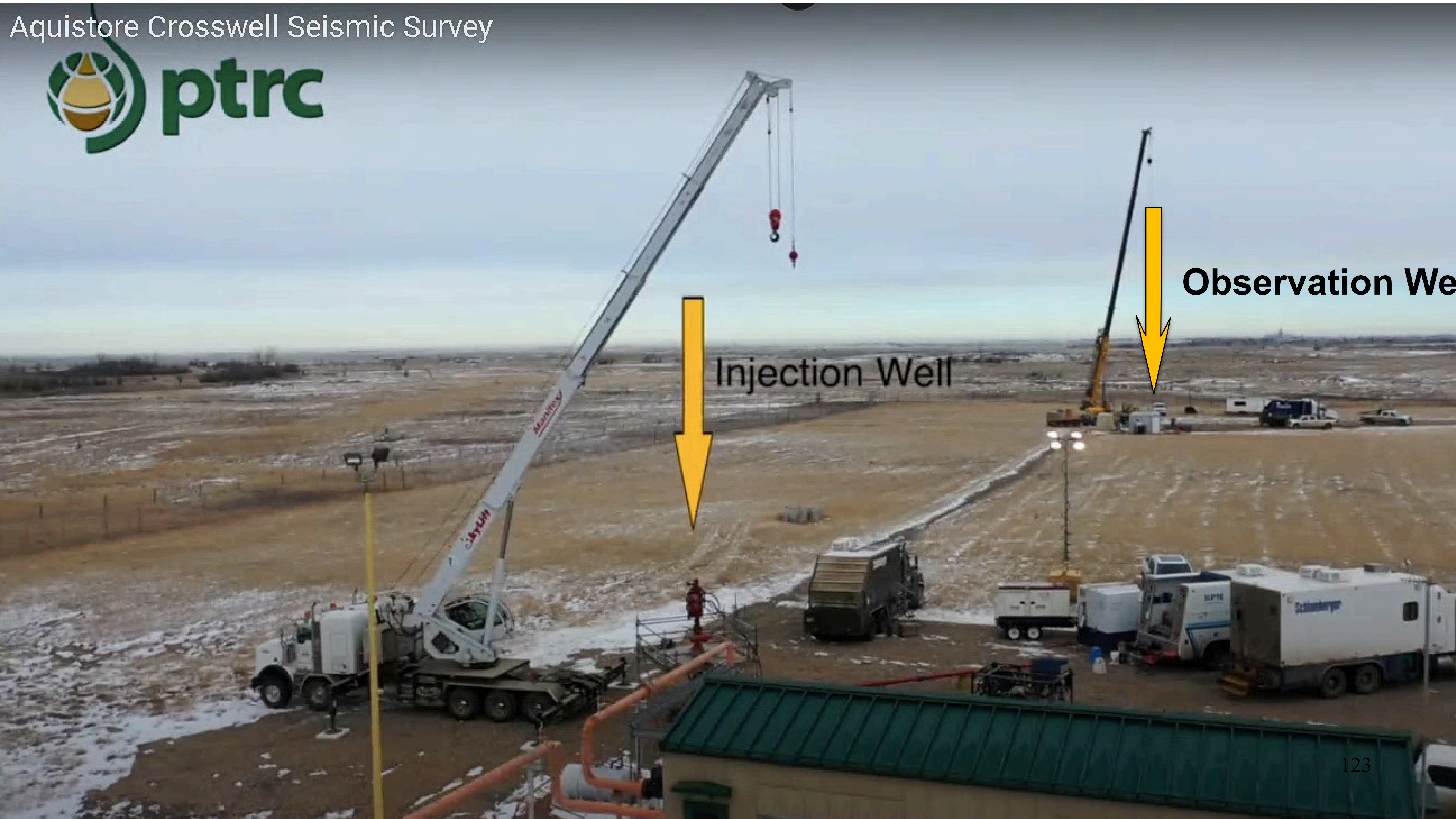
Correlated record length: 400 ms

Source type: Piezoelectric

Receiver type: Hydrophone – 20 levels

Baseline Reflection Tomography Image

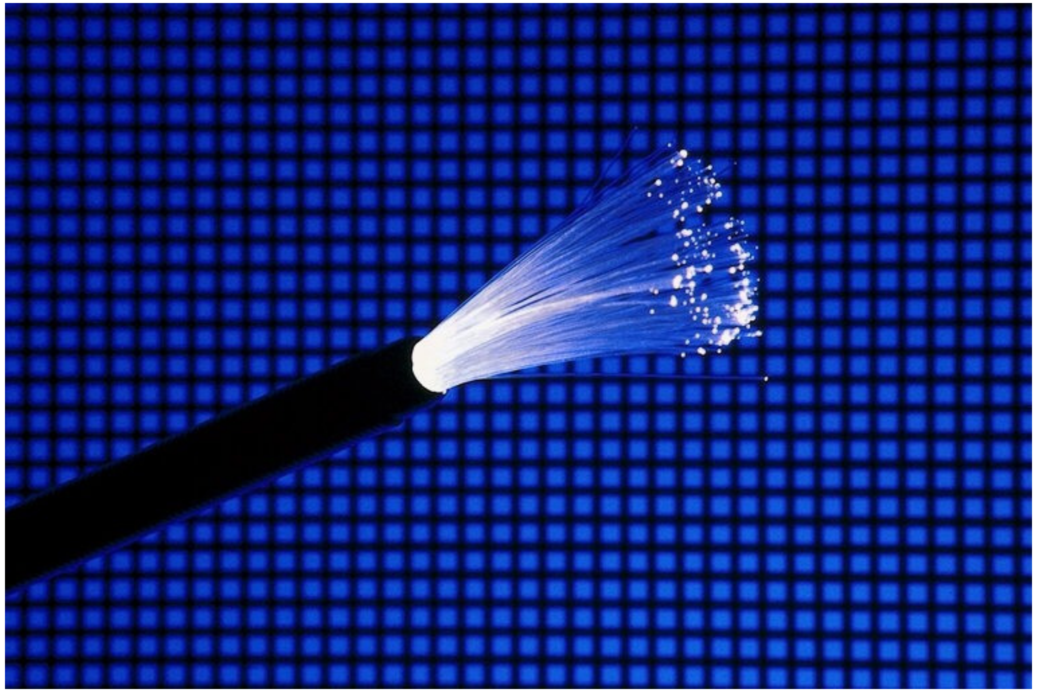




Aquistore Crosswell Seismic Survey
ptrc
Injection Well
Observation We

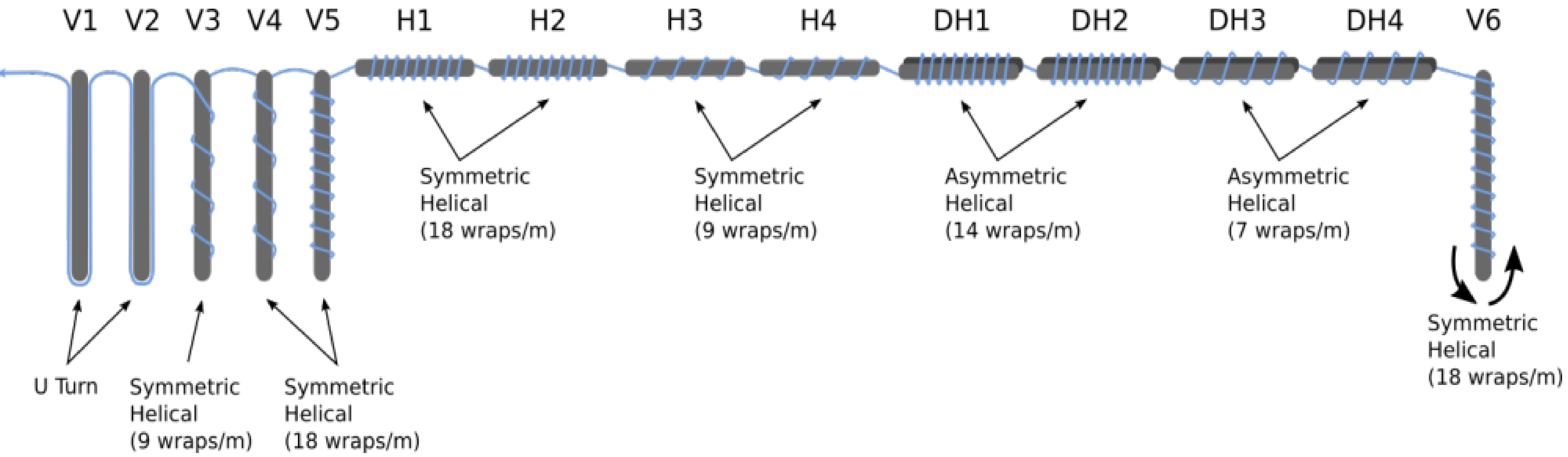
Geophones vs Distributed Acoustic Sensing (DAS Fibre)

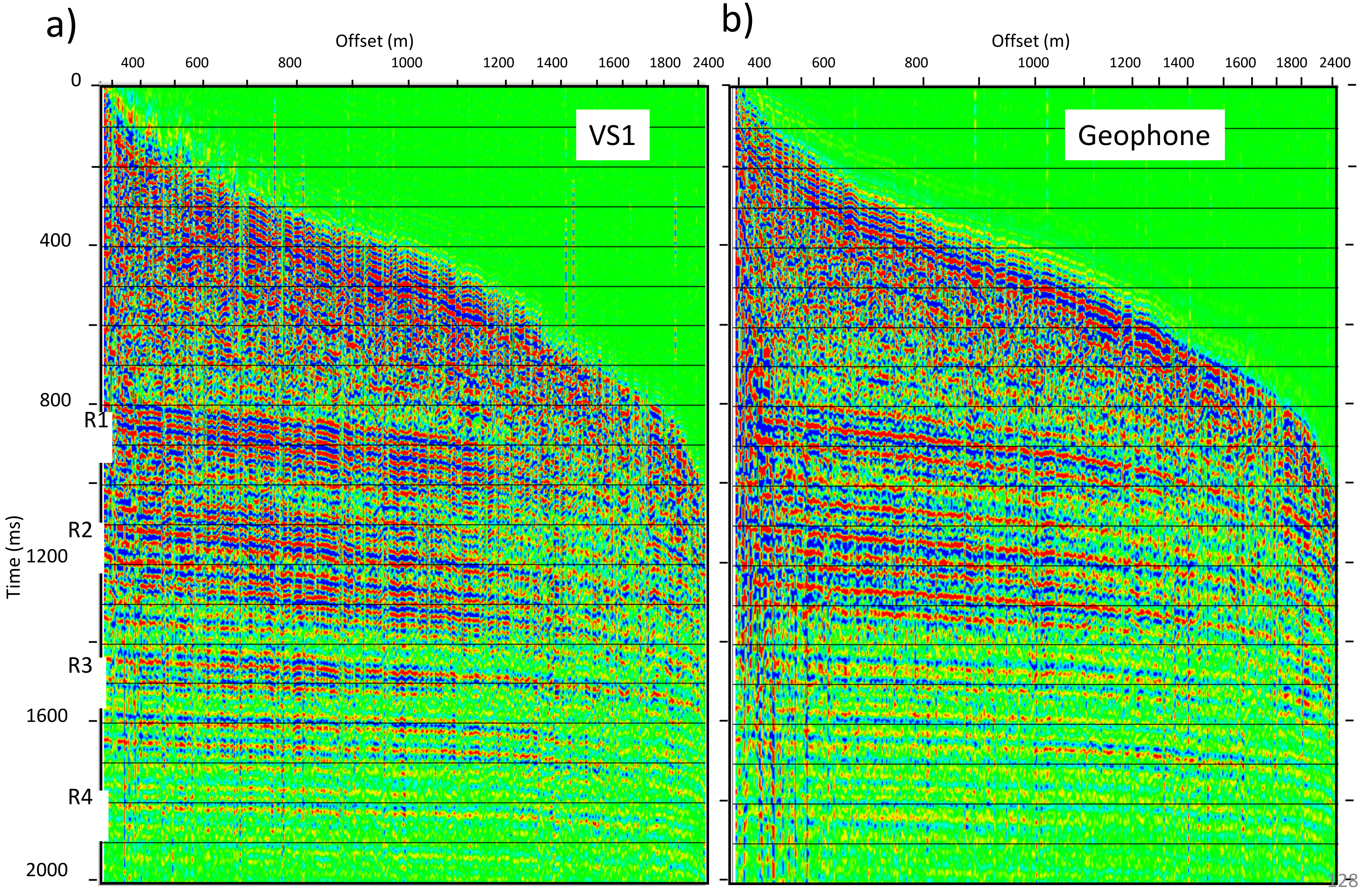
40 mm



6 mm

Experimental DAS Configurations (Fibre Optics)





a)
b)
Offset (m)
400
600
800
1000
1200
1400
1600
1800
2400
0
400
800
1200
1600
2000
Time (ms)
R1
R2
R3
R4
VS1
Geophone

CONTACT INFORMATION

- Don White
- 613-220-7963
- don.white@canada.ca

- Aquistore crosswell seismic survey
- Aquistore 4D seismic imaging
- CBC/Radio Canada: ‘Enfouir le CO_2’

THANK YOU!

For additional information about the EGP, please contact // Pour plus de détails sur le PGE, veuillez contacter :

Gilles Cotteret (Program Manager) gilles.cotteret@nrcan-rncan.gc.ca OR/OU
Joby Aubut Bernard (Program Planning & Coordination) joby.aubutbernard@nrcan-rncan.gc.ca
Réjean Couture (Division Director): rejean.couture@canada.ca

For additional information about the science, please contact // Pour plus de détails sur la science, veuillez contacter :

Project(s) Topic(s)	Project Leader
Environnemental impacts of permafrost degradation	mathieuj.duchesne@nrcan-nrcan.gc.ca
Processes responsable for plume attenuation in oil sands wetland, Infrastructure impacts on permafrost geochemistry	paul.gammon@nrcan-rncan.ca
Automatized clumped isotope measurements on dolomite for improved characterization of paleofluid	josue.jautzy@canada.ca
Environmental impact of diluted bitumen	jason.ahad@nrcan-rncan.gc.ca
Marine Oil Spill Studies	manuel.bringue@nrcan-rncan.gc.ca
National Guidelines for Dredge disposal at sea	gwyn.lintern@nrcan-rncan.gc.ca
Geological carbon storage	don.white@canada.ca

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