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Geological Survey of Canada
Scientific Presentation 118

Public presentations of May 19, 2020: Environmental Geoscience Program, current status of research projects for the 2019-2024 program cycle

N. Jacob, P.M. Outridge, G. Lintern, M. Bringué, J.M.E. Ahad, P.R. Gammon, C. Rivard, H. Kao, D. White, A.J. Desbarats, J.M. Galloway, and M.J. Duchesne

2020

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Public presentations of May 19, 2020: Environmental Geoscience Program, current status of research projects for the 2019-2024 program cycle

Date presented: May 2020

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Publications in this series have not been edited; they are released as submitted by the author.

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Environmental Geoscience Program (EGP)
Public presentation of project plans for 2019-2024

To increase awareness of EGP projects within NRCan, a public science presentation is taking place every year since 5 years. This year being different, all project leaders recorded their presentations on May 19, 2020 to show the status of their research according with the plan for the 2019-2024 program cycle. All recordings are on YouTube:
https://www.youtube.com/playlist?list=PLZixEEkoB5WAPDXoRmK8MsCYfES9kIbVl

All twelve of the PowerPoint presentations provided on May 19, 2020 are included in this synthesis.

Key words: Volcanoes, mercury, dredge disposal at sea, oil spills, diluted bitumen, oil sands, aquifer impacts, induced seismicity, geological storage of carbon, cobalt, climate change, Mackenzie River Basin, permafrost thaw, permafrost geochemistry, and cumulative effects.

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Environmental Geoscience Program (EGP)
Public presentations for the 2019-2024 program cycle

Canada

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Volcanic Mercury Emissions - Research in Support of the UNEP 2023 Global Mercury Assessment

Émissions de mercure d'origine volcanique - Recherche à l'appui de l’évaluation mondiale du mercure du PNUE 2023

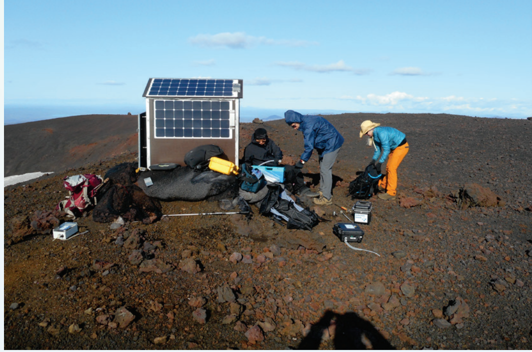
Peter Outridge May 19, 2020

Canada

ABSTRACT

- 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.

Gas monitoring, Hekla summit

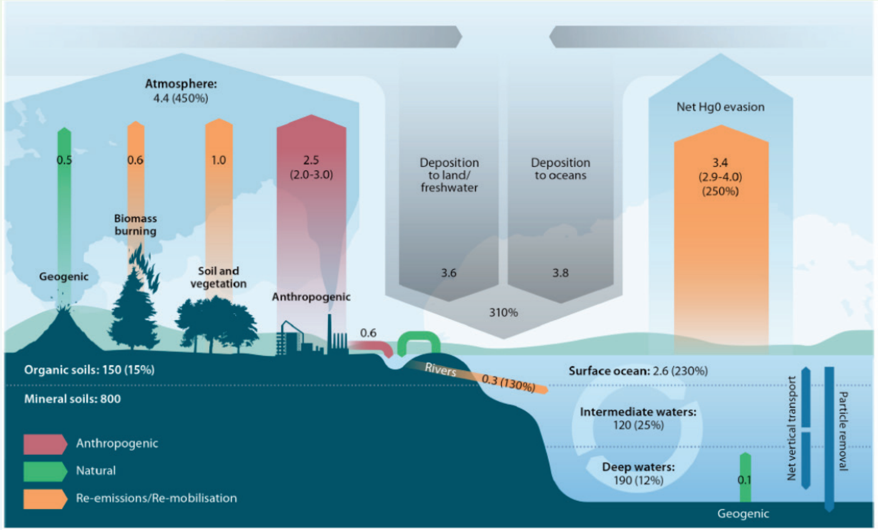


PROJECT MEMBERS

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

Project Context

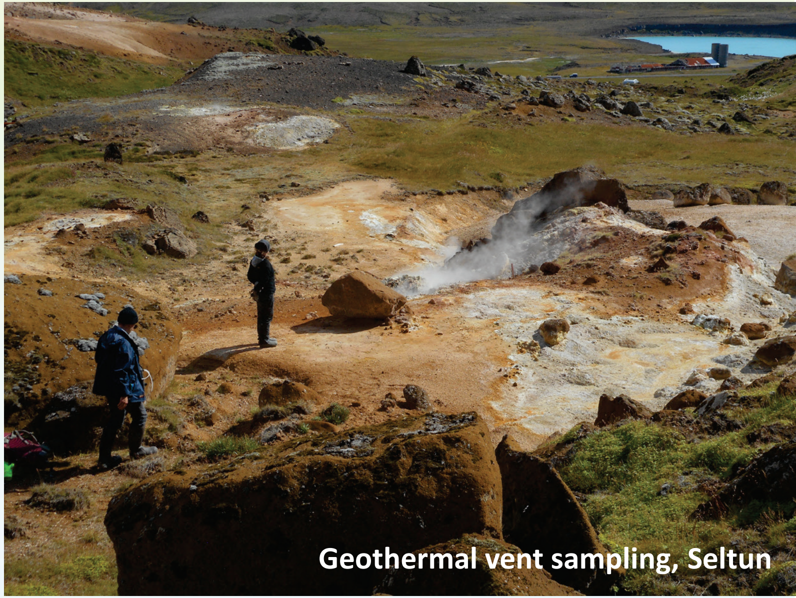
- Total geogenic Hg emissions to air poorly constrained (<1 – ~30% of anthropogenic emissions, i.e. <10 – 900 tonnes/yr).
- Volcanic systems (erupting + degassing volcanoes, & geothermal/hydrothermal) ~90% of total natural.
- Iceland Hg studies 1970s support very high natural emission estimate
  - many 10,000s ng Hg/m^3 (background 1-2 ng/m^3)



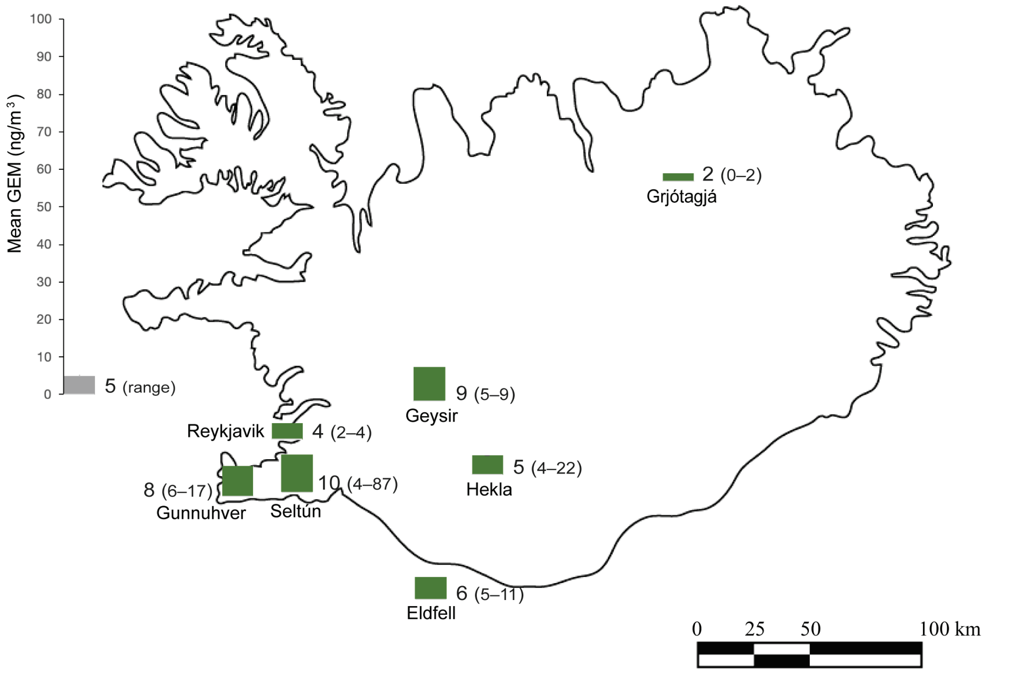
AMAP/UNEP (2018) Global Mercury Budget

Progress (May 19 - May 20)

- Hired Brock Edwards (RAP-PhD);
- Field recon (Iceland)
  with IMO gas geochemists;
- PhD course work completed;
- Draft MS Lit. Review on volcanic Hg


Geothermal vent sampling, Seltun

Icelandic volcanic Hg emissions 2019



Extremely low compared to 1970s measurements

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Developing National Guidelines for Dredge Disposal at Sea

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

Gwyn Lintern

May, 2020

Canada

This talk represents multiyear work. Data collection is still underway. Therefore, the description of objectives and methods presented in 2019* is still valid, and that is what follows…

*In 2019 the talk was entitled: "Science-based dredge disposal guidelines for port expansion"
"Directives fondées sur la science afin de disposer des dragages lors d'expansion portuaire"

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 modeling.

PROJECT MEMBERS

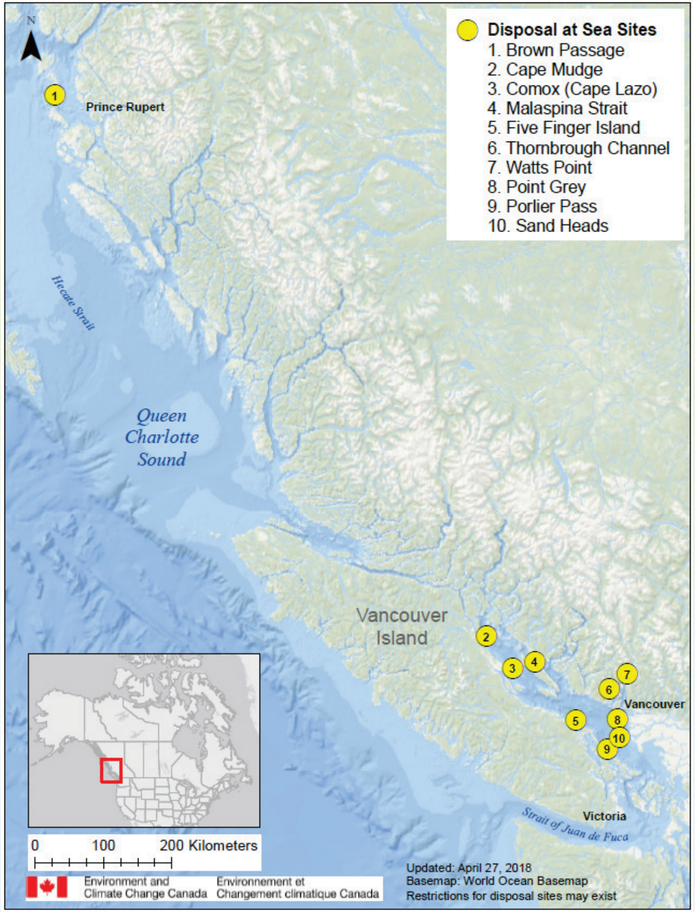
- Gwyn Lintern (GSC),
- Roanna Leung (ECCC)

Background

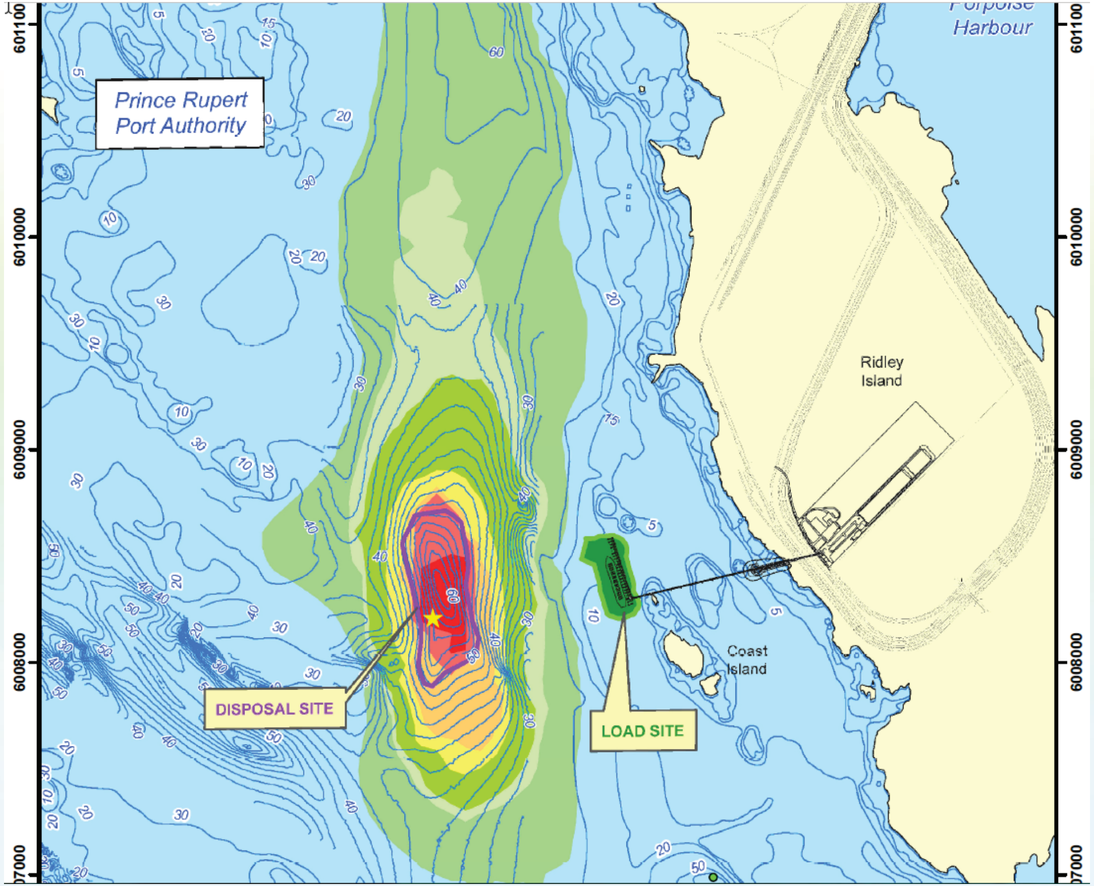
- Canada regulates Disposal at Sea (DAS) through a permit system under the *Canadian Environmental Protection Act 1999* (CEPA, 1999) and is required to conduct regular monitoring of DAS sites through *Schedule 6* of *CEPA*.
- Canada publishes results of monitoring activities in an annual compendium to fulfill its international obligation under the 1972 London Convention and its 1996 Protocol.
- A permit should require sites characteristics to be determined quantitatively, which would then set the criteria for what types of material can be dumped
- determine whether the proposed disposal site can be considered non-dispersive (use peak 1% bottom current speed <25 cm/s or other methods)

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

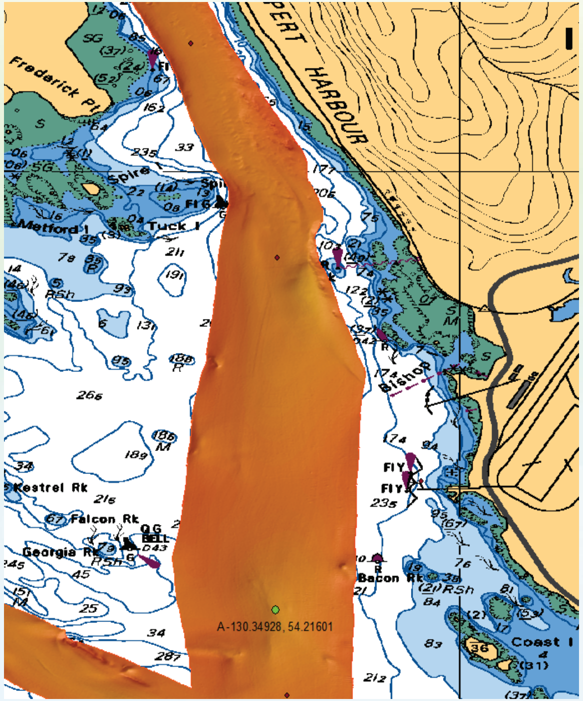


Example



Prince Rupert
Port Authority
Porpoise
Harbour
Ridley
Island
Coast
Island
DISPOSAL SITE
LOAD SITE
6011000
6010000
6009000
6008000
6007000

Dispersive or non-dispersive?



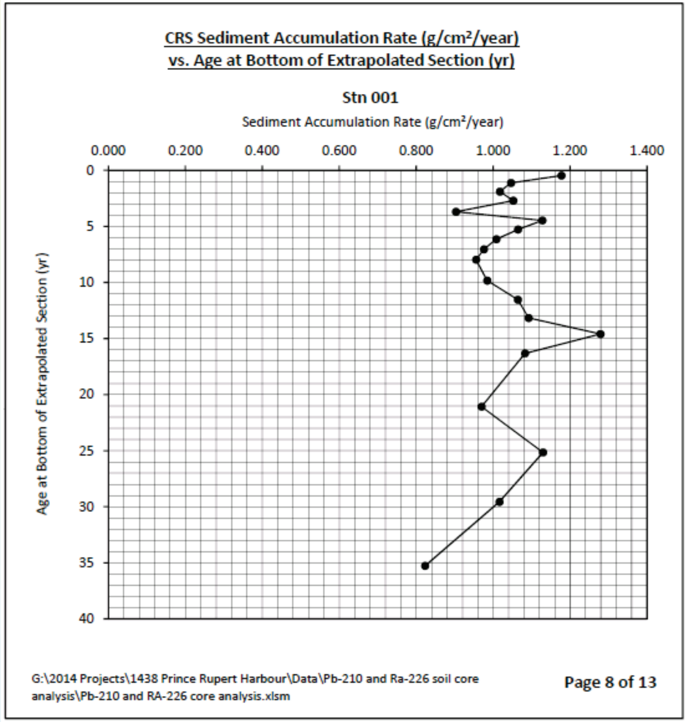
← Bathymetry

Backscatter →

- Darker = finer grained

Dispersive vs non-dispersive?

Coring and Pb210 and Ra226 isotope analysis



Dispersive or non-dispersive?

Hydrodynamic modeling

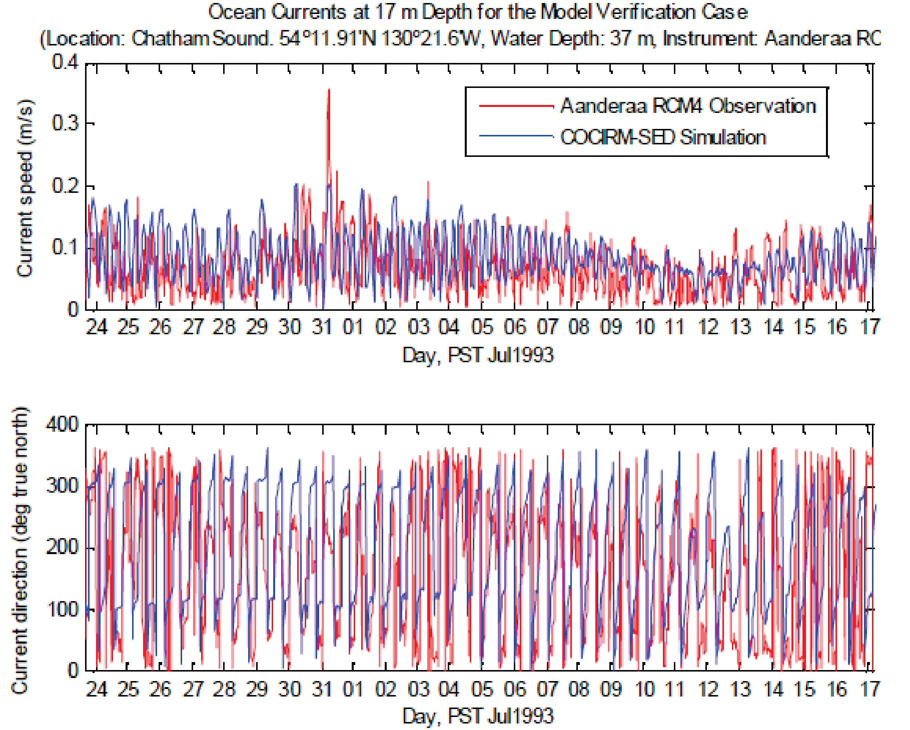


Figure 5: Verification modeled and measured ocean currents at 17 m depth near disposal site 1.

Dispersive or non-dispersive?

Actual measurements of currents and sediment

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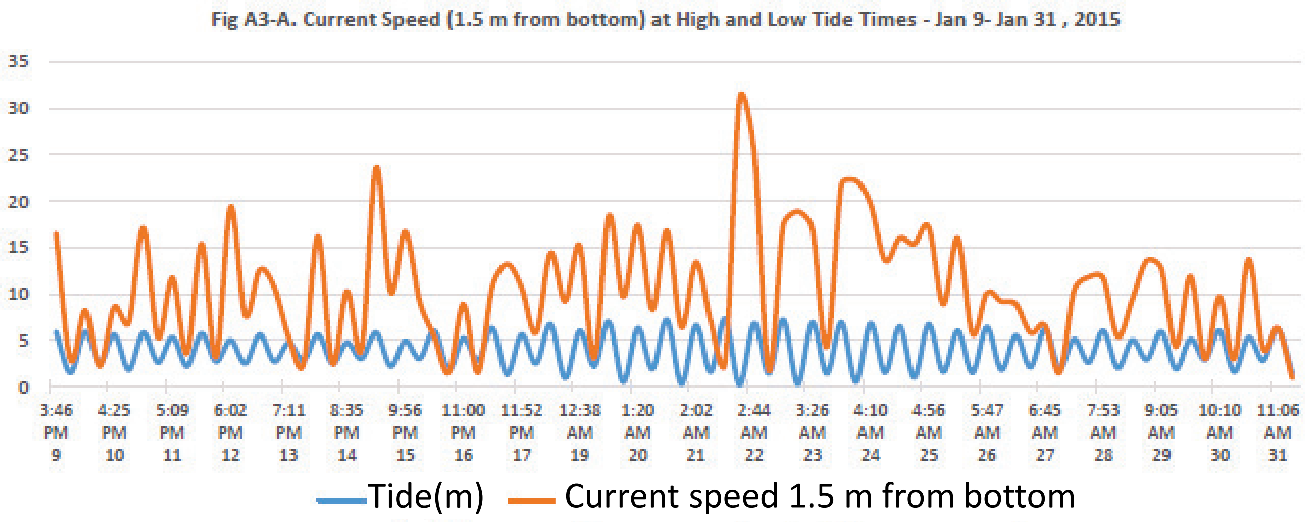
Dispersive or non-dispersive?

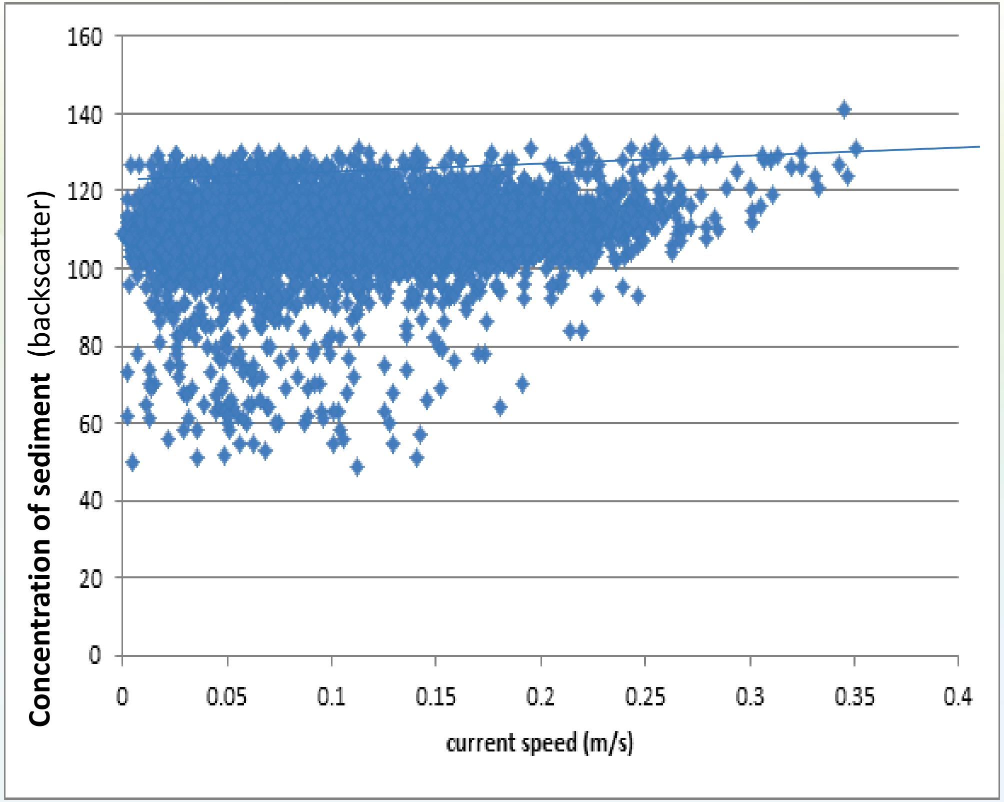
Testing:

Peak 1% bottom current speed <25 cm/s



Dispersive or non-dispersive?

Optical or acoustic backscatter of sediment in water



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THANK YOU!

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Project MOSS:
Marine Oil Spill Studies

Projet EDPM :
Études sur les déversements pétroliers marins

MANUEL BRINGUÉ

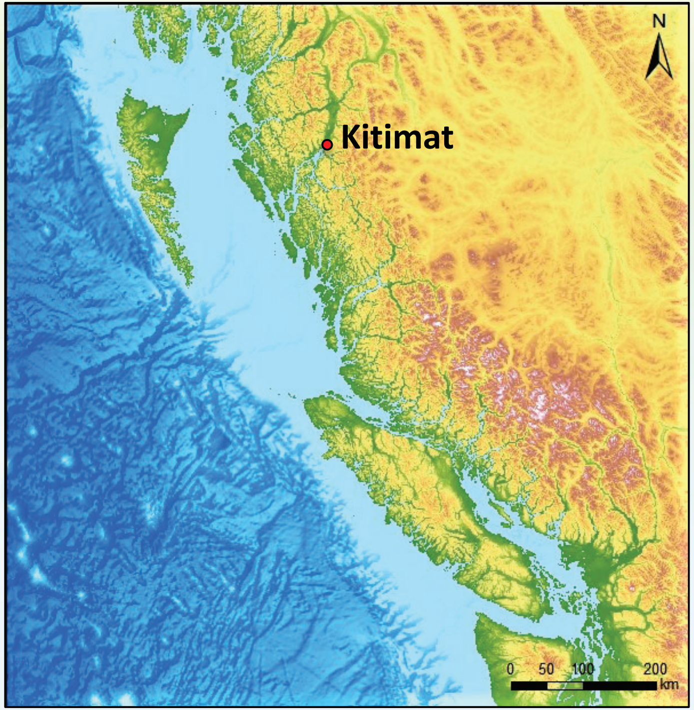
May 19, 2020

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

- Baseline of **natural variability** in Douglas Channel (e.g., temperature, productivity) on seasonal to millennial time scales
- Capacity of in-situ microbial communities to mitigate accidentally-released petroleum products **under reduced O_2 and lower pH conditions**

PROJECT MEMBERS

- Manuel Bringué (PL), Jennifer Galloway, Omid Ardakani (GSC-Calgary)
- Jason Ahad (GSC-Québec)
- Michael Parsons (GSC-Atlantic)
- Paul Gammon (GSC-Ottawa)
- Gwyn Lintern, Cooper Stacey (GSC-Pacific)
- Heather Dettman (CanmetENERGY-Devon)

- Sophia Johannessen (DFO, IOS Sidney)
- Kenneth Lee (DFO, BIO Dartmouth)
- Charles Greer (NRC, Montréal)
- Vera Pospelova (U. of Minnesota)

PROJECT OVERVIEW

1. Sediment trap component

To assess **seasonal variability** in phytoplankton communities and geochemical indicators (**calibration**)

2. Sediment cores component

- Short (box) cores: to **reconstruct past environmental variability** and trace possible **human impacts** over the last ~ 120 yrs
- Long (piston) cores: to reconstruct past variability over the Holocene (last ~ 11,000 years), for context.

3. Microcosm experiments

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**

1.

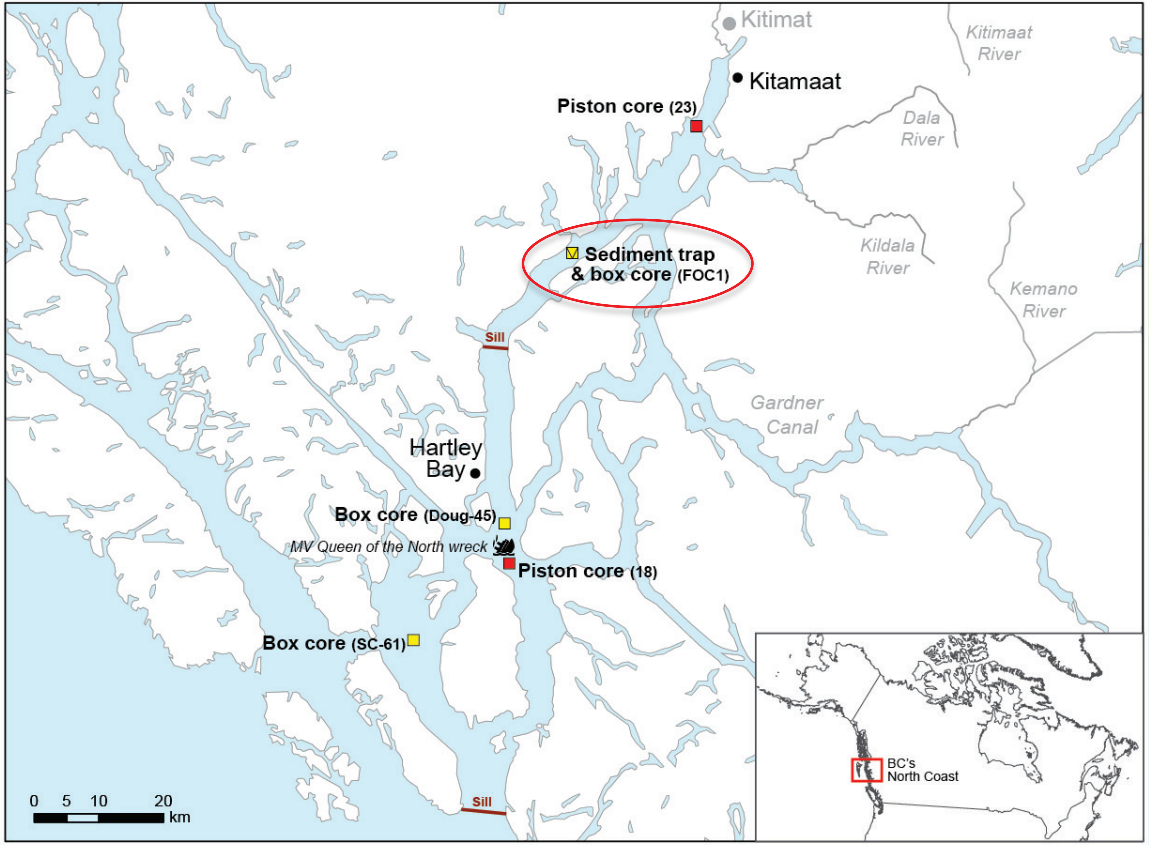
2.

3.

Sediment samples

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

All material provided by PGC & DFO



Analyses (as of May 2020)

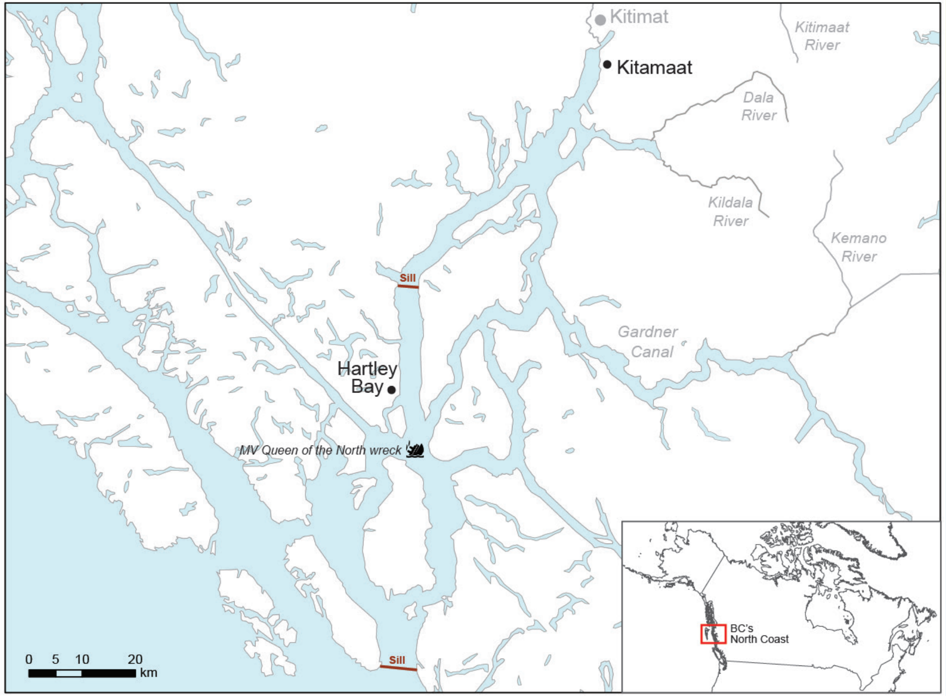
	Phase 1	Phase 2					Phase 3
	Sediment trap		**Box cores**		**Piston & trigger-weight cores**		Microcosm
Location	FOC1	FOC1	QotN wreck (Doug-45)	Squally Channel (SC-61)	Whale Channel (18)	Kitimat Arm (23)	experiments
# samples	88	21	~ 20	~ 20	65 (PC) + 24 (TWC)	79 (PC) + 16 (TWC)	(lab-based)
Time span	~ 3 yrs	~ 120 yrs	~ 120 yrs	~ 120 yrs	Holocene	Holocene	
Analyses							
Dating (^{14}C, ^{210}Pb)	N/A	✓	✓	✓	✓	✓	
Palynology	Lab	Lab	Lab	Lab	Lab	Lab	
Geochemistry							
Grain size					Lab	Lab	
Biogenic silica	✓	✓	✓	✓	Lab	Lab	
Total C, N, C_{org}, C_{inorg}	✓	✓	✓	✓	Lab	Lab	FY3/4
$\delta^{13}C_{org}$, $\delta^{15}N$	✓	✓	✓	✓	Lab	Lab	
ICP-OES/ICP-MS	N/A	FY2	FY2	FY2	FY2	FY2	
Focused							
PAHs	N/A		FY2		FY2	FY2	
Mo isotopes	N/A	FY2					

Gitga’at and Haisla Nations

Dialogue with Gitga’at (Hartley Bay) and Haisla (Kitamaat Village) Nations initiated in 2018

We are hoping for yearly in-person meetings, if travel is possible

Particularly important to determine together **which petroleum products to test** in microcosm experiments (phase 3)



CONTACT INFORMATION

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Also:

- Jason Ahad (PL of over-arching ‘oil spill’ project)
- (418) 654-2615
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Environmental impact of diluted bitumen

Impact environnemental du bitume dilué

Dr. Jason M. E. Ahad, GSC-Québec

19 May 2020

Canada

ABSTRACT

- To transport it by pipeline, bitumen is blended with lighter hydrocarbon fractions, yielding a less viscous, diluted bitumen ('**dilbit**')
- Although often considered safer than other means of transport (i.e., railways, barges), a number of incidents have highlighted the potential environment risk caused by dilbit pipeline rupture
- There are few detailed investigations into the fate and transport of dilbit in the environment, particularly shallow groundwater systems – a knowledge gap identified over five years ago

PROJECT MEMBERS

- **GSC:** Jason Ahad (Project Leader), Anna Smirnoff, Patrick Watt, Jade Bergeron, Hooshang Pakdel, Marc Luzincourt, Nicolas Benoit
- **INRS:** Valérie Langlois, Richard Martel, Scott Hepditch (PhD candidate)
- **McGill University:** Nagissa Mahmoudi, Leah Mindorff (MSc candidate)
- **CanmetENERGY:** Nicholas Utting, Heather Dettman, Qin Xin
- **Centre d'expertise en analyse environnementale du Québec (CEAEQ):** Gaëlle Triffault-Bouchet
- **University of Ottawa:** Jules Blais, Jose Luis Rodriguez Gil
- **Environment and Climate Change Canada:** John Headley, Kerry Peru

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 columns (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 (ELA, NW Ontario)*

LARGE COLUMN EXPERIMENTS

- Gault Nature Reserve (Mont-Saint-Hilaire)
- Managed by McGill University
- ‘Pristine’ well-drained sandy loam soil

Soil Collection, McGill’s Gault Nature Reserve (17 July 2019)

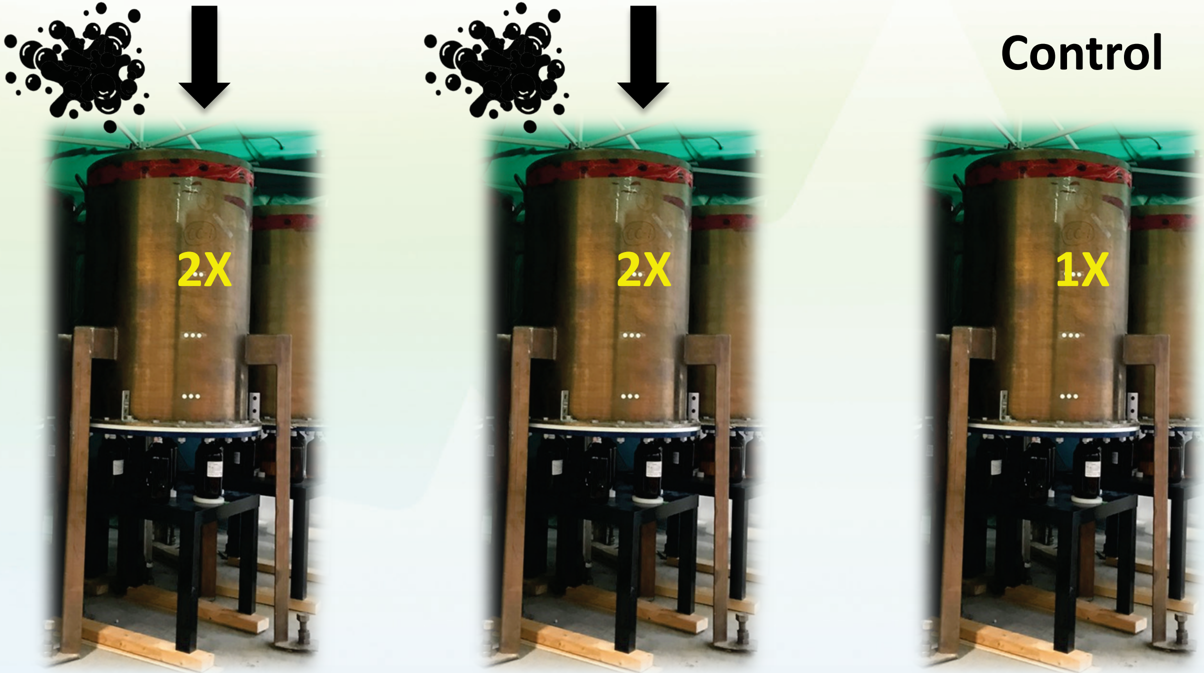
Sieving (2 cm mesh), homogenisation and weighing of soil (22-23 July 2019)

Soil compaction and ventilation tent installation (24 July 2019)

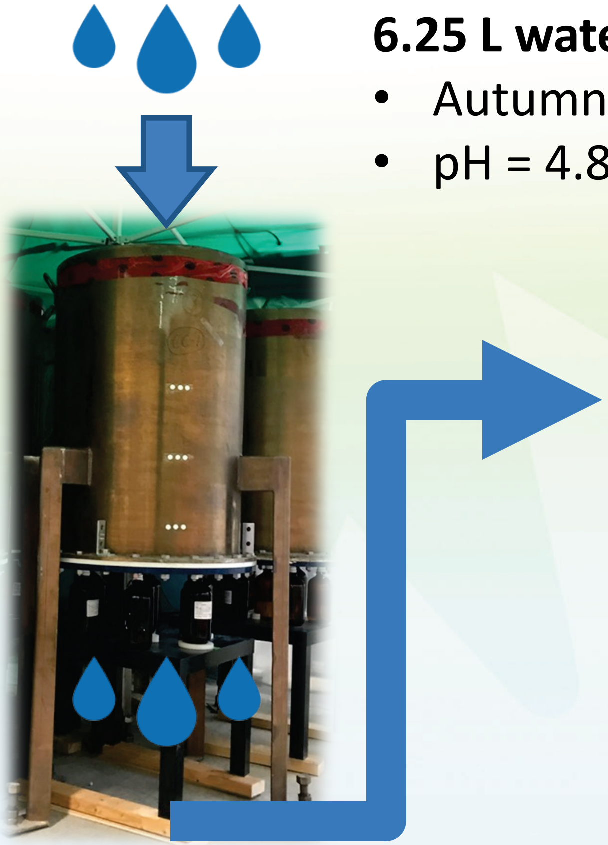
2 kg Diluted Bitumen

2 kg Heavy Conventional Crude

Control



DAY 0: Dilbit and conventional crude added (31 July 2019)



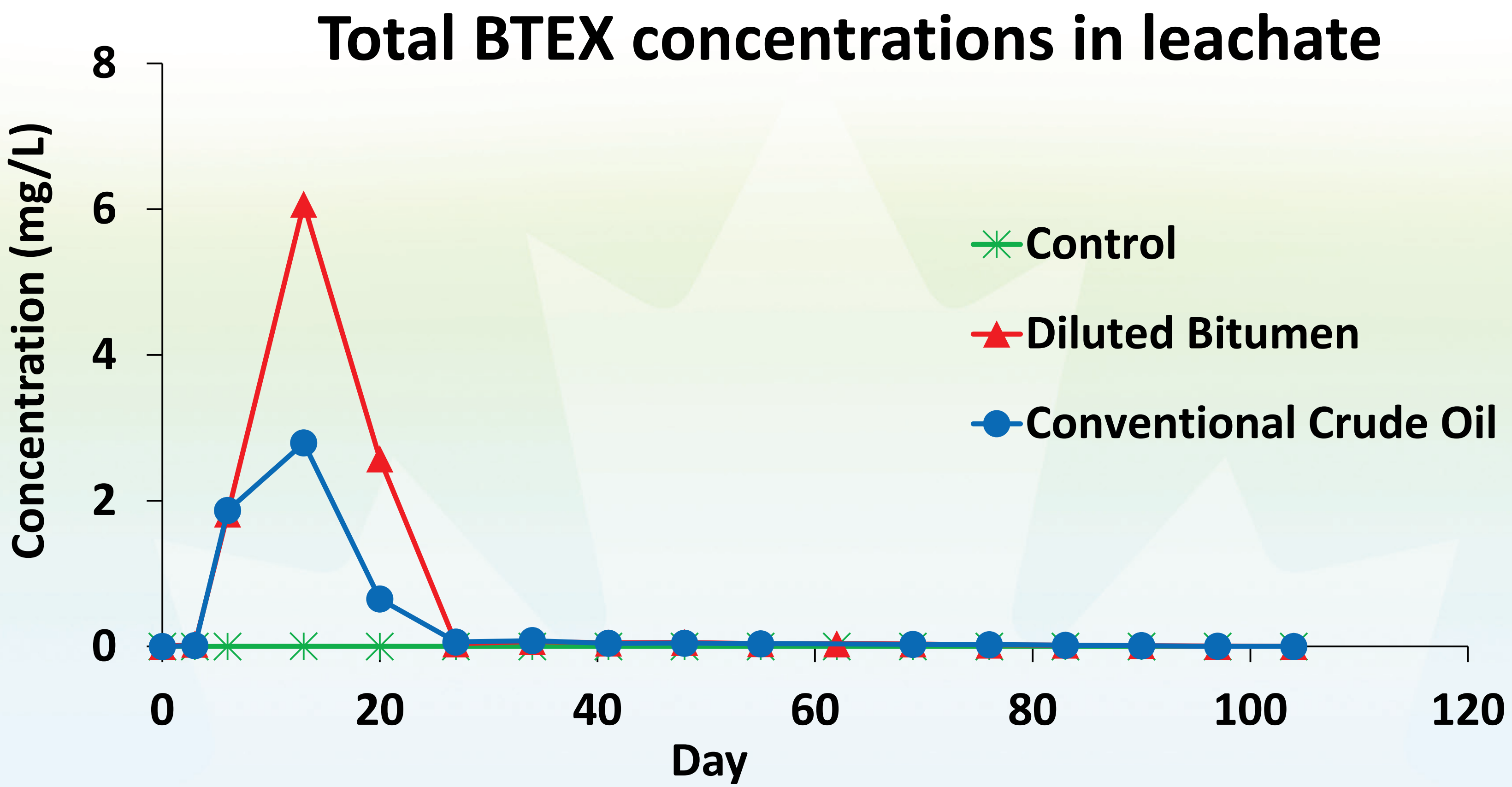
6.25 L water added each week (15 weeks)
- Autumn recharge (8 °C)
- pH = 4.80

Leachate (analyses carried out):
- Total organic/inorganic carbon (TOC/TIC)
- BTEX (benzene, toluene, ethylbenzene, xylenes)
- $\delta^{13}C$ analysis of benzene/toluene
- PAHs (polycyclic aromatic hydrocarbons)
- Acid extractable organics (naphthenic acids)
- Metals
- Toxicology Assays

10 cores collected

Soil cores (analyses ongoing):

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


Total BTEX concentrations in leachate
Concentration (mg/L)
8
6
4
2
0
0
20
40
60
80
100
120
Day
Control
Diluted Bitumen
Conventional Crude Oil

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SOURCES: A geochemical map of an oil sands plume - Initial results

SOURCES : Carte géochimique d'un petit panache dans les sables bitumineux - Premiers résultats

Paul Gammon

May 19, 2020

Canada

ABSTRACT

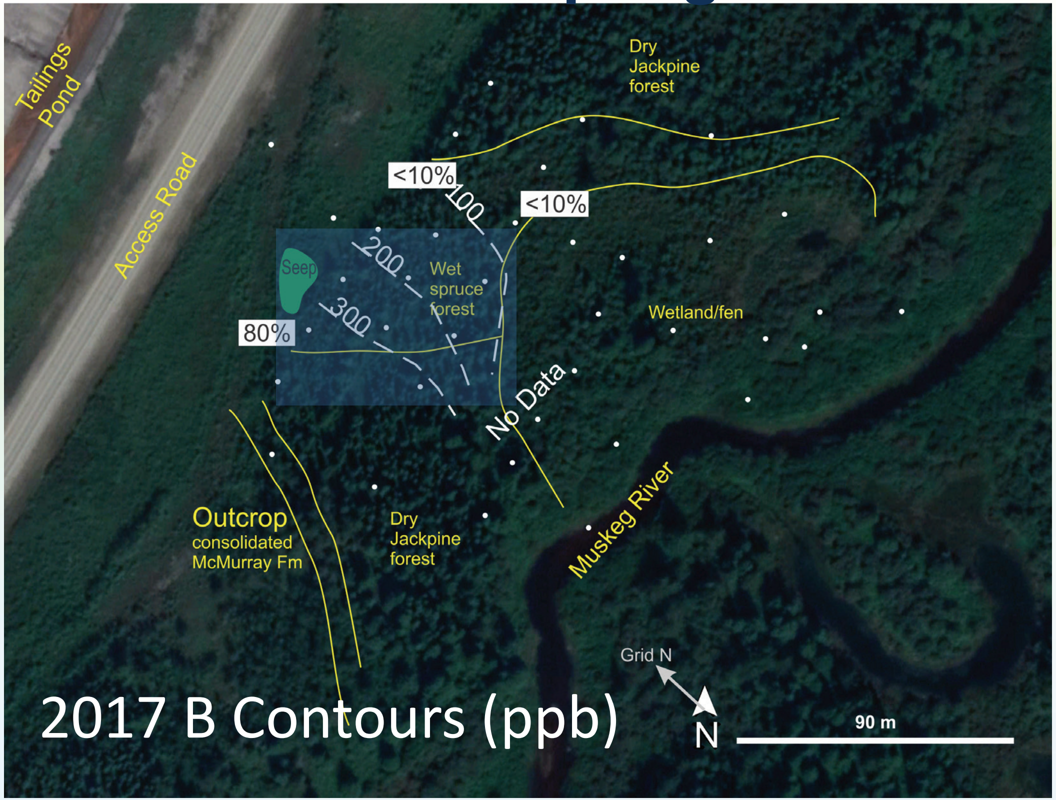
SOURCES contains 2 activities (Gammon, Ahad) plus legacy publications (Gammon, Ahad, Savard, Zheng). The externally-funded Ahad activity is scheduled to commence in 2020-21 FY. Two legacy papers were published in 2019-20, with 5 more submitted or in preparation.

The Reactive Transport Model (RTM) activity (Gammon, externally funded) extensively sampled the oil sands tailings-water plume discovered in the previous EGP cycle. Initial data demonstrates a bullseye circular surface-water plume map. The groundwater plume map is more irregular due to subsurface hydrogeological complexity that forms preferential flow paths. Calculation of boron attenuation factors indicates that there is rapid attenuation at a reaction front, possibly due to sorption processes. Time-consuming organic and eDNA analytical data is ongoing, but will fill in the emerging picture of this plume. The plume does not seem to reach the Muskeg River.

PROJECT MEMBERS

- Paul Gammon
- Jason Ahad
- Martine Savard
- James Zheng
- Richard Amos (Carleton U.)

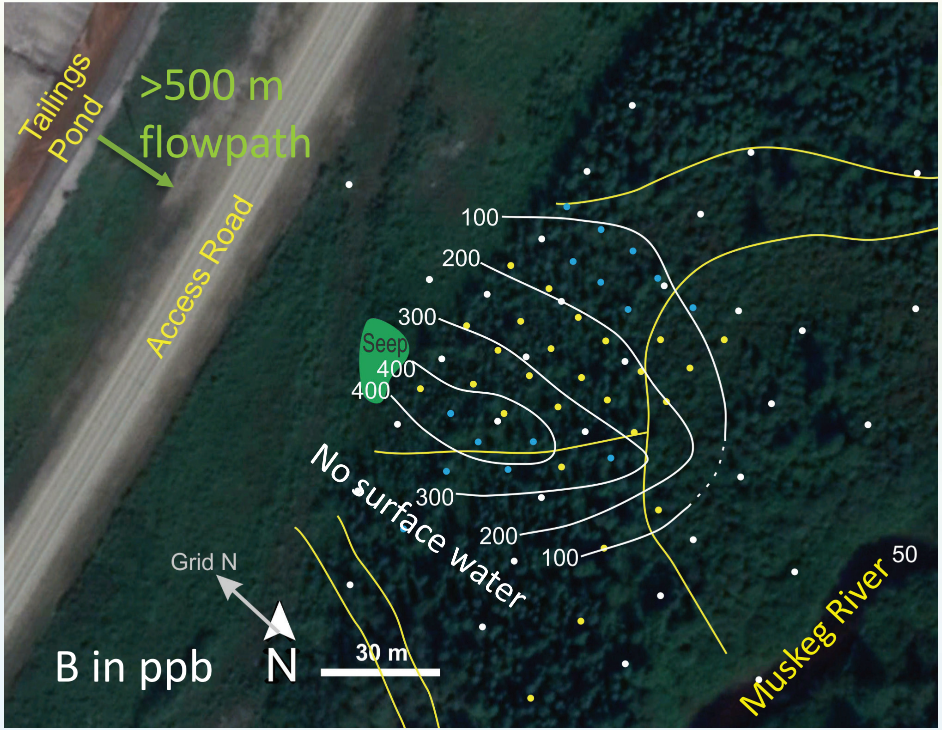
Sampling – where we were



2017 data: Sparse plume data (8 points); substantive data gaps; one plume NA sample

2019 Objective: detailed sample coverage of the plume.

Surface waters B contours - bullseye



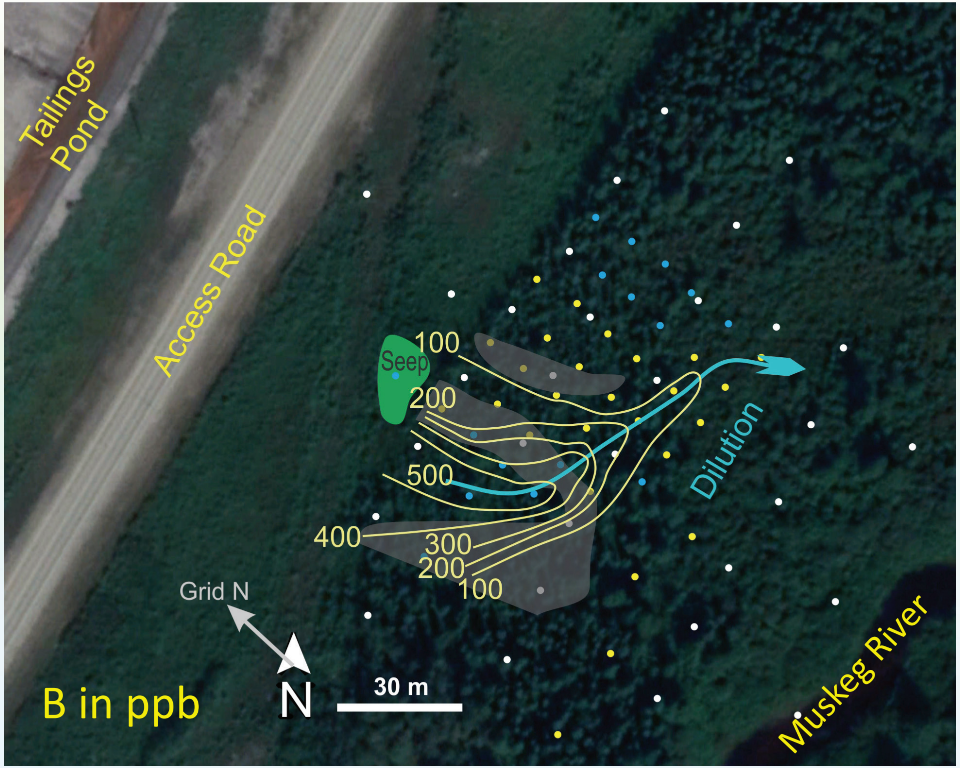
Detailed 10 m X 10 m grid fully captures surface water plume extent

Plume defined by textbook bullseye contour pattern.

Attenuation is very rapid (~60 m).

Ongoing organic and eDNA analyses…

Groundwater B contours - flowpath



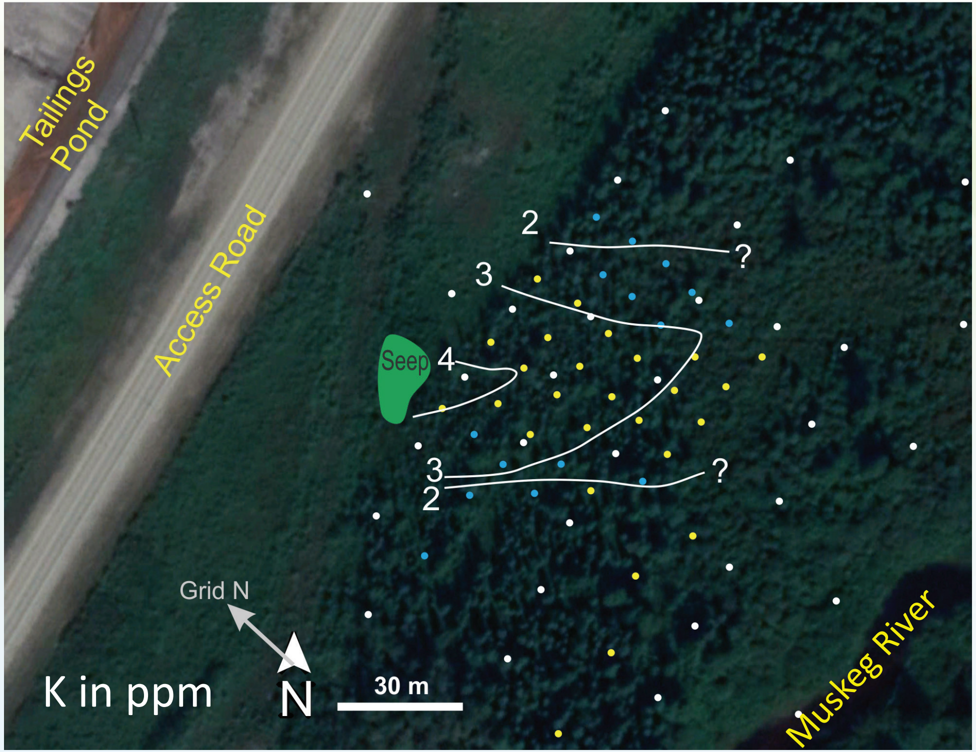
Contours define a preferred flowpath from seep to oxbow

Flowpath controlled by fine-grained aquitards.

Likely most flow pushed to surface in this area.

No evidence either surface or groundwater plume reaches river due to rapid attenuation.

Surface water K contours - dilution

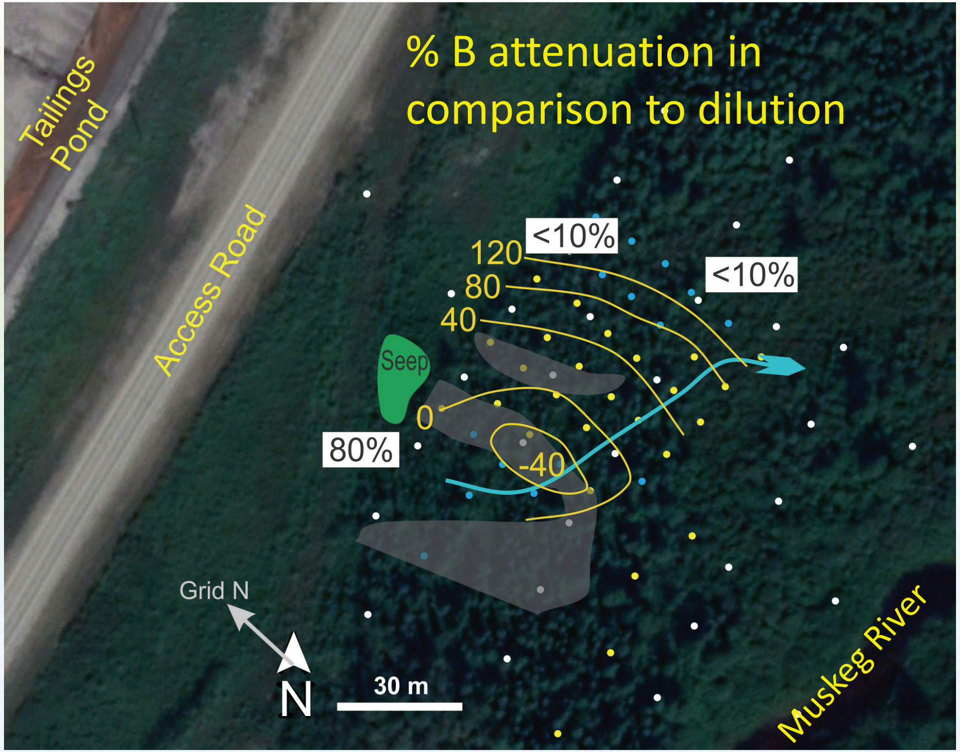


Contours similar to those for boron

K prefers staying in solution more than B

K contours better represent dilution profile

Surface B attenuation contours – reaction front



Rapid B attenuation >> dilution at edges of grid area. Suggests B controlled by sorption dynamics with a strong reaction front. Is this true for naphthenic acids?

Contours suggest fine grained material near plume entry point are perhaps a source of B.

Unclear relationship to subsurface preferential flowpath.

Conclusions

- Early days, but the plume is now well defined
- Surface map indicates rapid plume attenuation through reactive transport plus dilution
- Plume does not seem to reach the river.
- Much more sample analysis still to go…

Papers

Distinguishing Natural from Anthropogenic Sources of Acid Extractable Organics in Groundwater near Oil Sands Tailings Ponds. Environ. Sci. Technol. 2020, 54, 5, 2790-2799. https://doi.org/10.1021/acs.est.9b06875

Jason M. E. Ahad,* Hooshang Pakdel, Paul R. Gammon, Bernhard Mayer, Martine M. Savard, Kerry M. Peru, and John V. Headley

Response strategies of boreal spruce trees to anthropogenic changes in air quality and rising pCO_2. Environmental Pollution 261 (2020): 114209. https://doi.org/10.1016/j.envpol.2020.114209

Savard, M.M.; Bégin, C., Marion, J.

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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)

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

Christine Rivard

May 19, 2020

Canada

ABSTRACT

A multidisciplinary and multi-institutional project was initiated in the Fox Creek area, in west-central Alberta, in April 2019 to study environmental impacts of hydrocarbon exploration and production 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. Therefore, the project scope is now much larger and includes studies on vegetation, forest, snow cover, wetlands, landscape evolution and woodland caribou habitat. The project involves many collaborators from the federal and provincial governments, and academia.

Project members

(including EGP, GGP and cumulative effects)

C. Rivard[1], D. Lavoie[1], E. Konstantinovskaya[2], B. Smerdon[3], O. Haeri Ardakani[1], C. Paniconi[4], J. Lovitt[5], G. Bordeleau[4], A. Bahramiyarahmadi[2], L.I. Guarin-Martinez[1,4], R. Chalaturnyk[6], D. Alessi[2], S. Safari[2], K. von Gunten[2], B. Xu.[7], A. Mort[1], H. Kao[1], R. Lavoie[8], P. Leblanc-Rochette[1,8], S. Heckbert[3], D. Jiang[1], B. Giroux[4], A.C. Dip[4], I. Aubin[9], D. Degenhardt[9], J. Harvey[9], S. Leblanc[5], H.P. White[5], S. Grasby[1]

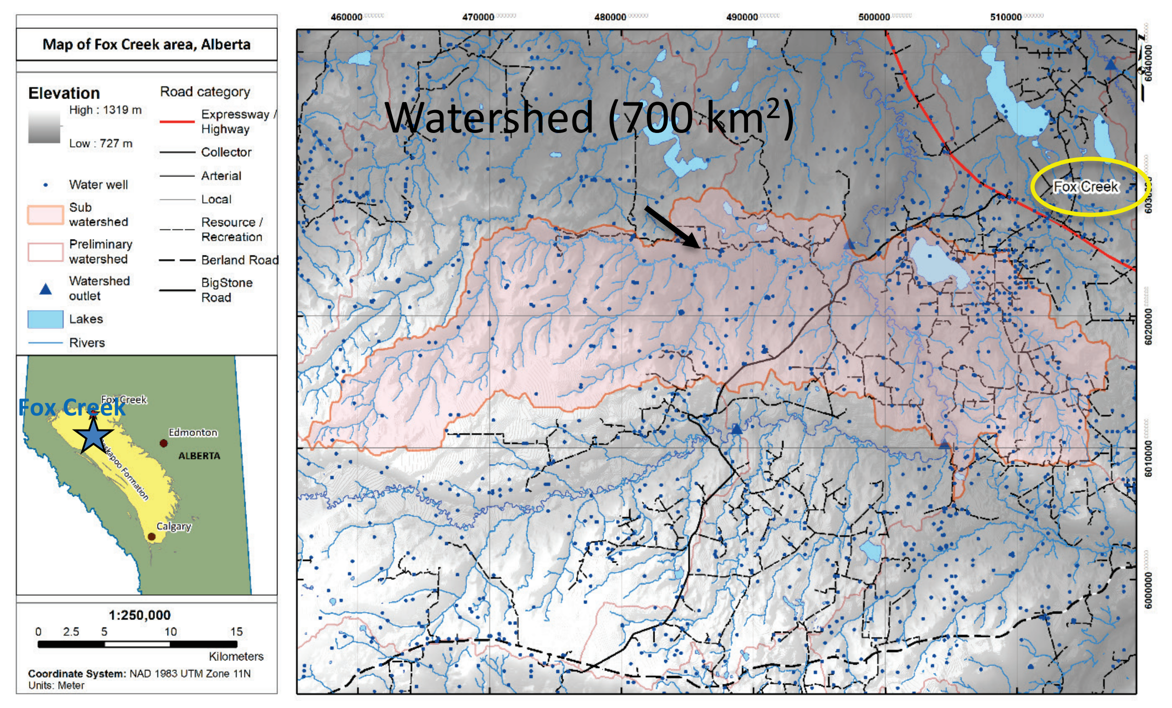
[1] *Geological Survey of Canada, Natural Resources Canada (NRCan);*
[2] *University of Alberta, Department of Earth and Atmospheric Sciences*
[3] *Alberta Energy Regulator*
[4] *Institut national de la recherche scientifique – Eau Terre Environnement (INRS-ETE)*
[5] *CCMEO, Natural Resources Canada*
[6] *University of Alberta, Faculty of Engineering*
[7] *Northern Alberta Institute of Technology (NAIT)*
[8] *Université Laval, École supérieure d'aménagement du territoire et de développement régional*
[9] *Canadian Forest Service, Natural Resources Canada*

≈30 people

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 Canada



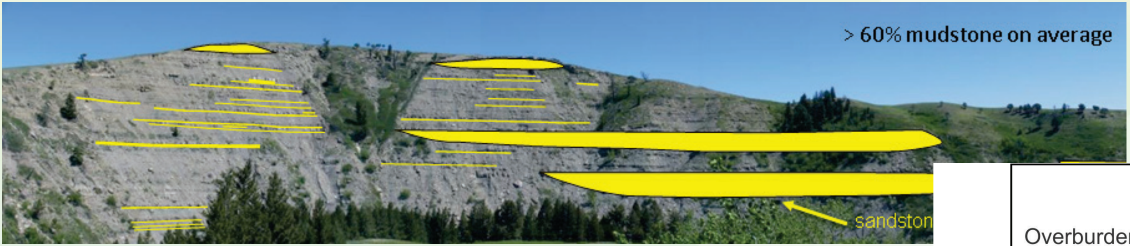
The study area is mainly forested and unpopulated

Elevations range from 785 to 1180 m

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

Project rationale

Paskapoo Formation: the most important groundwater supply in the province and the most important aquifer system in the Canadian Prairies



Objective: study the intermediate zone integrity

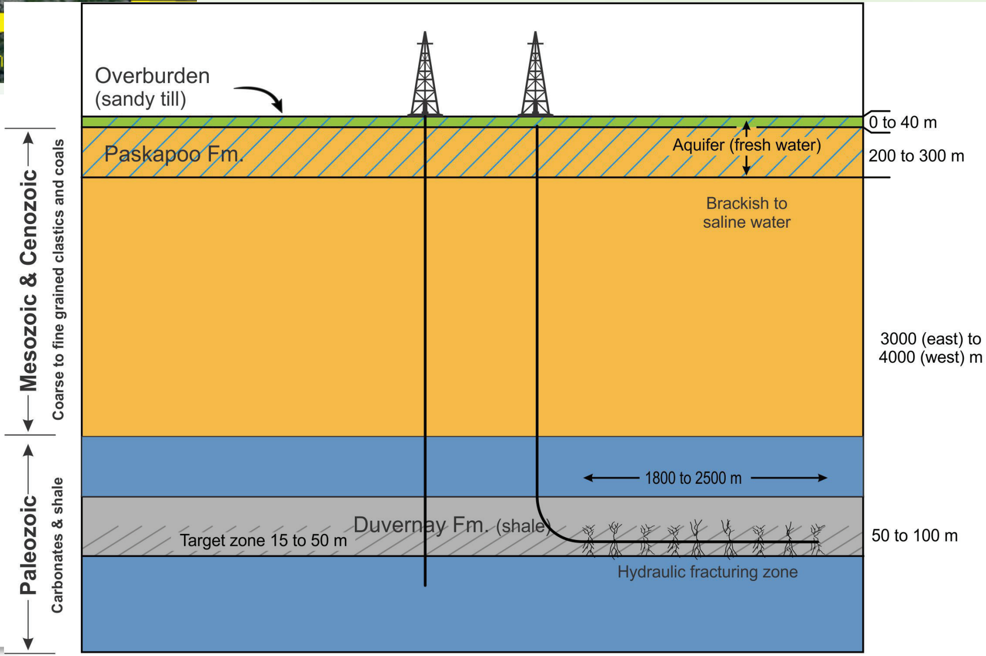
Mean water-well depth in the Paskapoo Fm: ≈50 m

Mean O&G well depth: ≈3500 m

Surficial aquifers

Intermediate zone

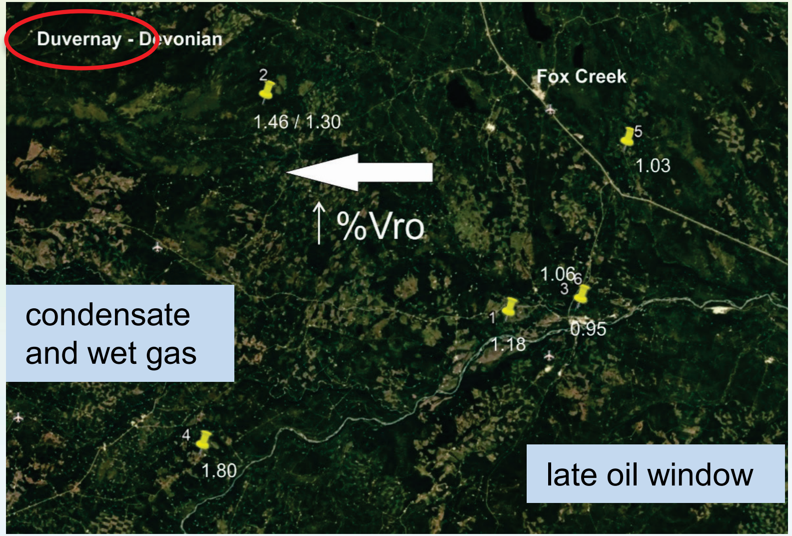
Zone targeted by the industry



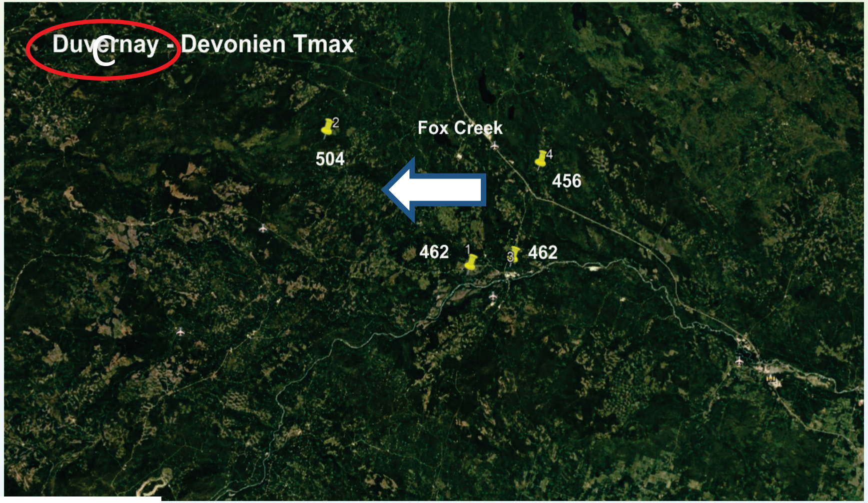
Organic petrology

Goal: to characterize the composition of organic matter and its thermal maturation

vitrinite reflectance



Rock Eval Tmax

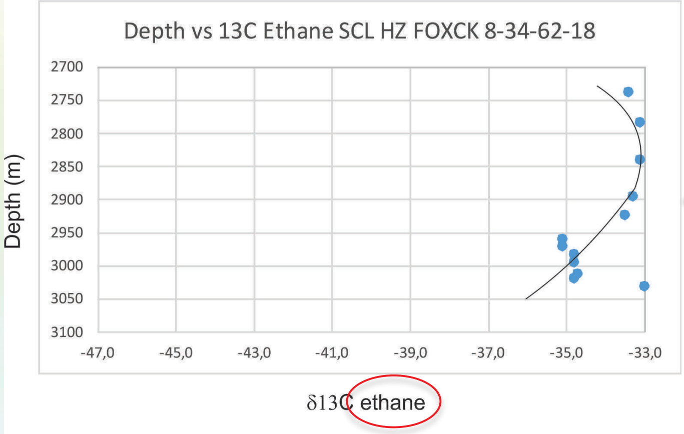


increase of thermal maturation from east to west

by Omid Haeri-Ardakani and Denis Lavoie

Gas composition in rocks

Goal: to characterize potential sources of dissolved hydrocarbons in GW

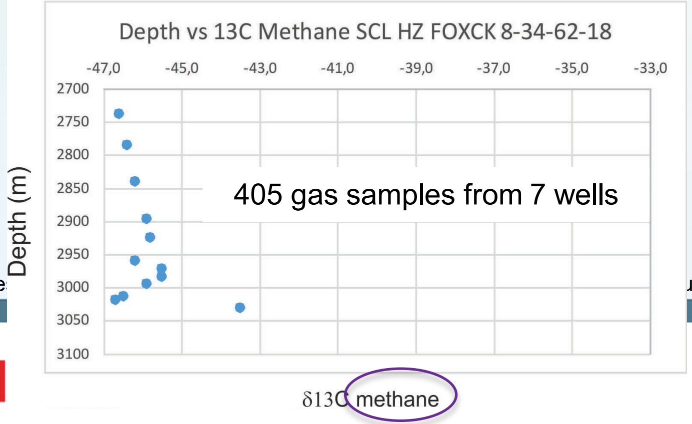


Isotopic roll-over: inversion of the expected trend of $\delta^{13}C$ of ethane with depth

+

statistically very similar $\delta^{13}C$ ratios of ethane

This will make the identification of hydrocarbon source more complex



by O. Haeri-Ardakani and D. Lavoie

Canada

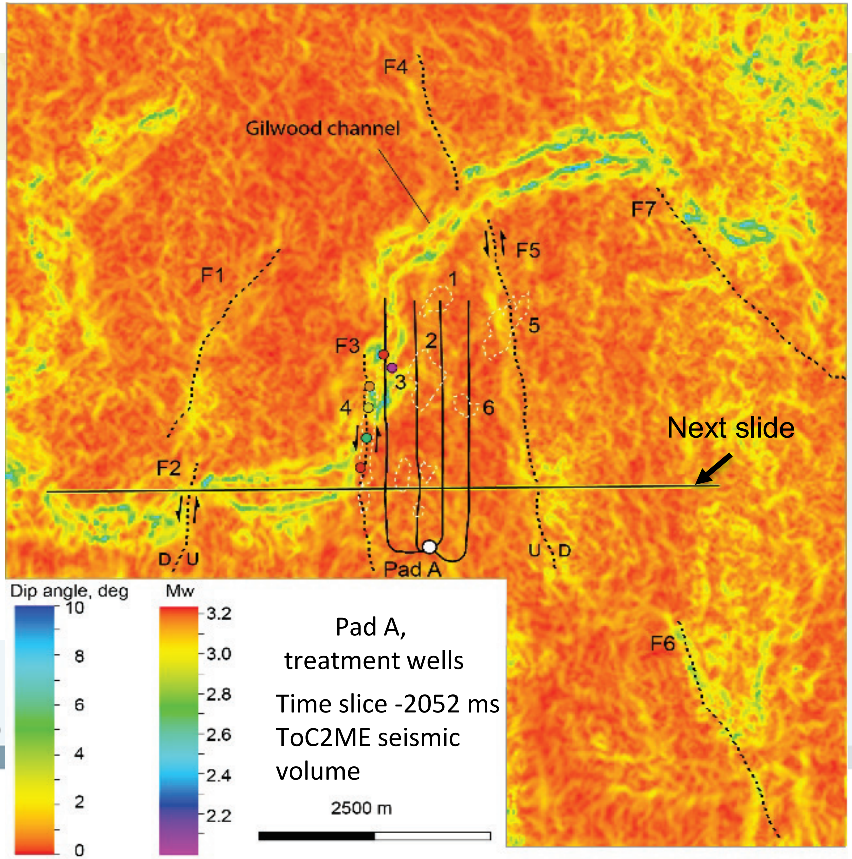
Geomechanical study

Goal: to better understand the behavior of the intermediate zone and develop a geomechanical model of the entire sedimentary succession

Fault interpretation from dip angle attribute

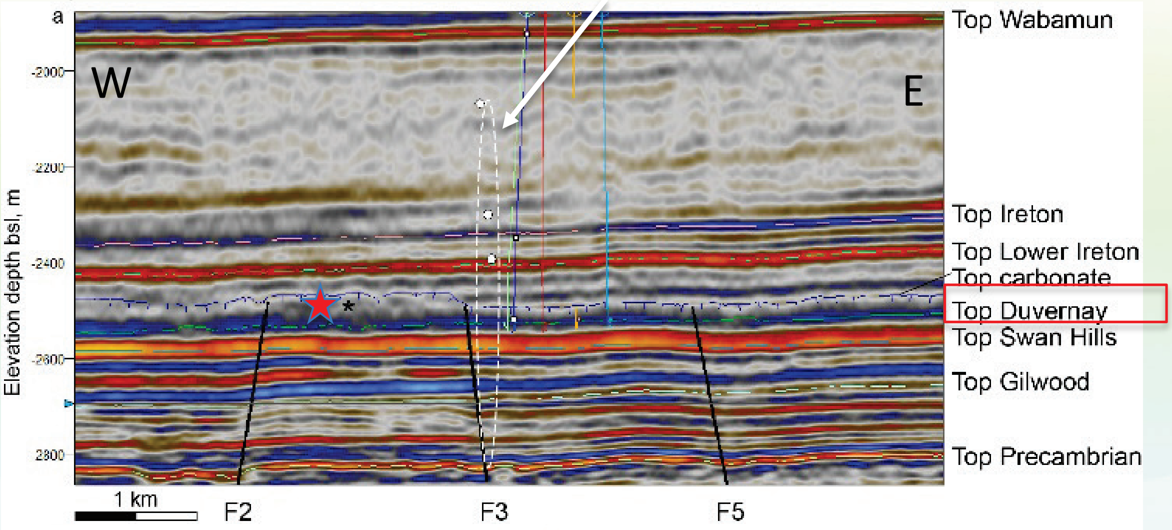
- Structural interpretation from seismic data
- Interpretation of faults: F1 to F7 correspond to high-angle strike-slip normal faults
- Fault F3 is aligned with epicenters of felt seismic events with Mw > 2.5 that may indicate the induced seismicity was related to a fault reactivation

by E. Konstantinovskaya and A. Bahramiyarahmadi (2020), based on Eaton et al. (2108)'s seismic data



Geomechanical study

Microseismicity and faults



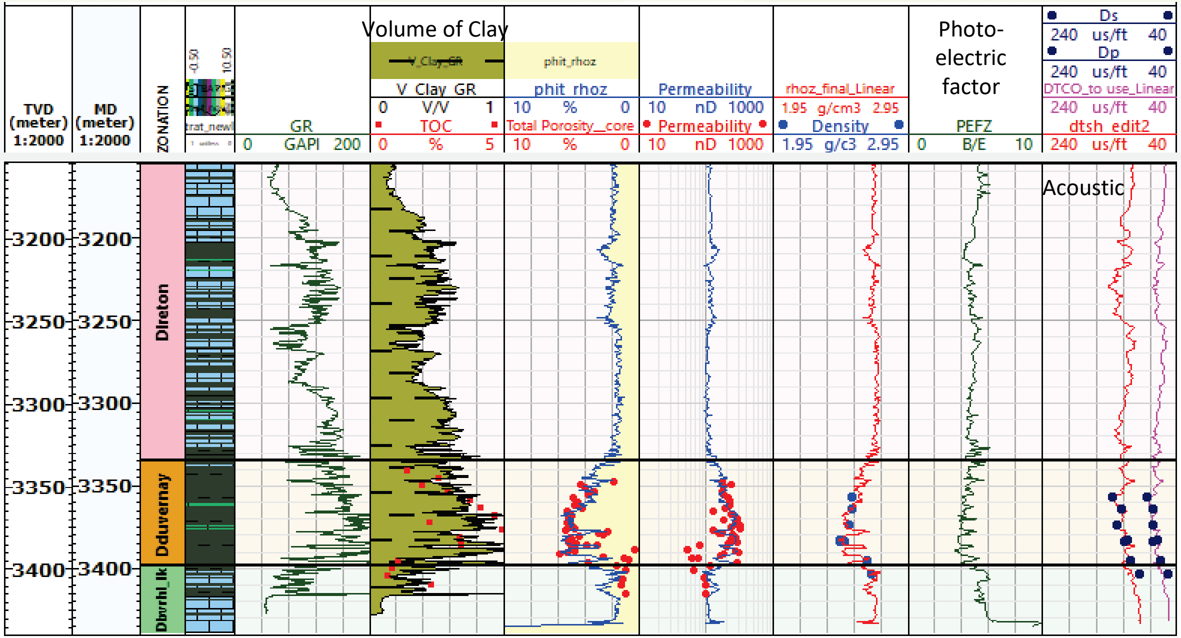
- Faults F1-F7 can be traced only below the top of the Duvernay Fm or basal layers of the Ireton Fm using 2D seismic data
- 3D seismic data could reveal lateral movements and show an extent of some of these faults through the Wabamun Fm (⇨ thermal dolomitization)

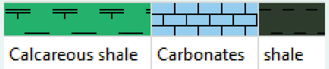
by E. Konstantinovskaya and A. Bahramiyarahmadi (2020), based on Eaton et al. (2108)'s seismic data

Geomechanical study

Duvernay Fm: petrophysical properties

Well CHEVRON KAYBOBS 14-20-59-19





by E. Konstantinovskaya and A. Bahramiyarahmadi (2020)

- Estimated log-derived profiles of clay content, total porosity and permeability are calibrated by laboratory petrophysical measurement of core samples (dots)
- In the Duvernay lower half portion: higher shale content and higher velocities (which indicate more brittle rocks) → zone targeted by the industry

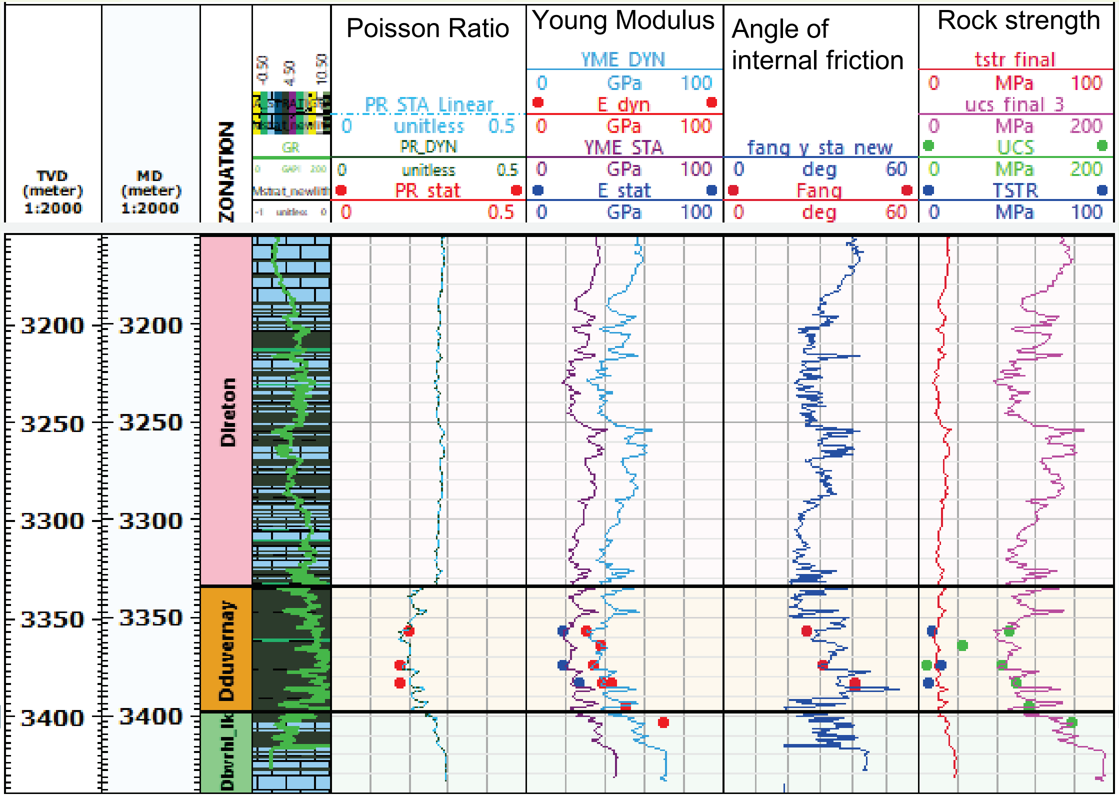
Geomechanical study

Duvernay Fm: geomechanical properties

- Estimated log-derived profiles of geomechanical parameters fit lab-measurements from vertical plugs (dots)

- The Duvernay Fm is characterized by a slightly more brittle composition in its bottom half, shown by an increase in:
  - Young Modulus
  - rock strength (brittleness index)

Well CHEVRON KAYBOBS 14-20-59-19



by E. Konstantinovskaya and A. Bahramiyarahmadi (2020)

Geomechanical study

In situ dynamic characterization of the shallow units using sCPTu and MASW

Goals: 1) Obtain geomechanical properties to feed the geomechanical numerical model.

Shear wave velocity (Vs) → Young Modulus and Poisson's ratio

2) Obtain porosity, permeability and stratigraphy, will also be useful to the hydrogeological characterization

sCPTu: seismic cone penetration tests
MASW: Multi-channel analysis of surface wave techniques

24 geophones spaced at 4m

Fieldwork for 2020-2021

Drilling of 4-5 monitoring wells :

depths from 50 to 100 m (core drilling)

- Rock sampling (with specific interests on rock heterogeneity and on eventual coal horizons for hydrocarbon source)
- Porosity and permeability on core samples
- Installation of different sensors (water-levels and physico-chemical parameters)
- Borehole geophysical logging

Maybe in 2021-2022: Groundwater sampling

Activities for 2020-2021

- interpretation of borehole geophysical logging data ;
- definition of the local stratigraphy based on the lithostratigraphic logging of cores from new shallow monitoring wells drilled in the study area ;
- analysis of hydrocarbon composition in rocks from new monitoring wells ;
- baseline groundwater geochemical study (if able to sample GW this year);
- identification of source (thermogenic or microbial) and provenance (geological unit) of hydrocarbons present in groundwater.

CONTACT INFORMATION

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Induced Seismicity Research Project:
A Brief Summary of 2019-20 Accomplishments

Projet de recherche sur la sismicité induite :
Un bref résumé des réalisations de 2019-2020




Honn Kao

May 19, 2020

Canada

ABSTRACT

The Induced Seismicity Research (ISR) project has a national scope with team members from NRCan offices in Sidney, Vancouver, 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 research universities, to address critical knowledge gaps in the understanding of induced earthquakes and to provide observation-based science to improve regulations on the development of unconventional hydrocarbon resources. Accomplishments during 2019-2020 include:

- Development of innovative methodologies for detection and location of small-magnitude injection-induced earthquakes (IIE);
- Delineation of source characteristics of significant IIE in BC and AB;
- Enhanced IIE monitoring for major shale gas basins in Canada;
- 2019 NRCan Departmental Achievement Award.

KEY PROJECT MEMBERS

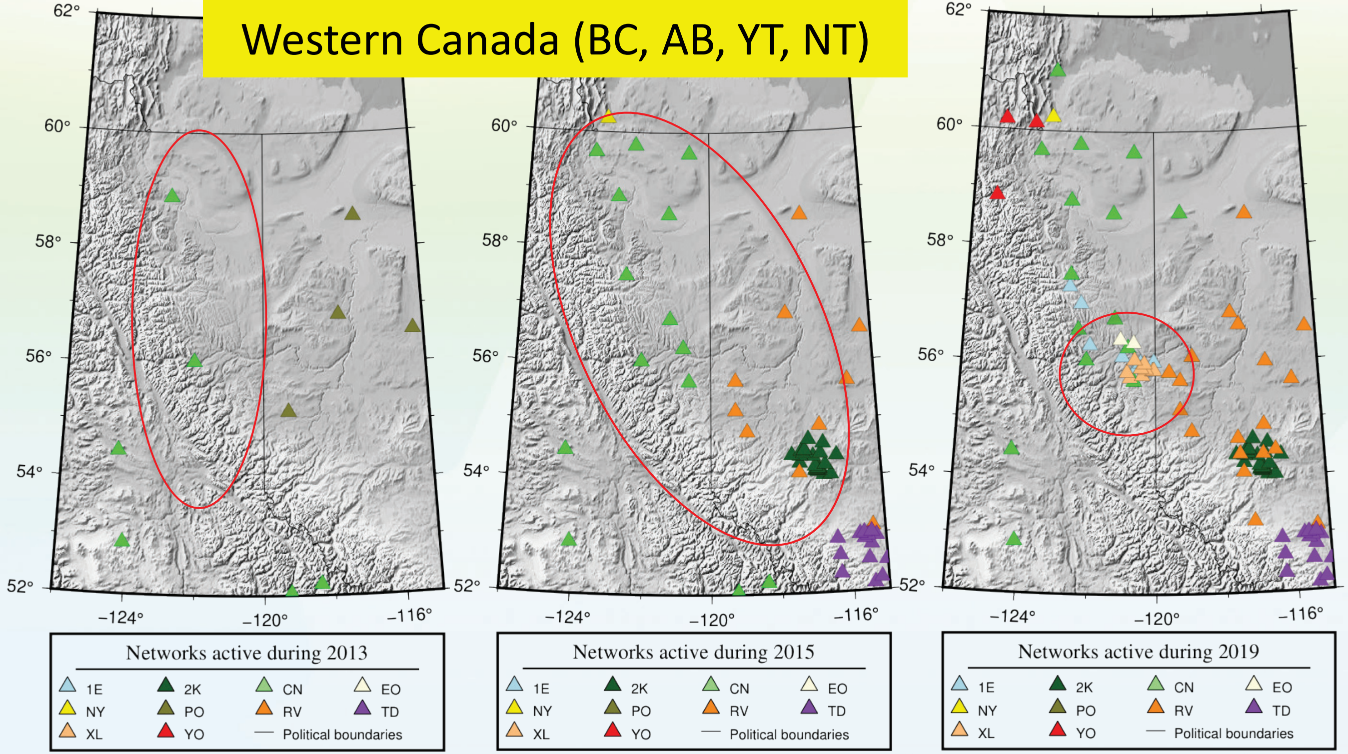
- GSC Research Scientists and Supporting Staff
  - Pacific: Honn Kao (Project Leader), John Cassidy, Ramin Dokht, Adebayo Ojo (NRCan PRP post-doc), Hongyu Yu (NRCan PRP post-doc), Ryan Visser (PC-2)
  - Ottawa: Maurice Lamontagne, Don White
  - Quebec: Nathalie Jacob and Christine Laberge (admin support)
- GSC Research Associates and Supports
  - Alireza Babaie Mahani (researcher funded by Geoscience BC)
  - Bei Wang (PDF funded by Geoscience BC)
  - Amir Farahbod (contractor and volunteer)
  - Dawei Gao, Ayodeji Kuponiyi, Jesse Hutchinson, Fengzhou Tan (UVic graduate students)
  - Byron Kontou and Chet Goerzen (co-op terms)

Awards and Collaboration Highlights

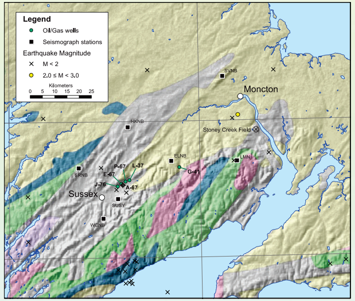
- NRCan Departmental Achievement Award
  - Impact Award, Excellence in Science (Honn Kao)
- External Research Grant
  - $154,800 from Geoscience BC to Honn Kao in support of injection-induced earthquake (IIE) research for NE BC
- Receive official acknowledgements from BC Oil and Gas Commission for successfully establishing an automatic monitoring system for small-magnitude IIE in BC.
- Densify Local and Regional Seismograph Coverage
  - McGill University, University of Victoria, University of Calgary, Ruhr University Bochum (Germany), Geoscience BC, Canadian Association of Petroleum Producers (CAPP)
- Joint IIE Research and Publications
  - McGill University, University of Victoria, University of Calgary, Ruhr University Bochum (Germany), Geoscience BC, and BC Oil and Gas Commission

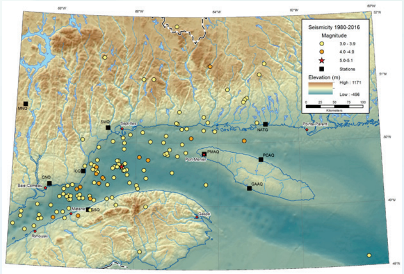
Unprecedented Seismograph Station Density in Major Shale Gas Basins

Western Canada (BC, AB, YT, NT)



Eastern Canada (NB, QC)





Key Scientific Achievements

- Innovative Methodologies for IIE Monitoring
  - Seismicity-Scanning based on Navigated Automatic Phase-picking (S-SNAP, *Tan et al.*, 2019, JGR)
  - Seismic phase identification and source location using deep convolutional neural network (*Dokht et al.*, 2019, SRL)

- Targeted Studies of Significant IIE Events and Seismogenic Characteristics
  - Group motion characteristics of the 30 Nov 2018 (Mw 4.6) event (*Babaie Mahani et al.*, 2019, SRL)
  - Remote dynamic triggering of local earthquakes in 3 major shale gas basins (*Wang et al.*, 2019, BSSA)
  - Aftershock decay rate of IIE in NE BC (*Farahbod et al.*, 2019, *Recorder*)
  - Regional stress field and earthquake pattern in the southern Montney Play, BC (*Babaie Mahani et al.*, 2020, SRL)

CONTACT INFORMATION

- Project leader: Dr. Honn Kao
- Tel: (250) 363-6625
- Webpage on Science.gc.ca: https://profils-profiles.science.gc.ca/en/profile/honn-kao-phd
- Email address: Honn.Kao@canada.ca

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Measuring, monitoring and verification of geological carbon storage

Mesure, surveillance et vérification de la séquestration géologique du carbone

Don White

May 19th, 2020

Canada

ABSTRACT

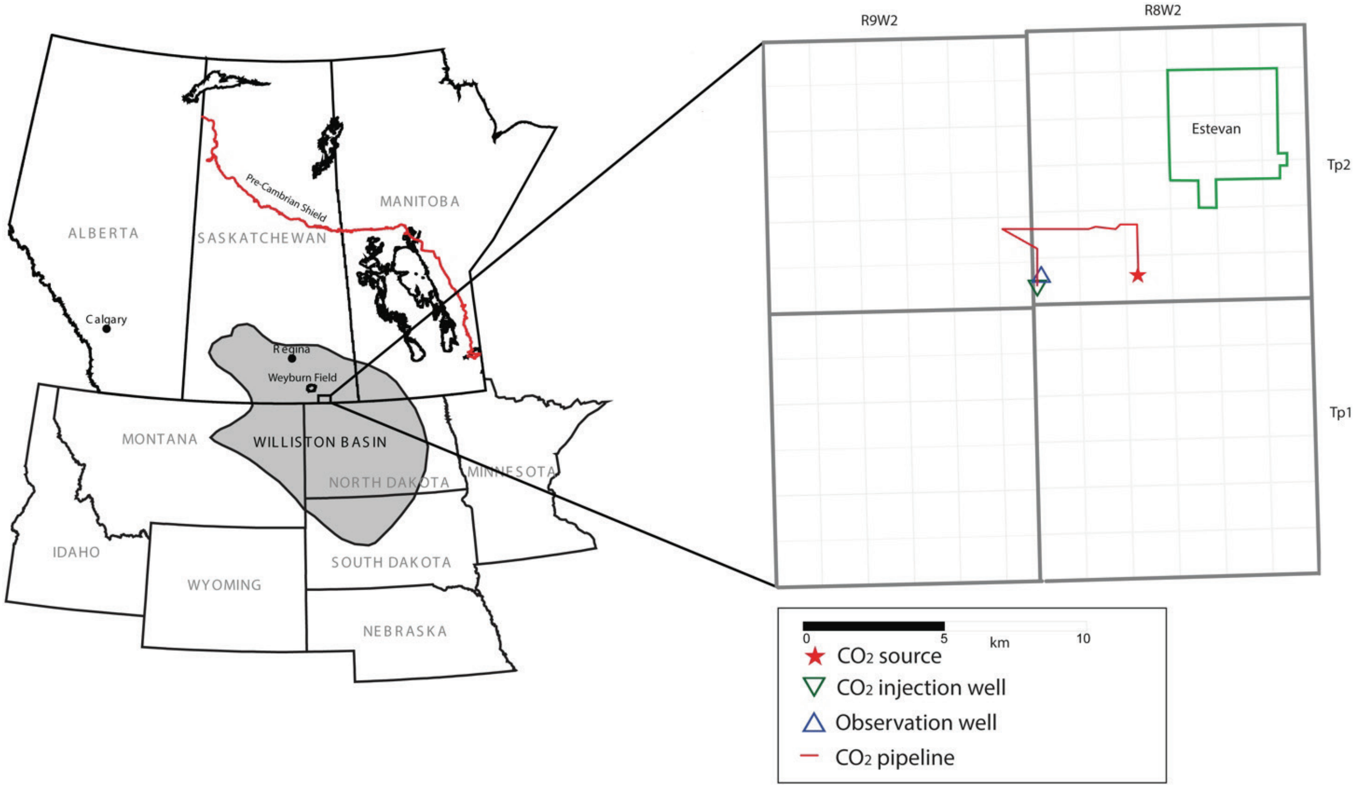
Aquistore CO_2 storage site: 5 years of monitoring

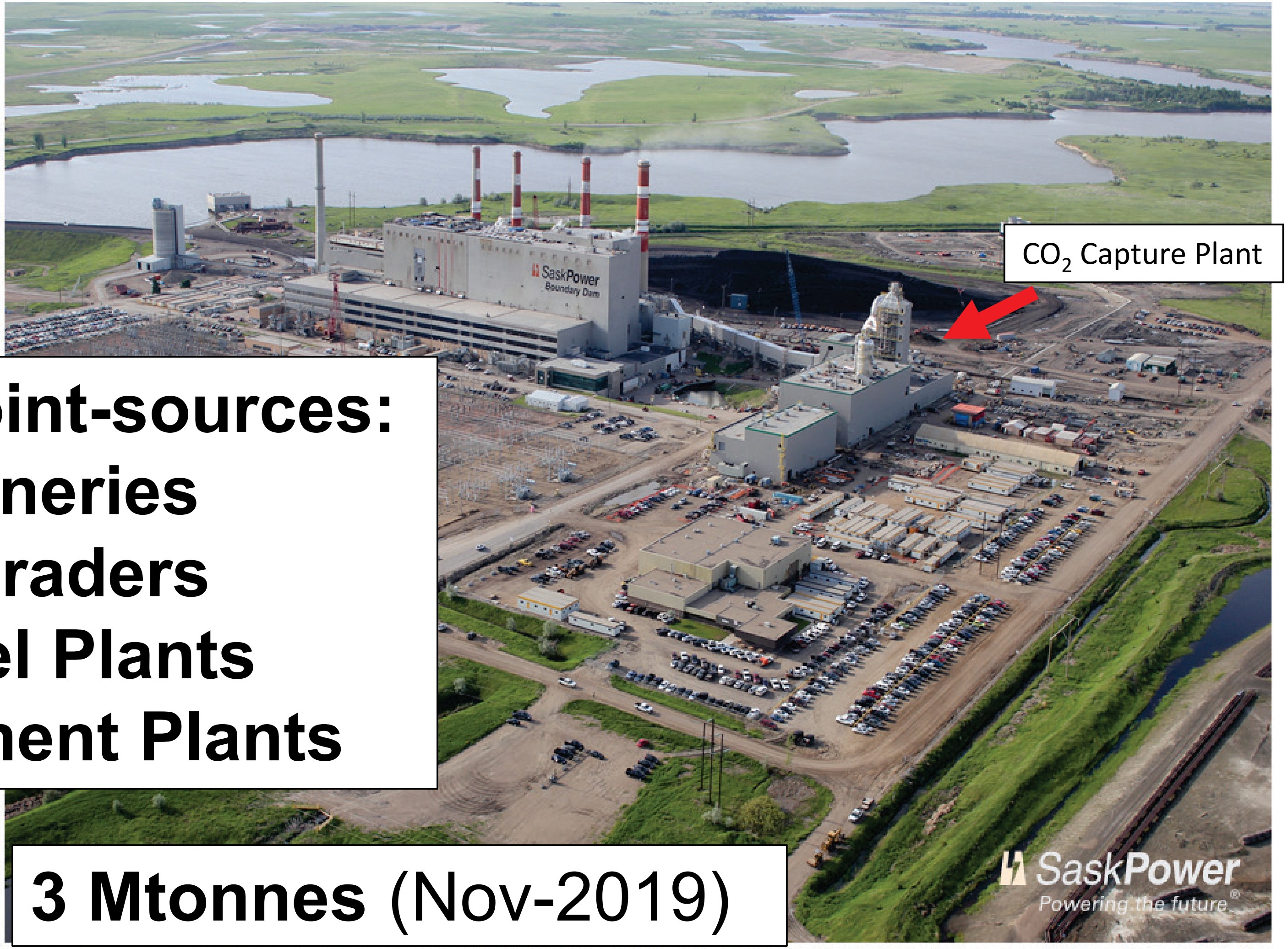
- Time-lapse seismic
- Induced seismicity

PROJECT MEMBERS

- Don White, Gilles Bellefleur (**GSC**)
- Mike Craymer, Jason Silliker (**CGS**)
- Sergey Samsonov (**CCRS**)
- Lisa Roach (**LAN Geophysics**)
- Darcy Holderness (**SaskPower**)
- Erik Nickel, Ivan Marsden, Zeinab Movahedzadeh (**Petroleum Technology Research Centre**)
- Ben Rostron (**University of Alberta**)
- Chris Hawkes (**University of Saskatchewan**)
- Anna Stork (**Bristol University**)
- Michelle Robertson (**Lawrence Berkeley National Lab**)
- Masashi Nakatsukasa, Mamoru Takanashi (**Japan Oil, Gas Metal NC**)
- Kevin Dodds (**Australian National Low Emissions Coal Research & Development**)

Aquistore CO_2 Storage Project





CO_2 point-sources:

- **Refineries**
- **Upgraders**
- **Steel Plants**
- **Cement Plants**

3 Mtonnes (Nov-2019)

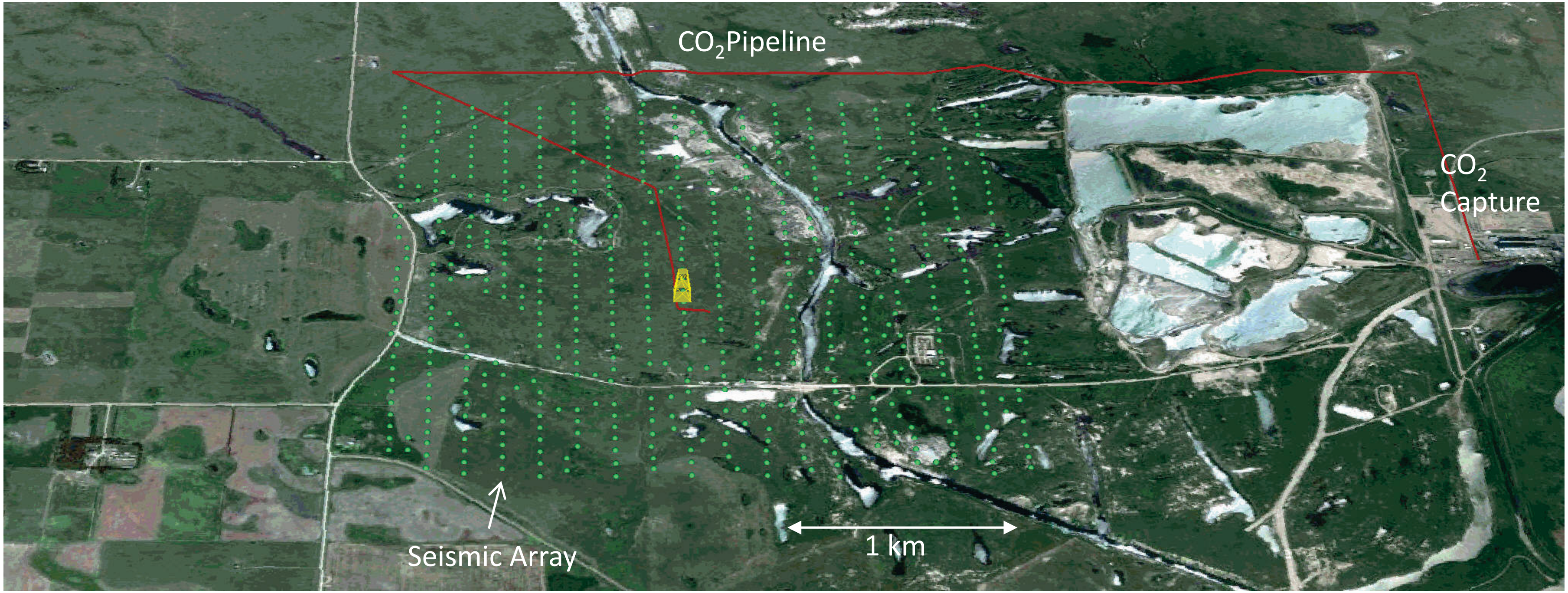
GSC Research Objectives

- Methods for monitoring CO_2 containment
- Induced seismicity

Outcomes

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

Aquistore CO_2 Storage Project

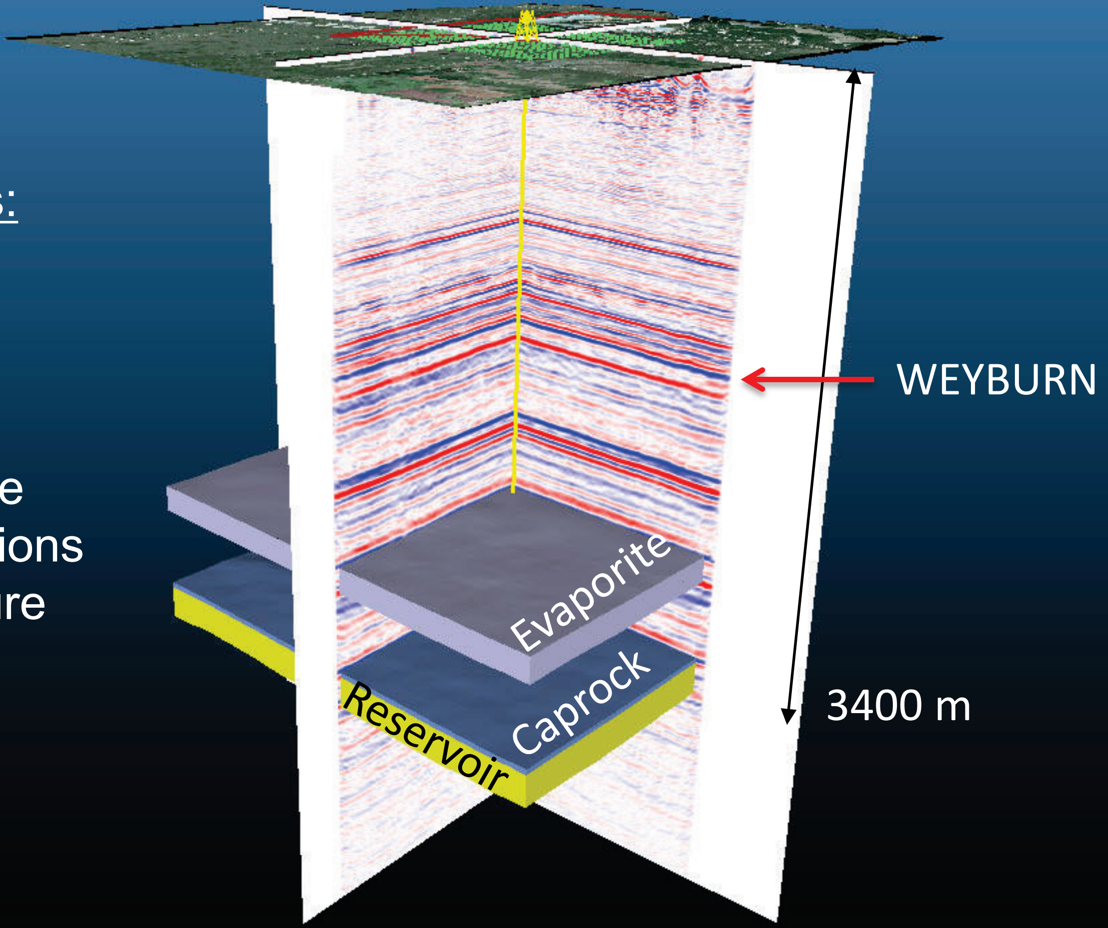


Monitoring Challenges:

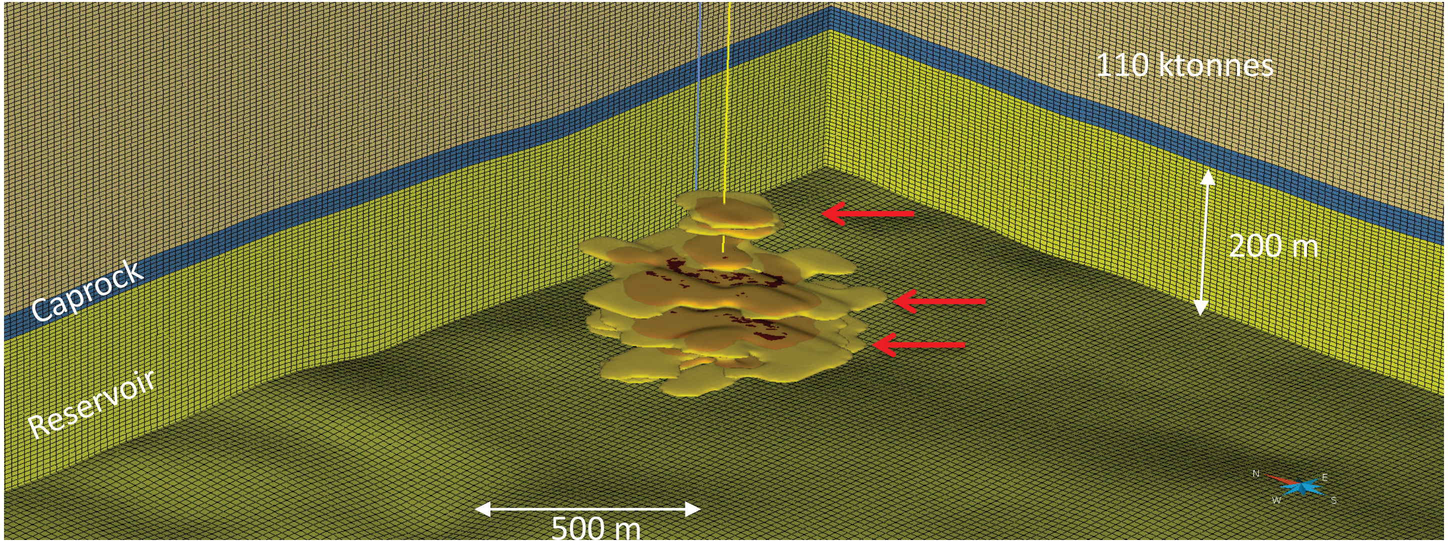
- Deep reservoir
- Low injection rate

Advantages:

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

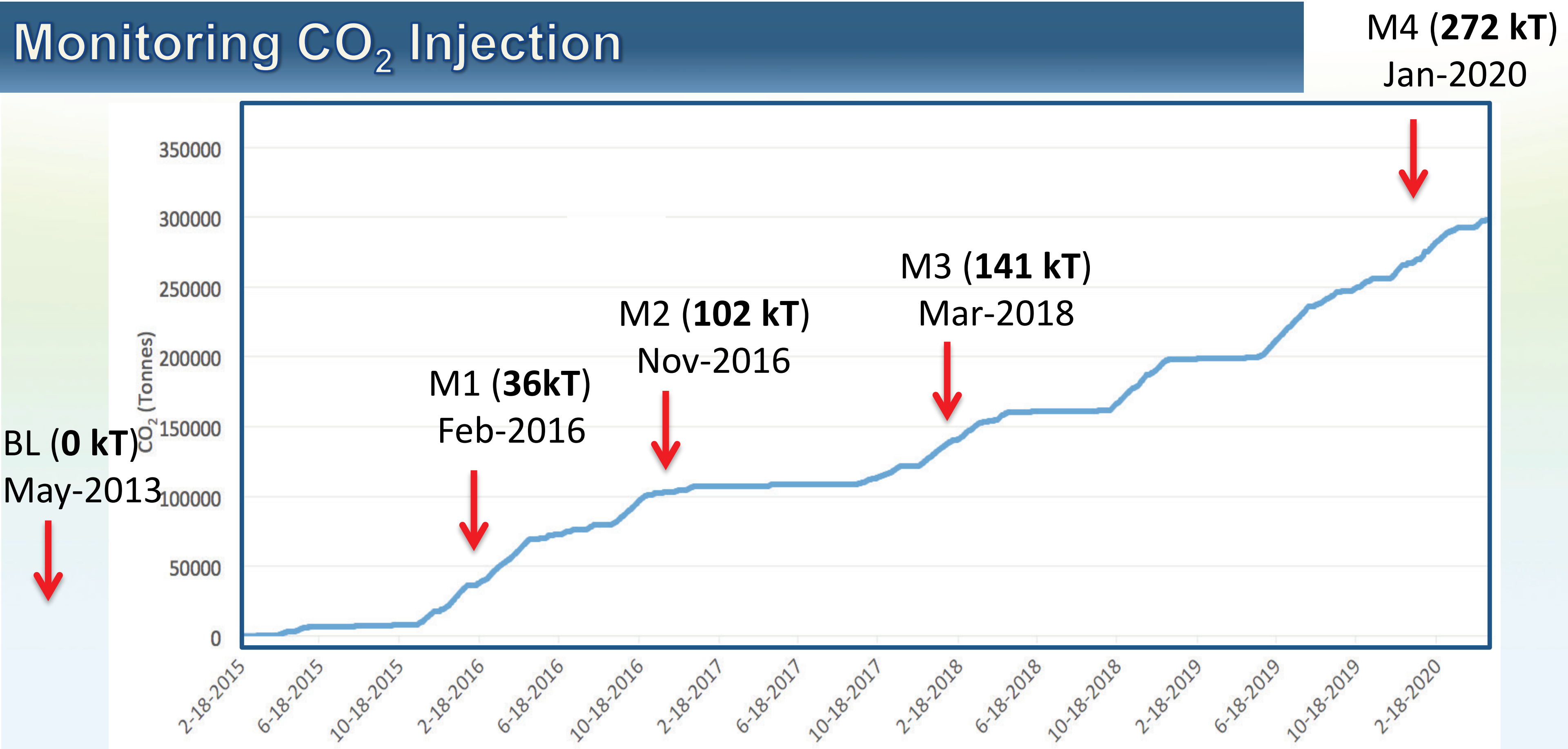


Model: 110 kT CO_2

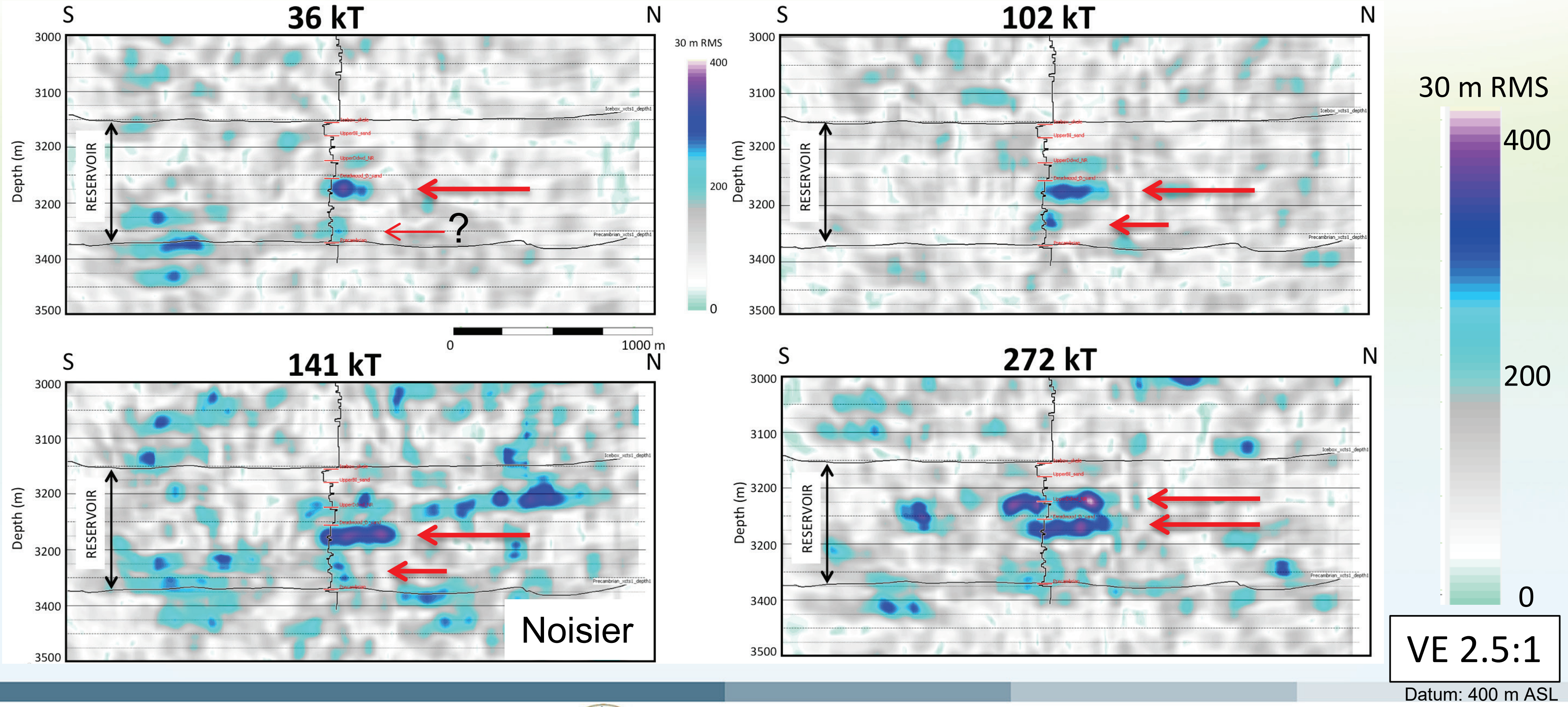


3400 m Depth

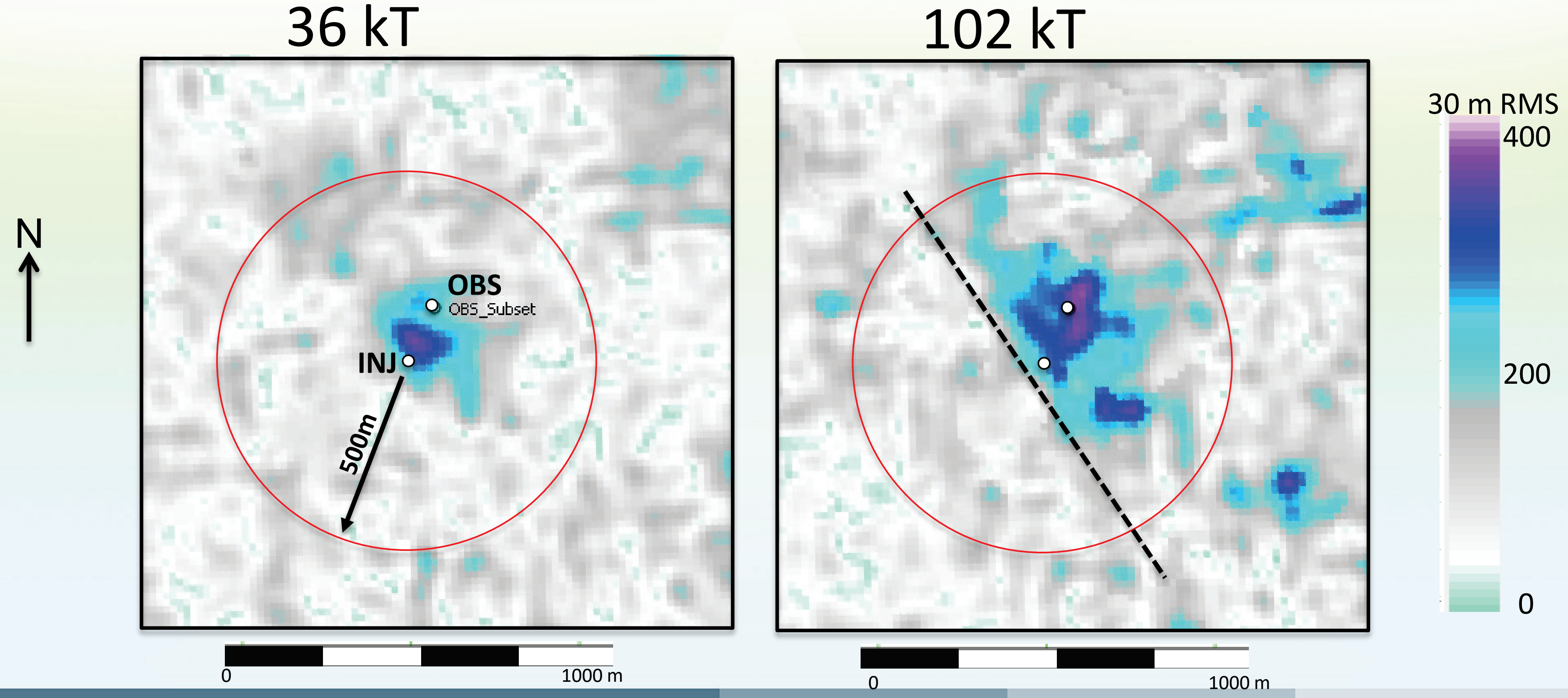
Monitoring CO_2 Injection



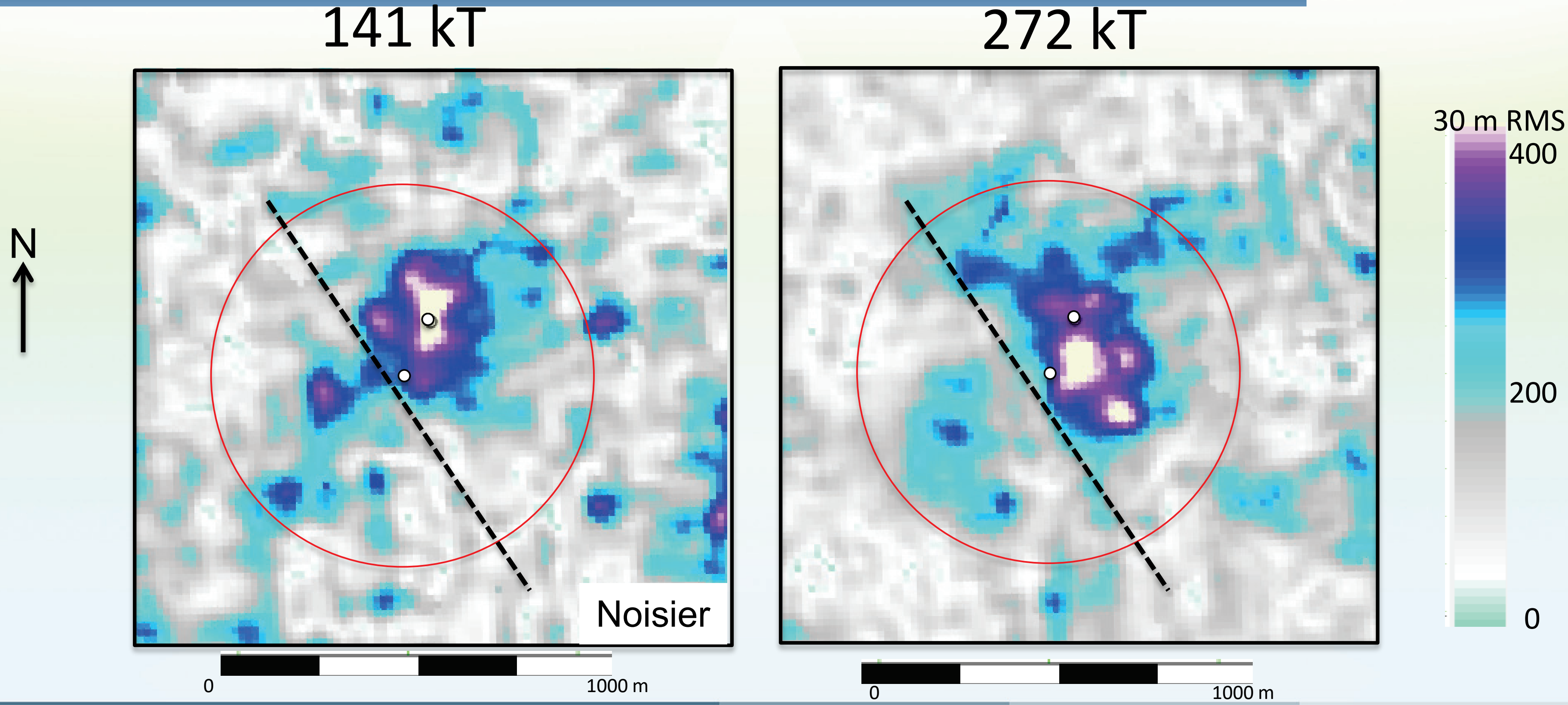
INJECTOR: 4D RMS AMPLITUDE DIFFERENCE



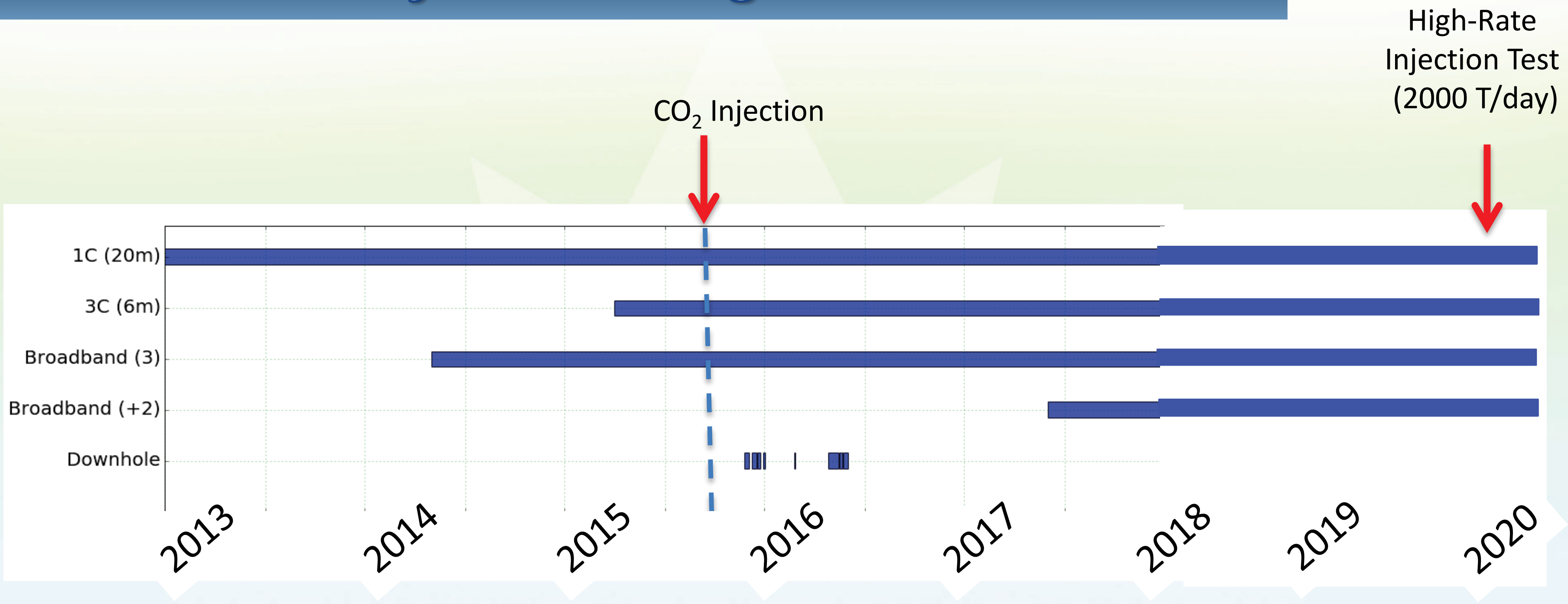
Upper Deadwood



Upper Deadwood



Induced Seismicity: Monitoring Period



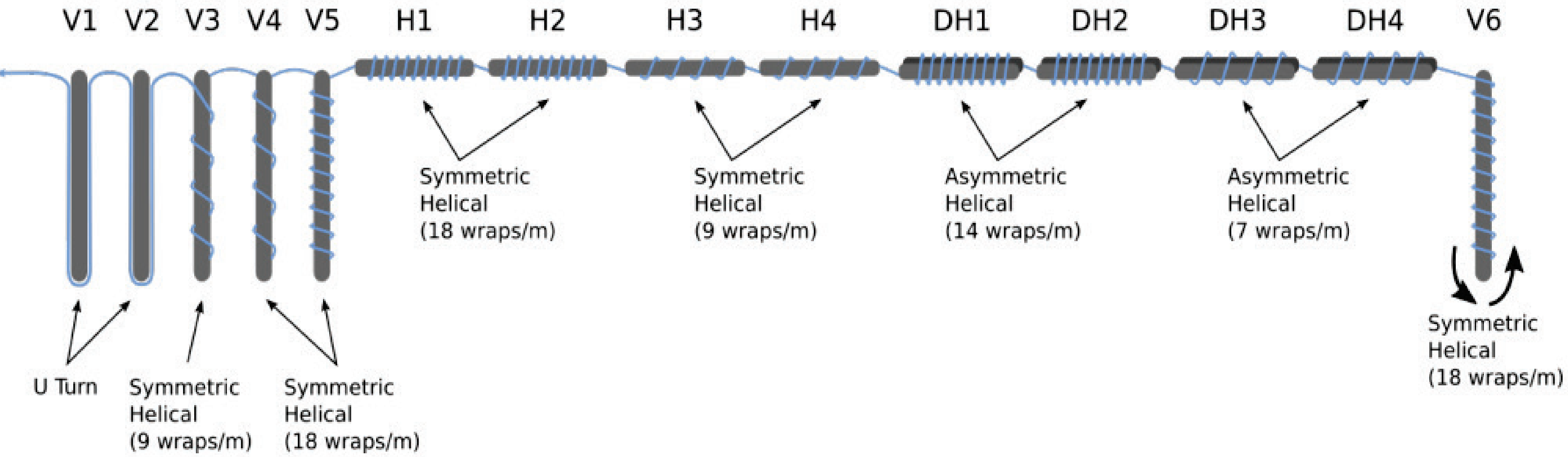
(Stork et al., 2018)

Induced Seismicity

- No induced seismicity during 5 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)

Experimental DAS Configurations (Fibre Optics)



Conclusions: Seismic Monitoring

- CO_2 plume contained within the reservoir.
- Vertical distribution of CO_2 in the reservoir illuminated.
- Lateral spread of CO_2 is generally consistent with direct detection of CO_2 in the observation well.
- Influence of reservoir structure is observed.
- 3D modelling confirms capability of 4D seismic to monitor deep CO_2 distribution.
- Ambient noise levels affect 4D sensitivity.
- No induced seismicity over first 5 years.

CONTACT INFORMATION

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Cumulative Effects of Resource Development on Mining-Impacted Watersheds

Effets Cumulatifs du Développement Minier dans les Bassins Versants Contaminés

Alexandre Desbarats

May 19th, 2020

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 their 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 their capacity to carry out or review environmental assessments and to ensure that decision makers have a better understanding of the cumulative nature of environmental impacts for the sustainable development of natural resources.

PROJECT MEMBERS

- Alexandre Desbarats (GSC-NC, leader)
- Paul Gammon (GSC-NC)
- Michael Parsons (GSC-ATL)
- Jeanne Percival (GSC-CC)
- Katherine Venance (GSC-CC)
- Jennifer Galloway (GSC-Cal)
- Suzanne Beauchemin (Health Canada)
- Tom Al (University of Ottawa)
- Danielle Fortin (University of Ottawa)
- Heather Jamieson (Queen's University)
- Jennifer Cole (CANMET-CMIN)
- Richard Goulet (CANMET-CMIN)

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

- How to assess environmental impacts of new mining 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 or tree rings 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 0: Partnership building with mining industry (Desbarats, lead)

FY 2019-2020 Achievements

- Partnership building with Agnico-Eagle Mines (AEM):

  Meeting with AEM representative (Chris Kennedy) and local consultants Story Environmental to present project and solicit feedback; obtained permission to access their properties; possibility of accessing AEM data sets
- Partnership building with First Cobalt (Frank Santaguida, VP):

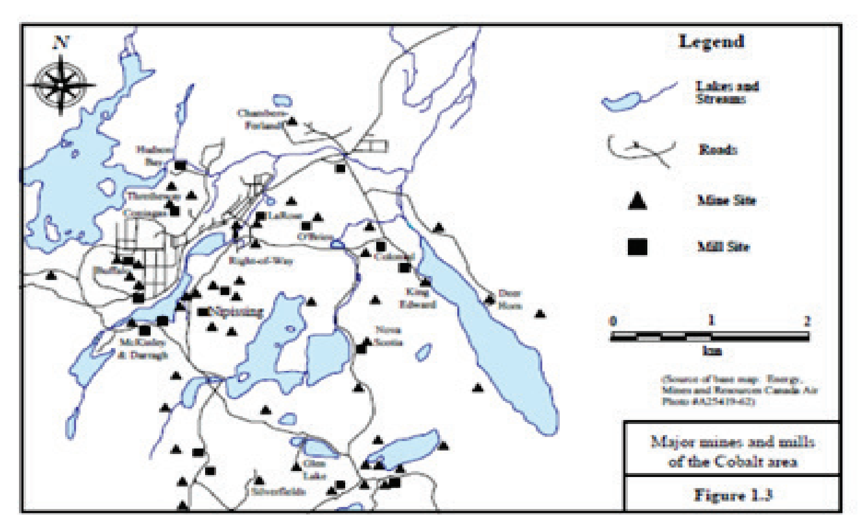
  Teleconference to present project and solicit feedback; obtained permission to access their properties

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

FY 2019-2020 Achievements:

- Field reconnaissance to locate sampling sites for mine-impacted groundwater (such as flooded shafts, adits, DDH) in the Cobalt and Silver Centre areas



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

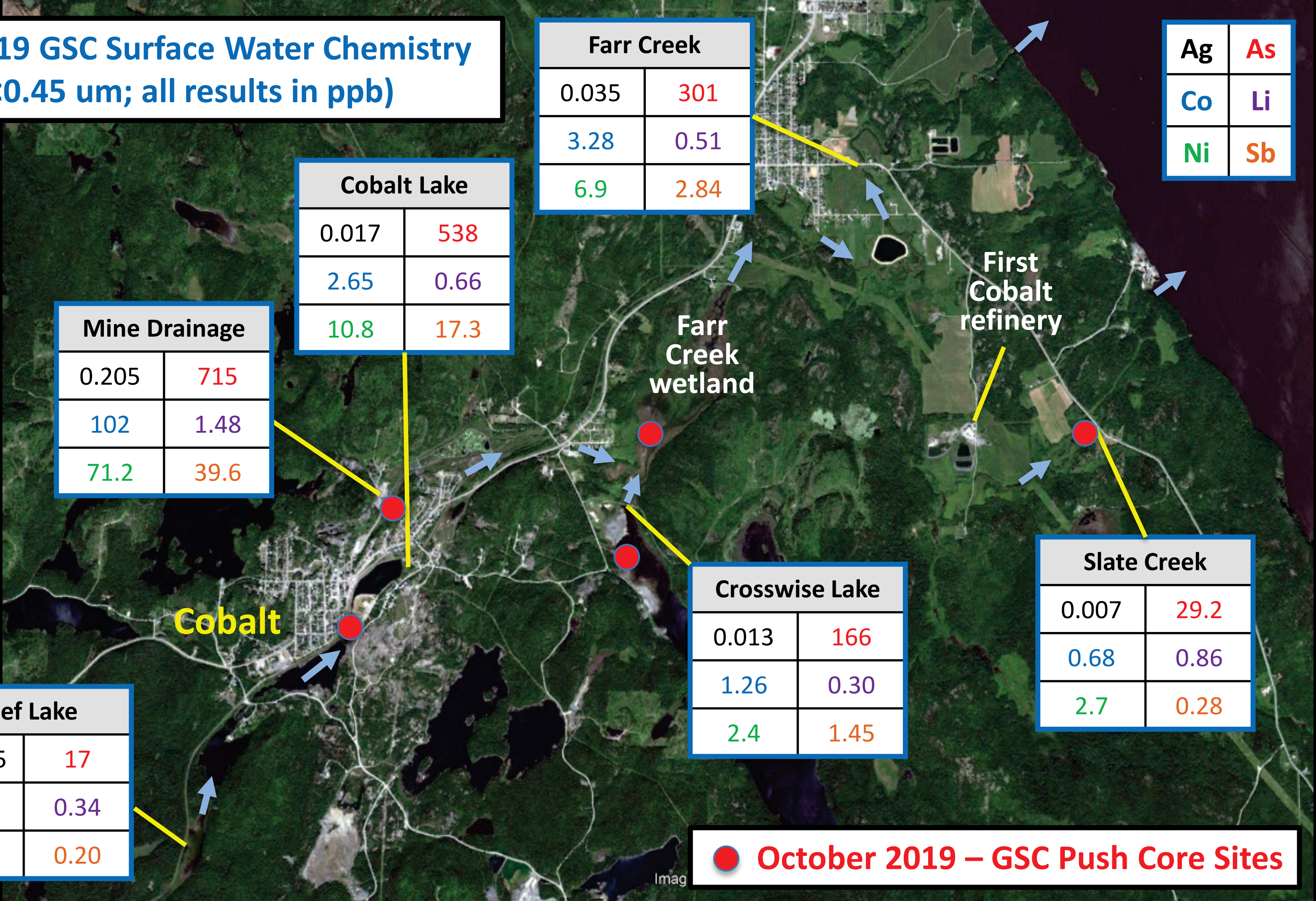
Task 2.1: Sample mine wastes, sediments, and surface waters upstream and downstream of mining-impacted areas to evaluate the concentration and speciation of Ag, As, Co, Hg, Ni, and Sb in pre-mining and near-surface sediments and pore water.

Lori Campbell holding push core of tailings collected from Crosswise Lake, Cobalt, ON

FY 2019-2020 Achievements

- Sampled surface waters from six locations in June 2019 to evaluate metalloid concentrations
- Collected five push cores of tailings and sediments in October 2019 to determine concentration ranges for key elements of interest
- Chemical analyses of solids and pore waters completed; insufficient pore water volume for investigation of stable metal isotopes

June 2019 GSC Surface Water Chemistry
(<0.45 um; all results in ppb)



Ag	As
Co	Li
Ni	Sb

Farr Creek	
0.035	301
3.28	0.51
6.9	2.84

Cobalt Lake	
0.017	538
2.65	0.66
10.8	17.3

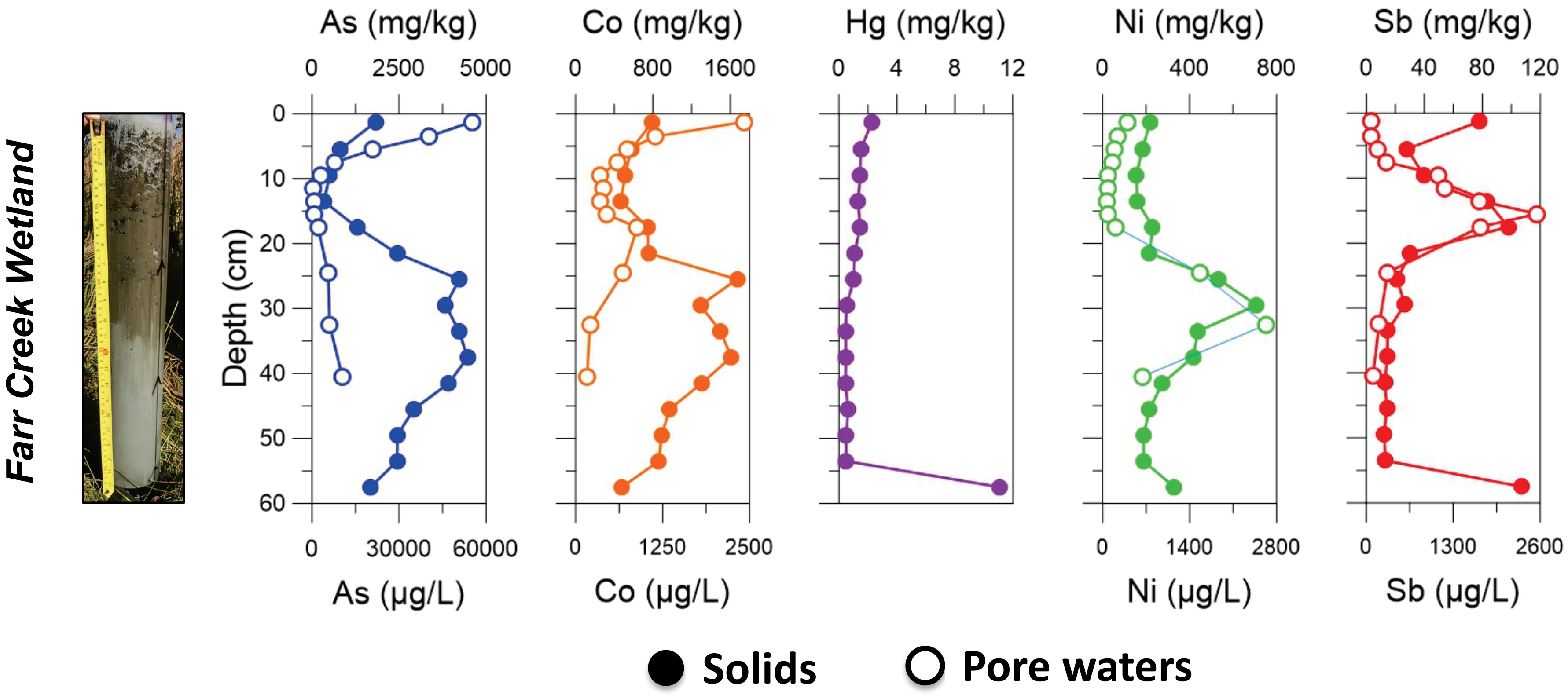
Mine Drainage	
0.205	715
102	1.48
71.2	39.6

Crosswise Lake	
0.013	166
1.26	0.30
2.4	1.45

Slate Creek	
0.007	29.2
0.68	0.86
2.7	0.28

Brief Lake	
<0.005	17
0.06	0.34
0.4	0.20

Metalloid concentrations in mine tailings from Farr Creek Wetland, Cobalt, ON

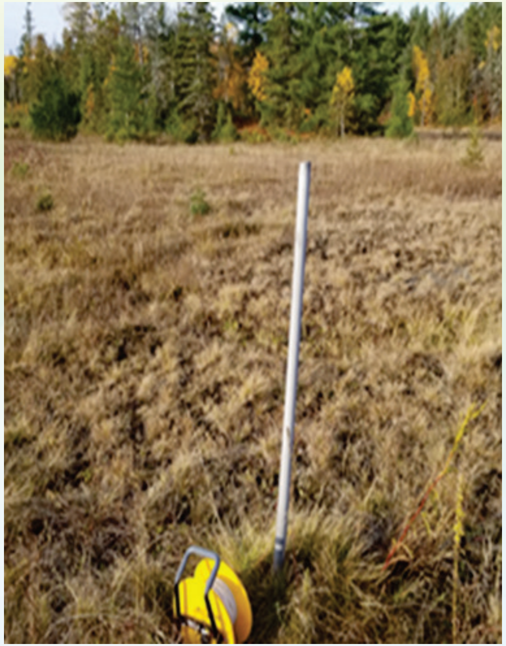


Task 5: Weathering processes in Cobalt-type Ag-Ni-Co arsenide tailings (Al, lead)

Task 5.1: Field sampling of in-situ weathering products of primary Ag-Ni-Co arsenide and sulphide minerals in mine tailings

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

- Cole Fischer M.Sc. Candidate, Advisors: Tom Al and Danielle Fortin
- Research topic: Geochemistry and geomicrobiology of the Cart Lake tailings



Task 5 (Continued)

FY 2019-2020 Achievements:

- Field orientation and study site selection
- Field work at Cart Lake tailings: sampling tailings pore water in piezometers; taking horizontal cores to analyze for microbiological activity
- Laboratory work: mineralogy (thin sections and XRD) of tailings

CONTACT INFORMATION

- Project leader: Alexandre Desbarats
- 613-995-5512
- alexandre.desbarats@Canada.ca

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

Dynamique hydrologique à long terme du plus grand bassin versant du Canada : Le bassin du fleuve Mackenzie

Jennifer Galloway

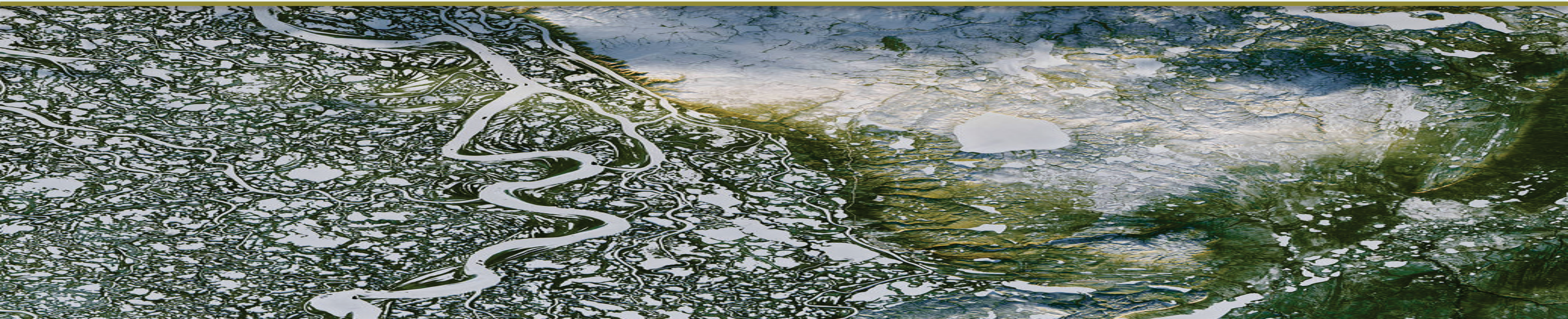
May 19, 2020

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, especially in NW Canada
- How will climate change affect water quantity in the MRB?
- Ice jam flooding vs. low water levels
- Carbon storage vs. export
- 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

Internal	Galloway, Jennifer (GSC-C)
	Hadlari, Thomas (GSC-C)
	Ardakani, Omid (GSC-C)
	Bringué, Manuel (GSC-C)
	Wolfe, Steve (GSC-N)
	Morse, Peter (GSC-N)
	Parsons, Michael (GSC-A)
	Whalen, Dustin (GSC-A)
	Dennis Jiang (GSC-C)
	Jaime Rafael Cesar Colmenares (GSC-C)
External	Falck, Hendrik and Kokelj, Steve (GNWT)
	Lantz, Trevor (University of Victoria)
	Shotyk, William (University of Alberta)
	Clark, Ian (University of Ottawa)
	Patterson, R. Tim (Carleton University)
	Chappaz, Anthony (Central Michigan University)
	Swindles, Graeme (Queen’s University, Belfast)
	Baird, Andy and Morris, Paul (University of Leeds)
	Gałka, Mariusz (University of Lodz)
	Lord, Sarah (Gwich’in Renewable Resources Board)
	Snowshoe, Sharon (Gwich’in Tribal Council, Dept. of Cultural Heritage)
	Clarke, Leon (Manchester Metropolitan University)
HQP	Lukas Frost and Andrii Oleksandrenko (PhDs) (U of Alberta)
	Tait Overeem (MSc, U Vic)
	Naomi Weinberg (MSc) and Anne Nguyen (PhD, pending) (Carleton)






PROGRESS TO DATE

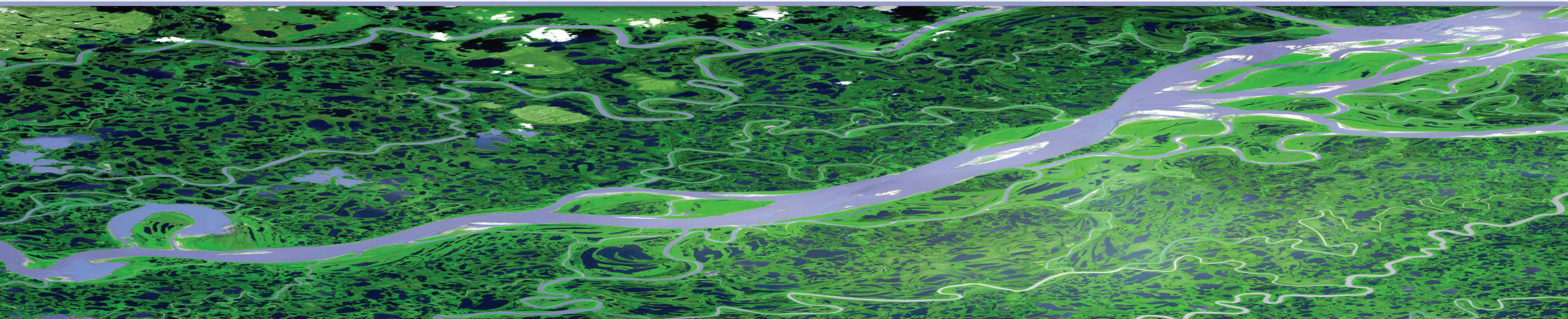
ArcticNet

- ArcticNet (#51) funding (FY 19-20 to 21-22)

- Traditional Knowledge study (Sharon Snowshoe, Gwich'in Tribal Council, Dept. of Cultural Heritage, Trevor Lantz, U Vic & Tait Overeem, MSc candidate, et al.) initiated. Focuses on synthesis of previously documented TK related to water levels in the Gwich'in Settlement Area. This synthesis includes 40 interviews carried out as part of the Tracking Change Project (www.trackingchange.ca) . Based on the synthesis and identified knowledge gaps new activities will be planned to document knowledge recorded in interviews stored in the Dept. of Cultural Heritage's digital archive. This approach builds on an existing body of work to prevent interview fatigue

AND

ASTER, Aug. 4, 2005, 68.6ºN, 134.7ºW; NASA/GSFC/METI/ERSDAC/JAROS, and U.S./Japan ASTER Science Team



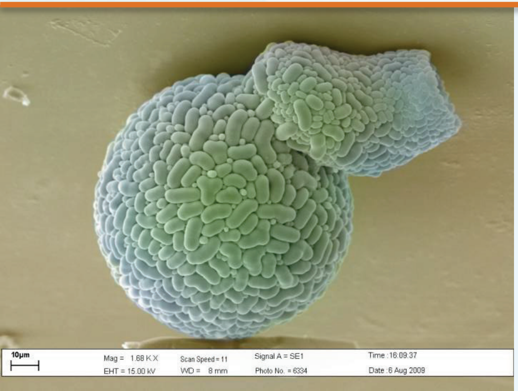
PROGRESS TO DATE

- Preparation and analysis of existing peatland monoliths and cores for pH, EC, ash content, HAWK pyrolysis, Hg analysis, organic contaminants, gamma spectrometry and AMS dating (^{210}Pb and ^{14}C), elemental analysis by ICP-MS, light stable isotopes, acid digestion (sequential, as needed), palynological analysis, plant macrofossils, and micropaleontological analysis (testate amoebae)

TO

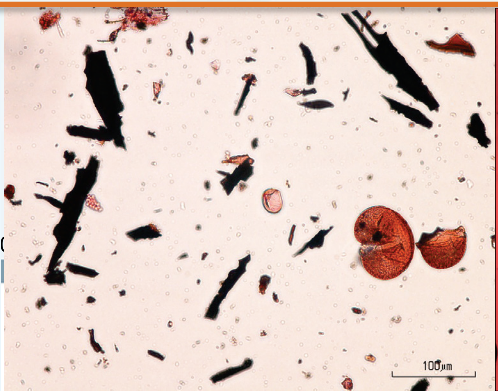
- Reconstruct depth-to-water table (quantitative), fire and vegetation history, chemical change, hydrological change, and synoptic-scale climate patterns (e.g., Pacific Decadal Oscillation) that may drive water quantity change in the MRB

Lesquereusia epistomium survives peat fires
(credit: Yuri Mazei)

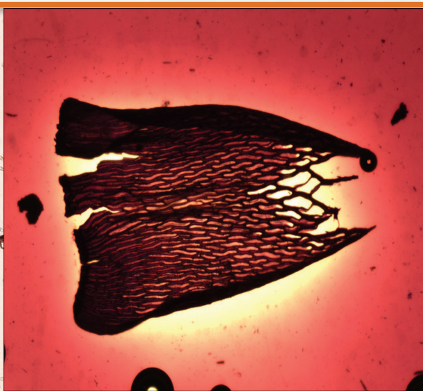


Picea (spruce) pollen (~125 µm)
(credit: Neotoma database)

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



Sphagnum riparium
(credit: Mariusz Gałka)



HIGHLIGHTS

- Climate warming results in increased production in subarctic lakes. The increase in organic matter mediates redox conditions leading to release of elements previously stored in sediments to the surface waters (Miller et al., 2020; Chem. Geol.). Climate change needs to be considered in Environmental Assessment and remediation strategies (Miller et al., 2019; STOTEN).

- Testate lobose amoebae respond to changes in the geochemistry of the sediments and are sensitive bioindicators of arsenic in subarctic lakes. They can be used to reconstruct quantities of this redox-sensitive element in sediment profiles (Nasser et al., 2020; PeerJ).

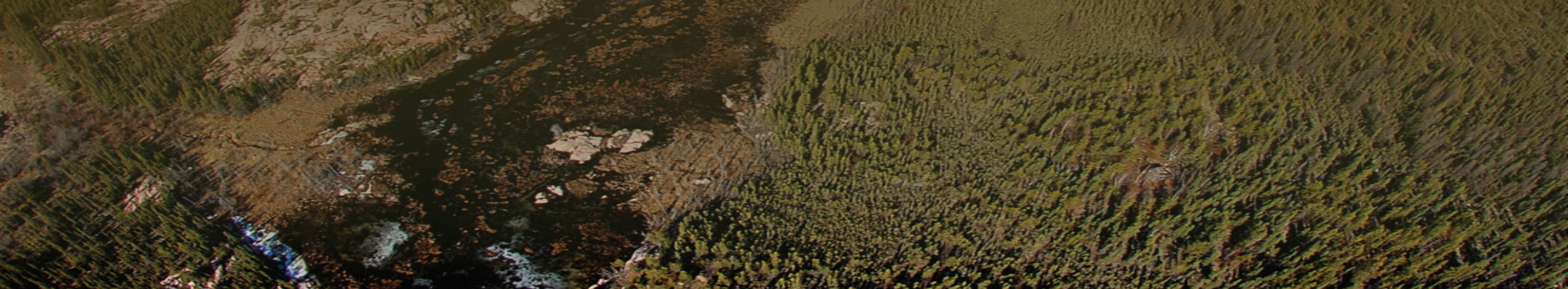


Photo: Paul Vecsei

OUTPUTS

- Galloway, J.M., Gałka, M., Swindles, G.T., Wolfe, S.A., Morse, P.D., Patterson, R.T., Falck, H., Kung, L. 2020. Ecohydrological dynamics of a degrading subarctic peatland: Implications for arsenic mobility. European Geosciences Union (EGU), virtual online meeting, May 3-8.
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- Nasser, N.A., Patterson, R.T., **Galloway, J.M.**, Falck, H. 2020. Intra-lake response of Arcellinida (testate lobose amoebae) to gold mining-induced arsenic contamination in northern Canada: Implications for environmental monitoring. *In press*. PeerJ.
- Nasser, N.A., Patterson, R.T., Roe, H.M., **Galloway, J.M**., Falck, H., Palmer, M.J., Sanei, H. 2020. Use of Arcellinida (testate lobose amoebae) arsenic tolerance limits as a novel tool for biomonitoring arsenic contamination in lakes. Ecological Indicators 113: 106277,
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- Miller, C.B., Parsons, M.B., Jamieson, H.E., Arkanaki, O.H., Gregory, B.R., **Galloway, J.M.** 2019. Influence of late Holocene climate on soild-phase speciation and long-term stability of arsenic in sub-arctic lake sediments. Science of the Total Environment 709: 136115.
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- Nasser, N.A., *Gregory, B.R.B., Steele, R.E., Patterson, R.T., Galloway, J.M. 2019. Behind the organic veil: assessing the impact of chemical deflocculation upon organic content reduction and lacustrine Arcellinida (testate amoebae) analysis. Microbial Ecology 79: 443-458.

Photo: Paul Vecsei

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https://scholar.google.ca/citations?user=x6SQcrsAAAAJ&hl=en

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THANK YOU!

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Environmental impacts of permafrost degradation

Impacts environnementaux de la dégradation du pergélisol

Mathieu J. Duchesne. May 19, 2020

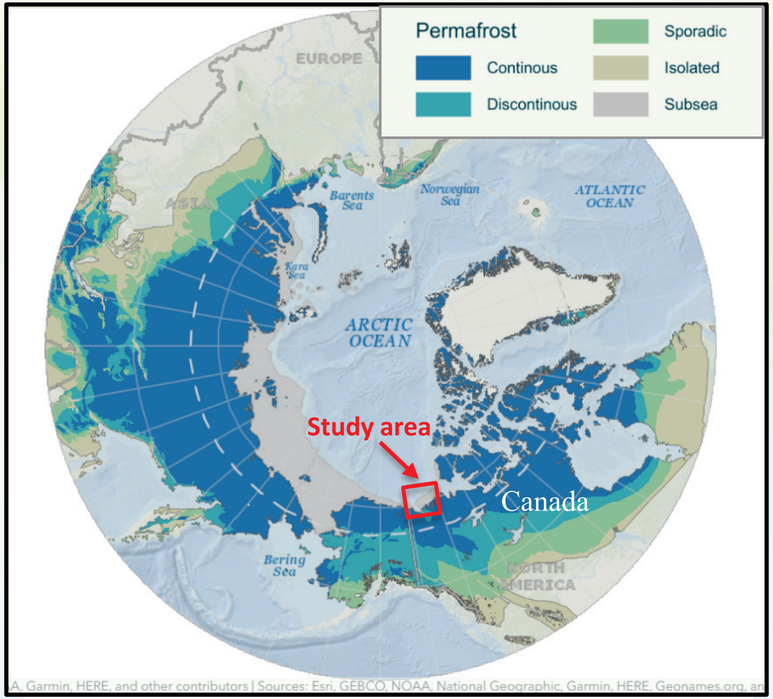
Canada

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

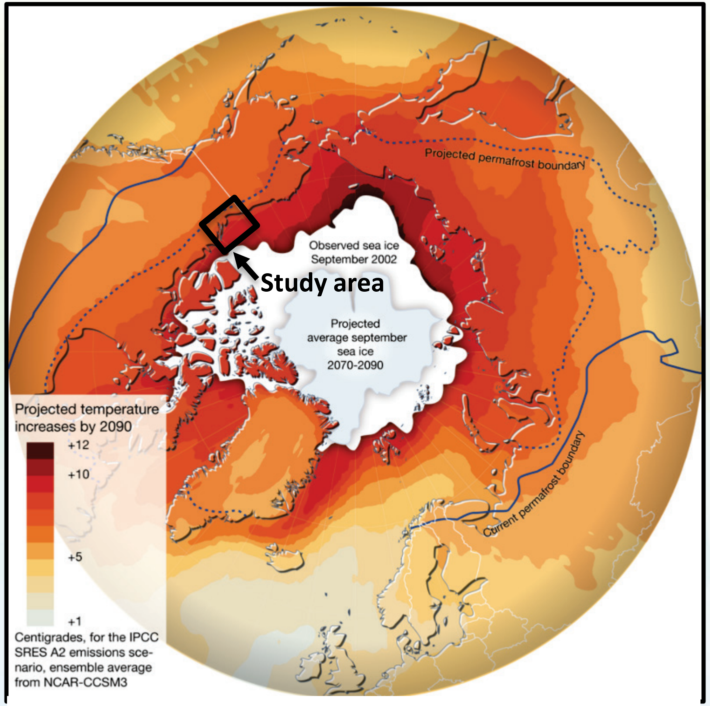


ESRI, GEBCO, NOAA, National Geographic, Garmin

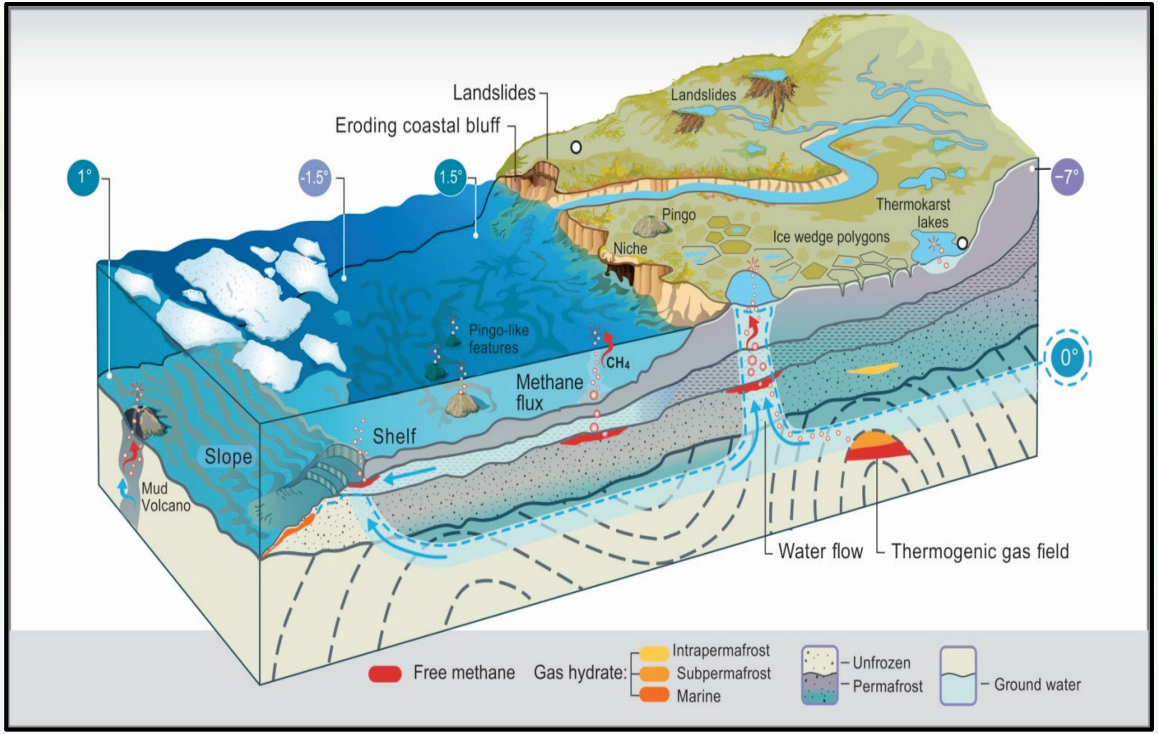
PROJECT MEMBERS

- GSC- Permafrost mapping and characterization: Bellefleur, G., Brake, V. I., Duchesne, M.J., Hu, K., Pinet, N.
- GSC- Environmental and Geochemistry: Outridge, P., Zheng, J., Côté, M., Dallimore, S., King, E., MacLeod, R., Morse, P., Wolfe, S.,
- External collaborators: Fabien-Ouellet, G. (Polytechnique Mtl), Giroux, B. (INRS), Risk, D. (St. Francis Xavier University), Greinert, J. (GEOMAR), Gwiazda, R. (MBARI), Jin, Y. K. (KOPRI), Kang, S.-G. (KOPRI), Lapham, L. (U. of Maryland), Orcutt, B. (Bigelow Lab.), Overduin, P. (AWI), Paull, C.K. (MBARI), Rhee, T. S. (KOPRI), Riedel, M. (GEOMAR), Wheat, G. (U. of Alaska)

Project Context



National Center for Atmospheric Research, 2008

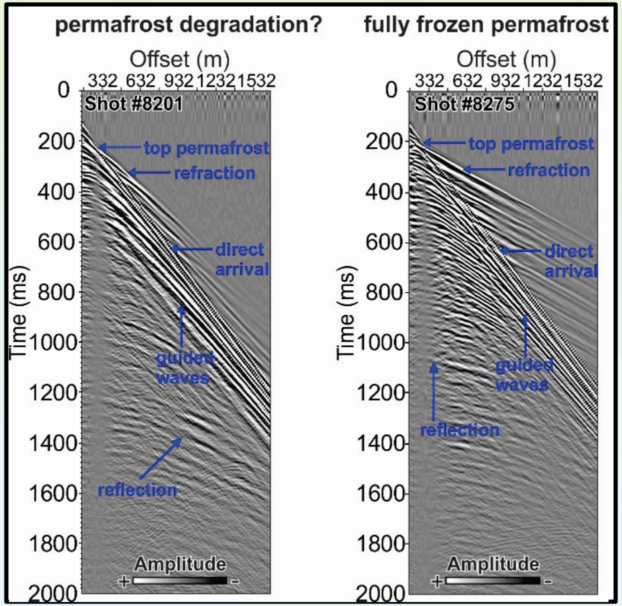


United Nations Environment Programme -Rapid Response Assessment-: Offshore and Coastal permafrost

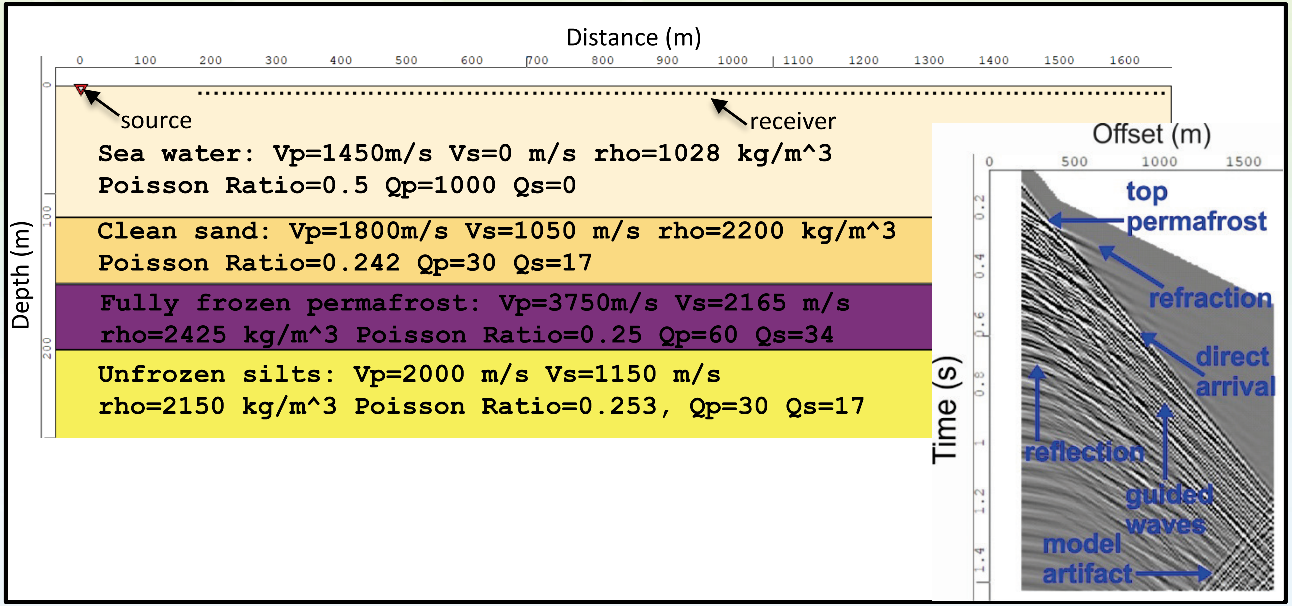
Progress (May 2019 - May 2020)

Seismic detection of permafrost degradation

Processing & analyzing field data

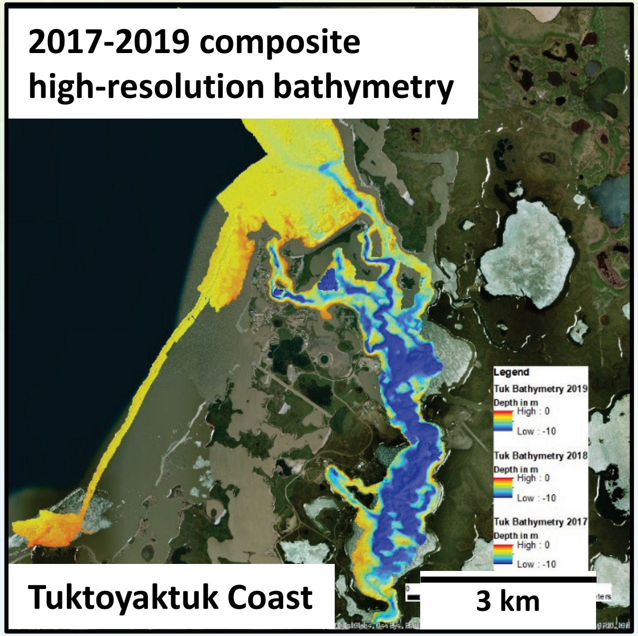


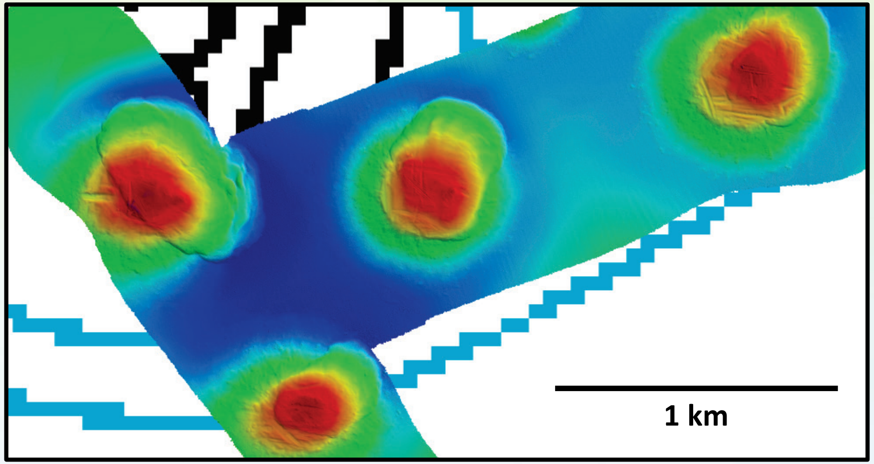
Seismic modeling



Progress (May 2019 - May 2020)

Change detection of marine permafrost features





Pingo-like features (Beaufort Sea shelf)

Progress (May 2019 - May 2020)

Methane release caused by permafrost degradation

Atmospheric methane survey

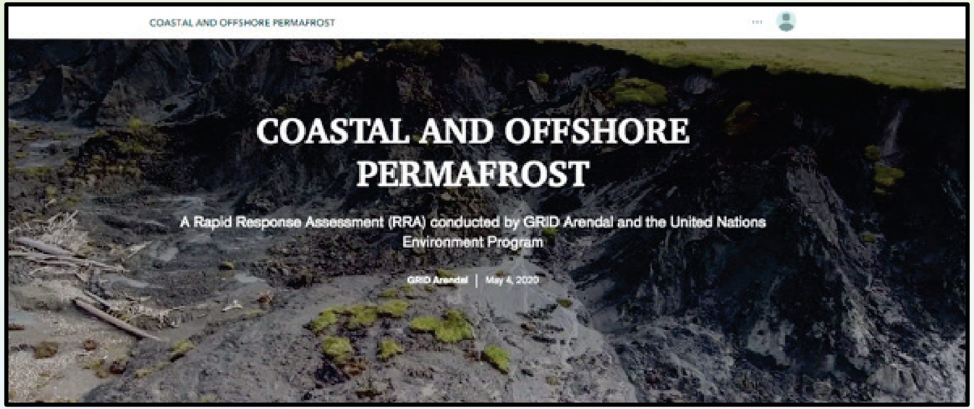
Ground sampling in support of remote sensing

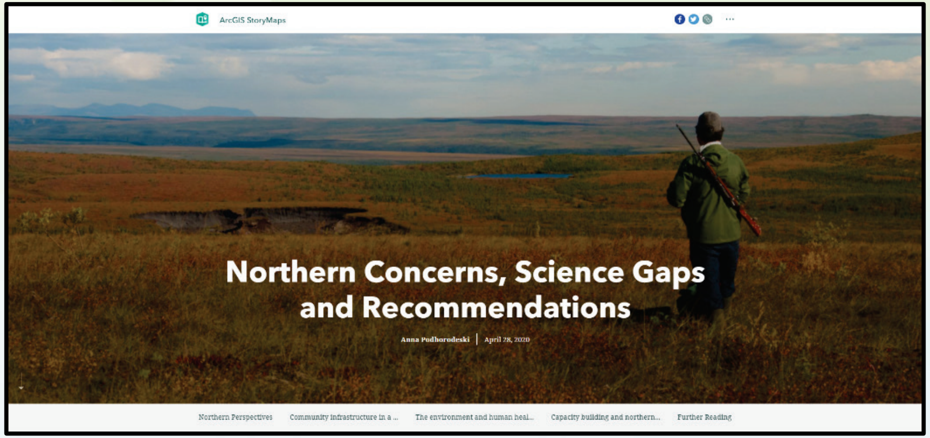
Monitoring of active methane seeps

Progress (May 2019 - May 2020)

United Nations Environment Program

Rapid Response Assessment on Coastal and Offshore Permafrost





http://coastalpermafrost.org/

Progress (May 2019 - May 2020)

Engagement and outreach –Tuktoyaktuk science day:

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Permafrost solute concentrations in an active gravel pit: Half-time results

Concentrations d'éléments dissous du pergélisol dans une gravière active : Résultats à mi-parcours

Paul Gammon

May 19, 2020

Canada

ABSTRACT

The geochemistry resulting from permafrost freeze-thaw processes are poorly understood. This EGP activity aims to refine our current understanding of these processes by investigating the geochemistry of a gravel pit associated with the building of the Inuvik to Tuktoyaktuk Highway (ITH). Construction-related water monitoring demonstrated that mining resulted in elevated concentrations for multiple elements in pit surface waters. Newly developed sampling techniques have added groundwater samples to surface water data. These demonstrate that there has been no amelioration of the high solute concentrations in either surface- or ground-water. The source of the high concentrations is local melting permafrost, although how the permafrost became so rich in solutes remains unclear. There are likely multiple ongoing water-rock interactions driven by these permafrost reactions. Unfortunately the water data is now orphaned because the companion ice could not be sampled due to COVID19 travel restrictions.

PROJECT MEMBERS

- Paul Gammon
- James Zheng
- Melissa Bunn
- Richard Amos (Carleton U.)

Sampling Challenges

Getting the timing right – sampling the chemistry at freeze-up

Groundwater freezes in sampling lines.

Hard to set bore at correct depth wrt permafrost.

The Research Site

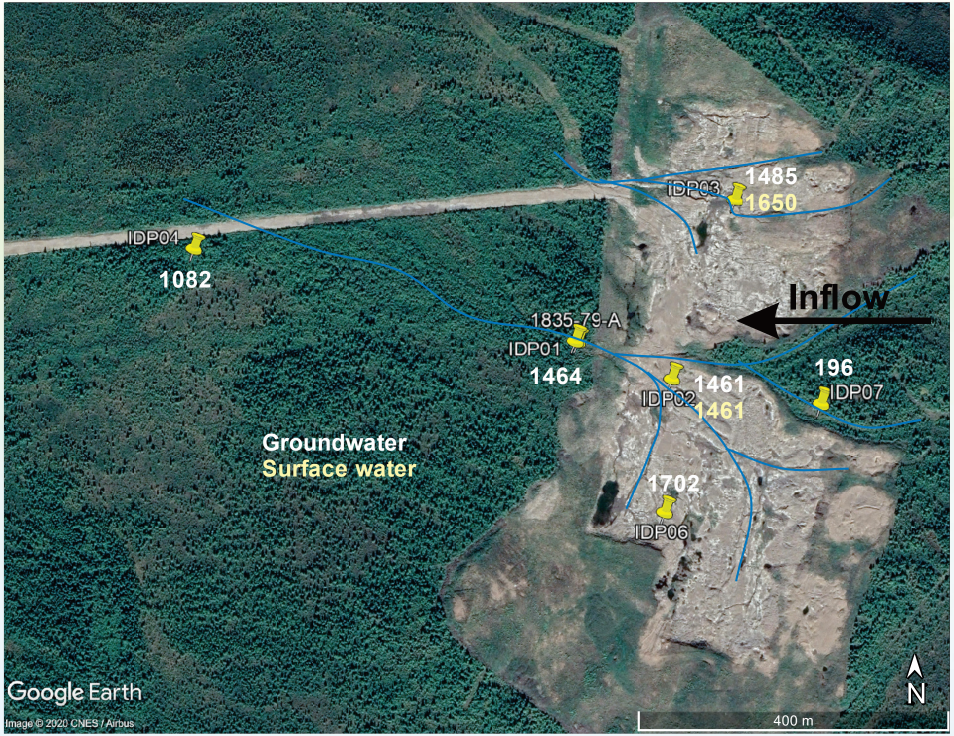


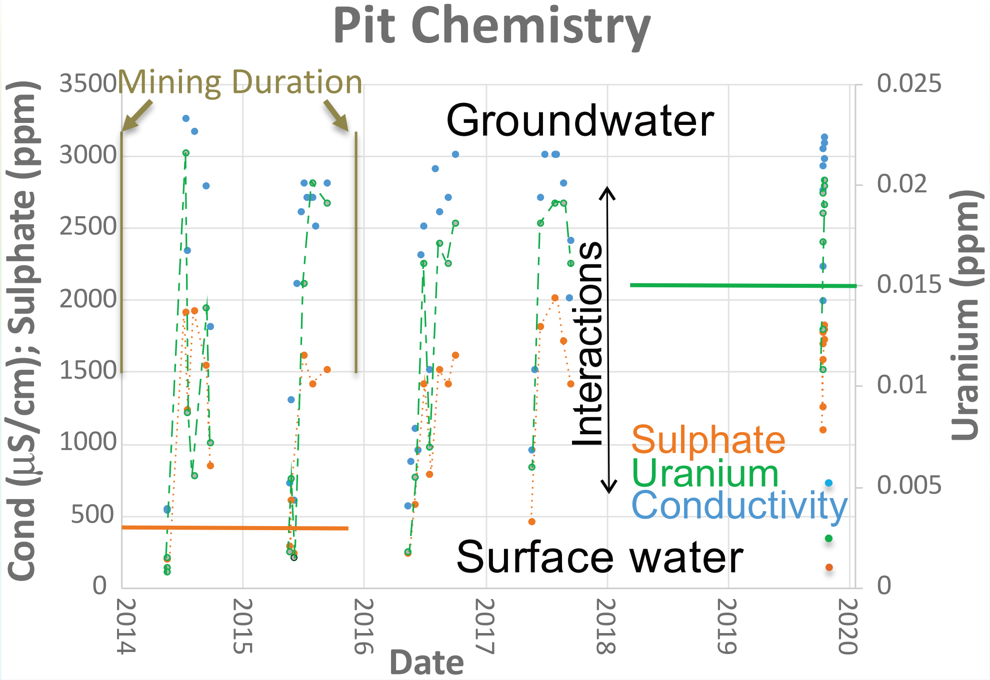
Image © 2020 CNES / Airbus

Inflow much lower concentration than outflow

Pit permafrost depth indicates substantial melting (inc. karst)

Sulphate chemistry indicates melting permafrost has high solute load.

Data: First half – water chemistry

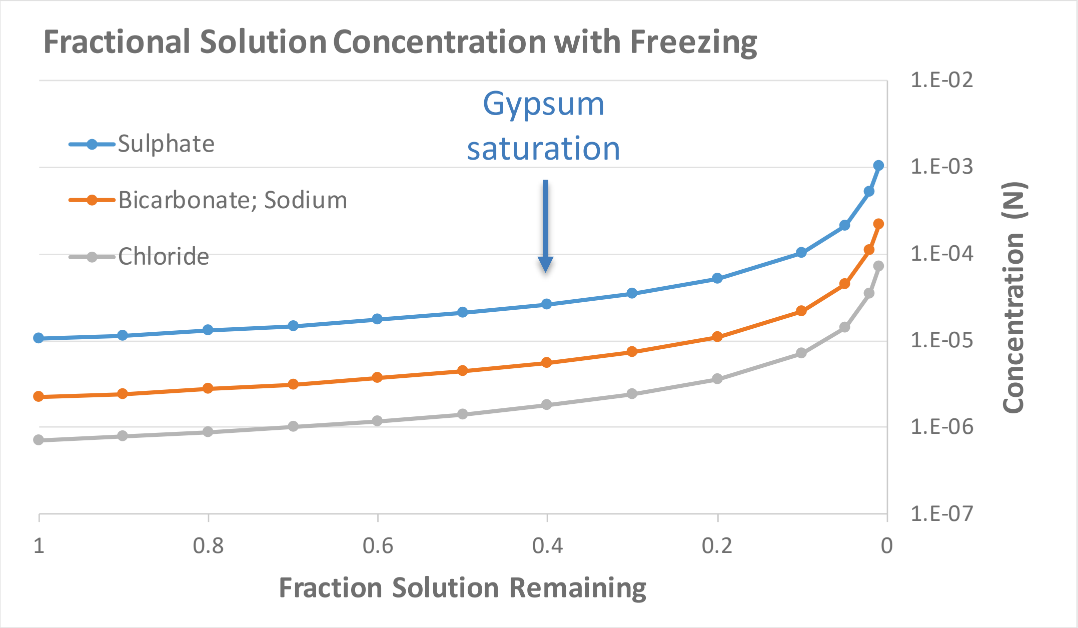


Solute concentrations for many elements above CCME guidelines

Concentrations have not decreased since mining ceased.

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

Data: First half – ice chemistry (possibly)



No ice chemistry due to COVID19 travel restrictions – so theoretical!

Model concentration curves suggest seawater salinities reached at ~90% freeze-up.

Gypsum saturation index high during freeze-up.

High salinity + bicarbonate spells trouble for clays, and buffers pH

Tentative Conclusions

- Permafrost melting likely the source of the high solute loads
  - How did the permafrost obtain those loads?
  - Groundwater dominates seasonal water chemistry.
- Seasonal phase transitions likely generate highly saline, CO_2-rich brines
  - Gypsum saturation suggests these brines generate significant water-rock interactions – which are poorly understood.
- The sampling techniques to solve these problems are now developed …

CONTACT INFORMATION

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THANK YOU!

Ressources naturelles Canada | Natural Resources Canada

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