Celebrating 175 yrs

Geological Survey of Canada
Scientific Presentation 70

Public presentations:
Environmental Geoscience Program,
current status of research projects

N. Jacob, J. Ahad, P. Gammon, C. Rivard, H. Kao, D. White, M. Parsons, and J. Galloway

2017

Celebrating 175 yrs

Public presentations: Environmental Geoscience Program, current status of research projects May 2017

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Environmental Geoscience Program (EGP) Public Presentations from coast to coast

To increase the program visibility, a public science presentation was offered to the entire department (NRCan) and key partners via Tandberg and NRCan live web on May 9th, 2017. All the Power Point presentations (7) are included in this report. Key words associated to the research are as follow: oil sands, groundwater, shale gas, induced seismicity, geological storage, critical metal deposits and geoscience tools.

Environmental Geoscience Program (EGP)
Public Presentations from coast to coast

Celebrating 175 yrs

SOURCES

SOurce apportionment Using isotope Ratio Characterization of oil sands Environmental Samples

Airborne contaminants – Northern Athabasca Oil Sands region

Sources des contaminants aériens dans l'environnement de la région des sables bitumineux

Jason M. E. Ahad, GSC-Québec

EGP Scientific Presentations, 9 May 2017

Abstract

A follow-up to the successful CORES Project (2009-2014), SOURCES (SOurce apportionment Using isotope Ratio Characterization of oil sands Environmental Samples; 2014-2019) is focused on the development and application of geochemical and isotopic methodologies to distinguish between natural and anthropogenic contaminants and to better understand processes controlling their distribution in Northern Alberta's Athabasca oil sands region. The project is divided into research projects centred on airborne and waterborne contaminants. The airborne component to SOURCES is examining inorganic nitrogen species (NH_3/NH_4 and NO_3) in air, soils and trees, and organic contaminants (polycyclic aromatic hydrocarbons – PAHs) in lake sediments and snow. The waterborne activity is focused on the surface water-groundwater interactions in areas potentially impacted by emissions from the large tailings ponds. The main contaminants of concern for the waterborne component are metals and naphthenic acids – a complex mixture of carboxylic acids found naturally in bitumen that become concentrated in oil sands process-affected water. As of spring 2017, most fieldwork required to support this research (both components) has been carried out. Analyses on PAHs in lake sediments and snow, nitrogen and nutrients in tree rings and soils, and metals and naphthenic acids in groundwater and surface water samples are ongoing.

Outline - Airborne Contaminants

Inorganic: N cycles: Air N species; N & nutrients in soils and trees

Organic: Polycyclic aromatic hydrocarbons (PAHs) in lake sediments and snow

- Analyses on PAHs in lake sediments and snow and N & nutrients in tree rings and soils are ongoing
- Presentation will include:
  - List of team members and main collaborators
  - Recent compilation and interpretation of isotopic triple ratios in air N species
  - Approach to sampling and dual ($\delta^{13}C$ and $\delta^{2}H$) isotopic characterisation of PAHs

Team

Jason Ahad (Que)
Christian Bégin (Que)
Jade Bergeron (Que)
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Paul Gammon (Ott)
Larissa Goh (Que)
Thamara Guzman (Que)
Marc Luzincourt (Que)
Joëlle Marion (Que)
Hooshang Pakdel (Que)
Hamed Sanei (Cal)
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Anna Smirnoff (Que)
Guillaume Tétrault (Que)

Partners

Service canadien des Forêt (Québec)
Northern Forestry Center (Edmonton)

Natural Resources Canada | Ressources naturelles Canada

Air Quality Research Division

Environment and Climate Change Canada | Environnement et Changement climatique Canada

INRS Université d'avant-garde

Alberta Environment and Parks

N cycle: Air Nitrogen species in Alberta

Southern and Central Alberta N-species to be compared with OS data previously published

What (objectives)

- **Help understand processes controlling distribution of ambient NH_3/NH_4 and NO_3**
- **Support development of effective emission reduction strategies**

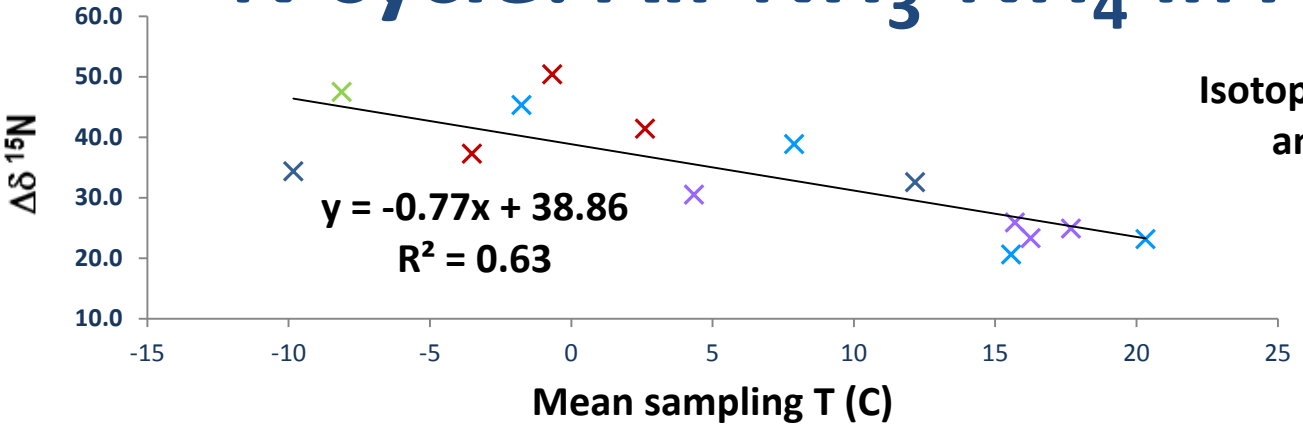
Why? Air N contaminants may…

- ***Cause acidification of aquatic and terrestrial ecosystems***
- ***Have a negative impact on human health***
- ***Influence climate dynamics***

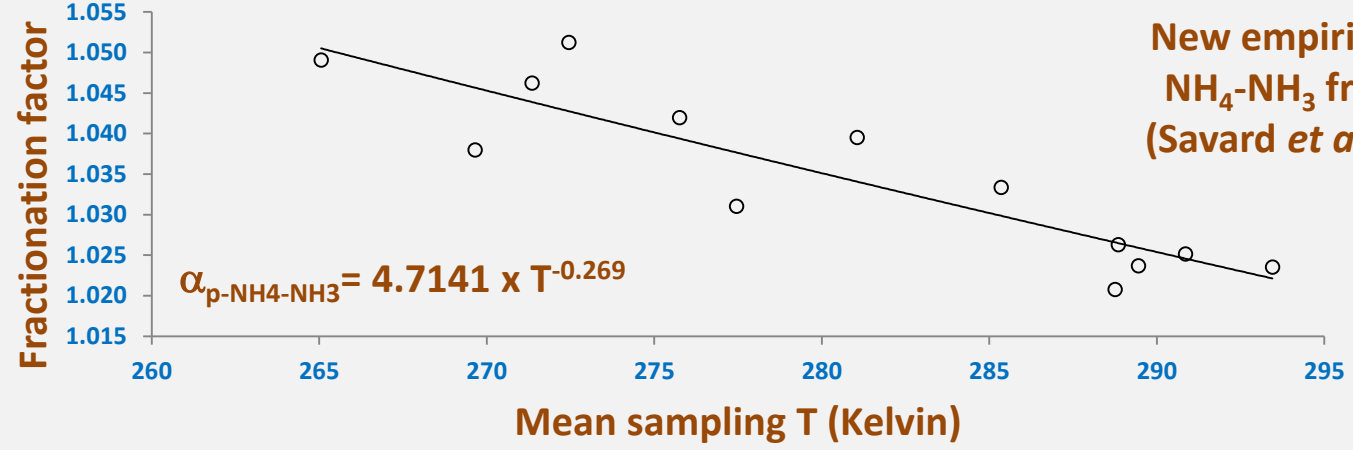
So What?

- **First full isotopic characterization of multiple air N-species in Canada**
- **New perspective on triple isotopic ratios of N-species as source indicators**

N cycle: Air NH_3-NH_4 in Alberta



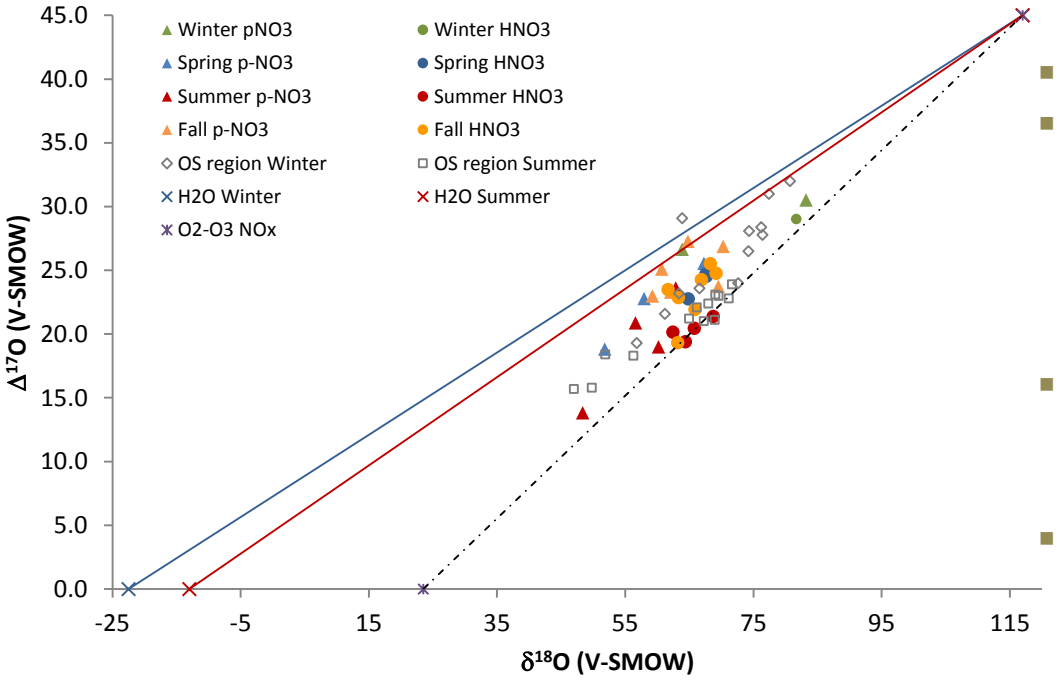
Isotopic departure between p-NH_4 and NH_3 correlates with T



New empirical relationship between NH_4-NH_3 fractionation factor and T (Savard *et al.* Atmos. Env., accepted)

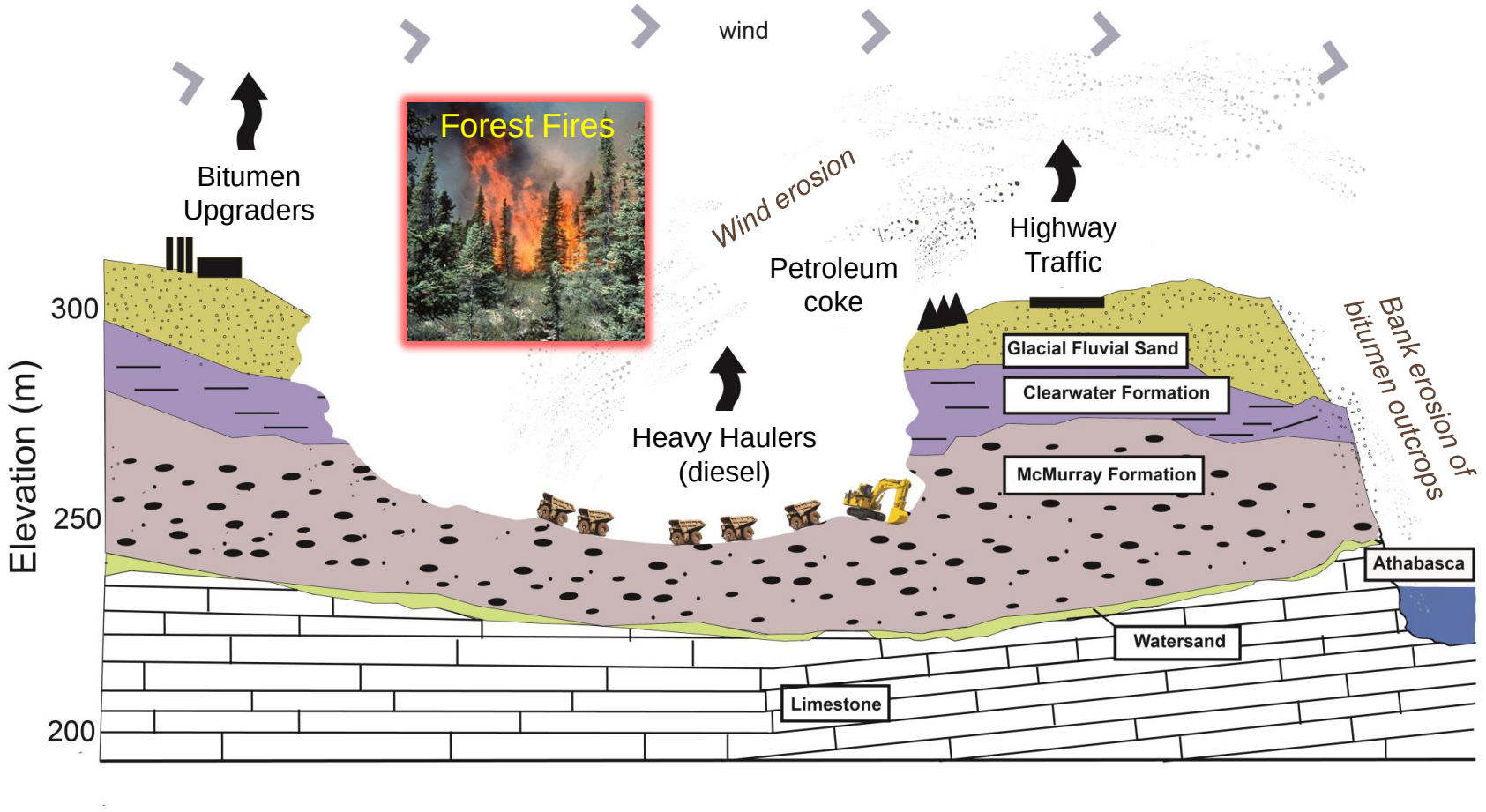
Canada

N cycle: Air HNO_3 & p-NO_3 in Alberta



- **Seasonal effects on O isotope ratios**
- **NOx transformation through two dominant chemical pathways:**
  - ***OH-N_2O (daytime & summer), and***
  - ***N_2O_5-H_2O (nighttime & winter)***
- **Coal-fired power plants, urban, industrial and OS stack emissions show common pathways**
- **No source fingerprinting possible with ^{17}O (Savard *et al.* in prep.)**

Potential sources of PAHs in the AOS region



Source apportionment of PAHs in AOS region: The importance of petcoke versus other sources

Environmental Science & Technology

Sept 2015

Article

pubs.acs.org/est

Isotopic Evidence for Oil Sands Petroleum Coke in the Peace–Athabasca Delta

Josué J. Jautzy,[†] Jason M. E. Ahad,[*,‡] Charles Gobeil,[†] Anna Smirnoff,[‡] Benjamin D. Barst,[†] and Martine M. Savard[‡]

[†]INRS Eau Terre Environnement, Québec, Québec G1K 9A9, Canada

[‡]Geological Survey of Canada, Natural Resources Canada, Québec, Québec G1K 9A9, Canada

Environmental Science & Technology

Jan 2016

Article

pubs.acs.org/est

Airborne Petcoke Dust is a Major Source of Polycyclic Aromatic Hydrocarbons in the Athabasca Oil Sands Region

Yifeng Zhang,[†] William Shotyk,[‡] Claudio Zaccone,[§] Tommy Noernberg,[‡] Rick Pelletier,[‡] Beatriz Bicalho,[‡] Duane G. Froese,[∥] Lauren Davies,[∥] and Jonathan W. Martin[*,†]

[†]Department of Laboratory Medicine and Pathology, University of Alberta, Edmonton, Alberta, Canada, T6G 2G3

[‡]Department of Renewable Resources, University of Alberta, 348B South Academic Building, Edmonton, Alberta, Canada, T6G 2H1

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Importance of *in situ* operations?

Contents lists available at ScienceDirect

Environmental Pollution

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

In-situ bitumen extraction associated with increased petrogenic polycyclic aromatic compounds in lake sediments from the Cold Lake heavy oil fields (Alberta, Canada)☆

Jennifer B. Korosi [a, 1], Colin A. Cooke [b, c], David C. Eickmeyer [a], Linda E. Kimpe [a], Jules M. Blais [a, *]

[a] 30 Marie Curie Pvt., Department of Biology, University of Ottawa, Ottawa, Ontario, K1N 6N5, Canada

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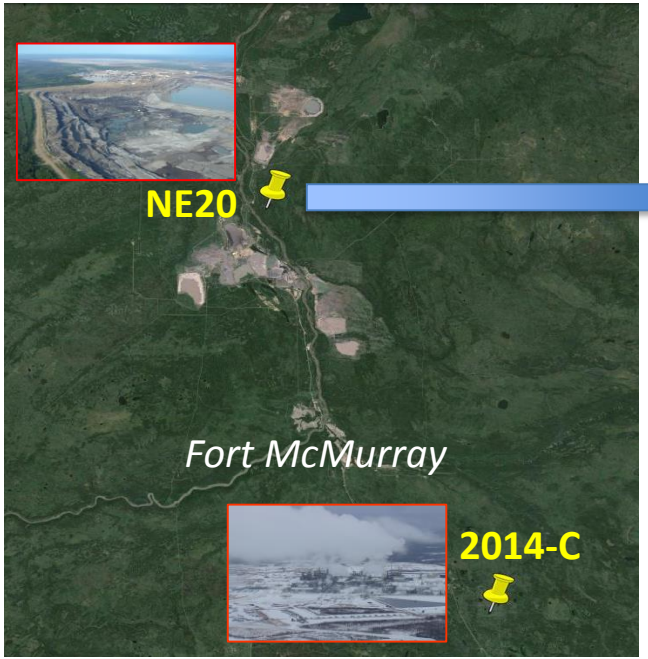
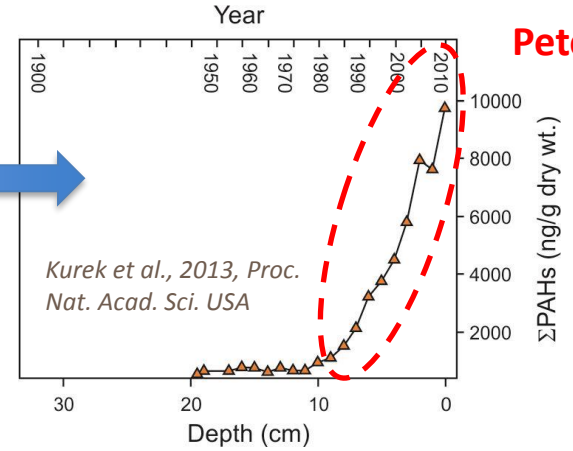
[c] Department of Earth and Atmospheric Sciences, 1-26 Earth Sciences Building, University of Alberta, Edmonton, Alberta, T6G 2E3, Canada

Aug 2016

Natural Resources Canada | Ressources naturelles Canada

Lake sediments: Natural archives for historical inputs

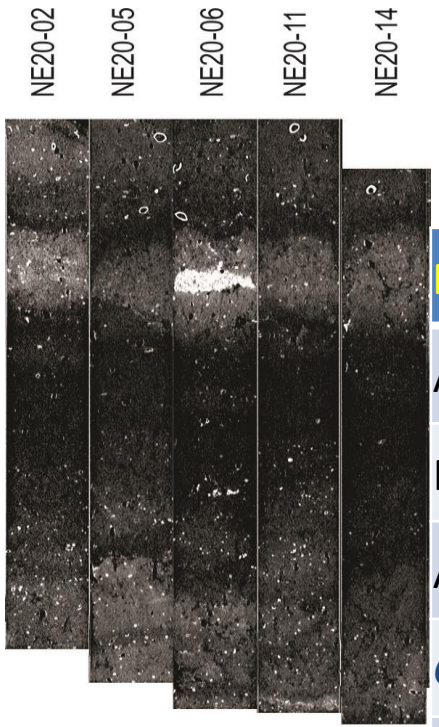




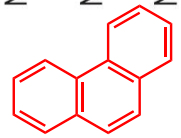
Petcoke, dust, upgraders, trucks?

~ 60 sediment cores collected in March 2016

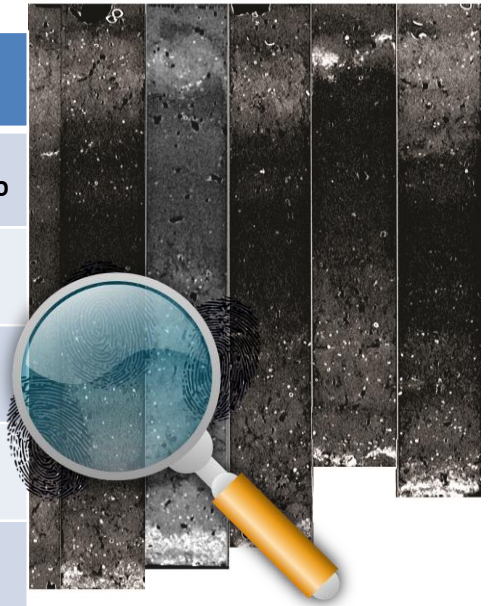
Need to properly align cores: (ex: CT Scan analyses)



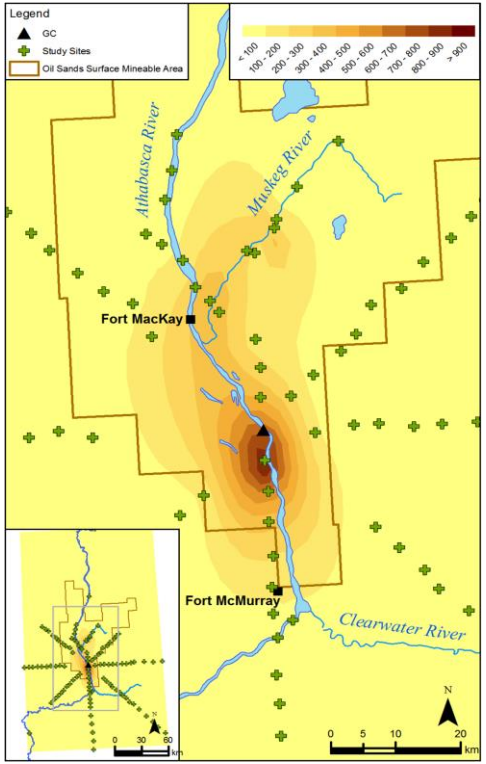
e.g., phenanthrene



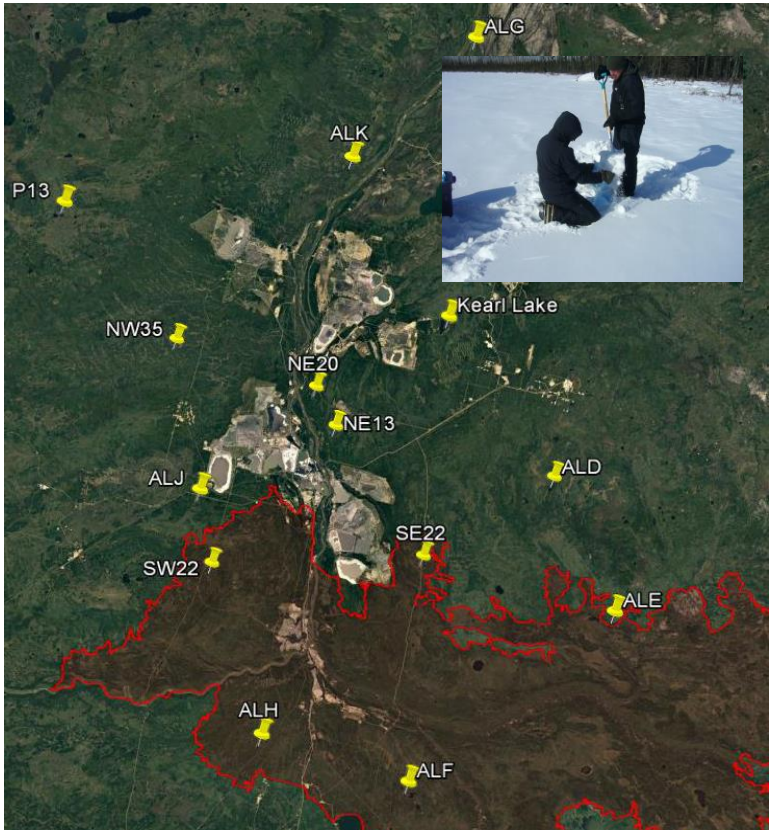
Potential Source	$\delta^{13}C$ (‰)	$\delta^{2}H$ (‰)
AOS bitumen	-30.2 ±0.3‰	-138.5 ±2.5‰
Forest fire	-26.7 ±0.3‰	-96.2 ±1.1‰
AOS petcoke	-32.6 ±0.5‰	-48.5 ±3.8‰
Gasoline soot	*-26.5 ± 0.5‰*	*-61.5 ±3‰*
Diesel soot	*-25.3 ±2.3‰*	*n.a.*



Contribution to surface sediments: Snow sampling, February 2017



Cho et al., 2014, Wat, Air & Soil Poll.



Sample	Dust mg/L
P13	2
ALD	8
ALG	8
ALE	9
NW35	14
ALF	15
SW22	15
Kearl	21
ALH	24
ALK	27
ALJ	34
SE22 bottom	54
NE13	71
SE22 surf	126
NE20	133

CONTACT INFORMATION:

- Martine M. Savard / Jason M. E. Ahad
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Thank you!!

Celebrating 175 yrs

SOURCES:
Waterborne Transport

Paul Gammon

May 9th, 2017

ABSTRACT

A follow-up to the successful CORES Project (2009-2014), SOURCES (SOurce apportionment Using isotope Ratio Characterization of oil sands Environmental Samples; 2014-2019) is focused on the development and application of geochemical and isotopic methodologies to distinguish between natural and anthropogenic contaminants and to better understand processes controlling their distribution in Northern Alberta's Athabasca oil sands region. The project is divided into research projects centred on airborne and waterborne contaminants. The airborne component to SOURCES is examining inorganic nitrogen species (NH_3/NH_4 and NO_3) in air, soils and trees, and organic contaminants (polycyclic aromatic hydrocarbons – PAHs) in lake sediments and snow. The waterborne activity is focused on the surface water-groundwater interactions in areas potentially impacted by emissions from the large tailings ponds. The main contaminants of concern for the waterborne component are metals and naphthenic acids – a complex mixture of carboxylic acids found naturally in bitumen that become concentrated in oil sands process-affected water. As of spring 2017, most fieldwork required to support this research (both components) has been carried out. Analyses on PAHs in lake sediments and snow, nitrogen and nutrients in tree rings and soils, and metals and naphthenic acids in groundwater and surface water samples are ongoing.

INTRODUCTION

- Understanding the processes controlling waterborne transport of potential emissions in the region.
- Tracing water movement through environments.
  - Hydrology - hydrogeology
  - Reactive transport
- Fingerprinting diverse input SOURCES within the waterborne load.
  - Geochemistry
  - Apportioning natural versus anthropogenic waterborne loads

PROJECT MEMBERS

Sources team

Paul Gammon (GSC-N)
Jason Ahad (GSC-Q)
Martine Savard (GSC-N)
James Zheng (GSC-N)
Isabelle Girard (GSC-N)
Pierre Pelchat (GSC-N)
John Sekerka (GSC-N)
Prof. Richard Amos (Carleton U.)
Sam Morton (PhD., Carleton U.)
Stephanie Roussel (MSc., Carleton U.)
Prof. Anh Pham (Carleton U.)
Prof. Tom Al (U. Ottawa)

Partners:

Government:

Environment and CC Canada

- Water Science and Technology Division

Alberta Environment and Parks

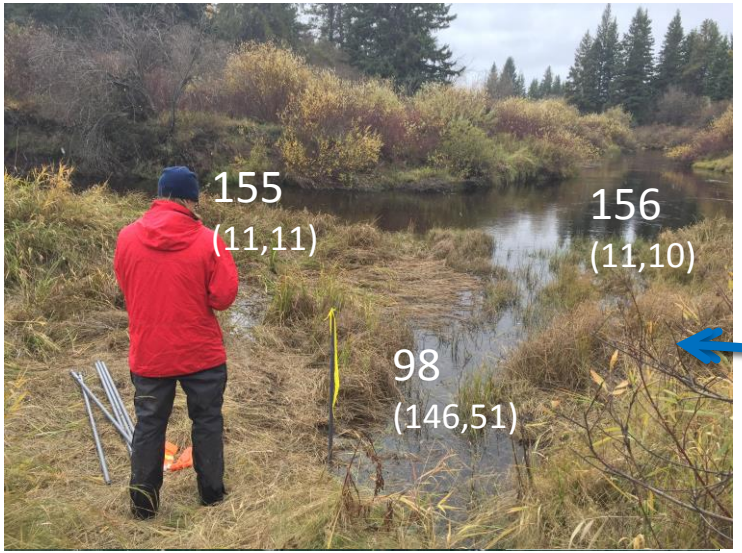
Universities:

Carleton U.; U. Ottawa; U. Alberta, U. Québec;

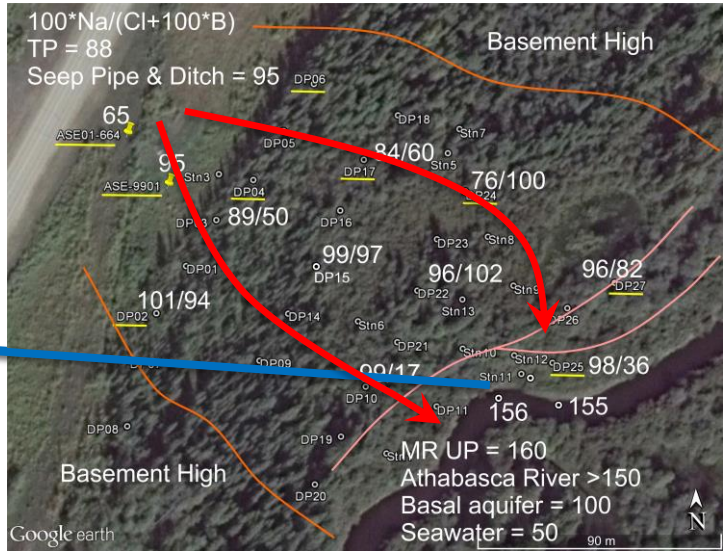
Industry:

COSIA; Shell Canada Ltd.; Syncrude Canada Ltd.

Transport Flux: Muskeg River Hydrology



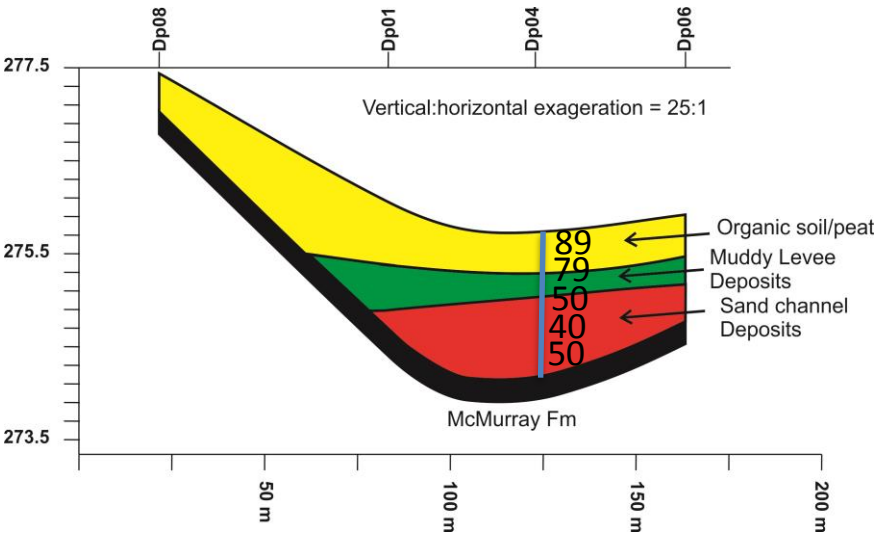
Groundwater seep with TP geochemical signature.



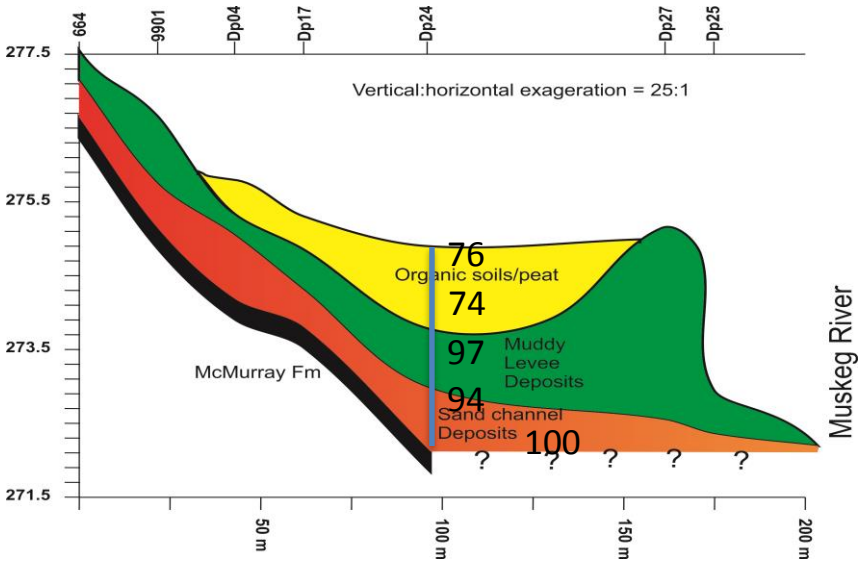
Index suggests groundwater derived from same source as TP.

Minimal impact on River.

Transport flux: Groundwater Hydrogeology

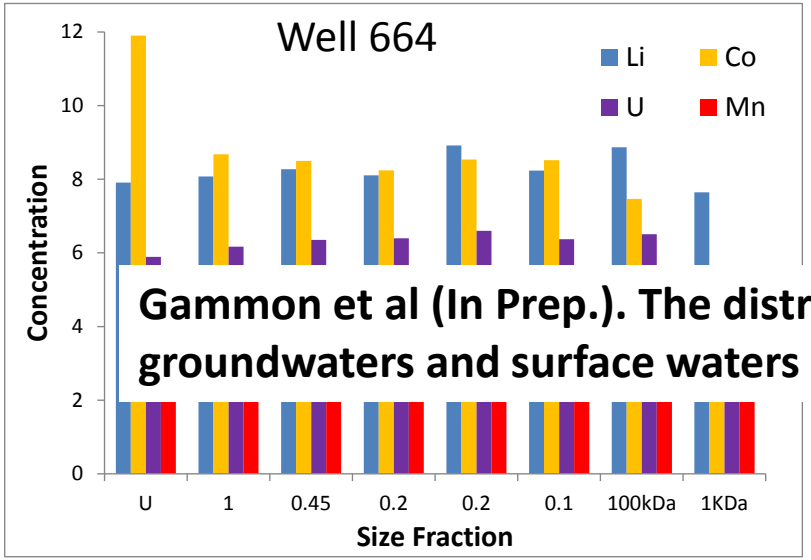


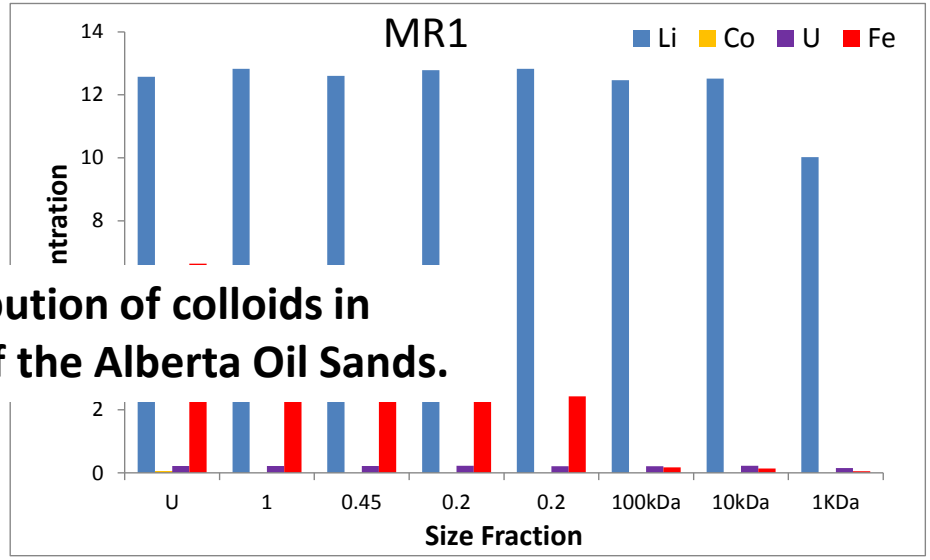
Transverse section. Shallow channel sand aquifer over impermeable McMurray Fm



Longitudinal section. Gyttja is a ponded hydrogeological unit. Sand connected to Muskeg River.

Sources: Hydrogeochemistry & Colloidal transport



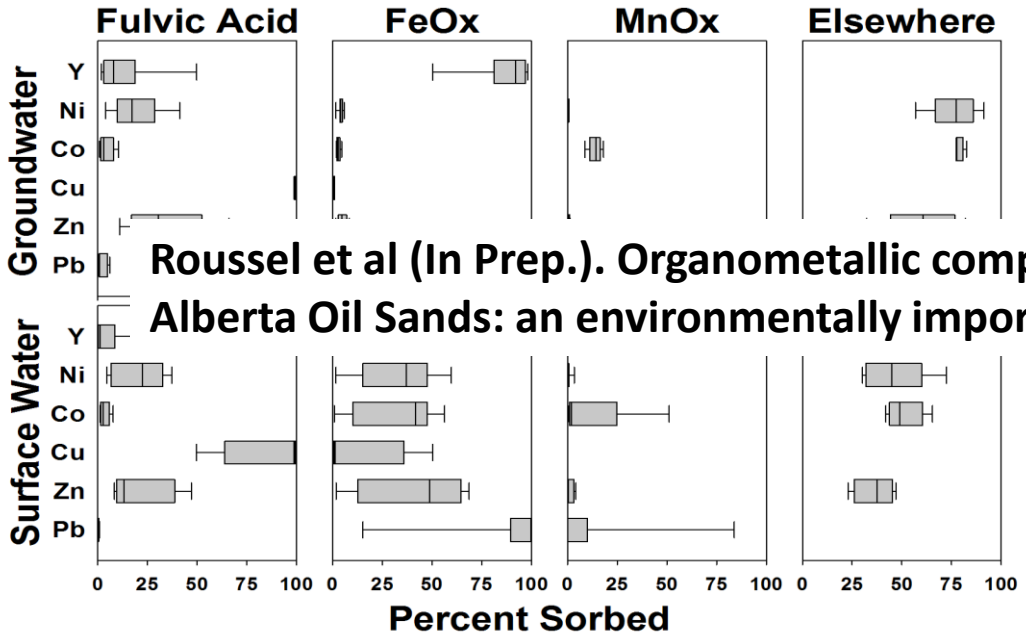


Gammon et al (In Prep.). The distribution of colloids in groundwaters and surface waters of the Alberta Oil Sands.

Reduced groundwater. Oxyhydroxide dissolution enhances trace metal transport. No significant colloids until >1kDa in size (i.e. colloids <~0.5 nm).

Oxidised surface water. Strong trace metal attenuation (sorption). Oxyhydroxide colloids >100kDa. Minor Li and U attenuation at 1kDa.

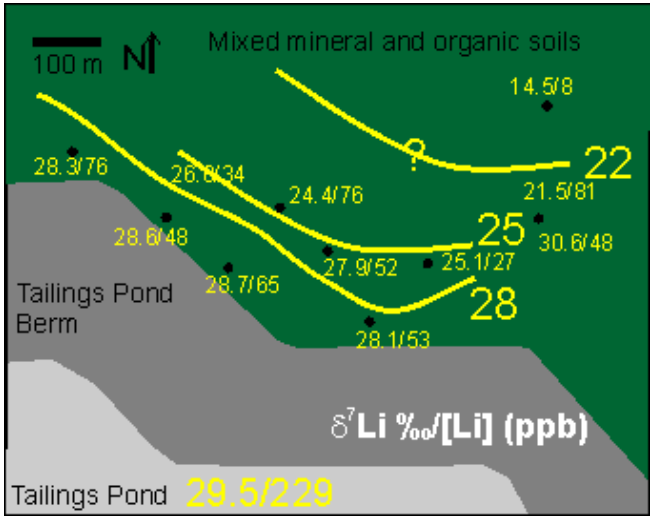
Sources: Organometallic transport



Roussel et al (In Prep.). Organometallic complexes in the Alberta Oil Sands: an environmentally important component

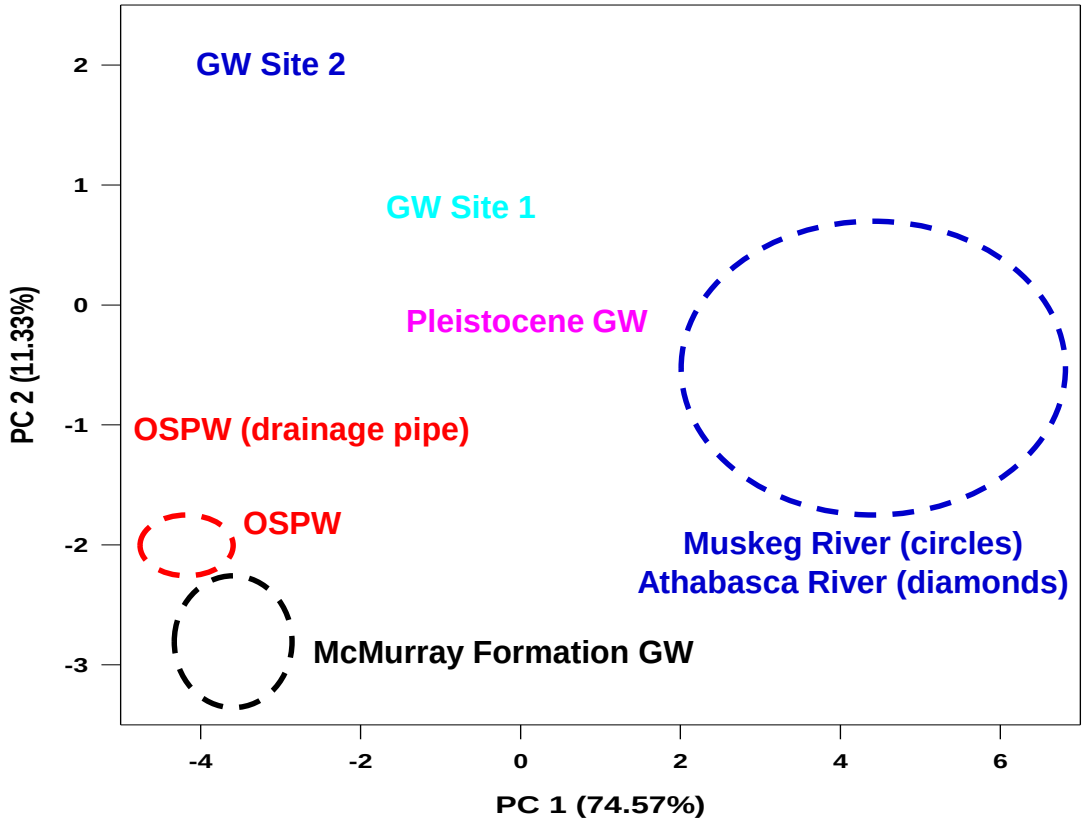
- Organometallics in groundwaters and surface waters modelled using WHAM7 and PHREEQC.
- Orbitrap data constrained dissolved AEO fractions as fulvic acids.
- c complexes are significant if not dominant in these muskeg regions.
- First attempt for muskeg waters?
- Not currently assessed in monitoring programs.

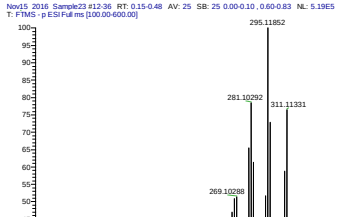
Sources: Fingerprinting via metal Isotopes



- ALMOST THERE - Clean Lab renovations
  - Originally scheduled for 3 months
  - Currently 15 months (and counting)

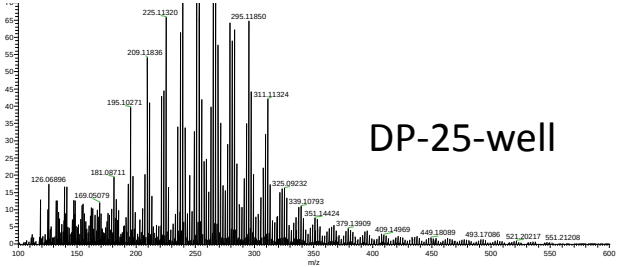
Sources: Identifying bitumen-derived AEOs?





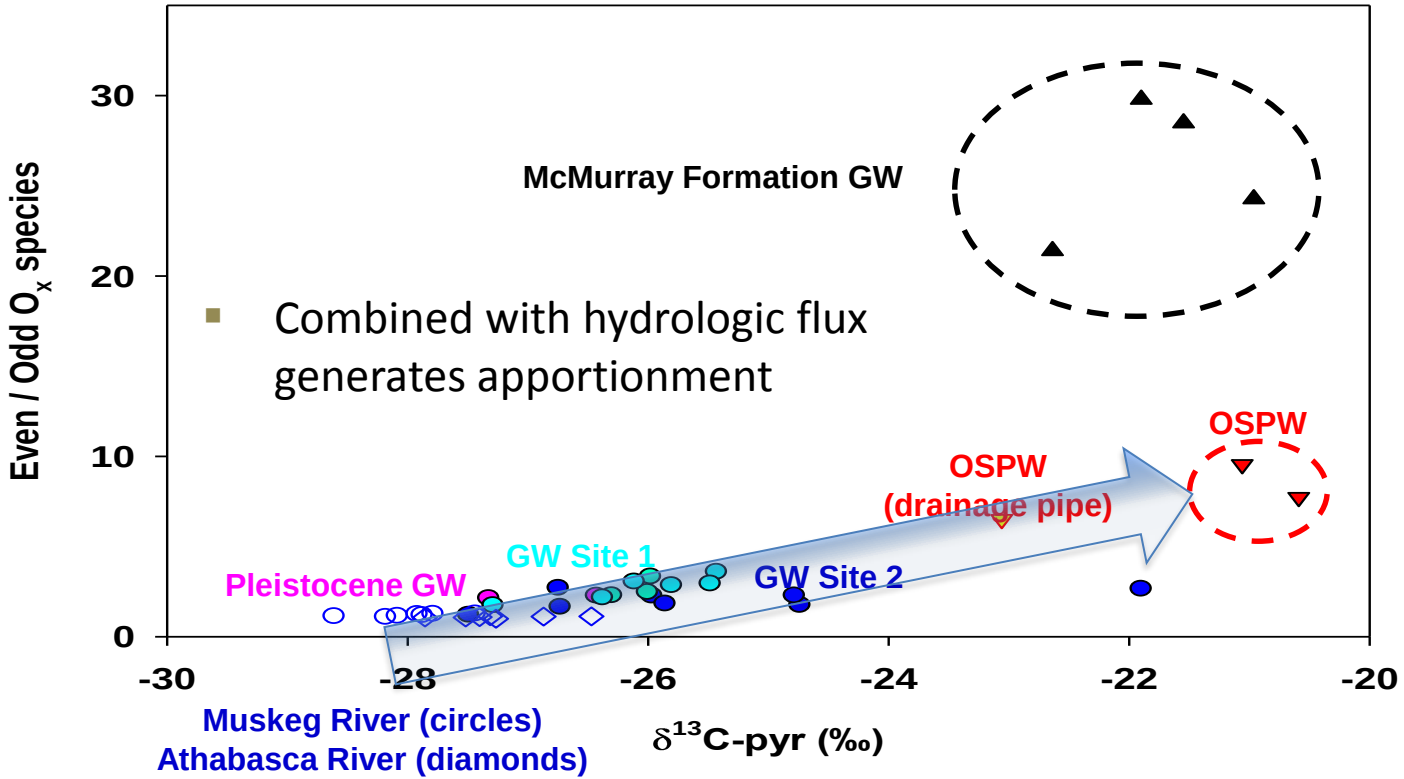
MR1023

Component scores for *Principal Component Analysis* of O, O_2, O_3, O_4, O_5, O_6, O_7, O_8, O_9, O_{10}, N_x, N_xS_x, N_xO_x, $N_xO_xS_x$, O_xS_x and S_x species

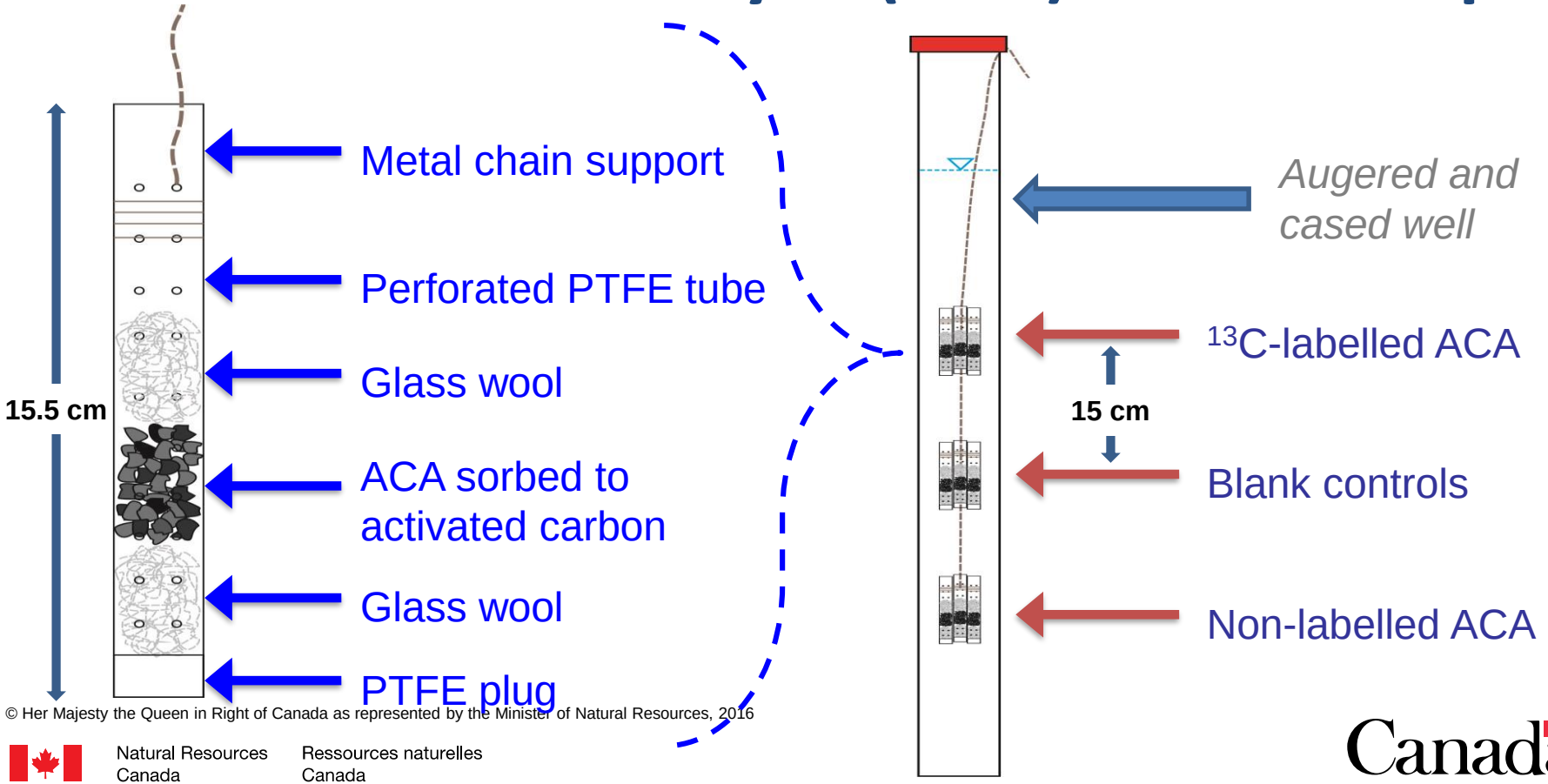


DP-25-well

Sources: Fingerprinting using O_x & $d^{13}C$

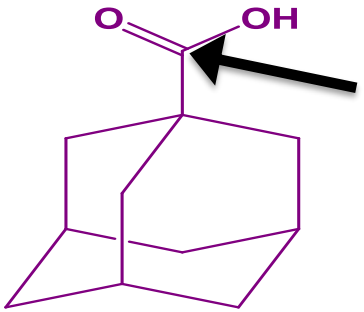


Adamantane carboxylic (ACA) acid biotraps



Attenuation of NA's in shallow groundwater

A higher molecular weight "naphthenic acid" previously detected in oil sands process-affected water(Rowland et al., *ES&T*, 2011)



^{13}C (99%)

1-ADAMANTANE CARBOXYLIC ACID

- **Oct 2016**: "Biotraps" seeded with ^{13}C-labelled adamantane carboxylic acid lowered into subsurface for two months
- **Mar 2017:** Microbial community analysis (University of Alberta)
- **May 2017:** δ^{13}C analysis of PLFAs → ^{13}C-enrichment provides direct evidence for *in situ* biodegradation of "naphthenic acids"

CONTACT INFORMATION

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THANK YOU!

Celebrating 175 yrs

Assessing groundwater vulnerability to shale gas activities in the Sussex area, southern New Brunswick

Évaluation de la vulnérabilité des aquifères à l'exploitation du gaz de shale dans la région de Sussex dans le sud du Nouveau-Brunswick

CHRISTINE RIVARD

May 9th, 2017

NATURAL RESOURCES CANADA - INVENTIVE BY NATURE

ABSTRACT

A project studying potential hydrocarbon migration through natural pathways or fracking-induced fractures from deep (~2 km) Carboniferous shale or tight sand units to shallow aquifers was initiated in 2015 in the Sussex area, southern New Brunswick. The study area includes the McCully gas field that has been in production since 2001 and the Elgin field that is investigated for its condensate potential. Because the intermediate zone located between shallow aquifers and units targeted for hydrocarbon production is poorly characterized, this project relies on the integration of data from different earth science disciplines, including geology, geophysics, geomechanics, hydrogeology and water and rock geochemistry.

Fieldwork in 2016-2017 comprised the drilling of observation wells, borehole geophysics, hydraulic tests and groundwater and rock sampling. Initial groundwater chemistry shows that only a few wells contain methane (< 5 mg/L) with either a thermogenic (McCully gas field) or a microbial (Elgin area) signature. One well in the McCully gas field showed some ethane in groundwater, as well as small amounts of gaseous methane in core samples, while drill cuttings revealed the presence of long-chain hydrocarbons. Rock-Eval analyses of shallow cores showed very low S1, S2 and TOC values, except for that specific well. 3-D seismic data have been reprocessed and the resulting geological interpretation revealed that faults are mostly confined within the Horton Group, where the two units targeted by the industry are located. In addition, the geomechanical study concluded that the intermediate zone provides an effective barrier to induced fractures, based on well logs. The development of numerical groundwater flow models (from 1D to 3D) is ongoing. This study will provide a scientific basis to support informed decisions by provincial authorities on future hydrocarbon development.

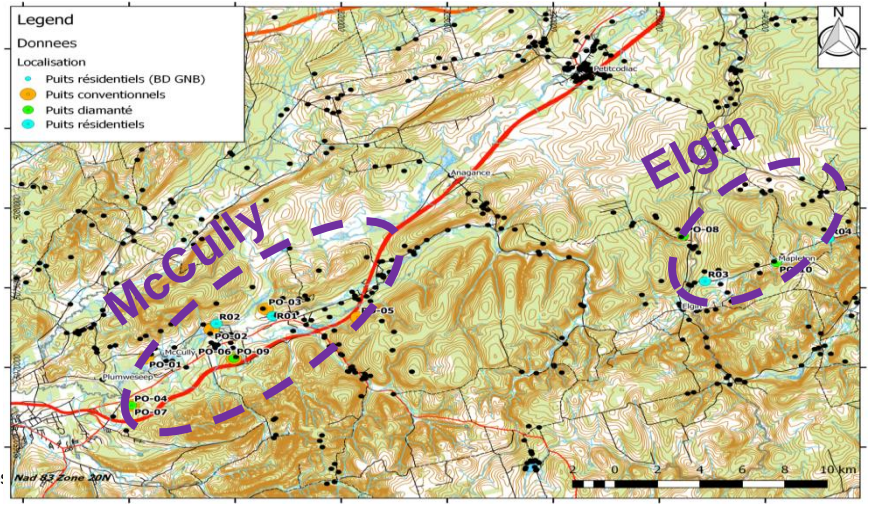
PROJECT MEMBERS

Christine Rivard, research scientist in hydrogeology
Denis Lavoie, research scientist in geology
Geneviève Bordeleau, research scientist in geochemistry
Xavier Malet, technician and database manager
Mathieu Duchesne, research scientist in seismic reflection
Gilles Bellefleur, research scientist in seismic reflection (GSC-Ottawa)
Nicolas Pinet, research scientist in structural geology – seismic reflection
Virginia Brake, geophysicist
Stephan Séjourné, structural geologist and geomechanics (Consultant)
Heather Crow, borehole geophysicist (GSC-Ottawa)
Dennis Jiang, research scientist in rock geochemistry (GSC-Calgary)
René Lefebvre, professor in hydrogeology at INRS
Tom Al, professor in hydrogeochemistry at U of Ottawa
Pierre Ladevèze, research scientist in geology
François Huchet (INRS) and David Barton (U Ottawa), M.Sc. students
Darryl Pupek and Mallory Gillis, hydrogeologists (NBDELG) ; Steve Hinds, geologist (NBDEM)
Tom Martel and John Comeau (Corridor Resources)

Introduction

The study area comprises two sub-regions

- McCully gas field: in production since 2001
- Elgin area (prospected): condensates (ethane, propane and butane)
- Duration: 2015-2019 (4 years)



39 gas wells

Introduction

Potential links between deep geological units targeted by the industry and surficial aquifers are not well documented.

A natural connection is presumed possible only if permeable discontinuities are present (e.g., fault zones) providing a preferential migration pathway.

Few data available

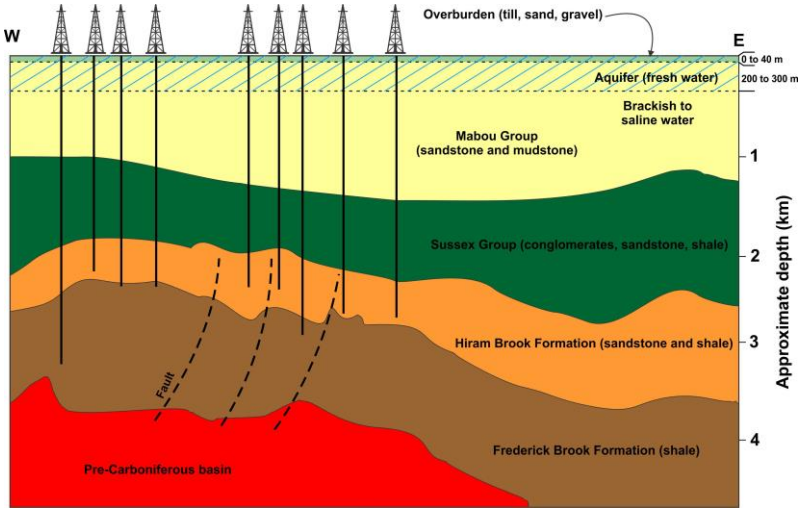
Use of indirect data

geophysical, geomechanical, hydrogeological and geochemical

Surficial aquifers

Intermediate zone (caprock)

Zone targeted by the industry



Introduction

Objective : To investigate potential natural migration pathways, which could be enhanced by hydraulic fracturing, to assess aquifer vulnerability.

Dissolved methane can be naturally present in groundwater in variable concentrations.

Two types of gas:

1) **microbial**: produced by microorganisms near the surface (from acetate fermentation or reduction of CO_2)
2) **thermogenic**: produced by thermal degradation of old organic matter

➡ Can come from different depths

Project St-Édouard

Fieldwork

Drilling of 10 conventional and diamond-drilled wells

- Core sampling
- Borehole geophysics
- Hydraulic tests (« slug tests »)
- GW sampling
- GW monitoring every 4 months
- Installation of sensors (water levels and TDGP)

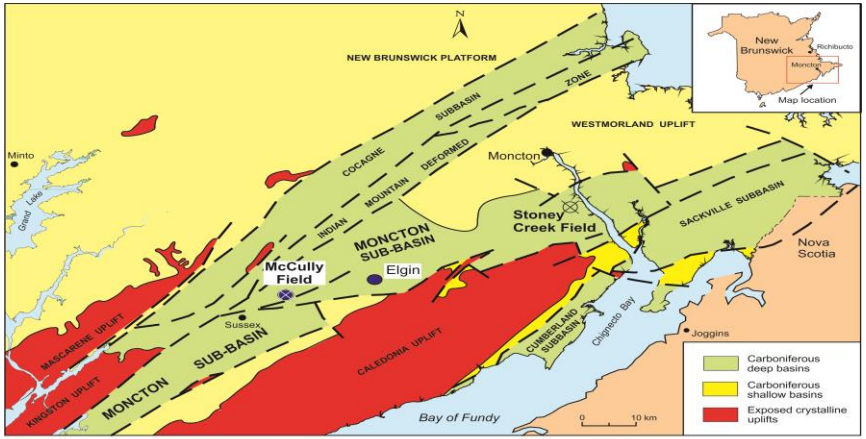
GW sampling in residential wells (6)

Permeability tests in surficial deposits

Fracture characterization (outcrops)

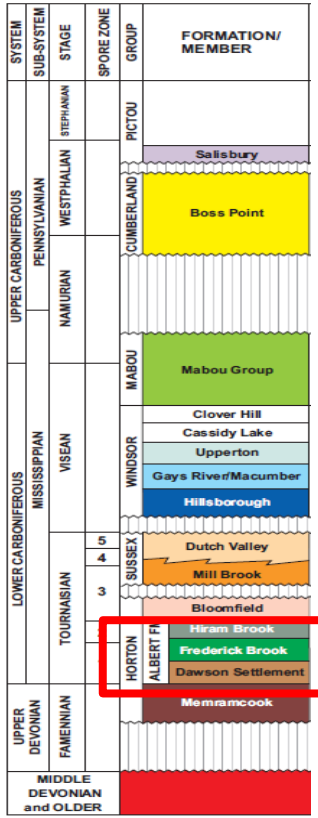
Geological context

39 gas wells completed in tight sandstone and shale



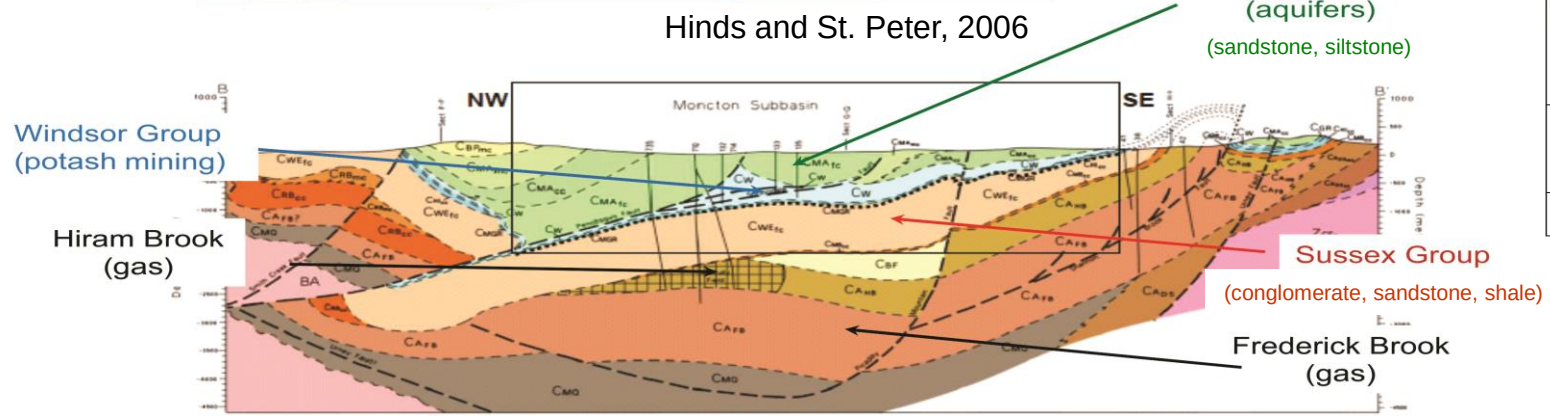
Hinds and St. Peter, 2006

Wells > 2000 m



Mabou Group (aquifers)

(sandstone, siltstone)

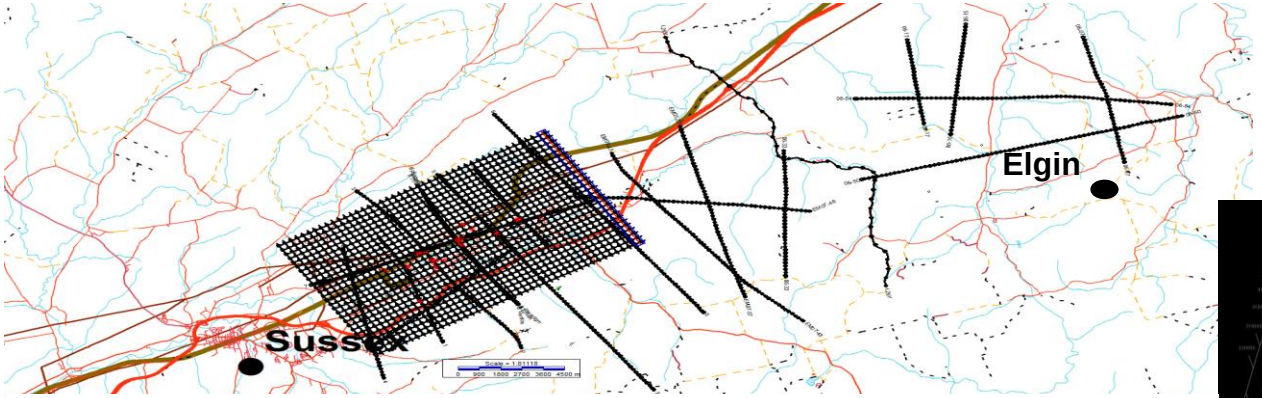


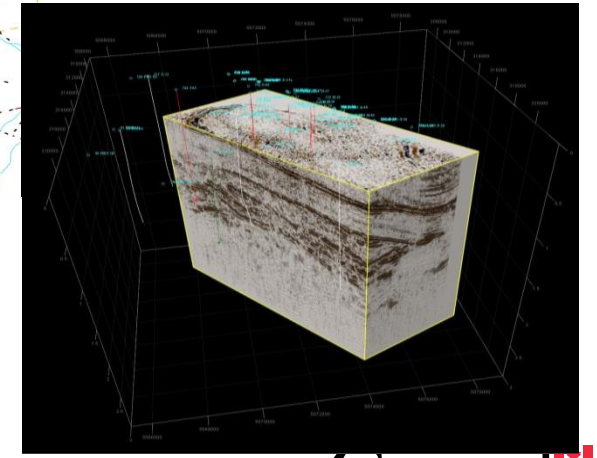
Canada

2D and 3D seismic

Data are numerous and of good quality:

- Seismic surveys carried out between 2000 and 2008
- 3D total area: 104 km^2 (8 x 13 km) with data collected every 3 sec (up to ~6.4 km)

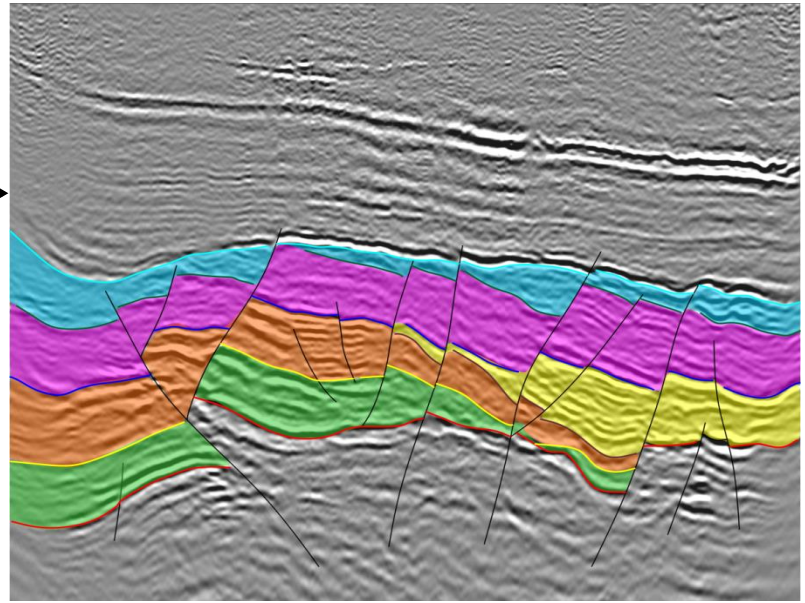




- ✓ Processing of 3D data completed and ready for the geological interpretation and geomechanical inversion;
- ✓ Time-depth curve construction for wells to be projected into the model is also completed;
- ✓ Geomechanical inversion will begin soon.

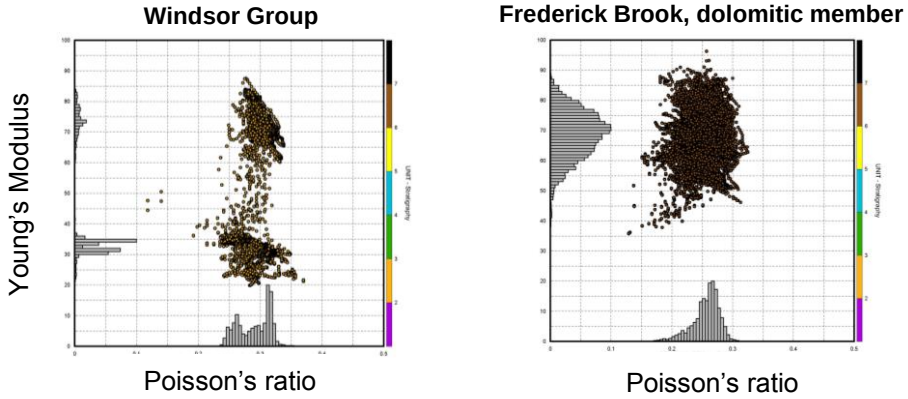
Geological interpretation from 3D seismic data (McCully gas field)

- The evaporite layer varies in thickness, but is present everywhere ➡ good protection
- The upper part of the Sussex Group does not seem to be affected by major brittle structures
- Faults appear to be present in the Horton Group



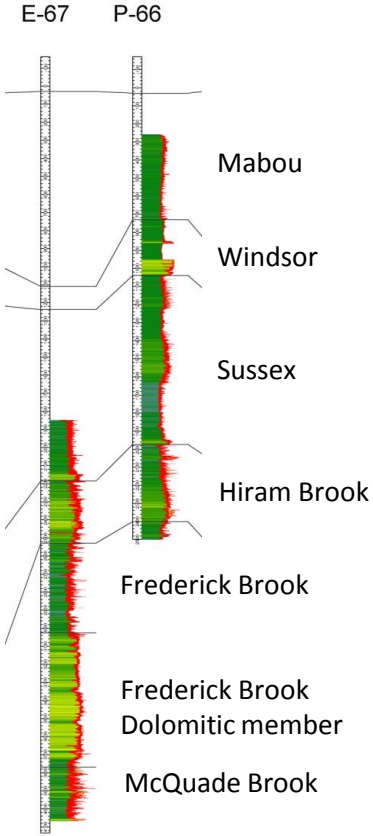
Geomechanics and petrophysics

Geomechanical property assessment



The intermediate zone seems to provide an efficient barrier due to the presence of layers with a low brittleness index

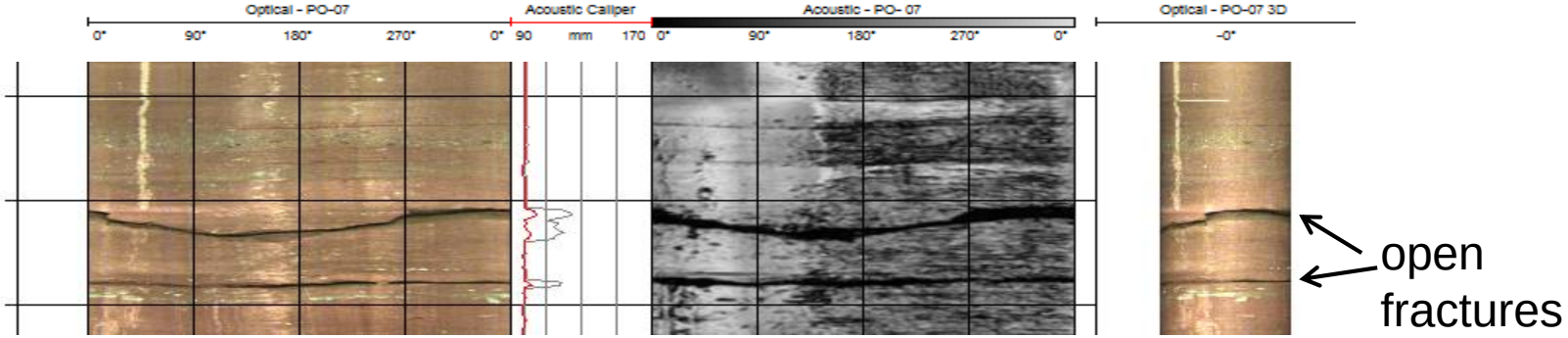
limited propagation of induced fractures



Poisson's ratio
Young's Modulus
Brittleness index
Sh_{min}
from 26 wells

Borehole geophysics and hydraulic tests

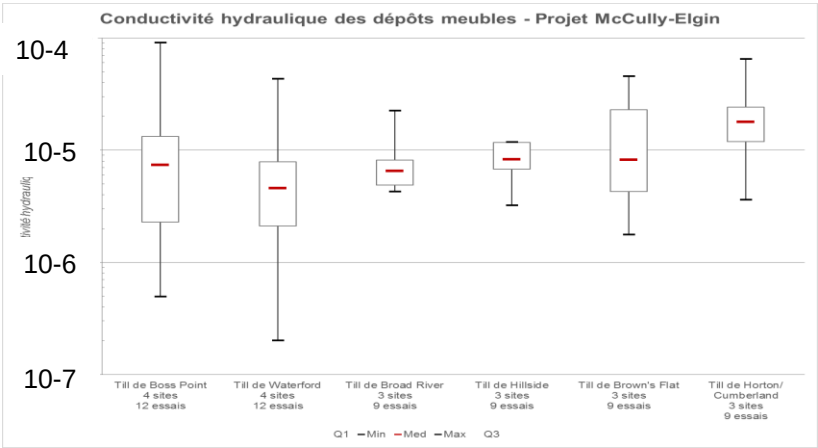
Borehole geophysics and « slug tests » carried out in observation wells



Sandstone ~ permeable: $10^{-6} < K < 10^{-4}$ m/s

Guelph permeameter tests in unconsolidated sediments:

Tills ~ permeable (similar K)

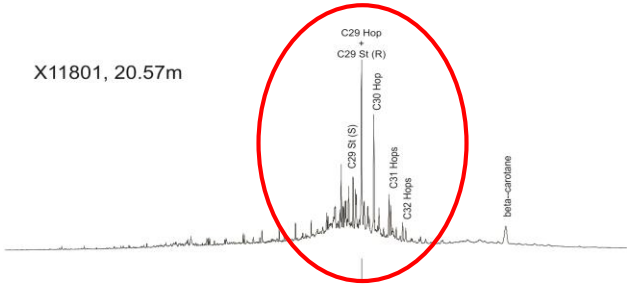


Rock organic geochemistry

Rock-Eval analyses: low values for S1, S2 & TOC

Only one site showed hydrocarbons (PO-6/PO-9):

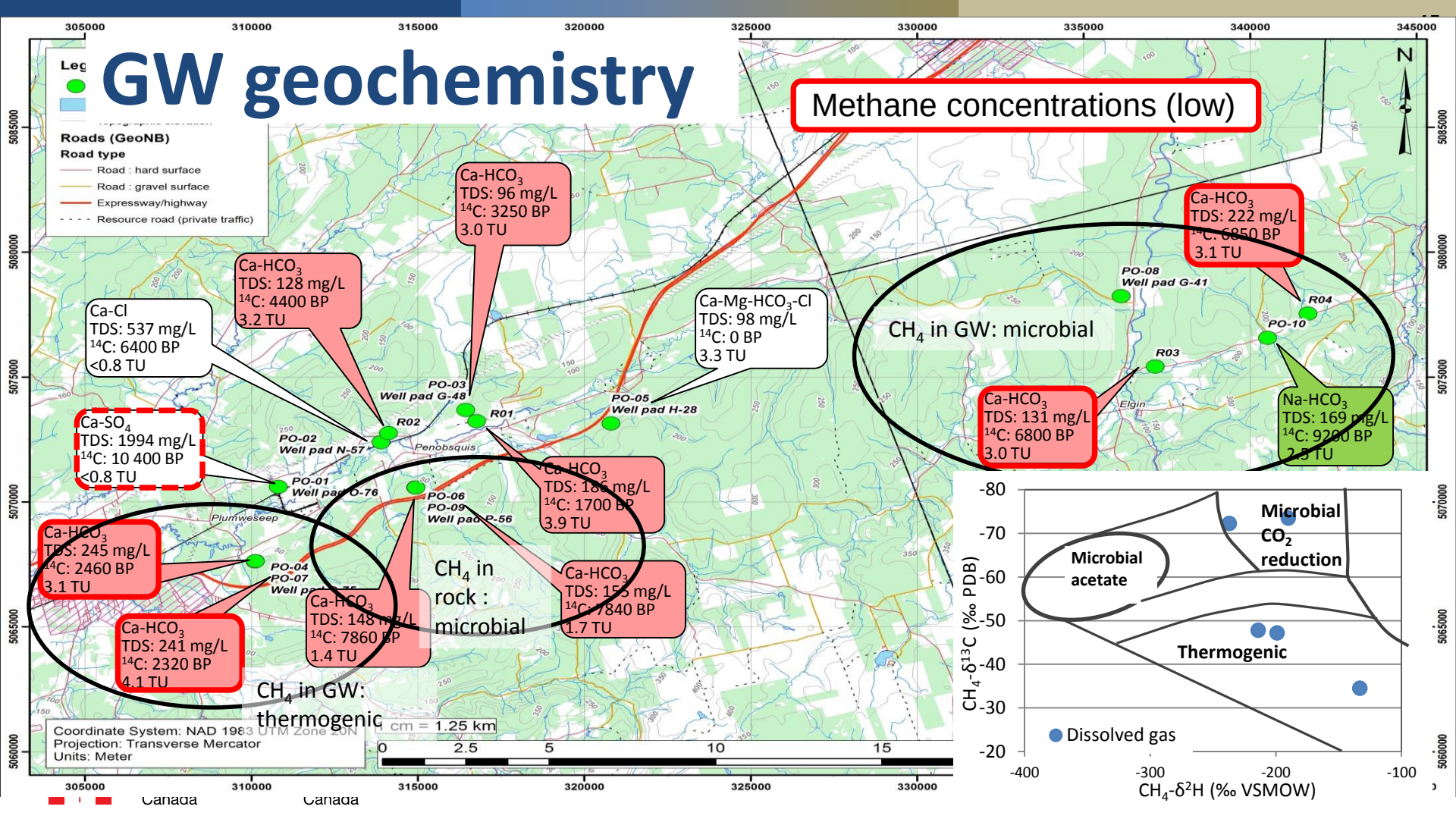
- Drill cuttings: C_{19+}
- Gas analyses (in isojars) : low value of methane at 60 m (microbial signature)



The origin of bitumen is unclear (immature kerogen or biodegraded oil).

Possible bitumen sources are shales from the Horton, Macumber or Mabou itself.

GW geochemistry



Highlights for year 2016-2017

- Preliminary geochemical results:

  McCully

  - 2 sites showed low concentrations of dissolved methane (< 1 mg/L) → thermogenic signature
  - One site showed gaseous methane and long-chain hydrocarbons in rock (C_{19+}), and ethane in GW

  Elgin

  - 4 residential wells contain methane (< 5 mg/L) → microbial signature

- Monitoring: marked variations in dissolved hydrocarbon concentrations (in space and time) have been observed;

Highlights for year 2016-2017

- Time-depth curves were constructed so wells can be tied to seismic data;
- The intermediate zone seems to provide an efficient barrier, based on results from the geomechanical study and the geological interpretation;
- Ongoing work:
  - Geomechanical inversion
  - 2D and 3D groundwater flow models
  - Estimation of recharge (with different methods: baseflows, hydrographs + water budget, HELP)
  - Geochemical characterization of gas and formation water (from gas wells)
  - Interpretation and analyses of data from seismic data, borehole geophysics, geochemistry and structural surveys.

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THANK YOU!

Celebrating 175 yrs

Induced Seismicity Research Project: Accomplishments and Looking Forward

Projet de recherche en sismicité induite: Accomplissements et prochaines étapes

Honn Kao

May 9th, 2017

NATURAL RESOURCES CANADA - INVENTIVE BY NATURE

ABSTRACT

- The development of unconventional oil and gas in North America has caused a significant increase of seismicity in areas of intense injection operations, including both hydraulic fracturing and wastewater disposal. These induced earthquakes have attracted considerable media attention due to their potential seismic hazards. In 2012, NRCan initiated the Induced Seismicity Research (ISR) Activity as part of the Shale Gas Research Project, under the Environmental Geoscience Program, to investigate the possible relationship between hydraulic fracturing (HF) of shale gas and the changing pattern of local seismicity. In 2015, the activity was expanded to a Project to include studies of all injection-related seismic events. NRCan's ISR Project has three major tasks. The first is to improve real-time earthquake-monitoring capability in major shale gas basins where the station coverage of regional seismograph network is sparse. The second is to establish the baseline of regional seismic pattern (i.e., the pre-development reference line) for places where the development potential of unconventional oil and gas is deemed high in the foreseeable future. The third is to conduct targeted studies on significant induced events to understand the relationship between their seismogenesis and man-made operations. In collaborations with many partners, new broadband seismograph stations have been installed in BC, AB, NB, SK, QC, NT, and YT. Studies of local seismicity before, during, and after HF operations have been completed for the northeast BC and western AB, the Moncton and Sussex areas (southern NB), and the Norman Wells area of the central MacKenzie Valley (NT). Regional earthquake baseline is also established for the areas of St. Lawrence Valley and Anticosti Island, QC. An increase of local seismicity in BC and AB is spatially and temporarily correlated with the peak period of injection operations associated with shale gas development. Injection volume appears to play a more important role than injection pressure in causing induced events. No abnormal seismicity can be observed when the injection volume is small. Research results of the largest hydraulic fracturing-induced earthquake to date (the August 17, 2015, Mw 4.6, northern Montney earthquake) indicate that the peak ground acceleration can be as high as 17% g at an epicentral distance of 5 km, suggesting that seismic hazards due to induced seismicity should not be overlooked. Future efforts of NRCan's ISR include the delineation of seismogenic patterns of injection-induced earthquakes and their implications for regional short- and long-term seismic hazards, detailed investigations of induced earthquake source characteristics with a multi-disciplinary approach, and the development and establishment of quantitative models to enhance and improve regulatory performances.

OUTLINE

- A brief review of NRCan's ISR history.
- Overall scope of NRCan's ISR.
- Representative research results.
  - Baseline study of background seismicity for major shale gas basins across Canada
  - Seismicity and injection operations in western Canada
  - Source characteristics of large injection-induced earthquakes in BC and AB
- Future plans

KEY PROJECT MEMBERS

- GSC Research Scientists
  - Honn Kao, John Cassidy, Ramin Dohkt (Pacific)
  - Maurice Lamontagne, Don White, David Snyder (Ottawa)
  - Denis Lavoie (Quebec)
- GSC Associates
  - Amir Farahbod (NSERC PDF, 2012-2016)
  - Alireza Babaie Mahani (Geoscience BC)
  - Ryan Visser, Brindley Smith, Jayden Rowley (Univ. of Victoria, co-ops)
  - Dawei Gao, Jesse Hutchinson, Ayodeji Kuponiyi (Univ. of Victoria, PhD students)
  - Dino G. Huang (Research contractor)
- CCMEO
  - Sergey Samsonov

Major Collaborators

- Governments/Crown Corporations
  - BC Oil and Gas Commission
  - Alberta Energy Regulator
  - Yukon Geological Survey
  - Northwest Territories Geoscience Office
  - New Brunswick Department of Energy and Mines
  - Ministère des Ressources Naturelles du Québec
  - Hydro Québec
- Professional Organizations
  - Geoscience BC
  - New Brunswick Energy Institute
  - Canadian Association of Petroleum Producers
- Academia
  - McGill Univ., Univ. of Ottawa, Western Univ., Univ. of Calgary, Univ. of Alberta (Canada)
  - Univ. of Bristol (UK)

NRCan's Induced Seismicity Research

- Initiated in 2012 as an Activity under the Shale Gas Research Project, Environmental Geoscience Program
- A coordinated effort involving both public and private sectors to address critical knowledge gaps in induced seismicity related to unconventional gas and oil development
- In 2016, the ISR Activity was expanded to the ISR Project to cover all types of induced earthquakes (hydraulic fracturing, wastewater injection, enhanced recovery and production, CO_2 sequestration, and reservoir impoundment)

National Scope of NRCan's ISR Project

Norman Wells, NT

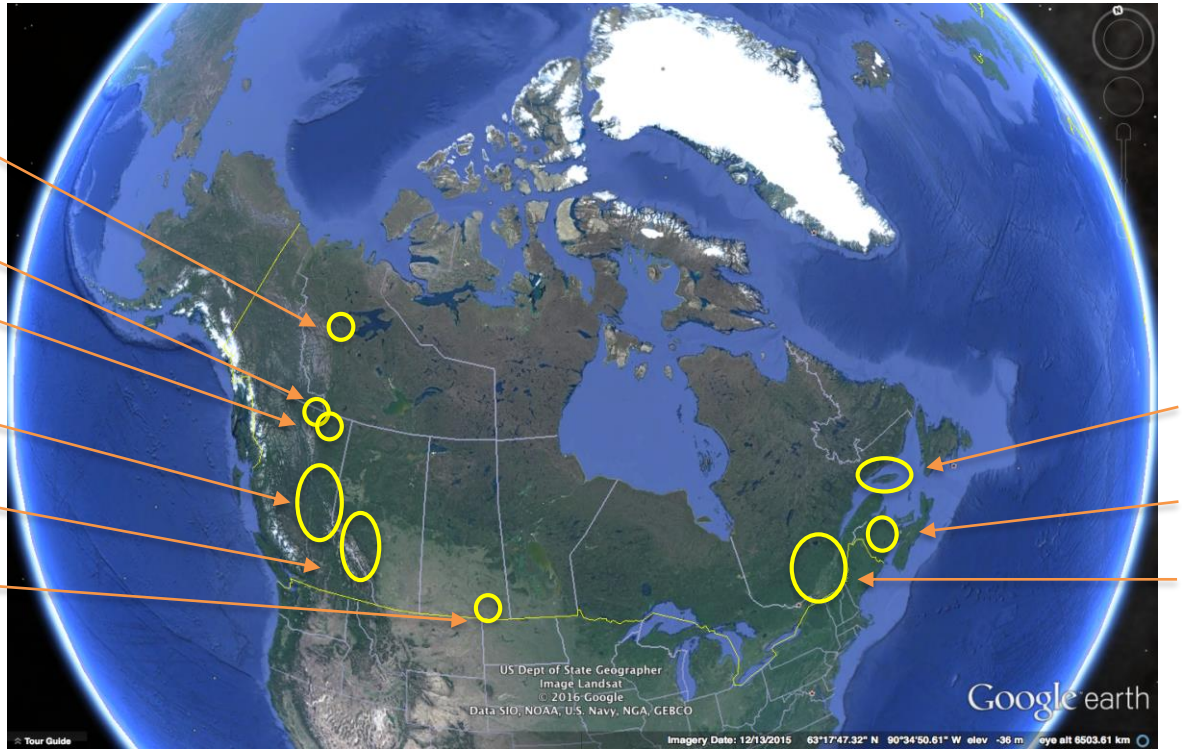
Liard Basin, YT

Horn River Basin, BC

Montney Play, BC

Duvernay Play, AB

Aquistore site, SK



Anticosti Is., QC

Moncton, NB

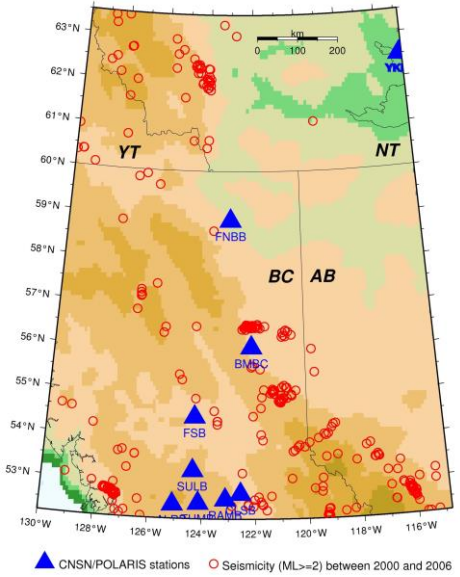
St. Lawrence Valley, QC

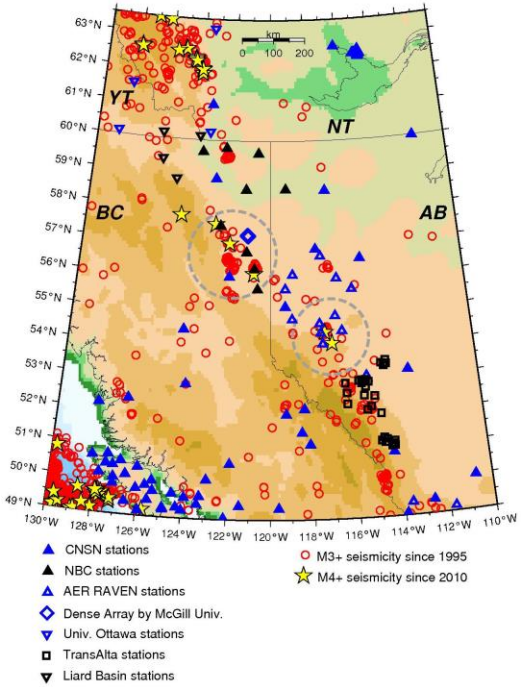
Research Results Update (1)

- Baseline Studies of Regional Seismicity for Major Basins of Unconventional Oil and Gas in Canada
  - Densification of regional and local seismograph networks.
  - Systematically identify and locate small/missing seismic events that occurred both before and after injection operations.

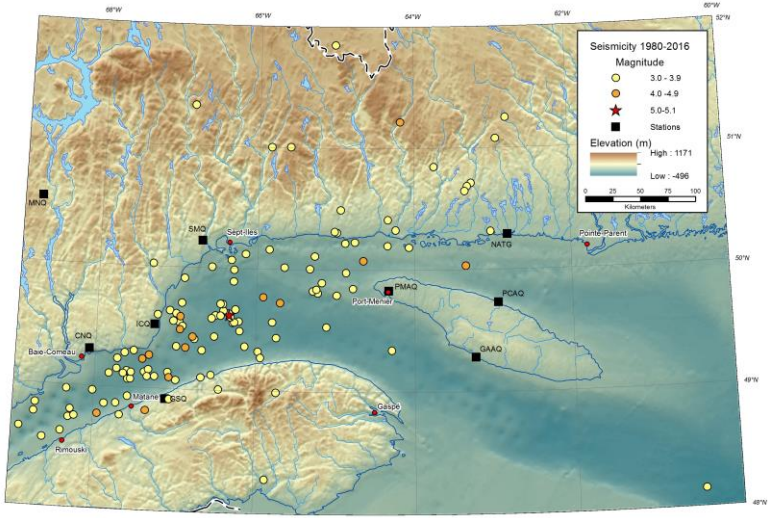
Seismic Baseline Studies

- Increasing seismicity in NE BC and W AB





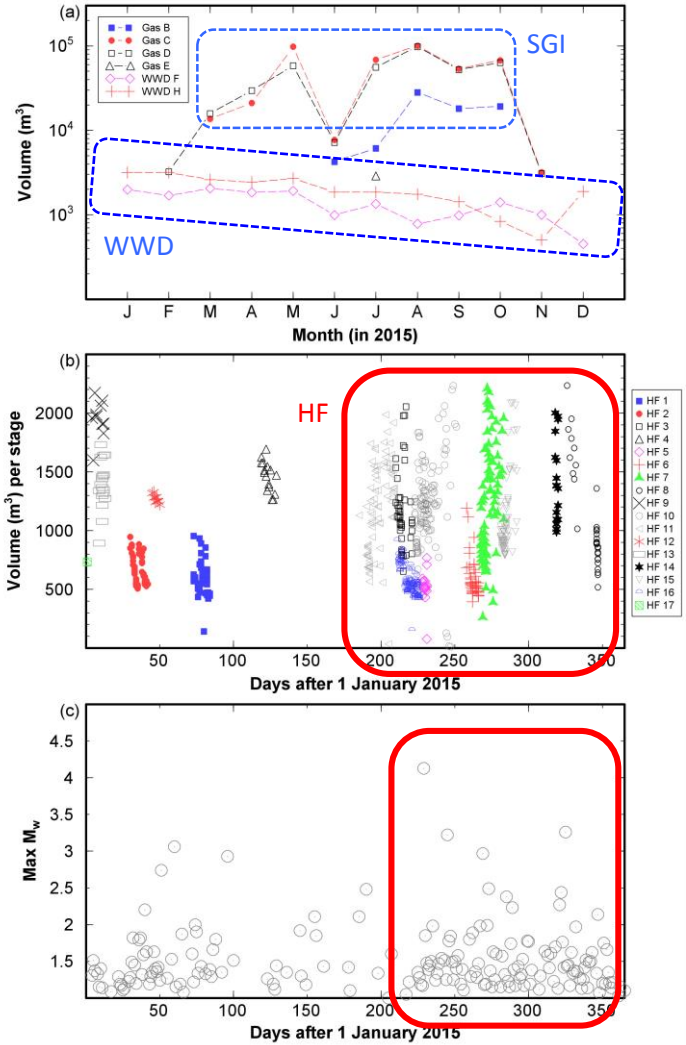
- Seismically quiet beneath Anticosti Is. QC

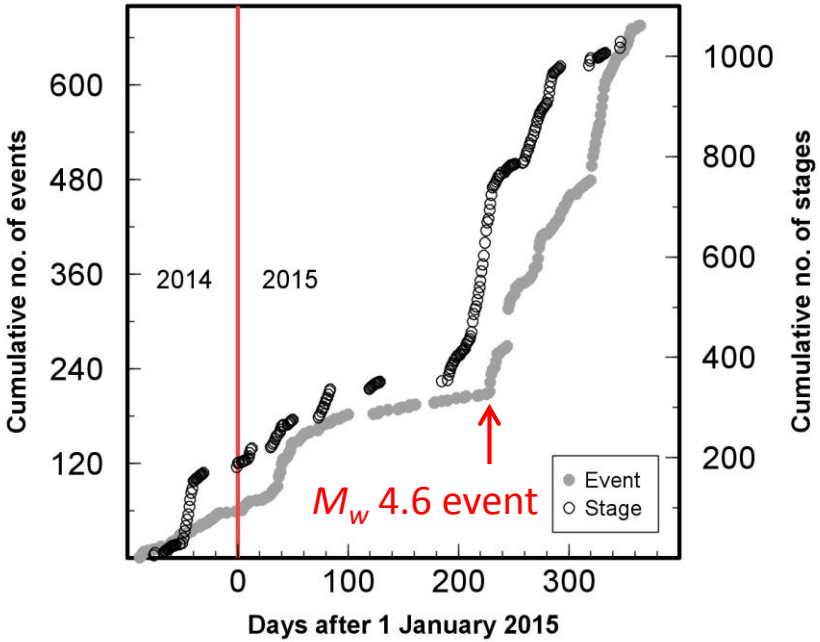


Research Results Update (2)

- Delineation of possible relationship between regional seismicity and industrial injection operations.
  - Horn River Basin, BC (hydraulic fracturing)
  - Montney Play, BC (hydraulic fracturing)
  - Duvernay Play, AB (hydraulic fracturing)
  - Norman Wells, NT (hydraulic fracturing)

Correlation Between Increasing Seismicity and Hydraulic Fracturing in Montney Play, BC



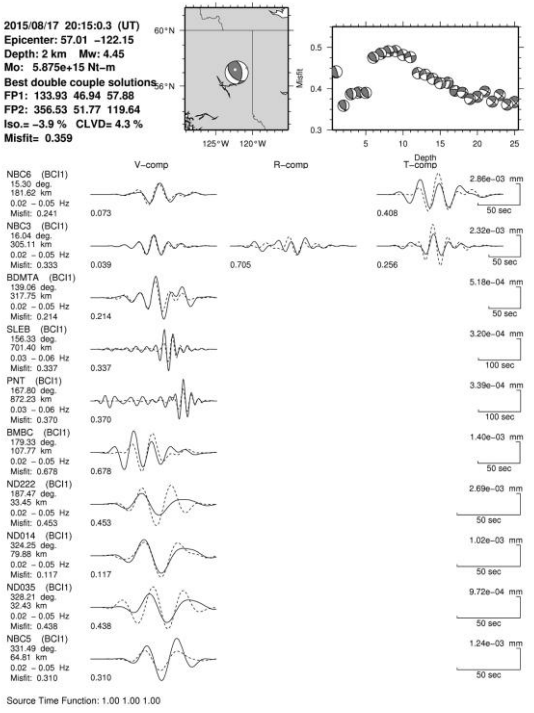


Research Results Update (3)

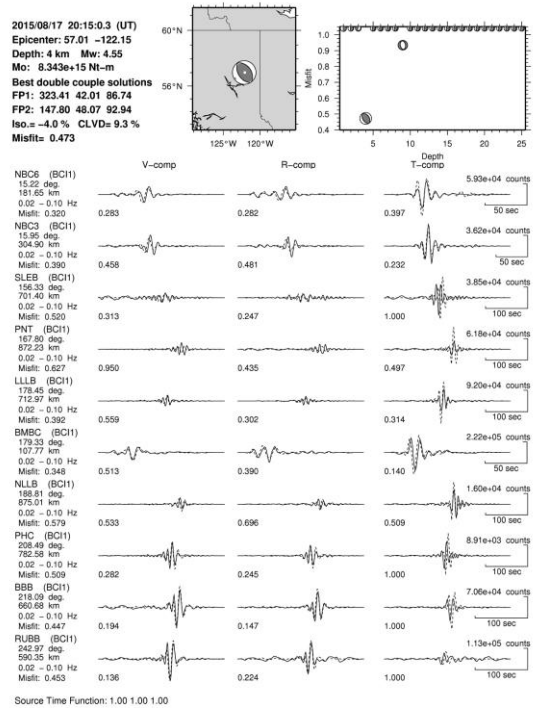
- Source characteristics of large injection-induced earthquakes in northeastern BC and western AB.
  - Improved moment-tensor inversion algorithm to study the focal mechanisms of IIEs.
  - Precise relocation of earthquake clusters to map the corresponding fault distribution.
  - Estimation of PGA generated by M>4 IIEs at source areas.

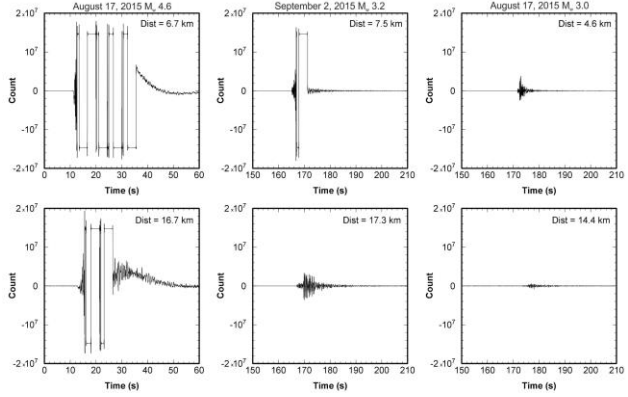
August 17, 2015, Mw 4.6 Earthquake in northern Montney, BC

Moment-tensor inversion: old approach

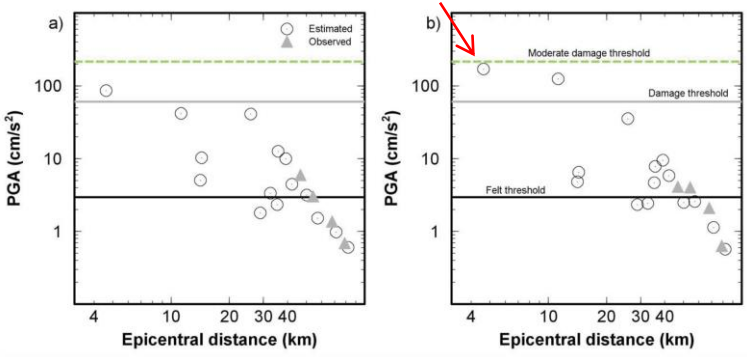


Moment-tensor inversion: new approach





~17% g at 4.6 km from the epicenter



Future Plans

- Seismogenic patterns of injection-induced earthquakes and their implications for regional short- and long-term seismic hazards.
- Multi-disciplinary approach (seismic, GPS, InSAR, and geomechanical modeling) to study source characteristics and faulting processes of different types of induced earthquakes.
- Development and establishment of quantitative models for induced seismicity to enhance/improve regulatory performances.

CONTACT INFORMATION

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THANK YOU!

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CCS: Geological Storage of CO_2 at the Aquistore Site / *CSC : Séquestration géologique du CO_2 au site Aquistore*

Don White

May 9th, 2017

NATURAL RESOURCES CANADA - INVENTIVE BY NATURE

ABSTRACT

- Carbon Capture and Storage (CCS) has been identified as a priority issue within the context of the North American Climate Change and Energy Collaboration and Mission Innovation. An important aspect of CCS is the need to improve public confidence in long-term geological storage of CO_2. A key to developing confidence for the longer term is a demonstration of safe and expected storage behaviour in the short term. Two primary concerns of the public and government regulatory bodies are the potential for induced seismicity and for CO_2 leakage. To alleviate these concerns, storage monitoring is critical in demonstrating that the subsurface CO_2 plume is behaving as expected, and that induced microseismic or seismic activity is being closely monitored. The Aquistore CO_2 Storage Project is a multi-year research and monitoring project to demonstrate that storing CO_2 deep underground is a safe and workable solution to help reduce greenhouse gas emissions to the atmosphere. The Geological Survey of Canada's studies within the project are focused on the development of improved monitoring methodologies and a better understanding of the relationship between CO_2 injection and induced seismicity.
- A total of 107 ktonnes of CO_2 were injected at the Aquistore site from April-2015 to Jan-2017. Injection is occurring within a saline formation at a depth of 3150-3350 m. In the first 4 months of 2016, CO_2 was injected at an average rate of ~400 tonnes/day. Passive seismic monitoring at the site which began in 2012 has not identified any seismicity associated with the injection process. The first time-lapse 3D seismic surveys were conducted in February and November of 2016 when the cumulative injected quantity of CO_2 was 36 ktonnes and 105 ktonnes, respectively. The resultant time-lapse seismic images show how the CO_2 plume is partitioned vertically within the reservoir and how it is spreading laterally. The seismic observations indicate that the initial geological model used for CO_2 flow simulations will have to be modified.

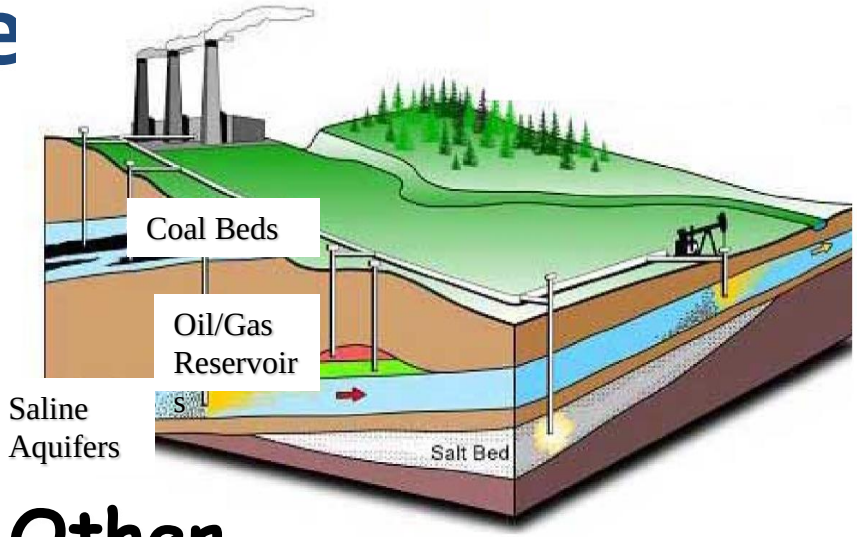
Outline

- What is CCS?
- International Context
- What is Aquistore?
- Why are we interested?
- Results to date

Geological Storage

Sedimentary Basins

- Depleted oil and gas reservoirs
- Coal beds
- Saline aquifers
- Gas hydrates*



Other

- Deep Ocean
- Marine sediments
- Ultramafic rocks

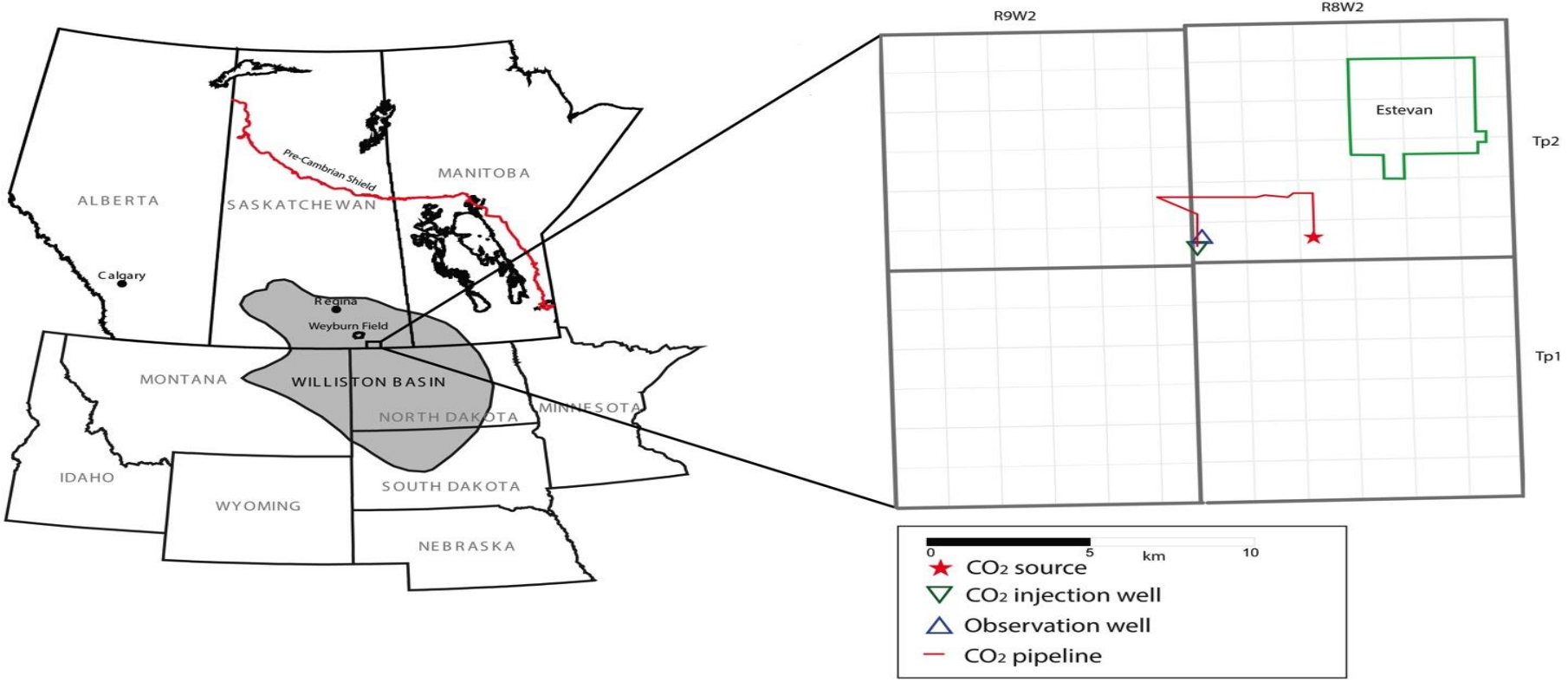
*** Arctic Canada, East and West Coasts**

International Context

North American MOU on climate change and energy collaboration: "… *promoting joint action to advance the deployment of carbon capture, use, and storage*"

Mission Innovation "Accelerating the Clean Energy Revolution" Challenge #3: Carbon Capture Innovation Challenge

Aquistore CO_2 Storage Project



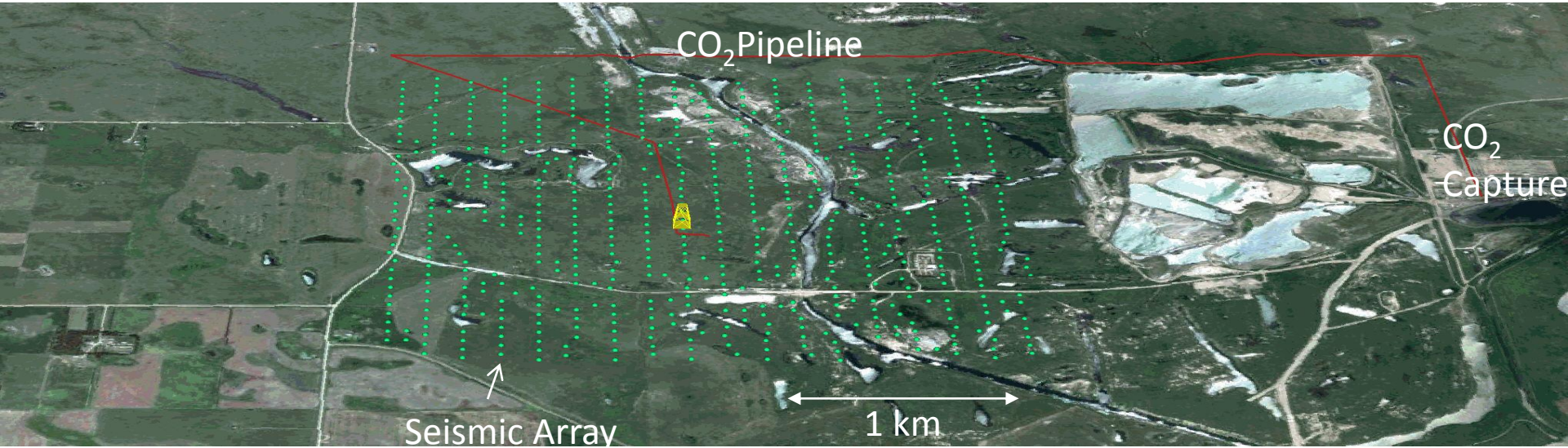

2013
CO_2 Capture Plant
SaskPower
Boundary Dam
SaskPower
Powering the future

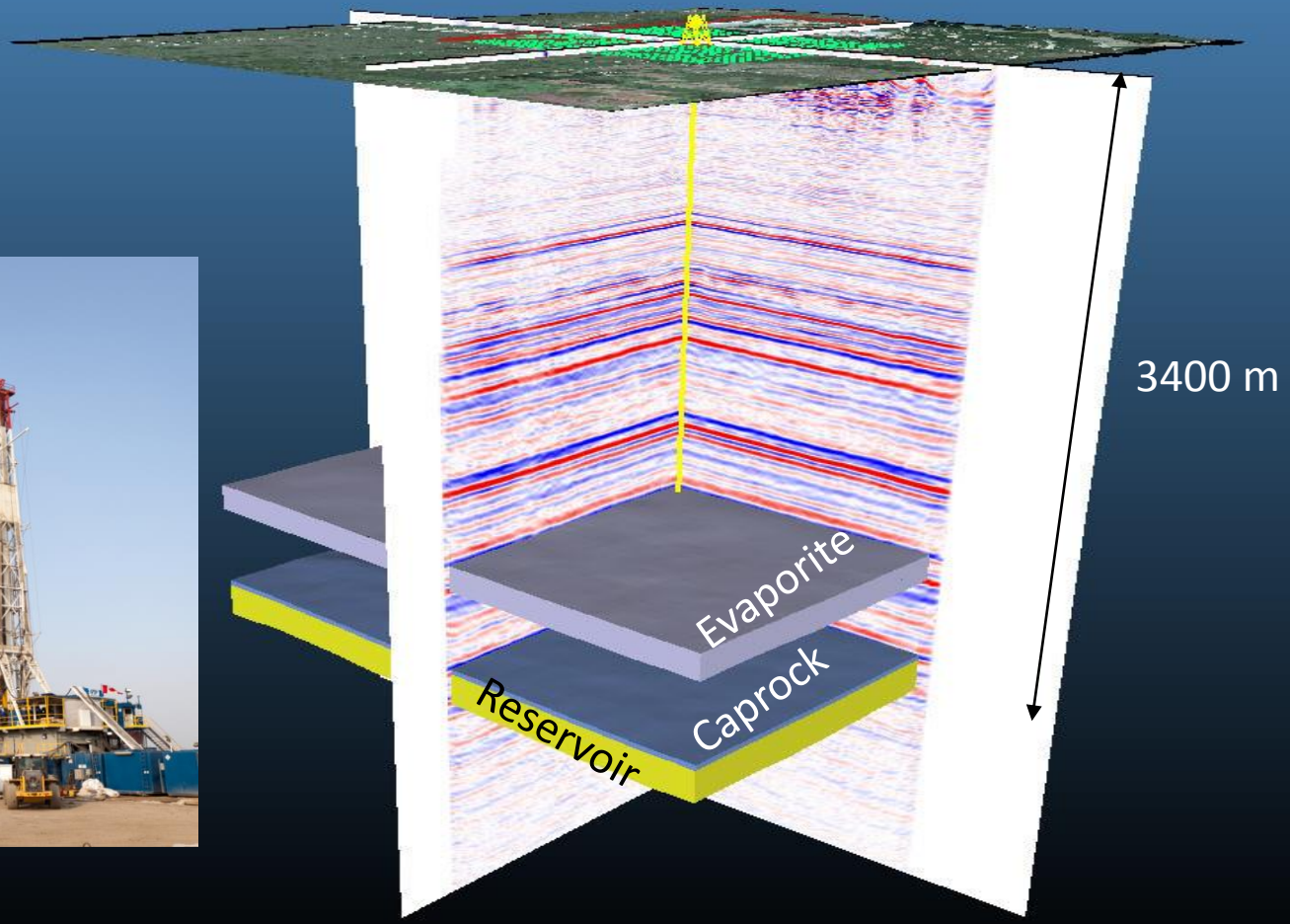
GSC Research Objectives

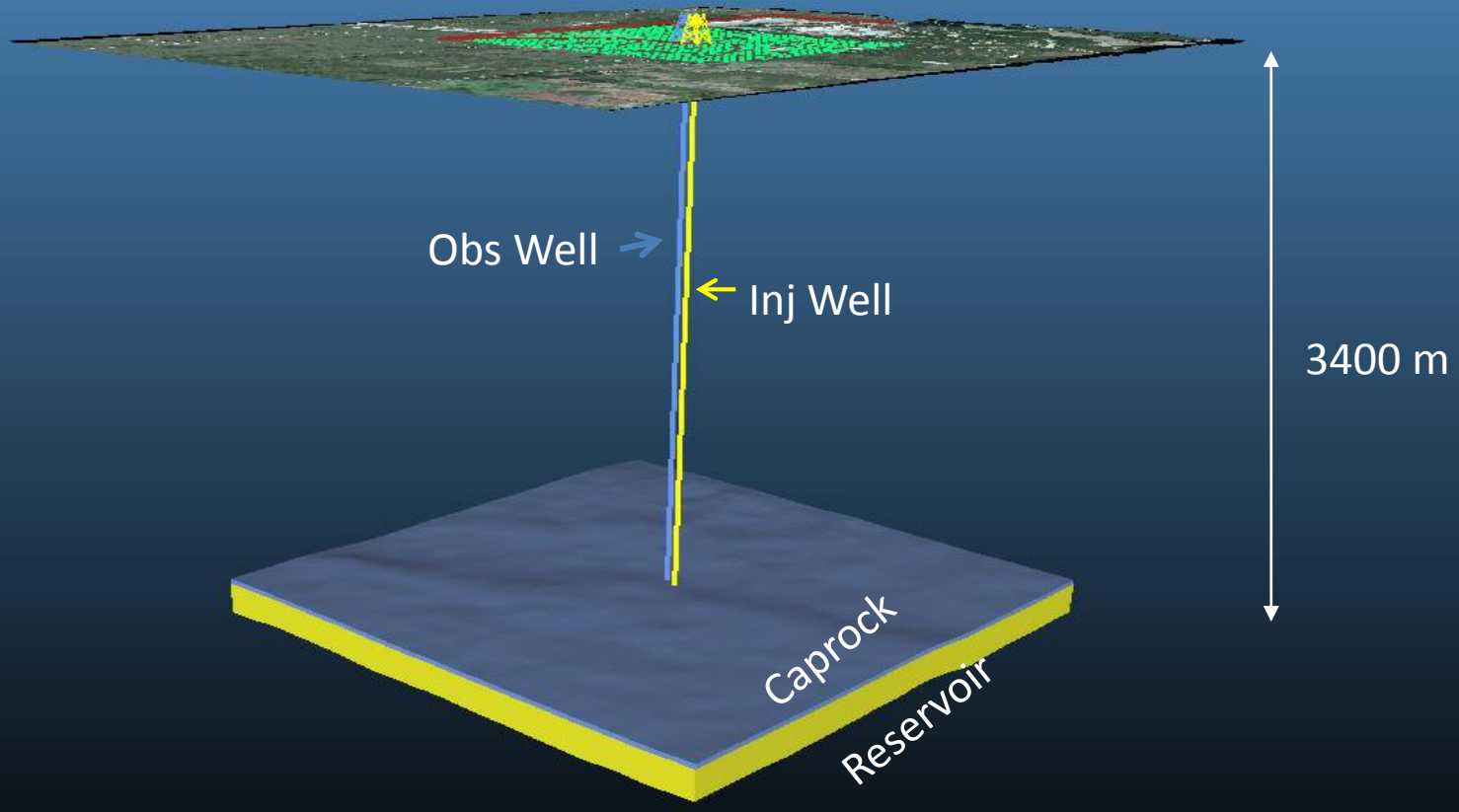
- Methods for monitoring CO_2 containment
- Induced seismicity

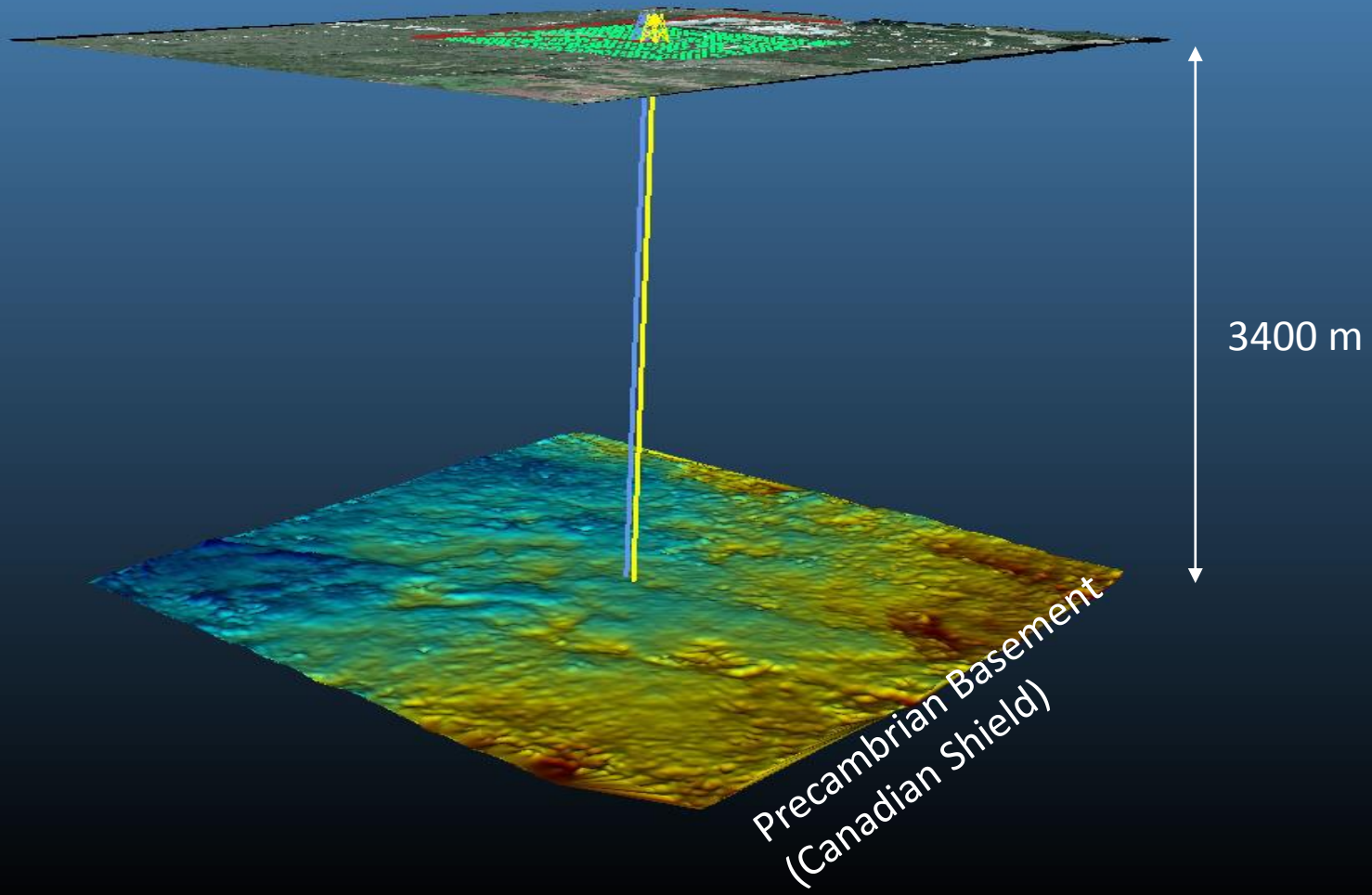
Outcomes

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

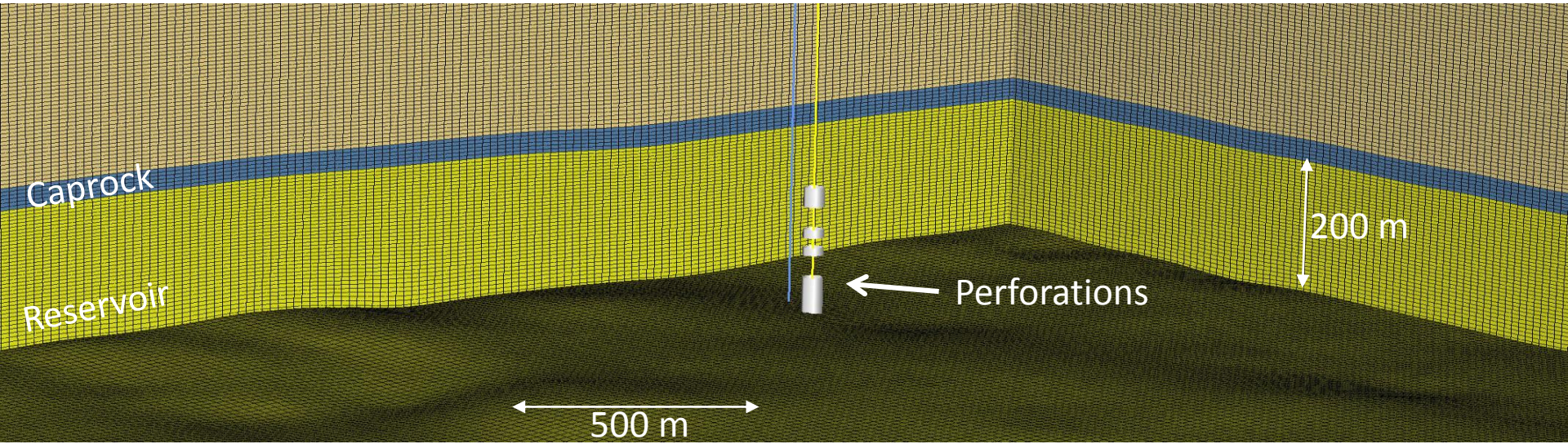



3400 m
Evaporite
Caprock
Reservoir


Obs Well
Inj Well
3400 m
Caprock
Reservoir

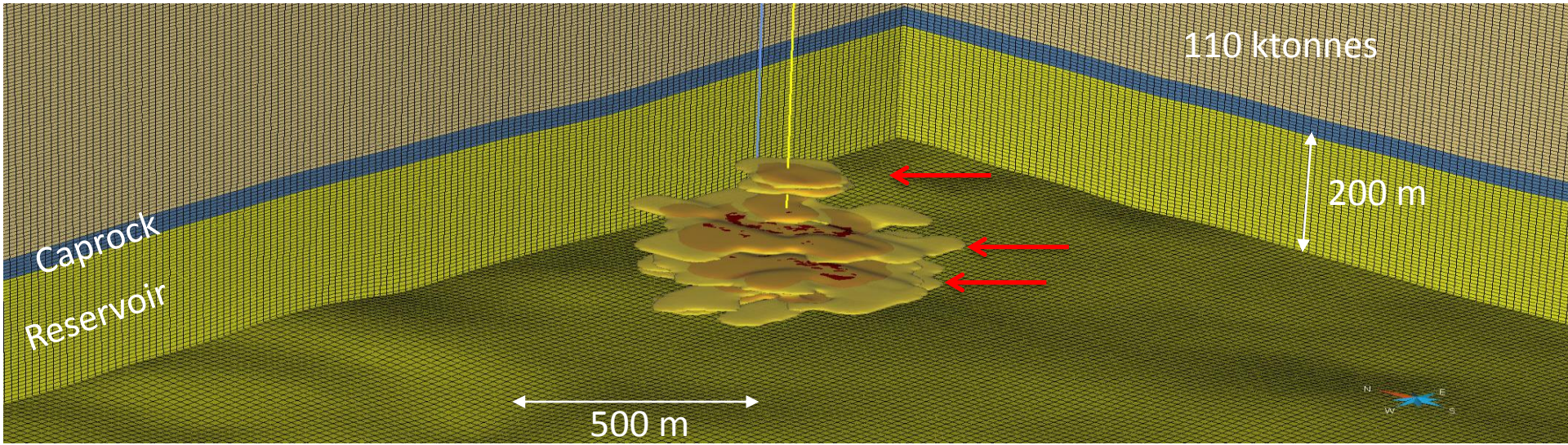

3400 m
Precambrian Basement
(Canadian Shield)

Injection Well Perforations



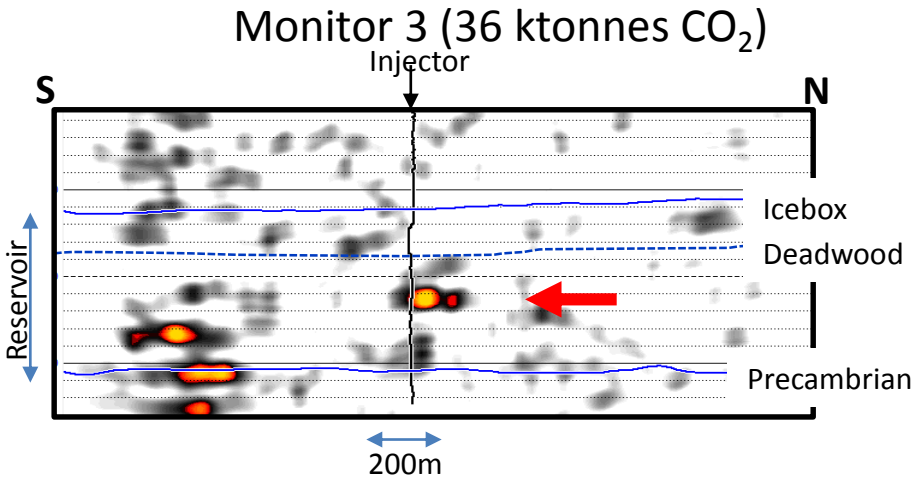
3400 m Depth

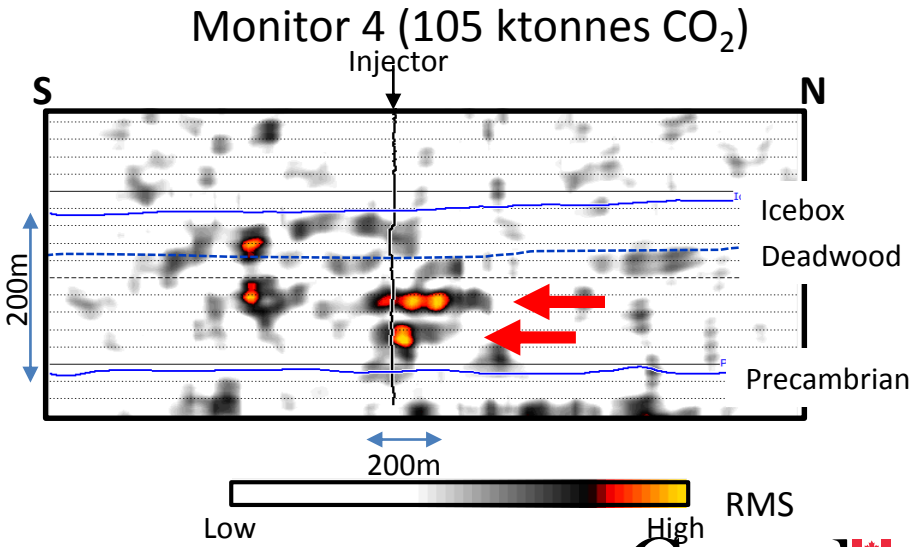
Model: 110 kT CO_2



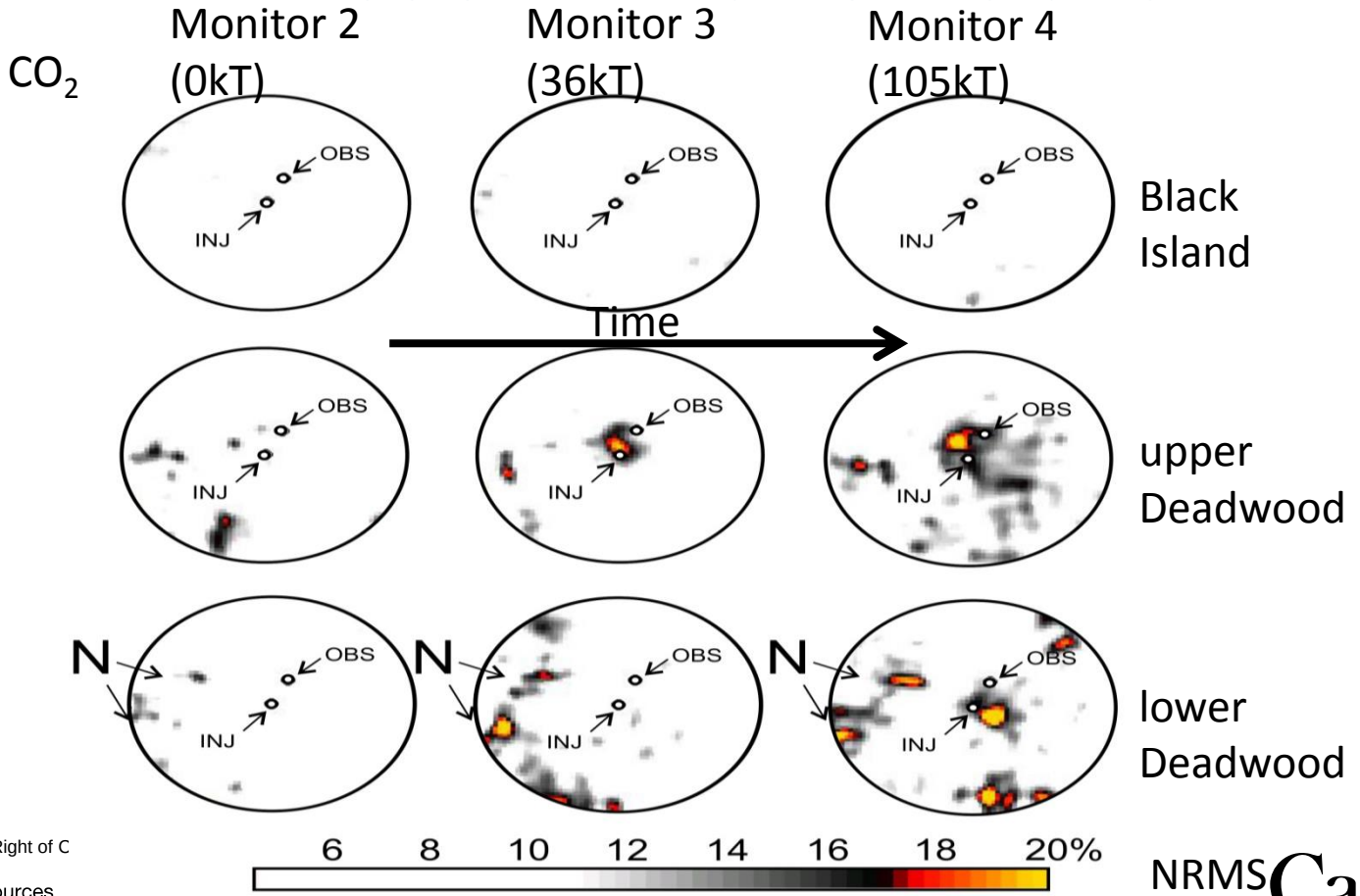
3400 m Depth

4D Seismic
Inline Slice

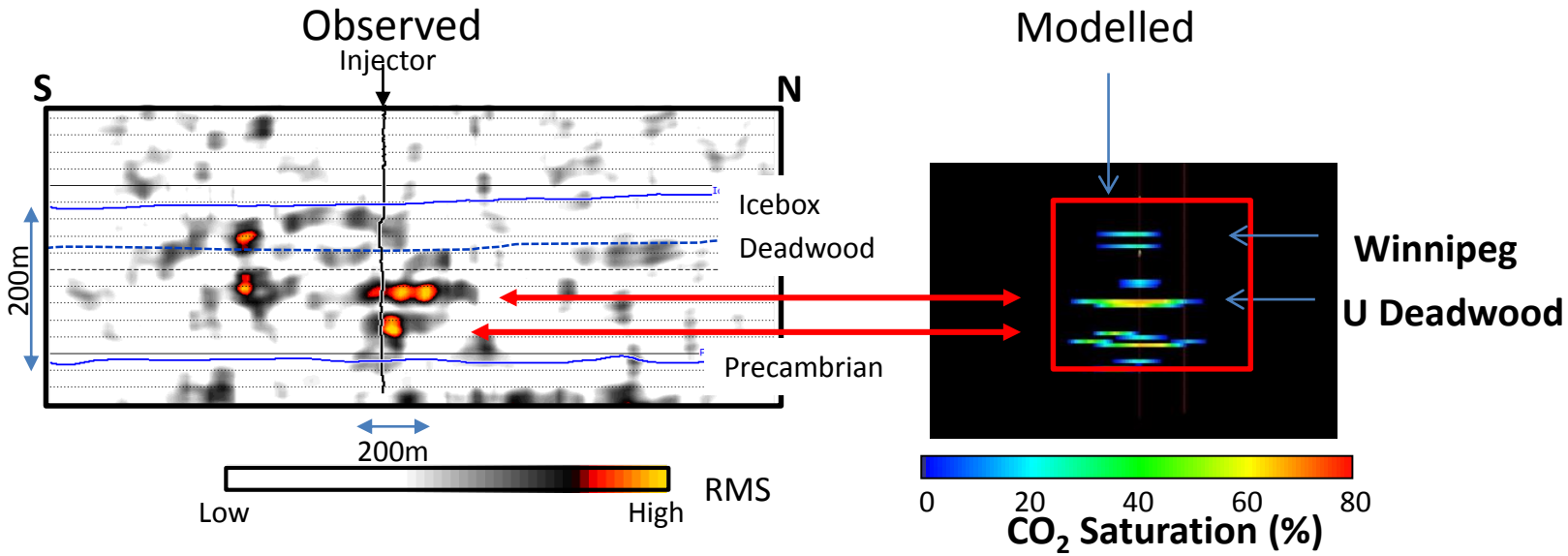




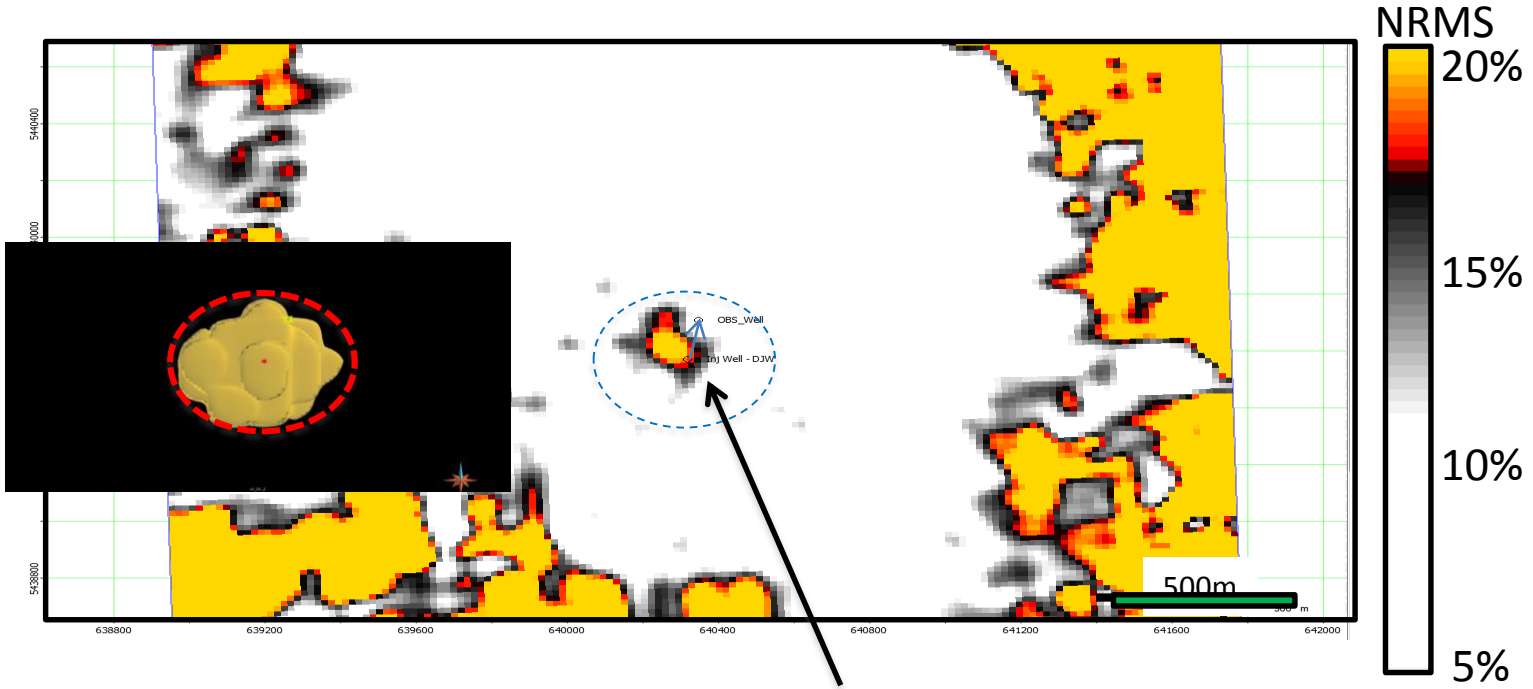
4D Seismic: Plume Evolution



Observed Seismic vs. Modelled CO_2 (105 kT injected)

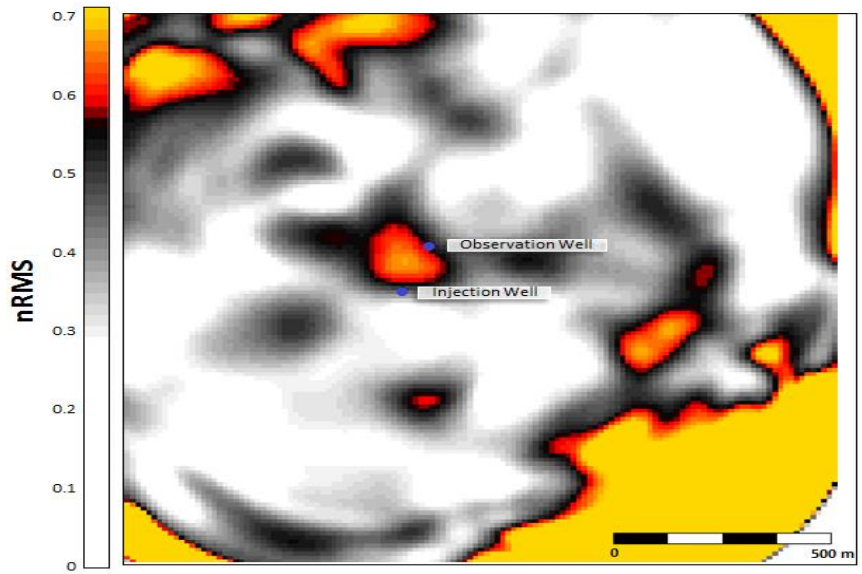


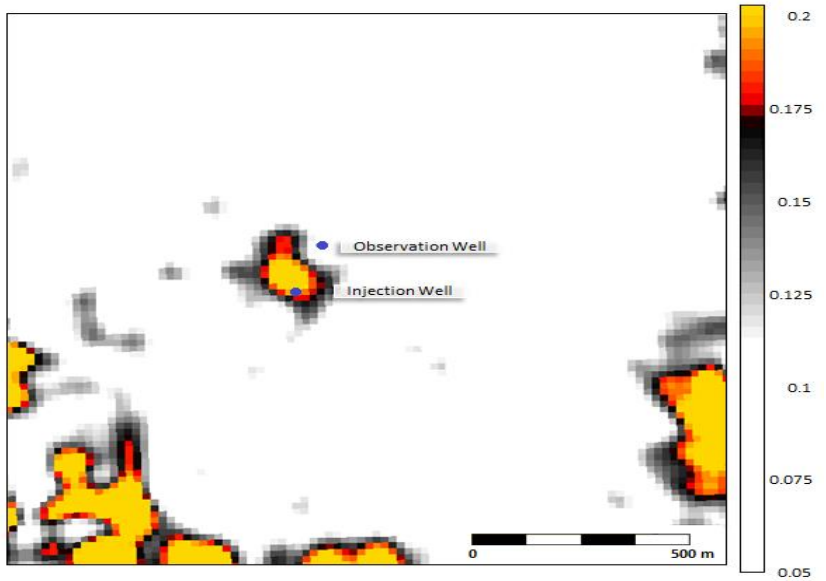
M3-Baseline: Upper Deadwood (36 ktonnes of CO_2 Injected)



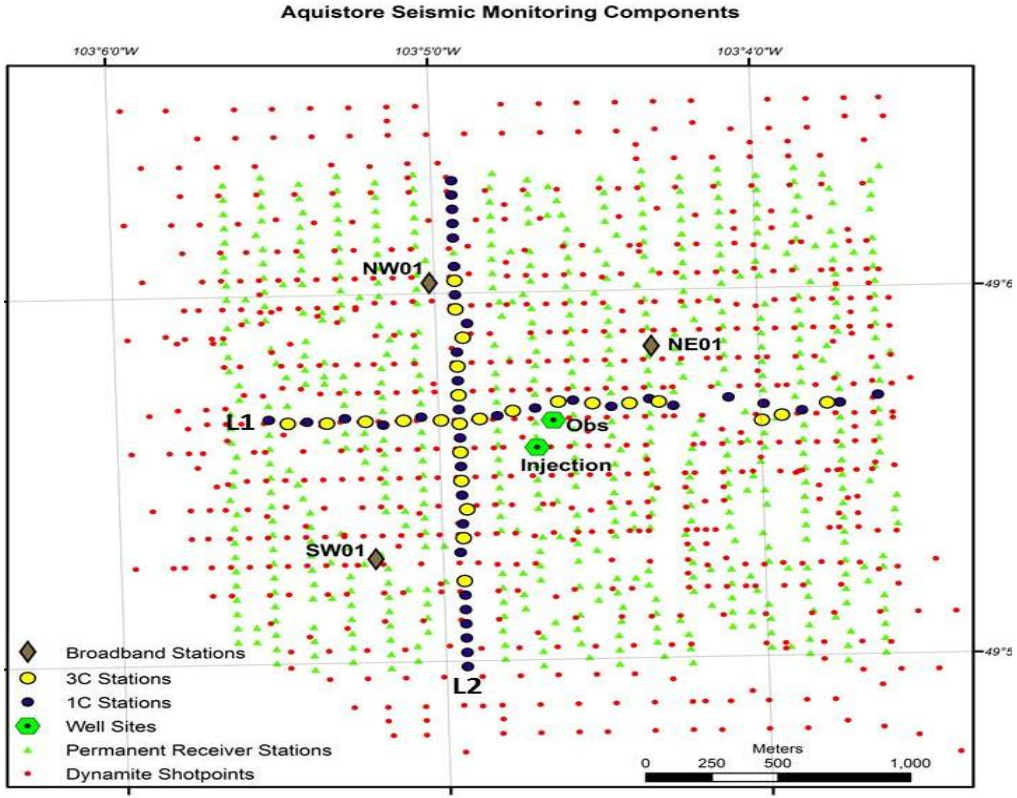
Clear CO_2 anomaly

Technology Testing: 3D seismic using Distributed Acoustic Sensing (DAS) fibre optic cable





Induced Seismicity Monitoring



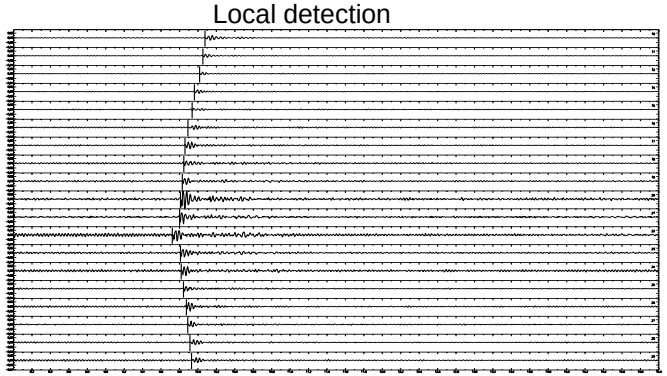
Aquistore Passive Monitoring Summary

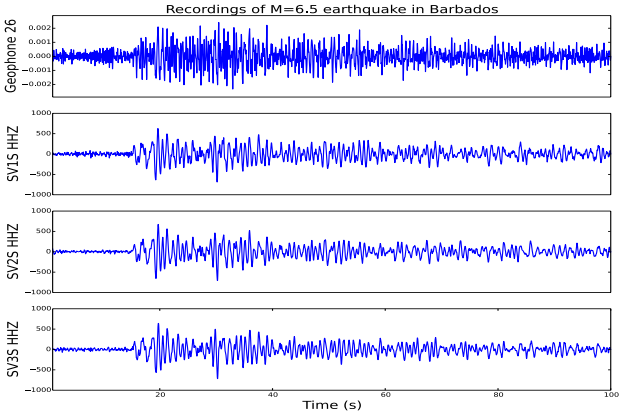
- No injection related seismicity (M_w *>1*) detected during first 2 years of operation.
- No smaller magnitude events (M_w *> -3)* recorded during 8 month deployment of more sensitive downhole system.
- Local events: mining blasts recorded.
- Regional and teleseismic events have been detected and recorded.

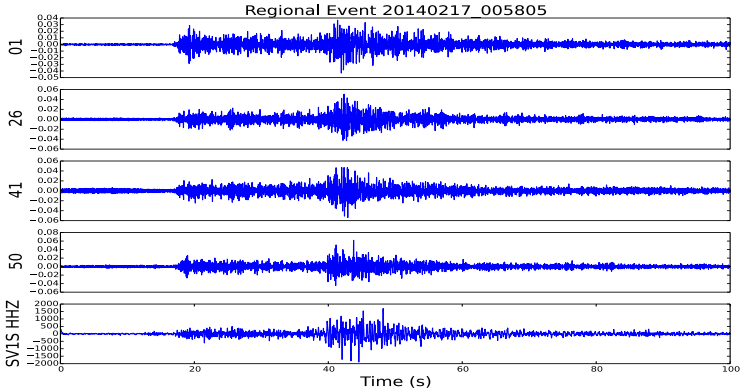
Passive Seismic Baseline

Seismic event detection

- STA/LTA coincidence trigger
- Local
- Regional
- Teleseismic
- Noise







Next Steps

- Continue passive monitoring for induced seismicity
- Conduct 4D seismic at 200 ktonne stage
- Update the geological model to match 4D seismic results

PROJECT MEMBERS

- Don White, Brian Roberts, Jim Craven (GSC)
- Kyle Harris, Saeid Cheraghi, Claire Samson (Carleton University)
- Sergey Samsonov (CCMEO)
- Mike Craymer, Jason Silliker (CGS)
- Lisa Roach (Leeds University)
- Anna Stork (Bristol University)
- Chris Nixon, Doug Schmitt (University of Alberta)

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THANK YOU!

Celebrating 175 yrs

Geoenvironmental Characteristics of Canadian Critical Metal Deposits

Caractéristiques géoenvironnementales de gisements métalliques critiques au Canada

Michael Parsons (GSC-Atlantic, Dartmouth, NS)

9 mai 2017 – May 9, 2017

NATURAL RESOURCES CANADA - INVENTIVE BY NATURE

ABSTRACT

The extraction and processing of critical metals such as niobium (Nb) and the rare earth elements (REEs) has led to environmental degradation in some parts of the world, but there are few published studies of these environmental impacts and related risks to human health. Recent studies in Quebec by the Geological Survey of Canada (GSC) are providing new geoscience knowledge on the geoenvironmental characteristics of Nb and REE deposits. This knowledge should help to reduce the environmental risks of future development of these important resources.

In FY 2016-2017, GSC scientists collected samples of mine waste, surface water and groundwater at the abandoned St. Lawrence Columbium mine in Oka, Quebec to better understand the distribution, transport, and fate of metals and radionuclides at this former Nb mine. A gamma-ray spectrometer was used to measure the radiation emitted by decay of naturally occurring uranium (U) and thorium (Th) in the mine waste, and a TerraSpec Halo spectrometer was used to identify specific minerals. Seasonal variations in water quality were measured using instruments installed in groundwater wells, data loggers installed in two flooded pits, and water samplers deployed from a Zodiac in July and October 2016 and from the ice surface in February 2017.

Analyses show that mine site surface waters are weakly alkaline and contain low concentrations of fluorine (F), Nb, REEs, U, Th, radium-226, radium-228 and lead-210. The concentrations of these elements are higher in groundwater and in low-oxygen water deeper than 30 m in one of the open pits. This suggests that potentially hazardous elements in the local bedrock and mine waste are relatively immobile in well-oxygenated surface water but may be transported in deeper groundwater. Information from this project will be shared with the Municipality of Oka to help with long-term management of the mine site. The results will also help industry to improve environmental predictions for future Nb- and REE-mines and regulators to develop new environmental guidelines.

GSC PROJECT MEMBERS

Michael Parsons, GSC-Atlantic (Co-activity lead)
Surface waters, mine wastes

Alexandre Desbarats, GSC-Ottawa (Co-activity lead)
Groundwaters, mine wastes

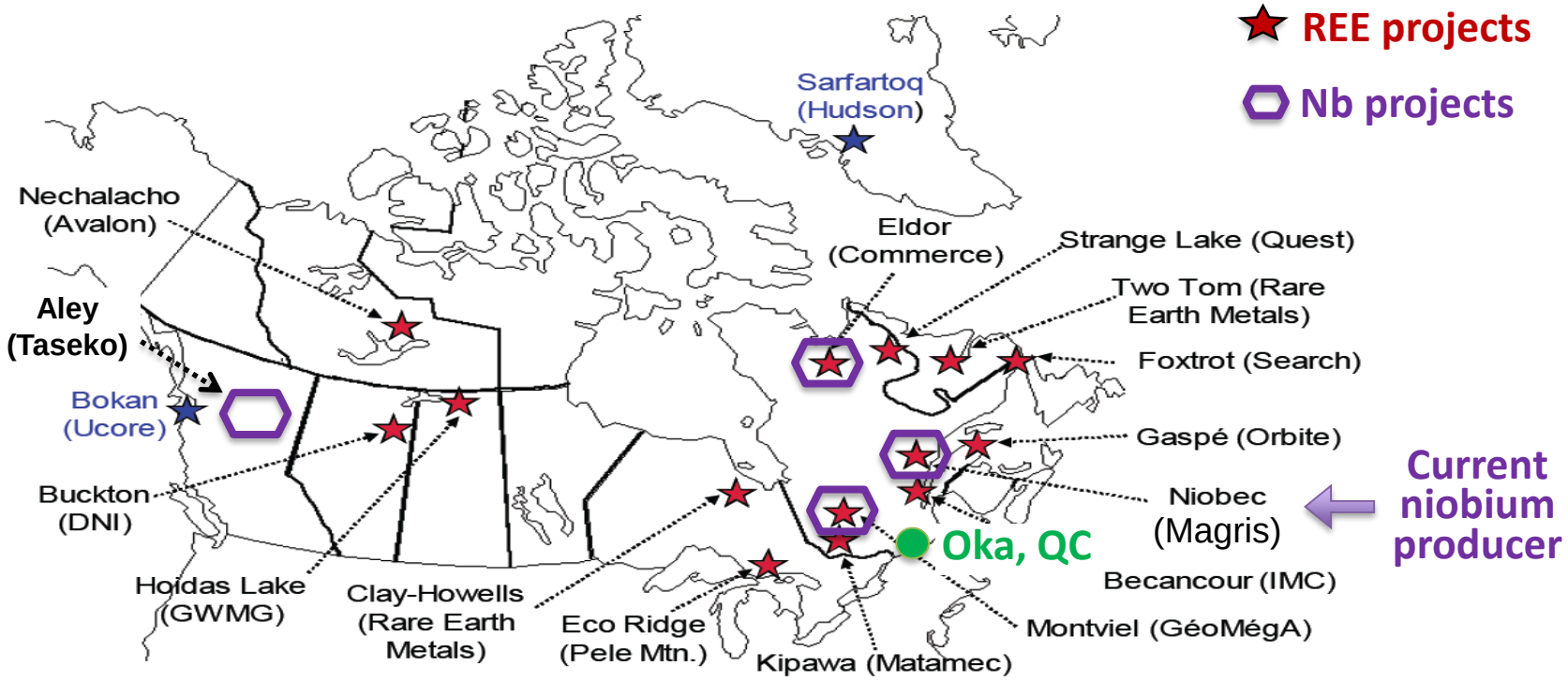
Jeanne Percival, GSC-Ottawa
Mineralogy

Katherine Venance, GSC Ottawa
Mineralogy

Lori Campbell, GSC-Atlantic
Field assistant, lab technologist

Alexandre Normandeau, GSC-Atlantic
Field assistant

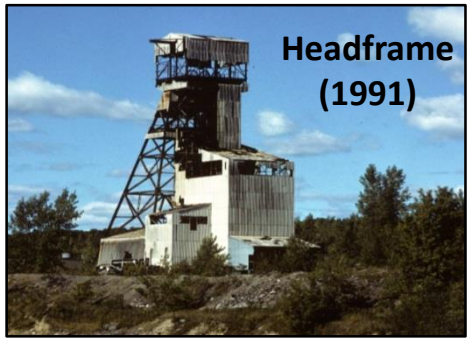
Canadian Rare Earth Element & Niobium Projects



Modified from Zinck (2013) & http://reechromite.ca/

St. Lawrence Columbium (Niobium) Mine

From Carbonneau & Caron (1965)



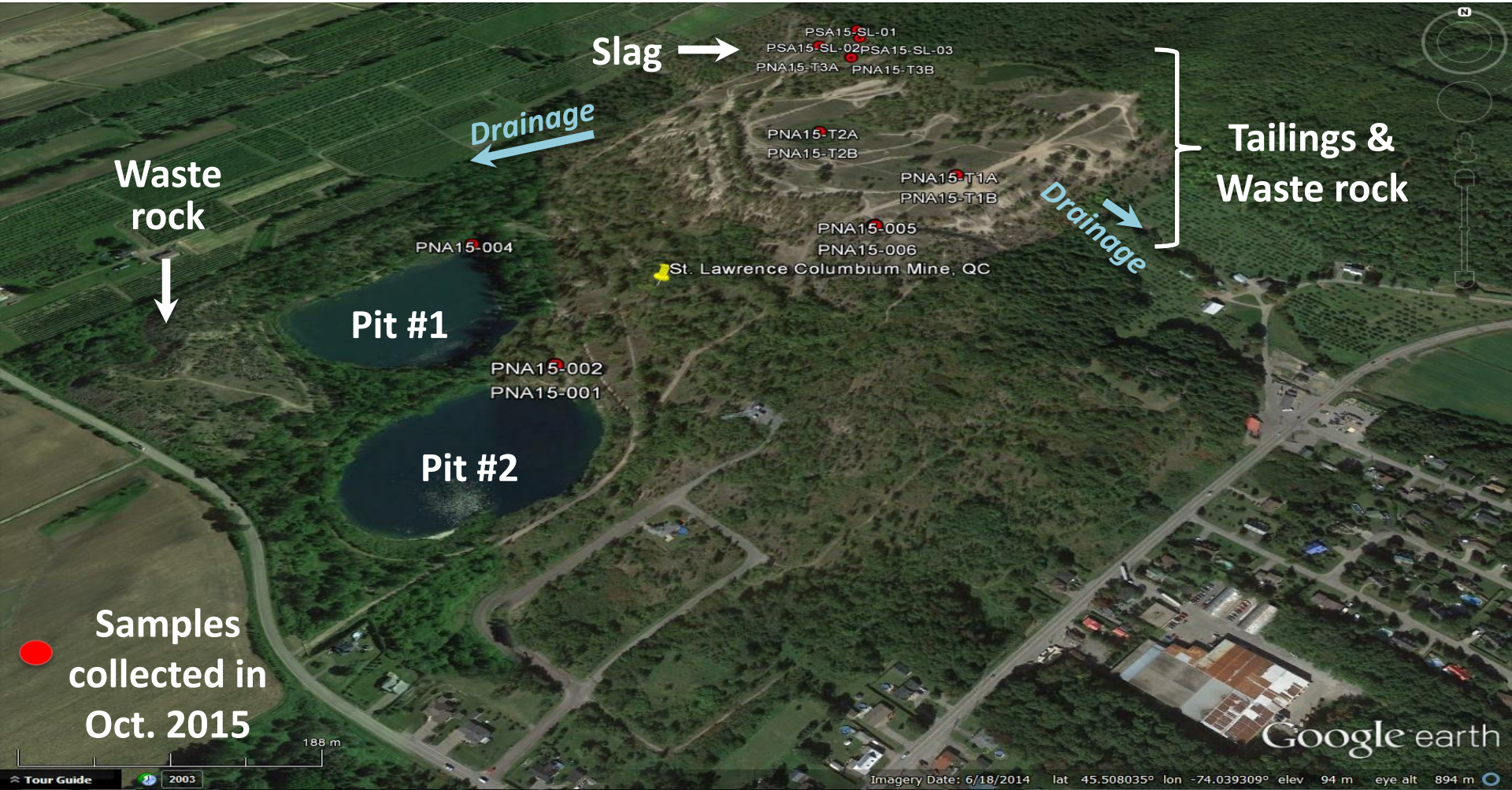
From mindat.org

- Located in Oka, QC, ~30 km NW of Montreal
- Mine operated from 1961 to 1976 using open pit and underground mining, an on-site mill (up to 2500-tons-per-day), and a ferroniobium smelter
- Ore hosted in carbonatite and alkaline rocks. Pyrochlore [$(Na,Ca)_2Nb_2O_6(OH,F)$] was main ore mineral; most REE are contained in apatite, niocalite, perovskite and pyrochlore
- Site is currently owned by the Municipality of Oka; several recent redevelopment proposals have raised concern in the local community; Province now investigating options for site reclamation
- **Only site in Canada with untreated Nb mine waste**

St. Lawrence Columbium Mine
June 1965


St. Lawrence Columbium Mine
May 1975
Slag
Tailings
Mill &
smelter
Waste
rock
Waste
rock
Headframe
Open
pits

St. Lawrence Columbium Mine, Oka, QC



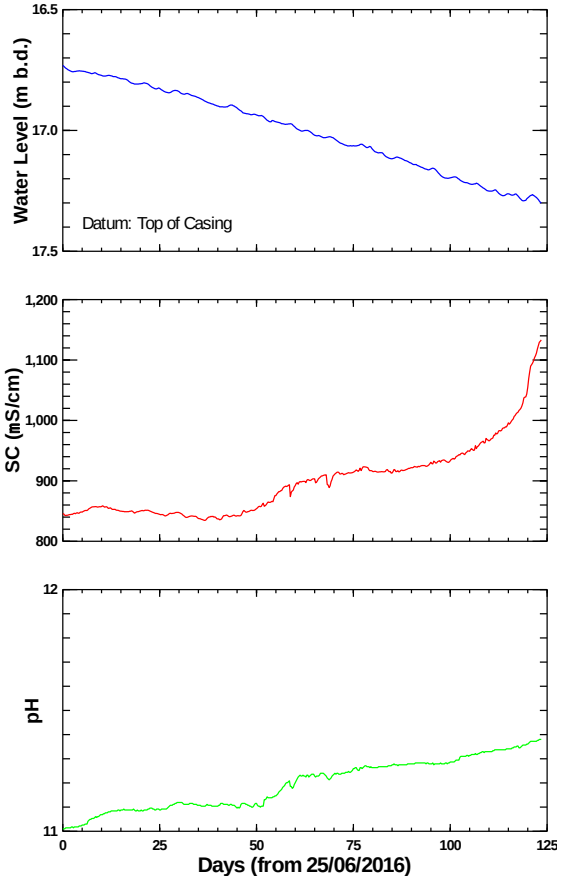
Task 1: Geochemistry of tailings seepage

Goal: Characterize groundwater-tailings reactions that control the mobility of trace elements (F, Nb, REE, U, Th, Ra-226) in seepage from infiltrating precipitation to discharge points

Sampling groundwater piezometers near the old tailings decant pond

FY 2016-2017 Achievements

- Installed 6 drive-point piezometers at depths from 3 to 24 feet in tailings, near the decant pond
- Constructed weir for measuring discharge from the tailings impoundment
- Sampled groundwater chemistry in piezometers
- Multi-parameter data logging in existing monitoring well near decant pond



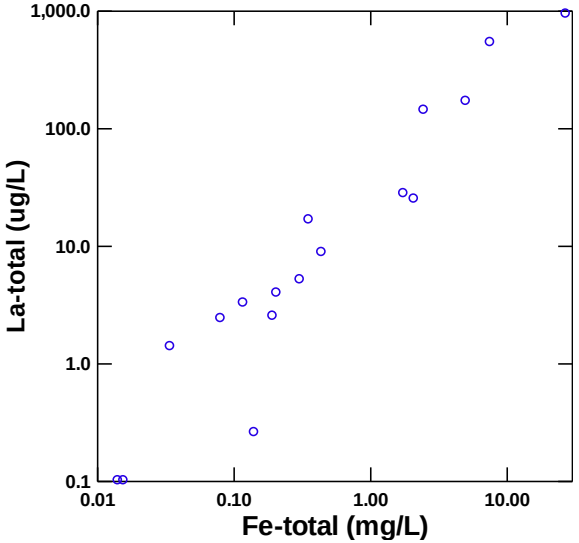
Task 1: Geochemistry of tailings seepage

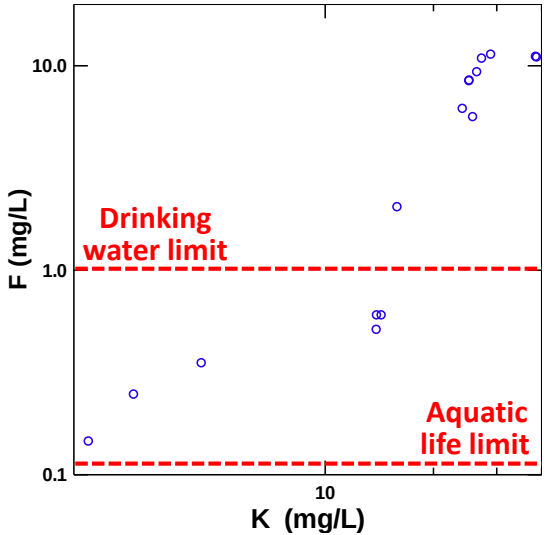
Some preliminary results: Data logging in monitoring well

(June – October 2016)

- Steady decline in water level during summer months
- Specific conductance of tailings pore water is high and increases during period
- pH of tailings pore water is very high (11.0 – 11.4) and increases during period

Task 1: Geochemistry of tailings seepage





Extremely high **REE** (La, Ce, etc.) in suspended particulate phase, sorbed on Fe or Mn oxyhydroxides

High **fluoride** levels (above human health and aquatic life guidelines) in tailings seepage – likely due to biotite dissolution

Task 2: Limnology and geochemistry of mine pit lakes

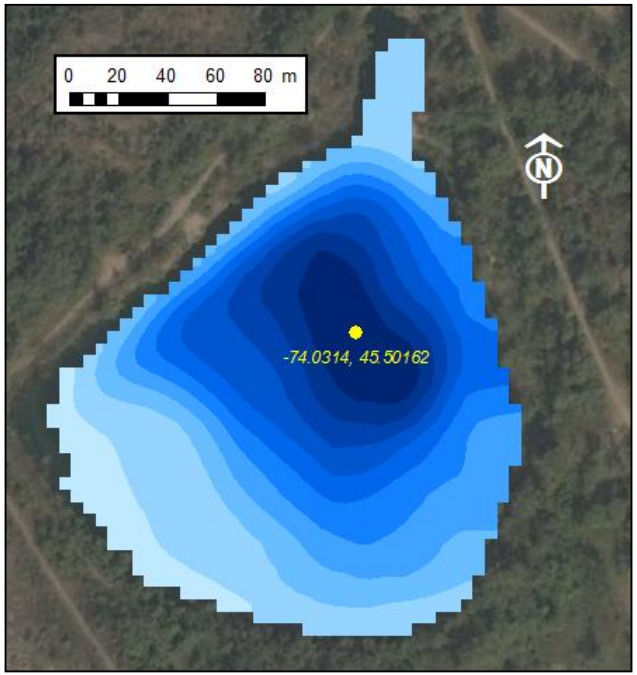
Goal: investigate the key controls on metal (e.g. U, Th, REEs) and radionuclide (e.g. 226-Ra, 210-Pb) concentrations in the pit lake water

Collecting water quality measurements to a depth of 100 m in Pit #2

FY 2016-2017 Achievements

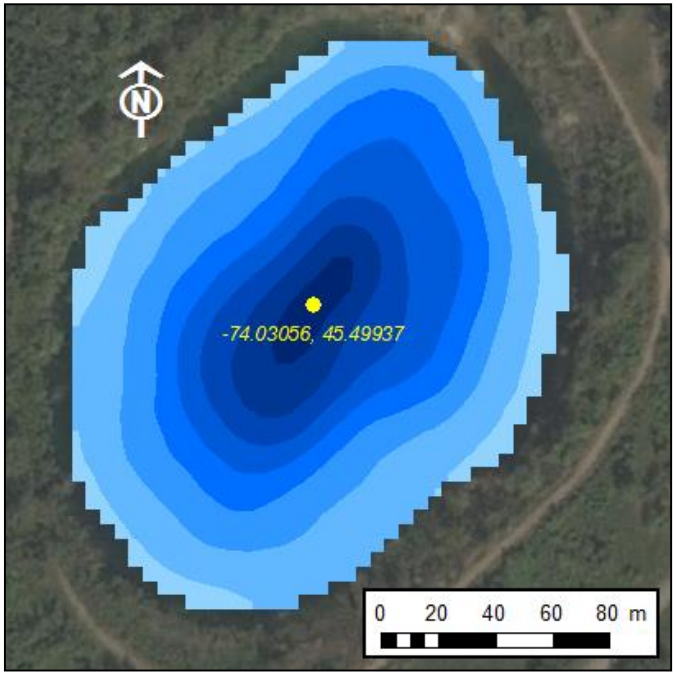
- Mapped the bathymetry of flooded pit lakes to help guide water sampling
- Conducted water column profiling and sampling at various depths from a Zodiac in July and October 2016, and from the ice in February 2017
- Collected sediments and waste rock for geochemical and mineralogical analyses

Task 2: Limnology and geochemistry of mine pit lakes



Bathymetry of Pit #1

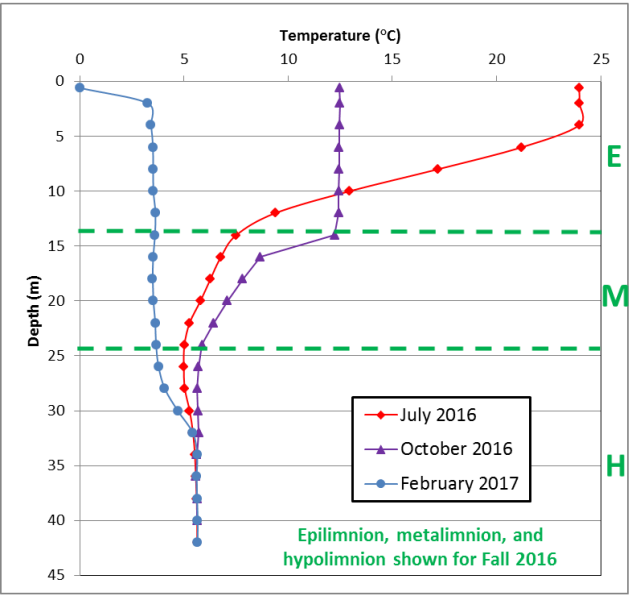
(Contour interval = 5 m; max. depth = 42 m)

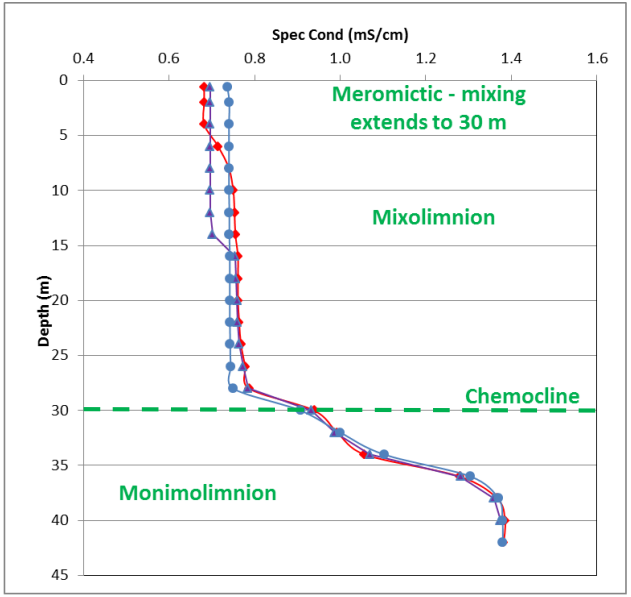


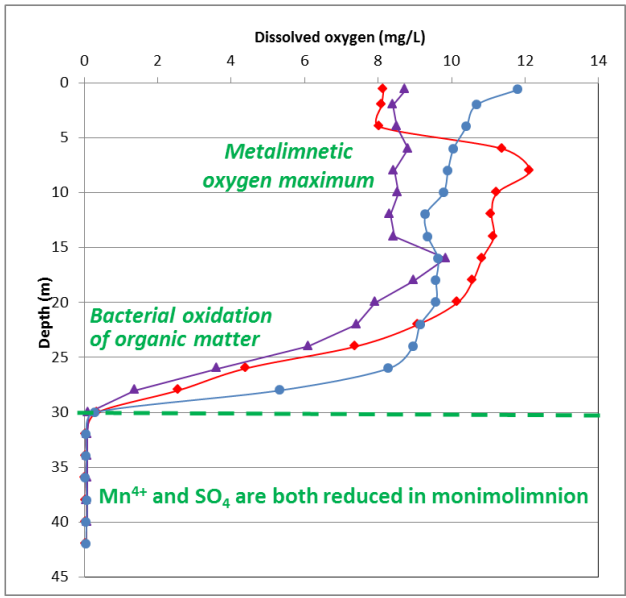
Bathymetry of Pit #2

(Contour interval = 10 m; max. depth = 99 m)

Task 2: Limnology and geochemistry of mine pit lakes







Hydrolab profiles showing variations of temperature, specific conductance and dissolved oxygen in Pit #1 in July 2016, October 2016 and February 2017. This pit exhibits a distinct chemocline at 30 m; at greater depths, oxygen is consumed and Mn, U and REE concentrations increase.

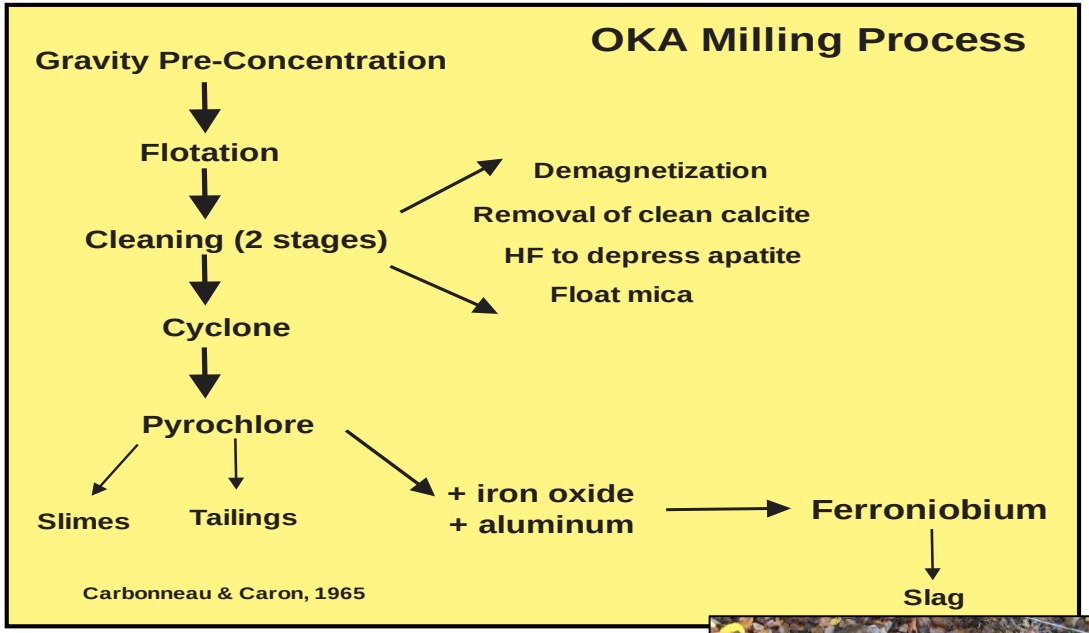
Task 3: Mineralogical Characterization

Goal: Characterize mineralogy and weathering reactions that lead to mobilization of Th, U and REEs from waste rock, tailings and slag materials

FY 2016-2017 Achievements

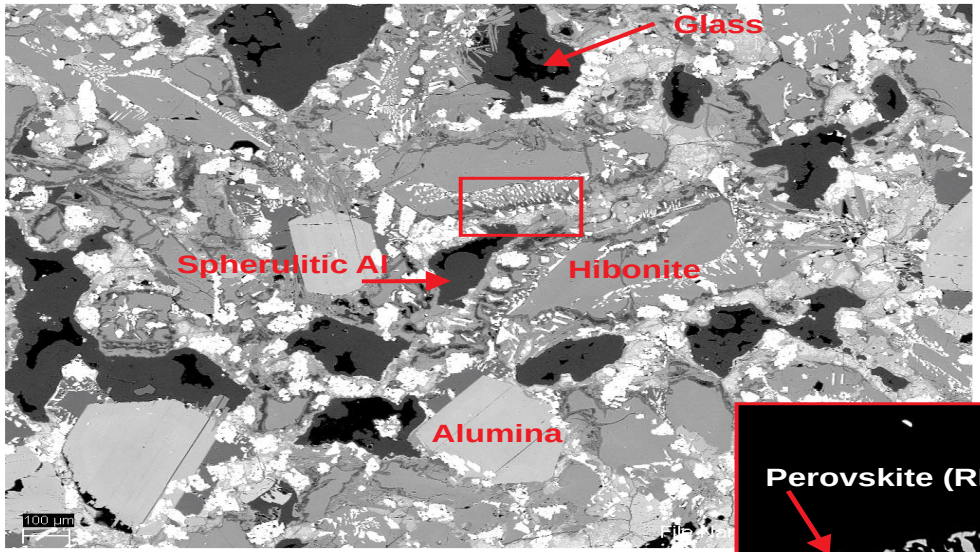
- Collected 25 waste rock samples for detailed petrological and mineralogical characterization
- Carried out *in situ* portable IR analyses to determine mineral species of mica, apatite, carbonate
- Completed autoradiography of 2015 samples
- In progress: whole rock XRD analyses; petrographic study of polished thin sections; SEM characterization of trace minerals and elemental chemistry

Mineral Processing and Environmental Risk



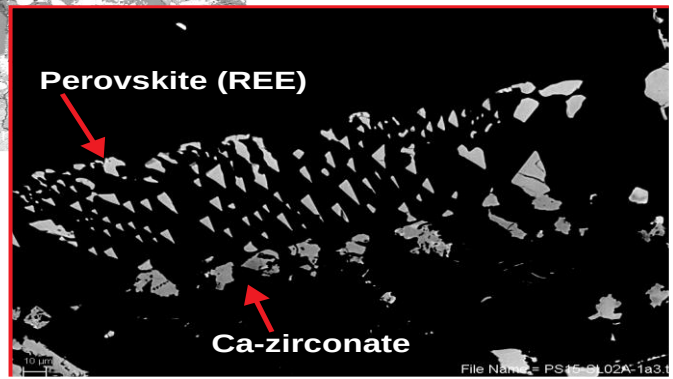
- Enriched trace elements: Nb, Th, U, Ta, Sn, Ba, P, and REEs
- Nb, Th, U and REEs in waste rock and tailings mainly in stable, insoluble minerals that decompose slowly
  - presence of carbonate will buffer any acid drainage production from sulphides
- Th, U and REEs in slag should be investigated; risk due to elevated radioactivity, rapid weathering of glasses formed during smelting

Task 3: Mineralogical Characterization



Slag PSA-15-02A

Dose Rate: 4.3 µS/hr
- 3.9%K
- 463 ppm U
- 371 ppm Th



Outputs

Natural Resources Canada / Ressources naturelles Canada

Geoenvironmental characteristics of critical metal deposits

In recent years, there has been a rapid increase in the global demand for many elements used in green energy and high-tech applications. The elements include antimony (Sb), cobalt (Co), indium (In), lithium (Li), niobium (Nb) and the rare earth elements (REE). These materials are used in a broad range of devices, including hybrid vehicles, photovoltaic cells, rechargeable batteries, mobile telephones, LCD screens, wind turbines and medical imaging equipment.

The term "critical metal" refers to elements that are essential for modern technology, but whose supply is at risk because of geological scarcity, political control of exports, low recycling rates or concerns over the environmental impacts of mining. Canada has abundant resources of these critical metals, and many companies are working hard to bring new mines into production. However, we know very little about the potential environmental impacts of mining critical metals compared to mining other commodities such as gold or copper.

Processing resources such as REEs has led to environmental degradation in some parts of the world, but there are few published studies of these environmental impacts and related risks to human health. Recent studies in Quebec by the Geological Survey of Canada (GSC) are providing new geoscience knowledge on the geoenvironmental characteristics of Nb and REE deposits. This knowledge should help to reduce the environmental risks of future development of these important resources.

Kemmerer sampling bottle used to collect water at depth in the flooded open pits

Location of Nb and REE exploration and development projects across Canada. At present, one Nb mine operates in Saint-Honoré, Quebec. There are no REE mines in Canada.

St. Lawrence Columbium mine

The abandoned St. Lawrence Columbium mine in Oka, Quebec, operated from 1961 to 1976 and, at the time, was one of the largest Nb producers in the world. Most of the Nb and REE minerals at this site are hosted in carbonatite, a relatively rare igneous rock. Geologically, the deposit at Oka is very similar to several other carbonatite deposits across Canada that are being considered for mining of Nb and REEs. Niobium ore was extracted by using open pit and underground mining methods, processed on-site, and sold mainly for use in steel production. Today, the mine site is inactive and contains piles of waste rock, tailings, slag, two flooded open pits, and underground mine workings that are filled with water.

Canada

In 2015, 2016 and 2017, GSC scientists collected samples of mine waste, surface water and groundwater to better understand the distribution, transport, and fate of metals and radionuclides. A hand-held gamma-ray spectrometer was used to measure the radiation emitted by decay of naturally occurring uranium (U) and thorium (Th) in the mine waste. Seasonal variations in water quality are being monitored over two years. The equipment being used includes data loggers installed in the flooded pits, sampling equipment that can collect water to a depth of 100 metres (m), and instruments installed in groundwater wells.

Key findings

1. About half of the St. Lawrence Columbium mine site is covered in tailings, which are a sand-sized waste from milling Nb ore. Analysis shows that the tailings are enriched with Nb and REEs, but have relatively low concentrations of potentially hazardous elements, including U, Th and naturally occurring radioactive isotopes (e.g. radium-226, lead-210).
2. In contrast, smelter slag at the mine site contains high concentrations of U, Th and radioactive isotopes that exceed Canadian guidelines for the disposal of radioactive waste.
3. Analysis shows that mine site surface waters are weakly alkaline and contain very low concentrations of Nb, REEs, U, Th, radium-226, radium-228 and lead-210. The concentrations of these elements are slightly higher in low-oxygen water deeper than 30 m in one of the flooded open pits. These results suggest that potentially hazardous elements in the local bedrock and mine waste are relatively immobile in well-oxygenated surface water but may be transported in deeper, low-oxygen groundwater.

Photomicrograph of carbonatite from Oka, Quebec. Mineral assemblage includes niccolite (yellow), calcite (white), perovskite (black) and apatite (grey). Field of view is 1 cm. Photo: T. Peterson, GSC.

Making a difference

The long-term goal of this project is to help expand Canada's role as an environmentally responsible supplier of critical metals. More studies are underway at the St. Lawrence Columbium mine. These will investigate seasonal variations in water chemistry, the long-term stability of mine waste, and the key processes controlling the composition of local surface water and groundwater. Results will be shared with the Municipality of Oka to help with long-term management of the mine site. The results will also help industry and regulators to improve environmental predictions for future Nb- and REE-mining projects and to support developing new environmental guidelines.

Hand-held gamma-ray spectrometer used to measure the radioactivity of mine waste

For more information, contact:
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Cat. No. M184-7/2017E-PDF (Online)
ISBN 978-0-660-08330-8

Aussi disponible en français sous le titre : Caractéristiques géoenvironnementales de gisements métallifères critiques

April 2017

Celebrating 175 yrs

Two-page fact sheet (available in both English and French)

Upcoming Conferences

Parsons, M.B., Percival, J.B., Venance, K.E., Desbarats, A.J. (2017) *Geoenvironmental characteristics of carbonatite-hosted niobium and rare earth element deposits: A case study from Oka, Quebec, Canada*. Abstract for the International Conference on the Biogeochemistry of Trace Elements in Zurich, Switzerland (July 2017)

Percival, J.B., Venance, K.E., Desbarats, A.J., Parsons, M.B., Bilot, I., Abraham, A.C., Laudadio, A.B. (2017) *Mineralogical Signature of the St. Lawrence Columbium Mine at Oka, Québec*. GAC-MAC abstract, Kingston, ON (May 2017)

Submitted a Special Session Proposal for the June 2018 Resourcing Future Generations Conference in Vancouver: "*Geoenvironmental characteristics of critical metal deposits*"

Task 1: Geochemistry of tailings seepage

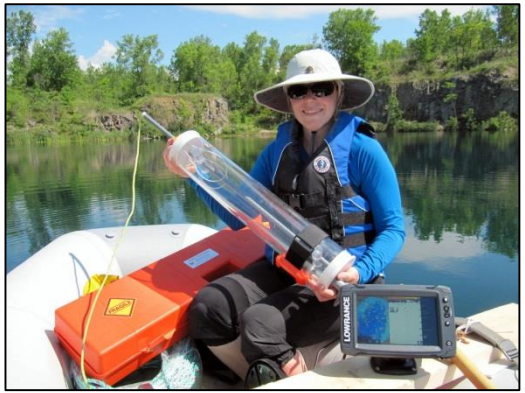
Tailings decant pond

Weir at tailings seepage point

Work plan (FY 2017-2018)

- Instrument existing monitoring wells on site
- Install data logger for monitoring flow rate, pH and conductivity in discharge from the tailings impoundment
- Obtain core samples of tailings at various depths
- Sample groundwater in piezometers
- Characterize mineralogy and chemistry of tailings
- Sequential leaches of tailings
- Construct test cells for field study of leaching from tailings and ferro-niobium slag material
- Start research project on slag chemistry with Tom Al Masters student (University of Ottawa collaboration)

Task 2: Limnology and geochemistry of mine pit lakes



Work plan (FY 2017-2018)

- Carry out water column profiling and sampling in flooded open pits in May and October 2017
  - Will include isotopic analyses in October to help fingerprint water sources to open pits
- Retrieve and re-deploy data loggers in Pit #2 to monitor daily fluctuations in water depth, temperature, and specific conductance over various seasons
- Characterize mineralogy and chemistry of pit sediments
- Start research project on weathering characteristics of waste rock with Sean Des Roches (Queen's University Masters student, co-supervised by Dr. Heather Jamieson).
- Assemble water chemistry data into GSC Open File

References

Carbonneau, C., Caron, J.C. (1965) The production of pyrochlore concentrates at St. Lawrence Columbium and Metals Corp., CIM Transactions, v. 68, pp. 71-79

Zinck, J. (2013) Realizing Canada's rare earth element resource potential: R&D perspective. Proc. 52nd Conf. of Metallurgists, pp. 25-35.

CONTACT INFORMATION

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THANK YOU!

Celebrating 175 yrs

Geoscience tools for supporting environmental risk assessment of metal mining

Outils géoscientifiques pour soutenir l'évaluation des risques environnementaux de l'exploitation minière des métaux

Jennifer Galloway et al.

May 9th, 2017

NATURAL RESOURCES CANADA - INVENTIVE BY NATURE

PROJECT MEMBERS

Environment and Climate Change Canada / Environnement et Changement climatique Canada — Canada

Indigenous and Northern Affairs Canada

POLAR KNOWLEDGE CANADA / SAVOIR POLAIRE CANADA

NWT CIMP

Northwest Territories

NORTHWEST TERRITORIES GEOLOGICAL SURVEY

canadian museum of nature / musée canadien de la nature

NORTH SLAVE METIS ALLIANCE

YELLOWKNIVES DÉNÉ FIRST NATION

Queen's University

Carleton University

NSERC CRSNG

TerraX

ABSTRACT

- The goal of this activity is to test the hypothesis that climate variability controls metal(loid) cycling in the environment. We initiated research in 2015-16 to provide missing baseline geochemical data and model the cumulative impacts of geogenic and anthropogenic processes, with a focus on climate variability, on the transport and fate of metal(loids) in the vicinity of the City of Yellowknife, Northwest Territories. Due to the complex geology of the Slave Geological Province and in particular, mineralized greenstone belts and hydrothermal alteration zones, geochemical background can be highly variable even on small spatial scales. In addition, the Yellowknife region has experienced ~75 years of gold ore mining and processing that resulted in release of substantial quantities of arsenic to the surrounding environment. The larger POLAR Knowledge Canada S&T funded activity will also focus on the Courageous Lake area that is thought to have been impacted by free-milling gold mining and processing at Tundra, Salmita, and Bulldog mines in the 1960s and 1980s, and the yet to be developed Hope Bay area (TMAC Resources Ltd.) in the central and northern Slave Geological Province, respectively.

OUTLINE

- Northern climates are rapidly changing
- Organic matter is important in mobility and fate of arsenic
- Permafrost peatlands are a potential source of deleterious elements

OBJECTIVES

How will climate variability impact transport and fate of elements of potential concern?

Journal of Geophysical Research: Biogeosciences

RESEARCH ARTICLE
10.1002/2014JG002809

Key Points:
- Enhanced winter streamflow in the Canadian subarctic changes water chemistry
- The largest changes are when chemical cycling and runoff become synchronous
- The best example of this new synchrony is NH_3-N loading

Evidence of a change in water chemistry in Canada's subarctic associated with enhanced winter streamflow

C. Spence[1], S. V. Kokelj[2], S. A. Kokelj[3], M. McCluskie[3], and N. Hedstrom[1]

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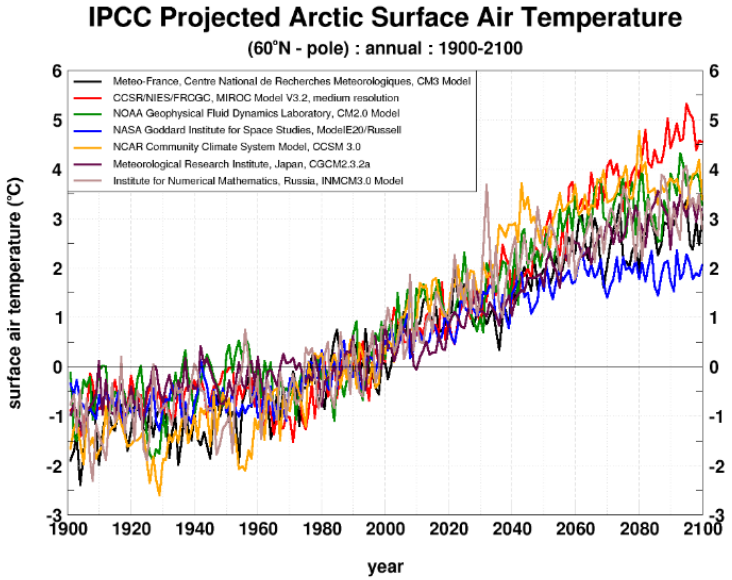
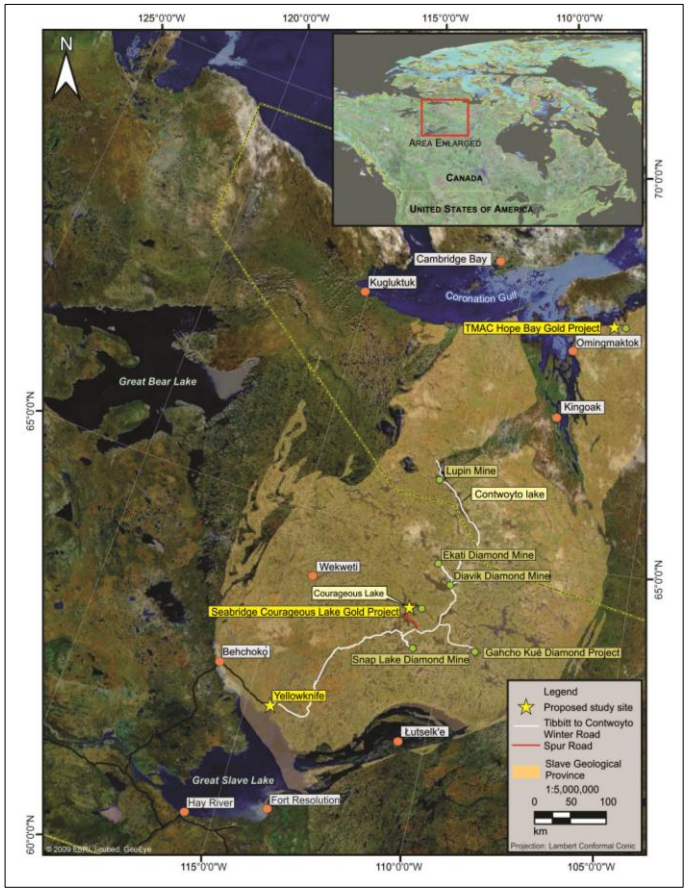


STUDY AREA

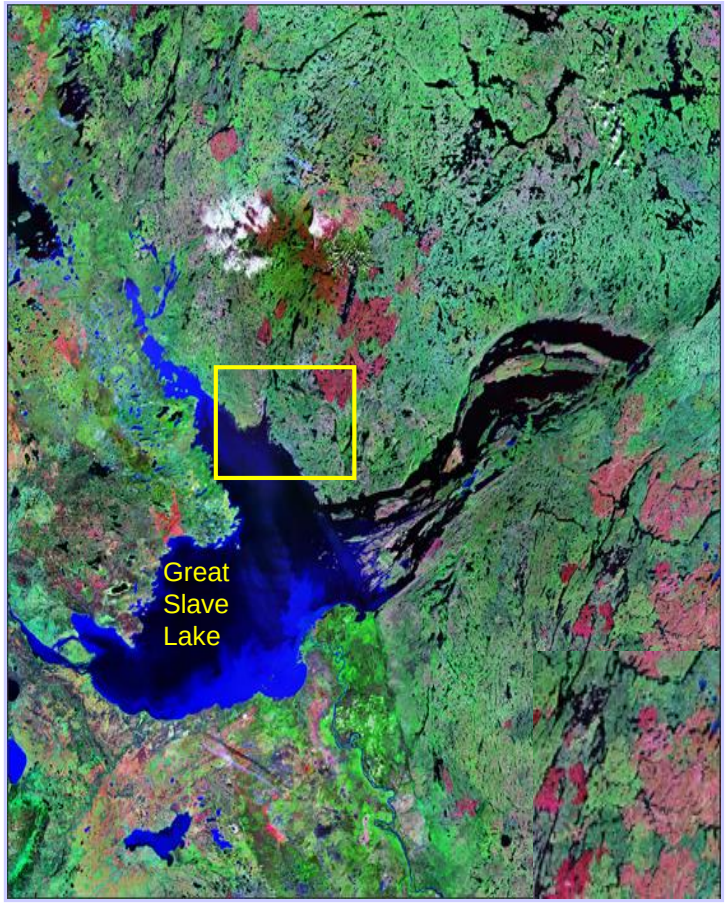


Archean greenstone hosted mesothermal gold deposits rich in As and other elements (Cu, Pb, Zn) mined for ~75 years in the Slave Geological Province of the NWT

Widespread emission of As to the environment

Concern about the impact of climate change on remediation, current, and future developments

STUDY AREA

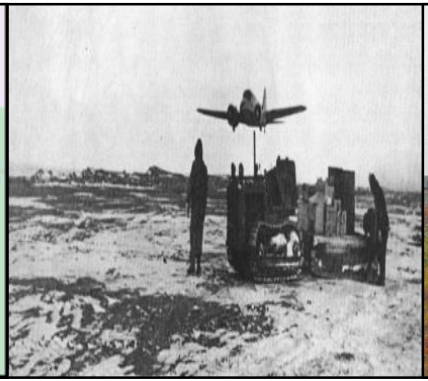


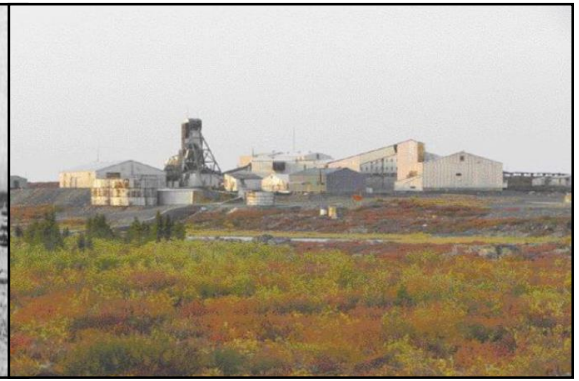
Giant Mine, Yellowknife

STUDY AREA

Courageous Lake

- Canada's second largest undeveloped gold resource (6.5M oz Courageous Lake 53 km greenstone belt)
- Free milling gold mining 1964-1968 (Bulldog and Tundra mines) and 1983-1987 (Salmita Mine)
- Has seepage from the Tailings Containment Area loaded As into Matthews Lake?
- Background geochemistry poorly known





METHODS

- Spatial lake sediment survey, lake sediment cores and pore waters, peat cores
- Inorganic and organic geochemistry (bulk, sequential extraction, mineralogy (ESEM MLA, µXRD/XRF), speciation in pore waters)
- Micropaleontology
- Traditional Knowledge and Inuit Qaujimajatuqangit

Yellowknife region



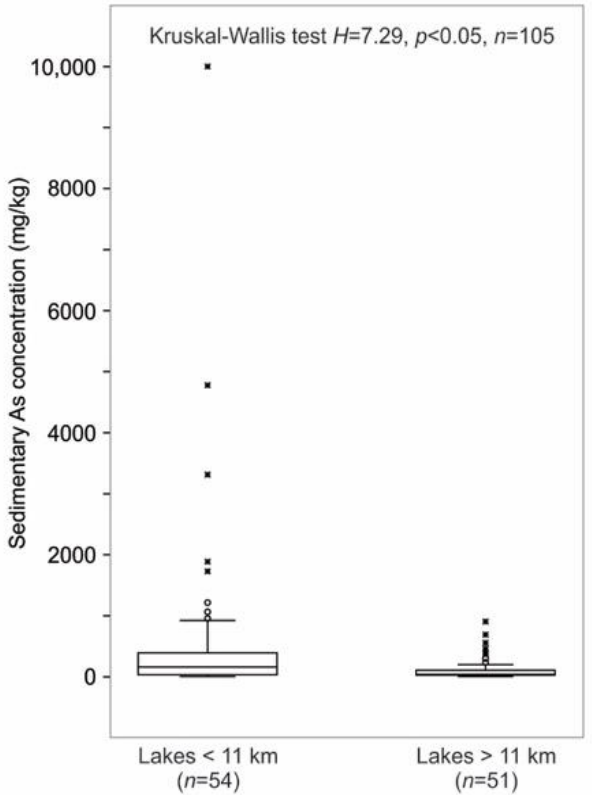
RESULTS

Near surface lake sediment survey (*n*=105) 30 km radius from Giant Mine, Yellowknife

Regional background [As] ~20-30 ppm; [As] ranges up to >10,000 ppm

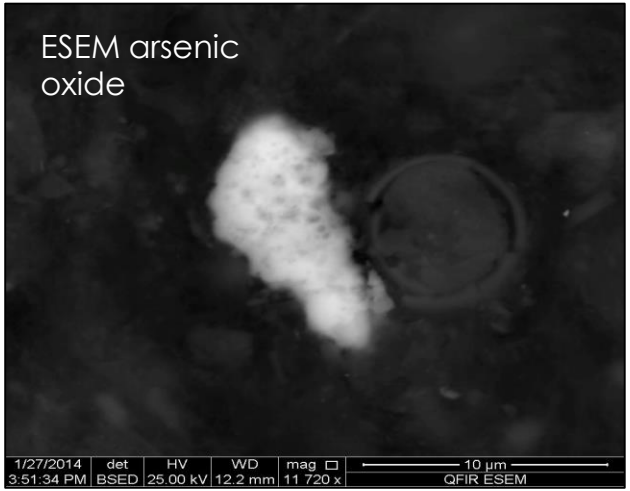
Lakes <11 km from the mine have >> [As] than those beyond

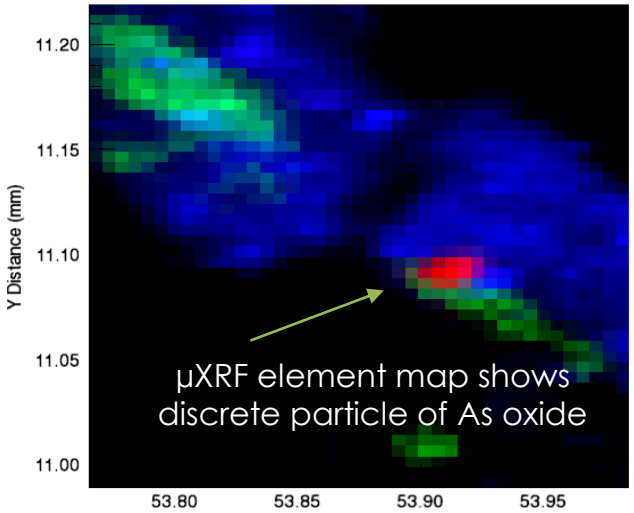
Galloway et al., 2015; Palmer et al., 2015



RESULTS

Anthropogenically-derived arsenolite (As_2O_3) is present in some Yellowknife area lakes (synchrotron-based µXRF and µXRD)



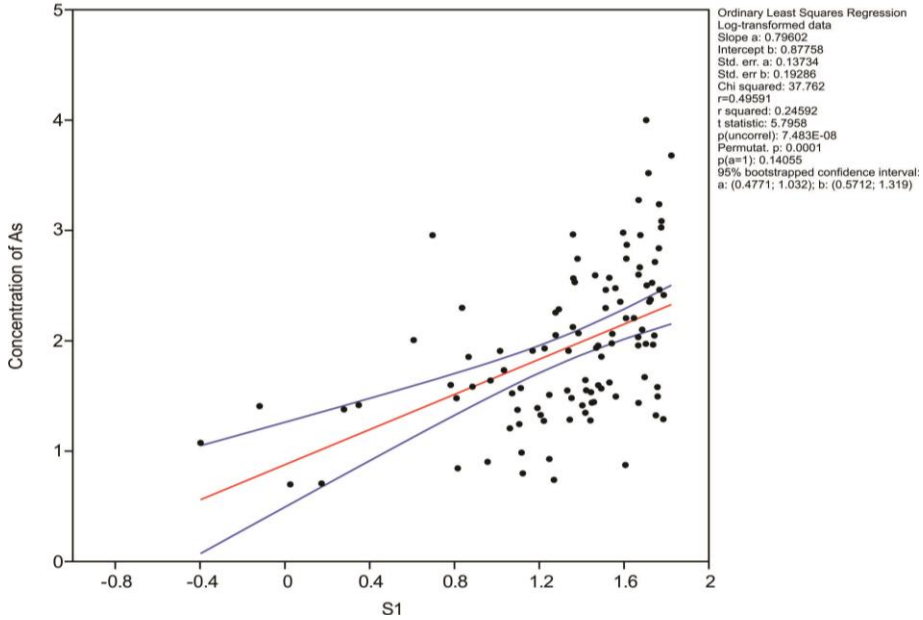


RESULTS

S1 carbon is also related to sedimentary [As] in Yellowknife area lakes

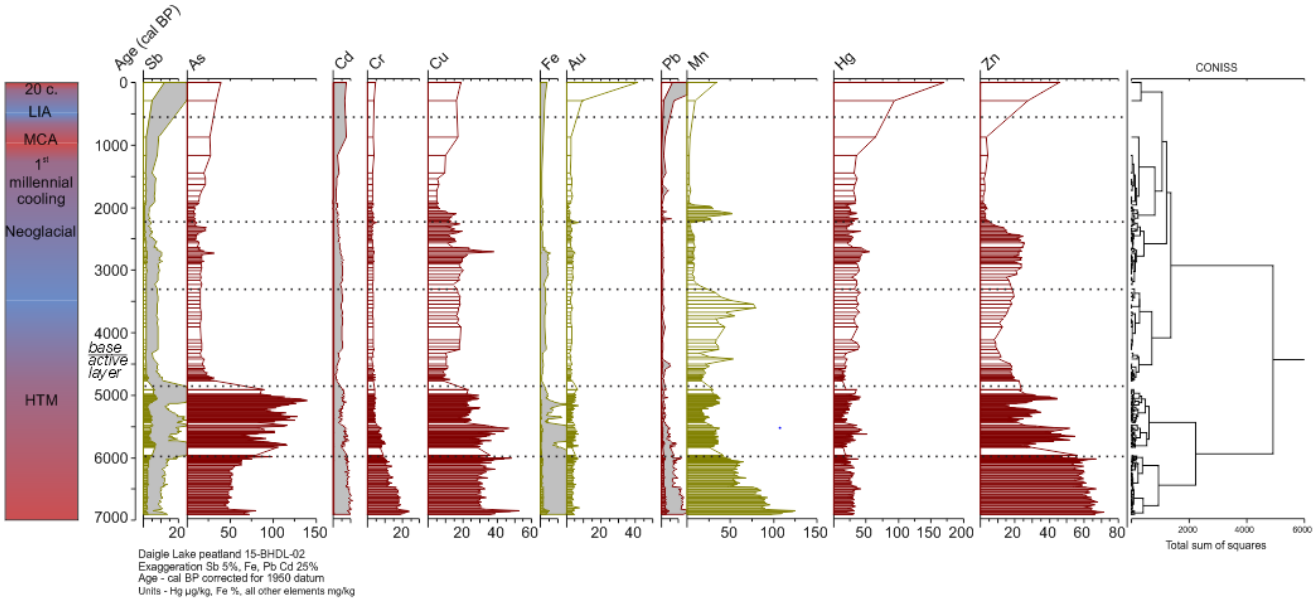
S1:As >11 km r=0.38, $p<0.05$, $n=54$
S1:As < 11km r=0.71, $p<0.05$, $n=51$
S1:As all lakes r=0.55, $p<0.05$, $n=105$

Lake order, Strahler stream order, lake area, connectivity, catchment type etc. non-significant



RESULTS

- Permafrost peatlands a sink for metal(loids)
- Permafrost expected to degrade substantially (reduction from 67% at present to 2% by 2100)
- Fire can thicken active layer by ~0.5 m
- Latent heat effects may slow deterioration



Canada

Courageous Lake

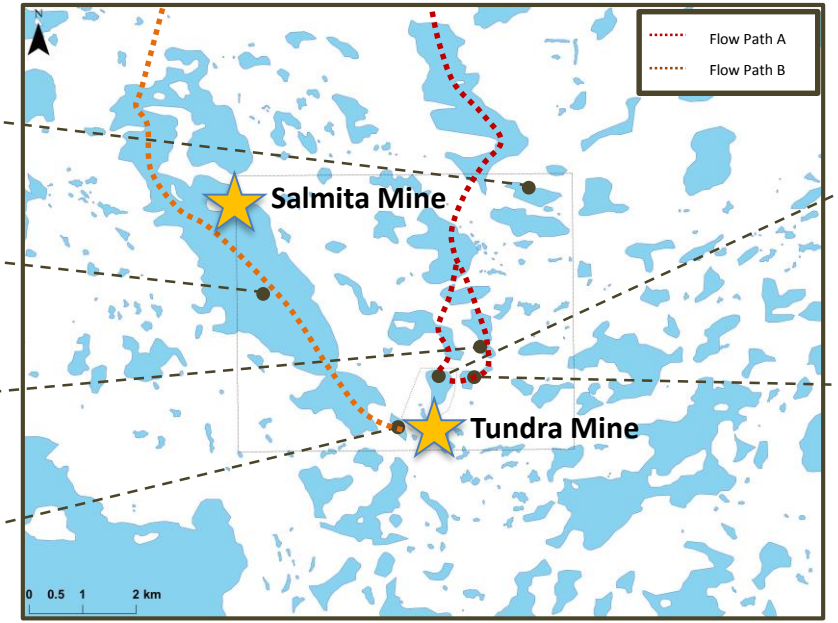
Winter 2016

Control Lake
- Water column sample
- 48 cm sediment core

Matthews Lake
- Water column sample
- 52 cm sediment core

Powder Mag Lake
- Water column sample
- 30 cm sediment core

Bulldog Lake
- Water column sample
- 37 cm sediment core



Summer 2016

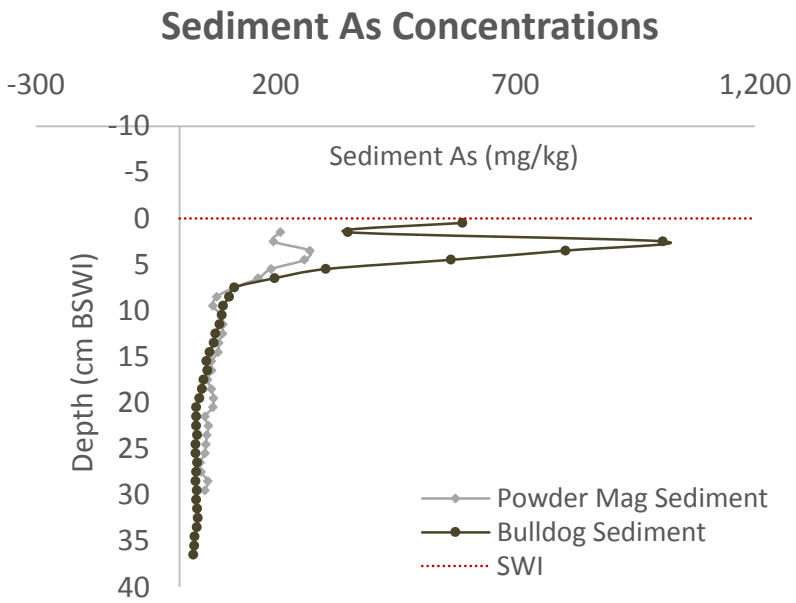
Tailings Confinement Area
- Three tailings cores
- Sampled at intervals from 0 – 40 cm

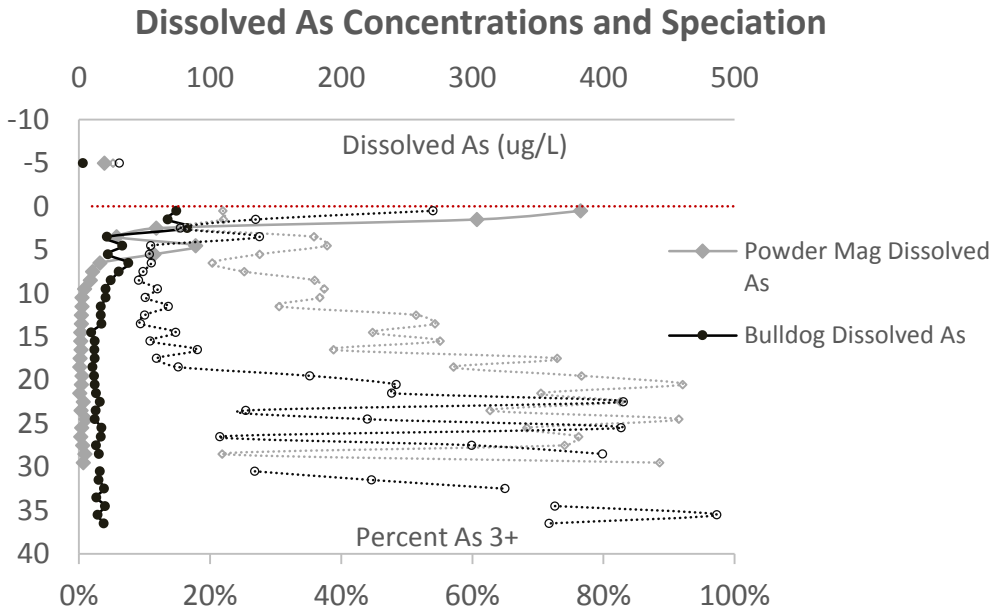
Hambone Lake
- 6 sediment grab samples along transect from tailings discharge

Courageous Lake

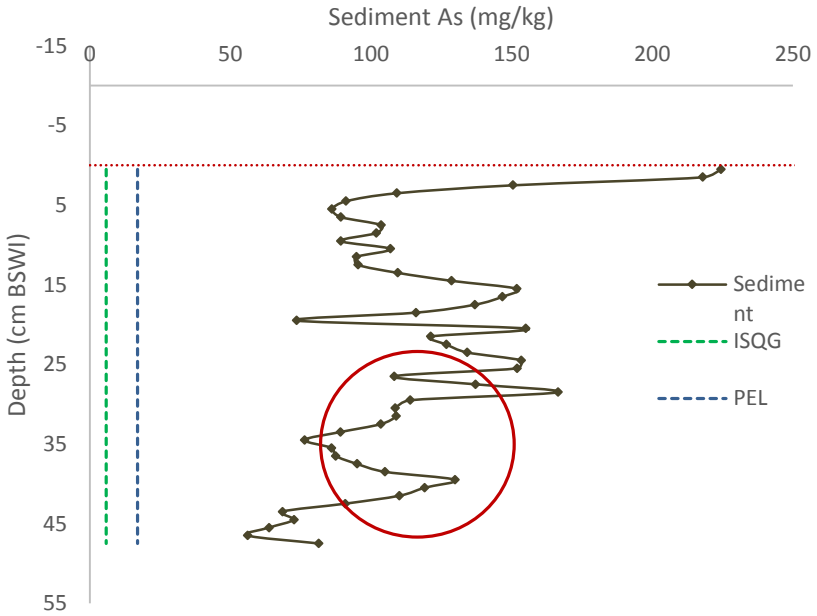
Mine Processing: Down-Stream Impact

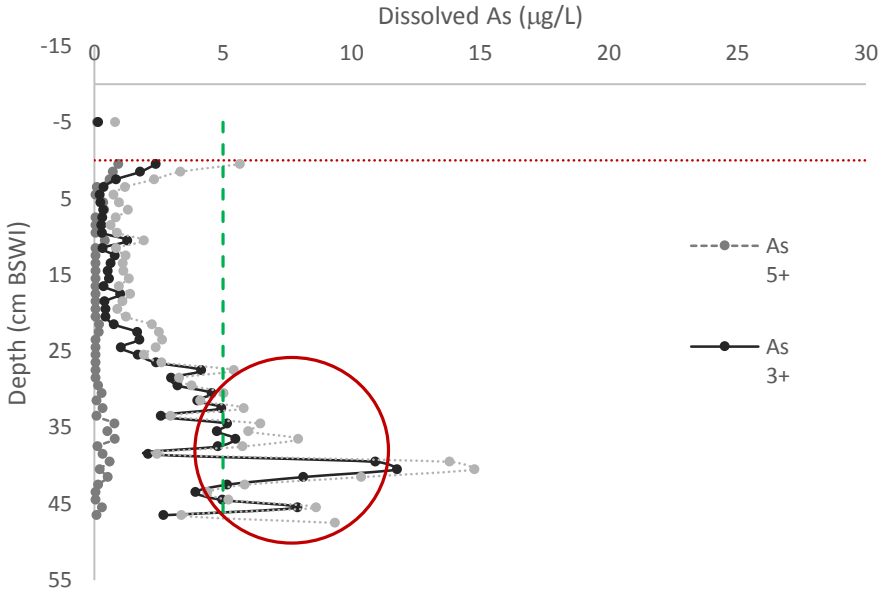
Powder Mag Lake and Bulldog Lake





Natural Baseline: Courageous-Mackay Lake Greenstone Belt
Control Lake





Traditional Knowledge

TK and IQ studies on past climate and environmental change and mine-related impacts to communities and ecosystems

RESULTS

Past Knowledge of Climate and Environment held by the Métis of Great Slave Lake

- Métis historical experience occurred at the cross-roads of Indigenous and Euro-Canadian encounters and interactions contains within it Indigenous and hybrid Indigenous-European modes of sustenance, labour, and knowledge production
- Historical meteorological data from traditional Métis territory (Hudson's Bay Company journals, John Franklin Expeditions, Meteorological Council of Great Britain, IPY)
- Cultural knowledge on climate and environmental change (Warburton Pike and interviews with NSMA members)

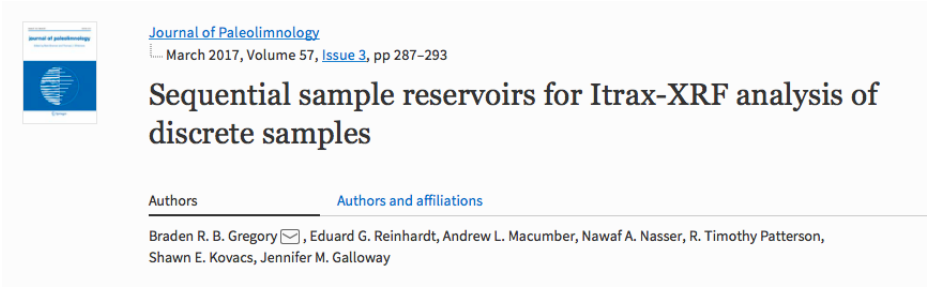
RESULTS

Tłı̨chǫ Traditional Knowledge Study
Summary Report for NRCAN

This summary outlines the process and preliminary results of the Tłı̨chǫ traditional knowledge study of climate change. The Tłı̨chǫ traditional land use areas lie within the boundary known as “Mǫwhì Gogha Dè Nı̨ı̨tłèè” and consists of the area between Great Slave Lake and Great Bear Lake, from the Horn Plateau in the southwest, and as far north as the Coppermine River and Contwoyto Lake. The four Tłı̨chǫ communities Behchokǫ̀, Whatì, Gamètì and Wekweètì, are located in the boreal forest, but their traditional land stretches north of the tree line into the tundra, where many of their fall hunting grounds for caribou are located. The Tłı̨chǫ harvesters monitor the conditions of the land during each season as they daily track, hunt, fish and trap animals throughout their traditional lands.

OTHER OUTPUTS

- New methods for rapid geochemical determination (Itrax XRF)
- New methods for water table reconstructions based on testate amoebae
- New methods for geochronological control
- Human Health Impact Advisory
- 2PhD, 2 MSc students



Journal of Paleolimnology

March 2017, Volume 57, Issue 3, pp 287–293

Sequential sample reservoirs for Itrax-XRF analysis of discrete samples

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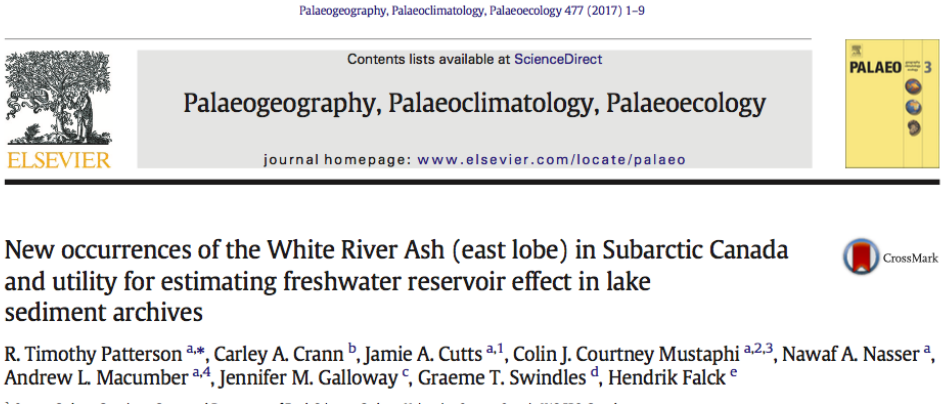


Palaeogeography, Palaeoclimatology, Palaeoecology 477 (2017) 1–9

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

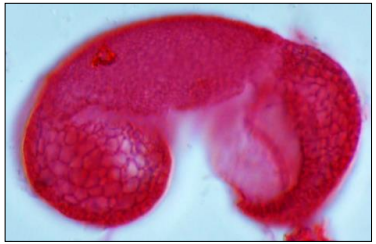
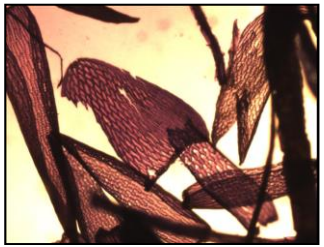
journal homepage: www.elsevier.com/locate/palaeo

New occurrences of the White River Ash (east lobe) in Subarctic Canada and utility for estimating freshwater reservoir effect in lake sediment archives

R. Timothy Patterson [a,*], Carley A. Crann [b], Jamie A. Cutts [a,1], Colin J. Courtney Mustaphi [a,2,3], Nawaf A. Nasser [a], Andrew L. Macumber [a,4], Jennifer M. Galloway [c], Graeme T. Swindles [d], Hendrik Falck [e]

YEAR 3

- On the land IQ camp (August 2017)
- What is the S1 fraction of OM exactly? Py-GC-MS (GSC-C)
- Why is As accumulating in peatlands? Uptake in plants? Sorbed onto plants? Sequential extraction experiments (U of A)
- Continued data analysis, synthesis, and production of outputs


CONTACT INFORMATION

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EGP –Public Presentations of May 9th 2017

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- Program manager: Gilles.Cotteret@Canada.ca

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- Shale Gas -Groundwater project leader: Christine.Rivard@Canada.ca
- Shale Gas -Induced Seismicity project leader: Honn.Kao@Canada.ca
- Carbon Capture and Storage project leader: Don.White@Canada.ca
- Critical Metals and Metal Mining project leader: Michael.Parsons@Canada.ca

Alignment with NRCan PAA 2014-2015

Strategic Outcome 2: Natural Resource Sectors and Consumers are Environmentally Responsible

Program 2.3: Responsible Natural Resource Management

Sub-Program 2.3.3: Environmental Studies and Assessments

ENVIRONMENTAL GEOSCIENCE PROGRAM LOGIC MODEL (2014-2019)

Responsible natural resource development

More effective/efficient environmental regulation and oversight

Decision makers (policy makers, project proponents) have better understanding of impact of natural resource development projects to enhance environmental performance

Public and private sectors develop environmental characterization methodologies

Greater capacity for project proponents to carry out and for public sector to review environmental assessments

Long term

Short term

Geoscience knowledge (scientific publications, databases…)

OUTPUTS

Carbon Capture & Storage

Metal Mining

Oil Sands

Shale Gas: Induced Seismicity

Shale Gas: Groundwater Vulnerability

2016-2017 ACTIVITIES