Hydrocarbon Systems in the Intracratonic Hudson Bay Basin: A New Prospective Frontier in the Canadian North*

(Geological Setting and Petroleum Potential of the Paleozoic Hudson Platform, Northern Canada**)

Denis Lavoie[1], Nicolas Pinet[1], Mathieu Duchesne[1], Virginia Brake[1], Esther Asselin[1], Kezhen Hu[1], Jim Dietrich[1], Shunxin Zhang[1], Rudolf Bertrand[2], Barry P. Kohn[3], Derek Armstrong[4], Michelle Nicolas[5], J. Galloway[1], and A. Sweet[1]; also Patrick Lajeunesse[6], Jonathan Roger[6], and Gabriel Huot-Vézina[1]

Search and Discovery Article #10327 (2011)
Revision posted September 26, 2011; original posted May 31, 2011

*Adapted from oral presentation at 3P Arctic - The Polar Petroleum Potential Conference & Exhibition, Halifax, Nova Scotia, Canada, August 30-September 2, 2011, hosted and organized by AAPG and Allworld Exhibitions, and from
**Oral presentation at AAPG Annual Convention and Exhibition, Houston, Texas, April 10-13, 2011

[1]Geological Survey of Canada, Quebec City, QC, Canada (Denis.Lavoie@nrcan.gc.ca)
[2]Institut National de la Recherche Scientifique, Quebec City, QC, Canada
[3]University of Melbourne, Melbourne, VIC, Australia
[4]Ontario Geological Survey, Sudbury, ON, Canada
[5]Manitoba Geological Survey, Winnipeg, MB, Canada
[6]Geography, Laval University, Quebec City, QC, Canada

Abstract

The Hudson Platform covers 600,000 km^2 and is one of the largest Paleozoic sedimentary basins in Canada. The Hudson Platform encompasses parts of Manitoba, Ontario and Nunavut, with two thirds of the area covered by waters of Hudson Bay. The Platform contains the large Hudson Bay Basin and the smaller satellite Moose River and Foxe basins.

The Hudson Platform is the least studied intracratonic basin in North America; its surface area rivals that of other intracratonic basins although it is characterized by a thinner preserved sedimentary succession. The succession of the Hudson Platform consists of Ordovician to Cretaceous strata, with a maximum preserved thickness of about 2500 m. The Paleozoic succession includes Ordovician to Devonian shallow marine carbonates, reefs and thin mudstones with thick Devonian evaporites. Paleozoic strata are unconformably overlain by thin, erosional remnants of Jurassic and Cretaceous non-marine and marine sandstones, mudstones and lignite seams.

The hydrocarbon potential of the Hudson Platform is poorly constrained, and the area is viewed as a frontier prospect. In a first phase of exploration (1970-1980), over 46 000 line-km of seismic reflection data were acquired and 5 exploration wells drilled. Most of the seismic profiles and all of the exploration wells are located in a relatively small area in the central part of Hudson Bay. A limited number of onshore

wells have also been drilled. Although bitumen was been reported in wells, all were dry and exploration companies abandoned the area in the 1980s.

The Geological Survey of Canada and its partners are carrying out a re-evaluation of the petroleum systems and energy resource potential of the Hudson Platform. Results indicate that many prospective petroleum reservoir and trap types, including porous hydrothermal dolomites and reefs. Upper Ordovician oil shales are widespread with TOC values up to 35% (average of 15%); the thickness of these Type I/II source rocks range between 5 to 15 metres. Thermal maturation data on well cuttings suggest that oil window conditions (Ro_{vit} of 1%) have been reached in the intervals that host the Ordovician source rocks. New high resolution bathymetric surveys in Hudson Bay have led to the recognition of circular sea-floor depressions similar to fluid or gas-escape pockmarks, possible evidence of hydrocarbon migration. New hydrocarbon systems data suggest that large areas of the Hudson Platform are prospective for oil accumulations.

Selected References

Armstrong, D.K., and D. Lavoie, 2010, Re-evaluating the hydrocarbon resource potential of the Hudson platform: Project introduction and preliminary results from northern Ontario, *in* Summary of Field Work and Other Activities 2010: Ontario Geological Survey, Open File report 6260, p. 39-1 to 39-9. http://www.mndmf.gov.on.ca/mines/ogs/ims/pub/sfw/sfwpdf/6260-39.pdf

Davies, G.R., and L.B. Smith, Jr., 2007, Structurally controlled hydrothermal dolomite reservoir facies: An overview: Reply: AAPG Bulletin, v. 91/9, p. 1342-1344.

Leighton, M.W., 1996, Interior cratonic basins: a record of regional tectonic influences, *in* B.A. van der Pluijm, and P.A. Catacosinos (eds.) Basement and Basins of Eastern North America: GSA Special Paper 308, p. 77-93.

Macauley, G., 1986, Geochemistry of the Ordovician Boas Oil Shale, Southampton Island, Northwest Territories: Geological Survey of Canada, Open File 1285, 15 p.

Macauley, G., 1987, Geochemistry of organic-rich Ordovician sediments On Akpatok and Baffin Islands, Northwest Territories: Geological Survey of Canada, Open File 1502, 27 p.

Sanford, B.V., and A.C. Grant, 1990, New findings relating to the stratigraphy and structure of the Hudson Platform: Geological Survey of Canada, Paper 90-1D, p. 17-30.

Stott, D.F., and J.D. Aitken, 1993, Sedimentary cover of the Craton in Canada: Geology of Canada No. 5, Geological Survey of Canada, Ottawa, 826 p.

Yin, H., and R.H. Groshong Jr., 2007, A three-dimensional kinematic model for the deformation above an active diapir: AAPG Bulletin, v. 91/3, p. 343-366.

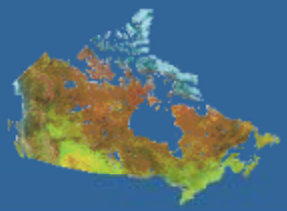
Hydrocarbon Systems in the Intracratonic Hudson Bay Basin: A New Prospective Frontier in the Canadian North

GEM

Lavoie, D.[1], Pinet, N. [1], Duchesne, M.[1], Brake, V.[1], Asselin, E.[1], Hu, K.[1], Dietrich, J.[1], Zhang, S. [1], Bertrand, R.[2], Kohn, B.[3], Armstrong, D.[4], Nicolas, M.[5], Galloway, J.[1], Sweet, A.[1]

[1]Geological Survey of Canada
[2]Institut National de la Recherche Scientifique
[3]University of Melbourne
[4]Ontario Geological Survey
[5]Manitoba Geological Survey

INTRODUCTION

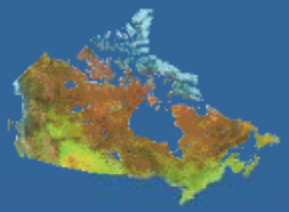


The Hudson Bay basin is the least known (unstudied) basin in the center of North America. Previous exploration round (1970's-1980's) resulted in 46,000 km of poor resolution seismic and 5 dry wells.

The temperature history of these basins is largely unknown; so it is not clear if oil or gas has been generated. Hudson Bay was not tested for the kinds of prolific oil and natural gas reservoirs that have been found in central USA since the first round of exploration.

New geoscience data are needed in order to evaluate the hydrocarbon systems of this large, predominantly marine, area. This presentation offers the preliminary results of a recent new research project by the Geological Survey of Canada

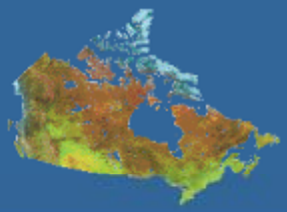
OUTLINE

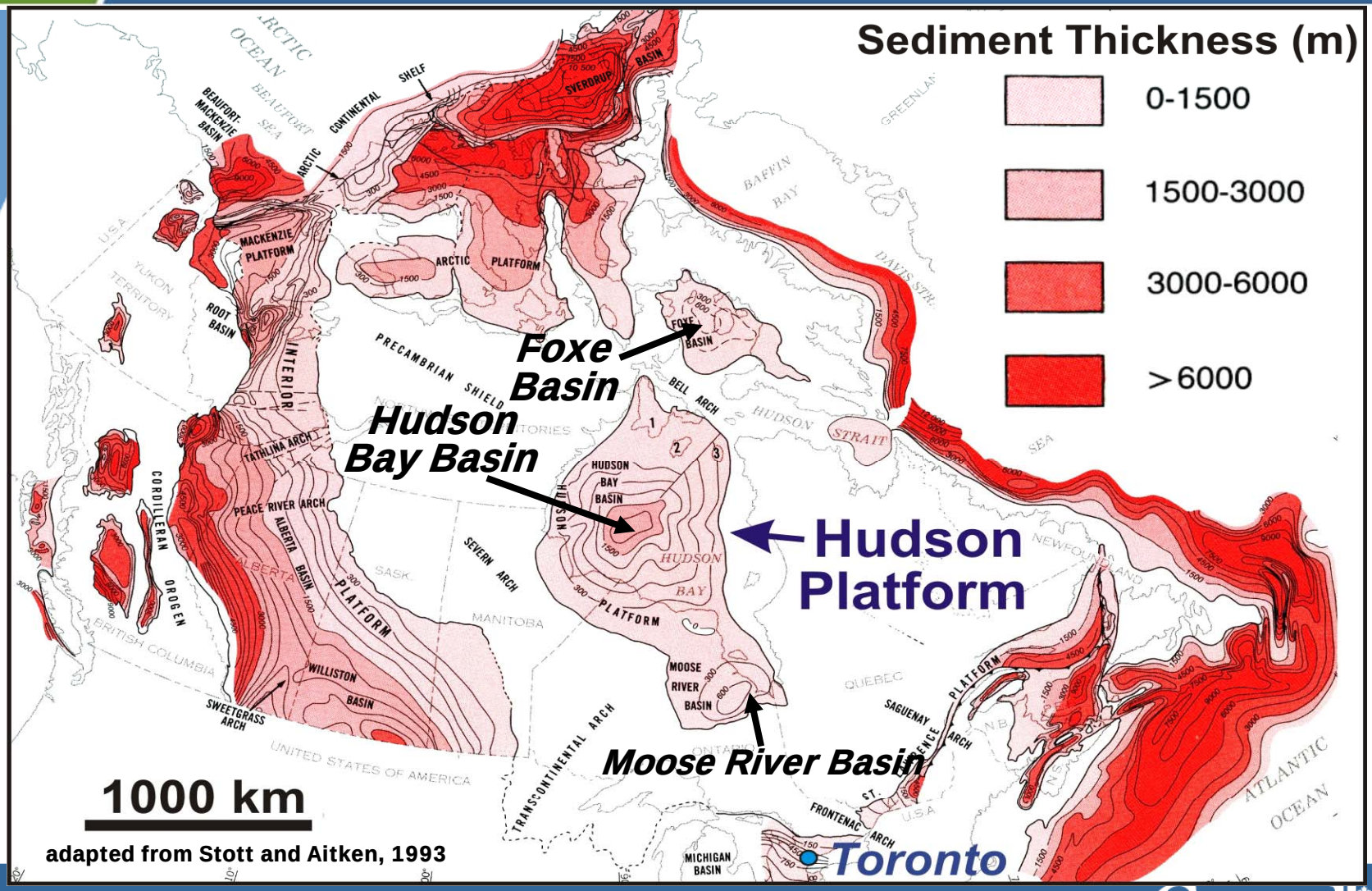


Hudson Bay Basin

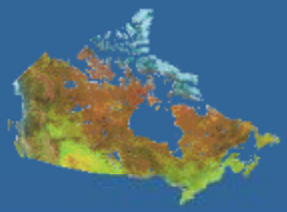
1. Geological setting and historical review
2. Stratigraphy
3. Hydrocarbon system data
   - Source rock – nature, distribution, maturity
   - Reservoir rocks – HTD and reefs
4. Evidence for active hydrocarbon systems
5. Conclusions

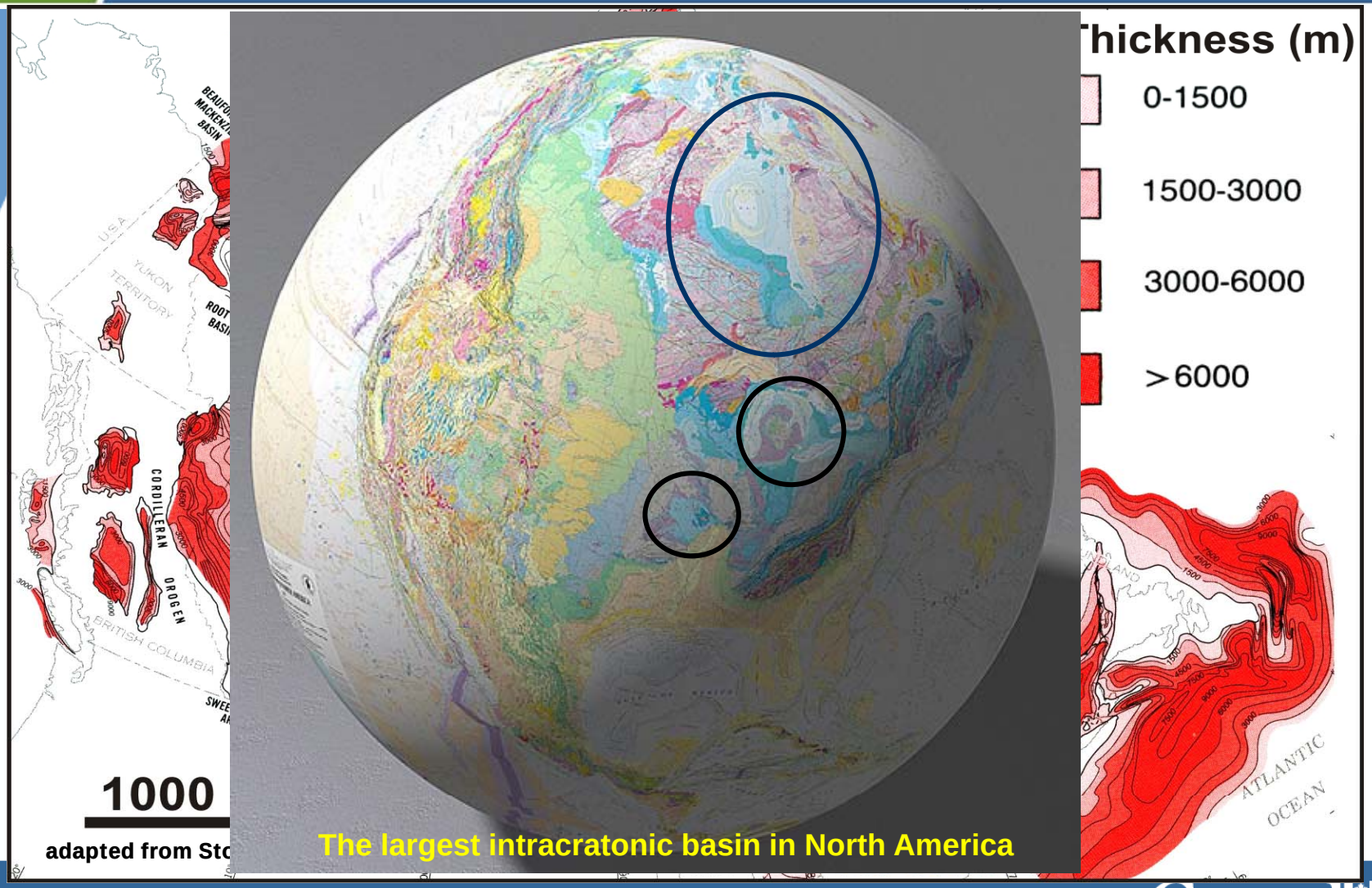
Hudson Bay Platform
A major FRONTIER sedimentary basin in Northern Canada



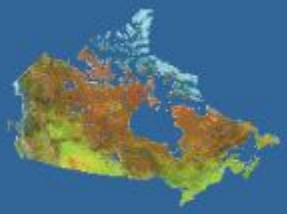


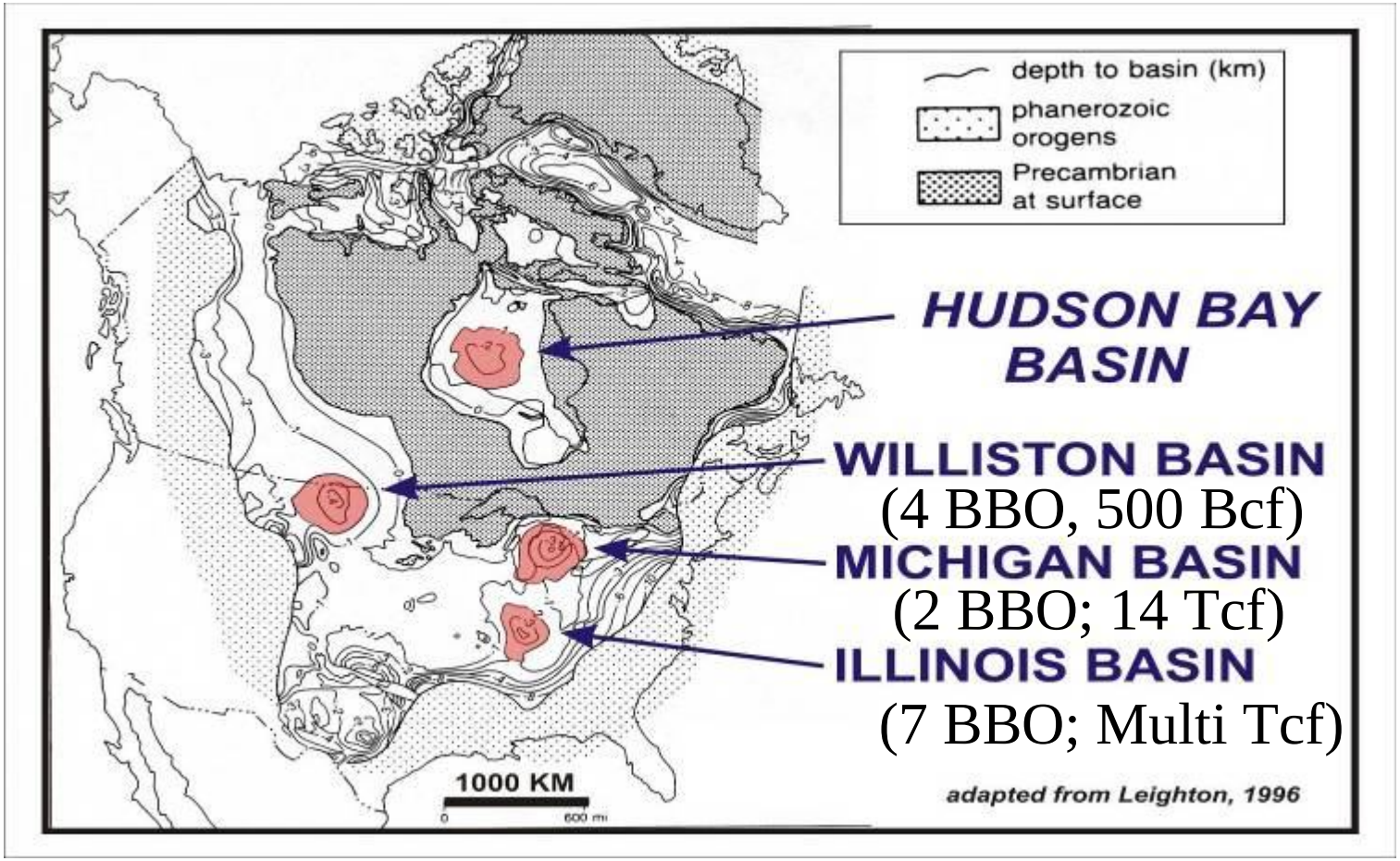
Hudson Bay Platform
A major FRONTIER sedimentary basin in Northern Canada



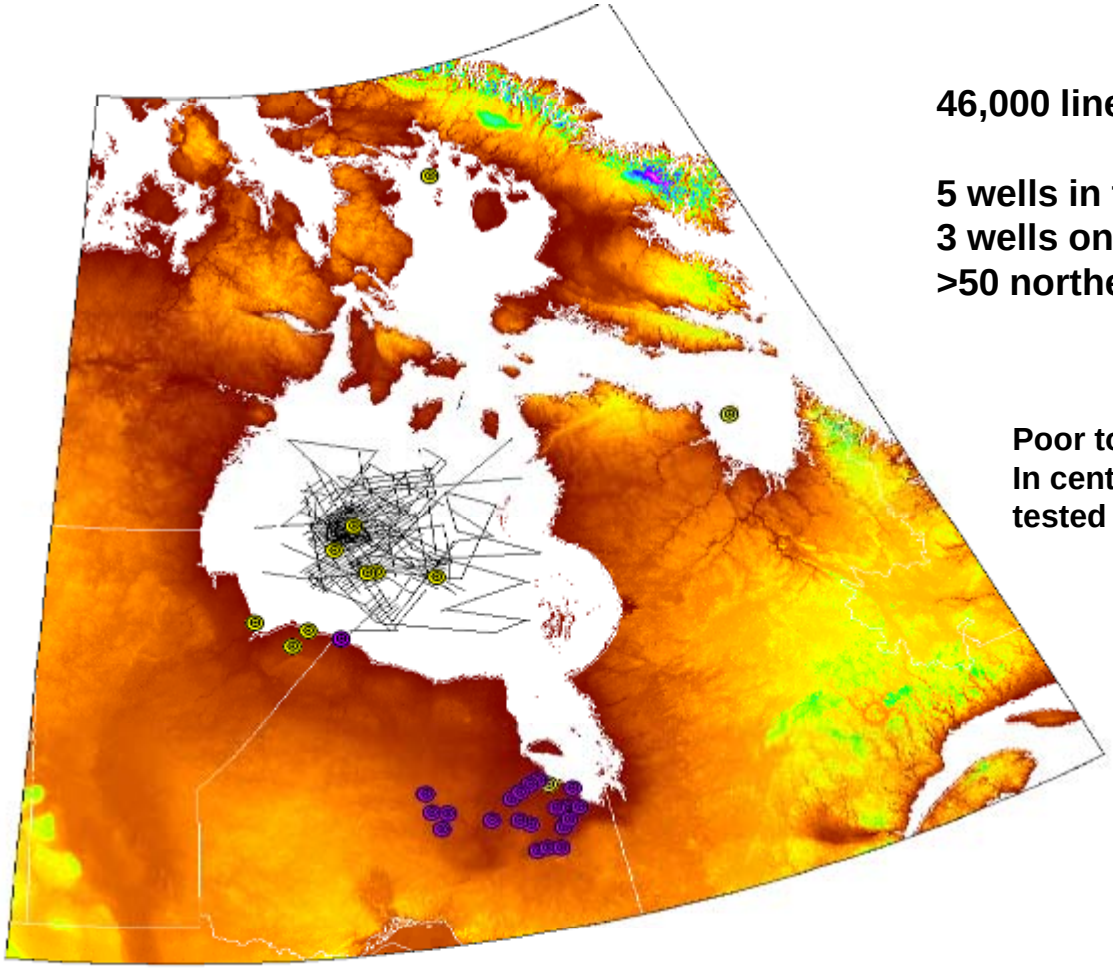


Regional and historic background





Regional and historic background

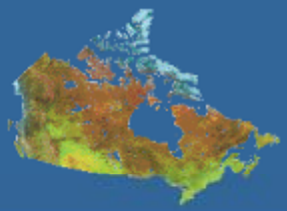


46,000 linear-km of seismic

5 wells in the Bay
3 wells onshore Manitoba
>50 northern Ontario

Poor to fair quality seismic
In central Hudson Bay
tested only structural highs

Main Research Activities 2009-2013



Reconstruct 3D model of basins architecture

Subsurface Maps – offshore seismic

Potential field data (airborne aeromagnetic and gravimetry)

Seafloor Maps and Satellite images

Define hydrocarbon systems data

Hydrocarbon source rocks – Stratigraphy, thermal conditions and geochemistry

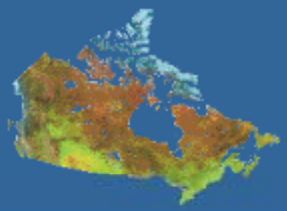
Hydrocarbon reservoir rocks – Stratigraphy, sedimentology, geochemistry and petrophysics

Derive hydrocarbon plays and resource evaluation

Basin and thermal modeling of the Hudson Bay – Foxe basins

Quantitative estimates of Hudson Bay – Foxe basins petroleum potential

Bedrock Geology



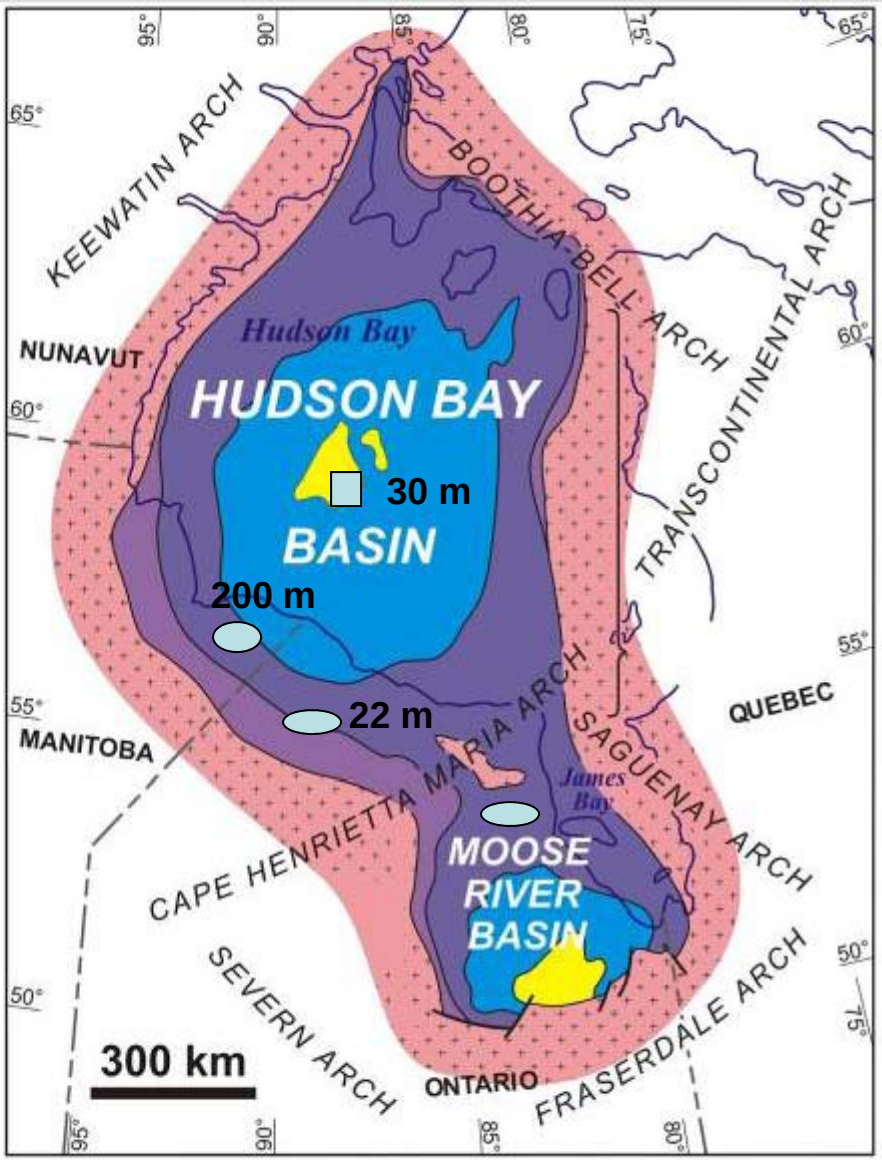
Jurassic/ Cretaceous

Devonian

Silurian

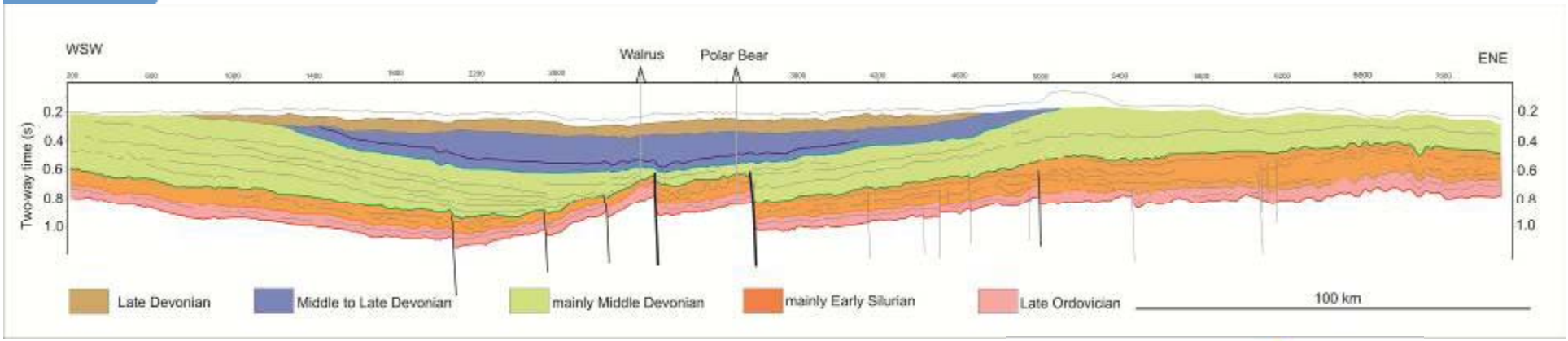
Ordovician

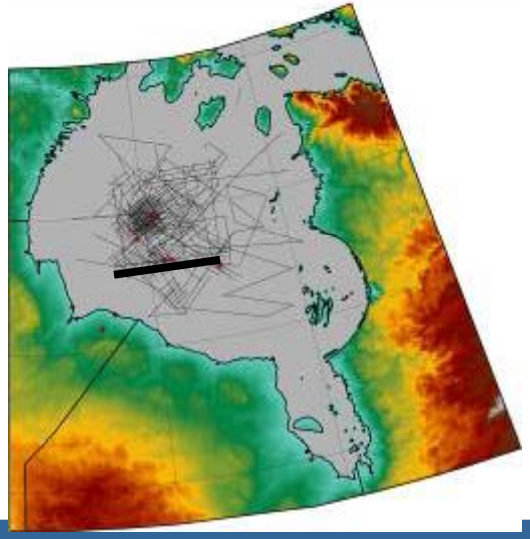
Precambrian



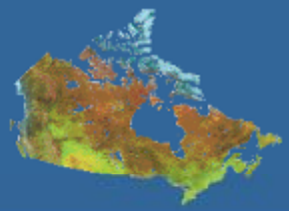
Tertiary

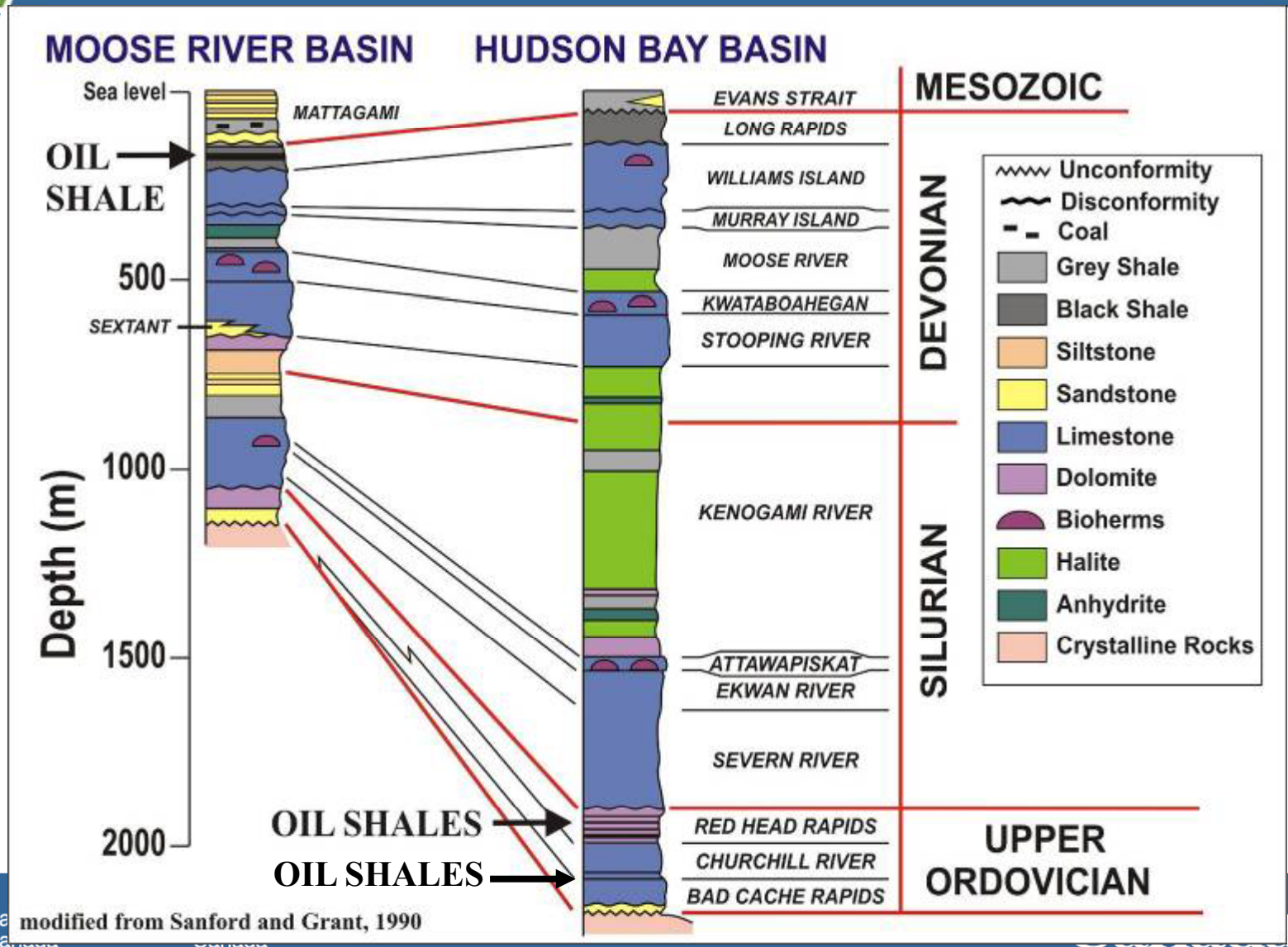
Basin geometry



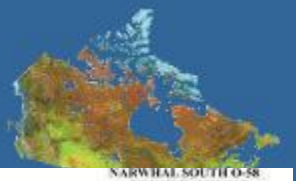


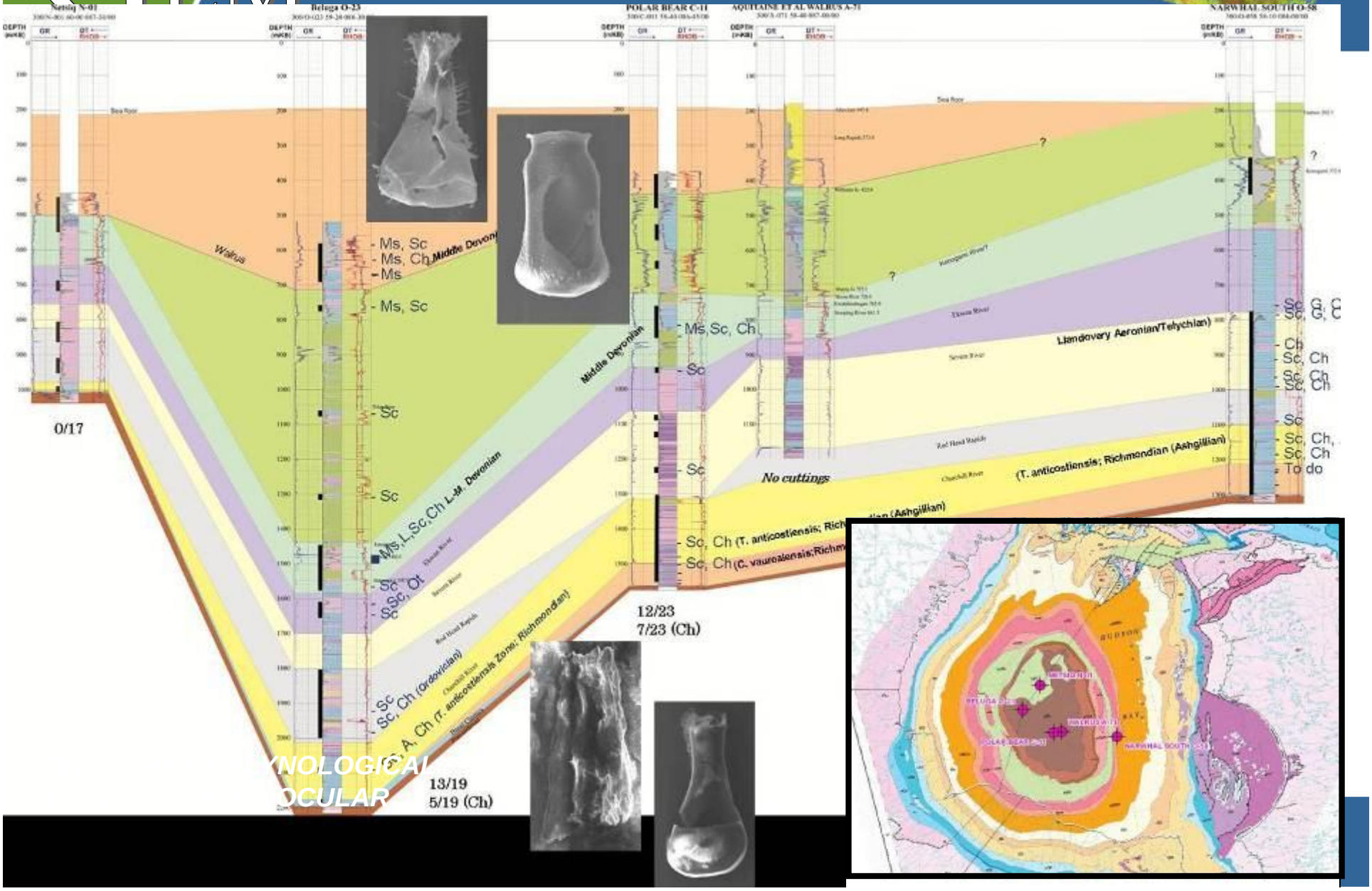
Carbonate platform with evaporites



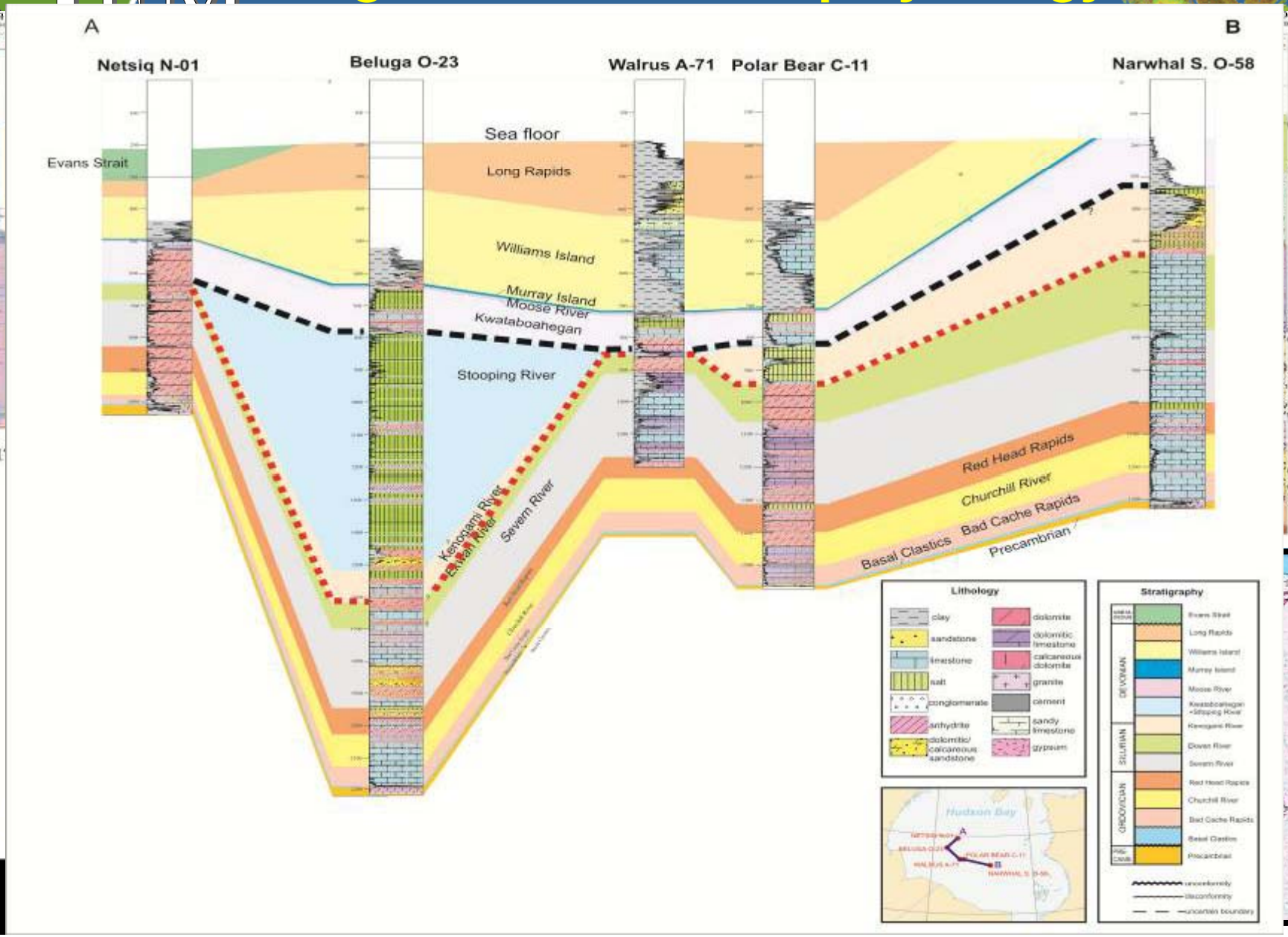


Hudson Bay - Log correlation and palynology

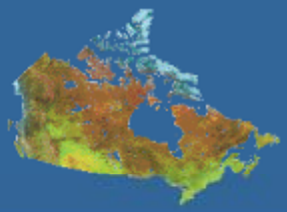


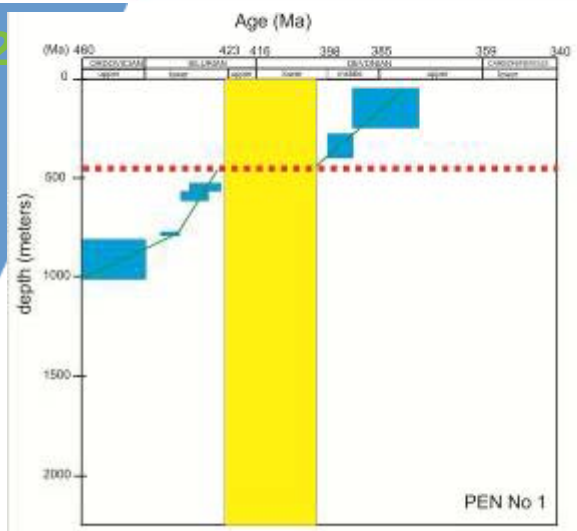


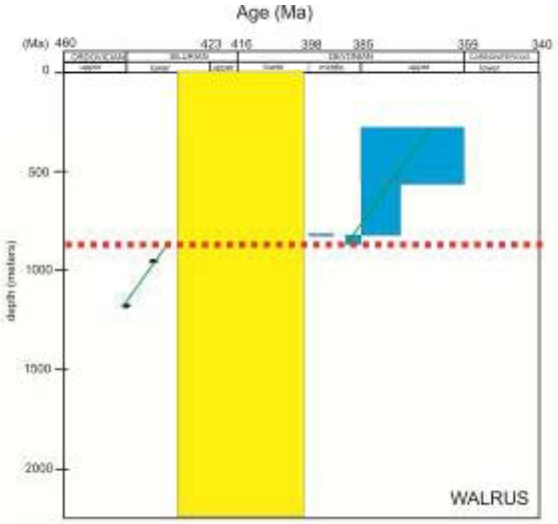
Hudson Bay - Log correlation and palynology

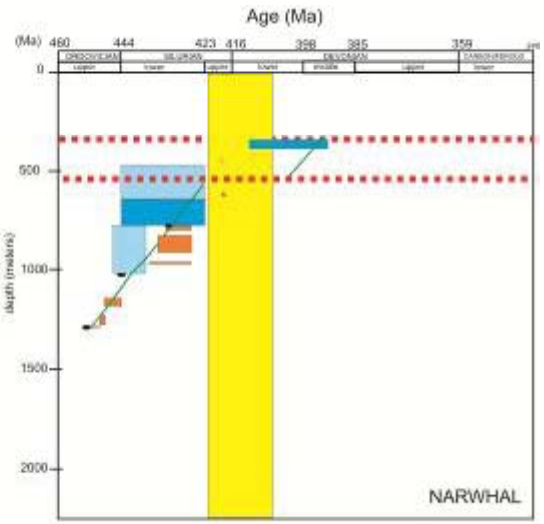


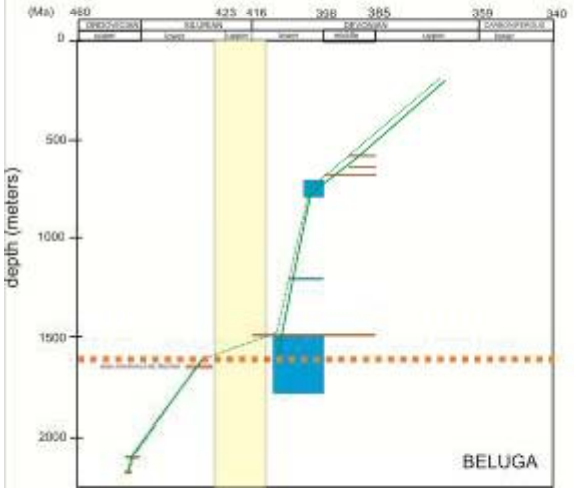
Stratigraphy and unconformities

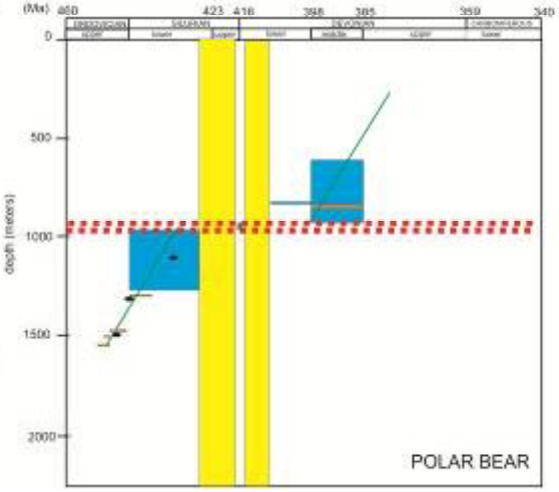


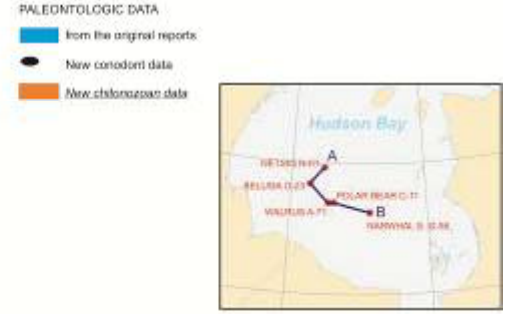




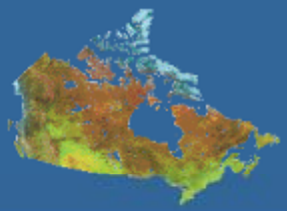


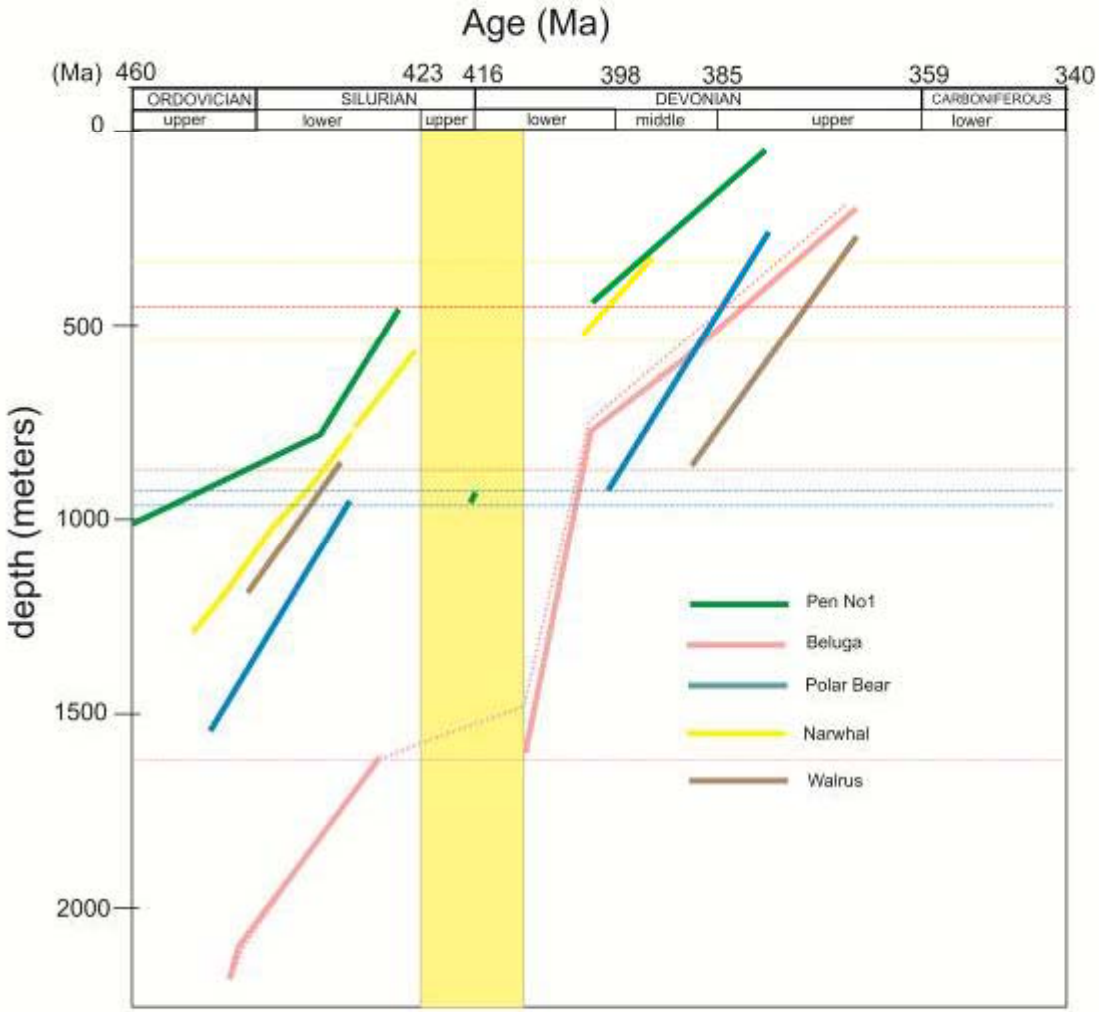


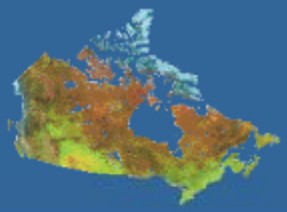




Stratigraphy and unconformities

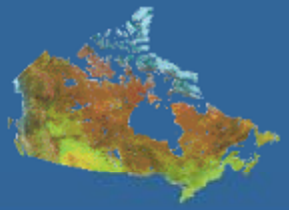






HYDROCARBON SYSTEM ELEMENTS

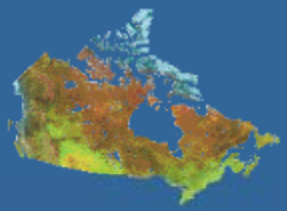
1. SOURCE ROCKS
2. RESERVOIRS
3. TRAPS AND SEALS



HYDROCARBON SYSTEM ELEMENTS

1. SOURCE ROCKS
   Quality, distribution and maturation

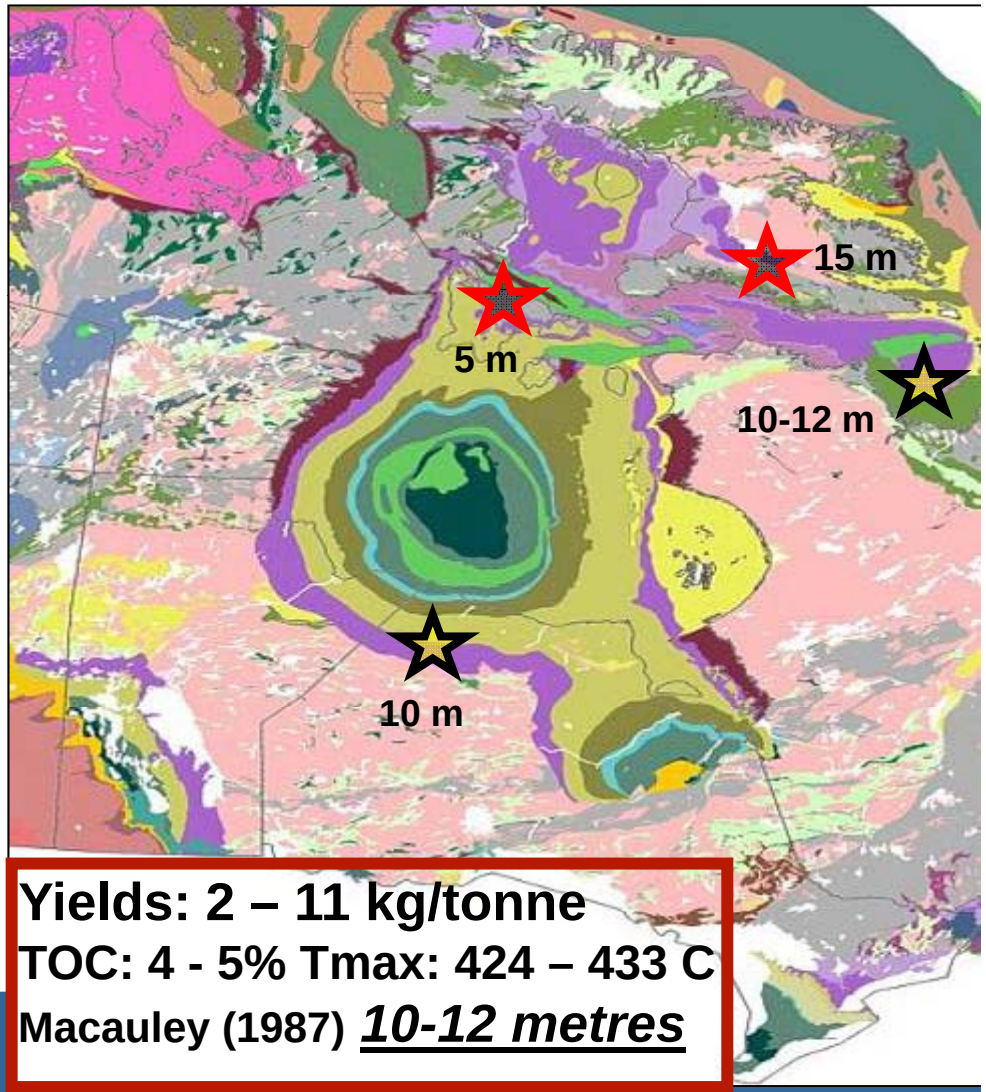
Source rock distribution (outcrop data)



Yields: 20 - 134 kg/tonne
TOC: 5 - 35% Tmax: 421 - 432˚C
Ro: 0.4 – 0.6%
— Macauley (1986); Zhang (2009, 2011)

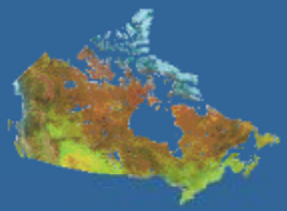
Yields: 16 - 99 kg/tonne
TOC: 3 - 15% Tmax: 409 - 427˚C
— Macauley (1987); *10-15 metres*

Boas River shale,
TOC: 3 – 15% Tmax: 420 - 426˚C
Ro: 0.6 – 0.8%
Armstrong and Lavoie (2010)
10 metres

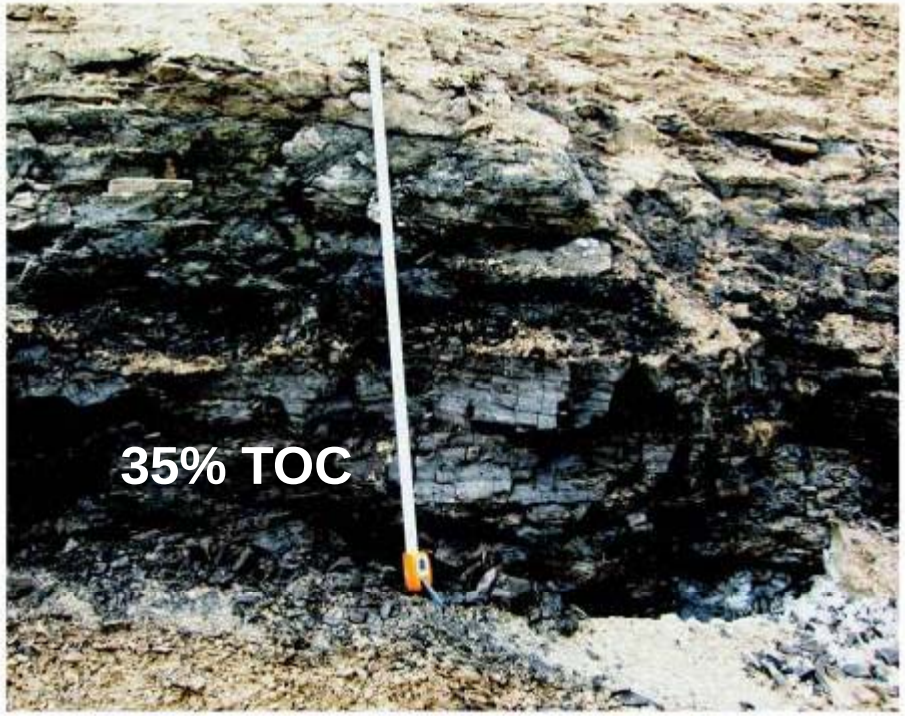


Yields: 2 – 11 kg/tonne
TOC: 4 - 5% Tmax: 424 – 433 C
Macauley (1987) *10-12 metres*

Ordovician source rock Southampton Island



Lower Oil Shale

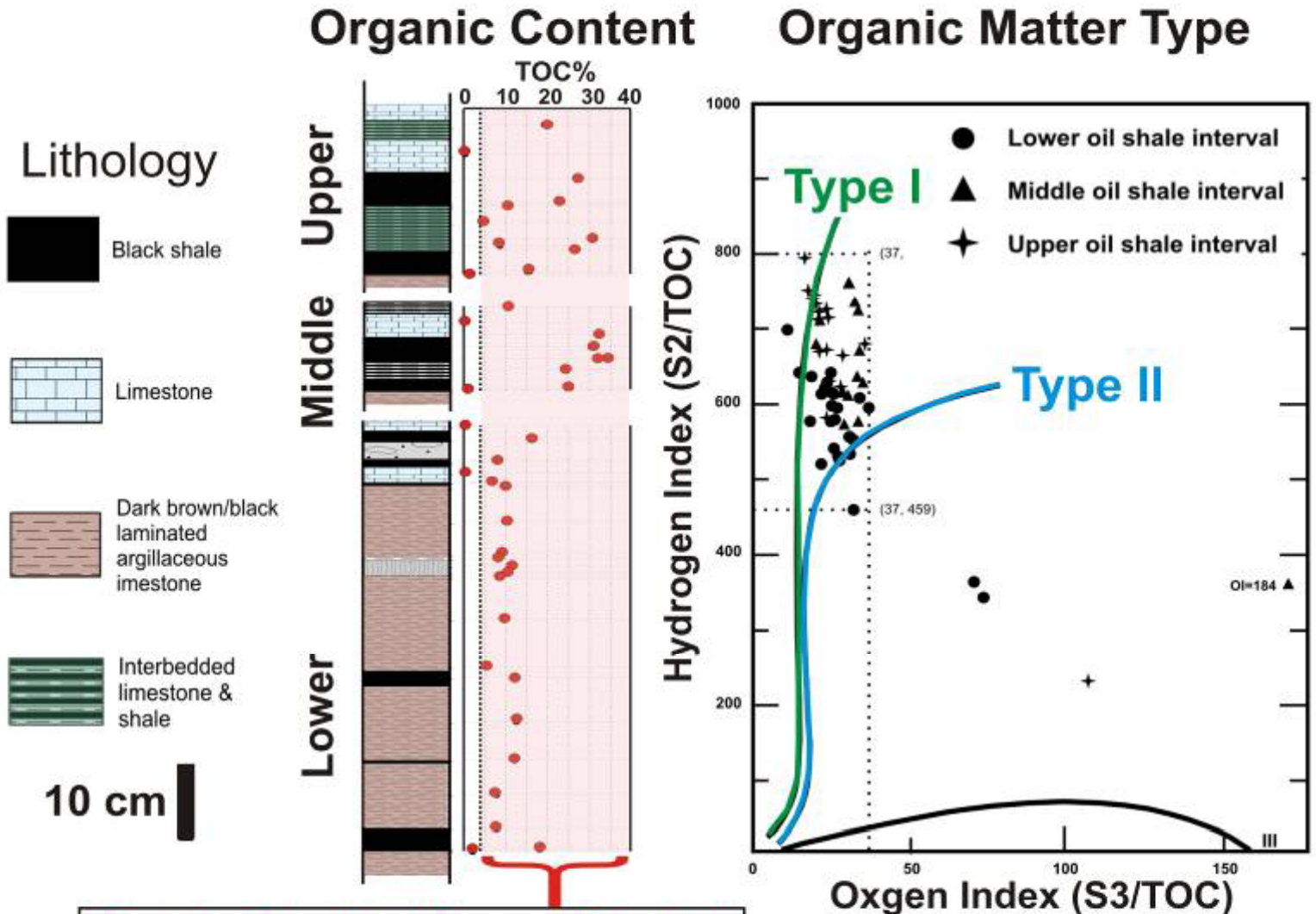


Upper Oil Shale

Upper Ordovician Red Head Rapids Fm.

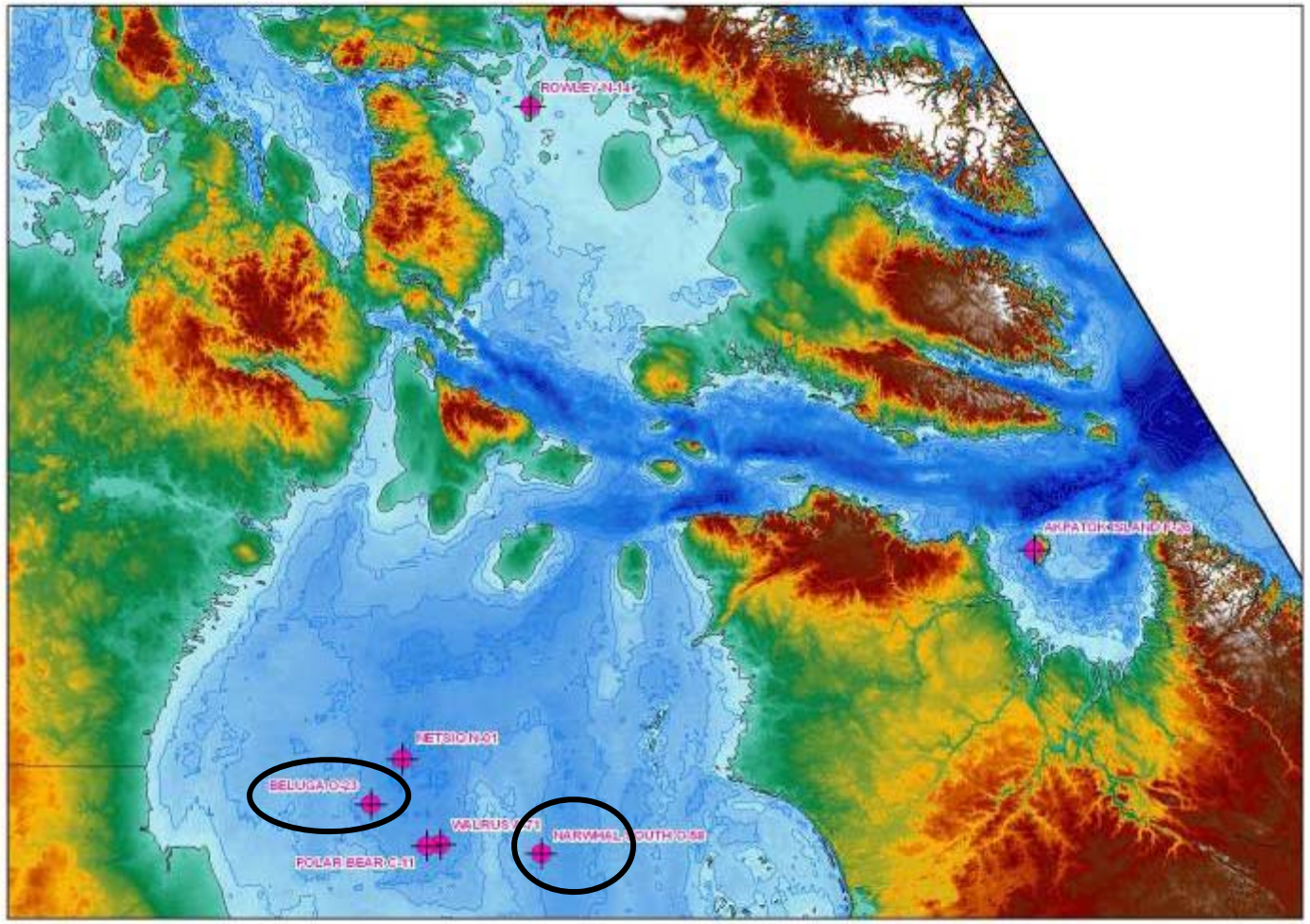
Oil shale geochemistry

Cape Donovan Oil Shales, Southampton Island



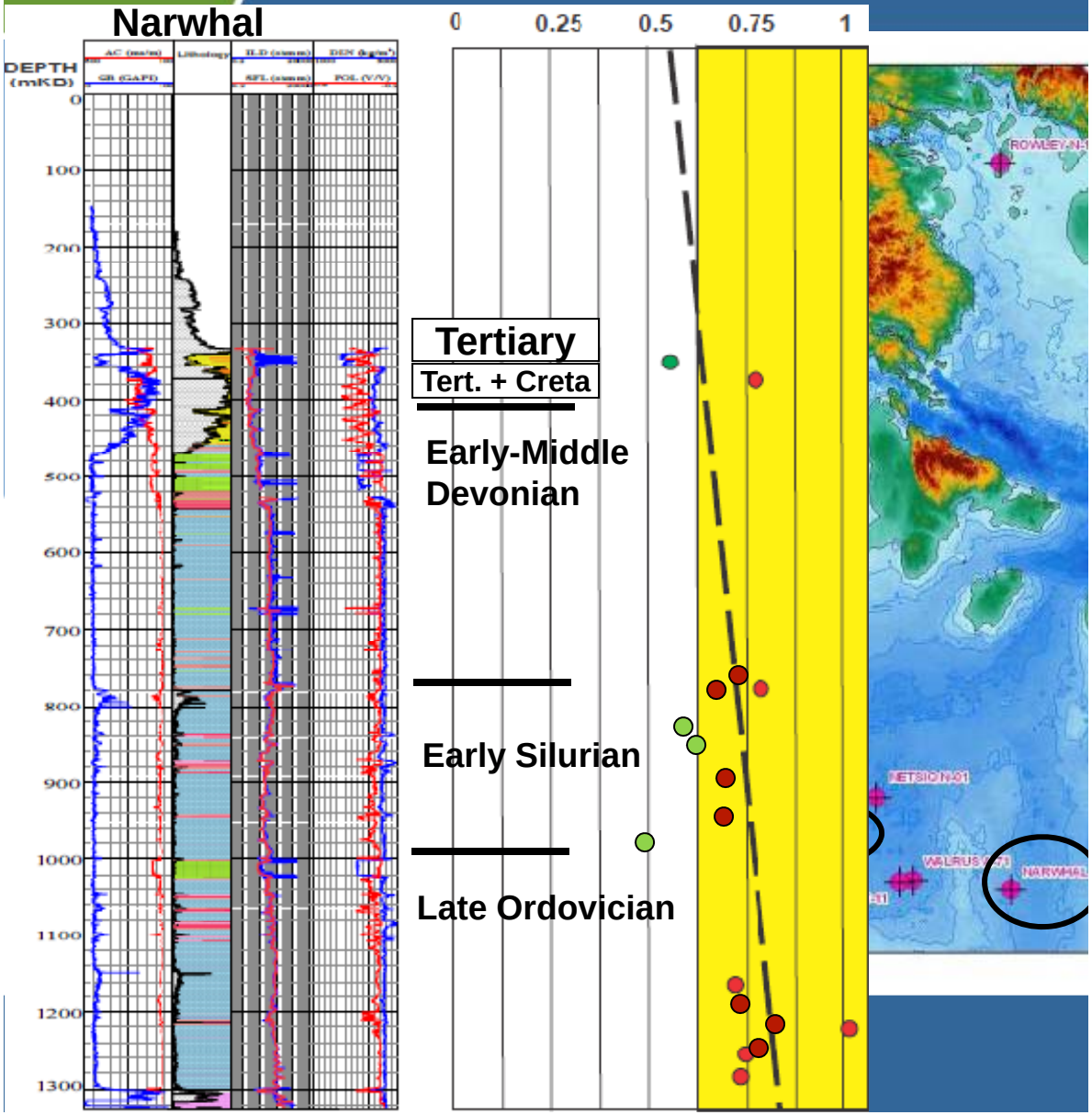
Good to Excellent Source Potential

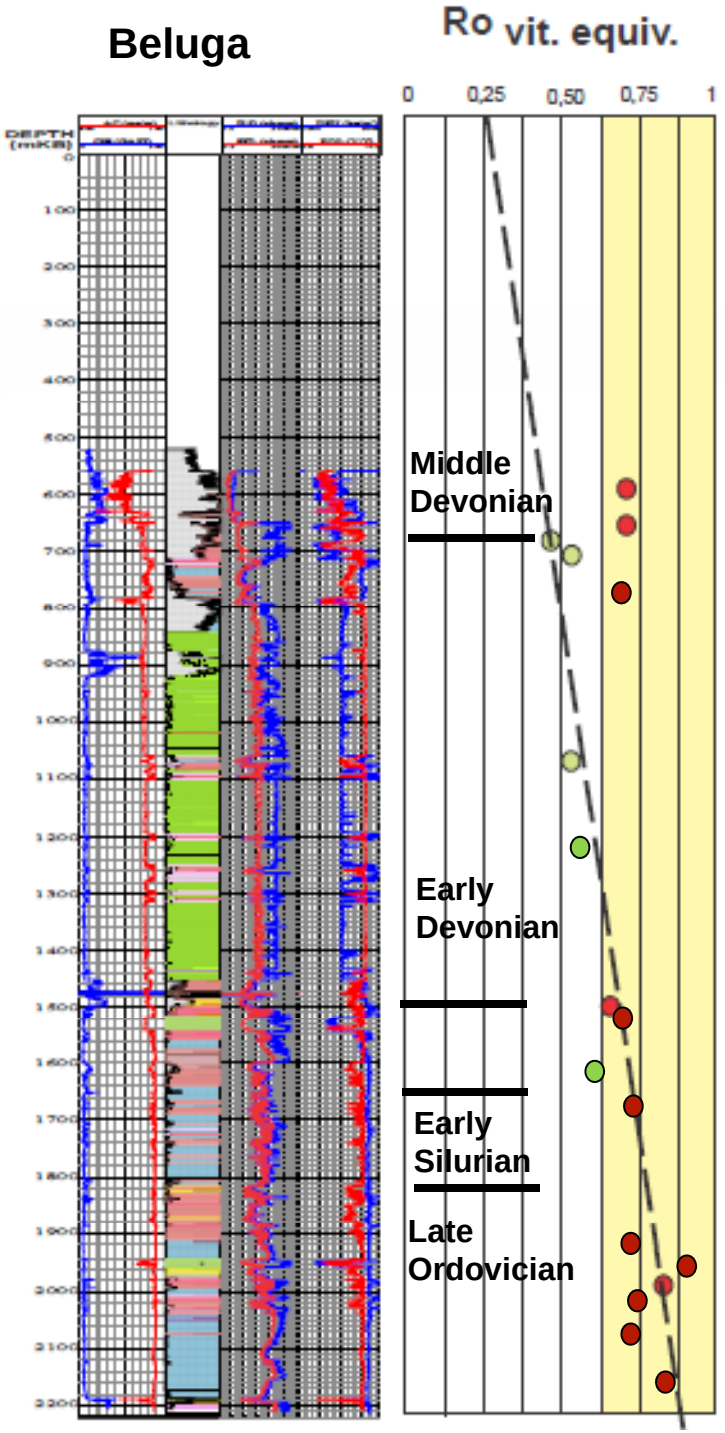
Organic matter reflectance

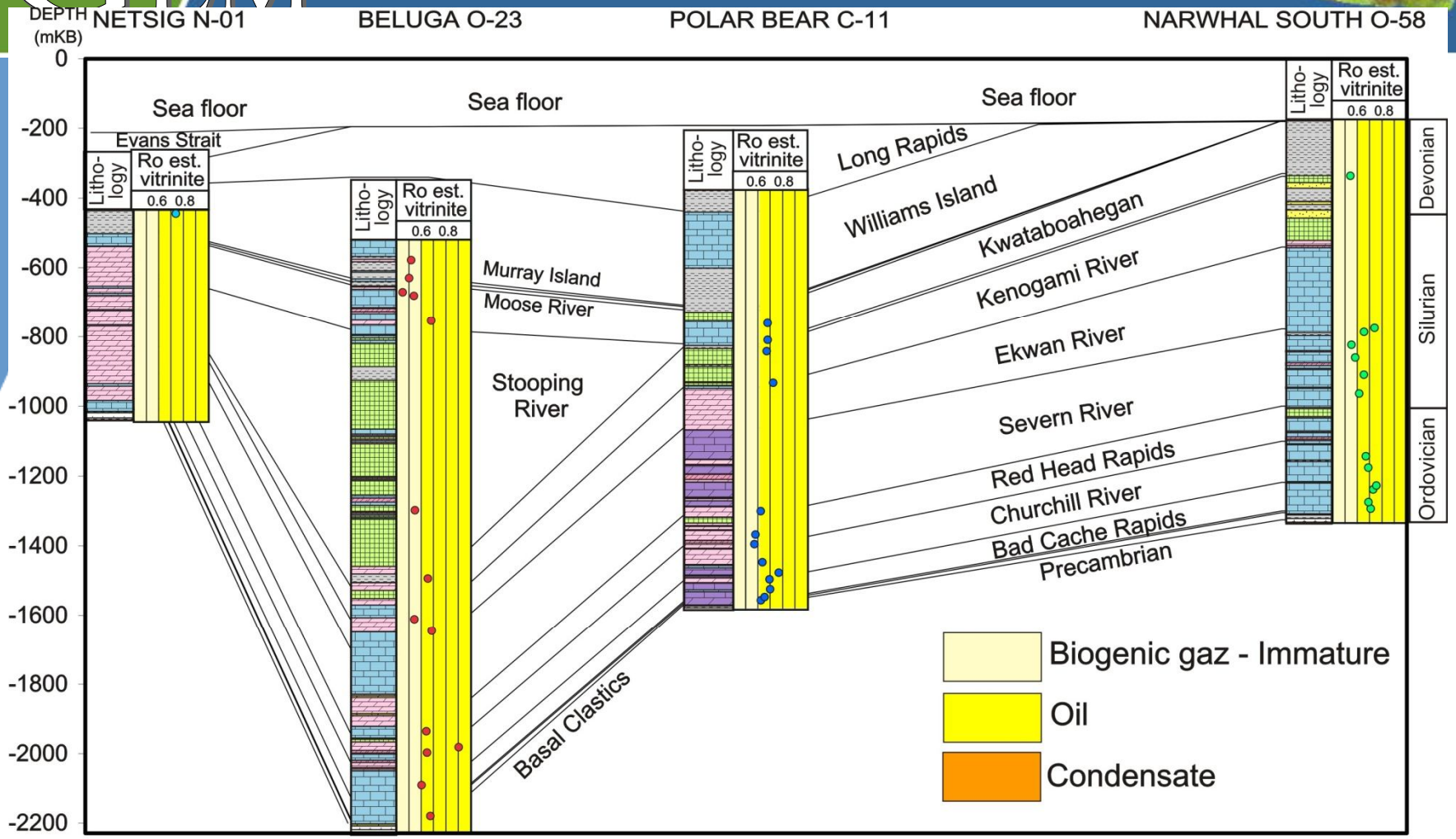


Organic matter reflectance

GEM

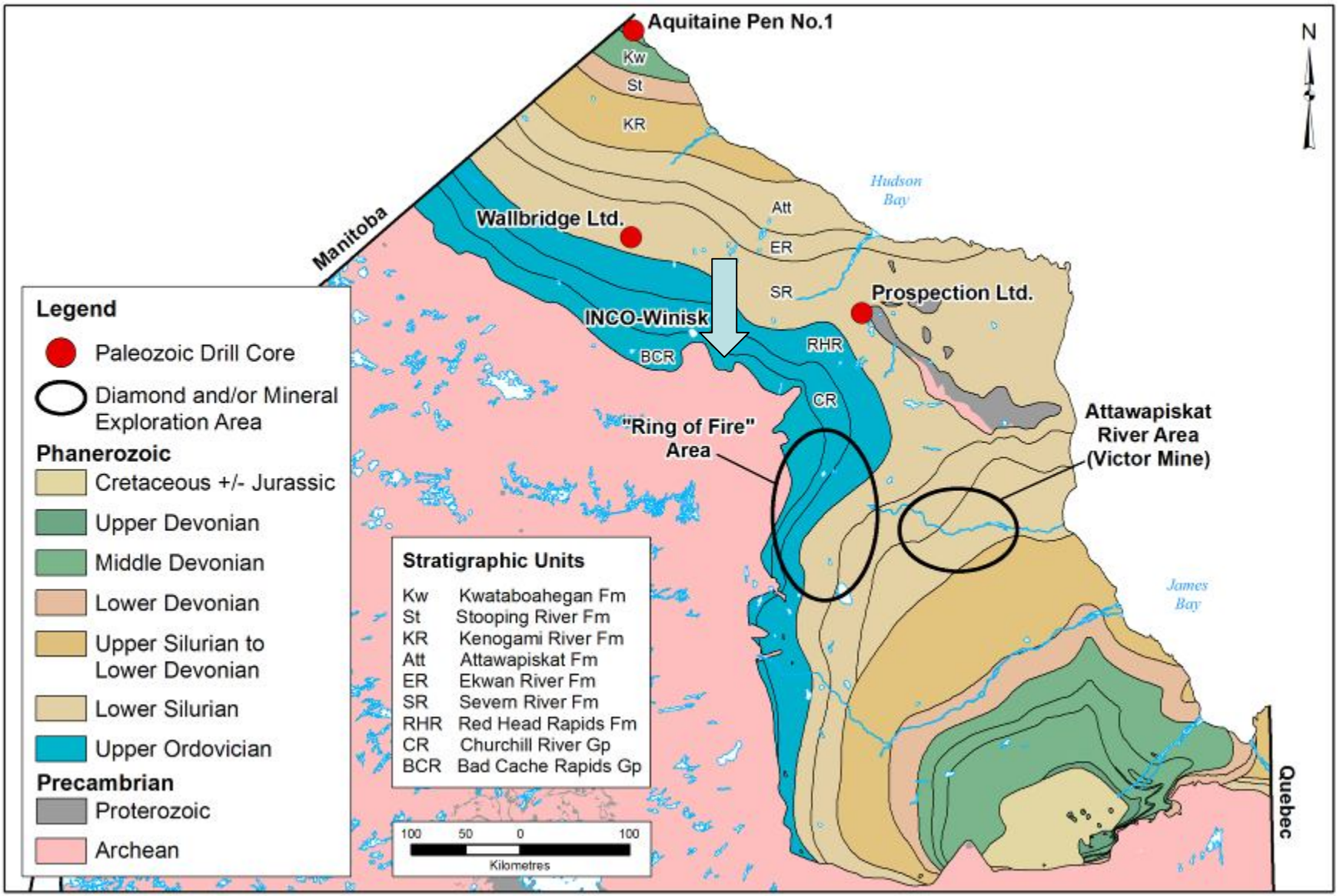




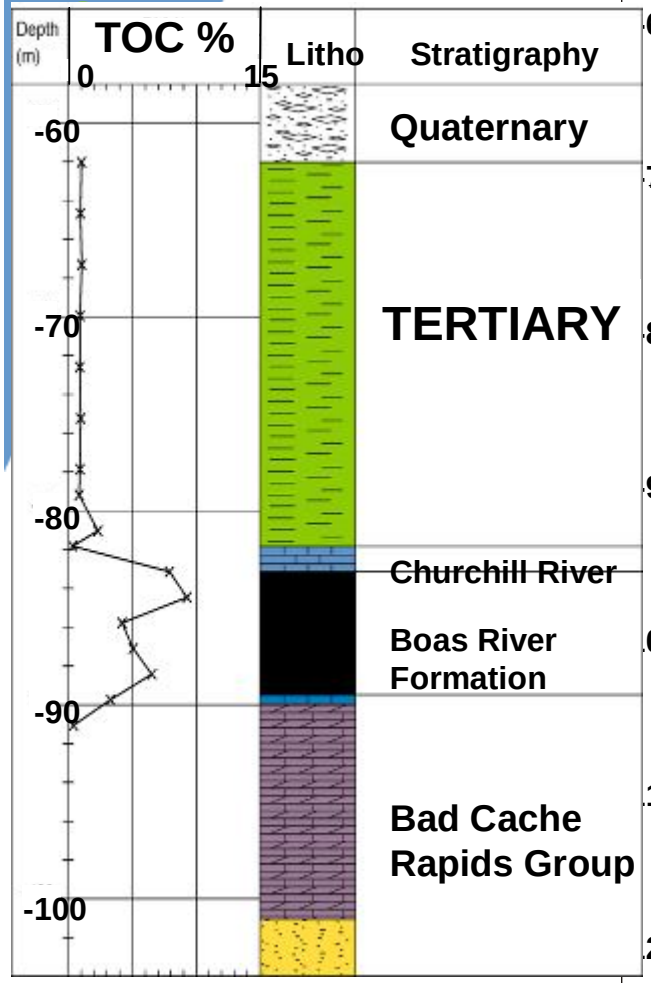

DEPTH (mKB)
NETSIG N-01
BELUGA O-23
POLAR BEAR C-11
NARWHAL SOUTH O-58
0
-200
-400
-600
-800
-1000
-1200
-1400
-1600
-1800
-2000
-2200
Sea floor
Sea floor
Sea floor
Evans Strait
Litho-logy
Ro est. vitrinite
0.6 0.8
Murray Island
Moose River
Stooping River
Basal Clastics
Long Rapids
Williams Island
Kwataboahegan
Kenogami River
Ekwan River
Severn River
Red Head Rapids
Churchill River
Bad Cache Rapids
Precambrian
Devonian
Silurian
Ordovician
Biogenic gaz - Immature
Oil
Condensate

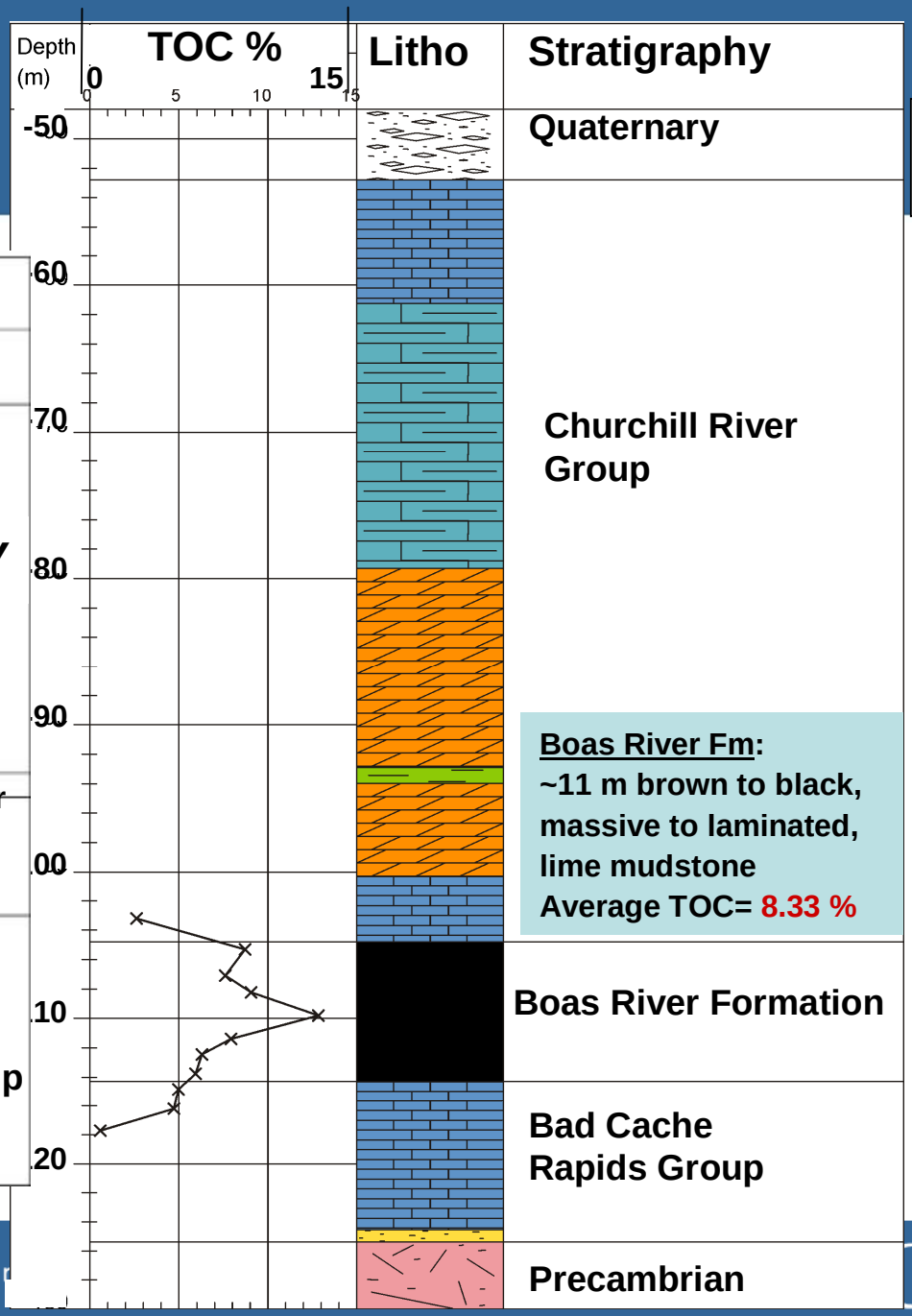
Ordovician source rock Northern Ontario

Boas River Shale in northern Ontario

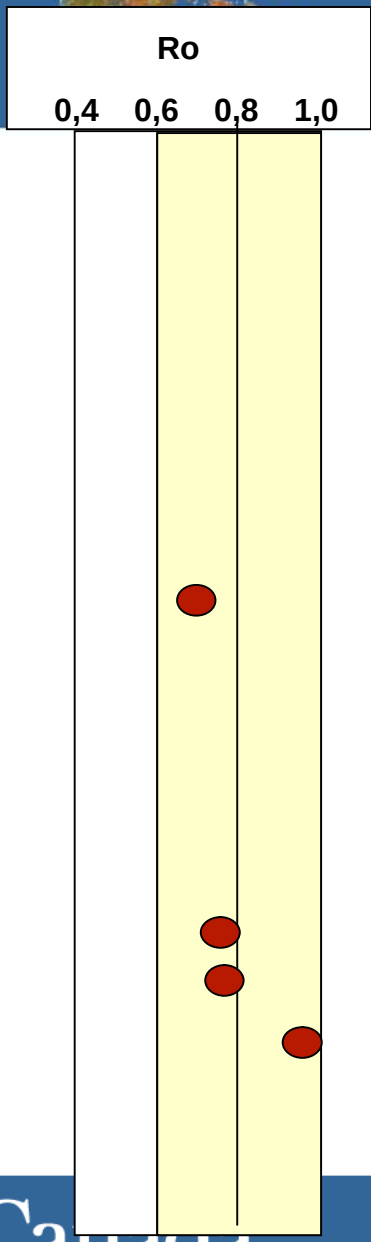


GEM

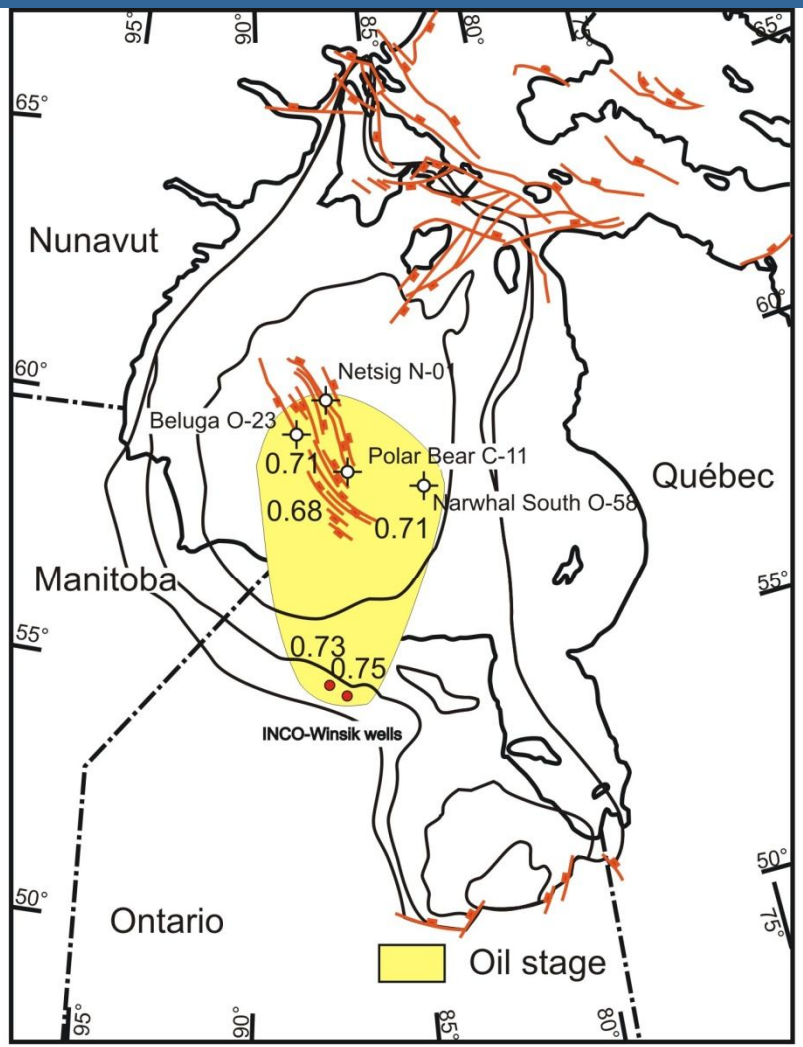


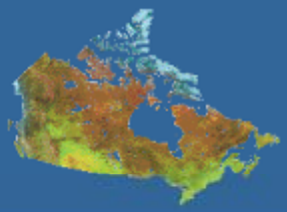


Boas River Fm:
~11 m brown to black, massive to laminated, lime mudstone
Average TOC= 8.33 %



Regional maturation of Upper Ordovician source rock





HYDROCARBON SYSTEM ELEMENTS

2. RESERVOIRS

Nature and seismic expression

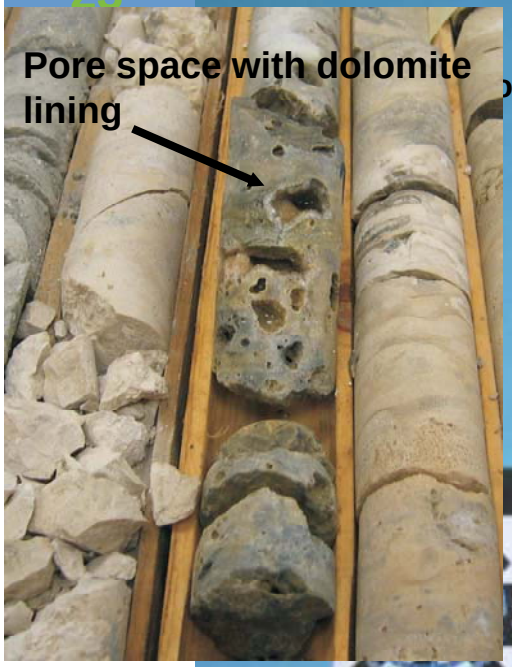
Potential hydrothermal dolomites

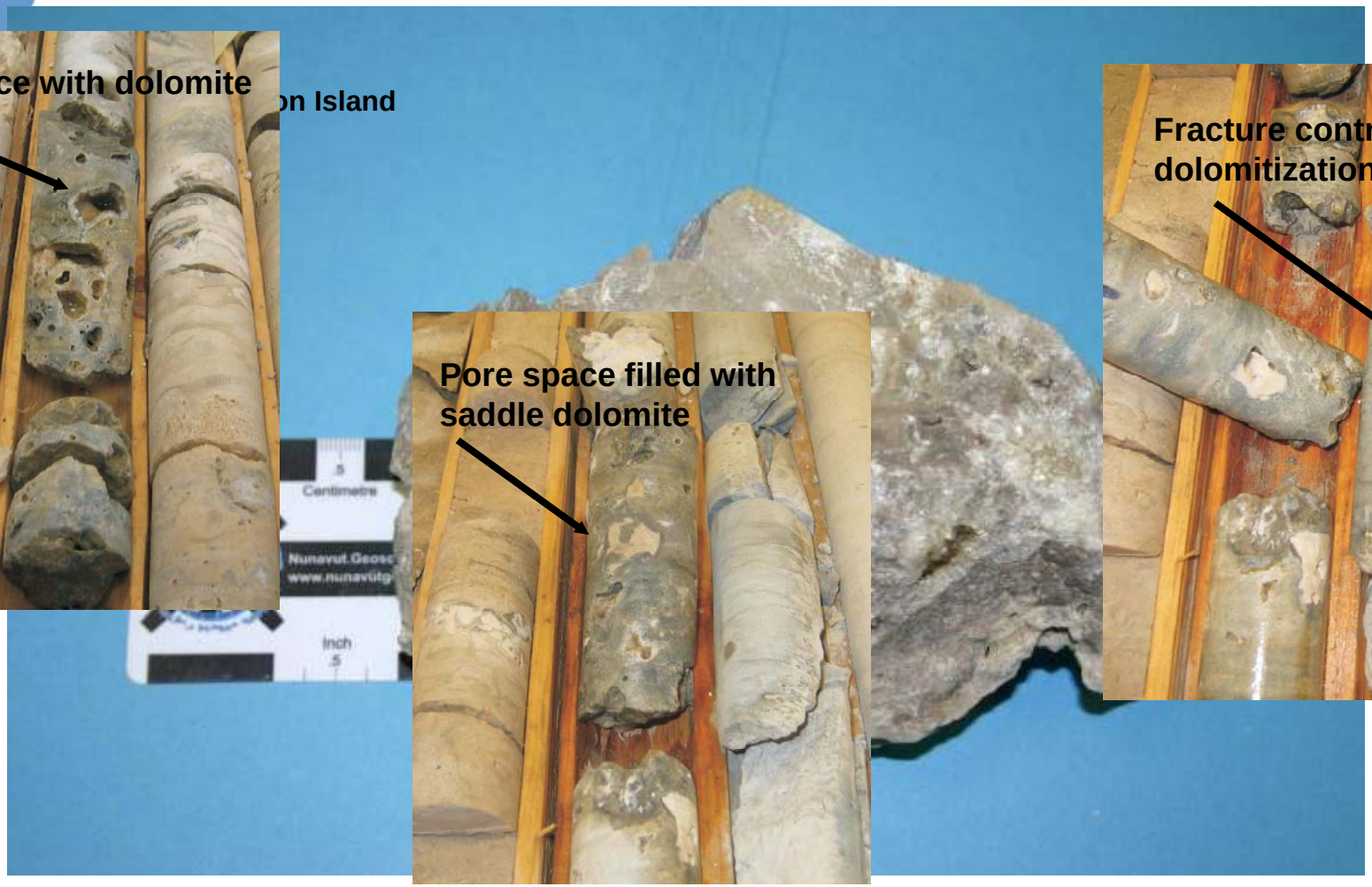
The most prolific play in the Michigan Basin

Potential hydrothermal dolomites

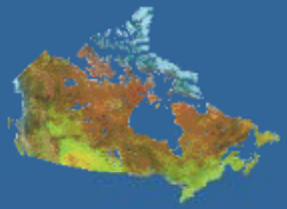
The most prolific play in the Michigan Basin

23

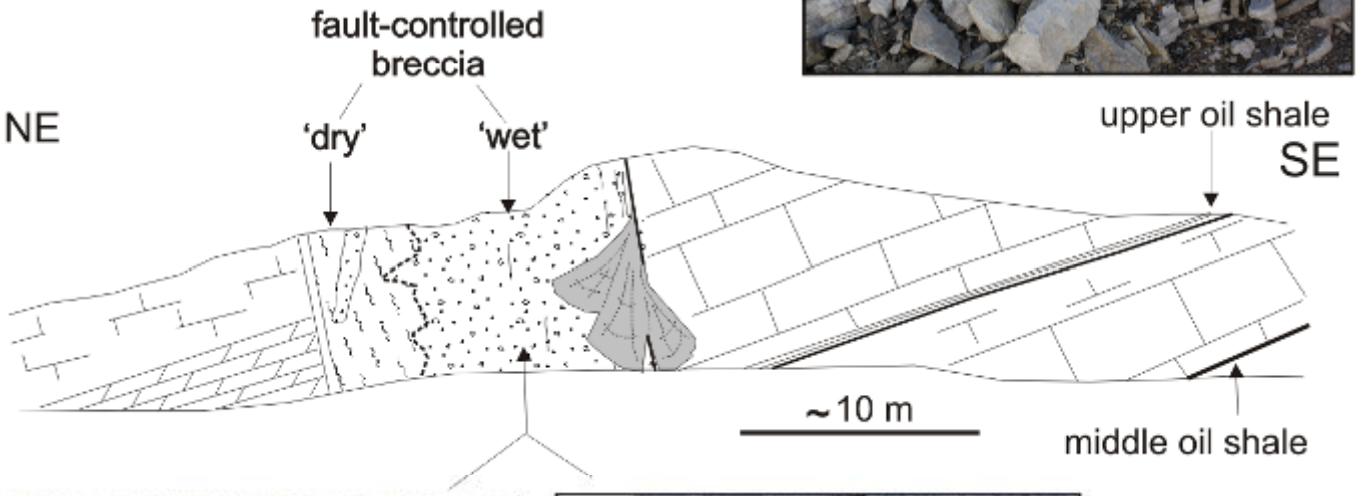




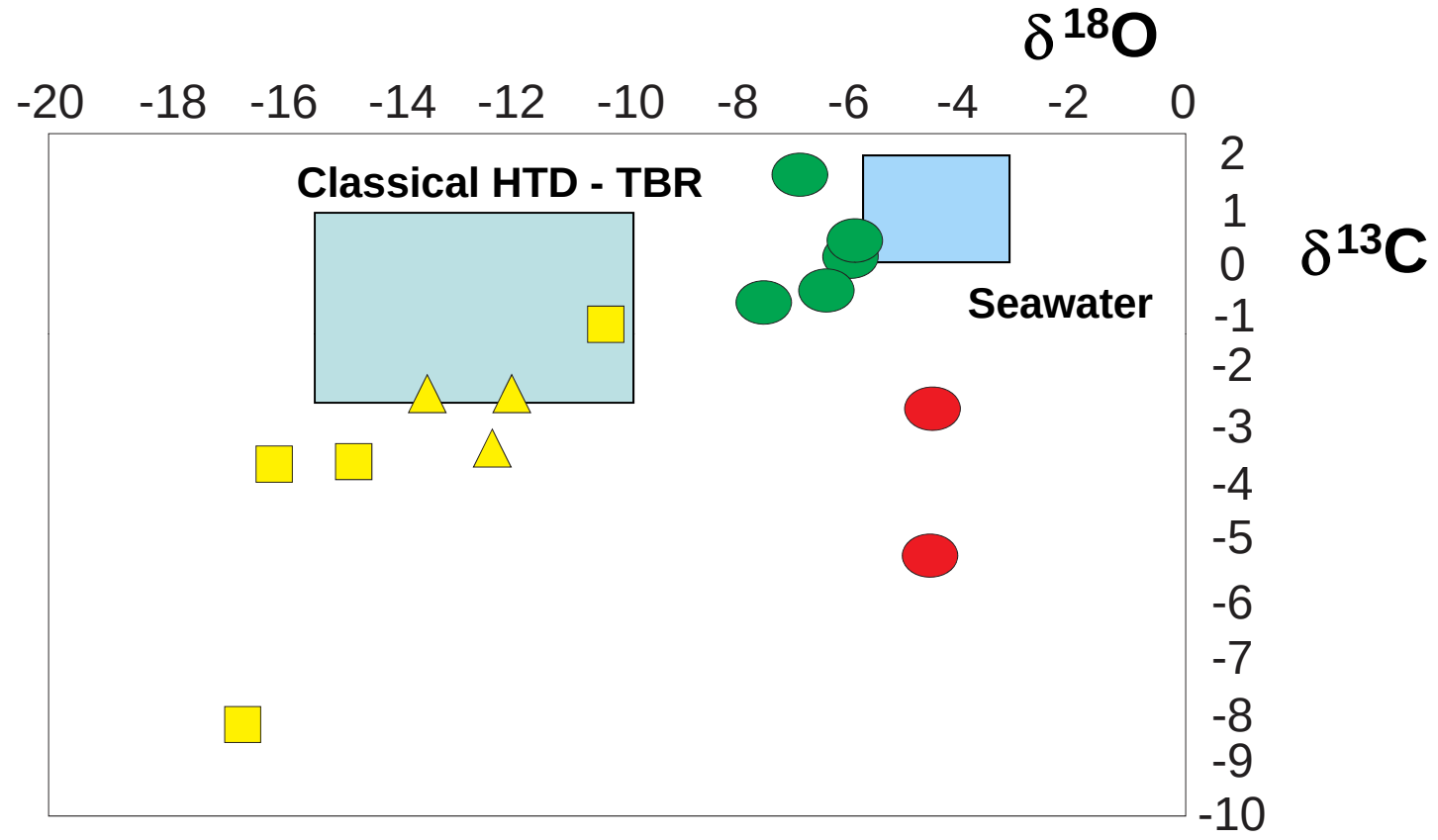
Significant HTD outcrops
North Southampton Island



Cape Donovan



Oxygen and Carbon isotope ratios of carbonates



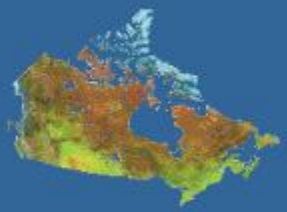
Southampton HTD-dolomite

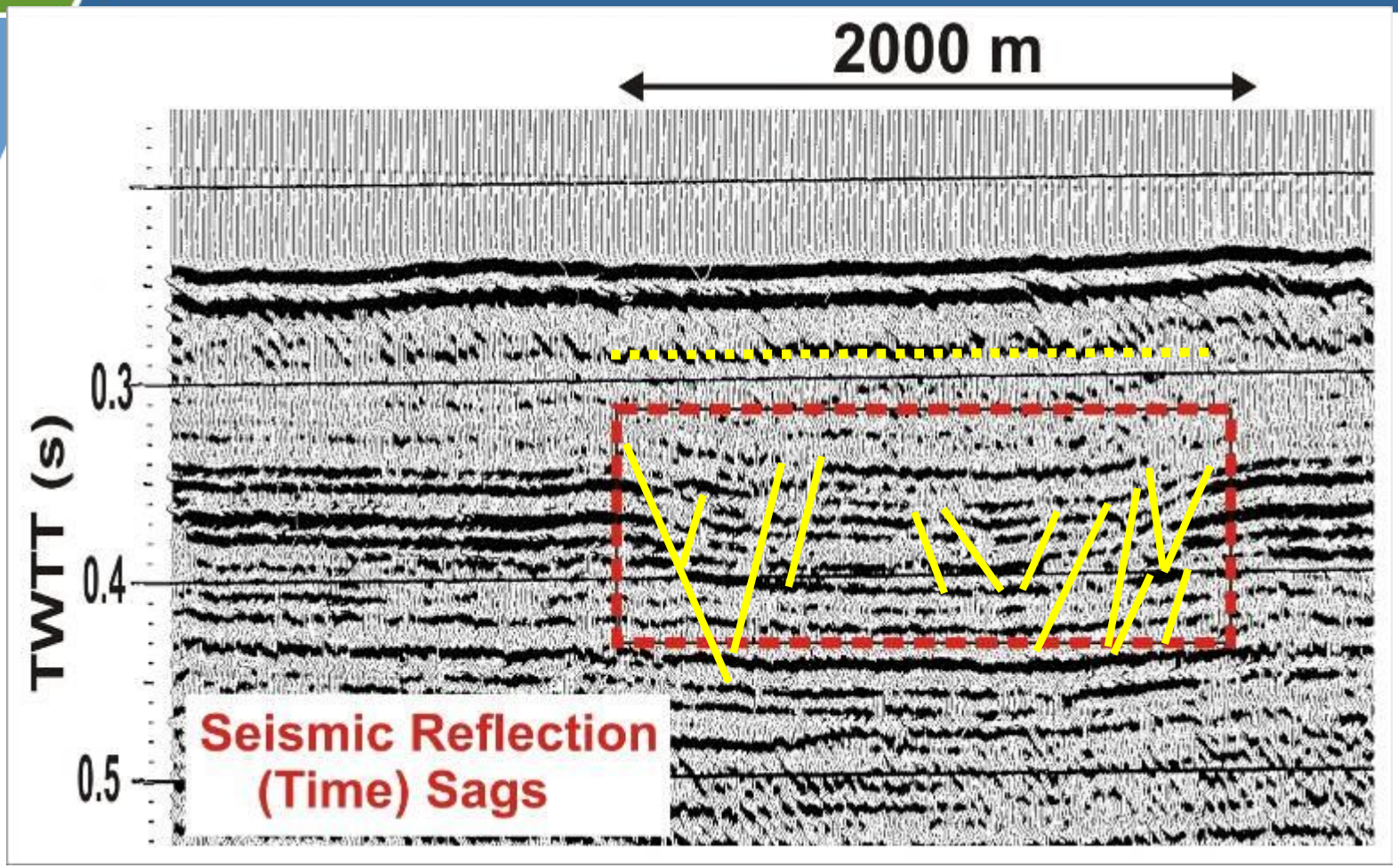
Manitoba HTD-dolomite

Manitoba dolomite

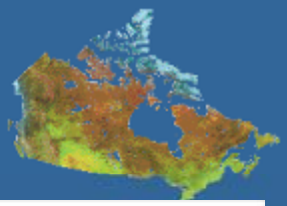
Rowley well dolomite

If HTD, could these be seismic sags?

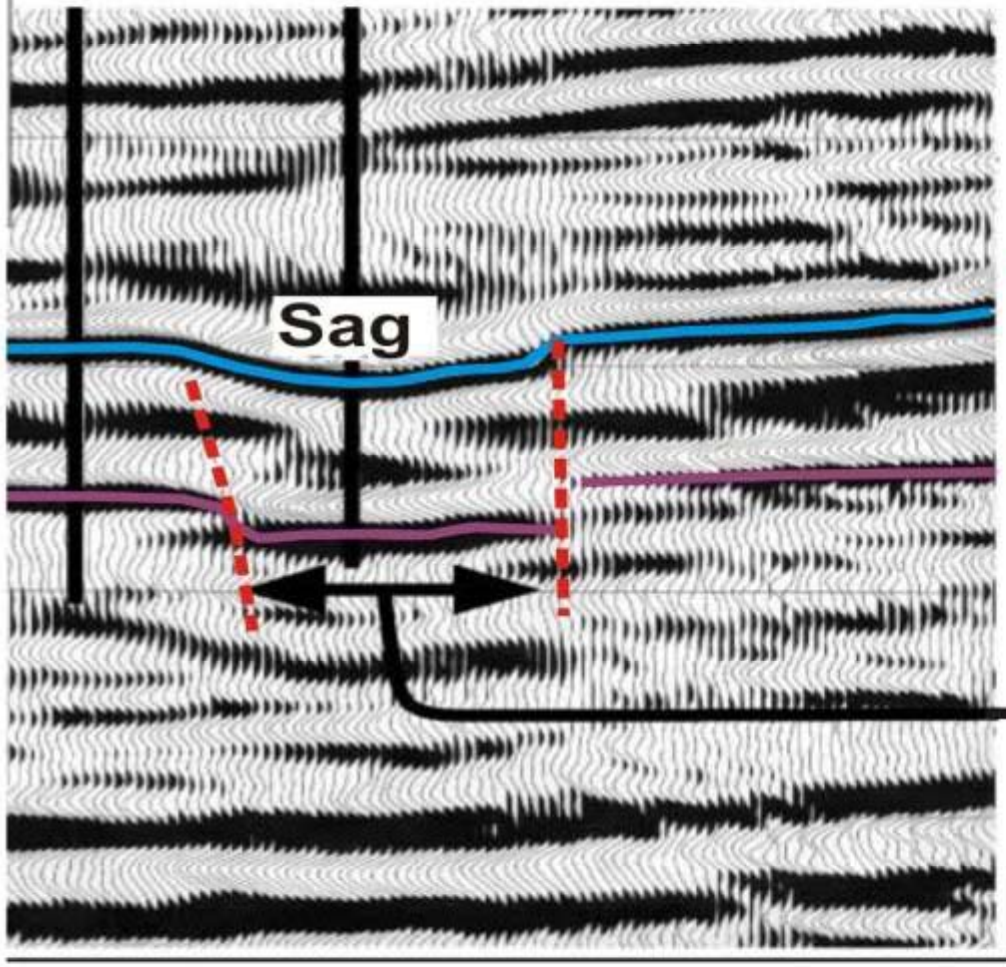




If HTD, could these be seismic sags?



Quackenbush Hill Gas Field



200M

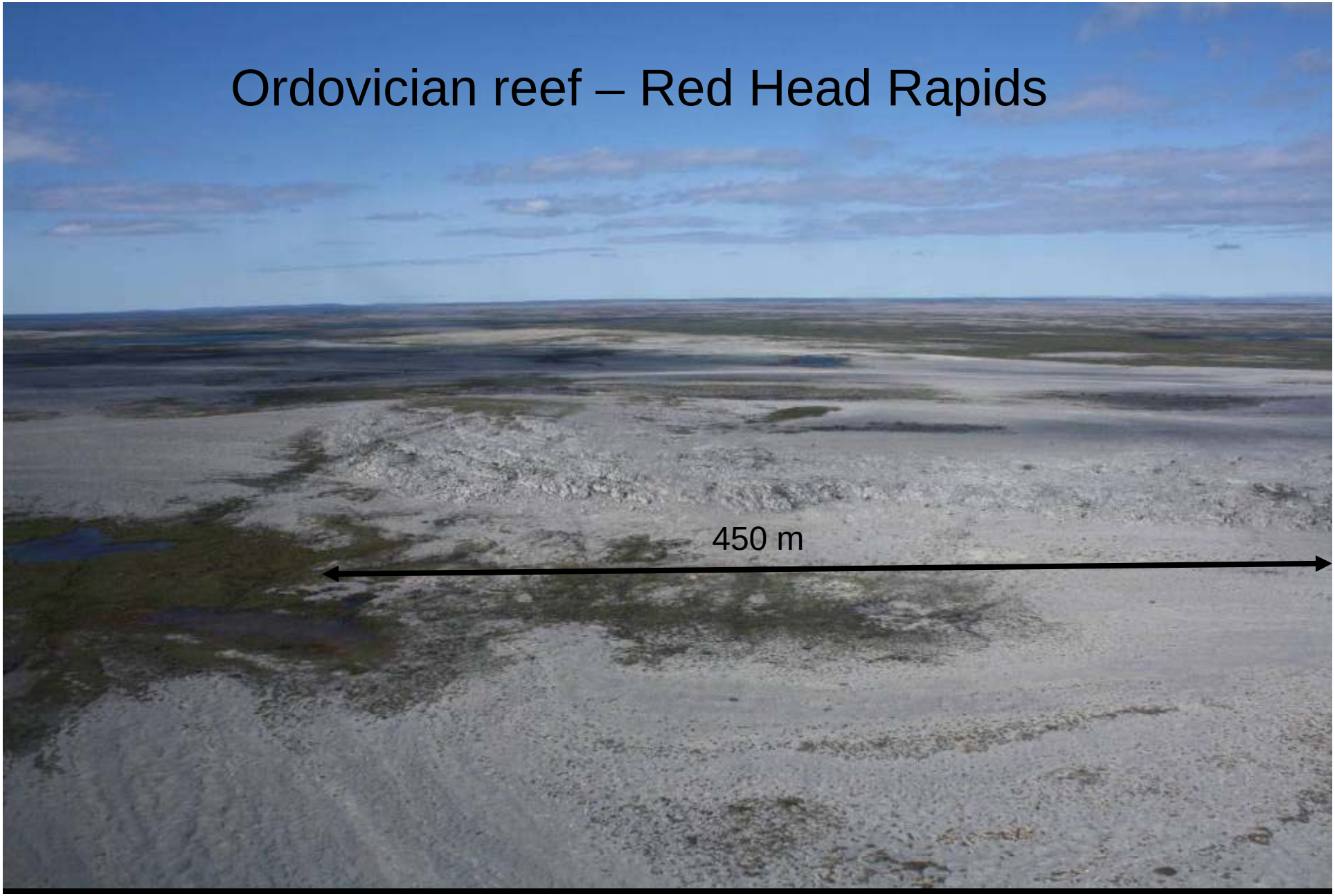
Trenton

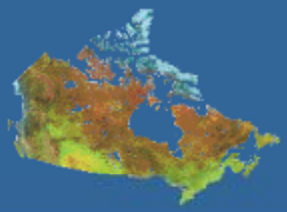
Black River

HYDROTHERMAL DOLOMITE (GAS RESERVOIR)

Davies and Smith, 2006

Ordovician reef – Red Head Rapids



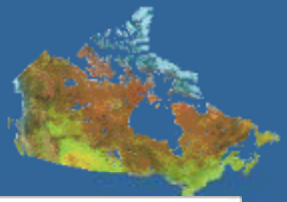


HYDROCARBON SYSTEM ELEMENTS

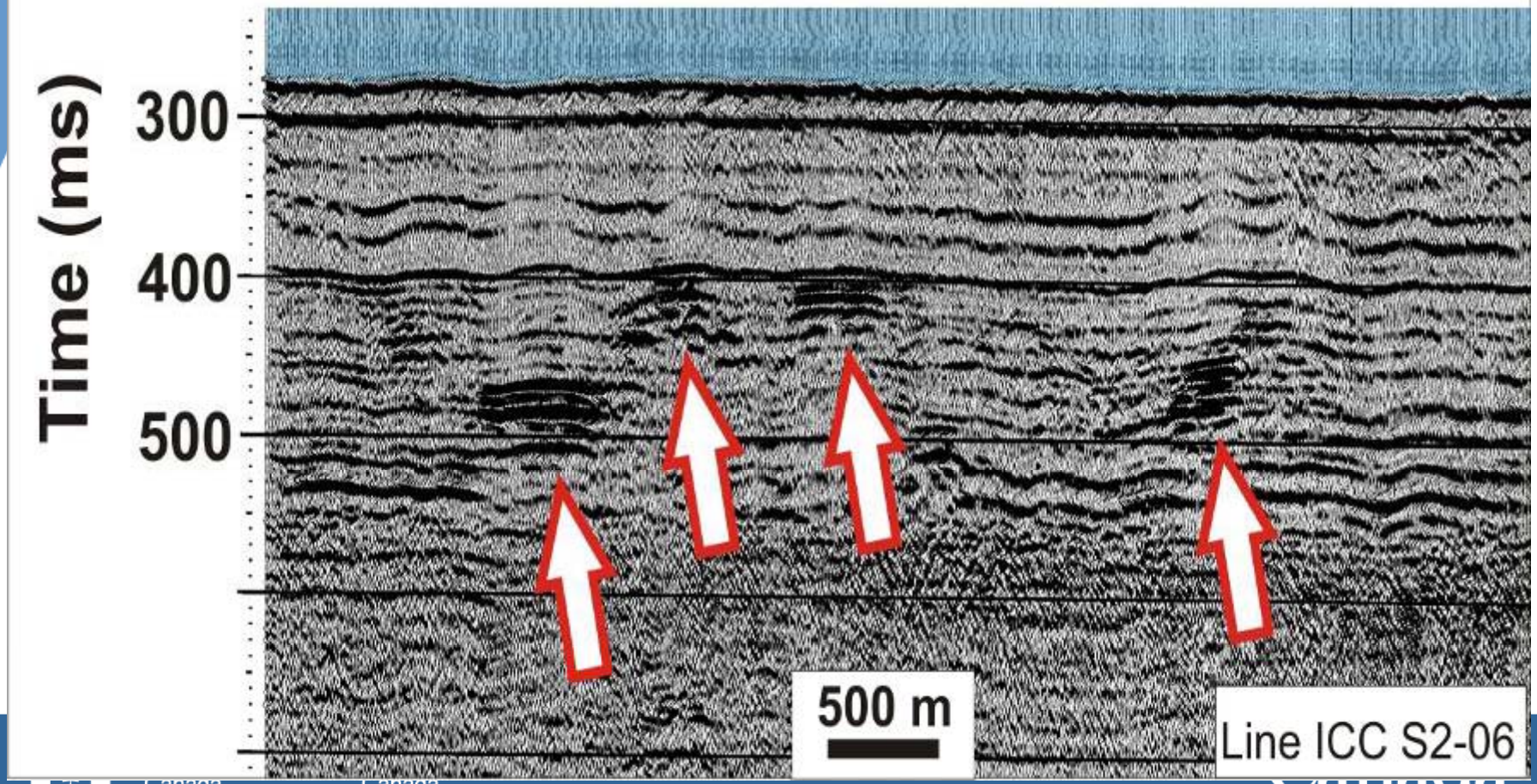
3. TRAPPED HYDROCARBONS

Seismic expression and evidence for active hydrocarbon systems

Other potential reservoirs
Silurian-Devonian reefs

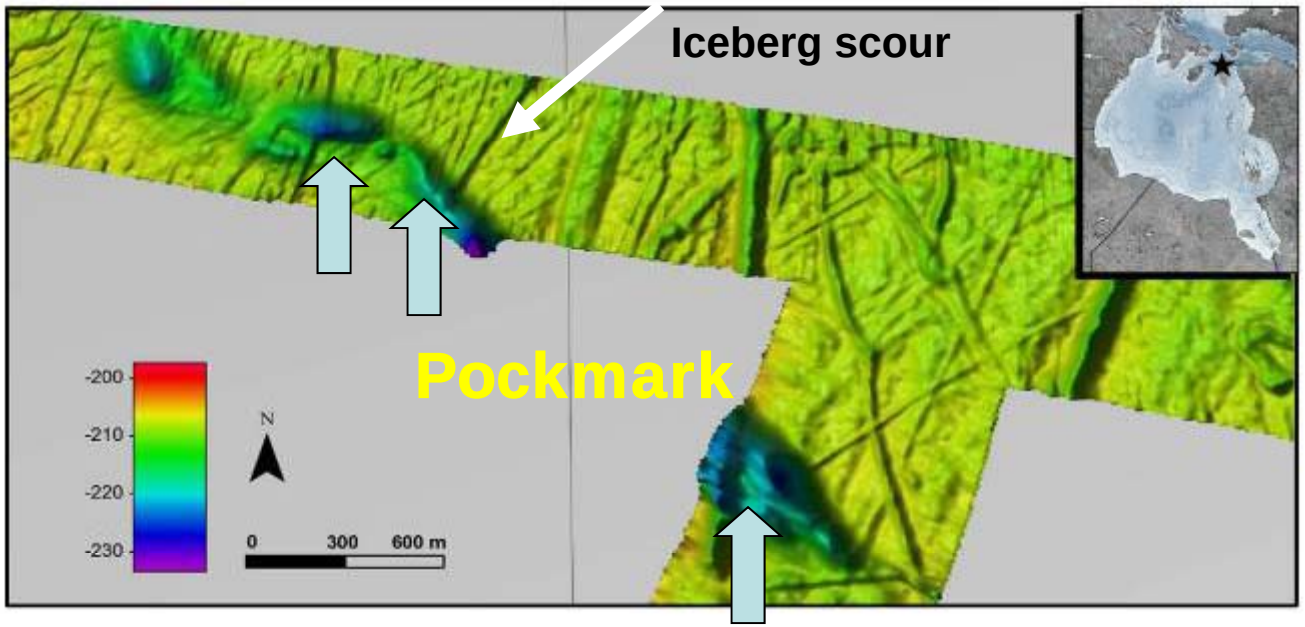


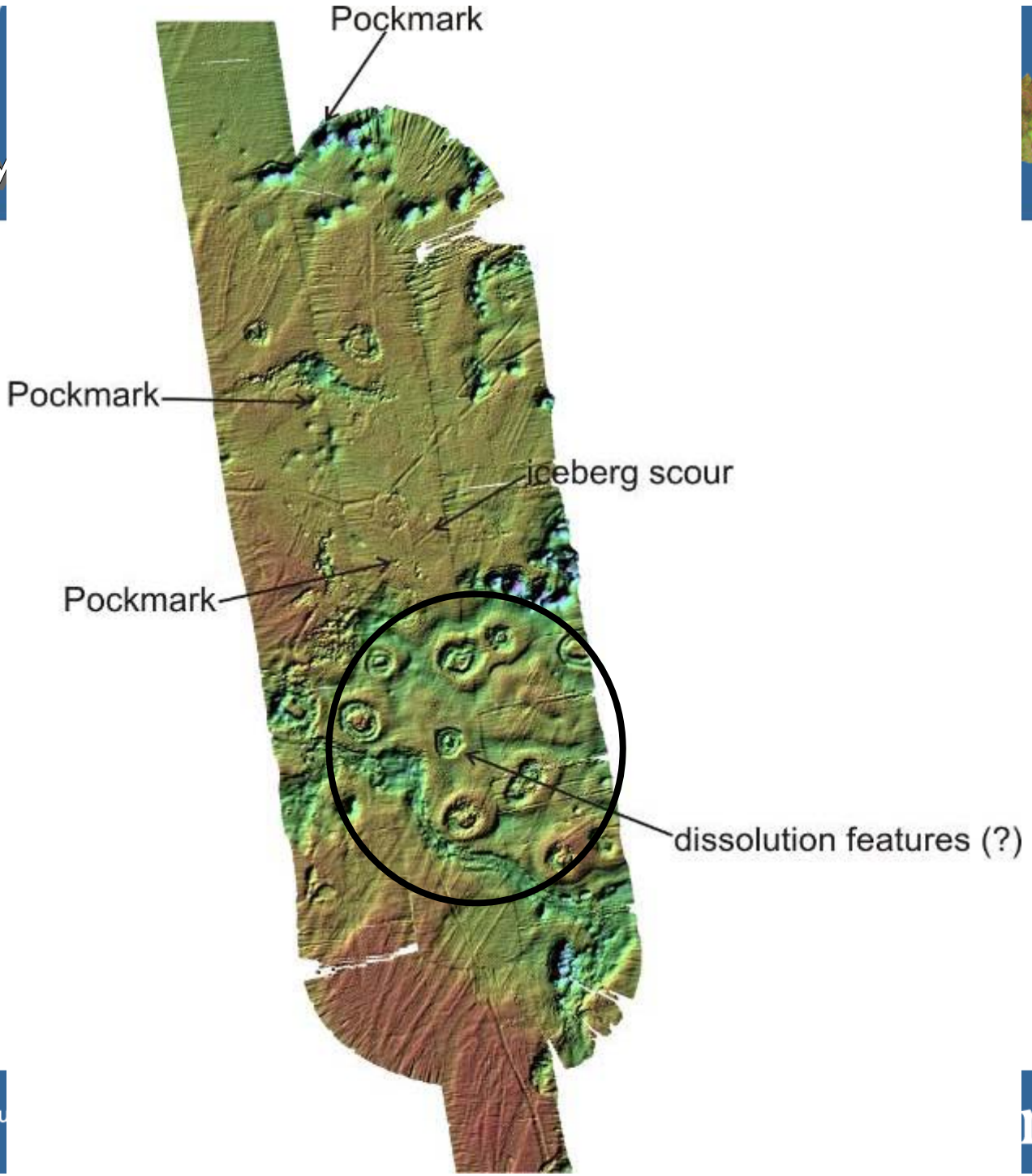
High Amplitude Seismic Reflection Anomalies in Devonian? Strata



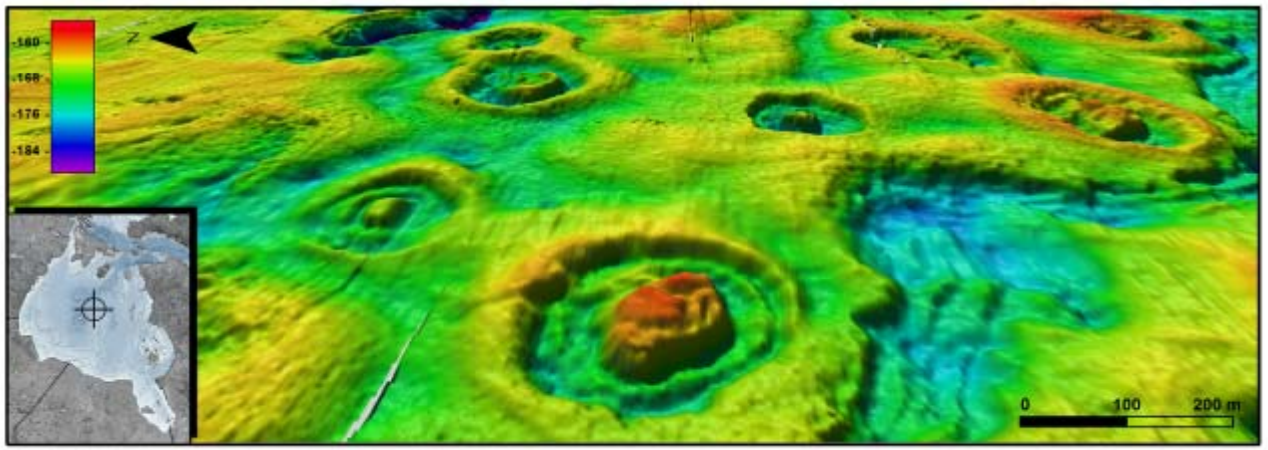
Smoking gun for hydrocarbon generation ?

Hihg resolution seafloor maps



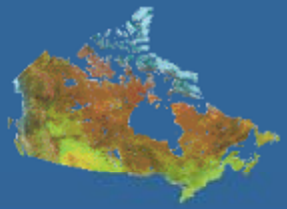

Pockmark
Pockmark
iceberg scour
Pockmark
dissolution features (?)

Salt movement in central Hudson Bay ?



Yin and Groshong, 2007 AAPG Bull

Conclusions



1. Upper Ordovician source rocks are now identified in northern Ontario. These source rocks are described all around the basin and in the wells in the central part.

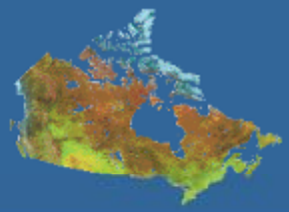
2. New organic petrology data indicate that the Ordovician source rocks are in the oil window.

3. Hydrothermal dolomites, the most prolific type of reservoirs in similar basins to the south, are recognized in the field and from geochemical data.

4. Sag-like features abound on the vintage seismic data.

5. New seafloor map in central and northern Hudson Bay allows identification of seafloor fluid-escape structures (pockmarks).

THANKS to our Partners



Governments of Nunavut, Ontario and Manitoba

National Energy Board (seismic and core data)
CNSOPB (access to core/cuttings)

University of Melbourne (AFT + U-Th\He)
University of Manitoba (Carbonate diagenesis)
University of Regina (Fluid migration events)
Memorial University (Fluid migration events, Mg isotopes)
Université Laval (Sea floor mapping)
Université du Québec à Rimouski (Sea floor mapping)
Institut National de la Recherche Scientifique (Organic matter maturation)

Thank You !