Ordovician-Aged Liquid-Rich Shales and Hydrothermal Dolomites Plays: An Updated Review of the Eastern Canada Anticosti Basin Hydrocarbon Potential*

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Abstract

Located in the Gulf of St. Lawrence in Quebec, Anticosti Island extends over a length of 220 km and a maximum width of 56 km and covers an area of 7,943 km^2 (3,103 mi^2). Anticosti is a large ESE-WNW oriented rhombohedra shaped structure situated along the Laurentia passive margin that extends from western Texas to Newfoundland. The geological units are of Paleozoic age, ranging from the Cambrian to the end of Silurian.

In 1970, ARCO drilled a stratigraphic well at the deepest point of the Island (3,838.2 m). It leads to the clear identification of a major source-rock, the middle Ordovician-aged Macasty Shale. Hydrocarbon expulsion from Macasty Shale reaches 75 billion bbl over the island with 2/3 generated in the "deep fairway". A second exploration phase targeted dolomitized carbonates located on the upper side of the Jupiter Fault zone. Shell Canada wells, drilled in the 90s, demonstrate the occurrence of HTD reservoir in Romaine and Mingan carbonates formation. The current exploration phase recognized the potential of the Macasty Shale as a liquid-rich resource play (potential for light oil/condensate production). Technical evaluation indicates that the level of thermal maturity observed thus far in the Macasty in the Deep Macasty Fairway compares favourably with published findings for the oil-rich Utica/Point Pleasant Shale and the Eagle Ford.

Resources assessment studies (P50 - Best Estimate) recently published by different groups corroborate the analytical results and the interpretation of the authors concerning the high hydrocarbon potential of the Anticosti Basin. In October 2009, a multidisciplinary team attached to the Geological Survey of Canada published a Petroleum Resource Assessment for the Paleozoic Succession of the St. Lawrence Platform. This report estimate the Resource in-place in the hydrothermally dolomitize carbonate at 957 million boe, mainly located in the Anticosti Basin. In July 2011, Corridor Resources published a Resource assessment report of the Macasty Shale. This report established the Total Resource Potential over an area of 1,550,000 acres at 33.9 billion boe, mainly located in the Shallow Macasty Zone. In September 2011, Junex Inc. published a Resource assessment report of the Macasty Shale situated in the Deep Fairway. This report established the Total Resource Potential over an area of 233,275 acres at 12.2 billion barrels.

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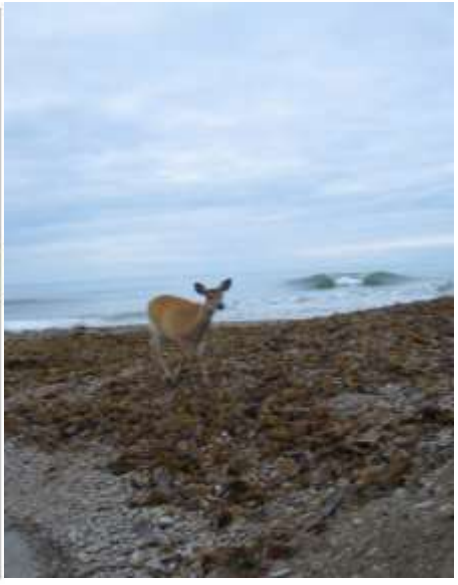
Table of Content

Located in the Gulf of St. Lawrence in Quebec, Anticosti Island extends over a length of 220 km and a maximum width of 56 km and covers an area of 7,943 km² (3,103 mi²). This presentation will cover the following key points regarding recent development of the Anticosti Basin exploration :

- Basin exploration history and review of the potential;
- Petroleum geology of the Anticosti Basin highlighted by recent research;
- The new structural map of Middle to Upper-Ordovician Carbonate sequence;
- Discussions on three different exploration plays in the Anticosti Basin;
- Perspectives and conclusions



The Technology Toolbox – Building a Database

Historical Data	Review old well data, vintage aeromag, gravity & seismic, reports
Basin Geology	Development of regional-scale basin models, local & regional stratigraphy
Shale Mineralogy	XRD, Thin-section, SEM, Shale Gas Log, Frac Fluid Sensitivity
Shale Petrophysics	Coring (Porosity, Permeability, Density), Detailed petrophysics
Organic Matter Type	TOC/RE, Biomarkers, Kerogen thermal maturity
Geochemistry	Stable isotopes, composition, origin (biogenic vs thermogenic)
Reservoir	Initial pressure, Production test, DST, integrate RM and microseismic data
Resource OIIP / OGIP	Core analysis (Canister Desorption & Adsorption Isotherms), GeoJar, TRAC
Geophysics	HRAM, FMI, CT-Scan, New Seismic (2D, Swath, 3D)
Drilling	Design, drilling fluids, well orientation, well evaluation, casing, cementing
Completions	Frac design (pressure, fluids, additives, proppants, pump rates, testing)

Continual Evolution & Refinement of Technology

Anticosti Island Geology and Petroleum Potential

From the 60s to 2010, a total of 21 wells were drilled, some old one on geologically poorly-defined targets or more recently, on HTD sag targets identified with seismic data.

Evaluation	Authors
Romaine	SOQUIP (1980)
Romaine-Mingan	Shell (1999)
Romaine-Mingan	CGC (2010)
Romaine MacAsty	Junex (2008, 2010, 2011)
Macasty	Petrolia (2011)

Play	Potential
Macasty Sh. OIIP	46,100 MMboe
HTD Mingan/Romaine	+500 MMboe
Vauréal/Ellis Bay	?

Exploration History of the Basin

Phase 1 : Consolidated, ARCO, SOQUIP and the National Research Institute (INRS) - 1960's to 1980's

Pioneering the oil and gas exploration over a 8000 km² island

Objectives : Stratigraphic well and exploration for oil in carbonate reservoir

Major results : Clear identification of a major source-rock, the middle Ordovician-aged Macasty Shale (in wells only, not outcropping in the basin) INRS reported : Hydrocarbon expulsion from Macasty Shale reach 75 billion bbl over the island with 2/3 generated in the "deep fairway" (Bertrand, 1986 and 1990). Oil generation dated Early Devonian time.

Phase 2 : Encal, Corridor, Shell Canada, Hydro-Quebec PG and the Geological Survey Canada (GSC) - 1990's to 2000's

Finding onshore an offshore-size discovery

Objectives : Dolomitized carbonates located on the upper side of the Jupiter Fault zone

Major results : Discovery of well developped dolomitized reservoirs in the Mingan and Romaine carbonates - but the reservoir were flushed and full of salty water. Oil Expulsion and migration dated Middle Devonian (Acadian) time (Lavoie, 2005).

Phase 3 : Corridor, Petrolia and Junex - 2010's

The independants never give up

Objectives : Dolomitized carbonates and liquid-rich shale

Major results : Recognized the potential of the Macasty Shale as a liquid-rich resource play (potential for light oil/condensate production)

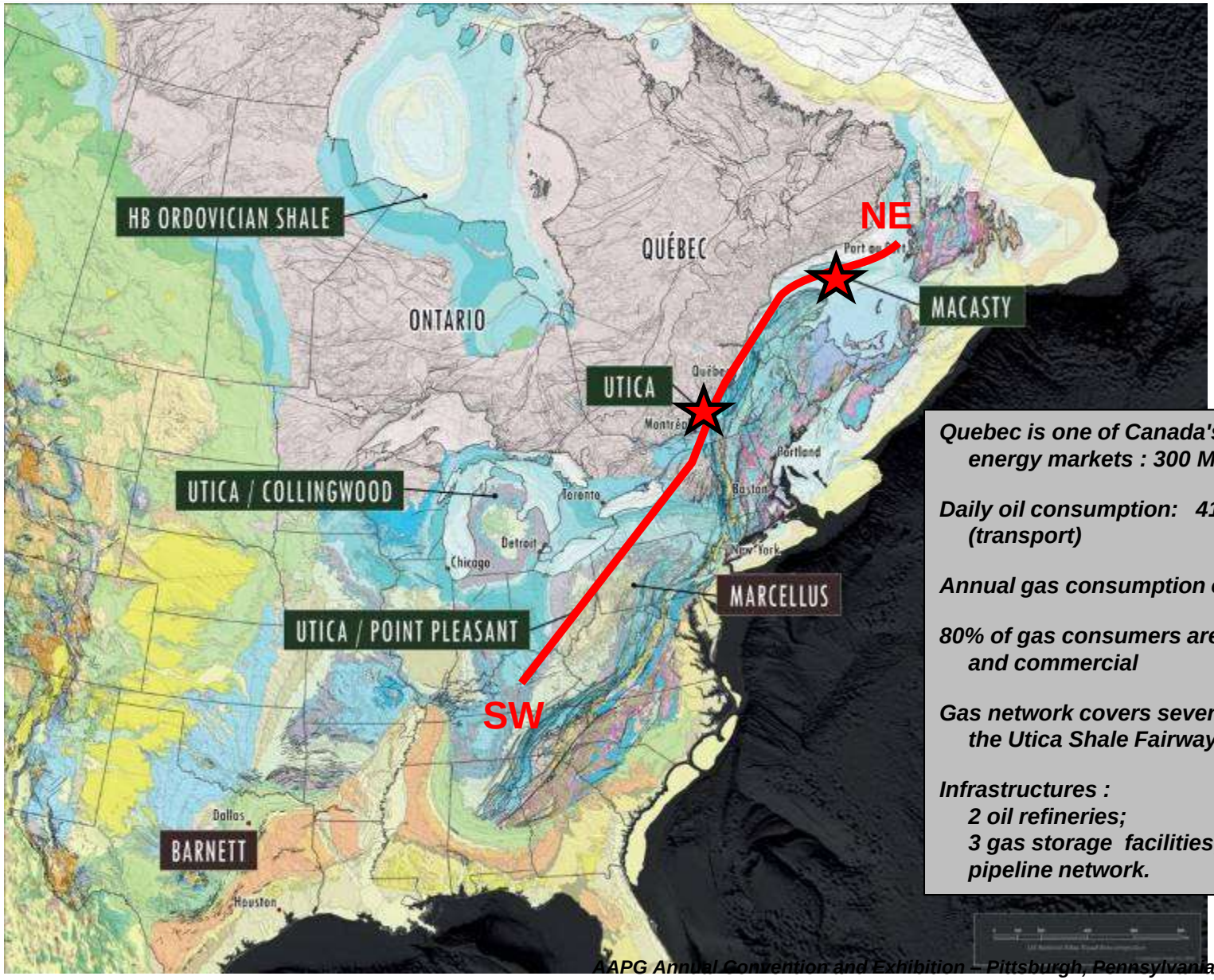
Petroleum System	Late Ordovician Macasty Shale
Exploration	21 exploratory wells drilled
Thermal Maturity	0.6 to 1.8 %Ro eq. Tmax : 440 to 458 °C
Source-rock depth	1 600 to 2 500 m
Play identified in the basin	Conventionnal : HTD Carbonates : 1,500 to 3,000m Unconventional : MacAsty (*liquid-rich*) : 1,500 to 2,500m Hybrid : Vauréal/Ellis Bay (fractured reefal limestones) : 500 to 2,000m Offshore (shallow water): Chicotte (reef system) : 1,000m

Review of the Petroleum Potential

Resources assessment studies recently published by different groups corroborate the analytical results and the interpretation of the authors concerning the high hydrocarbon potential of the Anticosti Basin.

- In October 2009, a multidisciplinary team attached to the Geological Survey of Canada published a Petroleum Resource Assessment for the Paleozoic Succession of the St. Lawrence Platform. This report estimate the Resource in-place potential in the hydrothermally dolomitized carbonate at **957 million boe (P50 - Best Estimate) mainly located in the Anticosti Basin**;
- In July 2011, Halifax-based Corridor Resources published a Resource assessment report of the Middle Ordovician Macasty Shale. This independent report completed by Sproule established the Total Resource Potential over an area of **1,550,000 acres at 33.9 billion boe (P50 - Best Estimate)** mainly located in the Shallow Macasty Zone;
- In September 2011, Quebec-based Junex inc. published a Resource assessment report of the Middle Ordovician Macasty Shale. This independent report completed by Netherland, Sewell, and Associates inc. established the Total Resource Potential over an area **of 233,275 acres at 12.2 billion barrels (P50 - Best Estimate)** mainly located in the Deep Fairway.

Ordovician Petroleum System of Northeast America



Quebec is one of Canada's largest energy markets : 300 Mboe/year

Daily oil consumption: 410,000 bbl (transport)

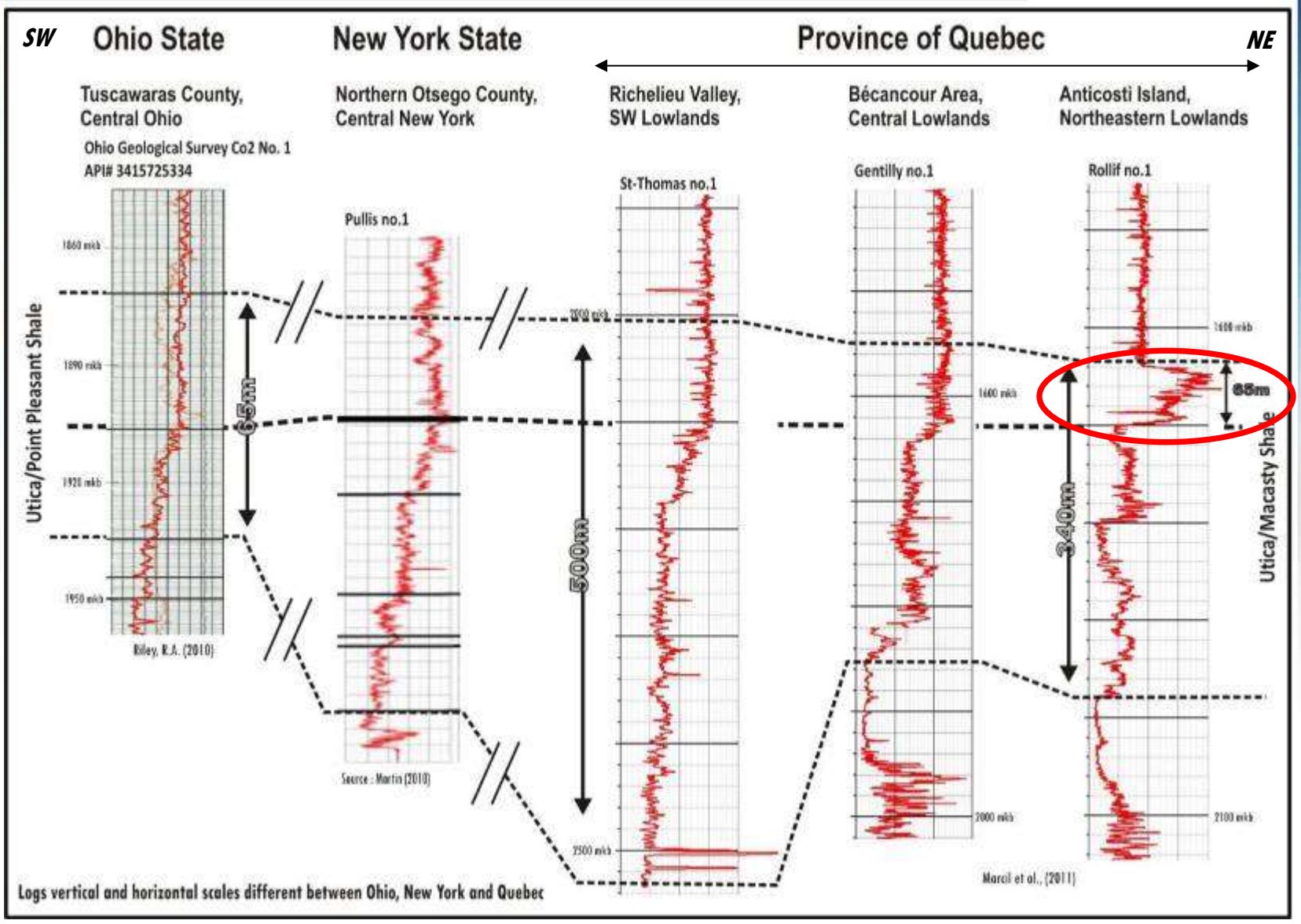
Annual gas consumption of 180 Bcf

80% of gas consumers are industrial and commercial

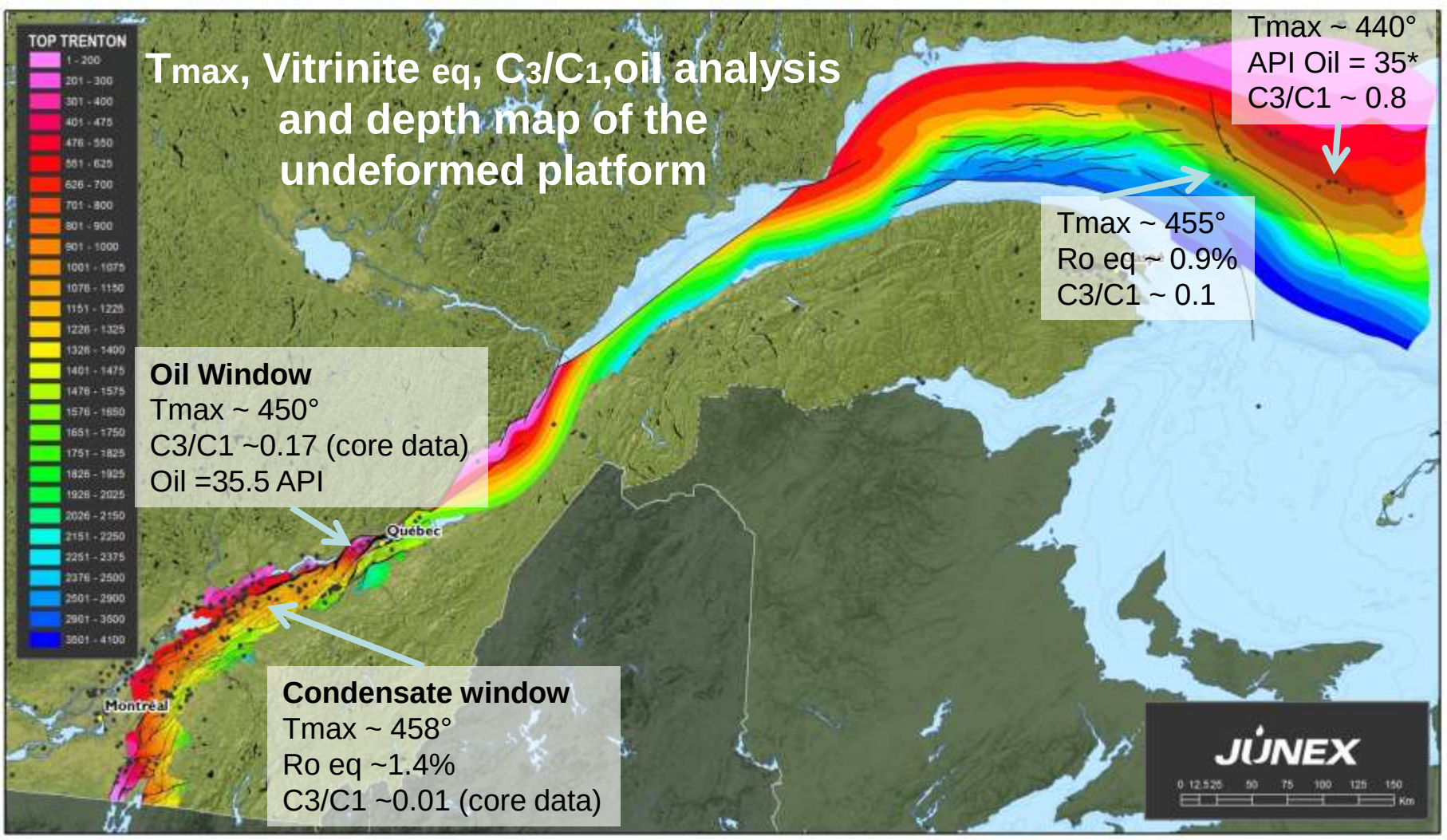
Gas network covers several areas in the Utica Shale Fairway

Infrastructures :
- *2 oil refineries;*
- *3 gas storage facilities;*
- *pipeline network.*

NE America – Ordovician Shale Correlation

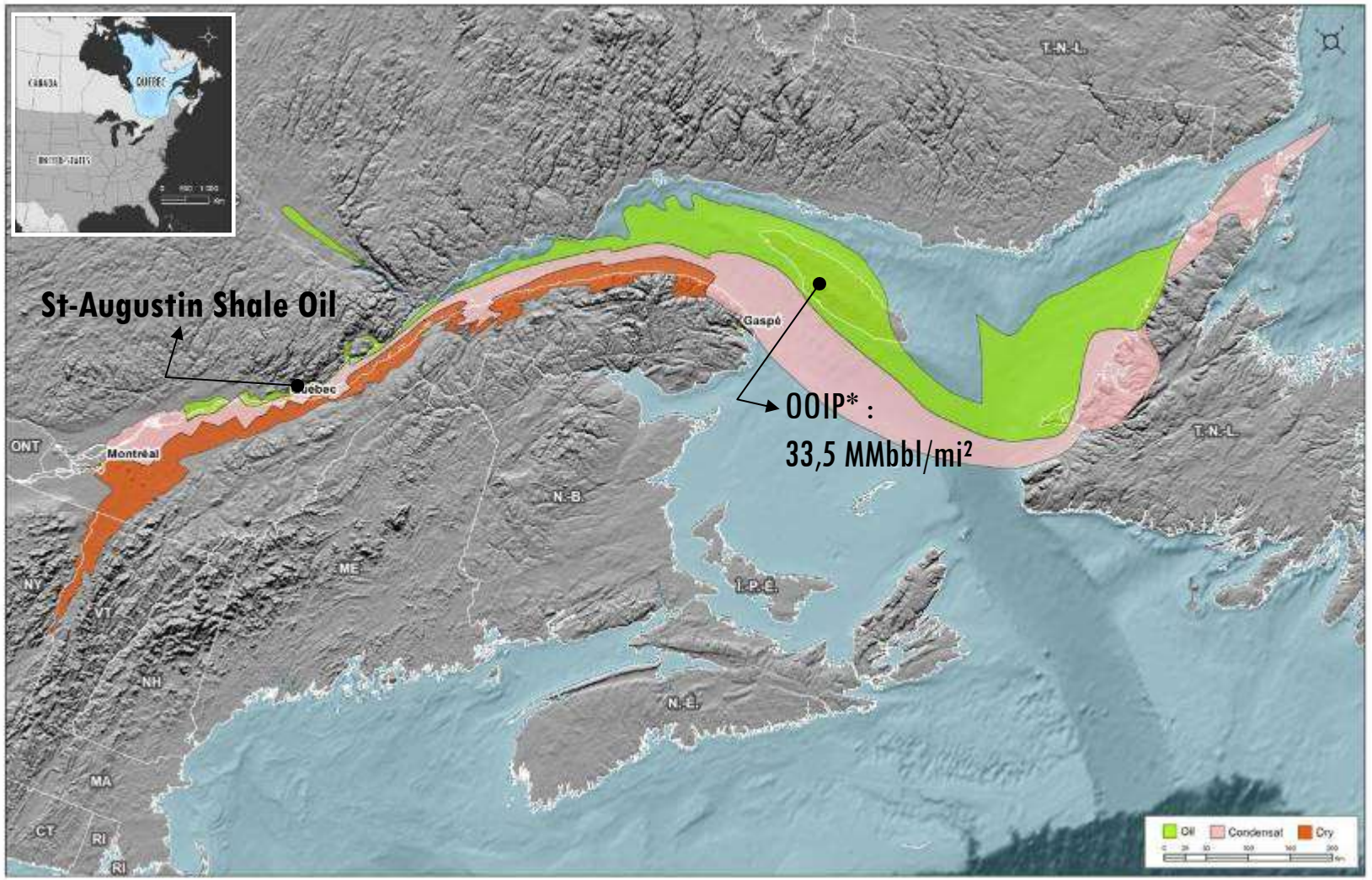


The Middle Ordovician Carbonate basins in Quebec



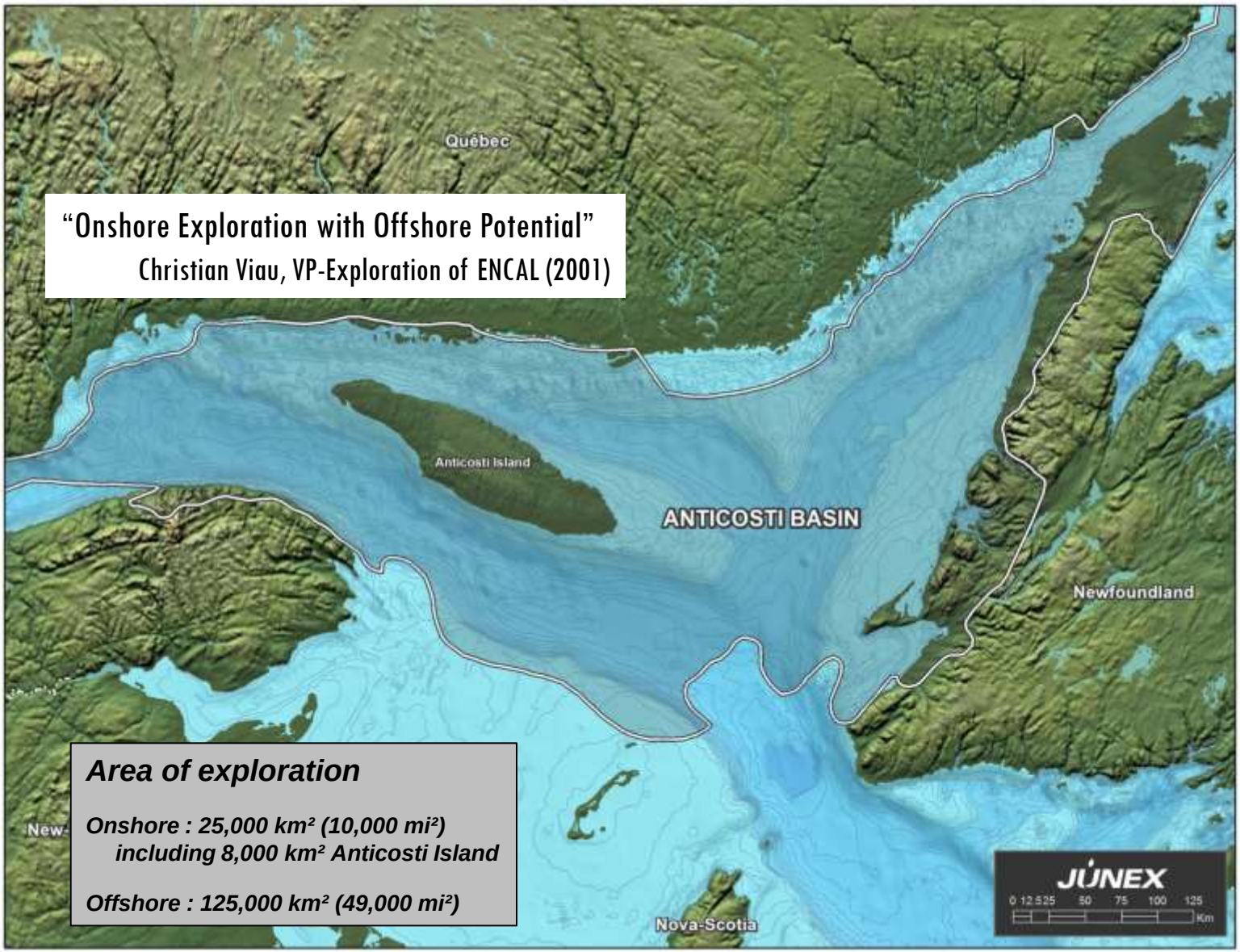
*From Pétrolia Press realease, 2011/02/09
Data from Junex database and Thériault (2008)

Ordovician Shale Thermal Maturity Zonation



* From September 2011 – Netherland Sewell and Associates Inc. Ressource Estimates Independant Report for South Anticosti Island

Anticosti Basin



"Onshore Exploration with Offshore Potential"
Christian Viau, VP-Exploration of ENCAL (2001)

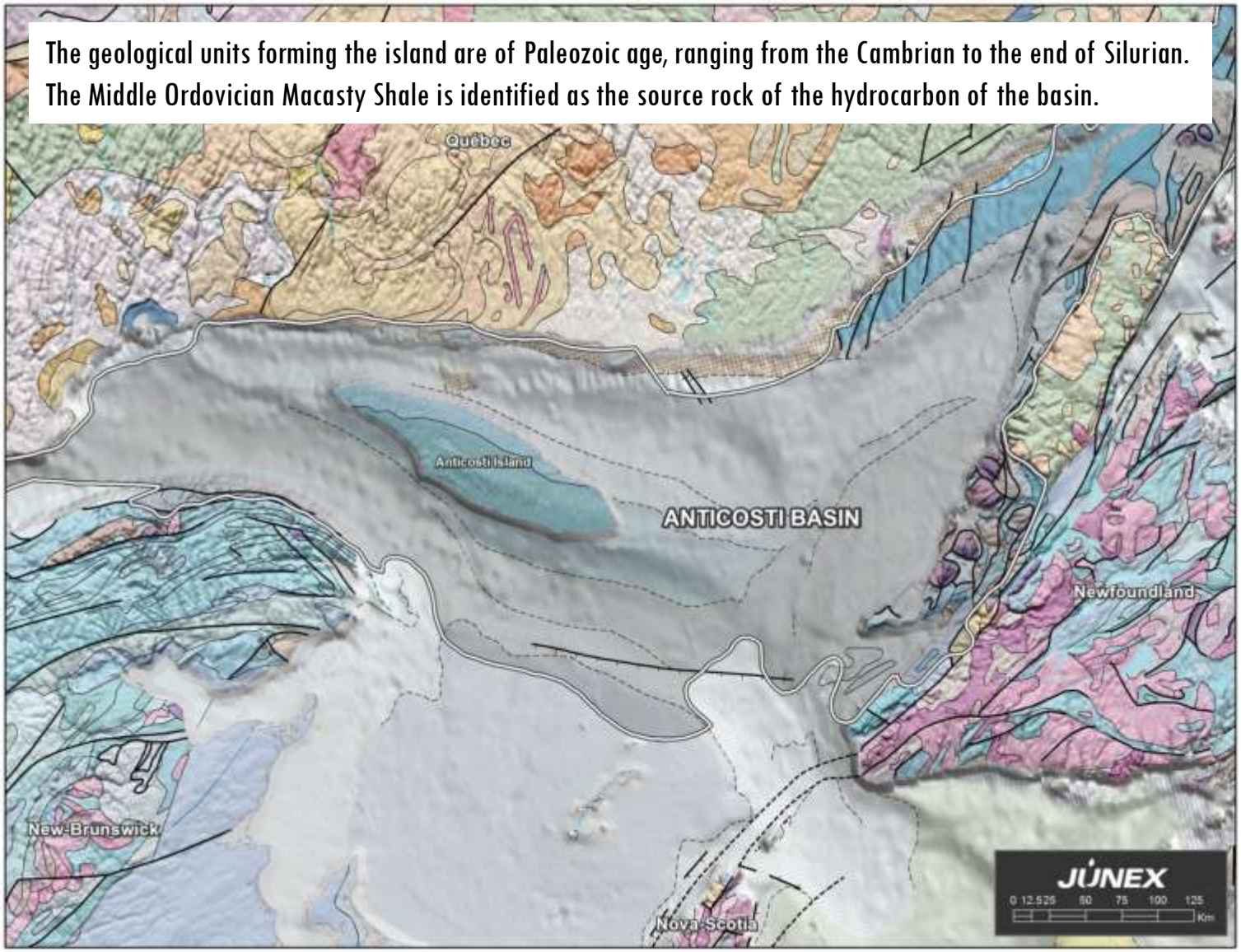
Area of exploration

Onshore : 25,000 km² (10,000 mi²)
including 8,000 km² Anticosti Island

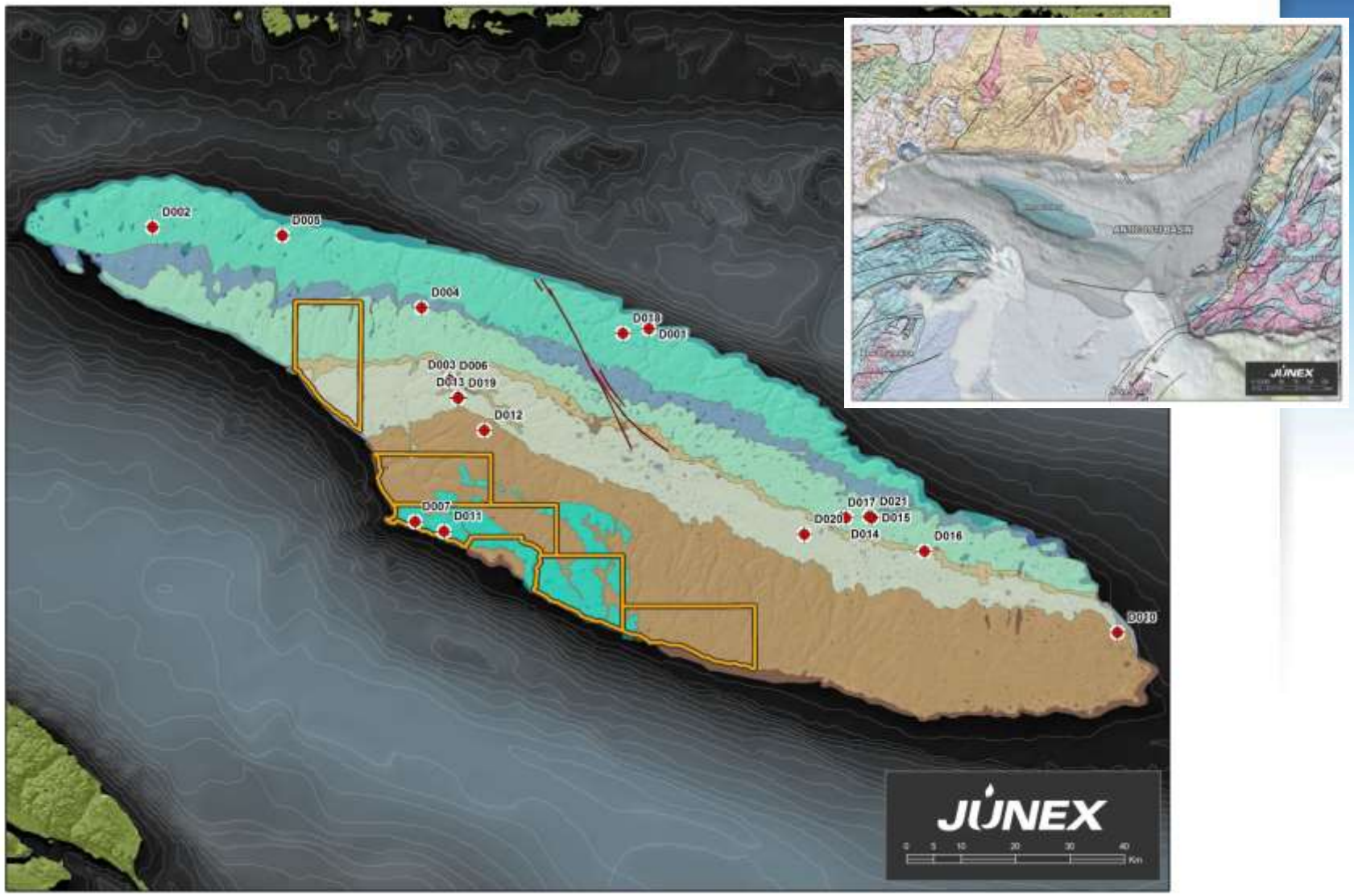
Offshore : 125,000 km² (49,000 mi²)

Anticosti Basin Regional Geology

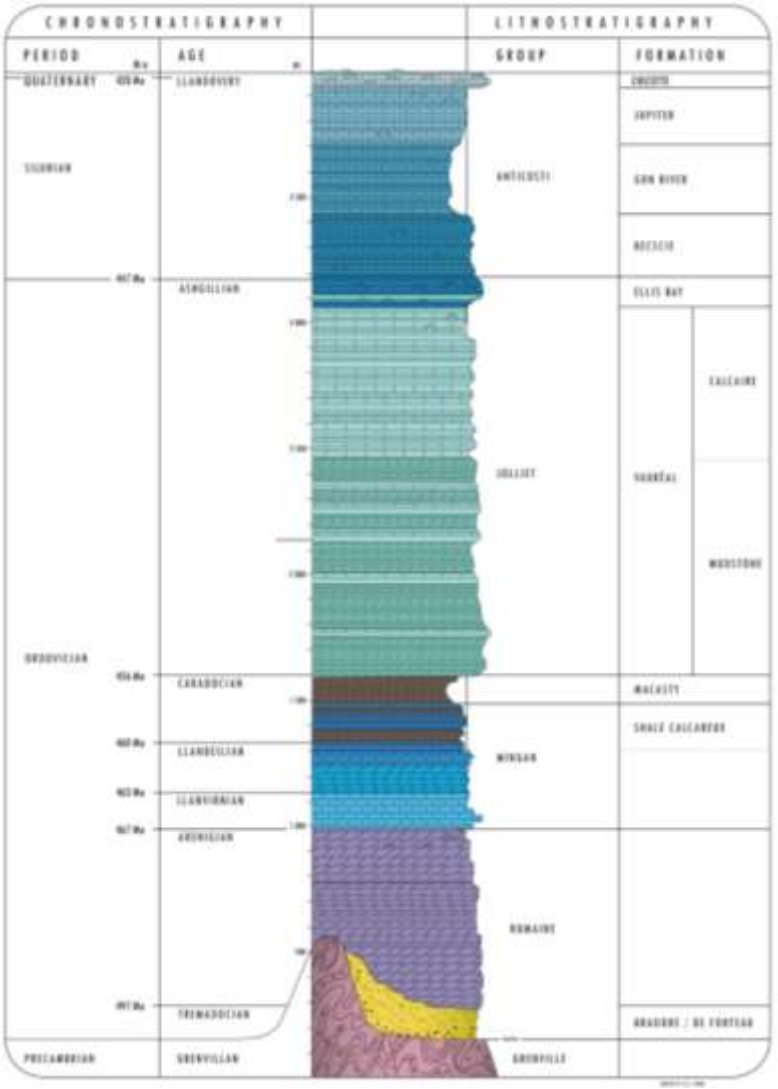
The geological units forming the island are of Paleozoic age, ranging from the Cambrian to the end of Silurian. The Middle Ordovician Macasty Shale is identified as the source rock of the hydrocarbon of the basin.

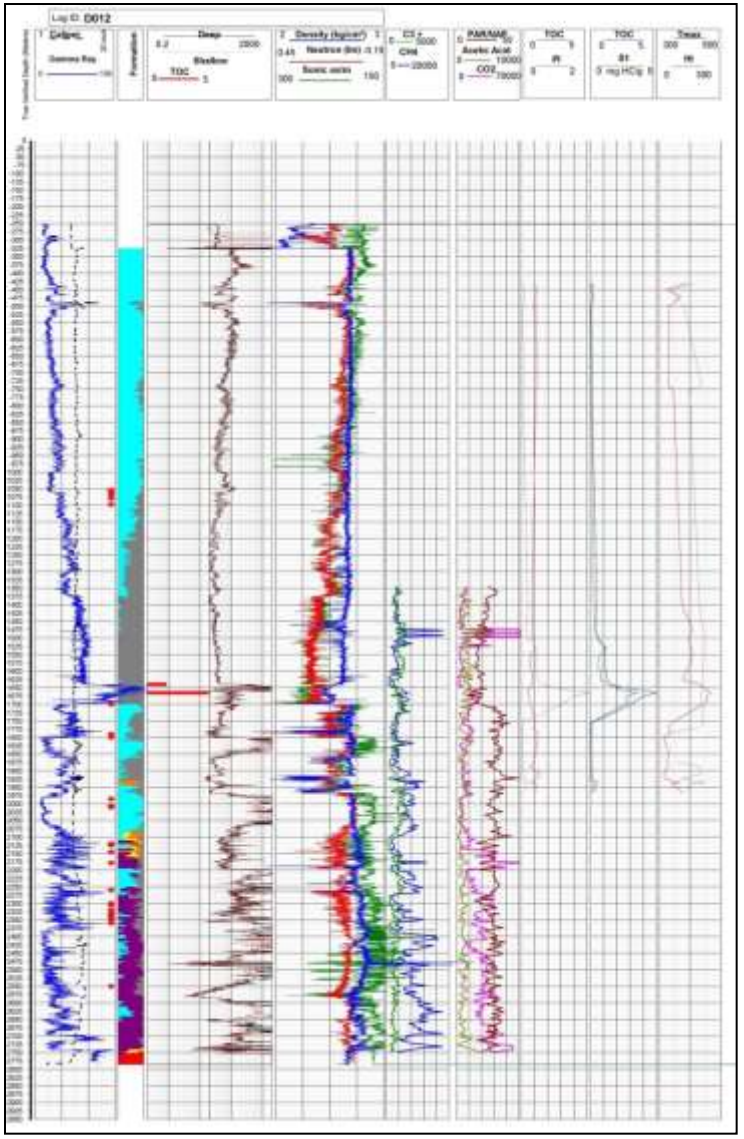


Anticosti Island Geology



Anticosti Stratigraphy – 4000m of Carbonates

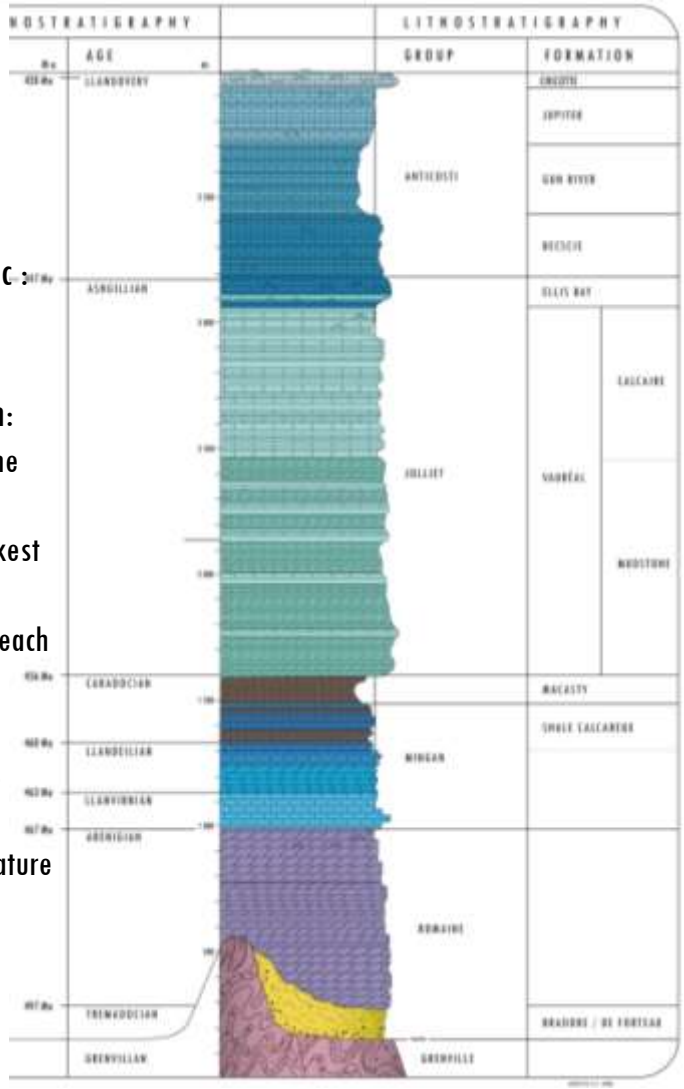




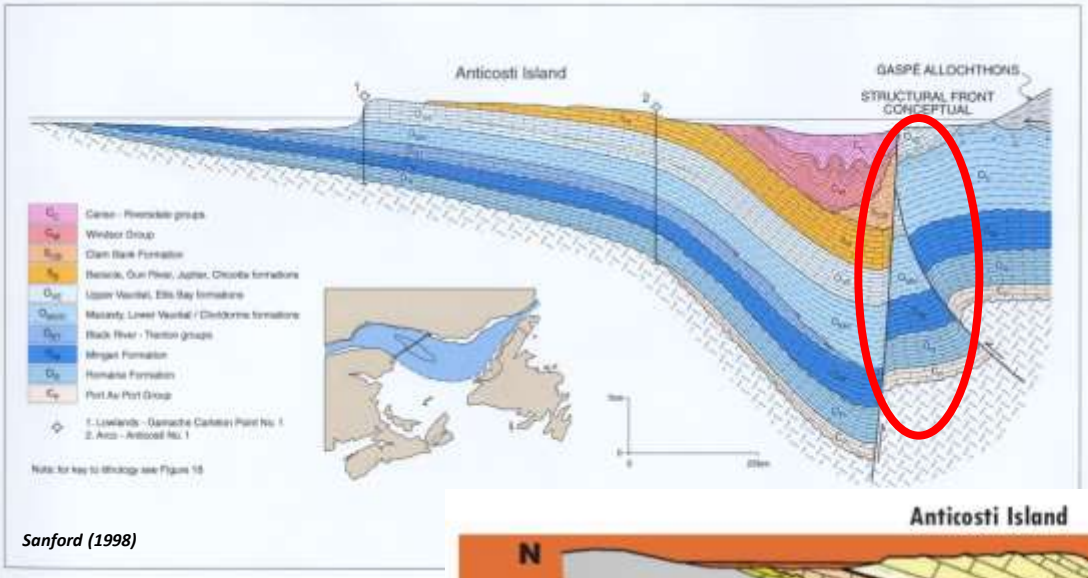
Anticosti Stratigraphy – Arco Anticosti #1 - D007

Stratigraphic Importance
of the Atlantic Richfield Anticosti #1 well (TD : 12,620fkb)

- Drilled as a deep stratwell, based on gravity data :
  - Reached the Grenville basement at 12,593fkb;
- The well have been one of the more studied well in province of Quebec :
  - Including several new research techniques used in the 70's by the Petroleum National Iresearch insttitute (INRS-Petrole);
- Available data from the study of this well are priceless for exploration:
  a) Macasty Shale at this location shows the highest maturity attend by the source-rock over the island;
  b) The stratigraphic sequence penetrated by the well represents the thickest sedimentary succession available onshore;
  c) In the region of the well, it is possible that some post-Macasty units reach their maximum thickness (Jolliet and Jupiter Groups);
  d) The well encountered liquid and wet gas zone in Vauréal Limestones;
  e) The well encountered and tested a gas zone in the Romaine Dolomites (eq. Beekmantown/Ellenburger Formation);
  f) Bottom-hole temperature at 160°F, implying that the average temperature of the shale is greater than 100°F.

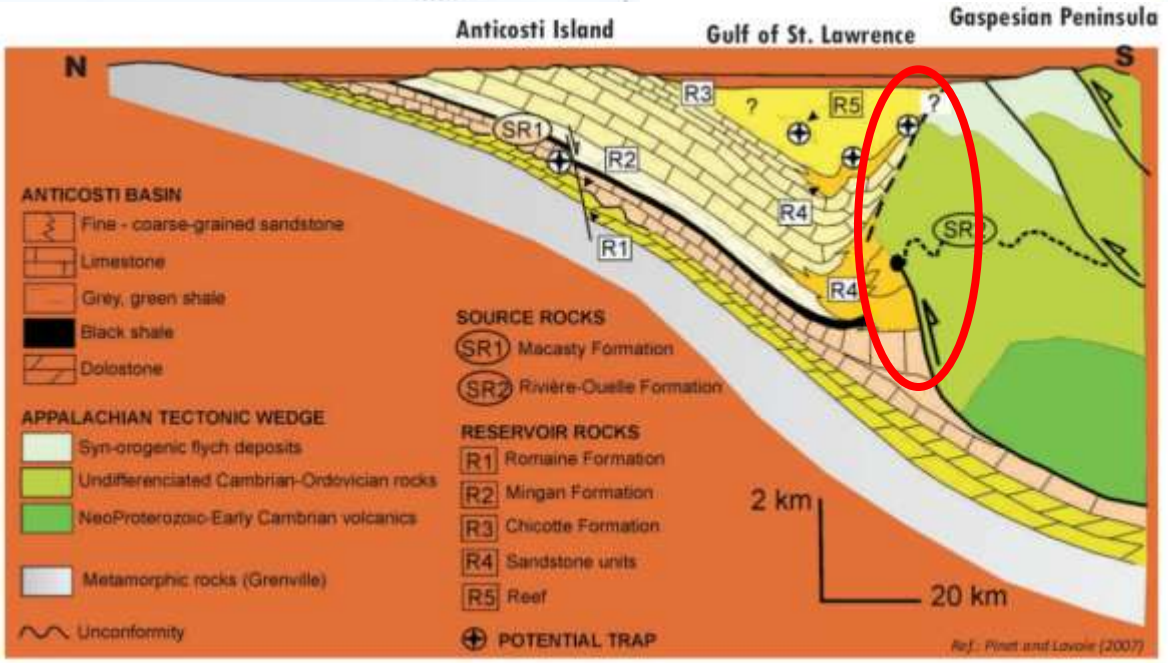


Anticosti Basin Regional Geology



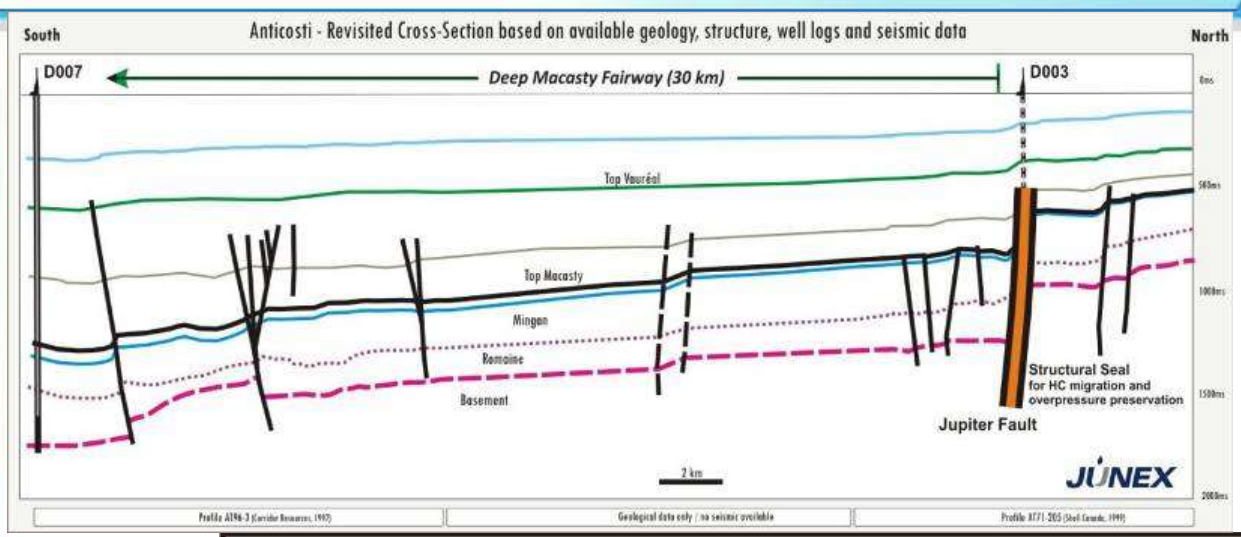
Sanford (1998)

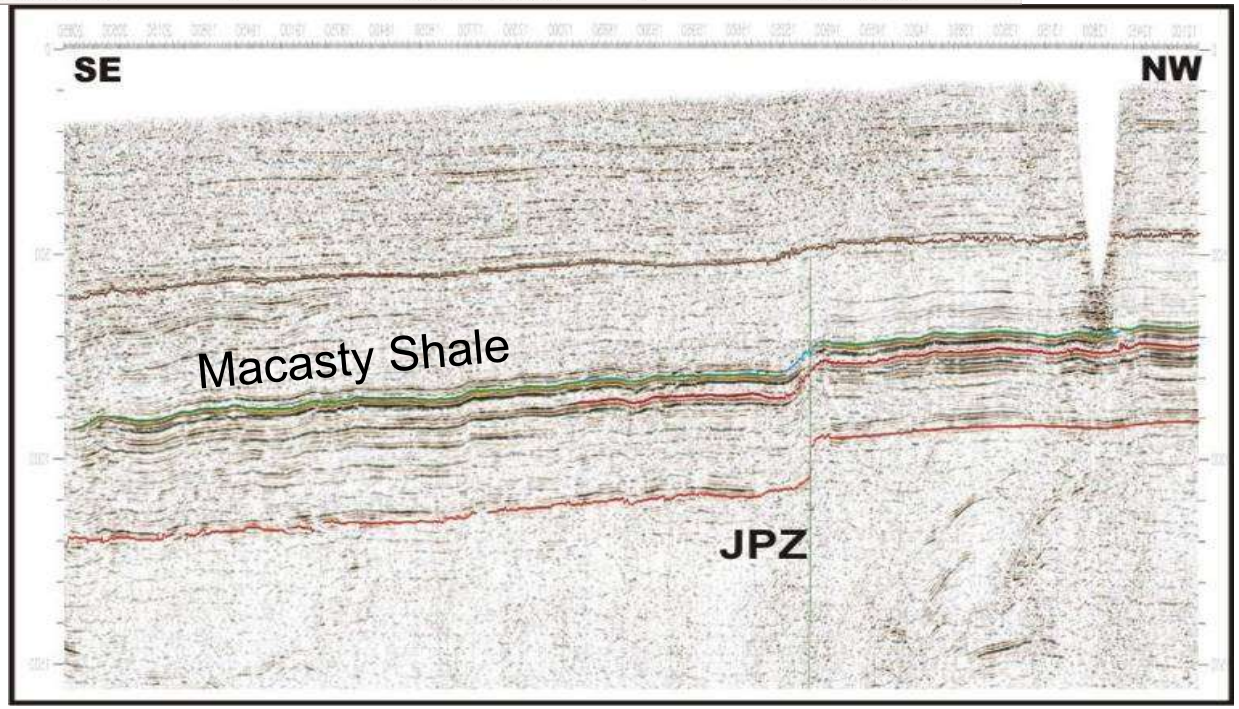
Due to the lack of well data and poor seismic data quality, questions remain concerning the interpretation of the deformed zone



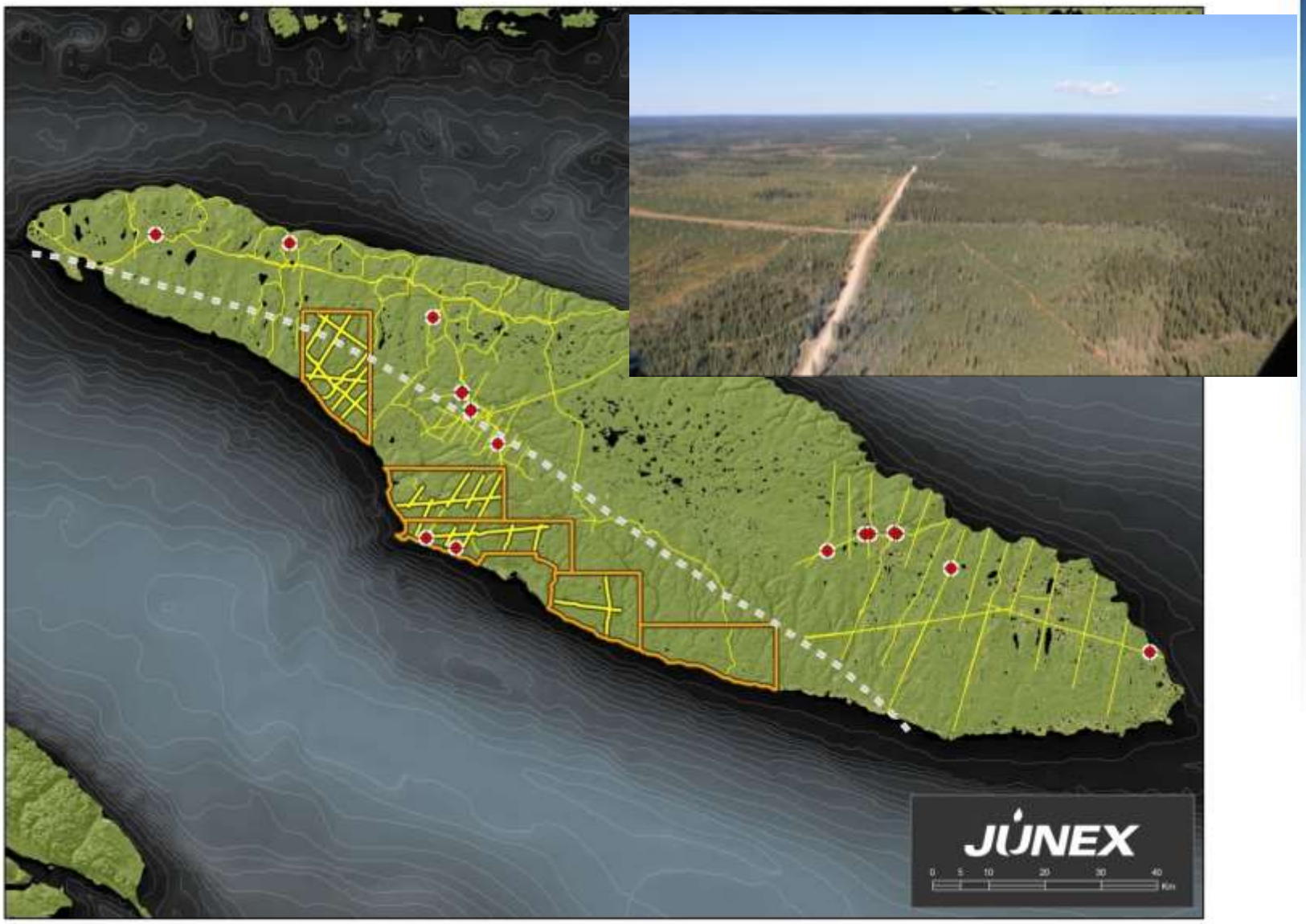
Geophysical coverage – pre-2010

Deep fairway X-Section Based on Regional Transect





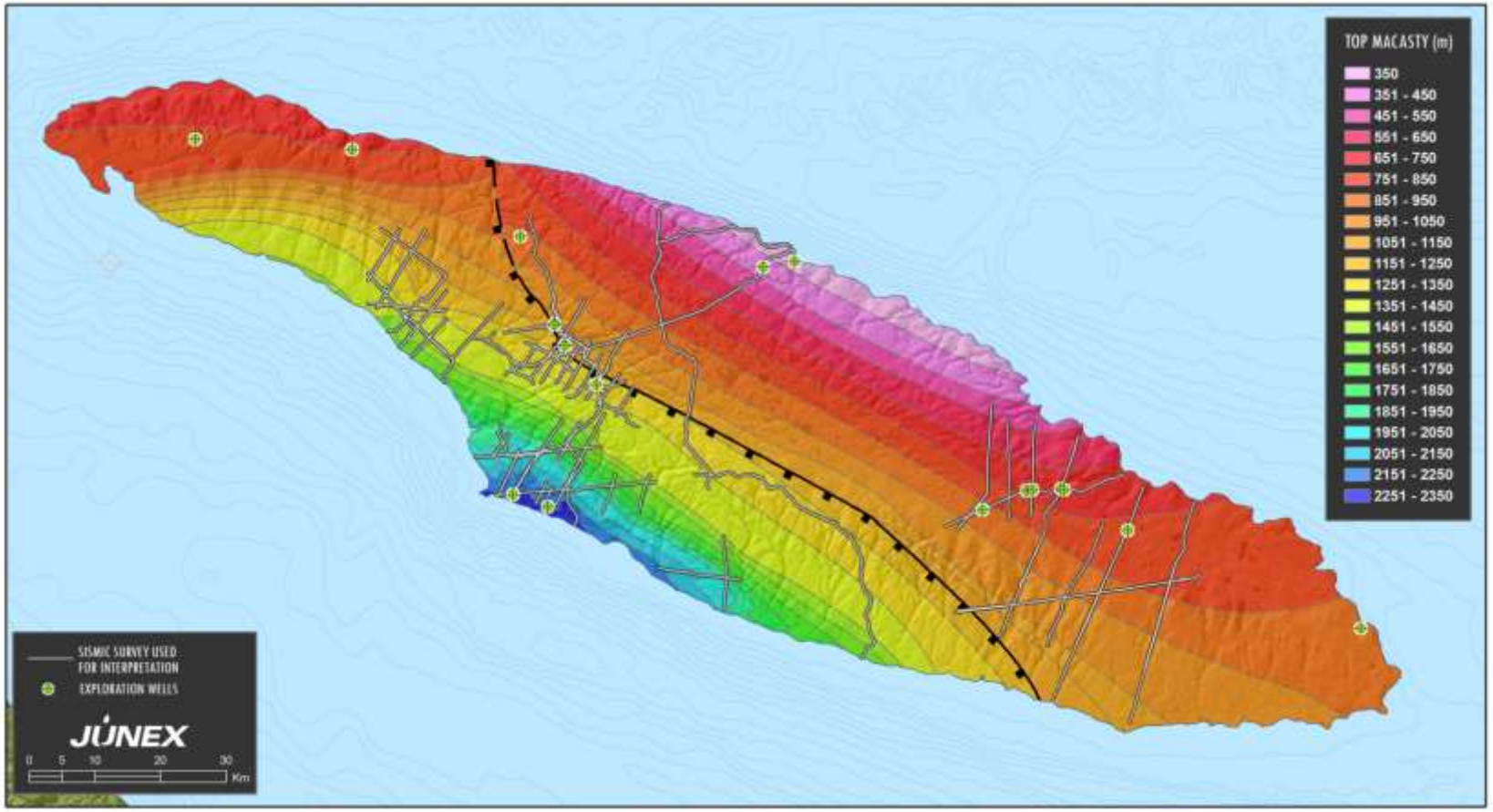
2012 – Deep Fairway Geophysical Survey



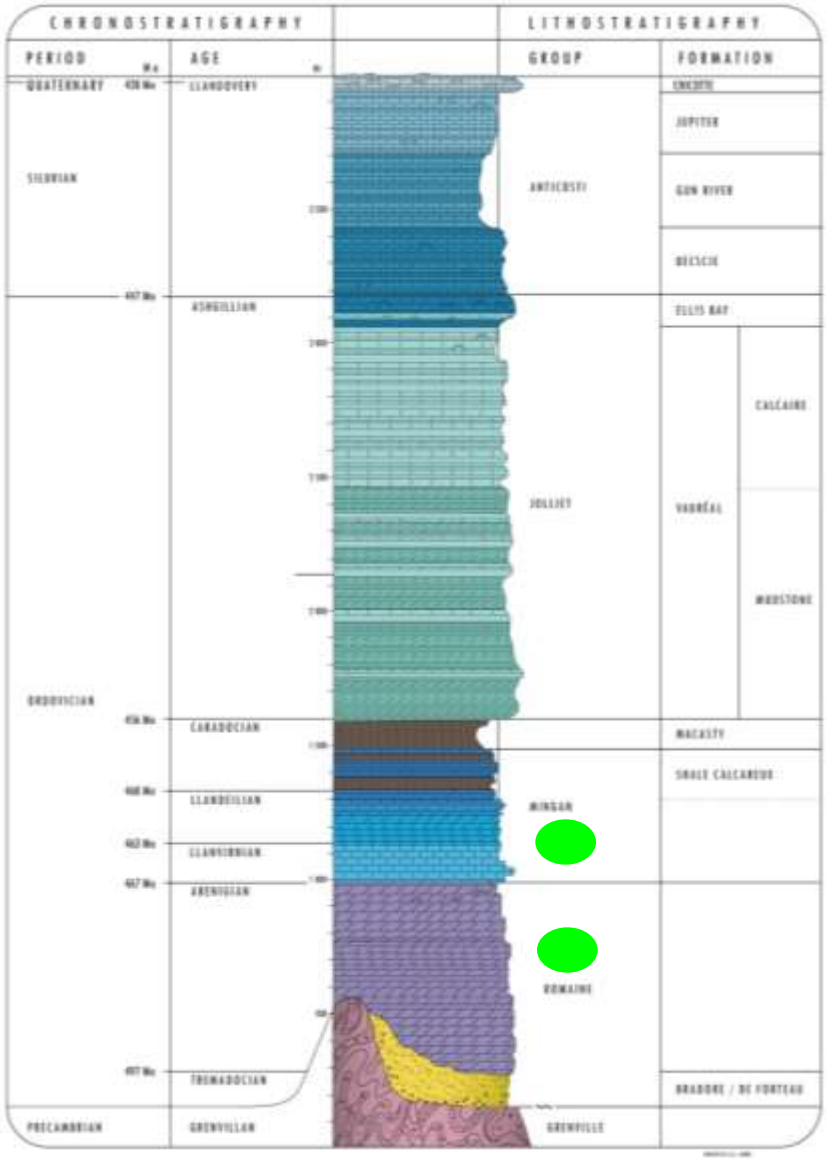
2012 – Deep Fairway Geophysical Survey

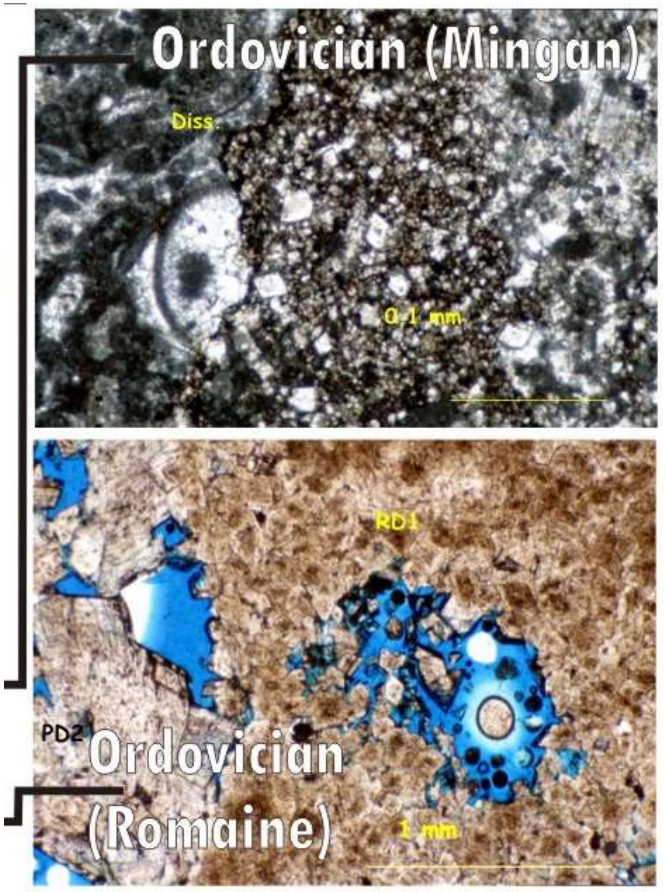
2012 – Deep Fairway Geophysical Survey

- *225 line-km of 2D seismic survey completed;*
- *Numerous prospects identified (top 6 to be permitted);*
- *Position of the Jupiter Fault Zone in the subsurface is better defined*



Play 1 : Dolomitized Ordovician Carbonates

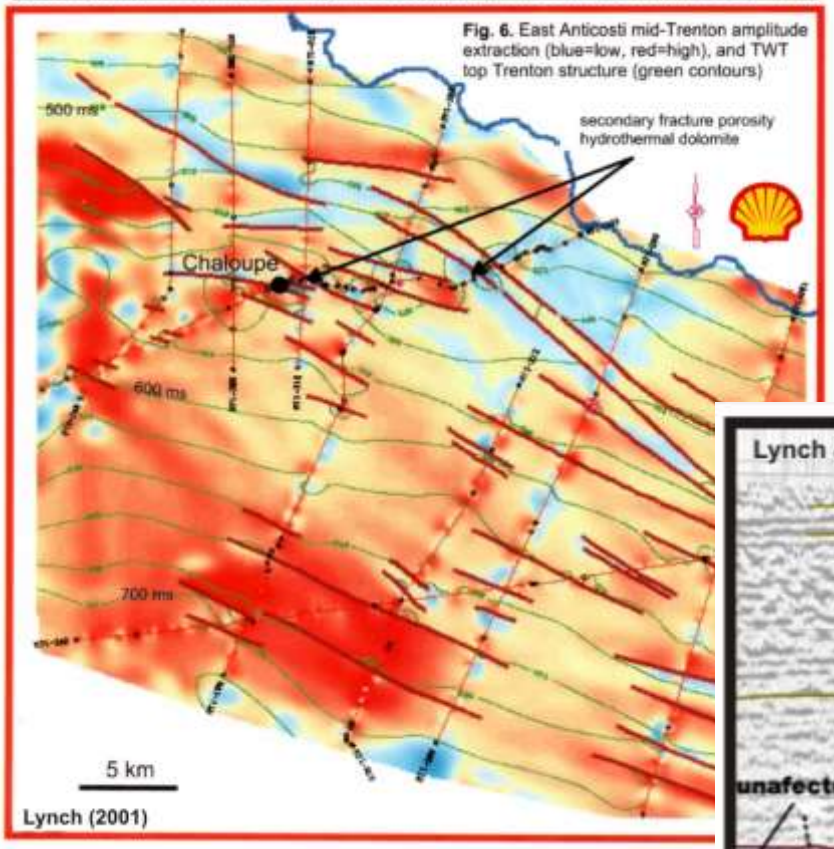




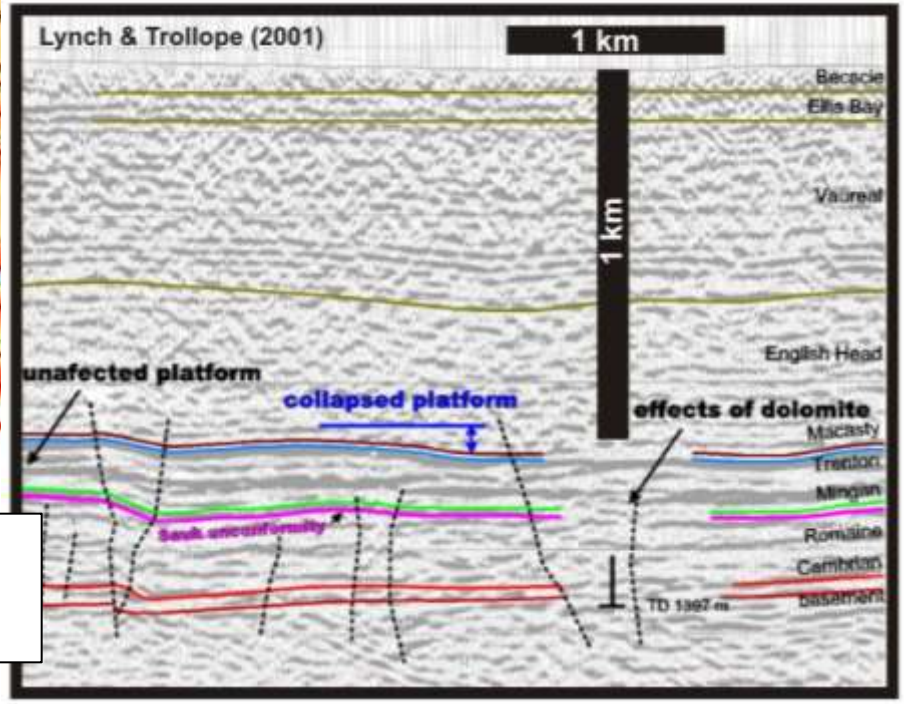
Lavoie et al. (2009)

Play 1 : Dolomitized Ordovician Carbonates

Shell Canada -Encal Energy, Anticosti Island Exploration, 1997-2000



Work done by Shell and its partners at the end of the 90's led to the identification several seismic anomalies. Five of them were drilled and excellent quality HTD reservoir were discovered in the Ordovician carbonates.



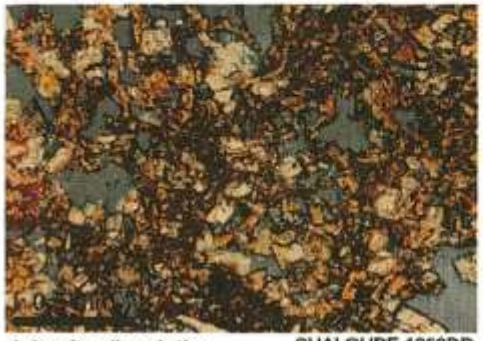
Shell et al. Chaloupe #1 well seismic anomaly located in the shallow fairway

Play 1 : Dolomitized Ordovician Carbonates

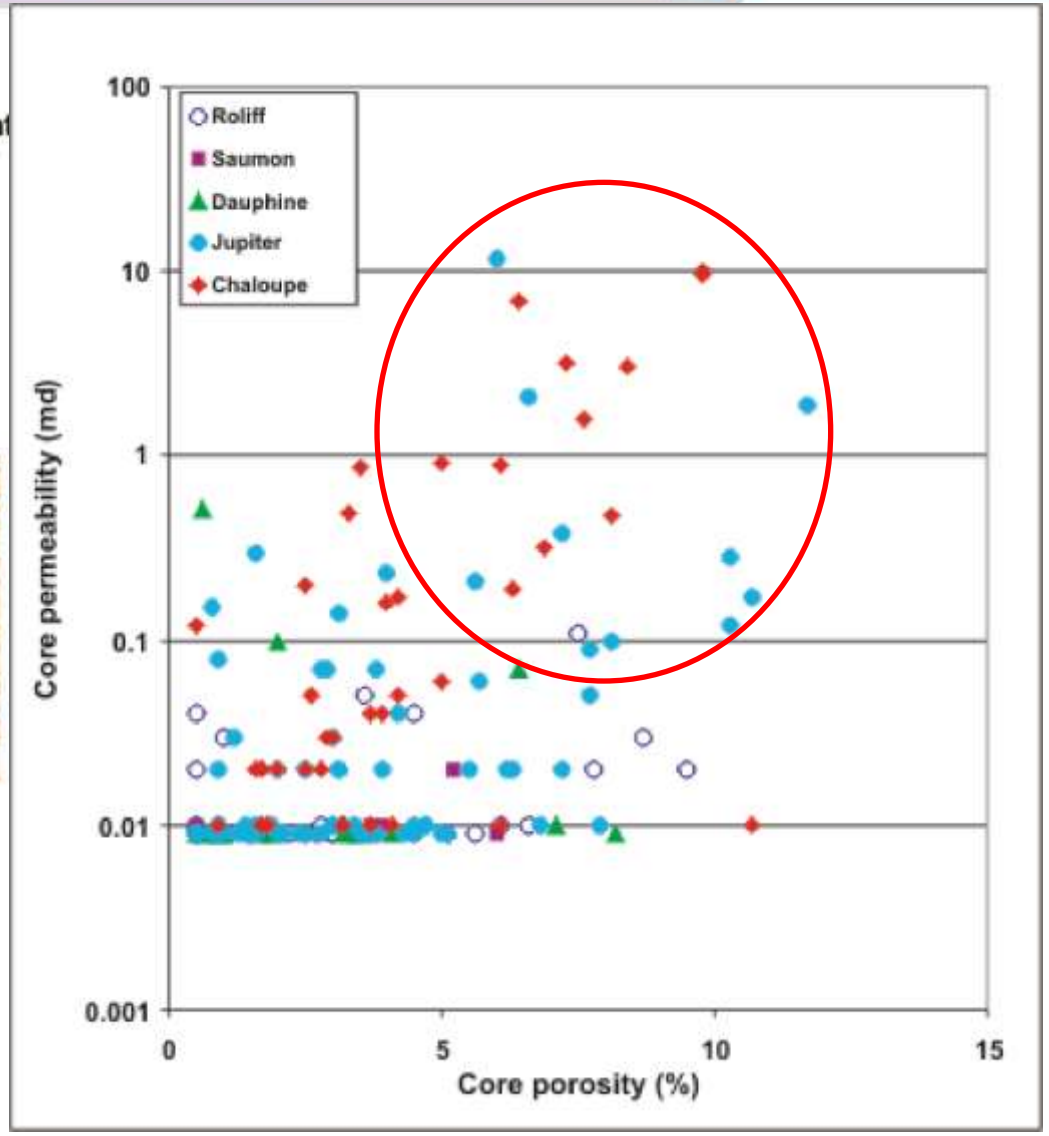
A DST from the Romaine Formation (1265-1305 m) demonstrated excellent permeability with formation water flow equivalent to 1651 barrels water/day. Intercrystal, vuggy, and fracture porosity occur in a 42 m (gross) interval..

Vuggy porosity seen in sidewall core (1258 m) from Chaloupe well

hydrothermal dolomite CHALOUPE 1250SD



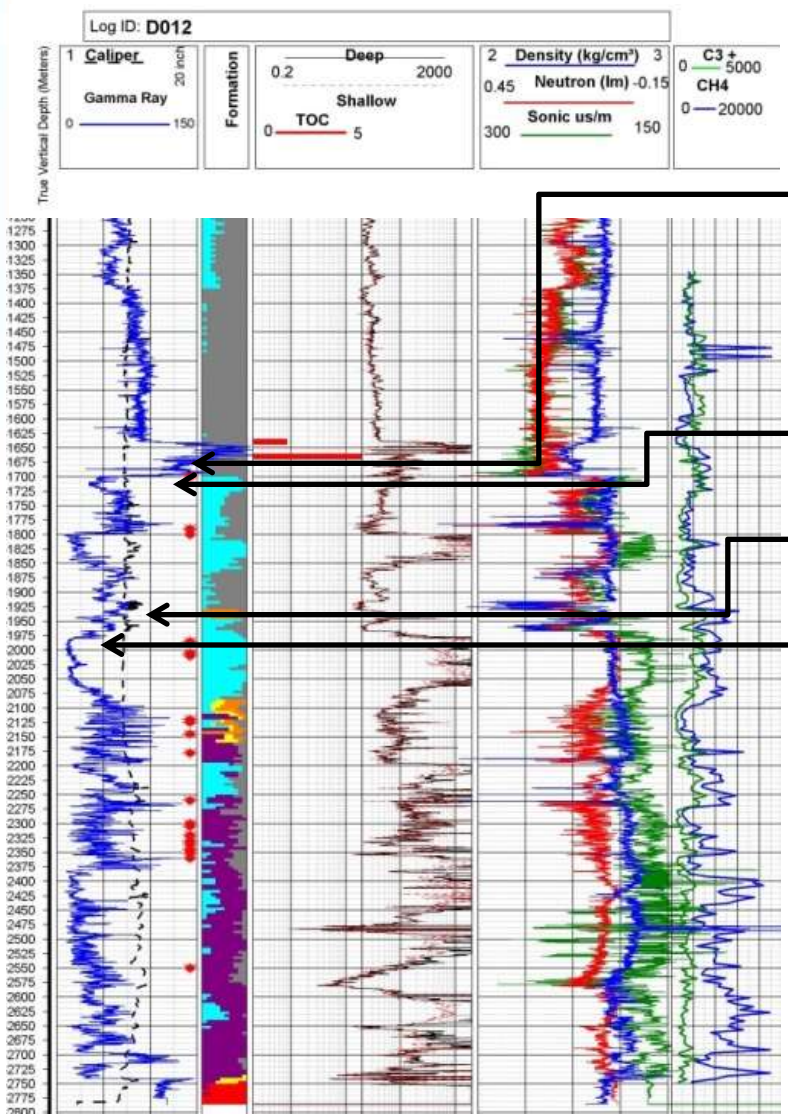
dolomite dissolution CHALOUPE 1258DD



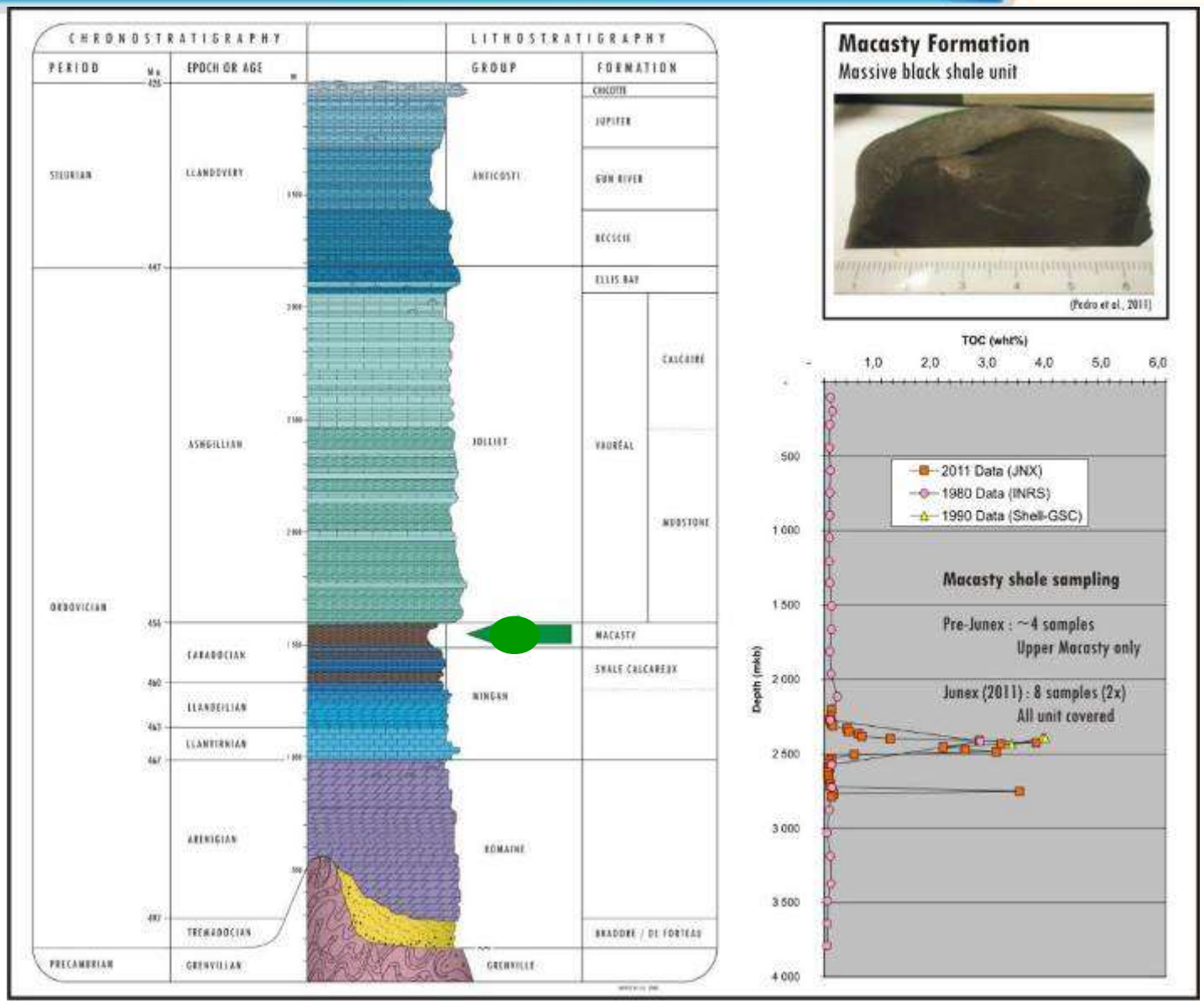
Lynch (2001)

Lavoie et al. (2009)

Play 1 : Prefered facies to chase

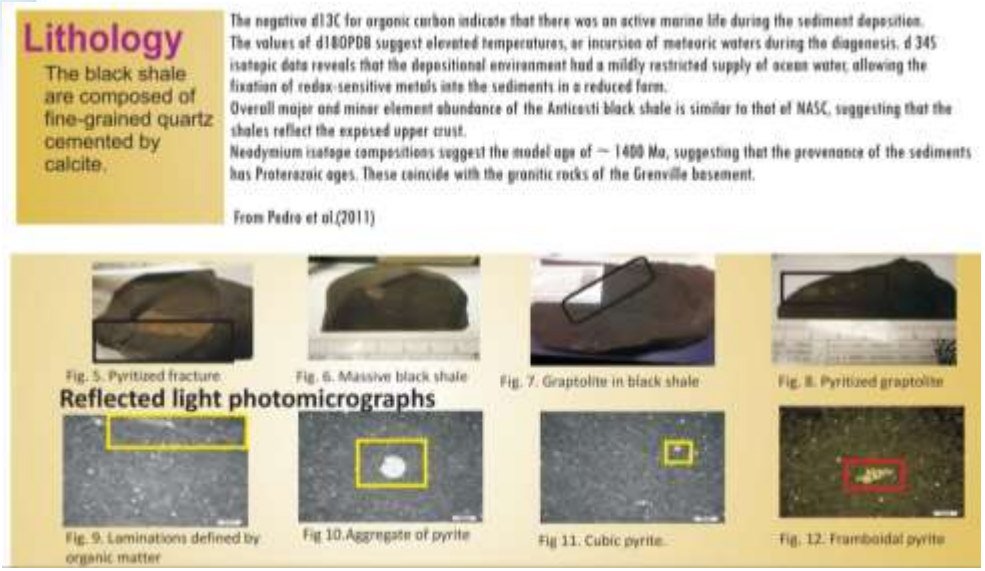


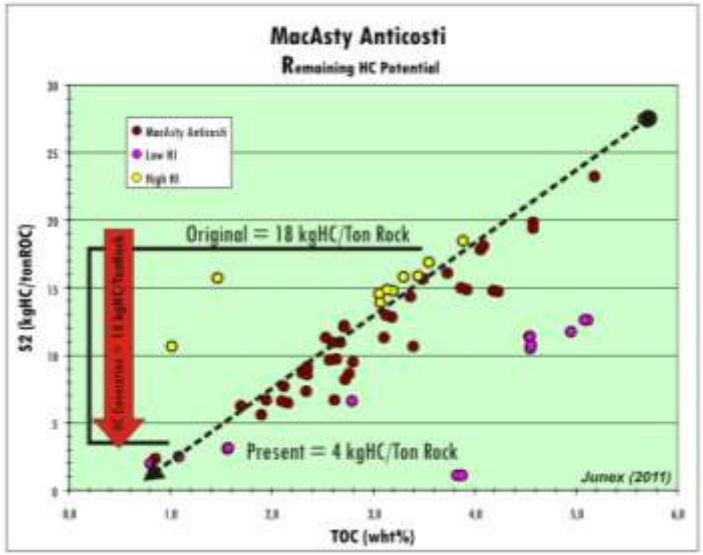
Play 2 - Macasty Shale



Macasty Shale - Geology

- *Macasty Shale belong to the Upper Ordovician Shale Sequence (Utica eq.)*
- *Thicker in Deep Fairway, southwest of the of Jupiter Fault zone*
- *"Brittle" mineralogy - ave. 50% Quartz + Feldspar, 35% Carb., and 15% Clays*
- *Good to Excellent Organic Richness with an average TOC content of 2.6 wt %*
- *Good Porosity – average porosity of 6.3% (range of 4.0 to 8.6%)*
- *Deep Fairway – dominantly in Oil window of thermal maturity*
- *Higher reservoir pressure = greater reservoir energy in Deep Macasty Fairway*





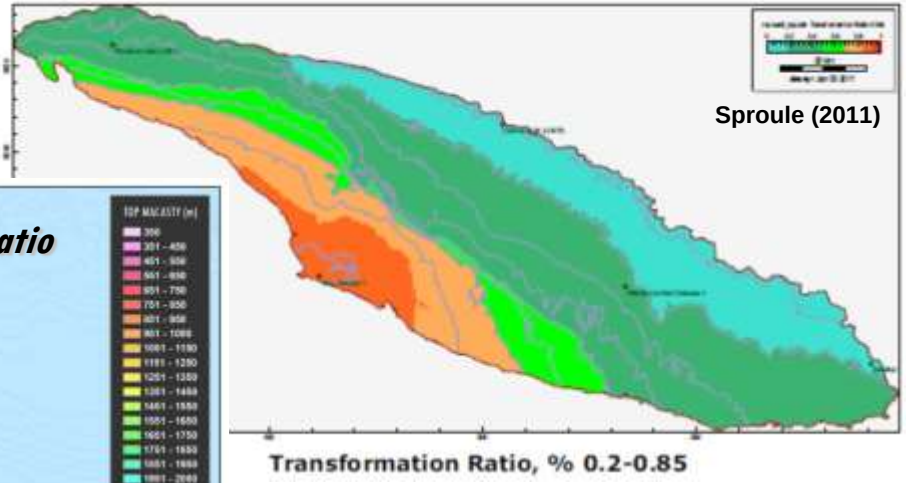
A Few Past Remarks

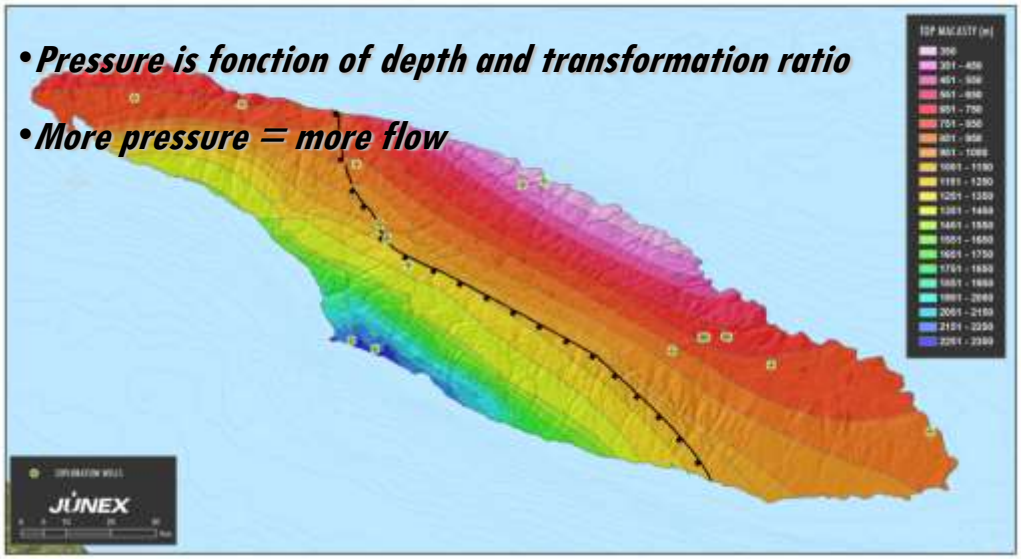
(excerpt from Dorrins et al. (2013))

"The Macasty Formation, for the entirety of Anticosti Island, could have generated the equivalent of about 178 billion barrels of hydrocarbons" (1987, Bertrand)

"The total quantity of hydrocarbons expulsed from the source rock, and could have consequently migrated towards reservoirs, is evaluated to be the equivalent of about 75 billion barrels. Two-thirds of these hydrocarbons (67%) are sourced from the southeastern portion of Anticosti Island, in the area near the ARCO well, where the Macasty is presently buried at more than 1.5 km." (1987, Bertrand)

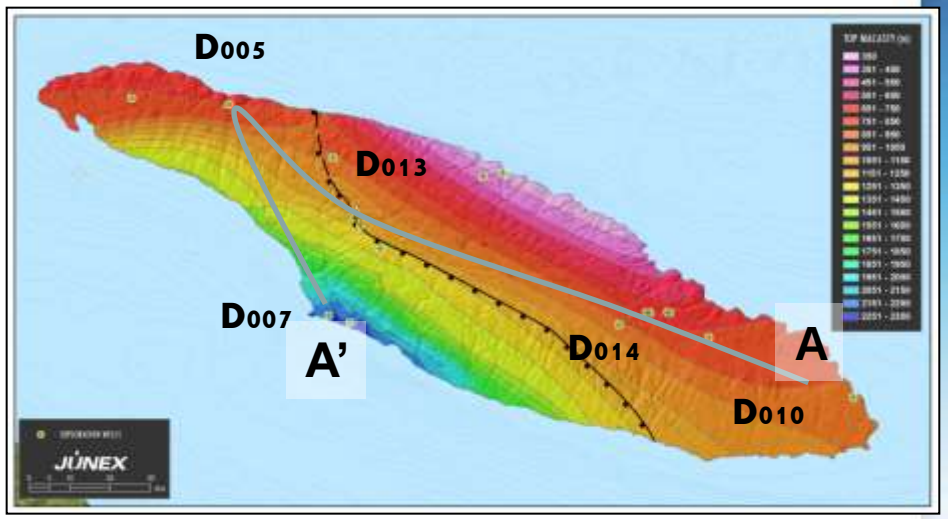
"Although the value of Tmax is abnormally low (447°C) in the Macasty Formation in the ARCO well, a value of 489°C is observed just below, at the top of the Mingan Formation (Trenton / Black River). This suggests that the Macasty Formation is fully within the (dry) gas zone (Ro vitrinite > 1.35%)…" (1987, Bertrand)

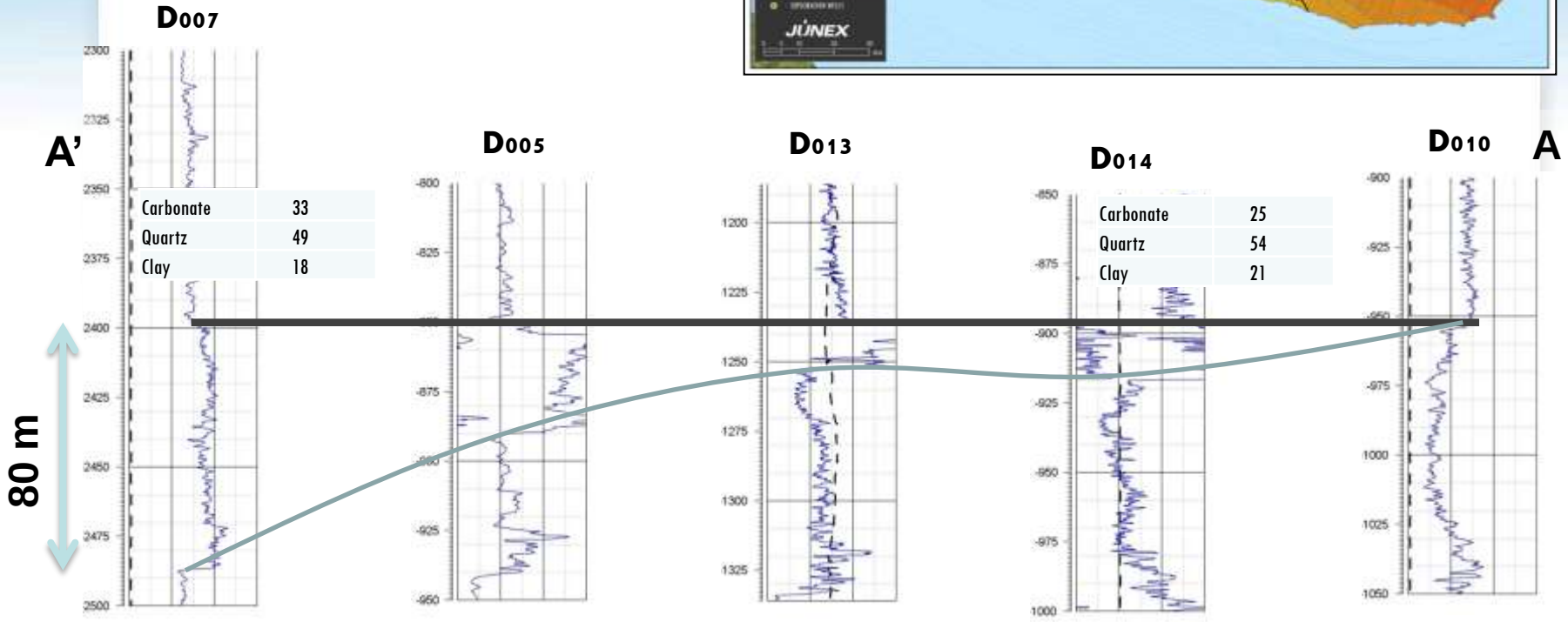




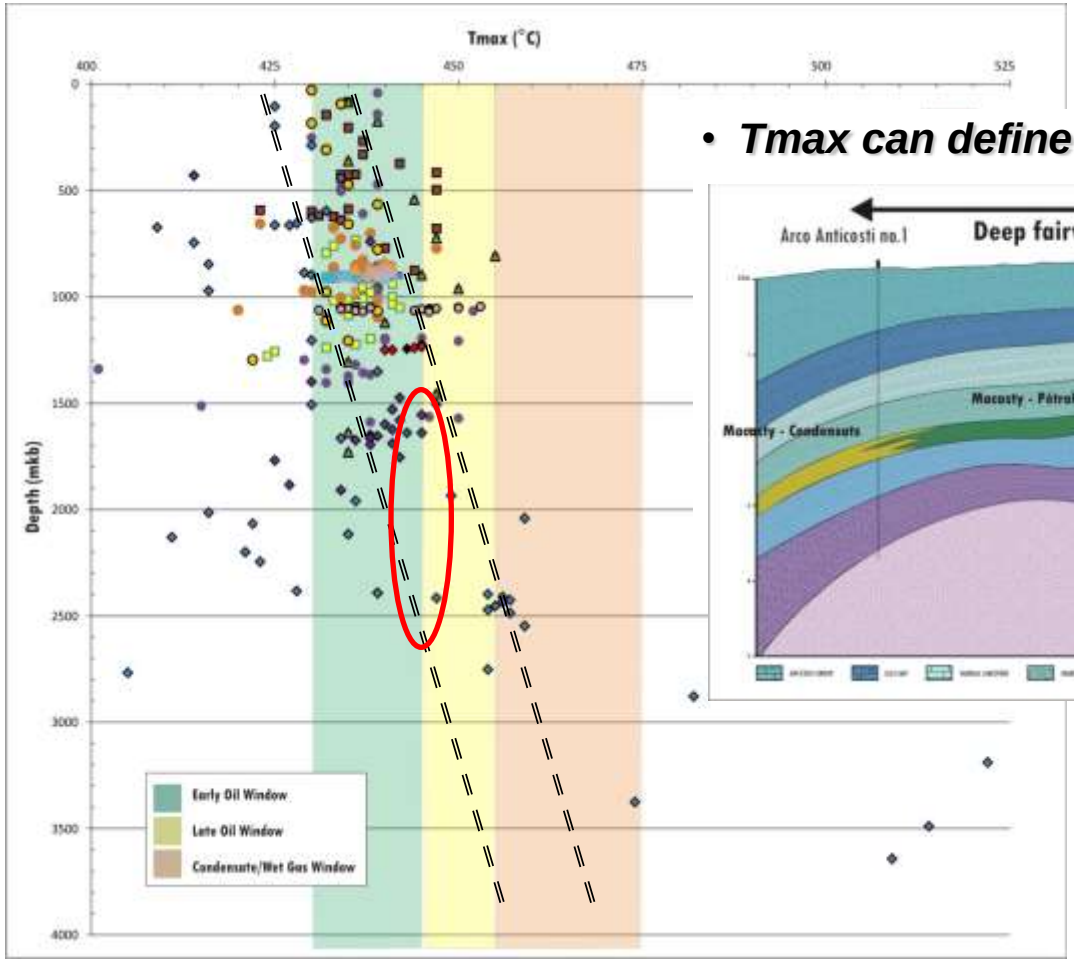
Thickness of the shale

- Gamma Ray shows less high values due to organic matters transformation
- Macasty shale is thickening toward south-west

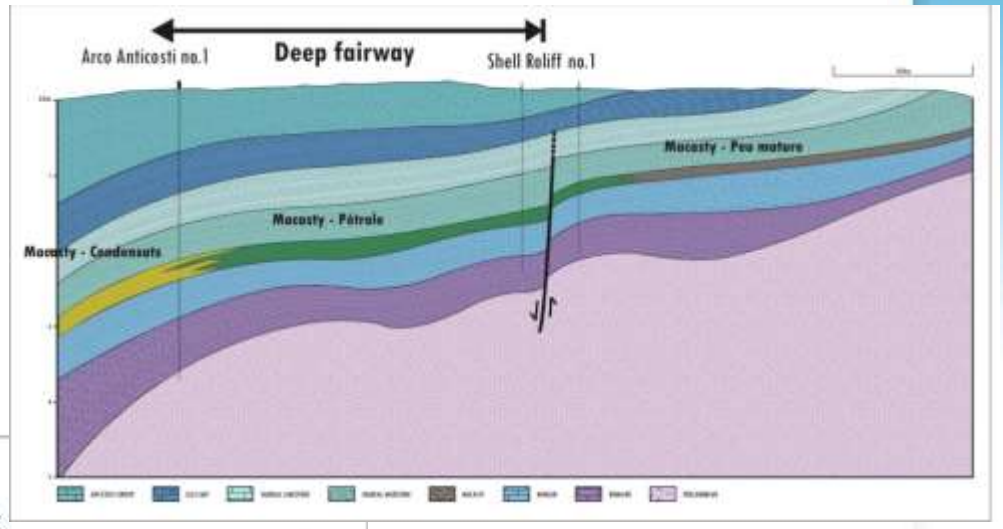




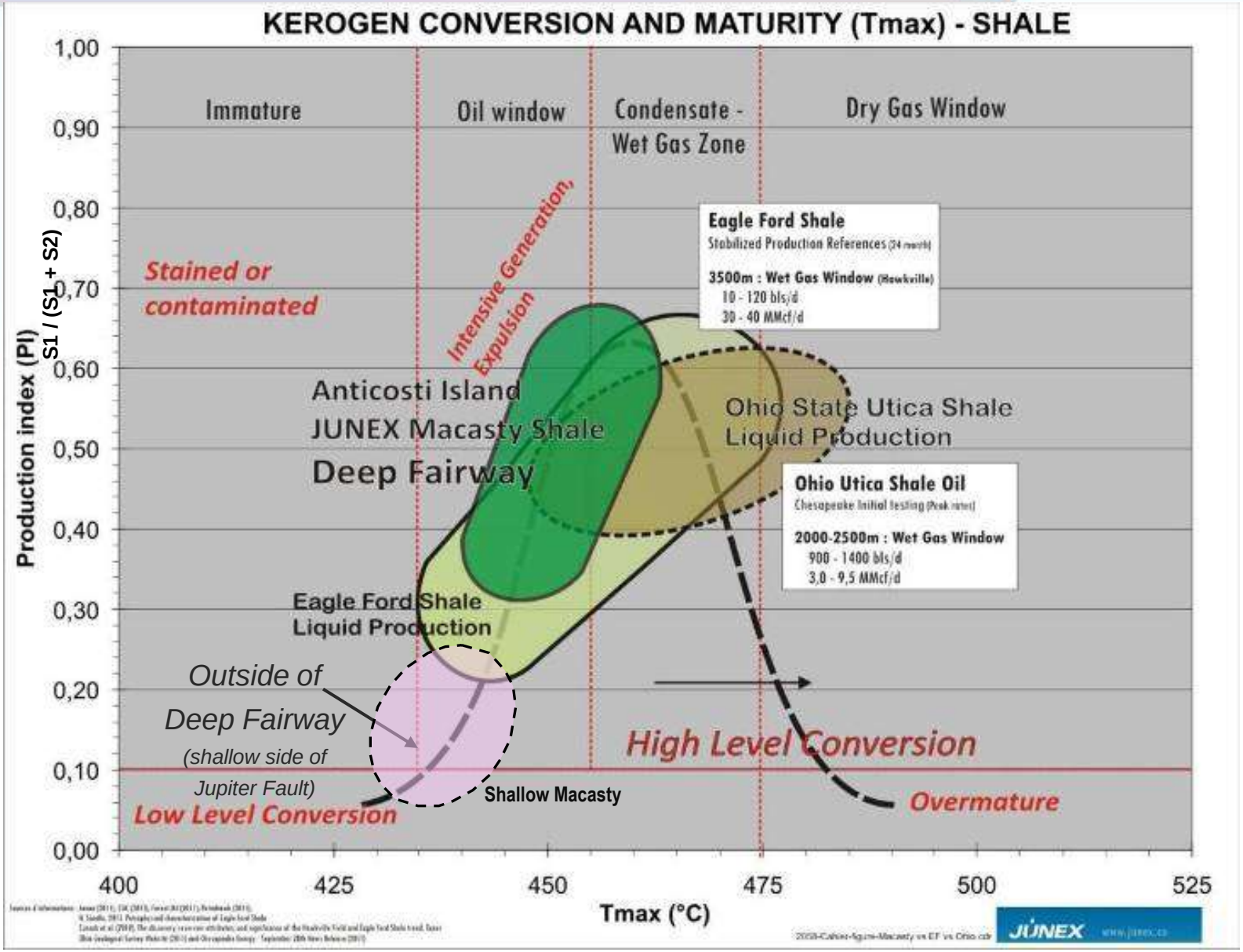
Thermal Maturity



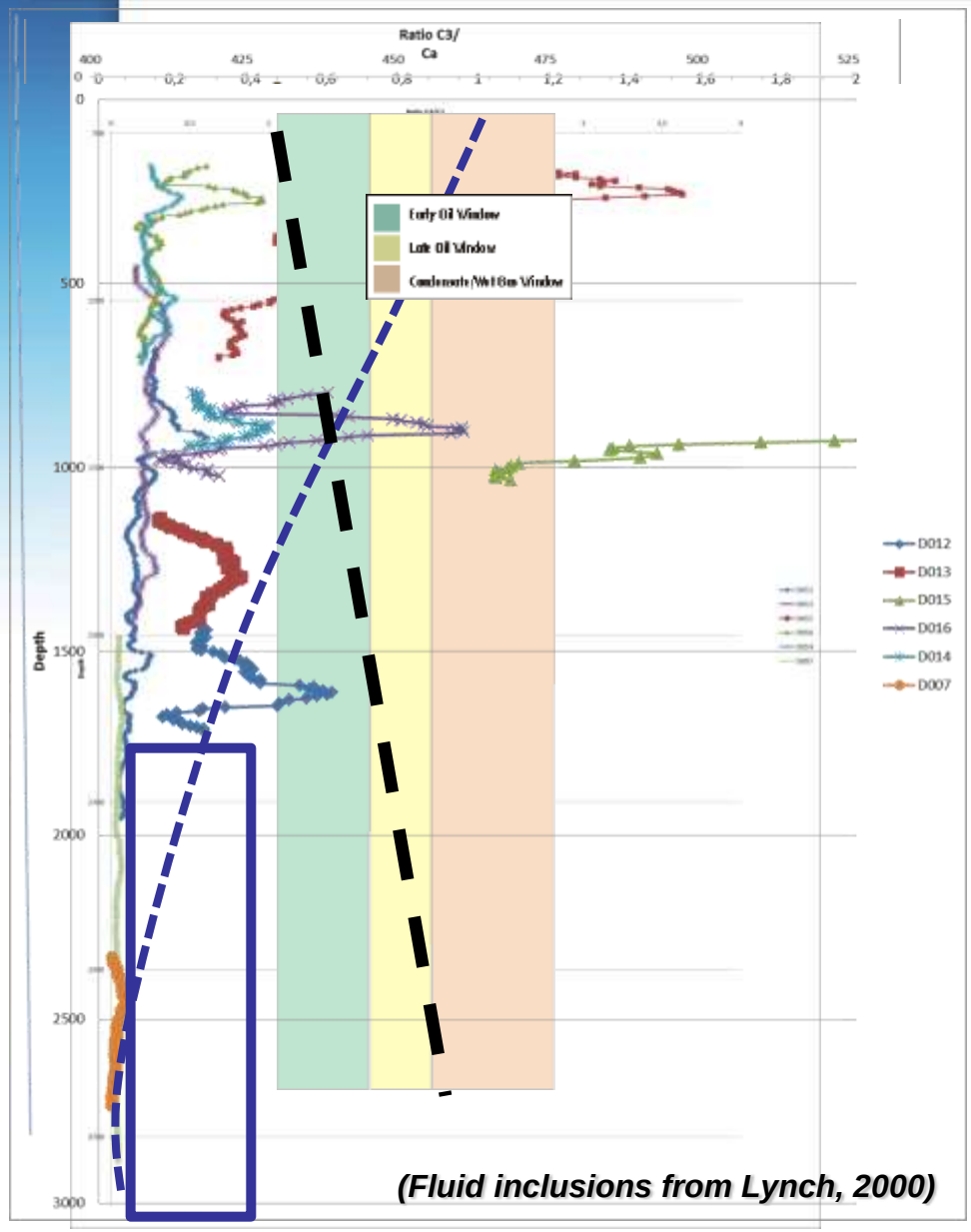
- ***Tmax can define a general trend***



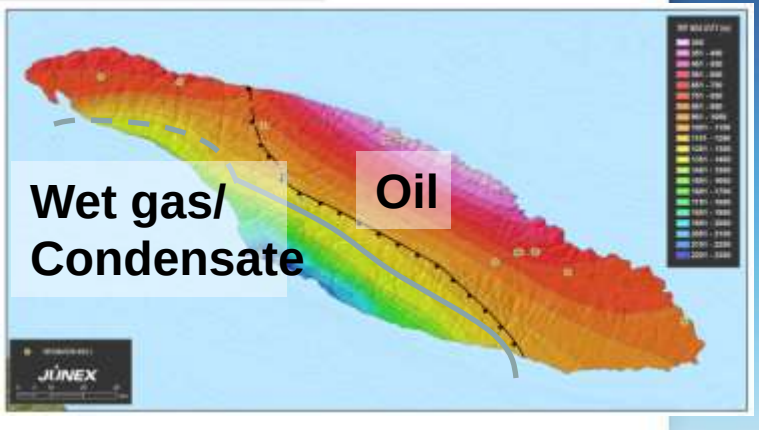
Comparison of Macasty to Utica & Eagle Ford



Fluid Inclusions Compared to Tmax



(Fluid inclusions from Lynch, 2000)



- *Wet gas / Condensate window*
  - *From Tmax*
    - *~1600 to ~2600 mkb*
  - *From Fluid Inclusion*
    - *~ 1800 to ~2800 mkb*

Overpressure from HC Generation

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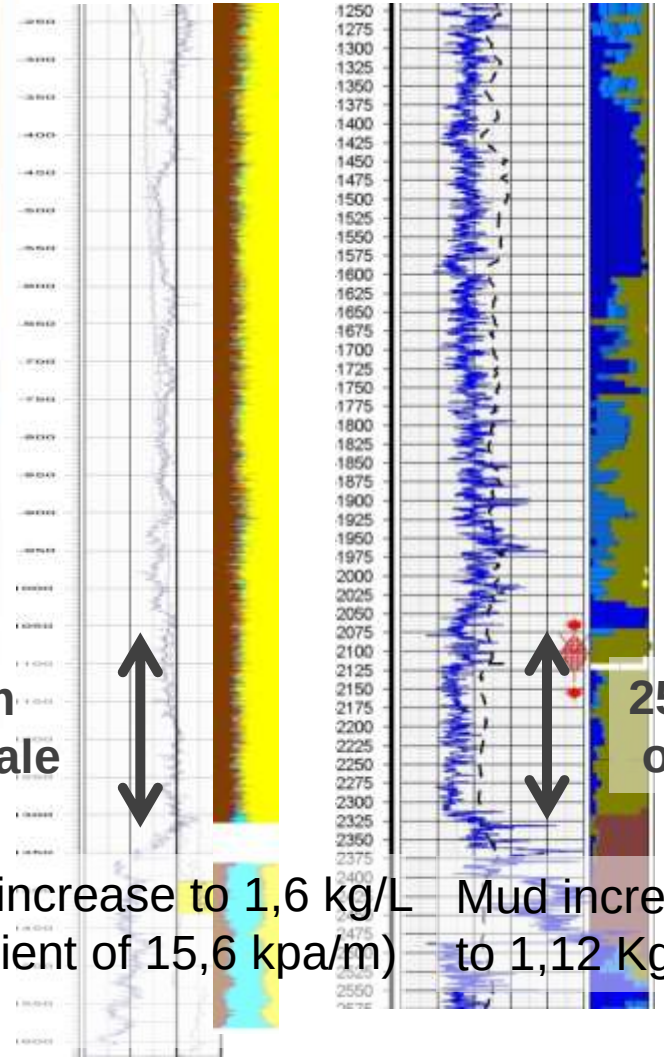
•Pressure is preserved by the fault and thickness of overlying shale

Lowlands **Anticosti- Arco**

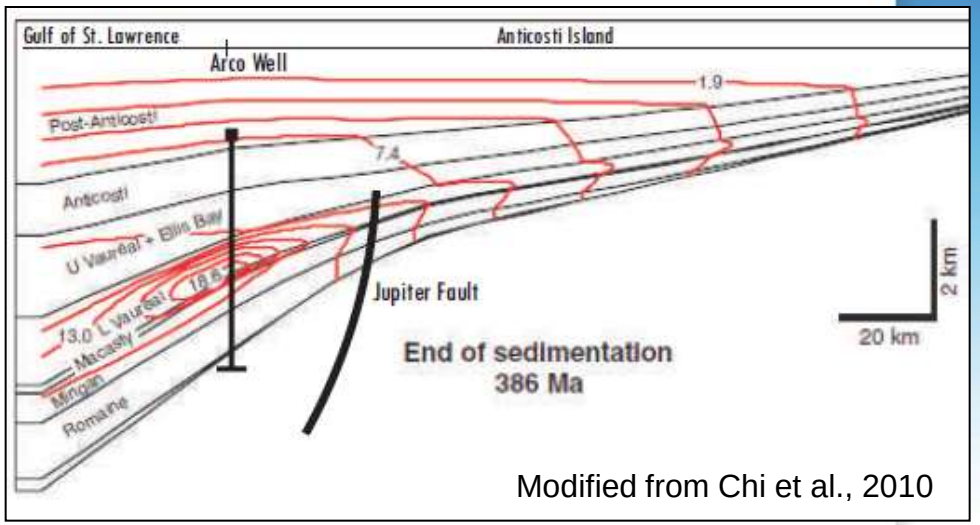


250 m of shale

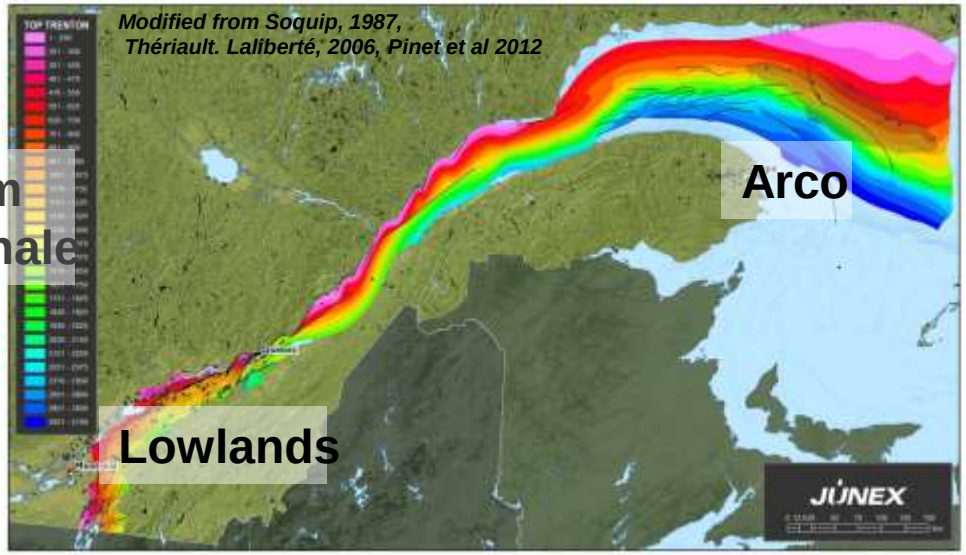
250 m of shale

Mud increase to 1,6 kg/L (gradient of 15,6 kpa/m)

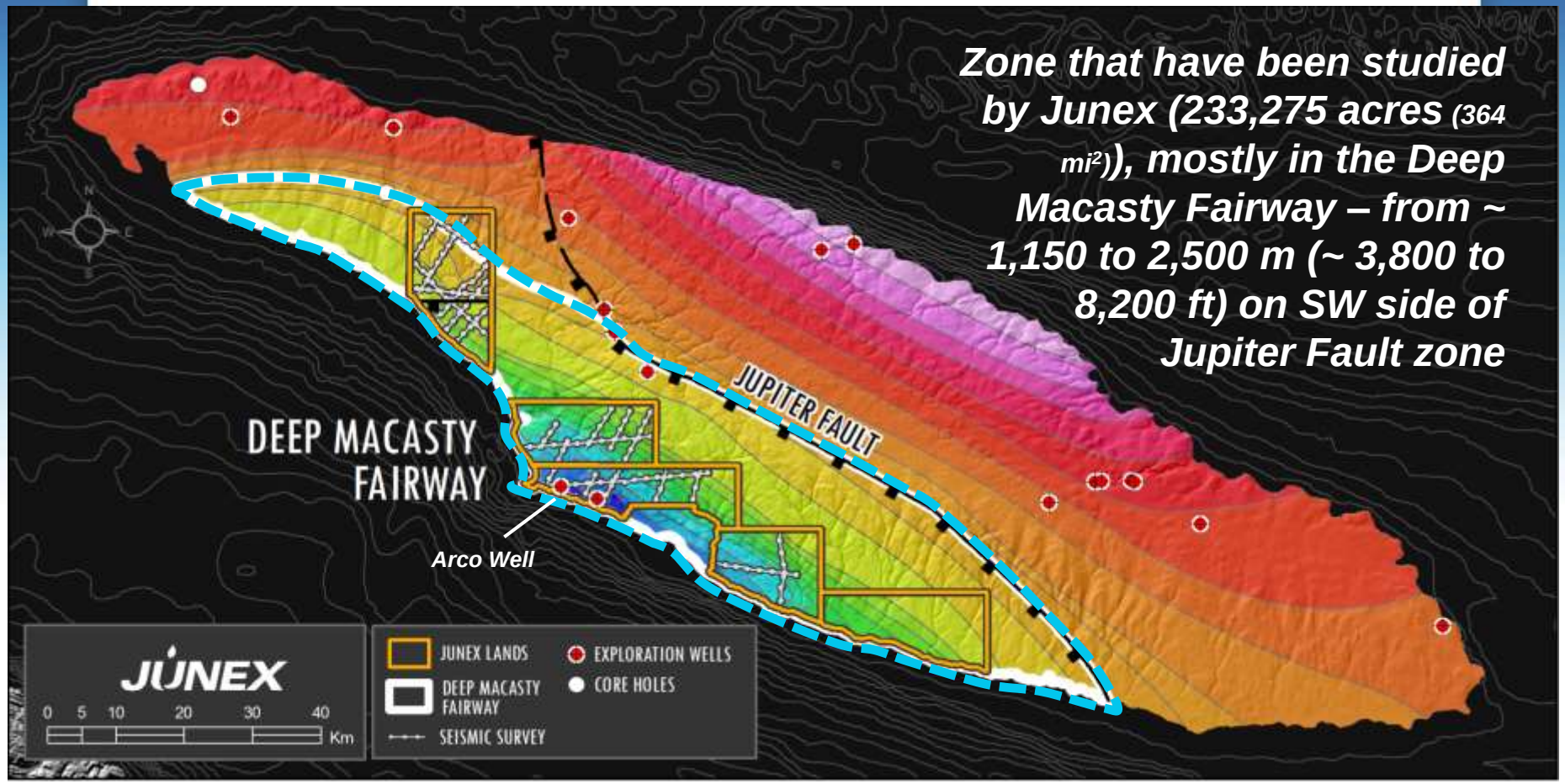
Mud increase to 1,12 Kg/L



Modified from Chi et al., 2010

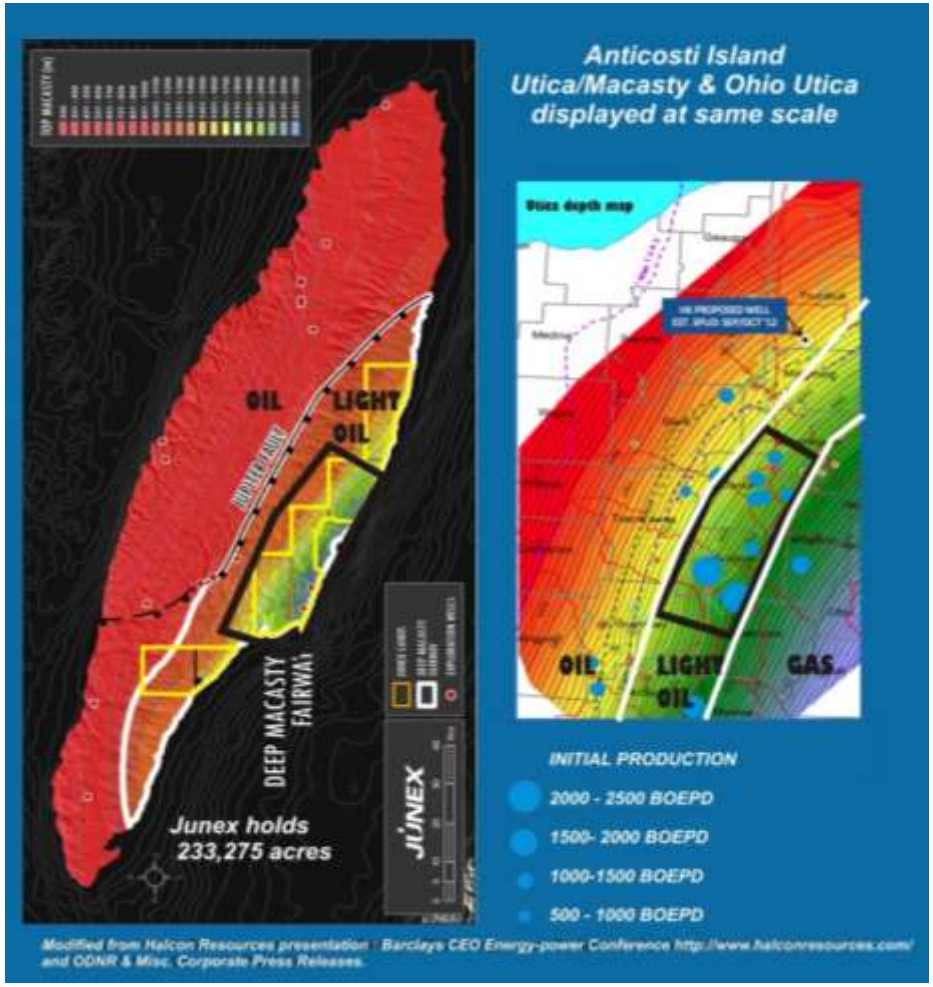


Anticosti Island – Macasty (Utica) Shale Oil Potential



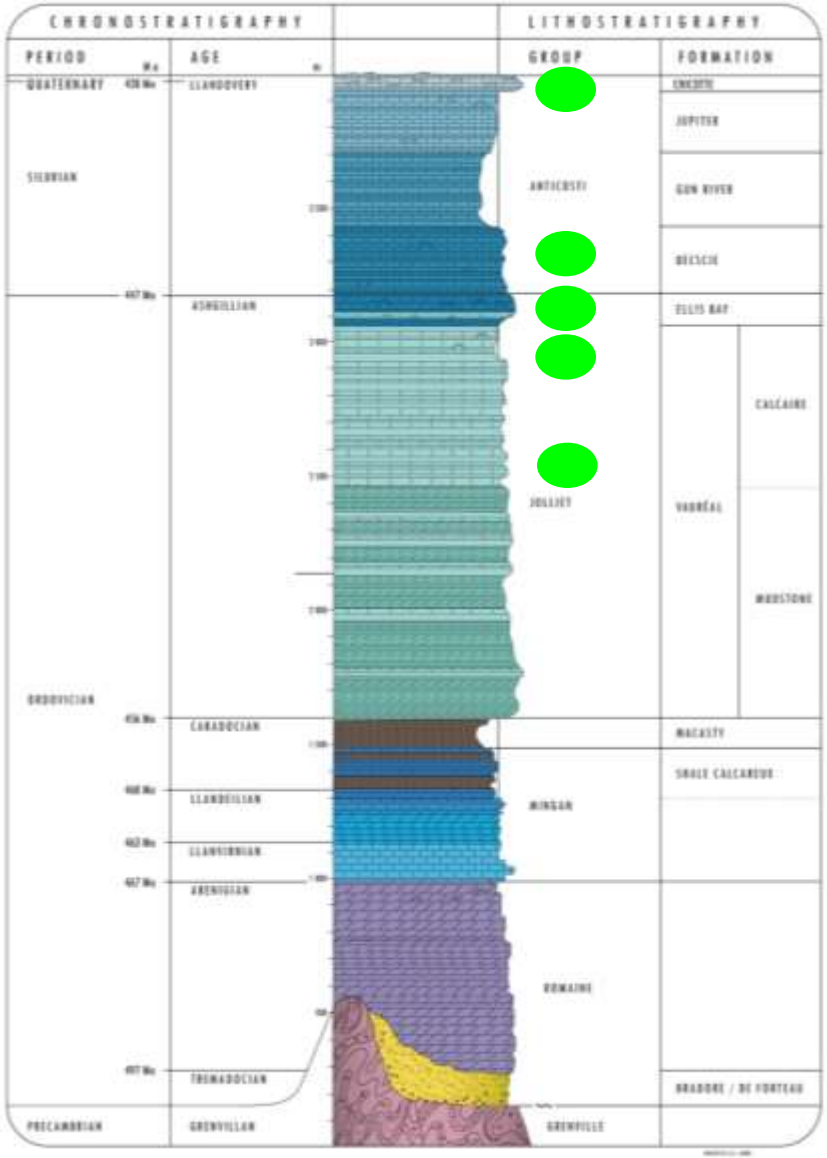
- *From the independent assessment completed by Netherland Sewell and Associats in 2011, 12.2 Billion Barrels Undiscovered Shale Oil Initially-in-Place ("OIIP") (NSAI P50) on this lands (33.5 million bbls/mi² OIIP).*

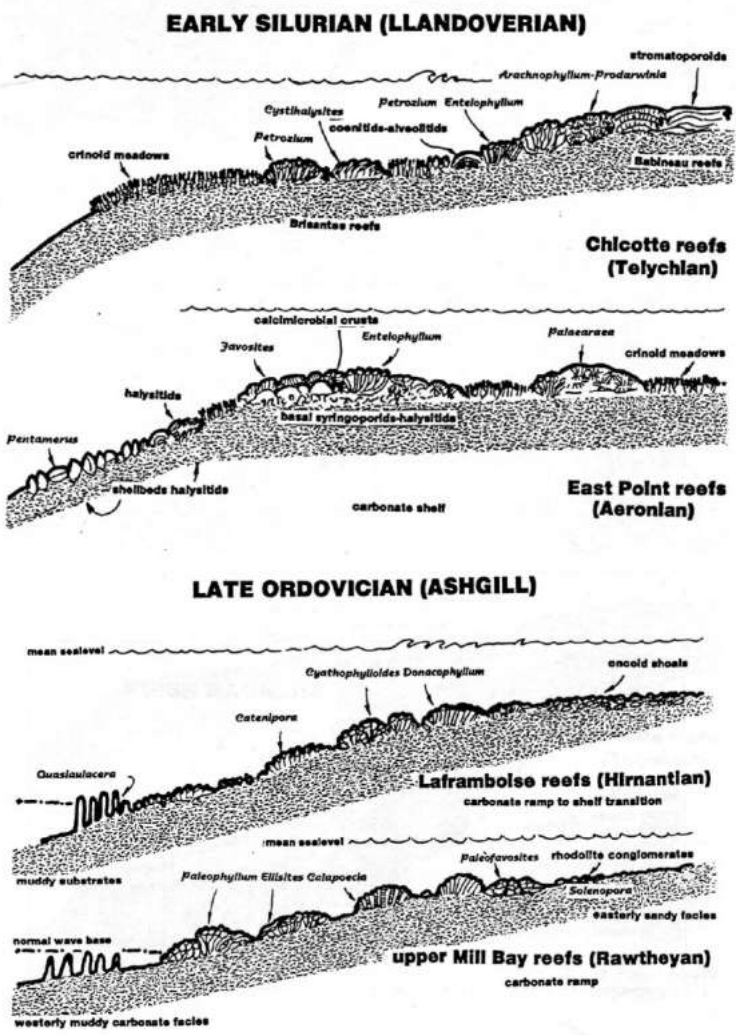
Fairway comparaison : Ohio vs Anticosti



- ***Both maps are at same scale***
- ***Both are Top Utica Structure Maps***
- ***Both have same contour interval (& color shading)***
- ***Black polygons at same scale on both maps***
- ***Deep Fairway: Higher reservoir pressure = greater reservoir energy***
- ***Deep Fairway compares favorably with Ohio Utica light oil belt*** ***(sufficient maturity in oil window as defined by geochemistry)***

Play 3 : Late Ordovician to Silurian Reefs

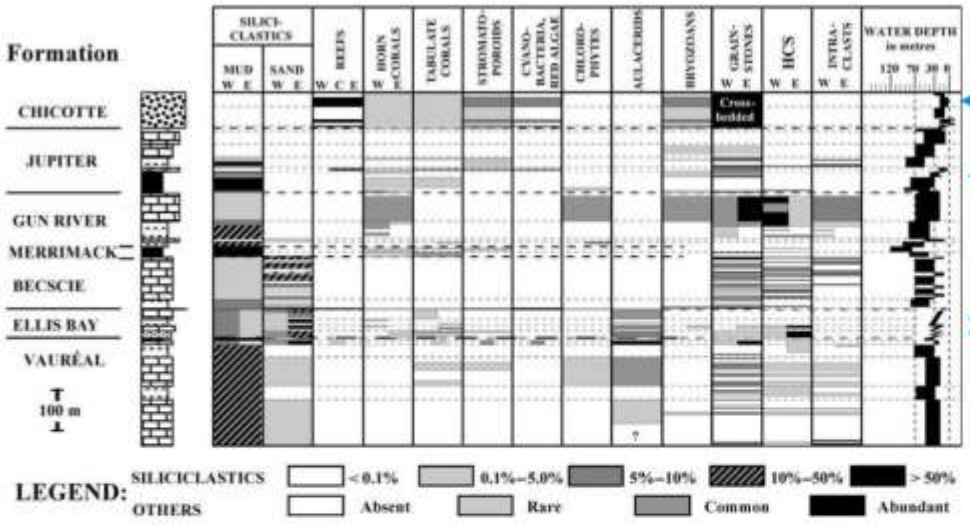


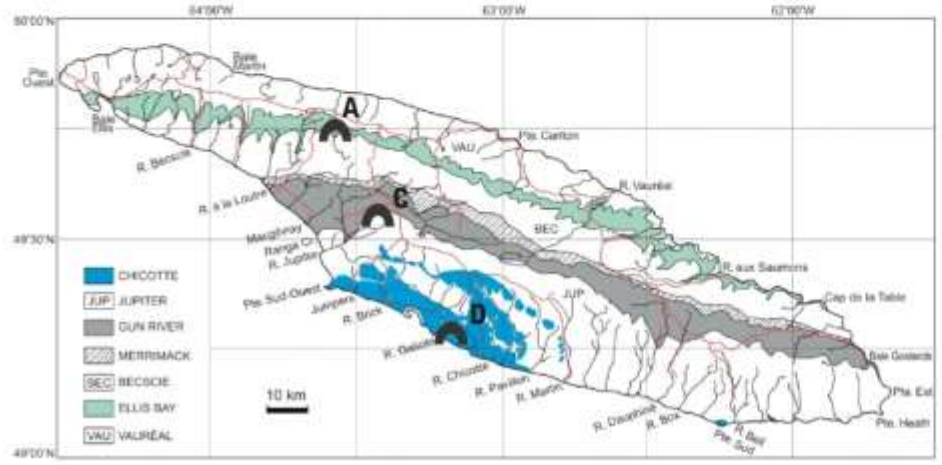


Copper (2001)

Play 3 : Late Ordovician to Silurian Reefs

Anticosti Reef Plays





Chicotte Fm

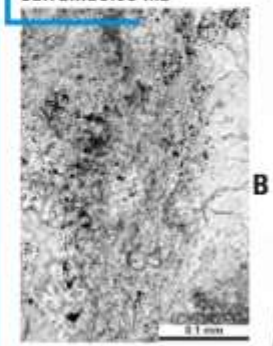
D

Jupiter Fm

Goeland Mb

Ellis Bay Fm

Laframboise Mb



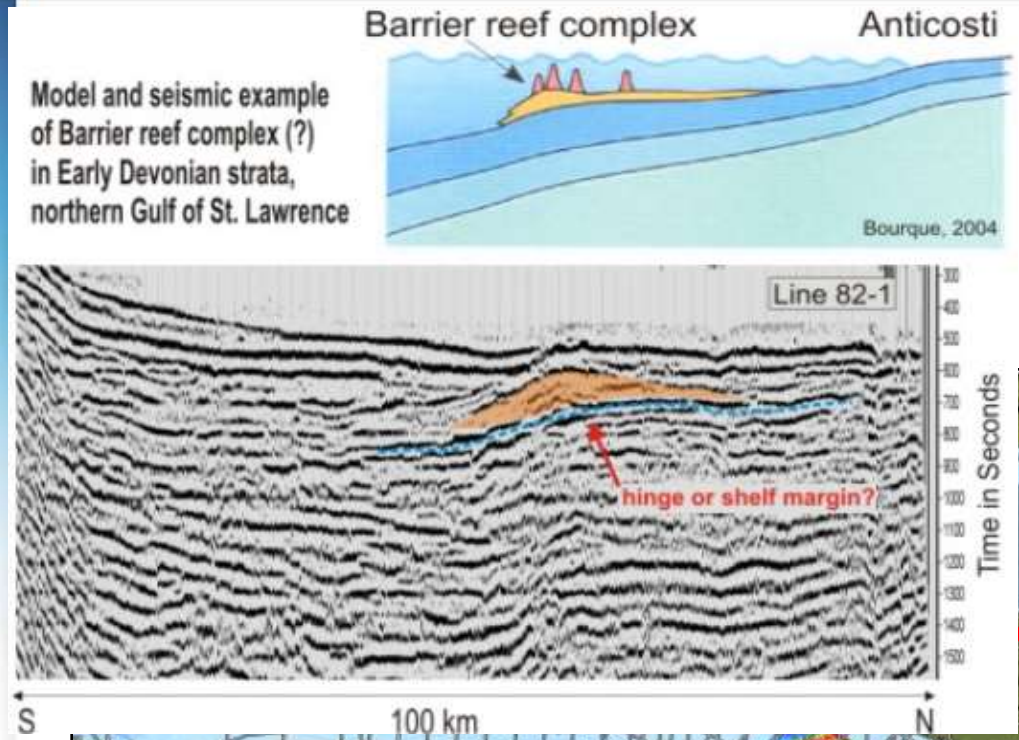
B

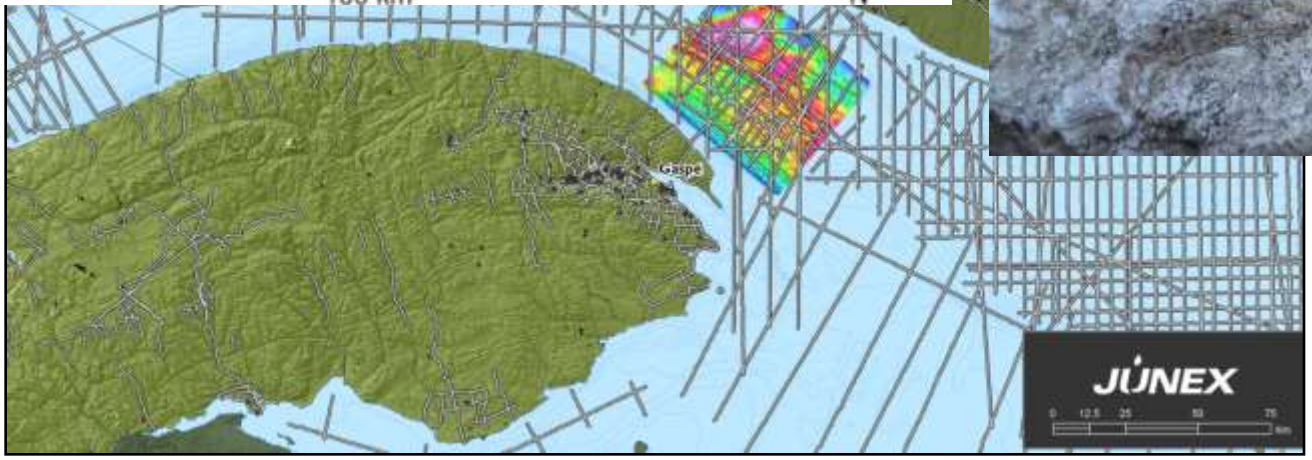
Ellis Bay Fm

Grindstone Mb

A

Play 3b : Offshore Silurian



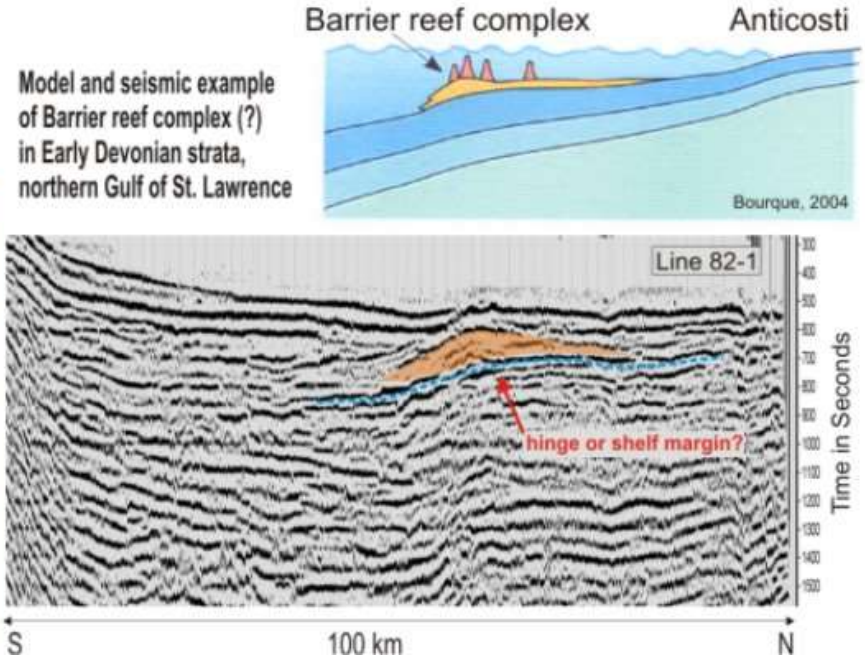


Play 4 : Offshore Silurian

Very porous, lower Silurian (Llandoverian) limestones of the Chicotte Fm crop out in a narrow zone along the southwestern shore of Anticosti Island (Desrochers, 2006). These limestones consist of a dominant encrinite facies associated with microbial mud mounds. Multiple sub-aerial exposures punctuate the unit : neverthless, the origin of the significant porosity in the encrinites (25 to 30 % in two grab samples) remains unknown. In the offshore part of the Anticosti basin, the nature and age of the sedimentaty units overlying the Chicotte Formation are presently unknown. (Lavoie, 2009)

Chicotte reefs - These coral-sponge reefs, exposed today on tidal flats in the Gulf of St Lawrence, Anticosti Island, are part of the very long research program of PARRC. These reefs are up to about 800m in diameter, and outcrop along a distance of ca, 70 km along the coast and inland. This helicopter view shows what you see from above.
Photo from Paul Copper Website

Model and seismic example of Barrier reef complex (?) in Early Devonian strata, northern Gulf of St. Lawrence



Conclusions : Conventional Exploration with Unconventional Potential

The Anticosti Basin present a high hydrocarbon potential with promising plays

Macasty Shales is a major source-rock with over 75 billion barrels generated

Play 1 : Dolomitized carbonates (million barrels potential OIIP)

Reservoir potential proven in wells drilled in 90's

Play 2 : Liquid-rich shales (billion barrels potential OIIP)

Over 46 Millions of barrel of undiscovered oil in place has been defined (P50) on Anticosti island

Based on geological feature, the southwest part of the island show better potential :

- In the late oil / condensate window with possible hgher pressure ;
- Thicker shale section with a higher OIIP (33.5 MMbbl/section based on NSAI P50)

Play 3 : Reefs/Bioclastics Limestones (potential to be studied)

New exploration opportunity to be tested

Offshore exploration still under moratorium

Conclusions : Conventional Exploration with Unconventional Potential

- Question to be answered by well drilled in the deep fairway
  - Is the petroleum system correctly sealed and overpressure?
  - What type of hydrocarbon remain in the system?
- Maintain the Technical Toolbox
  - Differentiate between data & interpretations
  - Re-visit and question these in light of evolving technologies
  - In an ideal world, all different types of data (geology, geophysics, geochemistry, engineering) pertaining to the same rocks should tell the same story…if not, then dig deeper – (i.e. sort-out discrepancies)
  - Well-tuned geochemistry tied to well data & other data can aid in identifying prospective areas
- Social and political impact of the last ten years of exploration in the province
  - Paradigm Shift in the way Quebecers see the energy potential of their land

Acknowledgments

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Brick Canyon, Anticosti Island, 2012

Thanks and congratulation to Junex 's employees

Many thanks to our dedicated field geologist

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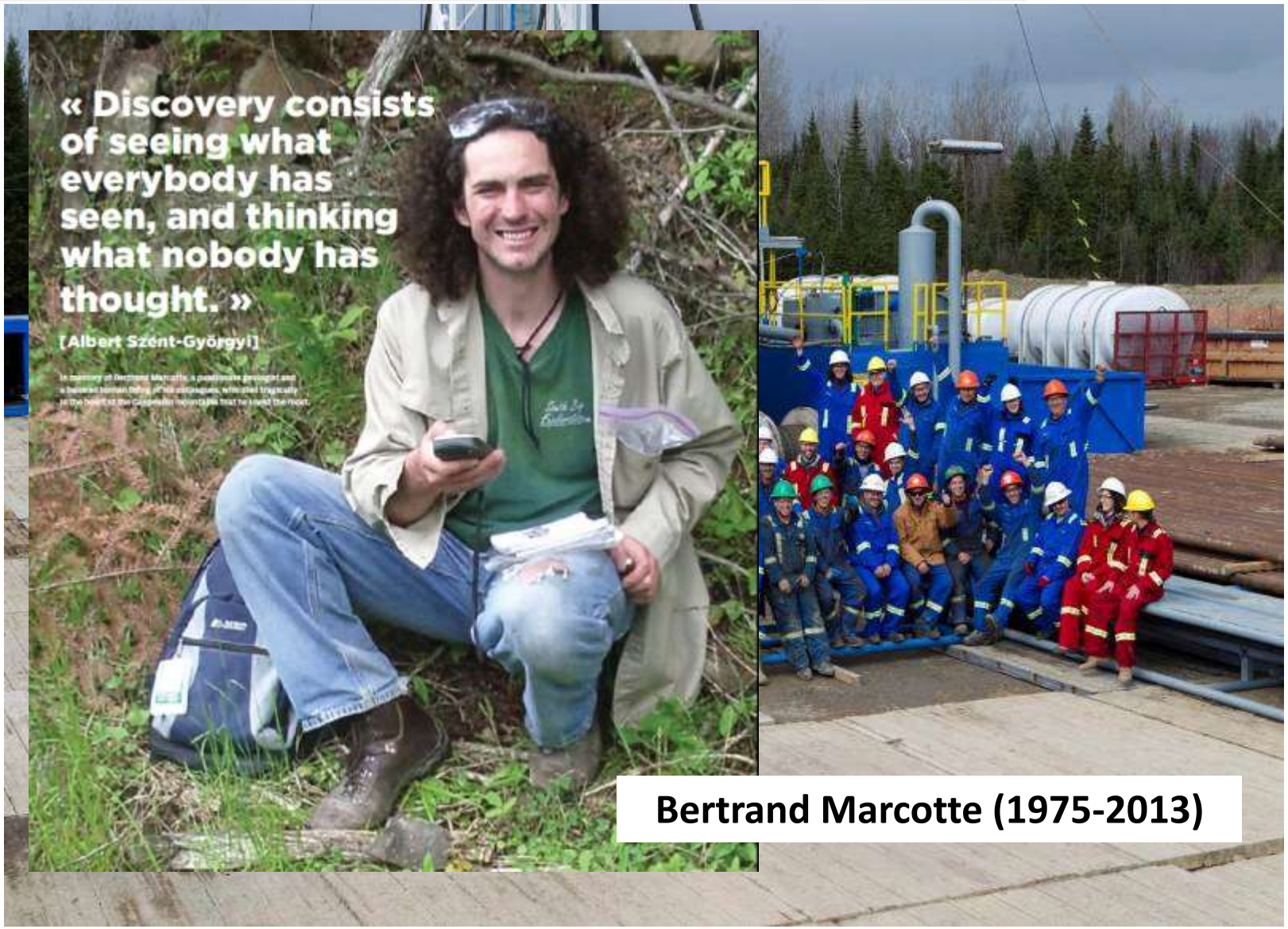

Bertrand Marcotte (1975-2013)