PS Resource Assessment of Oil and Gas Plays in Paleozoic Basins of Eastern Canada*

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Abstract

There are three major Paleozoic basins in eastern Canada:

- Cambrian-Ordovician St. Lawrence shallow marine platform and coeval deep water facies
- Silurian-Devonian shallow to deep marine Gaspé Belt
- Devonian-Permian terrestrial to shallow marine Maritimes Basin

The sedimentary successions are bounded by tectonically-generated unconformities - the Taconian unconformity separating Cambrian-Ordovician from Silurian-Devonian strata and the Acadian unconformity at the base of the late Devonian-Permian strata. Each basin contains unique source rock and reservoir units and specific trap types. All of the basins contain producing or discovered hydrocarbon fields but there has been no independent evaluation of their oil and gas resource potential.

Over the past five years the Geological Survey of Canada and its partners have acquired new hydrocarbon systems data, in preparation for a first regional hydrocarbon play assessment of Paleozoic strata in eastern Canada. A total of 16 conventional and 2 unconventional plays have been identified.

Seven conventional plays are recognized in Cambrian-Ordovician strata:

- Cambrian rift sandstones
- Lower Ordovician hydrothermal dolomite (HTD)
- carbonate thrust slices at the Appalachian structural front

- Middle-Upper Ordovician HTD
- passive margin slope clastics
- foreland sandstones and carbonates
- Quaternary sands

Six conventional plays are recognized in the Silurian-Devonian strata:
- Lower Silurian sandstones
- Lower Silurian HTD
- Upper Silurian HTD reefs
- lowermost Devonian HTD reefs
- Lower Devonian fractured carbonates
- Lower Devonian nearshore sandstones

Three conventional plays are recognized in Carboniferous strata:
- Lower Carboniferous sandstones
- Lower Carboniferous (Visean) carbonate reefs
- Upper Carboniferous sandstones and an unconventional coal bed methane play

Unconventional shale gas plays may occur in Cambro-Ordovician and/or Carboniferous strata.

Of the 16 conventional plays, 6 plays have enough production or exploration data to prepare quantitative estimates of resource potential:
- Lower Ordovician and Middle-Upper Ordovician HTD
- carbonate thrust slice
- Lower Devonian sandstone
- Lower and Upper Carboniferous sandstone

For each of the quantitative play assessments, we present play maps, parametric pool-size data, exploration risk factors, prospect numbers and estimates of in-place oil and gas resource potential.

References

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Executive Summary

The Paleozoic successions in eastern Canada belong to three domains, 1) the St. Lawrence Platform of Cambrian to Devonian rocks, 2) the Taconian to Acadian Appalachians of Cambrian to Devonian rocks, 3) Carboniferous to Permian rocks mainly offshore in the Gulf of St. Lawrence. A total of 15 conventional petroleum plays and 3 unconventional gas plays have been recognized.

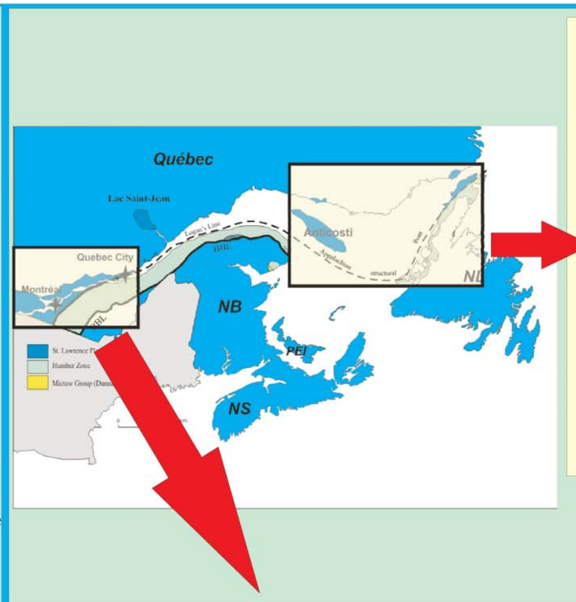
Of the 15 conventional Paleozoic plays, 6 have sufficient exploration and/or production data or good analogues to formulate a quantitative assessment. Of these 6 plays, 4 are assessed for oil and gas potential, 1 for oil potential, and 1 for gas potential. A large number of the conventional and all of the unconventional plays cannot be quantitatively assessed, the total resource presented herein is a minimum potential and evidence for hydrocarbon charge is present in most of the qualitatively assessed plays.

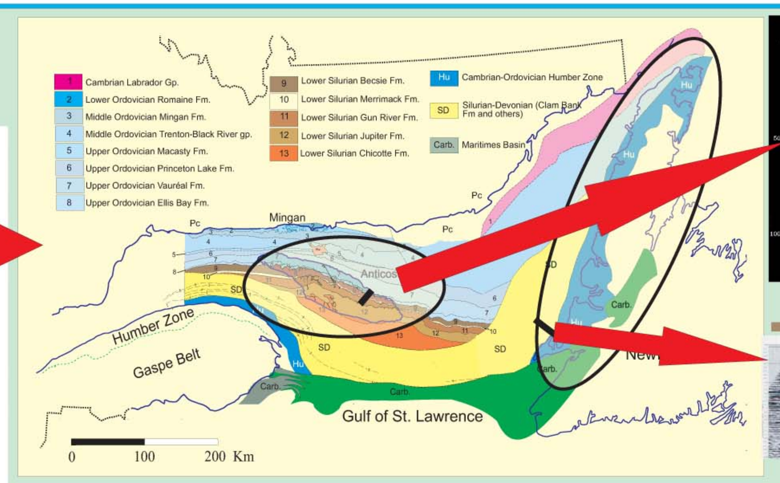
The assessed plays of the eastern Canada Paleozoic basins have a cumulative median (P50%) in-place potential of $1170*10^9$ m^3 (41 Tcf) of natural gas and $403*10^6$ m^3 (2.5 BBO) of oil. The Carboniferous Maritimes Basin accounts for about 95% and 60% of the total gas and oil resource potential, respectively.

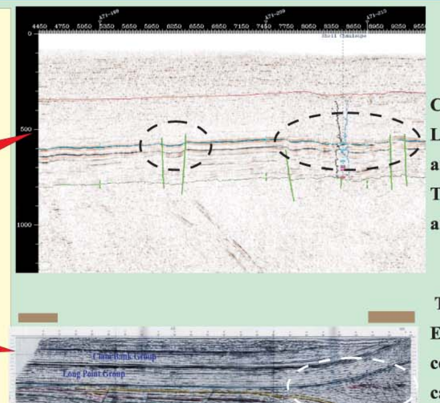
The assessment results provide important new insights into the energy resource endowment of Paleozoic basins in eastern Canada. In particular, the assessment results indicate Carboniferous basins have a large gas resource potential, much higher than previously estimated. The resource potential numbers represent a minimum potential for the region because many of the conventional and all of the unconventional plays were only qualitatively assessed.

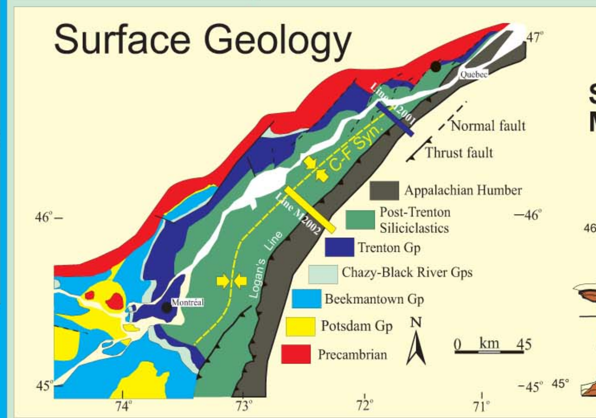
CONVENTIONAL Play	In-place Gas (10^9 m^3) P90	P50	P10	In-place Oil (10^6 m^3) P90	P50	P10
Lower Ordovician HTD - SLP	1.7	7	17.5	13,6	52	102,8
Lower Ordovician Humber Slices	1,4	5.6	19			
Middle Ordovician HTD - SLP	6,9	28.8	78,5	12,5	63,8	137,6
Lower Devonian Clastics - GB				N/A	16.2	103,8
Lower Carboniferous Clastics	171,6	452.1	672,4	47,8	124	188,4
Upper Carboniferous Clastics	342,8	656.7	1042	50,5	111	195,5
TOTAL	765,9 27 Tcf	1170 41.3 Tcf	1617,5 57,1 Tcf	274,9 1.7 Bbo	402.7 2.6 Bbo	543.7 3.4 Bbo

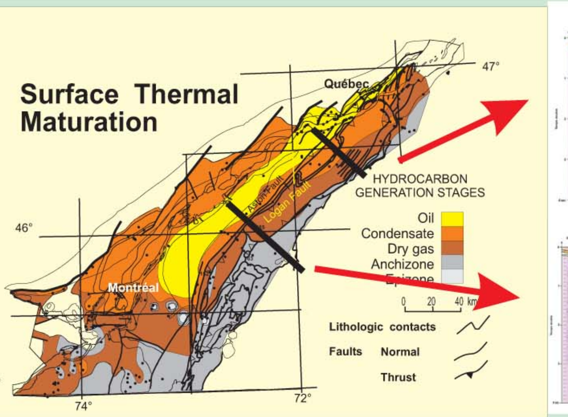
Details of assessment in Lavoie et al., 2009, GSC Open File 6174

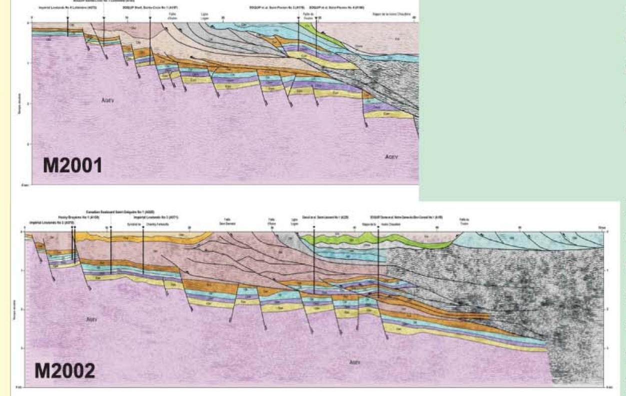




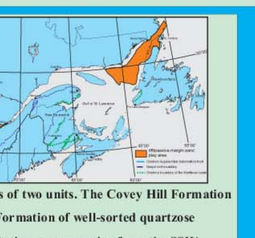








Cambrian rift-drift clastics (R1)



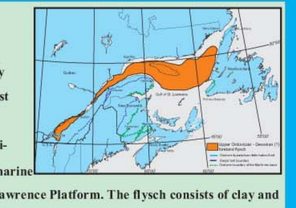
The Upper Cambrian Potsdam has yielded positive DST with gas flows up to 279 Mcf/d. In Western Newfoundland, the Cambrian Hawke Bay was a secondary target in exploration drilling.

Potential Reservoir: In southern Québec, the Upper Cambrian Potsdam consists of two units. The Covey Hill Formation of impure sandstone and overlying Cairnside Formation of well-sorted quartzose sandstone. In southern Quebec, the basal unit is time transgressive from the SSW towards the NNE. In western Newfoundland, the Lower Cambrian early drift Hawke Bay sandstone is well-sorted with abundant wave structures and desiccation polygons. In the Port au Port #1 well, the Hawke Bay is 64 m thick and has porosity up to 12.2%.

Geographic distribution: The Cambrian sandstone play is recognized in southern Quebec and Western Newfoundland, however, its is absent on Anticosti Island.

Traps and seals: Traps and seals could include, amongst others, lateral pinchout and channel-fill with various shale and mudstone seals. However, extensional (southern Quebec) and compressional (Western Newfoundland) structural features may significantly modify the trap geometry.

Middle Ordovician - Devonian foreland (R4)



Ordovician flysch sands are commonly gas and oil bearing in Quebec and West Newfoundland.

Potential Reservoir: The most significant foreland sand consists of deep marine Taconian flysch that overlies the St. Lawrence Platform. The flysch consists of clay and lithic clastics with significant thickness of coarser grained facies restricted to western Newfoundland.

Geographic distribution: The western limit of the play area corresponds to the Utica shale and correlatives. In the Gulf of St. Lawrence, the southern play limit corresponds to a 3 km thick Carboniferous cover. The Ordovician foreland sand play is gas-prone in southern Quebec, but oil-prone in the northeastern segment of Gulf of St. Lawrence.

Traps and seals: The most common trap is structural and consists of fold closures visible on offshore seismic lines. Faults may have also acted as traps preventing hydrocarbon migration out of the reservoirs. Finally, some stratigraphic pinch-out closures are expected.

Cambro-Ordovician deep-water clastics (R5)

In the early 1970's, fractured Lower Cambrian rift-related clastics were tested. Coeval rocks in Newfoundland carry live oil.

Potential Reservoir: The Lower Paleozoic continental slope offers thick accumulations of coarse-grained sandstone and conglomerate. Three intervals have potential, 1) Lower Cambrian rift sandstone, 2) Upper Cambrian passive margin impure sandstones and 3) uppermost Cambrian-lower Ordovician passive margin quartz arenite. Based on petrophysical, petrographic and field data, fractures have contributed to the porosity and permeability and have acted as migration corridors. Leaching of alumino-silicates has also been shown to enhance the secondary porosity.

Geographic distribution: This play area extends across the entire Humber zone in eastern Canada and is gas-prone

Traps and seals: The coarse-grained submarine fans are involved in fold and thrust structural traps, deep marine shales (locally potential source rocks) have likely provided impermeable caps.

Quaternary plays (R7)

In 1955, a significant gas accumulation was discovered in the Quaternary of southern Québec. The reservoir is 3 km long by 1 km wide and is 10 m thick and has a closure of 6 km^2. The sediment is highly porous (36%) and permeable (up to a few darcys). The shallow pay zone is 6 metres thick with water saturation ranging from 10-20%. In 2003 – 2004, a marine seismic survey (low penetration sparker source) in the St. Lawrence Estuary has documented numerous seismic anomalies in the Quaternary; these were later demonstrated to be related to natural gas charge.

Potential Reservoir: The Quaternary reservoir consists of clastics that unconformably overly the Paleozoic bedrock. Evidence for gas in Quaternary sediments in the St. Lawrence Estuary relies on abundant seismic anomalies. The presence of gas in the sediments is also confirmed by abundant (>1900) pockmarks found on the sea floor.

Geographic distribution: The onshore play limit has been drawn were Quaternary deposits overly the Upper Ordovician Utica shale. For the offshore, the distribution of the play is constrained by our recent seismic and high resolution bathymetric data set.

Traps and seals: The fluvial-deltaic sands offer number of tratigraphic traps, including lateral facies changes and pinch outs on basement highs.

GEOLOGY

Introduction

Cambrian-Ordovician sediments are preserved in the St. Lawrence Platform and the Appalachian Humber Zone. The St. Lawrence Platform consists of shallow to deep marine carbonates and clastics whereas slope and toe-of-slope sediments are preserved in the Humber Zone. These sediments were variously deformed by the Late Ordovician Taconian Orogeny. These two belts extend from southern Quebec to western Newfoundland and most of the onshore and offshore domains are hydrocarbon-prospective.

Stratigraphic framework

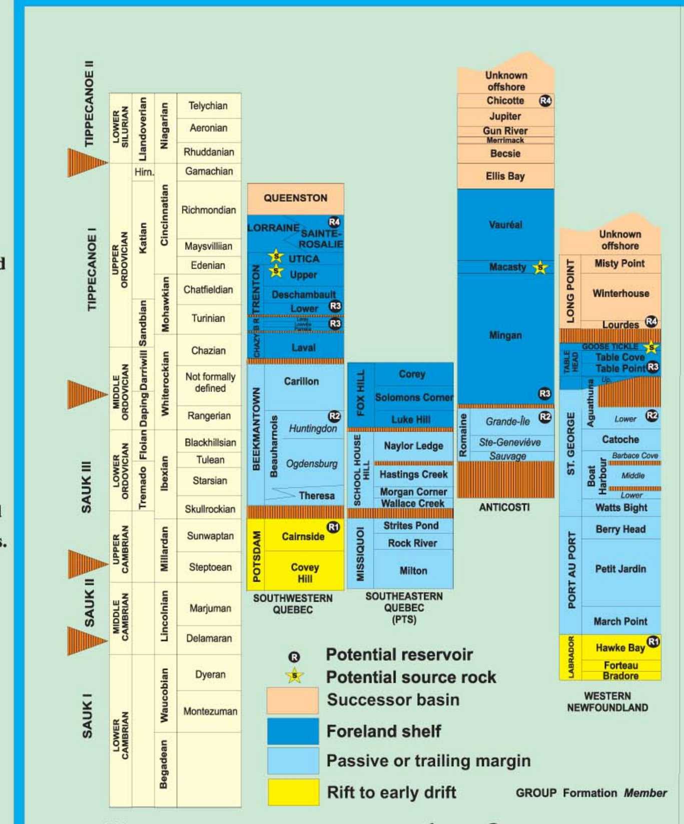
The oldest sediments are found in the Humber Zone and were deposited at the onset of break-up of Rodinia in latest Ediacaran time. In the St. Lawrence Platform, the succession unconformably overlies the Precambrian basement, it consists of an initial clastic rift to early drift succession, overlain by a Middle Cambrian to end-Lower Ordovician thick carbonate-dominated passive margin succession (the "Great American Bank"). The development of the Taconian foreland basin resulted in rapid carbonate then clastic sediment accumulation in fast subsiding tectonic basins. After the peak of the Taconian Orogeny (early Late Ordovician), sedimentation resumed in a Silurian to Early Devonian successor basin based on preserved rock record and interpreted marine seismic.

The nature of sediments deposited on the shallow marine continental margin and on the adjacent slope down to the base of the slope was controlled by the paleogeographic setting, tectonic events and sea level fluctuations. In Early Cambrian, clastics dominated the sediments shortly after rifting. In Middle Cambrian to late Early Ordovician, passive thermal subsidence under a tropical paleolatitudinal setting was favorable for diverse carbonate facies. In Middle to Late Ordovician, rapid tectonic collapse on the continental margin coupled with the progressive cooling of the hydrosphere led to the rapid demise of carbonate and the predominance of fine-grained clastic, especially organic-matter rick black shales. After the orogenic pulse and the wanning of Gondwana ice sheets, conditions became again favorable for the accumulation of carbonates in the Silurian.

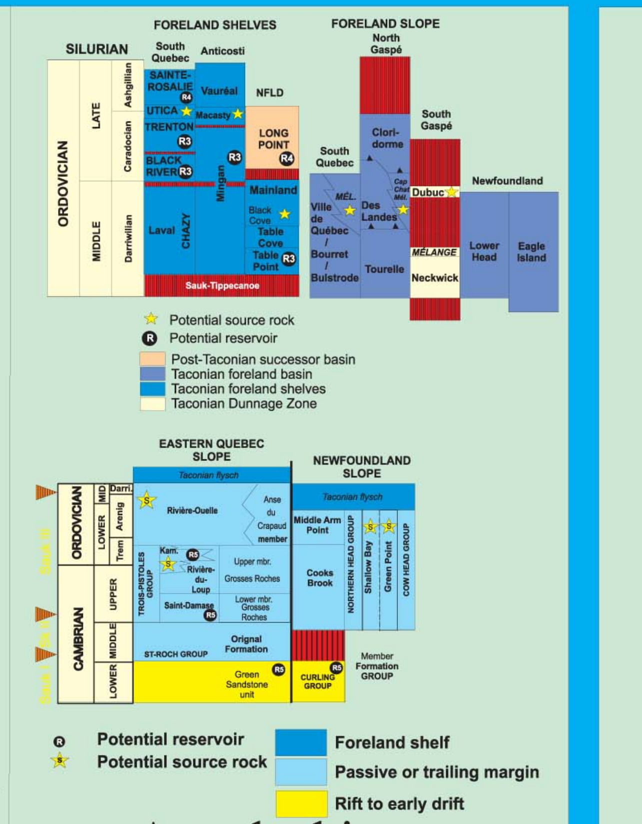
Structural framework

Most of the deformation in the Cambrian-Ordovician successions is generally ascribed to the Late Ordovician Taconian orogeny. However, polyphase history (Taconian overprinted by Acadian) has been documented at few places (northern Gaspé and western Newfoundland). In the St. Lawrence Platform, the main deformation events consists of extensional faulting (active during foreland basin; see seismic profiles to the right). In the Appalachian Humber Zone, significant thrust faulting is documented from southern Quebec to western Newfoundland (see seismic to the right), thin skinned tectonics is recorded in the Humber Zone succession of Quebec whereas in western Newfoundland, the thin-skin tectonics is overprinted by a Devonian thick-skin event that led to the formation of a triangle zone (see adjacent seismic).

Lower Paleozoic platform and slope facies

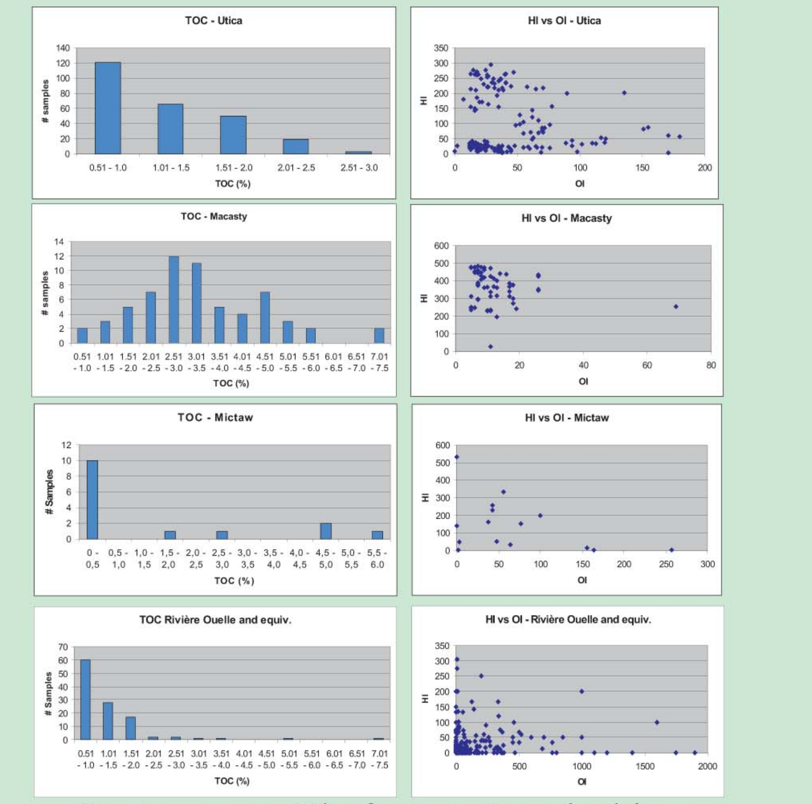


St. Lawrence Platform



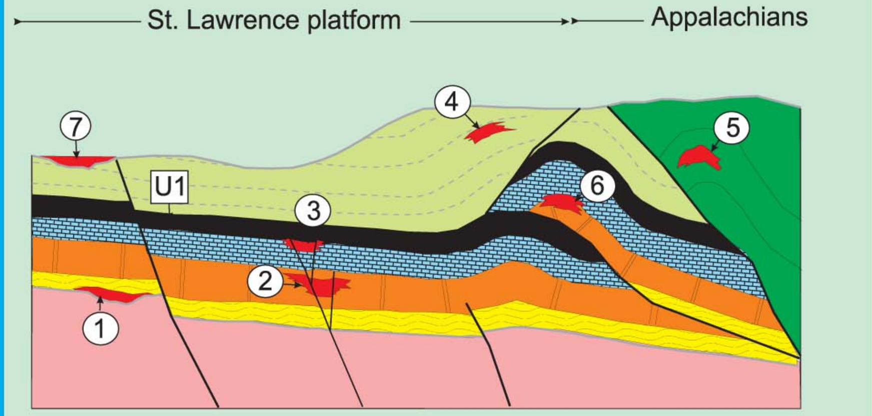
Appalachians

SOURCE ROCKS



St. Lawrence Platform + Appalachians

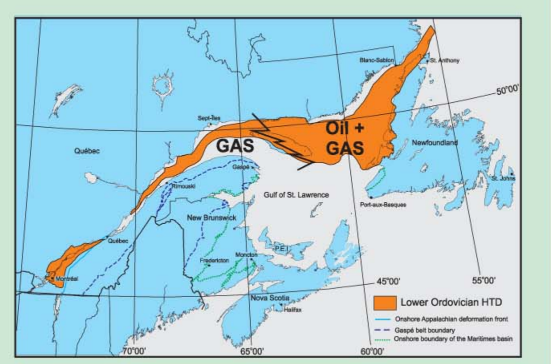
Lower Paleozoic plays Conventional and Unconventional



The conventional system include seven plays in Cambrian-Ordovician strata (above figure), 1) Cambrian rift sandstones, 2) Lower Ordovician hydrothermal dolomite (HTD), 3) Middle-Upper Ordovician HTD, 4) Upper Ordovician to Devonian ? foreland sandstones and carbonates, 5) Cambrian-Ordovician passive margin slope clastics, 6) Ordovician carbonate thrust slices at the Appalachian structural front and 7) Quaternary sands.

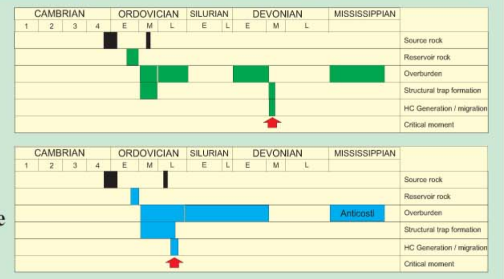
In the Canadian Appalachians, potential hydrocarbon source rocks occur in organic-rich shales deposited in Lower Ordovician passive margin, Middle Ordovician deep ocean basin and Upper Ordovician foreland basin. Geochemical analyses suggest that oil from Lower Ordovician reservoirs in Newfoundland is from the Lower Ordovician passive margin shales. Hydrocarbons in Ordovician reservoirs in southern Quebec were sourced from Upper Ordovician foreland basin black shales. The best quality reservoirs in the Cambrian-Ordovician are hydrothermal dolomites (HTD) in Lower Ordovician passive margin and in the Middle/Upper Ordovician foreland basin successions. Secondary potential reservoirs consist of nearshore and fluvial sands, and thick successions of turbidites and slope channel-fill sands . The carbonate and clastic reservoirs are involved in stratigraphic and tectono-diagenetic traps in the St. Lawrence Platform and in foothill-style traps at the Appalachian structural front. Of the 7 conventional and one unconventional plays identified (above figure), only three have enough production or exploration data to prepare quantitative estimates of resource potential: the Lower Ordovician and Middle-Upper Ordovician HTD plays and the carbonate thrust slice play. The other plays are evaluated on a qualitative basis.

Lower Ordovician HTD (R2)



The Lower Ordovician carbonates in southern Quebec, Anticosti and western Newfoundland have been the primary targets for hydrocarbon exploration drilling. The recent regional-scale recognition high temperature dolomitization provides a new exploration model for Lower Ordovician carbonate units.

The Garden Hill oil field was discovered in 1995 in western Newfoundland. The oil and gas are hosted in hydrothermally-altered dolostones of the Lower Ordovician St. George Group. The reservoir, at 3460 m deep, is 18.5 m thick and averages 10% porosity with 21 mD permeability.



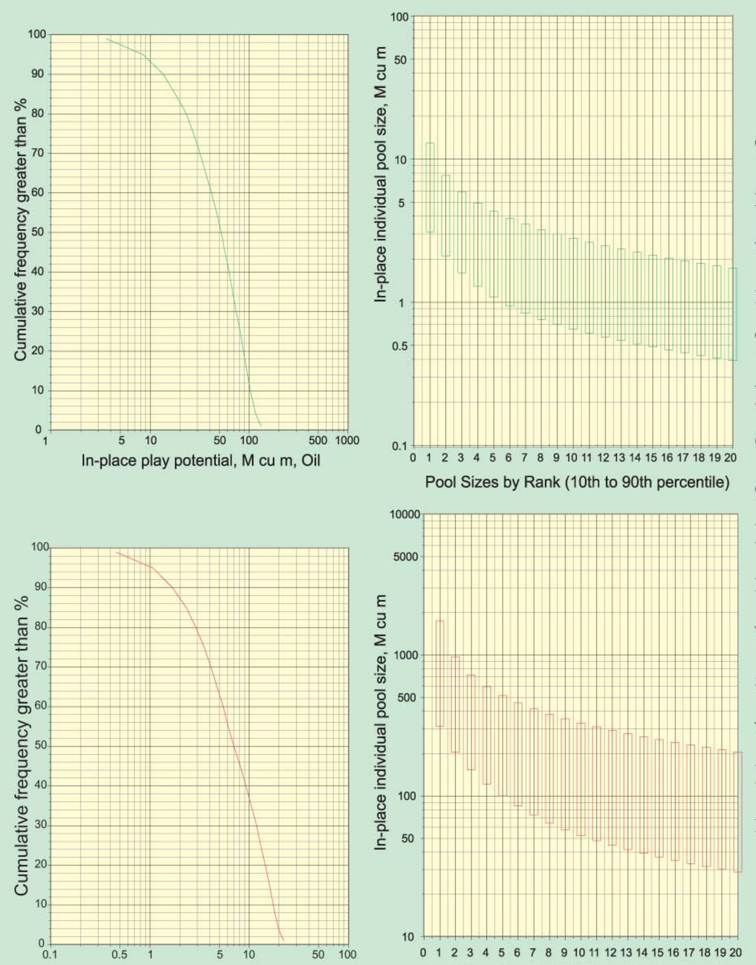
Potential Reservoir: Lower Ordovician carbonates were deposited on a passive margin Early dolomitization created a porosity / permeability system that was used by various fluids to alter the porosity of the carbonates. A late pulse of hydrothermal fluid is recorded during the Taconian foreland basin stage.. The geochemical evidences indicate that the late dolomitizing fluids were of high temperature, very saline fluids.

Geographic distribution The play has been defined using using the surface exposure and a ~3 km depth isocontour. The play area is west of the deformation front, except in southwestern Newfoundland where minor but significant compressive deformation is documented. The play is gas-prone except in the offshore domain between Anticosti and Newfoundland.

Source rock, maturation, generation and migration: Ordovician source rocks are the best candidates, these type I and II source rocks have generated their hydrocarbons.

Traps and seals: Transition from dolomite to tight carbonates. Structural features may modify seals.

Risk factors: The main risk factor is the presence of an adequate long term seal.



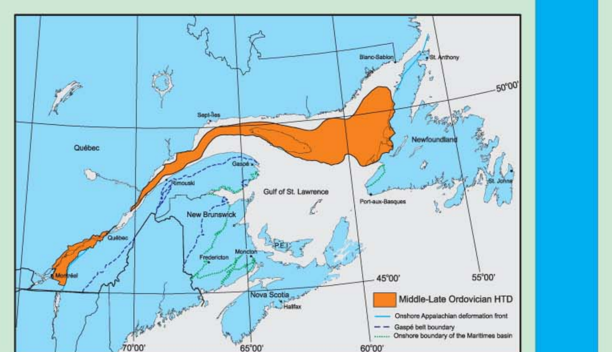
OIL

The Lower Ordovician play has an estimated in-place oil potential range (P90-P10) of 13.6 to 102.8 * 10^6 m^3 (86 to 650 MMBO), with a median volume of 52 * 10^6 m^3 (327 MMBO). The mean value of the number of predicted pools is 40. The largest undiscovered pool is expected to contain 6.5 * 10^6 m^3 (41 MMBO) of oil (median value).

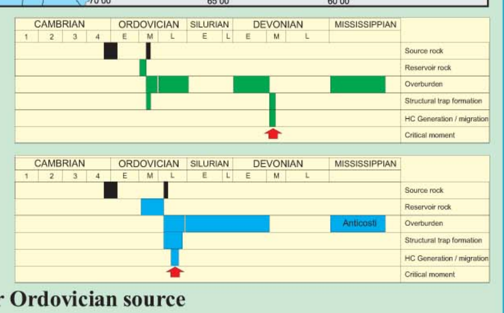
Potential for gas ranges from 1.7 to 17.5 * 10^9 m^3 (60 to 618 Bcf) in-place with a median volume of 7 * 10^9 m^3 (247 Bcf) The estimate assumes a total pool population of 98 (mean value), with the largest undiscovered pool having an initial in-place volume of 764 * 10^6 m^3 (27 Bcf) of natural gas

GAS

Upper Ordovician HTD (R3)



The hydrocarbon reservoir potential of the Upper Ordovician carbonates in southern Quebec and Anticosti has been recently been proven with a discovery The Gentilly #1 well found an Upper Ordovician hydrothermal dolomite reservoir in southern Quebec. The reservoir is hosted by Black River HTD. During initial testing, gas was produced at rates up to 9 MMcf/d.



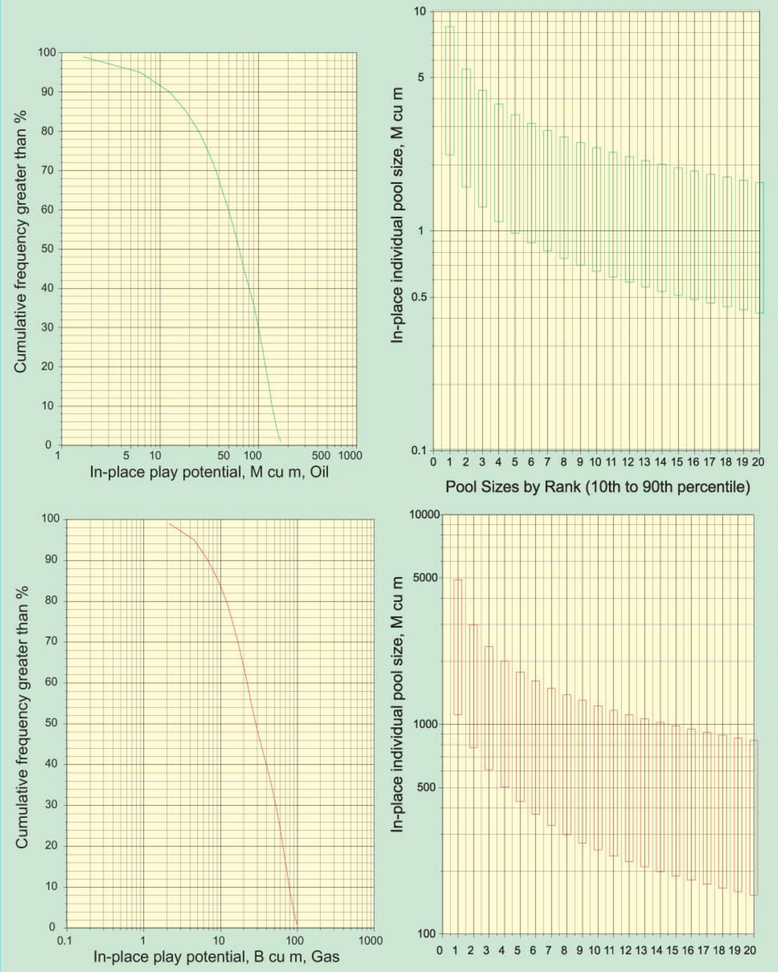
Potential Reservoir*:* The Upper Ordovician carbonates, commonly designated as the TBR (Trenton-Black River) play were deposited on a high energy shallow foreland basin carbonate The reservoir is formed through early dolomitization. High temperature fluids migrated in brecciated units along active Taconian faults. The early pulse of hydrothermal fluids is a regional event occurred shortly after or during the Taconian foreland basin.

Geographic distribution: The play extends from southern Quebec to Newfoundland. The play is gas-prone except in the offshore between Anticosti and western Newfoundland

Source rock, maturation, generation and migration: Lower and Upper Ordovician source rocks are the best candidates, these type I and II source rocks have generated their hydrocarbons

Traps and seals: Transition from dolomitized intervals to tight carbonates. Structural features may significantly modify the trap geometry.

Risk factors: The main risk factor for the Upper Ordovician HTD play is adequate long term seal.



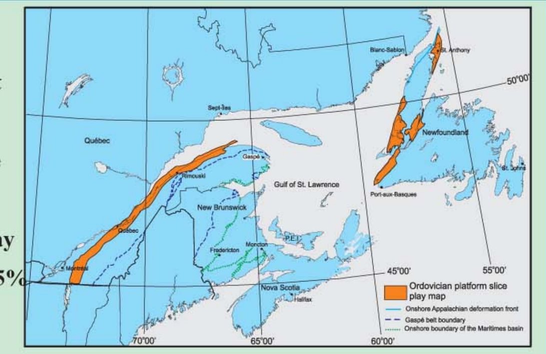
OIL

Estimates of the potential for the Upper Ordovican HTD oil play range from 12.5-137.6 * 10^6 m^3 (79 to 867 MMBO) with a median in-place volume of 63.8 * 10^6 m^3 (402 MMBO) distributed in 91 pools (mean value). The largest undiscovered oil pool is predicted to contain 4.6 * 10^6 m^3 (30 MMBO, median value).

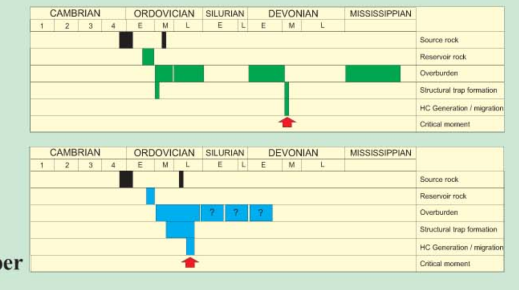
Assessment of the gas play predicts a mean value of 119 pools having a play potential ranging from 6.9 to 78.7 * 10^9 m^3 (244 to 2778 Bcf) with a median in-place potential of 28.8 * 10^9 m^3 (1016 Bcf) The largest estimated gas pool is 2426 * 10^6 m^3 (80 Bcf, median in-place volume)

GAS

Ordovician carbonate platform thrust slices (R6)



In southern Quebec, a major seismic program identified a large number of thrust slices at the Appalachian structural front, a limited number of which were subsequently drilled. A gas discovery was made and most of the thrust slices have tested some gas in the Lower Ordovician platform. In southern Quebec, the Saint-Flavien gas field produced 5.7 Bcf of gas, at 1.5 km deep with an average pay zone of 3.5 m. The St. Flavien reservoir has porosity values ranging from 2.8 to 15% and permeabilities are between 0.1 and 70 mD.



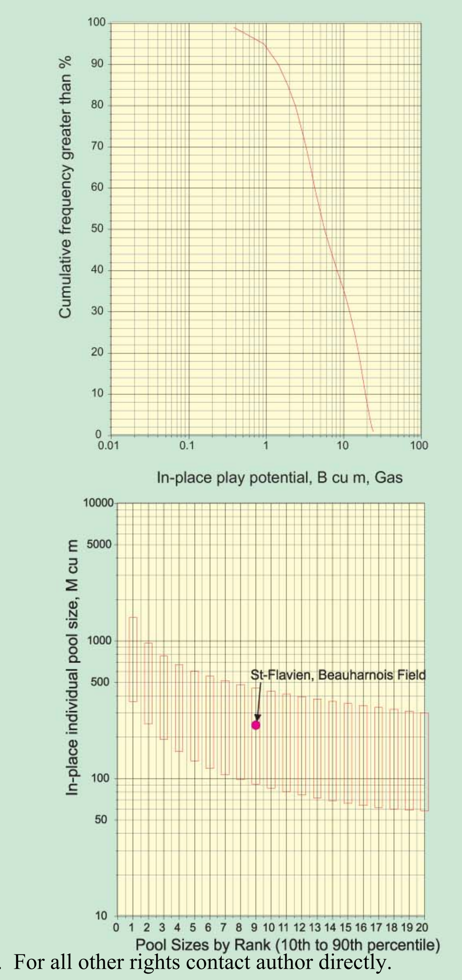
Potential Reservoir: The Saint-Flavien gas reservoir consists of thrust slices of Lower Ordovician dolomite (Beekmantown Group). The dolomite reservoir formed through multi-stage dolomitization events.

Geographic distribution: The play limits outline a ca. 23 km wide play area along the length of the Appalachians. In southern Québec, the recognition of this paly is based on a regional-scale study of seismic data.

Source rock, maturation, generation and migration: Lower and Upper Ordovician source rocks are the best, these type I and II source rocks have generated their hydrocarbons. From our understanding of thermal maturation, the entire play is gas-prone.

Traps and seals: Sstructural closures such as the one found at St. Flavien are.

Risk factors: The main risk factor for the carbonate slices play is probably the presence of an adequate long term seal.

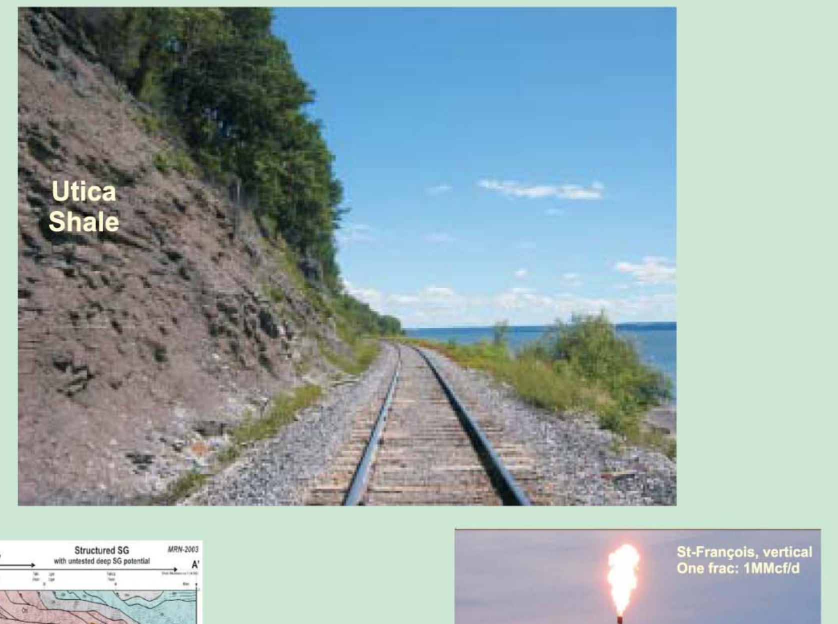


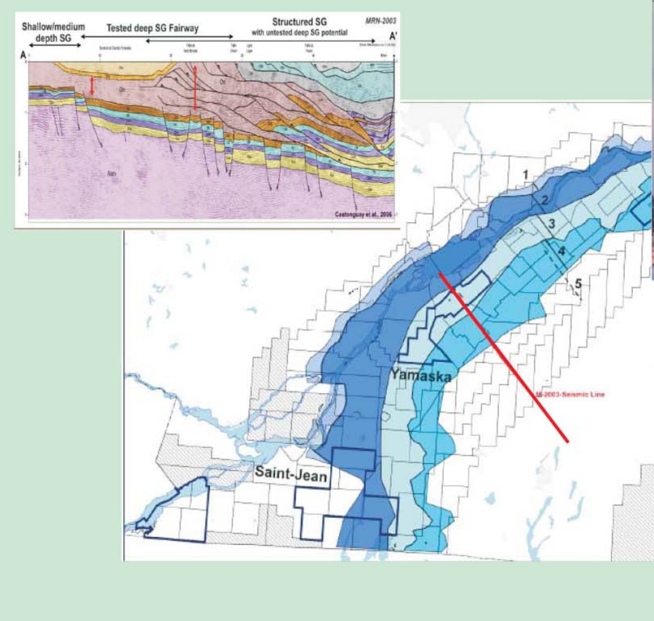
Play potential.

The total in-place median play potential is 5.6 * 10^9 m^3 (198 Bcf) of gas. Play potential ranges from 1.4 to 19 * 10^9 m^3 (49 to 671 Bcf) The predicted median of the largest pool is 776.5 * 10^6 m^3 (28 Bcf) in-place. The mean number of pools expected in the play is 42. The Saint-Flavien, Beauharnois pool has a reported in-place volume of 252 * 10^6 m^3 (8 Bcf) of natural gas. This volume matches most closely with the ninth largest predicted pool size (median in-place volume of 257.4 * 10^6 m^3 or 9.2 Bcf).

GAS

Unconventional shale gas





Geology

Shales of Middle to Late Ordovician occur throughout eastern Canada and were deposited in the deep marine Taconian Foreland Basin. These strata belong to the Table Cove/Black Cove/Winterhouse (Newfoundland), Macasty / Vauréal (Anticosti) and Utica / Lorraine / Pointe-Bleue (Quebec) units, which form thick units of dark grey to black, organic-rich mudstones. These successions are up to 1 km thick, with TOC up to 15%, and are thermally immature to overmature. The Utica Shale and overlying Lorraine siltstones in Quebec are in the active exploration phase and have the following characteristics: 700-1800 m depth, 150-300 m thickness, TOC 1-3%, thermal maturity 1.3-2.0 % Ro. Extensive new seismic, drilling and geotechnical study has documented three exploration fairways: 1) thermally mature, relatively undeformed shales between the Yamaska Fault and Logans Line, where current exploration and testing is focused, 2) deeper, tectonically-thickened shales in the dry gas zone, east of Logans Line, and 3) thinner, shallower, less deformed shales west of Yamaska Fault which may include thermogenic and biogenic possibilities.

Exploration History

In southern Quebec, shale gas activity has greatly increased over the past several years. Junex, a Quebec-based junior, has been actively exploring for Utica Shale for several years. The company is testing both thermogenic and biogenic potential, and estimates a potential of about 5 Tcf recoverable resources on their acreage. Forest Oil drilled two vertical wells in 2007, with production tests flowing up to 1 MMcf/d, and suggesting resource potential of 4 Tcf. The company has followed-up with three horizontal wells and massive fracturing. In February, the company reported maximum flows of up to 4 MMcf/d although the rates stabilized at 400 Mcf/d with incomplete recuperation of frac fluids. In 2008, Talisman Energy announced a successful test from Utica Shale in its vertical Gentilly well, which flowed at 800 Mcf/d, and further tests are expected for the overlying Lorraine shales. Talisman and its partner Questerre Energy have recently announced the casing of four successful vertical wells, yet to be tested.

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MIDDLE PALEOZOIC GASPÉ BELT

GEOLOGY

Introduction

The term Gaspé Belt designates the stratigraphic package of sedimentary and volcanic units that were deposited after the Taconian orogenic event (late Early to Late Ordovician) and before the sub-aerial unconformity that relates to the climax of the Acadian orogeny (Middle Devonian). The hydrocarbon-prone area is restricted to eastern Quebec and northern New Brunswick.

Stratigraphic framework

Uppermost Ordovician to Middle Devonian rocks belonging to the Gaspé Belt unconformably overly, or are in fault contact, with older rocks that have been attributed to the Laurentian margin (Humber Zone), to peri-laurentian oceanic domain(s) (Dunnage Zone) and peri-Gondwanian units (Gander zone).

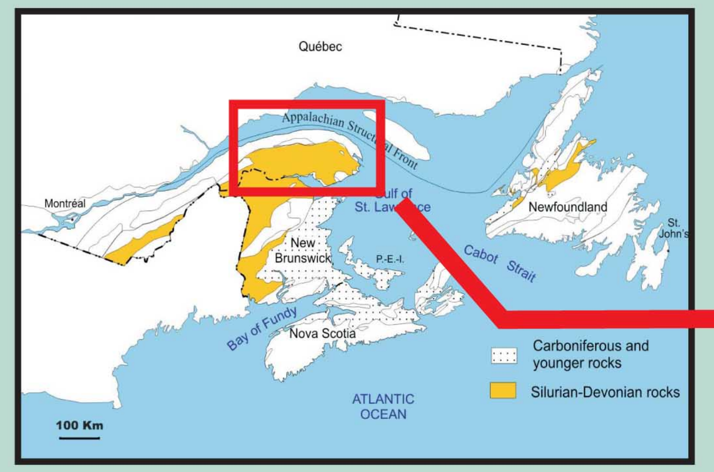
The sedimentary succession of the Gaspé Belt records three distinct regressive phases (R1 to R3) separated by two transgressive events (T1 and T2). The succession is divided in four broad temporal and lithological packages, with from the base to the top: 1) the Honorat and Matapédia groups (deep marine clastics and carbonates); 2) the Chaleurs Group (including a lower clastic assemblage, a middle carbonate assemblage, and an upper clastic assemblage with local reefs and volcanic flows); 3) the Upper Gaspé Limestones (relatively deep-water limestones) and 4) the Gaspé Sandstones (marine and terrestrial sandstones and conglomerates). In the areas surrounding the Gulf of St. Lawrence, the Gaspé Belt is unconformably overlain by Upper Paleozoic rocks belonging to the Maritimes Basin.

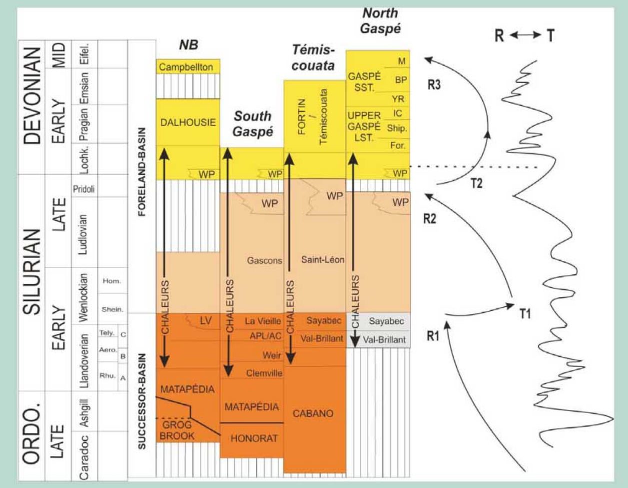
Structural framework

The main Acadian deformation features vary in style along the strike of the Gaspé Belt. Significant thrust faulting is documented in the Témiscouata area, whereas orogen-parallel transcurrent faulting prevails in the eastern Gaspé Peninsula and northern New Brunswick. Folds are generally open, with typical wavelength of ~ 5 to 15 km.

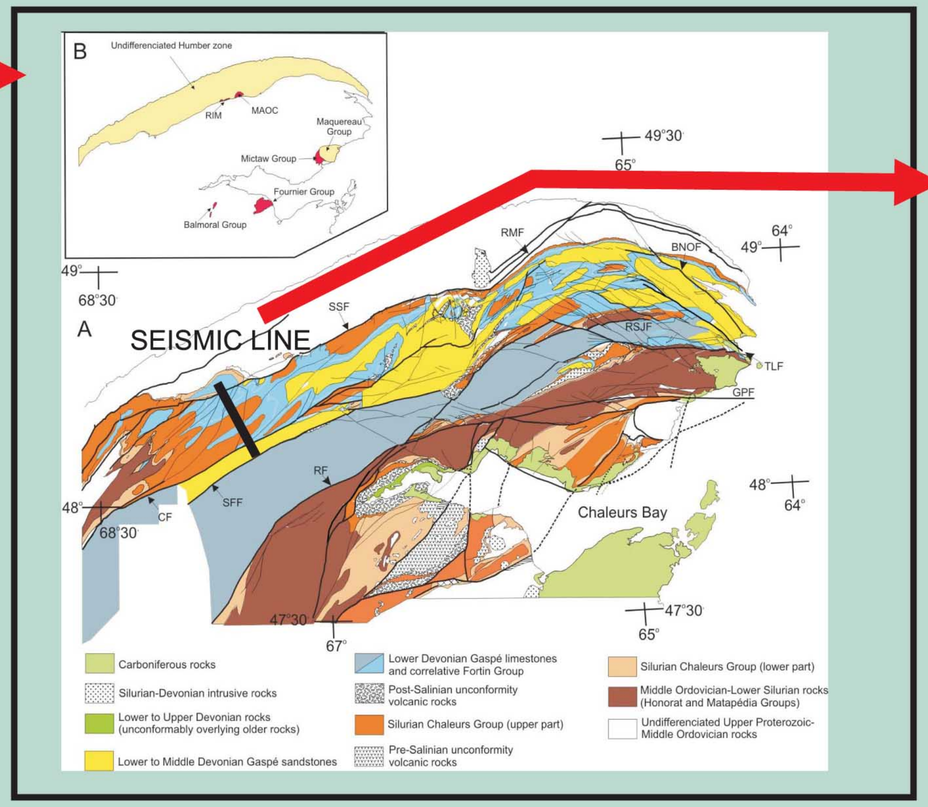
In detail, the geometry of the Siluro-Devonian succession may be locally complex such as the one illustrated on the seismic profile where both NW- and SE-dipping faults are documented in regional-scale anticlines.

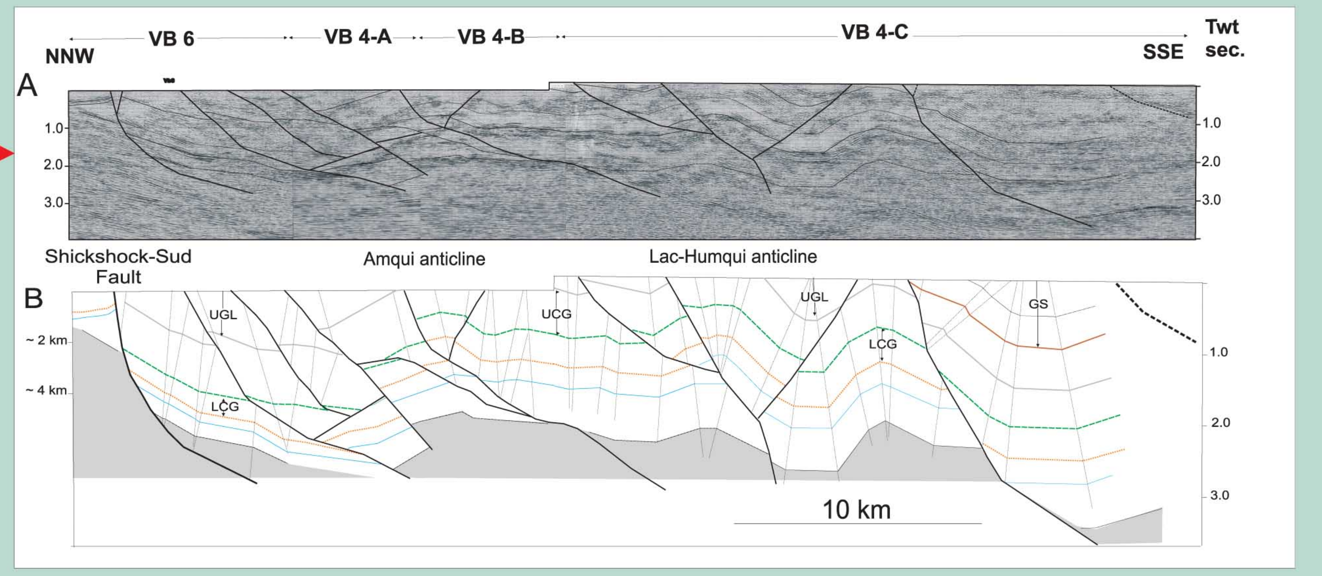
Post-Acadian deformation has traditionally been considered as minor. However, post-Acadian brittle motion along inherited faults is increasingly documented.





Stratigraphic framework of the Gaspé Belt.The major T-R events are shown; the Late Ordovician-Early Silurian R1 event; the Early Silurian-Late Silurian T1-R2 events and the latest Silurian-Middle Devonian T2-R3 events. The Silurian (R1-T1-R2 events) sea-level curve of Ross and Ross (1988, 1996) and the Devonian (T2-R3 events). Time hiatus are indicated by vertical lines





A, Seismic transect in western Gaspé Peninsula. B, Interpretation of the seismic transect shown in A. Horizontal and vertical scale are roughly similar. However, depths shown on the left side of the cross-section should be considered as approximations .
GS, Gaspé sandstone; LCG, Lower part of the Chaleurs Group; UCG, Upper part of the Chaleurs Group;

PETROLEUM GEOLOGY (1)

Exploration history

Exploration in Gaspé Peninsula started in the mid-19th century following the discovery of seeping oils in eastern Gaspé. Since 1860, 174 wells have been drilled in the Gaspé Belt, the vast majority being located in the Gaspé area. Initial drilling has targeted Lower Devonian sandstones and limestones with minimal success. In the Gaspé area, seismic surveys in early 80's led to the first geophysical-based drilling campaign. Only a small gas reservoir (Galt field, 728 MMcf gas field) was discovered and led to intermittent production.

Source Rocks

The presence of fair-quality potential hydrocarbon source rocks within the Gaspé Belt succession is restricted to the Upper Ordovician Boland Brook Formation in northern New Brunswick (TOC up to 1,4%), and to Lower – Middle Devonian rocks corresponding to some limy shale intervals in the Upper Gaspé Limestones (TOCmax = 1,75 %, HI = 83) and to thin coal seams.

High TOC and HI source rocks are found in various outliers of Ordovician deep marine shales belonging to the Dunnage Zone that are observed at various localities surrounding the Gaspé Belt. These rocks include Lower to Upper Ordovician black shales of the Ruisseau Isabelle Mélange (TOC values up to 2,73%), and the Middle Ordovician Dubuc Formation in Quebec (Mictaw Group; TOC values up to 10,7%; HI up to 257) and coeval Popelogan Shales, in northern New Brunswick (TOC values up to 1.8% even if the rocks are at the end of the dry gas

High TOC values are also documented in Cambro-Ordovician rocks belonging to the Humber zone that underlie parts of the Gaspé Belt.

Maturation, generation of hydrocarbon and migration

Maturation of organic matter is highly variable and ranges from locally immature to the dry gas zone. Analyses of core samples show that maturation positively correlates with depth and in most cases, isocontours of maturation data are parallel to geological contacts. These characteristics indicate that maturation is primarily related to burial and that maximum burial predates the main Acadian deformation event.

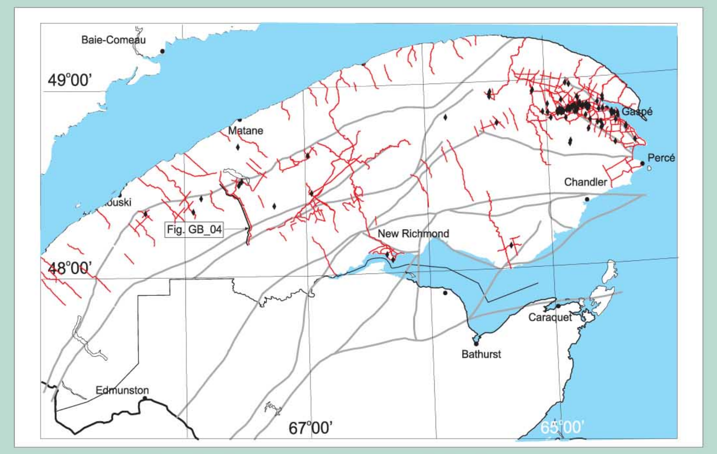
1D thermal modelling suggests that the potential Devonian source rocks have generated hydrocarbons in late Early to Middle Devonian. Detailed paragenetic studies suggest that the potential Ordovician source rocks have generated hydrocarbons relatively early in the history of the Gaspé Belt, i.e., during the Early Silurian or earliest Late Silurian.

Early migration from pre-Lower Silurian source rocks is recognized in Upper Ordovician to Lower Silurian units. Late migration from potential Devonian source rocks or dismigration from older reservoirs is recorded in post-Late Silurian units.

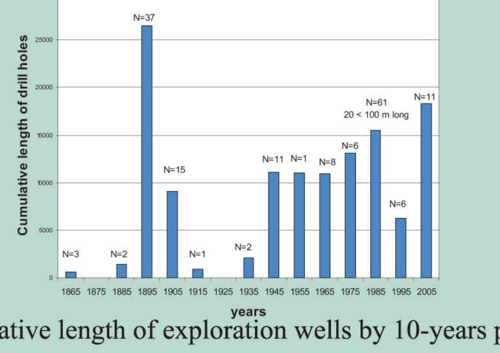
Hydrocarbon plays

Among the potential reservoir units, six have been considered in a specific play. Given the limited sub-surface information, only the Lower Devonian sandstone play has been be quantitatively assessed.

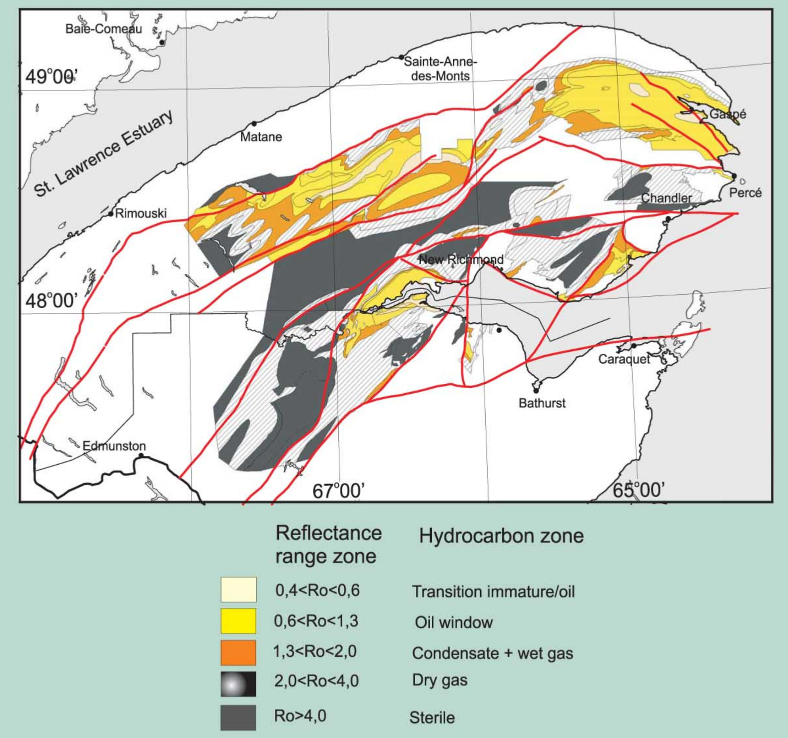
PETROLEUM GEOLOGY (2)



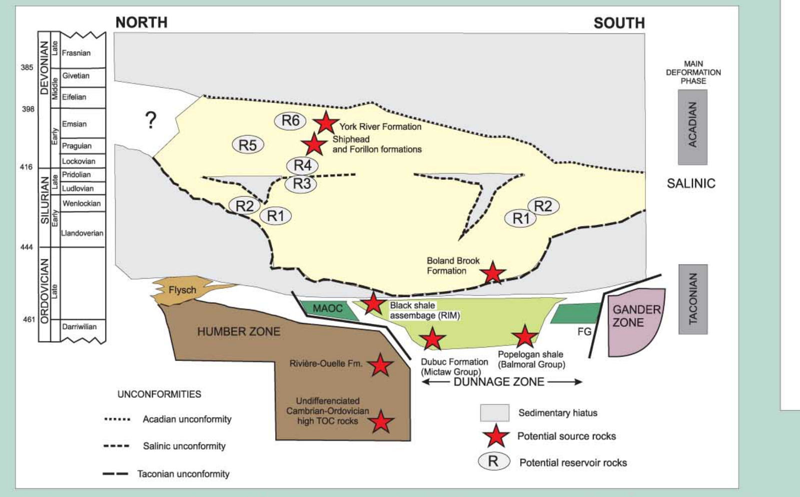
Location of seismic lines (red lines) and hydrocarbon



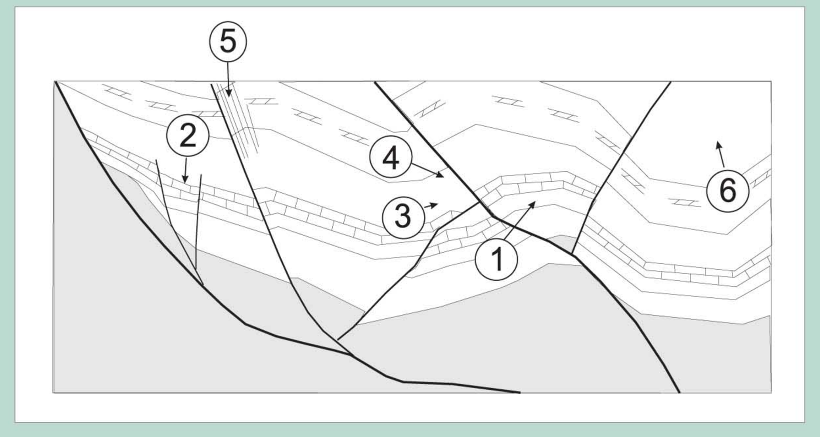
Cumulative length of exploration wells by 10-years period.



Surface zonation of thermal maturation in Gaspé and New

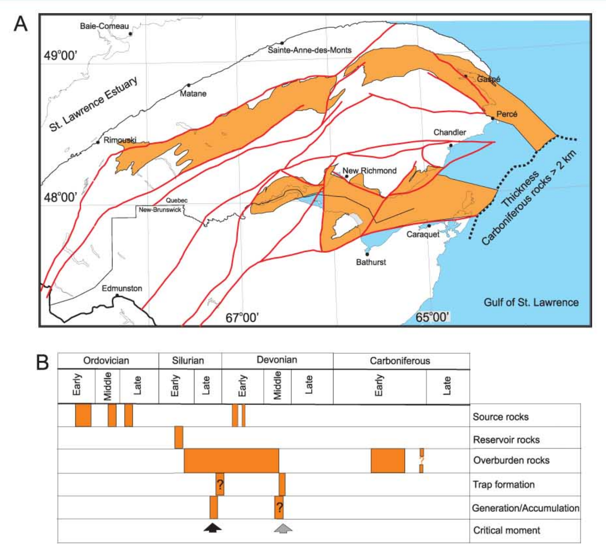


Schematic stratigraphic framework of the Gaspe belt illustrating the position of potential source and reservoir rocks and the various basement domains. The Gaspé Belt sedimentary infill is indicated by a yellow color. The Dunnage Zone comprises ophiolitic (dark green) and sedimentary rocks (light green).
FG, Fournier Group; MAOC, Mont-Albert ophiolitic complex



Conceptual sketch showing the Gaspé belt plays.
1- Lower Silurian clastics
2- Lower Silurian hydrothermal dolomite
3- Upper Silurian hydrothermal dolomite
4- Lower Devonian hydrothermal dolomite
5- Lower Devonian limestone
6- Lower Devonian sandstones

LOWER SILURIAN CLASTICS

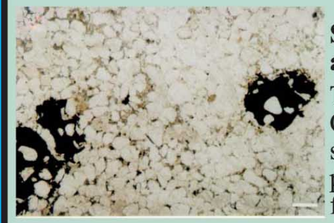


Exploration history and shows

The Lower Silurian clastic interval has been tested by only three drill holes. To date, there are no discoveries for this play.

Potential reservoir

The Lower Silurian nearshore to platform sands were deposited near the end of the first major regressive event.



Source rock, maturation, generation and migration

The best potential source rocks are Ordovician in age. An early charge of sandstone reservoirs is documented by the presence of abundant bitumen and fluorescent oil in primary to secondary pore space.

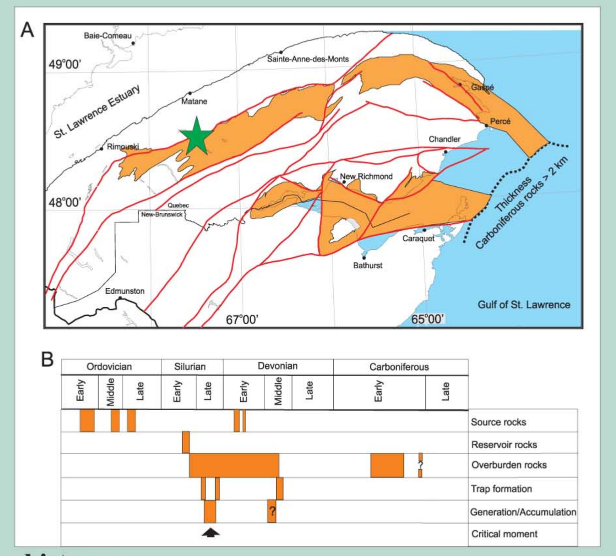
Traps and seals

Structural traps such as open folds associated with Silurian normal faulting or Devonian transpression or mixed structural/stratigraphic traps may offer suitable closures. Where not fractured or hydrothermally altered, the overlying limestones are tight and may act as seal. The Upper Silurian Salinic unconformity may also provide an adequate seal for Lower Silurian clastic units.

Risk factors

Little is known about the distribution of porous intervals within the lower Silurian clastic units. The presence of an adequate long-term seal may be problematic, especially in the hanging wall of Silurian tilted blocks that may have been subaerally exposed during the Salinic event.

LOWER SILURIAN HYDROTHERMAL DOLOMITE



Exploration history

The Lower Silurian limestone interval has been tested by only three drill holes, which were not targeting HTD. A bitumen-rich succession in northern Gaspé is interpreted as representing an exhumed oil field (green star on the map).

Potential Reservoir

Lower Silurian carbonates have formed in a laterally well-zoned carbonate ramp dominated by a wide peritidal flat flanked by a shallow subtidal narrow knob reef belt and a well sorted above fair-weather wave base limestone sand belt. These rocks are tight except when secondary porosity associated with hydrothermal dolomitization is present. Hydrothermal dolomites exhibit major dissolution cavities and fractures in breccia zones that are irregularly surrounded by massive dolostone.

Source rock, maturation, generation and migration

The best potential source rocks are Ordovician in age. Detailed studies indicate that high temperature dolomitization occurred early in the geological history, after the end of carbonate ramp sedimentation (late Early Silurian), but before the sub-aerial exposure in middle Late Silurian. Moreover, hydrocarbons have migrated soon after the dolomitization event as testified by the abundant bitumen filling small (mm-sized) to large (cm-sized) voids.

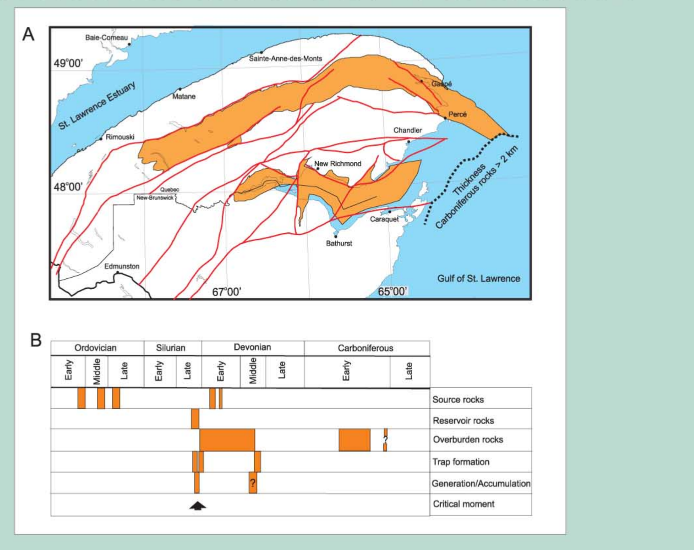
Traps and seals

Transition from dolomitized intervals to tight carbonate is expected to be the main trap- and seal controlling factor. However, deformation may significantly modify the trap geometry. The Late Silurian (Salinic) unconformity may provide an adequate seal.

Risk factors

The presence of a long-term seal is probably the main risk factor.

UPPER SILURIAN LIMESTONE AND HYDROTHERMAL DOLOMITE



Exploration history and shows

The Upper Silurian West Point Formation has been tested by four drill holes, which were not targeted for HTD. To date, there are no discoveries in this play.

Potential Reservoir

The Upper Silurian West Point Formation comprises three superposed reef complexes. The middle reef complex was formed during a major sea-level lowstand and evidence for sub-aerial exposition is found in that interval as well as in the underlying succession. The reef complexes are surrounded by fine-grained clastic facies.

The limestone shows little porosity in outcrop. However, significant porosity enhancement by hydrothermal dolomitization (and/or fracturing) cannot be excluded even though dolomitic breccia has only been locally observed .

Source rock

The best potential source rocks are Ordovician in age.

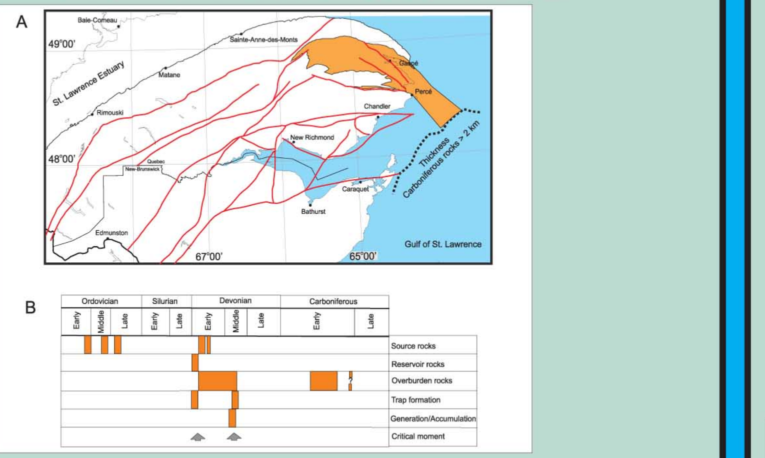
Potential trap

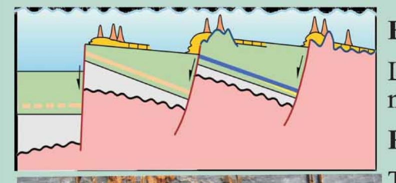
Transition from dolomitized intervals to tight carbonate is expected to be the main trap and seal controlling factor. However, deformation may have significantly modified the trap geometry. The Upper Silurian West Point reefs are surrounded by siliciclastic muddy facies that may act both as a lateral and upper seals.

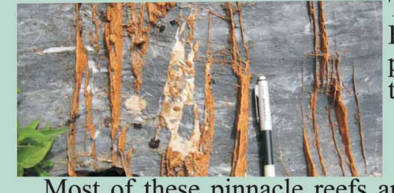
Risk factor

Geographically-restricted diagenetic analyses of the Upper Silurian West Point reef limestone from the Chaleurs Bay area suggest that meteoric water has influenced cementation early in the geological history and occluded pore space in the shallow burial environment.

LOWER DEVONIAN HYDROTHERMALLY ALTERED PINNACLE REEF







Exploration history and shows

Lower Devonian pinnacle reefs have never been tested by drilling.

Potential reservoir

The Lower Devonian West Point Formation consists in isolated pinnacle reefs that are up to 300 m thick and a couple of km wide.

Most of these pinnacle reefs are interpreted to have grown at the margin of tectonically active fault block; the presence of extensional faults offer the critical pathways for fluid migration leading to hydrothermal alteration of the carbonate facies. To date, hydrothermal dolomitization in the pinnacle reefs has been documented only locally.

Source rock

In northern Gaspé, the best potential source rocks are Ordovician in age.

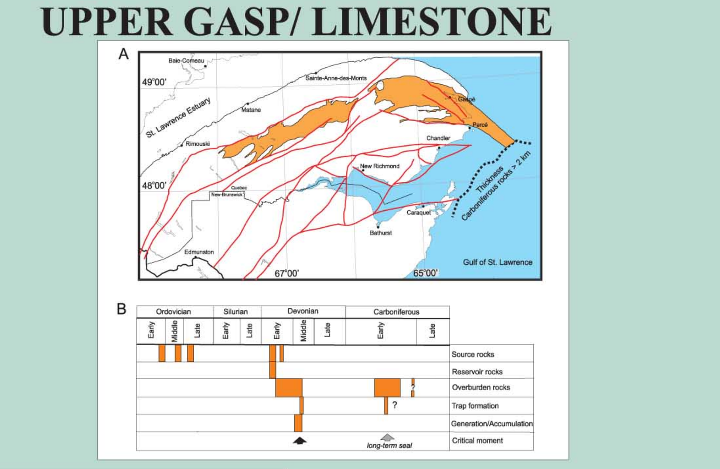
Traps and seals

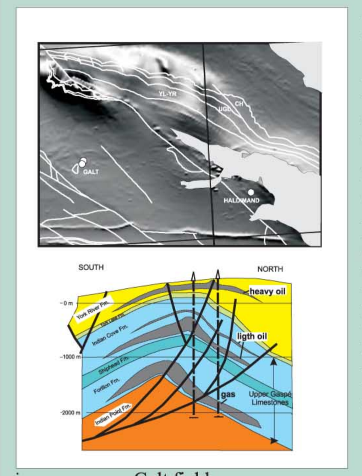
The presence of transition zones between dolomitized intervals and tight carbonates are expected to be the main trap and seal controlling factor. However, deformation may have significantly modified the trap geometry. The Upper Silurian West Point reefs are surrounded by siliciclastic muddy facies of the Indian Point Formation that may act both as a lateral and upper seals.

Risk factor

Geographically-restricted diagenetic studies suggest that the primary pores of the pinnacle limestone were not completely occluded before reefs were buried at significant depth suggesting that these rocks may have preserved their reservoir potential for a relatively long period of time.

LOWER DEVONIAN UPPER GASP/ LIMESTONE





Galt field

Exploration history

Since the late 19th century, most wells have targeted parts or entire succession of the Upper Gaspé Limestones. Small volumes of oil or gas are almost invariably encountered. In eastern Gaspé, the oil and gas fields of the Galt property are hosted by fractured Upper Gaspé limestones that have been hydrothermally altered. The gas reservoir has produced rates of 37 Mcf/d for a couple of years. A few hundreds of oil barrels are produced yearly.

Potential reservoir

The Lower Devonian Upper Gaspé Limestones Group is dominated by fine-grained, shaly and dolomitic calcilutite. The Upper Gaspé limestones are generally tight, but relatively high fracture porosity is observed close to NW-striking faults. Hydrothermal dolomitization has been only observed close to significant fracture networks and may have contributed to permeability enhancement.

Source rock

Source rocks of Ordovician and Devonian ages are documented.

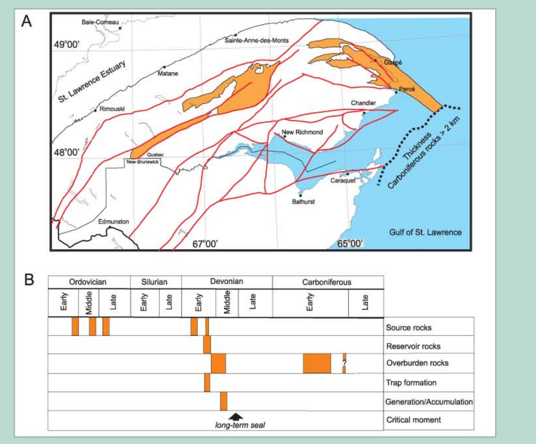
Traps and seals

Anticlinal folds have been a common exploration target in eastern Gaspé and the Galt field is hosted in such a structure. However, fractures appear as a key parameter for efficient porosity and permeability. Massive to little fractured rocks are expected to act as a seal.

Risk factors

The long-term sealing capacity of highly fractured zones appears as the

LOWER DEVONIAN GASPÉ SANDSTONES



Exploration history

The Gaspé Sandstones have been the first exploration target in the eastern Gaspé Peninsula Most wells show hydrocarbon indicators but gave only minimal production. The Haldimand field was discovered in 2006 and is still under evaluation.

Potential reservoir

The Gaspé Sandstones record an abrupt shoaling event, from shallow marine to terrestrial facies. The potential reservoir unit consists of high energy, marginal marine to fluvial sandstone that locally fills channels. Large scale migrating sand bars are locally highly porous.

Source rock and maturation

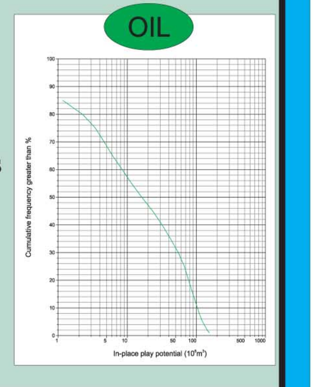
Source rocks of Ordovician and Devonian ages are documented. The regional maturation data indicates that this play is oil-prone.

Traps and seals

Stratigraphic traps and seals are likely in nearshore coarse-grained clastic units of the Gaspé Sandstones where rapid facies transition from porous channel/deltaic wedges to mud dominated units are documented. However, deformation may significantly modify the trap geometry as in the case of the Haldimand field.

Quantitative evaluation

The prospect sizes for the Lower Devonian clastic play are largely unknown in the Gaspé Belt. For quantitative evaluation purposes, data from the largely time and facies-correlative Lower Devonian Oriskany Sandstone in eastern United States has been used as an analogue. Other parameters such as the thickness of the net pay zone, its porosity and water saturation have been estimated from petrophysical data from wells in eastern Gaspé.



Median value of probabilistic assessment is 16.2 million m^3 (102 MMBO) of in-place oil distributed in 11 pools.

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Upper Paleozoic Maritimes Basin

Canada

LOCATION MAP

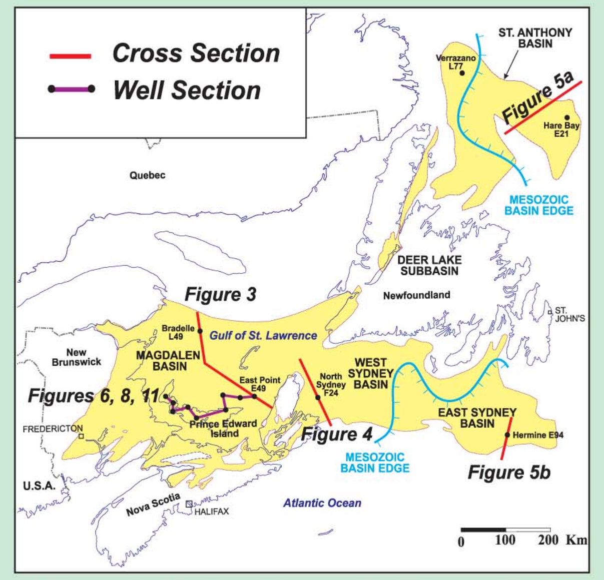


Figure 1: Carboniferous Maritimes Basin

REGIONAL SETTING

The composite Maritimes Basin is a large upper Paleozoic sedimentary basin underlying the southern Gulf of St. Lawrence and Cabot Strait, with onshore extensions in all five eastern Canada provinces (***Figure 1***). Upper Paleozoic strata underlie all of Prince Edward Island and the Magdalen Islands (Quebec). Basin strata extend eastward beneath the southern Grand Banks and northeastern Newfoundland continental shelves. Easternmost segments of the Maritimes Basin are overlain by Mesozoic-Cenozoic sediments of the Atlantic continental margin. The Maritimes Basin includes the Magdalen, Sydney and St. Anthony basins and a multitude of local subbasins. The Maritimes Basin encompasses a total area of 250,000 km 2, with about 75% of the basin area offshore.

The Upper Paleozoic Maritimes Basin developed in an active plate tectonic setting, resulting in a multicyclic and complex depositional and structural history. The basin's tectonic history included extensional settings (Late Devonian to Mississippian) and foreland basin settings (Pennsylvanian to early Permian). Regional strike-slip faults were active through most of the basin's development, resulting in local development of pull-apart basins and subsequent basin inversions and deformation. A late phase of deformation and uplift/erosion of Maritimes Basin strata was associated with Mesozoic rifting and formation of the Atlantic Ocean Basin.

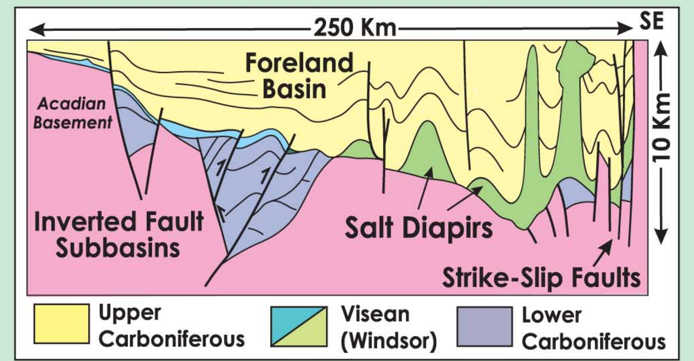


Figure 3

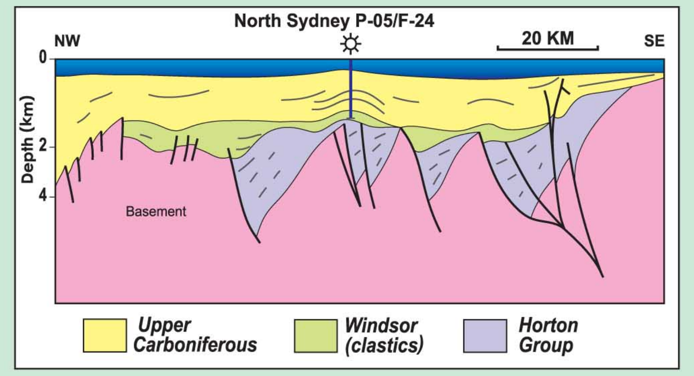


Figure 4

STRATIGRAPHY

The Maritimes Basin contains up to 12 kilometres of Late Devonian to Early Permian continental and shallow marine strata, deposited in three main tectono-stratigraphic packages: a late Devonian to early Carboniferous (Tournaisian) succession of alluvial and lacustrine clastics and volcanic rocks in deep, fault-bounded subbasins (Horton Group); a widespread early Carboniferous (Visean) succession of marine carbonates and evaporites and nonmarine clastics (Windsor and Mabou groups); and a thick middle Carboniferous to early Permian succession of alluvial, fluvial and estuarine clastics (Cumberland, and Pictou groups) (***Figures 2*** and ***6***). Coal-bearing sections (coal measures) are abundant in the Namurian -Westphalian Cumberland and Pictou groups. The Upper Carboniferous Pictou Group is up to 9000m in the central Magdalen Basin. Basin structures are associated with rift faulting, strike-slip related inversion tectonics (multiple phases), and salt diapirism.

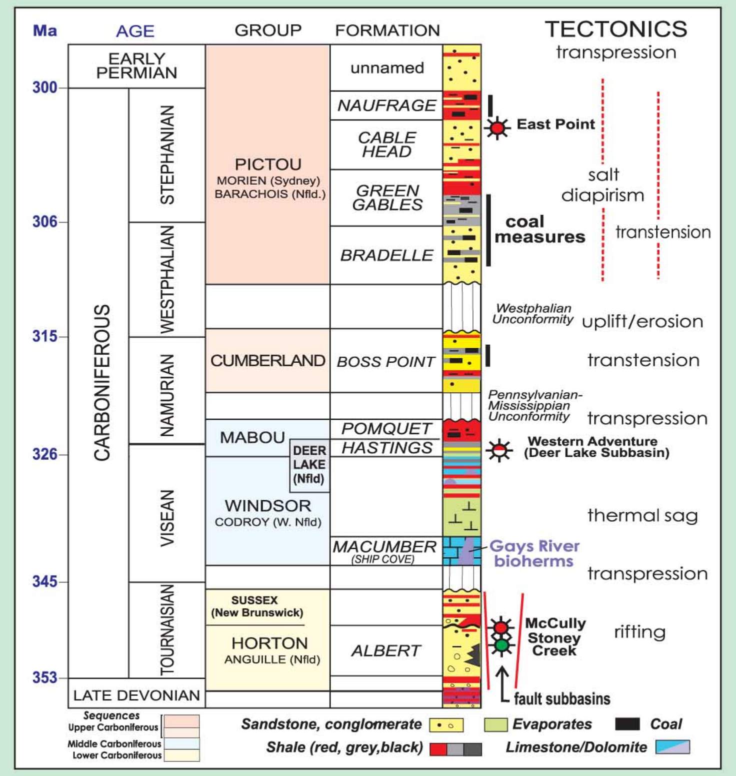


Figure 2

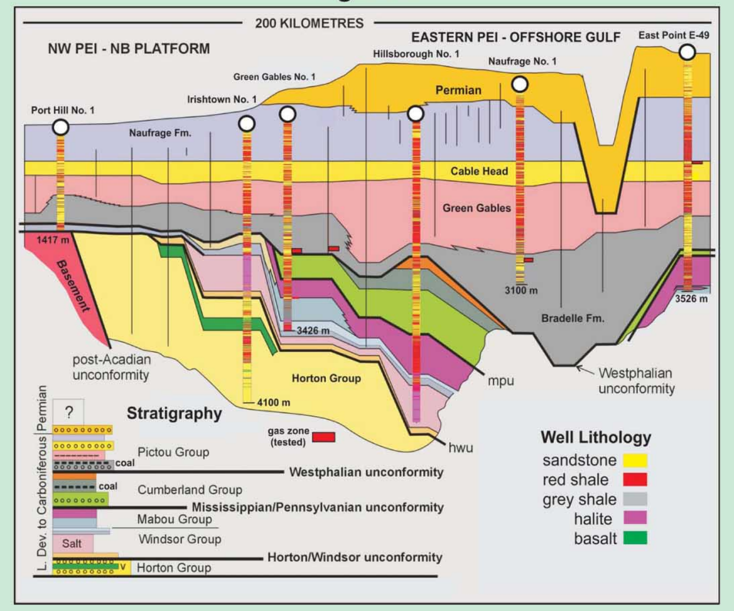


Figure 6

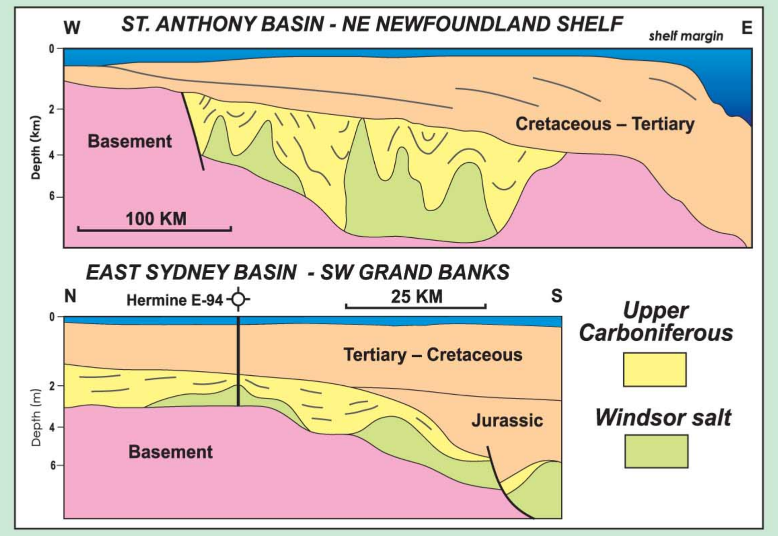


Figure 5

PETROLEUM SYSTEMS

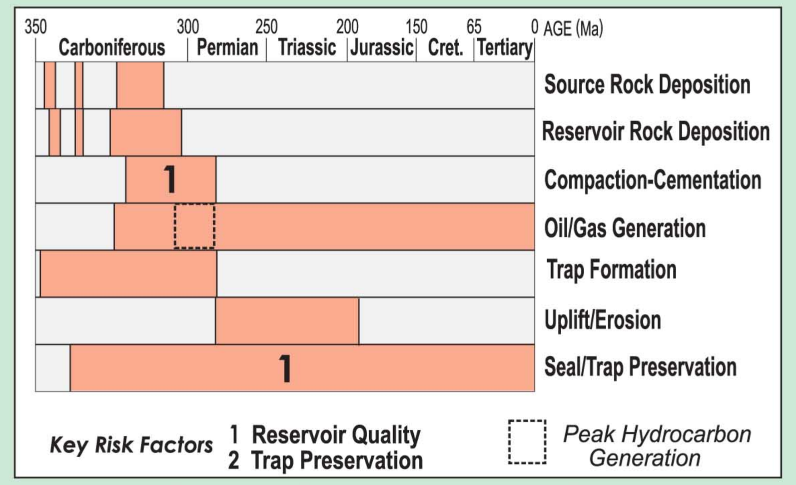


Figure 7 - Petroleum systems Chart

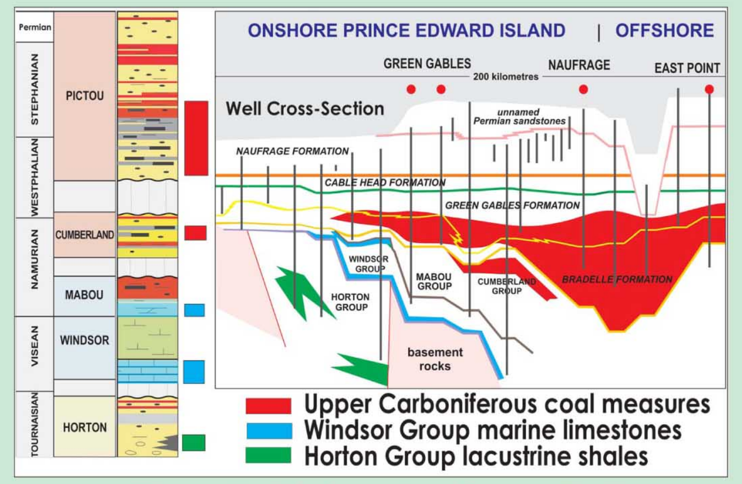


Figure 11 - Hydrocarbon Source Rocks

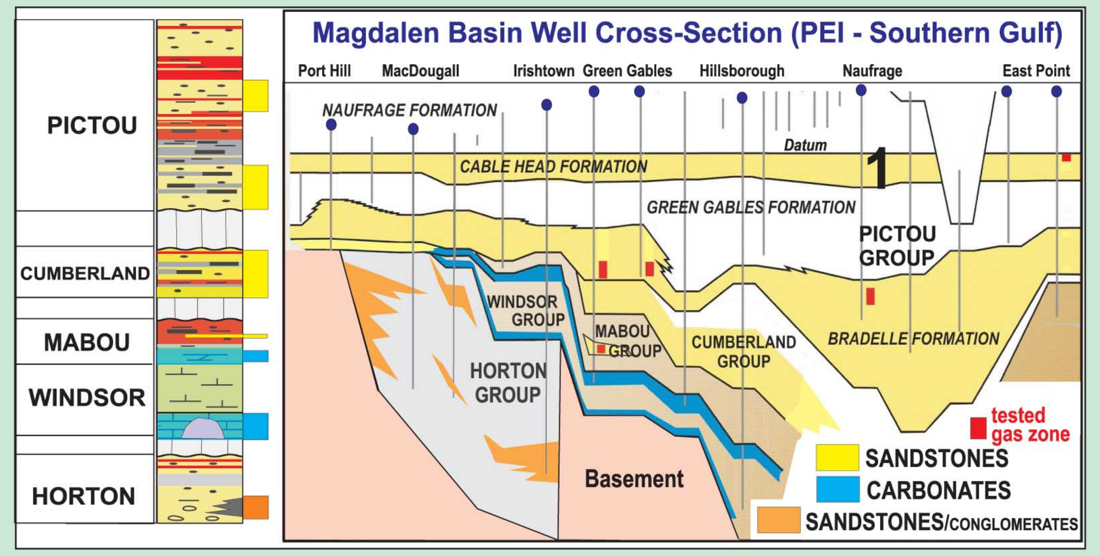


Figure 8 - Reservoir Rocks

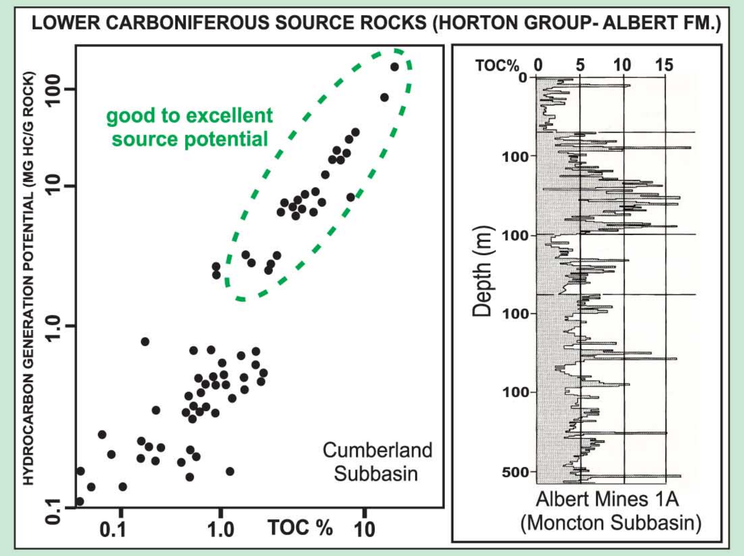


Figure 12

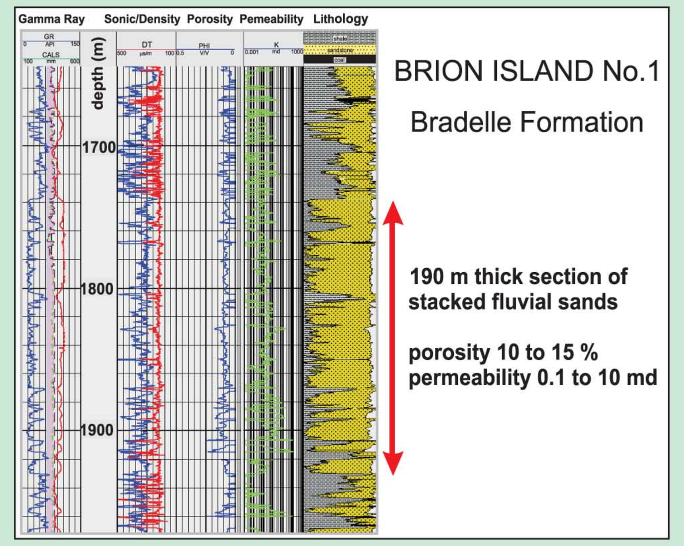


Figure 9 - Reservoir Example

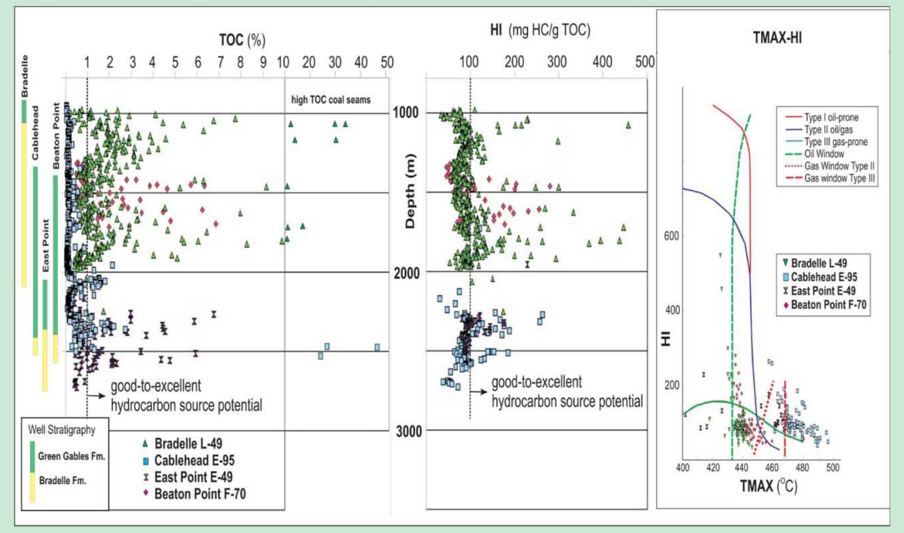


Figure 13 - Upper Carboniferous Source Rock (Rockeval) Data

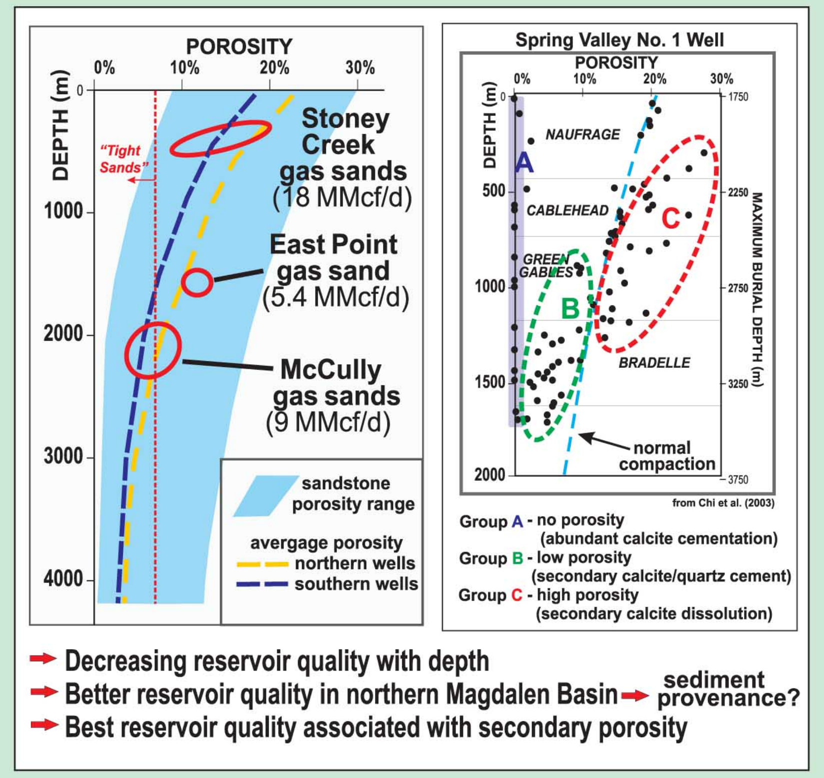


Figure 10 - Carboniferous Sandstone Porosity-Depth Trends

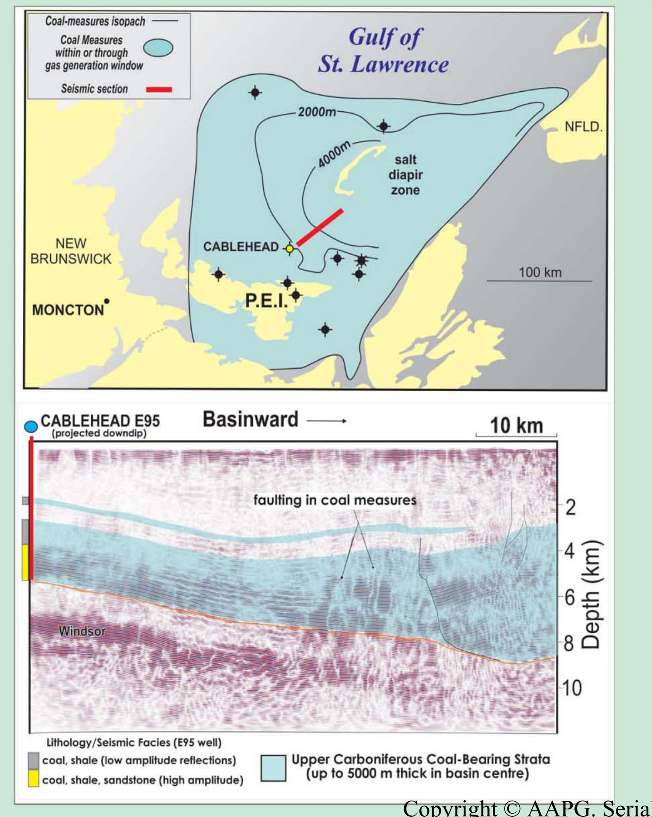


Figure 14 - Coal Measures Source Rocks

The Maritimes Basin contains the key petroleum-system elements for a substantial petroleum resource potential, including widespread reservoir rocks (***Figures 8***, ***9***) thick shale and salt sections (seals), large volumes of thermally mature source rocks (Type I organic matter in Horton Group lacustrine shales, and Type II-III organic matter in Upper Carboniferous coal measures; ***Figures 11*** to ***15***), and abundant and diverse trap types. The gas-prone Upper Carboniferous coal measures are the most widespread and thickest source rocks in the basin (***Figure 14***).

The main exploration risks in the Maritimes Basin are associated with reservoir quality and trap preservation. Carboniferous sandstones in the basin have generally low porosity and permeability in the depth range most commonly explored for oil or gas traps (***Figure 10***). However, good quality reservoirs (porosity of 10% or more) are present in all stratigraphic units over a wide range of basin depths. The best quality sandstone reservoirs occur in the upper Carboniferous Pictou Group in the northern Magdalen Basin. Sediment provenance and secondary porosity development are important factors in reservoir quality. The trap preservation risk is related to the timing of hydrocarbon generation and late-stage basin exhumation and erosion. The peak period of hydrocarbon generation for source rocks in many parts of the basin occurred in the late Carboniferous to early Permian, prior to (Mesozoic) uplift and erosion of upper parts of the basin fill. Long-term preservation or sealing of early-charged hydrocarbon traps may be problematic. Nonetheless, the known presence of several hydrocarbon accumulations in the basin attests to the local effectiveness of trap sealing.

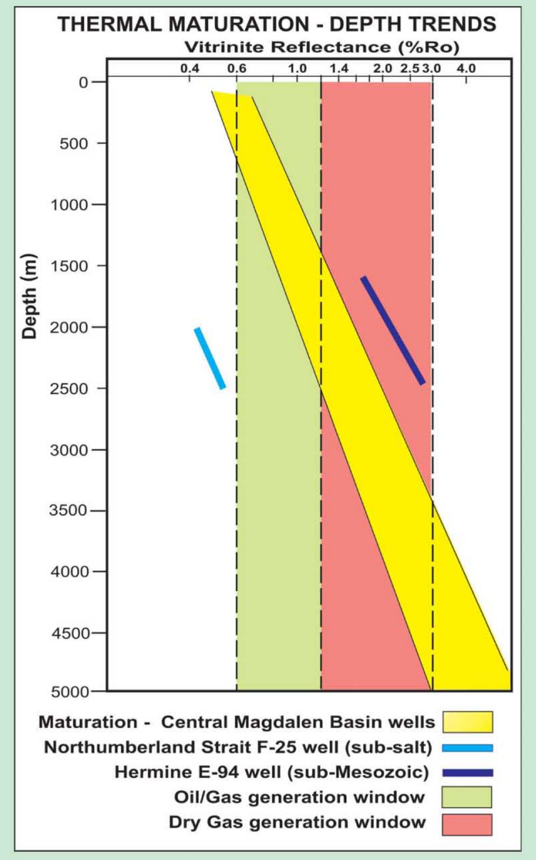
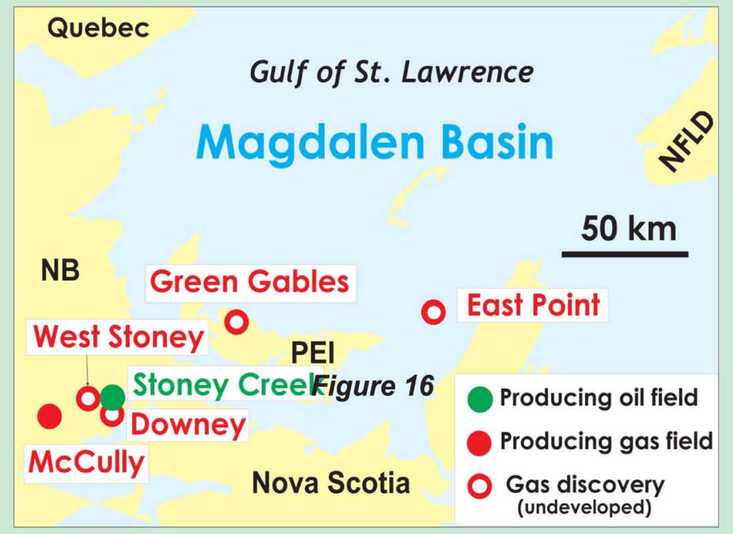


Figure 15

DISCOVERED FIELDS

Two onshore oil and gas fields have been discovered and developed in the Moncton Subbasin, New Brunswick (Stoney Creek and McCully; ***Figures 17***, ***18***). Other onshore gas discoveries (Green Gables in Prince Edward Island, West Stoney and Downey in New Brunswick, Western Adventure in Newfoundland) remain undeveloped. The offshore East Point gas field (***Figure 19***) was discovered in 1974, but development of the field was deemed uneconomic after a step-out well was unsuccessful.



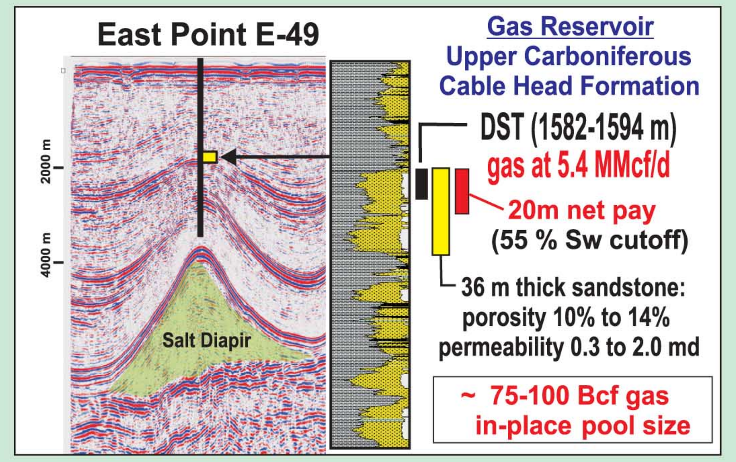


Figure 17 - Offshore East Point Gas Discovery Well

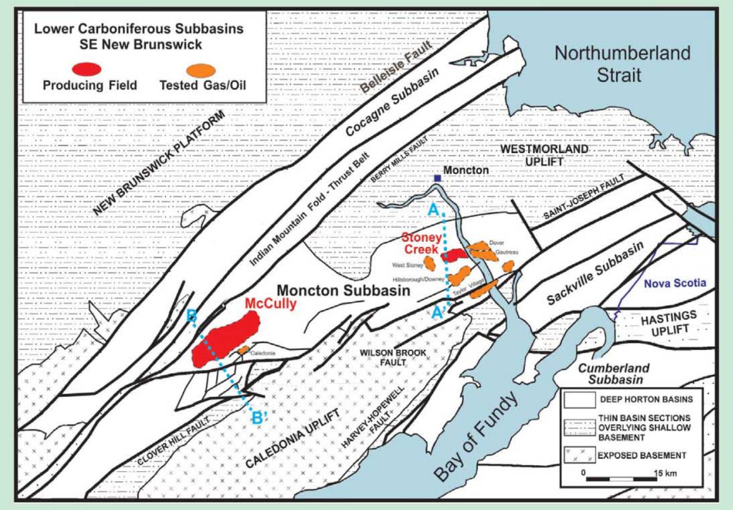


Figure 18 - Oil/Gas Discoveries in Moncton Subbasin

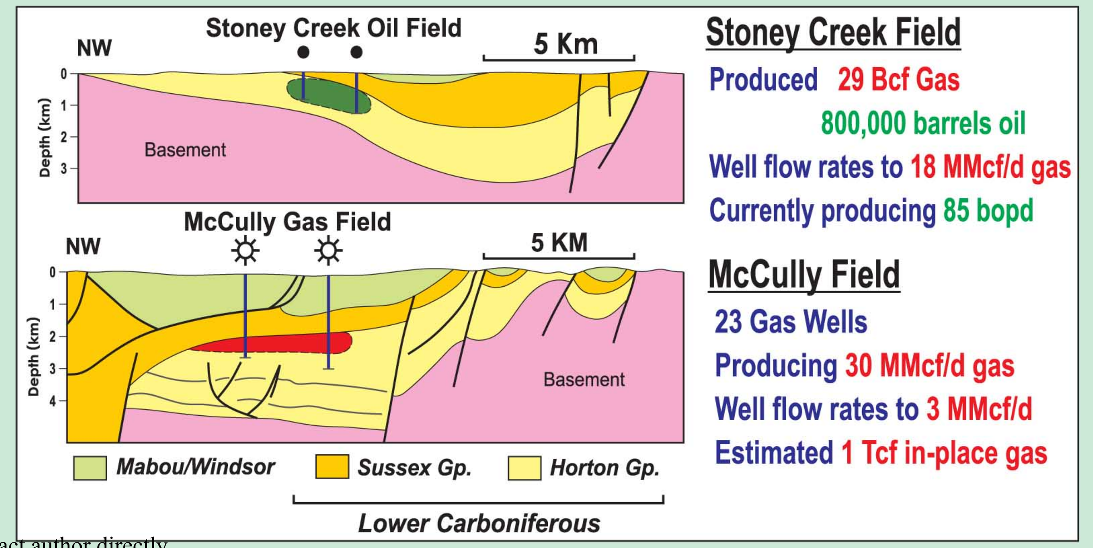


Figure 20 - Cross-sections A-A' (top) and B-B' in Moncton Subbasin

PETROLEUM PLAYS AND RESOURCE POTENTIAL

The primary exploration plays in the basin involve Horton Group sandstones or conglomerates in combined structural-stratigraphic traps, and Upper Carboniferous fluviatile sandstones in fault block and salt structure traps (salt withdrawal anticlines, salt pillows, salt-flank onlap and sub-salt traps (***Figure 20***). The sub-salt play includes potential Horton Group reservoir strata. The upper Carboniferous salt-structure play contains the largest number and sizes of known prospects in the region. A third exploration play, currently poorly delineated on a regional basis, involves carbonate reefs in the Windsor Group.

Quantitative assessments of the main exploration plays (Lower Carboniferous and Upper Carboniferous clastics: ***Figures 21***, ***22***) indicate the Maritimes Basin has low-to-moderate oil potential (***Figures 23***, ***24***) and high natural gas potential (***Figures 25***, ***26***). Further exploration in the basin will likely result in more gas discoveries, with potential for large (Tcf+)

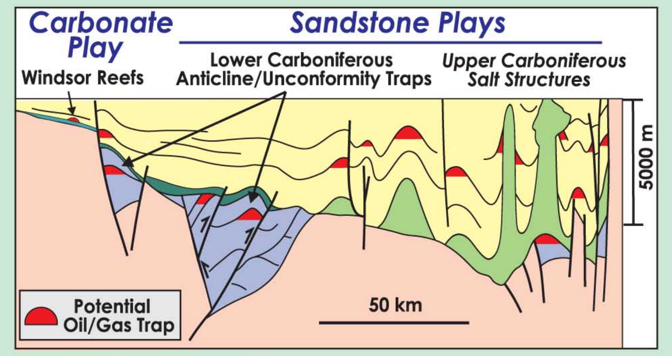


Figure 20 - Petroleum Plays

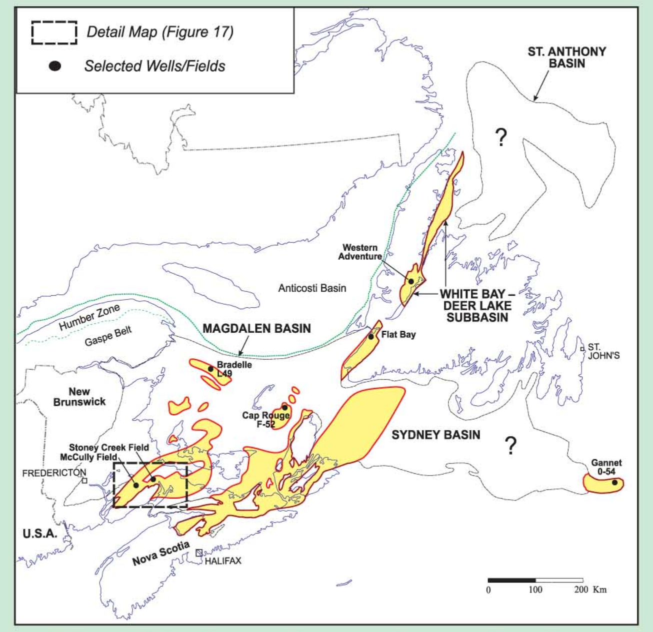


Figure 21 - Lower Carboniferous Play Area

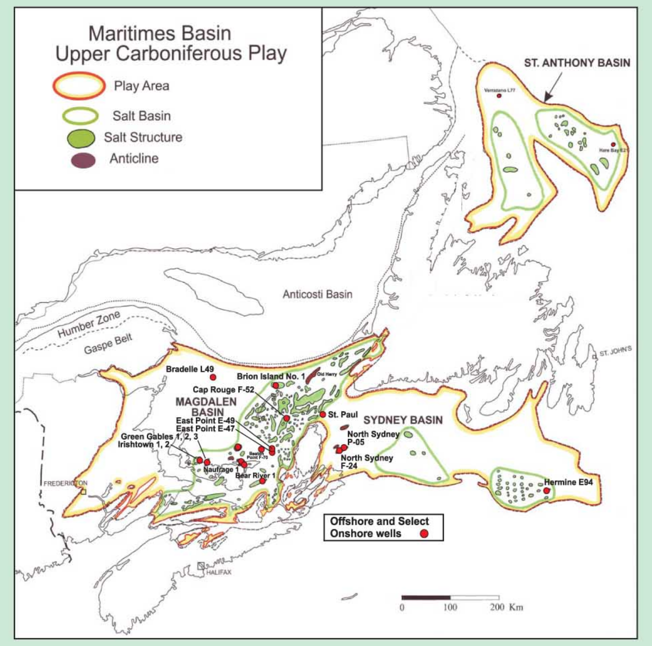


Figure 22 - Upper Carboniferous Play Area

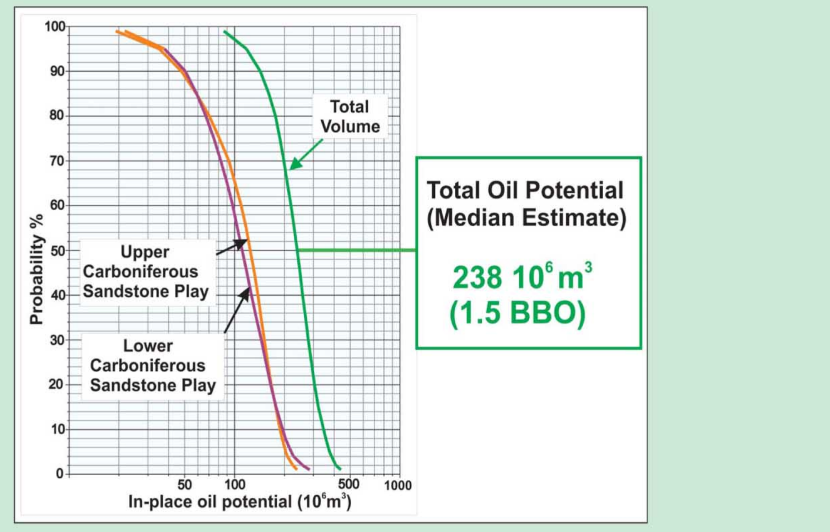


Figure 23 - Oil Potential

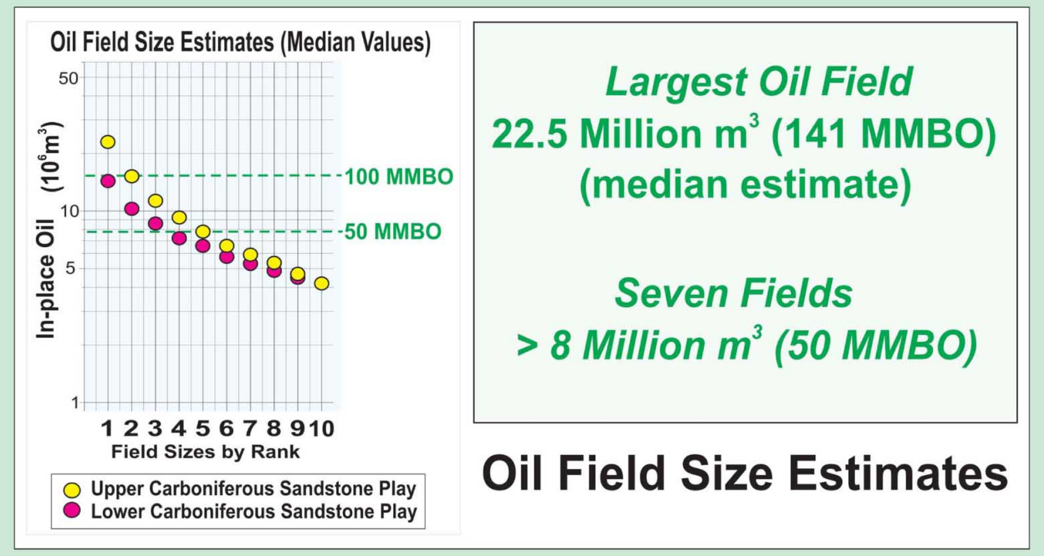


Figure 24 - Oil field Size Estimates (10 largest)

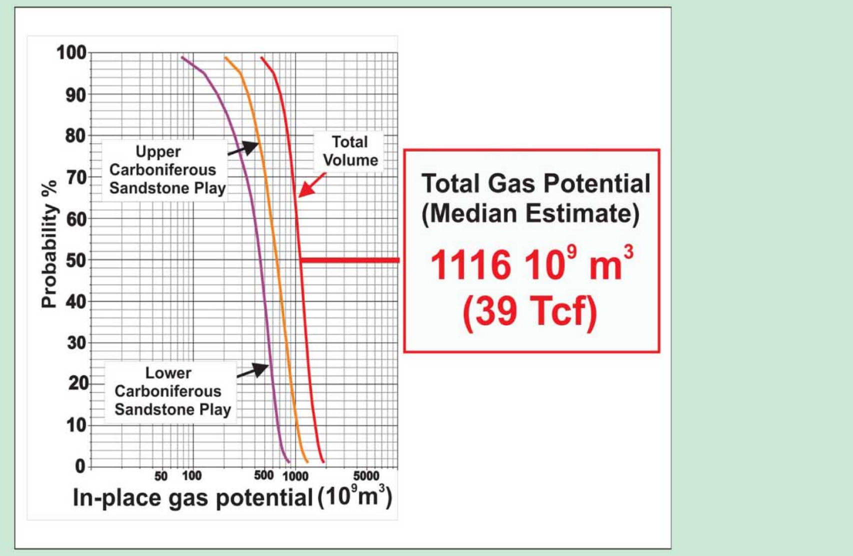


Figure 25 - Gas Potential

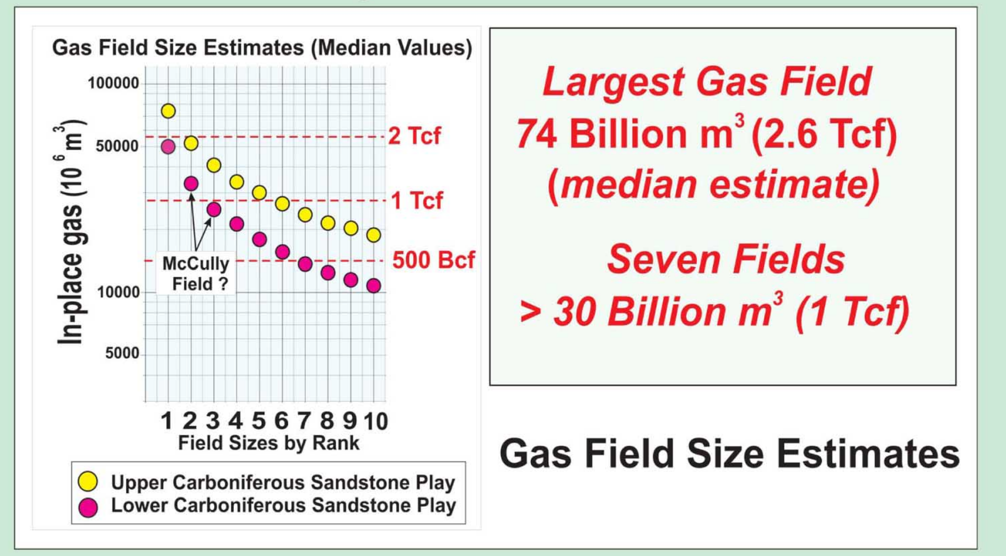


Figure 26 - Gas Field Size Estimates (10 largest)