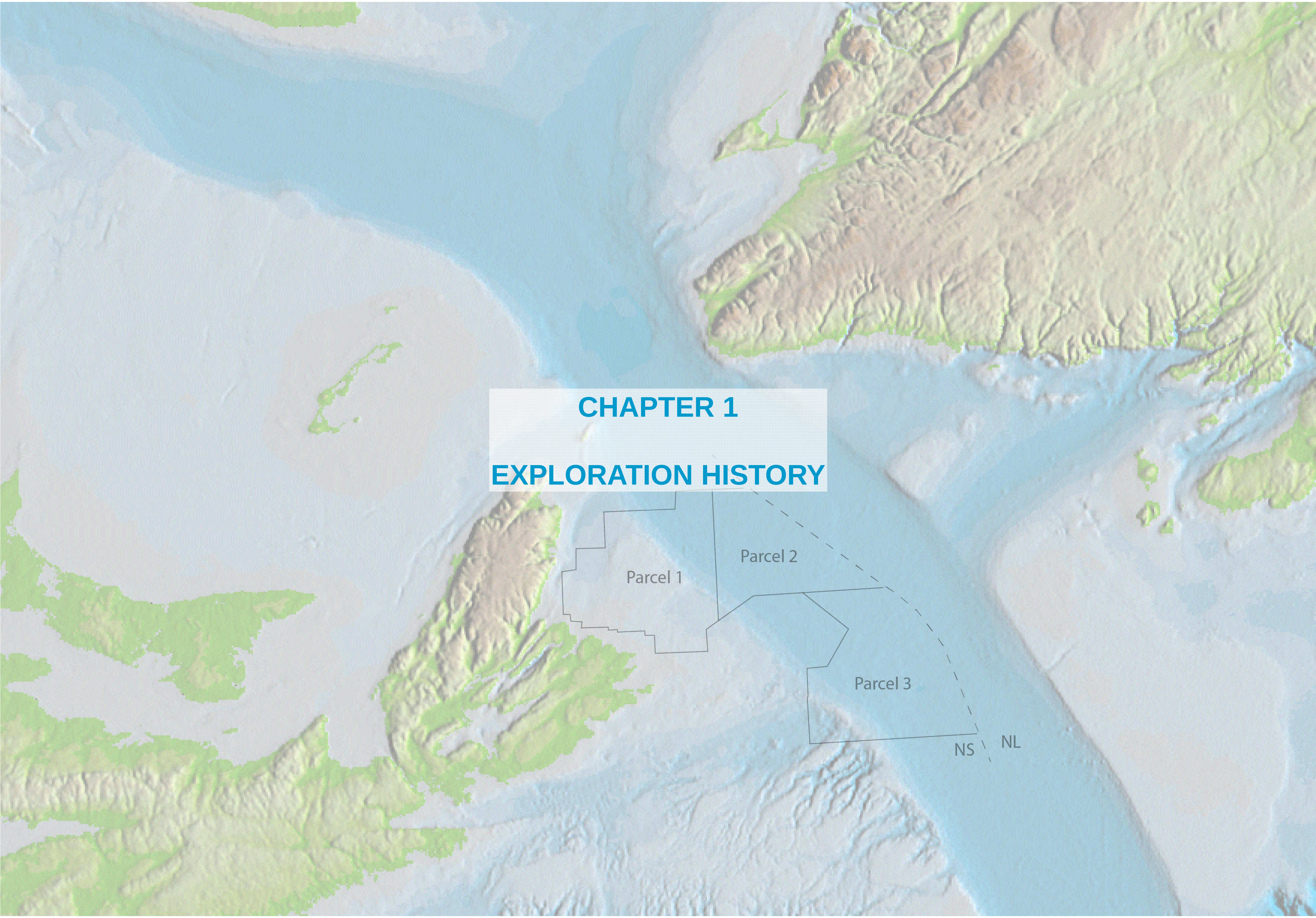
CHAPTER 1

EXPLORATION HISTORY



Exploration History

The first oil well in the world

Eastern Canada is one of the oldest explored and exploited oil provinces in the world. The first oil producing well in the world was actually completed in 1858 in the township of Enniskillen near the town later named Oil Springs in southwest Ontario. The well was drilled by asphalt producer James Miller Williams who created the first North American oil company. His company became known in 1860 as the Canadian Oil Company (Habashi, 2000; see also http://www.lambtonmuseums.ca/oil/). The effort for oil and gas exploration expanded across the eastern provinces, with New Brunswick starting its exploration program in 1859 (Figure 1), the same year Edwin Drake made his discovery in Titusville, Pennsylvania for Standard Oil (Ginsberg, 2009).

Stoney Creek field case

The first well in New Brunswick was completed in 1859, but it was not until 1909 that the first commercial discovery was made by Maritime Oilfields Ltd. (MOL) in what would become the Stoney Creek field. The discovery was made in the Albert Sandstone Formation of the Horton Group (Figure 4), and from 1909 to 1991 it has produced **800,000 bbl of oil and 28.7 bcf feet of gas** (Figure 3). As of today, Stoney Creek is the largest onshore oil and gas field in eastern Canada and estimates suggest that the Horton reservoir has produced only 5% of its commercial volumes.

From very early on, Stoney Creek has been considered as a tight sand and shale oil and gas field. To allow production, reservoirs were stimulated with nitroglycerin (Figure 2). But here is a paradox; Stoney Creek reservoir petrophysical properties are quite good with a reservoir 900 m deep, 33 m thick with average porosity and permeability of respectively 18% and 160 md (Enachescu, 2006a). Similar values have been reported from Irving/Chevron East Stoney Creek 1 well, as well by Chowdhurry and Noble (1992) and Contact Exploration Inc. (Kicking Horse) in 2010 (St Peter, 2000). Some of the porosity values were obtained from core plugs and density logs (Chowdhurry and Noble, 1992). Although reservoir values are good, the need for hydraulic stimulation suggests a highly compartmentalized reservoir system with less reservoir connectivity than what is known or expected (Figure 3).

Available information suggests that reservoir properties are good locally, but overall diagenesis significantly impacts reservoir quality, explaining the need for hydraulic stimulation to reach commercial production.

Figure 1: First Oil and Gas wells in Atlantic Canada (from Lavoie et al., 2009)

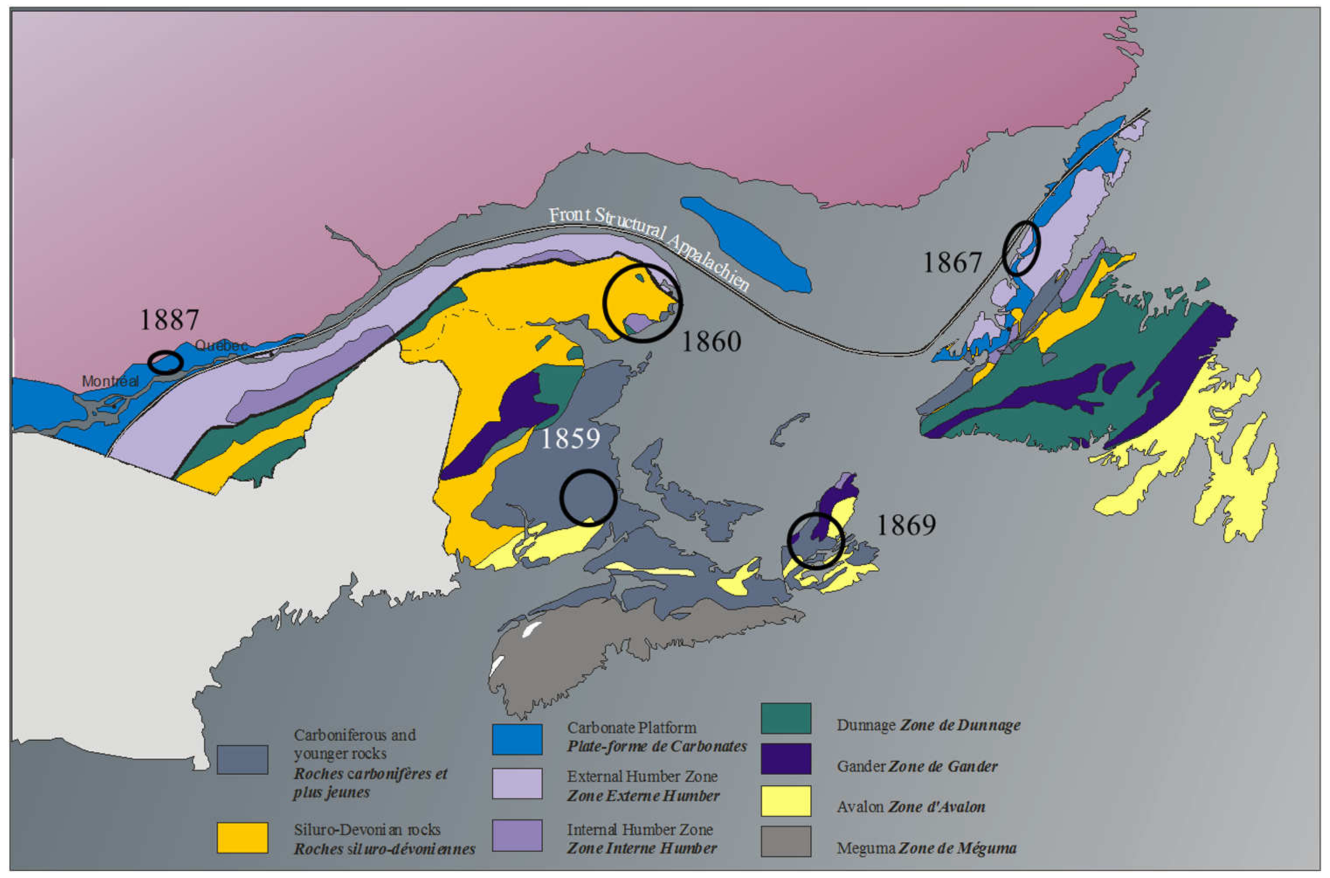


Figure 2: Fracturing Stoney Creek Field well with nitroglycerin, circa 1940 (Photo from St Peter, 2000).

Figure 3: Annual oil and gas production of Stoney Creek field from 1911 to 1991 (St Peter, 2000)

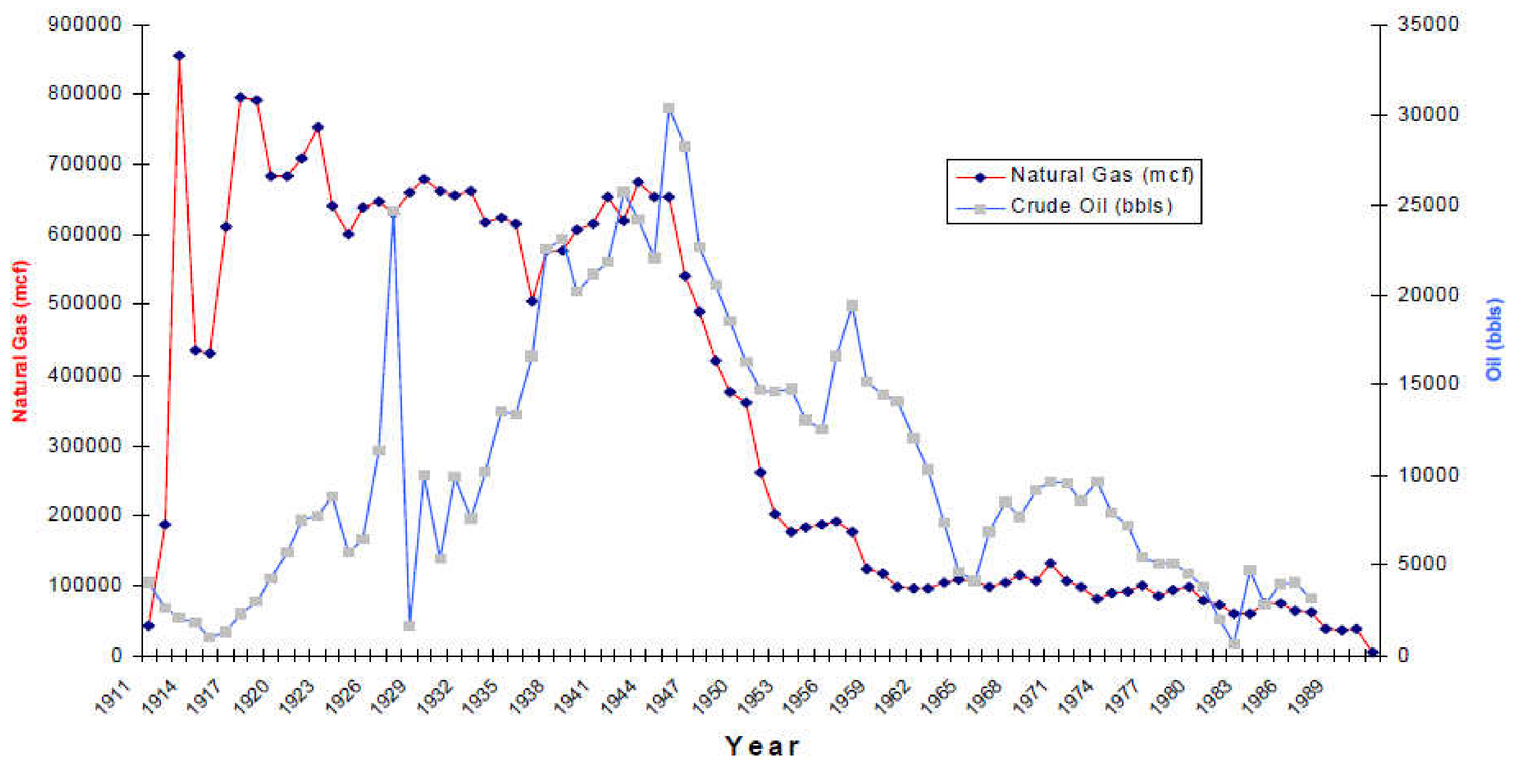
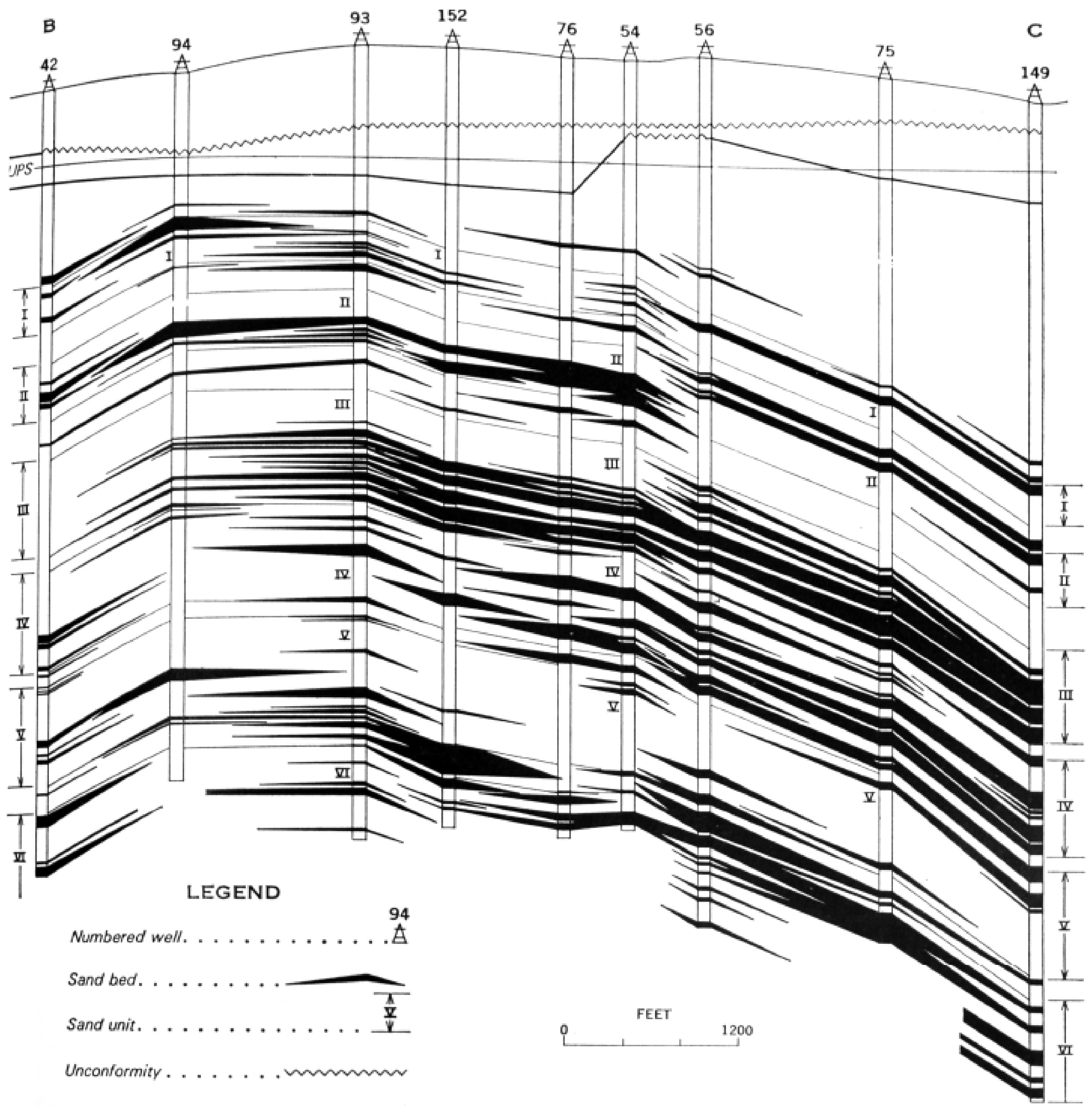


Figure 4: Cross section of Stoney Creek field showing distribution of sandstone in Albert Formation (Horton Group) (Howie, 1968).

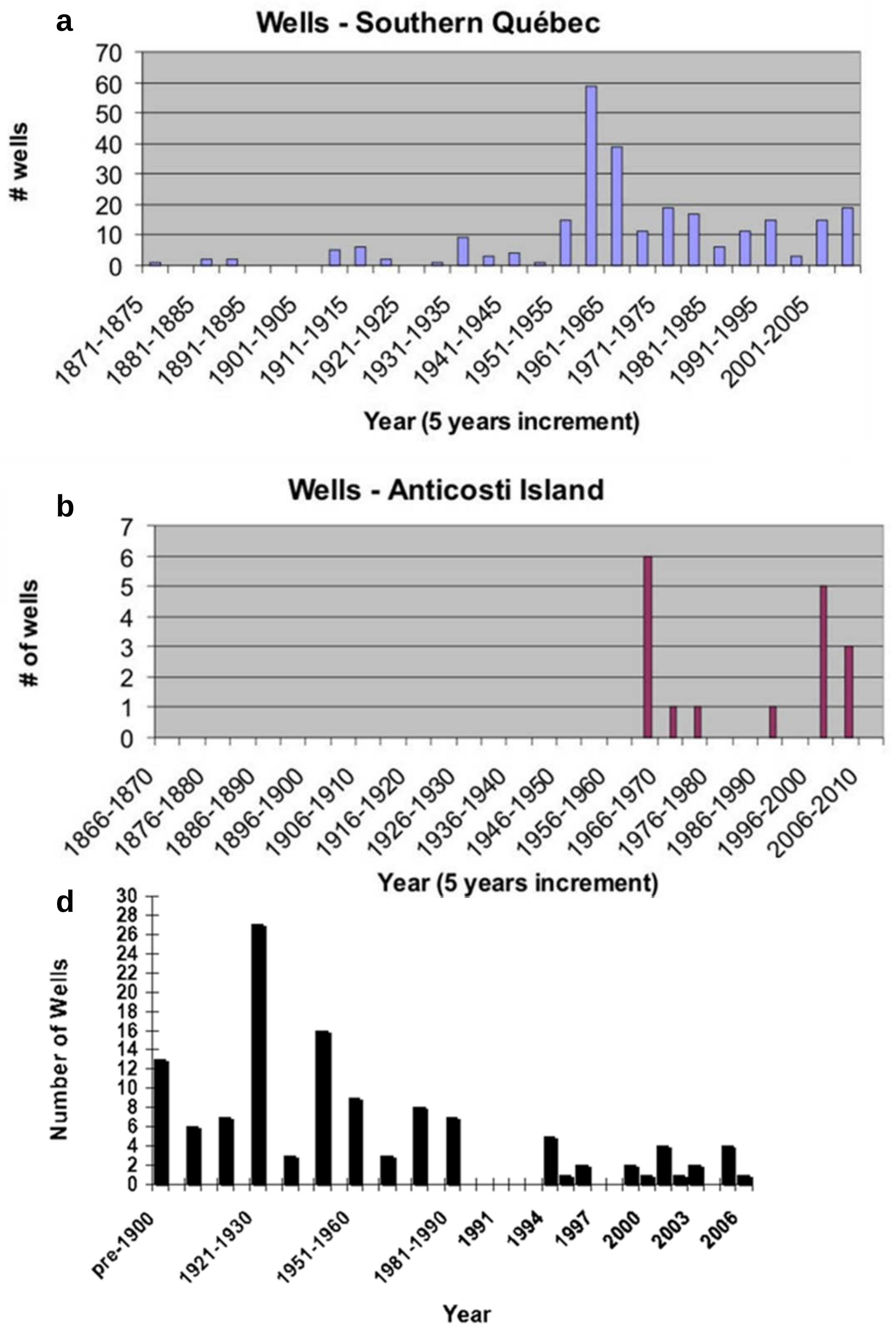


Maritime provinces exploration history: 1860 - 2000

From 1859, exploration expanded from New Brunswick to the rest of the province. Drilling started in 1860 in Quebec, 1867 in Newfoundland and 1869 in Nova Scotia (Figure 1). The first exploration wells in Quebec targeted Ordovician to Devonian plays due to reports of oil seeps from Devonian rocks (Lavoie et al., 2009). All wells had hydrocarbon shows but failed to reach commercial production. 75 years later, drilling activities sharply declined in the area. In 1887, 4 wells made small commercial discoveries in Quaternary reservoirs in the Trois Rivières area, and between 1905 and 1907 economic production was achieved (Lavoie et al., 2009).

In Newfoundland, both Carboniferous and pre-Carboniferous plays were targeted. By the early 1900s, minor oil production was achieved at Parsons Pond on the Ordovician carbonate platform (Enachescu, 2006a; Lavoie et al., 2009). Discovery of oil led a number of individuals and small companies to drill for oil all across western Newfoundland, but production was always sub-economic (Hicks, 2007; Lavoie et al., 2009).

Despite early exploration phases, particularly in the 1960s and 1970s, oil and gas exploration in the St Lawrence, Maritimes and Sydney Basins remained at an early stage (Figure 5). In the Québec Appalachians, 354 wells were drilled from 1860 to 2005 (Lavoie et al., 2009). In Newfoundland from 1867 to 2007, at least 85 wells were drilled, among them 62 prior to 1989 (Figure 5). New Brunswick provincial records suggest 322 wells have been drilled since 1908 in the Maritime and Fundy basins. Most of these wells were drilled prior the 1980s for potash and mining purposes (information provided on New Brunswick Energy department website: http://www2.gnb.ca/content/gnb/en/departments/erd/energy/content/minerals.html). Of these wells, 156 were drilled by New Brunswick Gas and Oilfield Ltd. (NBGO) up to 1940, within which 27 were exploratory and 99 production wells (St Peter, 2000). From those 99 production wells, 73 were producers in the Stoney Creek field. Although the number of wells drilled since 1908 seems significant, it's to be noted that only 80 wells have been drilled since 1990 (New Brunswick Natural Resource Department). In the Magdalen Basin, 10 wells were drilled offshore between 1942 and 1996. The Nova Scotia wells inventory shows there are 139 official exploration wells recorded for its onshore, but no production wells (https://data.novascotia.ca/Environment-and-Energy/Onshore-Petroleum-Wells/5q4c-27fh). There were an additional 20 or so coal bed methane wells drilled in the Stellarton region that are not included in the official count. Its offshore counterpart, the Sydney Basin, is the least explored part of the Eastern Canada Paleozoic basin, with only 3 wells drilled between 1974 and 1983 (Figure 5 and table 1). Of these 3 wells, all failed to reach their targets due to misunderstanding of basin architecture and underestimation of targeted depths.



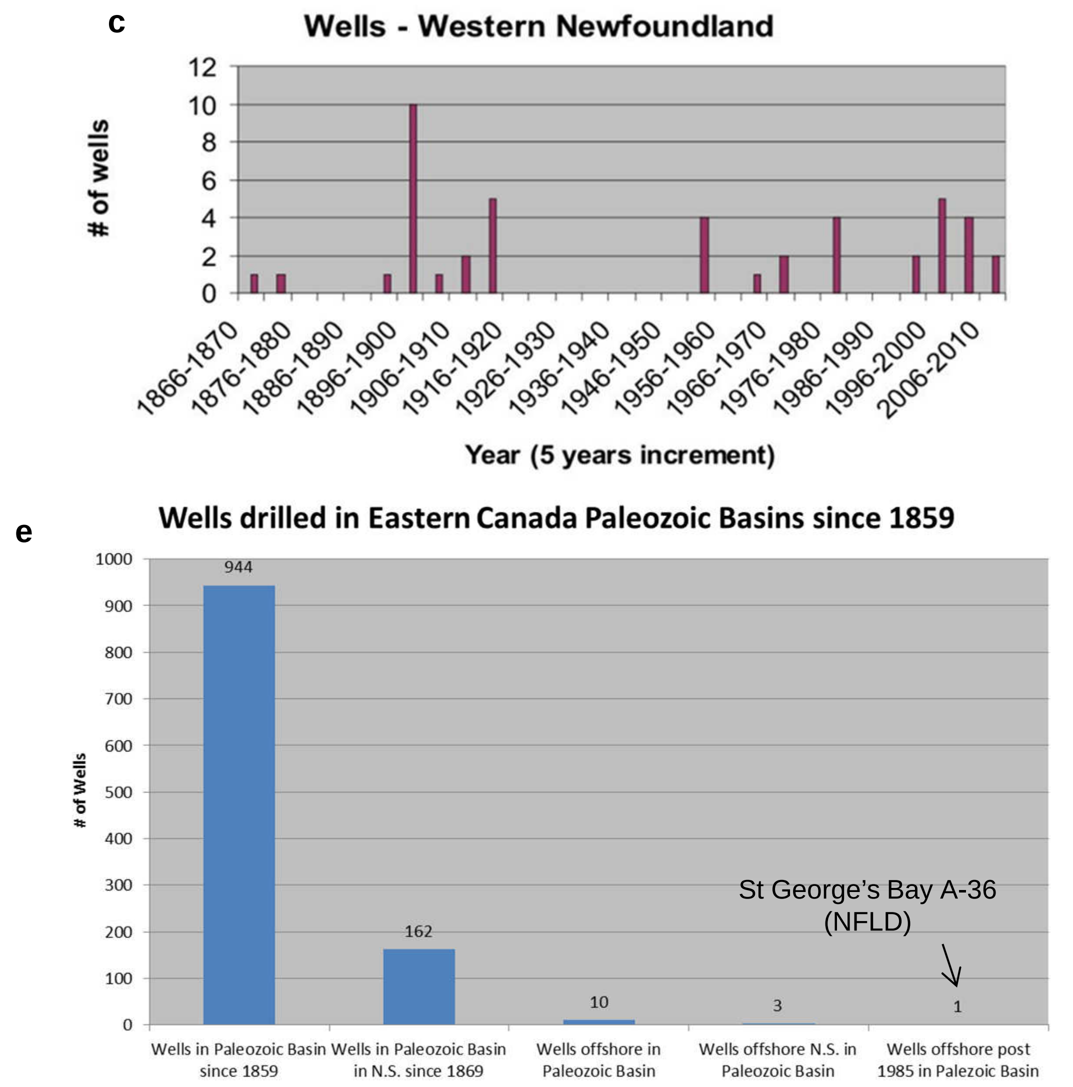
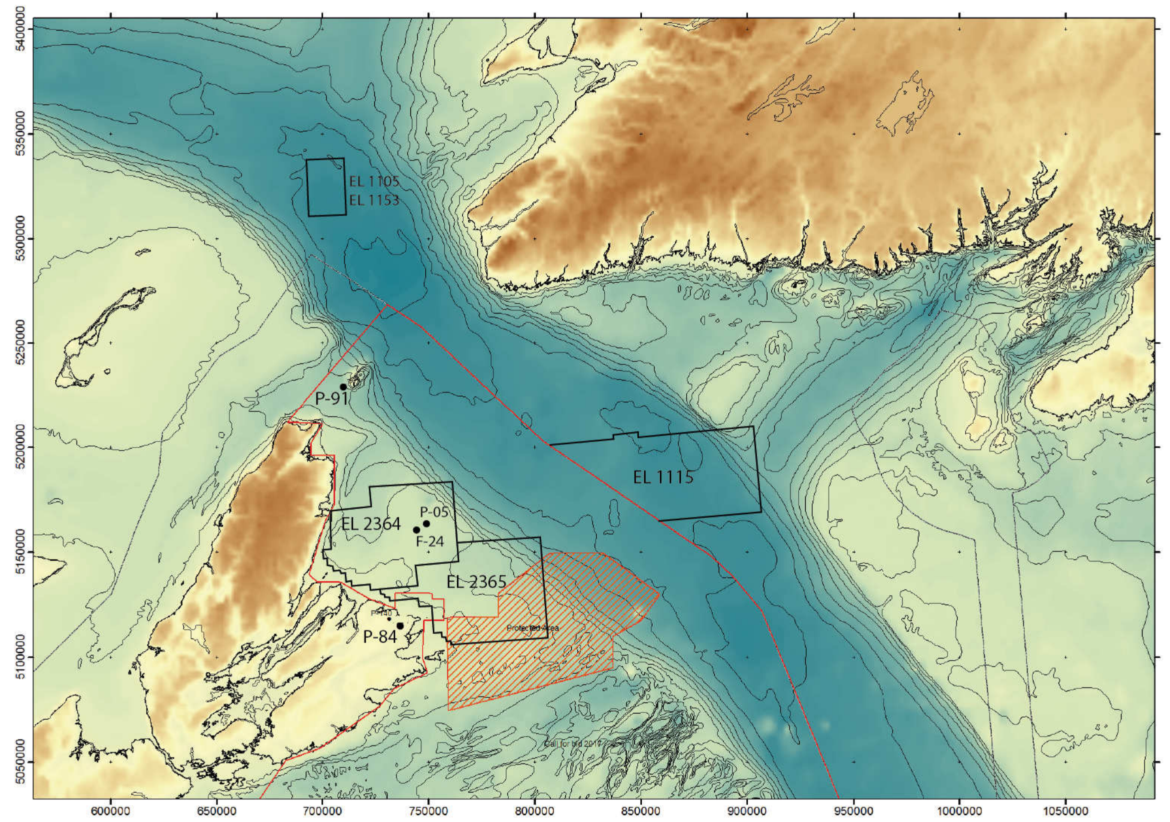


Figure 5: Number of wells drilled in Southern Québec (a), Anticosti Island (b), Western Newfoundland (c) (from Lavoie et al.); d) Number of wells drilled onshore Nova Scotia; e) number of wells drilled in Eastern Canada Paleozoic basins since 1859. Numbers are based on available data at the time of this PFA in 2017. It is possible that the number of wells is under estimated, particularly for the pre 1970s period. (Sources: Kendell and Harvey, 2006; Lavoie et al., 2009; Enachescu, 2013; Nova Scotia Department of Energy)

Maritime provinces exploration history: 2000 – 2017

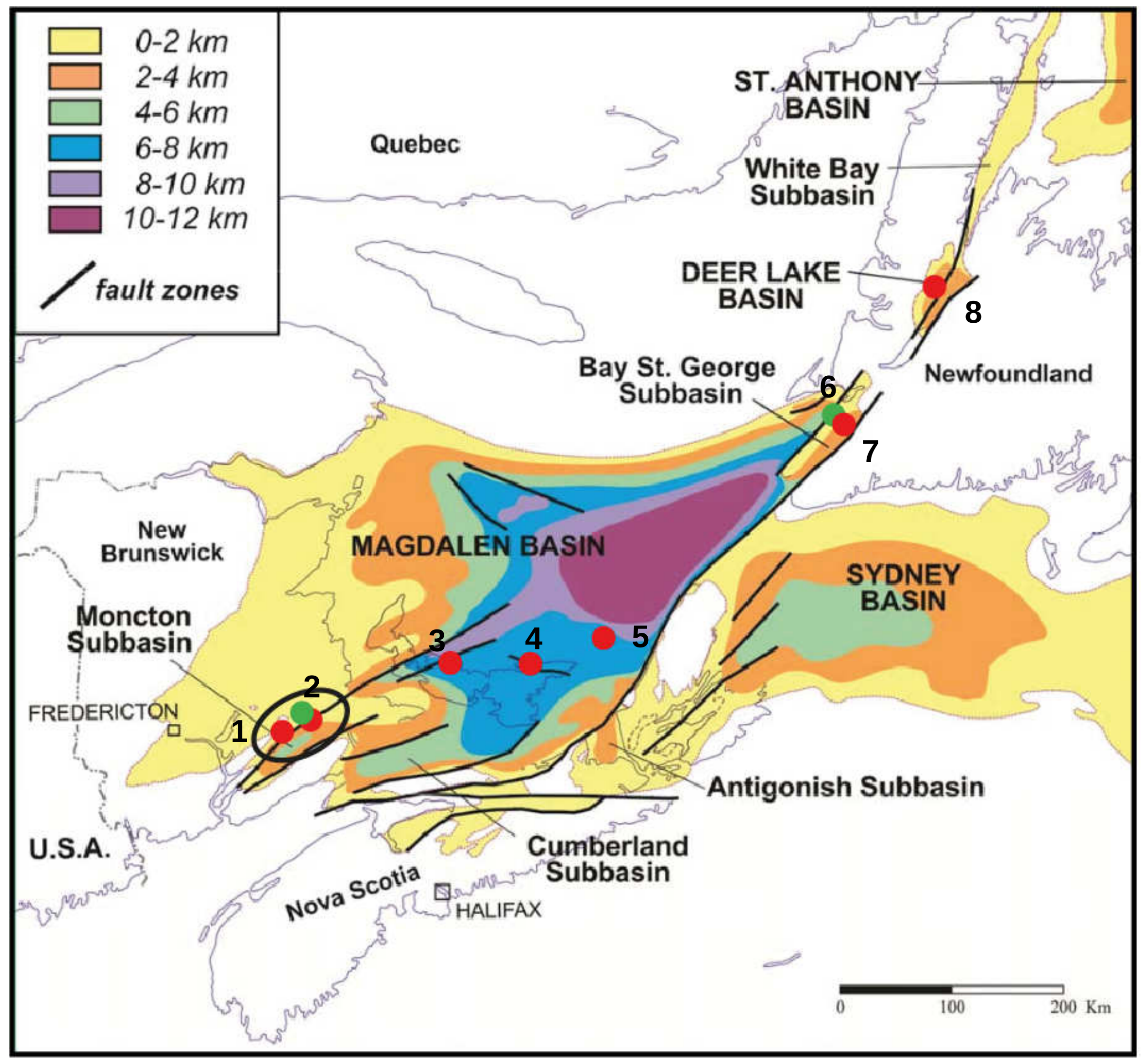
Interest in the Paleozoic basin of the Maritimes renewed in the late 1990s. The interest followed the 1996 Flat Bay 1 well discovery in the Bay St George area of Western Newfoundland (Figure 6). The well encountered bleeding oil from porous laminations in the limestone of the lower Windsor, as well as from the Anguille conglomerate (Horton). Free oil was circulated to surface (Brett, 1997). Additional wells failed production tests although minor live oil was observed weeping out fractures (Laracy, 2012). Since 2000, Elmworth Energy began to explore for shale gas in the Windsor Basin (Nova Scotia) and drilled Kennetcook #1 among others, which had gas flowing out after fracking the reservoir. As exploration for unconventional O&G plays was gaining momentum in 2014, moratoriums on hydraulic fracturing were enacted in New Brunswick, Nova Scotia and Quebec. In the meantime, exploration continued in Western Newfoundland. Robinson 1 and Red Brook 2 wells in 2009 drilled by Vulcan Mineral Inc. and InvestCan Energy Corp targeted a Horton Gp play. Both encountered gas in tight sandstone reservoirs which were successfully tested (Figure 6). Plans were made for stimulating natural fracturing, but this does not seem to have occurred.



The Sydney Basin remained off the radar until the late 1990s after failed drilling attempts in 1974, 1976 and 1983 in Nova Scotia waters. The Newfoundland side of the Sydney Basin wasn't explored until the early 2000s. Part of the delay in exploring the Newfoundland side was due to an international boundary dispute between Canada and France that lasted for over 25 years (Enachescu, 2006a and b). In 1998, Hunt Oil licenced two large blocs, EL 2364 and EL 2365, offshore from Cape Breton, Nova Scotia (Figure 7). Work commitments for each parcel were around 2.165 M$ with initial work focused on seismic acquisition and interpretation (http://www.cnsopb.ns.ca/sites/default/files/pdfs/IA-2364.pdf). 2D seismic was acquired in 2005 and interpreted in 2006, but unfortunately no drilling followed due to lack of partners. The licenses expired in 2007 and were subsequently surrendered to the province. In the meantime, exploration activity continued in western Newfoundland.

Figure 7: Location of acquired parcels as of 2008. The only remaining active licence in 2017 belonged to Corridor Resources Inc. (EL 1153)

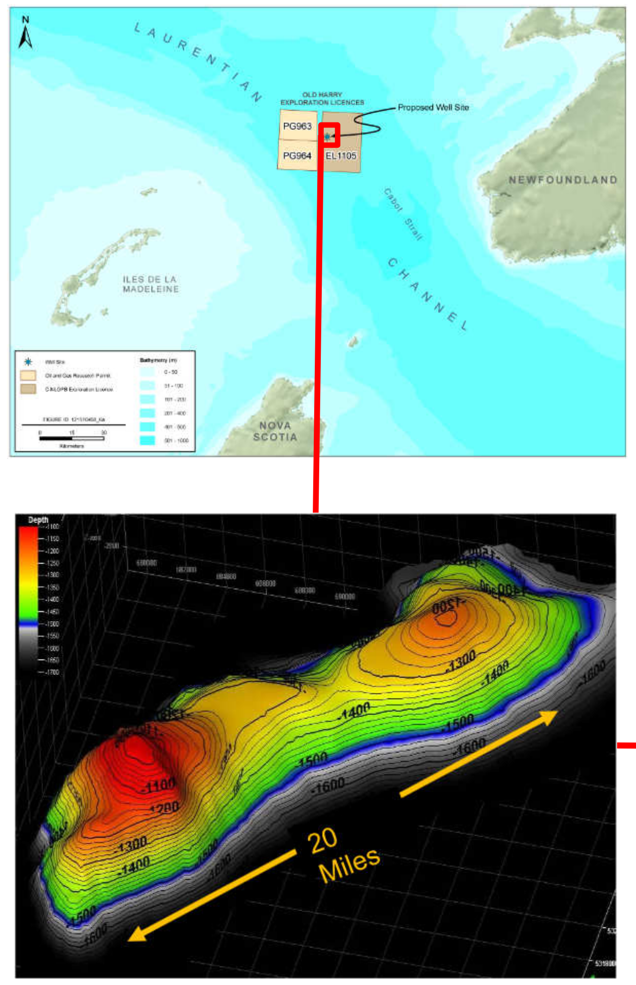
Figure 6: Oil (green) and Gas (red) discovery in Paleozoic basin. Only Moncton Subbasin has two producing fields: Stoney Creek and McCully fields (black circle. Isopach map from Lavoie et al., 2009). 1) McCully field, 2) Stoney Creek field, 3) Green Gable 2, 4) Naufrage 1, 5) East Point E-49, 6) Flat Bay 1, 7)Robinson 1), 8) Western Adventure 1. It's to be noted that all discoveries are made along the same structural trend. Wells in Bay St. George and Moncton are in the Horton Gp whereas wells 3 to 5 are in the Cumberland/Pictou Gp.



At that time, one of the difficulties in the exploration industry was the reliance on numerous but scattered information on Paleozoic petroleum basins. Work by Kendell (2005), but mostly Enachescu (2006 and 2008) for CNLOPB in support of NL06-2, NL08-3 and NL08-4 calls for bid, were the first comprehensive petroleum exploration studies in decades. A regional overview was completed in 2009 by Lavoie et al of the Geological Survey of Canada, and provided the largest overview of petroleum potential from Anticosti Basin to Sydney Basin. This overview included not only Carboniferous plays, but also Ordo-Silurian and Devonian plays.

Following these studies, two companies took an interest in the Sydney Basin in 2008. Husky Energy Inc. acquired parcel 1115 in Sydney Basin for 1.8 M$C and conducted a 2D survey in 2010 (Figure 7). Unfortunately, the parcel was primarily licensed as a potential go-to drilling location in the event that bad ice conditions interrupted Husky operations on the Grand Banks, and was later released (Husky Energy Inc., 2010).

Corridor Resources Inc. acquired block EL 1105 in Magdalen Basin (Figures 7 and 8), which became block 1153 after drilling authorisation was granted by Newfoundland in January 2017. The targeted prospect is called 'Old Harry' and corresponds to a large structure of about 30 km long and 12 km wide (Figure 8) at the border between Newfoundland and Quebec (Two additional licences were issued by the Quebec government as well). Based on company estimates, it is interpreted as the largest undrilled geological structure in eastern Canada with 43,000 acres under simple four-way closure (Figure 8). Corridor Resources Inc. announced that Old Harry has the potential to contain light oil (45-56 API gravity) and/or natural gas. They have observed several direct hydrocarbon indicators such as satellite seepage slicks or AVO anomalies (https://www.corridor.ca/core-operating-areas/old-harry/).



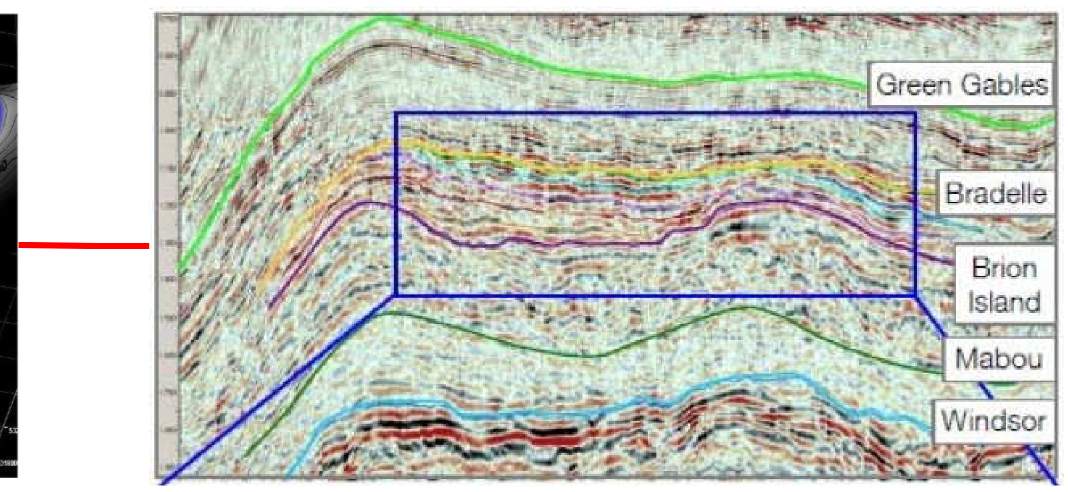


Figure 8: Old Harry prospect identified by Corridor Resources Inc. which obtained clearance for drilling in January 2017 (Enachescu, 2011; Corridor Resources Inc. 2017). The prospects are large carboniferous salt induced structures, and targeted reservoirs are probably the Westphalian C sands of the Bradelle Fm. Six oil seeps have been observed from satellite imagery.

Examples of targeted plays between 1972 and 2016

Geographic Location	Basin	Plays	Well Name	Year/Period	Hydro Carbon Type	Status	Reservoir type	Reservoir Stimulation	Company	Observation
P.E.I	Magdalen basin	Pictou (Cable Head & Bradelle Fms)	East Point E49	1974	Gas	Uneconomic discovery	Low porosity sandstone associated with Coal beds	Low natural flow	BP Canada Energy	Offshore Well
		Pictou (Bradelle Fm) & Mabou	Green Gable 2	1997	Gas	Tested but flow rates non commercial;	Low porosity sandstone	In 2006, plan for reservoir stimulation but didn't happen	Corridor Resources Inc.	Onshore Wells
		Pictou (Bradellle Fm)	Naufrage 1	1975	Gas	Only shows in DST	Low porosity sandstone	Non Applicable	SOQUIP et al.	
New Brunswick	Moncton Sub-basin	Horton/Lower Windsor	Hillsborough 1(different from the Hillsborough 1 well drilled offshore in 1943 by Is land Development Co.)	1985 (1981-1992)	Gas	Sub-commercial discovery; Plug and abandoned in 1993	Sandy conglomerate	Information unavailable for the study	Chevron & Irving Oil	Onshore Wells
		Horton	Downey 1	1997 - 2000	Gas	Discovery	Information unavailable for the study	Information unavailable for the study	MariCo O&G exploration	
			L44	2001	Oil	Discovery; Tested production then shut-in	Information unavailable for the study	Information unavailable for the study	Columbia Canada Natural Resources Limited & Corridor Resources Inc.	
			McCully A-67	2001 (2001 – 2017)	Gas	Commercial Discovery; Producing field	Tight sandstone	Natural flow; Hydraulic fracturation; EOR	Corridor Resources Inc. & Potash Corporation	
			TV 2 and AM 4	1997 - 2000	Oil	Unknown	Information unavailable for the study	Information unavailable for the study	MariCo O&G exploration	
Newfoundland	Western Newfoundland basin (Parson's Pond)	Lower Ordovician	Port au Port 1	1995	Oil and Gas	Sub-economic production	Lower Ordovician tight Dolostone	Low natural flow	Hunt Oil & PanCanadian	Onshore Wells
	Deer Lake basin	Visean Rocky Brook Fm (Windsor eq.)	Western Adventure 1	2000	Gas	Tested; no production	Sandy Conglomerate	Natural flow	Deer Lake Oil & Gas (Since 2014 Black Pruce Exploration Corp.)	
	Bay St Georges basin	Horton	Flat Bay 1	1996 (1996 – 2012)	Oil	Tested; no production	Tight sandstone and conglomerate	Bleeding oil and live oil noted; no more details available	London Resources Inc. then Vulcan Mineral Inc. and Investcan Energy Copr.	
			Red Brook 2	2009 (2006 – 2009)	Gas	Tested; no production	Fractured sandstone and conglomerate	Low natural flow; Plan for reservoir stimulation, but didn't happen	Vulcan Mineral Inc. and Investcan Energy Corp.	
			Robinson 1	2009	Gas	Gas shows in DST; Tests failed	Tight sandstone	No flow; Plan for reservoir stimulation, but didn't happen		
Nova Scotia	Sydney basin	Windsor (revisited in 2017 as being Mabou)	Birch Grove 1/P-84	1968	None	No shows; Tests failed	Fine to coarse sandstone	Non Applicable	Murphy Oil Company ltd et al.	Onshore Wells
		South Bar (Windsor and Horton targeted but not reached)	North Sydney P-05	1974	Gas (oil?)	Little Shows; No test	Tight sandstone	Non Applicable	Murphy Oil Company ltd et al.	Offshore Wells
		South Bar	North Sydney P-24	1976	Gas (oil?)	Shows; Tests failed	Tight sandstone	Stimulation with Acid	Shell el al.	
		Windsor (Horton targeted but not reached)	St Paul P-91	1983	None	No Shows; No test	Tight sandstone	Non Applicable	Petro-Canada	
Quebec	Gaspé Belt	Lower Silurian & Lower to Mid Devonian	Galt 1, 3 and 4	2012 - 2016	Heavy Oil, Light Oil, Gas	Application for production lease in 2016	Mid Devonian Sandstone; Lower Devonian tight Limestone	Low natural flow, natural fracturation, No stimultation yet	Junex	Onshore Wells
	Lower St Lawrence (Appalachian structural front and Humber zone)	Lower to Mid Ordovician	Gentilly 1 & St Edouard 1	2007 and 2009	Gas	Tested but no production	Lower – Mid Devonian hydrothermal Dolostone	Low natural flow	Talisman Energy	
		Middle to Upper Ordovician Utica Shale	Gentilly 1	2008	Gas	Tested but no production	Shale	Fracturation	Talisman Energy	
		Lower Ordovicien	St Flavien 1	1972 (1972 – 1994)	Gas	Depleting field	Lower Ordovician tight dolomite; natural vuggy porosity and fractures	Information unavailable for the study	Shell then SOQUIP et al.	

*Table 1: **Non exhaustive assessment of discoveries and hydrocarbon shows** in the St Lawrence and Maritime basins. The objective here is to highlight the potential for discovery and the different targeted plays (Sources: Bélan and Mroin, 2000; Enachescu, 2006; Enachescu, 2008; Lavoie et al., 2009; P.E.I Department of Energy; St Peter and Hinds, 2007)*

A working Carboniferous petroleum system; Reservoir issues

Evidence for Oil and Gas:

Evolution of exploration in Carboniferous basins is highly variable across Nova Scotia. Hunt Oil and Husky Energy Inc. dropped interest in Sydney Basin although there was evidence for oil and gas seeps in the Scotian side of the basin (Figure 9a and 9b). At the same time, western Newfoundland saw an increase in exploration activity, particularly in Carboniferous basins (Figure 10). Although exploration wells were successful, it appeared that commercial production could not be reached without reservoir stimulation. In New Brunswick as well, drilling was successful with the discovery of McCully field in 2000 (production started in 2003), and the rebirth of Stoney Creek field production by Contact Exploration Inc. in 2007. New estimates from Contact Exploration Inc. give reserves around 1.207 Mbbls of oil and 6.5 bcf gas assigned.

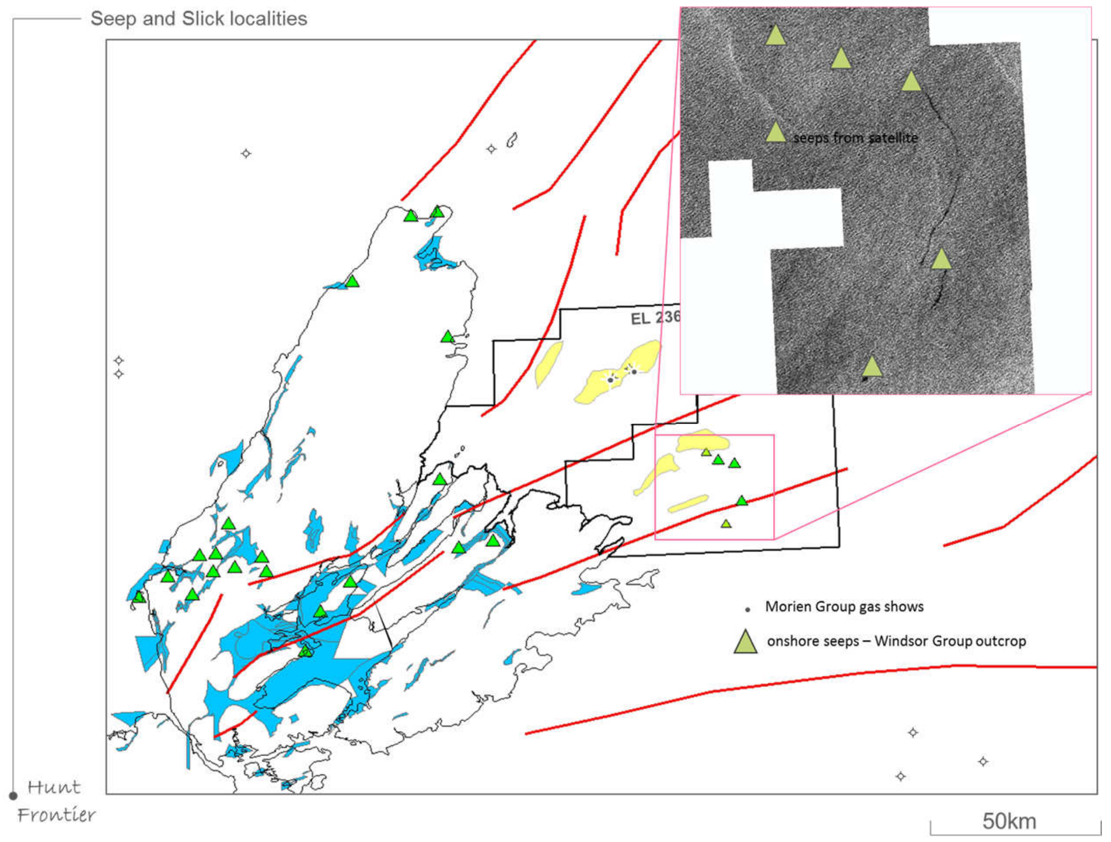


Figure 9a: Distribution of offshore seeps from satellite imagery. Onshore seeps from Windsor Group are also located (From Harvey, 2009)

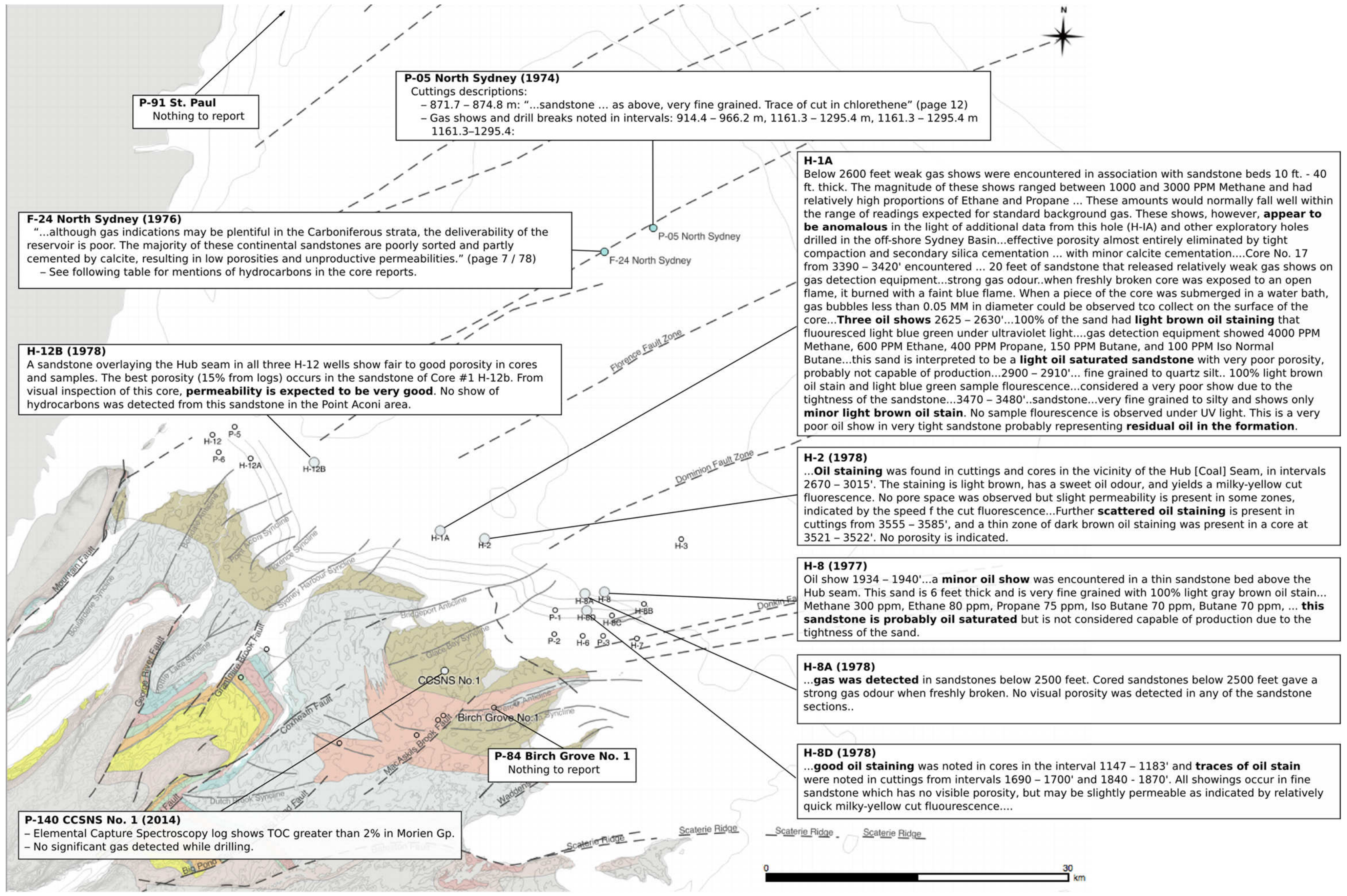


Figure 9b: Distribution of oil and gas shows from onshore and offshore well cores. Wells named H-x are coal wells (courtesy Nova Scotia Department of Energy)

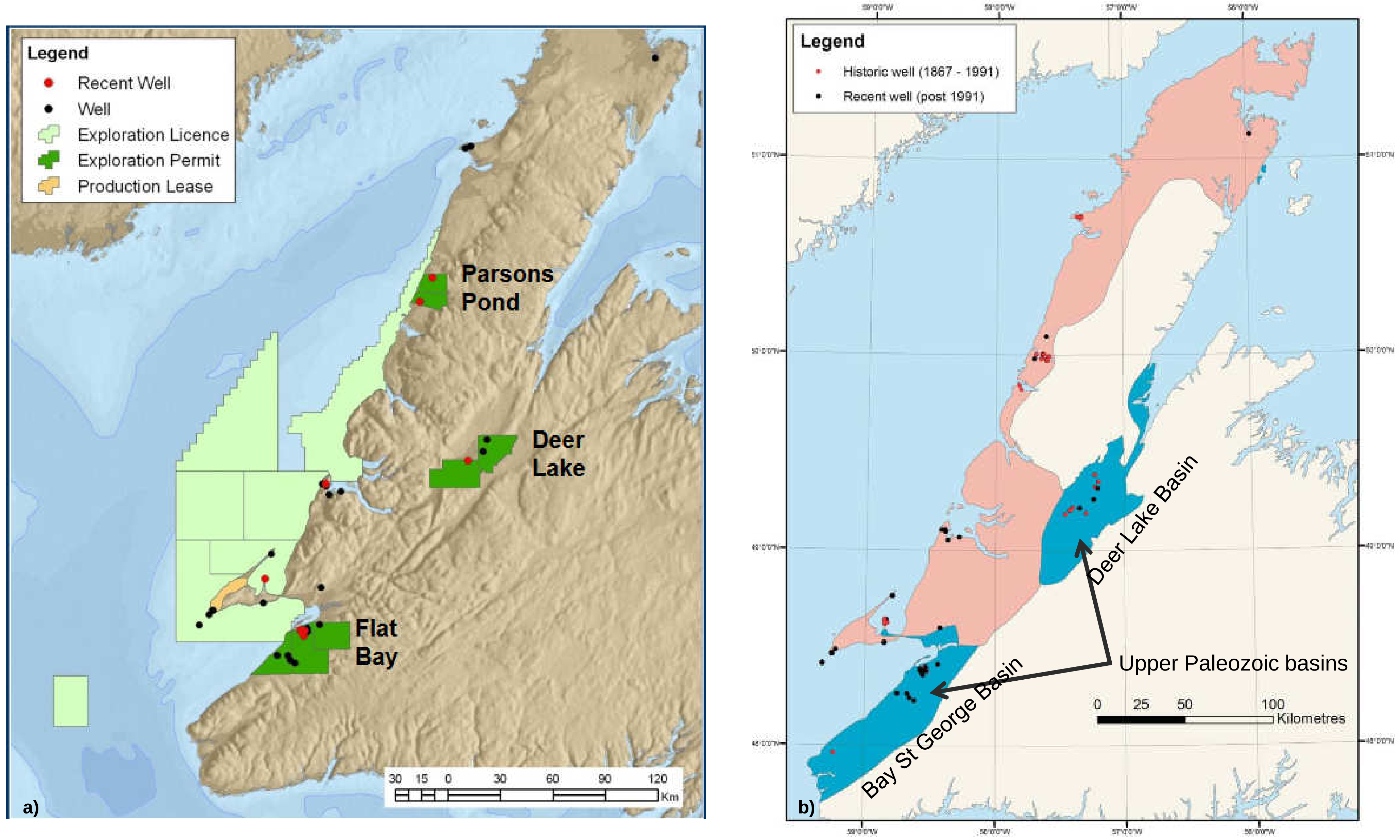


Figure 10: a) Distribution of the different type of blocks and their associated recent wells. Active exploration permits are predominantly in Carboniferous basins except Parson's Pond which doesn't have Carboniferous sediment. b) Distribution of historic wells from 1867 – 1991 in red, vs recent wells in black (post 1991). It is to be noted that most of the wells post 1991 are in Carboniferous basin (Hogg et al., 2015; NL Department Natural Resources 2012 at http://www.noia.ca/Portals/0/3-Foote.pdf).

The McCully field case

The McCully field is located 10 km northeast of Sussex, New Brunswick in the farming community of Penobsquis (Figure 11). The McCully field was discovered in 2000 by Corridor Resources Inc. and the Potash Corporation of Saskatchewan with the first well drilled and production started in 2007 (Corridor, 2016). The field produces dry gas from tight Carboniferous sandstone of the Albert Fm (1 barrel of condensate per million cubic feet of produced natural gas). Shale gas from the Frederic Brook Shale Fm (Horton Gp) has been tested as well (St Peter and Hinds, 2007). The field is covered by dense 2D line surveys and three 3D surveys have been shot covering about 97 km^2 (St Peter and Hinds, 2007). Although it is in a slightly different structural setting, McCully field is the best known Carboniferous petroleum system and so for now is the best analogue to Sydney Basin.

McCully gas development initially produced about 16 mmcfd gross from a 400 ha (12,000 acre) fractured anticline (Figure 11). In 2010, well N88 produced total fluid at rates between 100 bbls/day and 200 bbls/day, with oil cuts steadily improving to approximately 70%. Estimates in 2011 suggested that the structure contained about 438 Bcf proven and probable gas resource in tight Carboniferous sandstone. Additionally, an oil discovery (45º API oil) was made at the South Branch G-36 well, 3 km SE of McCully gas field (Enachescu, 2011). This area became the Caledonia oil field and was covered by a small 3D seismic program. A 67 Tcf undeveloped gross discovered resource was estimated in the Frederick Brook shale (Enachescu, 2011).

To date, 39 wells have been drilled in McCully field and all have encountered gas. Well fracturing techniques have been utilized to achieve optimum production from low porosity gas reservoirs (Hu and Dietrich, 2008) and Corridor considers that all wells in New Brunswick require hydraulic fracture stimulation to be commercially productive (Corridor, 2016). Since the moratorium on reservoir fracturing entered into effect in 2014, drilling and reservoir stimulation stopped and as a consequence, production began to decline (Corridor, 2016). In 2016, Corridor held an average working interest of 75% in 81,022 gross acres (60,976 net acres) in the McCully Field, which accounts for all of Corridor's current production (Corridor, 2016). Gross production from the McCully Field was approximately 7.7 mmscfpd (5.7 mmscfpd net) in December 2016 and 7.5 mmscfpd (5.8mmscfpd net) for the year ended December 31, 2016 (Corridor, 2016; Figure 11). In June 2017, a report from the Canadian Energy Research Institute recommended that the Atlantic provinces reevaluate the options regarding the moratoriums on hydraulic fracturing in light of potential economic outputs (Canadian Energy Research, 2017).

McCully field reservoir characteristics

The field produces gas from the Frederick Brook Member sandstones (Albert Fm of the Horton Gp). Although the field is on a fractured anticline, the petroleum trapping system has a significant stratigraphic component (Dietrich et al., 2011; Figure 11). Reservoirs are composed mainly of quartz and feldspars, with low permeability and low porosity due to diagenetic cementation rather than clay content (St Peter and Hinds, 2007). Clay coatings vary locally and in some reservoirs have frozen diagenesis potentially preserving some part of the reservoirs.

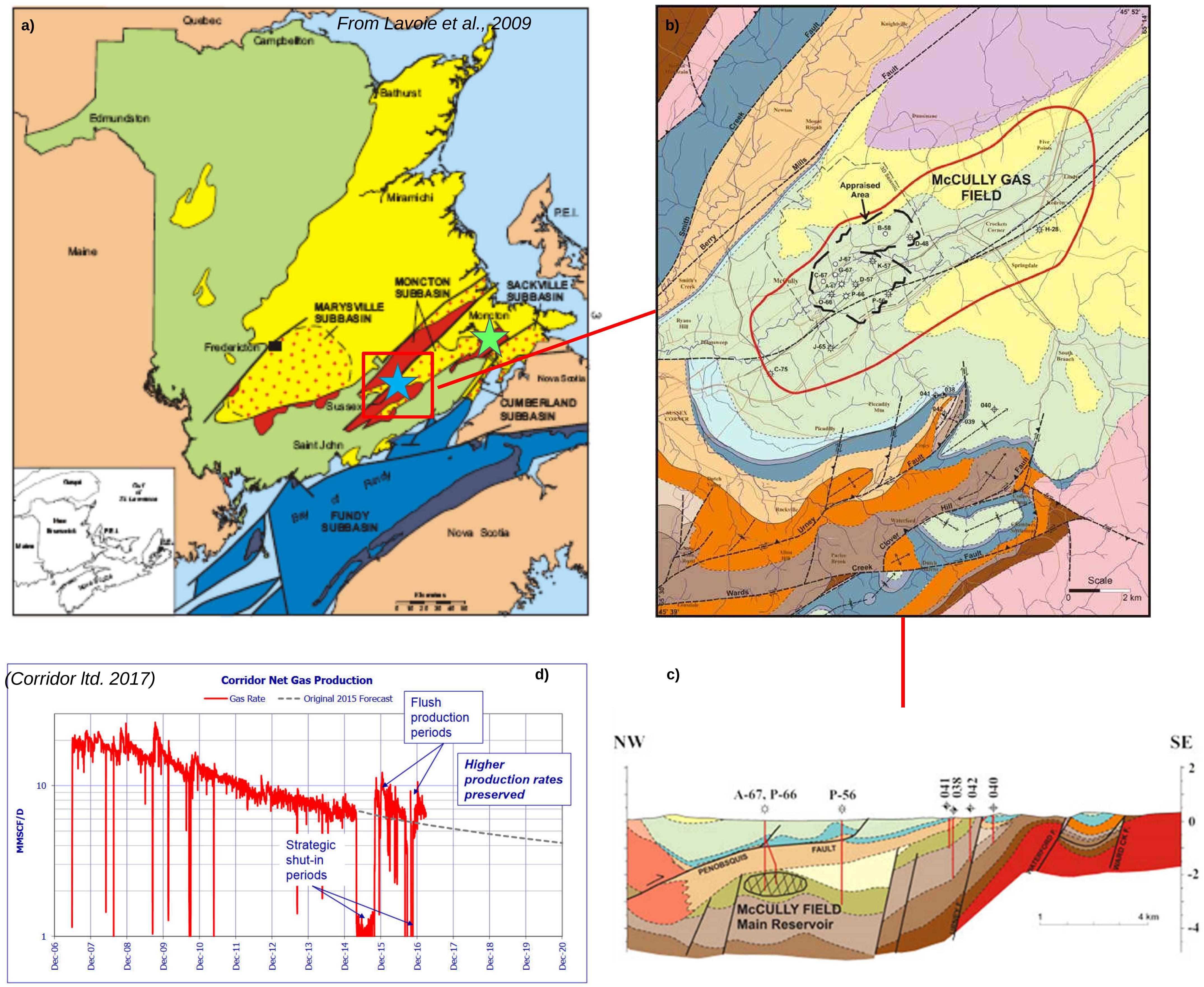


Figure 11: a) Location of McCully (blue star) and Stoney Creek (green star) fields; b) McCully field delineation and its appraised area; c) geological transect across the McCully field; d) Field production since December 2006 (from Lavoie et al., 2009; Corridor Resources Inc., 2017; Government of New Brunswick Energy and Resources Development Department)

Reservoir properties of targeted Carboniferous plays

Information regarding Carboniferous reservoir quality in eastern Canada is scattered and difficult to find. The most comprehensive synthesis was generated by Hu and Dietrich (2008). They focused their summary on five wells from the Magdalen Basin and one from the Sydney Basin (Figure 12).

Petrophysical interpretation

In the study, potential intervals were identified from the computed Net Pay based on petrophysical interpretations (Figure 13). The reliability of the petrophysical interpretation and the associated Net Pay may be questionable due to the vintage of the log data set and the lithological nature of some intervals. Old wells usually have a limited to very limited set of logs, which increases interpretation uncertainties. The occurrence of numerous coal beds within intervals can be a concern for an accurate petrophysical interpretation. If coal log responses are not correctly handled, the porosity and hydrocarbon saturation interpretation can be overestimated, which results in the misinterpretation of important net pay thickness.

Brion Island (Figure 14) has several intervals where the coal beds most probably impact the interpretation. The well test performed in Brion Island (DST#1 1471-1705,7) confirms the absence of Net Pay in this well and the possible bias of the petrophysical interpretation due to the occurrence of coal beds. The same observation can be made on the abundant coal intervals of East Point E-49 well.

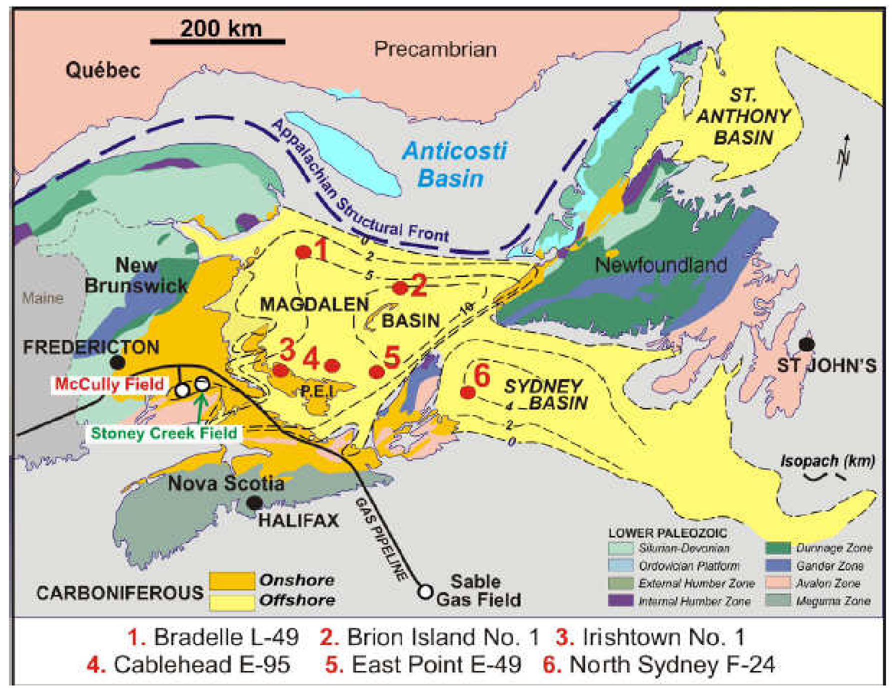


Figure 12: Petrophysical log analysis of part of the Cable Head E-95 well, illustrating a potential hydrocarbon zone according to petrophysical interpretation and associated computed Net Pay (Hu and Dietrich, 2008)

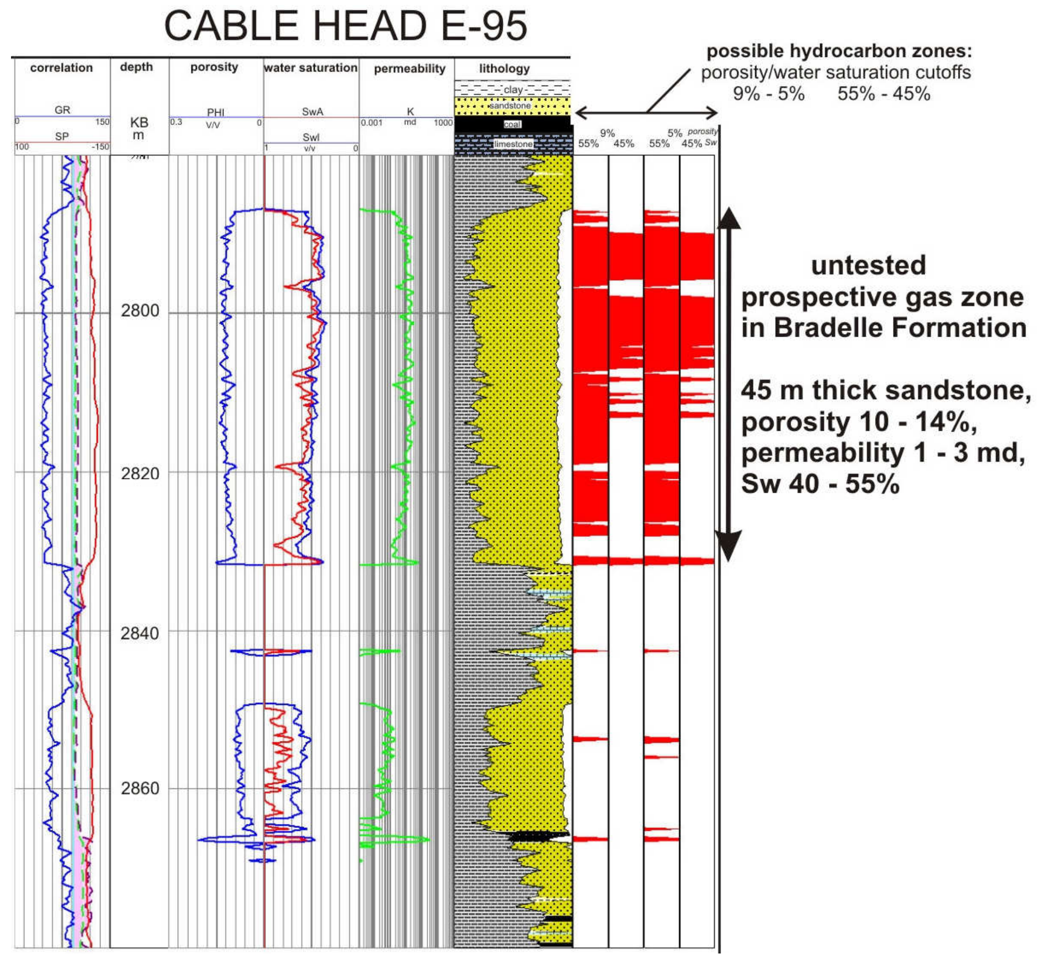


Figure 13: Well log analysis in the middle Bradelle Formation in the Cable Head E-95 well (Hu and Dietrich, 2008)

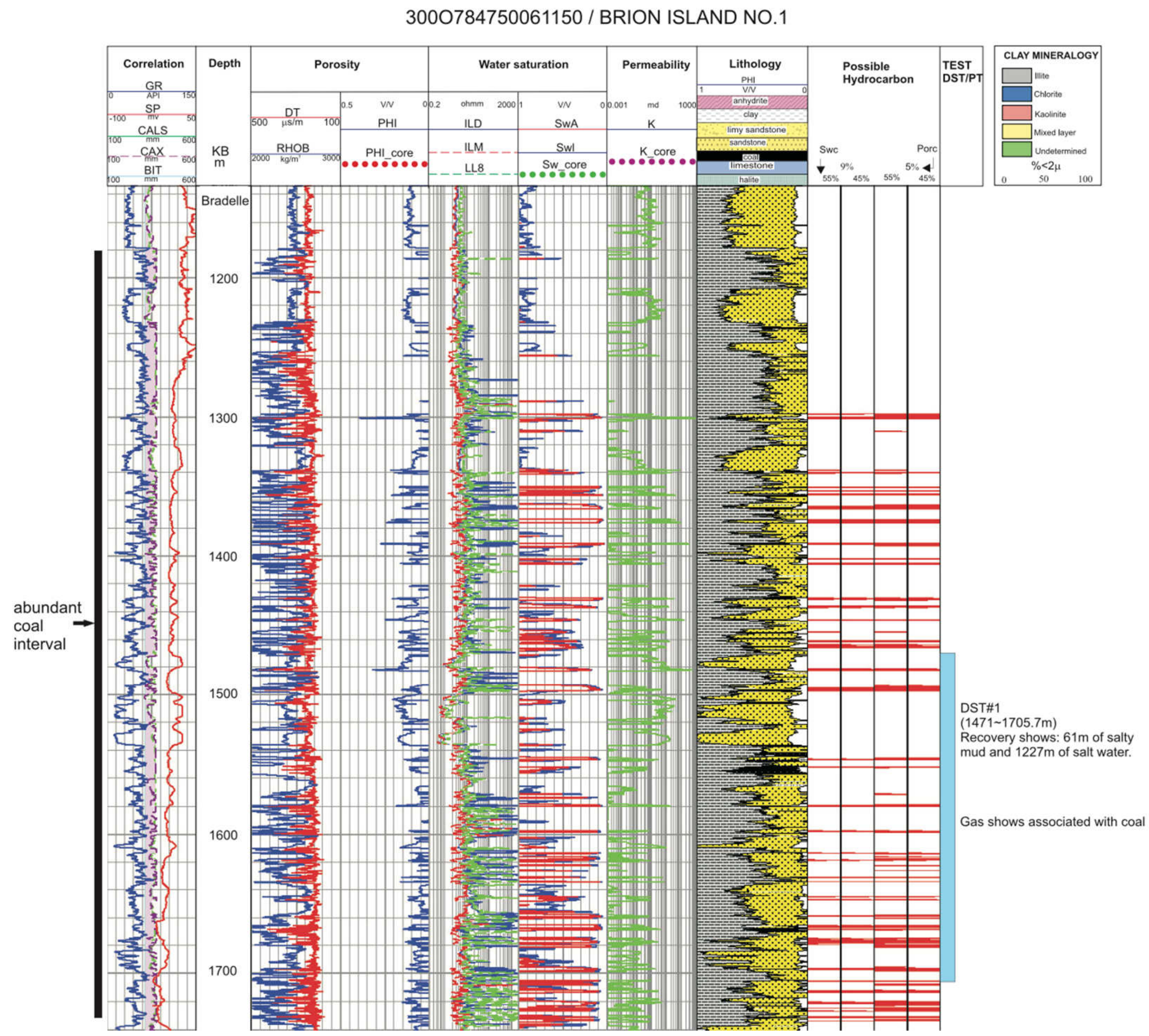
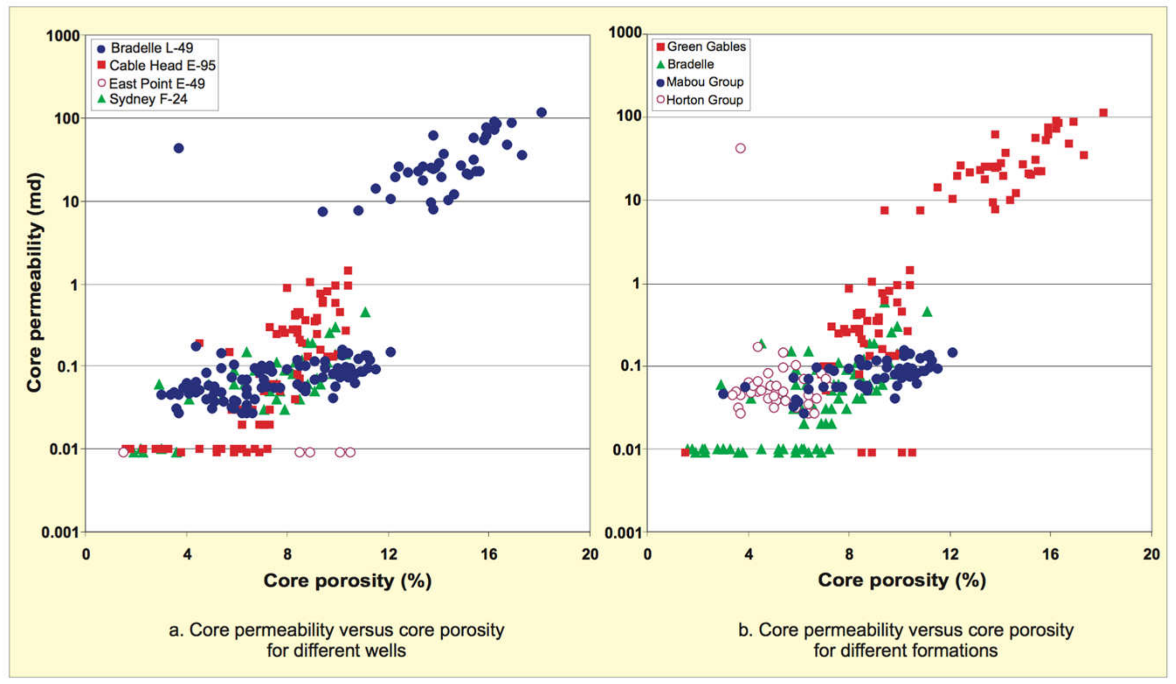


Figure 14: Petrophysical log analysis of part of the Cable Head E-95 well, illustrating a potential hydrocarbon zone according to petrophysical interpretation and associated computed Net Pay (Hu and Dietrich, 2008)

Petrophysical properties per formation:

The core porosity and permeability measurements from the 6 wells are displayed per well and per formation on Figure 15A. Figure 15B shows the porosity versus depth which is globally consistent with the petrophysical properties defined in the Sydney Basin from regional data and Sydney Basin well logs (Table 2). For the 6 wells from Hu et Dietrich study, the porosity and permeability range in the sandstone beds (according to the petrophysical interpretation presented in Hu and Drietrich synthesis in 2008) are displayed in Figure 15.

15A



15B

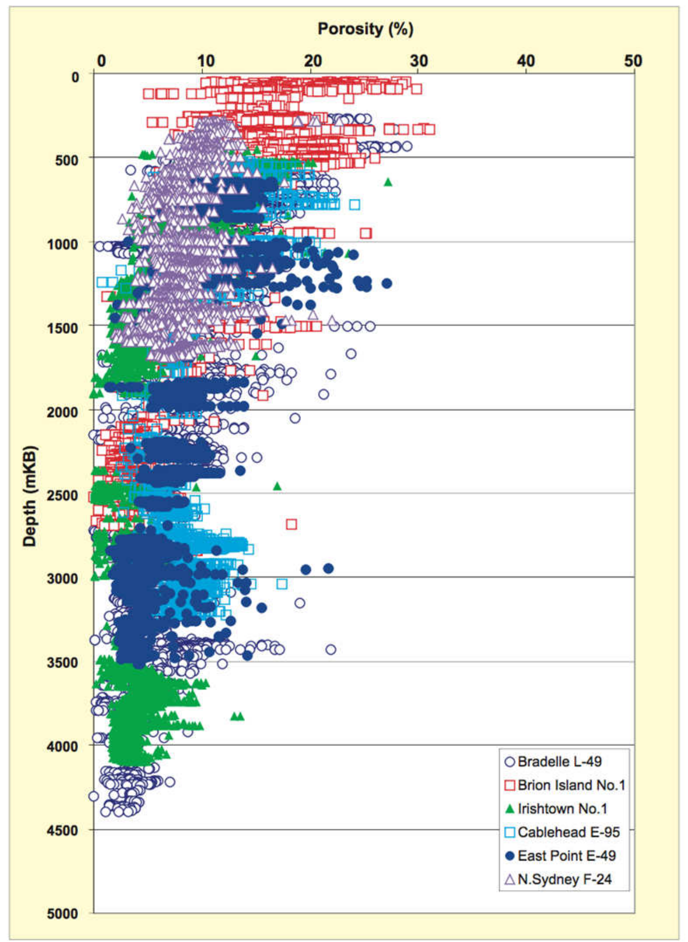


Figure 15A: Log-scale core permeability versus arithmetic-scale porosity from samples of Bradelle L-49, East Point E-49, Cable Head E-95 and North Sydney F-24 (Hu and Dietrich, 2008).

Figure 15B: Porosity versus depth for Carboniferous formations from samples of Bradelle L-49, East Point E-49, Cable Head E-95 and North Sydney F-24 (Hu and Dietrich, 2008).

Table 2: Petrophysical properties defined for Sydney Basin

Group	Formation	Effective porosity (%) Max	Effective porosity (%) Avg	Total porosity (%) Max	Total porosity (%) Avg	Permeability (mD) Max	Permeability (mD) Mode
Pictou	Pictou	10%	0,8%	21%	6,1%	100	0,2
Cumberland	Sydney Mines	10%	1,0%	23%	6,4%	30	0,1
	Waddens Cove	10%	2,7%	19%	6,4%		
	South Bar	10%	2,7%	19%	5,7%		
	Silver Mines	10%	0,8%	17%	6,5%		
Mabou	Point Edward Cape Dauphin	10%	1,5%	24%	5,7%	0,15	0,1
Windsor	Woodbine Road Meadows Road Sydney River Macumber	-	-	17%	8%	0,2	0,1
Horton	Upper Horton	-	-	10%	5%	1*	0,05*
	Middle Horton	-	-				
	Lower Horton	-	-				

Petrophysical properties considered for Sydney Basin

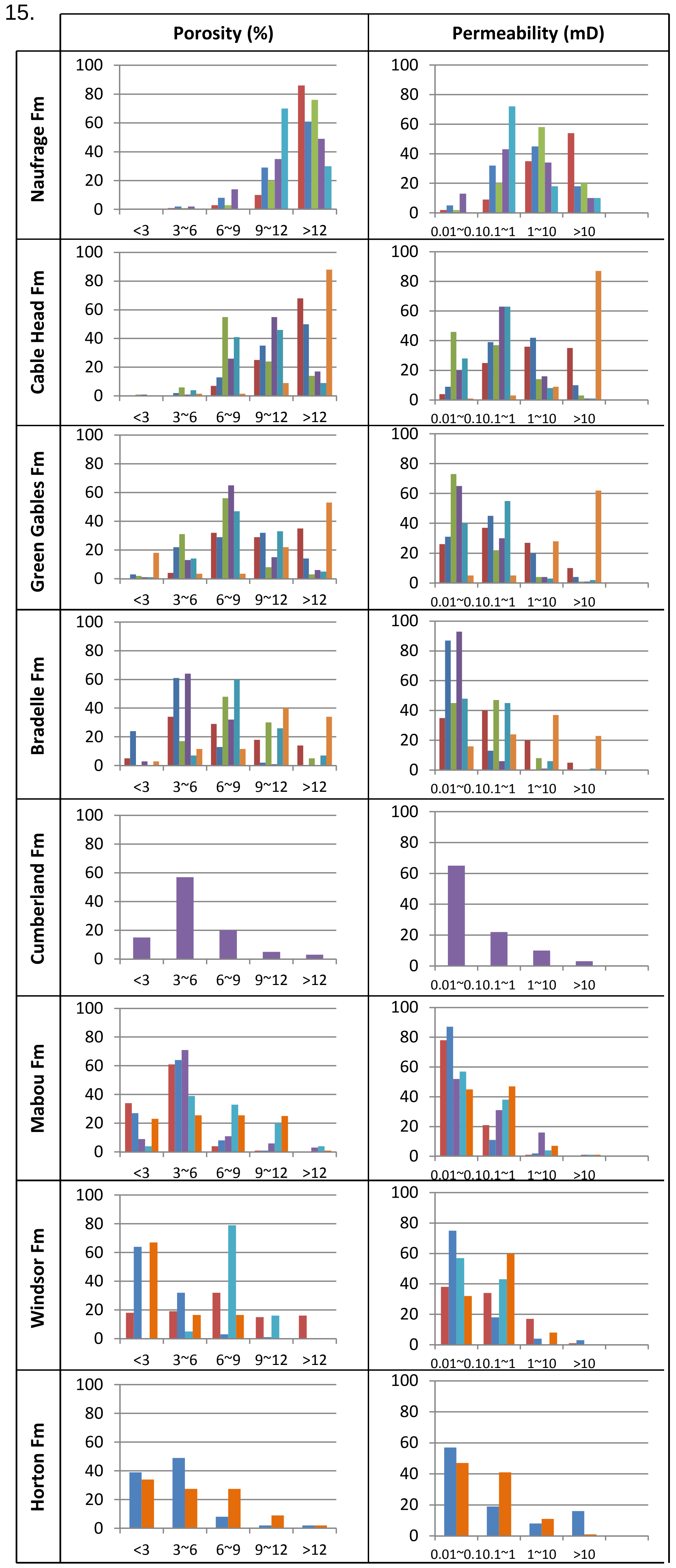


Figure 15: Percentage of sandstone beds in each formation with indicated porosity and permeability ranges for Bradelle L-49, East Point E-49, Cable Head E-95 and North Sydney F-24 (data from Hu and Dietrich, 2008)

Influence of diagenesis on reservoir quality

Reservoir quality in eastern Canada can be considerably influenced by diagenesis. The impact on a reservoir can be significantly more critical than sand cleanliness. According to Chi et al. (2003), favorable conditions for porosity development include:

- Shallow burial (preservation of significant primary porosity),
- early calcite cementation sufficient to strengthen the framework against physical compaction but which does not completely occlude primary porosity (Figure 17A),
- significant dissolution of calcite cements and framework grains which generate substantial secondary porosity.

The negative correlation between porosity and the amount of quartz cement is also presented Figure 16B. The quartz cement tends to increase with depth as it is shown is Figure 16.C.

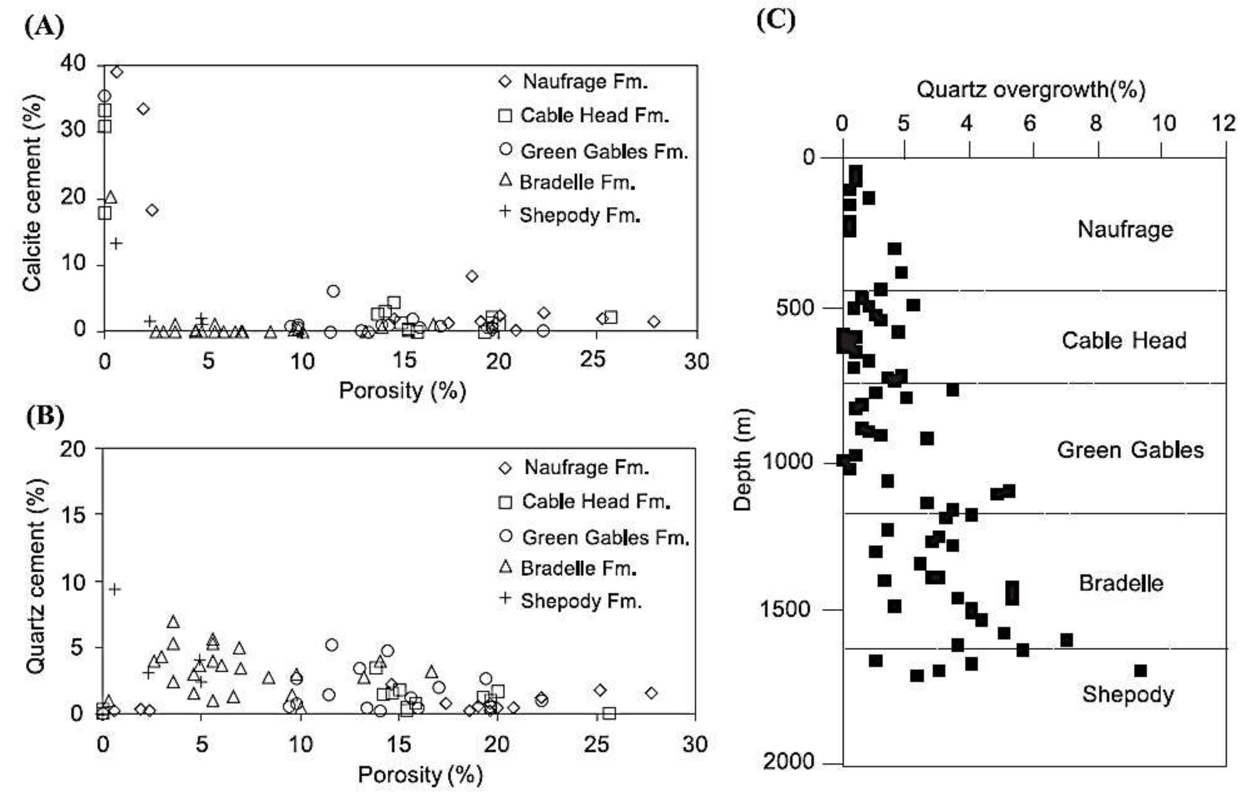


Figure 16:
(A) Correlation between abundance of calcite cements and porosity values.
(B) Correlation between percentages of quartz cement and porosity values.
(C) Variation of percentages of quartz cements with respect to drill depth.

The influence of the cementation on the porosity is illustrated by core measurements from Spring Valley #1 (Hu and Dietrich, 2008) (Figure 17).

The failed DST#2 in North Sydney F-24 (Figure 18) is possibly due to a siliceous cement described from nearby wells in the same formation.

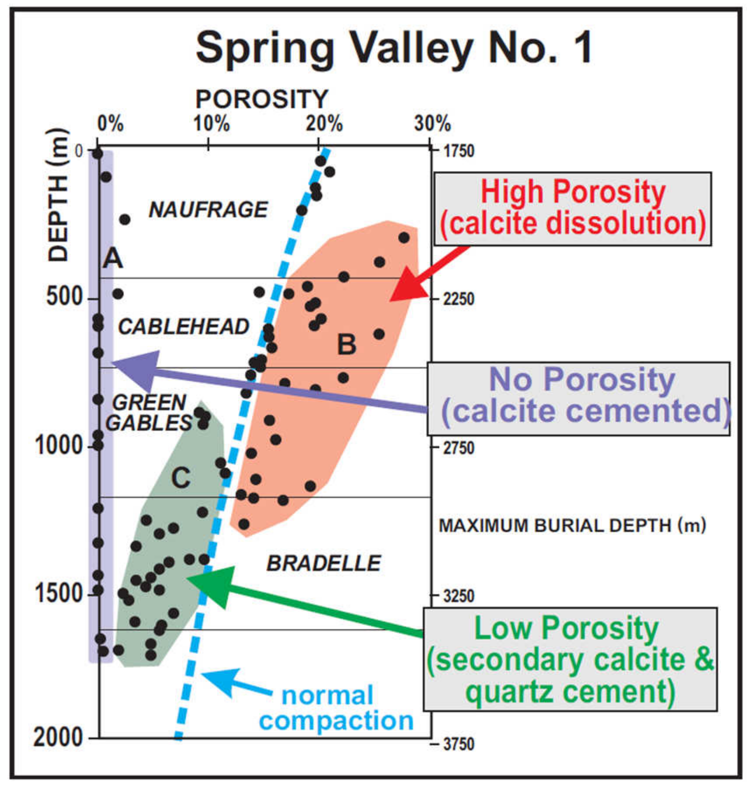


Figure 17: Core-data derived porosity-depth trends in upper Carboniferous strata in the Spring Valley No.1 well in the Magdalen Basin, onshore Prince Edward Island, figure adapted from Chi and others, 2003 (Hu and Dietrich, 2008)

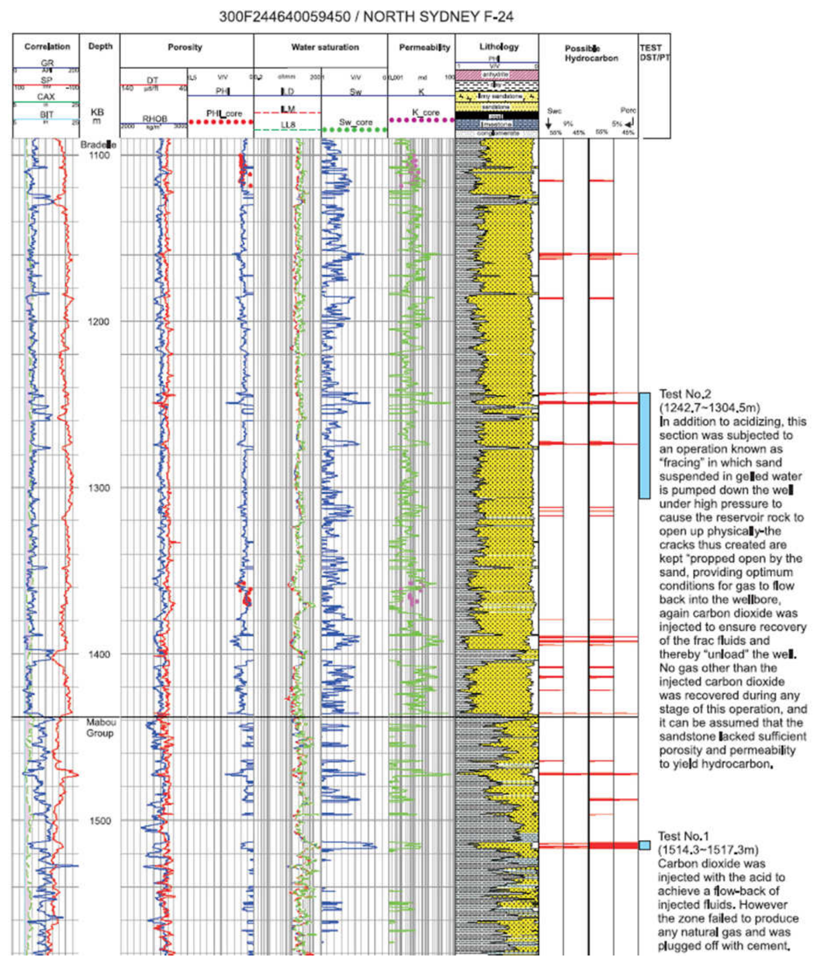


Figure 18: Well log analysis in the Bradelle formation in the North Sydney F-24 well (Hu and Dietrich, 2008)

The occurrence of chlorite in few Horton reservoirs also appears to preserve reservoir quality (McCully field).

Preservation of porosity through the development of specific diagenetic events is a possibility in the Horton Formation within Sydney Basin. However, an extensive understanding of the diagenetic processes and sedimentary sources of the basin is needed in order to predict the type and development of the diagenesis and its influence on porosity.

Well test results - Success and Failures

Few wells have been positively tested in the Carboniferous. Red Brook-2 shows a positive gas test up to 5400 mcf/d in the Carboniferous (Figure 18). East Point E-49 was tested in 2 intervals, with gas flowing at 10 mcf/d and less than 1 mcf/d (Figure 19). Finally, well F-58 in McCully field has showed high gas readings within Frederick Brook (Horton) shales (Figure 20). Successful and unsuccessful well test results known are listed in Table 3.

Table 3: Test results

Well name	Formation name	DST #	interval (m)	PhiE (%)	K (mD)	Sw (v/v)	Fluid to surface	Flow rate (mcf/d)	Comment
Robinson #1	Snakes Bight	3	2963 – 2990	3	-	0.3	Mud	-	No Gas to Surface - Sweet gas was collected for analysis from the down hole sample chamb
	Snakes Bight	4	2574 – 2640	4	-	0.4	Mud	-	No Gas to Surface - Partial Communication around bottom packer indicated. No Initial Shut-In Recorded
	Snakes Bight	5	2517 – 2572	6	-	0.4	Mud	-	No Gas to Surface - Failed test due to leaking upper packer
RedBrook #2	Spout Falls	-	1558-1573	10	0.4	0.5	Gas	10	Highest rate in St. George Basin
	Spout Falls	-	1297-1311 & 1324-1334	8	0.2	0.67	Gas	1	
Brion Island #1	Bradelle	1	1471-1705,7	7	-	0.3	Salty mud/water	-	
East Point E-49	Cable Head	PT#2	1581.9-1594.1	10	-	0.45	Gas	5400	
	Cable Head	PT#3	1684,5-1710,5	9	-	0.5	-	-	No flow
North Sydney F-24	Bradelle	2	1242,5-1304,5	7	-	0.6	-	-	No gas recovered
	Mabou Group	1	1514,3-1517,3	9	-	0.3	-	-	Zone failed to produce any natural gas

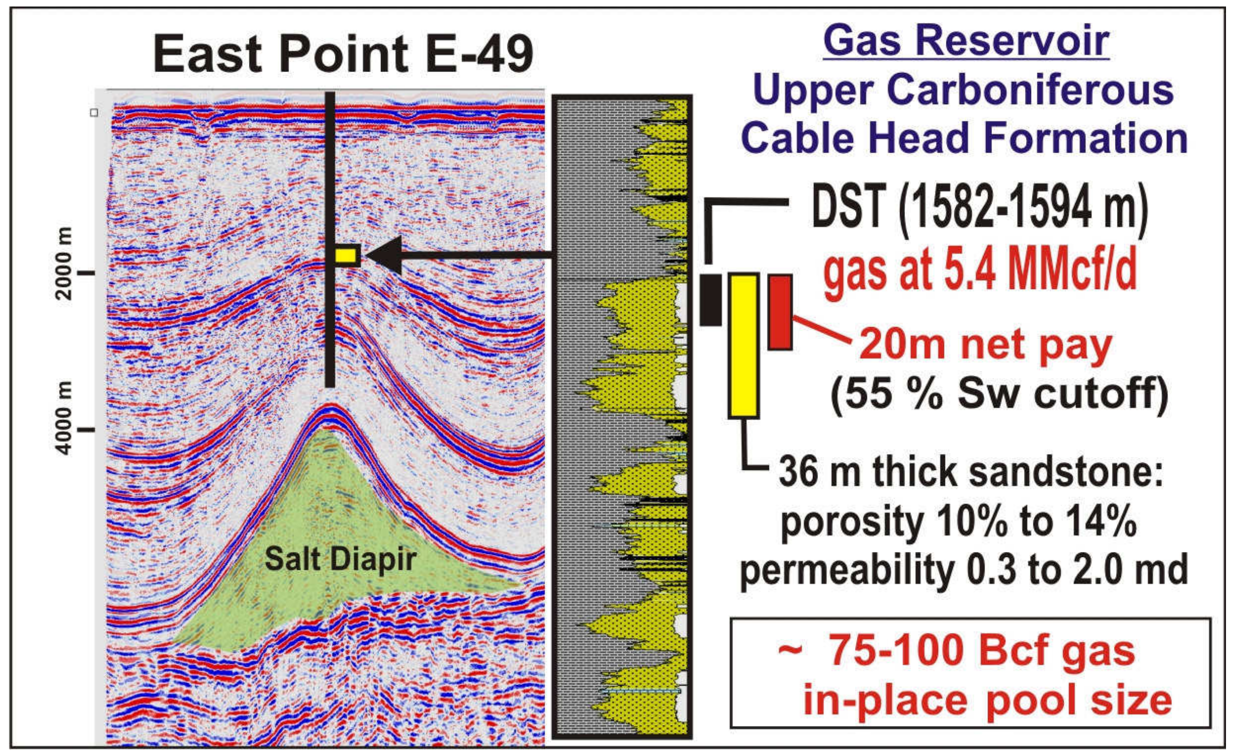


Figure 18: Migrated seismic section across East Point E-49 gas discovery well, illustrating deep-seated salt diapir and position of gas-bearing sands. Gas zone is detailed in log-derived lithology plot, with reservoir parameters and estimates (Hu and Dietrich, 2008).

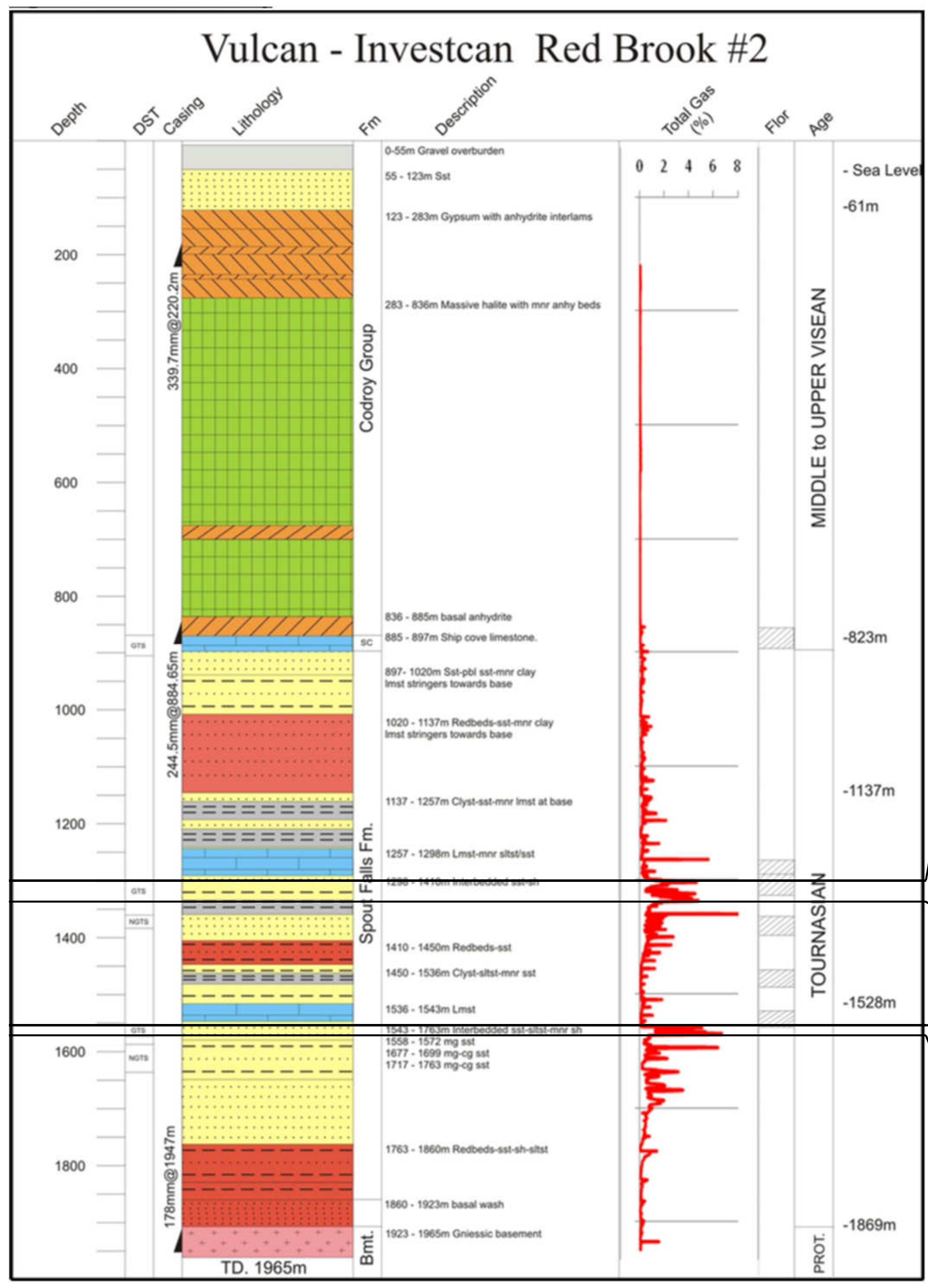
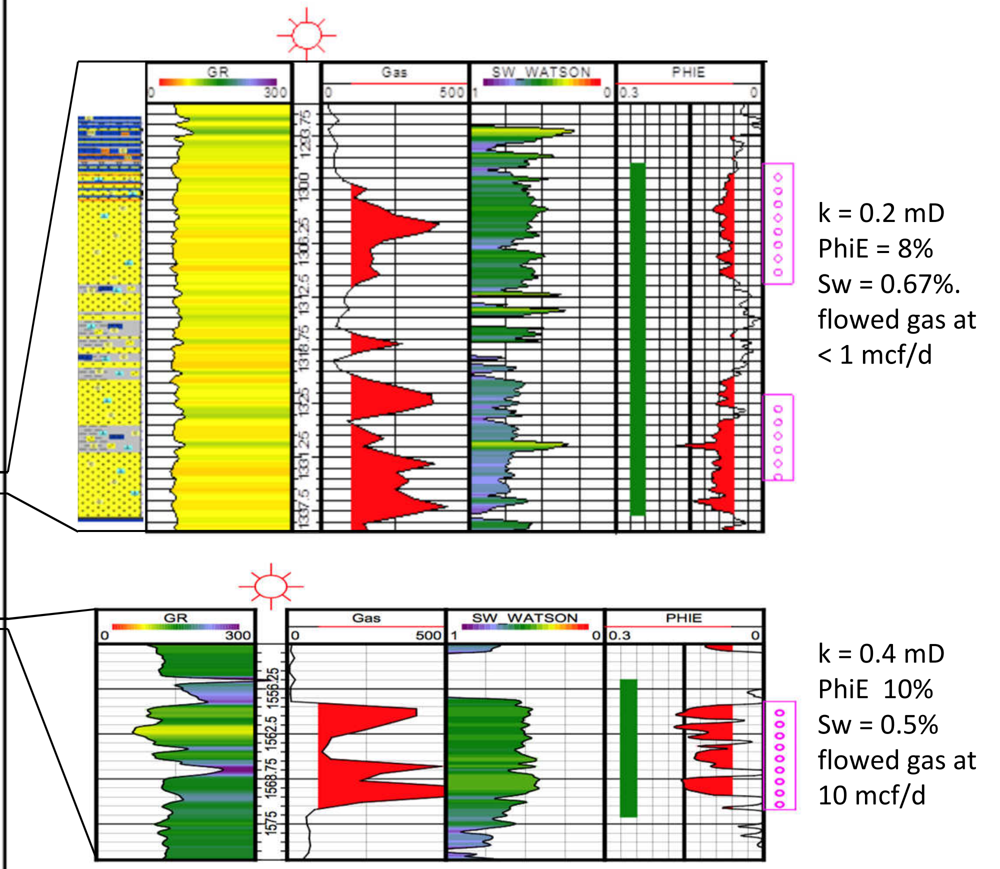


Figure 19 : Positive gas test performed on Red-Brook-2 (right) replaced on the lithological chart and the Total Gas readings (Investcan Energy Corp., 2009)



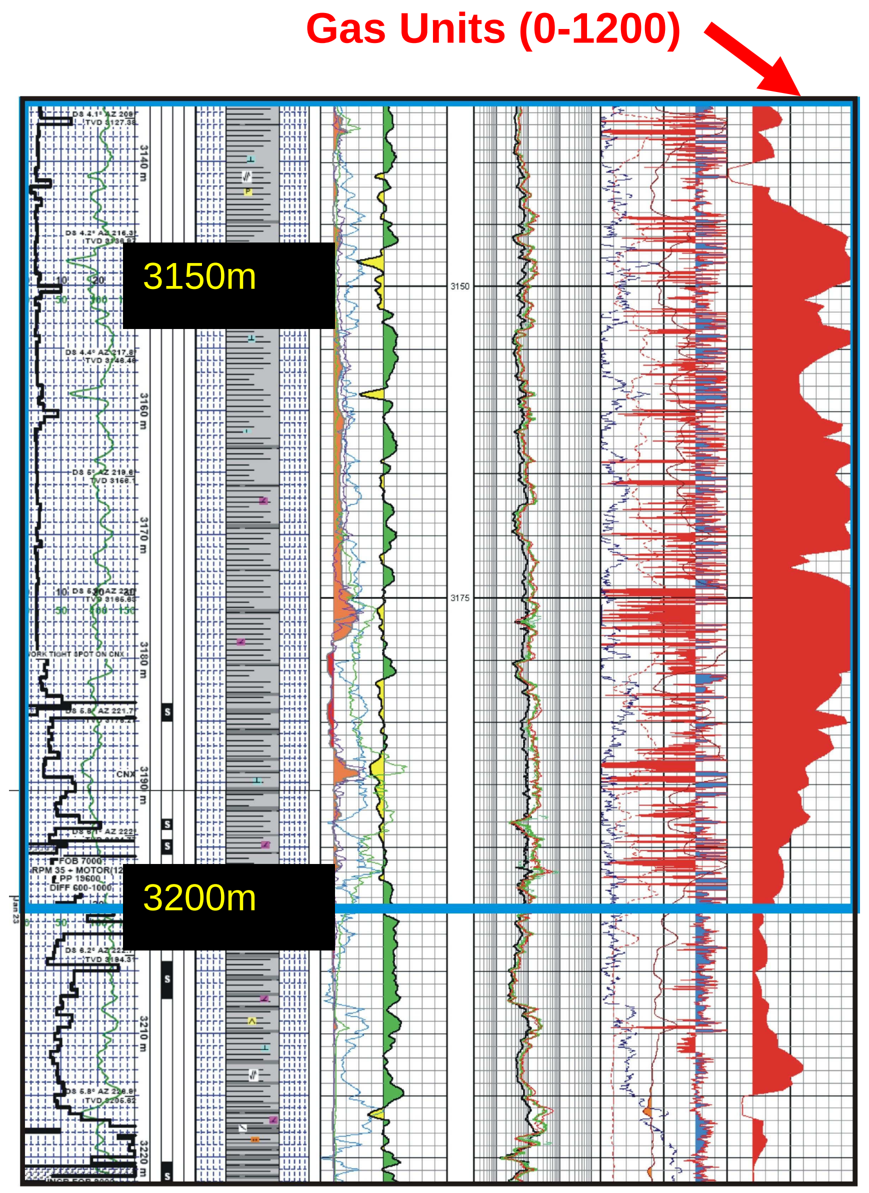


Figure 20 : Fractured Frederick Brook organic shale (Horton); McCully field well F-58 showing the presence of gas within the shales (from St Peter & Hinds, 2007);

Carboniferous Plays and Traps in Eastern Canada

Carboniferous plays have been the least explored of all Paleozoic petroleum plays in eastern Canada, and its offshore component is a true frontier basin. Paradoxically, producing fields and exploration wells suggest a highly prospective basin. Three main plays are classically identified across the province:

- A clastic lower Carboniferous play corresponding to the Horton Gp or equivalent (Tournaisian)
- A lower to mid Carboniferous play corresponding to the Windsor Gp (Carbonate) and Mabou (clastic) (Visean - Namurian)
- Two clastic mid upper Carboniferous plays corresponding respectively to the Cumberland and Pictou Gps (Namurian to Permian)

Below is an overview of the different targeted plays and traps in eastern Canada Carboniferous subbasins, based on available literature.

New Brunswick

The Moncton Basin is probably the most known part of the Carboniferous basin, although it is still at an early stage of development. The only two producing fields in Carboniferous basin are located in New Brunswick (Figure 21). The basin consists of a series of fault-bounded depocenters with sometimes complex depositional and structural patterns (Lavoie et al., 2009). Both fields produce from the Albert Fm (Horton Gp) sourced by the Frederic Brook Shale Fm (Horton Gp) which is also a non conventional play. These plays have a significant stratigraphic component (Figures 3 and 21) with lenticular reservoir sandstones interbedded with mudrocks and oil shales. For the Stoney Creek field, although it lacks good seismic coverage, data correlation indicates structural (gentle dip) and stratigraphic traps (sand lenses appear to pinch out up-dip into mudstones) (St Peter 2000; St Peter and Hinds, 2007). The McCully Field is a large faulted anticline with stratigraphic component similar to the Stoney Creek field. The Horton Group beds are folded and truncated by the overlying Sussex Group which act as seal instead of the usual Windsor Gp (St Peter and Hinds, 2007).

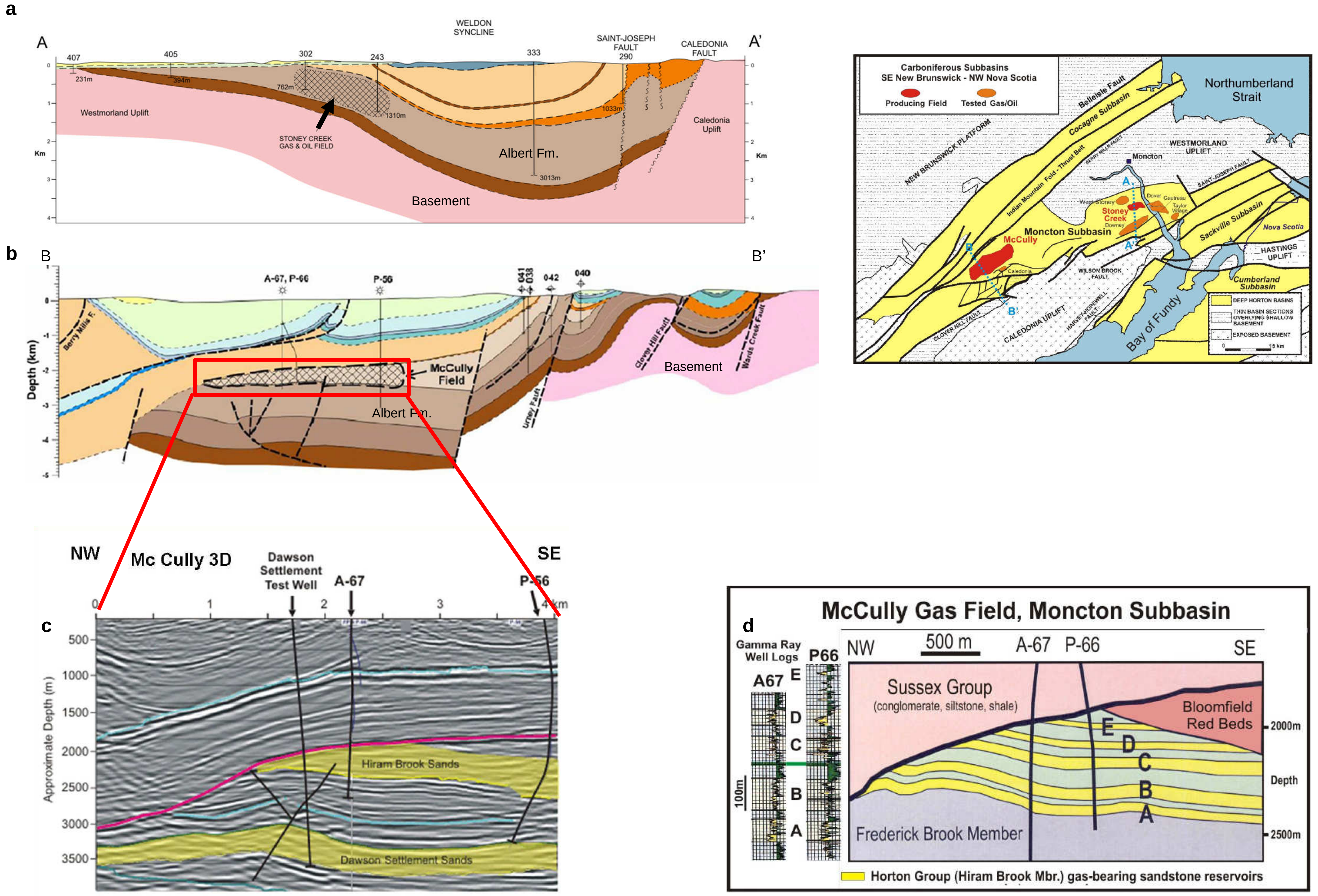
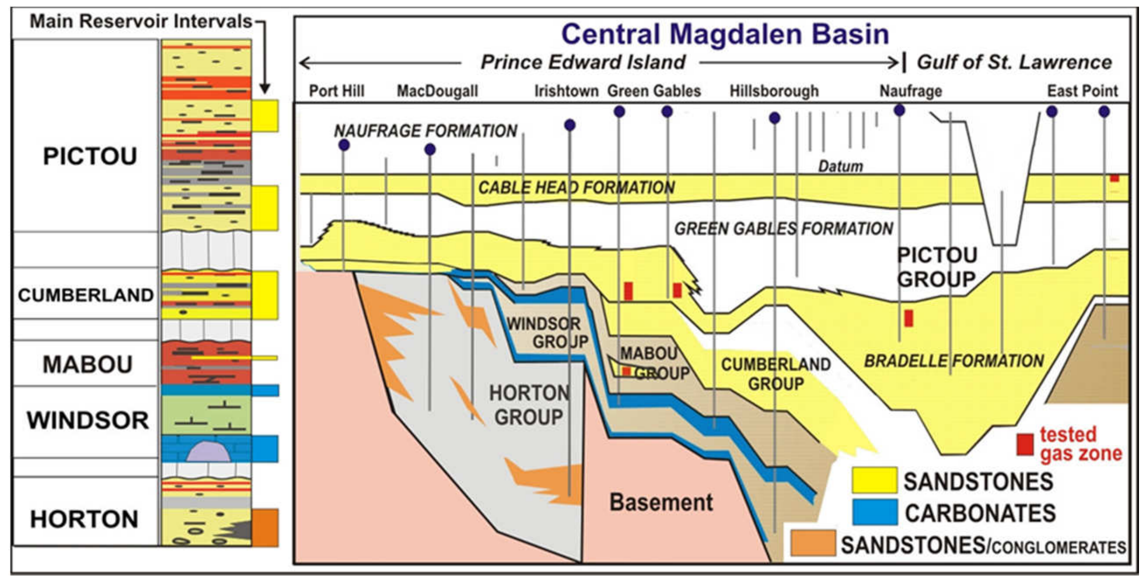


Figure 21: a) Geological cross-section of the Stoney Creek field; b) Geological cross-section of the McCully oil field. Gas is produced from the Hiram Brook sandstone member of the Albert Formation (Horton Group); c) 3D seismic section across the McCully oil field showing gas sands within the Horton Group; d) stratigraphic cross-section and well logs showing the stack of gas charged reservoirs as well as the structural and stratigraphic components of the traps (Source: Fyffe and St. Peter, 2006; Enachescu, 2006; Martel and Durling, 2006 and Corridor website).

Magdalen Basin

Carboniferous plays extend to the Magdalen Basin where over 12 km of sediment accumulated from Tournaisian to Lower Permian times (Figure 5). That is also where discoveries in Bradelle Fm were made onshore and offshore Prince Edward Island (PEI). Magdalen Basin together with Sydney Basin present the largest succession of Carboniferous plays and a wide range of structural and stratigraphic traps (Figures 22 to 24). Inverted fold and sub-salt prospects have been targeted but no commercial discovery has been made so far. Around PEI typical traps are structural within the Pictou Group, which result from folding, faulting and a combination of the two (Enachescu, 2006a and b). Traps are often related to Windsor salt domes and compressional anticlines related to transpression phases.



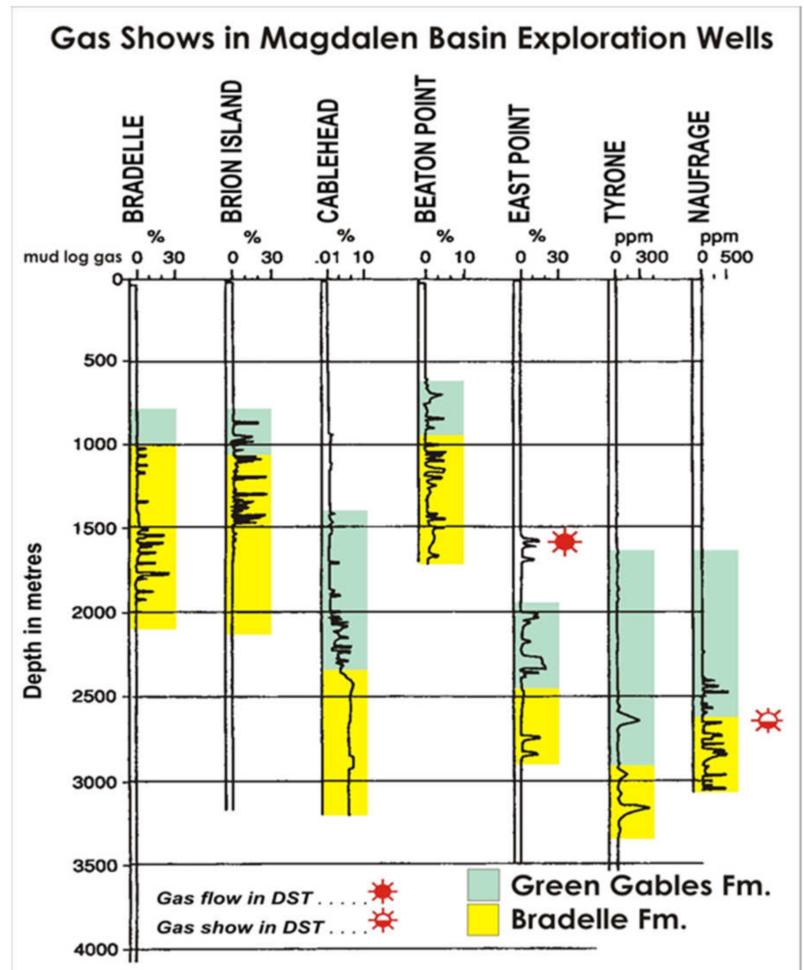


Figure 22: a) Well cross-section showing reservoirs with tested gas zone (red bar). Gas was discovered in Bradelle Fm and Mabou Gp; b) Gas show in upper Carboniferous Formations and related DST. Gas flowed in East Point E-49 and showed in Naufrage DST (From Lavoie et al., 2009)

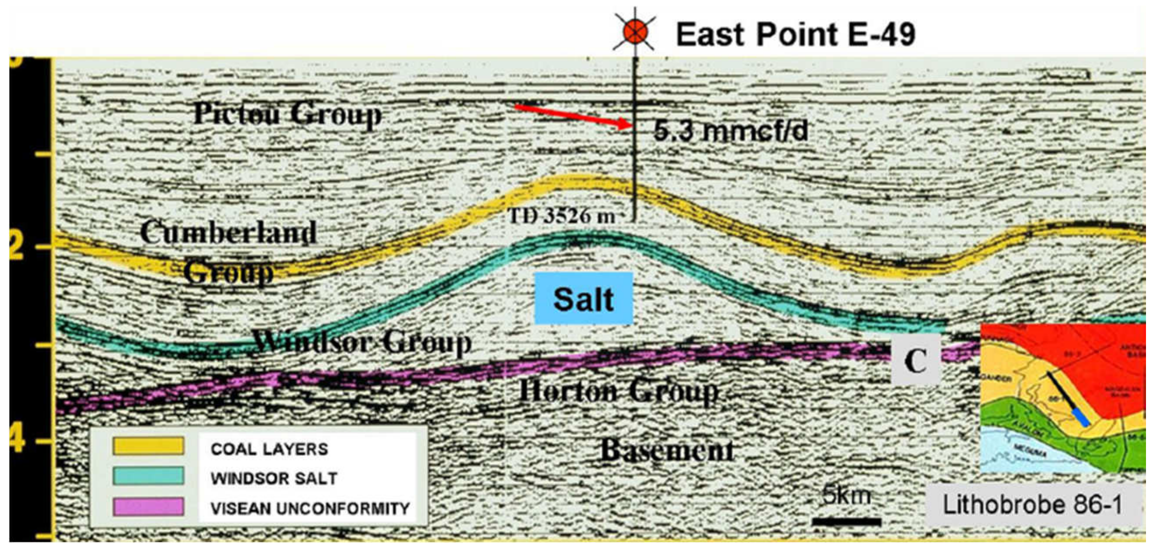


Figure 23: a) Seismic section of Lithoprobe 86-1 over East Point E-49 in Magdalen Basin. E-49 was drilled over an induced salt structure (from Enachescu, 2008). These structures are present in both Magdalen and Sydney Basins.

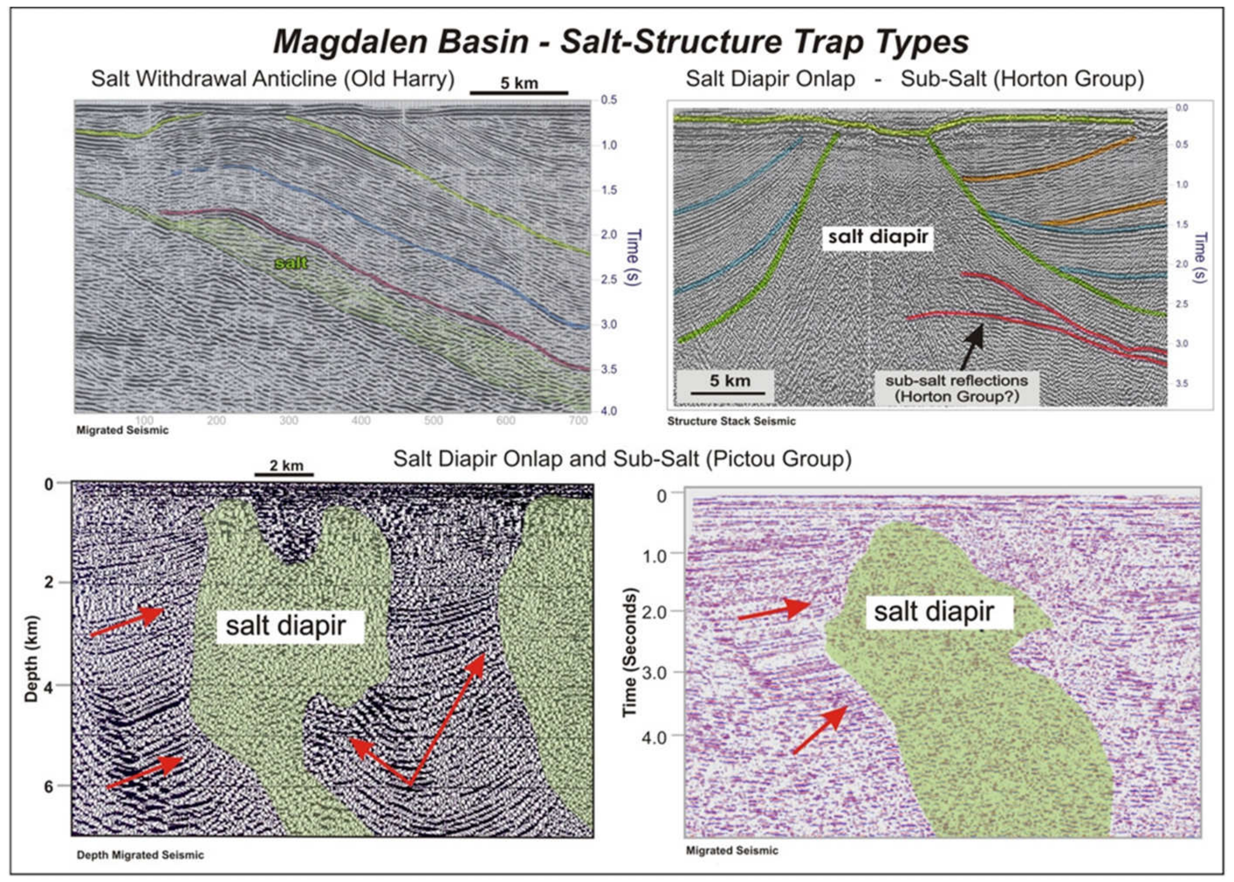
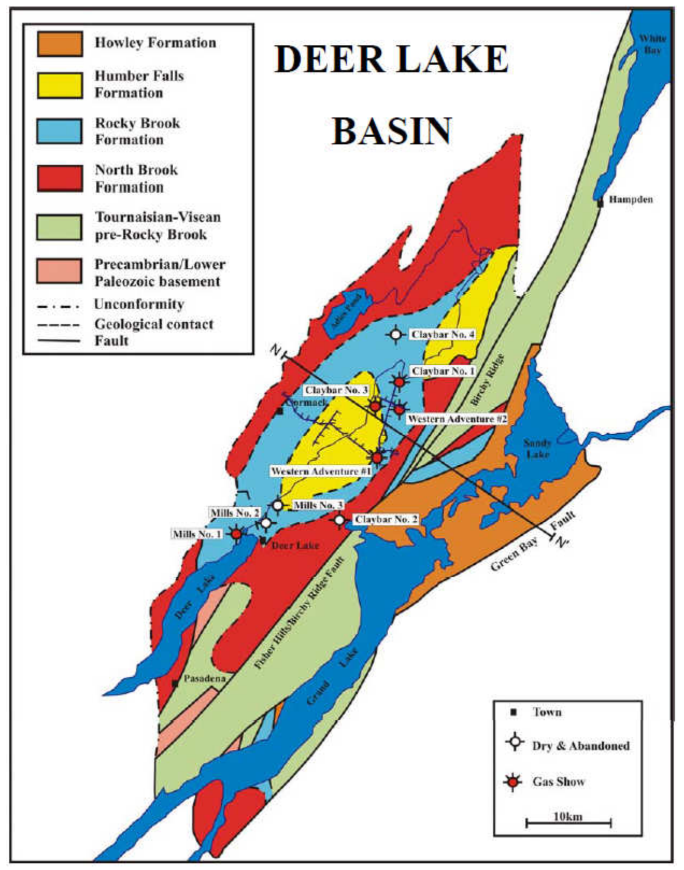


Figure 24: a) Seismic sections illustrating different salt related traps in the Magdalen Basin (from Lavoie et al., 2009). Similar structures are observed in Sydney Basin.

Western Newfoundland

Most of the exploration activity onshore Newfoundland is located on its western side and since the mid-1990s Carboniferous basins have been the main focus of the attention. O&G discoveries have been made in Deer Lake and Bay St George basins.

The Deer Lake Basin (Figures 25) is a strike-slip inverted pull apart basin that lies unconformably on the Ordovician carbonate platform (Enachescu, 2006a and b). The sedimentary record is predominantly lacustrine, and contains the Mississippian lacustrine shales and dolostones of the Forty Five Brook and Rocky Brook Formations (Enachescu, 2006a and b). Plays involve rotated and inverted blocks containing porous and permeable North Brook sandstone (Carboniferous). The Western Adventure #1 well drilled in 2000 (Table 1) tested 100,000 cu ft of gas per day, with some condensate from sandstone units within the North Brook Formation (Enachescu, 2006a and b).



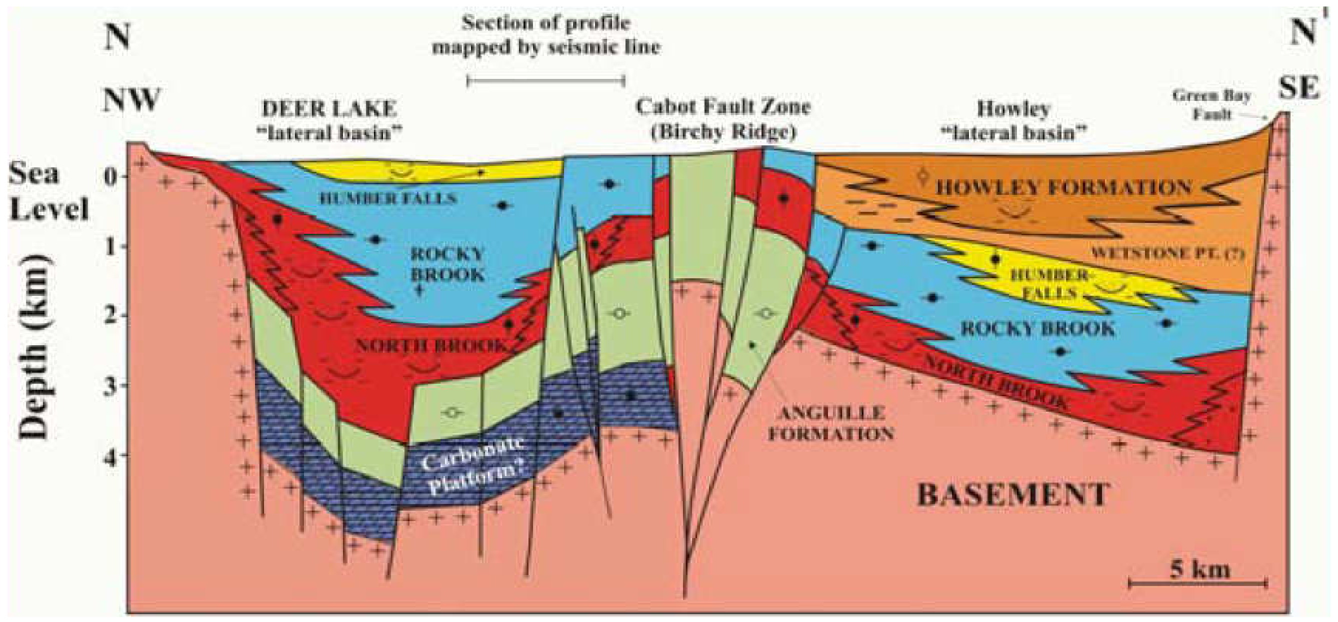


Figure 25: a) Cross section of the Deer Lake Basin (Newfoundland)illustrating the main geological features. The flower structure is was on the target trap (from Hicks, 2007)

Bay St George Carboniferous basins show a more complex structure, with half graben carboniferous basins developed on the hinterland of a thrust (Hall et al., 1992) (Figure 26). Half grabens are 3 – 4 km deep and are infilled with alluvial fan deposits grading up into flood plain coal beds (Hall et al., 1992). Transpression phases have had a greater impact there with several anticlines formed across the basins. (Figure 26b). Several large structures have been observed and successfully targeted such as flank plays along the Flat Bay anticline (Figure 26b). As for Deer Lake Basin, prospective Carboniferous basins lie over prospective Ordovician series (Figure 26a).

a

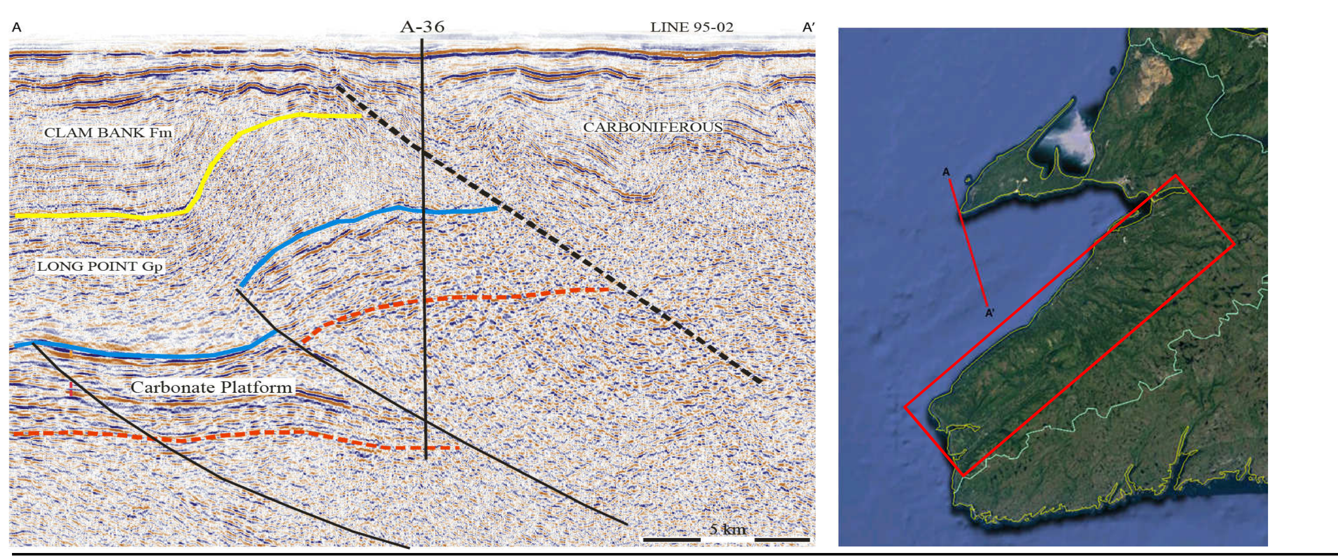
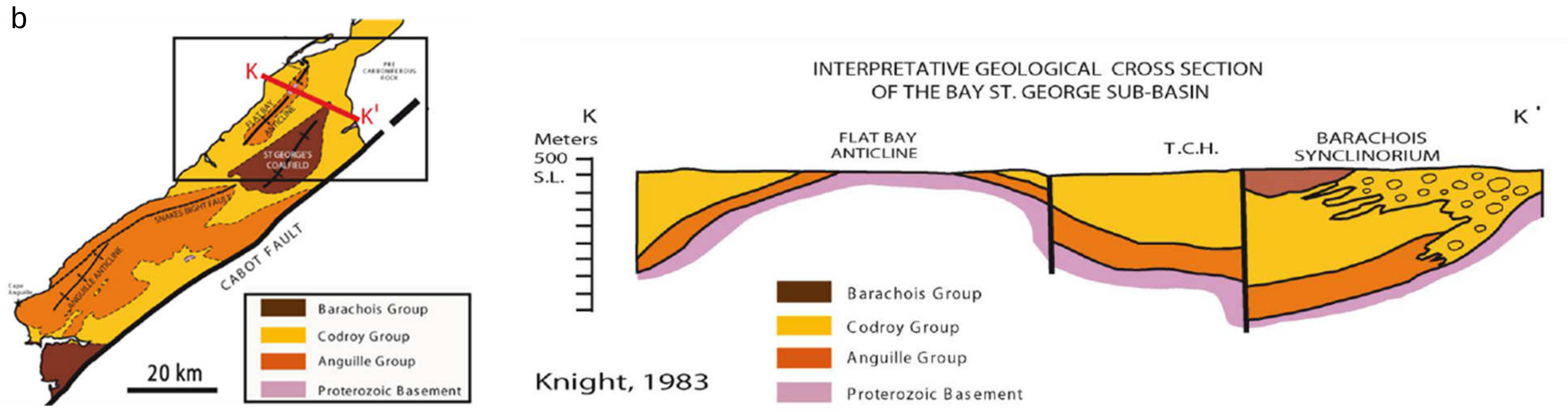


Figure 26: a) seismic transect across Bay St George showing the structural thrust and the transition from Ordovician terranes to Carboniferous ones; b) Structural cross section across the northern part of Bay St George showing the Flat Bay anticline along which several wells have been drilled and discovered hydrocarbons (from Hicks, 2007 taken from Knight, 1983)

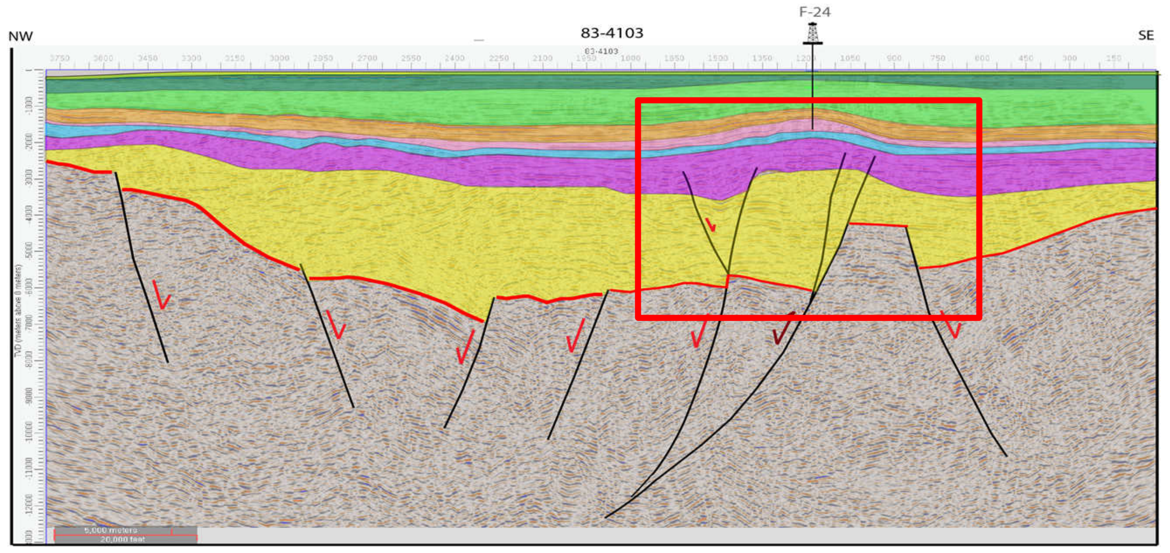
b



Sydney Basin, Nova Scotia

Sydney Basin is the least explored of all eastern Canadian Paleozoic basins. The only offshore wells to date have been in the Scotian part of the basin and none of them reached their initial targets, i.e. Horton series. Compared to western Newfoundland or New Brunswick Carboniferous basins, the Sydney Basin appears to be structurally less complex with typical half grabens up to 6 km deep (Figure 27). The main inversion phase that occurred during the late Carboniferous/Lower Permian has not significantly impacted the basin much in comparison with the other Paleozoic basins of eastern Canada (Figures 27 to 31; see also Chapters 2 to 5). Most of the faults are inactive since the Visean period except in the Cabot Fault complex which is active throughout the stratigraphic record. Sydney Basin shows various types of structural traps, stratigraphic traps and combination traps (Figures 27 to 31). Salt diapirism is less developed than in Magdalen Basin but enough so they locally creates significant anticlines (Figure 30). None of those structures have been tested.

Figure 27: Gentle transpressional anticline (four-way closure). North Sydney P-05 and F-24 wells targeted the structure but missed the stratigraphic target, i.e. Horton. This structure is the largest in the basin, and new estimates give 690 MM bbl of oil and 1.9 Tcf of gas in place (see also chapter 8).



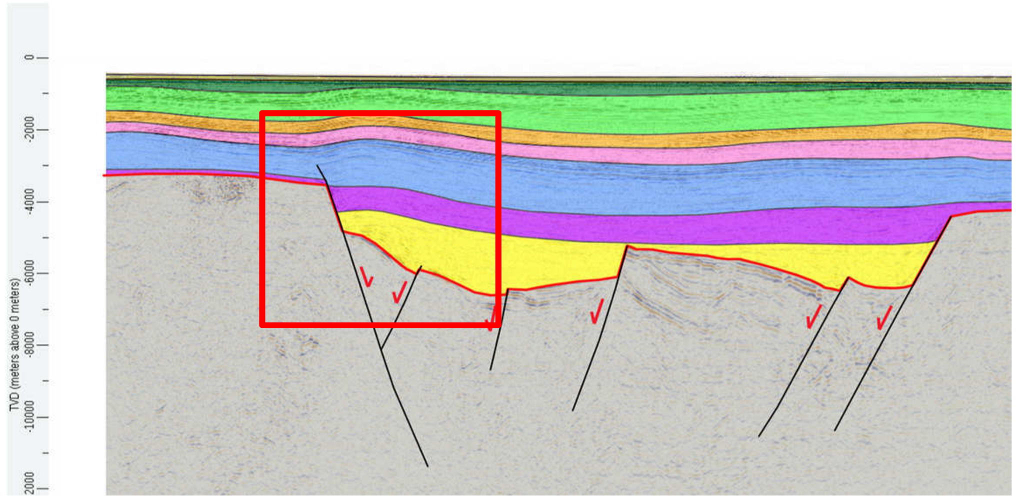


Figure 28: Gentle transpressional anticline against basement related fault (three-way closure)

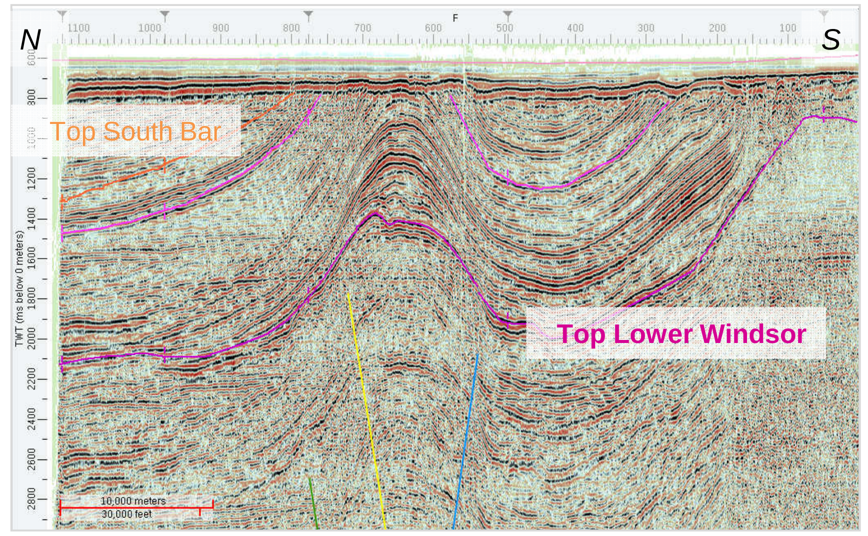
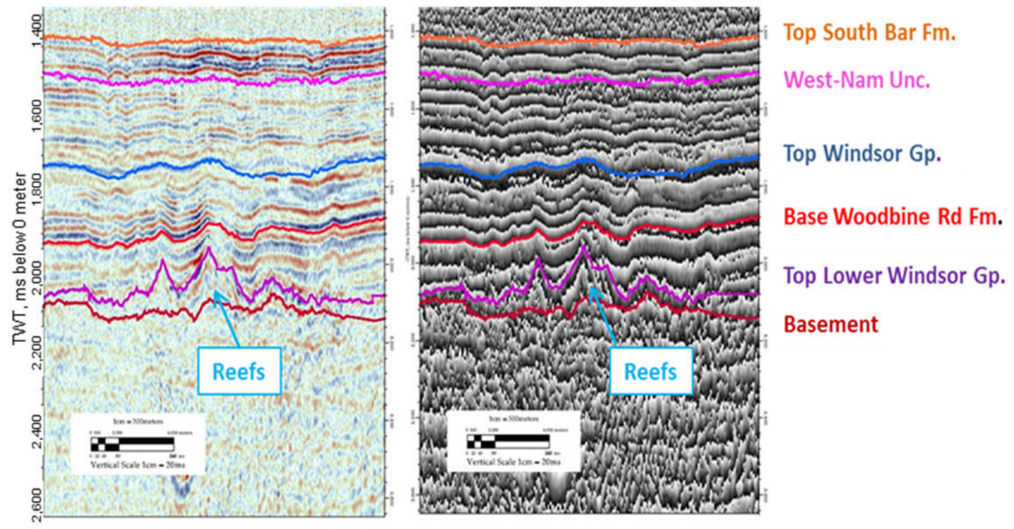


Figure 30: Salt diapir related anticline and subsalt structure (four-way closure)

Figure 29: Example of reefal structures of the Windsor Gp developed on a basement top (four-way closure).



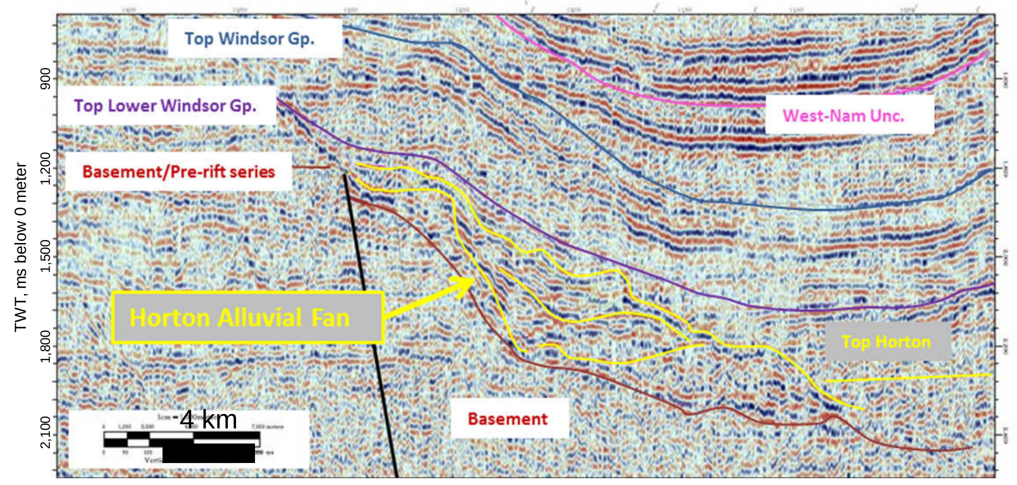


Figure 31: Example of an Horton alluvial fan against a basement related fault (three-way closure).

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