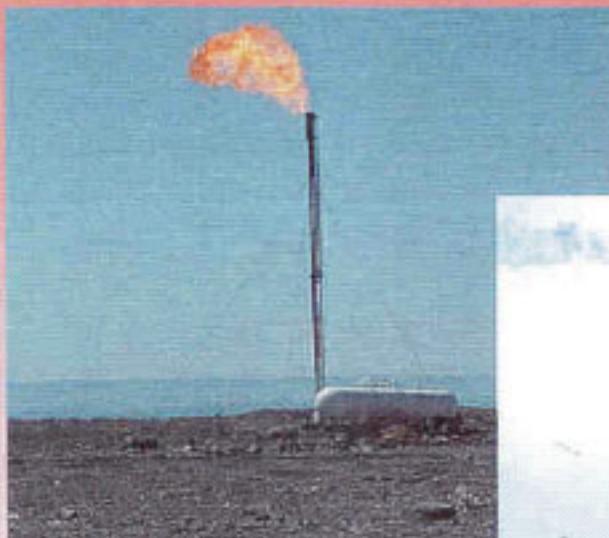


SEDIMENTARY BASINS AND HYDROCARBON POTENTIAL OF NEWFOUNDLAND AND LABRADOR



GOVERNMENT OF NEWFOUNDLAND AND LABRADOR

Department of Mines and Energy

Energy Branch

Report 2000-01

LEGEND



Sandstone



Basement



Volcanics



Carbonate



Pebby Sandstones
in braided stream



Salt



Unconformity



Shales & Siltstones
are identified and
represented by a
variety of colors



Proven Source Rock



Possible Source rock



A reservoir that has
flow tested oil or
natural gas



A formation known to
have porosity and
permeability that has
not flow tested oil or gas



Oil Zone



Gas Zone



Abandoned Oil Well



Oil Show



Dry & Abandoned



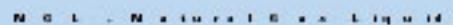
Gas Show



Gas Well



Oil & Gas Show



C-NOPB - Canada-Newfoundland Offshore Petroleum Board

GSC - Geological Survey of Canada

FPSO - Floating Production Storage and Offloading Vessel

NHOC - Newfoundland Hunt Oil Company

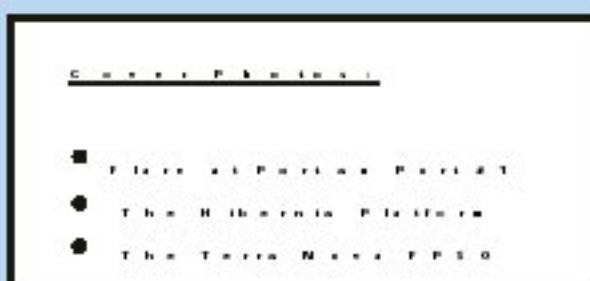
PCP - Pan Canadian Petroleum Company

PAP #1 - Port au Port #1

mmcf/d - million cubic feet per day

bopd - barrels oil per day

This legend applies generally to figures throughout this report. Additional legend information is provided in individual figures where required.



Sedimentary Basins and Hydrocarbon Potential

Foreword

The purpose of this report is to provide information on the geology and petroleum potential of selected sedimentary basins in the Newfoundland and Labrador offshore and onshore areas. The report is, for the most part, based on a review of previously published and unpublished geologic literature including government reports, journal articles and publicly available industry reports. Seismic data is reinterpreted, where appropriate, to provide new play concepts as well as emphasize known but untested targets. Maps and cross-sections are presented to provide the reader with a quick look at selected basins with particular emphasis on petroleum source, reservoir and trapping potential. Regional seismic lines and cross-sections are included to illustrate basin structure and play types, but for detailed geology, the reader is referred to the bibliography, and to the industry reports publicly available through the Canada-Newfoundland Offshore Petroleum Board (C-NOPB). Information presented is current to May 2000.

ACKNOWLEDGMENTS

This report was prepared by the Petroleum Resource Development Division (PRDD) of the Newfoundland and Labrador Department of Mines and Energy (DME). Regional interpreted seismic lines in the Whale, South Whale and Bonnition basins were provided by the Geological Survey of Canada. Additional interpretation of these lines was carried out by geophysical consultant Ian Atkinson and Phonse Fagan of the Department of Mines and Energy. The History of Exploration (up to 1984) was based on a 1984 speech by Martin Sheppard of the C-NOPB. The rest of the text was prepared by Fagan and Atkinson with selected contributions by Ian Knight. Figures were drafted by students Jason Nash, Corinna Basha and Mike Winsor, and by Lisa Clarke and Donna Taylor of DME. Anne Lake of PRDD typed the text and Tracy English of the Petroleum Projects Monitoring Division (DME) assisted in the layout. Lisa Clarke formatted the report for publication. Pictures of the Hibernia platform were provided by the Hibernia Management and Development Company; the Terra Nova FPSO by Petro-Canada; and the photograph of the Port au Port #1 flare was taken by Donna Taylor. Thanks are extended to: Iain Sinclair of the Hibernia Management and Development Company; Don McAlpine, Phil Moir and Sonya Dehler of the Geological Survey of Canada; Neil DeSilva, Judith McIntyre, Glen Power, Trevor Bennett, Paul Rideout, Sheila Duff and Judy Ryall of the Canada-Newfoundland Offshore Petroleum Board; Jim Wright and Rick Hiscott of Memorial University; Ian Knight and Gerry Kilfoil of the Newfoundland and Labrador Geological Survey; Cabot Martin of Deer Lake Oil and Gas; and Patrick Laracy of Vulcan Minerals for valuable assistance in the gathering of information. David Hawkins, Director of the PRDD was a source of constant guidance and critical information from start to finish. Special thanks are extended to Ian Knight, Iain Sinclair, David Hawkins, Neil DeSilva, Phil Moir, Chris Pereira and Hans Wielens for their critical reviews.

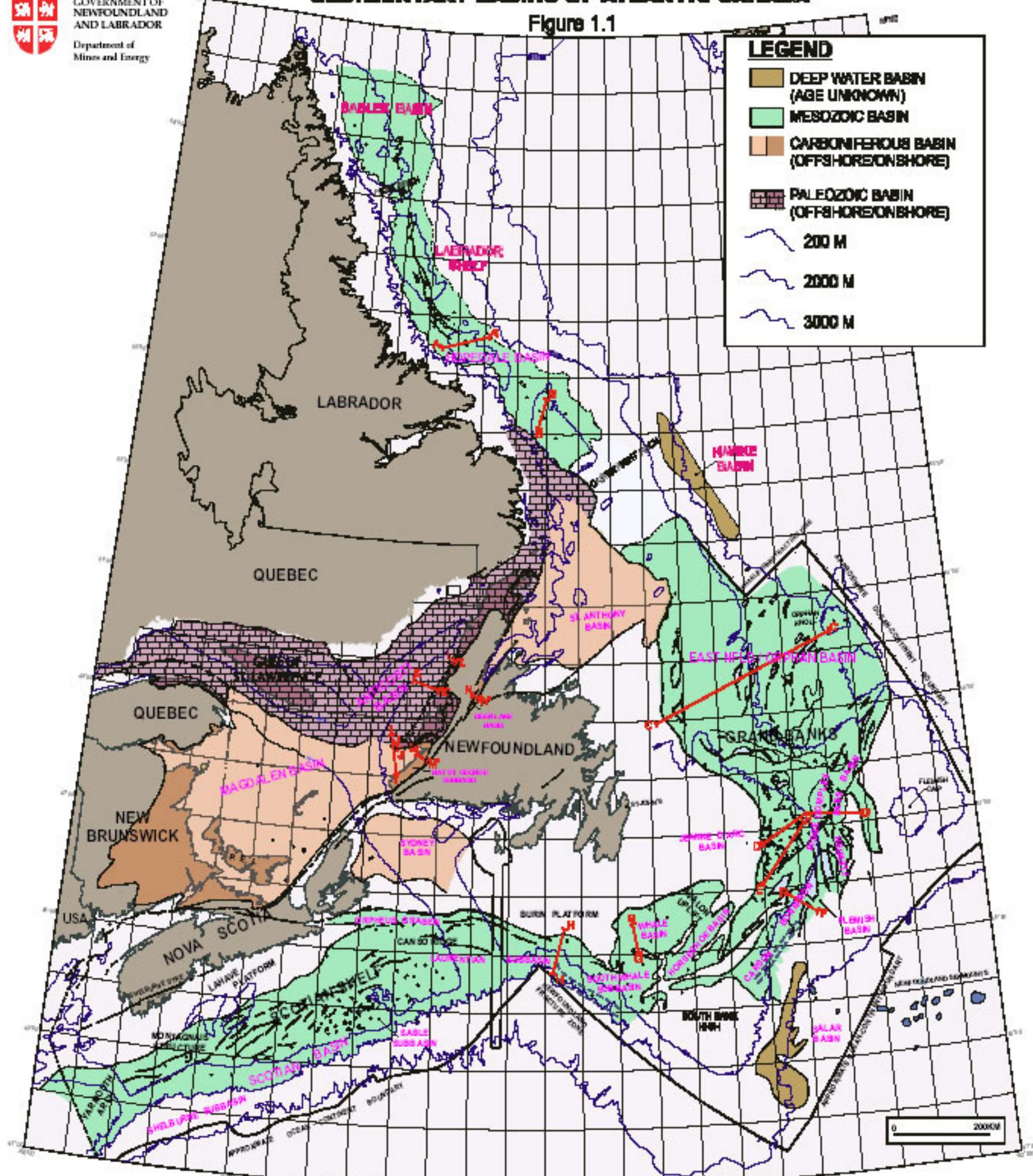
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SEDIMENTARY BASINS OF ATLANTIC CANADA

Figure 1.1



Modified after: Canada-Newfoundland Offshore Petroleum Board and Geological Survey of Canada

This map outlines the Paleozoic and Mesozoic cover of eastern Canada. The Labrador Shelf outline is based on the GSC's Basin Atlas map of the Lower Tertiary Cartwright Shale. The locations of cross-sections presented in this report are also shown.

Section 1

Introduction

Although still in the early stages of exploration, the east coast of Canada, including offshore Nova Scotia and offshore Newfoundland and Labrador, has recently come to prominence as a major new territory of petroleum production. The Sable gas project, offshore Nova Scotia, is currently producing about 400 mmcf/d from a multi-field development near Sable Island. The Hibernia field, on the Grand Banks of Newfoundland, began production from a gravity based structure in November 1997 and is now producing about 180,000 barrels per day (figure 1.2). Thirty five kilometres south of Hibernia, the Terra Nova field will begin production in March 2001 using a floating production storage and off-loading system (FPSO), and is expected to produce about 125,000 barrels per day at start up. Husky Oil recently announced a development proposal to produce 75,000 to 100,000 barrels per day

from the White Rose field by late 2003, and Chevron is currently studying the possibility of bringing the Hebron/Ben Nevis fields into production. Based on these four developments alone, offshore Newfoundland will likely to be producing about 500,000 bopd by mid-decade.

In Newfoundland and Labrador, petroleum exploration has focused primarily on the Mesozoic basins off the Province's east coast. However, during the last decade, exploration has also occurred in the Paleozoic rocks of western Newfoundland (figure 1.1). To date, 125 exploration wells, 31 delineation wells and 27 development wells have been drilled offshore Newfoundland and Labrador. Technically recoverable resources of 2.1 billion barrels of oil, 9.3 trillion cubic feet of natural gas and 413 millions barrels of Natural Gas Liquids (NGL)

The Hibernia Platform on the Grand Banks commenced production in November 1997.

have been discovered (table 1.1). The international petroleum industry, along with local companies and research institutions, has successfully adapted technologies developed in the North Sea, Gulf of Mexico and elsewhere to meet the challenges of the northwest Atlantic environment in a manner that provides for safe and profitable access to the area's extensive petroleum resources.

All of the major oil discoveries, thus far, are located in the Jeanne d'Arc Basin which covers an area of about 14,000 square km. The Hibernia, Terra Nova, White Rose and Hebron/Ben Nevis fields contain an estimated 1,978 million barrels of recoverable oil and 4050 bcf of natural gas and 266 million barrels of NGL (C-NOPB, 2000). Undiscovered resources studies have focused primarily on the Northern Grand Banks and have resulted in estimates ranging from 6 to 12 billion barrels of recoverable oil. These estimates will probably change significantly as further drilling occurs, and new areas and play concepts are explored. As evidenced by figure 1.1, the Jeanne d'Arc Basin constitutes but a small part of the Mesozoic cover off Newfoundland and Labrador. Significant oil and gas shows have also been encountered in several other lightly drilled Mesozoic basins, as well as within the Paleozoic rocks of western Newfoundland.

Petro-Canada has estimated it's finding costs for the Jeanne d'Arc Basin at less than US\$1.00/bbl and extraction costs for the Terra Nova Field at US\$ 7.50 per barrel. This extraction cost is based on a reserve of 370 million barrels although the company estimates that an additional 100 million barrels is likely to be present in an undrilled fault block on the east side of the field.

Figure 1.2



Table 1.2 presents the value of bids in recent land sales held by the Canada-Newfoundland Offshore Petroleum Board (C-NOPB). The 1999 sale saw a record total of C\$192 million, with one parcel in the Flemish Pass Basin going for C\$110 million. The fact that most of these work commitments are for parcels located within the Ridge Complex and Flemish Pass Basin clearly indicates that exploration is about to expand beyond the Jeanne d'Arc Basin. The Flemish Pass Basin, located in deeper waters (~1000 metres) to the east of the Jeanne d'Arc, has had only three wells drilled to date. Although all three were dry holes the limited drilling has proven the presence of the same rich Kimmeridgian source rock that occurs in the Jeanne d'Arc Basin, as well as equivalent age reservoir rocks. Also, during 1998 and 1999, large speculative seismic programs were shot in the Flemish Pass and throughout the basins of the southern Grand Banks. This, combined with the recent posting of large land blocks (see figure 1.3) in the Carson, Bonnition and South Whale basins is a further indication of the onset of a new round of exploration. This round will re-visit areas such as the Flemish Pass and southern Grand Banks with an improved understanding of stratigraphy and trapping mechanisms, and will be bolstered by the major advances in subsurface mapping provided by 3D seismic data.

Significant Discoveries - Discovered Resources						
Discovered Resources	Newfoundland Offshore Area			NGL's		
	Oil	Gas	bcf	m ³ X 10 ⁶ MMBbls	m ³ X 10 ⁹	
Field Name						
Hibernia	140.5	884	38.7	1375	23.0	145
Terra Nova	64.6	406	7.6	269	2.2	14
Hebron	51.6	325	-	-	-	-
White Rose	43.5	274	59.0	2091	12.2	77
West Ben Nevis	5.4	34	-	-	-	-
Mara	3.6	23	-	-	-	-
Ben Nevis	8.7	55	8.9	315	4.7	30
North Ben Nevis	2.9	18	3.3	116	0.7	4
Springdale	2.2	14	6.7	238	-	-
Nautilus	2.1	13	-	-	-	-
King's Cove	1.6	10	-	-	-	-
South Tempest	1.3	8	-	-	-	-
East Rankin	1.1	7	-	-	-	-
Fortune	0.9	6	-	-	-	-
South Mara	0.6	4	4.1	144	1.2	8
North Dana	-	-	13.3	472	1.8	11
Trave	-	-	0.8	30	0.2	1
West Bonne Bay	5.7	36	-	-	-	-
Sub-Total (Grand Banks)	336.3	2117	142.4	5050	46.0	290
North Bjarni	-	-	63.3	2247	13.1	82
Gudrid	-	-	26.0	924	1.0	6
Bjarni	-	-	24.3	863	5.0	31
Hopedale	-	-	3.0	105	0.4	2
Snorri	-	-	3.0	105	0.4	2
Sub-Total (Labrador Shelf)	-	-	119.6	4244	19.9	123
Total	336.3	2117	262.0	9294	65.9	413

Source: C-NOPB

Table 1.1

Recent Landsale Results			
Year	Number of Parcels	Bids(\$Can Millions)	Bid
1995	1	95.8	
1996	8	126.1	
1997	7	97.0	
1998	13	175.2	
1999	5	192.3	
Total	34	686.4	

Table 1.2

Newfoundland and Labrador Petroleum

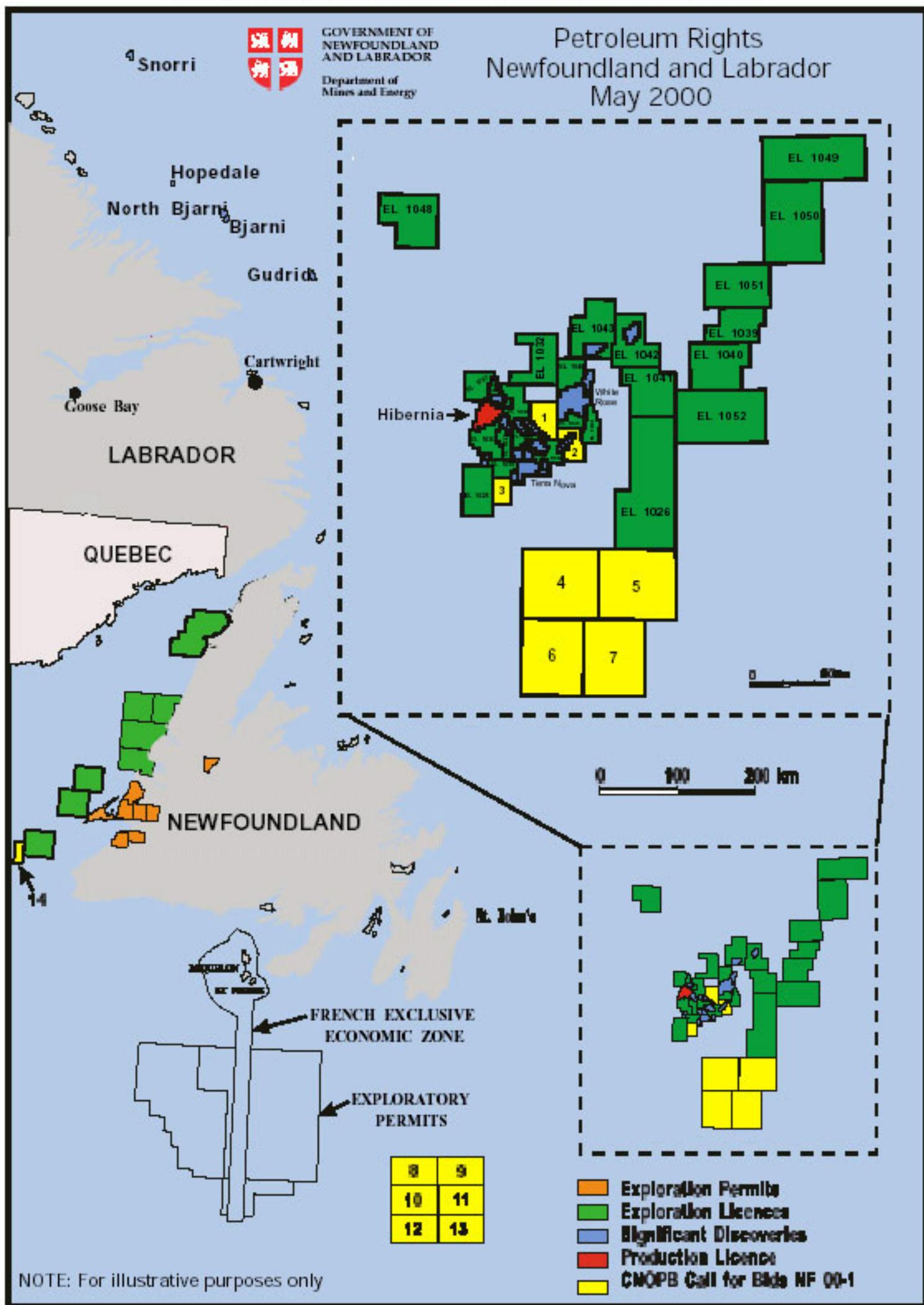


Figure 1.3

Section 2

History of Exploration

Western Newfoundland

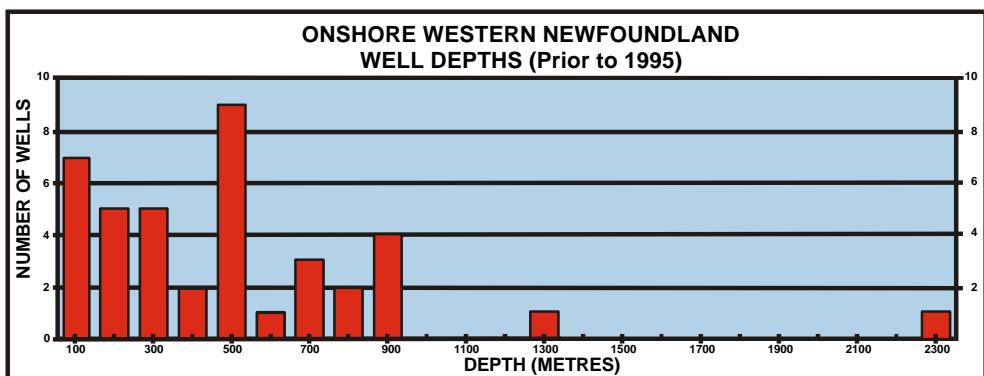
The Paleozoic rocks of onshore western Newfoundland were the first in the Province to be recognized as having petroleum potential. In 1812, a Mr. Parsons noticed oil floating on the surface of Parson's Pond on the Great Northern Peninsula, which he collected and used as a treatment for rheumatism. The first oil-exploration well was drilled at

Parson's Pond in 1867 to a depth of 213 metres and encountered "some oil". Numerous oil seeps and shows in water wells led to the drilling of about 60 wells onshore western Newfoundland in several pulses of activity between 1900 and 1965. Unfortunately, the drilling was carried out with poor quality equipment and insufficient financial backing to assess the area properly. Most of the wells were less than 500 metres deep (figure 2.1), with a few exceeding 700 metres, although it is now known that the sediment thickness often exceeds 3000 metres in the areas drilled. The NALCO 65-I, well drilled in 1965 at Parsons Pond, reached a depth of 1302 metres and had to be abandoned when it started to spew gas and caved in, causing the well to be terminated. This was the deepest well western Newfoundland had seen and although drilled without the benefit of seismic data came very close to penetrating a thrust slice that is now recognized from modern seismic. (More discussion of this prospect is provided in Section 8). In fact, none of the wells drilled were based on seismic mapping, and so these early explorers were essentially drilling blind and, as it turns out, too shallow. In 1995, Hunt Oil and its partner, PanCanadian, drilled the first modern well in western Newfoundland that was based on seismic mapping. The *Port au Port #1* well was a discovery that flow-tested approximately 2000 bopd and 1.3mmcf/d of gas from a carbonate reservoir at 3400 metres depth. Follow up drilling in four additional deep wells in the Port au Port area failed to produce further discoveries and exploration activity has slowed. The legacy of the most recent round of exploration is the availability of new seismic and well data that have proven the presence of a viable petroleum system in the deeper rocks of western Newfoundland, as well as presence of several large undrilled structures.

Grand Banks and Labrador Shelf

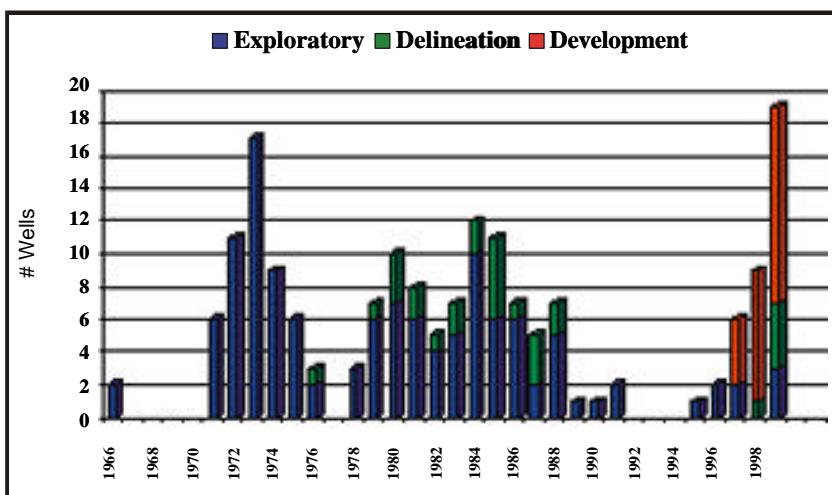
The marine geology of eastern Canada was first studied in the 17th century when seamen measured the water depths and collected bottom samples to aid in locating suitable anchorage and harbour sites. Airborne magnetometer and seismic refraction surveys conducted in the late 1950's and early 60's revealed that the offshore geology was quite different from that of the rocks exposed onshore. These findings established that sediments in excess of 4000 metres thickness blanket the Grand Banks of Newfoundland. Oil companies were quick to determine that the area could be a favourable habitat for petroleum, and consequently, the first federal offshore permits to explore for hydrocarbons were issued on Newfoundland's continental shelf in 1964.

Figure 2.1



Historic drilling in western Newfoundland has been to shallow depths and did not test the deeper features now recognized from modern seismic. The deepest well shown was drilled in 1973 and all the others were drilled prior to 1966.

Total Offshore Wells Drilled



Total Offshore 2D & 3D Seismic Data

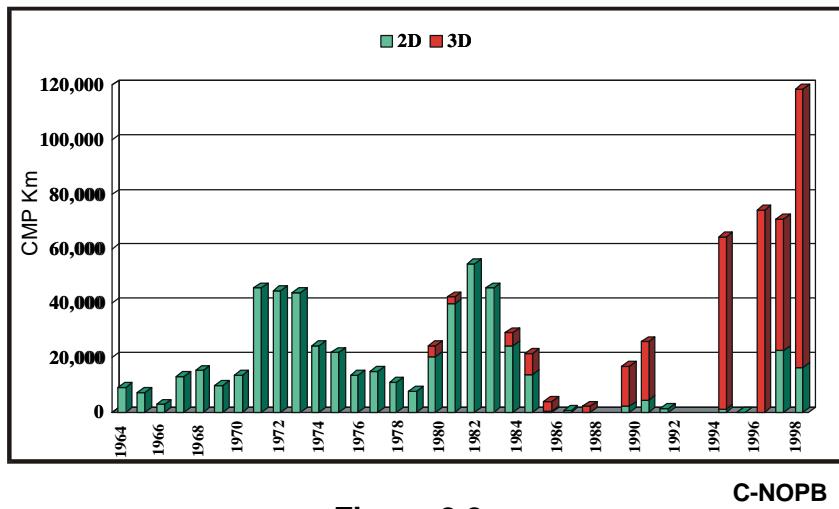


Figure 2.2

between the federal and provincial governments over ownership of the offshore led to a reduced level of drilling offshore Newfoundland. At this time drilling was initiated in the Orphan Basin and continued off Labrador (see Appendix A). Geophysical investigations indicated the existence of a variety of favourable structures on the Grand Banks, including salt domes, basement highs and tilted fault blocks - but drilling had failed to identify commercial pools of oil or gas. However, there were some significant shows: the *Adolphus 2 K-41* well, drilled on a salt piercement structure in the Jeanne d'Arc Basin, tested minor flows of oil and solution gas from thin Upper Cretaceous sandstones; and, not far from the initial Tors Cove well, *Heron H-73* tested 22 barrels of 7° API gravity oil from an Upper Cretaceous limestone. Between 1974 and 1976, there were also three wet gas discoveries made on the Labrador Shelf - *Bjarni H-81*, *Gudrid H-55* and *Snorri J-90*.

No wells were drilled in 1978, but drilling resumed in 1979 on the Grand Banks with the spudding of *Gabriel C-60* in the Flemish Pass Basin. Gabriel was the first well in the Flemish Pass and, although a dry hole, proved the presence of petroleum in the basin by way of a Lower Cretaceous core that bled oil. Shortly after Gabriel had spudded, Chevron Standard farmed into a 213,000 hectare block controlled by Mobil Oil in the Jeanne d'Arc Basin. In order to meet their obligations, Chevron spudded

One year later, the land position on the Grand Banks was dominated by Amoco (then called Pan American) which held 14 million hectares. Work commitments were only 12 cents per hectare for the first 3 years on a permit's 12 year life and vast tracts of land were subsequently acquired. In 1966, Amoco and Imperial Oil drilled the first wildcat well offshore Canada. *Pan Am A-1 Tors Cove* was plugged and abandoned in Jurassic salt after encountering minor shows of methane during formation testing. Four days after the well was completed, a second well, *Pan Am Grand Falls* was spudded 170 km to the northeast. The well was a dry hole and failed to reach its projected total depth due to deteriorating weather conditions. Having drilled two dry holes, the companies stopped to reconsider their exploratory efforts. Subsequently, all drilling programs were halted for a four year period and efforts concentrated on the acquisition of reflection seismic data.

In 1971, drilling resumed on the Grand Banks as well as on the Labrador Shelf. By the end of 1974, 40 dry holes had been drilled on the Grand Banks. This lack of success combined with escalating drilling costs and a jurisdictional dispute

the *Hibernia P-15* well. When drillstem tested, the well flowed at a combined rate of 11,415 barrels per day of high quality oil and 11.2 mmcf/d of gas through a 26/64" choke. The well had an estimated flow potential of more than 20,000 barrels of oil per day making Hibernia the first field on the Atlantic Shelf of North America thought to be capable of commercial production. Under the terms of the farm-out agreement, Mobil assumed operatorship of the field. Nine delineation wells were drilled on the Hibernia structure, only one of which was a dry hole, confirming the presence of a "giant" oilfield. The discovery of Hibernia demonstrated that Cretaceous faulting had the proper timing to trap oil in the d'Arc Basin. During the next six years, fourteen additional discoveries were made in the Jeanne d'Arc Basin and Ridge Complex, including Hebron (1981), Terra Nova (1984) and White Rose (1985) - setting the stage for multiple developments.

In February 1985, the jurisdictional dispute between the federal and provincial governments was resolved by means of the Atlantic Accord. This led to the establishment of the Canada-Newfoundland Offshore Petroleum Board (C-NOPB) to administer the offshore area on behalf of the governments of Newfoundland and Canada. With the Atlantic Accord in place, Mobil submitted a development plan for Hibernia in September 1985, but when oil prices dropped in 1986 plans to develop the field were put on hold. With sustained low prices, drilling gradually dropped off so that only four wells were drilled between 1989 and 1995. Nevertheless, a fiscal arrangement by which Hibernia could proceed was finalized in 1990 and construction of the Bull Arm facilities began immediately. In 1992, drydock construction of the Hibernia GBS began at Bull Arm and in November 1997, Hibernia achieved first oil production. Development drilling at Hibernia has proven that the sands of the Hibernia Formation are a better reservoir than originally anticipated and has resulted in daily production rates being increased from the initial estimate of 135,000 barrels to 180,000 barrels. The C-NOPB has also increased its reserve estimate for Hibernia from 666 million barrels to 884 million barrels recoverable. These numbers could continue to increase as development drilling unfolds and with further delineation of the field.

The installation of the Hibernia production system on the Grand Banks put in place crucial infrastructure that is facilitating a rapid expansion of the province's petroleum sector. The 1.2 million tonne fixed platform, which was built to meet the challenges of the northwest Atlantic environment, including collision by icebergs, is essentially a concrete island 300 km from shore that is playing a supporting role for exploration and development on and beyond the Grand Banks. The sharing of warehouse space, helicopter support, and various services with other operators has simplified logistics and brought new efficiencies to exploration and development throughout the province.

In March 2001, the 400-500 million barrel Terra Nova field will begin production at about 125,000 barrels per day using an FPSO. With the startup of Terra Nova, the Province will have gone from zero production to more than 300,000 barrels per day - about 1/3 of Canada's conventional light oil production - in just over three years. This is possible because of the high flow capacity of the

Percentage Wells per Area

Total Exploration and Delineation wells drilled = 154

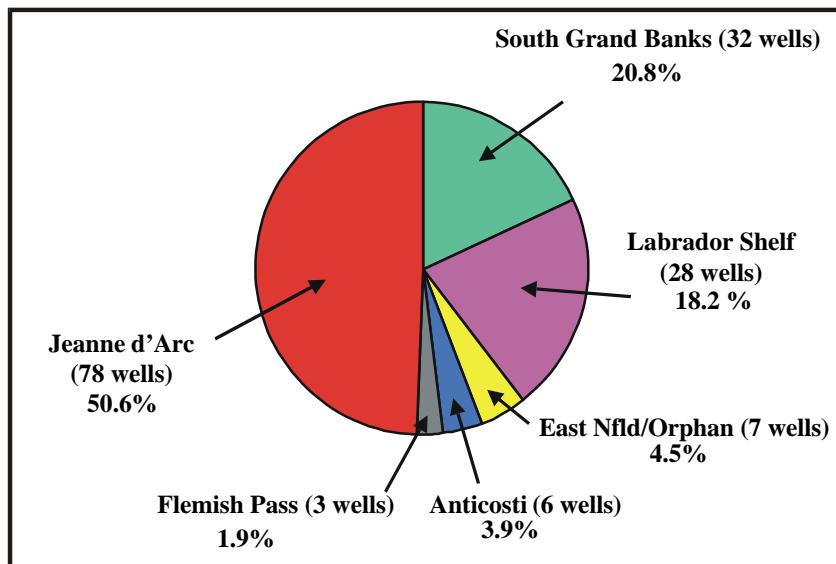


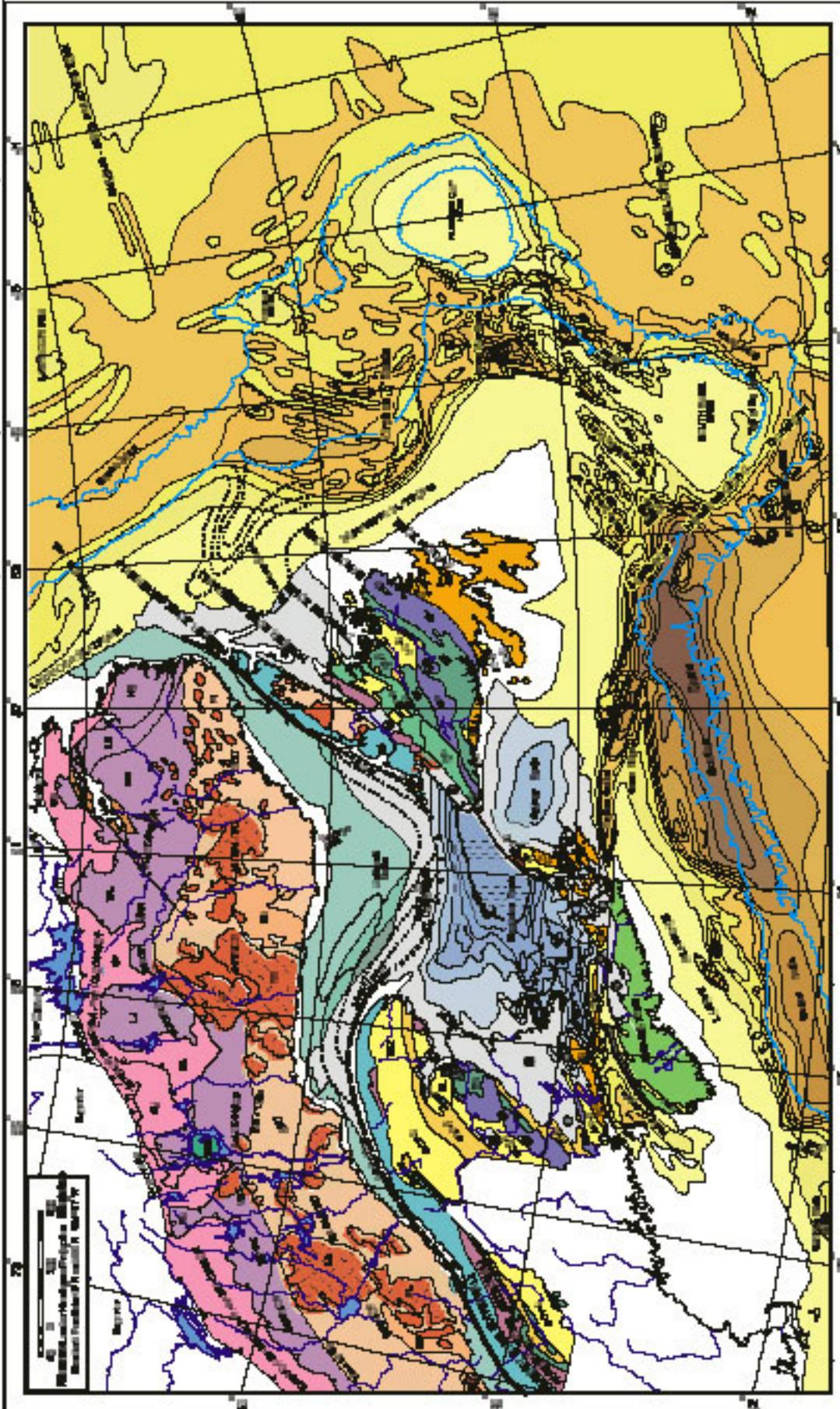
Figure 2.3

Grand Banks reservoirs (for example; individual Hibernia wells are capable of producing in excess of 50,000 bopd from the sandstones of the Hibernia Formation alone). Terra Nova will produce via subsea templates that have been installed in twelve metre deep glory holes that protect wellheads from iceberg scour. Although precautions must be taken in regard to icebergs, the probability of a berg hitting an installation is very low. When a berg does approach a drilling rig or production system it can normally be towed by supply vessels to sufficiently alter its course.

As previously stated, Husky Oil recently announced its intention to develop the White Rose field by FPSO. Chevron and partners are currently studying the feasibility of developing the Hebron/Ben Nevis fields, which the C-NOPB estimates to contain 414 million barrels of recoverable oil and 313 billion cubic feet of natural gas. Chevron has indicated that they are considering both fixed and floating systems as possible modes of development. Other smaller fields in the basin may be developed as multi-pool projects or by subsea tie-backs to the larger developments. In the meantime exploration continues.

Figure 3.1

TECTONIC ASSEMBLAGES MAP (GSC Open File 3657)



This tectonic assemblages map shows depth to basement along the Grand Banks and Scotian Shelf and also illustrates the thickness of the Cenozoic wedge that progrades seaward over the shelf edge. Map provided courtesy of the Geological Survey of Canada.

Section 3

Geological Framework

Twenty sedimentary basins and sub-basins, ranging in age from Early Paleozoic to Late Cretaceous, have been identified onshore and offshore Newfoundland and Labrador (figures 1.1 and 3.1). The early Paleozoic Anticosti Basin, which contains the oldest sediments, extends from the Gulf of St. Lawrence to the southeastern coast of Labrador where it is overlain by Mesozoic strata of the Labrador Shelf. Mesozoic sediments have been preserved as passive margin sequences along the entire outer shelf and in a series of failed rifts that trace a northeast transect across the Grand Banks. The Mesozoic basins are overlain by an undeformed Cenozoic wedge that progrades seaward over the continental slope.

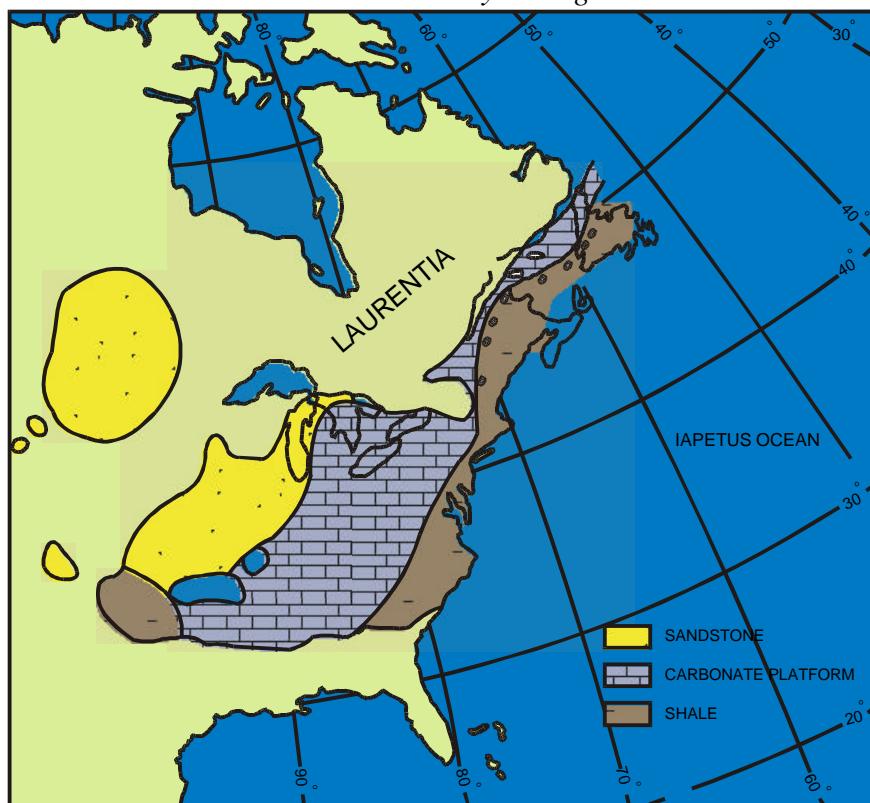
Paleozoic Basins

The Early Paleozoic Anticosti Basin is one of a number of basins that preserve Cambrian to Ordovician shelf and foreland basin rocks along the broad sweep of the Appalachian trend of eastern North America (figures 3.2 and 3.3). Cambrian and Ordovician rocks of the Anticosti Basin include sandstones and carbonates that once formed part of a broad continental shelf that bordered the ancient continent of Laurentia. South of this margin stretched the wide expanse of the warm, Early Paleozoic “Iapetus Ocean” (figure 3.2). When Iapetus closed, the continental margin became deformed in a long sinuous orogenic mountain belt constituting the present day Appalachian Mountains. In present day western Newfoundland, the ancient shelf is preserved within and to the west of the External Humber Tectonostratigraphic zone (Williams, 1978, 1995; see figure 3.1) as a lightly deformed, mainly carbonate, authochthonous (non-transported) sequence. Onshore and nearshore western Newfoundland

the shelf sequence is locally overlain by allochthonous (transported) slope-to-basin sediments and ophiolites that were thrust westward by the closing of Iapetus. The transported sequence contains the Green Point Formation shale that is believed to be the source rock for the numerous oil seeps throughout the area, as well as oil and gas in the *Port au Port #1* discovery. Within the Gulf of St. Lawrence, the carbonate shelf is overlain by a relatively undeformed sequence of Silurian and Devonian clastics that were shed from orogenic sources to the east. Basins such as these in Quebec and Ontario have produced oil and gas from reservoirs in Ordovician carbonates. Southward, in Texas and Oklahoma, considerable quantities of petroleum have been recovered from large carbonate reservoirs in the Lower Ordovician

Figure 3.2

Circa 470 million years ago



Schematic map shows early Middle Ordovician Sedimentary Facies on the Eastern Margin of North America (Modified after Dott and Batten, 1971)

Ellenburger and Arbuckle groups in the Midland, Val Verde, Anadarko, Fort Worth and Arkoma basins (figure 3.3).

Carboniferous sediments were deposited in a series of large basins that extend throughout the Maritime provinces of eastern Canada and into New England (figure 1.1). Two Carboniferous basins (the Deer Lake Basin and the Bay St. George Subbasin) are located onshore western Newfoundland. A few shallow wells drilled in these basins have yielded some significant oil and gas shows but no discoveries have yet been made in the Carboniferous rocks of Newfoundland. The Bay St. George Subbasin extends offshore

into the southern Gulf of St. Lawrence where it merges with its parent Magdalen Basin (figures 1.1 and 8.1). Carboniferous sediments are also preserved within offshore basins to the south (Sydney Basin) and north of Newfoundland (St. Anthony Basin) where they are ultimately onlapped by Mesozoic strata.

Mesozoic Basins

Mesozoic basins off eastern Canada were formed by rifting and seafloor spreading associated with the breakup of the supercontinent, Pangea. Seafloor spreading advanced from the south, reaching Nova Scotia in the Late Triassic (figure 3.4) and creating a northeast trending rift valley within the Grand Banks crustal block, known as the Grand Banks Trough. The rift failed to propagate through the continental crust of the Grand Banks, but the rift valley was eventually inundated by the proto-Atlantic and became the precursor of the Grand Banks basins. An important event in the Late Jurassic (Kimmeridgian) was a marine transgression that deposited an organic rich shale across the Grand Banks, as well as within the basins of the North Sea. This shale, known as the Egret Member on the Grand Banks, is recognized as the primary source of the oil and gas that has been discovered in the Jeanne d'Arc Basin.

With the northward advance of rifting stalled at the Grand Banks, seafloor spreading was accommodated by strike slip movement along the Newfoundland Transform (figure 3.4.A & B). Near the end of Late Jurassic, the spreading centre stepped to the east of the Grand Banks, initiating the separation of the eastern Grand Banks from Iberia. It was at about this time, perhaps in isostatic response to the changed rift pattern (Kerr 1985), that the continental crust beneath the Grand Banks arched upwards along a fairway running southeast from the Avalon Peninsula known as the Avalon Uplift (figure 3.4.C). This led to erosion of older Jurassic sediments along the arch and separated the evolving basins of the northeast Grand Banks from those of the southwest Grand Banks. Seafloor spreading advanced northward, eventually separating Greenland from Labrador during the Early Cretaceous. The Grand Banks Trough remained tectonically active during the Early Cretaceous and became fragmented by a series of northeast trending ridges which became new sources of sedimentation. Throughout the Early Cretaceous a series of marginal marine and fluvio-deltaic sequences were deposited, including most of the proven hydrocarbon reservoirs. By Late Cretaceous, crustal cooling in the Grand Banks area led to regional thermal subsidence and the deposition of a relatively undisturbed sequence of Upper Cretaceous and Tertiary sediments across the shelf.

Figure 3.3

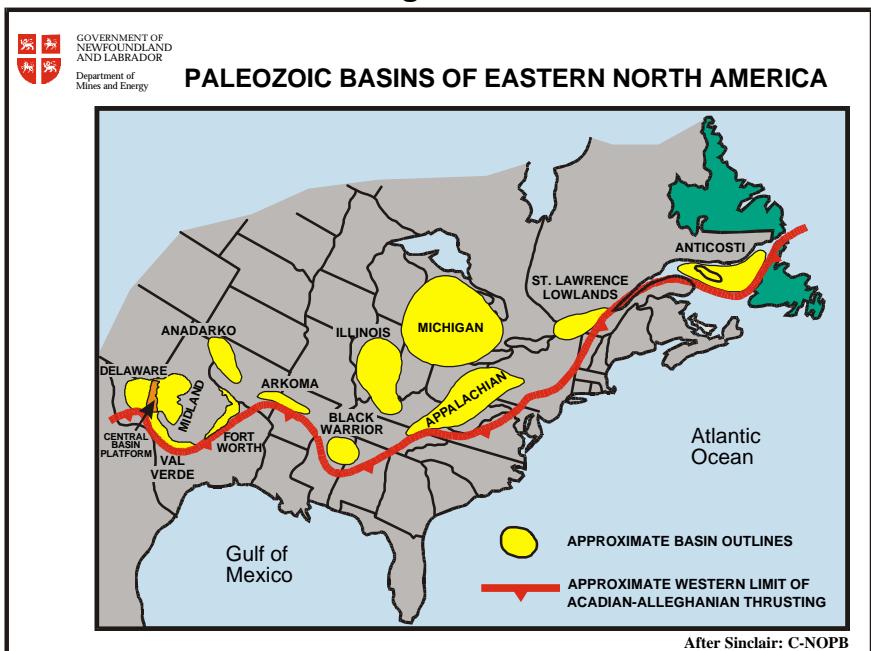
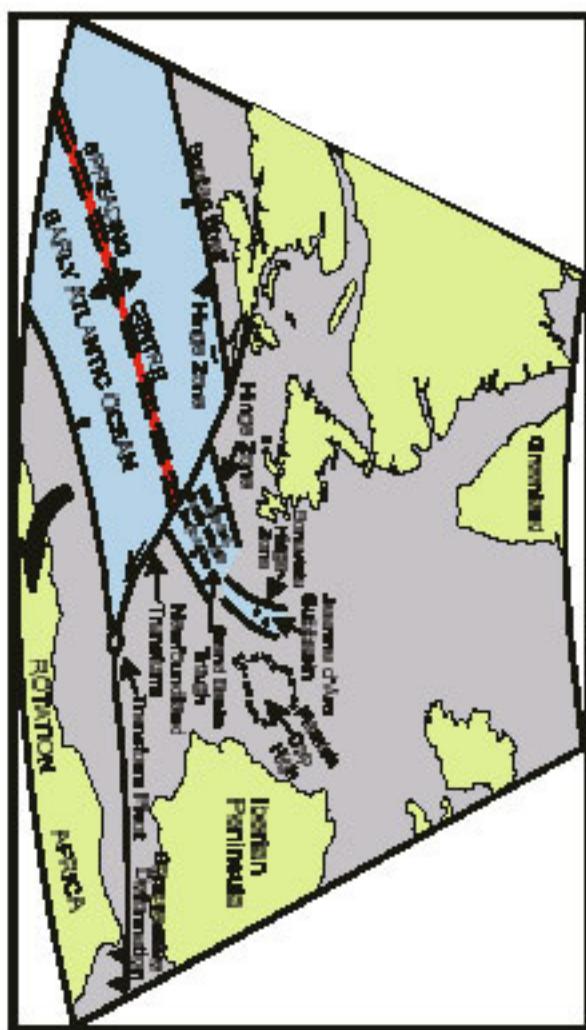


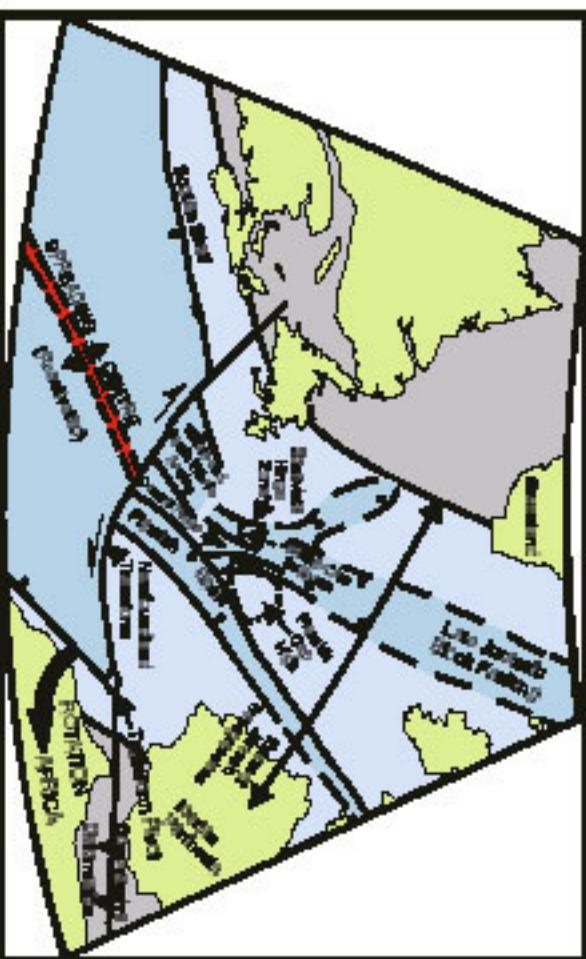
Figure 3.4

A



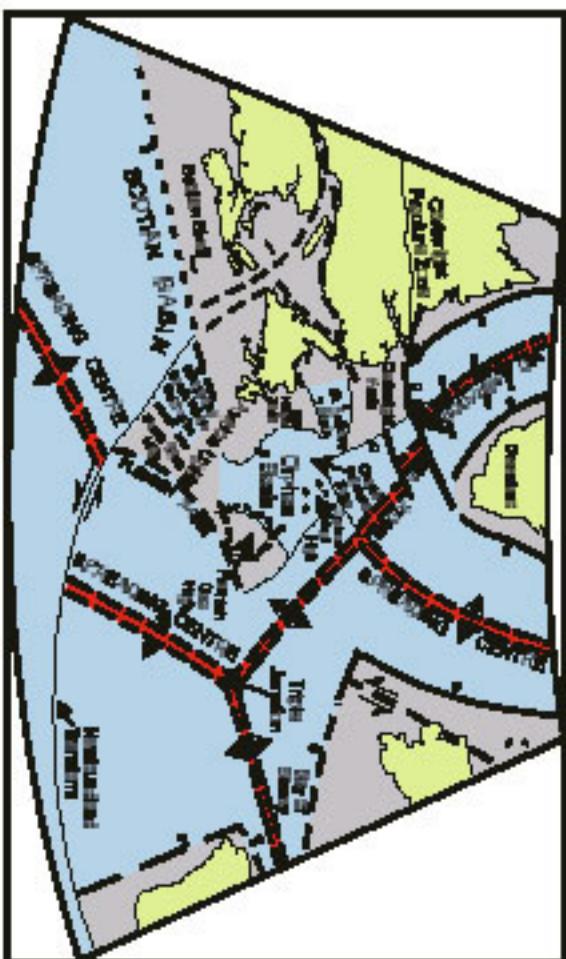
Late Triassic - 230 MY

B



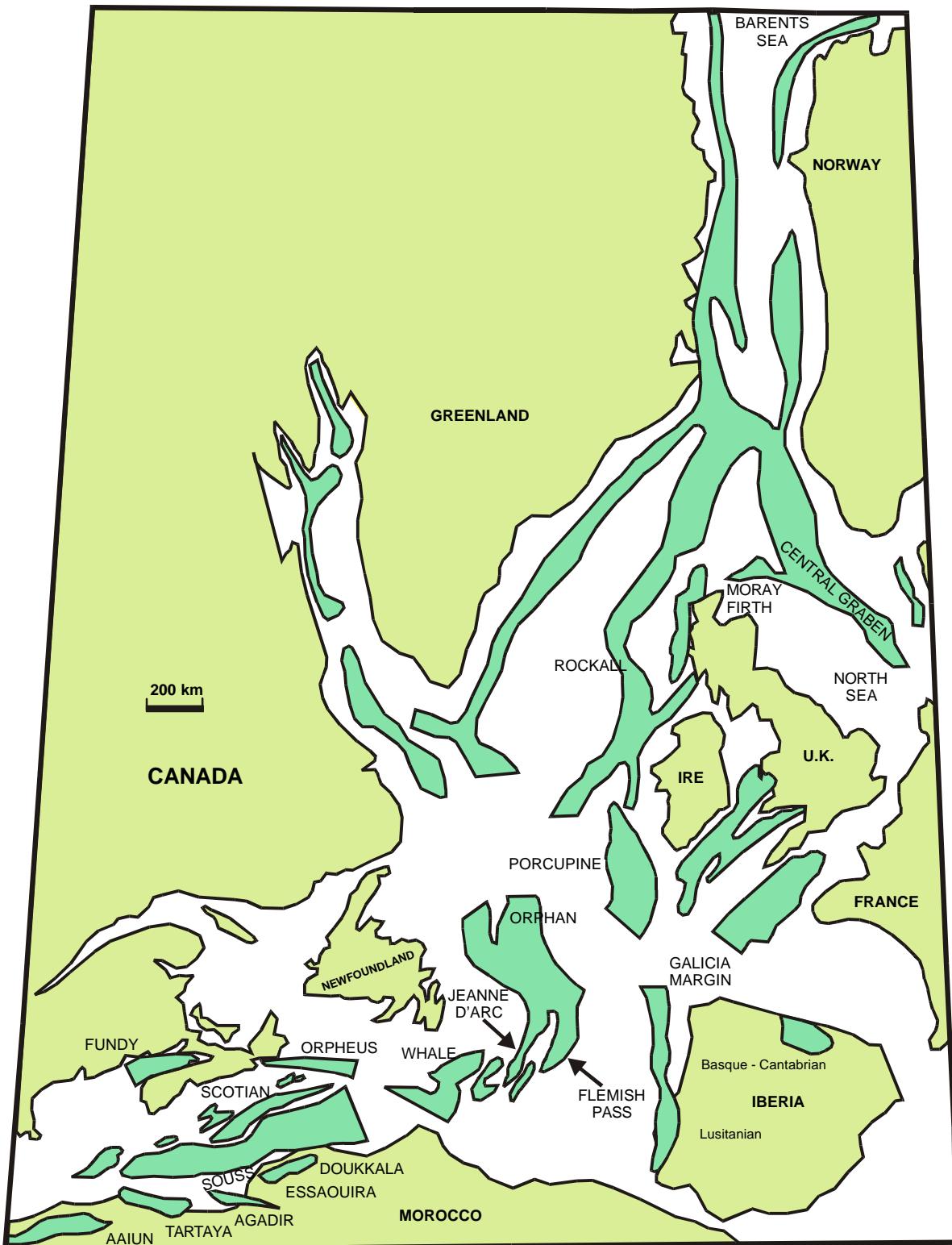
Mid Jurassic - 175 MY

C



Late Jurassic to Early Cretaceous - 150 to 100 MY

Figure 3.5

**Predrift rift basins of the North Atlantic margins:**

Schematic map of the early North Atlantic ocean showing the location of sedimentary basins formed by the rifting and seafloor spreading that began in the Late Triassic. After A.J. Tankard, 1989.

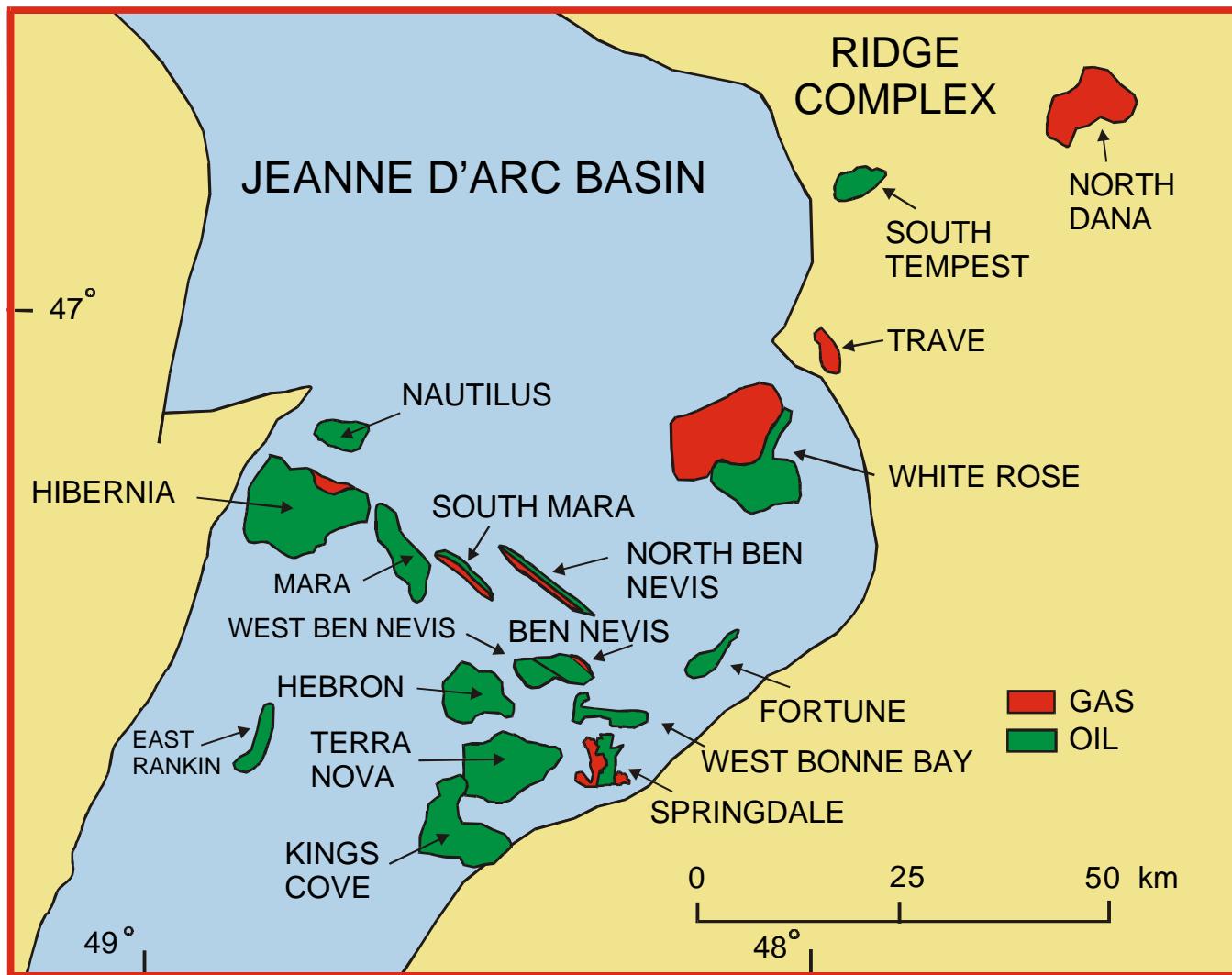
Section 4

Ongoing and Future Developments

This section provides a brief overview of the four largest fields in the Jeanne d'Arc basin. The Hibernia field started production in 1997; Terra Nova will begin production in 2001; and both the White Rose and Hebron/Ben Nevis are expected to be developed in the near future. The Jeanne d'Arc basin and adjacent Ridge Complex contain an additional 14 smaller discoveries, some of which will be brought to production via multi-pool developments or by subsea tie-backs to the stand alone projects.

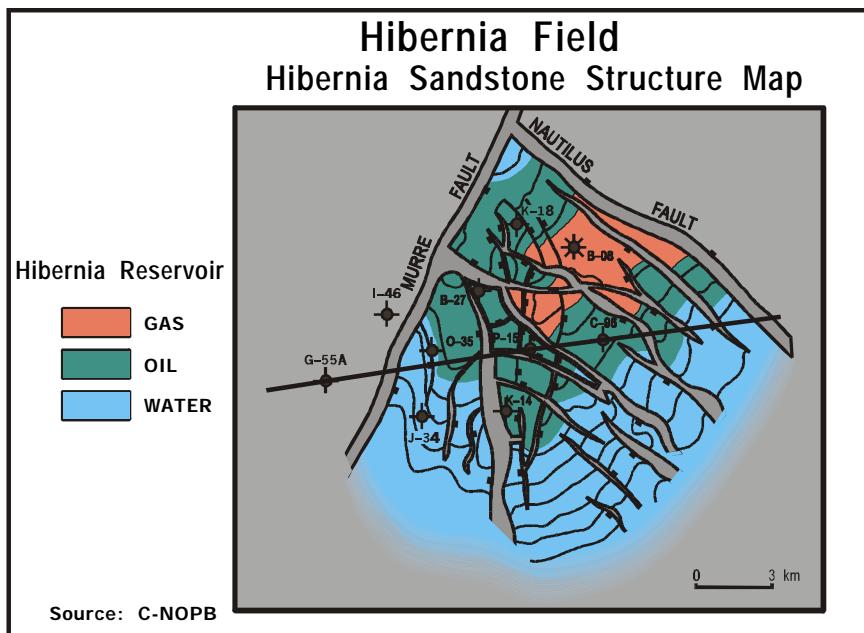
The Canada-Newfoundland Offshore Petroleum Board and Geological Survey of Canada estimate that the Jeanne d'Arc basin and Ridge Complex contain discovered resources of 2.1 billion barrels of oil, 5.05 Tcf of gas and 290 million barrels of natural gas liquids. They estimate the undiscovered resources for this area to include 2.5 billion barrels of oil and 13.8 trillion cubic feet of natural gas.

Figure 4.1



Schematic map of oil and gas fields in the Jeanne d'Arc Basin and Ridge Complex on the Grand Banks of Newfoundland. Modified after C-NOPB.

Hibernia Field



Water Depth

- 80 metres

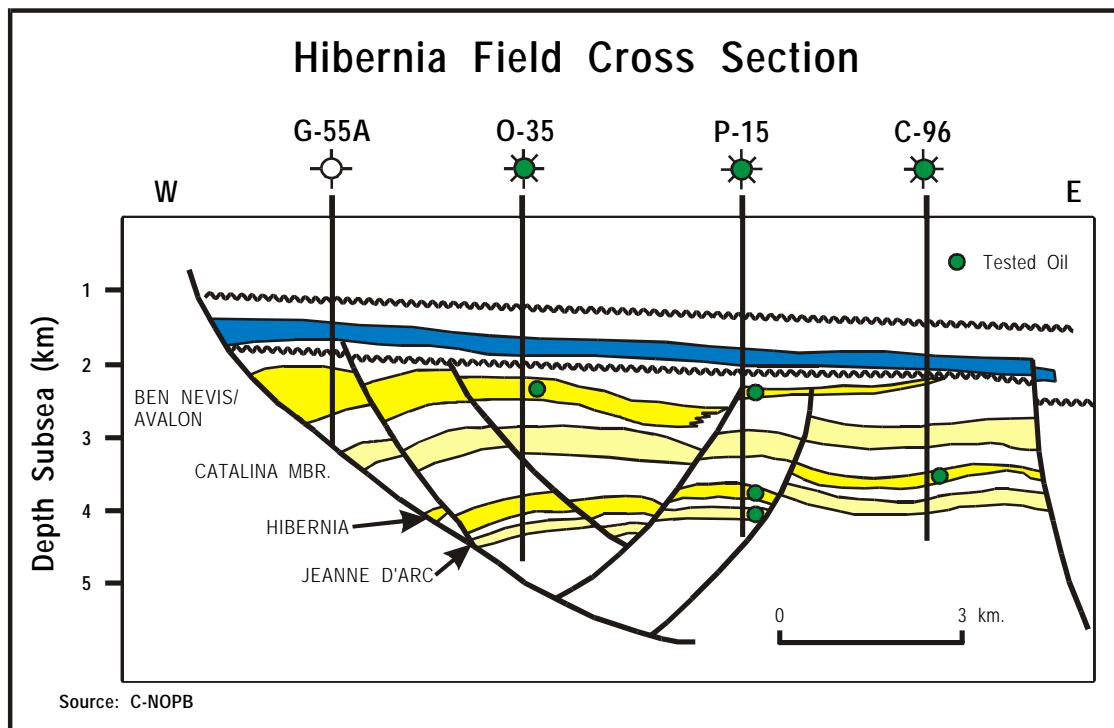
Key Reservoirs:

- Hibernia Sandstone
- Ben Nevis-Avalon Sandstone

Recoverable Reserves

- 884 million barrels oil
- 1.375 Tcf natural gas
- 145 million barrels NGL

Source: C-NOPB



The Hibernia field is the first to be developed offshore Newfoundland and Labrador and is currently producing about 180,000 bopd from seven wells, from the Hibernia Reservoir. Development drilling of the shallower Ben Nevis-Avalon Reservoir has recently begun, and production is to begin shortly.

Figure 4.2

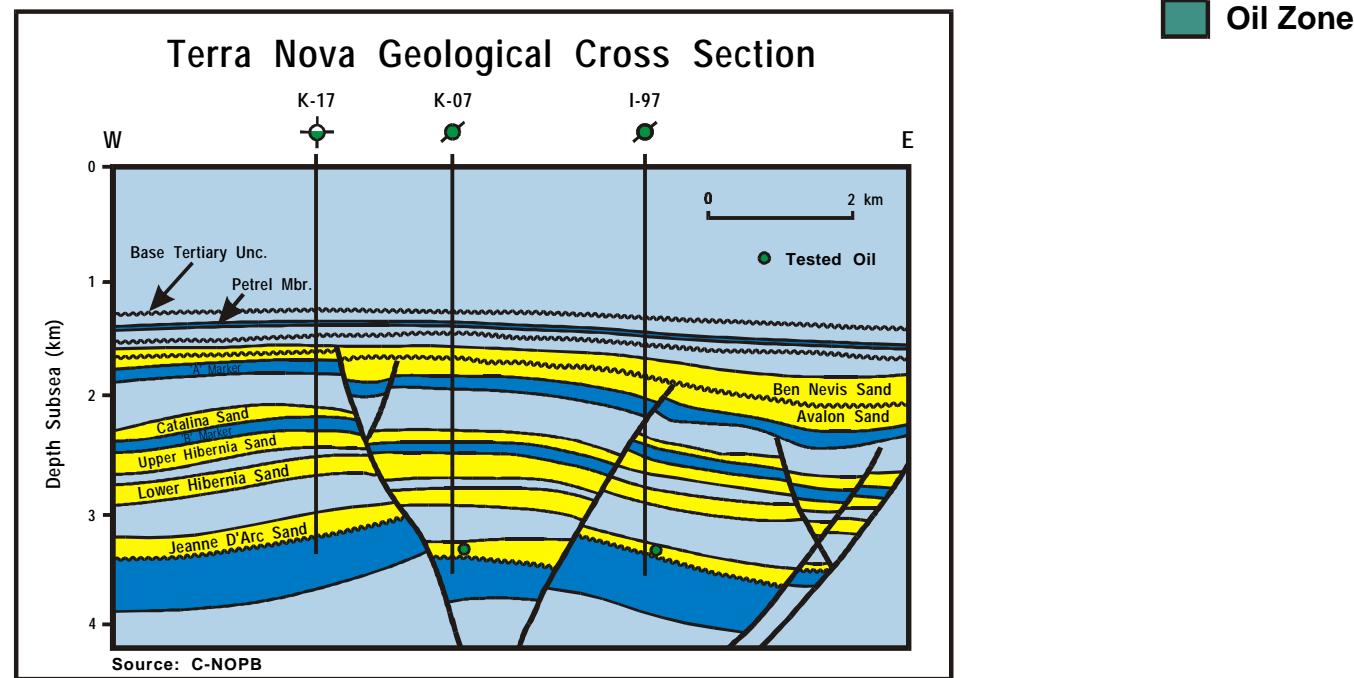
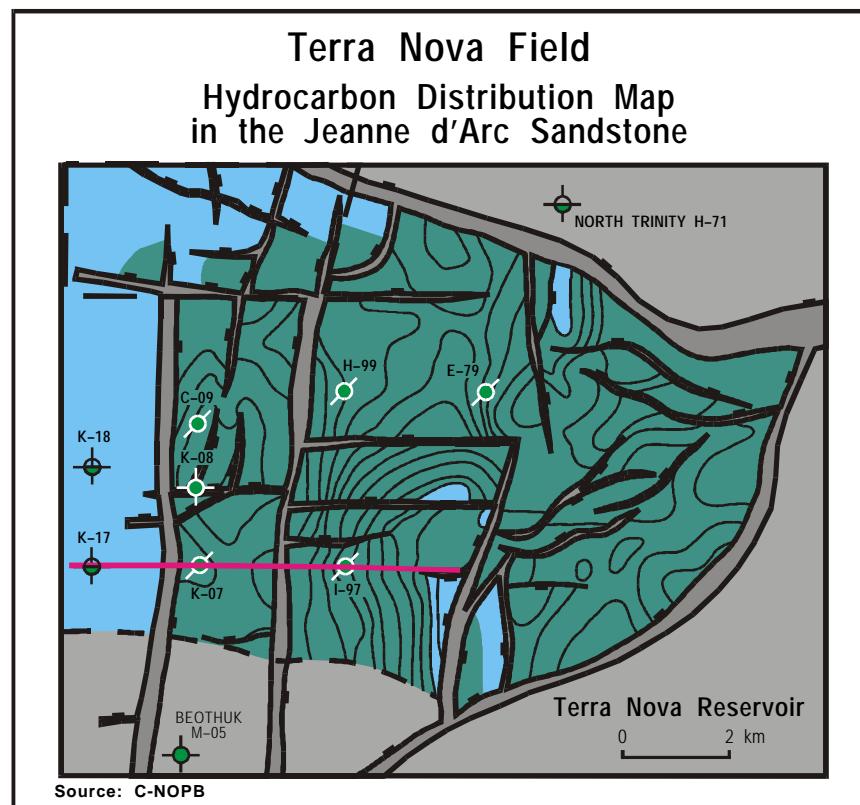
Terra Nova Field

Water Depth
 • 93 metres

Key Reservoir:
 • Jeanne d'Arc Sandstone

Recoverable Reserves
 • 406 million barrels oil
 • .269 Tcf natural gas
 • 14 million barrels NGL

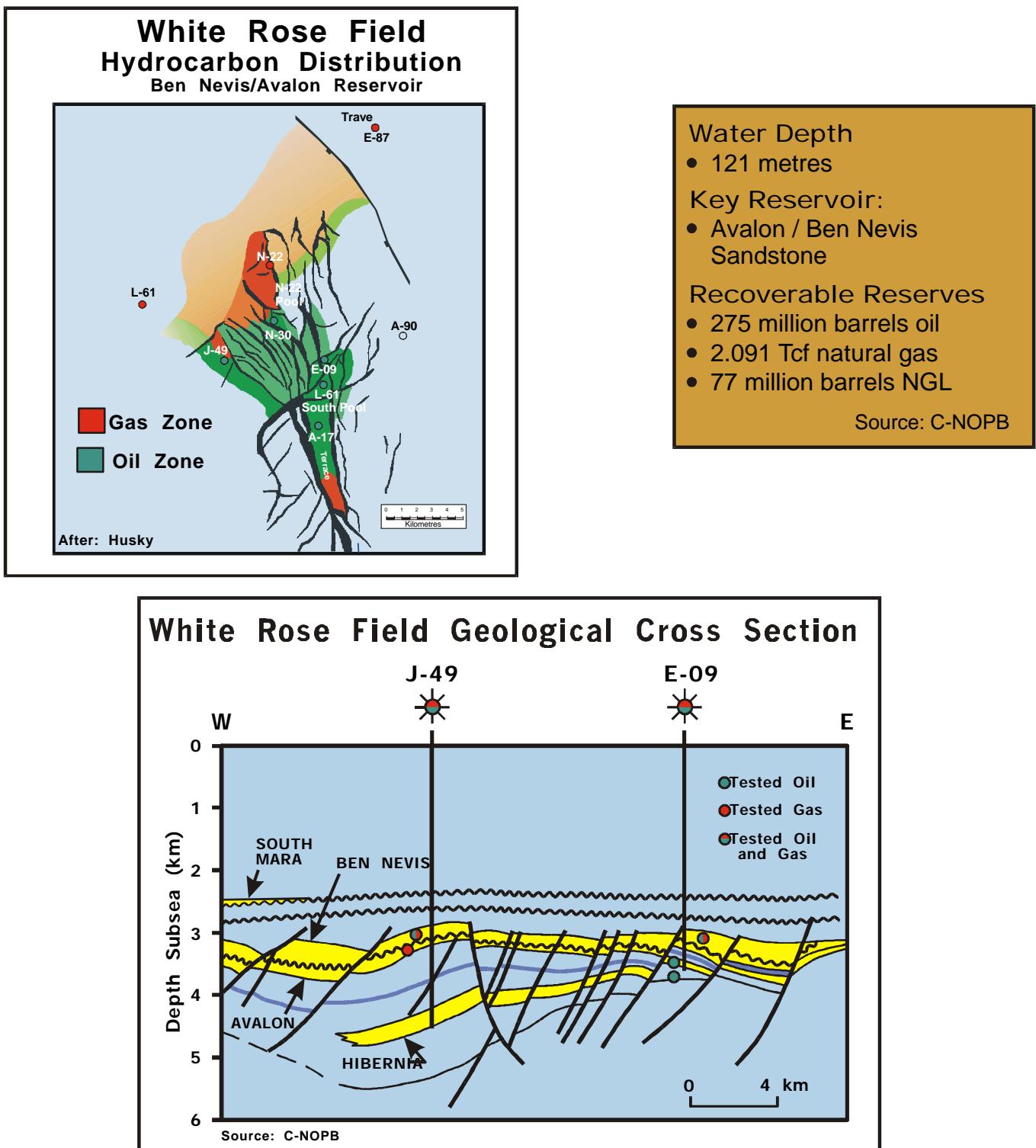
Source: C-NOPB



Petro-Canada (the designated operator) estimates that the Terra Nova Field contains 370 million barrels in the Graben and East Flank and an additional 100 million barrels in the undrilled Far East Block. The field will be brought on production by FPSO in March 2001, and will produce at about 125,000 bopd at startup.

Figure 4.3

White Rose Field



Husky oil recently announced its intention to develop this field by FPSO. First oil is planned for late 2003 with production ranging between 75,000 and 100,000 bopd.

Figure 4.4

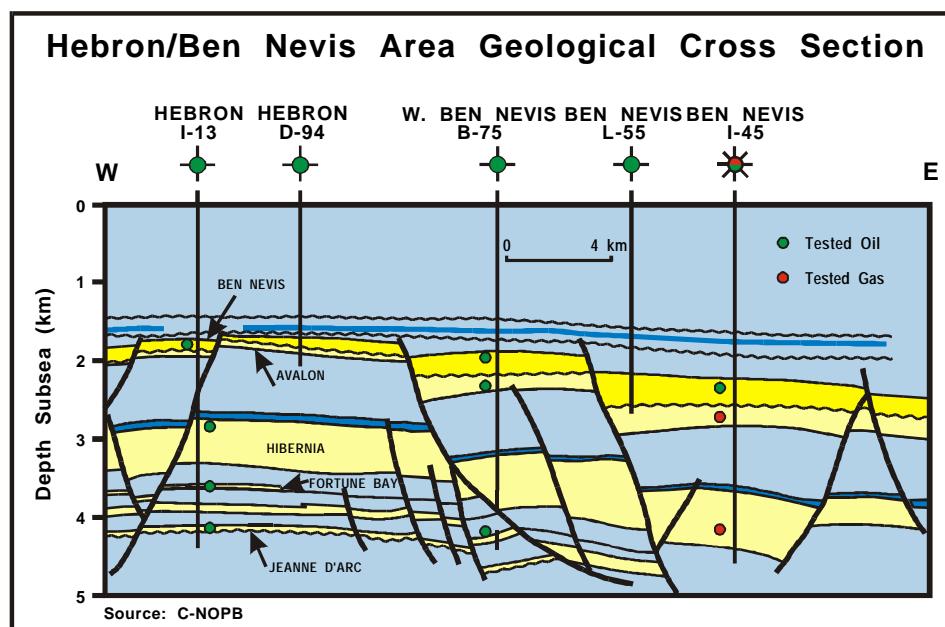
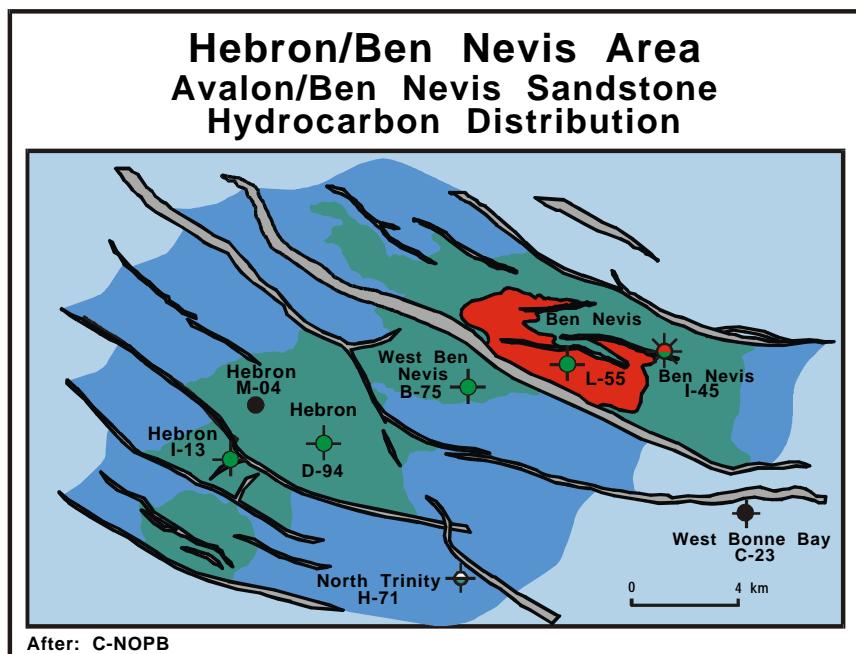
Hebron/Ben Nevis Complex

Water Depth
 • 99 metres

Key Reservoirs:
 • Avalon / Ben Nevis Sandstone
 • Hibernia Sandstone
 • Jeanne d'Arc Sandstone

Recoverable Reserves
 • 414 million barrels oil
 • .313 Tcf natural gas

Source: C-NOPB



The Hebron/Ben Nevis Complex consists of three adjacent fault blocks that, although designated as separate discoveries, would likely be developed together because of their close proximity. Further delineation drilling is needed to better determine the quality and the quantity of the reserves. One challenge that will have to be addressed is that much of the oil within the Avalon/Ben Nevis Reservoir in the Hebron block is heavy (21° API). Chevron and partners are currently studying the feasibility of development. First oil production is possible by 2005.

Figure 4.5

Northern Grand Banks Stratigraphic Chart

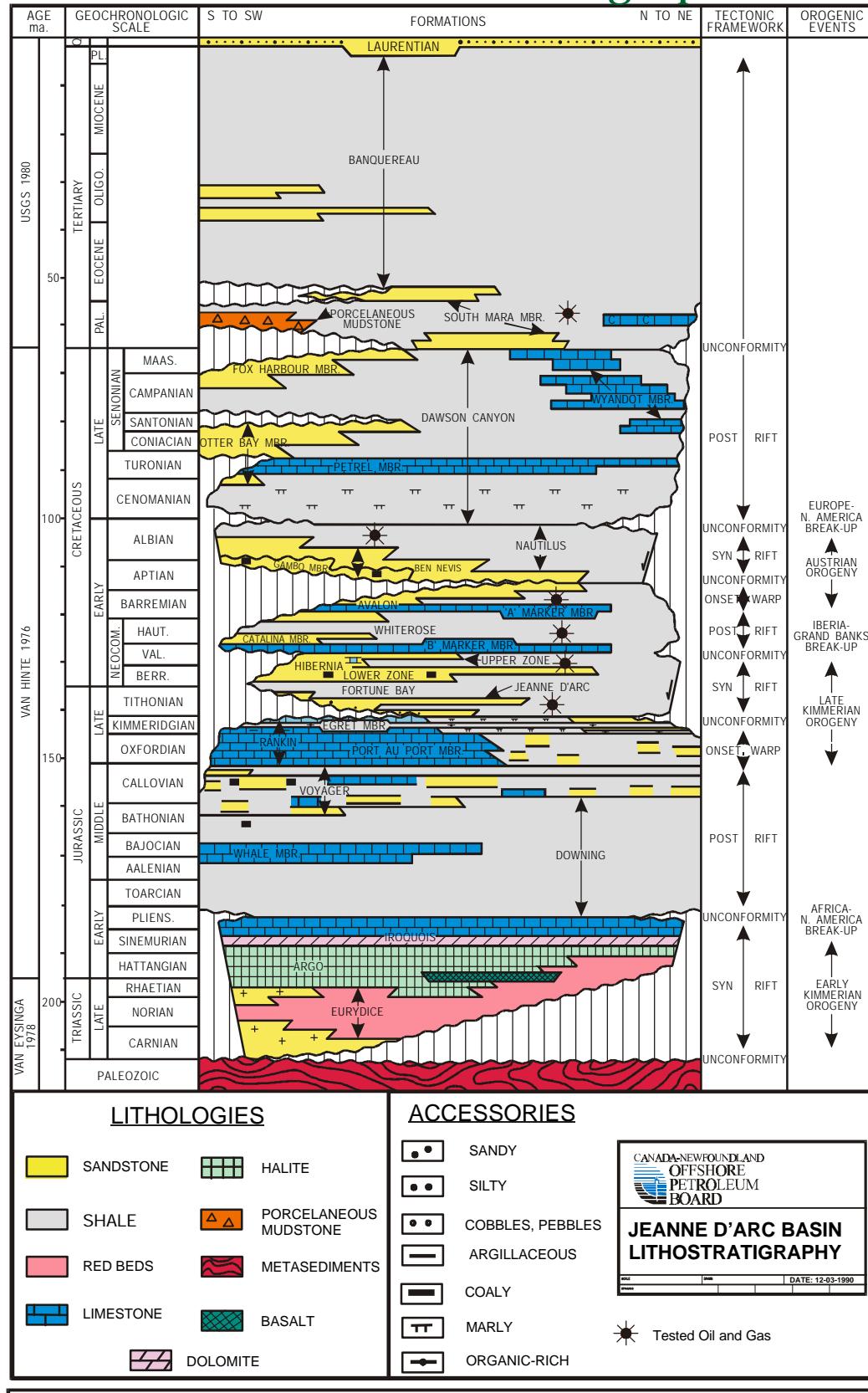


Figure 5.1

Section 5

Section 5.1

Introduction

The northern Grand Banks is underlain by a collage of sedimentary basins and subbasins (including the Jeanne d'Arc, Northeast Newfoundland/Orphan, Flemish Pass basins), and intervening ridges. Sediment thicknesses range up to 20,000 metres (see figure 3.1) and are thinned or locally absent over the ridges. Although the basins have seen most of the drilling, the ridges cannot be written off as exploration targets. Three discoveries have been made on the Ridge Complex that separates the Jeanne d'Arc Basin from the Flemish Pass Basin (figure 4.2).

Section 5.2

Jeanne d'Arc Basin

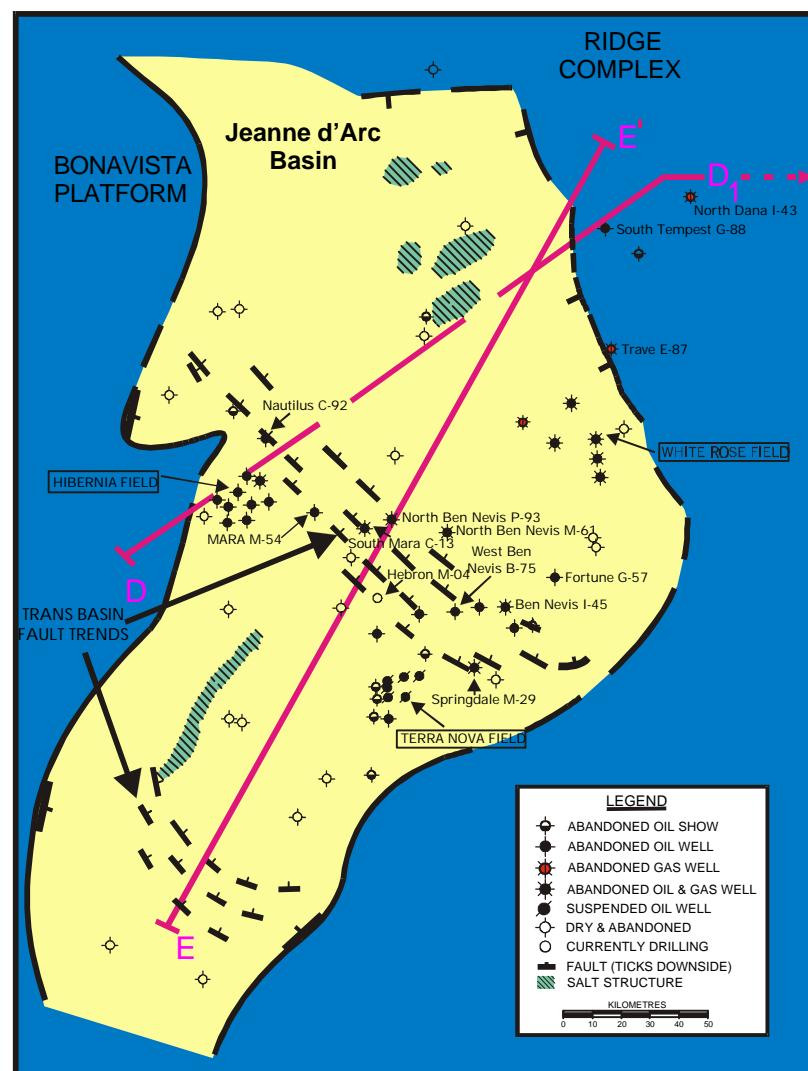
The Jeanne d'Arc Basin is bounded, to the west by the Bonavista Platform, to the east by the Ridge Complex, to the south by the Avalon Uplift, and opens to the north into the East Newfoundland/Orphan basin. All of the major oil discoveries to date (including Hibernia, Terra Nova, White Rose and Hebron/Ben Nevis) are located within this basin along with eleven additional smaller discoveries. Two gas discoveries (Trave and North Dana) and one oil discovery (South Tempest) are located on the adjacent Ridge Complex.

Figure 5.2 is a simplified map of the basin demonstrating that many of the discoveries are associated with a trans-basin fault trend running roughly southeast from Hibernia. Most discoveries were made in the early eighties after the discovery of Hibernia established the trapping significance of these faults. Figure 5.3 is a cross-section running along the axis of the basin that illustrates this fault trend, as well as other trapping mechanisms. Although almost all of the drilling in offshore Newfoundland and Labrador has been focused on structural traps, the *Mara M-54* discovery, which flow-tested 620 barrels of oil per day from a Lower Tertiary submarine fan (South Mara Sandstones), demonstrates the potential for successful stratigraphic plays.

The most important reservoirs thus far are the Lower Cretaceous Avalon/Ben Nevis sandstones, the Hibernia sandstones and the Upper Jurassic Jeanne d'Arc sandstones. The Hibernia Sandstone

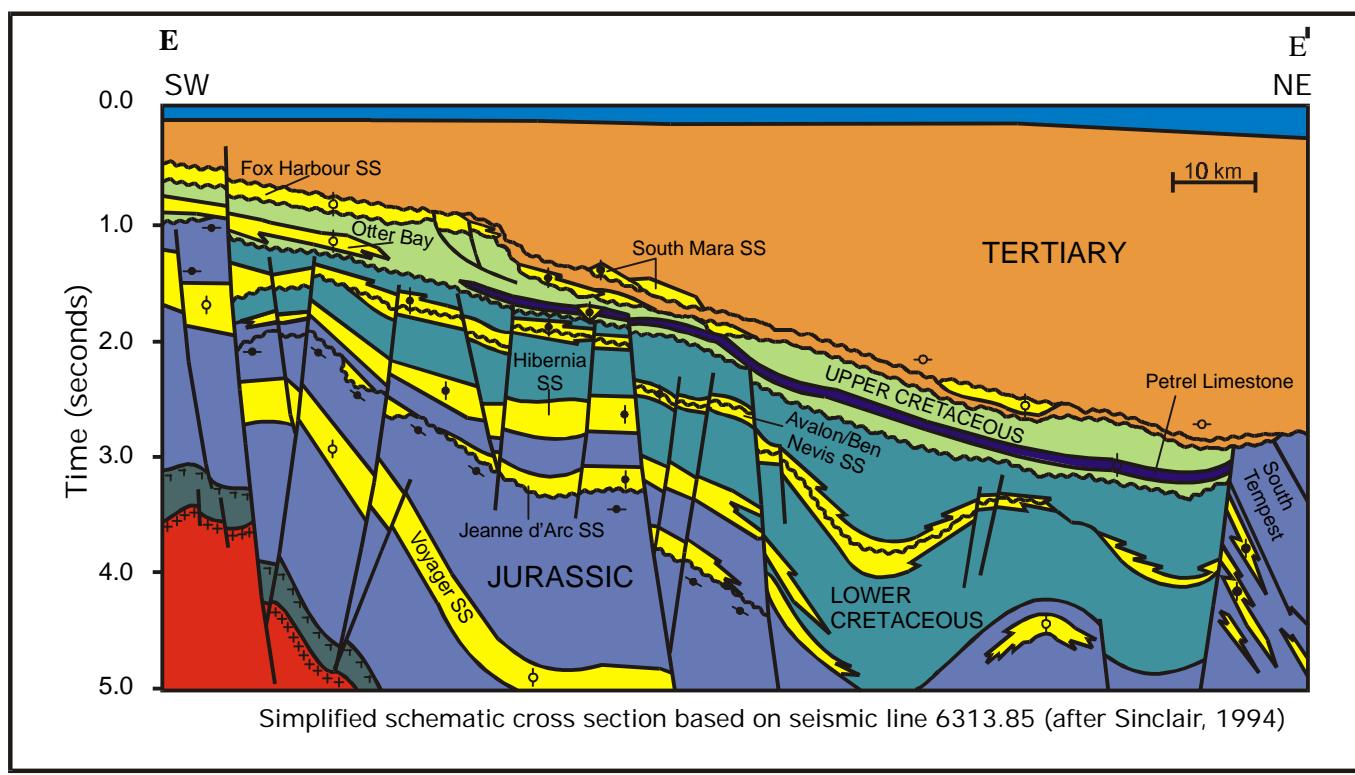
Northern Grand Banks

Figure 5.2



Simplified map of Jeanne d'Arc Basin illustrating the trapping significance of the trans-basin fault trend running southeast from the Hibernia Field

Figure 5.3



A cross section along the axis of the Jeanne d'Arc Basin that illustrates the presence of stacked sandstone reservoirs throughout the basin and the principal trapping mechanism associated with normal faults that trend SE across the basin. See figure 4.2 for section location.

reservoir (at the Hibernia field), is currently the only reservoir with a production history and has demonstrated an exceptional productive capacity. The Hibernia field is currently producing approximately 180,000 bopd from seven wells. The permeability of the Hibernia Sandstone has been measured as high as 26.9 darcies, and as having porosity as high as 21% (19.3% median).¹

The oils within the basin are sweet with typical API indices in the thirties. One notable exception is the Avalon/Ben Nevis reservoir within the Hebron field, which contains sweet but heavier oil of 21° API. This oil is believed to have either been biodegraded or water-washed because of adjacency to a fault (Sinclair et al, 1992).

The primary source rock in the Jeanne d'Arc Basin is recognized as the, Kimmeridgian, Egret Member. Other potential source rocks have been identified in the Voyager and Jeanne d'Arc formations but are believed to be of limited hydrocarbon generative capacity and restricted areal extent (Sinclair et al, 1992). Organic rich shales identified in the Lower Tertiary at *Nautilus C-92* are immature and incapable of generating petroleum because of syndepositional oxidation (Sinclair, 1988). As *Nautilus C-92* is located at the western margin of the basin it is possible that these organic shales could exist in an anoxic state in deeper parts of the basin and may also move into the oil window as the Tertiary section thickens to the north.

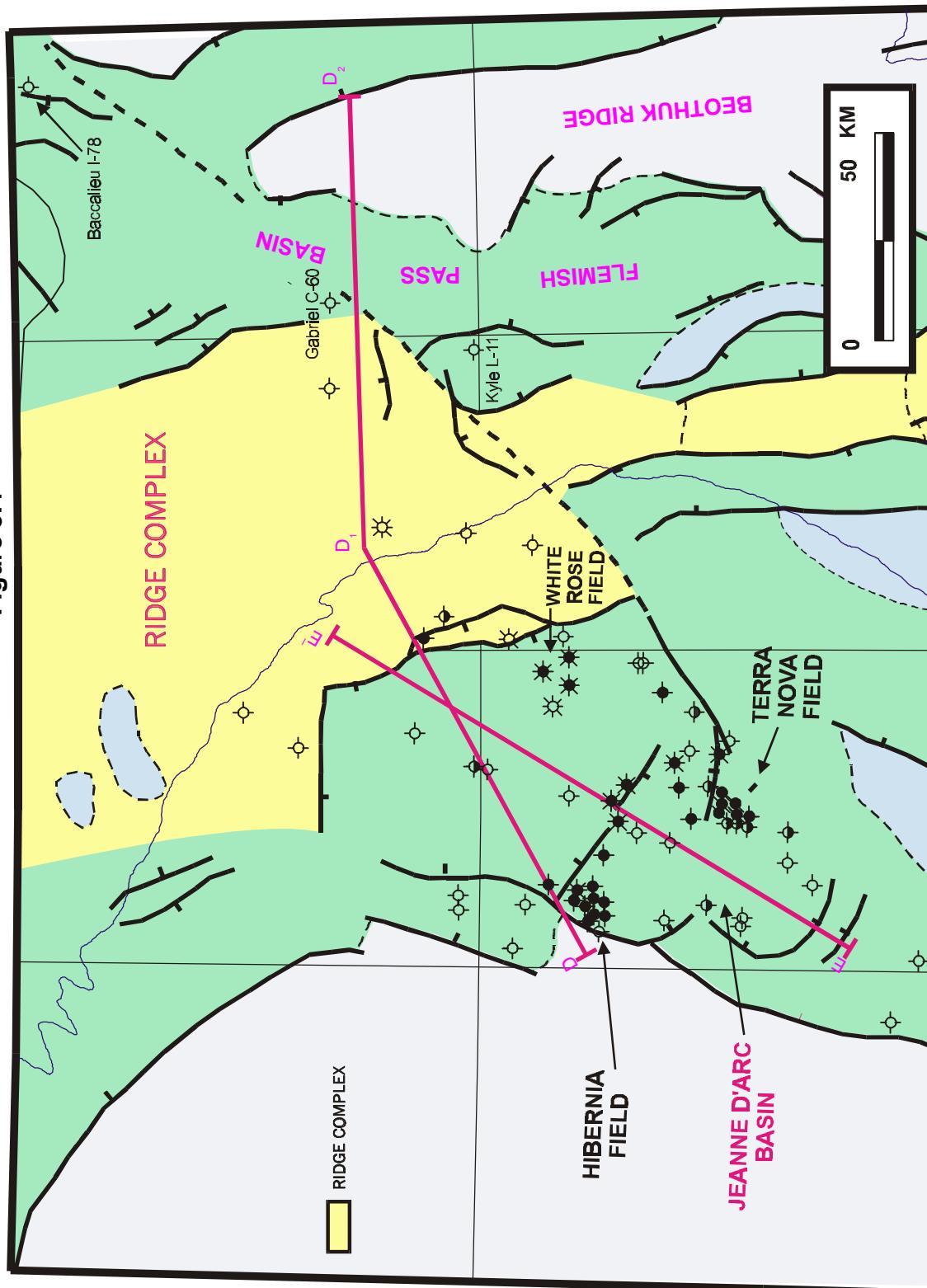
1. Permeabilities to air in laboratory. Source HMDC, unpublished data.

Jeanne d'Arc and Ridge Complex	
Exploration Wells	52
Significant Discoveries	18
Source Rock: Egret Member (Kimmeridgian)	
Potential Source: Organic rich Tertiary Section	
Reservoirs:	
<ul style="list-style-type: none">• South Mara Sandstones• Ben Nevis Sandstones• Avalon Sandstones• Catalina Sandstones• Hibernia Sandstones• Jeanne d'Arc Sandstones• South Tempest Sandstones	
Play Types:	
<ul style="list-style-type: none">• Rollover anticlines (Hibernia Field)• Horst block fault features (Mara Structure or Ridge Complex)• Tilted fault blocks (Ben Nevis, West Ben Nevis, Hebron)• Stratigraphic pinchouts in the Jeanne d'Arc sand (Terra Nova Field)• Drape over deep salt swells (White Rose) and other deep features• Drape over and pinchouts against salt diapirs (Adolphus)• Prograding sand wedges; channel sands; fans & turbidites (South Mara)	

Table 5.1

Flemish Pass Basin

Figure 5.4



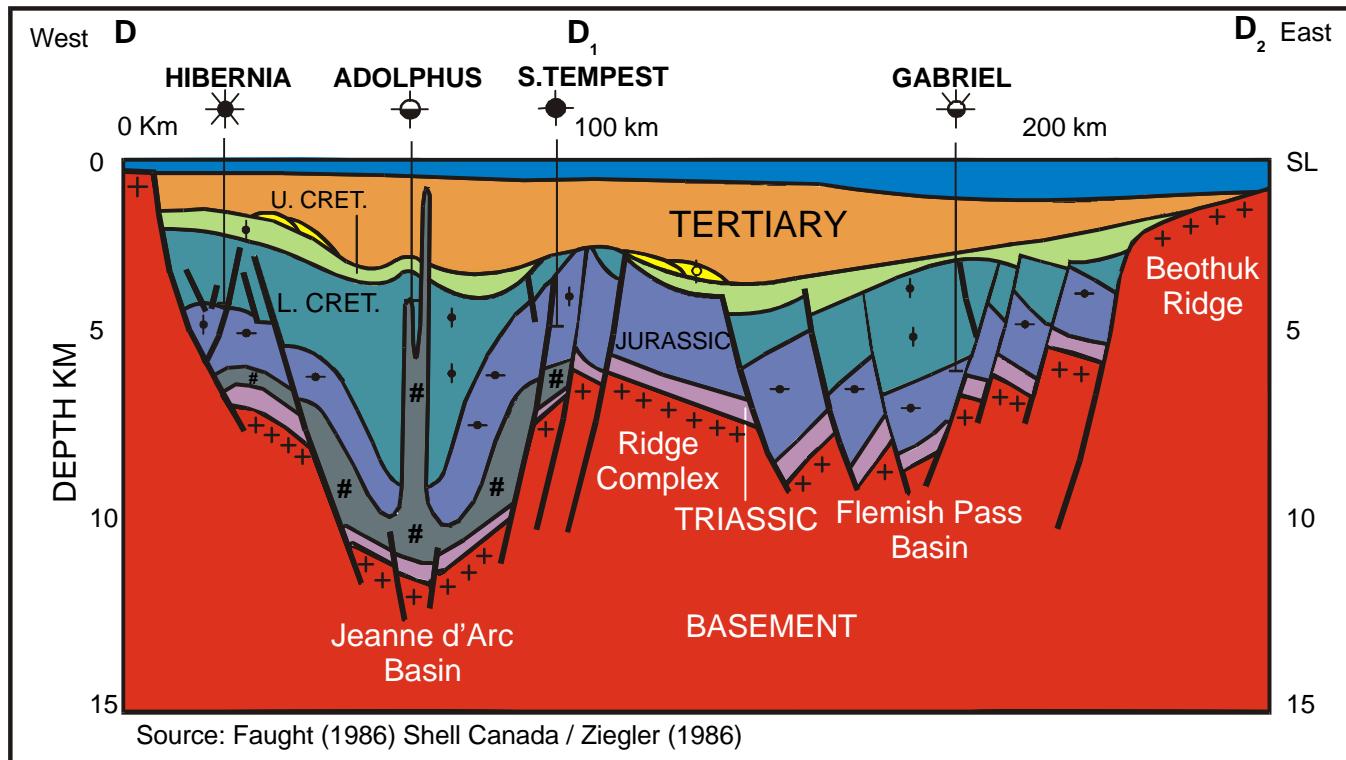
After: C-NOPB

This basin outline map shows the location of the Flemish Pass Basin with respect to the Ridge Complex and Jeanne d'Arc Basin and identifies the three wells drilled in the Flemish Pass Basin so far.

Flemish Pass Basin

The Flemish Pass Basin (figure 5.4) has only three wells drilled to date - *Kyle L-11*, *Baccalieu I-78*, and *Gabriel C-60*. These wells have proven the existence of both reservoir and source rocks. *Gabriel C-60* is listed as having an oil show (a sandstone core of equivalent age to the Hibernia Formation bled oil), and gas shows while drilling. Most of the basin is in water depths of about 1000 metres. Recent landsale parcels in this basin have attracted record bids and extensive 3D seismic has been acquired over the past couple of years. Petro-Canada has indicated that it has identified five targets in this basin, each having reserve potential in the 500 million barrel range.

Figure 5.5

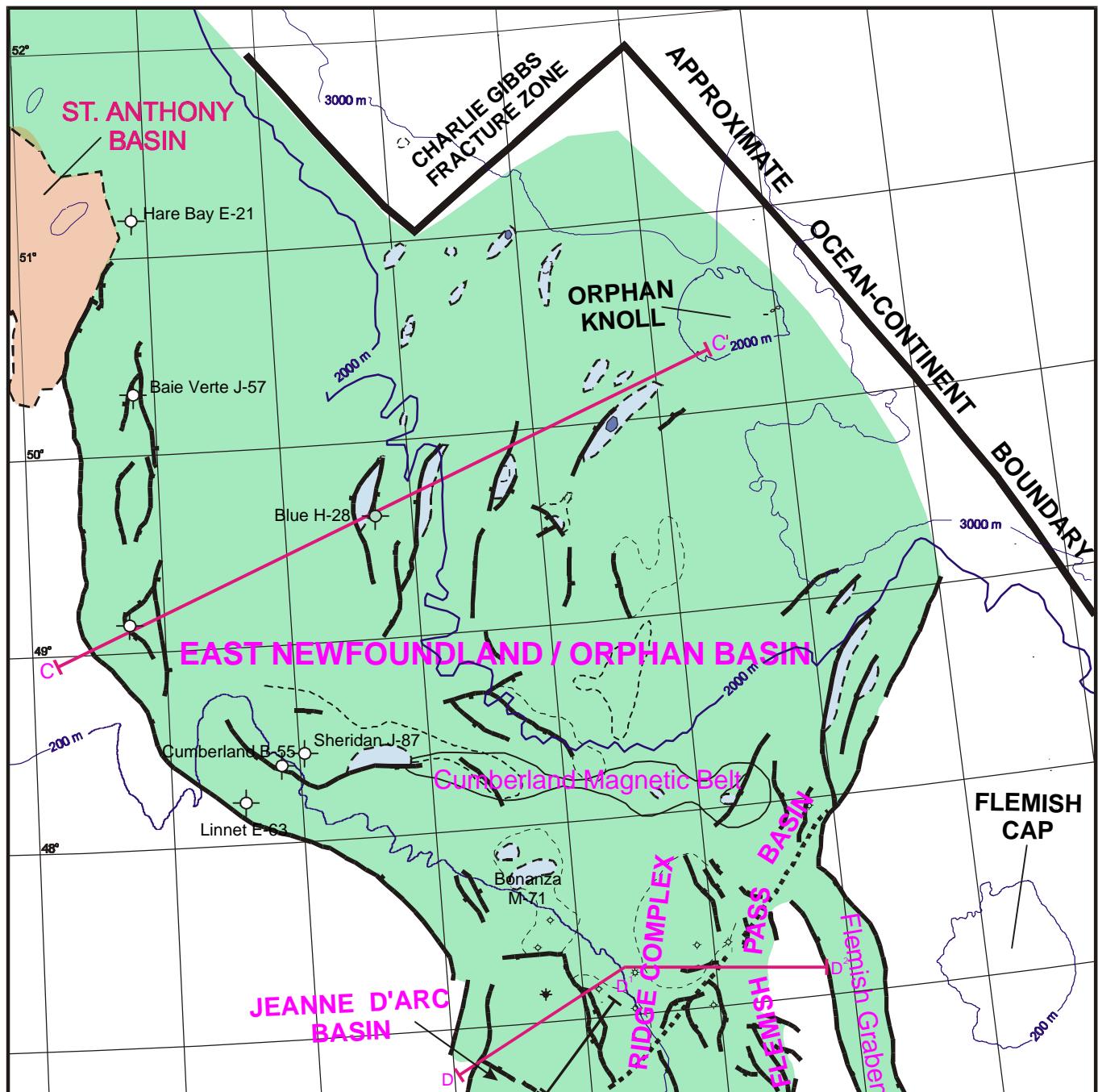


This cross section illustrates the similarities between the Jeanne d'Arc and Flemish Pass Basins, which were connected until the uplift of the Ridge Complex during the Early Cretaceous. Drilling has confirmed the presence of equivalent-age source and reservoir rocks in the Flemish Pass Basin as have been found in the Jeanne d'Arc Basin. See figure 5.4 for section location.

<p>Flemish Pass Basin</p> <p>Exploration Wells 3</p> <p>Oil and Gas Shows 1 (<i>Gabriel C-60</i>)</p>	<p>Play Types:</p> <ul style="list-style-type: none"> • Tilted fault blocks • Rollover anticlines • Stratigraphic pinchout of Jeanne d'Arc sands against Tithonian unconformity • Stratigraphic pinchout of Avalon sands against mid-Cretaceous unconformity • Prograding sand wedges, channel sands, fans and turbidites in the lower Tertiary.
<p>Source Rock: Egret Member</p> <p>Reservoirs: Hibernia and Jeanne d'Arc</p> <p>Sandstone equivalents have been encountered. Other reservoirs similar to Jeanne d'Arc Basin expected.</p>	

Table 5.2

East Newfoundland/Orphan Basin



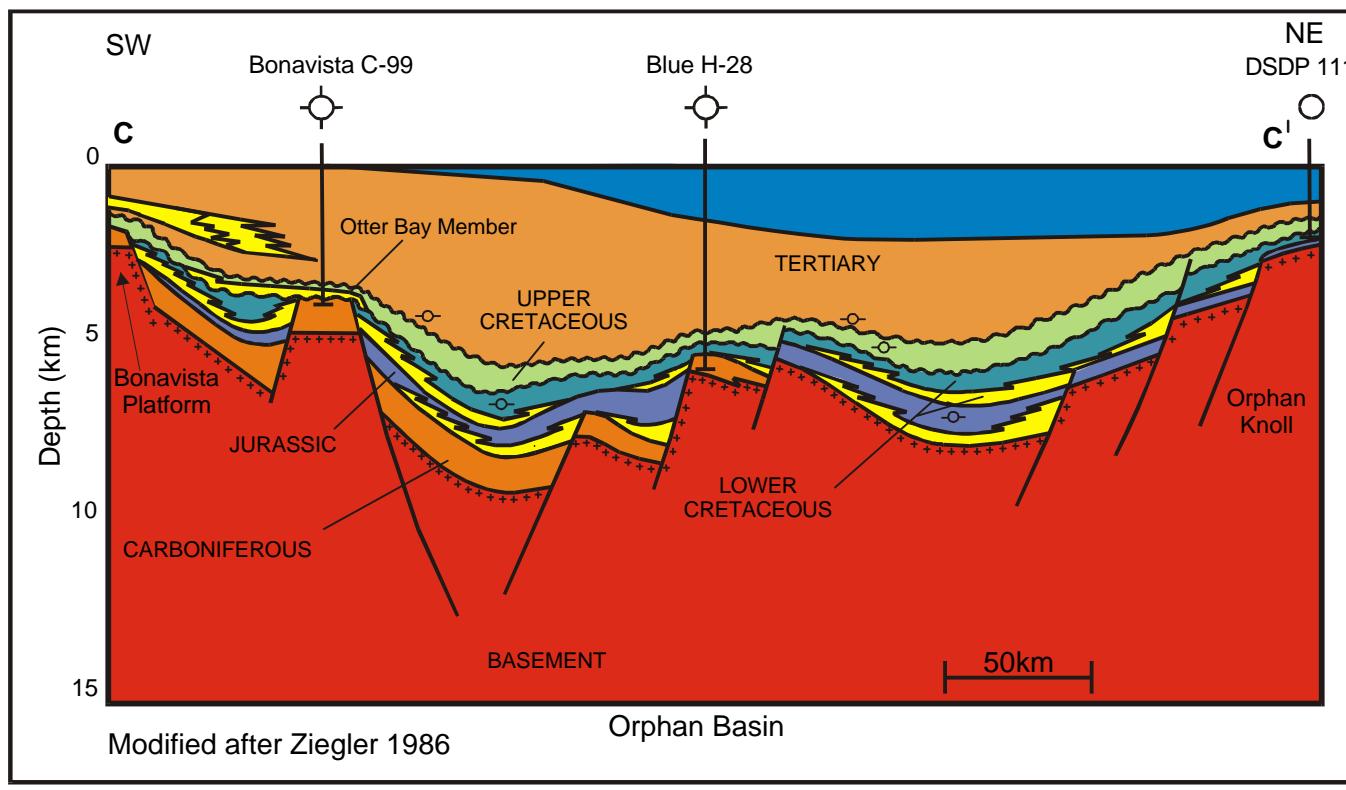
After C-NOPB

Figure 5.6

Section 5.4

Orphan Basin

Figure 5.7



Orphan Basin Cross-Section: Although no Jurassic section was intersected in the petroleum exploration wells it was encountered in the Deep Sea Drilling Program hole #111 on the Orphan Knoll (Ziegler, 1986).

The East Newfoundland/Orphan Basin (hereinafter referred to as the Orphan Basin) is bounded to the west by the Bonavista Platform, to the east by the ocean continent boundary, to the north by the Charlie Gibbs Fracture Zone and to the south by the Cumberland Magnetic Belt. This encompasses an area of about 150,000 km² with Mesozoic and Cenozoic sediments reaching thickness exceeding ten kilometres. Although the basin contains a number of very large structures only seven wells have been drilled to date. Most of the eastern side of the basin lies in deeper water (greater than 2000 metres). A series of en-echelon ridge-like structures dominate the centre of the basin, one of which was drilled at *Blue H-28*. The *Bonavista C-99* and *Cumberland B-55* wells were drilled on a high terrace on the west side of the basin intersected a shallow-marine, Upper Cretaceous section overlaying Carboniferous sediments. The *Linnet E-63* well was drilled slightly off the crest of a similar structure, and encountered a shaly Lower Cretaceous section with interbedded sandstones. Seismic data indicate a thick succession of Mesozoic was preserved between the ridges, so it is likely that a full section of Lower Cretaceous and Jurassic exists within the deeper parts basin. The presence of Jurassic is supported by the results of Deep Sea Drilling Program hole #111 that bottomed in Jurassic sediments on the west flank of the Orphan Knoll.

Minor gas shows were encountered in the *Blue H-28* and *Cumberland B-55* wells, but with so little of the section drilled it is not surprising that a source rock has yet to be identified. Based on depth

of burial it is expected that the Egret Member, if present, would be overmature (Sinclair et al, 1992). Another possible source rock is the equivalent of the organic rich Lower Tertiary shales that were encountered in *Nautilus C-92*, in the Jeanne d'Arc basin. These shales were immature in the Jeanne d'Arc but could have entered the oil window as the Tertiary wedge thickens into the Orphan basin. It is also possible that the equivalent of the Upper Cretaceous Markland Shale, which sourced the gas off Labrador, could be preserved in the deeper parts of the basin. The Carboniferous sediments encountered in the Orphan basin (see figure 5.7) have been described as meta-sediments in some wells but it is the subject of some debate whether these wells are representative of the Carboniferous throughout the basin. In western Newfoundland, rich Carboniferous source rocks are preserved adjacent to sediments that have been locally "cooked". Possible sources for reservoir quality sands would be the Bonavista Platform to the west and the Orphan Knoll and Flemish Cap to the east. If the ridges arose at the same time as the Ridge Complex to the south it is likely that they were once covered by Lower Cretaceous (and possibly Jurassic) sediment that was later eroded and deposited along the flanks (figure 5.6). Seismic data, although of poor quality, support this interpretation, suggesting that the flanks of the ridges may present better drilling targets than the crests, in the central part of the basin.

Orphan Basin

Exploration Wells 7

Source Rock:

- Not yet identified

Possible Source Rocks:

- Lower Tertiary shales
- Lower Cretaceous Markland Shale
- Upper Jurassic Egret Shale
- Carboniferous Shales

Reservoir Quality Sands Encountered Wells:

- Oligocene Sandstones
- Base of Tertiary fans and channel fill (South Mara equivalent)
- Fox Harbour/Otter Bay sandstones (Upper Cretaceous)

Other Possible Sandstone Reservoirs

- Lower Cretaceous sandstones were encountered in the Linnet E-63 well and are expected to exist in downdip locations where they were may have been shed from the crests of local highs
- Jurassic sandstones may also have been shed from local highs and deposited on the flanks

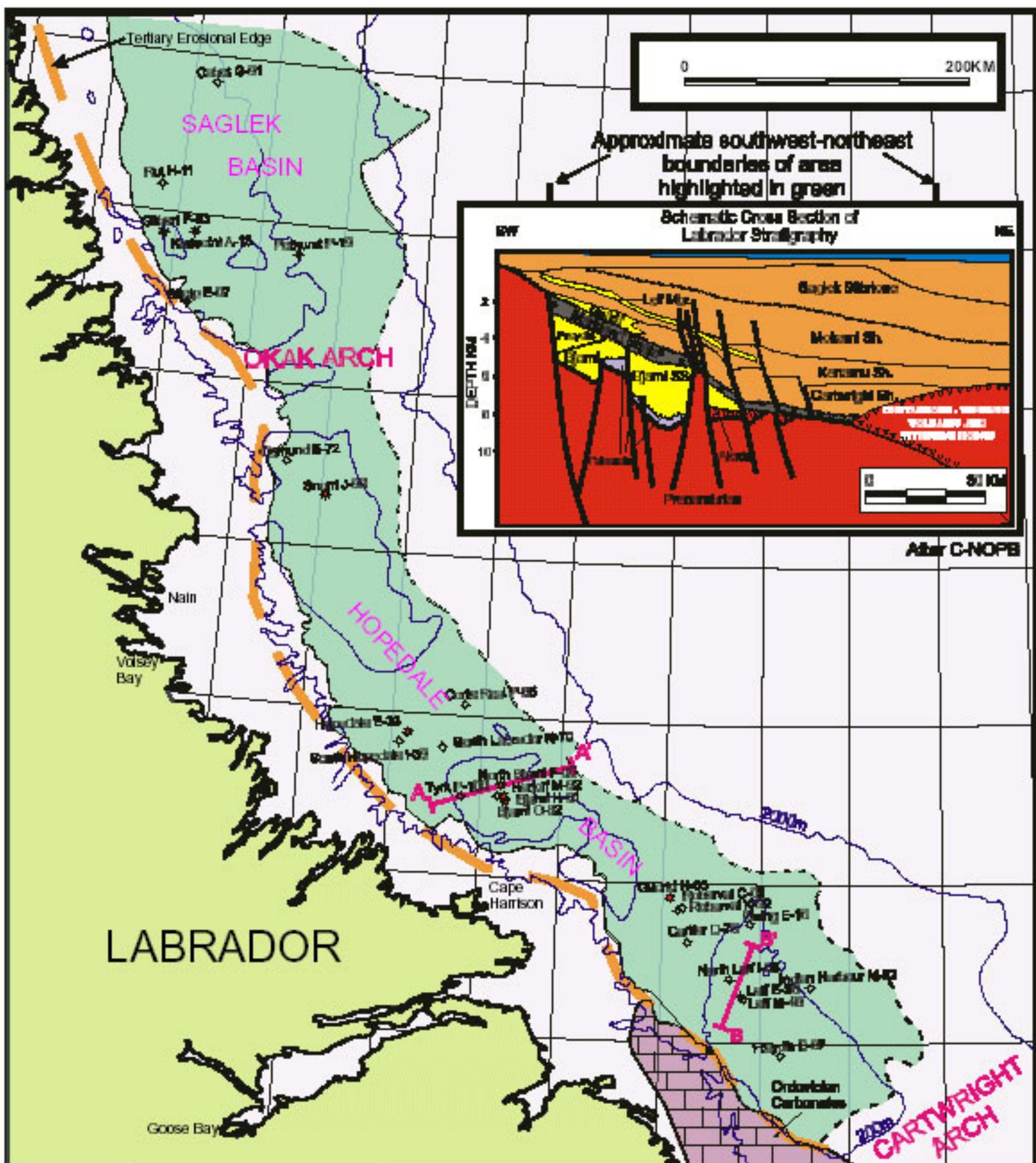
Play Types

- Drape of Lower Tertiary Sands over basement horsts and tilted fault blocks
- Stratigraphic pinchouts Lower Cretaceous and Jurassic on the flanks of basement highs
- Prograding wedges, fans and channel sandstones at the base of Tertiary

Table 5.3

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Labrador Shelf



Simplified map of Mesozoic cover offshore Labrador, showing significant discoveries and shows. (Modified after top Cartright Formation Map, GSC Labrador Sea Atlas, 1989) Remnants of the Lower Paleozoic carbonate shelf that extend beneath the Hopedale Basin have tested high rates of natural gas. The inset shows the generalized structural and stratigraphic framework.

Figure 6.1

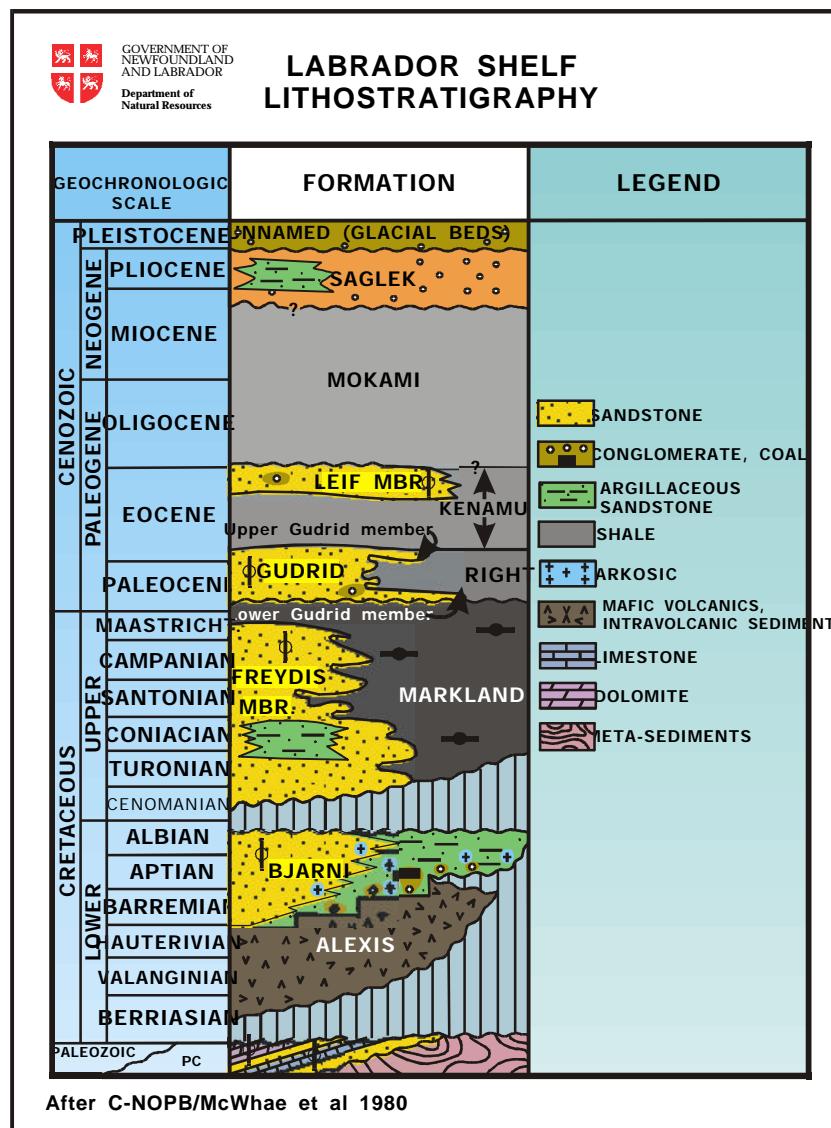
Section 6

Labrador Shelf

The Labrador Shelf includes the Saglek and Hopedale basins, that are separated by an easterly-trending basement high (the Okak Arch) with thinned Mesozoic cover (figure 6.1). To date, all the Labrador hydrocarbon discoveries are located in the Hopedale Basin, although gas shows have been recorded in some of the Saglek wells (e.g. *Karlsefni A-13*). The discoveries contain estimated recoverable resources of 4.2 Tcf of natural gas and 123 million barrels of NGL (C-NOPB). The largest single discovery is North Bjarni, with 2.2 Tcf of gas and 82 million barrels of NGL (figure 6.3). The undiscovered Labrador Shelf natural gas potential has been estimated at 22 trillion cubic feet (Drummond, 1988).

A number of Cretaceous to Paleocene sandstone reservoirs, in particular the Bjarni, Freydis and Gudrid sandstones, mark the Hopedale Basin (figure 6.2). The key trapping mechanisms are drape of Cretaceous and Lower Tertiary sands over uplifted basement blocks, and pinchouts against the flanks (figures 6.3 and 6.4). A Paleozoic carbonate, (believed to be an erosional remnant of the Cambro-Ordovician platform observed in the Anticosti Basin) underlies parts of the Hopedale Basin, and tested gas at high rates at *Hopedale E-33* (19.5 MMcf/d) and *Gudrid H-55* (8.1 MMcf/d). The Markland

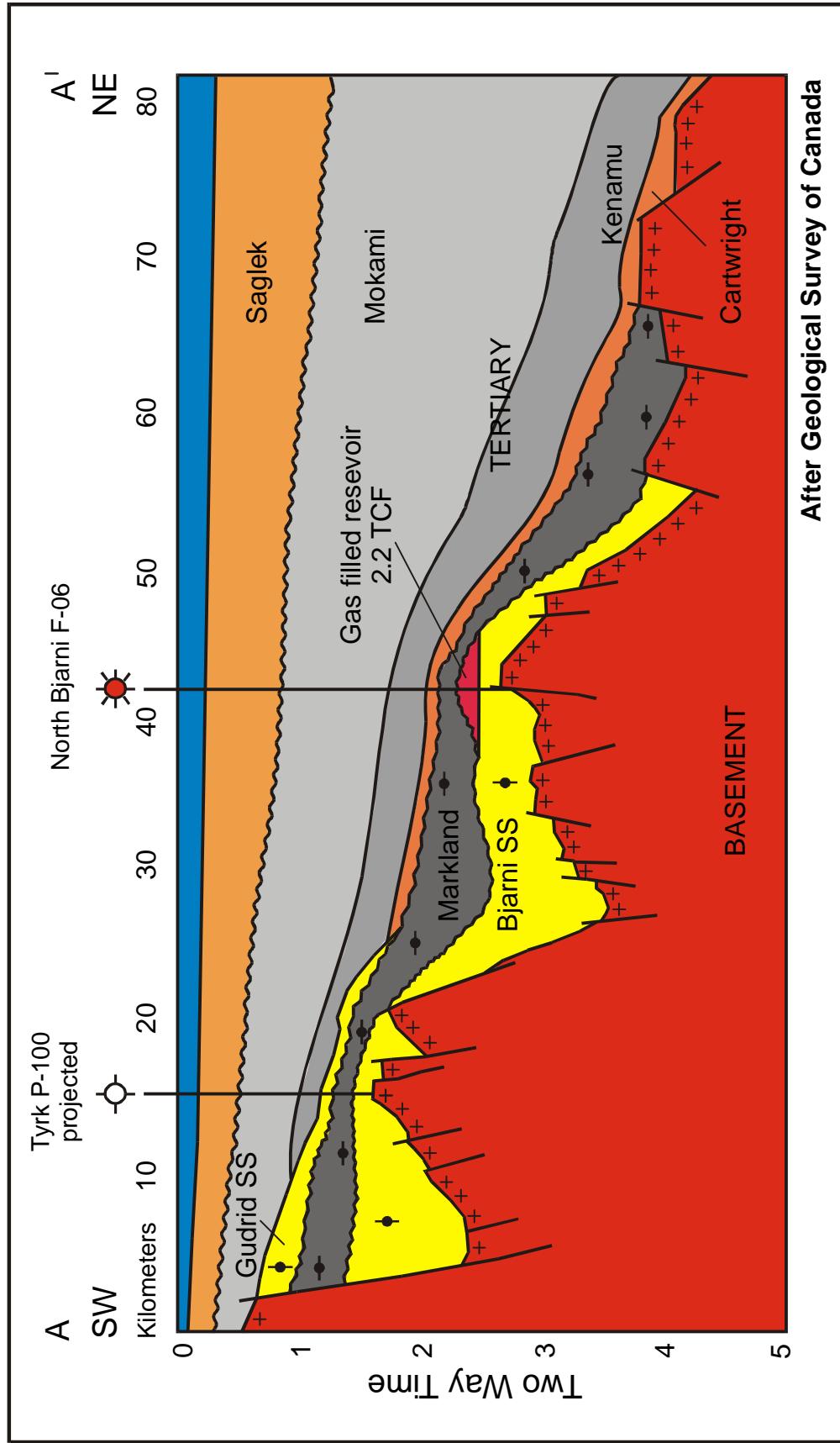
Figure 6.2



Shale is rich in terrestrially derived organic matter and is believed to be the primary source rock for the discovered gas.

With only 21 wells drilled and 4.2 Tcf discovered, the Hopedale Basin is obviously a favourable geological province for the accumulation of large quantities of natural gas. However, development of Labrador Shelf gas faces the challenges of a short drilling season (limited to about 3 months by pack ice and weather), high iceberg traffic and remoteness from major markets. The Department of Mines and Energy studied the feasibility of developing Labrador's gas resources in 1992 and concluded that certain critical technological advances would be required, including: improved pipeline trenching methods to protect against iceberg scouring, and long distance multiphase and metering technologies.

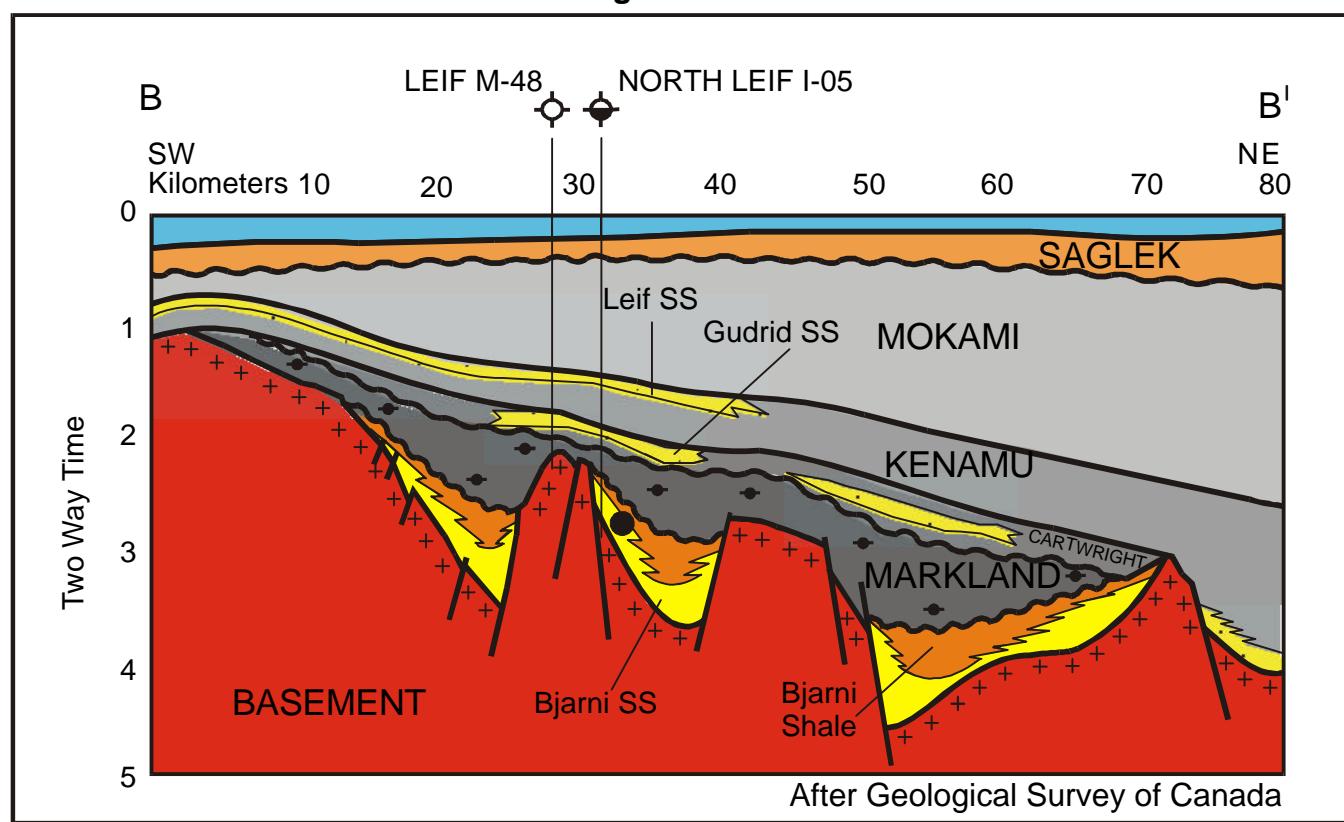
Figure 6.3



After Geological Survey of Canada

North Bjarni Cross-section: The North Bjarni structure contains over 2.2 Tcf of natural gas - more than half of all the Labrador Gas discovered to date. When it was drilled in 1980 it intersected the thickest continuous pay section in Canadian history (194 Metres). The gas/water contact is visible as a seismic flat spot and indicates that the structure is filled to the spill point. See Figure 6.1 for section location.

Figure 6.4



North Lief Cross-Section: North Lief I-05 is the only Labrador well to have recovered oil on drill stem test (32° API, waxy oil). This cross-section re-enforces the fact that structures in this area that were devoid of reservoir on the crest, can have reservoir quality sands on the flanks. See figure 6.1 for section location.

Labrador Shelf	Source Rock: Markland Shale
Exploration Wells	27
Significant Discoveries	5
Oil Shows	1
Reservoirs:	Tertiary sandstones (Leif and Gudrid Members), U. Cretaceous Sandstones (Freydis Member), L. Cretaceous Sandstones (Bjarni Formation), Lower Paleozoic Carbonates

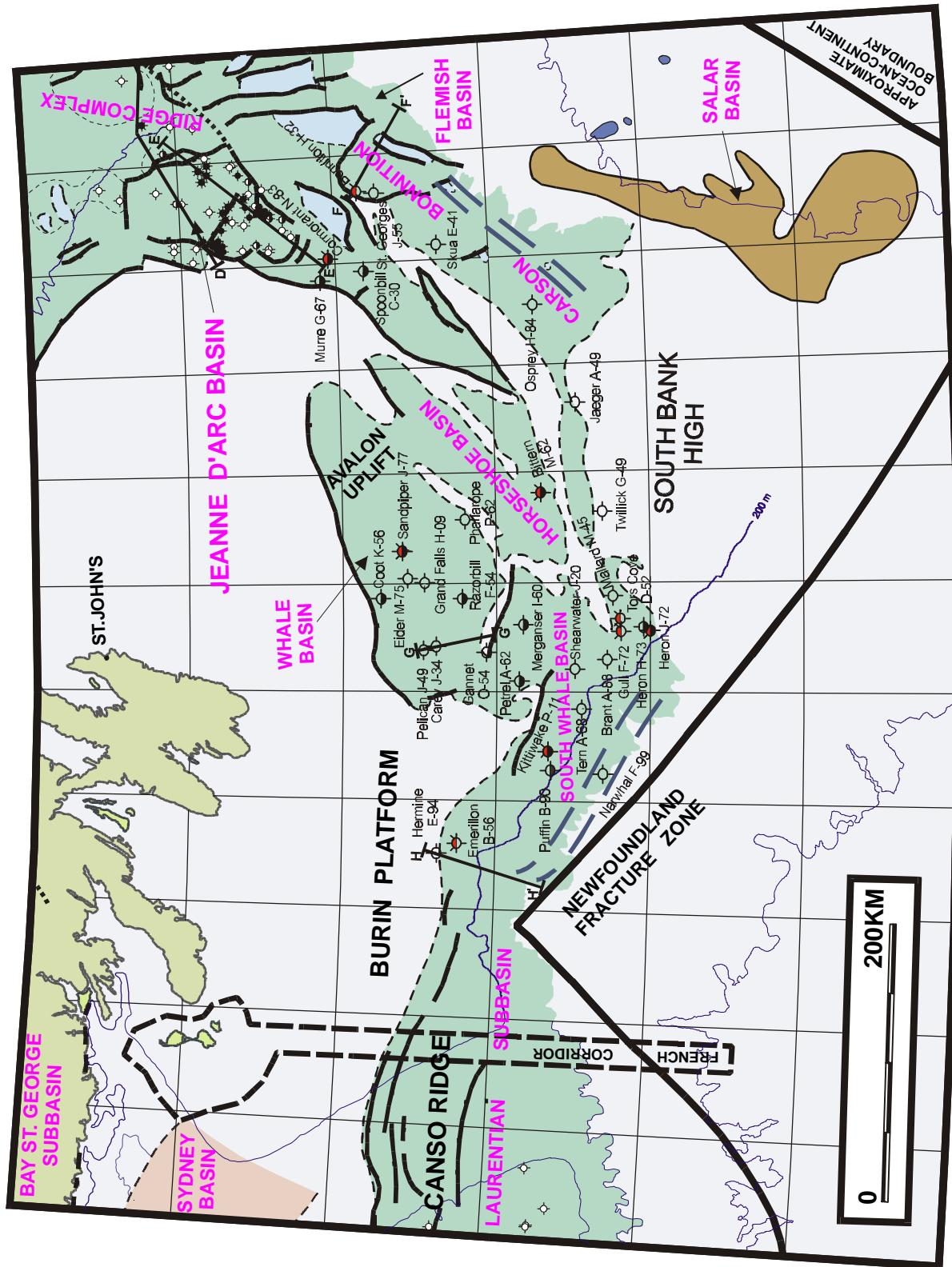
PLAY TYPES:

- Crests of basement highs
 - with preserved L. Cretaceous sands
 - with preserved Lower Paleozoic Carbonates
- Drape of Tertiary and Cretaceous sands over tilted fault blocks
- Pinchout of the Bjarni sands against flanks of a tilted fault blocks

Table 6.1

Southern Grand Banks

Basins of the Southern Grand Banks



Modified after: Canada-Newfoundland Offshore Petroleum Board and Geological Survey of Canada

Section 7

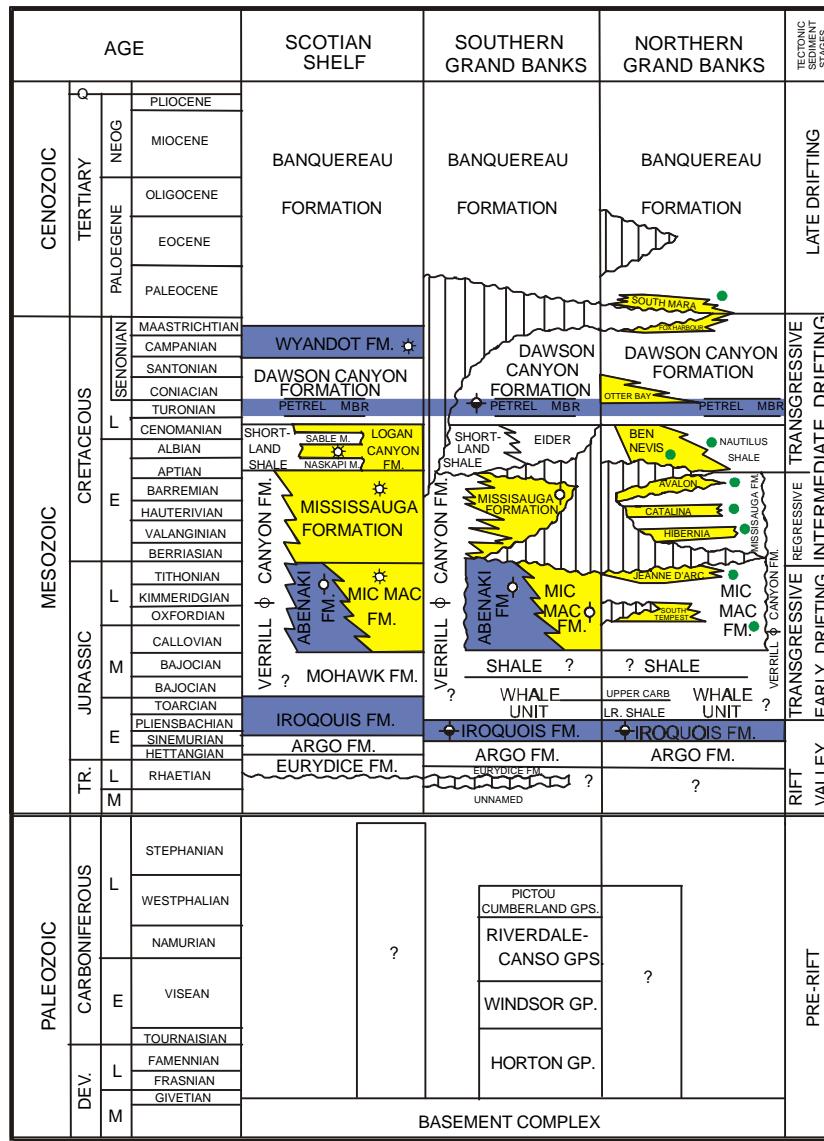
Southern Grand Banks

7.1 Southwest Grand Banks

The southwest Grand Banks include several Mesozoic basins (namely the Whale and Horseshoe basins and the South Whale and Laurentian subbasins; see figure 7.1), that are extensively underlain by Carboniferous sediments. The Mesozoic strata underlie a thick Tertiary wedge that covers most of the continental shelf and progrades seaward over the shelf edge (figures 7.2 & 7.3). The GSC's depth to basement map of the area indicates an additional basin, the Salar Basin, in deeper water (figures 3.1 & 7.1) of which little is currently known. Drilling has not occurred in the Laurentian subbasin because the

area has been the subject of jurisdictional disputes - first between Canada and France (the islands of St. Pierre and Miquelon in this area belong to France) and more recently between the provinces of Newfoundland and Nova Scotia. The petroleum rights (issued in the 1960's but effectively under "moratorium" since that time) are held by Mobil, Gulf and Imperial. The Geological Survey of Canada has studied the area and estimates that it contains 8 to 9 Tcf of natural gas and 600 to 700 million barrels of oil (MacLean and Wade, 1990). The companies holding the lands in the basin have recently been acquiring seismic data in preparation for a resolution of the interprovincial boundary dispute - expected in the spring of 2002.

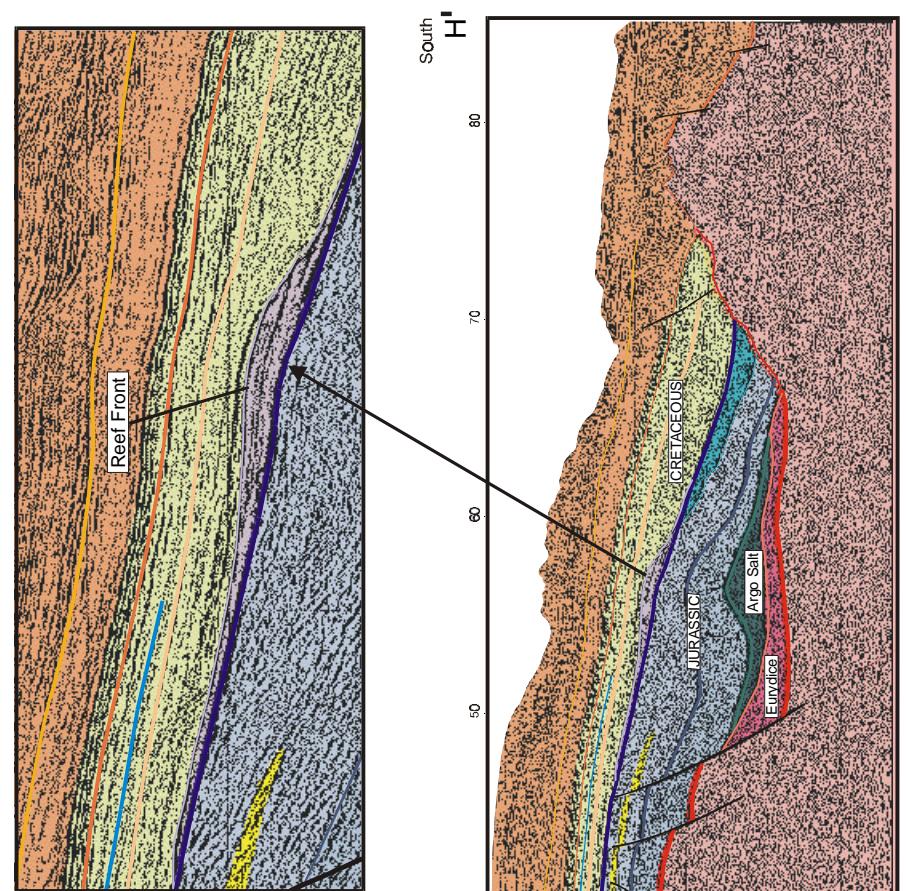
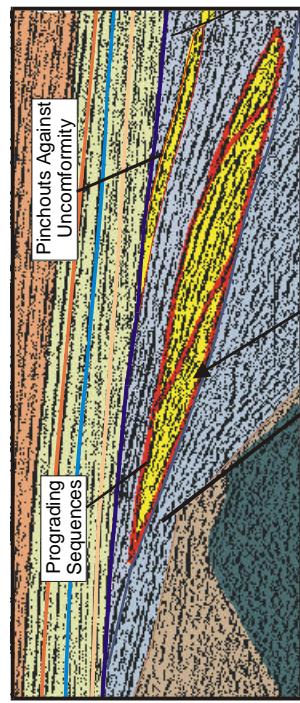
Figure 7.2



After Northcor Energy Report 1984 & MacLean and Wade, 1990

Comparitive stratigraphy of Scotian Shelf, Southern Grand Banks and Northern Grand Banks.

South Whale Basin



Seismic line STP17: indicates a thick Jurassic section downlapping into a restricted basin bounded to the south by a basement ridge. A number of trapping mechanisms are evident including a reef front at what is believed to be the Abenaki level. Similar reef-like character has been observed on seismic data up to 35 km to the west, suggesting the possibility of a large regional play. The basement high interpreted in the central part of the section appears on several widely spaced lines, presenting the possibility of a large linear closure. Interpreted seismic section provided by GSC. Additional interpretation by Dept of Mines and Energy. See figure 7.1 for section location.

Figure 7.3

Section 7.2

South Whale Subbasin

The South Whale subbasin was the first to see the drill bit in the Newfoundland and Labrador offshore area. The relatively ice-free and shallow waters, combined with an abundance of salt piercement features that were familiar trapping mechanisms in the Gulf of Mexico, made it an attractive place to begin exploratory drilling. Twenty seven wells were drilled in the basins of the southwest Grand Banks basins between 1966 and 1974, of which 15 were located in the South Whale subbasin. Although good reservoirs and several oil and gas shows (figure 7.1) gave encouragement, no discoveries resulted. It is noteworthy, however, that 11 of the 15 wells in South Whale were drilled over the crests of and adjacent salt domes, or on basement-cored ridges with thinned sedimentary cover. Drilling over and adjacent to salt domes did not prove to be an effective strategy, possibly because the latest movement of the Lower Jurassic Argo Salt postdated the migration of hydrocarbons. This approach also resulted in very limited penetration of the sedimentary package, and so a great deal remains unknown about the off-structure basin stratigraphy. The southwest Grand Banks basins were connected to the Jeanne d'Arc Basin from the onset of rifting in the Late Triassic until the rise of the Avalon uplift in Late Jurassic, providing the opportunity for deposition of similar Jurassic reservoirs and source rocks as in the Jeanne d'Arc. The Late Jurassic Kimmeridgian shale has not been intersected in any of the wells and, as such, a major source rock for the basin has yet to be identified. However, given the number of oil and gas shows and similar tectonic history to both the northern Grand Banks and the Scotian Shelf, it is likely that the equivalent of the Egret Member (which has sourced the Jeanne d'Arc basin) and/or the Verrill Canyon shales (which have sourced the Scotian Shelf) are present in the deeper parts of the South Whale subbasin.

The Avalon Uplift resulted in erosion of older Jurassic sediments in the Whale and Horseshoe basins and the shedding of erosional detritus into the surrounding basins; likely including the Jeanne d'Arc, Carson/Bonnition and South Whale depocentres. After separation from the northern Grand Banks by the Avalon uplift, the South Whale subbasin evolved throughout the Cretaceous as a passive margin, similar to the Scotian Shelf.

A tectonic factor that differentiates the southwest Grand Banks from the Scotian Shelf is that the SW Grand Banks was influenced by strike slip movement along the Newfoundland Transform throughout the Jurassic. This is likely the cause of the large basement ridges (observed on seismic) that run parallel to the shelf, outboard of the main Jurassic depocentres (figure 7.3). Kerr (1985) speculates that such ridges could have provided the restricted marine conditions necessary to create an oil prone source rock, as opposed to the gas prone source rocks of the Scotian Shelf.

The South Whale subbasin contains the equivalent of Micmac and Mississauga sandstone reservoirs that have been the key producers in the Scotian Basin. Additionally, seismic line STP17 (figure 7.3) indicates the possibility of an Abenaki reef-front play. The Abenaki reef-front offshore Nova Scotia is known to contain thick porous sections in the Demascota and Bonnet wells (Eliuk, 1978; Harvey & MacDonald, 1990). Indeed, PanCanadian has recently announced a major gas discovery beneath the Panuke oil field. The sandstone reservoir of the Panuke field is known to drape over the Abenaki carbonate reef front (Harvey and MacDonald, 1990). PanCanadian has since confirmed that the discovery is within a Jurassic reef front, by a map and cross-section published on its web site.

Another possible stratigraphic play identified on seismic line STP17 is a large undeformed marginal marine progradational package within the Jurassic. Clearly there is no shortage of reservoir or trapping possibilities in the South Whale basin, and as such it must be considered one of the more prospective areas for future exploration.

South Whale Subbasin Exploration Wells 15 <ul style="list-style-type: none"> • 9 on salt features • 2 on ridges Oil Shows 4 Gas Shows 3 Oil & Gas Shows 2	Source Rock: <ul style="list-style-type: none"> • Not yet identified Possible Source Rocks: Verrill Canyon Shale Kimmeridgian Shale (Egret equivalent)
	Reservoirs: Lower Tertiary Sandstones Logan Canyon Sandstones (Eider) Mississauga Sandstones Micmac Sandstones Abenaki Reef Front Iroquois Carbonate

Play Concepts

- Subcrop of Jurassic sandstones below the base-of-Tertiary unconformity
- Late Jurassic sandstones (MicMac Formation) draped over the horst feature that strikes along the basin for tens of kilometers (Figure 7.3)
- Stratigraphic traps in the base of Tertiary sandstones (fans, channel fill, etc.)
- Drape of Eider sandstone over deeper structures (equivalent to Upper Logan Canyon in the Scotian Basin)
- Drape of known Jurassic and Lower Cretaceous sandstones (Micmac, Mississauga, Eider) and Carbonates (Iroquois and Abenaki) over deep seated structures such as salt swells in the Argo Formation and Windsor Group, and over basement highs.
- Rollover anticlines in the Jurassic/Cretaceous
- Marginal marine progradation sequence observed on seismic (See Figure 7.3)
- The Abenaki reef front play (See Figure 7.3)
- Drape of Mississauga and Eider sandstones over the Abenaki reef front
- Fore-reef detritus pinchouts at the toe of the reef front slope
- Subcrop of Micmac and Mississauga sandstones against unconformities
- Lower Tertiary turbidites below the shelf break and adjacent to large ridges (such as the Narwhal Ridge) that run parallel to the continental slope

Table 7.1

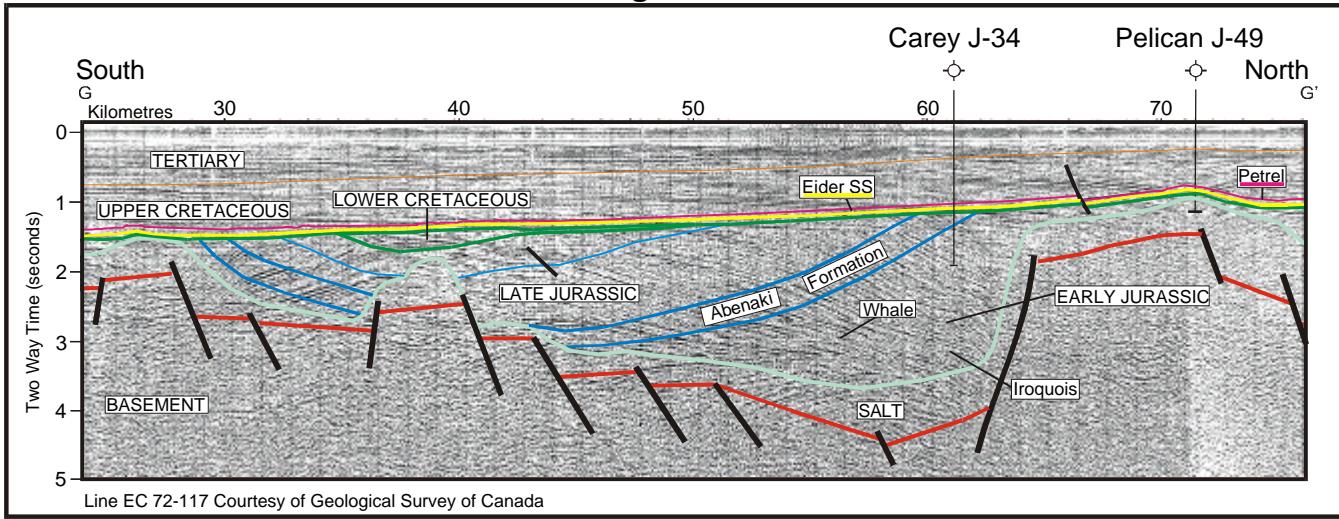
Section 7.3

Whale and Horseshoe Basins

The Whale and Horseshoe Basins are considered to be less prospective than other southwest Grand Banks basins because they were subjected to extensive erosion of Jurassic sediments during the Avalon Uplift. However, the seismic line shown in figure 7.4 indicates that a thick Jurassic section is preserved in the southwestern part of the basin. The *Carey J-34* well encountered carbonates of the Abenaki Formation below the base of Cretaceous unconformity. The Upper Jurassic section to the south of *Carey J-34* could contain the sands and shales of the Rankin, Jeanne d'Arc and Fortune Bay Formations, including the Kimmeridgian source rock.

7.3 Whale and Horseshoe Basins

Figure 7.4



Seismic section EC 72-117 and interpretation provided by Geological Survey of Canada. Additional interpretation by Department of Mines & Energy. See figure 7.1 for section location.

Whale and Horseshoe Basins

Exploration Wells	13
Oil Shows	2
Oil & Gas Shows	2

Source Rock:

- Not Yet Identified

Possible Source Rocks:

- Verrill Canyon Formation
- Egret Member

Reservoirs:

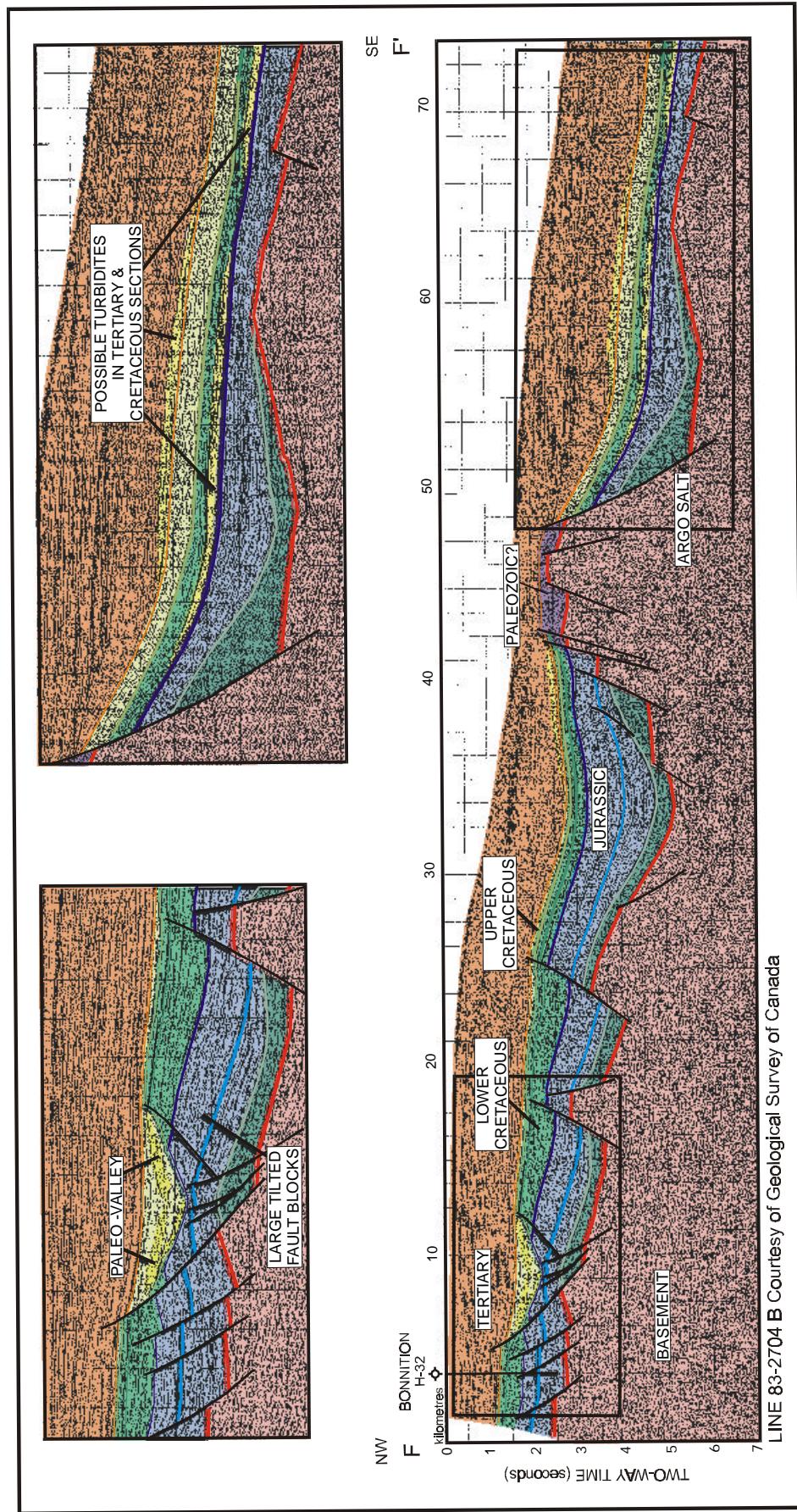
- Lower Tertiary Sandstones
- Logan Canyon Sandstones (Eider)
- Missisauga Sandstones
- Mimac Sandstones
- Abernaki Carbonate Bank
- Iroquois Carbonate

Play Concepts

- Subcrop of Jurassic reservoir rocks against Avalon unconformity where the Eider is also closed or not present
- Drape of the Eider sandstone over deeper structures
- Drape of Jurassic reservoirs, that are not breached by the Eider, over deeper structures
- Faulting against regional dip of Jurassic reservoir rocks
- Drape and stratigraphic pinchout of lower Tertiary reservoirs

Table 7.2

Bonnington Basin Seismic Lines



Bonnington Basin Seismic Section: This section shows the presence of a thick sequence of Jurassic and Cretaceous sediments with a number of possible trapping mechanisms including an Upper Cretaceous or Tertiary paleo-valley, tilted fault blocks, and possible turbidites within the Tertiary and Lower Cretaceous sections. Interpreted line provided by GSC. Additional interpretation provided by Dept of Mines and Energy. See figure 7.1 for section location.

Figure 7.5

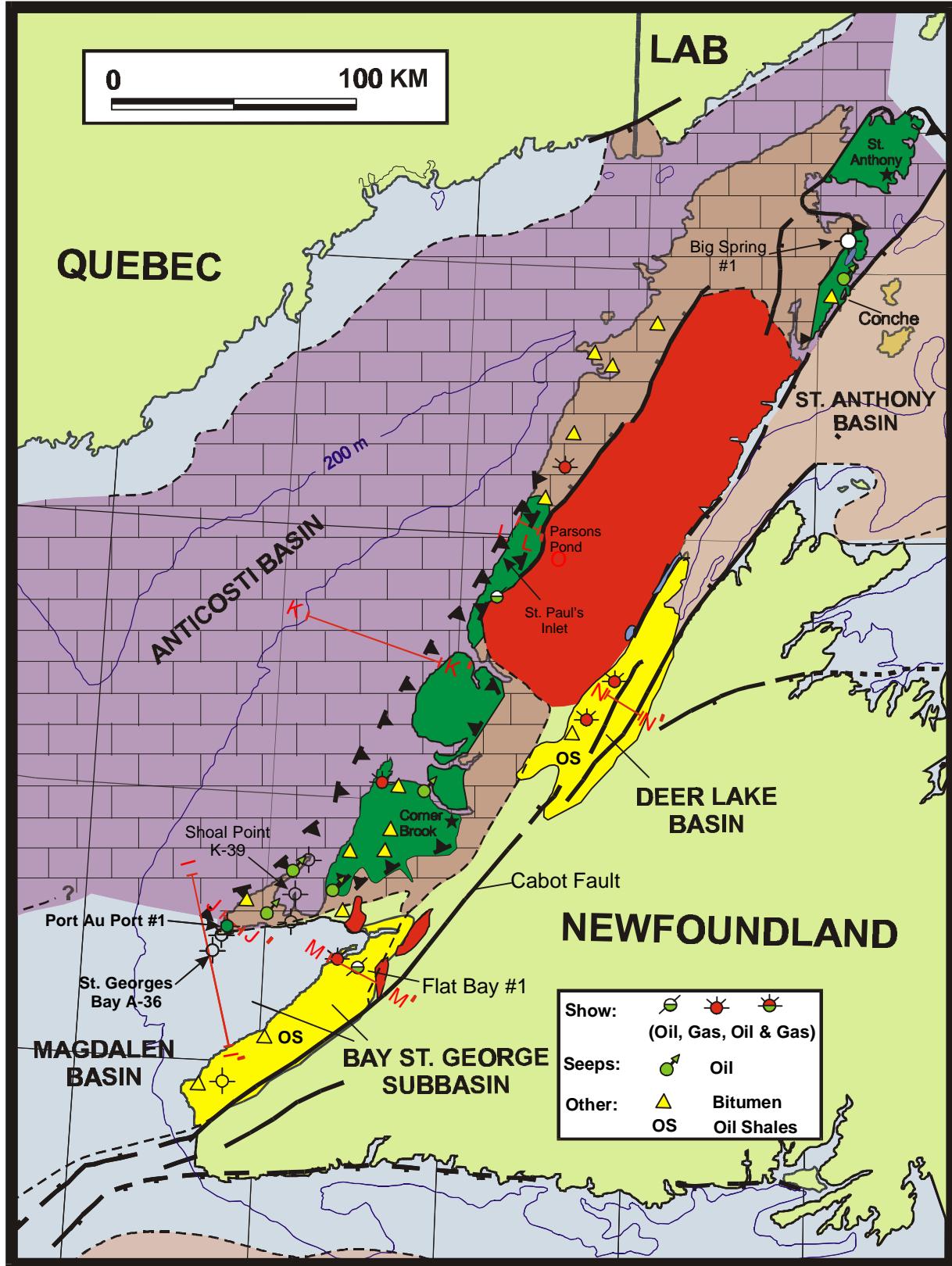
7.4 Southeast Grand Banks

The southeast Grand Banks includes the Carson/Bonnition and Flemish basins (in some texts the latter is referred to as the South Flemish Pass basin). Only four wells have been drilled in these basins, all of which were located along an elevated terrace running along on the northwest margin, that had a thinned Jurassic and Cretaceous section. The *Bonnition H-32* and *St. George J-55* wells encountered Lower Cretaceous and Jurassic sandstones, and *Bonnition* had gas shows in Lower Cretaceous Mississauga sands. Section FF' (figure 7.5) indicates that the Cretaceous and Jurassic sediments thicken considerably to the southeast of the terrace. Several play possibilities are evident including a large Upper Cretaceous or Lower Tertiary paleo-valley, that in addition to containing possible reservoirs, provides evidence of a river system that could have fed considerable quantities of sand into the area. Tilted Cretaceous fault blocks similar to those that created traps in Jeanne d'Arc Basin provided the trapping mechanism for most of the fields discovered to date. Additionally, broad continuous mounds within the Tertiary and Lower Cretaceous have been interpreted to be turbidites - which can be very large, laterally continuous and contain stacked reservoirs. A number of large fields discovered offshore West Africa, Gulf of Mexico and Brazil are located in turbidite reservoirs, but such features have not yet been actively pursued as exploration targets offshore Newfoundland or Labrador.

Carson /Bonnition / South Flemish Pass Basins:
Exploration Wells 4
Gas Shows 1 (Mississauga Sandstone in Bonnition H-32)
Possible Source Rocks:
<ul style="list-style-type: none"> • Egret Member • Verrill Canyon Shale equivalent
Reservoirs:
<ul style="list-style-type: none"> • Lower Cretaceous sandstones (Avalon/Ben Nevis and Hibernia equivalent) • Jurassic sandstones (Jeanne d'Arc, Tempest, Voyager Equivalent) • Jurassic carbonates (Iroquois) • Sandstone fill within a Lower Tertiary or Upper Cretaceous paleo-valley • Lower Tertiary and Lower Cretaceous turbidites
Play Concepts:
<ul style="list-style-type: none"> • Drape of Lower Cretaceous and Jurassic reservoirs over deep seated structures (basement faults, basement arches) • Tilted fault blocks and horsts within the Cretaceous and Jurassic • Stratigraphic subcrops against the base-of-Tertiary unconformity and pinchouts against basement-cored ridges • Submarine fans and turbidites

Table 7.2

Western Newfoundland



Geological map of western Newfoundland showing geological terranes, hydrocarbon shows and well locations.

Figure 8.1

Section 8

Section 8.1

Western Newfoundland

Introduction

As discussed in Section 2 (History of Exploration) about sixty old wells were drilled in western Newfoundland since the first exploratory well in 1867. These wells were concentrated in four areas - Parsons Pond, St. Paul's Inlet, the Deer Lake Basin and at Shoal Point on the Port Au Port Peninsula. The failure to make a commercial discovery can be reasonably explained by the following:

- (1) None of the drilling locations were chosen with the help of any sort of geophysical survey and many were drilled with very little geological control or scientific analysis. Drilling locations were chosen largely on the basis of surface oil seeps.
- (2) Most of the wells drilled were shallow (less than 700 metres) and only two exceeded 1000 metres, despite sediment thicknesses that typically exceed 3000 metres. Therefore, many of the deeper rock units, which may have the better hydrocarbon potential, were never penetrated.
- (3) Most of the wells drilled were concentrated very close together (27 near Parsons Pond and 13 at Shoal Point) so only a small percentage of the prospective area was actually tested.

Much of the exploration to date, including many of the old wells drilled in the area, targeted the Lower Paleozoic strata of the Anticosti Basin, within foreland fold and thrust belt of the External Humber Zone (figure 3.1). Rocks within this terrane consist of essentially autochthonous to parautochthonous Cambrian to Middle Ordovician shelf and foreland basin strata along with allochthonous deepwater sediments of coeval age. These sediments are both overlain and onlapped by a Late Ordovician to Middle Devonian foreland basin succession (figure 8.2). The second prospective terrane is bounded within a number of Carboniferous wrench basins that straddle the Cabot Fault, including two basins (the Deer Lake Basin and Bay St. George Sub-basin) that are exposed onshore western Newfoundland.

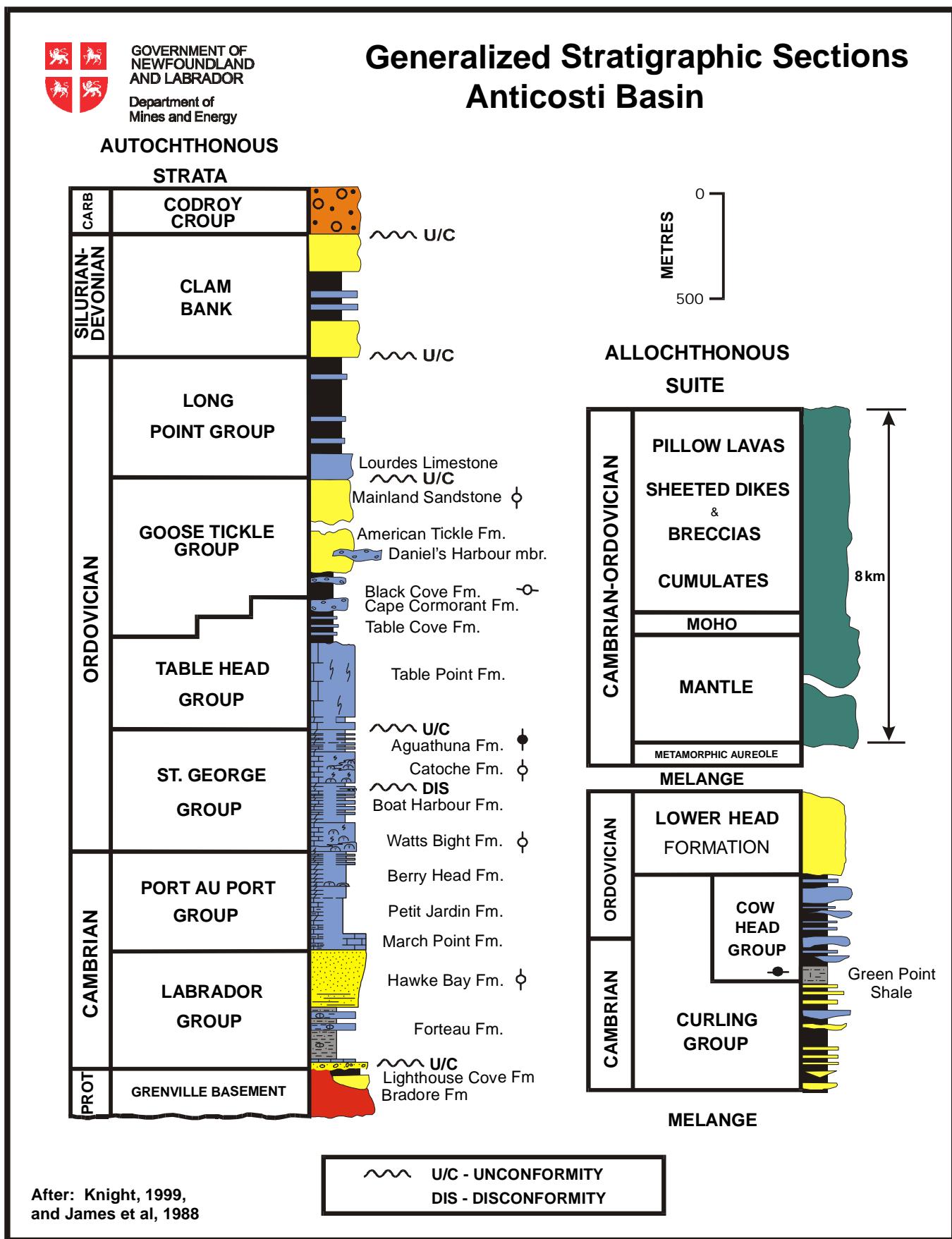
Over the past 25 years, stratigraphic and mapping studies by the Government of Newfoundland and Labrador Geological Survey and at Memorial University delineated a solid stratigraphic framework for western Newfoundland (figures 8.1 and 8.2) that has benefitted recent exploration. It was the structural studies of Stockmal and Waldron, however, that helped stimulate the latest phase of exploration. In 1990 Stockmal and Waldron proposed that the Cambro-Ordovician carbonates of the Port au Port Peninsula, which had been previously interpreted as autochthonous (non-transported), rather were allochthonous, carried by a major westward thrust into the Anticosti Basin. This movement was believed to have created a triangle zone that was exposed along the western shore of the peninsula. This hypothesis was primarily based on a re-interpretation of a couple of old, poor quality, seismic lines, but was proven to be largely correct by more recent seismic data (figure 8.8). During the early 1990's, large land positions were acquired by Mobil, Norcen, BHP and Hunt Oil, and about 5000 km of seismic data was acquired offshore western Newfoundland, along with about 800 kilometres onshore. Five deep wells were subsequently drilled in the Port au Port area, during the 1990's, that resulted in one discovery.

Western Newfoundland

Old Exploration Wells	60 (estimated)
Modern Exploration Wells	8 (Including: 5 deep wells in the Port au Port area; one one well that failed to reach its target and was abandoned at 700 metres; one well on the Great Northern Peninsula; and one shallow well in the Flat Bay area)
Significant Discoveries	1
Oil Shows:	Numerous in old wells and surface seeps
Gas Shows:	Numerous in old wells and in mining exploration holes

Table 8.1

Figure 8.2



Section 8.2

Port au Port Area

In 1994 Hunt Oil spudded *Port au Port* #1 (PAP#1) which was the first well ever drilled in western Newfoundland based on seismic mapping (figure 8.3). The well encountered four zones of good porosity in the Cambro-Ordovician carbonate platform. The two lower zones were water-bearing but two upper zones, within the Aguathuna Formation, flowed oil at rates of 1528 and 1742 bopd (the two tested zones may be in communication). During an extended (9 day) test the pressure dropped off, indicating either a very limited reservoir or

complicated geology near the wellbore. The fact that there were problems with paraffin buildup and salt plugging during the extended test, and that the reservoir had been invaded by more than 2200 barrels of drilling mud, may have also affected the test results. A new series of tests to determine the productive capacity of the well is currently being undertaken by Canadian Imperial Venture Corp, who later farmed into the project. Follow-up drilling at five other locations in the Port au Port area failed to provide new discoveries. (The Inglewood *Man of War* I-42 well shown in figure 8.3 failed to reach its target depth and was abandoned at 700 metres).

Released well information from four wells drilled during the 1990's indicates that all the carbonate reservoirs are within dolostones. The factors controlling porosity within the Aguathuna Formation (the productive zone in PAP#1) are not well understood and the porosity appears to be highly variable. However, deeper reservoirs, such as the Watt's Bight and Catoche Formations (which were water-bearing in PAP#1) may provide more regional and predictable dolostone targets. The PAP #1 well has proven the existence of a viable petroleum system within the deeper rocks of western Newfoundland. The oil in the well is high quality and sweet (51° API) and is consistent with a Cambro-Ordovician source. The recognized Cambro-Ordovician source rock in western Newfoundland is a shale within the Green Point Formation (figure 8.2).

Cross-section JJ' (figure 8.4) through PAP#1 (based on a Hunt Oil seismic line), illustrates that the structural mechanism is a footwall thrust. Figure 8.5 (cross-section II') is based on a seismic line through *St. George's Bay* A-36, that illustrates how the reverse faulting onshore gives way to a wrench fault-induced flower structure at the interface between the Carboniferous Bay St. George Subbasin and the Lower Paleozoic Anticosti Basin. The Carboniferous basins of western Newfoundland are known to have evolved in response to strike slip tectonics along the Cabot Fault. It is not known if the Cambro-Ordovician carbonate platform extends beneath the Bay St. George Carboniferous sediments (figure 8.5) because of poor seismic resolution below the Windsor Salt.

Figure 8.3

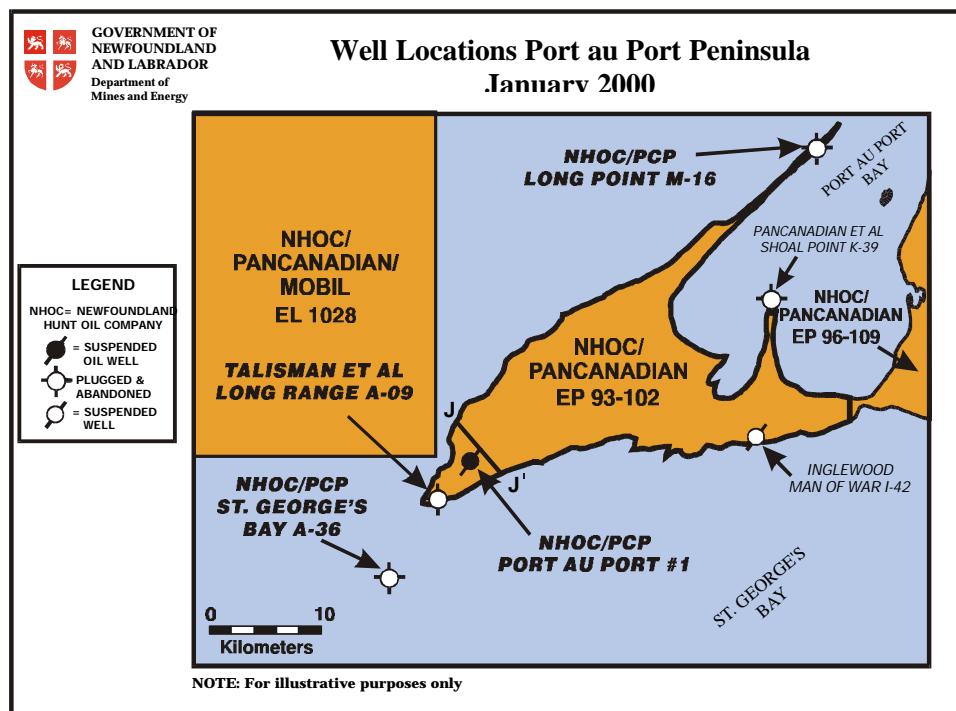
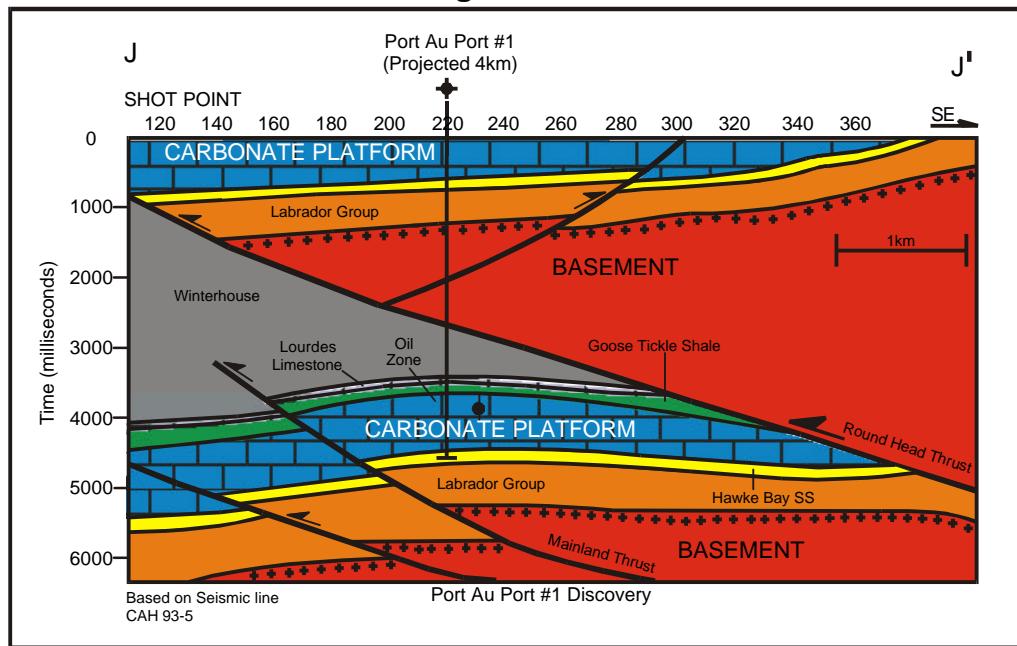


Figure 8.4



Cross-section of the Port au Port #1 discovery: The Hunt/Pan Canadian Port au Port #1 well tested about 2000 bopd and 1.3 mmf/d of gas from a 15 metre net pay section within the Aguathuna Formation at the top of the carbonate platform. See figure 8.1 for section location.

Port au Port Area

Old Wells: 13 relatively shallow wells at Shoal Point

Modern Wells: 6

Significant Discoveries: 1

Source Rock: Green Point Formation shale

Possible Source Rocks: Black Cove Formation shale, and Carboniferous shales in the adjacent Bay St. George Subbasin

Reservoirs:

Within and beneath the Carbonate Bank

- Aguathuna Formation
- Catoche Formation
- Watts Bight Formation
- Hawke Bay Sandstone (Labrador Group)

Other:

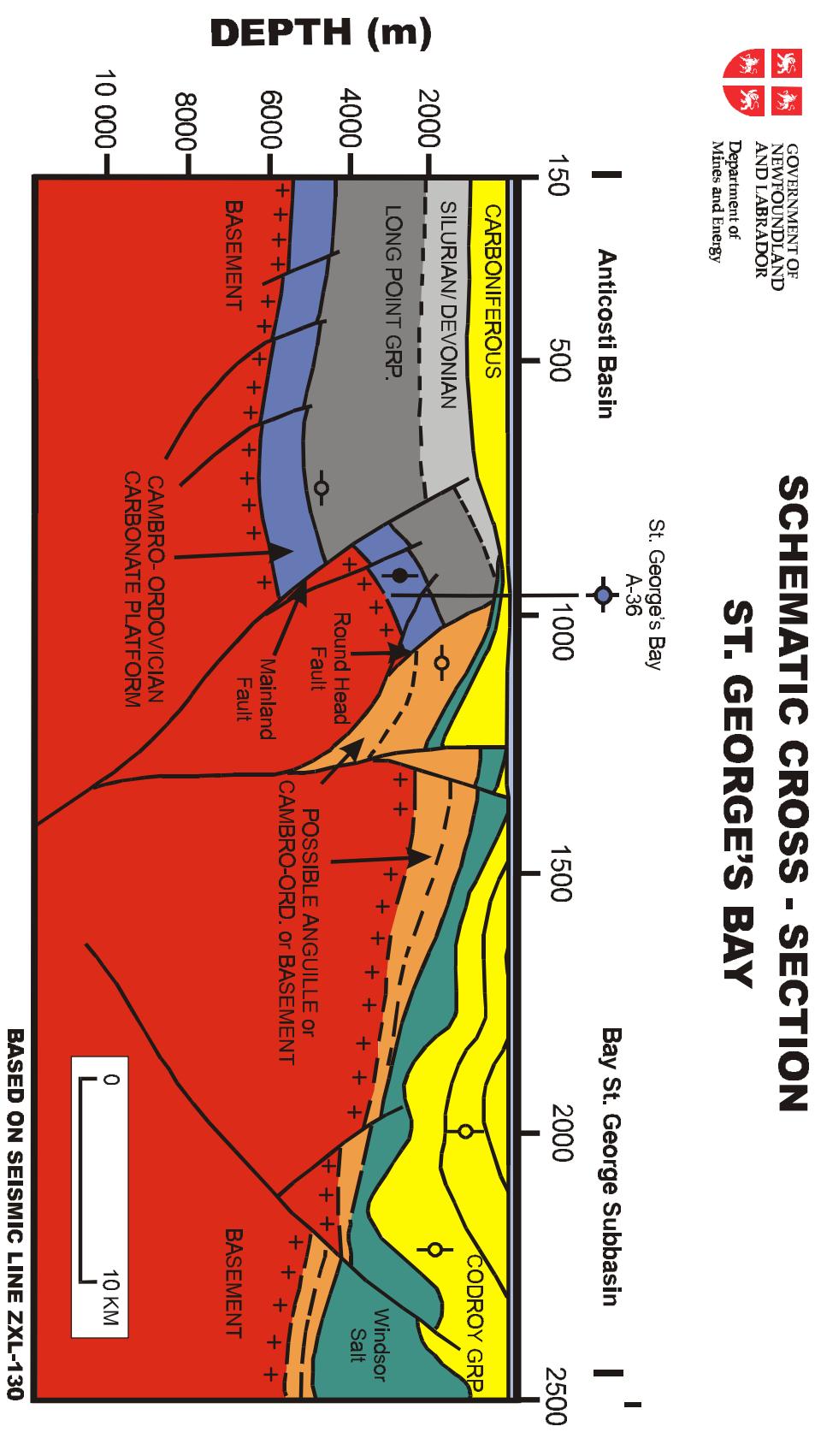
- Dolomitized carbonate conglomerates and calcarenites, and thin bedded massive turbidic sandstones within the Humber Arm allochthon
- Devonian / Silurian reefs (based on seismic anomalies)
- Possible sands within the flysch sequence and within the marginal marine sections of the Long Point and Clam Bank sequences of the foreland basin

Play Concepts: (Cambro-Ordovician)

- Thrusted sections of the carbonate platform (as per Port au Port #1)
- Horsts and tilted fault blocks of the carbonate platform within the foreland basin
- Stratigraphic traps: including Devonian/Silurian reefs and diagenetic porosity within carbonate bank

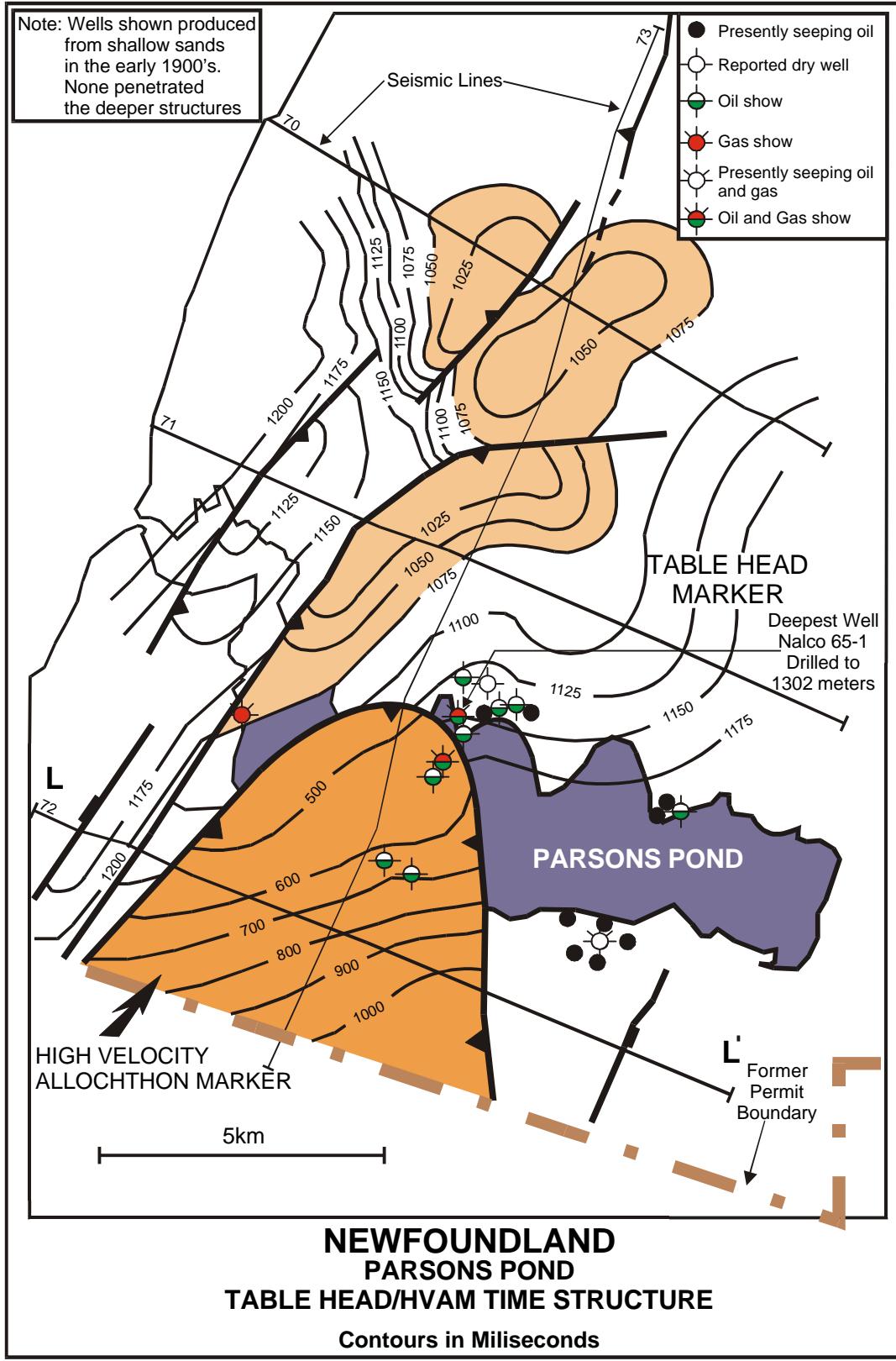
Table 8.2

Figure 8.5



Seismic Line ZXL 130; located to the southwest of the Port au Port Peninsula, shows a flower structure at the interface of the Early Paleozoic Anticosti Basin and Carboniferous Bay St. George Subbasin, that was drilled by St. George's Bay A-36 in 1996. It is not known if the carbonate platform extends beneath the Carboniferous sediments in the Bay St. George Subbasin. See figure 8.1 for section location.

Parsons Pond Area



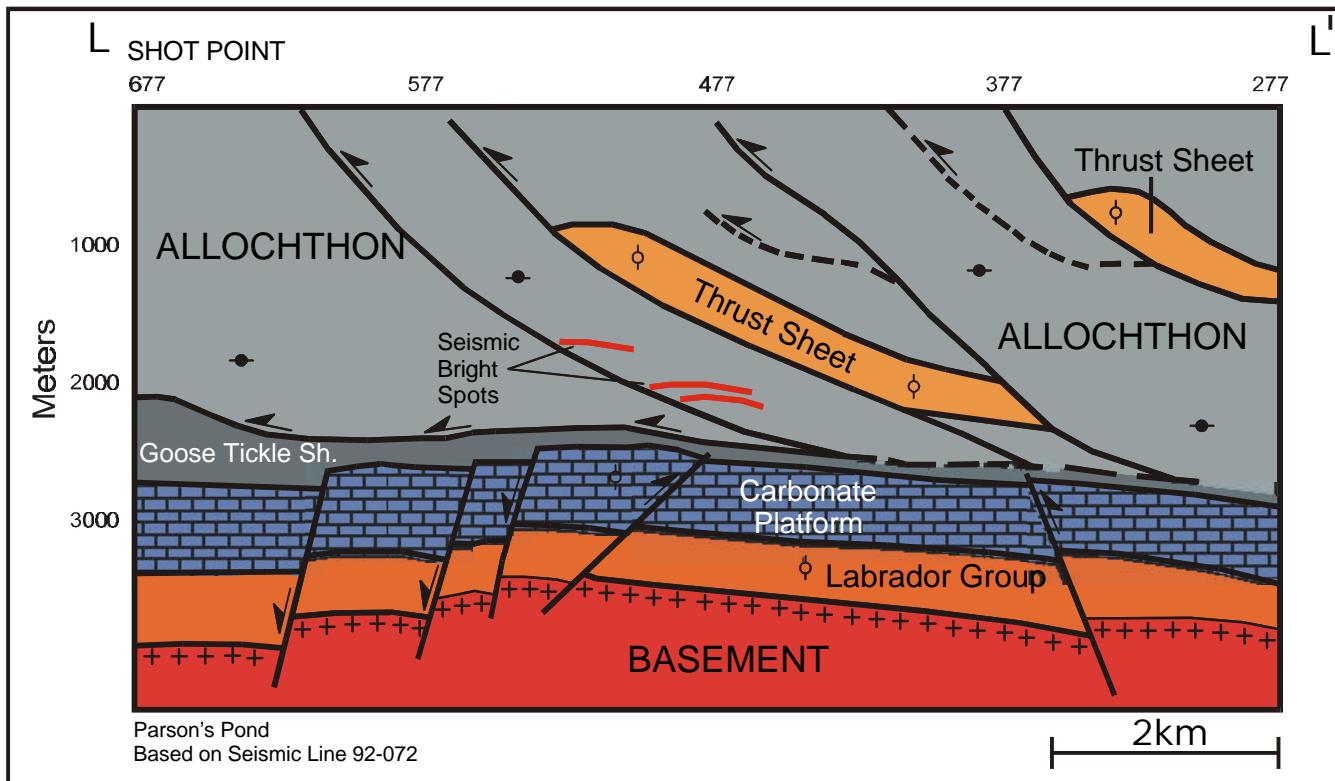
This time structure map prepared by Norcen, shows three closures at the top of the carbonate platform as well as a thrust slice within the allochthon, referred to here as the "High Velocity Allochthon Marker". None of these features have been penetrated by the wells shown.

Figure 8.6

Section 8.3

Parsons Pond Area

Figure 8.7



This section illustrates the structural style and possible traps at Parsons Pond. None of the wells drilled in the area were deep enough to test these structures. One well (NALCO 65-I) may have come close to penetrating the larger thrust sheet shown, but was abandoned when the cable tool bit was lost due to caving. The well "belched" gas for a month after it was abandoned. See figures 8.1 and 8.6 for section location.

Parsons Pond Area

Oil seeps were widely encountered throughout the Parsons Pond area in old wells and in community water wells. The area is characterized by an imbricated thrust stack of allochthonous Cow Head Group (including organic rich shales within the Green Point Formation) and Lower Head Formation turbidites, which overlie Cambro Ordovician shelf carbonates and flysch (figure 8.7). Both rock sequences have the potential to host hydrocarbon pools. Up to 40 metre thick sections of porous dolostone occur in the top of the Catoche Formation and locally at the base of the Table Point Formation. Near Port au Choix, 60 km to the north, these same dolostones hosted a, now-exhumed, oil field within a block faulted paleo-high (Baker and Knight, 1992). Structural plays within the shelf sequence are created by reverse and normal faults locally associated with rollover folds. These features could potentially be sourced from down dip areas where overlying Green Point Formation source rocks are juxtaposed with the carbonates.

Within the overlying imbricate thrust stack, seismic data have identified thrust sheet targets within the Cow Head Group and the Lower Head Formation (figure 8.7). Source rock shales of the

Green Point Formation outcrop locally in the area and are expected at depth. Reservoirs may occur in dolomitized carbonate conglomerates and calcarenites carried in the hangingwall of thrusts. The thrust sheets shown in figure 8.3 could contain such reservoirs. Similar thrust-based carbonates are exposed at the Arches Provincial Park north of Parsons Pond where the limestone conglomerate and calcarenite has been replaced by a highly porous dolostone, that is also petroliferous. Alternatively, thick bedded massive turbidite sandstones of the Lower Head Formation may provide a suitable reservoirs. The presence of several horizontal bright spots in a number of thrust slices near Parsons Pond provide further evidence of the area's hydrocarbon potential.

A time structure map prepared by Norcen (figure 8.6) delineates undrilled prospects in the Parsons Pond area. The "high velocity allochthon marker" noted on the map is the larger thrust that is shown in cross-section LL' (figure 8.7). The other closures shown in figure 8.6 are mapped at the top of the carbonate platform. Although drilling records are incomplete, indications are that none of the old wells were deep enough to test the mapped structures. The 1965 NALCO well, drilled to 1302 metres, may have started to tag the edge of the larger thrust sheet shown in figure 8.7. The records report that the well "was abandoned at 1302 metres when considerable caving was encountered and the drill stem broken. Gas was encountered, with the best showing at 1302 metres. Belching could be heard for 9 - 12 metres from the well and continued for one month" (Petroleum Directorate, 1982). Given the size and number of structures identified, combined with the ubiquitous oil and gas shows, this area would be considered highly prospective for future exploration.

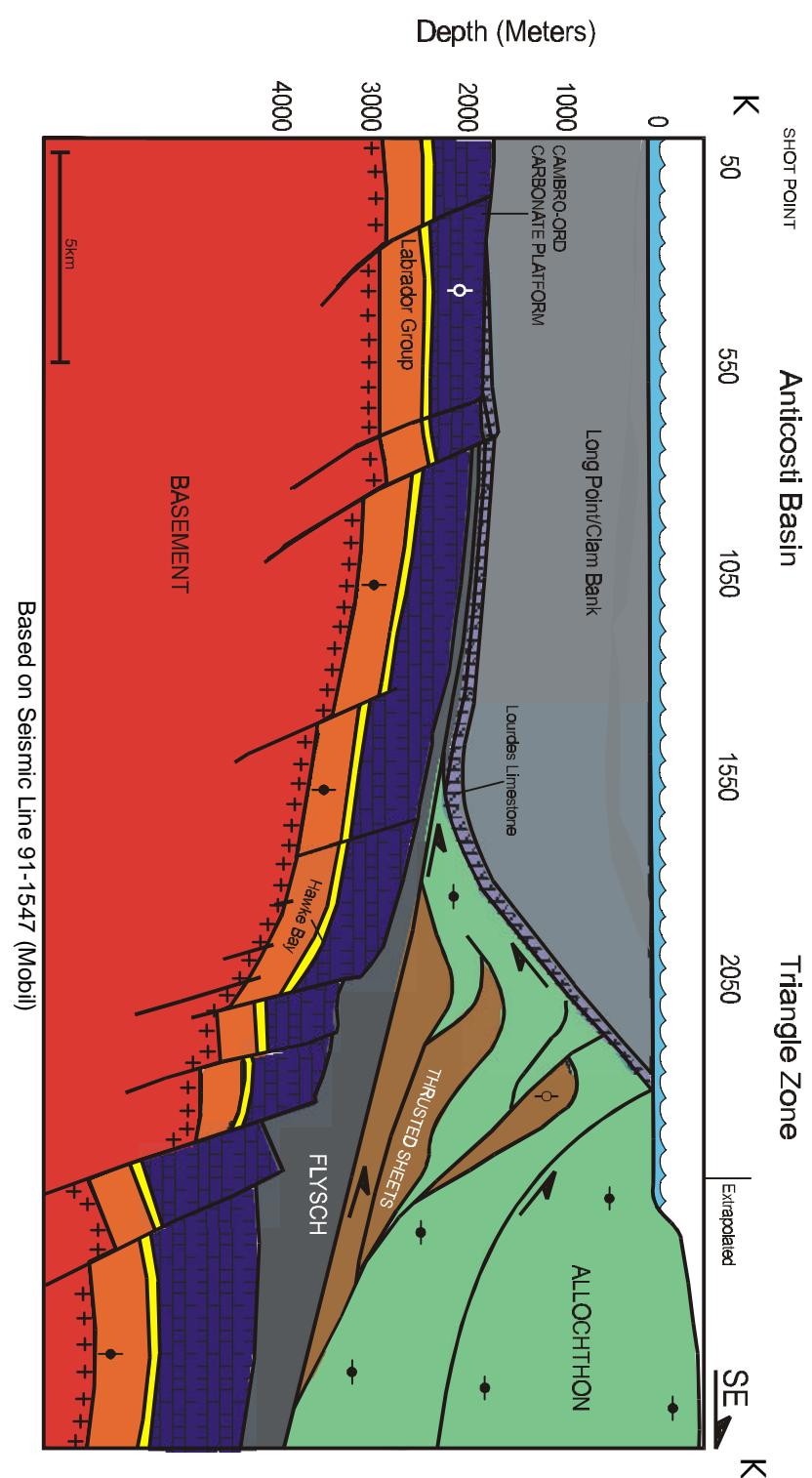
Oil Analysis of NALCO 65-1 Well

by Core Laboratories Canada Ltd., Calgary, Alberta, December, 1965

API @ 69°F	43.4
Sulphur wt.%	0.26
Viscosity S.U.S. @ 60°F	52.4
Viscosity S.U.S. @ 70°F	49.5
Viscosity S.U.S. @ 100°F	43.0
Pour Point	20°F
Salt Content lb NaCl/1000 Bbls	14.3
B. S. & W of Oil Layer	Trace of H ₂ O

Table 8.3

Triangle Zone Near Bonne Bay



This offshore section, based on a Mobil seismic line located about 70km south of Parsons Pond, shows thrust sheets within the triangle zone as well as large block faults within the foreland basin to the west. None of these plays have yet been tested in Western Newfoundland. See figure 8.1 for section location.

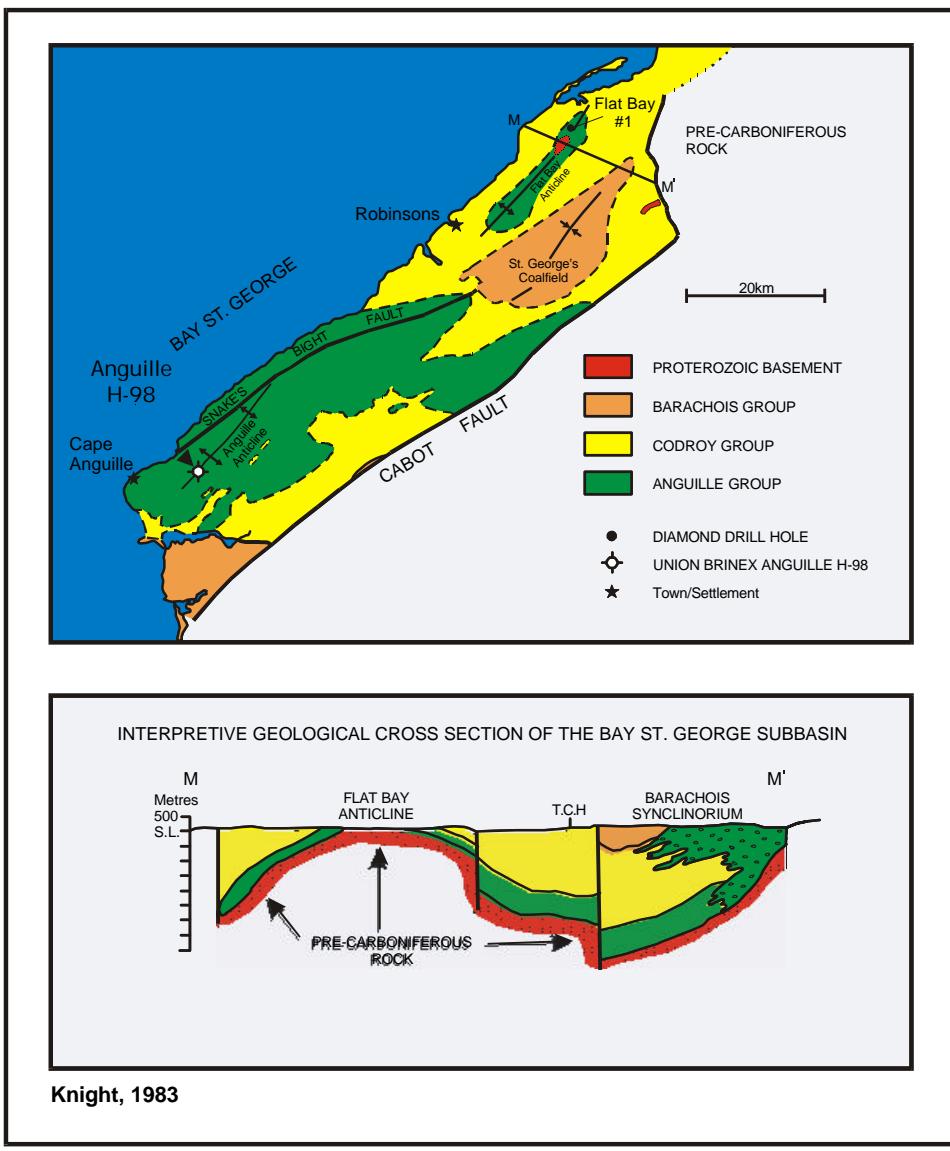
Figure 8.8

Section 8.4

Bay St. George Subbasin

This Carboniferous basin has had a number of notable gas shows during extensive drilling for gypsum in the late 1950's (McKillop 1957). Most recently a live oil zone noted by McKillop was confirmed by a shallow exploration well drilled by Vulcan Minerals in 1999 that encountered live oil over a 100 metre interval (Vulcan Minerals press release - September 1999). One deep well (*Anguille H-98*) was drilled to 2311 metres in 1973 in a highly structured zone and encountered only traces of poor porosity. Seismic surveys and bedrock mapping suggest that Bay St. George subbasin is a collage of grabens, half grabens and horsts of various ages with sedimentary thickness locally of more than 5 km (figure 8.5, 8.9 and 8.10).

Figure 8.9



Simplified geological map and cross-section through the onland part of the Bay St. George Subbasin (modified after Knight, 1983).

Excellent marine and nonmarine sandstone reservoirs occur, especially in the north of the basin. Carbonate reefs (within the Codroy Road Formation) with high interskeletal porosity which outcrop at Ship Cove (figure 8.10), and on the north shore of the Port au Port Peninsula are expected to be present at depth. Salt diapirs are known from gravity and seismic surveys. Black shales developed in and below a basal evaporitic sequence in the Codroy Group as well as black deepwater lacustrine shales in the Anguille Group may provide suitable source rocks. Wrench faulting has produced large northeasterly trending folds and flower structures with significant fault offsets. A major wrench fault appears to run close to the coastline of St Georges Bay where it separates the onshore structure (figure 8.9) from the structure seen beneath the bay itself (figure 8.5).

Bay St. George Area Subbasin

Exploration Wells: 2 (Flat Bay #1 & Anguille H-98)

Oil Shows: 3 (in shallow drill holes)

Gas Shows: Several in old mining exploration holes

Source Rocks:

- Snake's Bight Shales
- Blanche Brook Coal Beds

Reservoirs:

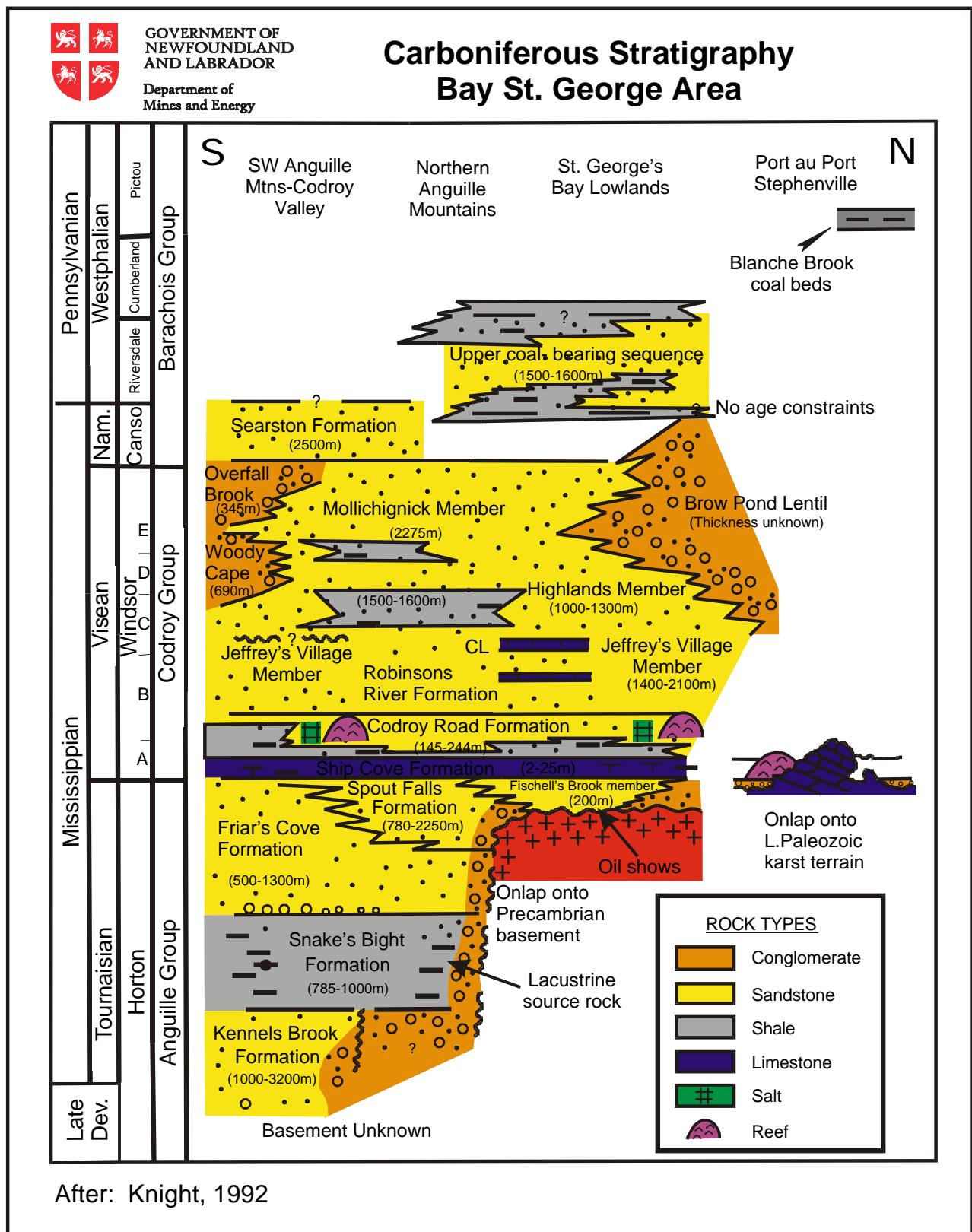
- Sandstones of the Codroy and Anguille Groups
- Algal laminites, dolomites and biothermal limestones of the Codroy Group
- Possibly carbonate platform preserved beneath the Carboniferous.

Play Concepts

- Pinchout of Anguille and Codroy sandstones against the Flat Bay Anticline
- Drape of sands over salt swells
- Pinchouts against salt diapirs
- Flower structures and folds produced by wrench faulting
- Faulting within the Codroy and Anguille Groups
- Reefal buildups in Codroy Road formation overlain by Windsor evaporites. The exposed part of such a reef at Ship Cove is 10 to 15 metres high and 200 metres in width and exhibits high interskeletal porosity (Knight, pers. comm.) Similar reefal buildups are observed to occur on the north shore of the Port au Port Peninsula in the stratigraphic equivalent of the Ship Cove formation.

Table 8.4

Bay St. George Area Stratigraphic Chart

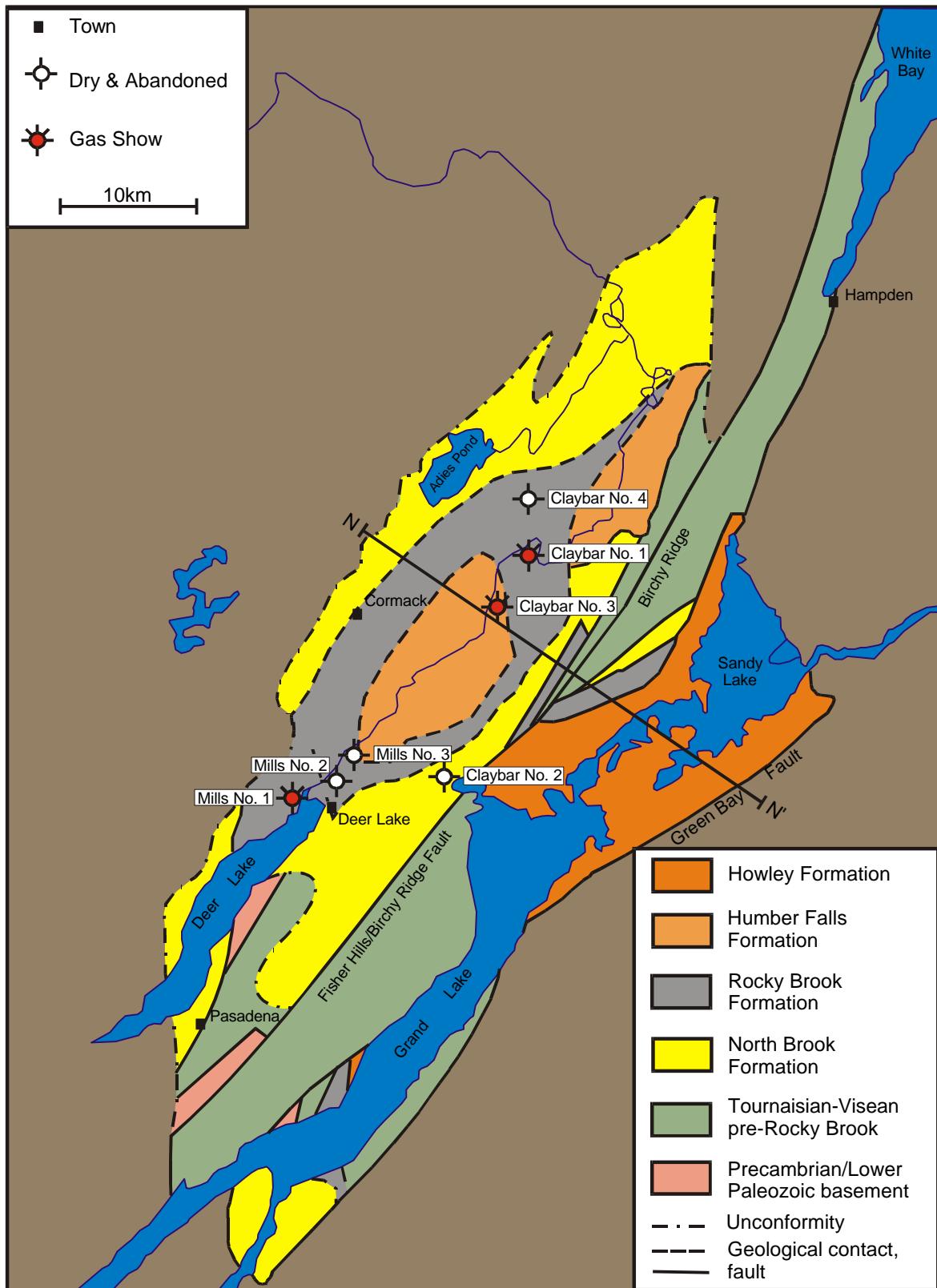


Lithostratigraphy of the Bay St. George Sub-basin

Figure 8.10

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Deer Lake Basin



Simplified geological map of the Deer Lake Basin showing the location of wells, all of which were drilled prior to 1960.

Figure 8.11

Section 8.5

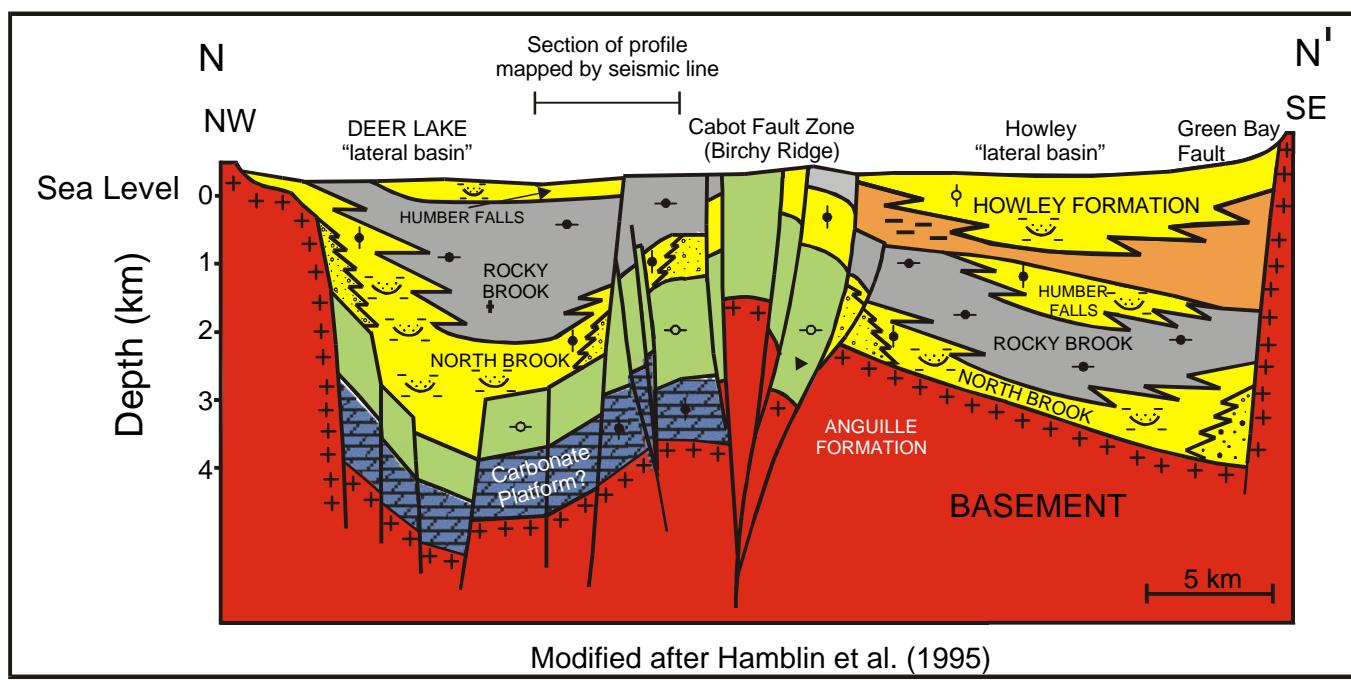
Deer Lake Basin

Deer Lake Basin

The Deer Lake Basin is the site of seven old exploration wells drilled in the early and mid 1900's (figure 8.11) one of which (*Mill's #1*) was a gas blow out that caught fire and destroyed the rig. Gas still bubbles from the well today. Of the four Claybar wells drilled, two flowed significant gas to surface. Flow rates were not measured.

The basin contains predominantly non-marine sediments which include alluvial fan, braided and meandering river, lacustrine and swamp deposits that were laid down in a strike slip structural setting. Syntectonic uplifts along the axis of the basin have partitioned it into a series of interconnected depocentres, and created a number of potential drilling targets (see figure 8.12). The early exploration efforts demonstrated the oil and gas generative capacity of the organic rich Rocky Brook shales and the reservoir quality of the North Brook sandstones. Given that the well locations were chosen without the benefit of seismic data it is unlikely that they were drilled in optimal locations. In the late 1990's seismic data was acquired in the basin (most of which is still proprietary).

Figure 8.12



Section NN' illustrates the structural style and possible petroleum plays, of the Deer Lake Basin. This section is, for the most part, based on surface geology and gravity and magnetic data, with a short section to the west of the Birchy Ridge based on released seismic data. See figure 8.11 for section location.

Deer Lake Basin Exploration Wells <ul style="list-style-type: none">• 7 early wells• Gas shows: 3 significant flows to surface
Source Rock: <ul style="list-style-type: none">• Rocky Brook Shales
Reservoirs: <ul style="list-style-type: none">• North Brook sandstones and conglomerates (porosities ranging from 12-18%)
Possible Reservoirs <ul style="list-style-type: none">• Sandstone and conglomerates within the Humber Falls and Howley formations• Ordovician Carbonate Platform beneath the Carboniferous. It is not yet known if reservoir quality carbonates exist below the Carboniferous cover.
Play Concepts <ul style="list-style-type: none">• Anticline features and fault traps• Pinchouts and channel sandstones in the North Brook Formation• Alluvial fan pinchouts against basin margins and Birchy Ridge• Faulting of the Ordovician Carbonate platform (if preserved and porous) beneath the Carboniferous

Table 8.5

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GSC Basins Site.....	http://agc.bio.ns.ca/BASINS/

APPENDIX A
WELLS PER BASIN BY YEAR

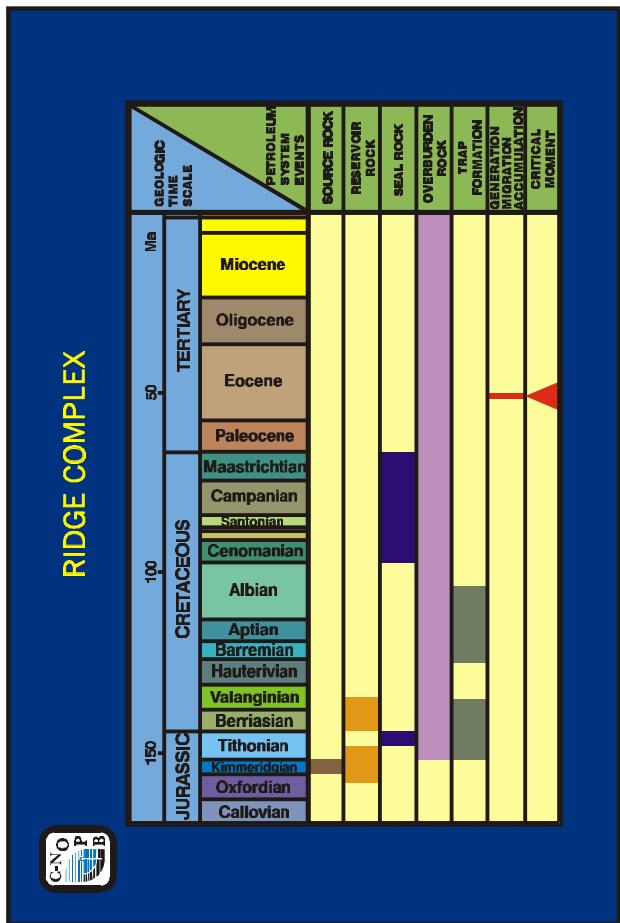
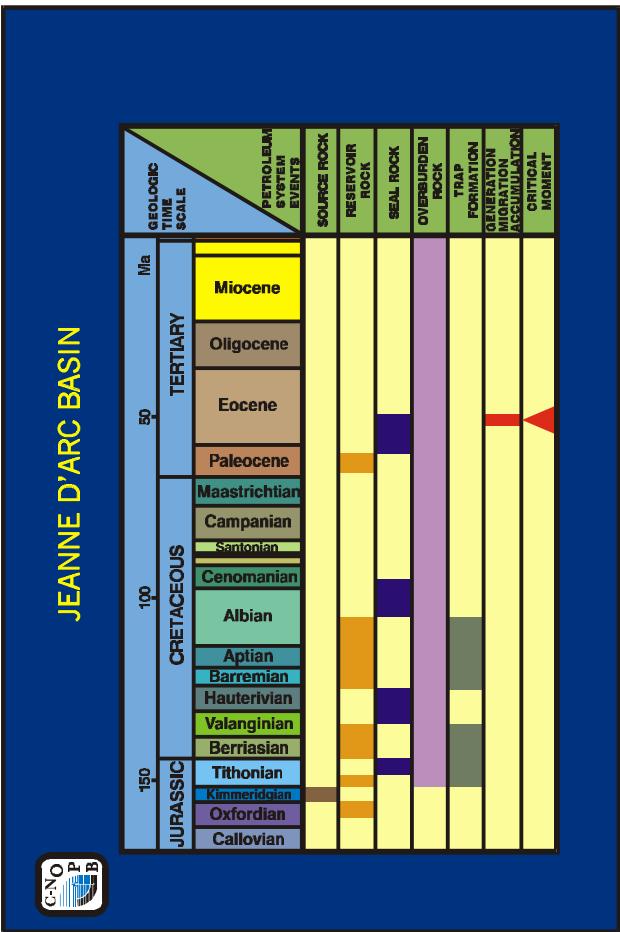
Wells Per Basin Per Year

Basin Name	1966	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	Totals
Whale	1	0	0	0	2	0	5	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10			
South Whale	1	0	0	0	2	6	5	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	15			
Horseshoe	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3			
Carson	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3			
Bonntition	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1			
Jeanne d'Arc	0	0	0	0	1	3	3	2	0	0	0	1	4	5	1	4	12	8	3	4	6	1	2	0	0	0	0	1	1	6	69				
Ridge Complex	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	2	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	9			
Flemish Pass	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	3			
East Nfld./Orphan	0	0	0	0	0	0	0	1	1	0	0	2	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7			
St. Anthony	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1			
Labrador Shelf	0	0	0	0	1	0	2	1	5	3	0	3	3	5	2	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28			
Anticosti	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	1	0	1	6		
Bay St. George	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2			
Sydney	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Totals	2	0	0	0	0	6	11	18	9	6	4	0	3	7	10	8	5	7	12	11	7	5	7	1	1	2	0	0	1	2	2	1	8	157	

DOES NOT INCLUDE HIBERNIA AND TERRA NOVA DEVELOPMENT WELLS

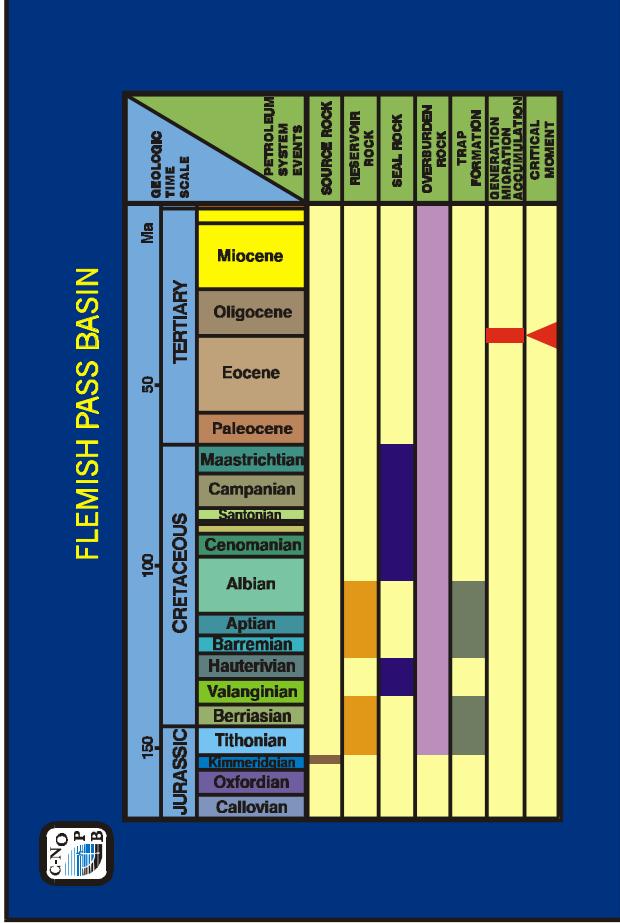
APPENDIX B
PETROLEUM SYSTEMS EVENTS

PETROLEUM SYSTEMS EVENTS



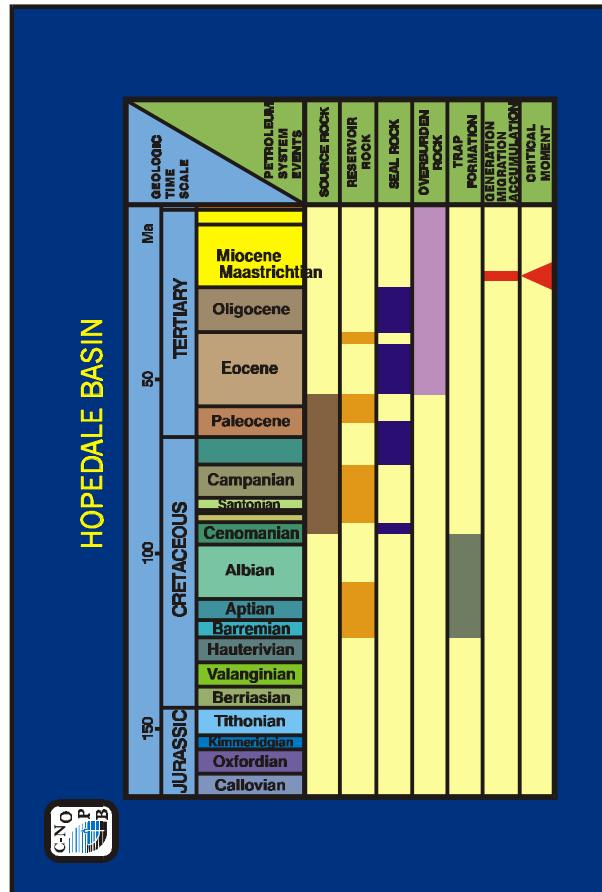
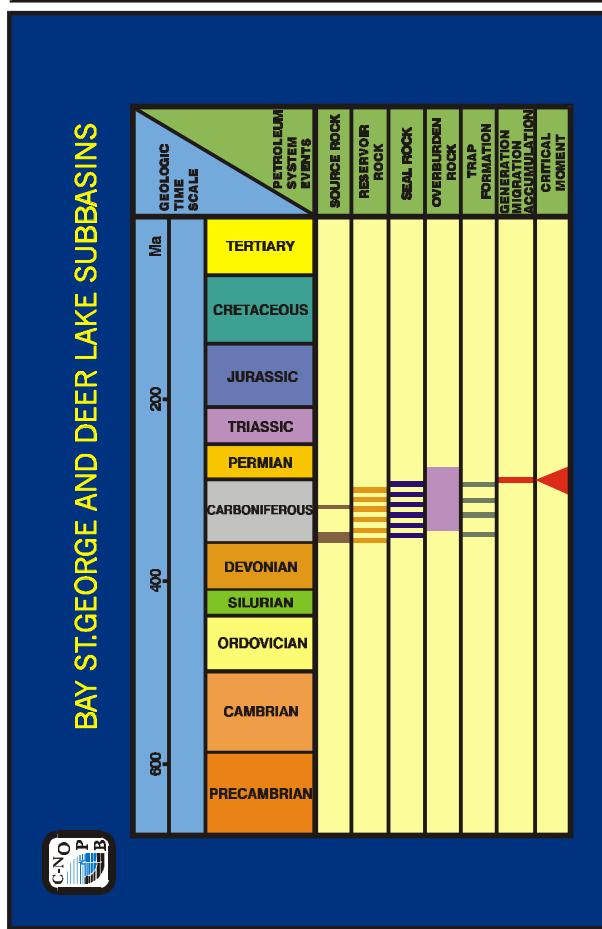
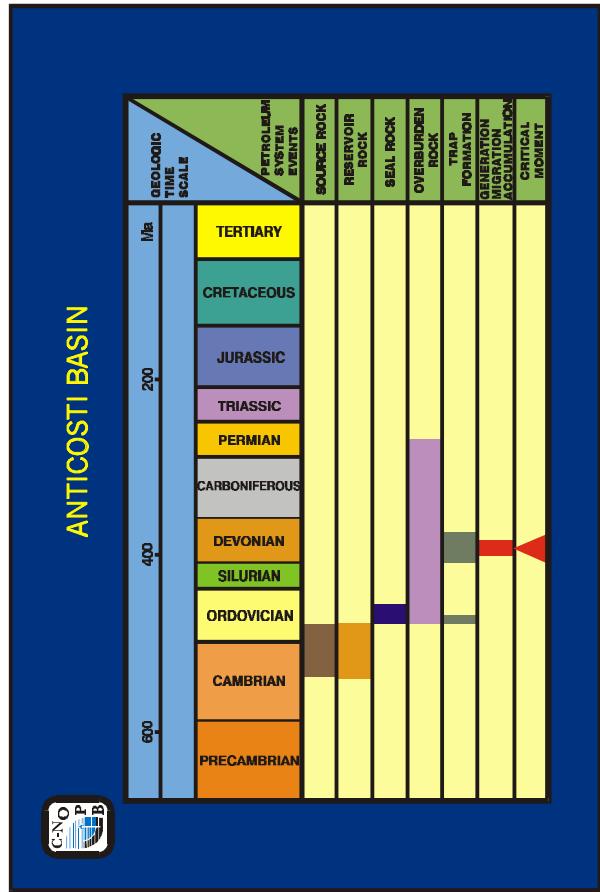
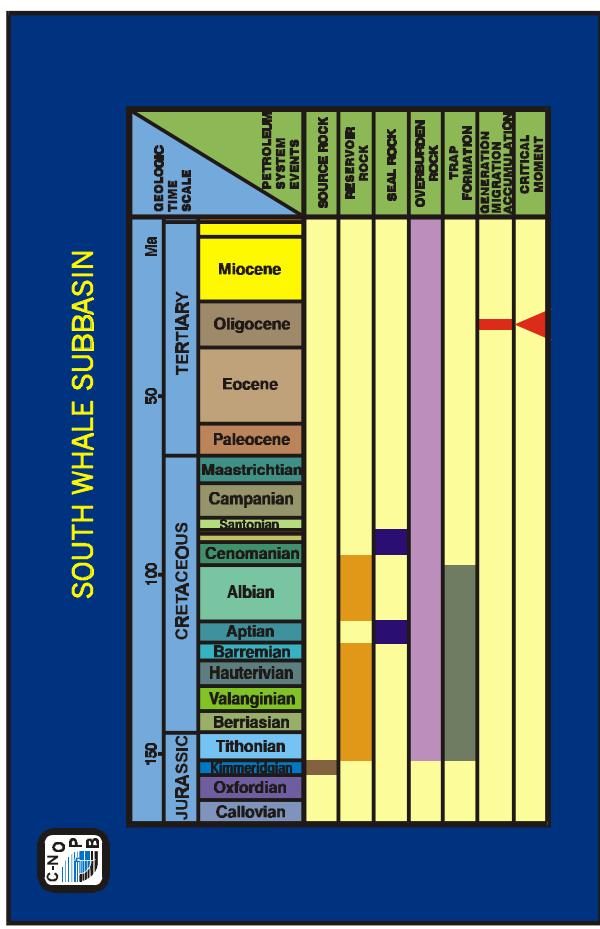
These figures summarize critical data on key sedimentary basins in Newfoundland and Labrador. (DeSilva, 1999)

The “critical moment” is the point in time that best depicts the generation, migration, and the accumulation of most hydrocarbons in a petroleum system.



After Desilva, 1999

PETROLEUM SYSTEMS EVENTS



After Desilva, 1999