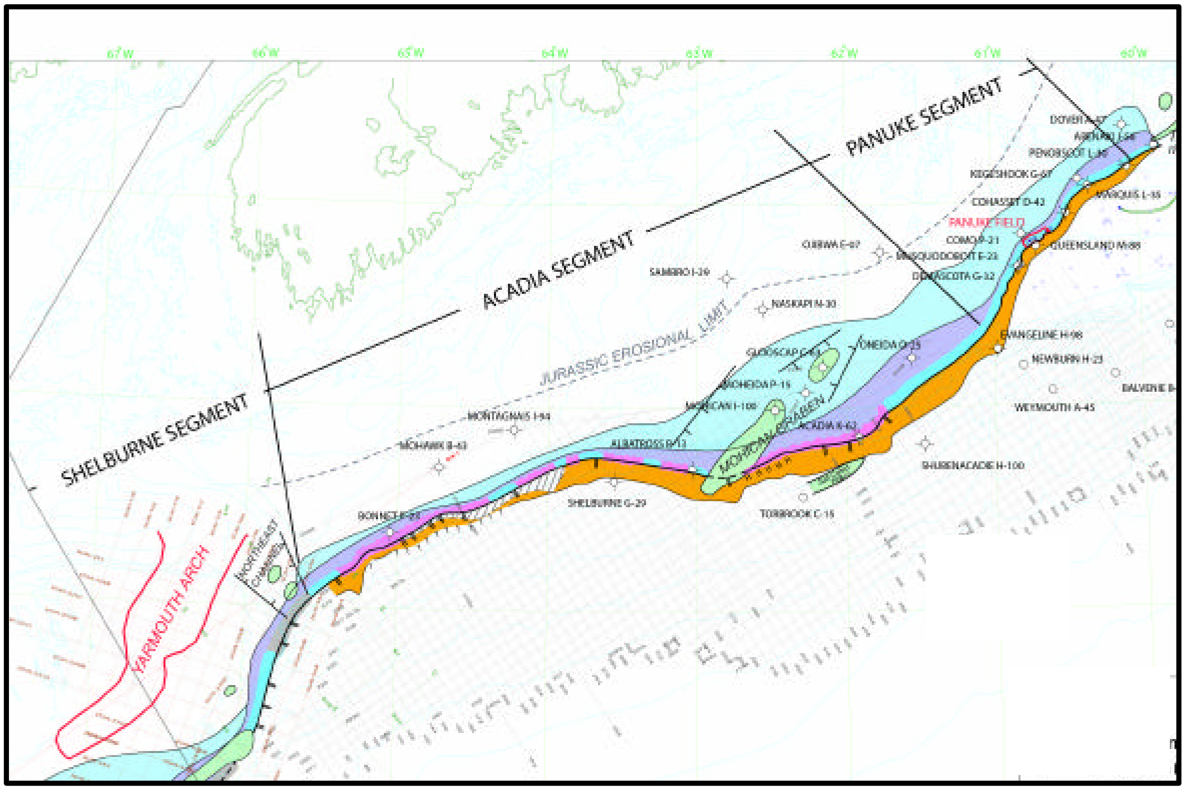
CANADA-NOVA SCOTIA
OFFSHORE PETROLEUM BOARD

The Upper Jurassic Abenaki Formation Offshore Nova Scotia: A Seismic and Geologic Perspective



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June 2005 – Version 1.0

HALIFAX, NOVA SCOTIA, CANADA

CONFIDENTIALITY

This Report was originally created by the Canada-Nova Scotia Offshore Petroleum Board for its exclusive internal use. This version has been edited for public release, as the original work contained portions of well, seismic, and other information currently held under confidentiality agreements between the respective owners of the data and the CNSOPB. Most of the figures that were included in the original Report are included herein, and where appropriate, with the express permission of the data owners.

ACKNOWLEDGEMENTS

The authors hereby acknowledge the ongoing support of the Canada-Nova Scotia Offshore Petroleum Board, especially Steve Bigelow, Manager-Resources & Rights, for providing the resources required for this study, and guidance and integration of human resources with day-to-day operational responsibilities. His vision of accomplishing a study of this magnitude, to further enhance the knowledge base for the Nova Scotia Margin, is admirable. We also warmly thank our CNSOPB colleagues Carl Makrides, Andrew McBoyle, Christine Bonnell-Eisnor and Troy MacDonald for their continuous input, support and encouragement. We greatly appreciate the generous support of John Hogg, John Weissenberger, Rick Wierzbicki and Nancy Harland (EnCana), Kim Abdallah (TGS-NOPEC), Ian Davison (Earthmoves) and Gabor Taru (Vanco), and thank them and their firms for permission to use selected seismic profiles and figures. We recognize Sonya Dehler, Lubomir Jansa, John Wade and Don McAlpine (Geological Survey of Canada-Atlantic), Haddou Jabour (ONAREP/ONHYM), and Paul J. Post (U.S. Minerals Management Service) for their insights and advice. Finally, we sincerely thank Jim Dickey, CEO of the CNSOPB for his endorsement and support of the study.

RECOMMENDED CITATION

Kidston, A.G., Brown, D.E., Smith, B. and Altheim, B., 2005: *The Upper Jurassic Abenaki Formation, Offshore Nova Scotia: A Seismic and Geologic Perspective.* Canada-Nova Scotia Offshore Petroleum Board, Halifax, Nova Scotia,168 p.

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EXECUTIVE SUMMARY

This study documents the geology of the Upper Jurassic Abenaki Formation carbonate platform located along the edge of the continental margin, offshore Nova Scotia. The study area extends for 650 kilometres from Sable Island southwest to the U.S. border.

During Upper Jurassic time, the circum-North Atlantic was fringed by carbonate platforms and related facies. Within the Abenaki offshore Nova Scotia, three main depositional facies are recognized; an inner low energy shelf, an outer high energy shelf including the bank edge, and a deeper water foreslope. Analogues to the Abenaki are similar aged strata along the U.S. Atlantic margin, on the conjugate margin offshore Morocco, and both U.S. and Mexican Gulf of Mexico.

Based on geological characteristics, the Nova Scotian Abenaki carbonate platform and margin succession is subdivided into three segments along the trend: Panuke, Acadia and Shelburne.

The Panuke Segment is 120 km long and lies adjacent to the Sable Sub-Basin and includes EnCana's Deep Panuke gas discovery made on the bank edge in 1999. This area has 14 of the 21 exploration wells, seven on the bank edge, six in the back-reef and one on the foreslope. The latest 3D seismic surveys were used for detailed mapping in time and depth. The Cohasset/Panuke oil production (44MMB) was from Cretaceous sands draped over the bank edge.

The Acadia Segment extends 400 km from the edge of the Sable area to the Northeast Channel adjacent to George's Bank. The modern 2D regional seismic survey by TGS-NOPEC was used. Unlike the Panuke area this segment is faulted, eroded and intruded by salt but the presence of reefal facies bodes well for likely reservoir development. There are seven wells in this area, three on the bank edge and four in the back-reef with no discoveries but with reservoir and mud-gas shows.

The Shelburne Segment is about 120 km long and includes the George's Bank Moratorium area and extends to the U.S. border. This area is the least understood because of dated 1970 and 1980 seismic and a lack of wells.

From 1970 to the present (2004), there have been 28 wells drilled on the Abenaki Platform in the study area: ten bank edge wildcats, seven delineation wells at the Deep Panuke field and 11 other wells either landward or basinward. Only two wells were drilled in the Abenaki along the U.S. margin in the late 1970s and early 1980's but without success. On the conjugate Moroccan margins several wells encountered oil shows but none of commercial value. To date, the prolific Mexican "Golden Lane" trend in the western Gulf of Mexico is the only region with production from Middle and Upper Jurassic carbonate bank margins in the circum-Atlantic realm.

1. INTRODUCTION AND SCOPE OF STUDY

This study documents the Canada-Nova Scotia Offshore Petroleum Board's* seismic and geologic study of the Upper Jurassic carbonate bank margin offshore Nova Scotia from Sable Island to the U.S. border. The Abenaki was compared to analogues from the circum-North Atlantic region including the United States, Northwest Africa and Mexico. The global map (Figure 1) shows the traditional continental fit of North America between the Bahamas and the Grand Banks to Africa from Morocco to Sierra Leone. More specifically is the conjugate continental margin comparison of offshore Nova Scotia from the Grand Banks to the New England chain of seamounts relative to the equivalent margin off Morocco from Gibralter south to the Canary Islands. The present-day North American continental shelf is broad compared to the narrow shelf of Northwest Africa. During Middle-Upper Jurassic time, the former area including the Gulf of Mexico was rimmed by a carbonate-prone continental shelf.

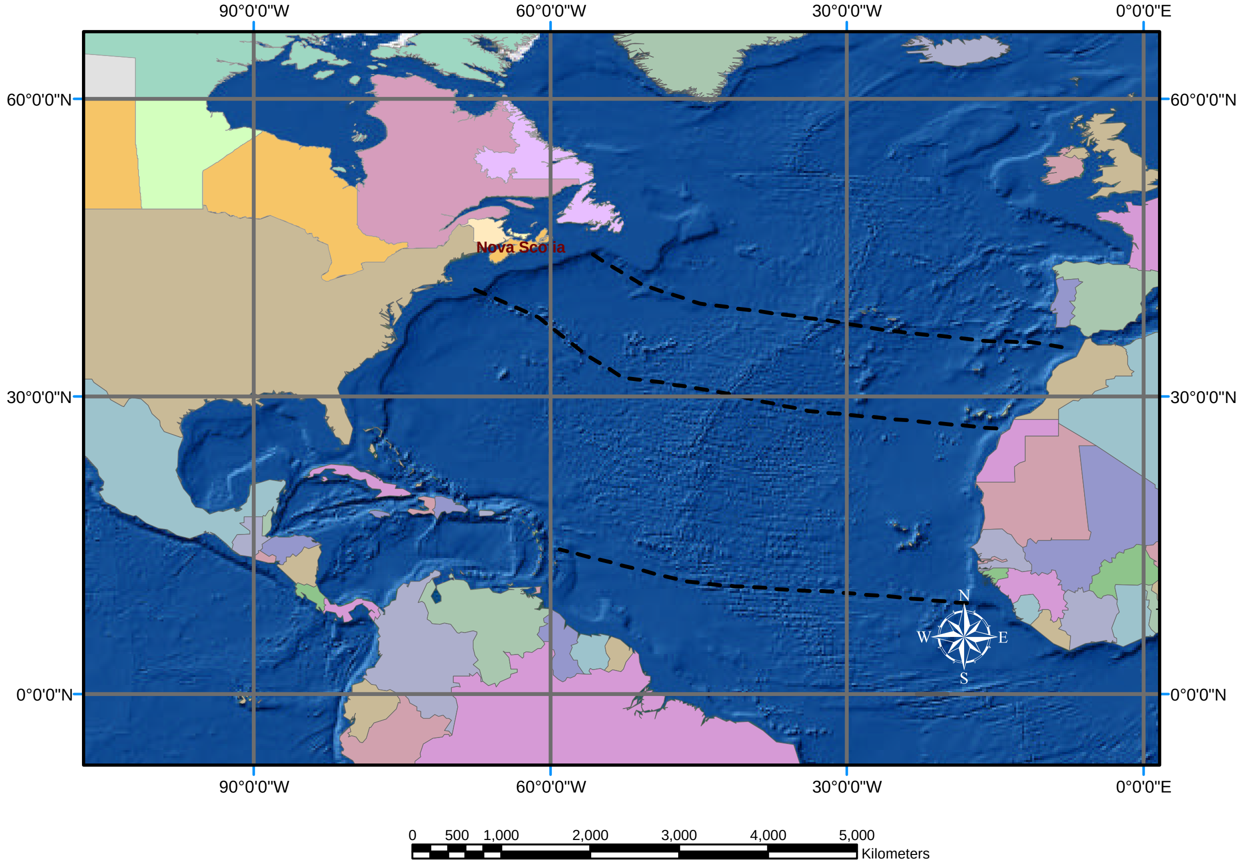


Figure 1. Location map of the circum-Central and North Atlantic region. Dark lines follow oceanic fracture zones that show relationships to the respective conjugate margins.

A map of the Scotian Basin illustrates the components of the basin from the Yarmouth Arch in the southwest to the Avalon Uplift of the Grand Banks in the northeast, a distance of 1200 km (Figure 2). The Jurassic carbonate shelf is a major component of the Scotian Basin and it extends in a non-linear fashion across the basin. The carbonate shelf profile changes dramatically just north of Sable Island from steeply-dipping in the southwest to a low-angle ramp in the northeast. The steeply-dipping bank edge or rimmed margin of the Jurassic Abenaki Formation from Sable Island to the U.S. border will be the subject of this study.

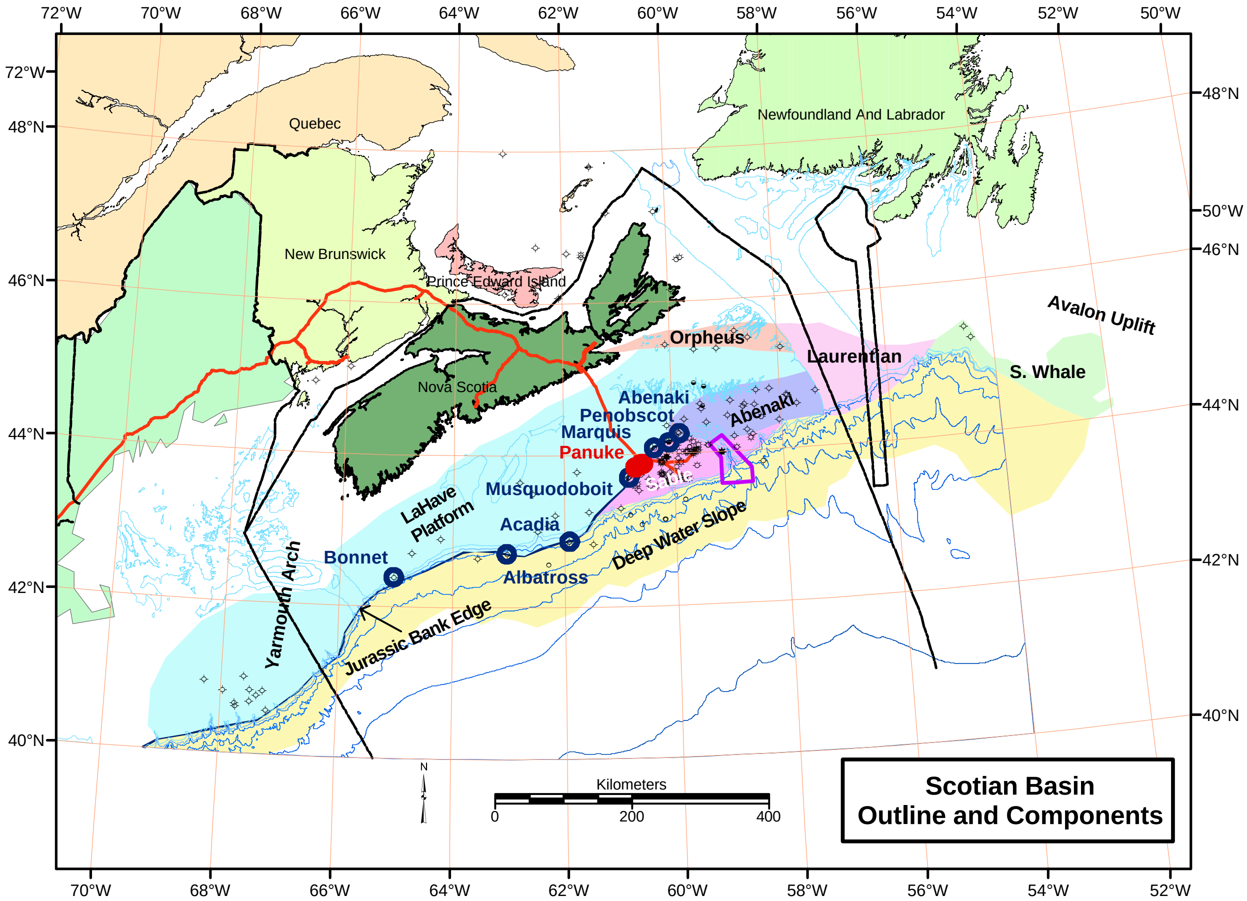


Figure 2. The Scotian Basin, its subbasins and related tectonic elements. Significant Abenaki wells are highlighted.

The Upper Jurassic Abenaki Formation is divided into four members and in ascending order are the Scatarie, Misaine, Baccaro and Artimon. Based on our study of the bank margin and its physical attributes, the Abenaki bank margin can be subdivided into three areal segments; from the northeast to the southwest they are termed the Panuke, Acadia and Shelburne Segments. The study areas extend from the platform interior on the shallow Scotian Shelf to the margin foreslope in deepwater on the Scotian Slope (Figure 3).

The bank edge reef facies of the Abenaki carbonate margin was first drilled in 1973. While the carbonate target was dry, an oil discovery was made in shallower overlying draped sands of the Upper Cretaceous Logan Canyon Formation. This discovery was eventually developed and became part of the Cohasset/Panuke oil project that produced 44.4 million barrels (MMB) of light gravity crude from 1992 – 1999. Since 1973, another ten exploration wells were drilled on features along the bank margin resulting in a single gas show until PanCanadian (EnCana) discovered the Deep Panuke field in 1999.

Analogue carbonate margins off northwest Africa and the U.S. Atlantic margin were used for same-age comparisons. The Middle Cretaceous carbonates of Northeast Mexico as well Western Canada Sedimentary Basin (WCSB) Devonian systems were also compared. While there are producing Jurassic-age carbonate platforms in the world, there are no known significant Upper Jurassic carbonate bank edge producing regions.

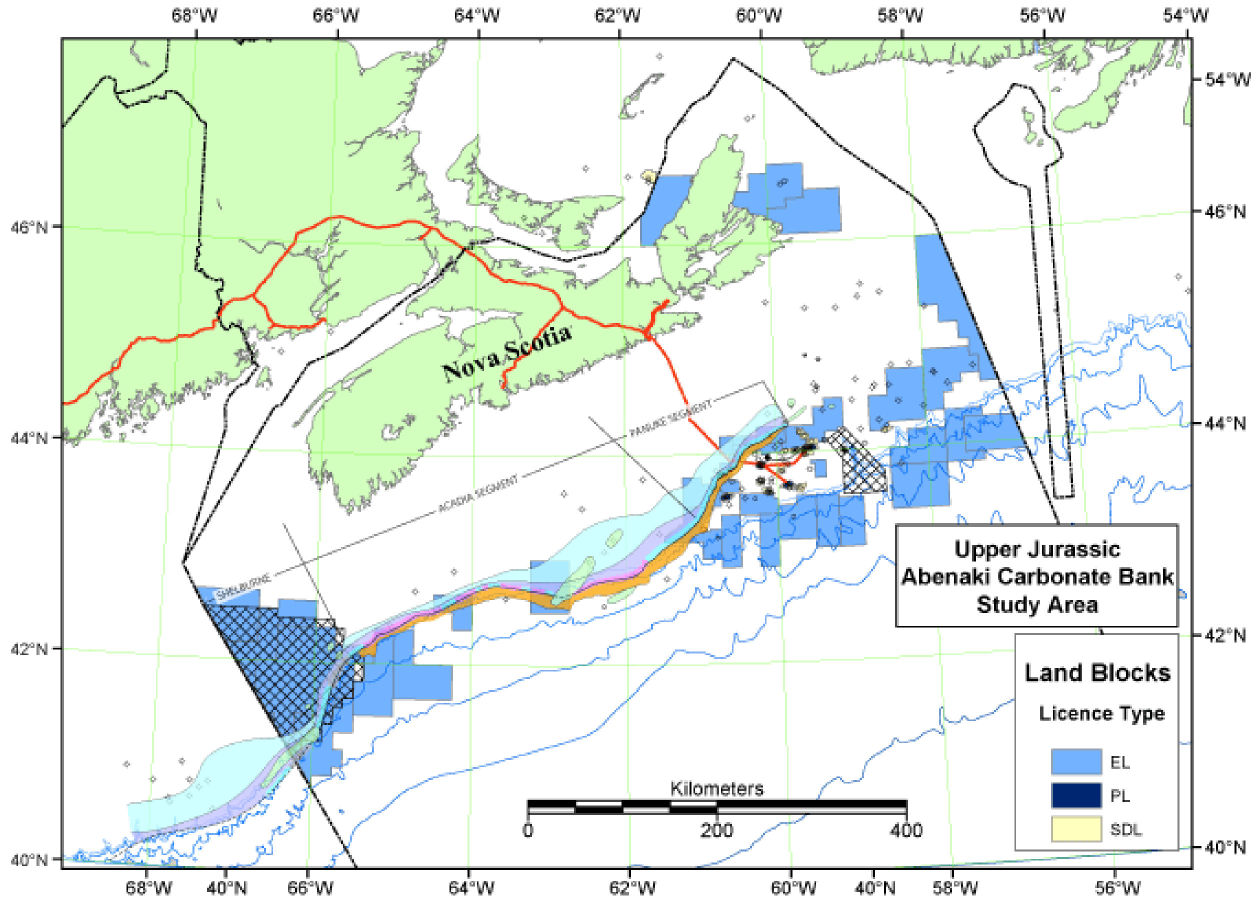


Figure 3. Location map of Abenaki study area, offshore Nova Scotia. Red lines indicate gas pipelines. Cross-hatched areas define exploration moratorium (SW) and marine protected areas (NE) respectively. Land block licenses: EL – exploration, PL – production, SDL - significant discovery.

With a single significant commercial hydrocarbon discovery off Nova Scotia and none encountered off the U.S. or Morocco margins, the success factors of this play remain to be determined. The variable quantity and quality of relevant datasets inhibit a comprehensive numerical analysis of the entire platform and margin succession. Additional seismic data, well results and future discoveries are required to better understand and more accurately quantify the resource potential of the Abenaki carbonate margin and equivalent plays offshore Nova Scotia, Morocco and the United States.

* Herein referred to as “the Board” or “CNSOPB”.

2. DATABASE

A number of geological and geophysical data sources were used in the preparation of this study. Well data is sourced from both existing (public) and recently drilled (proprietary) exploration and delineation wells held in the CNSOPB Archives. Confidentiality periods range from 90 days (delineation wells) to two years (exploration wells) from the date of the rig release from the well site. The seismic data is of variable vintage, quality and coverage, ranging from 1970's vintage programs in the Shelburne Segment to the latest proprietary 3D surveys in the Panuke Segment. Given this mix of public and confidential data, strict editing was required to prepare this report for release into the public domain (see Confidentiality Clause). Finally, a number of definitive papers from the late 1970's and early 1990's are briefly reviewed as they form the basis for most of the current understanding of the Abenaki Formation and Deep Panuke field. Well and seismic line and program locations are shown in Figure 4.

2.1 Wells

Twenty-eight exploration wells were drilled on the carbonate margin from Sable Island to the U.S. border. Of these, 10 are defined as bank-edge new field wildcats (NFW), seven as existing field delineation wells (all at Deep Panuke) and 11 as off-reef wells, i.e. landward on the shallow interior platform or seaward on the deep foreslope.

On the U.S. Atlantic Margin, a total of 54 wells were drilled to test various structures and play types similar to those encountered on the Nova Scotia margin (Figure 5). Five industry-sponsored COST wells (Continental Offshore Stratigraphic Test) were drilled in 1976-77 and were then followed by 49 exploration wells drilled between 1981 and 1984. The chronology of exploration is important because the acquisition of data and the objectives and subsequent results of each well is a learning experience. The wells provide data on basic lithology, stratigraphy, ages, and most importantly identifying and quantifying the petroleum systems elements and the viability of the different play types. For example, in order to understand the controlling factors of existing and potential hydrocarbon accumulations in the Abenaki carbonate margin off Nova Scotia, it is important to know the results of the 54 wells drilled in equivalent strata in American waters. Surprisingly, only two of those wells tested the Abenaki equivalent reefal facies.

For wells offshore Nova Scotia, publicly-accessible well data in the Board's Data Archives provided information such as logs, cores, cuttings, etc. The well data files were consulted to identify any minor shows, mud-gas anomalies, etc. that could further assist in the evaluation of the Abenaki petroleum systems (see Section 3.2).

2.2 Seismic

A variety of seismic surveys were available for use in this study, ranging from an old 1974 2D program shot on the George's Bank to the very latest 3D acquired in 2003 over the Panuke Field. The following 2D surveys were studied and digital data from selected programs were used for mapping purposes. All digital datasets were interpreted on a Sun workstation using Geoquest software. CNSOPB Program Numbers are indicated in brackets. Some of this seismic data is confidential and could only be shown where permission from the owner has been obtained.

GSI, 2001 (Marquis Survey) – 2100 km, 120-Fold (NS24-G05-04P)
This recently-obtained survey completed the seismic coverage from the 3D coverage over the Panuke area to the Penobscot wells in the northeast and to the limit of the steep-banked carbonate margin.

TGS-NOPEC, 1998-1999 – 30,000 km, 80-Fold (NS24-G65-01P
This survey was used for the Board's 2002 deep-water study and had sufficient bank edge crossings (47 lines) from southwest of Bonnet P-23 near the Northeast Channel to the edge of the Sable Subbasin near Evangeline H-98. Data quality is from good to excellent but there are places where the bank edge is poorly imaged and the lines are too short. The data processing employed post-stack time migration.

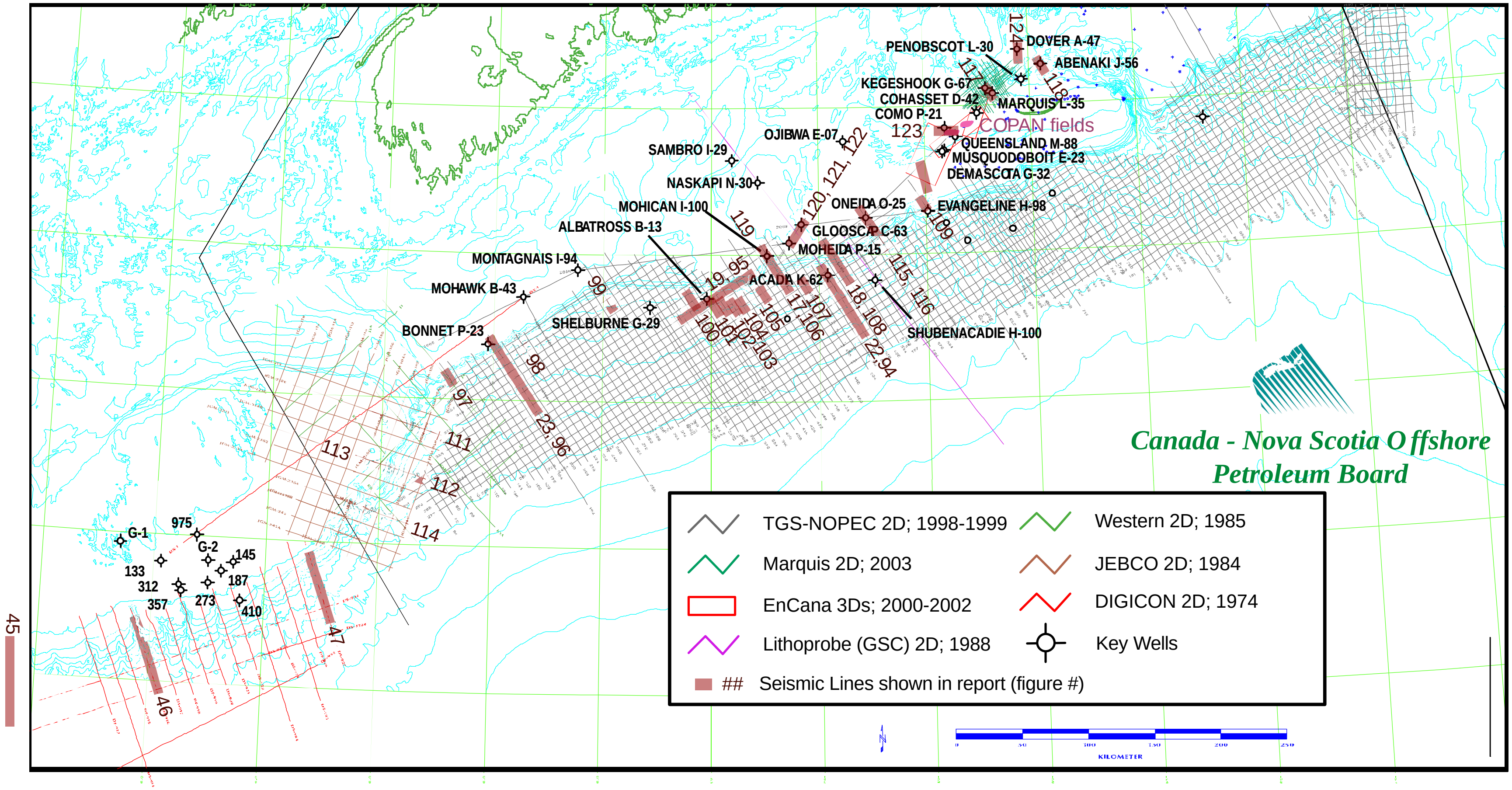


Figure 4. Well and seismic base map. Locations of seismic lines illustrated in this study are identified and indicated as heavy brown lines.

OFFSHORE NOVA SCOTIA DRILLING - Upper Jurassic Carbonate Platform, Western Shelf

(Based on Rig Release)

	Expl	**Deln**	**Off-reef**	**Exploration (Bank Edge)**	**Delineation**	**Off-Reef**
1970			1			Oneida O-25
71			1			Abenaki J-56
72			1			Mohican I-100
73	1			Cohasset D-42		
74	1			Demascota G-32		
75						
76			1		US Atlantic Margin	Penobscot L-30
77			1		5 COST Wells	Moheida P-15
78	2			Acadia K-62, Cohasset L-97		
79						
1980						
81					US Atlantic Margin	
82					49	
83					Exploration	
84	1		2	Bonnet P-23	Wells	Glooscap C-63, Dover A-43
85	1		1	Albatross B-13		Kegeshook G-67
86	1			Panuke B-90		
87			1			Como P-21
88						
89						
1990						
91						
92						
93						
94						
95						
96						
97						
98						
99	1	1		Deep Panuke PP-3C (J-99)	Panuke P1-1A (J-99)	
2000		3	1		Panuke M-79/M-79A, Panuke H-08	Panuke F-09
1	1	1		Musquodoboit E-23	Panuke P1-1B (J-99)	
2	1		1	Marquis L-35		Queensland M-88
3		2			Margaree F-70, MarCoh D-41	
4						
5						
Totals	10	7	11			
Total All		28				

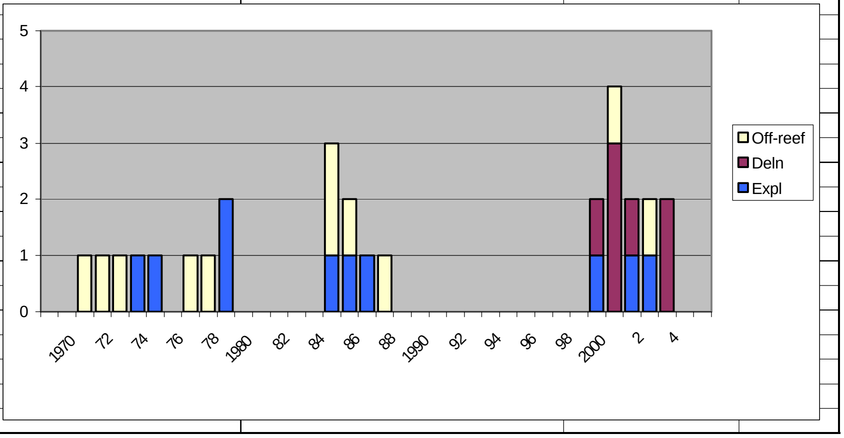


Figure 5. Chronology of exploration and delineation drilling in the Abenaki Formation, offshore Nova Scotia.

GEOLOGICAL SURVEY OF CANADA (WESTERN), 1988, - 350 km, 30 Fold (AGC 88-1 & 88-1A)

A deep crustal seismic line (25 seconds TWT) was shot by the GSC extending from the coast of Nova Scotia out into the deep abyssal plain. Digital data and paper sections were used to assist in regional and well correlations, definition of basement architecture, structural styles, timing of tectonic events and deep water stratigraphy.

WESTERN, 1985 – 40-Fold (8624-W013-004P)
Several lines were used to fill in gaps between the TGS and Jebco surveys. Available paper sections were interpreted and digitized into the mapping program.

JEBCO, 1984 – 6800 km, 60-Fold (8624-J13-001P)
This 1983 survey covered what became the "George's Bank" Moratorium Area and covered from where the TGS survey ended to the US border. Data quality is variable from good to very good however the bank edge imaging is degraded because it lies beneath the present-day continental slope which is highly eroded in places. Only paper sections were available for interpretation and digitizing into the mapping program.

DIGICON, 1974 – 36-Fold (8624-D001-005P)
A regional line reproduced from microfiche was required to make the important 300 km correlation between the Canadian Mohawk B-93 and American Exxon Block 975, No.1 wells. Paper sections were interpreted and digitized into the mapping program. In addition, a number of lines from the American side of the border were obtained from the GSC but are part of the same project number above.

PANCANADIAN / ENCAN - Three proprietary 3D surveys were used covering the Panuke Segment:

Huckleberry– PanCanadian, 1998
Abenaki – PanCanadian, 2001
Part of EL2356 – EnCana, 2002

2.3 Key Papers

There are numerous volumes written on carbonate platform and reef margin geology worldwide and several excellent AAPG Memoirs on the subject, but for the local Scotian Basin Abenaki Formation one is limited to a few but excellent significant papers that follow the evolution of knowledge of the Scotian Basin and the Jurassic carbonate platform within the basin. Although these are "must-read" papers, they are nonetheless dated given the number of new wells and seismic data now available. It is interesting to note that while the earliest research was limited to data from but a handful of industry wells, geoscientists formulating the framework and evolution of Atlantic-style tectonically stable passive margins intuitively postulated that such margins would include Jurassic age carbonate platforms. The following are brief notes on eight key papers listed in chronological order with full citations appearing in the References.

(1) N. L. McIver, Shell Canada, 1972
"Cenozoic and Mesozoic Stratigraphy of the Nova Scotia Shelf"
For the first time the offshore Nova Scotia Cenozoic – Mesozoic stratigraphy was defined and nomenclature proposed. The first stratigraphic schematic cross-section was also presented and this paper became the cornerstone for all subsequent work. By 1972 the carbonate platform had been penetrated by several wells including the Shell Oneida O-25 which became the type section for the Abenaki Formation. Although the carbonate bank-edge reefal facies had not yet been penetrated, the regional seismic surveys revealed the margin's existence.

(2) Don Sherwin, Energy, Mines & Resources Canada, 1973
"Scotian Shelf and Grand Banks"
This is an excellent paper on the eastern region of the Atlantic offshore embracing both the Scotia Shelf and the Grand Banks of Newfoundland. The history of earth science for the region is documented including the early efforts of American and Canadian geological research. For the first time, maps were published on basin fill, paleogeography, extent of salt and carbonates, and Cretaceous drainage concepts plus regional scale geological cross-sections. The paper was also the first to discuss volumetric estimates of hydrocarbon potential for the various shelf, slope and rise areas.

(3) Lubomir F. Jansa and John A. Wade, 1974
"Geology of the Continental Margin off Nova Scotia and Newfoundland"
This was the first comprehensive Geological Survey of Canada paper on the East Coast offshore region and contained significant number of cross-sections, maps and stratigraphic descriptions that greatly advanced the sub-surface understanding of both the Scotian and East Newfoundland Basins. However, the only bank-edge wells of the time,

Mobil Cohasset D-42 and Shell Demascota G-32 were not publicly available for study.

(4) Mary M. Given, Shell Canada Ltd. 1977

“Mesozoic and Early Cenozoic Geology of Offshore Nova Scotia”

Given discussed sedimentation on the Nova Scotia Shelf since Late Triassic in the context of Falvey’s (1974) plate tectonics model for an Atlantic-type continental margin. She had at her disposal 33 Shell wells plus 8 competitor wells and a 75,000 km seismic grid from which 7 major seismic events were correlated and mapped. It is interesting to note that while only two Abenaki bank-edge wells existed (Shell Demascota G-32 and Mobil Cohasset D-42), Shell’s vast seismic database permitted Given to describe the massive Baccaro limestone shelf-edge complex and advance basin understanding from earlier work by Jansa and Wade, Sherwin, and McIver.

(5) Leslie J. Eliuk, Shell Canada Ltd. 1978

“The Abenaki Formation, Nova Scotia Shelf, Canada – A Depositional and Diagenetic Model for a Mesozoic Carbonate Platform”

Eliuk’s research was undertaken about the same time as Given’s but concentrated solely on the Abenaki Formation. His work is a landmark study, being a detailed examination of the stratigraphy, paleontology, paleogeography, lithofacies and diagenesis of the entire Abenaki Formation. Included is an Abenaki facies template, core analysis and core photos and descriptions. Using the existing carbonate platform wells and Shell’s extensive seismic database, Eliuk was able to extrapolate across the bank margin and prepare a suite of regional maps that even today remain extremely useful. He also interpreted depositional sequences relative to eustatic sea-level fluctuations for insights into subaerial exposure and porosity enhancement. He identified a key factor for exploration with the identification of Abenaki paleo-highs on which the likelihood of subaerial exposure and porosity enhancement is increased.

(6) Lubomir F. Jansa, Geological Survey of Canada,, 1981

“Mesozoic Carbonate Platforms and Banks of the Eastern North American Margin”

As more industry wells and data became available from offshore Canada and the U.S., the extent of the Jurassic carbonate margin from the Grand Banks to the Bahamas was recognized. Key observations are discussed, such as the carbonate margin younging southward to the Bahamas where it still thrives today. A global observation was that coeval Tethyan bank edges were involved in Alpine orogenesis whereas the Atlantic margin was tectonically stable and hence preserved.

(7) John A. Wade, Geological Survey of Canada - Atlantic, 1990

“Part 1: The Stratigraphy of George’s Bank Basin and Relationships to the Scotian Basin”

“Part 2: Aspects of the Geology of the Scotian Basin from Recent Seismic and Well Data”

This is a comprehensive update of the Scotian Basin by the GSC incorporating four additional Abenaki bank edge wells that improved understanding of the stratigraphy and facies of the Abenaki Formation. The study extended to the southwest to include the Shelburne Subbasin (George’s Bank area).

(8) Lubomir F. Jansa, Geological Survey of Canada - Atlantic, 1993

“Early Cretaceous Carbonate Platforms of the Northeastern North American Margin”

This is an excellent summary of then-current thinking on the Early Cretaceous carbonate successor facies to the extensive Jurassic carbonate platform complex. Jansa discusses the platform facies distribution, carbonate platform geometries and finally platform drowning.

3. EXPLORATION HISTORY

Exploration on the carbonate platform has undergone three cycles of exploration drilling since Shell drilled Oneida O-25 in 1970 looking for draped reservoir over a basement high. This was followed by two more platform wells by Shell (Abenaki J-56, Mohican I-100) which were then followed by Mobil who drilled Cohasset D-42 on the bank margin in 1973 (Figure 5, Table 1). Three more bank edge wells were drilled at Demascota G-32 (Shell), Acadia K-62 (Chevron) and Cohasset L-97 (Mobil) along with the foreslope Penobscot L-30 and the platform interior Moheida P-15 wells both drilled by Petro-Canada & Shell.

A six year hiatus in Canadian drilling of the margin ensued following the aforementioned wells. During this time, industry aggressively explored the American Atlantic Margin drilling a total of 49 exploratory wells and five COST wells (Continental Offshore Stratigraphic Test) mostly on the shelf. Only two closely spaced wells targeted features on the Jurassic bank edge in the Baltimore Canyon area (see Section 5.1 for detailed descriptions).

In 1984-85, Petro-Canada drilled the Bonnet P-23 and Albatross B-13 wells without success. Four platform interior wells were drilled on structures during this period: Glooscap C-63 (Husky), Dover A-43 (Petro-Canada), Kegeshook G-67 (Shell) and Como P-21 (Petro-Canada), again without success.

In 1986 Shell drilled the Panuke B-90 well which only penetrated about 300 m of the Abenaki (Bacarro Member) limestone. However, while the Abenaki reservoirs were tight, light gravity (~55ºAPI) oil was discovered in overlying sands of the Early Cretaceous Logan Canyon Formation in a shallow structural closure draped over the underlying reef margin. Details on the Cohasset-Panuke oil fields can be found in Section 7.1.

For the next 12 years there was no exploration activity on the bank margin until 1999 when PanCanadian (now EnCana) drilled an Abenaki prospect beneath the shallow Panuke oil field from the Panuke J-99 production platform. The Deep Panuke gas discovery well, PP-3C, encountered approximately 75 metres net pay of vuggy and cavernous limestones and dolomites and tested between 50-55 MMcf/d gas from the Abenaki 5 interval (Baccaro Member). Seven delineation wells were drilled following the discovery.

Since 1999, four more wildcats were drilled all in the vicinity of Deep Panuke targeting the Abenaki: two bank-edge wells - EnCana Musquodoboit E-23 and Canadian Superior Marquis L-35; one back-reef well EnCana F-09; and one fore-reef well, EnCana Queensland M-88. All were subsequently abandoned.

3.1 Drilling Results to Date

For the discussions that follow, the emphasis will be on the 10 bank-edge wildcats, and the two off-reef wells - Panuke F-09 and Queensland M-88 respectively. This focus reflects the natural bias to the success at Deep Panuke with the discovery of commercial quantities of gas in the margin reefal facies. The availability of new 2D and 3D seismic datasets facilitates the study. The aforementioned 12 wells are also listed in Figure 5 with generalized comments on their results which are further expanded in Section 3.2. Information from the remaining nine wells that penetrated the Abenaki Formation, located on the platform interior was also used in this assessment. Potential plays also exist in the carbonates of the underlying Middle Jurassic Scatarie Member (Abenaki Formation) and Early Jurassic Iroquois Formation.

Notwithstanding the success at Deep Panuke, industry has yet to aggressively pursue the bank-edge play along most of the Scotian Basin margin, despite the wealth of knowledge on carbonate depositional systems. Nor did industry earlier pursue this play off the U.S. Atlantic coast in the 1980s: of the 54 wells drilled, only two targeted potential bank-edge reefal reservoirs in structural closures off the Baltimore Canyon. Indeed, notwithstanding the water depths, limited technology, costs, oil versus gas potential and so forth, this play was probably just not sufficiently attractive at the time. In the 20 years that have passed, natural gas has become the North American fuel of choice. The Scotian Basin's Deep Panuke discovery may thus be the catalyst required for a re-evaluation at this play in jurisdictions encompassing the circum-North Atlantic region.

3.2 Tests and Shows

Of the 21 exploration wells (Table 1) drilled on the Abenaki platform offshore Nova Scotia, there has been one significant discovery and the others, though dry, nevertheless yielded important data (Figure 5). Ten wells focused on the bank edge, and of these seven were drilled on the Panuke Segment and three on the Acadia Segment, while none have been drilled on the Shelburne Segment.

Year	Operator	Name	ID	FTD (m)	Status	Comments
1970	Shell	Oneida	O-25	4110	D&A	Platform – overlying basement structure
1971	Shell	Abenaki	J-56	4569	D&A	Platform – flank of salt piercement diapir
1972	Shell	Mohican	I-100	4393	D&A	Platform – overlying salt swell
1973	Mobil	Cohasset	D-42	4427	D&A	Bank Edge – some porosity, mud gas (oil in Cretaceous Logan Canyon Fm. sands)
1974	Shell	Demascota	G-32	4672	D&A	Bank Edge – 168 m porosity, mud gas, tested water
1976	PetroCanada	Penobscot	L-30	4267	D&A	Bank Edge – no porosity, mud gas
1977	PetroCanada	Moheida	P-15	4298	D&A	Platform – overlying basement structure
1978	Chevron	Acadia	K-62	5286	D&A	Bank Edge – good porosities, no mud log, tested water
1978	Mobil	Cohasset	L-97	4872	D&A	Bank Edge – some porosity, tested gas-cut mud
1984	Husky	Glooscap	C-63	4542	D&A	Platform – overlying salt swell
1984	PetroCanada	Bonnet	P-23	4336	D&A	Back Reef (25km) – extensive zones of lost circulation, no tests, incomplete mud gas log
1984	PetroCanada	Dover	A-43	4525	D&A	Platform – high side of a tilted fault block
1985	PetroCanada	Albatross	B-13	4046	D&A	Bank Edge – some porosity, mud gas, no tests
1986	Shell	Panuke	B-90	3445	D&A	Bank Edge – oil discovery in Cretaceous Missisauga Fm. sands
1987	Shell	Kegeshook	G-67	3540	D&A	Platform – overlying basement structure
1987	PetroCanada	Como	P-21	3540	D&A	Platform – overlying basement structure
1999	PanCanadian	Panuke	J-99 (PP3C)	4163	Gas	Bank Edge – gas discovery in Abenaki 5 / Bacarro (well also known as PP3C)
2000	PanCanadian	Panuke	F-09	3815	D&A	Back Reef - oolitic facies, tight
2001	PanCanadian	Musquodoboit	E-23	3818	D&A	Bank edge – up-dip step-out from Demascota G-32, mud gas, no porosity
2002	PanCanadian	Queensland	M-88	4401	D&A	Fore Reef – by-pass sand play, but important for stratigraphy
2002	Cdn.Superior	Marquis	L-35	4501	D&A	Bank Edge – no porosity, low mud gas

Table 1. Chronological List of Abenaki Formation Exploration Wells.

The ten bank edge wells include one gas discovery and nine dry holes but well symbols on the maps do not tell the whole story. To understand and appreciate the results of the drilling, a close examination of their respective details is required: final total depth, thickness of Abenaki penetrated, mud gas readings, tests, cores, drilling breaks, etc. It also most enlightening to learn what the pre-drill objectives were versus the results. The exploration wells are located in Figure 4 and are discussed in a northeast to southwest progression, with seismic profiles across all wells presented in Chapter 7. The Abenaki stratigraphic nomenclature is detailed and discussed in Section 5.2. Depths and elevations are based on True Vertical Depths (TVD) well logs measured from the rig Rotary Table (RT) unless otherwise noted.

Penobscot B-41 & L-30

The B-41 well was drilled on a seismically defined structural closure to test for shallow Early Cretaceous oil-prone sands draped over the Abenaki bank margin. Non-commercial hydrocarbons were discovered in the sands but none in the 24 m of limestone penetrated at the base of the well (3420-3444 m). The L-30 delineation well penetrated a significantly greater 708 m thick sequence, but with no porosity, oil staining or trace gas shows (all less then 1%) throughout the Abenaki (Baccaro / Abenaki 7-3).

Marquis L-35/L-35A

A vertical and a sidetrack well were drilled on this prospect to test for Abenaki reefal porosity following the success at Deep Panuke. The first well, L-35, penetrated the entire Baccaro Member and the upper part of the Misaine Member shales. It encountered minor mud-gas peaks throughout the Abenaki (Baccaro/Abenaki Sequences 7, 6, 4 & 3) ranging in values from 40-114 total gas units (TGU) though no tests were run. The L-35A sidetrack well was drilled to test an additional seismic amplitude event interpreted as porous reefal facies. The well found porous reefal facies with one good 154 TGU mud-gas peak in the thin Abenaki 7 but was not tested. There were no wash-out or lost circulation zones encountered in either well. An excellent full suite of well logs and cuttings were obtained from both wells.

Cohasset D-42

Two wells were drilled on this structural feature to test for possible shallow Lower Cretaceous draped sands and porous reef facies. The D-42 well drilled the Abenaki Formation from 3170-4427 metres. A 1259 metre thick section was penetrated which included the entire Baccaro Member (Abenaki 6-2), Misaine Member shales and ended up in the lowermost Scatarie Member (Abenaki 1). Approximately 35 metres of oil-bearing sands were discovered in the overlying Logan Canyon Formation. Within the deeper Abenaki, oil staining occurred at 3280, 3315, 3330 and 3612 metres (Baccaro / Abenaki 6-5). An isolated gas show also occurred at 3330 m and several minor shows from 3414-4427 m. A drillstem test (DST) was run over the interval 3481-3512 m and recovered gas-cut mud.

Cohasset L-97

The L-97 well penetrated the entire Abenaki Formation from 3158-4768 m (1610 m), bottoming in the sandstones of the Middle Jurassic Mohican Formation. Scattered oil staining and minor gas shows were seen from 3188-3490 m. Mud gas peaks were recorded from 3600-3625 m (Baccaro/Abenaki 6) and at 4725 m (Scatarie/Abenaki 1) with a DST run over the interval of 3599-3620 m recovering gas-cut mud. It is yet to be determined if the gas-bearing porous reefal facies extends northeastwards into the structurally shallower Abenaki at Cohasset D-42.

Deep Panuke Field

Seven delineation and exploration wells have been drilled into the Abenaki Formation to test for gas in the Baccaro Member / Abenaki 5) at or in the immediate vicinity of the Deep Panuke Field. Four of the wells flow-tested gas in excess of 50 MMcf/d (Panuke PP-3C, M-79A, PI-1B, H-08). The remaining three wells (Panuke M-79, PI-1A & F-09) encountered varying volumes of mud gas but either did not test these occurrences or could not flow gas to surface.

Demascota G-32

The Demascota G-32 well was drilled to test a structural high at the edge of the Abenaki bank margin and penetrated almost the entire Abenaki Formation from 3400-4672 m (1471 m), bottoming in the Scatarie Member (Abenaki 1). Mud gas peaks >100 TGU and scattered vuggy porosity were observed throughout the Upper Baccaro (Abenaki 5). Within this section, 168 metres of secondary dolomitized porosity was present in reefal lithofacies (Harvey, 1990; Weissenberger et al., 2000; Wierzbicki et al., 2002). Two DST's recovered only formation water from intervals at 3860-3921 m and 3813-3828 m. These tests were several hundred metres below the petrophysically-defined field-wide -3504 mTVDSS gas-water contact at Deep Panuke (PanCanadian, 2002).

Musquodoboit E-23

The Musquodoboit well was an up-dip step-out from the Demascota well targeting interpreted porous reef seismic amplitudes. It drilled a 471 m thick Abenaki section (Baccaro/Abenaki 7-5) from 3347-3818 m. Two mud-gas peaks were recorded in the Abenaki 5 at 3552 m (103 TGU) and 3572 m (138 TGU). Tests in these intervals showed no porosity development.

Acadia K-62

The K-62 well was drilled on the northeastern part of the Acadia Segment to test a bank-edge structural closure delineated by seismic. The entire Abenaki Formation was penetrated from 3306-4950 m (1644 m) and bottomed in the distal oolitic limestone facies of the Iroquois Formation (4962-5287 m / 325 m thick). Fair to good porosities were observed throughout the Abenaki section in oolitic grainstones and in dolomitized peloidal skeletal lime sands in the Abenaki 4 (Weissenberger et al., 2000). Circulation was lost over the 4677-4790 m interval (Iroquois Formation) possibly indicating good porosity or a fault intersection. Due to this event there is no mud gas log over this and deeper intervals. A single flow test was run in the Iroquois from 4822-4838 m which recovered formation water. There was no mention of oil staining or gas in the cuttings report from any of the formations drilled.

Albatross B-13

The Albatross B-13 well was drilled on a pronounced structural high at the edge of the Abenaki bank margin. About 1035 metres of the Baccaro Member was penetrated and the well bottomed in shales of the Misaine Member. Scattered porosity was observed throughout the section with partial loss circulation occurring over the same section. Mud gas peaks were recorded (~ 100 TGU's) at two intervals, 3434-3440 m and 3012 m (Abenaki 3, 2) though no DSTs were attempted.

Bonnet P-23

This is the westernmost well on the Scotian Shelf and was drilled to test a tilted fault block 6 km from the edge of the Abenaki margin. The entire Abenaki Formation was penetrated (2091-3525 m / 1435 m thick) with the facies dominated by outer shelf oolitic shoal environments. No reefal limestones were drilled. Fair porosities are observed in the oolites but were good to very good in dolomitized vuggy lagoonal facies (4325-4434 m, Baccaro / Abenaki 6 & 5). The lower Baccaro / Abenaki 3 & 2 section appears to be dominated by dolomitized oolites with fair porosity. There were extensive intervals of lost circulation and caving over this lower interval and cuttings recovery was poor to nil. This may be the result of enhanced porous intervals and or the several large faults in this section. In the deeper Iroquois Formation, modest porosity development is seen in the dolomites though again, much of the interval had no sample recovery due to caving and lost circulation problems. Four gas peaks under 100 TGU were encountered over this section and oil staining in two samples. No DSTs were attempted (probably due to hole conditions) though a core was cut at the bottom of the well (4325-4334 m) and recovered nine metres of dolomitized vuggy lagoonal mudstones (Weissenberger et al., 2000).

4. REGIONAL GEOLOGY

The presence of a thick carbonate platform and reefs beneath the Atlantic margin was first indicated by geophysical studies and dredging in the mid-1960's as described by Jansa (1981). With over 200 industry wells drilled offshore North America plus 5 deep stratigraphic tests on the U.S. shelf and 10 Deep Sea Drilling Project holes on the U.S. lower slope and rise plus about 400,000 km of seismic the development of the Atlantic passive margin was gradually revealed. An integral part of this margin development is the almost continuous carbonate bank from the Grand Banks to the Bahamas. The map of Jansa (1981) has not been modified for subsequent well locations since it was published (Figure 6).

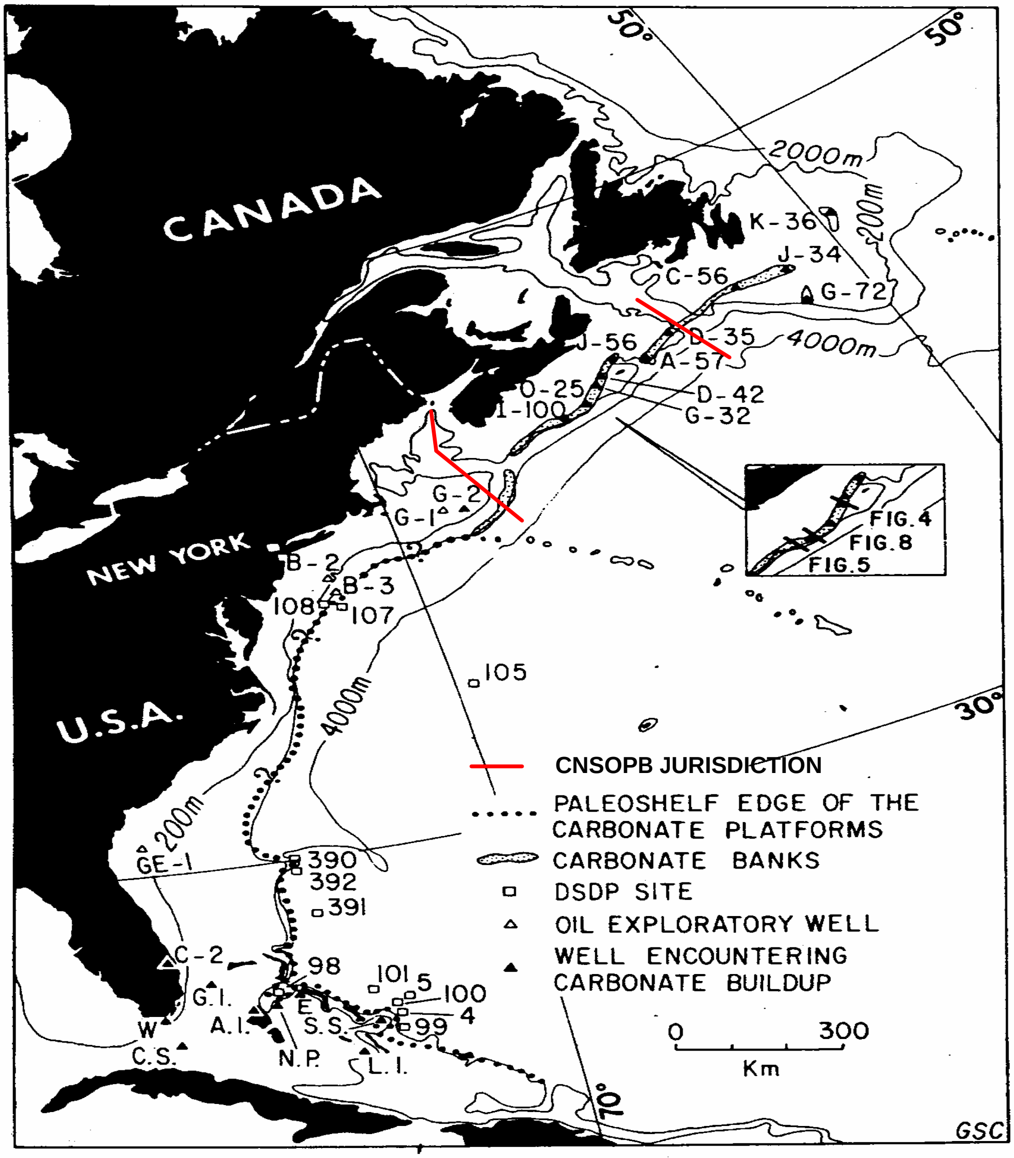


Figure 6. Extent of the Jurassic carbonate succession along the North American offshore margin (Jansa, 1981).

Unlike the dominantly East-West trending Mesozoic carbonate platforms of the European Tethys that became involved in the Alpine orogeny, the Northeast-Southwest North America platform has been tectonically stable (Jansa, 1981). It was this undisturbed nature that allowed the Atlantic style passive margin model to be developed. In particular, the continuous transition from nearshore facies across the shelf into the deep ocean basin provided evidence of the role of carbonates in passive margin building and plate tectonic processes during the late rift to early drift period (Jansa, ibid).

As more and more data becomes available the complexities of this Mid to Late Jurassic/Early Cretaceous carbonate bank along the Atlantic margin becomes more evident. The following discussions of the stratigraphy and morphology will reveal many changes along strike during and after deposition of the bank and the difficulties in locating the original bank edge.

4.1 The Scotian Basin

The Scotian Basin exists along the entire length of offshore Nova Scotia and southern Newfoundland (Figure 2). It extends 1200 kilometers from the Yarmouth Arch and the United States border in the southwest to the Avalon Uplift on the Grand Banks of Newfoundland in the northeast. With an average breadth of 250 km, the total area of the basin is approximately 300,000 km^2. Half of the basin lies on the present-day continental shelf in water depths less than 200 m with the other half on the continental slope in water depths from 200 to 4000 m. The subbasin components of the basin are shown with the Upper Jurassic Baccaro Bank rimming the LaHave Platform from the U.S. border to just north of Sable Island.

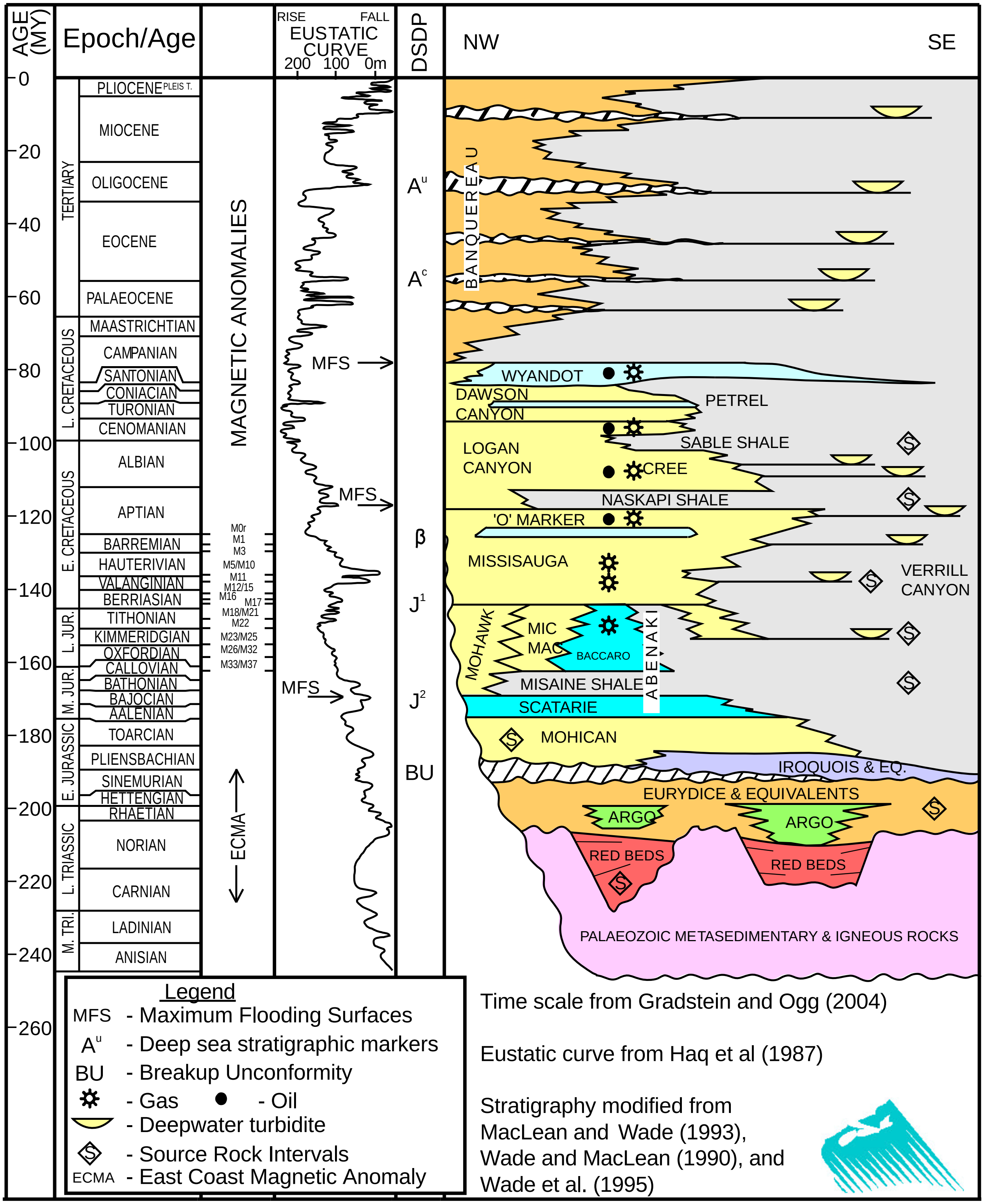
For clarification purposes, George's Bank is a physiographic feature that straddles the Canada/United States border. The George's Bank Basin lies wholly on the American side and is separated from the Scotian Basin by the Yarmouth Arch and experienced a different geological history and basin evolution. On the Canadian side of the Yarmouth Arch the subsurface rocks are in the Shelburne Subbasin, a sub- component of the Scotian Basin. An exploration moratorium on the George's Bank area is in place until December 31, 2012.

4.2 Geological History

This section of the report discusses the geology and geologic history of the Scotian Basin and surrounding region. It is not an exhaustive geological study, and the interested reader can access the excellent publications by staff of the Geological Survey of Canada (e.g. Wade and MacLean, 1990; GSC, 1991) and others although published material on the older sediments underlying the Scotian Slope is lacking.

The Scotian Basin is a passive continental margin that developed after rifting and separation of the North American and African continents beginning in the Middle Triassic (Figure 7). The rift phase was characterized by continental fluvial/lacustrine/playa red bed and evaporite deposition while the drift phase was characterized by typical clastic progradational sequences with periods of carbonate deposition. A prominent carbonate platform developed in the western part of the basin during the Middle to Latest Jurassic-earliest Cretaceous and its eastern extent was limited by a major deltaic depocentre located in the Sable Island area during the Late Jurassic and Early Cretaceous. Major transgressive sequences continued throughout the Late Cretaceous and Tertiary as relative sea level rose (Wade and MacLean, 1990; Welsink et al, 1989; Balkwill and Legall, 1989). These were punctuated by major sea level drops and regressive low-stand sequences were deposited as turbidite deposits further seaward.

Break-up and rifting of the Pangaean supercontinent commenced in the Middle Triassic Period about 225 million years ago (mya). At that time, the Nova Scotia region occupied a near equatorial position situated adjacent to Morocco to the east, with most of its older Paleozoic rocks having direct Moroccan affinities. A series of narrow, interconnected, below-sea level basins were created, in which were deposited fluvial and lacustrine red bed sediments as well as volcanic rocks (Fundy-type sequences). As sedimentation continued throughout the Late Triassic, the interconnected basins filled and coalesced, eventually to form a long, narrow, intracratonic rift basin by the Early Jurassic.



Time scale from Gradstein and Ogg (2004)

Eustatic curve from Haq et al (1987)

Stratigraphy modified from MacLean and Wade (1993), Wade and MacLean (1990), and Wade et al. (1995)

Figure 7. Scotian Basin Generalized Stratigraphic Chart (CNSOPB).

By the latest Triassic-earliest Jurassic, tectonic motion had moved the North American and African plates slowly northward, with the Nova Scotia-Moroccan region now in the more arid sub-equatorial climate zone (ca. 10-20°N paleo-latitude). Renewed Late Triassic rifting of continental crust further to the north and east in the Grand Banks / Iberia region breached topographic barriers and permitted the first incursions of marine waters from the eastern Tethys paleo-ocean to flood into these interconnected syn-rift basins. Restricted, shallow marine conditions were established with some carbonate sedimentation (Eurydice Formation). Due to the hot and dry climate and sub-sea level elevation, these waters were repeatedly evaporated, resulting in the precipitation of extensive salt and anhydrite deposits of perhaps one to two kilometers in thickness in this central rift system (**Argo Formation**). Marine incursions eventually covered the basin with a narrow, shallow and restricted sea within which thin sequences of carbonate and clastic sediments accumulated. Coarser grained clastic sediments from fluvial sources were deposited concurrently on the basin margins sourced from adjacent high relief terrains.

An earliest Jurassic phase of siliciclastic deposition is observed in the west-central part of the Scotian Basin that may exist elsewhere along the margin. This eastward-directed pulse of sediments conformably overlies and deforms (through loading) Argo Formation evaporites in the Mohican Graben (see Figure 17). The west-dipping listric faults inboard of the margin hinge-line on the Mohican and Naskapi grabens are interpreted as the antithetic response to extension in the Fundy Basin during the Late Triassic (Wade et al., 1996). These grabens acted as loci for clastic deposition for newly established fluvial drainage systems (GSC, 1991), with the source of the sediments from the current mainland region of Nova Scotia. While not yet encountered in wells or observed elsewhere along the margin, the age of this succession can be reasonably inferred as early Hettangian to perhaps mid- to late Sinemurian since it conformably overlies the Argo Formation and is later truncated by the younger Break-up Unconformity as described below.

Near the region of the interpreted central rift axis, deep crustal seismic (Lithoprobe AGS 88-1A) reveals the presence of highly rotated fault blocks exhibiting westward-thickening reflection sequences later truncated by the mid- to late Sinemurian Break-up Unconformity. These features are interpreted to represent the products of post-salt / pre-break-up thermal bulging along the central rift axis and shoulder regions inboard of the basin hinge line. The west-directed deposition seen in deepwater seismic profiles is thought to have been sourced from erosion of highly attenuated and serpentinized continental crust at the incipient rift axis. Such a setting would suggest not a single central rift salt basin but paired basins opposite the Nova Scotia and Moroccan margins respectively (e.g., model of Jackson et al., 2000) separated by an elevated and highly attenuated continental crust delineating the future rift axis and spreading centre.

Renewed tectonism in the central rift basin during the Early Jurassic (mid-Sinemurian) is observed in the complex faulting and erosion of Late Triassic and Early Jurassic sediments and older rocks. This phase of the rifting process is known as the Break-Up Unconformity (BU) and defines the final separation of the North America and Africa continents, creation of true oceanic crust through volcanism, seafloor spreading and opening of the proto-Atlantic Ocean.

The basins and platforms created on the Nova Scotia and Moroccan margins appear to have been defined by landward extensions of regularly-spaced oceanic fracture zones onto continental crust. (Welsink et al., 1990) From the southwest to the northeast, a series of alternating “highs and lows”, or platforms and depocentres, occur along the entire Scotian margin, these being the Georges Bank/Shelburne Basin, La Have Platform, Sable and Abenaki Subbasins, Banquereau Bank Platform and the Orpheus Graben/Laurentian Subbasin (Figure 2). A basement hinge zone in these areas defined the landward limit of maximum tectonic extension and subsidence of the seaward basinal portion of the margin. This antecedent basement morphology would thus come to assert a strong control on sediment distribution and deposition in the region for the next 190 million years.

As a result of the final continental separation event (Break-Up Unconformity), the Scotian Basin margin consisted of a heavily faulted, complex terrane of grabens and basement highs that underwent a significant degree on peneplanation. Transgressive shallow water to tidally influenced dolomites and clastics were laid down in localized areas on the seaward portion of the margin under slightly restricted marine conditions (**Iroquois Formation**) (Adams, 1986). This sequence was later followed by a thick succession of coeval fluvial sandstones and shales (**Mohican Formation**), which eventually prograded out over the margin to fill graben lows and bury basement highs by the lower Middle Jurassic. The fine muds from this succession were transported by marine processes further out into relatively deeper water and began to slowly infill basinal lows and cover new oceanic crust in this depositional setting.

The combination of sea-floor spreading, thermal subsidence and global sea level rise caused the Atlantic Ocean to become broader and deeper (~1000 metres) by the Middle Jurassic. A carbonate platform and margin succession was established along the outer basin hinge zone (**Scatarie Member, Abenaki Formation**) and prograded out into deeper waters where marls and clastic muds were deposited (~DSDP J2 Reflector). Continued margin subsidence coupled with global sea level rise resulted in transgression of these waters over the shelf and blanketing the carbonates with deeper marine shales (**Misaine Member**, Abenaki Formation)

From the late-Middle to the end of the Jurassic, carbonate reef, bank and platform environments were formed and thrived along the basin hinge line on the La Have Platform (**Baccaro Member**, Abenaki Formation). A shallow mixed carbonate-clastic ramp succession existed on the Banquereau Platform on the northeast margin. Deep-water sedimentation was represented by a thin sequence of shales and limestones (DSDP J1 Reflector). Concurrent with carbonate deposition, regional uplift to the west resulted in an influx of clastic sediments and the establishment of the mixed energy (current and tidal) Sable Delta complex in the Laurentian Subbasin, and slightly later in the Sable Subbasin. In the southwest, a similar progradation of sediments may have occurred at an embayment in the vicinity of the Northeast Channel (Shelburne Delta of Wade, 1990) however the existing seismic data is too poor to unequivocally interpret a deltaic system. These sediments were primarily sourced from the adjacent thick (14+ km) blanket of latest Devonian to Permian sediments centered in the Gulf of St. Lawrence region that covered the entire Atlantic Provinces region and parts of New England. The **MicMac Formation** records this first phase of delta progradation into these subbasins, represented by distributary channel and delta front fluvial sands cyclically interfingering with prodelta and shelf marine shales of the **Verrill Canyon Formation**. Sediment loading of unstable shelf shales south of the basement hinge zone initiated subsidence and development of seaward-dipping growth faults which acted as traps for further sand deposition.

During periods of sea level lowstand, rivers quickly down-cut into the exposed sand-rich shelf with shelf-edge delta complexes possibly created at the edge of the continental shelf. Turbidity currents, mass sediment flows and large slumps carried significant volumes of sands and muds into deep-water (500+ metres) and depositing these on the slope and abyssal plain. Sediment loading mobilized deeply buried Jurassic-age resulting in structural relief at the seafloor. Continuous sedimentation accentuated this process, and in areas such as the Sable and possibly Shelburne Deltas where sedimentation was high, the salt moved both vertically and laterally seaward in an upward-stepping manner forming diapirs, pillows, canopies and related features. This salt motion has been ongoing from about the Middle Jurassic to the present day.

Throughout the Cretaceous Period, the Atlantic Ocean became progressively wider and deeper with significant surface and deep-water circulation patterns. The ancestral St. Lawrence River was well established by the earliest Cretaceous, delivering increasing supplies of clastic sediments into the Scotian Basin that overwhelmed and buried the carbonate reefs and banks on the La Have Platform and later the Banquereau Platform. The **Missisauga Formation**, a series of thick sand-rich deltaic, strand plain, carbonate shoals and shallow marine shelf successions, dominated sedimentation throughout the Early Cretaceous. The Sable Delta prograded rapidly southwest into the Laurentian and Sable Subbasins and out over the Banquereau Platform. In the Shelburne Subbasin the postulated Shelburne Delta disappeared due to the exhaustion of its river's sediment supply. Along the La Have Platform, small local rivers draining off of southwest Nova Scotia mainland provided modest amounts of sands and shales to this region and associated deeper water realm.

Within the Sable and Laurentian Subbasins, growth faulting accompanied this time of rapid deposition, moving progressively seaward as the delta advanced. When sea levels dropped, large volumes of sands were deposited as lowstand delta complexes along the outer reaches of the delta (Cummings and Arnott, in press) and further out into deep-waters on the slope. Such high deposition rates further loaded salt features that in turn initiated renewed salt motion with turbidite fan and channel sediments filling intra-salt minibasins. Shales of the deep-water Verrill Canyon Formation continued to dominate sedimentation in this environment throughout the Cretaceous.

Deltaic sedimentation ceased along the entire Scotian margin following a late Early Cretaceous major marine transgression that is manifested by thick shales of the overlying **Naskapi Member, Logan Canyon Formation**. Subdued coastal plain and shallow shelf sand and shale sedimentation of the Late Cretaceous **Logan Canyon Formation**, and later deeper marine shales (and some limestones) of the **Dawson Canyon Formation** reflected continued high sea level and a lower relief hinterland, together reducing sediment supply to the basins. During periods of sea level fall, mud-rich sediments were still being transported out into the deep-water basin though in reduced quantities (Verrill Canyon Formation).

The end of the Cretaceous period in the Scotian Basin saw a rise in sea level and basin subsidence and deposition of marine marls and chalky mudstones of the **Wyandot Formation**. These strata were eventually buried by Tertiary age and marine shelf mudstones and later shelf sands and conglomerates of the **Banquereau Formation**. Throughout the Tertiary on the Scotian margin, several major unconformities related to sea level falls occurred. During Paleocene, Oligocene and Miocene times, fluvial and deep-water current processes cut into and eroded these mostly unconsolidated sediments and transported sediments out into the deeper water slope and abyssal plain. During the Quaternary Period of the last 2 million years, several hundred metres of glacial and marine sediments were deposited on the outer shelf and upper slope.

5. THE ABENAKI FORMATION

5.1 Depositional Setting

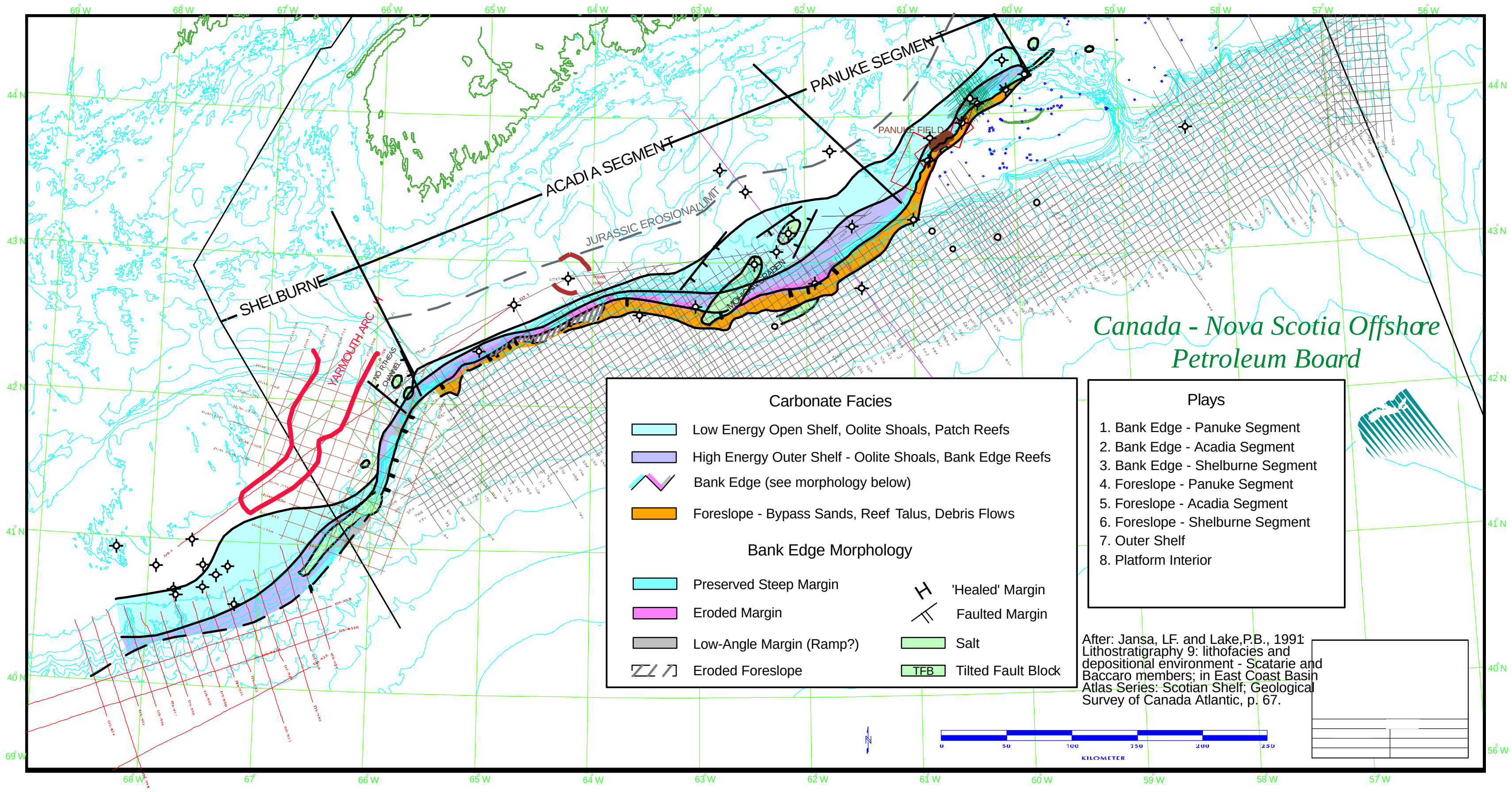
During the Middle Jurassic to Early Cretaceous, carbonate deposition dominated sedimentation around the entire North Atlantic margin, reflecting a period of continuous global sea level rise and gentle downwarping and thermal subsidence of rift-bounding continental crust. Reef, platform and related facies were established along the margins of the Atlantic and Tethys Oceans under ideal conditions of broad, stable, low relief and shallow shelves, warm oxygenated waters with limited oceanic circulation, limited background clastic sedimentation and low fluctuations of oxygen and nutrient levels. Jansa (1993) suggests that in the Atlantic realm there was a NE-SW flowing, margin-parallel current in existence throughout the Late Jurassic, at which time the Gulf of Mexico and Central America were connected to the Pacific Ocean by shallow seas.

In the Late Jurassic, Nova Scotia was positioned between 25-30º north paleolatitude. The regional climate was arid with significant seasonal shifts to monsoonal conditions punctuated by clastic influxes sourced from the western hinterland. These factors infer limited erosion and fluvial deposition in the rift region, and further enhancing conditions favourable for carbonate deposition.

Seismic and well data reveal the Abenaki Formation carbonate platform and margin complex, a second-order stratigraphic sequence succession, as extending for over 2500 kms along almost the entire length of the current North American offshore continental margin edge and slope; from the Sable Basin offshore Nova Scotia in the northeast down to the Blake Plateau Basin off northeast Florida in the southwest. (Figure 6) Eroded remnants of the Abenaki extend further south to the Bahama Platform (Schlee et al., 1988). The Abenaki's northern limit is the area immediately north of Sable Island where carbonates extended out beyond the hinge line and into the Sable Subbasin depocentre; an area of significant subsidence and greater influx of clastics (Figure 3).

On the Scotian Basin margin, the Abenaki was deposited along the edge of the basin hinge zone in a homoclinal to steepening ramp and later platform setting. Except for the Misaine Member shales, the Abenaki is composed of repetitive shallowing-upward carbonate successions. Coeveal, predominantly siliciclastic delta-strand plain facies of the Mic Mac Formation were deposited in the eastern part of the Sable Basin, i.e. Sable and Laurentian Subbasins (Figure 2). Here, Jurassic age carbonates equivalent to the Abenaki are encountered in wells and observed in seismic profiles capping clastic regressional sequences in a ramp-like setting. Thinner coastal plain successions of the Mohawk Formation are present on the northwestern margin of the La Have Platform. Shales and other fine clastics of the Verrill Canyon Formation represent deposition in the deeper water marine setting along the entire basin margin. The entire Abenaki is buried under a thick prism of Cretaceous and Tertiary clastic sediments upwards of four kilometres thick.

Given its setting, the width and thickness of the Abenaki facies' belt is variable (Figure 8). On the La Have Platform, it exists as a narrow belt from 10-40 km in width with thicknesses from 600 – 1000 metres. It is slightly thicker and considerably wider in the U.S. part of the Georges Bank Basin further to the west. It is much wider, up to 150 km, on the northeastern part of the Platform over the Mohican Graben where the underlying basement is attenuated and faulted. Hettangian-age bedded evaporites (Argo Formation) and in places a previously unrecognized Hettangian-Sinemurian siliciclastic succession underlie the carbonates, and as will be discussed later have an important influence on its deposition. Thickness of the Abenaki is greatest in this area, and to the east along the hinge line margin opposite the Sable Subbasin depocentre. Seismic and well data indicate maximum thicknesses of greater than 1600 metres in these areas (GSC, 1991).



After: Jansa, LF. and Lake,P.B., 1991: Lithostratigraphy 9: lithofacies and depositional environment - Scatarie and Baccaro members; in East Coast Basin Atlas Series: Scotian Shelf; Geological Survey of Canada Atlantic, p. 67.

Figure 8. Abenaki Formation morphology, carbonate facies and hydrocarbon plays. Details on the subdivision of the Shelburne, Acadia and Panuke Segments are detailed in Chapter 7.

5.2 Lithostratigraphy

5.2.1 Abenaki Formation

The Abenaki Formation was first described from offshore well data by McIver (1972) and correlated regionally by Jansa and Wade (1974, 1975). Given (1977) described in detail the Abenaki's regional setting, stratigraphic relationships and petroleum systems' attributes on the Scotian Shelf. Eliuk has been the most consistent researcher on the Abenaki, with a seminal work (1978) providing an extremely comprehensive description of the formation and its various members, facies models, diagenesis, paleontology, etc., followed by a subsequent update (1981) and studies focusing on various members and facies (Eliuk, 1989; Ellis, Crevello and Eliuk, 1985; Eliuk and Levesque, 1998, Wierzbicki, Harland and Eliuk, 2002). Other workers such as Pratt and James (1988), Wade (1990) and Wade and MacLean (1990) have contributed further knowledge on the Abenaki. Williams et al. (1985) compiled all historic information and related stratigraphic details for the Abenaki and its members. Using well and seismic datasets, Wiessenberger et al. (2000), and later Wierzbicki et al. (2002), defined the Abenaki facies models and further subdivided the formation into defined third- and fourth-order depositional sequences based on biostratigraphy, well log character, stacking patterns and seismic sequence stratigraphy. Based on biostratigraphic information from offshore wells (references cited above), the age of the Abenaki Formation extends from the Middle Jurassic (mid Bajocian) to the lowermost Early Cretaceous (basal Vallanginian); a period of virtually continuous carbonate deposition lasting approximately 40 million years.

The Abenaki Formation is a member of the Western Bank Group as defined McIver (1972) and later refined by Given (1977) that includes five formations which for the most part were laterally equivalent through time: Mohawk (continental clastics), Mohican (fluvial-strand plain), Abenaki (carbonate platform and reef margin), Mic Mac (fluvial-deltaic) and Verrill Canyon (prodelta and open marine, deepwater shales). Weissenberger et al. (2000) recognized this succession as a first order stratigraphic sequence with the individual formations as second order events, with attendant hierarchical subdivisions within the Abenaki.

The Abenaki is divided into four members representing different stages of the Jurassic platform and margin facies' evolution (Figure 7). In ascending order, these are the Scatarie, Misaine, Baccaro and Artimon Members. The informally termed Roseway Unit (Wade, 1977; Wade and MacLean, 1990) might be considered as part of the Abenaki. It is Berriasian-Valanginian (earliest Cretaceous) age with its distribution limited to the La Have Platform. It may be the shallow water equivalent to the deeper water transgressive Artimon Member.

Utilizing newly acquired extensive 2D and 3D seismic datasets and information from recently drilled wells, Weissenberger et al. (2000) and Wierzbicki et al. (2002) defined the Abenaki within a sequence stratigraphic framework, particularly for the Bacarro Member within which over 1 TCF of gas was discovered in 1999 at the Deep Panuke field (PanCanadian Energy, 2002) (Figure 9). Their nomenclature for these third-order sequences - Abenaki 1 to Abenaki 7 (oldest to youngest) - is used in this report in conjunction with the previously defined nomenclature. Details on the following Members are sourced from the aforementioned citations noted previously in this Section 4.3, above.

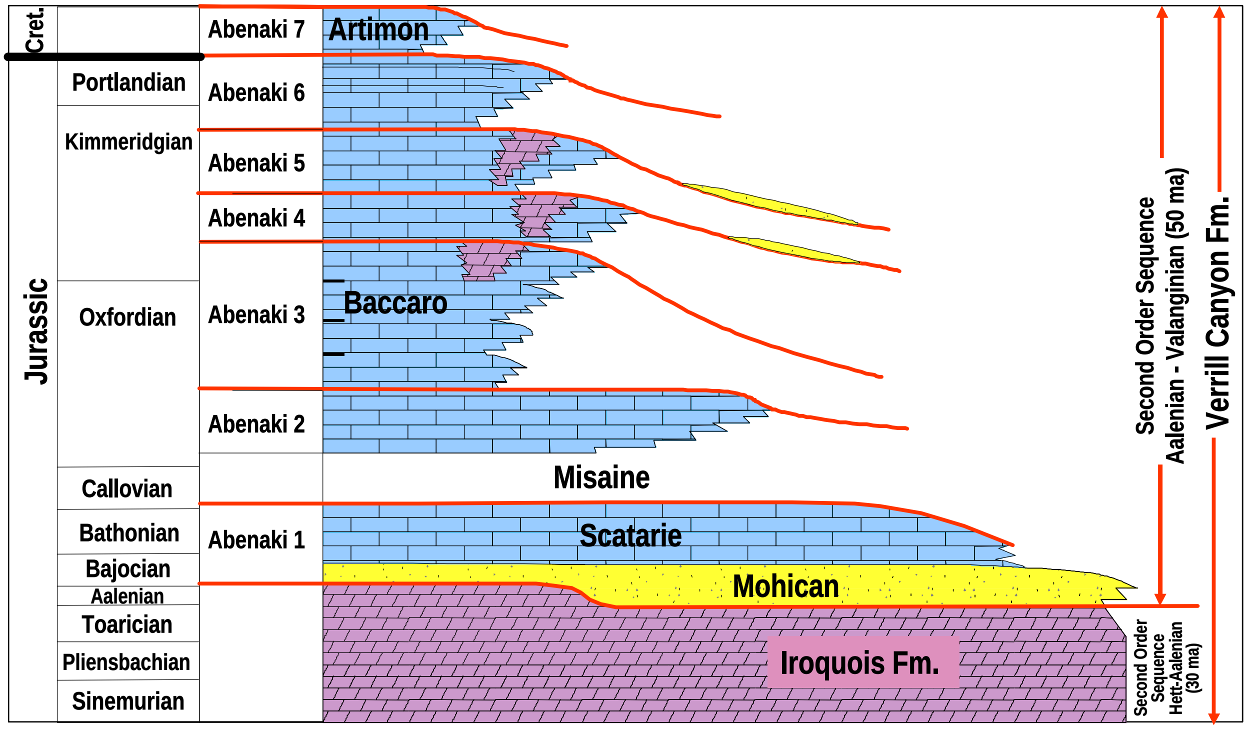


Figure 9. Detailed sequence stratigraphic chart for the Abenaki Formation (EnCana).

5.2.2 Scatarie Member (Abenaki 1)

The basal Scatarie Member (Abenaki 1 of Weissenberger et al. (2000) and Wierzbicki et al. (2002) is the most areally extensive sequence of the Abenaki Formation. It is the only member that can be continuously mapped on the eastern part of the Scotian Basin (Banquereau Bank), east of Sable Island. It conformably overlies Mohican Formation shallow water progradational coarse clastics and nearer the basin's seaward margins may be underlain by Iroquois Formation anhydritic, peritidal dolomites and minor clastics. Along the western and northern margins of the La Have Platform and Canso Ridge respectively, the Scatarie sits unconformably on early Paleozoic basement rocks. It is conformably overlain by, and probably intercalated with Mic Mac Formation deltaic clastics on the platform margins and eastern Sable Basin; elsewhere by Misaine Member transgressive deepwater shales.

In profile, the Scatarie is a seaward-thickening wedge of predominantly platformal oolitic lime grainstones and packstones, with at least four deepening-upward transgressive sequences recognized. It thickens to the southeast from its depositional limit on the platforms to its maximum thickness of greater than 600 metres along the La Have Platform's seaward margin. Seismic reveals the Scatarie extending well beyond the Jurassic platform edge out into adjacent basinal region opposite the La Have Platform. This reflection, the interface between encasing shales, equates to the deepwater J2 seismic horizon / marker. Seaward of the Canso Ridge (Abenaki and Laurentian Subbasins), the continental margin was a broad, highly faulted basement terrain over which deltaic facies of the Mic Mac Formation were advancing. Here, the Scatarie was deposited in a ramp-like setting and intercalated with the Mic Mac with the carbonates shaling-out into deeper waters.

Biostratigraphic studies of Scatarie sediments suggest an age of about middle Bajocian to middle Callovian.

5.2.3 Misaine Member (Abenaki 2 equivalent)

The Misaine Member is the only clastic component of the Abenaki Formation and this neritic facies is representative of the Callovian global transgressive event in the Sable Basin. It is best developed along the Jurassic shelf margin being conformable with older Scatarie and younger Bacarro Member limestones respectively, however, it is recognized in the subsurface only where overlain by the latter (i.e., areas west of the Sable Subbasin depocentre). The sequence stratigraphic nomenclature for the Abenaki constructed by Weissenberger et al. (2000) and Wierzbicki et al. (2002) is limited to its carbonate members, hence the exclusion of the Misaine from their ranking.

The Misaine is composed predominantly of dark grey, slightly calcareous shales with minor beds of pelleted and laminated lime mudstones. It is thickest along the Abenaki platform margin (almost 300 metres in the Mohican I-100 well) and pinches out landward over the platforms where it becomes interbedded with or coeval to coarser grain proximal clastic sediments.

The age of the Misaine is dated from about middle Callovian to possibly early Oxfordian (Wierzbicki et al.; 2002). The Oxfordian age supports Wade and MacLean's (1990) observation that on the Western La Have Platform the Misaine could be younger than Callovian due to continuous shale deposition that created conditions unsuitable for carbonate deposition.

5.2.4 Bacarro Member (Abenaki 2, 3, 4, 5, 6)

The Baccaro Member is the thickest and best developed carbonate unit of the Abenaki Formation. However, its areal extent is limited to a variable, narrow, 15-25 km wide belt that follows the Jurassic hinge line and defines the seaward limit of the Abenaki platform margin (Figure 8). It extends along the entire Jurassic margin and its physiographic expression had a significant impact on regional depositional patterns and facies development during the Jurassic. It conformably overlies the Callovian Misaine Member shales, and where present is overlain by deeper water carbonates and marls/muds of the Artimon Member (Abenaki 7). Elsewhere, it is buried by prograding and onlapping fluvial-deltaic siliciclastic successions of the Early Cretaceous Missisauga Formation and its equivalents.

The Baccaro Member is composed of numerous stacked, shoaling-upwards, agrading and prograding parasequences. Over the width of Baccaro belt, a number of laterally equivalent sedimentary facies were developed - lagoonal to inner shelf, oolitic shoal, coral-stromatoporoid reef, and beyond this, reef margin foreslope fans and aprons. The dominant lithology is limestone with minor shale and sand intervals representing the reworked remnants of lowstand events. Dolomite is recognized in a number of wells and is present in the Abenaki 2 to 5 sequences. It is of secondary origin, with dolomitization following post-depositional leaching of existing primary carbonate porosity

Eliuk (1978) and later Weissenberger et al. (2000) subdivided the Baccaro into five, third-order sequence stratigraphic units - Abenaki 2 to 6. Each of these sequences is made up of a number of stacked shallowing-upward parasequences as defined by the facies models constructed by the above authors: A-3 (four), A-4 (one), and A-5 (three). The acquisition of additional well and seismic data from the Deep Panuke gas field allowed Wierzbicki et al. (2002) to further refine their respective tops and ages. Within this area, each of the sequences range in thickness from about 100-300 metres. Maximum thickness of the complete Baccaro Member is estimated to be almost 1200 metres along the eastern margin of the La Have Platform (Figure 8).

The Abenaki 2 is the basal segment of the Baccaro Member and is transitional from the underlying transgressive shales of the Misaine Member (Abenaki 2, *senso stricto*). This transition to lime mud- and wackestones and oolitic grainstones is variable in thickness and lithologic content depending on location. It is virtually non-existent in western platformal areas though where present includes silty oolitic limestones, and minor marlstone, shale, siltstone and sandstone interbeds.

The Abenaki 3, 4 and 5 together make up the bulk of the Baccaro Member. They exhibit a number of shallowing-upwards sequences and record the progradation and aggradation of the Abenaki platform margin during the upper Jurassic. The Abenaki 2–5 sequences are dominated by limestones representing lagoonal, oolitic shoal, reef and reef margin and talus facies. Siliciclastic content in these rocks is minor except where proximal to deltaic facies (northeast): in the Penobscot L-30 well, almost the entire Abenaki 3 is made up of fine grain siliciclastics. It is within the Abenaki 4 and 5 reef and lower reef margin facies that post-depositional dolomitization has generated impressive, highly porous reservoirs within which over 1TCF of gas was found at the Deep Panuke field.

Rocks of the Abenaki 6 record carbonate deposition in a progressively deeper water transgressive bank margin setting. Resultant mud-rich coral-strom rudstones and floatstones were subsequently overlain by deeper water, argillaceous upper foreslope limestones, though shallow water carbonate facies persist along the southern part of the margin.

The age of the Baccaro Member extends from early Oxfordian to the latest Portlandian (mid-Berriassian) age.

5.2.5 Artimon Member (Abenaki 7)

The Artimon Member is the youngest sequence of the Abenaki Formation. It is also the thinnest (30-115 metres) with a very modest and patchy areal distribution limited to the eastern part of Abenaki platform margin edge. It has been encountered in a number of well penetrations confirming its existence in the Cohasset-Panuke area and eastern limit of the Abenaki margin.

Lithologically, the Artimon is composed of argillaceous, cherty limestones representing thrombolitic sponge and stromatoporoid mound deposition, with occasional interbedded calcareous shales. The associated fossil assemblage infers a reef middle foreslope depositional setting in water depths between 100-200 metres near the limits of the photic zone (Eliuk, 1978). The presence of these sponge-stromatoporoid mounds at the top of the drowned platform margin edge reflects depositional response to a major sea level rise during the earliest Cretaceous (Berriasian). Based on its lithologies and age, Wade and MacLean (1990) suggest that the Artimon should be considered a facies of the Verrill Canyon Formation. The Artimon sponge mounds were eventually buried by fluvial-deltaic clastics of the Missisauga Formation, effectively terminating carbonate deposition in this region, though coeval deposition of shallow water carbonates continued on the western portion of the La Have Platform as recognized in lithologies of the Roseway Unit.

The Artimon Member is the only part of the Abenaki Formation that extends into the Cretaceous and is considered to be upper Berriasian (Ryanzanian) age. (Wierzbicki et al., 2002)

5.2.6 Roseway Unit

While not a member of the Jurassic Abenaki Formation, lithologies of the Roseway Unit are important as they represent a continuation of favourable conditions for carbonate deposition extending well into the Early Cretaceous. Similar age and younger carbonate sequences dominate the North American continental margin south of the Sable Basin.

The Roseway Unit is an informal term used to define the regressive succession of mixed shallow water limestones, sandstones, siltstones and shales. It conformably overlies the Baccaro Member carbonates on the central and western portions of the La Have Platform, and in the proximal setting of these areas, siliciclastics of the Mic Mac Formation (Wade, 1977; Wade and MacLean, 1990). The Roseway is considered the lateral equivalent of the fluvial-deltaic-strand plain successions of the Missisauga Formation (ibid.). With a recorded maximum thickness of 270 metres it is quite thin when compared to the 1000s of metres of Missisauga sediments. This essentially condensed section is the response to its position on the stable La Have Platform, slow subsidence, distal position to deltaic depocentres in the east and northeast, and marine conditions favourable for carbonate deposition.

The Roseway is known from a single penetration; the Mohawk B-93 well. However, interpretation of seismic data confirms its significant areal extent, and in profiles, reveals it as a seaward-tapering wedge of moderate to high amplitude reflections downlapping onto the top of the Baccaro Member. In areas of poor well control, the internal reflections can be confused with the Missisauga's ubiquitous 'O' Marker", a highly mappable Barremian age oolitic limestone facies common throughout the eastern and central Scotian Basin.

The Roseway's age extends over the entire Neocomian - Berriassian to Barremian (Wade and MacLean, 1990).

5.3 Abenaki Platform Margin Facies Models

The Middle-Late Jurassic-age Abenaki Formation offshore Nova Scotia has long been recognized as a classic trailing margin carbonate platform and basin margin succession from early well results and seismic data. McIver (1972) and his team at Shell Canada utilized data available from the 23 wells drilled on the Scotian Shelf to establish the basic stratigraphic framework for the Abenaki Formation and the remaining Mesozoic and Tertiary sequences. Further expansion of knowledge on the Abenaki was presented by Jansa and Wade (1974) and followed by research from another Shell Canada member, M.M. Given (1977). It was during this period from 1969-1977 that most of the exploration wells drilled into the Abenaki were completed.

The most significant contribution to defining Abenaki facies relationships was made by yet another Shell Canada geoscientist, L. S. Eliuk (1978). Eliuk's monumental work remains the foundation upon which all subsequent research has been built upon and most of his interpretations remain valid today. In his study, Eliuk drew upon results from 22 wells from which the data were then available (end of 1976) as well as four subsequent wells, all of which penetrated Abenaki Formation or its equivalents. Seismic data was used to assist with well correlations, areal extent of the Abenaki, internal facies characteristics and the like. The log, cuttings and core data were used to determine stratigraphic relationships, lithologies, identification, textures, bedding and sedimentary structures, range and distribution of macrofossils, microfossils, diagenetic features, reservoir characteristics, etc. These were all interpreted in a paleoenvironmental framework and lithofacies and regional paleographic maps created. Slightly revised and enlarged copies of these maps were published by the Geological Survey of Canada (1991).

From his research, Eliuk (1978) defined two deepening-upward megasequences within which are 10 facies associations extending from the open ocean to terrestrial environment: open marine (bathyal, neritic), fore-reef, open marine/offshore bank (sponge reef, skeletal-rich, coralgal reef, mud/pelleted, oolitic), moat, nearshore ridge, lagoonal/continental, mixed carbonate-deltaic and deltaic. He interpreted possible distribution of these various facies through time in a paleoenvironmental and paleotectonic context with broad insights on the development of the Jurassic carbonate bank margin. Four major transgressive cycles were also identified within the Baccaro Member. Additional data and later research by Eliuk and colleagues refined interpretations of some aspects of the Abenaki: two types of deep water carbonate build-ups: thrombolite-stromatolite bioherms on the upper portion of foreslope ramps and steep platform margins of the Baccaro Member, and younger sponge reefs patchily distributed on the rapidly-drowned and deepened Baccaro platform (Ellis et al., 1985; Eliuk and Levesque, 1989; Jansa et al., 1989); and Baccaro Member shallow water coral and sponge reef facies (Pratt and Jansa, 1989). Jansa (1981) and Jansa and Weidmann (1982) discussed the Abenaki Formation in a circum-Atlantic context.

Following the discovery of the Deep Panuke Field by PanCanadian (EnCana) in 1998, subsequent delineation and exploration wells in and around the field provided an excellent database over a geographically confined area. Based on current sequence stratigraphic concepts, Weissenberger et al., (2000); and Wierzbicki et al. (2002) subdivided the Jurassic carbonate platform succession into two second-order depositional sequences (representative example, Figure 10; Abenaki details in Chapters 4.2 & 5.2). Briefly, the initial sequence contains four Formations of Early to Middle Jurassic age lasting about 30 million years and includes Argo evaporites, Eurydice peritidal siliciclastics, Iroquois shallow marine carbonates and Mohican fluvial clastics. The second sequence lasted about 50 million years and extended from the Middle Jurassic to earliest Cretaceous represented by the Abenaki carbonate platform succession, and Mohican and MicMac fluvial-deltaic clastics. Within the Abenaki Formation, six (6) third-order depositional sequences were defined by Weissenberger et al., (ibid) and later modified to include a seventh (Wierzbicki et al., ibid): Abenaki 7 (Artimon Mbr.), Abenaki 6 (Baccaro Member), Abenaki 5 (Baccaro Member), Abenaki 4 (Baccaro Member), Abenaki 3 (Baccaro Member), Abenaki 2 (Misaine and basal Baccaro Members), and Abenaki 1 (Scatarie Member).

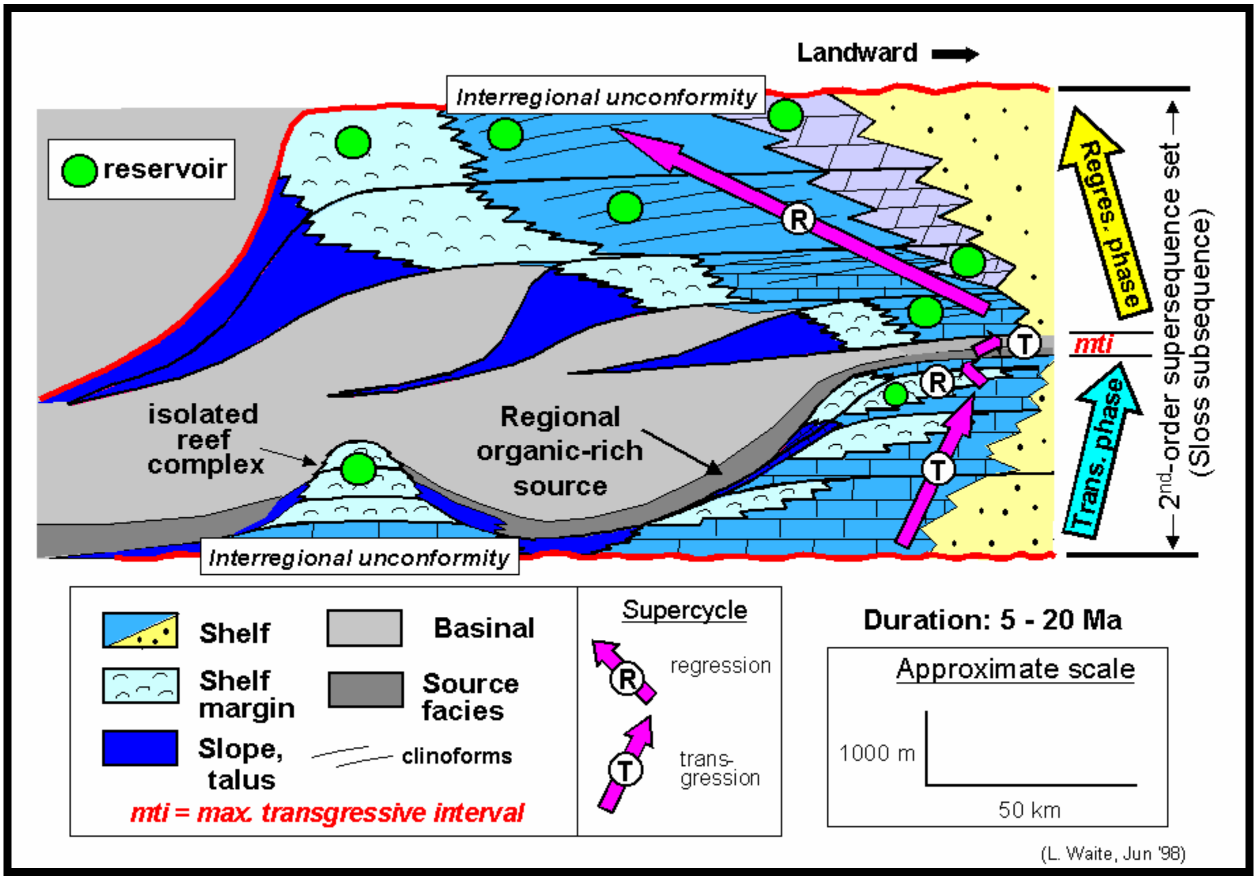


Figure 10. Generalized Wilson carbonate sequence stratigraphic model (L.E. Waite, 1997).

The relationship of these sequences (Figure 9) incorporates new biostratigraphic information (Wierzbicki, personal communications, 2003; Wierzbicki et al., 2002). Lithostratigraphic details are provided in the previous Chapter 5.2.

The excellent quality log data, cuttings, limited cores and seismic data, coupled with a detailed review of analogue successions in Europe, Morocco and North America, permitted Weissenberger et al., (2000) and later Wierzbicki et al. (2002) to create a detailed facies model for the Baccaro Member carbonates (Figures 11 & 12). Their representative fourth-order shoaling-upwards sequence model included 14 facies associations and closely followed that originally defined by Eliuk (1978). Each of the Baccaro/Abenaki 2 to 6 carbonate sequences consists of multiple sets of 10-30 metre thick four-part accretionary low-stand to high-stand bundles (progradational, aggradational, progradational and offlapping).

The type of carbonate build-up long the Abenaki bank margin, within which the Deep Panuke reservoir facies occur, was initially recognized by Eliuk (1978) as being dominated by stromatoporoid-coral-algal framestones, boundstones and reef debris. The Abenaki margin profiles ranged from ramp-like to escarpment. He further noted several paradoxes in the succession: extensive high energy oolitic shoal facies inboard of the bank margin, and the high level of micritic muds within the reefal sediments. The oolite facies was thought to represent inboard shoaling. Microbialite crusts were recognized as stabilizing the reef in this high-energy zone. Both were postulated to indicate reef systems occurring in slightly deeper water near wave-base. The “knoll-reef ramp” in the Oxfordian Swiss Jura of Wilson (1975) was considered the best analogue to describe the Abenaki reef margin system.

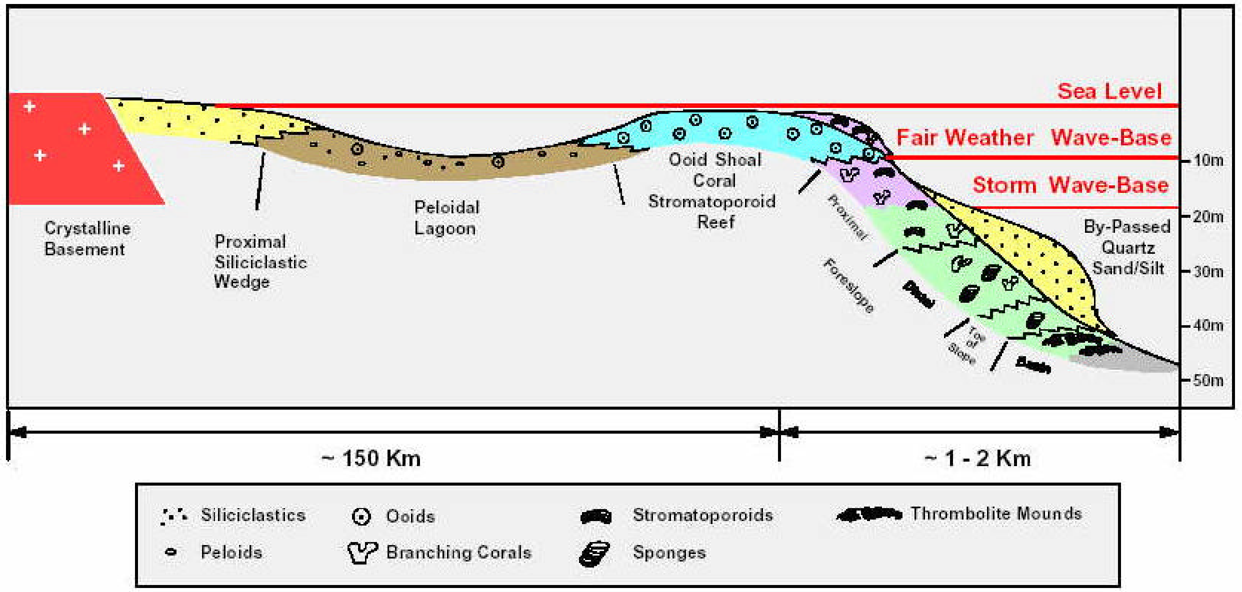
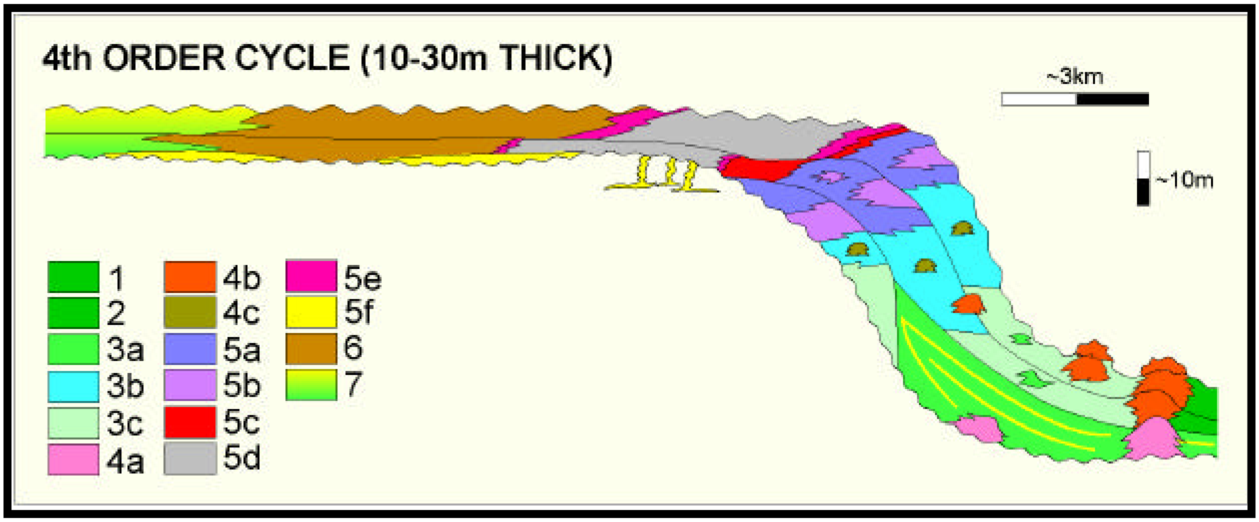


Figure 11. Simplified Abenaki Fm. carbonate facies model and associations (Weissenberger et al., 2000)

Weissenberger et al. (2000) and Wierzbicki et al. (2002) expanded upon Eliuk’s (1978) interpretation. They considered that data from newer wells supported Eliuk’s selection of Wilson’s (1975) knoll-reef model having a broad, platform-crest oolitic shoal facies with slightly downslope coralgal debris reefs. The presence of high levels of micritic muds and evidence of boring organisms supported the bioerosion source for the muds, and the reef position below fair weather wave base would preserve the muds prior to binding by encrusting organisms or downslope movement into deeper water. Detailed core study by Harland and Weirzbicki (2003) and Eliuk (2003) further refined the facies definitions, and also the significance of syndeposition bioerosion and the effects of future diagenetic events on its products (Eliuk, ibid.).

Seminal work on global Jurassic reef ecosystems has been published by Leinfelder (1993; 2001; 2002). Leinfelder (1993) recognized that the majority of Jurassic bioclastic reefs are poorly preserved with little framework organisms and features observed, and as such exist mostly as bioclastic piles of debris: debris reefs. Few frame-building organisms are present and the associated coral and siliceous sponge taxa also high amounts of micritic mud which are interpreted to be the possible result of an insidious boring epifauna. Leinfelder (2001; 2002) noted that in areas with elevated nutrients levels (e.g., proximity to delta complexes) there are corresponding increases in bioerosion with the organisms identified as various filter feeders (boring bivalves, serpulid worms) and echinoids. They appear to help preserve the reefs in these settings by feeding off the biota attracted by elevated nutrient levels. Furthermore, it is suggested that Jurassic corals may have been somewhat more tolerant of elevated nutrient levels, more so than existing corals.

In the Jurassic, the binding organisms were not as effective as those existing today for debris fixation and so steep reef margins assisted in exporting large quantities of reef debris into deep water thus permitting the microbial crusts to stabilize the remaining material (Leinfelder, 1993; 2002). The creation of significant volumes of reef debris and preservation of finer micritic sediments infers a near-wave base setting. The remaining high energy reef limestones are thus rich in both crusts and debris which seem to be indicative of bypass margin situations. Such reefs are also associated with autochthonous oolite sands (as noted by Eliuk, 1978) indicative of a shallow water, high energy environment with the reefs in a slightly deeper downslope position.



	FACIES ASSOCIATIONS	DEPTH RANGE (m)
1	OPEN MARINE – Deep	>200
2	OPEN MARINE – Shallow	100 – 200
3	FORESLOPE	
3a	Channel – debris flow or turbidite related	10 – 100+
3b	Proximal – fore-reef	10 – 70
3c	Distal - microbial mud mounds “5c”	70 – 100
4	FORESLOPE – BIOHERMS & BIOSTROMES	
4a	Siliceous Sponge (hexactinellid,& lithistid) Reef	>100
4b	Lithistid Sponge-Chaetetid-Stromatoprroid Reef	30 – 100
4c	Coral-Demosponge (lithistid- stromatoporoid-chaetetid) ‘Shallow’ Reef	10 – 50
5	OPEN MARINE PLATFORM MARGIN	
5a	Skeletal-Rich (fore-reef rubble, reef crest & back reef sand flat)	10–50 / 1–2 / 1–5
5b	Coral-Stromatoporoid-Chaetetid-Algal Reef	2 – 10
5c	Pelleted Mudstone to Grainstone (lagoon, back reef, inter reef) “3c”	5 – 10
5d	Oolitic Grainstone Shoals	1 – 5
5e	Oncolitic Back-reef (shallow back-reef to shoal margin)	1 – 5
5f	Sandstone (by-pass, lowstand, reef infiltrate)	1 – 3
6	CARBONATE PLATFORM INTERIOR – “Moat”	5 – 20
7	MIXED CARBONATE SLICICLASTIC PLATFORM INTERIOR	3 – 10
8	COASTAL DELTAIC SYSTEM (lagoonal to continental)	1 – 5

Figure 12. Detailed Abenaki Fm. carbonate facies model and associations (Weirzbicki et al., 2002)

5.4 Bank Profiles

When evaluating carbonate bank margins the first objective is to understand their location and morphology. This is not a simple matter because the reef-building organisms can follow very circuitous routes in their quest for survival followed by subsequent exposure to erosion and faulting. During deposition a carbonate bank acquires varying profiles as a function of sea level, climate, siliciclastic sediment supply, salt movement, faulting, etc. A facies map of the Great Bahama Bank, which is a large feature, measures about 600 km in its long direction and about 350 km wide (Figure 13). As an ellipse its uninterrupted perimeter would be approximately 1250 km but if all embayments are measured with potential for framebuilding the perimeter is almost doubled to 2500 km.

The block diagrams of Read (1985) display various styles of carbonate bank edges (Figure 14). The ‘A’ or accretionary rimmed shelf diagram depicts the general situation offshore Nova Scotia. Seismically, this profile is the familiar sigmoidal bank edge seen along the

Panuke Segment and in places along the Acadia Segment where it has been preserved. The steeper escarpment style of block 'C' and the erosional margin of block 'D' are prevalent along the Acadia Segment. The degree of faulting and/or erosion is not clear but can have significant impact on the preservation, diagenesis, reservoir formation and hydrocarbon migration. Seismic examples of these and a map of occurrence are presented in Chapter 7.

A series of profiles based on seismic profiles illustrates the major differences in margin profiles along the circum-North Atlantic (Figure 15). Those profiles off Nova Scotia grade from a gently dipping ramp margin with inter-fingered carbonate and clastic facies at Penobscot to a steeper sigmoidal bank margin at Deep Panuke, an eroded margin at Acadia and a faulted/eroded margin at Bonnet. The profile from the Baltimore Canyon shows a seaward aggrading profile. On the conjugate margin the profiles are similar to Deep Panuke and Acadia and these will be examined in more detail in Chapter 6. The Mauritania profile resembles the Bonnet section but this is a cursory comparison. The rimmed or barrier shelf edge is not continuous along the eastern seaboard but where it does occur is restricted to a narrow belt as envisioned off Nova Scotia (Eliuk, 1978) and in the Baltimore Canyon (Prather, 1991) (Figure 16). Whereas this positive relief may not be a critical factor in trapping, it is nonetheless a favourable circumstance.

It is important to accurately map the paleo bank edge to capture the optimum skeletal reef zone. On a regional basis the steep bank edge can be inferred but on a local, i.e. prospect basis, the bank edge is compromised by faulting, mass movements, erosion and the ensuing seismic imaging problems. Accurate mapping for the narrow play fairway will require 3D seismic surveying.

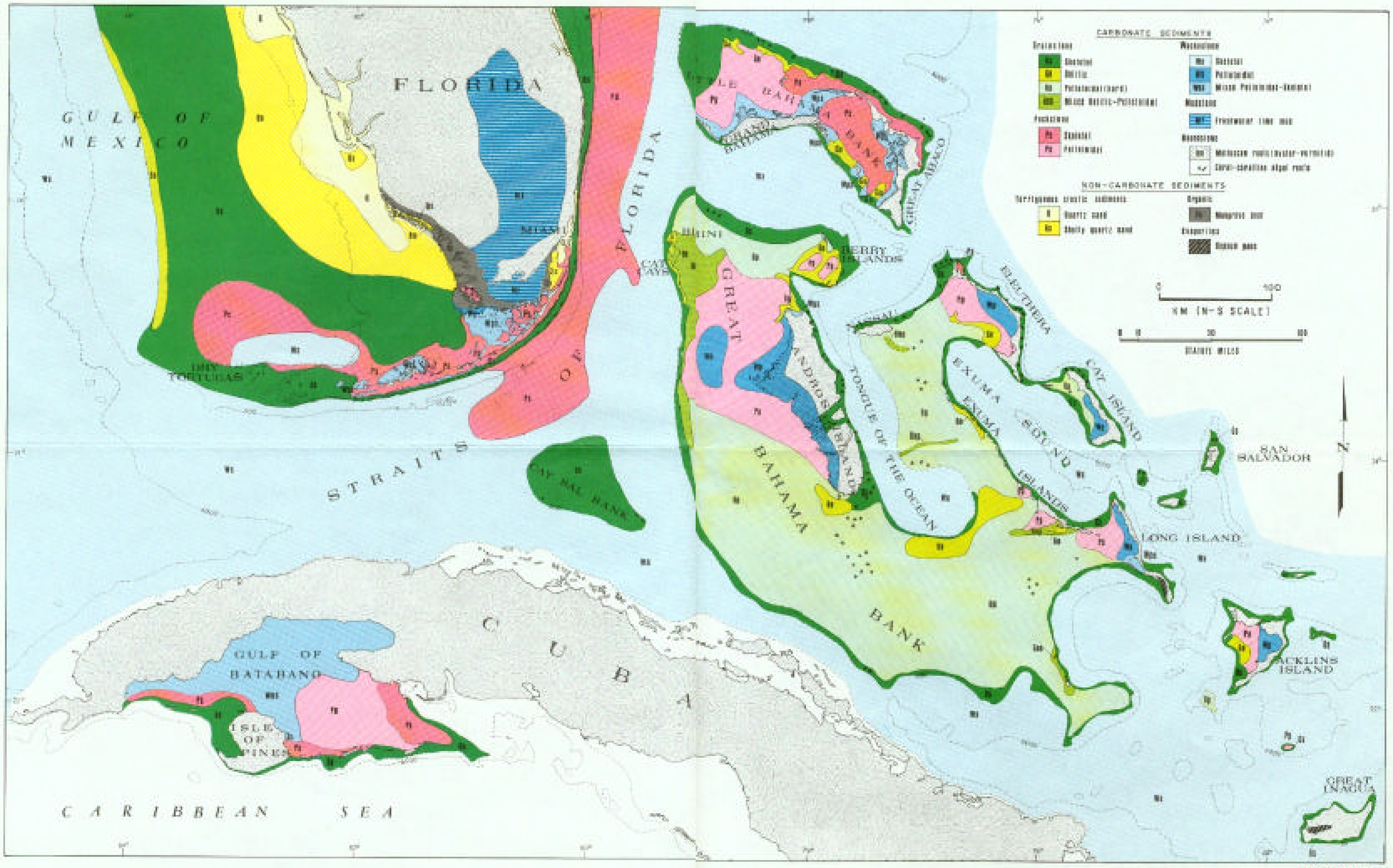
Schlee et al (1988) illustrate the different types of paleoshelf edges interpreted along the U.S. Atlantic margin in map view (Figure 16). The main styles are rimmed (or rather preserved rim) platform, ramp, eroded and faulted/eroded. The symbol designating a "rimmed" platform along George's Bank and to the northeast is oversimplified. The new map created as a result of our research annotates the complexities of the paleo-bank edge and the ensuing difficulty of tracking what is left of the original belt of reefal facies, the exploration target for this play (Figure 8). To the list of preserved, faulted and eroded rim margins, we have added salt disruption and longitudinal channel erosion. These appear as destructive influences rather than reservoir or trap enhancers and as such will add to the play risk especially in the Acadia and Shelburne Segments.

5.5 Pre-Platform Geology, Salt Tectonism and the Montagnais Impact Event

The lithostratigraphy of the pre-Abenaki geologic succession is detailed in Chapter 4.

Rifting was initiated on the Nova Scotia and Moroccan conjugate margins sometime in the Middle Triassic. Significant thermal doming and extension permitted reactivation of earlier Variscan-age compressional features both on a regional and local scale. On the Scotian margin, extensional rift basins were formed in the Bay of Fundy region, Orpheus Graben, La Have Platform and the regions seaward of the margin hinge-line out to the future rift axis (Wade and MacLean, 1990; Wade et al., 1996). The more inboard (Fundy and Orpheus) and platformal (Naskapi and Mohican) have little or no overlying post-rift successions and reveal significant extensional motion and subsidence and filled with thick continental fluvial, lacustrine, aeolian and playa sequences. Rift proximal basins along the hinge line and beyond are deeply buried and very poorly if at all imaged, though most likely had similar stratigraphic successions with some marine components in the Late Triassic.

Marine incursion into the proto-Atlantic rift basin occurred during latest Triassic (Norian) to earliest Jurassic (Hettangian) time and is recorded via the presence of variably thick Argo Formation evaporites (Wade and MacLean, 1990). The Argo was deposited in depositional lows along the fractured hinge line region that in some cases extended well inboard onto platformal regions (e.g. Orpheus Graben, Mohican Graben). The inboard reach of the Argo is confirmed through well penetrations and seismic correlations (e.g. Mohican I-100 well: (Figure 16) and in MacLean and Wade, 1993). Maximum thickness of the Argo is estimated to have been in the order of at least 1800 metres (Jansa and Wade, 1975) along the seaward margin of the basin hinge-line.



ENOS, FIGURE 1
Surface Sediment Facies of the Florida-Bahamas Plateau
The Geological Society of America, 1974

Figure 13. Surface sediment facies of the Florida-Bahamas Plateau (Enos, 1974).

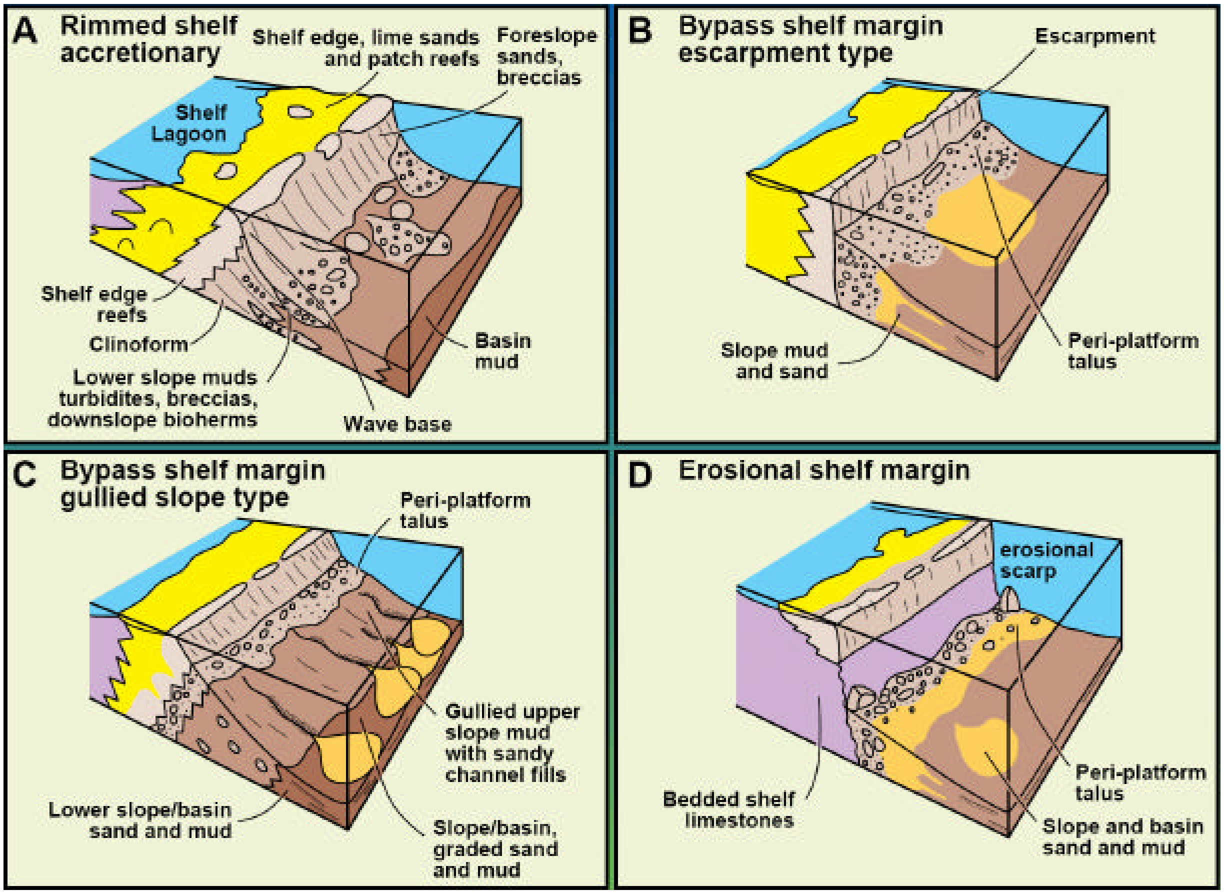


Figure 14. Isometric models of carbonate margin types (Tucker and Wright, 1990 in Moore, 2001).

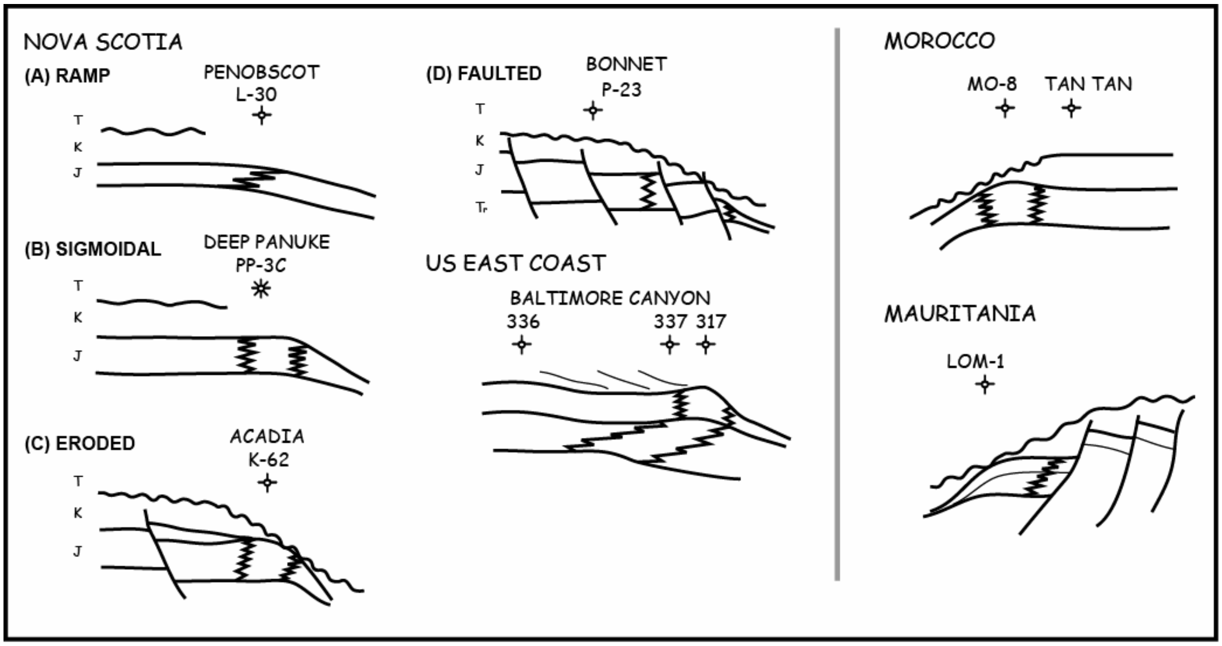


Figure 15. Simplified profiles of the various Jurassic carbonate bank margin types, circum-North and Central Atlantic region.

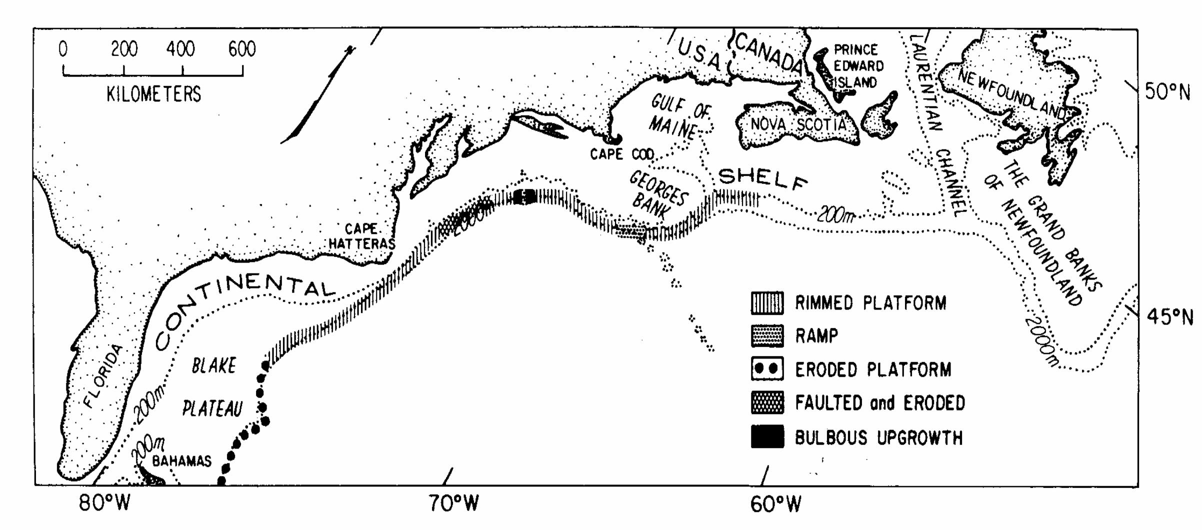


Figure 16. Jurassic carbonate bank margin types, Eastern North America (Schlee et al., 1988).

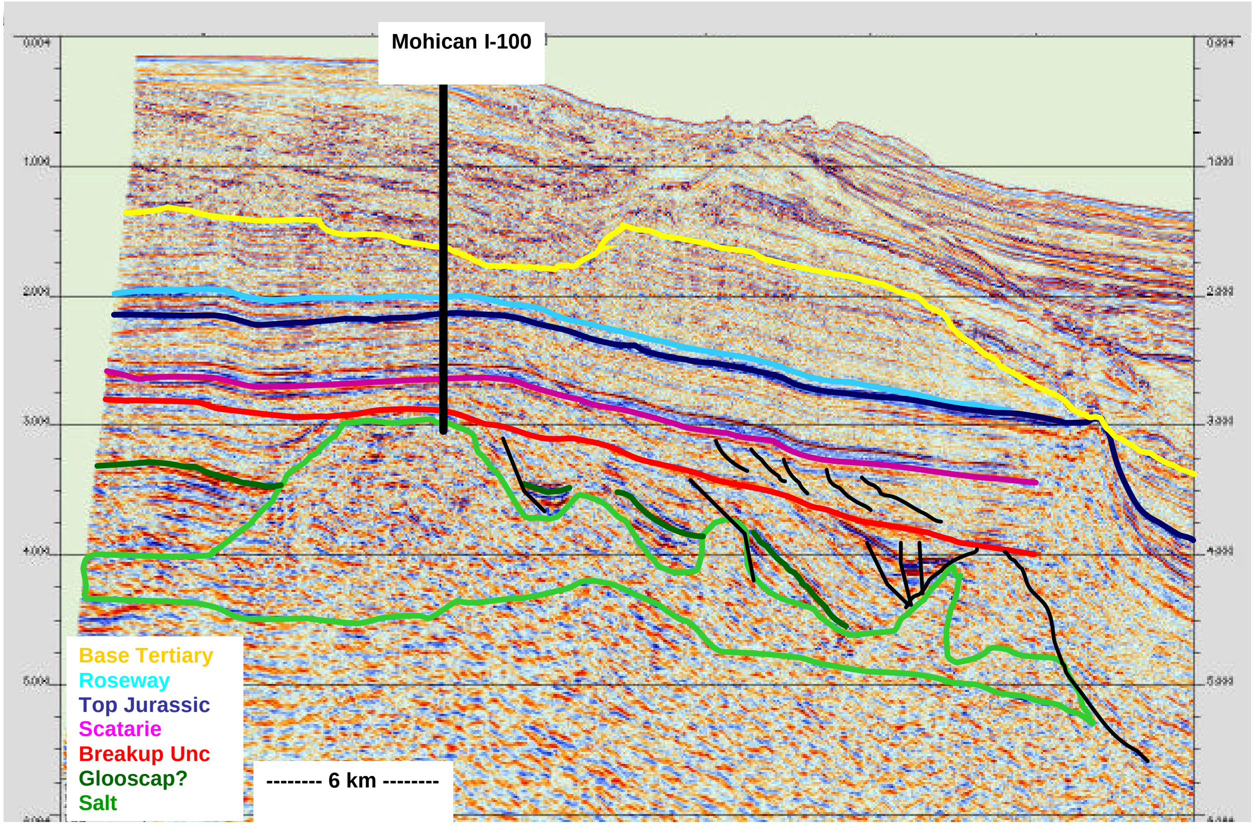


Figure 17. TGS regional seismic line through the mouth of the Mohican Graben and Mohican I-100 well. Post-salt sedimentation (Heracles Unit) deformed Argo Formation (Hettangian) salt deposits creating structures that predate the ca. mid-late Sinemurian Breakup Unconformity (BU). Note that in the synclinal basin northwest (left) of the salt features sediment reflectors appear concordant with the BU. Deeper high amplitude reflections may be extrusive volcanics encountered in the nearby (35 km NE) Glooscap C-63 well. Subsequent post-BU Middle Jurassic to Early Cretaceous carbonate deposition built up and over

the stabilized margin. Later tilting and destabilization of the margin may have been triggered by the Early Eocene Montagnais Impact Event. Line location in Figure 4.

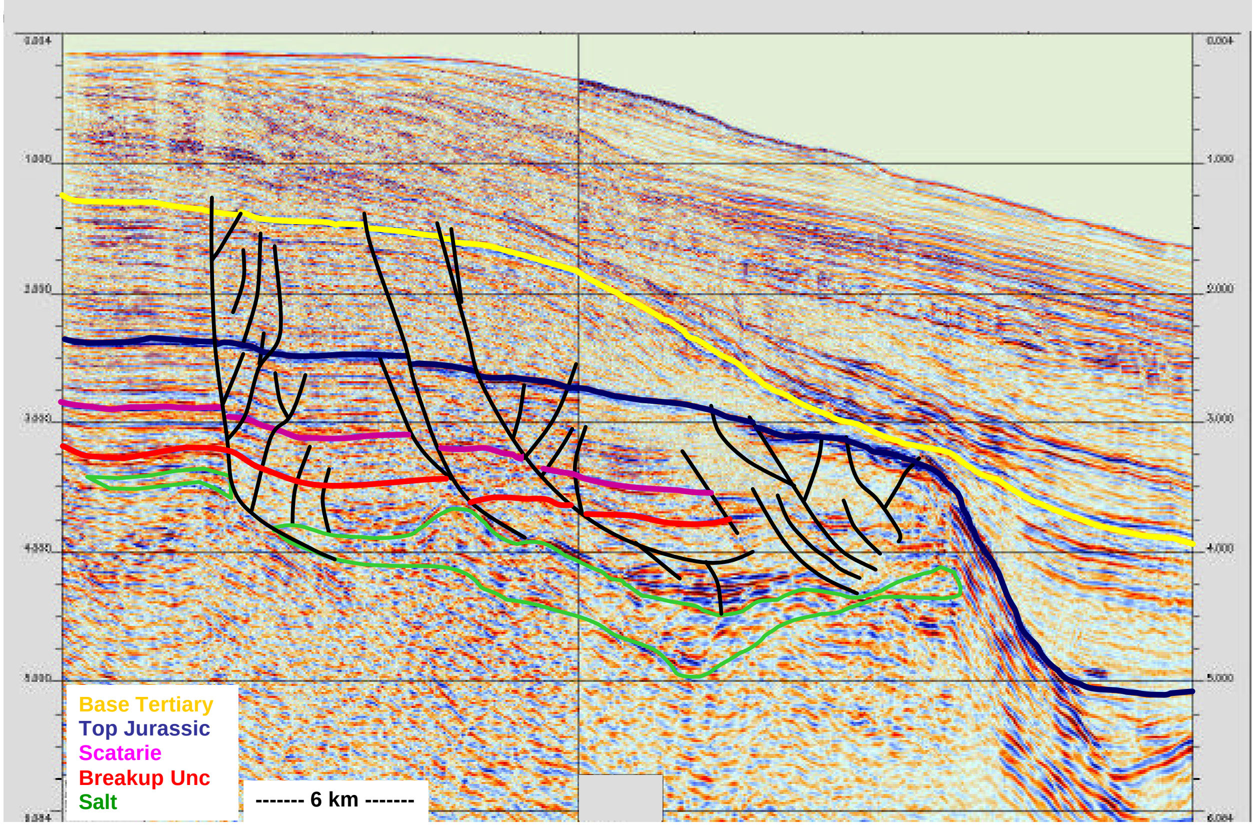


Figure 18. TGS regional seismic line through the mouth of the Mohican Graben about 42 km northeast of the line shown in Figure 17. Significant faulting of the margin and platform is present with faults soling on to Argo Formation salt features. There is no evidence of growth in adjacent strata and vertical fault penetration is limited to small offsets of the Base Tertiary unconformity (yellow). Pre-BU high amplitude reflections ponded above the salt are thought to be basalts equivalent to the Hettangian Glooscap volcanics equivalent to the tholeiitic basalts of the North Mountain Formation in the Fundy Basin (Wade and MacLean, 1990, Wade et al., 1996). Line location in Figure 4.

Seismic data along the carbonate bank margin reveals an intimate relationship between the Argo Formation evaporites and deposition of the Abenaki carbonate back margin. Two phases of pre-Abenaki salt deformation are observed, both driven by rapid sediment loading: 1) Post Salt/Pre-Break-up Unconformity (early Hettangian to middle Sinemurian), and 2) Post-Salt/Post-Break-up Unconformity (late Sinemurian to middle Bajocian). These two events resulted in the formation of salt swells and ridges, and provide insights on related depositional successions and the margin's evolution. Several phases of post-Jurassic salt motion were geographically restricted and variably deformed the bank margin in defined locations. Diapiric salt structures on the margin foreslope, and beyond, show episodic motion extending from the Middle Jurassic to the present.

The driving force for the pre-Break-up Unconformity (BU) salt deformation phase on the platformal areas of the Acadia Segment (and probably the hinge line regions as well) was loading of the Argo strata by a progradational wedge of interpreted clastics sourced from the northwest. This as-yet undrilled sequence appears to conformably overlie the Argo Formation in the Mohican Graben and its distribution is probably limited to local depocentres along and adjacent to the hinge line area. Maximum thickness is estimated to be about 1000 metres. Seismic profiles in this region show the sediments displaying wedge-shaped geometries with thickening into evacuated lows and thinning onto salt feature highs, thus indicating syndepositional salt motion. This succession is best imaged in the Mohican Graben (Figures 17 & 18) and along the corresponding seaward margin. In keeping with the pedigree and nomenclature of its related formations, this sequence is herein informally termed the “Heracles Unit”.

Sediments of the Heracles Unit prograded onto and rapidly loaded the underlying Argo evaporites forming salt evacuation synclines inboard of salt swells and ridges moving to the seaward edge of the margin. A portion of a regional strike line from the TGS survey shows a dramatic juxtaposition of salt penetrating the platform beneath the bank margin and in front of the bank at the mouth of the Mohican Graben (Figure 19).

On the platforms, high amplitude reflectors at the Argo Formation stratigraphic interval are interpreted as evaporite/carbonate/clastic sequences. These events can be linked to salt swells and diapers located near the edge of the platformal areas. It is interpreted that these amplitude events represent the deflated remains of the bedded evaporites now lacking salt. These intervals appear to have acted as salt welds, with most moveable salts converging through buoyancy into diapiric structures moving in a seaward direction towards the Abenaki platform margin.

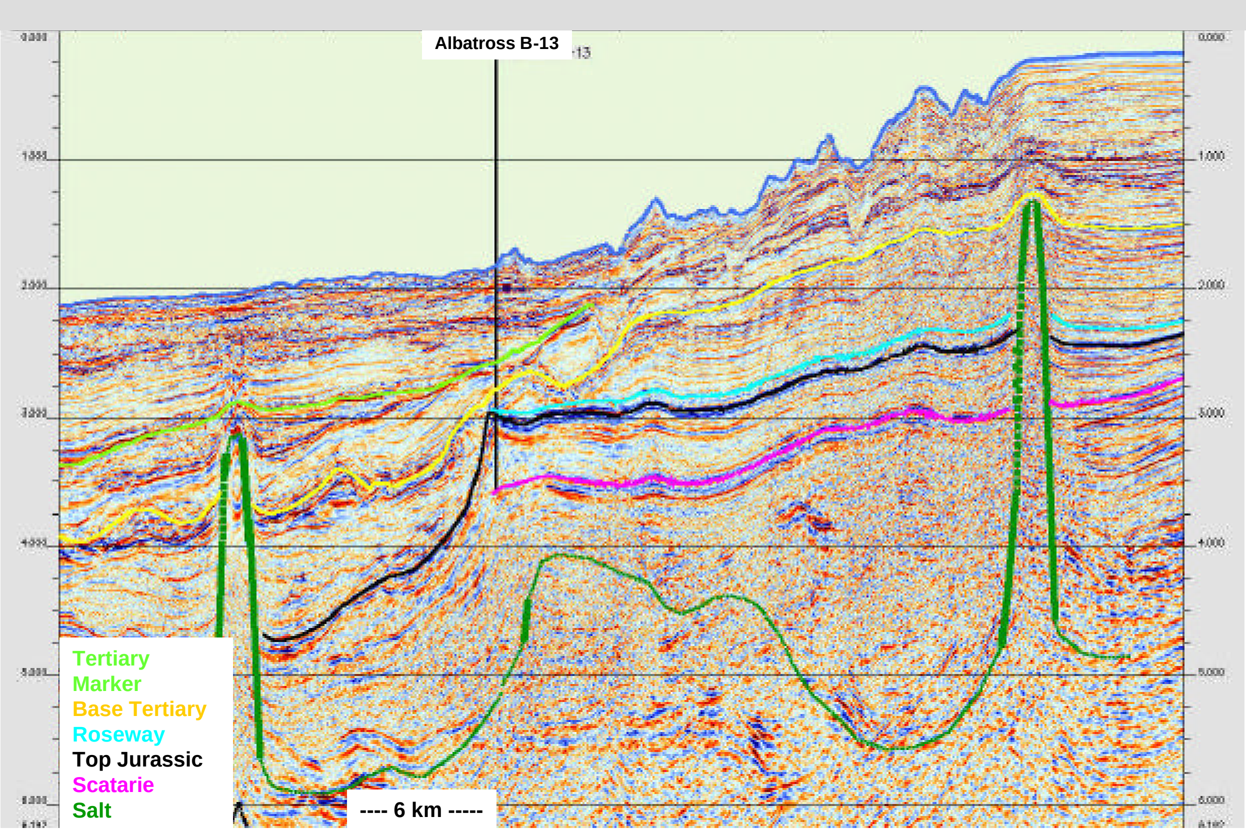


Figure 19. TGS regional seismic line through the Albatross B-13 well, southwest Scotian Slope. Margin subsidence was possibly triggered by the Montagnais Impact Event resulting in deflation of the underlying margin salt and creation of salt diapirism in the basinal and platformal successions. The platform diapir (NW) is located at a hinge line location that in similar lines is defined by a basin-dipping normal fault. Line location in Figure 4.

Relief generated by salt motion acted as baffles and barriers which further contained and/or captured these early Jurassic sediments. Both the salt and the Heracles strata were onlapped, truncated and/or eroded during the BU event of approximate Late Sinemurian age (Wade and MacLean, 1990). Based on stratigraphic relationships, the Heracles Unit probably extends from the earliest Hettangian to possibly the Middle Sinemurian.

The mid-late Sinemurian Break-up Unconformity on the Scotian Margin represents the final phase of rifting and separation of Nova Scotia and Morocco. It is observed as a mappable erosional event with variable angularity in the underlying successions depending on the region. Major faulting occurred at the basin hinge line along the entire Nova Scotia continental margin related to the separation of Nova Scotia and Morocco. This event had the additional effect of stranding significant sequences of salt and related evaporites on the platformal footwall and down-dropping the thicker succession on the hanging wall, now at the newly-formed continental margin.

The Break-up Unconformity has the appearance of a transgressive surface of erosion and marks the first phase of global Jurassic sea level rise, with younger strata displaying onlapping relationships. This latter succession is made up mostly of shallow marine dolomites (Iroquois Formation) and then a major carbonate bank and platform complex forming along most of the margin's length (Abenaki Formation). Along the Acadia Segment, the first phase of salt tectonism appears to have ceased at about the time of the BU with the Argo evaporites establishing equilibrium with the overlying sediments.

The post-Break-up Unconformity salt deformation event is observed in seismic and wells on the Panuke Segment of the Abenaki bank margin. In this region, Iroquois Formation shallow marine dolomites were laid down over the BU surface followed by southeast to southwest-directed progradational siliciclastics of the Mohican Formation, the latter possibly a precursor succession of the Sable Delta Complex. Seismic dip profiles on the northeast extent of the Panuke Segment near the Kegeshook G-67 well show the Mohican fluvial sandstones deposited in salt-evacuation synclines formed by loading of the sediments. Long linear salt ridges were created by this process and their shapes may provide clues to the underlying basement morphology and original salt distribution (various maps in Wade and MacLean, 1990 and in GSC, 1991). Seaward of Kegeshook ridge, Mohican sediments prograded out into the basin, and over a probable deep basement hinge line fault. Salts in this setting were also laterally deformed and the resultant evacuation syncline probably formed a temporal local bathymetric low.

The salt structures appeared to reach equilibrium with the overlying and surrounding strata by the time of the next sea level rise and deposition of the Scatarie/Abenaki 1 ramp margin facies. The margin break appears to correspond with the underlying Kegeshook ridge and the seismic profiles show the Baccaro Member of the Abenaki prograding seaward from this position. The seismic data indicates syndepositional salt movement in the post-BU Middle to Upper Jurassic Iroquois and Abenaki Formations, however, this appears limited to the basinal region seaward of the platform margin. In this setting, only minor post-Jurassic faulting and deformation by loading of later sediments is seen.

This post-BU salt motion may have been an influencing factor in the structural component of the Deep Panuke field. Time and depth maps for the top of the Abenaki 5 and 6 sequences reveal a distinctive long, bank-parallel, northeast-plunging syncline immediately behind the eastern half of the Deep Panuke field (see Figures 26-28, 33-33). The deeper time map on the Lower Jurassic "Near Basement" infers an older structure in which deposition of Argo salts could have been concentrated (see Figure 78).

Along the edge of the margin and especially the foreslope region, later post-Jurassic diapiric intrusion and faulting of the Abenaki sequences did occur sometime during the Cretaceous (based on observed fault penetrations) though it is unclear as to what was the regional extensional tectonic event which triggered the structuring. Perhaps it was the Early Cretaceous age Avalon Unconformity, which is the erosional manifestation of rifting and separation of Iberia and the Grand Banks – i.e., the collapse of its precursor, the "Avalon Uplift" (AU). MacLean & Wade (1990, p.214) believe that the AU is of early Cretaceous age, being short-lived and locally severe. The unconformity, as traced over the Abenaki

Subbasin and Banquereau Banks, shows little angularity. Subsidence following the Avalon Uplift was slow and intermittent creating a series of smaller unconformities. Similar types of unconformities and diapirism affecting the Lower Cretaceous are observed in the Whale and South Whale Basins, though here have associated salt withdrawal synclines, infill successions, onlapping relationships and minor erosion. Similar features appear only at and/or adjacent to the Abenaki Bank Margin.

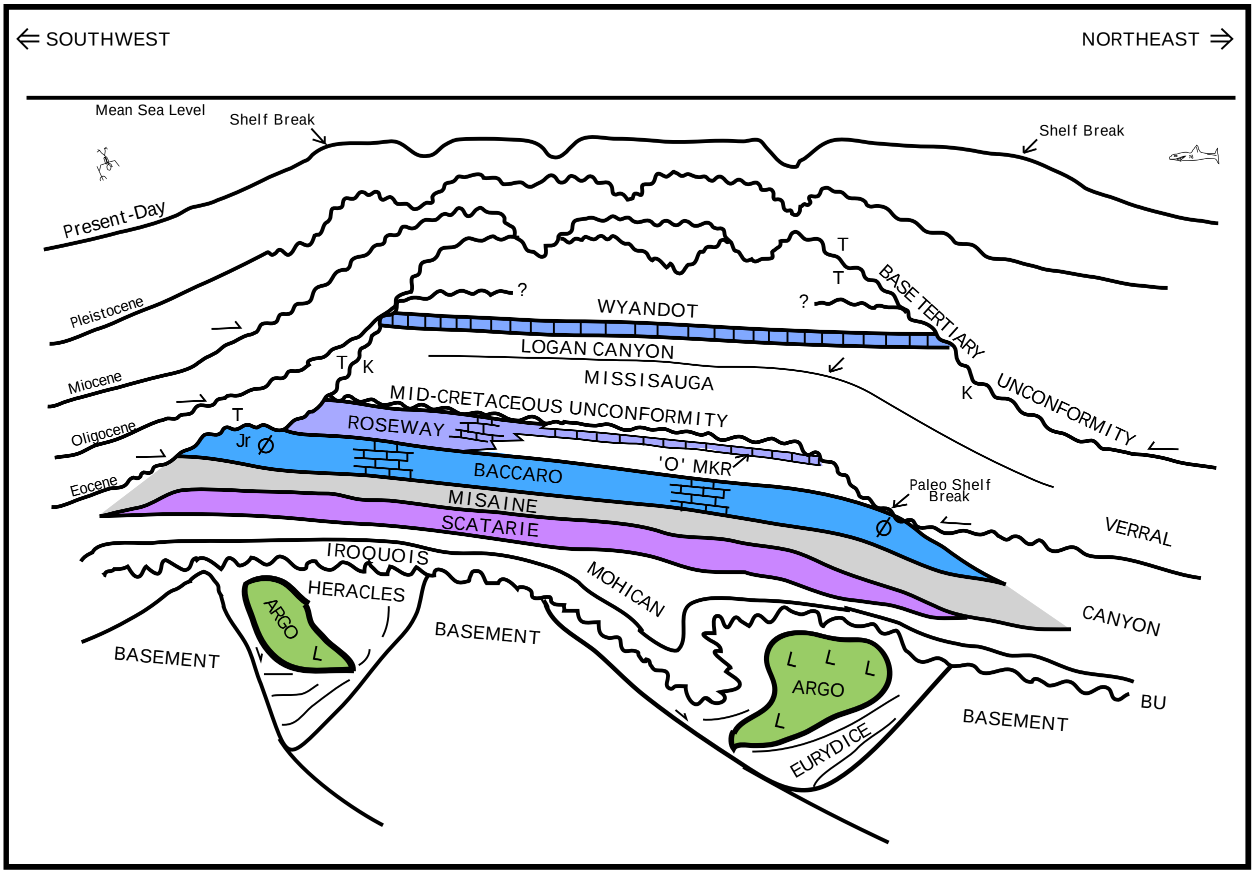


Figure 20. Regional schematic strike section illustrating the stratigraphic relationships of the Abenaki Formation and related formations. The line of section approximates the trace of the platform margin along the edge of the Scotian Shelf and extends about 650 km from the Shelburne Subbasin in the southwest to the Gully area northwest of Sable Island. Given the geometry of the Abenaki shelf margin break and later Tertiary events, is uncertain if the mid-Cretaceous unconformity reached the top of the Abenaki strata. Where observed on seismic, any physical erosion of the margin edge is appears minor. Most of the margin edge is intact suggesting possible slope contour current erosion that swept the shelf edge margin of softer sediments down to the harder carbonates.

In the early Tertiary, the edge of the La Have Platform (Acadia Segment) west of the Mohican Graben was subjected to a major bolide impact event. The Montagnais structure is believed to be of impact origin and is dated at 50.50±0.76 Ma (Early Eocene), creating a crater complex approximately 45 km in diameter (Bottomley and Gates, 1988; Jansa et al., 1989; Wade and Mac lean, 1990). The Board's mapping, using the latest TGS seismic dataset, suggests a smaller diameter of about 35 km. In the outer crater ring walls, Cretaceous and Jurassic age sediments were variably tectonized, with Abenaki strata subjected to significant thrust and reverse faulting. At the mouth of the Mohican Graben, segments of the continental margin underlain by salt (up to 30 km in width) were normally faulted with these faults terminating in lower Tertiary strata (Figure 18). In addition, since there is no seismic evidence for post-BU sediment-induced salt tectonism, it is postulated that the faulting is related to the Montagnais event. This process is analogous to the 'regional shaking' and subsequent mass transport event of Late

Cretaceous platform margin reefal sequences onto the deep water slope and base of slope in response to the K/T Chicxulub impact in the Western Gulf of Mexico (Magoon et al., 2001, p.117).

5.6 Overcrop and Unconformities

The carbonate bank has been subjected to erosion at different times throughout it's history and to varying areal extent. A schematic drawing illustrates the current definition of unconformities observed in the seismic interpretation (Figure 20). The Baccaro is topped by the Roseway in the west which is believed coeval to the 'O' Marker in the east. In the Sable Subbasin the Mid-Cretaceous Unconformity truncates the 'O' Marker and also breaches the Baccaro bank edge in isolated areas. Due to the influx of the Cretaceous Sable Delta siliciclastics the Tertiary unconformities do not reach the bank edge. To the west the situation is very different.

Because of the reduced Cretaceous loading, the Tertiary unconformities eroded the bank edge and sometimes merge. The base of Tertiary can be mapped with some confidence but with a paucity of well data the ages of the subcrop and overcrop are speculative. This is best illustrated by Wade et al (1995) where they confronted the stratigraphic problem of correlating across the shelf break. Based on the available seismic data, Figure 21 delineates those areas of the Abenaki margin which were affected by of Tertiary and Middle Cretaceous erosional events. The Tertiary erosional edge of the Upper Cretaceous Wyandot chalk is also mapped.

The carbonate bank edge has functioned as a hinge line for sedimentation, compaction, and erosion over time. This has resulted in many unconformities converging above this bank edge area. It was very difficult to correlate these unconformities over an extended area and across the carbonate bank edge. The Base Tertiary Unconformity (BTU) appears to be a fairly reliable pick but the age of the subcrop beneath this unconformity was often difficult to interpret.

The Mid-Cretaceous Unconformity (MCU) was more difficult to correlate on the margin edge but is conformable over much of the carbonate shelf. The zone between the (BTU) and the Jurassic Bank Edge thins towards the west making it very difficult to correlate the MCU through this section.

The regional profile across the Bonnet P-23 well illustrates the high basement block-like appearance with a faulted bank margin and the well positioned substantially landward of the edge (Figure 23). The base Tertiary erosion has again tagged the faulted bank edge and preservation of any reservoir-prone facies at the top of the Jurassic may be compromised.

5.7 Reservoir Development and Diagenesis

Significant hydrocarbon-bearing reservoirs in the Abenaki Formation are currently restricted to the bank margin reefal facies of the Baccaro Member / Abenaki Sequences 4, 5 and 6 (Figure 24). Eliuk (1978) first recognized that Abenaki reservoirs were best created through the secondary dolomitization of reefal facies that existed as a narrow band along the platform margin. Harvey and MacDonald (1990) and Harvey (1993) modeled and described the seismic attributes of porous reef facies. Well data and 3D seismic data from the Deep Panuke field confirmed the observations and interpretations of these researchers.

The Baccaro Member bank margin reefal facies is best described as an amalgam of debris reefs, composed of effective but limited numbers of stabilizing encrusting fauna and having high levels of silt- and mud-size carbonate material created by bioeroding organisms (Leinfelder, 1993; 2001; 2002). Preservation of these fine sediments infers that these reefs existed in a moderate energy marginal setting at the fair weather wave base though still subjected to significant physical erosion. A wide belt of oolitic shoals occupied the higher energy crestal position.

Regularly spaced series of two kilometer-wide promontories and reentrants are common along the Panuke margin as imaged by 3D seismic (see Figures 26-28, 33-33). It is most probable that the same morphology exists along the entire trend of the Abenaki platform margin but has yet to be imaged and requiring 3D seismic. The scalloped and fractured margin strongly supports the interpretation of a bank margin that underwent continuous syndepositional biological and physical erosion, the latter via localized rock falls, debris flows, turbidites and occasional larger scale faulting until stabilized by the transgression of forereef facies during sea level high stand events. Similar modern features and processes are documented on the Great Bahama Bank by Grammer et al. (1993).

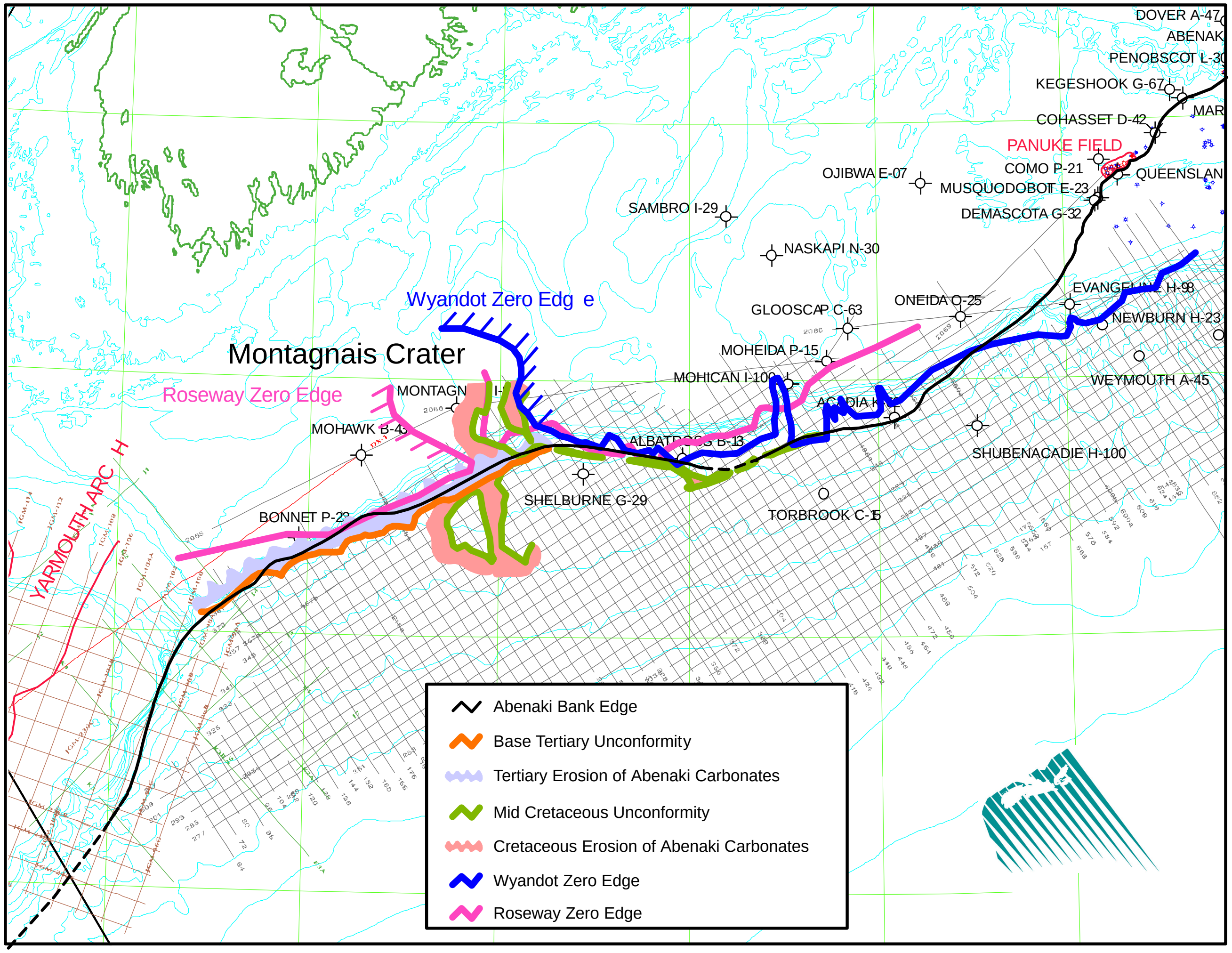


Figure 21. Map of regional unconformities and depositional pinch-outs as related to the Abenaki Formation. Most of the effects from the erosional events are observed converging adjacent to the Early Eocene age Montagnais impact event suggesting that the results of the event significantly affected later drainage patterns and dispersal in this area. The Roseway Unit ‘zero edge’ may be reflecting the influence of older basement features related to the Mohican Graben.

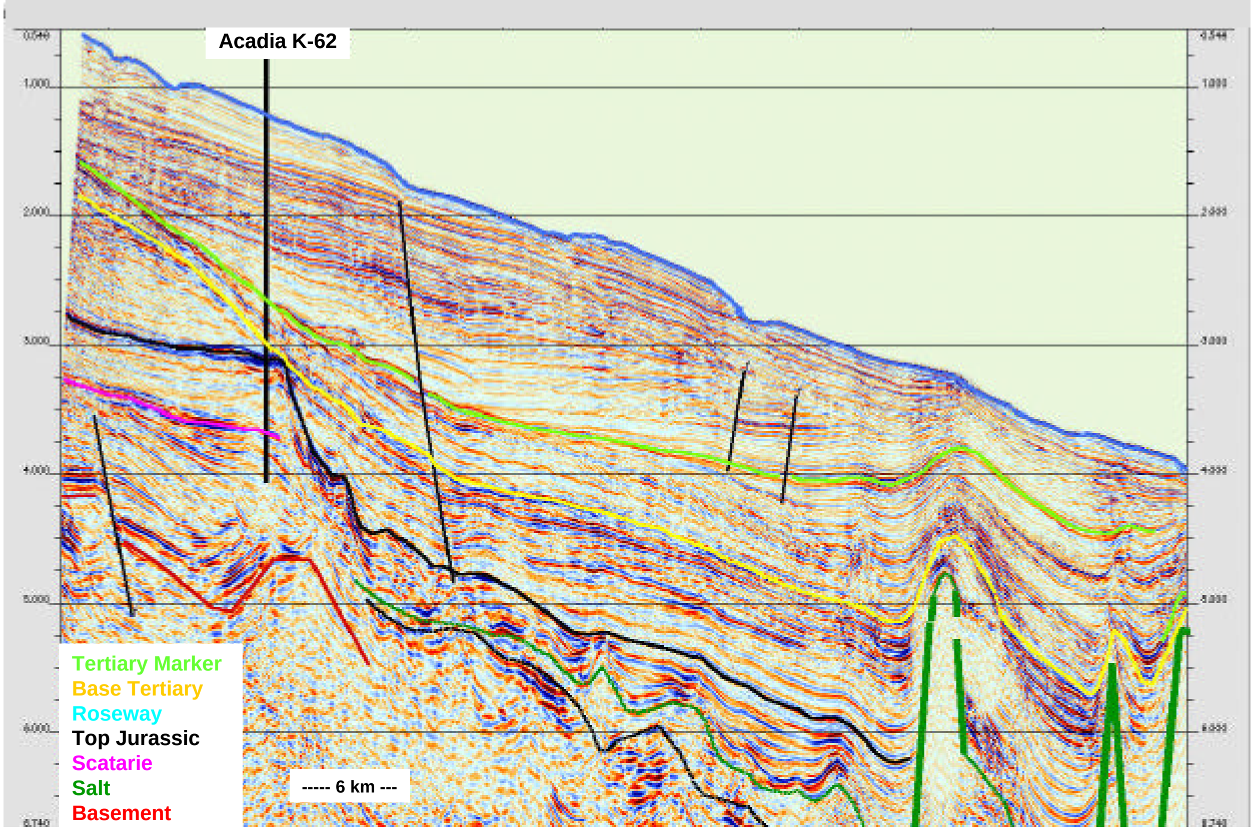


Figure 22. Regional TGS seismic line extending 65 km from the edge of the Acadia Segment out into the diapiric salt province. Note the board belt of Jurassic sediments underlain by thin salt layer of salt between the platform margin / basin hinge line and salt diapirs. Deep structure beneath the platform margin may be a basement high, though the geometry of overlying high amplitude reflections of possible basaltic origin ("Glooscap Volcanics") suggests a deep-seated salt feature. An enlarged view of the Acadia K-62 well is presented in Figure 80. Line location in Figure 4.

Diagenesis of Abenaki carbonates is so far known to be dominantly in the reefal and adjacent fore- and backreef facies of the Baccaro Member (Weissenberger et al., 2000). Several stages of diagenesis are recorded in the Deep Panuke reservoirs (Baccaro/Abenaki 4, 5 and 6) and include at least three phases of dolomitization and a later leaching event (Weissenberger, ibid; PanCanadian, 2002). The leaching followed the last phase of dolomitization (hydrothermal) which enhanced existing dolomitic porosity and profoundly affected the previously unaltered limestones. Recorded porosity types in the Baccaro include inter- and intracrystalline, matrix microcrystalline, vuggy and cavernous. A dual porosity system is interpreted for the Deep Panuke field: high permeability-high porosity, connected-vug limestone to limy dolomites to coarse-grained dolomites, and a widespread low porosity-low permeability partially leached limestone matrix type (PanCanadian, ibid.). The presence of micrite muds in the reefal sediments is believed to have enhanced the effectiveness of the dolomitization and leaching processes.

Eliuk (1978) originally postulated that the source of the dolomitic diagenesis was via a 'mixing zone' type process, although no evidence has been found indicating periods of subaerial exposure of the Abenaki. It is now thought that the cause of Abenaki diagenesis was through the movement of deep basinal and underlying fluids into the platform margin complex via deep-seated marginal normal faults. Long, linear, margin-parallel fractures are observed in the 3D mapping of the Abenaki 5 and 6 sequences and are most probably precursors to eventual faulting and margin failure (see Figures 26-28, 33-33). Fracture zones are well known to have profound implications for carbonates in creating secondary fracture porosity and avenues for diagenesis and migration. They can be formed in a variety of ways including loading on unstable substrates, faults and fractures due to normal loading (margin parallel), deep-seated older faults (parallel – listric / normal to margin – transverse faults), earthquakes, and salt diapirism / evacuation. Vertical penetration of faults and fractures into overlying strata affects the extent of possible diagenesis and also pathways for hydrocarbons and is especially true in porous reefal facies at the platform margin.

The fault-related diagenetic model may be applicable to other areas beyond the Deep Panuke field and other facies types. Dolomitization and creation of vuggy porosity in lagoonal sediments in the Bonnet P-23 and peloidal-skeletal sand in the Acadia K-62 well (Weissenberger et al., 2000) suggest that diagenetic fluids entered into these otherwise tight rocks through fractures, which in turn may be related to larger scale, deep-seated platform margin faults. If correct, then potential reservoirs could be developed through diagenesis in carbonates independent of their depositional facies.

5.8 Play Types

Based on analogues and interpretation of available well and seismic data, possible play types associated with the Abenaki carbonate platform margin are illustrated in Figure 24 over the three main zones associated with this carbonate platform.

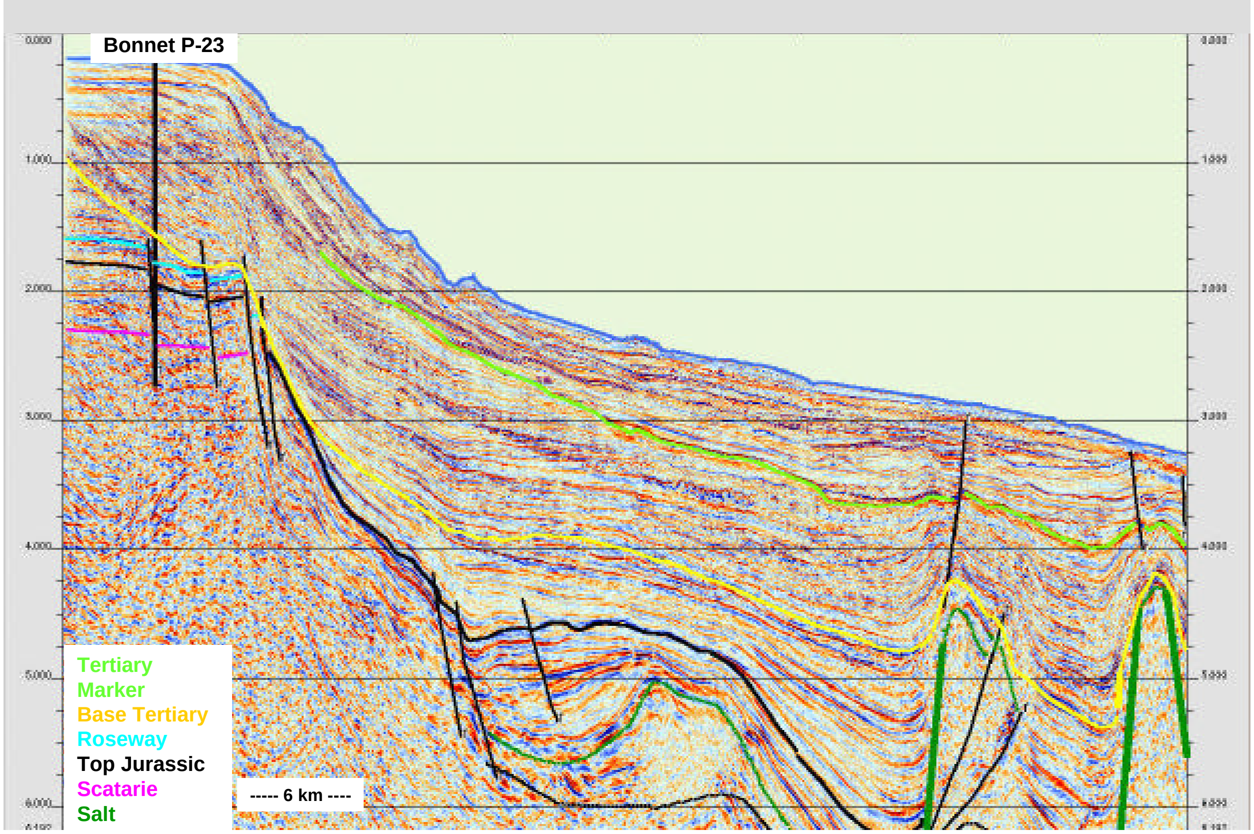


Figure 23. Regional TGS seismic line extending 65 km from the edge of the Shelburne Segment out into the diapiric salt province. This bank margin is steeper and more escarpment-like than that of the previous Figure 22, with an apparently greater offset along the hinge line fault. The location and dimensions central salt feature (pillow) could infer an underlying Late Triassic – Early Jurassic local depocentre. An enlarged view of the Bonnet P-23 well is presented in Figure 92. Line location in Figure 4.

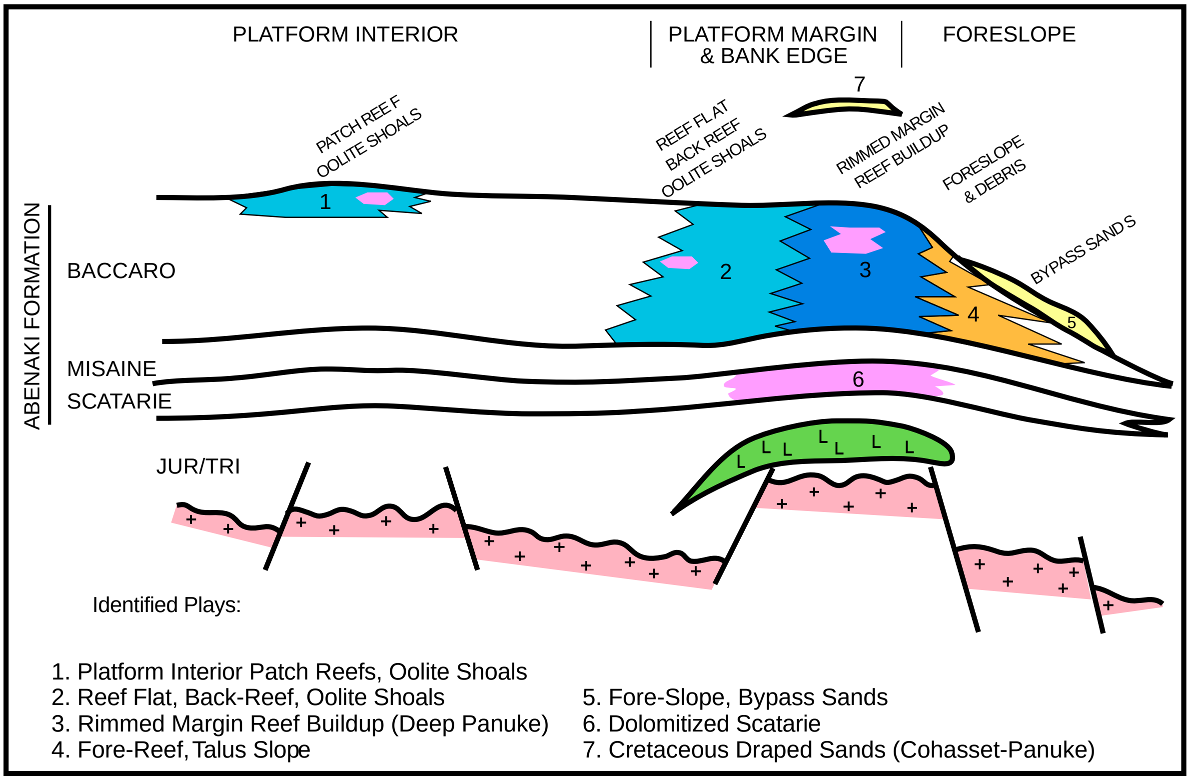
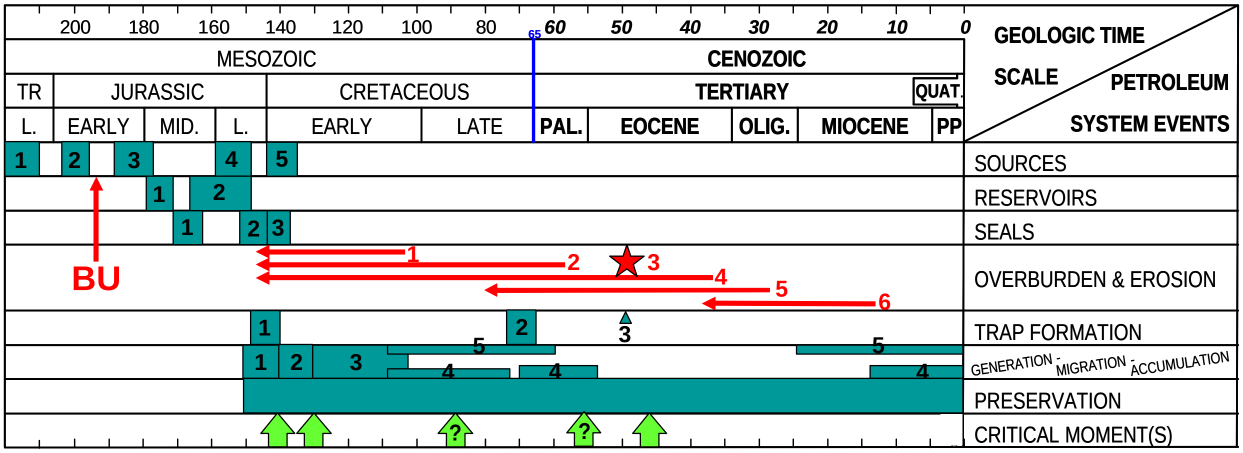


Figure 24. Schematic drawing of Scotian Basin Jurassic carbonate platform play types – Western Scotian Shelf. 1) rimmed margin reefal buildups (Deep Panuke), 2) foreslope, 3) reef flat/back-reef, 4) bypass sands, 5) platform interior patch reefs/oolitic shoals, 6) Scatarie Member reefal facies, and 7) Late Cretaceous draped sands (Cohasset-Panuke).

The platform interior has potential for patch reefs and oolite shoals that are structured by underlying basement highs or purely stratigraphic traps by lateral facies changes. Drape over basement highs can induce fracturing and be sites of dolomitization and enhanced porosity. The platform margin includes the bank edge, reef flat/oolite shoals and back-reef. This is the optimal zone as revealed by the Deep Panuke discovery in fractured dolomitized skeletal framework reservoir. The forereef or foreslope includes the reefal debris that is constantly deposited in front of an active reef. Where reefal buildups occur there is typically a rimmed margin but seismic suggests this is probably not a continuous situation. Where there is not a rim the margin will more likely be the site of high energy oolitic shoals.

Through breaks or channels along the margin there can be significant deposition of bypass sands, either siliciclastic and/or carbonate. This was the objective of EnCana's Queensland M-88 well drilled and abandoned in 2002 (see Section 3.2 for details). The Scatarie Member, while not at present a sought-after target, could contain fractured and dolomitized zones. Overlying Cretaceous sands draped over the platform margin may create traps like the Cohasset/Panuke oil discoveries.

The various play types are thus ranked in order of relative importance by today's available data and information (Figure 24; see also Figure 125). With the Deep Panuke discovery, still not fully delineated, and the overlying Cretaceous oil discoveries at Cohasset and Panuke, the petroleum system and controlling success factors are yet to be completely understood. The source rocks are expected to be from the Verrill Canyon marine shales but the potential for early synrift and postrift sub-platform sources cannot be dismissed. The predictability of dolomitization and fracturing is not yet possible so a detailed description of the petroleum systems is premature.



BU = Break-up Unconformity (~mid-late Sinemurian)

SOURCES

1. Early Synrift (Triassic: Carnian - Norian)
2. Late Synrift (Jurassic: Hettangian - Sinemurian)
3. Mohican (Toarcian – Aalenian)
4. Jurassic Verrill Canyon (Oxfordian - Kimmeridgian)
5. Cretaceous Verrill Canyon (Berriasian - Valanginian)

RESERVOIRS

1. Scatarie / Abenaki 1 (Bajocian – Callovian)
2. Baccaro / Abenaki 4, 5 & 6 (Callovian – Kimmeridigian)

SEALS

1. Misaine / Abenaki 2 for Scatarie / Abenaki 1
2. Top Abenaki 6 for Baccaro / Abenaki 4, 5 & 6
3. Lower Cretaceous Shales for Baccaro / Abenaki 4, 5 & 6

OVERBURDEN

Several periods of variable erosion:

1. Early Cretaceous (Aptian?)
2. Early Eocene
3. Late Eocene (Montagnais Impact Event)
4. Late Paleocene
5. Middle Oligocene
6. Middle Miocene

TRAP FORMATION

1. Diagenetic & Subsidence (L. Jur. – E. Cret.)
2. Tectonic & Structural (L. Cret.)

TIMING

Expulsion periods based on previously modelled deepwater succession (Kidston et al., 2002 – Sites 3-5).

Figure 25. Events Timing Chart – regional Abenaki Formation. This chart does not reflect the differences for each of the three defined segments. Individual charts for the Panuke and Acadia Segments are shown in Figures 92 and 109 respectively.

The Abenaki Formation composite events timing chart (Figure 25) represents the conceptualized petroleum systems for the entire formation on the Scotian margin. This figure includes data and concepts for the Panuke and Acadia Segments but excludes the Shelburne segment due to the lack of and/or quality of data. Charts for the Panuke and Acadia Segments are presented in Figures 93 & 110 respectively. The lack and quality of data and information precluded creation of a similarly detailed events timing chart for the Shelburne Segment.

The most striking features of the composite chart are the at least four periods of submarine erosion of the Scotian Margin throughout the Tertiary, as well as an earlier one in the Early Cretaceous. Pointedly, these events occurred after deposition and probable formation of the Abenaki reservoirs via diagenesis and do not appear to have cut deep enough to breech potential reservoirs. The structural component of trap formation probably occurred syndepositionally through subsidence and also during the Late Cretaceous in proximal delta settings. The Eocene-age Montagnais impact event is interpreted to have had an instantaneous effect on the bank margin in causing listric faulting, and thrust faulting around the crater rim. Diagenesis was probably early post-depositional.

As discussed previously, there exists a number of potential source rocks for Abenaki hydrocarbons; pre-, syn- and post-depositional. The episodic removal of overburden must have had the effect of delaying the maturation of those possible source facies adjacent to the bank margin, though the effects of these events for each source have yet to be quantified and modeled. Critical moments for hydrocarbon expulsion and migration are dependant on the age of the source rocks and creation of effective migration pathways.

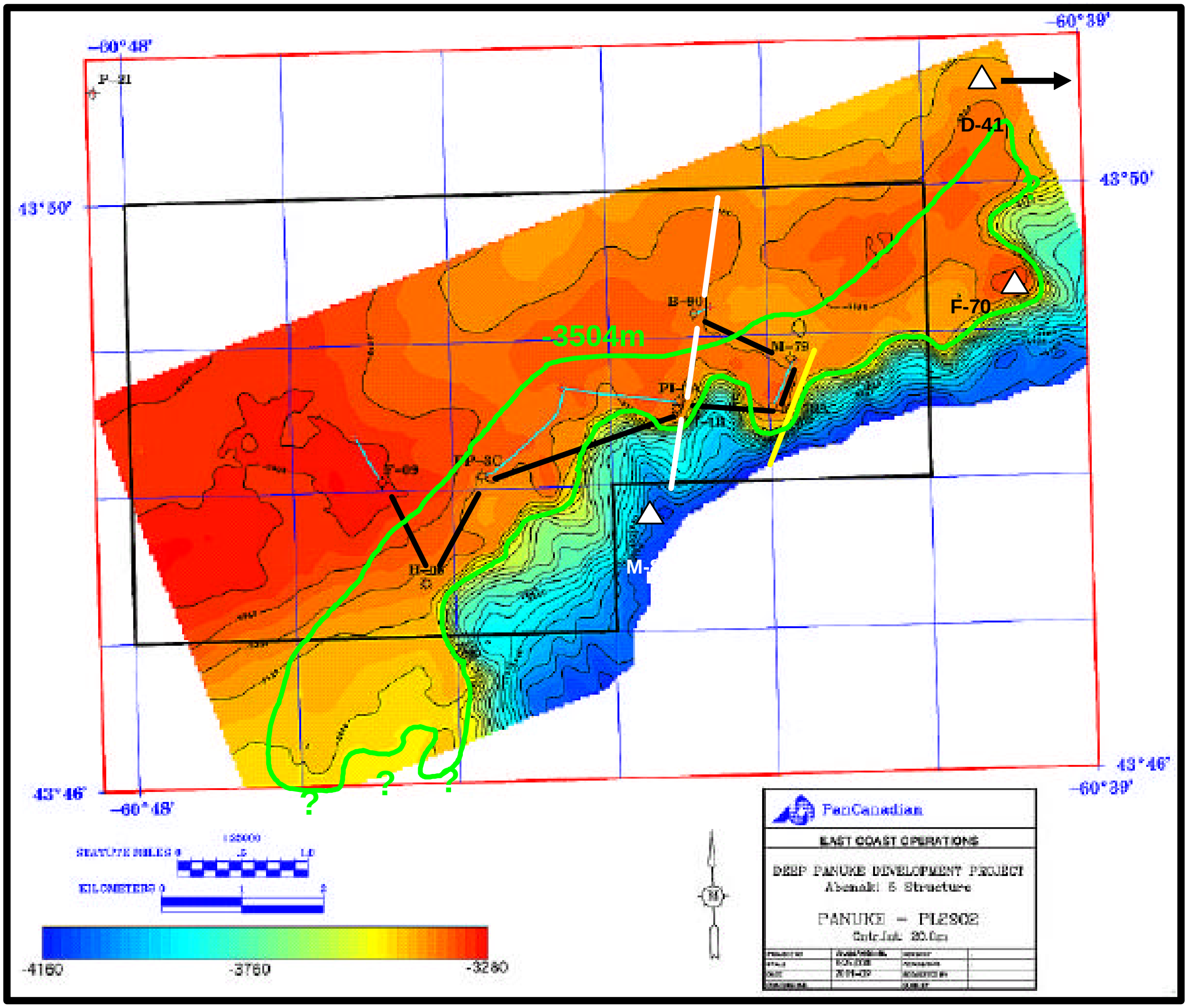


Figure 26. Deep Panuke depth structure map, top of the Abenaki 5 sequence. Approximate field boundary delineated by the -3504 mSS gas/water contact (green line) and facies boundaries, though the lateral extent of the field is not yet completely defined. Black line shows the location of the cross section in Figure 29; yellow and white lines the seismic profiles in Figures 30 and 31. Contour interval is 20.0 metres (slightly modifies after PanCanadian, 2002).

5.9 Deep Panuke Gas Field

The following information and related figures are sourced from PanCanadian's (EnCana's) public document "Deep Panuke Offshore Gas Development – Development Plan: Volume 2" (2002) unless otherwise indicated. Information on currently confidential Margaree and MarCoh wells is from press releases available on the EnCana corporate web site. Total depths for these wells are in the public domain and listed in the 2003 Weekly Activity Reports on the CNSOPB web site. Additional seismic profiles through the field are shown in Figures 83-92.

The Deep Panuke Gas Field was discovered by PanCanadian (now EnCana) in 1998 with the PP-3C discovery well finding gas beneath its shallow Panuke oil field. The field is located in about 40 metres of water, and subsequent drilling along the Jurassic bank margin has delineated the field as a narrow, northeast-southwest trending belt approximately 1-2 km wide and at least 11 km long (Figures 26 & 27). Subsequent drilling was undertaken to confirm the field's lateral extent (Figure 28). Gas has been identified within the Abenaki 5 sequence, and to a much lesser extent in underlying

Abenaki 4 and overlying Abenaki 6. Although the Abenaki 4 has significant reservoir development, it is mostly present beneath the field-wide gas/water contact of ~3504 m subsea (Figures 9 & 29). Further delineation drilling is planned with development of the field still pending as of June 2005.

Deep Panuke is a combined stratigraphic / structural trap. The gas is located in a structural high along the Abenaki platform margin within dolomitized and leached limestones of the Abenaki 5 sequence. It is overlain by tight upper foreslope limestones of the Abenaki 6 that provides an excellent and effective top seal (some thin, modest porosity exists at the base of this zone) (Figures 30 & 31). Structural closure is present along strike and facies changes with tight backreef (oolitic) and forereef (mudstone) facies provide lateral seals. Listric, syndepositional faulting has created a scalloped bank margin which has also aided in the seaward lateral seal (Figures 26 & 27).

Porous intervals within the Abenaki are observed and delineated by seismic attribute analysis of the 3D dataset, with estimation of porosity and its identification best in those zones that have vuggy and cavernous porosities (Figures 32 & 33, 83-92). Calculation of porosity and permeability in the vuggy and cavernous zones is hampered by the lack of core recovered from these intervals, hence their values are understated. Calculation of net gas pay is based log and MDT data using cut-offs for porosity (>0.05), water saturation (<0.40) and thickness (<1.0 m). Several wells have tested high rates of flow over extended periods with little draw-down and rapid build-ups (Data from well history reports now in the public domain; CNSOPB) (Table 3).

The Abenaki 5 sequence (Baccaro) is the main reservoir interval and is composed of stacked, shallowing-upward, aggrading and prograding platform margin successions dominated by coral, stromatoporoid chaetedid rudstones and boundstones (Figures 11 & 12). These debris reef limestones were later subjected to deep burial diagenesis that included three phases of dolomitization and a later hydrothermal phase. The complex fracturing, dolomitization and leaching diagenesis created a dual porosity system dominated by a low porosity / low permeability partially leached matrix, and an areally restricted and narrow high porosity / high permeability vuggy to cavernous limestone and limey dolomite to coarse crystalline dolomite. Because of its cavernous nature, extraordinary porosities and permeabilities are recorded which are now avoided due to the potential for serious loss circulation events. Details on the facies and diagenetic history of these sediments as seen in cores are described by Wierzbicki et al. (2002).

Year	Operator	Name	ID	TVD (m)	Status	Comments
1998	PanCanadian	Panuke	J-99 (PP-3C)	4163.0	Gas	Bank Edge – Initial gas discovery. Tested 59.7 MMcf/d gas from the Abenaki 5/4 zones.
1999	PanCanadian	Panuke	J-99 (PI-1A)	4030.0	Gas	Bank Edge – Thin gas pay. Well plugged and whipstocked to test adjacent seismic event at PI-1B.
1999	PanCanadian	Panuke	J-99 (PI-1B)	4046.3	Gas	Bank Edge –Discovered 24.2 m gas pay and tested 52.6 MMcf/d gas from the Abenaki 5.
2000	PanCanadian	Panuke	H-08	3682.0	Gas	Bank Edge – Discovered 108 m of net gas pay; tested 51.2 MMcf/d gas from the Abenaki 5.
2000	PanCanadian	Panuke	M-79	4598.3	D&A	Bank Edge – No gas pay, well plugged and whipstocked to test adjacent seismic event.
2000	PanCanadian	Panuke	M-79A	3934.7	Gas	Bank Edge –Discovered 11.4 m gas pay and tested 63.2 MMcf/d gas from the Abenaki 5.
2000	PanCanadian	Panuke	F-09	3815.0	D&A	Back Reef - Oolitic facies amplitude prospect; tight, no gas pay.
2003	EnCana	Margaree	F-70	3677.0	Gas	Bank Edge – Discovered ~70 m gas pay, tested >52 MMcf/d gas. Data confidential until August 6, 2005.
2003	EnCana	MarCoh	D-41	3625.0	Gas	Bank Edge – Discovered ~100 m gas pay, not tested. Well data confidential until October 23, 2005.

Table 2. Chronological List of Deep Panuke Abenaki Discovery and Delineation Wells.

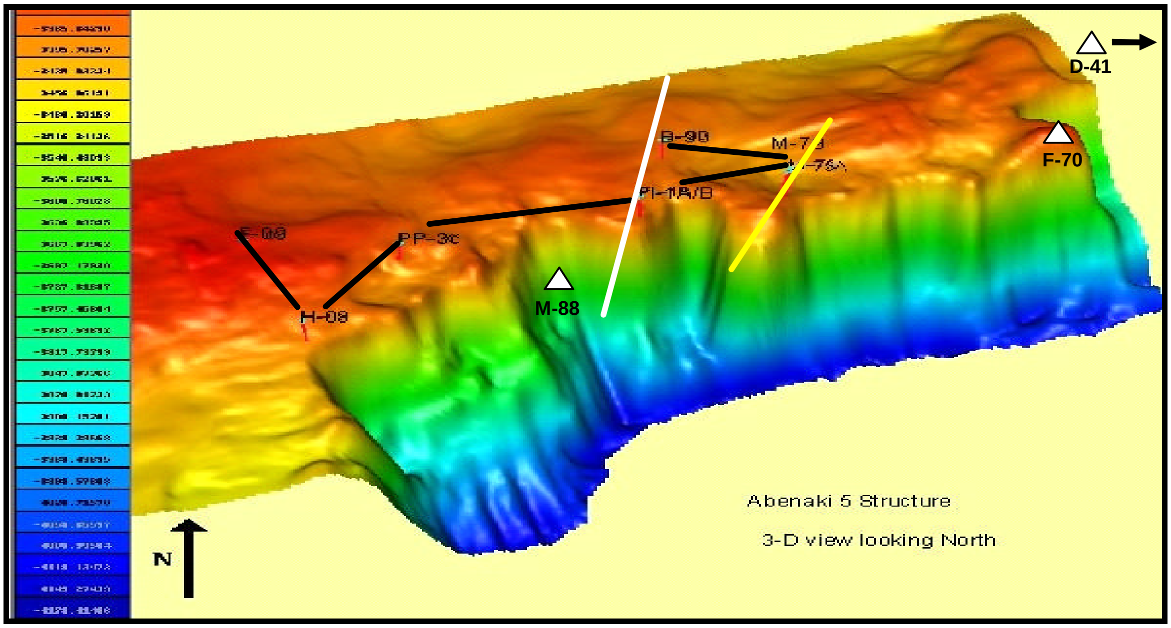


Figure 27. North view 3D depth structure of the main Deep Panuke gas reservoir, top Abenaki 5 sequence. Black line shows the location of the cross section in Figure 28; yellow and white lines the seismic profiles in Figures 29 and 30. Contour interval 20 metres, scale ranges from -3280 mSS (red) to -4160 mSS (blue) (slightly modified after PanCanadian, 2002).

Well	Zone	Gross Thickness (M)	Net Pay (M)	Porosity	Sw
Panuke PP-3C	Abenaki 6	182.7	0.0	--	--
	Abenaki 5	125.8	44.6	0.24	0.28
	Abenaki 4	87.8	0.0	--	--
	Total	**396.3**	**44.6**	**0.24**	**0.28**
Panuke PI-1A	Abenaki 6	193.5	2.0	0.06	0.19
	Abenaki 5	133.7	1.5	0.06	0.19
	Abenaki 4	39.7	0.0	--	--
	Total	**366.8**	**3.5**	**0.06**	**0.19**
Panuke PI-1B	Abenaki 6	192.2	0.0	--	--
	Abenaki 5	124.4	13.9	0.07	0.08
	Abenaki 4	27.9	10.2	0.06	0.10
	Total	**344.5**	**24.2**	**0.07**	**0.09**
Panuke H-08	Abenaki 6	131.0	3.2	0.08	0.32
	Abenaki 5	145.0	104.7	0.24	0.22
	Abenaki 4	108.0	0.0	--	--
	Total	**383.9**	**108.0**	**0.23**	**0.22**
Panuke F-09	Abenaki 6	151.4	0.0	--	--
	Abenaki 5	116.7	0.0	--	--
	Abenaki 4	114.7	0.0	--	--
	Total	**382.8**	**0.0**	**--**	**--**
Panuke M-79	Abenaki 6	195.9	0.0	--	--
	Abenaki 5	124.8	0.0	--	--
	Abenaki 4	134.8	0.0	--	--
	Total	**455.6**	**0.0**	**--**	**--**
Panuke M-79A	Abenaki 6	177.9	0.0	--	--
	Abenaki 5	67.1	11.4	0.10	0.05
	Total	**245.0**	**11.4**	**0.10**	**0.05**
Margaree F-70	**Well data confidential until August 6, 2005.**				
MarCoh D-41	**Well data confidential until October 23, 2005.**				

Table 3. Deep Panuke Well Reservoir Data.

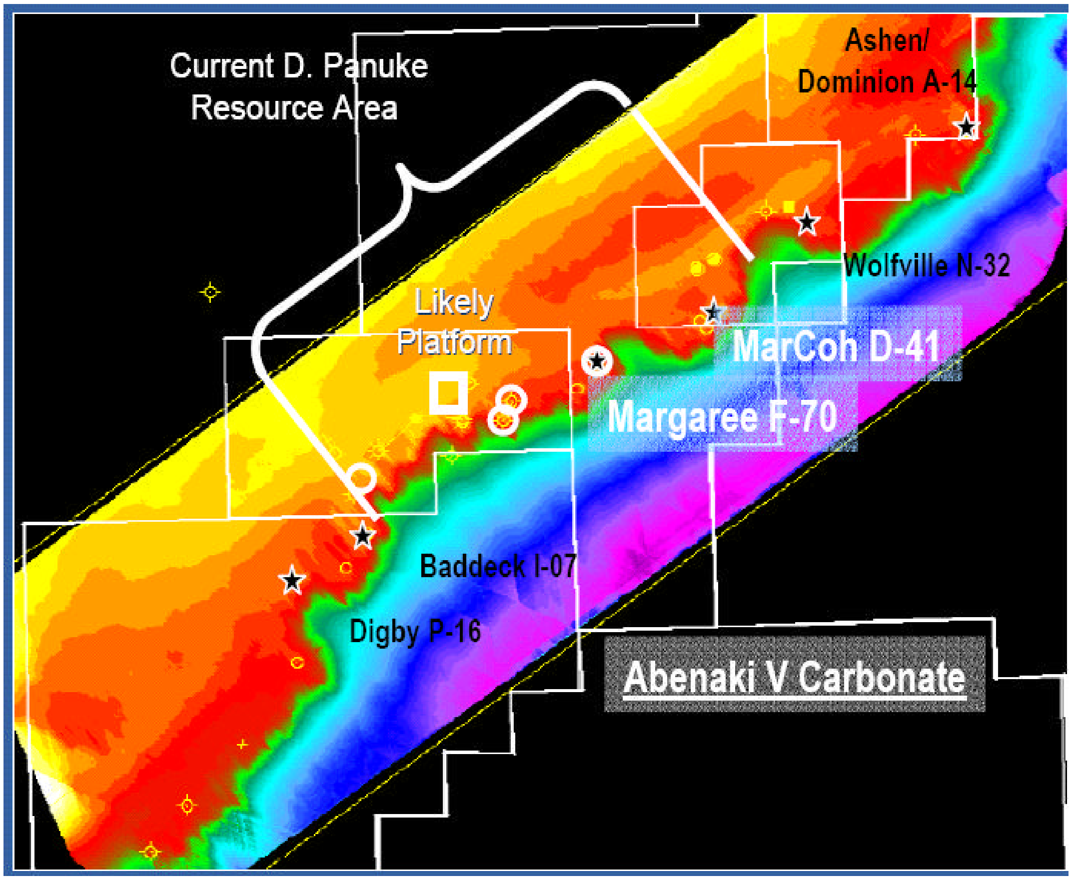


Figure 28. Deep Panuke Abenaki 5 structure map. Note the elongate syncline behind and paralleling the northeastern extension of the field which is interpreted as related to possible pre-Break-up siliciclastic loading and salt withdrawal. The Margaree F-70 and MarCoh D-41 wells have been drilled and discovered significant gas pay (~70m and >100m respectively). The Wolfville N-32, Ashen/Dominion A-14, Baddeck I-07 and Digby P-16 locations are proposed well locations only (Source: Encana website - http://www.encana.com/investor_hub/pdfs/2003/InvestorDayFoothillsFrontier.pdf).

Well	Zone	Depth (TVD)	Test No.	Pressure (Kpa / Psi)	Max. Gas Rate (E^3m^3/D / MMcf/D	Condensate Ratio m^3/E^6m^3 / Bbl/MMcf	Water Ratio m^3/E^6m^3 / Bbl/MMcf
PP-3C	Abenaki 5/4	3475.7	2	36510 / 5294	1690 / 59.7	8.1 / 1.4	10.0 / 1.8
PP-3C	Abenaki 5/4	3475.9	4	36440 / 5284	1650 / 58.3	12.0 / 2.1	20.0 / 3.6
PI-1B	Abenaki 5	3454.6	2	36768 / 5331	1490 / 52.6	12.5 / 2.5	8.3 / 1.5
H-08	Abenaki 5	3448.0	1	36355 / 5271	1450 / 51.2	6.9 / 1.2	17.5 / 3.1
M-79A	Abenaki 5	3355.5	1	36310 / 5265	1790 / 63.2	20.0 / 3.6	6.3 / 1.1

Table 4. Deep Panuke Drill Stem Test Data.

Conventional drill stem tests all tested the Abenaki 5 with one exception (Abenaki 4) with rates in the former ranging from 50-65 Mmcf/d AOF. Gas from the Abenaki 5 is normally-pressured and is on a common pressure system. It is very lean, with a calculated rate of about 2000 bbls of condensate per day based on peak gas production of 11.6 E^6m^3/d (400 MMscf/d) with low levels of H_2S (~2000 ppm / 0.2%) and CO_2 (~35,000 ppm / 3.5%). Reservoir temperature averages 123ºC with measured DST pressure ranges in the Abenaki 5 zone from 36310-36768 kpa.

PanCanadian's (2002) probabilistic reserves calculations for the Abenaki 5 zone estimate an expected value (EV) of 1.2 Tcf / 33.0 E^9m^3 OGIP. Recoverable (sales) gas volumes were similarly calculated at 929 Bcf / 26.3 E^9m^3. Mean (P50) OGIP values are 1.1 Tcf / 31.0 E^9m^3, with an upside (P10) of 1.5 Tcf / 43.7 E^9m^3 and base case (P90) of 777 Bcf / 22.0 E^9m^3. The most recent figure for recoverable (sales) gas volumes is 950 Bcf / 26.9 E^9m^3 (various EnCana press releases, 2004, 2005).

Additional information related to the Deep Panuke field can be found elsewhere in this report including seismically derived 3D isometric views (Figures 26-28, 33-33) and seismic profiles through selected Panuke field wells (Figures 83-92). Complete technical and other information on the proposed Deep Panuke development is available in EnCana's Development Plan – Volume 2 (2002).

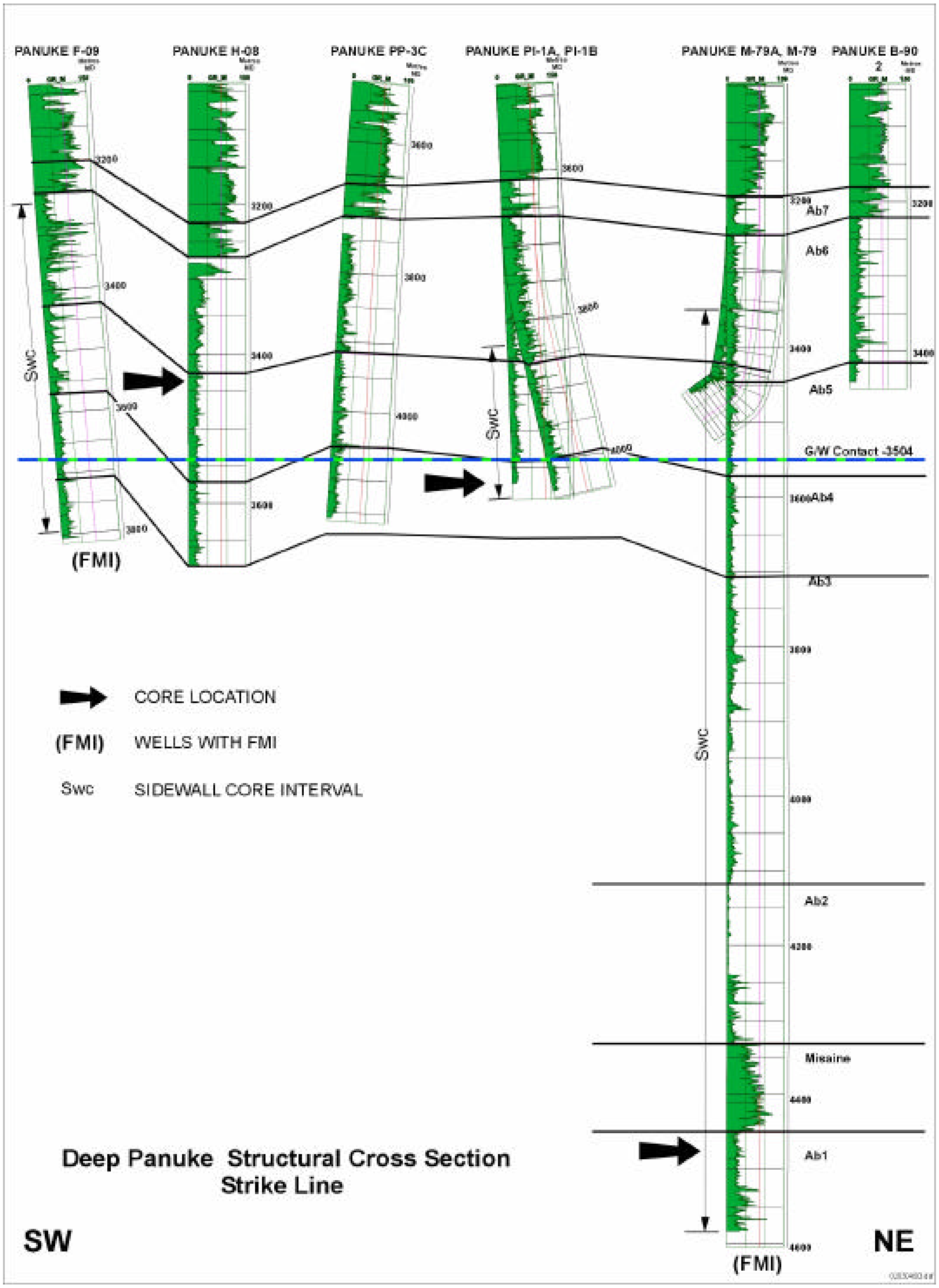


Figure 29. Strike-orientated gamma log structural cross section along the Deep Panuke gas field illustrating the main stratigraphic subdivisions, pay intervals, gas/water contact and conventional and sidewall core locations. Well depths are measured depths from the KB. Wells drilled since 2002 and not noted in this figure include EnCana Queensland M-88, Margaree F-70 and MarCoh D-41 though are shown in Figures 26 and 27 (slightly modifies after PanCanadian, 2002).

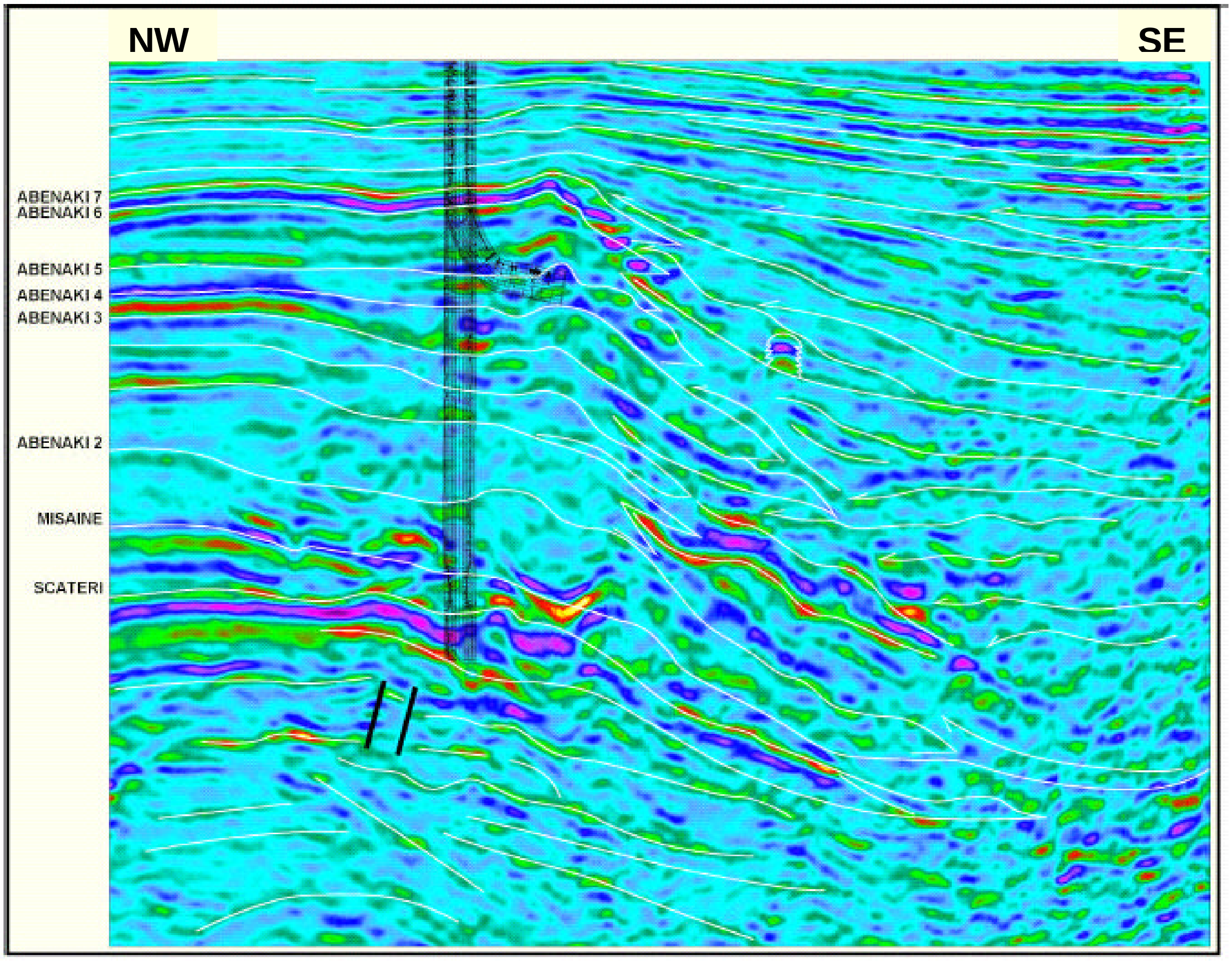


Figure 30. Seismic dip profile (depth) through the Panuke M-79 (vertical) and M-79A (deviated) wells. Length of section is about 2 kilometers with the location indicated by the yellow line in Figures 26 and 27 (PanCanadian, 2002).

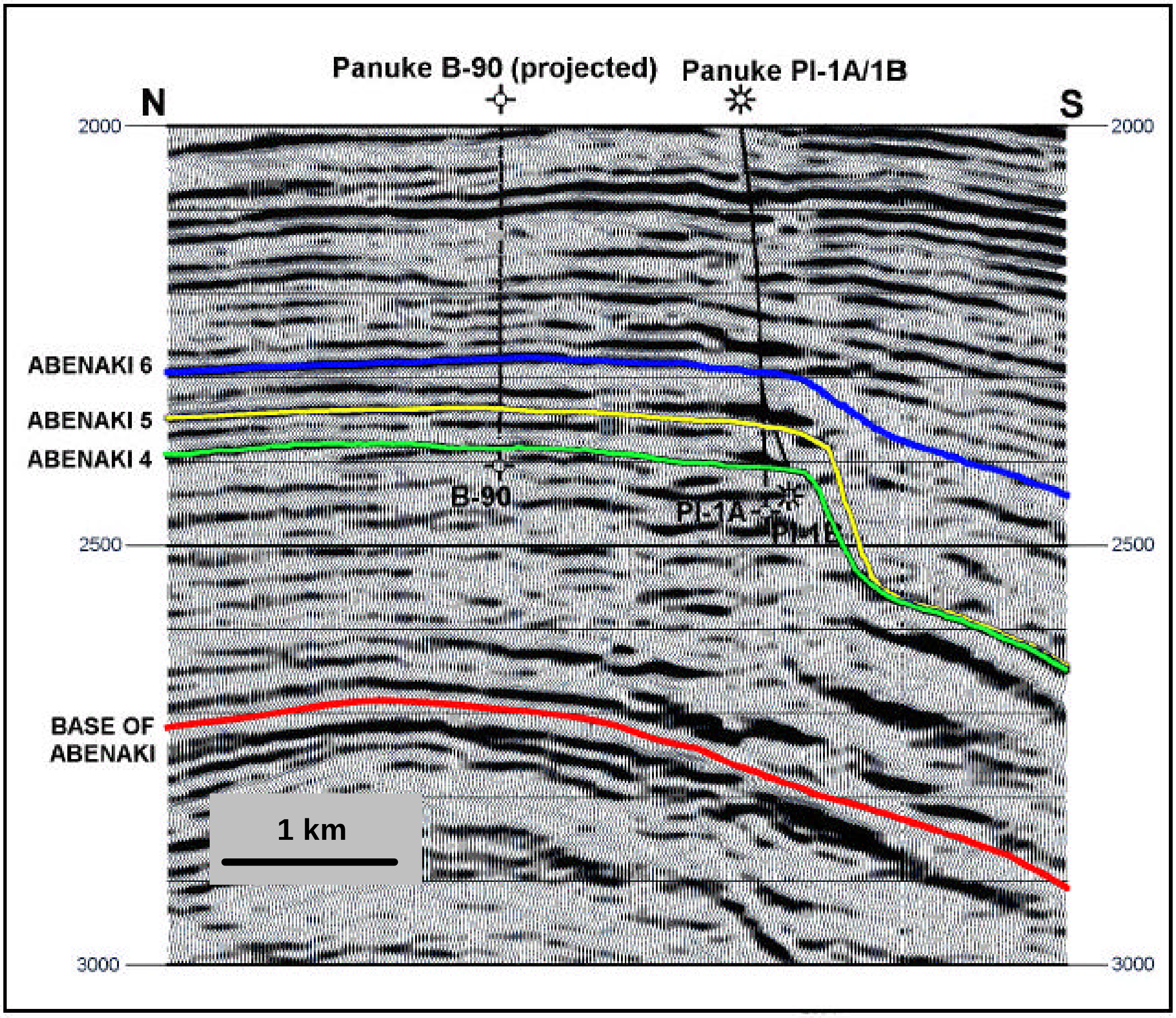


Figure 31. Seismic dip profile (time) through the Panuke B-90 and Panuke PI-1A and PI-1B wells. Length of section is about 3.5 kilometers with the location indicated by the white line in Figures 26 and 27 (PanCanadian, 2002).

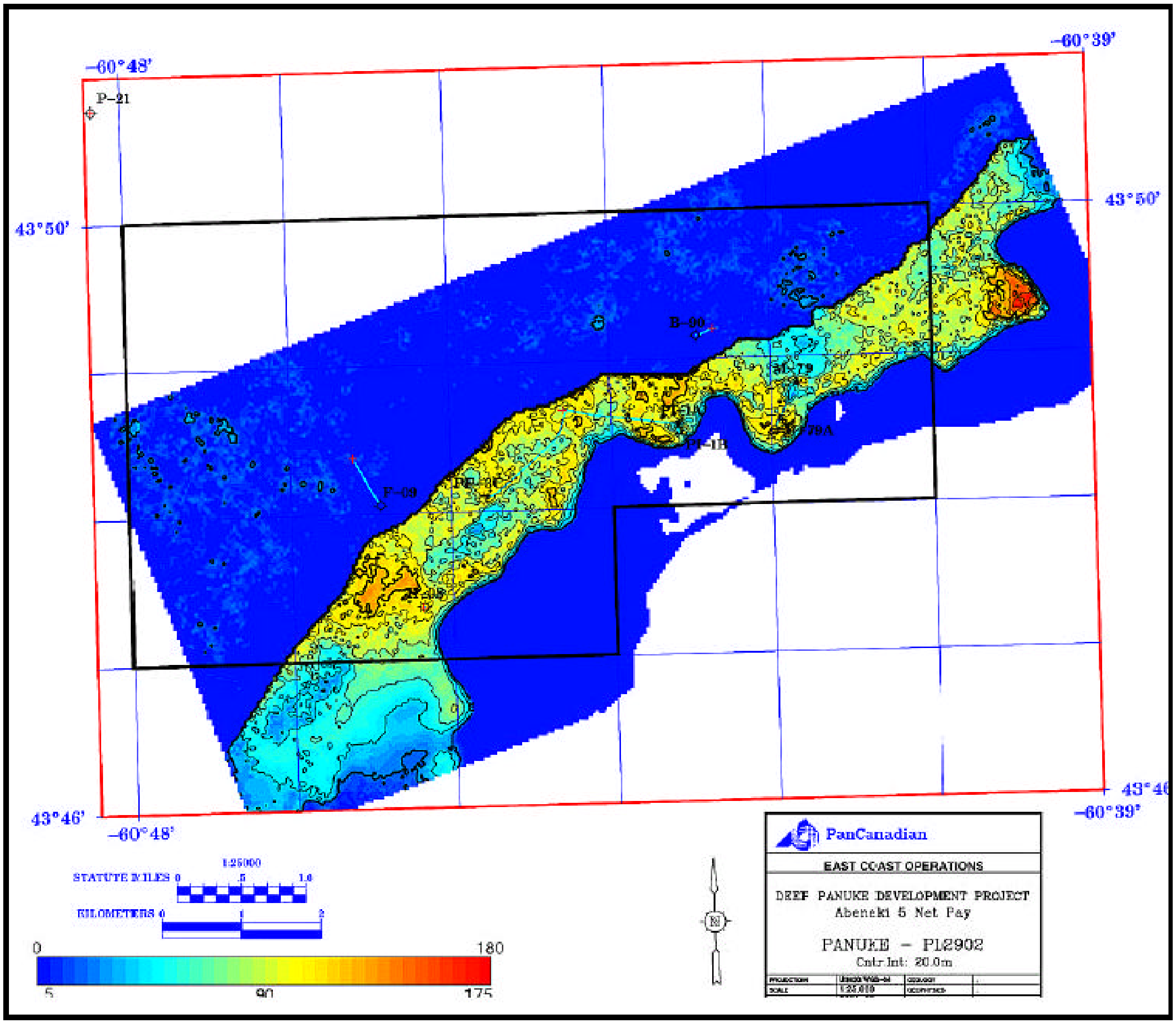


Figure 32. Abenaki 5 net pay map with average seismic porosity. Contour interval 20 metres (PanCanadian, 2002).

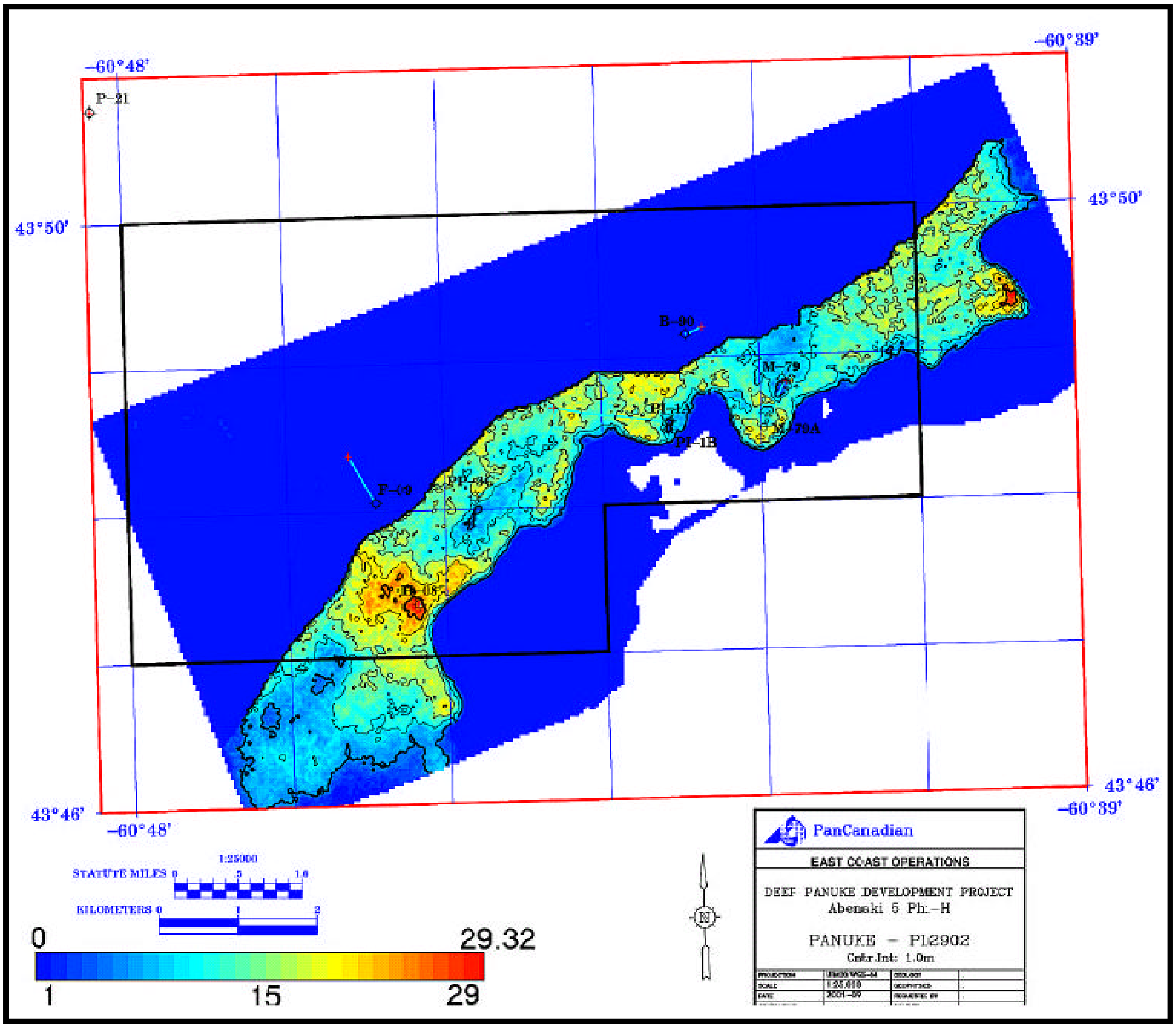


Figure 33. Abenaki 5 Phi-h map with average seismic porosity. Contour interval 1.0 metres (PanCanadian, 2002).

6. ANALOGUE BASINS

The proto-North Atlantic Ocean was rimmed by a carbonate prone shelf from Mid-Jurassic to Late Jurassic and later. Figure 34 shows the juxtaposition of northwest Africa with the eastern seaboard of North America during the Early Jurassic, with the Moroccan Essaouira and Aauin-Tarfaya Basins offsetting the Scotian and George's Bank Basins respectively. The following section offers an overview of several of the conjugate basins containing Late Jurassic carbonate margin successions as well as brief comments on respective historic petroleum exploration programs.

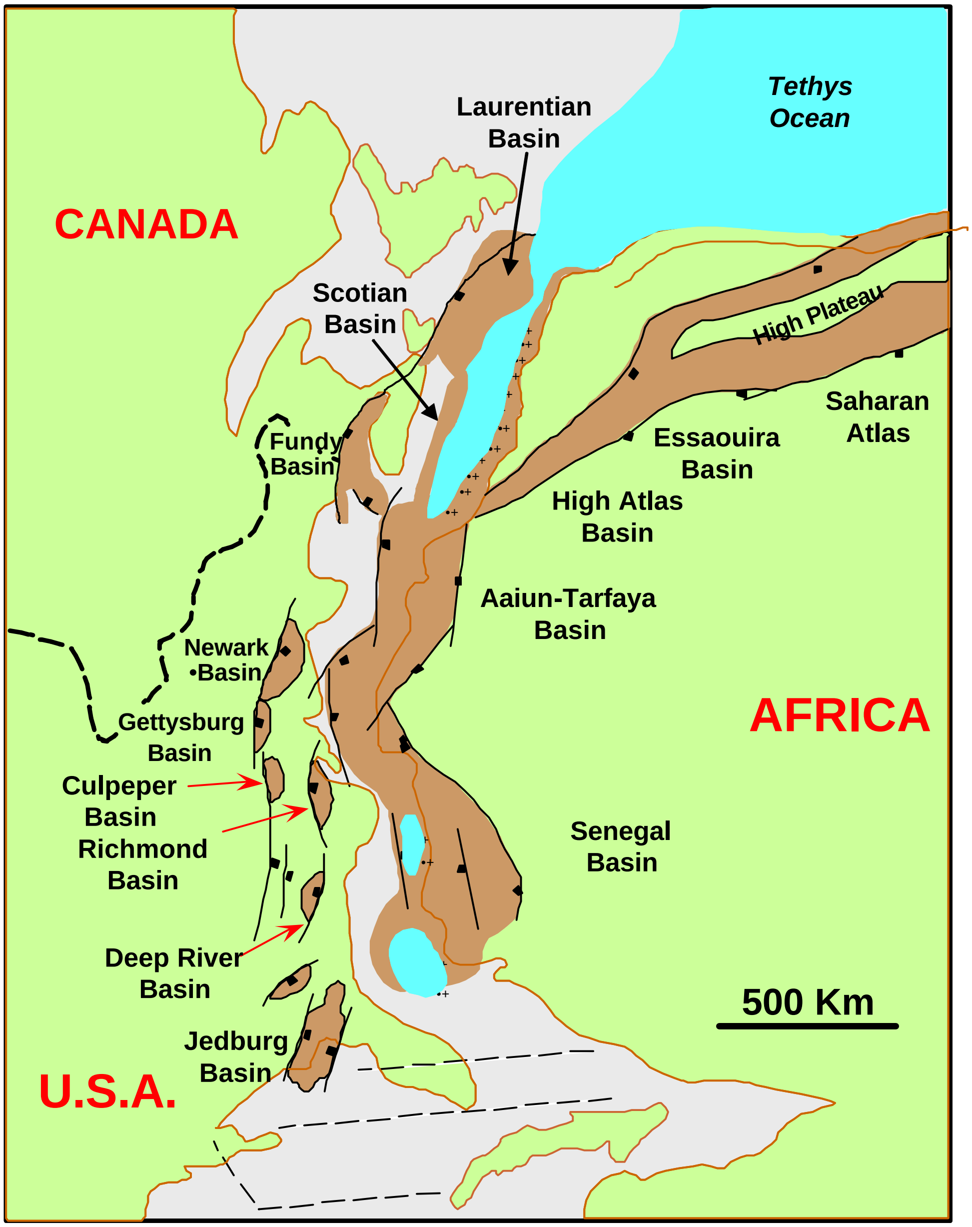


Figure 34. North Atlantic Lower Jurassic depositional setting, pre-Break-up unconformity (mid-late Sinemurian): early synrift basins (brown), uplands (green), ocean waters (blue), future continental margins (white) (ONAREP, 2000b).

6.1 U.S. Atlantic Margin

A total of 54 wells have been drilled off the U.S. Atlantic coast; 49 industry exploratory wells and five COST wells (Continental Offshore Stratigraphic Test) (Figure 35). The five COST wells were drilled during 1976 and 1977 in advance of lease sales to industry. Two of the wells (G-1 and G-2) were drilled on George's Bank, two were drilled in the Baltimore Canyon (B-2 and B-3) and one (GE-1) in the Georgia Embayment. Of the 49 exploratory wells, eight were drilled on George's Bank, 32 in the Baltimore Canyon, six in the Southeast Georgia Embayment and three in the Dry Tortugas off Florida. Although significant natural gas was tested in the Baltimore Canyon area with individual flow rates up to 19 MMcf/d, none were deemed commercial (Mattick, 1988).

The 54 wells were mostly drilled on the Late Jurassic shelf, targeting clastic and carbonate reservoirs in structural and stratigraphic traps. The schematic geological cross-section (Figure 36) illustrates the prograding shelf and post-breakup unconformity. An important aspect is the position of the present-day shelf edge relative to the Upper Jurassic shelf edge which has adversely affected seismic data quality. This issue will be discussed in detail in Sections 6.1.1 and 6.1.2.

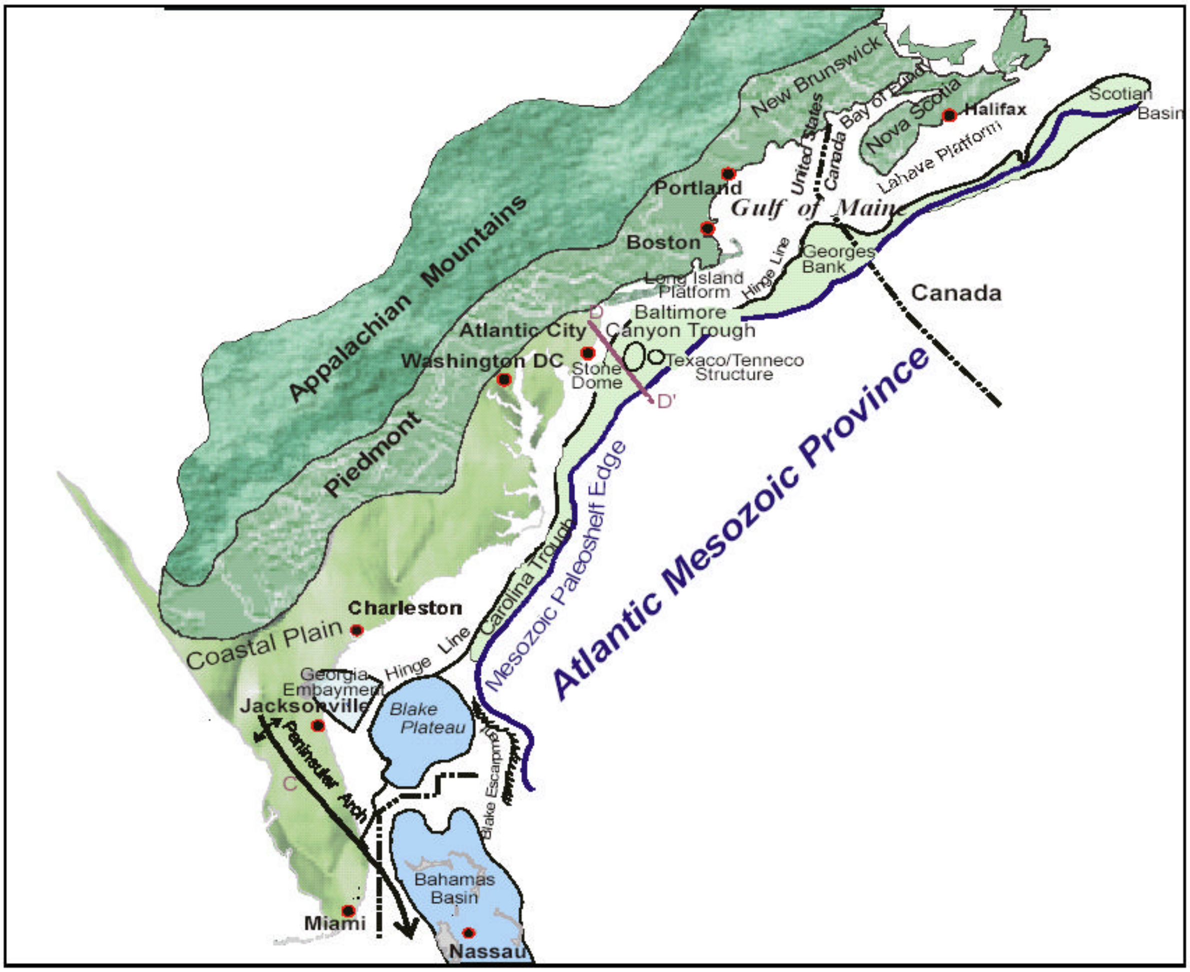


Figure 35. Tectonic elements, eastern North America (Lore et al., 2001).

In 1983-84, the focus briefly shifted to the Jurassic bank edge beneath the present-day deepwater slope in water depths up to 2000 m. Four wells were drilled without success though only two were bonafide bank edge wells. It is interesting to note that during this latter period, industry in Canada had completed five wells targeting the Abenaki; four in the Panuke Segment and one in the western Acadia Segment, Chevron Acadia K-62 (1978). Indeed, for the entire bank edge play west of Sable Island, only one well was drilled in the 1000 km distance between Sable Island and the Baltimore Canyon.

Available seismic data for the U.S. Atlantic margin is difficult to obtain. Published seismic profiles are generally too small and lack resolution to see any details. Any seismic data acquired prior to 1975 is not releasable by the U.S. Minerals Management Service (MMS) and that seismic shot after 1975 has a 25 year confidentiality period. Based on available data, seismic imaging of the steeply dipping carbonate bank margin is considered inadequate by today's standards. While beyond the scope of this study, much of the interpretations related to these data are by necessity based on single widely-spaced lines rather than a regional survey interpretation.

Along the US Margin there were a total of 10 lease sales from 1959 (Florida Straits), but most occurred during 1976 to 1983 period. The 433 leased blocks garnered almost US$3 billion in cash bonuses. Currently there are no existing active leases, a as 1990 Presidential Executive Order cancelled any further sales for an unspecified period.

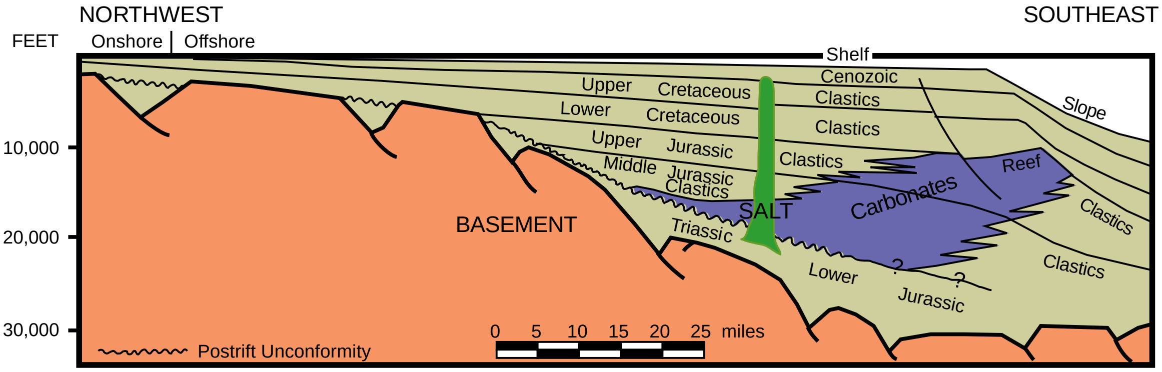


Figure 36. Geological cross section, U.S. Atlantic Margin. Line of section D-D' is shown in Figure 27 (Lore et al., 2001).

6.1.1 Baltimore Canyon Trough

The Baltimore Canyon Trough location map (Figure 37) shows the clustering of wells in that basin. Major drilling programs were concentrated in areas of large structural relief on the continental shelf later attributed to salt and, sometimes, igneous intrusions (Mattick and Libby-French, 1988) (Figure 38). Four of the wells were in deeper water (93-1, 586-1, 587-1 and 372-1), but only 587-1 and 372-1 targeted the bank edge, the other two were drilled on back-reef structures. Although a number of wells on the "Texaco-Tenneco Structure" tested gas and oil/condensate from Late Jurassic and Early Cretaceous sands, none were deemed to be of commercial size. Five wells tested gas at rates of 1 - 19 MMcf/d and three wells tested oil/condensate at 18-630 bopd.

A regional seismic line (Figure 39) clearly shows the prograding carbonate shelf edge and the present-day shallow depth of burial beneath the continental slope. Figure 40 is another seismic profile that illustrates the bank edge test which indicates that the 587-1 well was testing back-reef facies about 3000 m landward of the main carbonate buildup. However, given a progradational carbonate platform setting the well could have tested earlier and deeper interpreted bank edges although they do not appear to have a "rimmed" morphology.

The structure map on the top of Valanginian carbonates (Figure 41) shows the bank edge rimming reefal buildups and the overall structural closure along the platform margin. Based on the seismic and well data, Prather (1991) notes:

“Leached rock fabrics and fossil moldic porosity in the Berriasian reefal limestones suggest that rising sea level was followed by subaerial exposure and freshwater leaching during a sea level lowstand in the Late Berriasian. Freshwater leaching may account for the fact that the shelf-margin limestones consist of approximately 25% reservoir quality rock (f > 8%). Exposure was followed by a rapidly rising sea level which drowned the platform.”

Petroleum geology of U.S. Atlantic continental margin

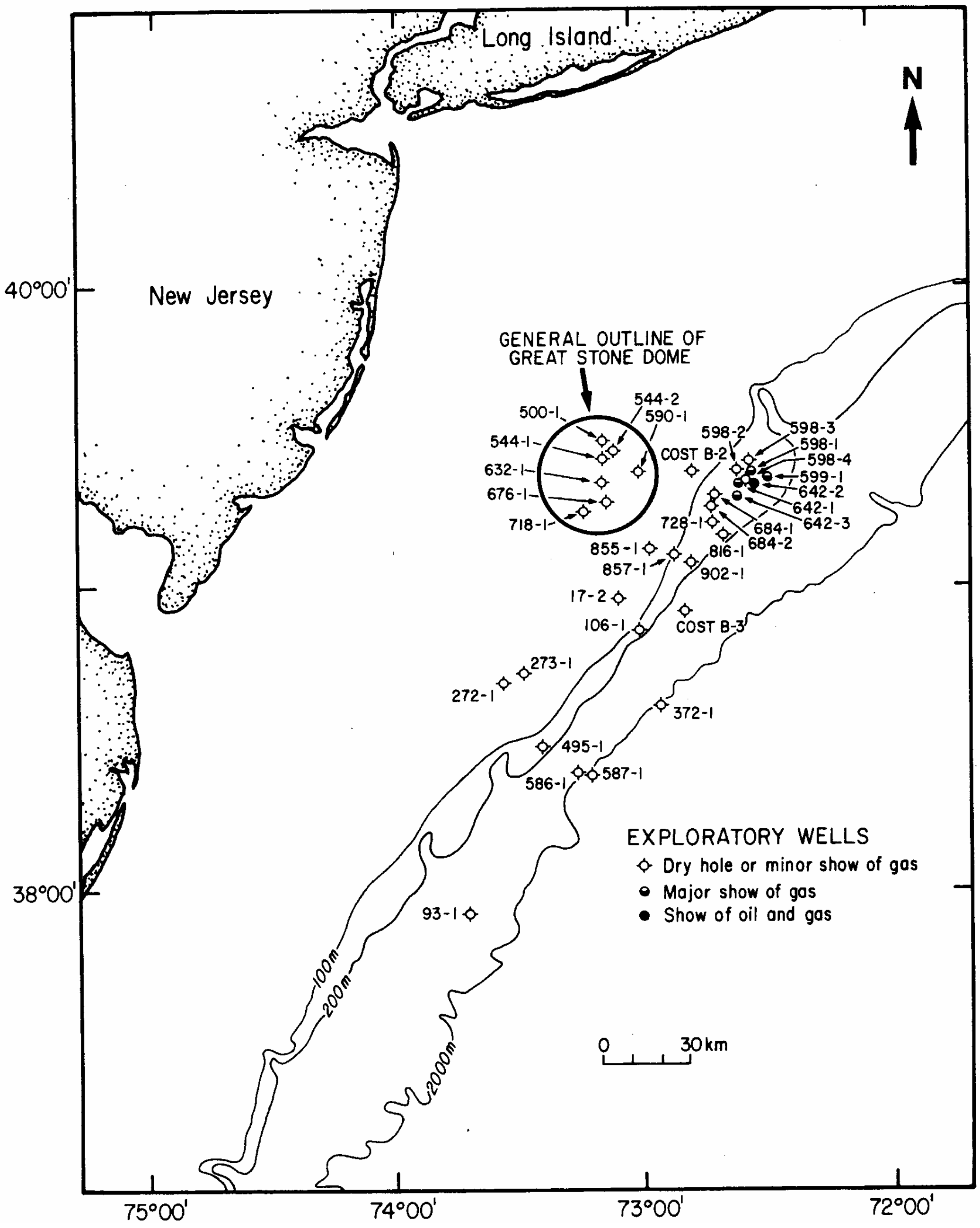


Figure 37. Baltimore Canyon well location map (Mattick and Libby-French, 1988).

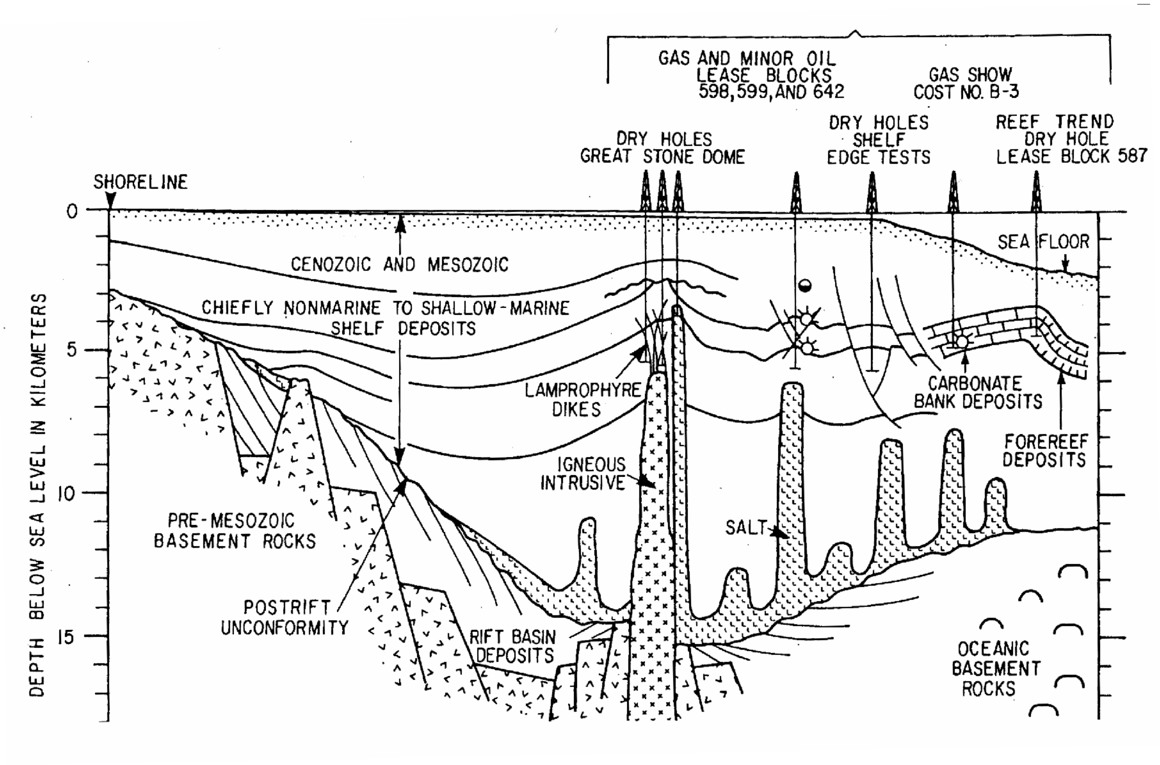


Figure 38. Geological cross-section, Baltimore Canyon (Mattick and Libby-French, 1988).

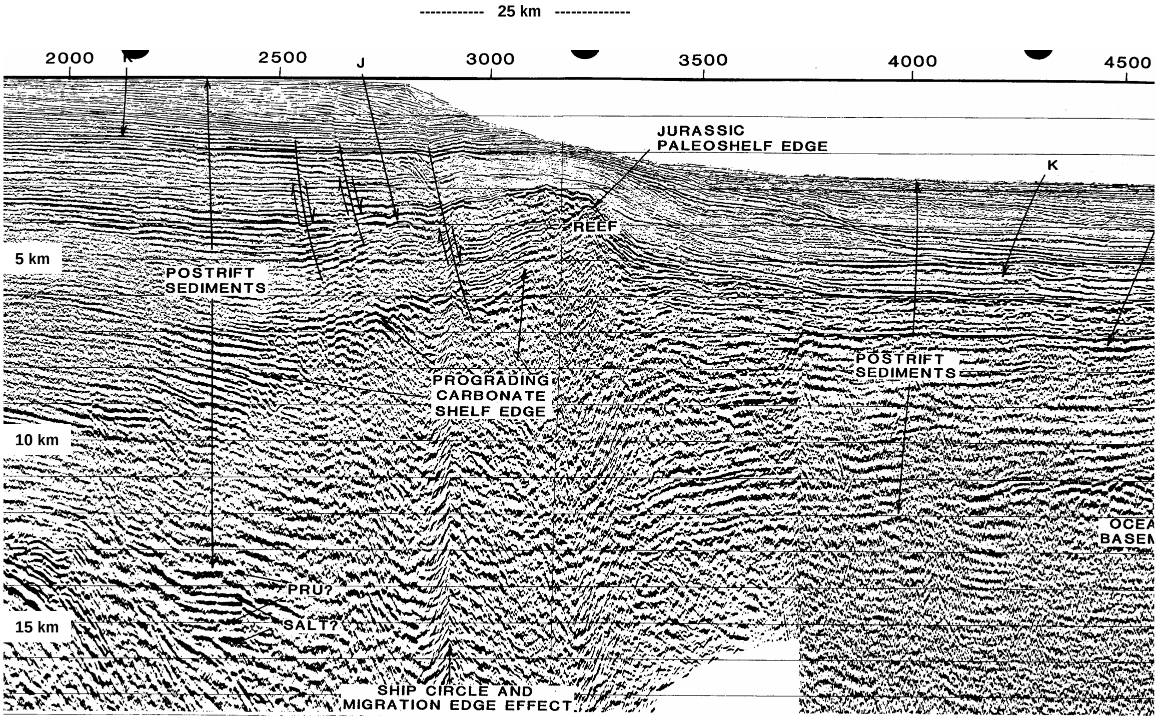


Figure 39. Regional seismic Line 25 through the Baltimore Canyon Trough (Grow et al., 1988).

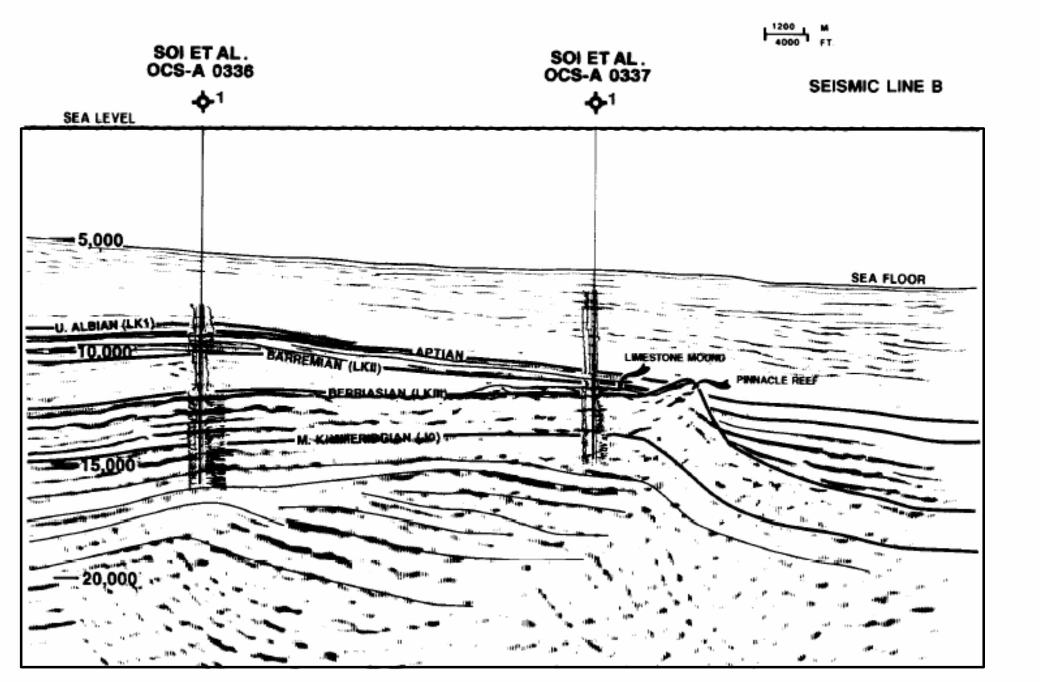


Figure 40. Detailed seismic line, Baltimore Canyon Trough. Shell et al OCS-A 0337 and Shell OCS-A 0336 are company designations and are identified by the MMS as Shell 587-1 and Shell 586-1 respectively (Prather, 1991).

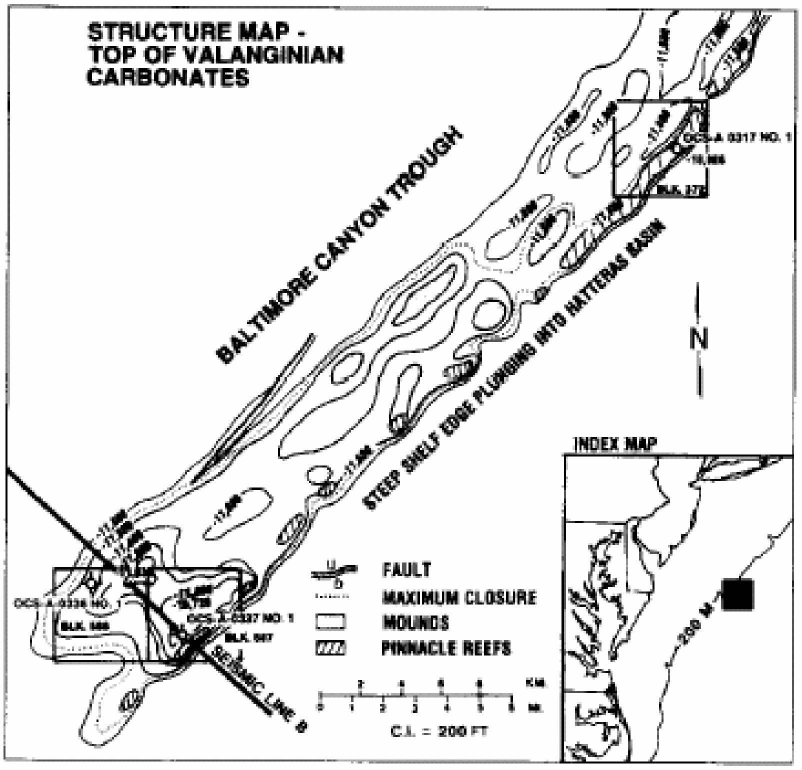


Figure 41 Structure map, top of Early Cretaceous shelf-margin carbonates, Baltimore Canyon defining possible mound and reef structures (Prather, 1991).

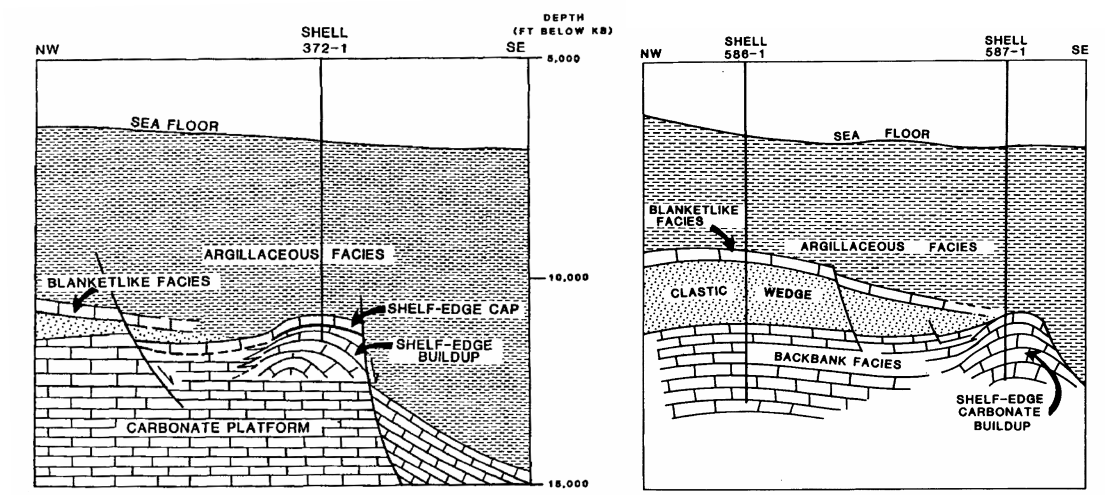


Figure 42. Diagrammatic cross sections through Baltimore Canyon wells: A) Shell 372-1 (Edson, 1988) and B) 586-1 and 587-1 wells (Edson, 1986 and 1987).

Schematics from the MMS well summaries (Edson, 1986, 1987, 1988) show offlapping facies during the drowning of the carbonate platform and bank (Figure 42). However, the 587-1 well is in a contradictory position relative to the previous figure, hence there is a question of the diagnosticity of this well. Based on the then-available data, it was eventually concluded that while the Baltimore Canyon Trough contained good reservoirs and top seals, the lack significant hydrocarbon shows in any of the wells inferred the absence of adequate and mature source rocks, and/or migration pathways (Prather, 1991).

6.1.2 George's Bank Basin

Up until the 1970's, the presence of a carbonate platform in the subsurface of George's Bank was largely an assumption based on seismic and drilling results from the Scotian Basin. In 1977, the deep diving submersible "Alvin" was able to collect rock samples from several submarine canyons confirming age and lithological correlations with the regional stratigraphy (Ryan and Miller, 1981).

The George's Bank drilling program began with two COST wells G-1 (1976) and G-2 (1977) followed by eight exploration tests in 1981-1982 drilled during a period of exploration hiatus offshore Nova Scotia. The wells were all within 65 km of each other in water depths ranging from 63 – 138 m (Figure 43). The exploration targets were Middle/Late Jurassic oolite banks, reefs and drape structures over basement highs and/or salt swells. Indicators were high amplitude reflectors and apparent structural closures at depths between 2750 – 4875 m. However, drilling results revealed low-porosity micrites, wackestones and packstones while volcanics and halite/anhydrites were responsible for some "bright spots". Source rock potential was discouragingly lean, < 1% TOC:

> *"In summary, the source rock potential in the currently drilled portion of George's Bank Basin at sufficient depths for thermal maturity, 8,000 to nearly 22,000 feet (2440 – 6700 m) (the deepest drilling), is poor." (Edson et al., 2000a)*

Along the edge of George's Bank, the inferred Jurassic bank edge lies at a shallow depth beneath a channelized slope which results in its poor imaging by seismic. When Ryan and Miller (1981) successfully sampled Late Jurassic/Early Cretaceous outcrops in submarine canyons, they acknowledged the potential loss of hydrocarbons through leakage by continental-margin erosion has significant economic implications. They also stated that submarine canyon erosion was active in Mesozoic time as was the syndepositional mechanical defacement of high-standing carbonate escarpments. The steep bank edge thus may also have suffered faulting and erosion with removal of high-energy reefal facies.

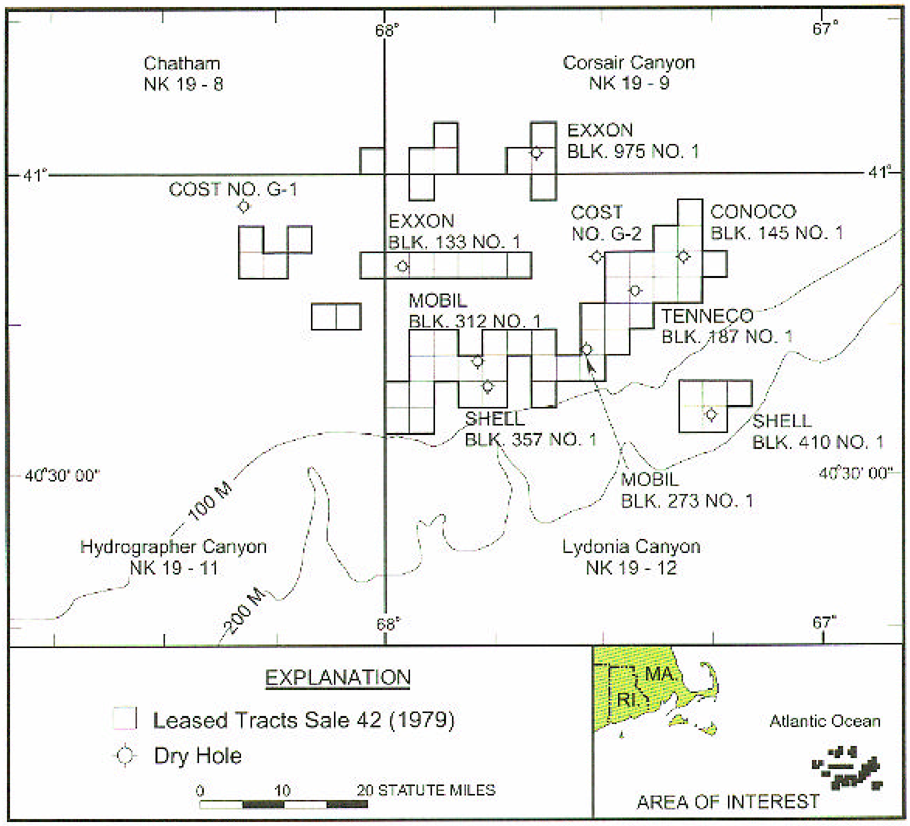


Figure 43. Land parcel and well locations (1982), Georges Bank Basin (U.S.) (Edson et al., 2000a).

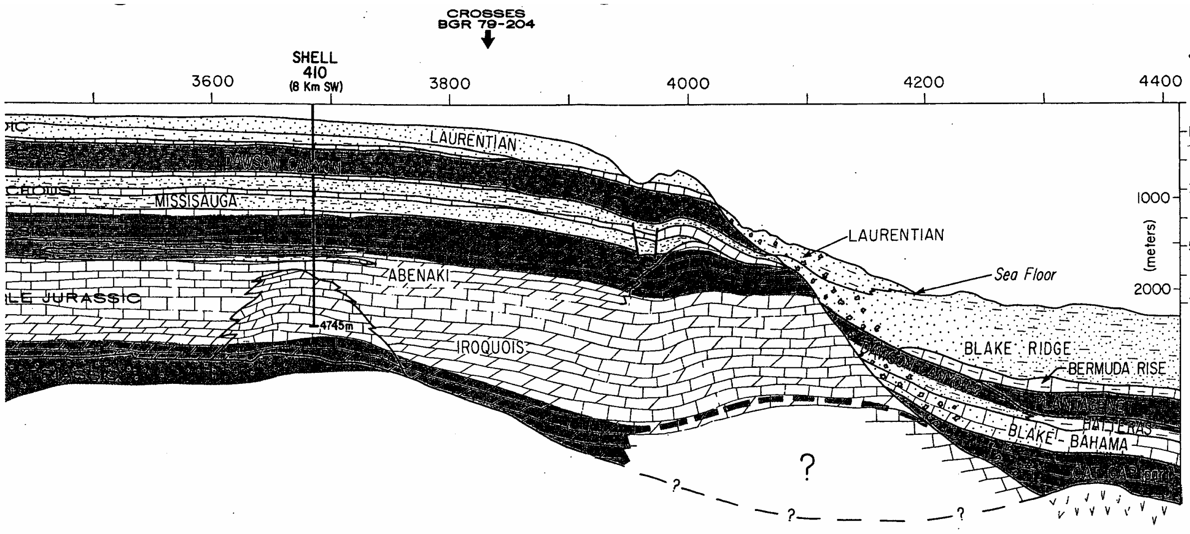


Figure 44. Geological cross section based on NW-SE seismic Line 19 through the outer margin of the Georges Bank Basin (modified from Plate 3A of Poag and Valentine, 1988). The Shell 410 well targeted a suspected Jurassic (reefal) closure that was not present.

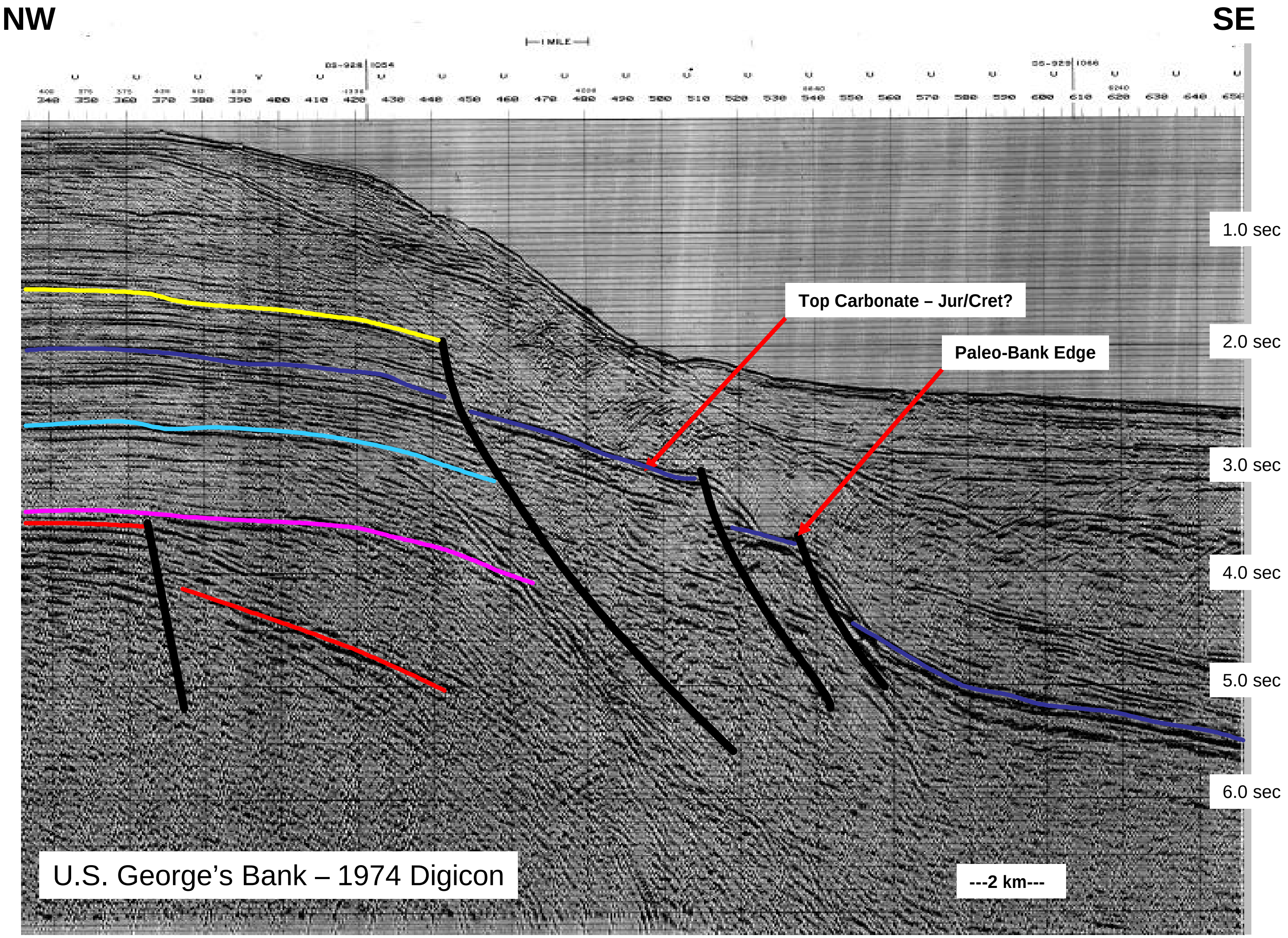


Figure 45. Southern Digicon (1974) seismic line through the edge of the George's Bank Basin. See text for details. Line location on Figure 4.

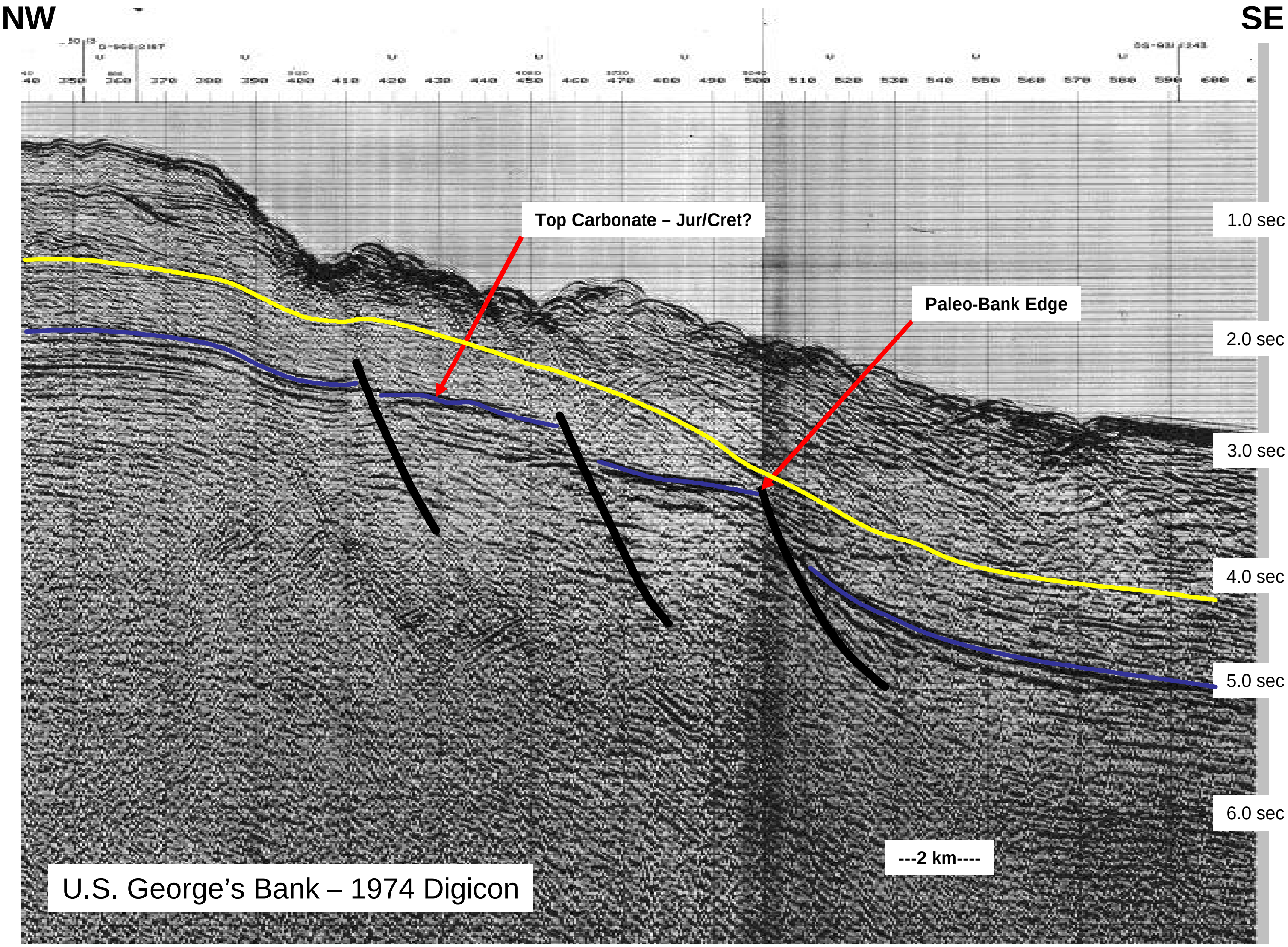


Figure 46. Central Digicon (1974) seismic line through the edge of the George's Bank Basin. See text for details. Line location on Figure 4.

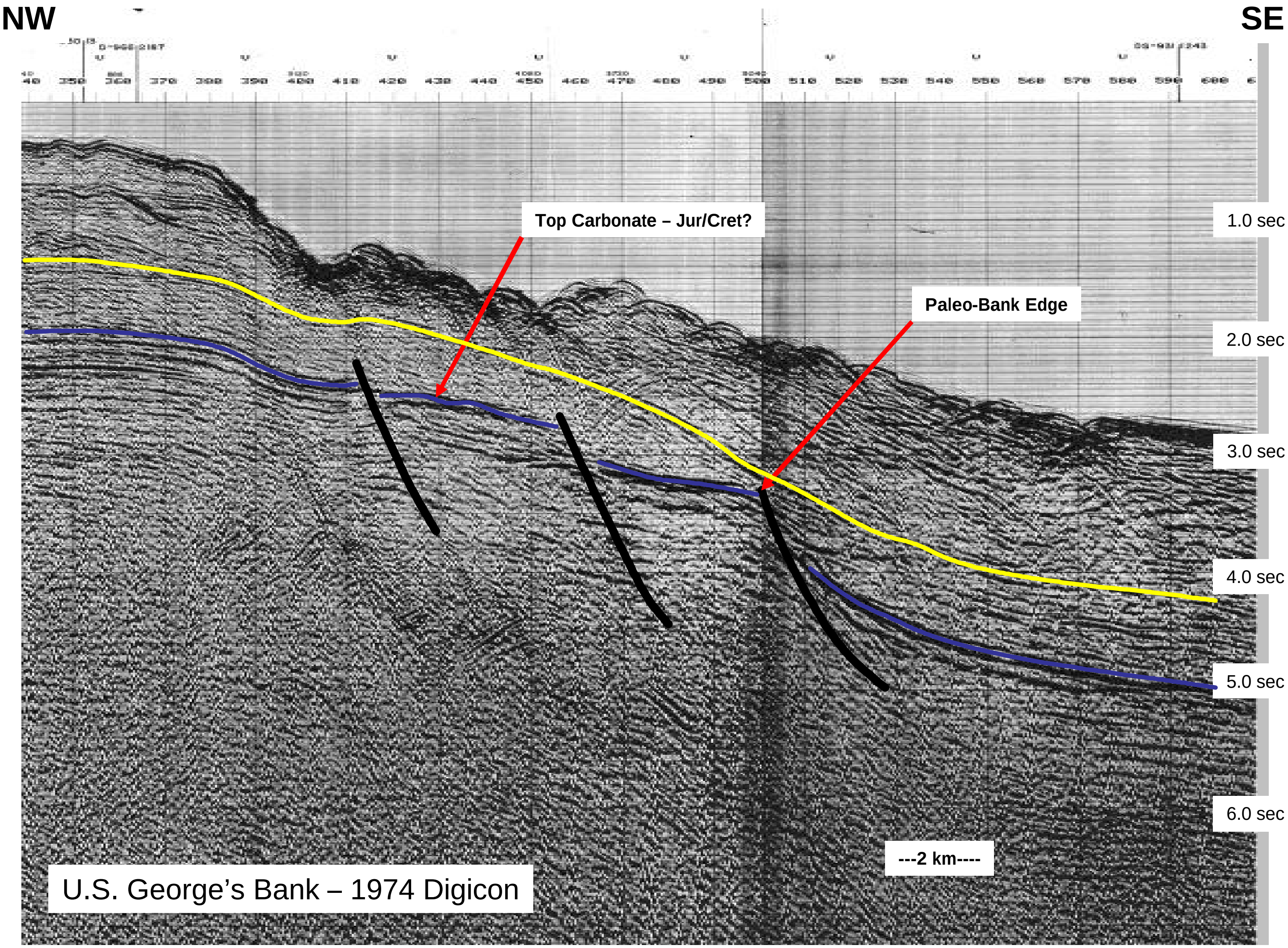


Figure 47. Northern Digicon (1974) seismic line through the edge of the George's Bank Basin. See text for details. Line location on Figure 4.

A geological cross-section (Figure 44) shows the closest American bank edge well, Shell 410, located about 20 km from the platform margin. The well drilled 2895 m (1722 to 4617 m) of predominantly oolitic limestone with shale interbeds. The Abenaki interval is age dated as Early Valanginian to an undetermined Bajocian or older age below 3474 m. The carbonate section had generally poor porosity except for dolomites below 4328 m (Edson et al., 2000b).

Three seismic profiles over George's Bank typify the carbonate bank morphology from south to north (Figures 45-47). Their exact locations and identity of the data are confidential due to the petroleum exploration moratorium over the area. The interpretations are projected from research on the Canadian side and knowledge of the adjacent wells but are not directly tied into the wells. The illustrative point to show with these lines is the general morphology of the carbonate bank edge and the clarity of its seismic imaging, or lack thereof. The Jurassic/Cretaceous bank edge lies beneath the present-day shelf-slope break which is very disruptive for seismic imaging and in particular applies to the mapping of the shale/carbonate interface and the internal character.

Figure 45 southwest of the wells shows the carbonate bank edge, probably of Early Cretaceous age (Berriasian) dipping seaward and faulted. The actual paleo reef-prone margin is thus difficult to pick and any diagnostic seismic attributes within the carbonate front probably impossible to extract. The blue horizon is analogous to the Top Jurassic marker as interpreted on the Canadian side, especially in the deepwater, but these ages are not precisely determined.

Figure 46 illustrates more seismic interference from the uneven (slumped?) seafloor but an assumed sigmoidal shape of the margin the Jurassic shelf break can be interpreted. Questions of low-angle ramp versus high-angle rim are not easily addressed unless the water wedge effect in depth sections is removed. However, the variability of carbonate platform edge morphology that occurs along strike is acknowledged.

Figure 47 is a profile approaching the Canadian border and reveals a zone of interpreted salt disruption of the bank edge. The line displays the interpreted escarpment-like bank edge lying very close to the seafloor and a steep high displacement fault extending from the paleoshelf to the deepwater. Such mechanical defacement, however accomplished, is nonetheless destructive to bank edge preservation.

		Mean UCRR	
Assessed Plays	**Probability**	**Oil (BB)**	**Gas (Tcf)**
Lower Cretaceous Clastics[1]	1.0	0.7	11.8
Upper Jurassic Carbonates[2]	1.0	0.2	1.5
Upper Jurassic Clastics[3]	1.0	0.8	9.0
Middle Jurassic Carbonates[4]	0.64	0.1	0.6
Middle Jurassic Clastics[5]	0.90	0.4	4.9
Totals		**2.3**	**27.7**

Comments:

[1] Scotian Basin analogue; Missisauga Fm. et al. Well 642-2 tested 640 bopd

[2] GOM analogues, reef/back-reef porosities, subaerial exposure, 3 wells porosity, no hydrocarbons

[3] GOM, Scotian Basin (Mic Mac), 5of 8 wells in Hudson Canyon, gas to 19MMcf/d

[4] GOM analogues, shallow water platforms and ramps

[5] GOM and Scotian Basin

Table 5. MMS 2000 Assessment, U.S. Atlantic Mesozoic Margin: Ultimate Conventional Recoverable Reserves (Lore et al., 2001)

6.1.3 Minerals Management Service Resource Assessment

The assessment of the U.S. Atlantic Mesozoic Margin was based on eleven plays in the Atlantic Region stretching from Florida to the Canadian border (Lore et al., 2001). Five plays were assessed with a total mean value of 2.3 BB of oil and 27.7 Tcf of gas. The remaining six plays were described but not assessed. Table 5 lists the results of Ultimate Conventional Recoverable Reserves (UCRR) with the major potential predicted in Cretaceous (0.7 BB, 11.8 Tcf) and Jurassic clastics (0.8 BB, 9.0 Tcf) using the Sable Subbasin as an analogue.
In their assessment, the USGS did not assess the following conceptual plays based on the noted restrictions:

Upper Cretaceous Clastics
- Shallow depth, lack of proximity to mature source

Lower Cretaceous-Upper Jurassic Transitional
- High structural risks

Cretaceous-Jurassic Diapirs
- "Diapir structures off Nova Scotia unsuccessful" (sic)

Upper Cretaceous-Upper Jurassic Floor Fans
- Source rocks thin and immature

Lower Jurassic-Triassic Rift Carbonates
- Great depth and over-mature source rocks

Lower Jurassic-Triassic Rift Clastics
- a/a

Of most interest is the Atlantic Upper Jurassic Carbonate (AUJ B1) Play consisting of Late Jurassic shelf-edge reef complexes with associated back-reef carbonate platforms and reef-face carbonate talus. As described by Lore et al. (2001) in their report:

> *"Potential reservoirs are located in the reef itself, in the fore-reef talus, and in the back-reef as oolitic, pelletal, or reef detritus grainstones. Reef and back-reef deposits have the best potential for enhanced porosity because of subaerial exposure. Traps are mainly stratigraphic on the carbonate platform. Combination stratigraphic and fault traps occur within the reef complex on the shelf edge and in reef talus on the slope. Potential source rocks include Jurassic shelf and slope shales, and possibly lagoonal and platform carbonates." (p.569-570).*

As far as can be determined, the bank edge proper was never very appealing to industry with only two bank edge tests in the Baltimore Canyon area about 35 km apart with one of these apparently in a back-reef setting. The 1998 Deep Panuke gas discovery confirms that this play works and a reevaluation of its potential along the entire American margin is warranted.

6.2 Northwest Africa Margin

6.2.1 Morocco

Prior to the breakup of Pangaea, Northwest Africa and Eastern North America were juxtaposed. As a result of rifting, the Aaiun-Tarfaya Basin was created opposite to the Baltimore Canyon and George's Bank Basins while the Essaoiura Basin formed opposite to the Scotian Basin (Figure 34). The Moroccan margin, like the Scotian margin, developed a thick Jurassic carbonate platform but the present-day shelf is comparatively very narrow. Potential carbonate plays offshore Morocco are much the same as existing offshore Nova Scotia, i.e. bank margin traps sourced by either seaward marine shales or underlying synrift Late Triassic lacustrine facies (Figures 48-50).

A close-up of the Moroccan offshore and adjacent coastal region geology (Figure 51) shows the location of the 26 exploratory wells (now 28) drilled up to 2000 and the seismic coverage. The wells are clustered north of Tarfaya and off Agadir and Essaoiura and in addition are six Deep Sea Drilling Project (DSDP) bore holes on the continental rise and slope. Figure 52 illustrates the trace of the Jurassic shelf edge and several of the ten wells drilled along it, most of which were drilled in the 1960's. The carbonate margin lies beneath the present-day shallow continental shelf which facilitates good quality seismic imaging.

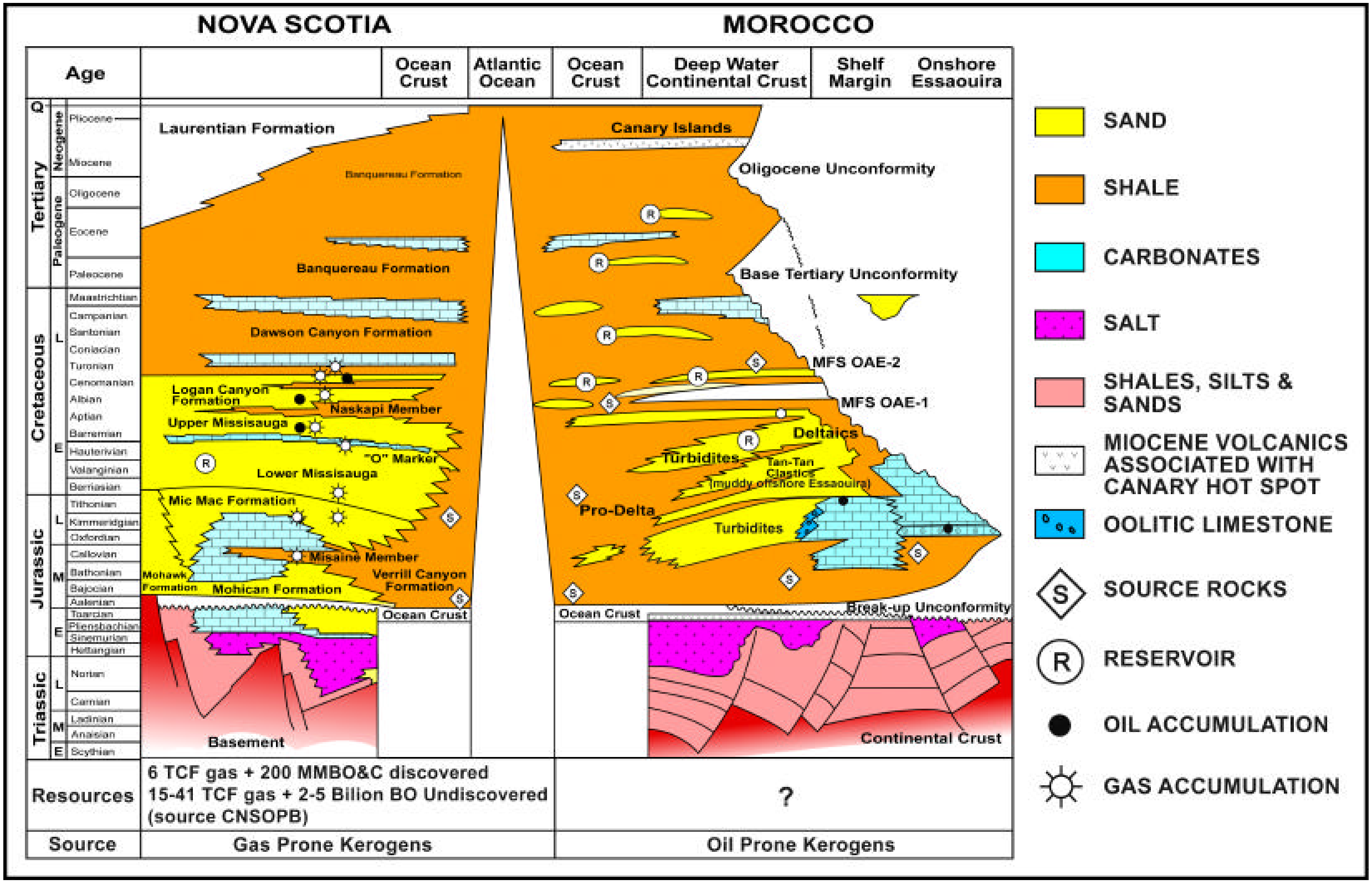


Figure 48. Comparative stratigraphic chart for the Nova Scotian and Moroccan offshore successions (via G. Tari / Vanco, 2005).

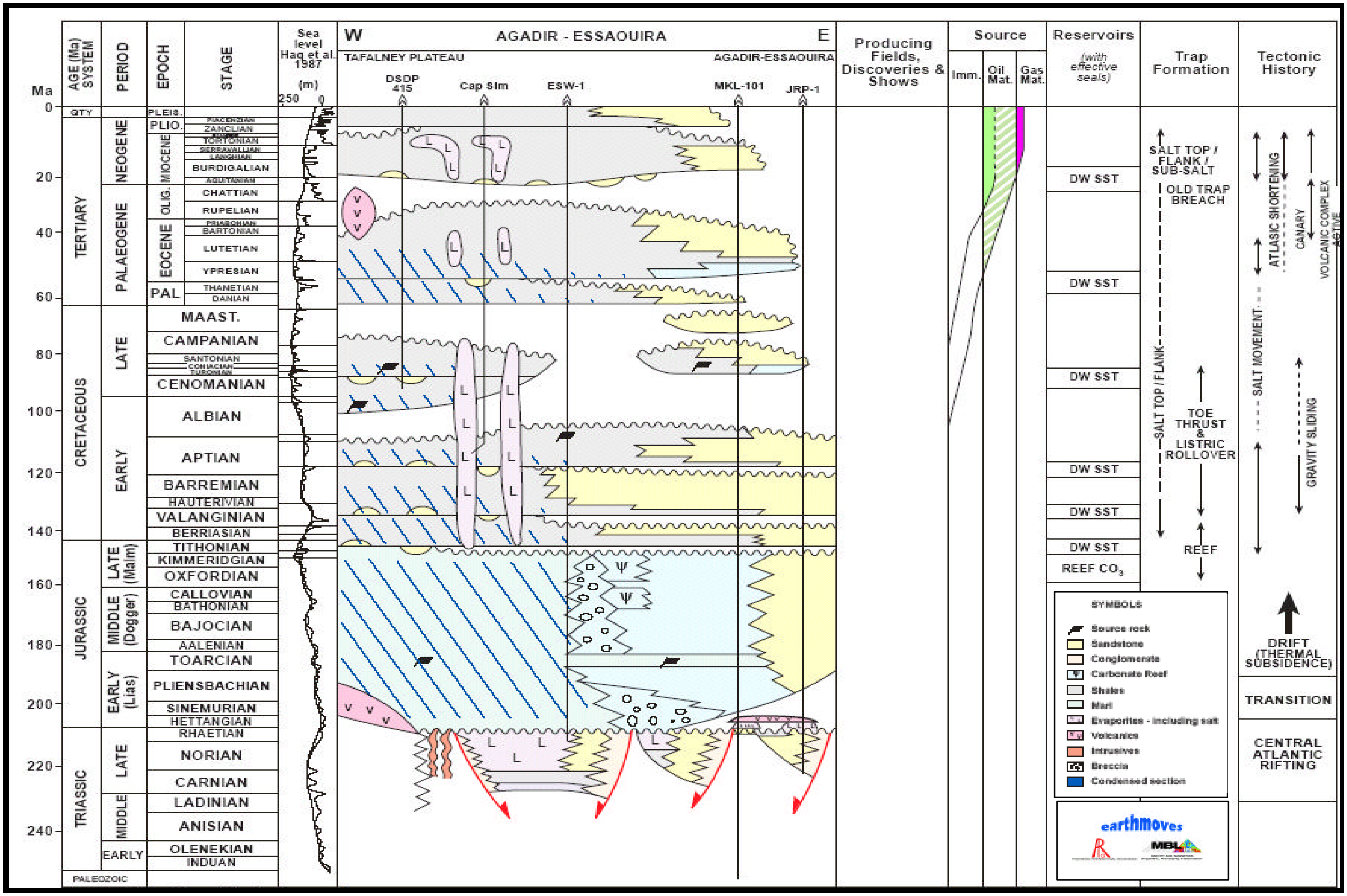
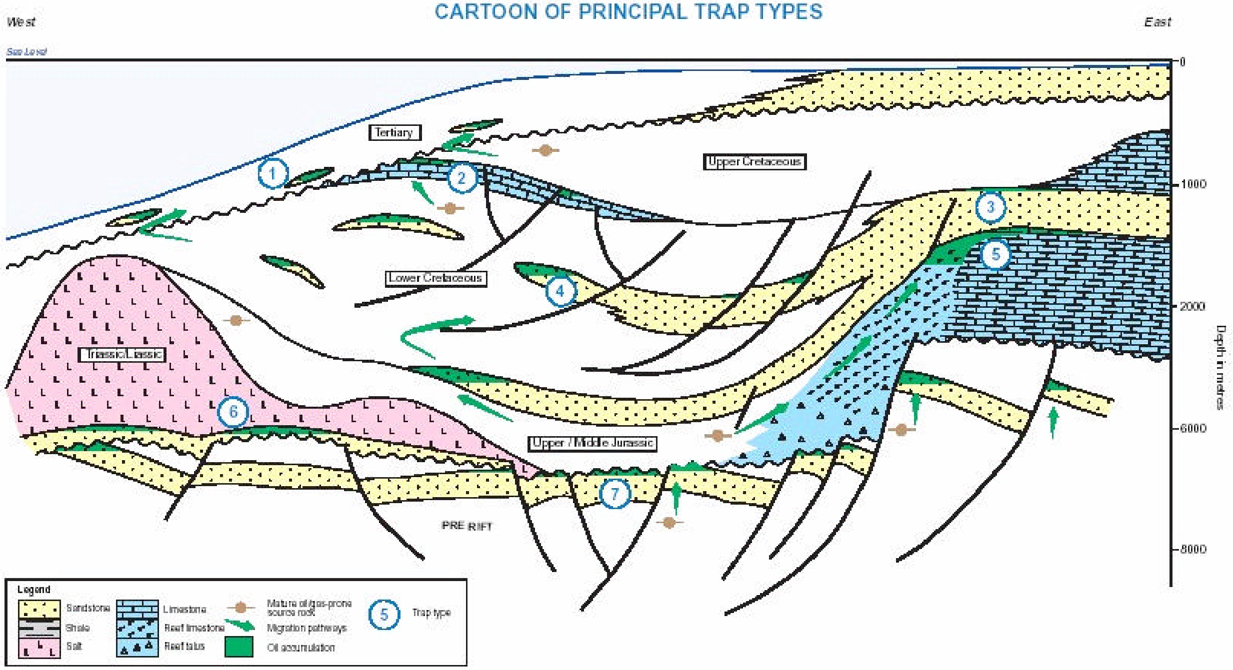


Figure 49. Stratigraphic chart, tectonic history and petroleum systems for the onshore and offshore portions of the Agadir-Essaouira Basin, Morocco (via I. Davison, Earthmoves, used with permission).

OFFSHORE MOROCCO
RESERVOIRS SEALS & TRAPS COMPOSITE SUMMARY

CARTOON OF PRINCIPAL TRAP TYPES



	Objective	Source Rock	Based on
①	Tertiary channel and fan sands, debris flows and turbidites in stratigraphic traps on continental slope.	Turonian shales	Seismic evidence. Analogy with other West African marginal basins.
②	Outer shelf Senonian carbonate shoals associated with underlying L. Cretaceous rotated fault blocks.	Turonian shales	Encountered in well 51A-1 (Spansah). Turonian shales over 50m thick, TOC 6-10% in Tarfaya Basin.
③	Inner shelf L. Cretaceous continental sands in closures associated with underlying Jurassic carbonate edge.	Oxfordian shales	Encountered in well A1-32 (Amoseas). Oxfordian source shales present in Essaouira Basin.
④	L. Cretaceous deltaic, nearshore and outer shelf sands trapped in rotated L. Cretaceous fault blocks.	Oxfordian shales	Encountered in well 47A-1 (Gulf).
⑤	Jurassic reef carbonates and associated reef talus on seaward edge of carbonate platform.	Liassic shales	Encountered in well MO-5. Liassic source shales with type II kerogen in Tarfaya Basin.
⑥	Syn rift alluvial and fluvial sands underlying Triassic / Liassic salt.	?Carboniferous ??Trias	Gas field at Meskala (Essaouira Basin). Trias source rocks in Newark Basin (N. American counterpart basin).
⑦	Pre rift tilted fault blocks containing clastic, carbonate (reef) and weathered basement reservoirs.	Silurian shales	Oil field at Sidi Fili (Prerif Basin) in granite wash & fractured quartzites. Devonian reefs in Doukkala Basin. Excellent oil prone source rocks in Silurian.

Figure 50. Play concept schematic, offshore Morocco (via D. Hallett, 2003).

ExxonMobil (then Esso Exploration – Morocco) drilled seven wells along the bank edge in the late 1960's and early 1970's looking for closures incorporating reefal or high energy carbonate build-ups in the Abenaki-equivalent Puerto Casando Formation (information from MO-2, -5, -8, Tan Tan 1 and Cape Juby 1 well composite logs and related data – via ONAREP). Their seismic data defined the Jurassic carbonate margin edge very well with several culminations interpreted to be potential reefs, and several wells discovered heavy 10-15º API biodegraded oil with traces of H_2S in the large Cap Juby Anticline (Figure 53). The MO-2 well tested two porous dolomitic limestone intervals (karsted?) at the top of the formation and recovered 12º heavy oil at a rate of 2300 bopd. The MO-8 well recovered several barrels of lighter gravity 38º oil in a DST from carbonates at the top of the Middle Jurassic (Scatarie / Abenaki 1 equivalent?). Several barrels of 10.5º heavy oil were also recovered from the Cap Juby 1 well (twin of the MO-2 well) from strata at the top of the Jurassic similar to the MO-8 well. Estimated reserves in the Cap Juby structure are noted as being between 40-70 MMB heavy oil (Baraka Petroleum Limited: http://www.barakapetroleum.com/pdf/050524.pdf).

The seismic line through the MO-8 well (Figure 54), and south of it (Figure 55) reveal an eroded bank margin very similar to the Tertiary erosion along the Acadia Segment of the Scotian Basin. Tertiary lowstand erosional events have cut through the Cretaceous strata and into or along the Jurassic carbonate bank. While only isolated seismic lines off Morocco are available, some of these Tertiary features could be submarine canyon cuts. However, on the southwest Nova Scotia margin, along-strike belts exist where the bank edge is beveled off. It is not clear on the Moroccan seismic exactly how close the erosion comes to the carbonate surface. Trap integrity may be compromised by not only physical breaching but also by fracturing to negate top seal. While oils are present at Cap Juby and infer trap seal preservation, their heavy nature may be the result of biodegradation due to proximity of the erosional surface. Whether hydrocarbon migration pre- or post-dates this erosional event is not known.

Another seismic profile at a near-by but unidentified location to the northeast (Figure 56) shows the bank margin well buried and landward of the effects of Tertiary erosion like that of the Sable Subbasin (ONAREP, 2000b). This setting should be the better environment for trap preservation and a working petroleum system. The domal features beneath the bank appear like the salt features mapped beneath the Abenaki bank off Nova Scotia but this has not been confirmed.

A large prospective lead in the Jurassic succession has been identified by ROC Oil & Gas Company of Australia (Figure 53). The Trident Lead is a large, 19x3km, four-way closure along the edge of the Jurassic carbonate reef margin. Reservoirs are predicted to have been developed in Middle and Lower Jurassic oolitic and grainstone facies at about 3200 mTVDSS (Scotian Basin Abenaki Formation Scatarie Member and Iroquois Formation equivalents?). The structure's style, dimensions and setting appear identical to that of the Deep Panuke Field, offshore Nova Scotia. ROC has calculated an estimated volumetric potential for the Trident Lead of 2.85 BB OOIP with unrisked potential reserves (UPR) of 700 MMB. (Source: ROC Oil Company Limited – http://www.rocoil.com.au-Pages-Company_Reports-ROC_1999_Prospectus.pdf).

The USGS World Petroleum Assessment (2000) did not assess offshore Morocco although it is identified as an area for future consideration. Modern seismic across the Jurassic margin wells combined with logs are required to make accurate comparisons with conjugate basins and successions offshore Nova Scotia and the United States.

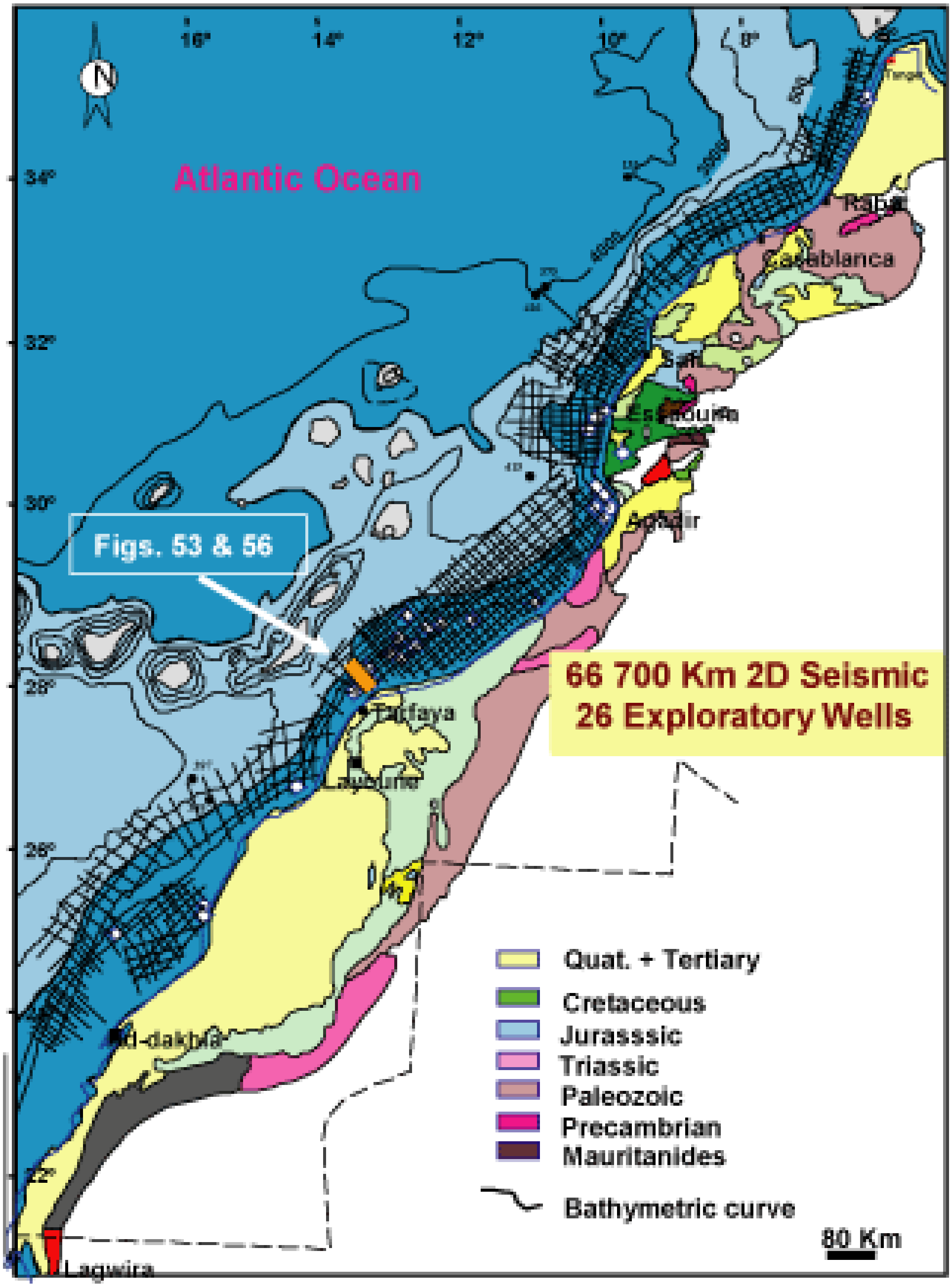


Figure 51. Moroccan Atlantic margin geology (ONAREP, 2000b). With few exceptions, most industry wells were drilled in water depths of less than 100 m. Legend: Industry exploration wells (well symbols – D&A), DSDP boreholes (numbered black dots), regional seismic lines (black lines), Figures 53 and 56 (orange line), light grey areas (Canary Islands – Tertiary volcanics).

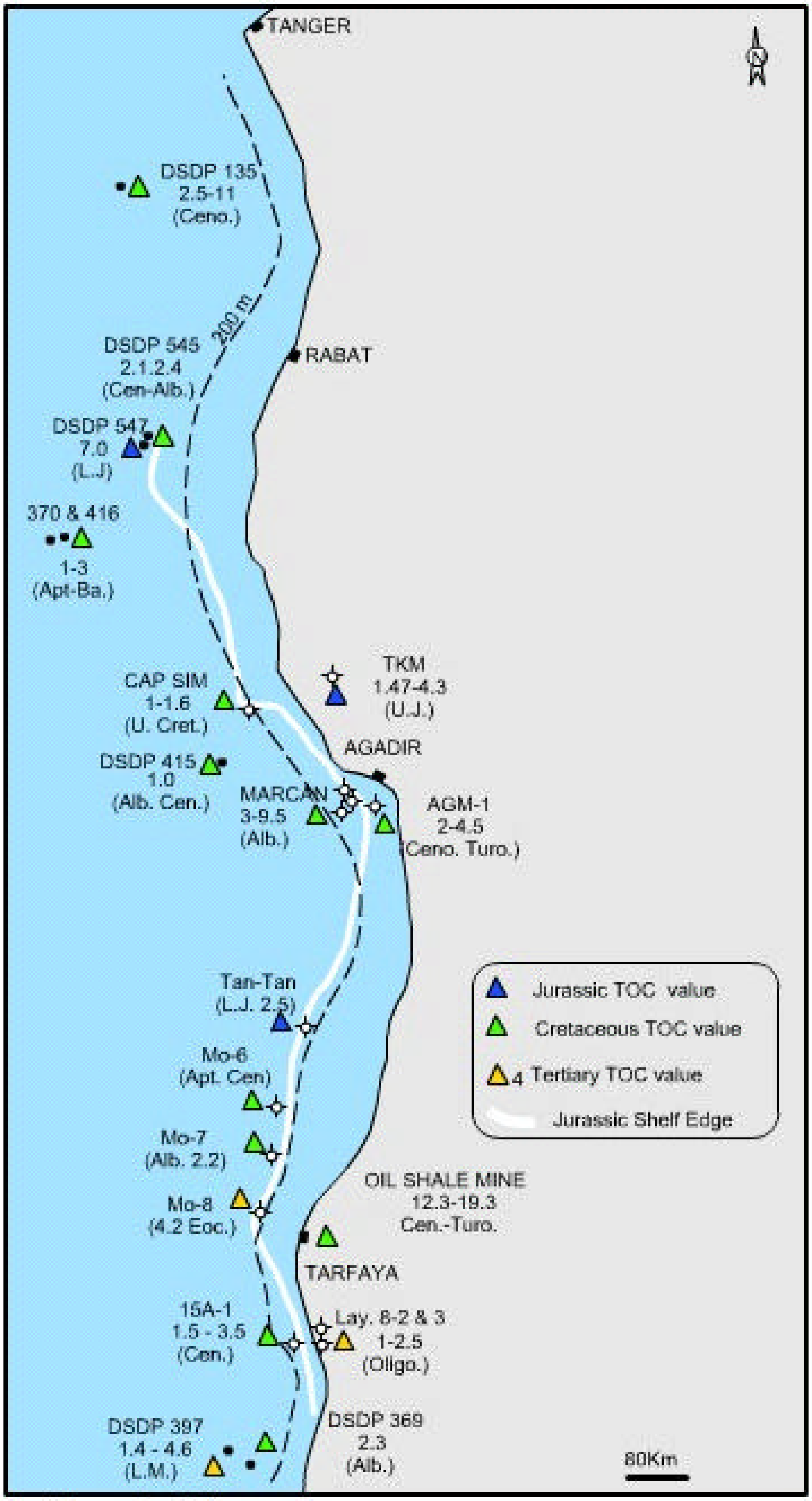


Fig 4: Source Rock Richness

Figure 52. Trace of the Upper Jurassic carbonate bank margin, Puerto Cansado Fm. (ONAREP, 2000b).

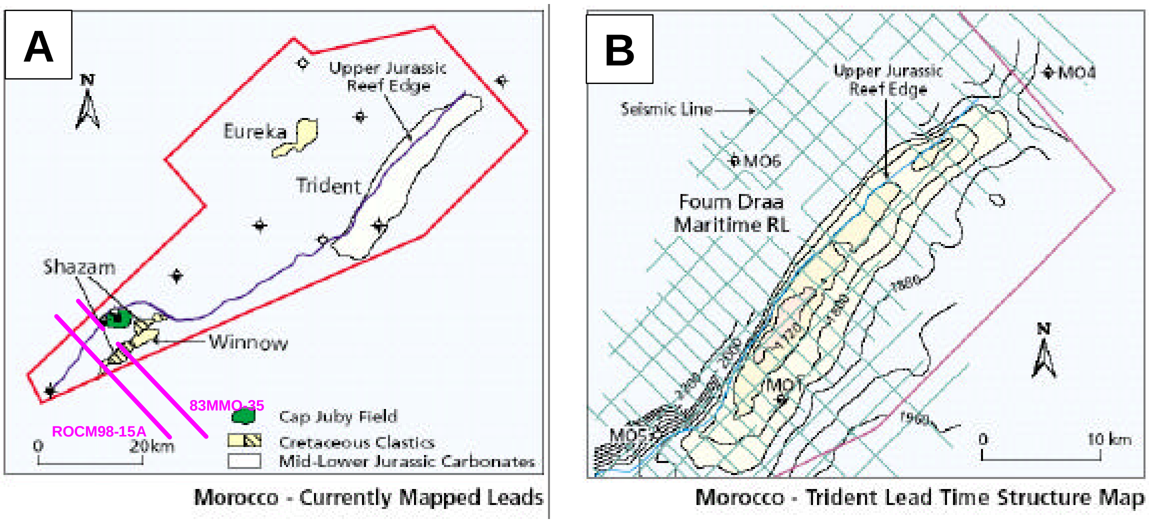


Figure 53. A. Location map of the Cap Juby Field and Trident Lead, offshore Morocco. B. Top Jurassic time structure map of the Top Jurassic, Trident Lead. Seismic line in Figures 54 and 55 indicated by violet lines. (Source: ROC Oil Company Limited - http://www.rocoil.com.au-Pages-Company_Reports-ROC_1999_Prospectus.pdf).)

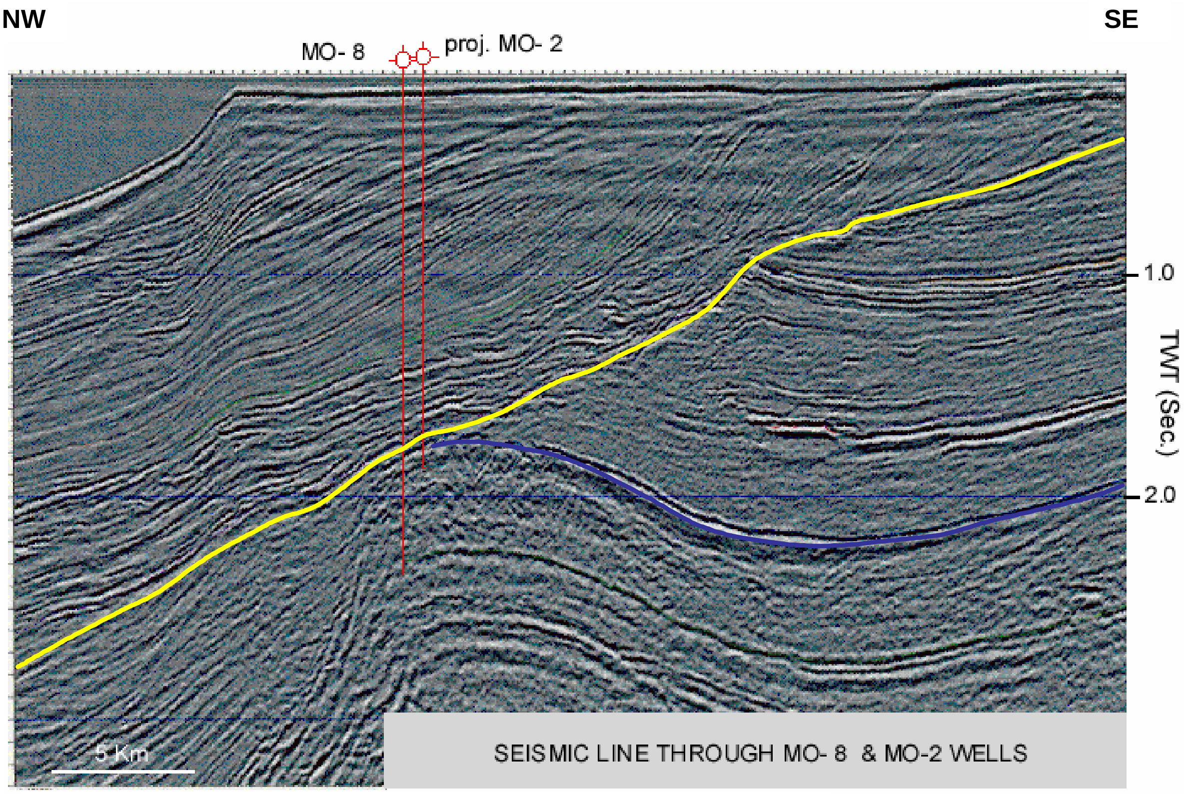
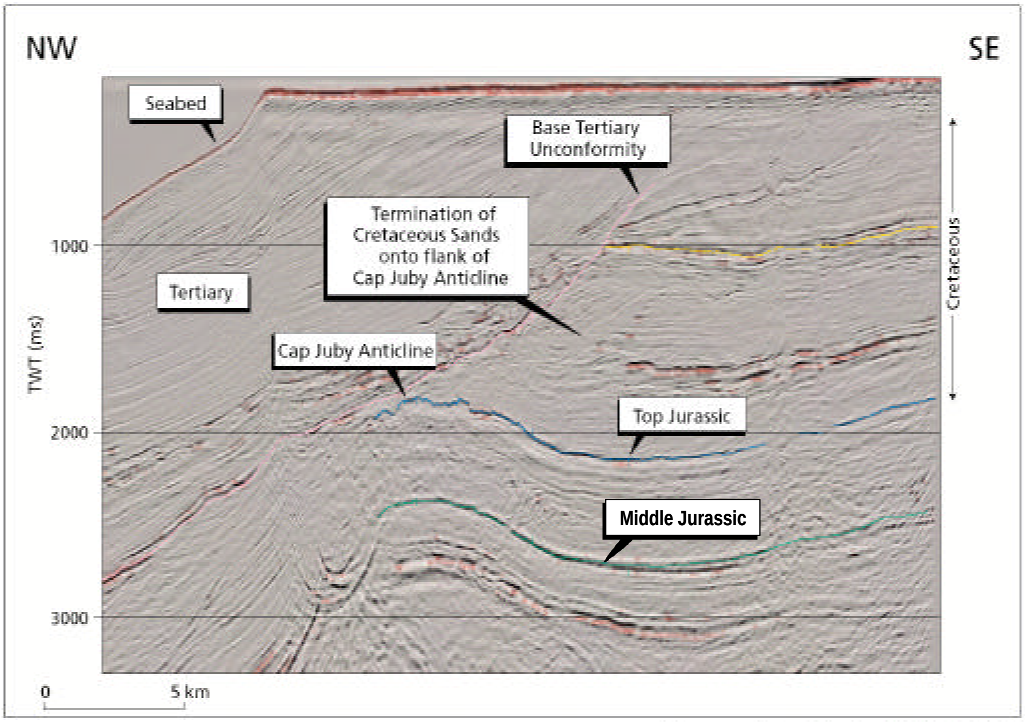


Figure 54. Regional seismic line 83MMO-35 through MO-8 and MO-2 (projected) wells, Cap Juby Anticline. The domal shape to the bank margin suggests deformation via an underlying salt feature similar to those observed in lines on the Acadia Segment, offshore Nova Scotia. See Figures 51 and 53 for line location. Slightly modified after ONAREP, 2000b.



Morroco - Seismic Section ROCM98 - 15A

Figure 55. Regional seismic line ROCM98-15A through the Cap Juby Anticline, approximately 7 km southwest of Figure 54. See Figures 51 and 53 for line location. (Source: slightly modified from ROC Oil Company Limited - http://www.rocoil.com.au-Pages-Company_Reports-ROC_1999_Prospectus.pdf).

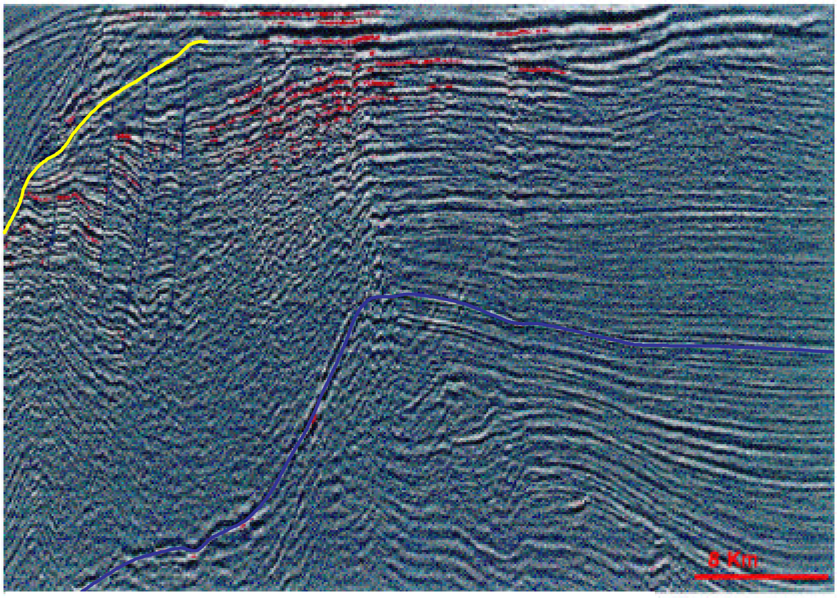


Figure 56. Regional seismic line 83MMO-??, exact location unknown (slightly modified after ONAREP, 2000b). The bank margin in this area northeast of the Cap Juby Anticline is deeply buried under Cretaceous (Tan Tan Fm.) and Tertiary siliciclastics and not affected by later erosional events and is in a setting analogous to the Panuke Segment offshore Nova Scotia.

6.2.2 Mauritania

The offshore Mauritanian Basin is an extension of the Moroccan Atlas Basin and shares a similar geologic history (Figure 57). Though details are unavailable, the Jurassic carbonate margin is estimated to be over 2000 metres thick and has a steep escarpment-like morphology (Figure 58). Adjacent to the landward edge of the margin, hydrocarbon shows were found by the Autruche-1 well in faulted Cretaceous sandstone reservoirs. Rich, oil-prone Early Cretaceous (Neocomin) shales are believed to be the main oil and gas source. While not penetrated offshore Mauritania, deeper early synrift lacustrine sources are believed to exist that would provide an additional hydrocarbon source for potential carbonate and younger reservoirs.

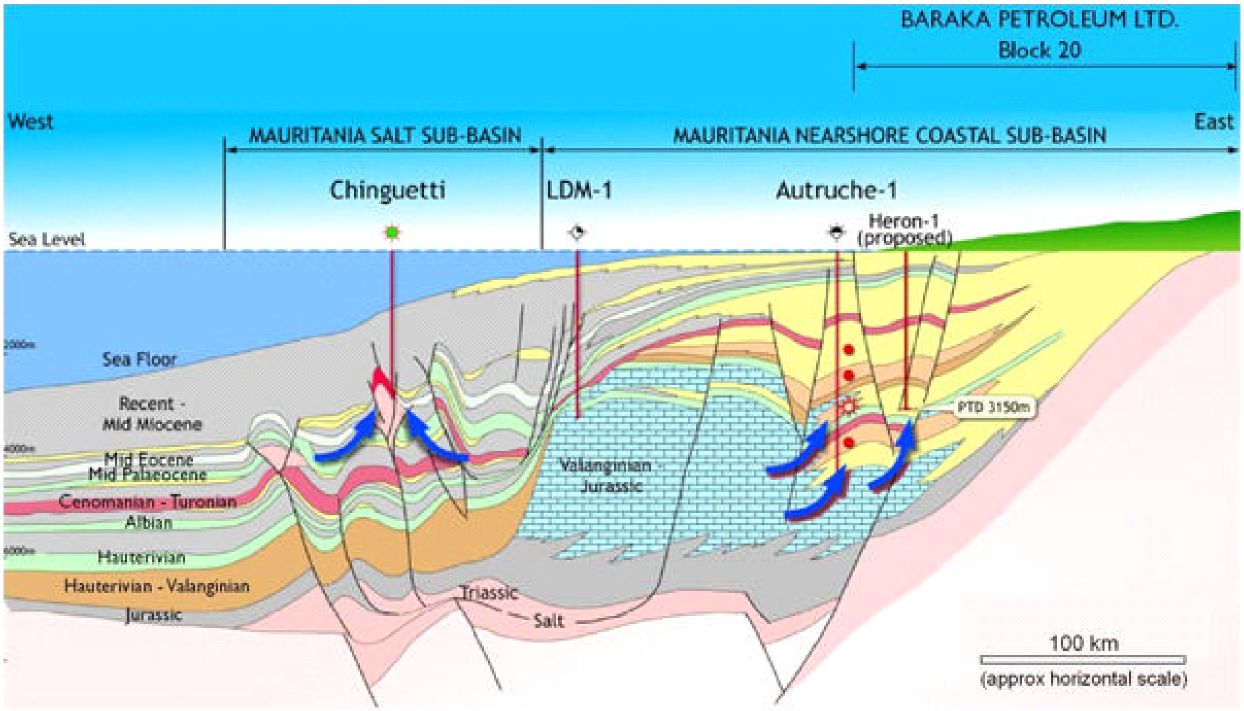


Figure 57. Schematic geological cross section through Mauritanian coastal basin, offshore continental margin (Source: Baraka Petroleum, 2005 - http://www.barakapetroleum.com/prospectus.pdf)

6.3 Gulf of Mexico

The Upper Jurassic carbonate platform that rimmed the North Atlantic from Newfoundland to the Bahamas continued around the Gulf of Mexico to the Yucatan Peninsula (Figure 59). The Smackover Formation is on the American side of the Gulf and broadly equivalent strata of the Pimienta-Tamabra(!) on the Mexican. In the latter region, observations on the influence of the Chicxulub impact crater on carbonate margin has some important implications as it relates to Montagnais impact crater off southwest Nova Scotia.

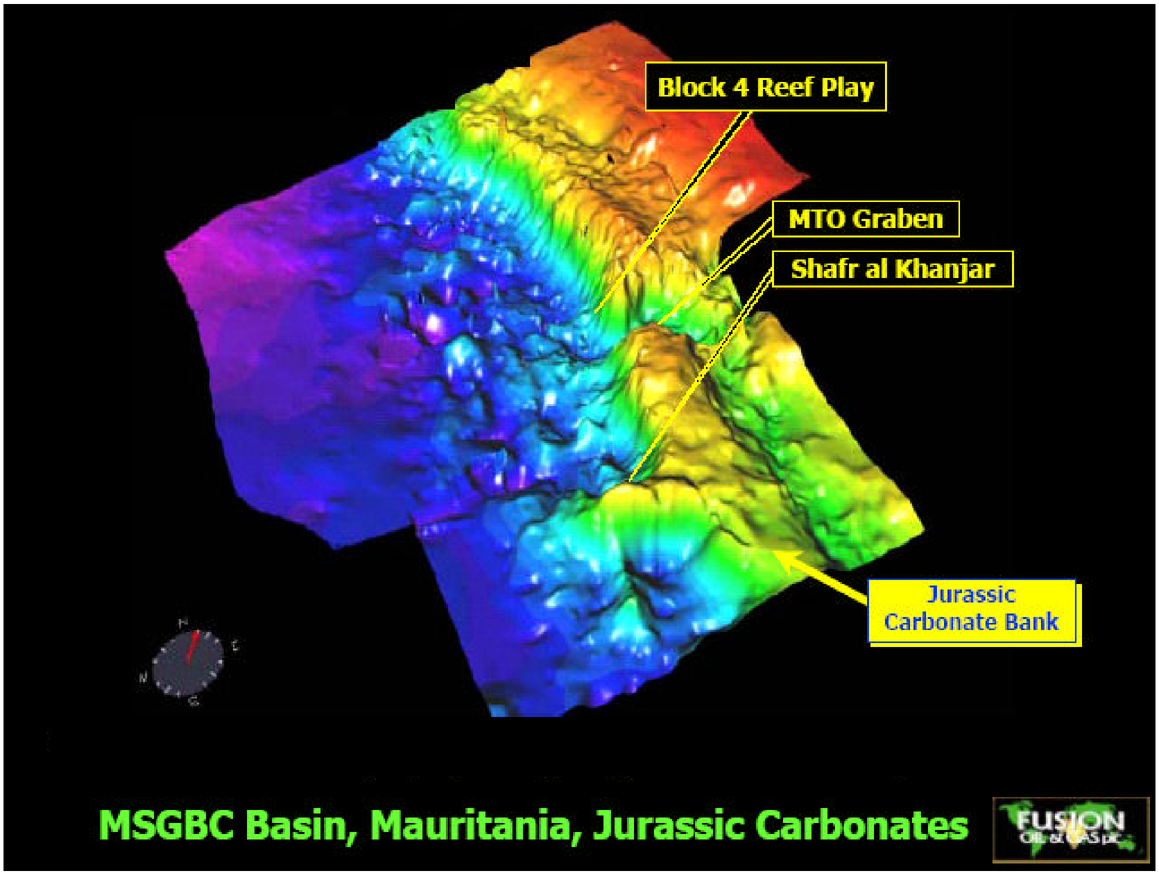


Figure 58. A 3D isometric view of the top Upper Jurassic-Earliest Cretaceous carbonate platform margin, offshore Mauritania. The 'Block 4 Reef Play' may be a detached block from the margin now resting at the base of the reef slope, or a carbonate debris fan or apron. The 'Shafr al Khanjar' feature appears to be an isolated structural spur off the main reef trend. Pock-marked deepwater area reflects the effects of sedimentary loading upon deeper Late Triassic salt (Source: Fusion Oil & Gas Plc website).

6.3.1 United States

The Upper Jurassic Smackover Formation is age equivalent to the Upper Jurassic Abenaki Formation offshore Nova Scotia (Figures 59-61). The Smackover is a shallow marine carbonate ramp facies, with oolite shoal and detrital limestones deposited on bathymetric highs (Figure 62). The analogy may be appropriate for the Abenaki ramp facies east of Sable Island which was not studied for this report, but was used for evaluating the platform interior region west of Sable Island. Seismic data over the interior Abenaki Platform has limited coverage, large grid sizes and poor quality such that the delineation of Smackover type plays cannot be undertaken.

The Upper Jurassic Smackover Formation is one of the most productive hydrocarbon reservoirs in the northeastern Gulf of Mexico. Cumulative production to date is over 1 billion barrels of oil and 4 trillion cubic feet of gas. Production comes from three plays; basement ridge play, regional peripheral fault play and salt anticline play (Mancini, 2002). The fields are often relatively small (10-30 MB) but are numerous and prolific producers. Nevertheless, there is potential for large fields such as the Jay Complex with reserves in the 500 MMB and 1 Tcf range. A lower Smackover facies composed of a transgressive, low-energy sub-tidal carbonate mudstone sequence is known as an excellent source rock (Fails, 1990). The trap types (Figure 63) are both structural and stratigraphic / facies dependant (Moore, 1984).

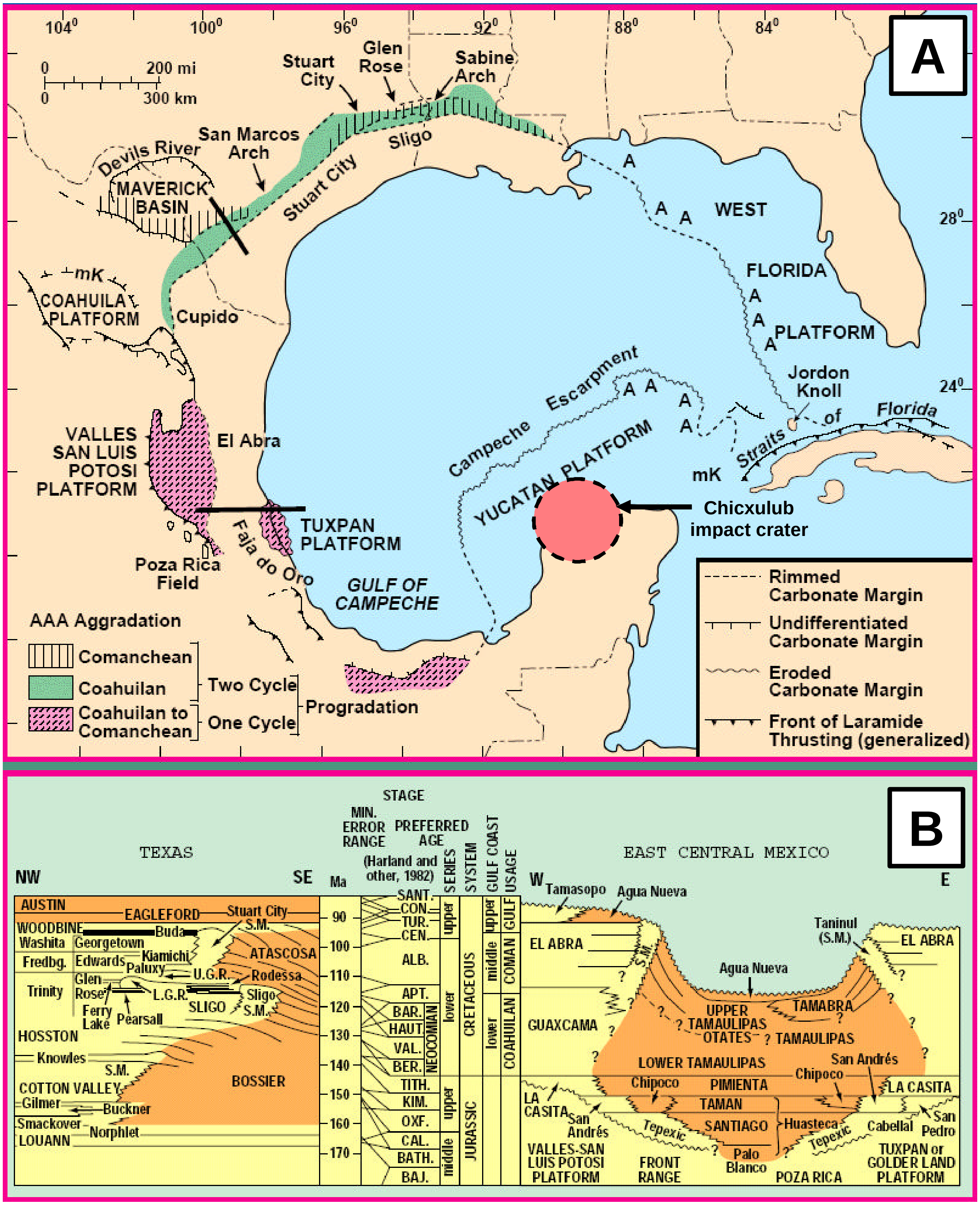


Figure 59. Map and general stratigraphy of the Jurassic- Cretaceous succession in the Gulf of Mexico region (slightly modified after Winkler and Buffler, 1988 in Moore, 2001).

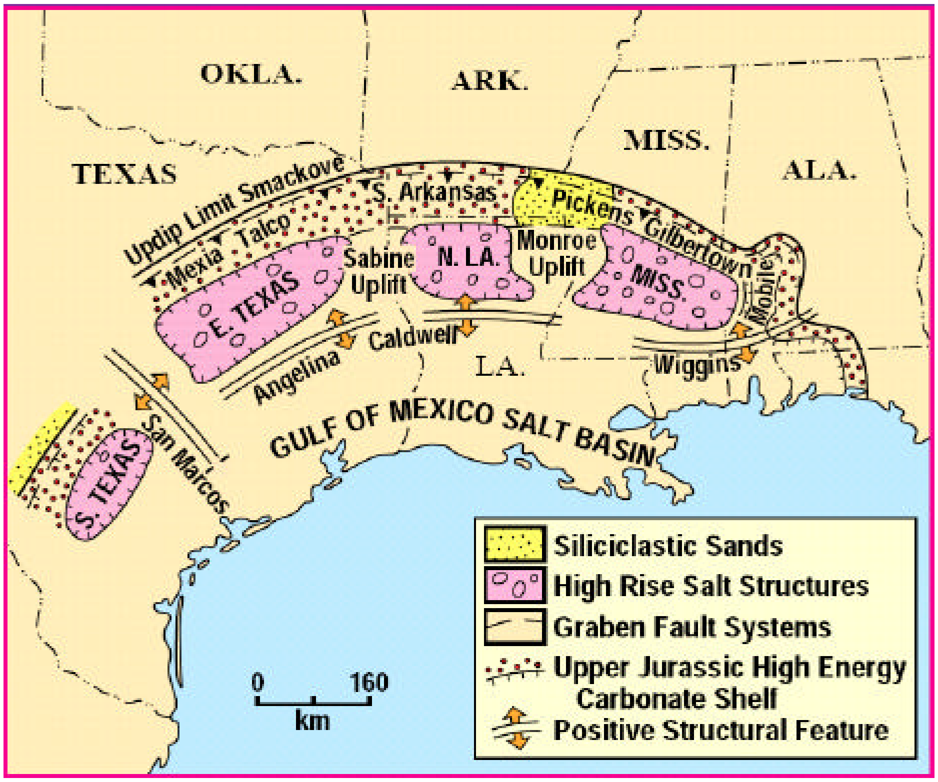


Figure 60. Structural setting of the Upper Jurassic, central Gulf of Mexico region (Moore and Heydari, 1993 in Moore, 2001).

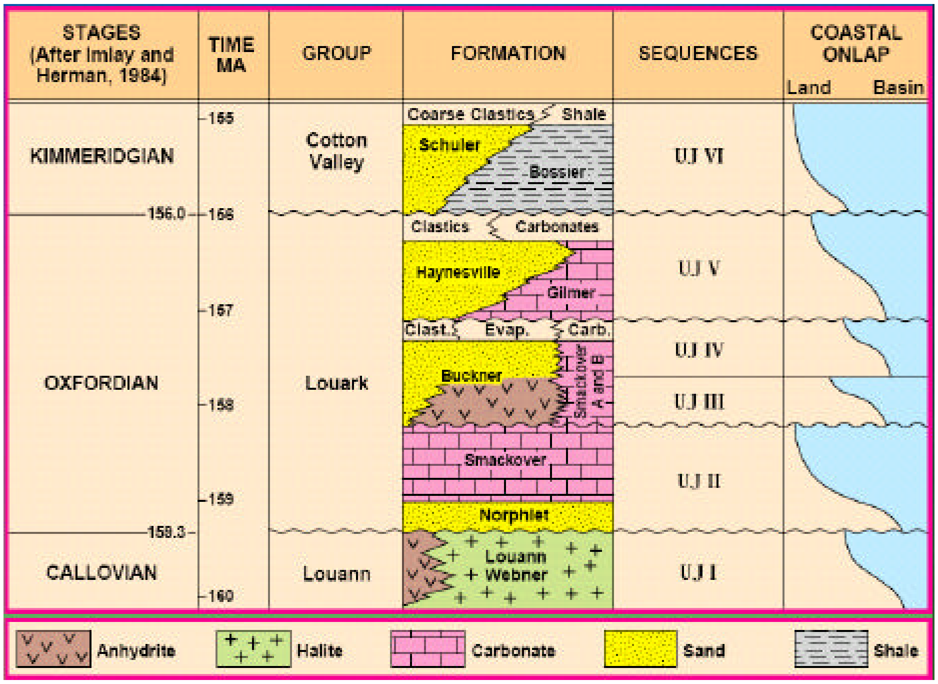


Figure 61. Stratigraphic relationships and lithologies of the upper Jurassic in the Central Gulf of Mexico region (Moore and Heydari, 1993 in Moore, 2001)

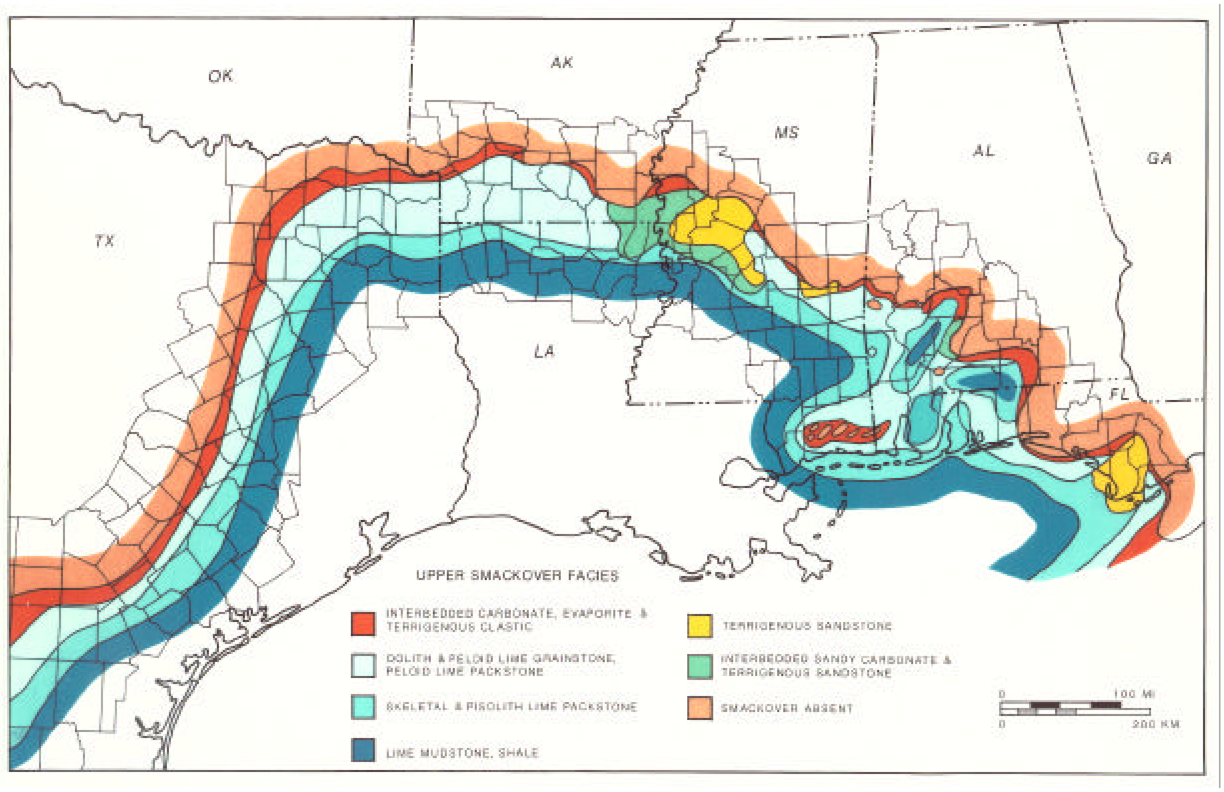


Figure 62. Areal extent, lithologies and facies distribution of the Smackover Formation. Dark blue represents basinal facies, lighter blues shelf and slope environments. Most discoveries and production are concentrated in the shelf and shallow slope facies. (Source unknown, 1986).

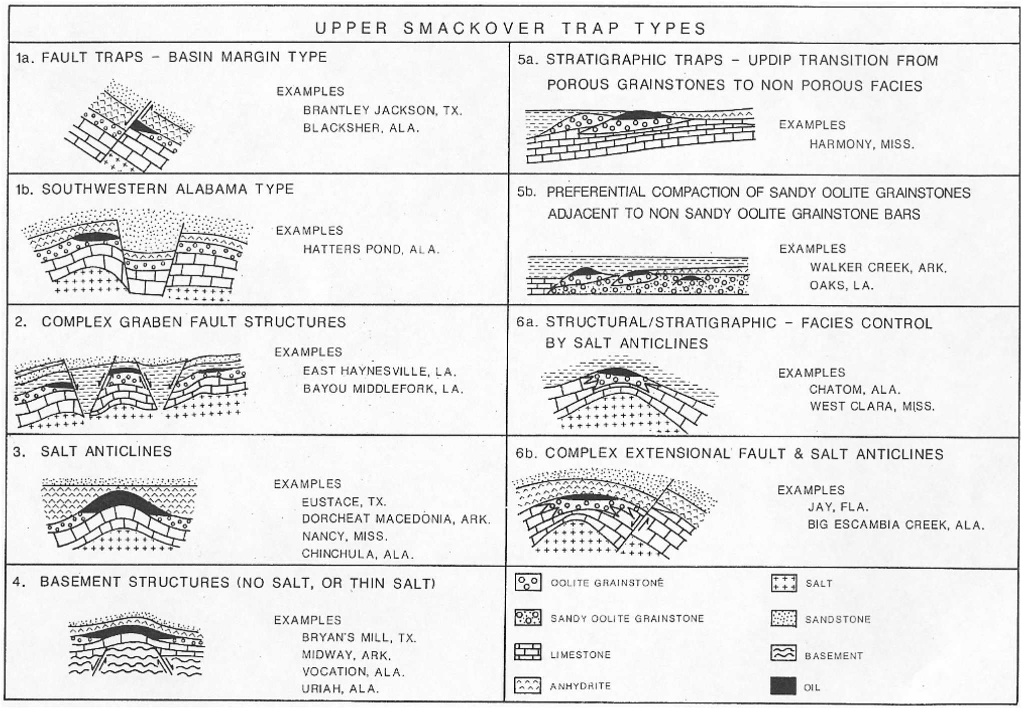


Figure 63. Upper Smackover trap types (Source unknown, 1986, after Moore, 1984).

6.3.2 USGS Resource Assessment

The USGS evaluated and assessed the hydrocarbon resources of the onshore Smackover Formation plays across three assessment provinces; East Texas Basin, Louisiana-Mississippi Salt Basin and the Western Gulf (Schenk and Viger, 1995). Seven plays were isolated as having correlative value with the five most significant noted below. Reserves assessments are presented in Tables 6 and 7.

1) Alabama/Florida Peripheral Fault Zone Oil and Gas Play (USGS Play No. 4910)
Reservoirs are grainstones and packstones of the upper Smackover Formation. Porosity ranges up to 15 percent, permeabilities up to 100 mD and depth to undiscovered reservoirs between 1800-6000 m. Source rocks are the organic-bearing carbonate mudstones of the lower Smackover Formation. Traps occur along faults within the regional peripheral fault zone. This play contains 19 oil reservoirs with a median size of 6.2 MMB and three gas reservoirs with a median size of 248 Bcf. The Jay Field, discovered in 1972, is one of the largest onshore discoveries in the U.S. in the previous 25 years. The potential for undiscovered oil and gas in this play is estimated to be moderate to high.

2) East Texas-Southern Arkansas Peripheral Fault Zone Oil and Gas Play (USGS No. 4916)
This is a continuation of the above play but with an increased structural component of anticlines, faulted anticlines and salt structures along the peripheral fault zone. Porosities range up to 25 percent, permeabilities up to 150 mD and depth to undiscovered reservoirs between 1200-3650 m. The play contains 14 oil reservoirs with a median size of 5 MMB and 12 gas reservoirs with a median size of 20 Bcf. The probability for its undiscovered potential is estimated to be moderate.

3) Alabama/Florida Updip Oil Play (USGS No. 4911)
Reservoirs in this play are carbonate grainstones and packstones of the upper Smackover Formation. Porosity ranges up to 15 percent and permeability to 150 mD. Traps are associated with small basement structures updip from the regional peripheral fault zone. This play contains eight oil reservoirs with a median size of 3.7 MMB and two gas/condensate reservoirs of 9 and 17 Bcf.

4) East Texas-South Arkansas Updip Oil Play (USGS No. 4917)
This is a continuation of the previous play but with reduced porosity range up to 10 percent, permeabilities up to 10mD and depths from 1200-2750m. The play contains three oil reservoirs with a median size of 2.5 MMB and one gas reservoir of 16 Bcf.

5) Salt Basins Gas and Oil Play (USGS No. 4912)
The reservoirs are upper Smackover grainstone, packstone and boundstone facies with porosities up to 20 percent and permeabilities up to 100mD. Traps are structural, occurring in salt structures, anticlines and faulted salt anticlines. This play contains 58 oil reservoirs with a median size of 6.4 MMB and 44 gas reservoirs with a median size of 24 Bcf.

6.3.3 Mexico

One of the most prolific petroleum systems in the world is the Pimienta-Tamabra(!) in the southern Gulf of Mexico, both onshore and offshore. Known reserves, including production-to-date, are 44.5 BB of oil and 50.8 Tcf of gas (Magoon and Schmoker, 2000) plus undiscovered potential of 23.3 BB and 49.3 Tcf (USGS, 2000) for an EUR of 67.8 BB and 100.1 Tcf (84.5 BOEB).

Play	**Discovered Resources**		Mean Field Size		No. of Fields	
	Oil (MMB)	Gas (Bcf)	Oil (MMB)	Gas (Bcf)	Oil	Gas
1			6.2	248	19	3
2			5.0	20	14	12
3			3.7	13	8	2
4			2.5	16	3	1
5			6.4	24	58	44

Table 6. USGS Assessment, Smackover Formation, Discovered Resources

Play	**Undiscovered Potential**		Mean Field Size		No. of Fields	
	Oil (MMB)	Gas (Bcf)	Oil (MMB)	Gas (Bcf)	Oil	Gas
1	91	640	3.9	58	23	11
2	47	424	4.1	23	12	19
3	125		4.3		29	
4	88		2.8		32	
5	104	960	5.6	31	19	31
Sum	**455**	**2024**				

Table 7. USGS 2000 Assessment, Smackover Formation - Undiscovered Potential

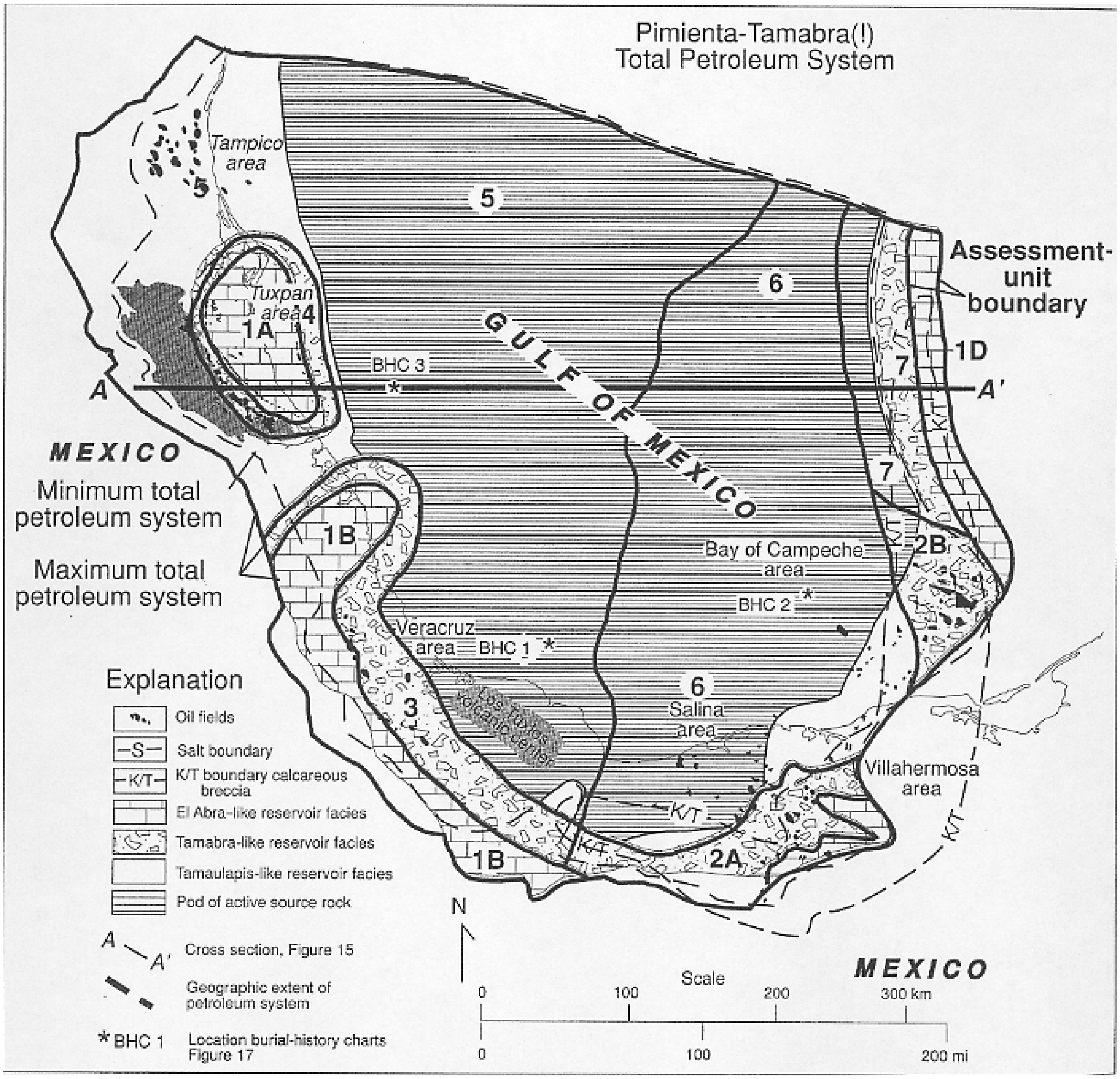


Figure 64. Map of the Pimienta-Tamabra(!) trend showing components of its total petroleum system (Magoon et al., 2001). Numbers refer to USGS (2000) assessment areas

In the southern Gulf of Mexico, the stratigraphic nomenclature is not consistent over the entire area (Figure 59). In northeast Mexico, the Zuloaga Formation marks the onset of open-marine conditions and is correlative with the Smackover of the Northern Gulf Coast (Goldhammer and Johnson, 2001). The carbonate regime was interrupted by deposition of the Cotton Valley (Texas) and La Casita (Mexico) siliciclastics but reaffirmed itself until the Mid-Cretaceous (Late Albian)

The petroleum system consists of excellent Upper Jurassic source rocks and outstanding Cretaceous carbonate reservoirs was followed by sufficient Tertiary siliciclastic sedimentation to thermally mature the source rock (Galicia, 2001; Magoon et al., 2001) (Figure 64). The Pimienta-Tamabra(!) petroleum systems events timing chart reveals that petroleum generation-migration-accumulation which started in the Eocene continues to the present-day (Figure 65). Comparatively, the events timing chart for the Abenaki Formation (Figure 25) relies on assumptions for the presence of source rocks, and the effects of Cretaceous and Tertiary erosion are not completely understood.

The major plays in the Pimienta-Tamabra(!) petroleum system are Early to Middle Cretaceous age carbonates, especially carbonate slope, base-of-slope and basinal carbonate debris flow facies. The most significant productive play is the Tamabra carbonate debris flow breccias and turbidity current facies encompassing the outer perimeter of the El Abra carbonate platform complexes (Figure 66). The carbonate traps exist in a near-perfect setting, but the geological and physical processes illustrate some degree of similarity to certain aspects of the Upper Jurassic Abenaki Formation which are noted elsewhere in this report.

The eroded profile of the Golden Lane reef complex (Figure 67) is of particular interest because the steep profile survived with the breccia facies apron accumulating downslope. A representative seismic line run across this profile (Francisco and Castillo-Tejero, 1970) might probably reveal a profile and reflection pattern resembling the steep margin bank existing along the Acadia Segment off Nova Scotia (see Figures 94-109) and would infer the potential for a similar downslope breccia play here as well. This facies of the Abenaki formation has yet to be drilled.

There are two reasons for comparing the Abenaki Formation to the El Abra/Tamabra margin. The main analogy is the degree of physical degradation of the Acadia Segment by syn- or early post-depositional erosion (subaerial and/or submarine) that has potential for creating debris flow fans and aprons on the foreslope. The second is the effect of the Montagnais impact crater which is somewhat comparable to the Chicxulub meteor crater on the Yucatan Peninsula.

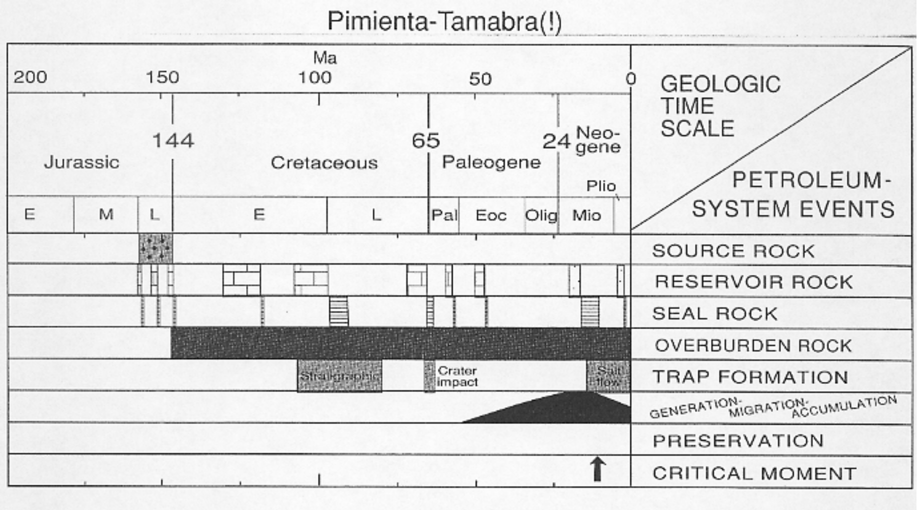


Figure 65. Pimienta-Tamabra(!) events timing chart (Magoon et al., 2001).

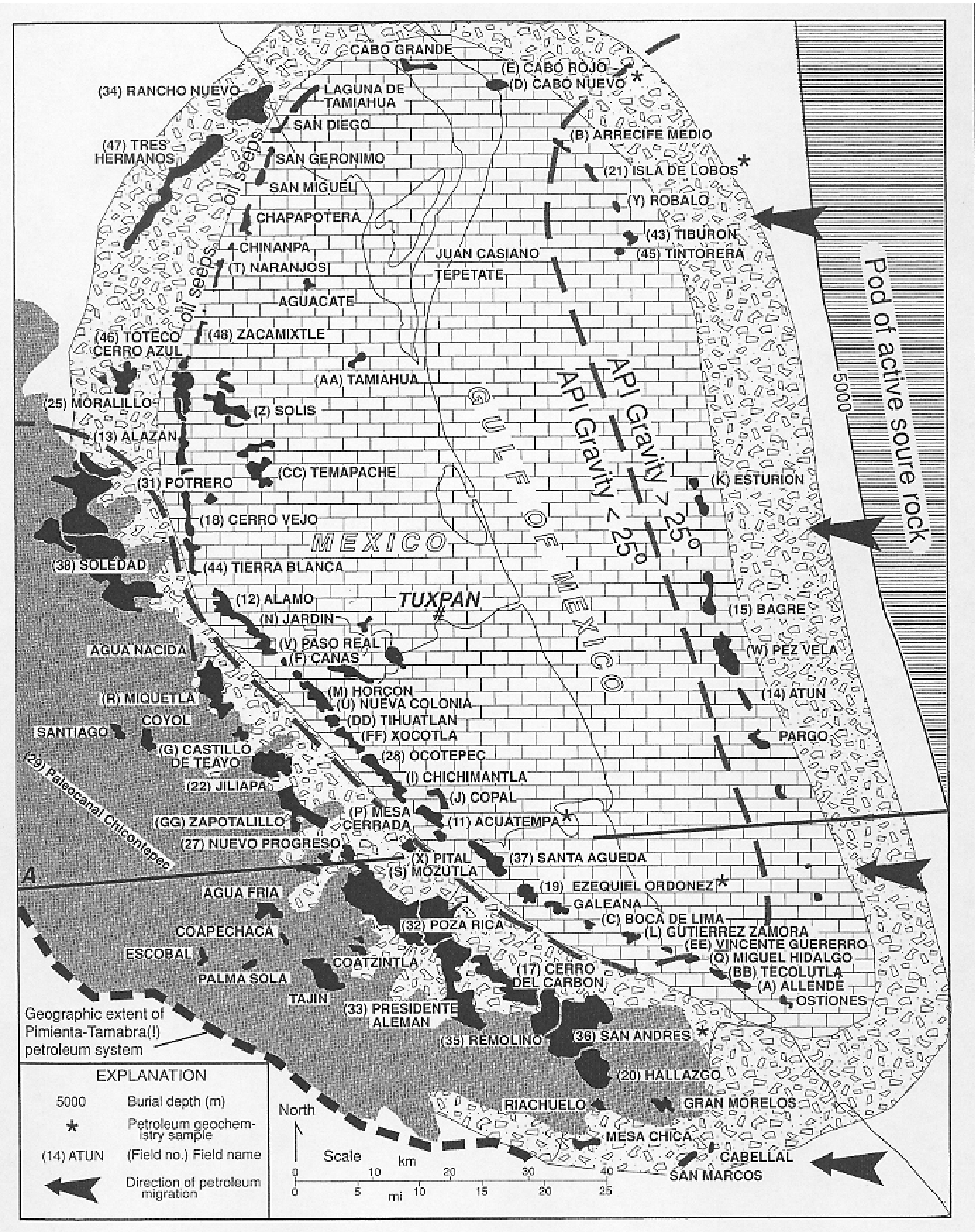


Figure 66. Map of Tuxpan area oil and gas fields (Magoon et al., 2001). Not the location of the source rock area and hydrocarbon migration pathways with the majority of fields in the margin-flaking debris flow breccias (USCG Assessment Units 2, 3, and 4).

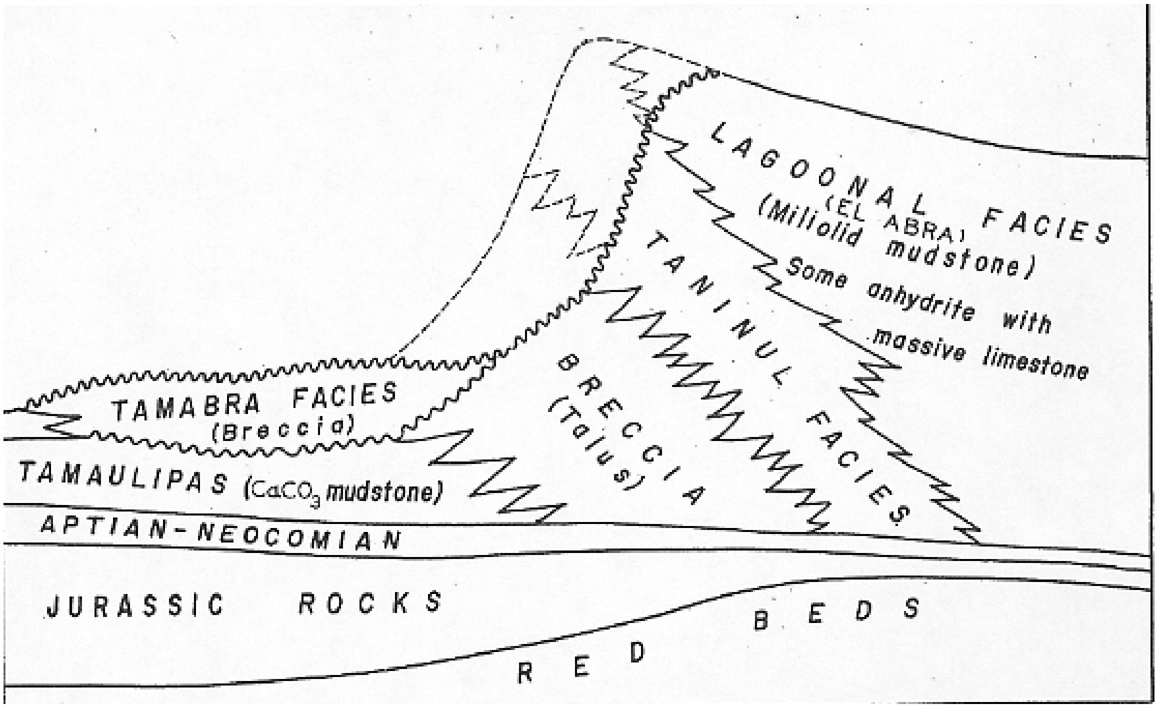


Figure 67. Schematic of the Mid-Cretaceous Pimienta-Tamabra(!) carbonate reservoir facies (Francisco and Castillo-Tejero, 1970).

As will be discussed and illustrated in Chapter 7, the Abenaki platform margin facies along the Acadia Segment is interpreted as reflecting a high-energy environment setting with post-Jurassic with erosion, faulting and disruptive salt. In Mexico, allochthonous carbonate debris-flow breccias and carbonate turbidity-flow deposits can be formed in at least two ways, either by eustatic sea-level changes that expose the bank edge to erosion and/or earthquakes and related tsunamis (Magoon, 2001). Even extra-terrestrial causes are cited:

> *“In Pimienta-Tambra, regional shaking from the Chicxulub meteorite impact dislodged and relocated reef material onto the slope and base of slope.” (Magoon, 2001)*

Offshore Nova Scotia, the Montagnais impact of Eocene age (~50 mya) was too late to influence later carbonate deposition of the Upper Jurassic bank edge though appears to have altered the subsequent local Tertiary drainage pattern and focus submarine erosion in its locality. Furthermore, the related “regional shaking” profoundly disturbed Jurassic carbonates in the areas immediately adjacent to the impact site and appears to have released deep salt under the carbonate platform which further modified the margin.

6.4 Western Canada Sedimentary Basin

There is a global paucity of producing Jurassic carbonate platform margins. Notwithstanding the environmental differences between the Devonian and Jurassic worlds, the Devonian of the Western Canada Sedimentary Basin (WCSB) was nevertheless affected and influenced by similar geologic processes and provides useful information in helping understand the Abenaki succession.

Figure 68 illustrates divisions within the Western Canada Devonian reef systems which include the Elk Point, Beaverhill Lake, Woodbend, Winterburn and Wabamun Groups of central Alberta and their equivalents. Reefs are most extensively developed in the Woodbend, to a lesser degree in the Beaverhill Lake and Elk Point, and to a minor degree in the Winterburn and Wabamun. A general transgression of reef facies progresses from north to south from Elk Point through Woodbend time. Regressive beds of the Upper Woodbend and younger Devonian overlie the older reef-bearing beds. While the

Leduc reefs and large bioherms are most famous there are some bank edge examples to draw upon and even the "bank" edges of large bioherms.

The Redwater reef of Central Alberta (Figure 69) is a large bioherm with an area of 512 km^2 and thickness of 244 m. It has long been Canada's second largest oil field with 850 MB of recoverable oil and in-place gas of 1300 MB (RF=65%). In section the reef is an atoll with an exterior rim of skeletal facies and detritus. The porosity is included in this rim and the oil is trapped in the updip edge of the reef (Jardine et al., 1977).

Clarke Lake (Figure 70) is a Mid-Devonian bank edge gas field in Northeast British Columbia. The field covers an area of about 115 km^2 and had marketable gas reserves of 1.5 Tcf. Local dolomitization has occurred along fracture zones at the bank edge. Porosity is limited to the dolomitized intervals which are narrow and difficult to map, resulting in a poor exploration and delineation drilling record with a success rate of 50%. Maximum pay is 106 m and the better wells deliver up to 30 MMcf/d (Jardine et al, 1977).

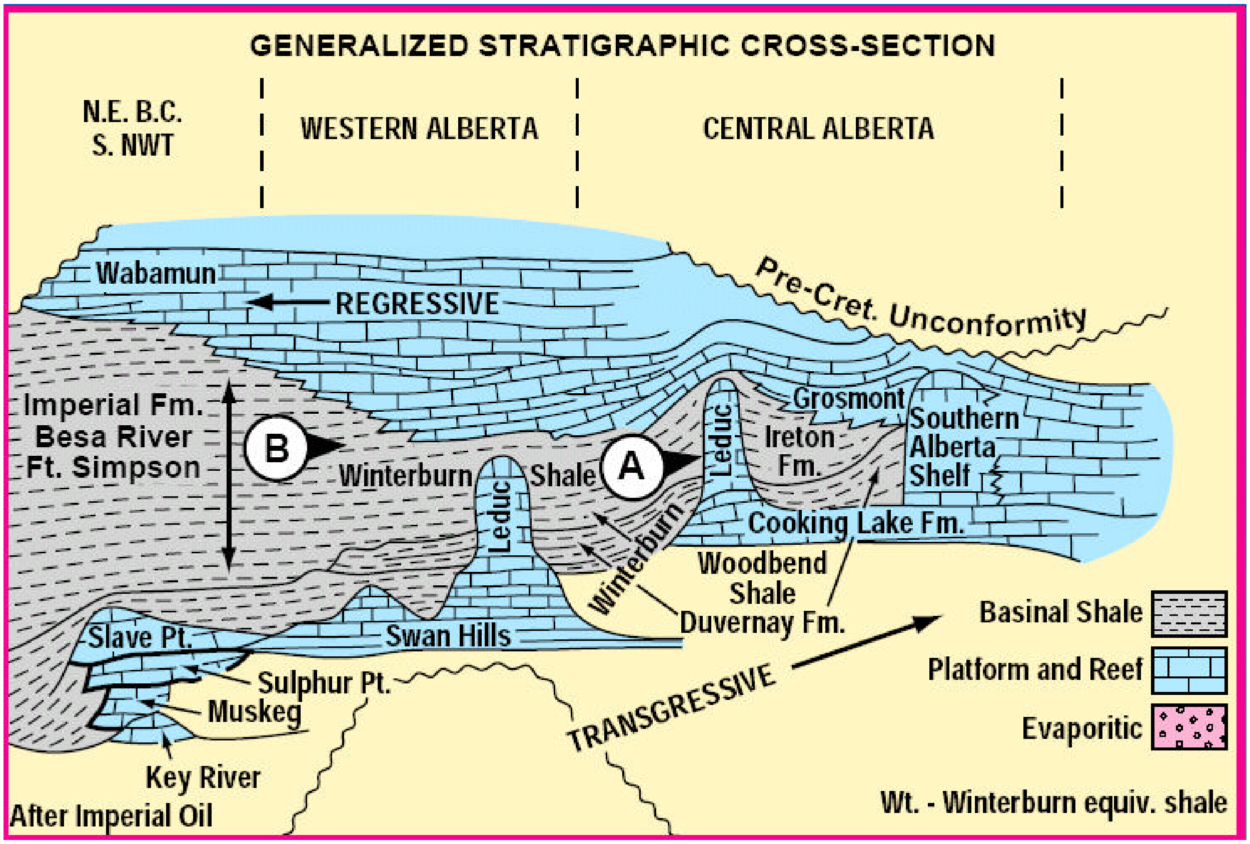


Figure 68. Schematic cross section showing the subdivision of Western Canada Sedimentary Basin Upper Devonian Woodbend-Winterburn Group strata and their relation to key type sections (Figure 12.7 of Switzer et al., 1994).

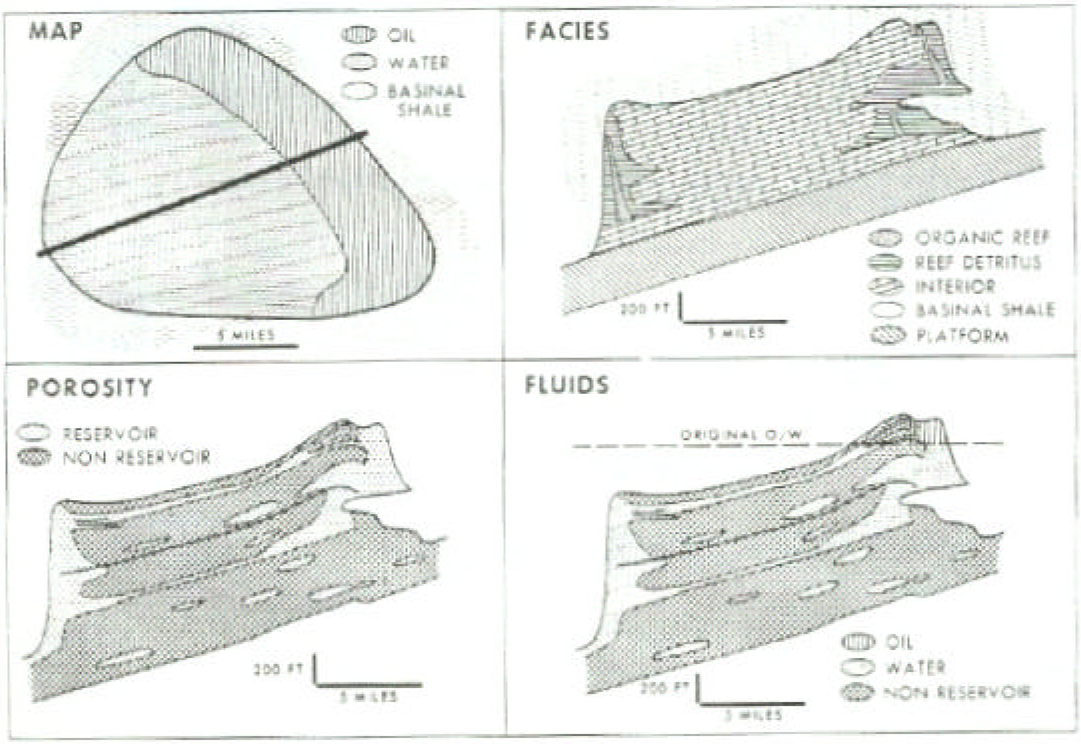


Figure 69. Redwater oil field, central Alberta: maps and cross sections illustrating lithofacies, porosity and fluid distribution (Jardine et al., 1977)

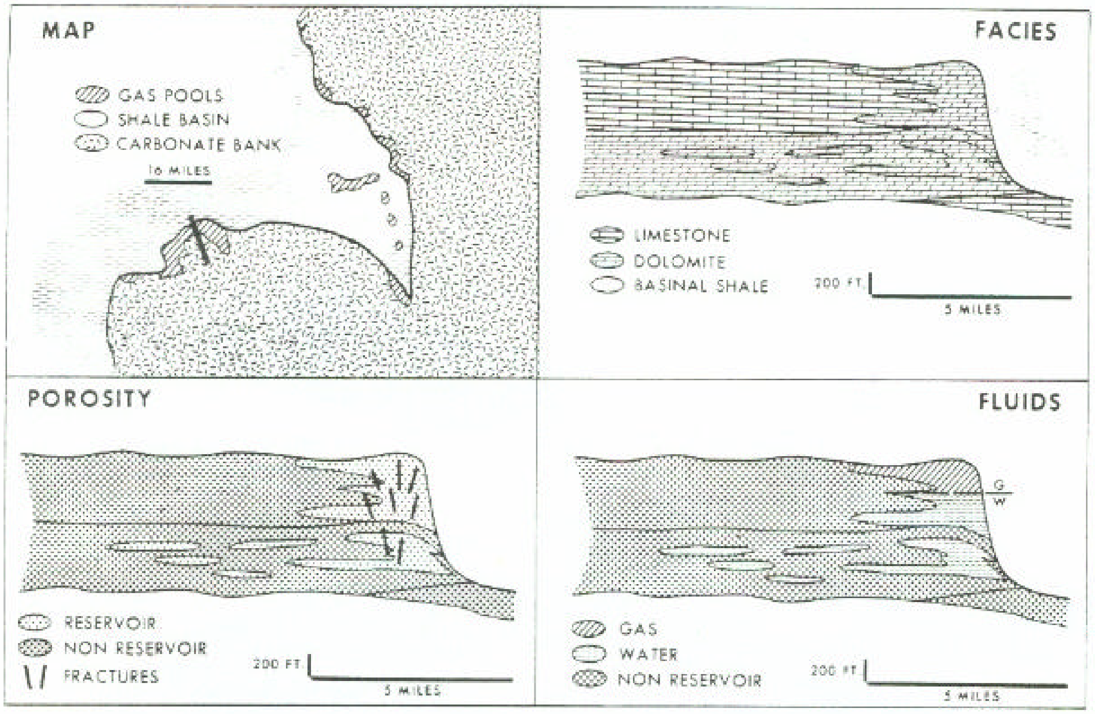


Figure 70. Clarke Lake gas field, northeast British Columbia: maps and cross sections illustrating lithofacies, porosity and fluid distribution (Jardine et al., 1977)

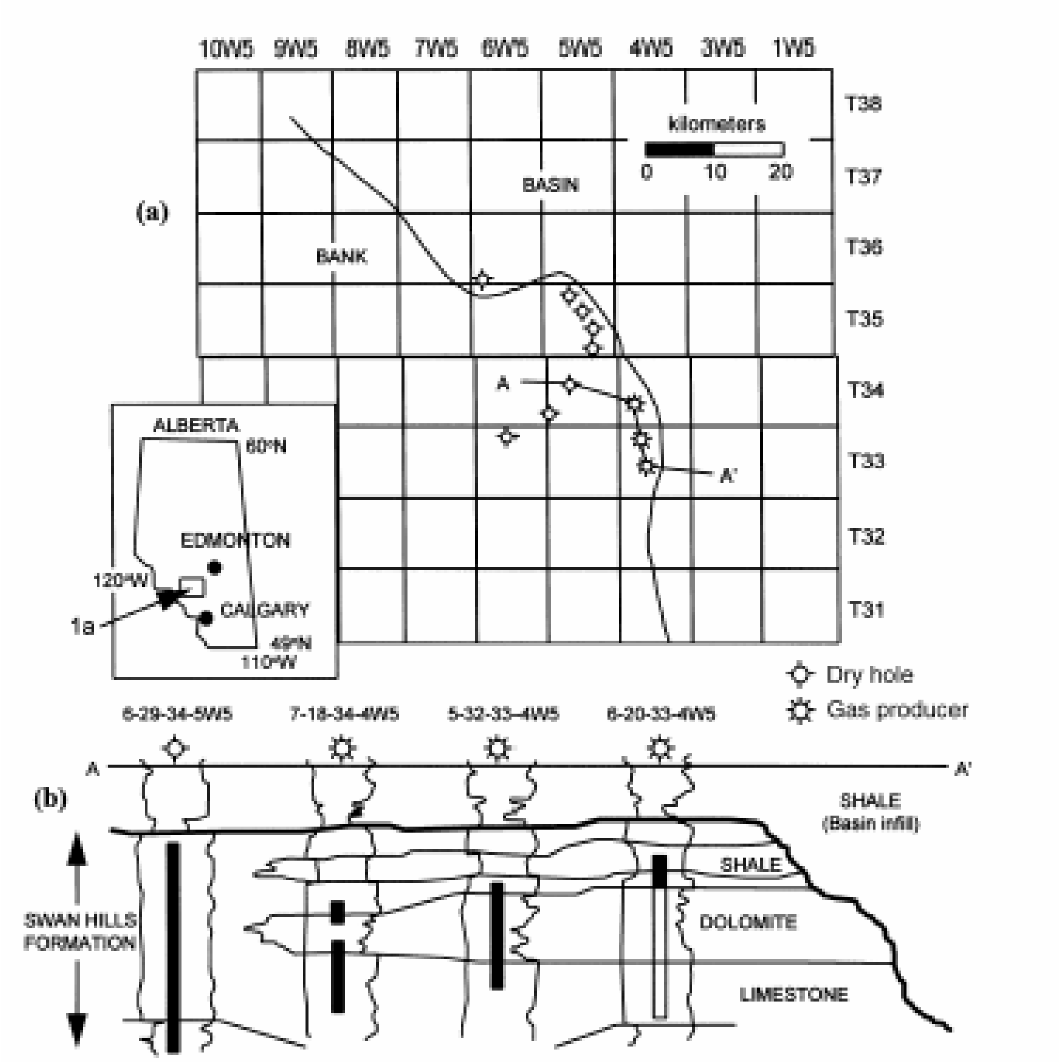


Figure 71. Location map and cross section of the Devonian Caroline gas field, southwest Alberta (Source unknown).

The last significant carbonate bank margin discovery was made by Shell in 1986 at Caroline in southwest Alberta (well 7-18-34-4W5) in the Swan Hills Formation (Figure 71). The bank margin consists of several backstepping cycles of reefal buildups with porosity in the high-energy dolomitized reef margin facies. Recoverable reserves were estimated at 250 MB and 2 Tcf with reservoir-quality porosity restricted to a 1-2 km belt along the reef margin.

A field size distribution (Figure 72) of the Swan Hills dolomitized bank margin reservoirs was used by the Canadian Gas Potential Committee (2001) in their assessment of Play A331. The fields include stacked reservoirs in Beaverhill A and B pools. The distribution is lognormal and Caroline, the last discovery in 1986, became the second largest field. In the same figure is a field size distribution of the Slave Point/Sulphur Point bank margin, assessed by the CGPC as Play F337. Clarke Lake, at over 2 Tcf, was ten times the next largest discovery so it was removed from the population. The remaining fields were run through the assessment program and then Clarke Lake was reinserted with the result that the distribution does not appear lognormal.

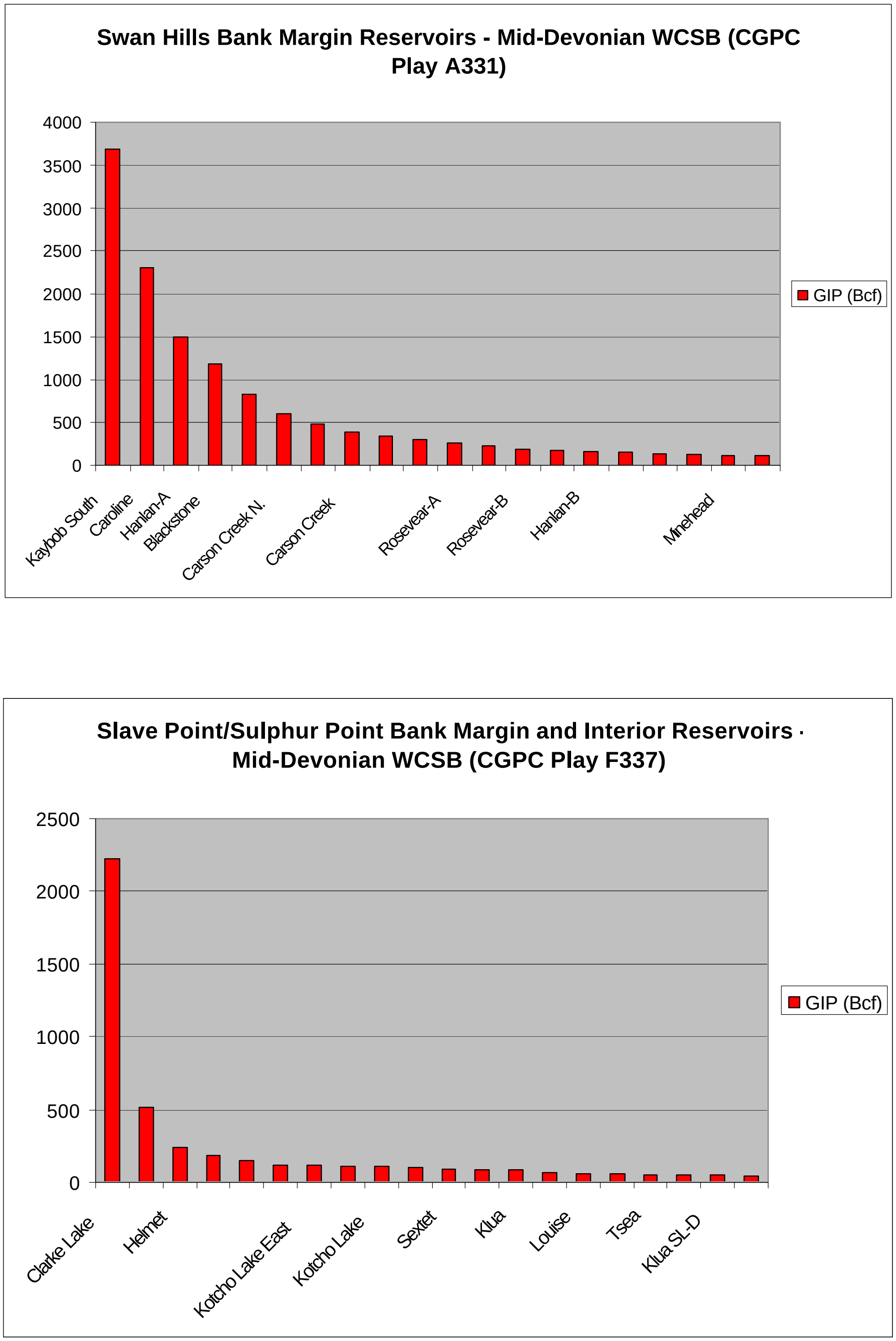


Figure 72. Field size distribution for the mid-Devonian Swan Hills and Slave Point/Sulfur Point bank margin and interior plays (Canadian Gas Potential Committee, 2001). Individual field names are along the horizontal axis.

7. ABENAKI BANK MARGIN

The nature of the carbonate regime along the Scotian Basin hingeline varies along depositional strike. West and southwest of Sable Island, the Abenaki succession existed as a rimmed shelf with a well developed bank margin profile. To the east and northeast, the influx of siliciclastics from the coeval Sable Delta resulted in the establishment of a low angle ramp margin of mixed clastic and carbonate facies. The bank margin from Sable to the American border, the subject of this study, was subdivided into three segments based on geologic and physiographic attributes. The Panuke, Acadia and Shelburne Segments each reveal unique variations in structural, depositional and preservation history (Figure 8).

7.1 Regional Late Jurassic Mapping and Play Concepts

A detailed time structure regional map on the top of the Abenaki Formation was created using available seismic data and is correlative with the top of Jurassic. The map was constructed by merging three separate internal interpretations of the TGS-Nopec survey for the Acadia Segment, the JEBCO survey in the Shelburne Segment and the PanCanadian/EnCana 3D surveys in the Panuke Segment. Since the data with which this map was constructed remains confidential, horizon maps cannot be included in this report.

A three-dimensional image of the Top Abenaki surface (Figure 73), using only the TGS 2D seismic data, illustrates the rimmed nature of the margin along the Acadia Segment. The Shelburne Segment, while mapped, is not part of this perspective, and the Panuke Segment, located to the northeast, is discussed later in the report. Only the well bores that intersected the bank edge are included which also shows the paucity of data points.

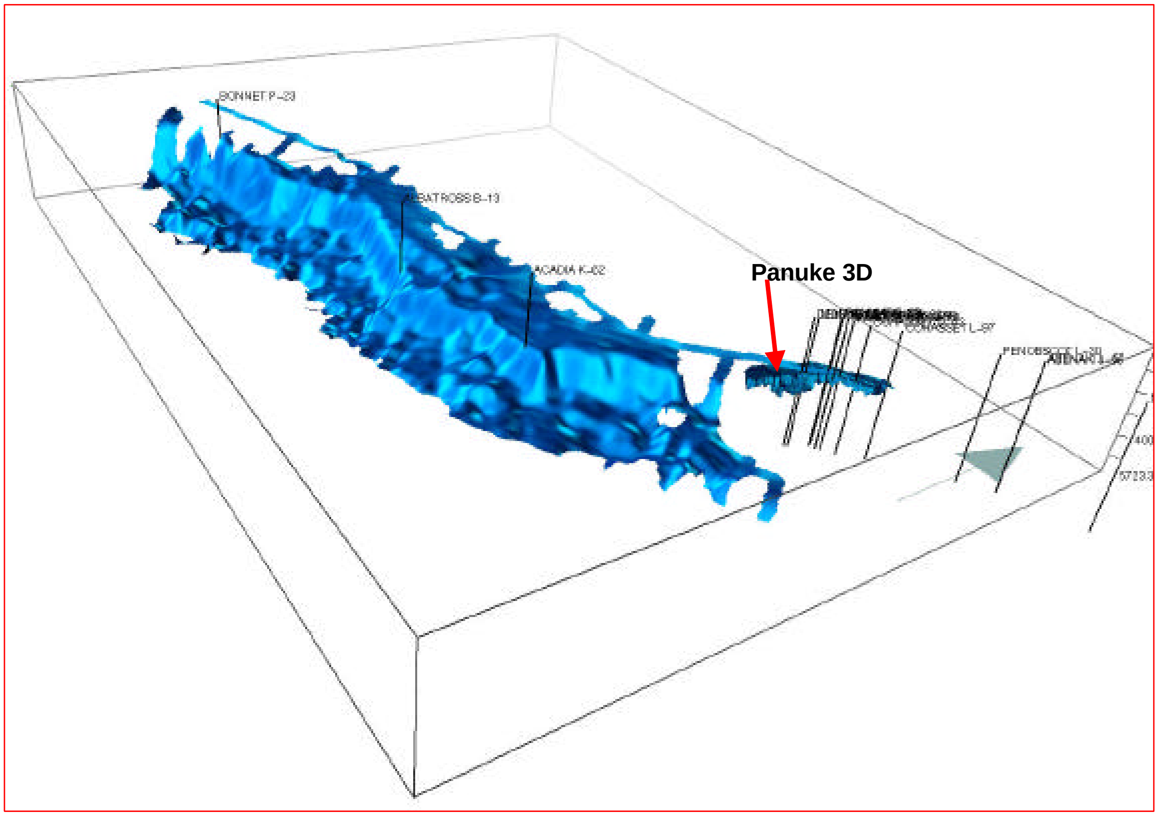


Figure 73. Isometric 3D image of the regional Top Jurassic horizon (~ Abenaki 7) viewed to the northwest. The relative size and area of the Panuke 3D seismic survey is indicated. Note the concentration of wells in the Panuke Segment.

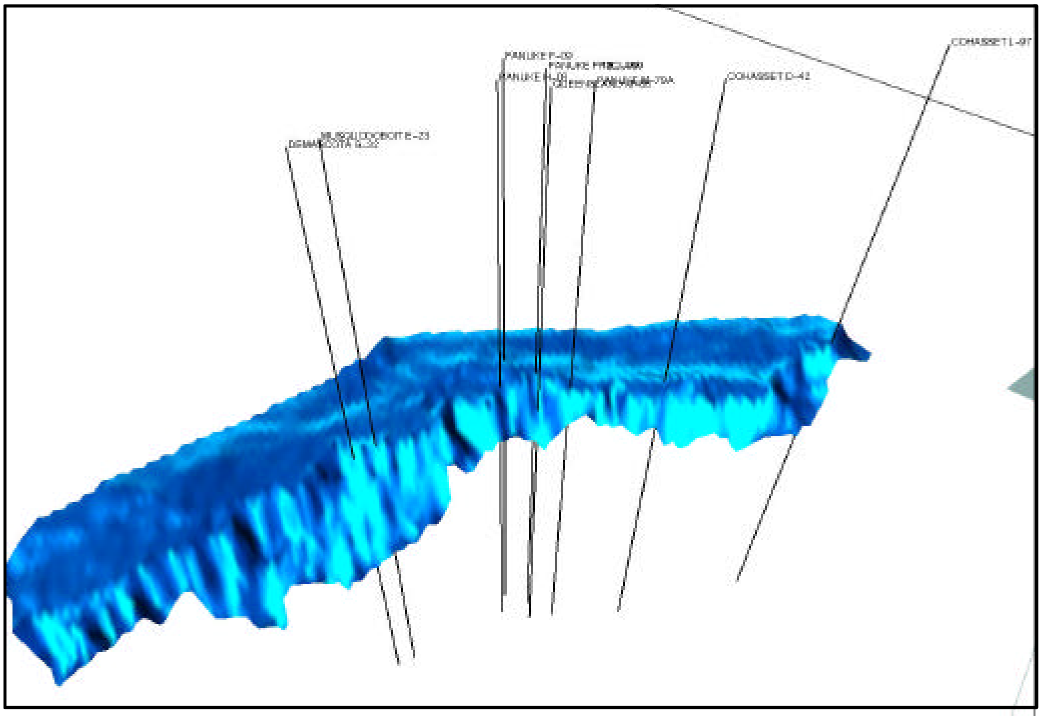


Figure 74. Isometric 3D image of the Top Jurassic horizon, Panuke Segment, viewed to the west (coarse gridding).

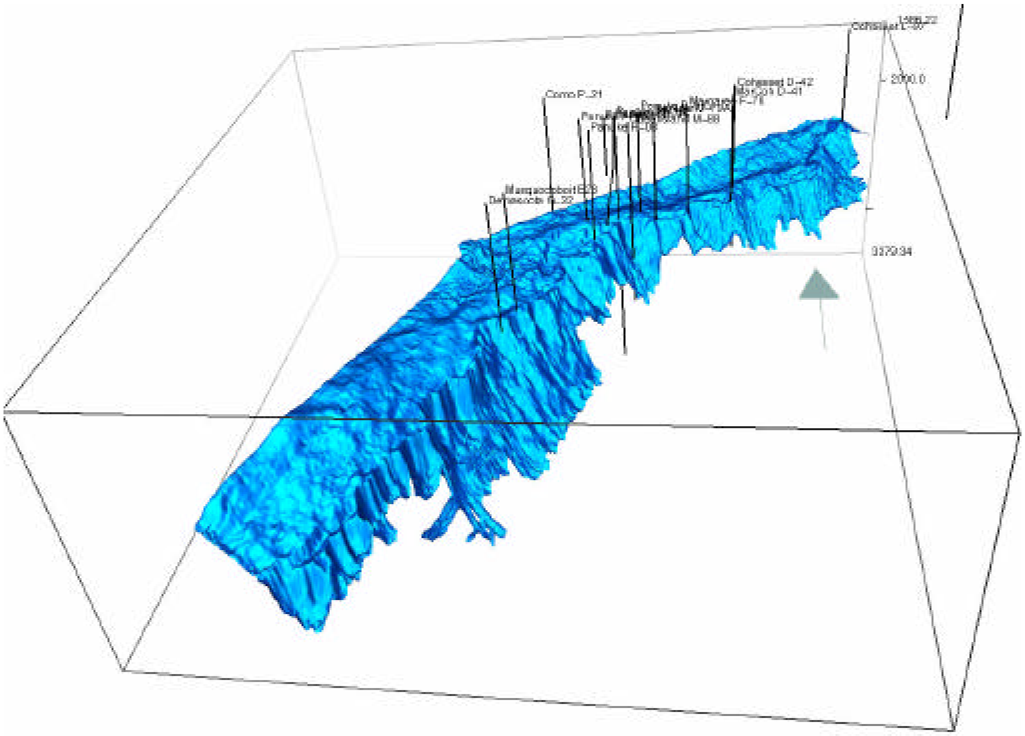


Figure 75. Isometric 3D image of the Abenaki-6 horizon (depth map), Panuke Segment, viewed to the north (fine gridding). Note the complexity of the scalloped bank margin with its numerous promontories and reentrants. The sag behind the margin in the northeast may be related to a subtle salt withdrawal feature.

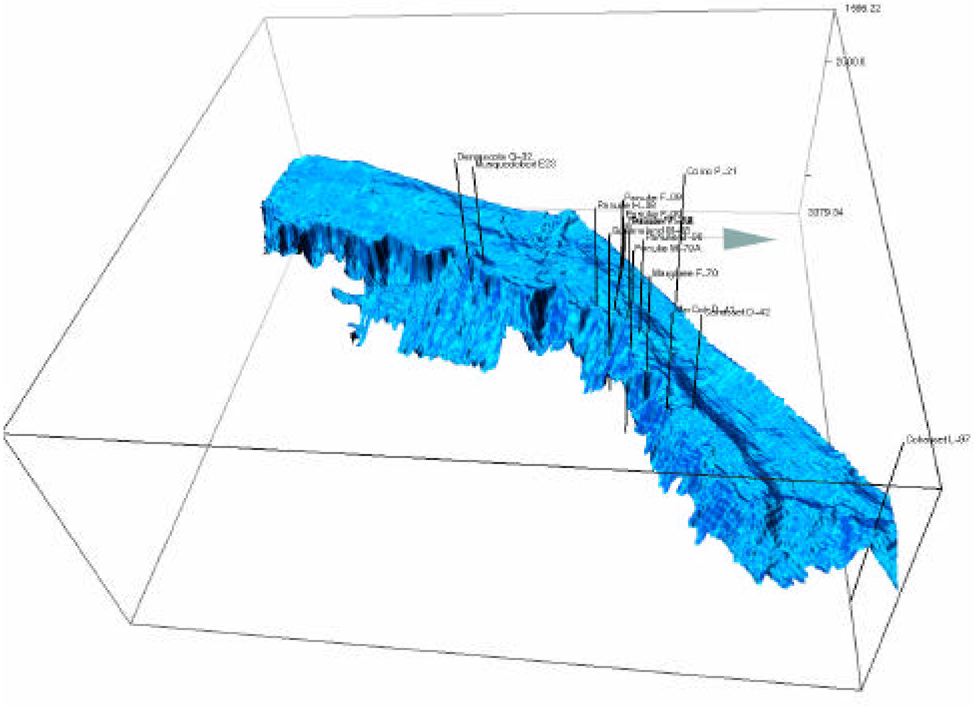


Figure 76. Isometric 3D image of the Abenaki-6 horizon (depth map), Panuke Segment, viewed to the west (fine gridding). The rimmed appearance of the margin at its northeastern end may be an exaggeration due to the back reef low reflecting deeper structural elements.

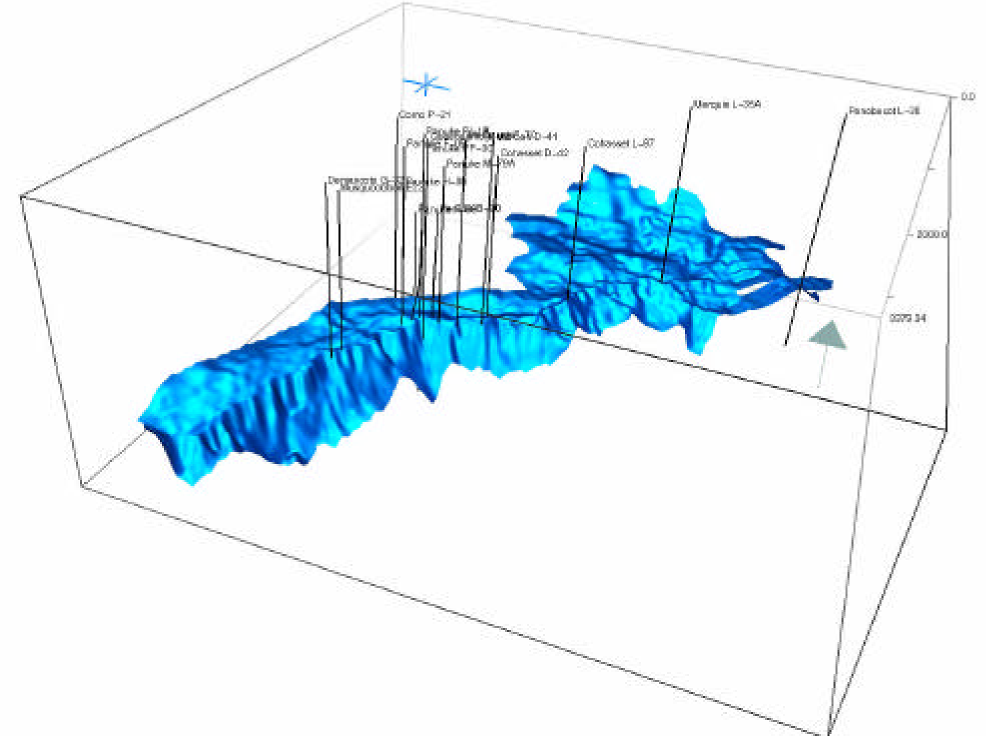


Figure 77. Isometric 3D image of the Abenaki-6 horizon (depth map) including the Marquis 2D survey to the northeast (coarse gridding). At its eastern end, definition of the Abenaki bank margin becomes more difficult and reflects the transition from a rimmed margin to a carbonate ramp.

The sinuosity of the bank edge may not be altogether random but reflecting the underlying basement architecture as discussed in Section 4.5. The change in strike at the Northeast Channel / Shelburne Segment (Figure 8) and the salt features within the subsurface below the channel imply a failed rift arm (triple junction?). The mouth of this feature would be the probable locus for suspected mid-late Jurassic age deltaic deposition (Wade, 1990); the informally-termed 'Shelburne Delta'.

The promontory from Albatross B-13 to Acadia K-62 built across the mouth of the Mohican Graben forms a large bulge between the Sable Subbasin and the re-entrant to the southwest. There are major salt diapiric features that obliterate the bank edge at the mouth of the Mohican Graben and in the Shelburne Subbasin near the American border. These features are observed on the seismic as being clearly of at least post-Early Cretaceous and younger (Eocene) age. Although not visible in Figure 8, there is a saddle or low in the vicinity of the Evangeline H-98 well where the top of the carbonate platform rises both to the southwest and northeast. On close inspection, the bank edge seismic pick does not always agree with the steep contoured gradient which is a function of erosion and/or faulting where the bank edge has been disturbed.

Figure 8 illustrates the carbonate platform facies and the bank edge morphology along with major features like the Northeast Channel, the Mohican Graben, several salt features and the Montagnais Crater. Whereas the bank edge holds the most current interest, the foreslope cannot be ignored given its prominence in the example from the Golden Lane trend of Mexico (Section 6.3.3). However, while addressed in the discussions for each of the Segments, little seismic interpretation has been completed in this facies except for acknowledging a zone of foreslope that may capture reefal debris.

7.2 Panuke Segment

The Panuke Segment extends southwest from Penobscot L-30 to the seaward limit of the Sable Delta in the vicinity of Evangeline H-98 and is adjacent to the hydrocarbon-prolific Sable Subbasin. It is within this subbasin and the adjacent carbonate bank where all 22 of the significant oil and gas discoveries off Nova Scotia have been made. This juxtaposition of source and reservoir within a prograding delta complex appears to be the dominant controlling factor for its successful hydrocarbon system.

The small patch of 3D mapping in the Panuke Segment attached to the regional 3D image (Figure 73) is shown on a larger scale (Figure 74) but with the same coarse gridding as the regional survey (6 X 6 km). The resolution at this scale is quite poor but when gridded properly for the 3D coverage the resolution improves dramatically (Figure 75). The two opposing views of the Panuke Segment (Figures 76 & 77) show the tremendous degree of detail along the bank margin and the rimming of the bank edge with a sag or moat in the back-reef direction.

The bank edge as seen from the 3D mapping has a scalloped shape in plan view and these features are interpreted as syndepositional slumps and/or gravity slides induced perhaps by active basement fracture trends. The bank edge is a highly irregular line much like the present-day Great Bahama Bank (Figure 13). It is also interesting to observe the Deep Panuke field is located on or about the bend in the bank edge. Unlike the previous map perspectives, the addition of the Marquis 2D survey to the 3D survey (Figure 7) yields additional data on the rimmed margin to the northeast.

7.2.1 Seismic Data and Well Control

The Panuke Segment has the densest well control and is mostly covered by 3D seismic with some 2D in-fill data available to fill in the gaps. The best dataset is amalgamated PanCanadian/EnCana 3D seismic programs. Exploration in the Abenaki has been intermittent as the chronological listing of wells indicate, with most being drilled following the Deep Panuke discovery:

Year	Operator	Name	ID	FTVD (m)	Status	Comments
1973	Mobil	Cohasset	D-42	4427.0	Oil	Back Reef – Discovered 38 m light oil pay in thin, stacked Early Cretaceous Logan Canyon Fm. sands in a shallow drape closure. Minor mud gas and porosity in the Abenaki (Bacarro).
1974	Shell	Demascota	G-32	4672.0	D&A	Bank Edge - Discovered 168 m of dolomitized and highly porous limestone (Abenaki 5). Minor mud gas shows, tested water.
1976	PetroCanada	Penobscot	L-30	4267.0	Oil	Back Reef – Discovered light oil in shallow drape closure within Early Cretaceous Missisauga Fm. sands. Minor mud gas and porosity in the Abenaki (Bacarro).
1978	Mobil	Cohasset	L-97	4872.0	D&A	Back Reef – Some minor porosity and mud gas shows present. Tested gas-cut mud.
1986	Shell	Panuke	B-90	3445.0	Oil	Back Reef – Discovered 10 m light oil pay in several stacked Early Cretaceous Missisauga Fm. sands in a shallow drape closure.
1998	PanCanadian	Panuke	J-99 PP-3C	4163.0	Gas	Bank Edge – Initial gas discovery. Tested 59.7 MMcf/d gas from the Abenaki 5/4 zones (also known as PP-3C).
1999	PanCanadian	Panuke	J-99 PI-1A	4030.0	Gas	Bank Edge – Thin gas pay. Well plugged and whipstocked to test adjacent seismic event at PI-1B.
1999	PanCanadian	Panuke	J-99 PI-1B	4046.3	Gas	Bank Edge – Whipstocked from PI-1A. Discovered 24.2 m gas pay and tested 52.6 MMcf/d gas in the Abenaki 5.
2000	PanCanadian	Panuke	H-08	3682.0	Gas	Bank Edge – Discovered 108 m of net gas pay; tested 51.2 MMcf/d gas from the Abenaki 5.
2000	PanCanadian	Panuke	M-79	4598.3	D&A	Bank Edge – No gas pay, well plugged and whipstocked to test adjacent seismic event at M-79A.
2000	PanCanadian	Panuke	M-79A	3934.7	Gas	Bank Edge – Whipstocked from M-79. Discovered 11.4 m gas pay, tested 63.2 MMcf/d gas from the Abenaki 5.
2000	PanCanadian	Panuke	F-09	3815.0	D&A	Back Reef - Oolitic facies amplitude prospect. Target was shale. Other limestones were tight with no gas pay.
2001	PanCanadian	Musquodoboit	E-23	3813.9	D&A	Bank Edge – Significant porosity encountered within the Abenaki 5 but was located below the field-wide gas/water contact.
2002	PanCanadian	Queensland	M-88	4470.0	D&A	Bank Slope – Targeted lowstand by-pass sands. One minor sand present. High amplitude events were thick foreslope limestones with minor porosity and gas shows.
2003	EnCana	Margaree	F-70	3677.0	Gas	Bank Edge – Discovered ~70 m gas pay, tested >52 MMcf/d gas. Well data confidential until August 6, 2005.
2003	EnCana	MarCoh	D-41	3625.0	Gas	Bank Edge – Discovered ~100 m gas pay, not tested. Well data confidential until October 23, 2005.

Table 8. Panuke Segment - Wells and Shows

7.2.2 Interpretation

The Abenaki stratigraphy of the Panuke Segment is best illustrated by EnCana's stratigraphic framework (Figure 9). The Baccaro Member is dominantly an oolite-rich carbonate platform with a complex reef margin (Eliuk, 2002). The Deep Panuke reservoir consists of dolomitized and leached reefal limestone in a combination stratigraphic/structural trap with the main hydrocarbon-bearing zone the Kimmeridgian age Abenaki-5. Drilling results indicate that a common gas/water contact (ca. -3504 mSS) exists within the Segment (PanCanadian, 2002).

Structure maps of the approximate "Lower Jurassic" marker are believed to ghost the probable 'basement' morphology and reveal a dominant southwest-northeast trend as shown in Figure 78. This likely reflects basement highs and lows associated with Middle-Late Triassic age rift grabens and half-grabens along with Early Jurassic salt swells that likely migrated out of the rift basins. The superposition of the Deep Panuke field with a major high trend is suggestive of a deeper influence on formation of bank edge, reservoir diagenesis and gas accumulation. This suggests that more study should be directed towards understanding the pre-platform morphology (basement and pre-Breakup Unconformity succession) in order to understand these relationships and assist in defining similar attributes elsewhere on the Abenaki margin.

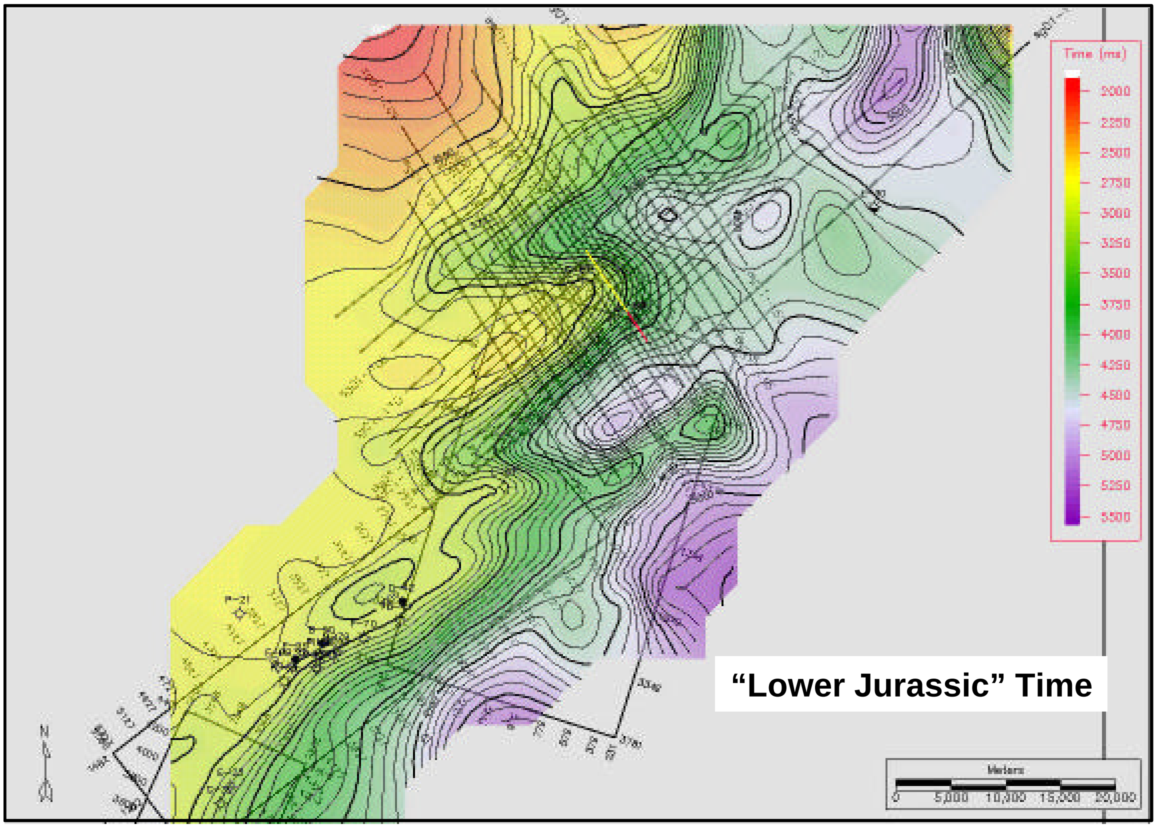


Figure 78. “Near Basement Morphology”, Lower Jurassic horizon time map. The strong northeast-southwest orientation of the horizon infers probable basement faults and related depocentres that were loci for earliest Jurassic salt deposition. Well cluster to the southeast is the Deep Panuke field. The Penobscot L-30 well is outboard of the basement trend and may be underlain by a subtle salt feature.

Mapping of the stratigraphically higher Abenaki 6 time structure and the companion depth map (not included in this report) reveal a striking similarity of the features seen in the “Lower Jurassic” marker map due to the relatively horizontal and uniform overlying sedimentary section, and the near-flat seabed; i.e. no water wedge to distort the time/depth conversion. There is a structural high associated with the Deep Panuke field with a paralleling long, linear embayment (moat) on landward side to the northwest. This combination invariably contributed to the development of the positive rimming of reefal facies built up along the bank edge, and continues further to the northeast. Near its eastern extremity, the wells at Marquis and Demascota do not appear to have been drilled on a positive rim. The intervening Cohasset L-97 was drilled a structural feature on a rimmed margin and while encountering tight limestone with a few modest shows may have been positioned slightly away from the reef margin. Time structure and depth maps for the slightly deeper Abenaki 5 horizon, the closest horizon to the major pay zones (not included in this report), also reveal the same observations but are not quite as distinct.

The very narrow reservoir fairway presents challenges in a costly offshore setting and a number of wells missed the main reservoir facies. The following suite of seismic time profiles through the wells drilled along the trend is mostly extracted from the PanCanadian/EnCana 3D data volume. They reveal the diversity of seismic responses within a very small area and are presented in chronological order of drilling with reservoir intervals annotated where permitted.

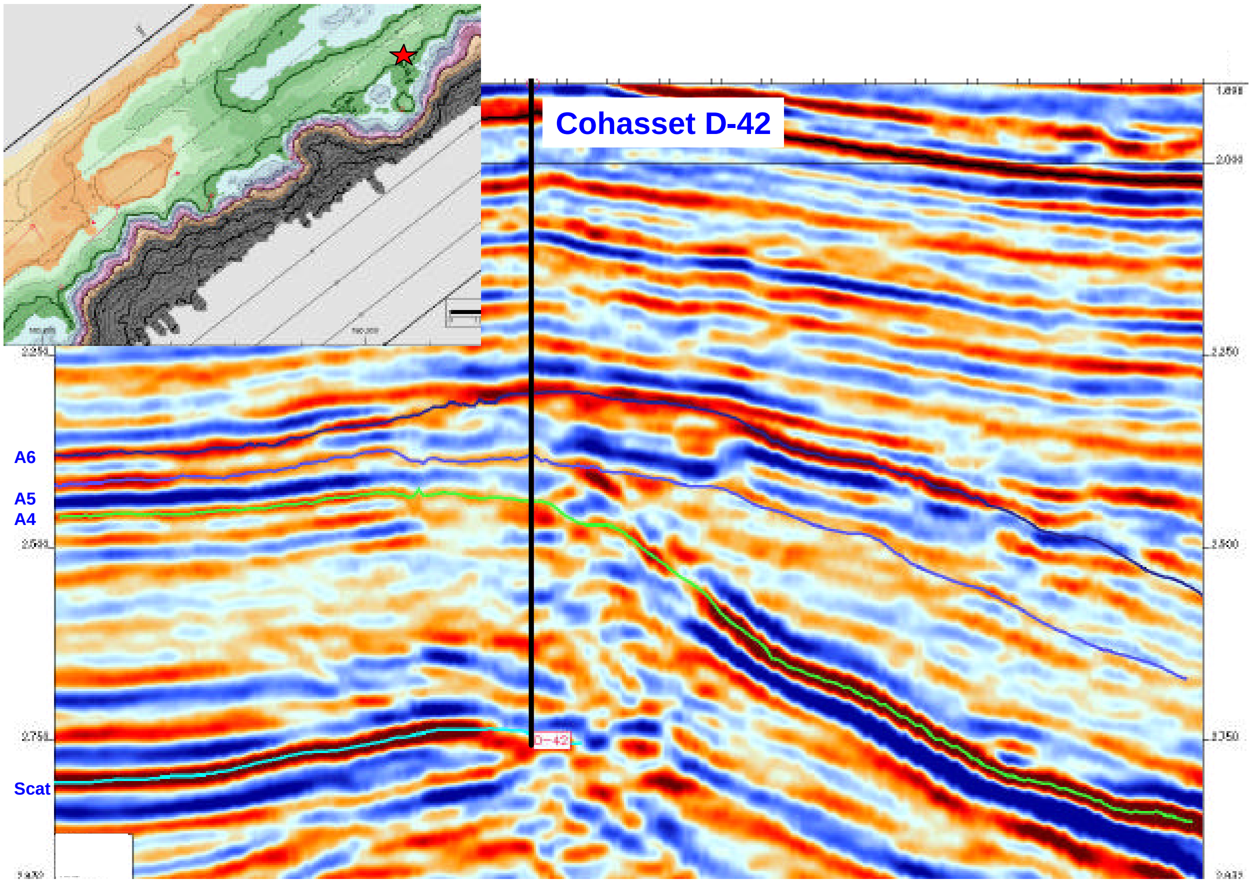


Figure 79. Detailed seismic profile – Cohasset D-42 exploration well. See inset map for location. Legend: A6, A5 & A4 = Abenaki 6, 5 & 4, Scat = Scatarie (Abenaki 1).

Mobil Cohasset D-42 (1973) (Figure 79) was the first well drilled to test the carbonate bank edge. The structural reversal on the Abenaki 6 horizon is quite obvious with internal amplitude configurations. The D-42 well penetrated the entire Abenaki Formation, revealing a thickness of 1088 m. The Early Cretaceous succession drapes over the bank margin and light oil within stacked sands of the Lower Logan Canyon Formation were developed through the Cohasset oil field.

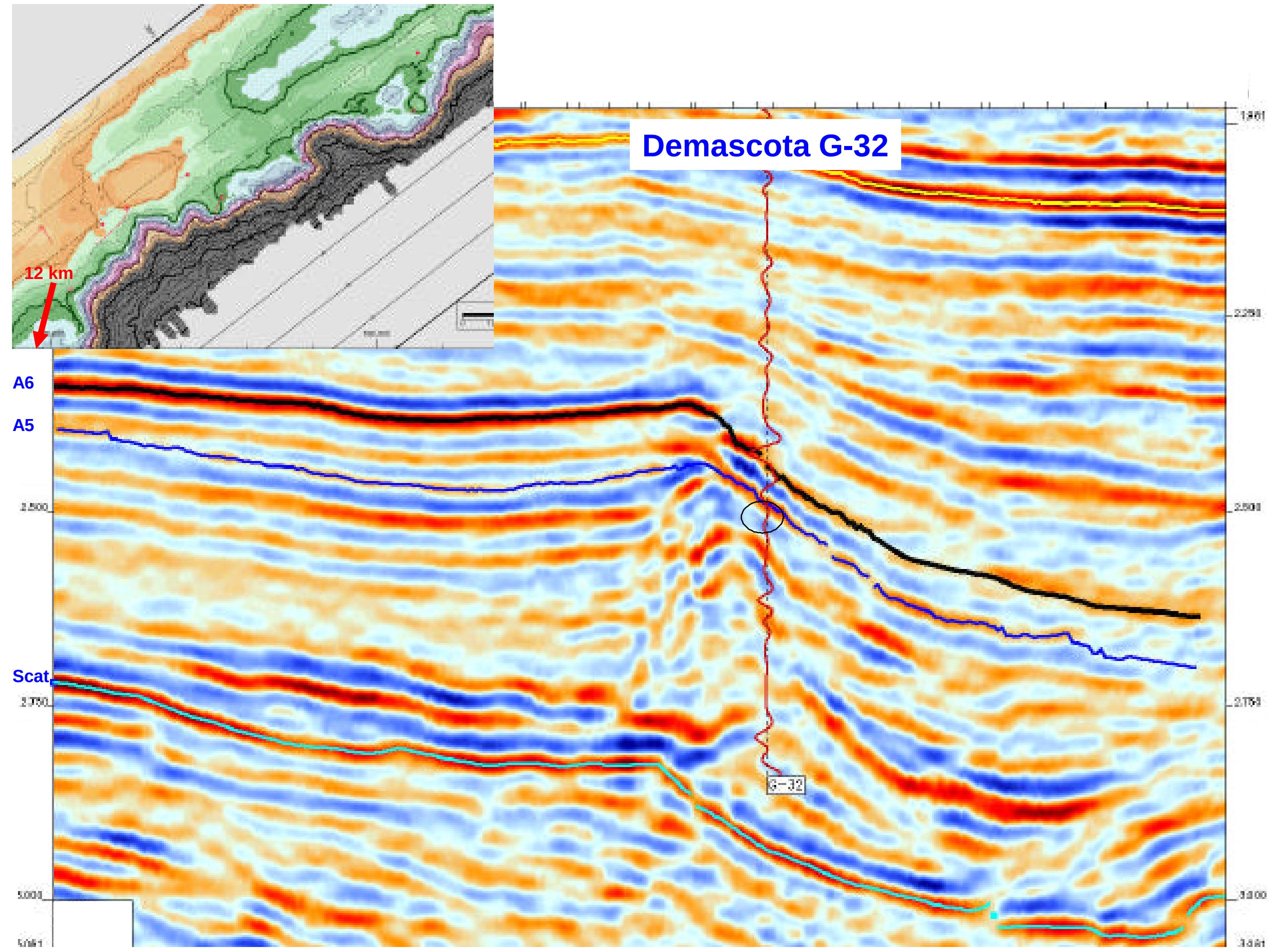


Figure 80. Detailed seismic profile – Demascota G-32 exploration well. See inset map for location.

Shell Demascota G-32 (1974) (Figure 80) was positioned slightly in front of the bank edge with a possible fault zone just west (left) of the well. A complex zone of high amplitudes is apparent at the margin edge and the overall 168 m of reservoir quality dolomitic porosity is shown (circled) located just beneath the top of the Abenaki 5 sequence. The seismic expression and attributes of this excellent thick porosity was modeled by Harvey (1990, 1993) which was utilized by PanCanadian in its exploration along the trend. EnCana drilled the Musquodoboit E-23 well in 2001 to investigate the porosity above the water line in a similar margin setting..

Penobscot L-30

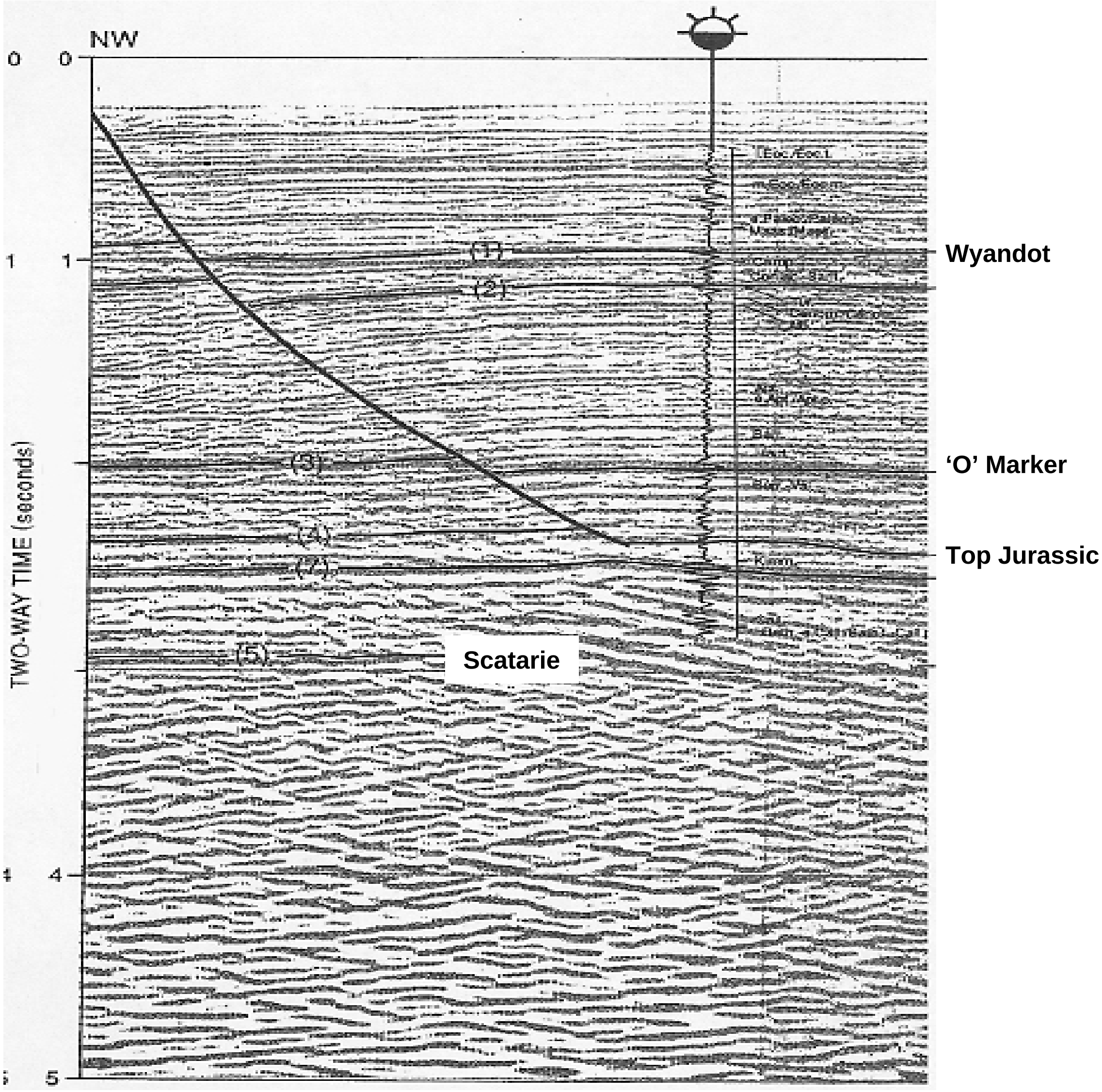


Figure 81. Detailed seismic profile – Penobscot L-30 exploration well. See Figure 4 for location.

PetroCanada Penobscot L-30 (1976) (Figure 81). This well's objective was a Cretaceous rollover in front of a down-to-basin listric fault. Oil pay was defined on logs and RFT's but no tests were carried out. Low-angle foreslope limestones of the Abenaki were intersected near the well TD, as in this region the steeply dipping rimmed margin grades into a ramp-like margin.

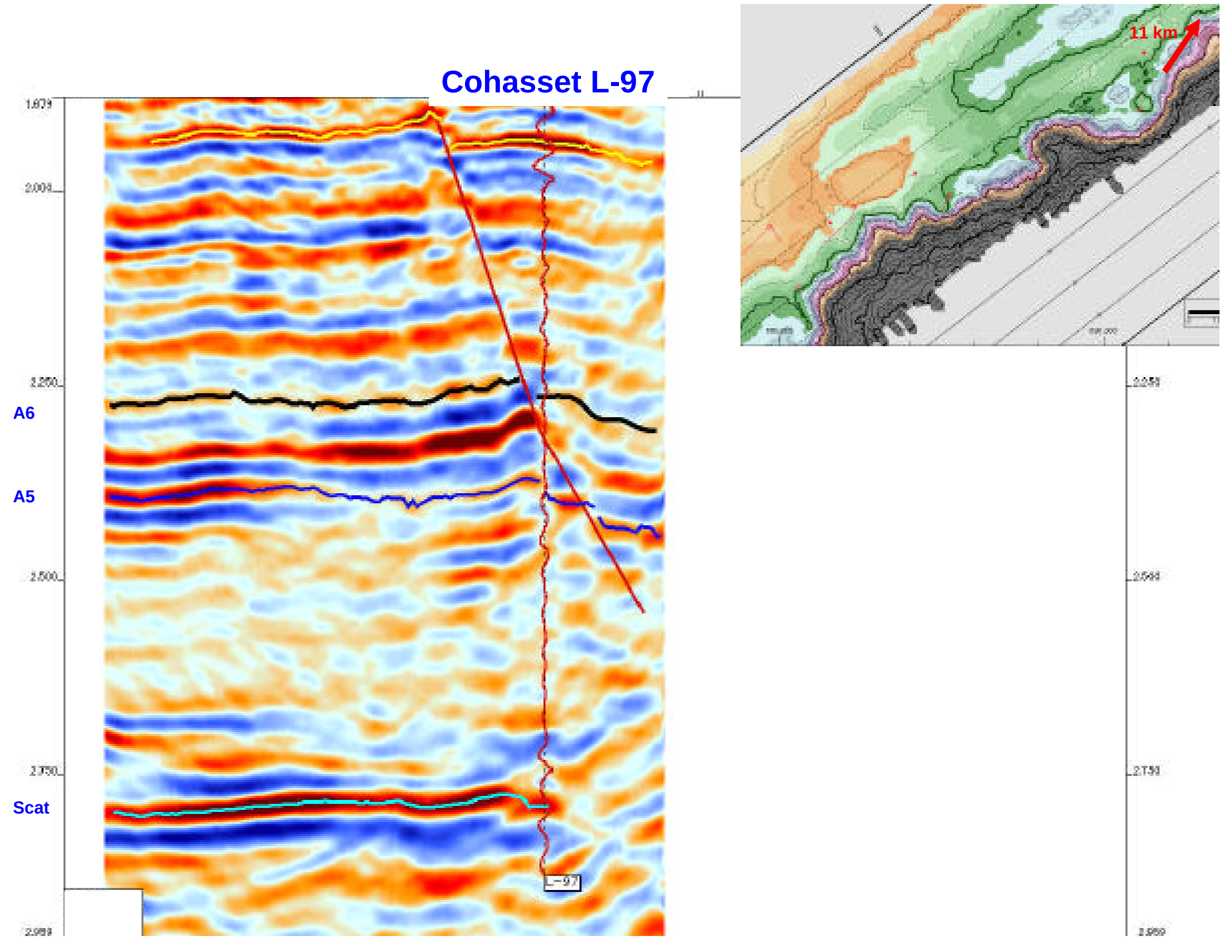


Figure 82. Detailed seismic profile – Cohasset exploration L-97 well. See inset map for location.

Mobil Cohasset L-97 (1978) (Figure 82) is an abbreviated profile but shows a fault at or near the bank edge. This is one of the few wells that penetrated the entire Abenaki Formation. The carbonates were mostly tight with some dolomitic intervals and modest porosity development though no significant hydrocarbon shows were present. The track of the well bore penetrated the fault and extended basinward in front of an amplitude anomaly that in hindsight could have been evaluated via whipstocking.

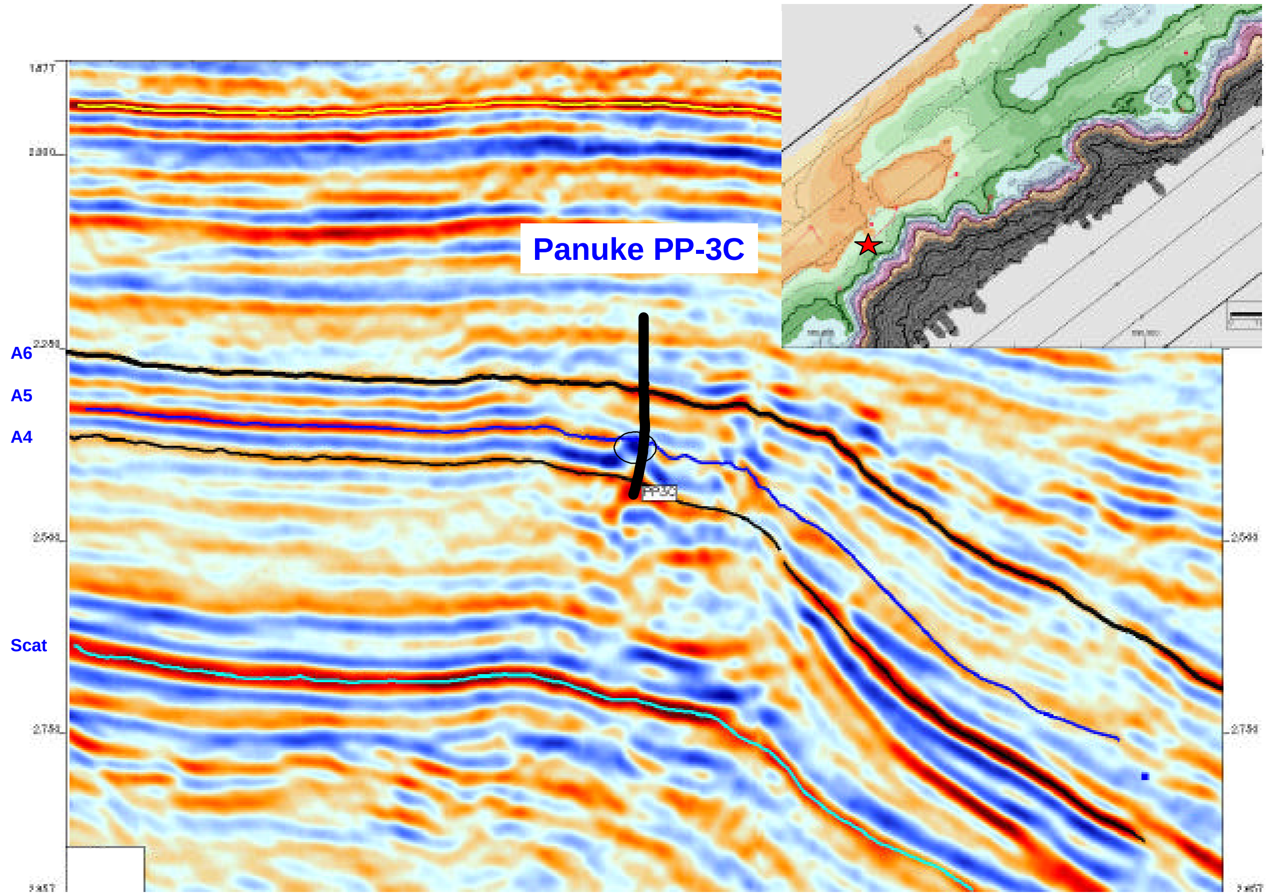


Figure 83. Detailed seismic profile – Deep Panuke PP-3C discovery well. See inset map for location.

PanCanadian Panuke (Deep) PP-3C (1999) (Figure 83) was drilled from the J-99 surface location of the decommissioned Panuke oil production platform and was the discovery well for the Deep Panuke gas field. The main gas reservoir zone (circled) appears as low amplitude (blue) events within the Abenaki 5 interval. The reservoir is a dolomitized and leached vuggy and cavernous limestone reefal facies with porosities from 3-40+%, permeabilites from 1 md to several darcies, and net pay values from 30-100 m. The well tested flow rates up to 59 MMcf/d which was the limit of the testing equipment. Traces of H2S were also encountered at 0.2% (2000 ppm).

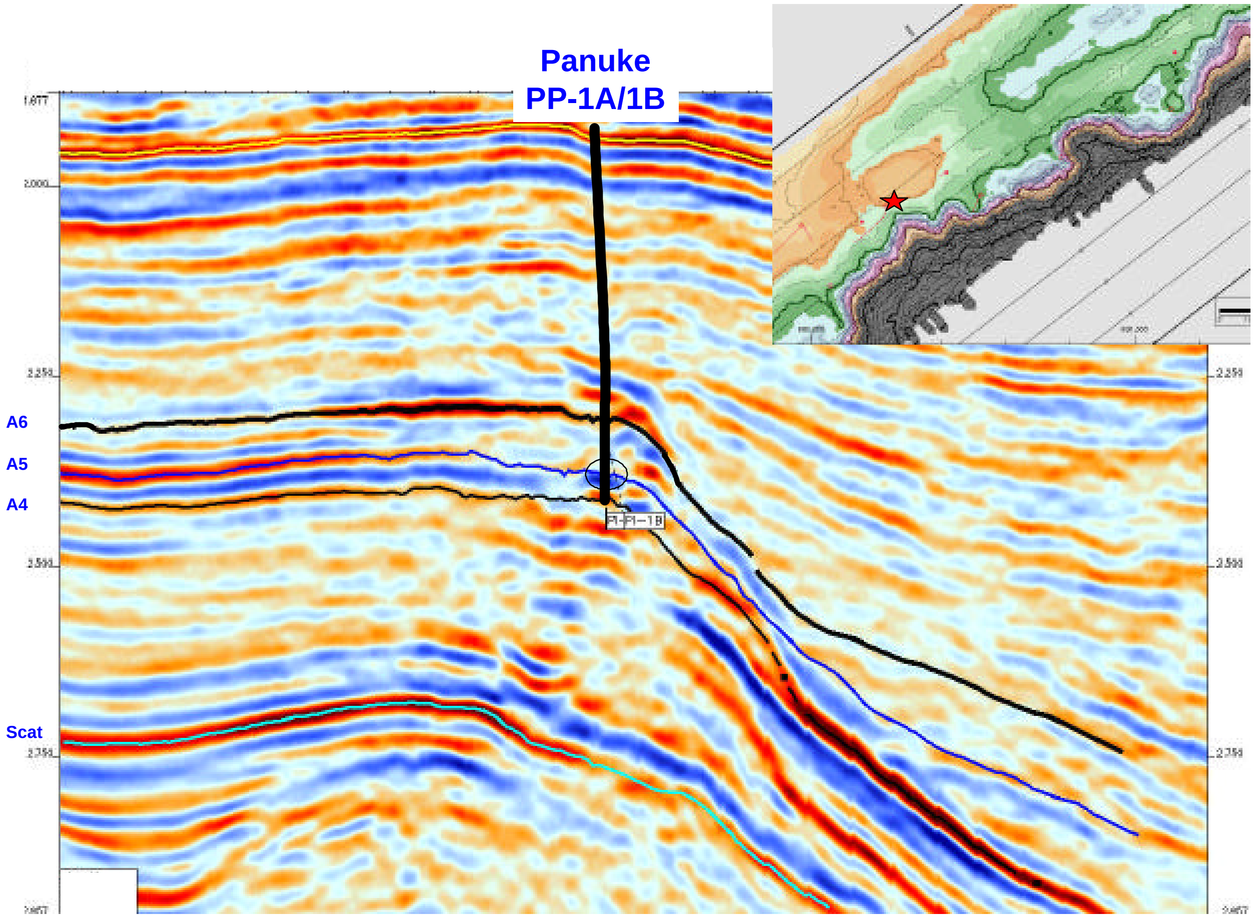


Figure 84. Detailed seismic profile – Deep Panuke P1-1A/1B, first appraisal well. See inset map for location.

PanCanadian Panuke (Deep) PI-1A/1B (1999) (Figure 84) was the first appraisal well directionally drilled from the J-99 platform about 2.3 kilometres along-strike to the northeast. PI-1A missed the main reservoir zone and PI-1B was whipstocked a short distance into the reservoir zone (circled) and tested gas at 51 MMcf/d.

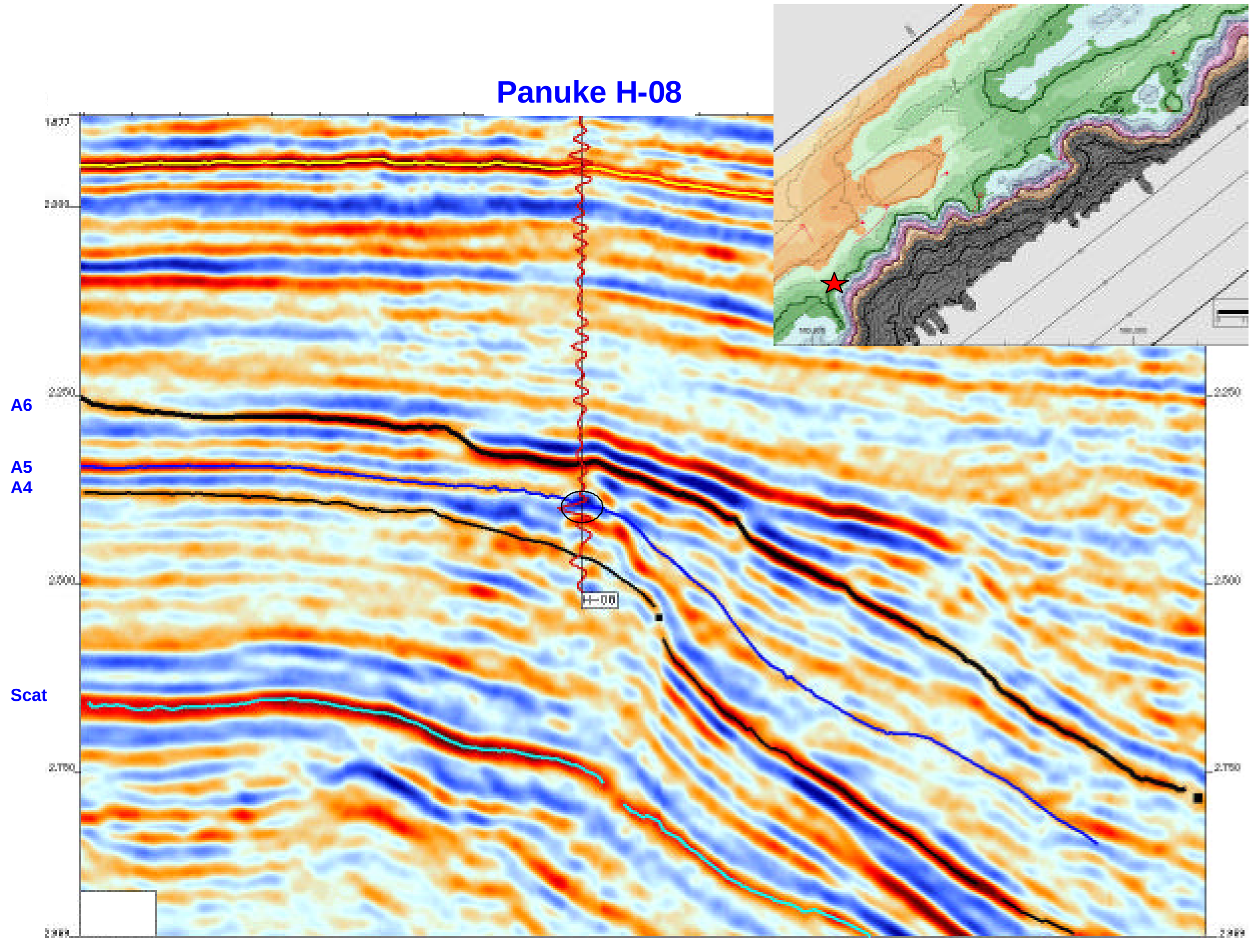


Figure 85. Detailed seismic profile – Deep Panuke H-08, second appraisal well. See inset map for location.

PanCanadian Panuke (Deep) H-08 (2000) (Figure 85) was the second appraisal well drilled about 2.3 km southwest from the discovery well. It encountered reservoir conditions similar to PP-3C (circled) and tested gas at 50-57 MMcf/d.

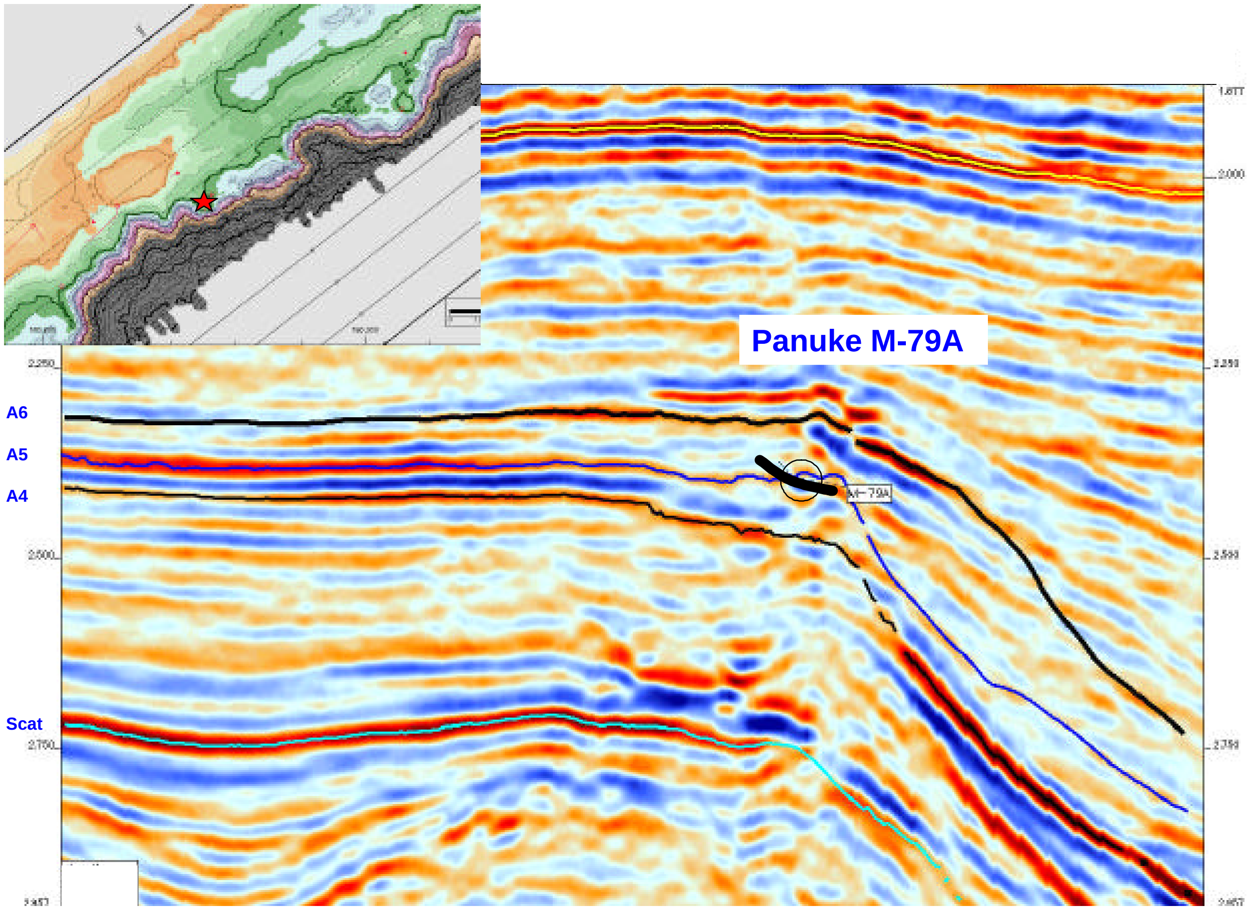


Figure 86. Detailed seismic profile – Deep Panuke M79A, third appraisal well. See inset map for location.

<u>PanCanadian Panuke (Deep) M-79 and M-79A</u> (2000) (Figure 86) was the third appraisal well drilled about 1.3 km northeast from the P1-1B well and tested gas up to 63 MMcf/d. The M-79 well was vertical and missed the gas zone but M-79A was whipstocked into the seismic amplitude horizon (circled) and tested gas up to 63 MMcf/d. This well demonstrated the very short lateral transition distance between tight oolitic back reef and reef margin facies (Wierzbicki et al, 2002).

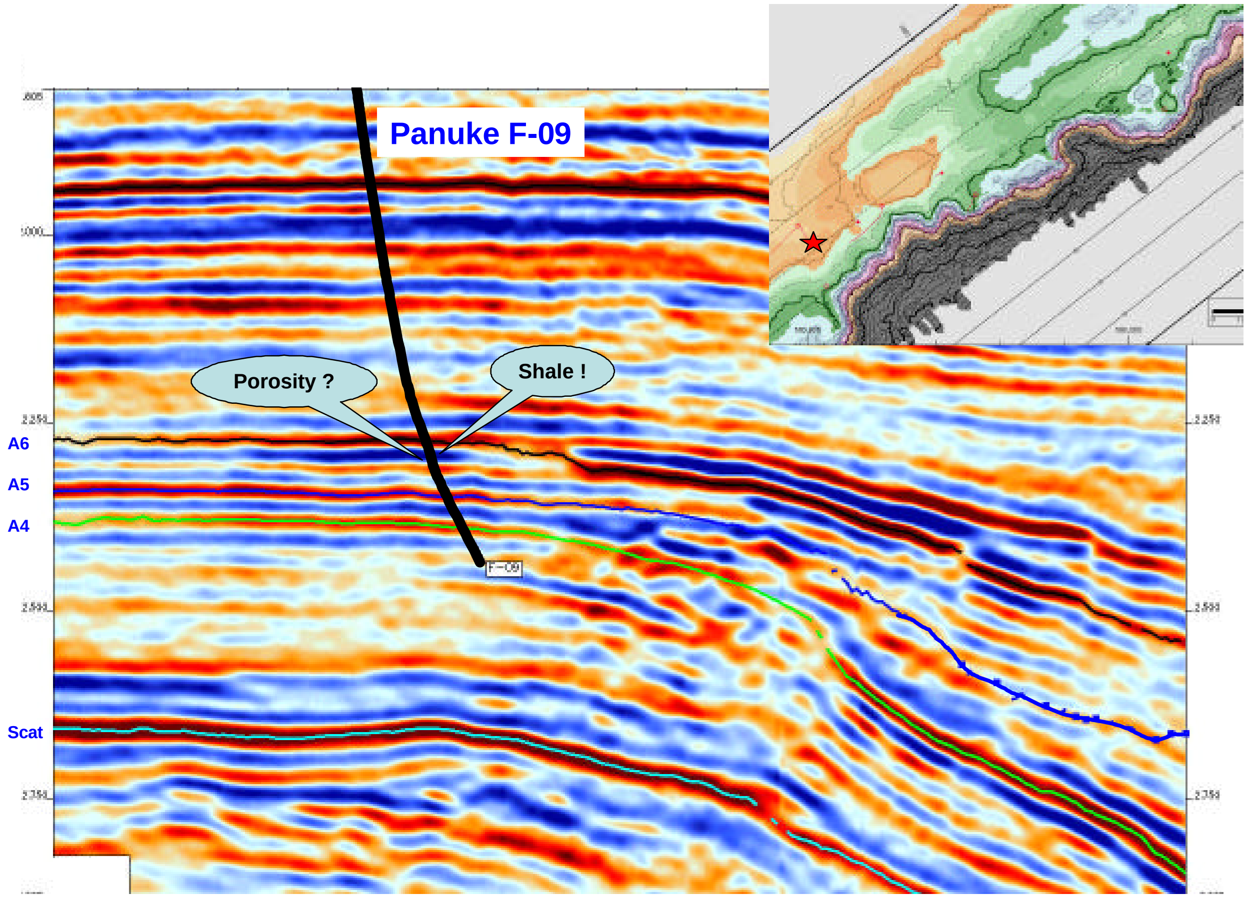


Figure 87. Detailed seismic profile – Panuke F-09 exploration well. See inset map for location.

<u>PanCanadian Panuke F-09</u> (2000) (Figure 87) was drilled about 1.8 km landward of the main gas zone of Deep Panuke in an attempt to extend the play into the back-stepping Abenaki 6 sequence. No reservoir was encountered in the Abenaki 6, the target amplitudes were determined to be due to shale, and further drilling penetrated tight back-reef facies in the Abenaki 5.

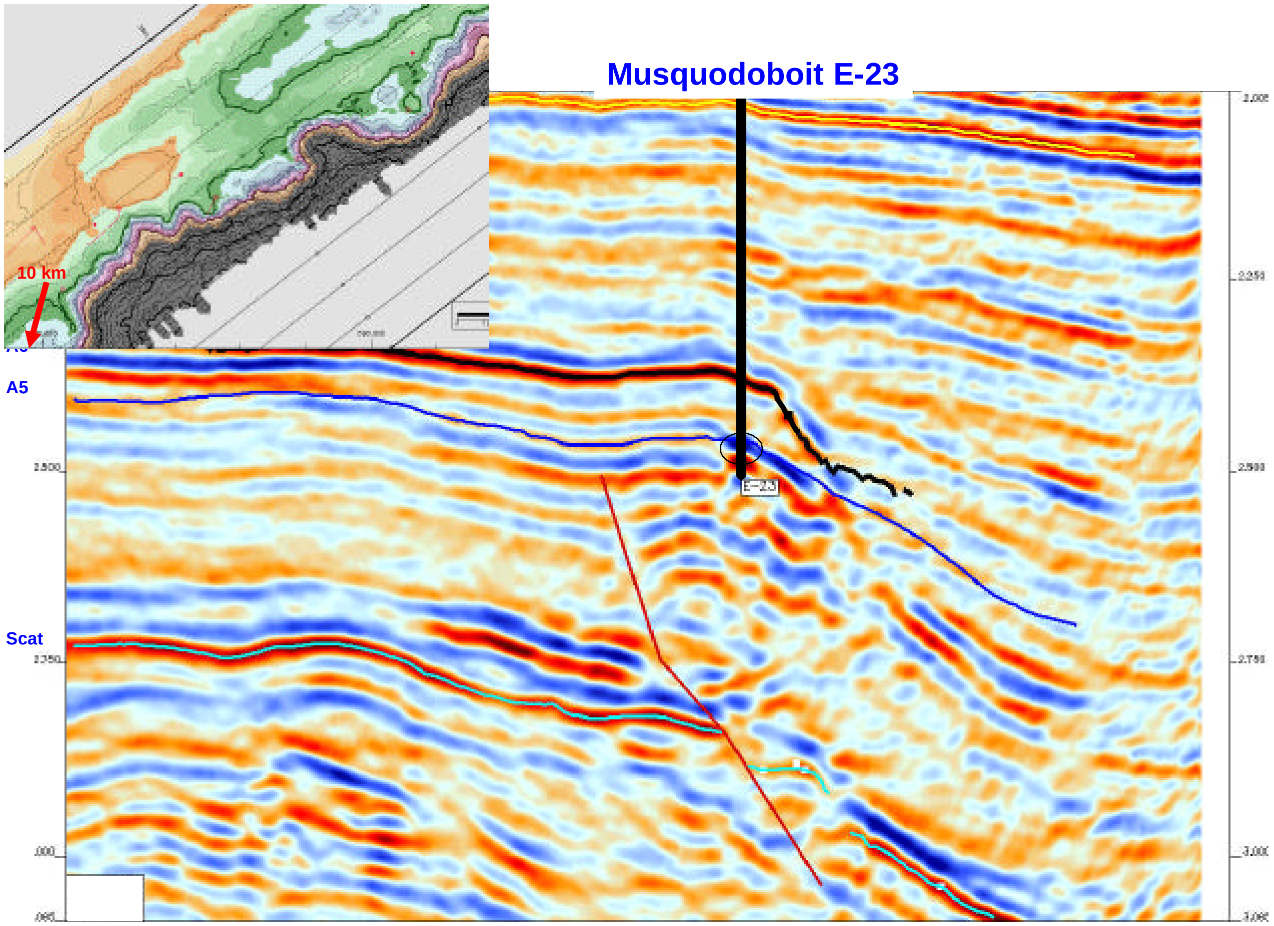


Figure 88. Detailed seismic profile – Musquodoboit E-23 exploration well. See inset map for location.

<u>PanCanadian Musquodoboit E-23</u> (2001) (Figure 88) was drilled updip from Demascota G-32 to test reservoir above the now established -3405 mSS gas/water line defined at Deep Panuke. However, the Abenaki 5 reservoir (circled) fell beneath the water line and no gas was encountered.

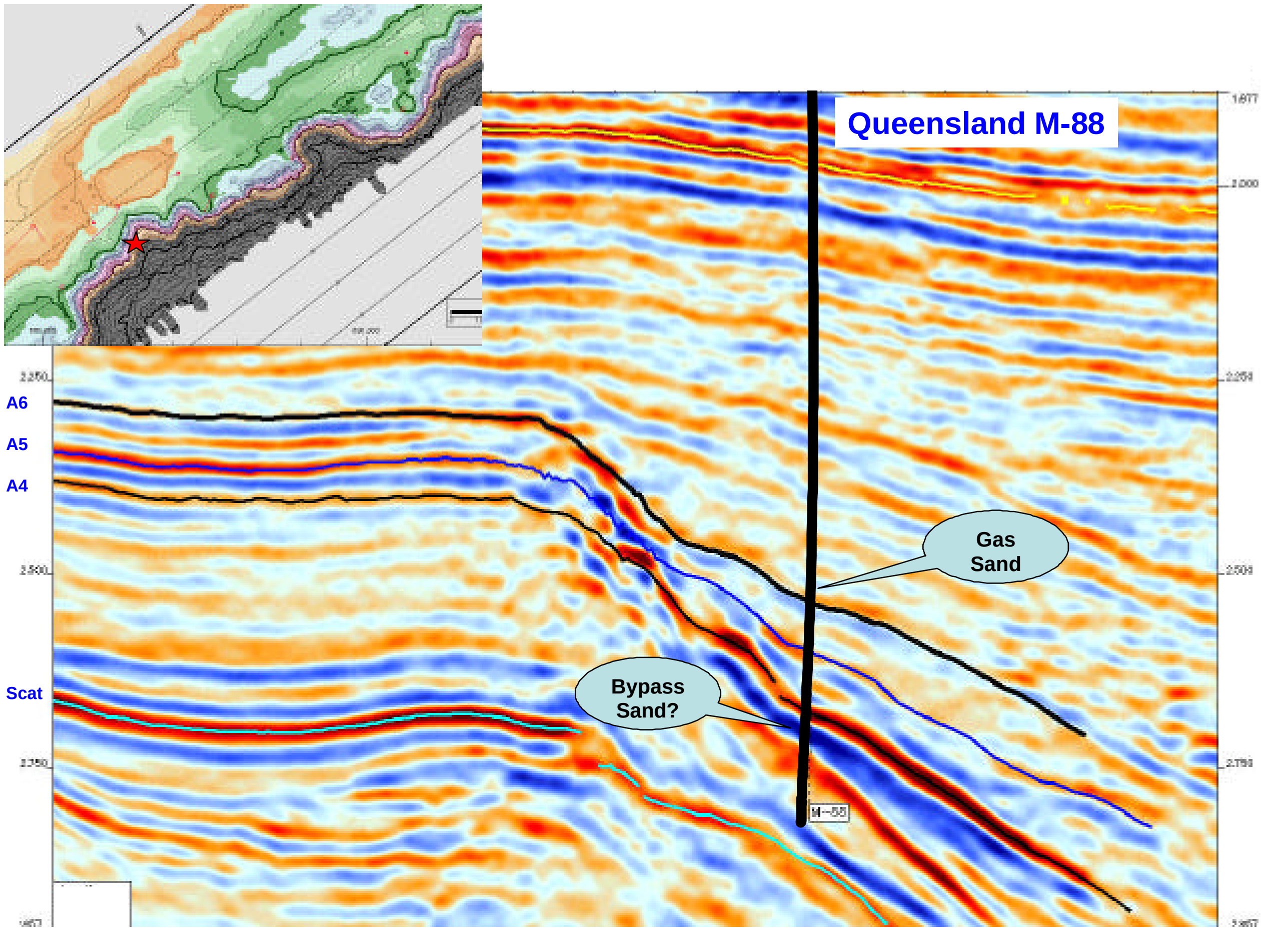


Figure 89. Detailed seismic profile – Queensland M-88 exploration well. See inset map for location.

PanCanadian Queensland M-88 (2002) (Figure 89) was drilled in a fore-reef position to test the carbonate talus slope and bypass sand play on the reef margin slope. However, no significant sands or reservoir were encountered.

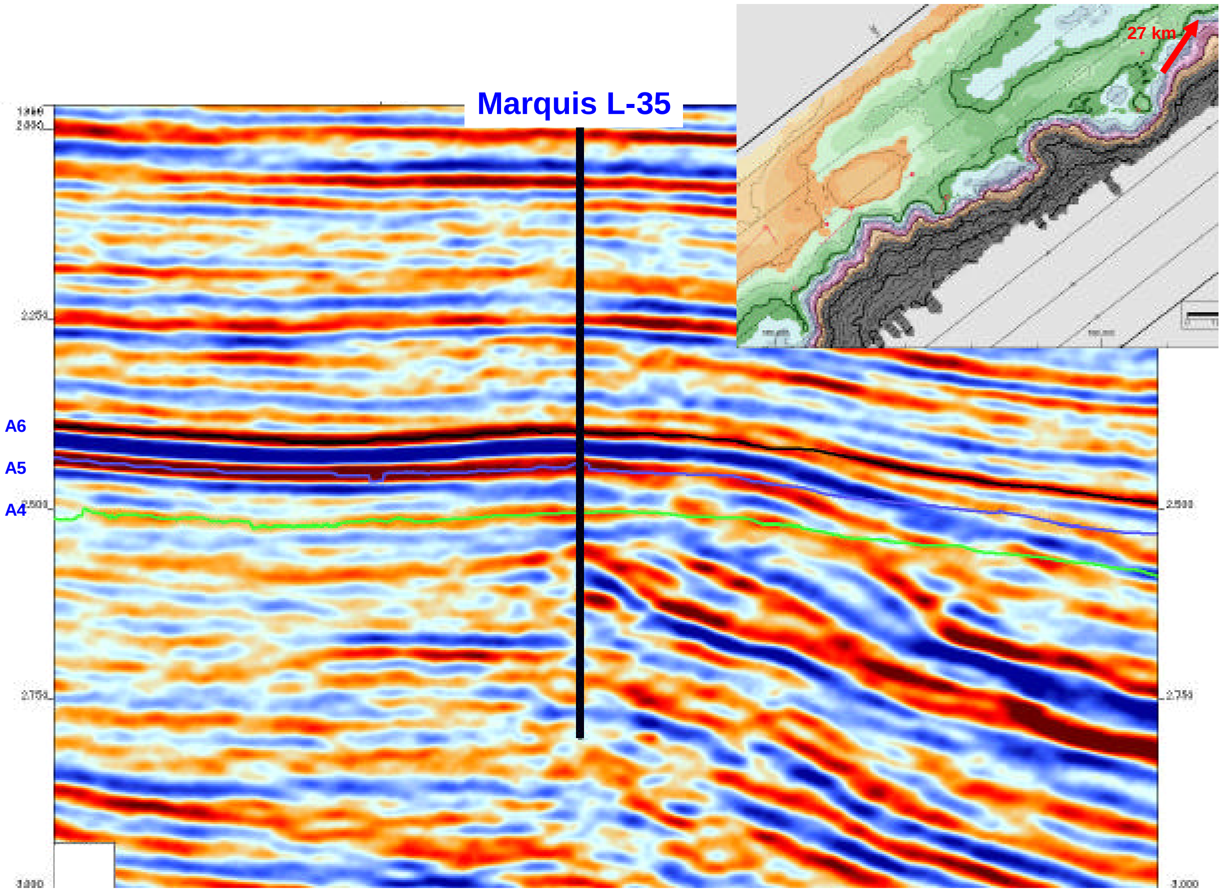


Figure 90. Detailed seismic profile – Marquis L-35 exploration well. See inset map for location.

Canadian Superior Marquis L-35 (2002) (Figure 90) was drilled near the bank edge about 35 kilometres northeast of later MarCoh D-41 well but encountered tight limestones. A whipstock (L-35A) also failed to find significant reservoir zones above the -3405 mSS structural elevation. The margin appears sigmoidal in shape and may be a transitional form between escarpment-like and ramping margin profiles.

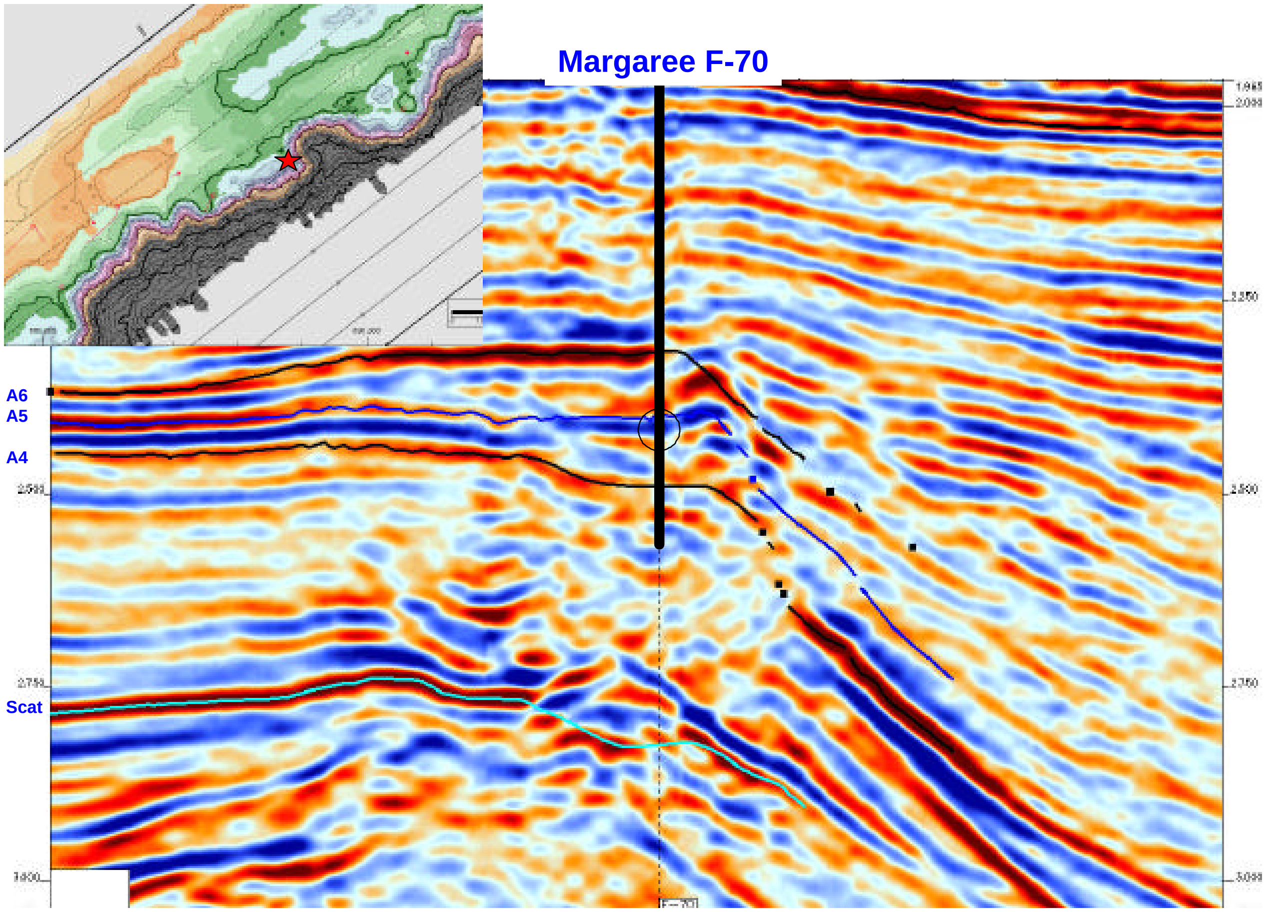


Figure 91. Detailed seismic profile – Margaree F-70, fourth appraisal well. See inset map for location.

EnCana Margaree F-70 (2003) (Figure 91) was drilled to the northeast of the Deep Panuke field. Press releases indicated the well discovered about 70 m of net gas pay which tested >52 MMcf/d gas. Data on this well remains confidential until August 6, 2005.

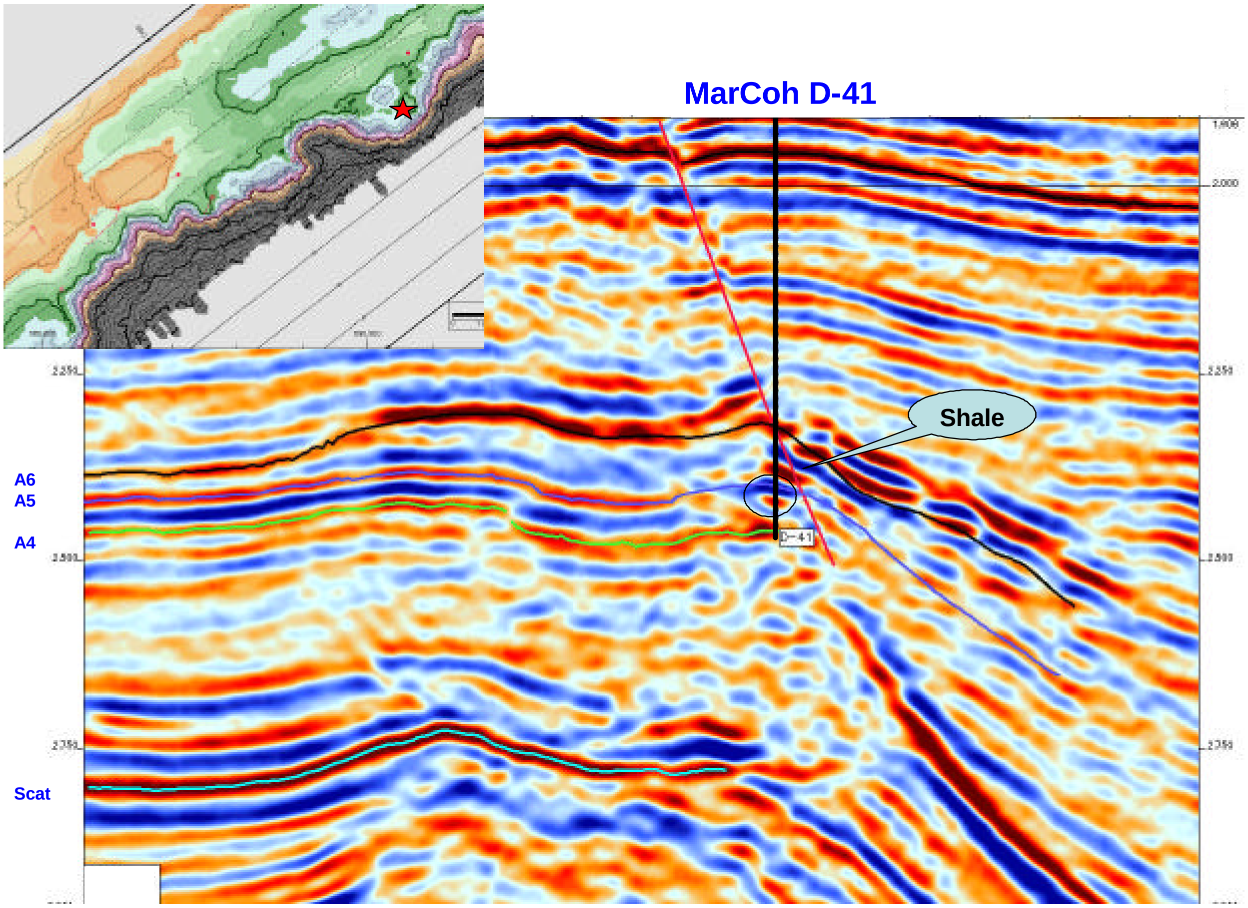


Figure 92. Detailed seismic profile – MarCoh D-41, fifth appraisal well. See inset map for location.

EnCana MarCoh D-41 (2003) (Figure 91) was the fifth appraisal well and is the furthest northeast along the Deep Panuke trend. EnCana press releases stated that the well found over 100 m gas pay but was not tested due to its proximity and close similarity to adjacent wells. Data on this well is confidential until October 23, 2005.

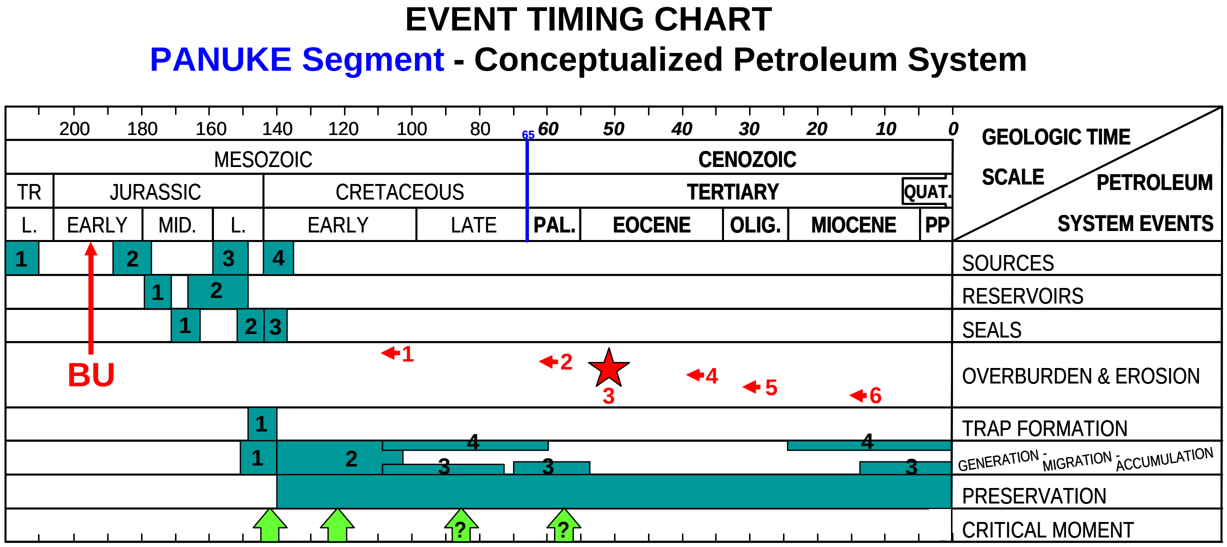
7.2.3 Play Concepts

Within the Panuke Segment, hydrocarbons in the Abenaki Formation are found in combined structural and stratigraphic traps within diagenetically-produced porosity formed in the skeletal framework of debris reefs along the carbonate bank margin. Maps and 3D images of the Abenaki 5 and 6 horizons based on 3D seismic in this segment reveal a highly scalloped margin composed of an alternating series of regularly spaced promontories and embayments about 1-2 kilometers across (Figures 26-28, 31-33, Figures 72-76). It is believed that these are natural features related to syndepositional loading, margin-parallel fracturing and failure on the margin, with reef talus debris deposited in deeper water adjacent to the margin as talus cones and aprons, and on the fore-slope in debris flow and turbidite deposits (Grammer et al., 1993). Mapping of the Deep Panuke Field suggests that the main controlling feature of the play is porosity distribution in the margin. Narrow amplitude events interpreted as reef-related porosity are observed at the head of the embayments connecting similar events spread out across the promontories. It is probable that the scalloping of the margin exists along the entire Abenaki margin though is not visible due to the large 6x6 kilometer grid of the latest regional seismic dataset.

The wells and seismic in the Panuke Segment indicate a carbonate porosity play existing across a very narrow 1 - 3 km band along the bank margin edge. The porosity has been encountered within the Abenaki 6, 5 and 4 intervals though mostly in the 5. The high porosity, leached, vuggy and cavernous zones produce a strong amplitude trough which is evident on the seismic data. The high amplitude areas are patchy in plan view and mostly occur right at the bank edge. Areas that may still contain good matrix porosity appear similar to tight limestone making it difficult to accurately map the extent of the productive zones. Often the highest amplitude areas are associated with cavernous lost circulation zones during drilling and are avoided where possible.

The Deep Panuke Field has in-place gas reserves of approximately 1.2 Tcf (PanCanadian, 2002) though the full lateral extent of the field is not yet confirmed. A limiting factor may be a structural reversal along strike plunging both to the southwest and the northeast of Deep Panuke combined with a field-wide (regional?) water line (-3405 mSS).

The events timing chart for the Panuke Segment is presented in (Figure 93). Its proximity to the prograding Sable Delta during the Late Jurassic (MicMac Fm.) and Early Cretaceous (Missisauga and Logan Canyon Fms.), facilitated rapid burial and preservation of the bank margin. These successions also contributed dispersal of volumetrically large quantities of terrestrial (Type III) organic matter in thick prodelta sequences which acted as a seal and potential gas source. Source facies in adjacent and underlying sediments could also be contributors of liquid and gaseous hydrocarbons. The deeper Middle Jurassic Mohican Formation sediments deposited in interpreted salt evacuation synclines are unique to this Segment and could contain possible source rocks. The reservoir porosity was probably formed early as combination of facies-related diagenesis and burial subsidence. Relative to the generic Abenaki chart (Figure 25), the erosional hiatuses, if present, would have been brief.


EVENT TIMING CHART

PANUKE Segment - Conceptualized Petroleum System

BU = Break-up Unconformity (~mid-late Sinemurian)

SOURCES

1. Early Synrift (Triassic: Carnian - Norian)
2. Mohican (Jurassic: Toarcian – Aalenian)
3. Jurassic Verrill Canyon (Oxfordian - Kimmeridgian)
4. Cretaceous Verrill Canyon (Berriasian - Valanginian)

RESERVOIRS

1. Scatarie / Abenaki 1 (Bajocian – Callovian)
2. Baccaro / Abenaki 4, 5 & 6 (Callovian – Kimmeridigian)

SEALS

1. Misaine / Abenaki 2 for Scatarie / Abenaki 1
2. Top Abenaki 6 for Baccaro / Abenaki 4, 5 & 6
3. Lower Cretaceous Shales for Baccaro / Abenaki 4, 5 & 6

OVERBURDEN

Several periods of modest erosion:

1. Early Cretaceous (Aptian?)
2. Late Paleocene
3. Early Eocene (Montagnais Impact Event)
4. Late Eocene
5. Middle Oligocene
6. Middle Miocene

TRAP FORMATION

1. Diagenetic & Subsidence (L. Jur. – E. Cret.)

TIMING

Expulsion periods based on previously modelled deepwater succession (Kidston et al., 2002, Sites 3-5).

Figure 93. Petroleum system events timing chart – Panuke Segment.

7.3 Acadia Segment

The Acadia Segment extends from a structural saddle or low northwest of the Evangeline H-98 well and southwest to just past the Bonnet P-23 well on the east side of the Northeast Channel (Figure 8). This segment is characterized by a steep bank margin which faced a deeper proto-Atlantic ocean unlike the Panuke segment that lay adjacent to the embayment where the Sable Delta formed. In contrast to the Sable Delta embayment, the carbonate bank in the vicinity of the Albatross and Acadia wells formed a promontory out over the mouth of the Mohican Graben.

The segment was a passively subsiding platform and margin underlain by the pre-existing rift topography. The Mohican Graben complex, orientated at an acute angle with the Abenaki trend, is mostly inboard of the margin hinge line and contains significant salt and evaporite deposits. There were several periods of tectonism and erosion, with the most significant erosion occurring during Tertiary lowstand events. The question of subaerial versus submarine erosion is not fully understood but the latter is favoured. There was also renewed faulting and salt disruption during this time, probably triggered by the Montagnais Impact Event.

7.3.1 Well Control and Seismic Data

There are only two bank edge wells along this 400 km segment: Albatross B-13 and Acadia K-62. The Bonnet P-23 well is considered a backreef test as it was located about 6 km landward of the faulted margin. All three wells were dry and abandoned but each suffered individual drilling related problems such as lack of a mud-gas logging, lost circulation, no testing, etc. (see Section 3.2).

Year	Operator	Name	ID	FTVD (m)	Status	Comments
1978	Chevron	Acadia	K-62	5287.0	D&A	Bank Edge – Several good porous dolomite zones were discovered in the Abenaki 6 and 5, and oolitic porosity common in the Abenaki 5-2 zones but no shows present. Three DSTs all recovered water.
1985	PetroCanada	Albatross	B-13	4047.0	D&A	Bank Edge – Several scattered porous zones in the Bacarro, minor gas shows in the Abenaki 3 and 2, no tests.
1984	PetroCanada	Bonnet	P-23	4336.2	D&A	Back Reef – Facies dominated by oolitic shoals. A number of thick dolomite intervals encountered with good to very good porosities. A number of loss circulation zones drilled. Several minor mud gas shows noted, but not tested.

Table 9. Acadia Segment - Wells and Shows

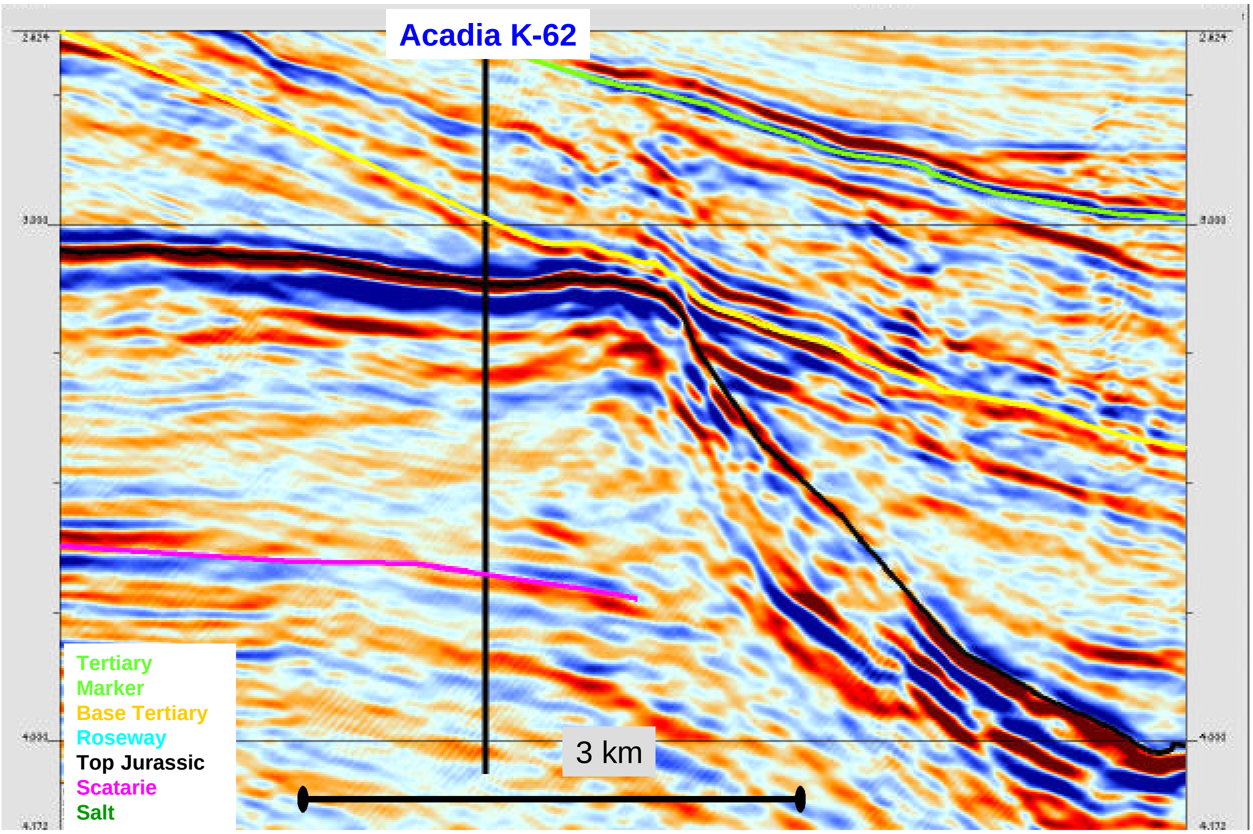


Figure 94. Detailed seismic profile: Acadia K-62 exploration well. See Figure 4 for location.

Chevron PetroCanada Acadia K-62 (1978) (Figure 94) was located somewhat back from the rimmed bank edge and missed the prime skeletal debris reef facies evidenced by an array of high-amplitude events. The Deep Panuke seismic examples illustrate how narrow the reservoir fairway is and how two wells had to be whipstocked short distances from non-reservoir to reservoir zones P1/1B (Figure 84) and M-79/M-79A (Figure 86).

The Base Tertiary unconformity marker is shown to approach the bank margin at a high angle and literally bounce up and over the carbonate "massif". At the well however, 184 m of Late Cretaceous was identified from fossils including thin (remnant?), Wyandot and Petrel limestone stringers resting unconformably on the Jurassic (or Roseway) carbonates. Thus, in the GSC's interpretation (MacLean and Wade, 1993), a Mid-Cretaceous unconformity exists across the western shelf. Even with the improved seismic data such as the TGS survey used extensively in this report, the segregation of the Tertiary unconformities from prior Cretaceous erosion will require intensive seismic correlations and reworked biostratigraphy (Crux and Gard, 2003).

The K-62 well drilled a complete Abenaki section of Roseway (528 m), Baccaro (780 m), Misaine (218 m), Scatarie Members (648 m) and bottomed in 337 m of Lower Jurassic Iroquois Formation dolomites (MacLean and Wade, 1993). The distinction between Roseway and Baccaro is not seismically evident and this report places the Top Jurassic seismic marker at the top of the massive limestone section resulting in 1308 m of the Abenaki. Seismically, the Roseway as tied to other wells is seen to downlap onto the pronounced Top Jurassic reflection as a transgressive sequence following the flooding of the carbonate shelf. As described in Section 3.2, the well was poorly evaluated: there was no mud gas logging, a lost circulation zone was encountered from 4677 – 4790 m, and one flow test in the Abenaki recovered formation water. There was no mention of hydrocarbons in the cuttings report.

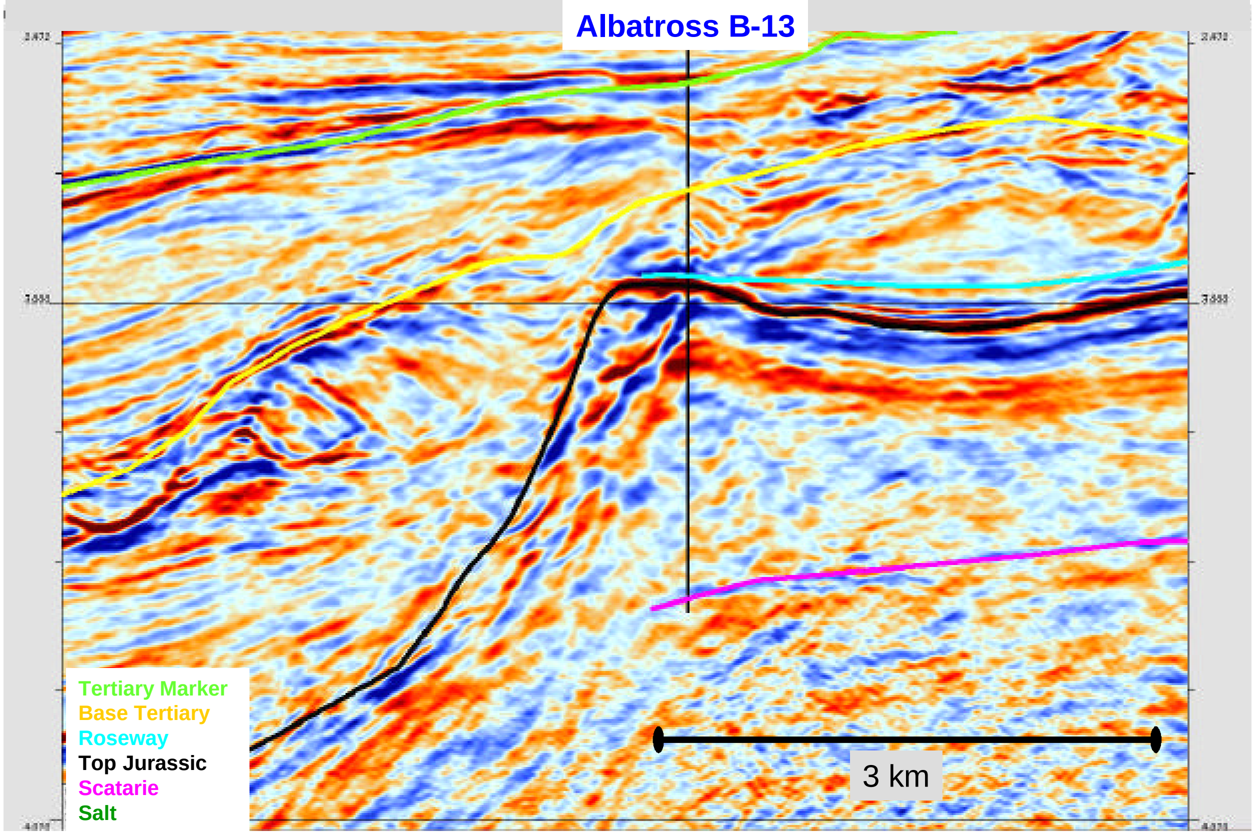


Figure 95. Detailed seismic profile: Albatross B-13 exploration well. See Figure 4 for location

PetroCanada Texaco Albatross B-13 (1985) (Figure 95) was drilled a complete Abenaki section of Roseway (546 m) and Baccaro Members (944 m) and bottomed in the Misaine shale (MacLean and Wade, 1993). To be consistent with the Acadia K-62 well, the combined figure of 1490 m of massive limestone would all fall within the Upper Jurassic section as defined by regional seismic correlations.

The seismic window shows the overlying Tertiary unconformities with large-scale slumps on the seaward side of the bank edge. A pronounced high amplitude, steeply-dipping event seen within the bank edge is either a fault zone (possible lost circulation below 2925 m, see Section 3.2) or some form of seismic interference. As described in Section 3.2 the well encountered scattered porosity with a partial lost circulation zone below 2925 m, low mud gas peaks but no DST's were run.

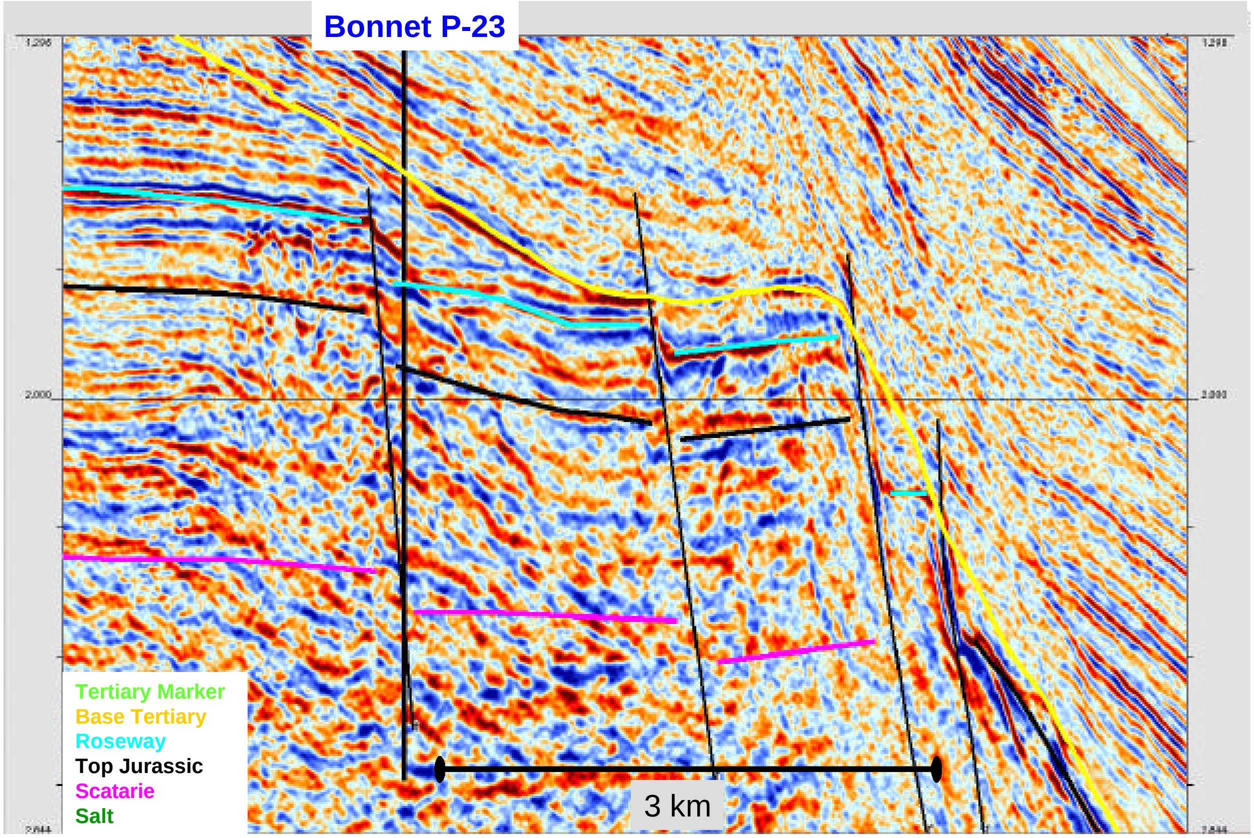


Figure 96. Detailed seismic profile: Bonnet P-23 exploration well. See Figure 4 for location.

PetroCanada Bonnet P-23 (1984) (Figure 96) was located about 6 km back from a highly faulted bank margin and indeed may have drilled a fault zone due to extensive zones of lost circulation from 2830 m to TD (see Section 3.2). As a result this well is a considered a backreef test in our inventory.

The P-23 well drilled a complete Abenaki section of Roseway (296 m), Baccaro (1087 m), Misaine (168 m), Scatarie (179 m) and bottomed in 811 m of Iroquois (MacLean and Wade, 1993). The distinction between the Roseway and Baccaro is not seismically evident and this report places the Top Jurassic seismic marker at the top of the massive limestone section resulting in 1383 m of Abenaki strata. The Base Tertiary unconformities have cut down through the Cretaceous section much like at the Acadia location. As detailed in Section 3.2, the well encountered extensive zones of lost circulation, incomplete mud-gas logging and several low mud gas peaks. No DST's were run.

7.3.2 Interpretation

The basin setting of the Acadia Segment differs from the Panuke Segment in several significant ways. Foremost, there is no Sable Delta equivalent and the carbonate platform now lies at a higher structural elevation covered by a thinner Cretaceous section. Secondly, the Tertiary unconformities were able to erode down to the top of the Abenaki margin which appears on seismic as a very steep slope. There are also suggestions in the data that parts of the original bank margin may have faulted or collapsed into the basin (see below). The assessment of exploration risks must include the possibility of a lack of preserved reefal facies through erosion and/or faulting.

The following suite of seismic profiles is included to illustrate the dramatic changes in morphology along the 400 km stretch of the Acadia Segment. The sections are shown both uninterpreted and interpreted and begin in the southwest and progress toward the Panuke Segment in the northeast. The vertical scale is in time; therefore, the overlying water wedge distorts the structural picture by depressing the seismic markers as the water column increases. The changes in the bank edge are annotated in map form (Figure 8). Unless otherwise indicated, all lines are dip lines and oriented in a NW (left) to SE (right) direction, and the distance between seismic cross (strike) lines indicated at the top of each section is six (6) kilometers.

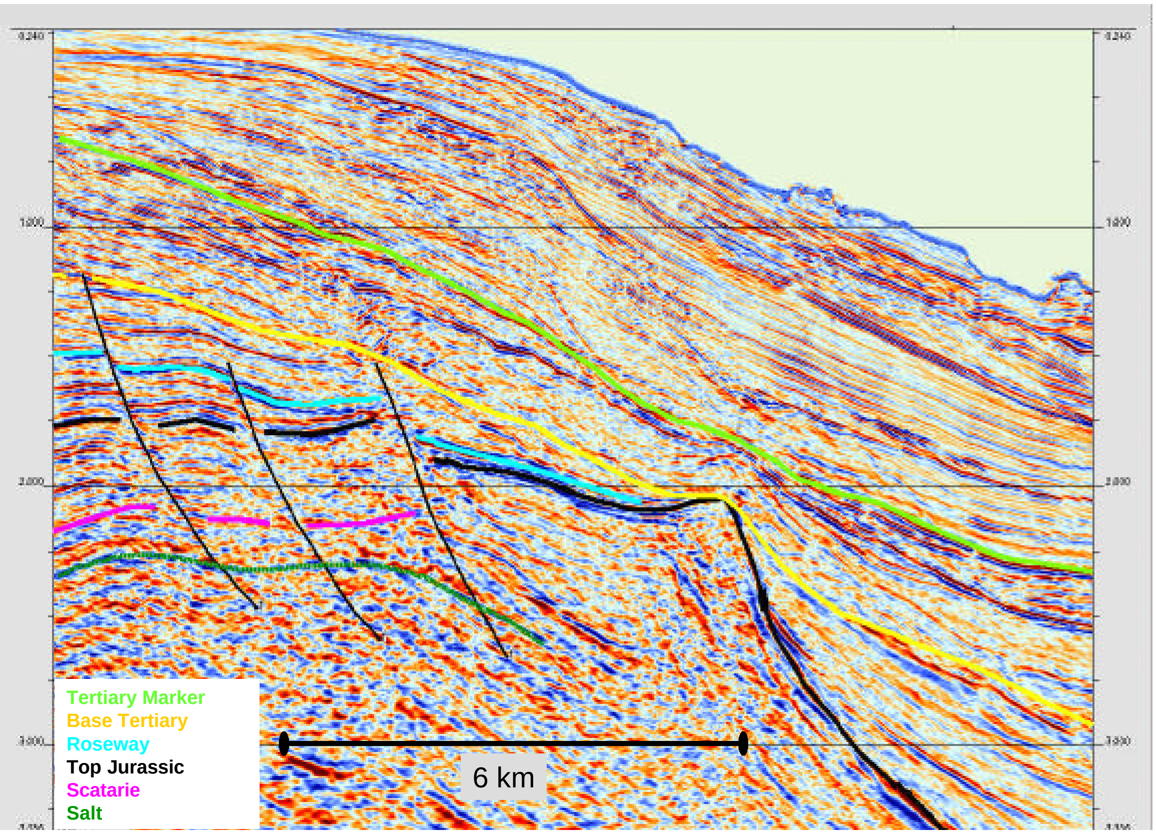


Figure 97. Seismic profile - southwest of Bonnet P-23 well, southern limit of TGS NOPEC survey. See Figure 4 for location.

Figure 97 is 40 km southwest of Bonnet P-23 and shows a post-depositional faulted margin with the preserved rim possibly breached by the Base Tertiary unconformity. Another indication for the actual paleo-bank edge is the seaward side onlapping pinch-out of the Cretaceous section.

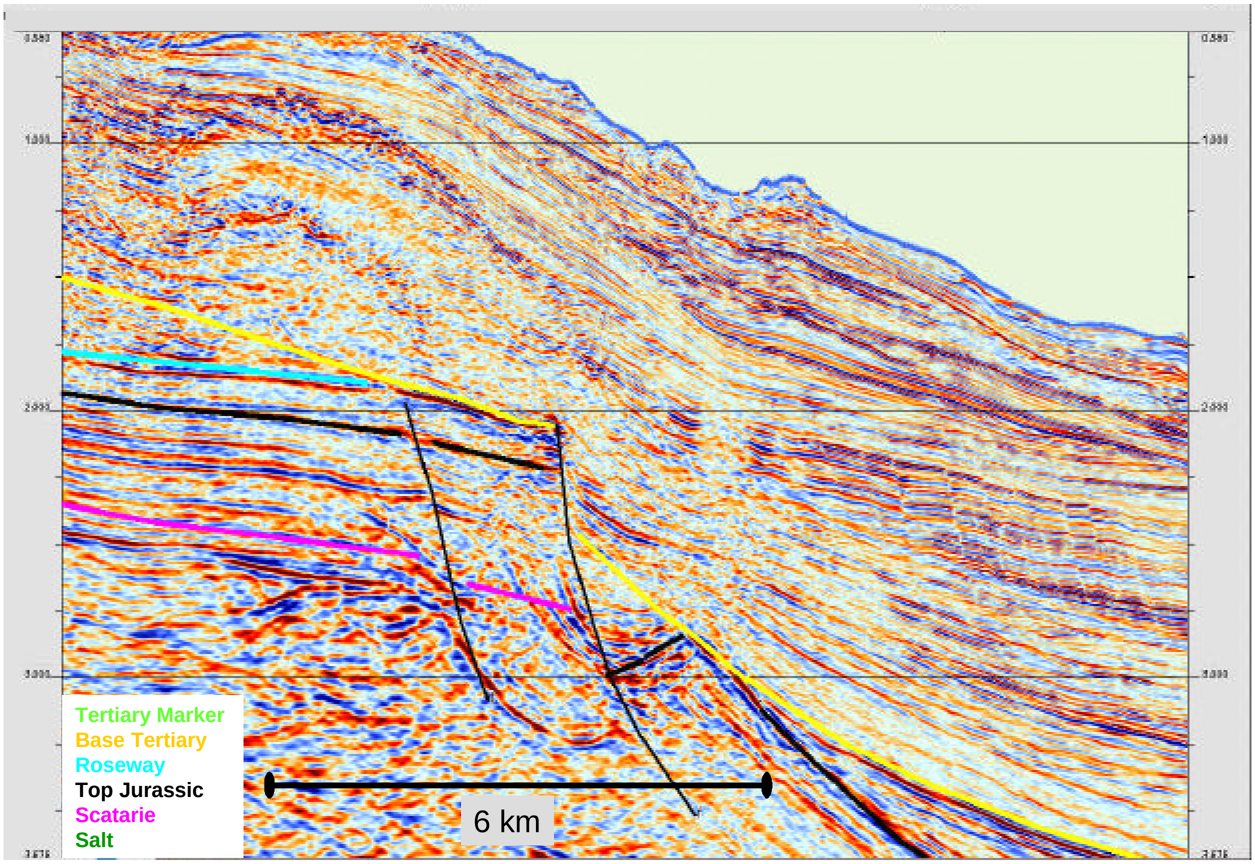


Figure 98. Seismic profile – rotated fault block on the Abenaki bank margin, east of the Bonnet P-23 well. See Figure 4 for location.

Figure 98 is 25 km east of Bonnet P-23 and shows a very steep bank edge with a faulted morphology that reoccurs in other locations. The favoured interpretation is the original bank edge faulted and rotated into the basin. The Base Tertiary unconformity follows the very steep fault scarp. Unlike the previous example, prediction of where the high energy reefal facies on this line is located is challenging.

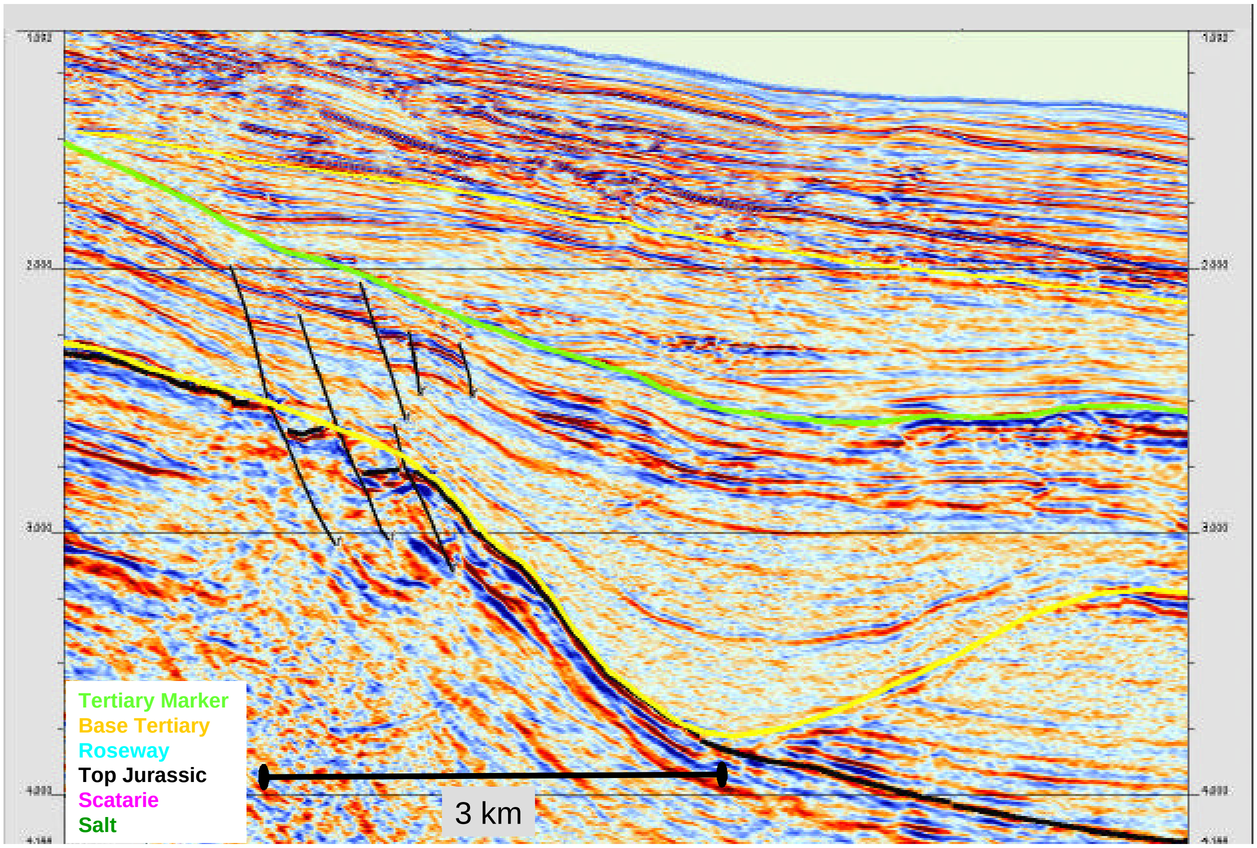


Figure 99. Seismic profile, TGS Line 320 – margin-parallel Base Tertiary erosional trough.

Figure 99 is immediately east of the Montagnais I-94 well (and crater) and reveals a deep Lower Tertiary-age erosional channel running sub-parallel to the bank margin. The depth of erosion is close to the top carbonate on the platform but has cut deeply into the section basinward. The original bank edge is hard to determine and the profile is less steep than previous examples. It is unknown if this feature is related in some manner to the early Eocene impact event.

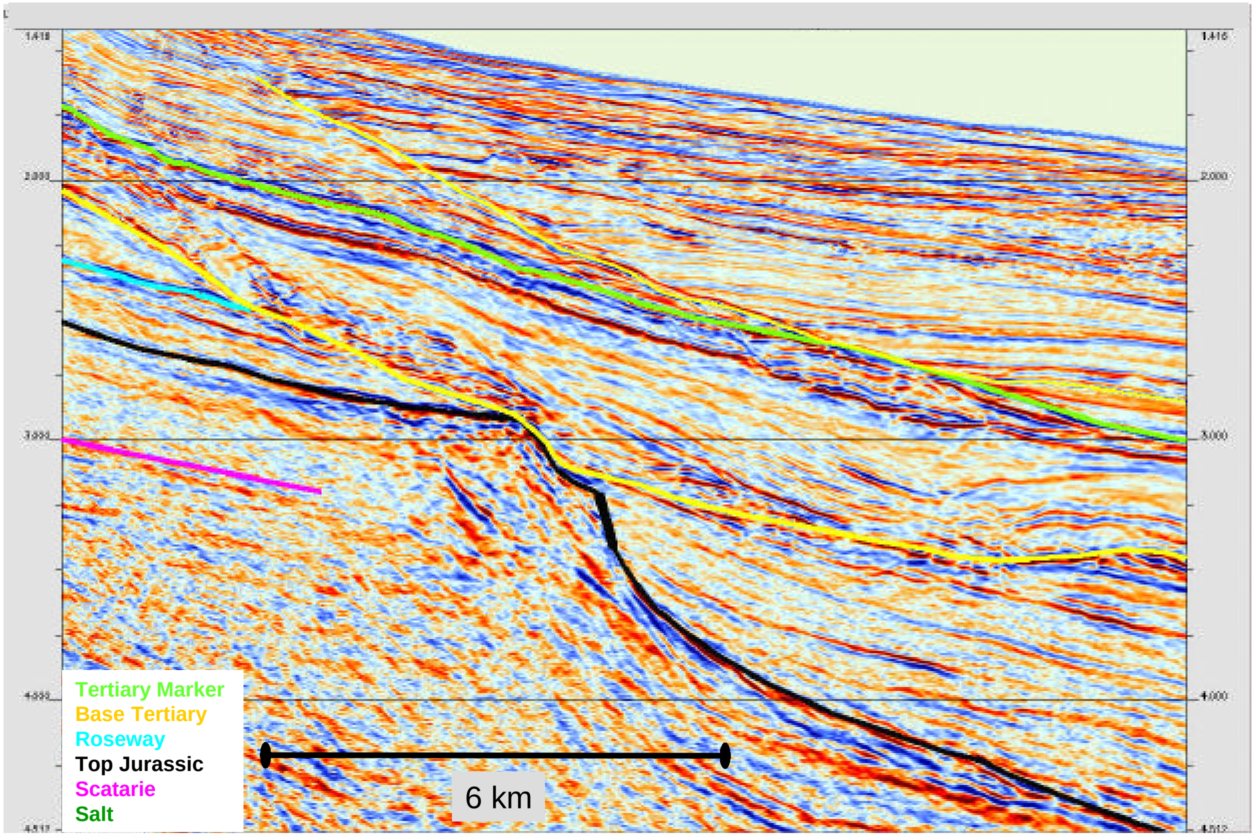


Figure 100. Seismic profile – eroded platform margin west of the Albatross B-13 well. See Figure 4 for location.

Figure 100 is 10 km west of Albatross B-13 and illustrates the Base Tertiary unconformity incising the bank edge with an apparent fault and/or slump in front. The foreslope limit is indicated by seismic amplitude character.

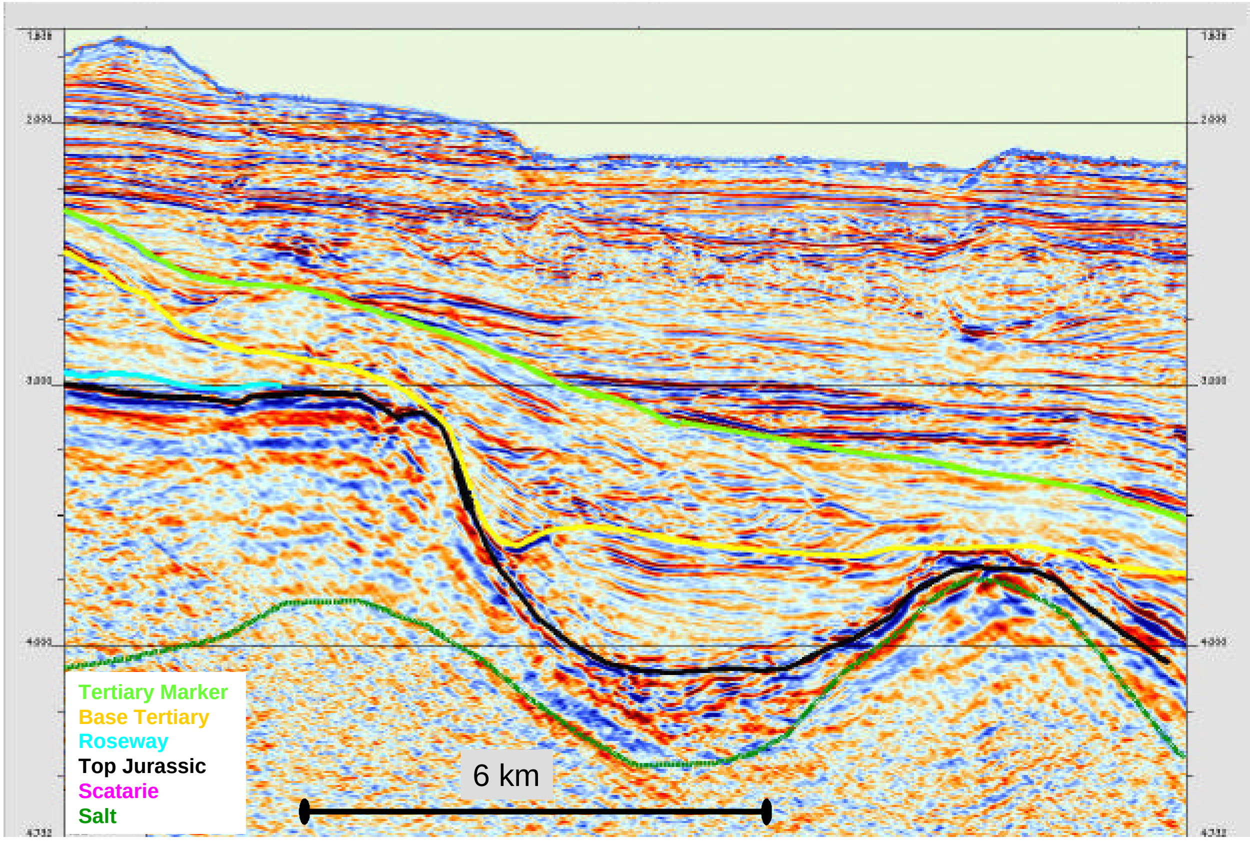


Figure 101. Seismic profile – upper extent of the margin-parallel Base Tertiary erosional trough and underlying salt features. See Figure 4 for location.

Figure 101 is immediately east of Albatross B-13 and displays a minor channel in front of the bank and a mini-basin developed between the bank and a salt feature. This line crosses the mouth of the Mohican Graben which intersects the bank edge at about a 30 degree angle. In this area significant Argo salt is observed beneath the bank itself with salt movement probably coeval with the adjacent Lower Cretaceous mini-basin following similar earlier antecedent motion in the earliest Jurassic.

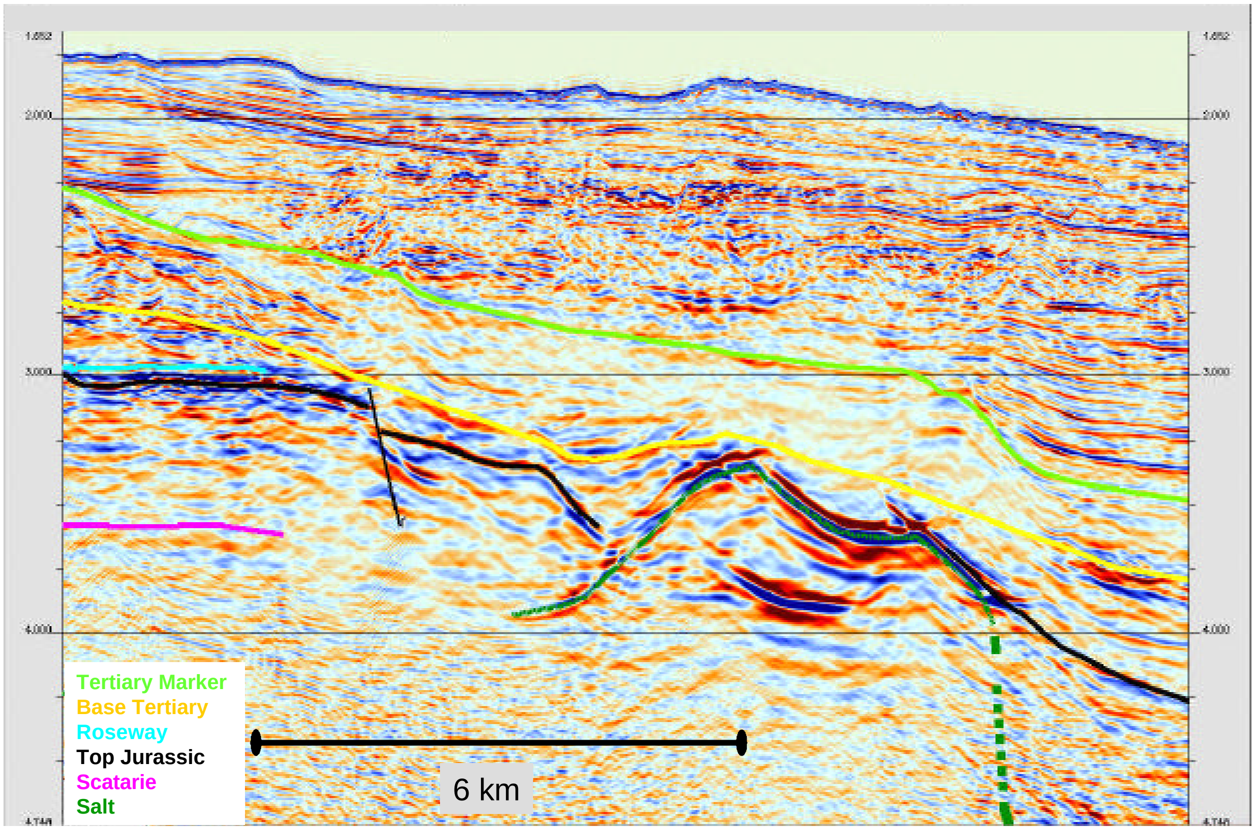


Figure 102. Seismic profile – salt tectonism at the platform margin edge at the mouth of the Mohican Graben. See Figure 4 for location.

Figure 102 is a strike line across the front of the Mohican Graben where the salt feature in the previous figure intersects the bank edge at an acute angle. The original bank edge should be located to the left of the salt feature but actual delineation is difficult.

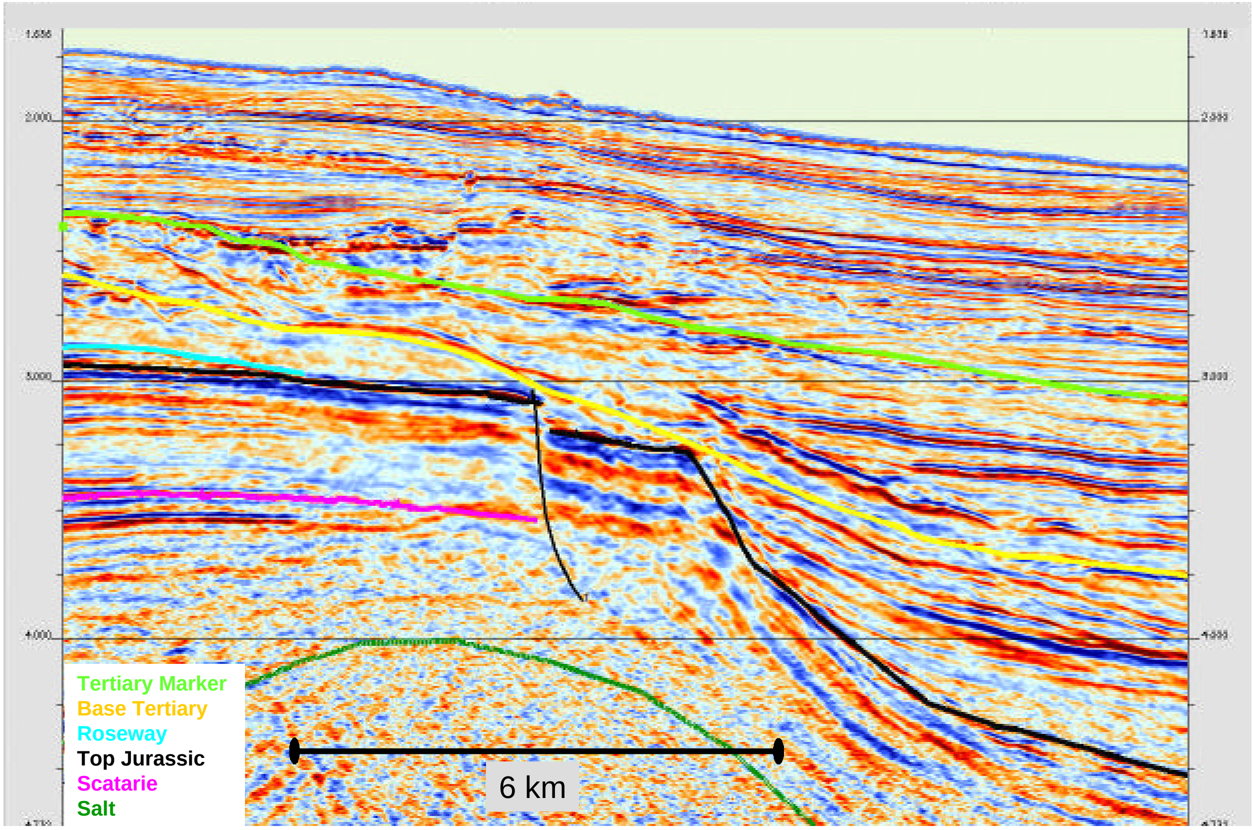


Figure 103. Seismic profile – faulted platform margin edge and (older) underlying salt structure. See Figure 4 for location.

Figure 103 is 20 km east of Albatross B-13 and profiles a down-faulted margin with erosion younger overlying erosion. The clearly visible Cretaceous sedimentary wedge pinches out against the bank from the seaward side and facilitates the bank-edge pick. Note the large salt feature (pillow?) underlying the bank margin.

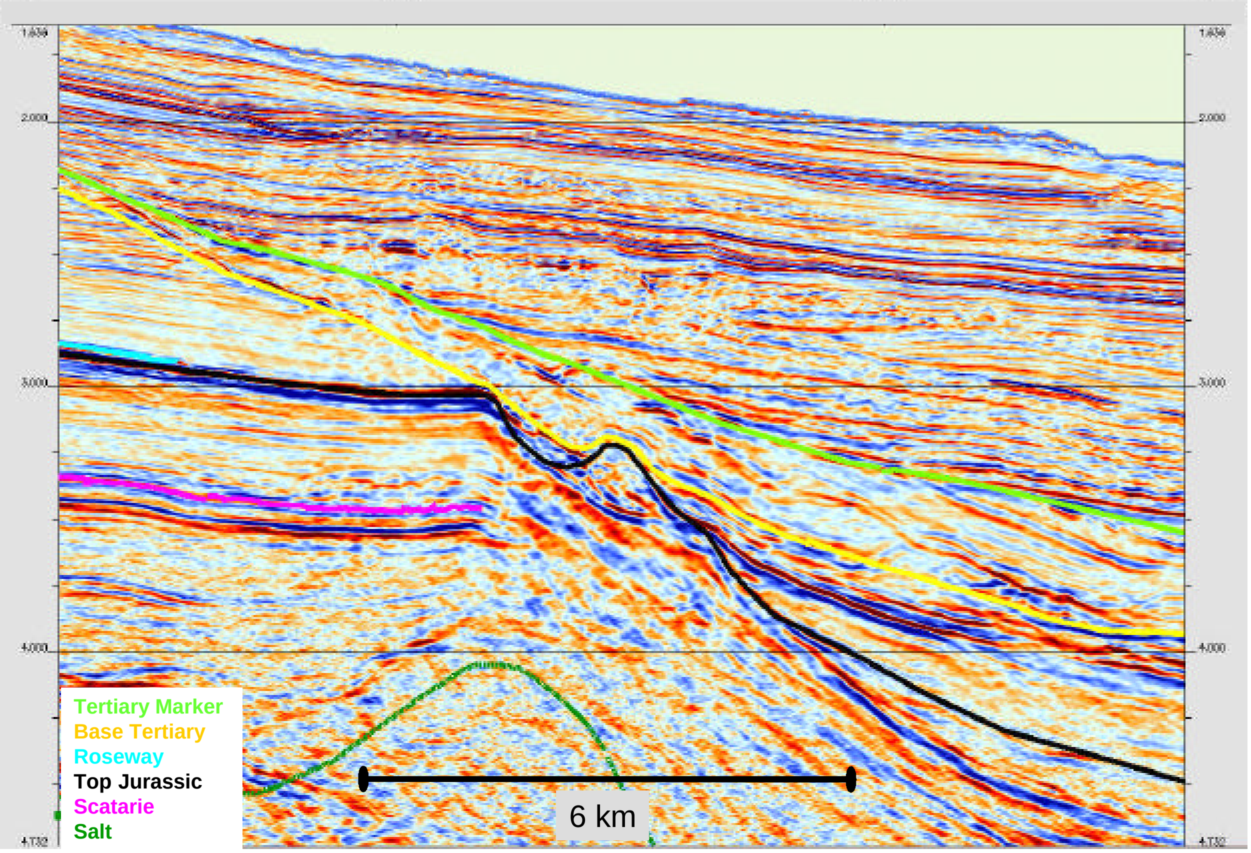


Figure 104. Seismic profile – interpreted down-slope carbonate build-up / mound east of the Albatross B-13 well. See Figure 4 for location.

Figure 104 is 30 km east of Albatross B-13 presents an interesting configuration that could be a downslope carbonate mound on a previously faulted and/or eroded bank margin (Artimon Member?). The Cretaceous wedge pinch-out indicates the location of the original bank-edge. Given an earlier failure of the bank the margin carbonate system would attempt to heal itself hence the suggestion that this could be a downslope sponge mound (Eliuk and Levesque, 1989). Alternate explanations include a sediment slump or some seismic imaging artifact.

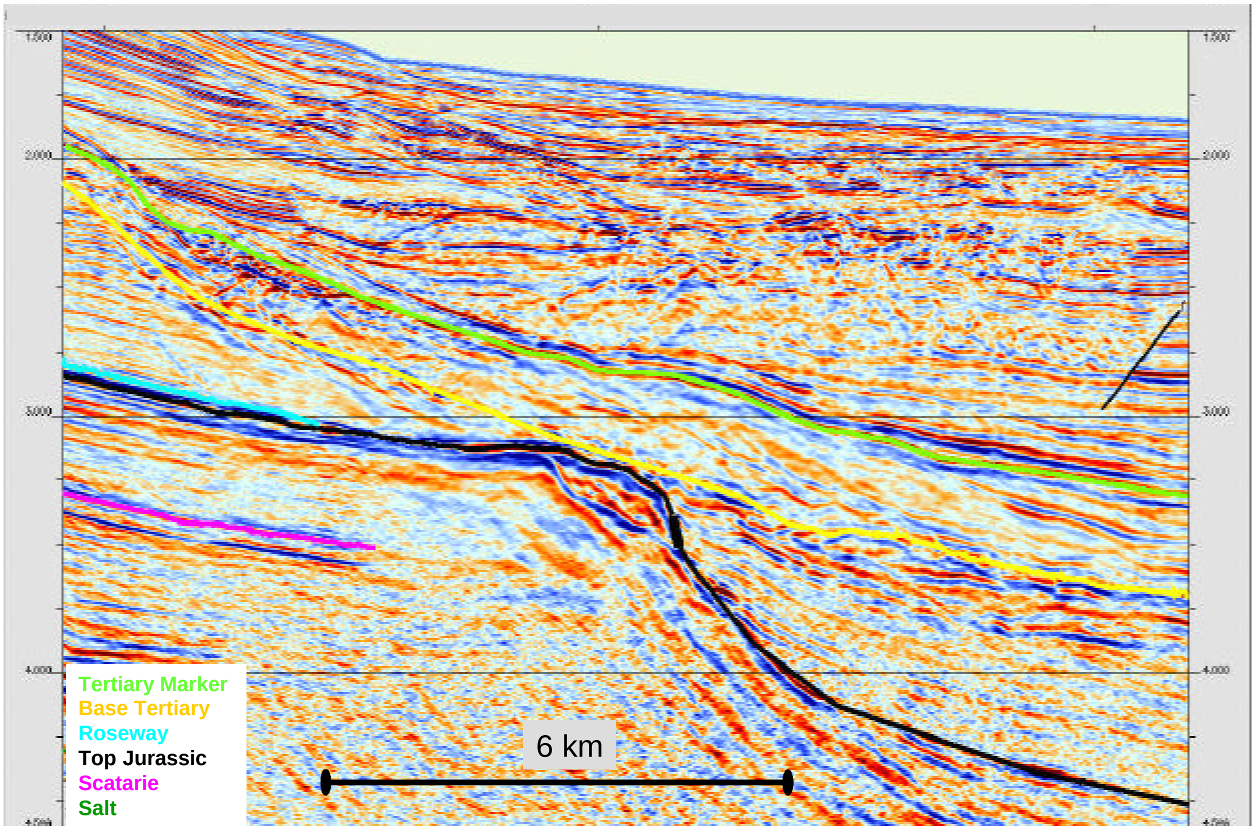


Figure 105. Seismic profile – unknown feature variably interpreted as an incipient fault / failure zone, healed fault or slope mound built within a margin-edge scar zone. See Figure 4 for location.

Figure 105 is midway between the Albatross B-13 and Acadia K-62 wells and shows a clear image of a preserved bank edge but with a feature variably interpreted as an incipient failure zone, a previously healed failure or an Artimon-age sponge reef succession infilling the margin failure scar. Again, the basinal Cretaceous wedge pinch-out is a good indicator of the paleo-bank edge.

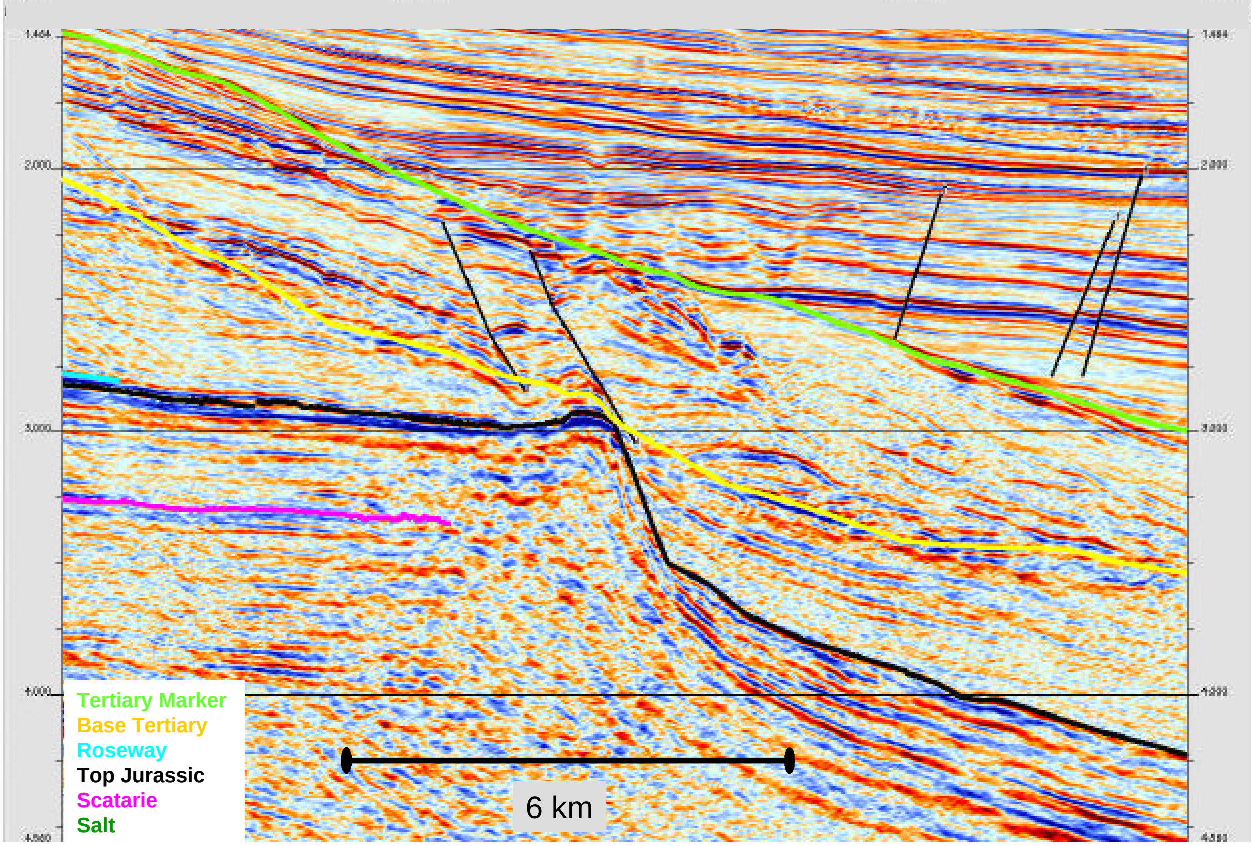


Figure 106. Seismic profile – preserved rimmed platform margin tagged by the Tertiary unconformity southeast of the Mohican I-100 well. See Figure 4 for location.

Figure 106 goes through the Mohican I-100 well to the northwest with the bank edge 25 km southeast of the well. The preserved rimmed margin is tagged by the Tertiary unconformity but otherwise the bank margin appears well preserved with no evidence of post-depositional faulting.

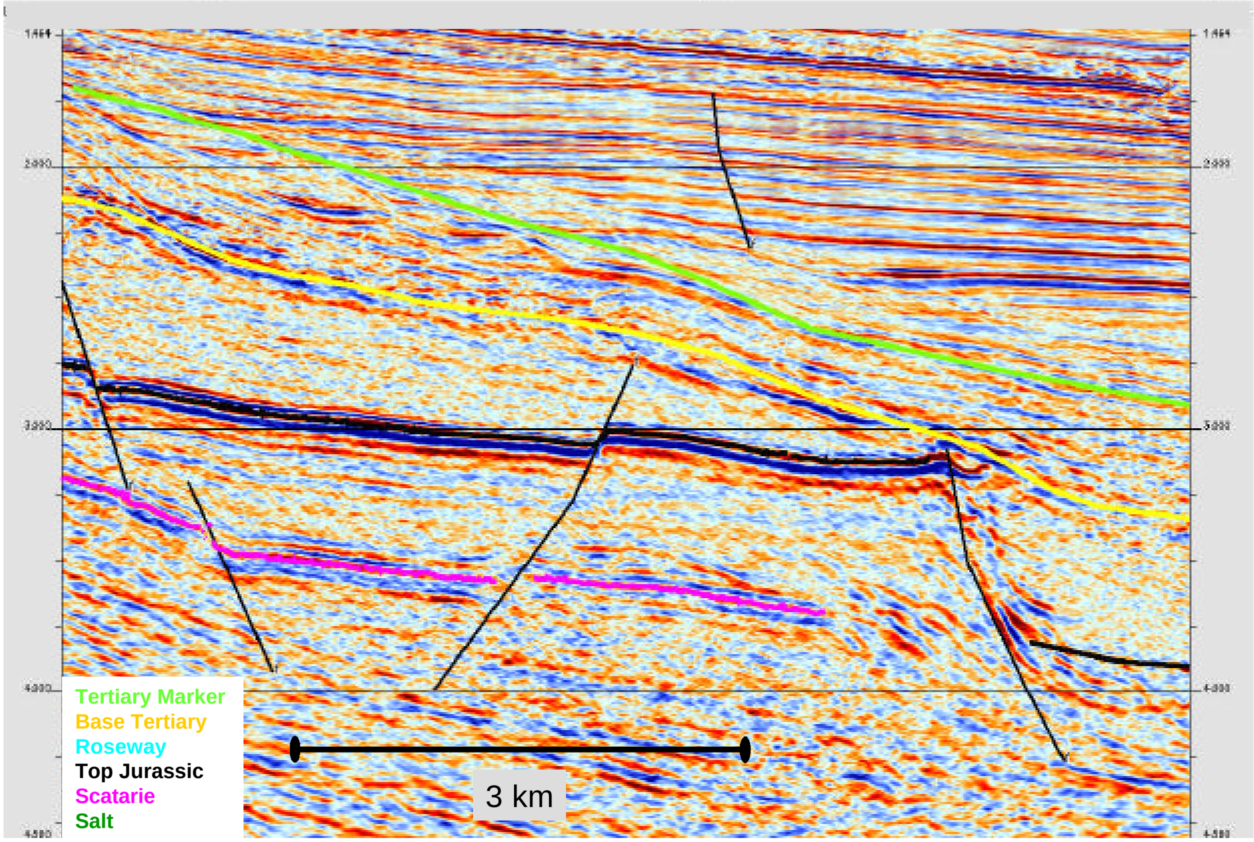


Figure 107. Seismic profile TGS – keystone faulted platform margin due to deeper salt withdrawal, west of the Acadia K-62 well. See Figure 4 for location.

Figure 107 is positioned 15 km west of the Acadia K-62 well and shows the rimmed margin with a large down-faulted block in a landward position. Deep salt evacuation to the southeast is interpreted as the cause of this feature.

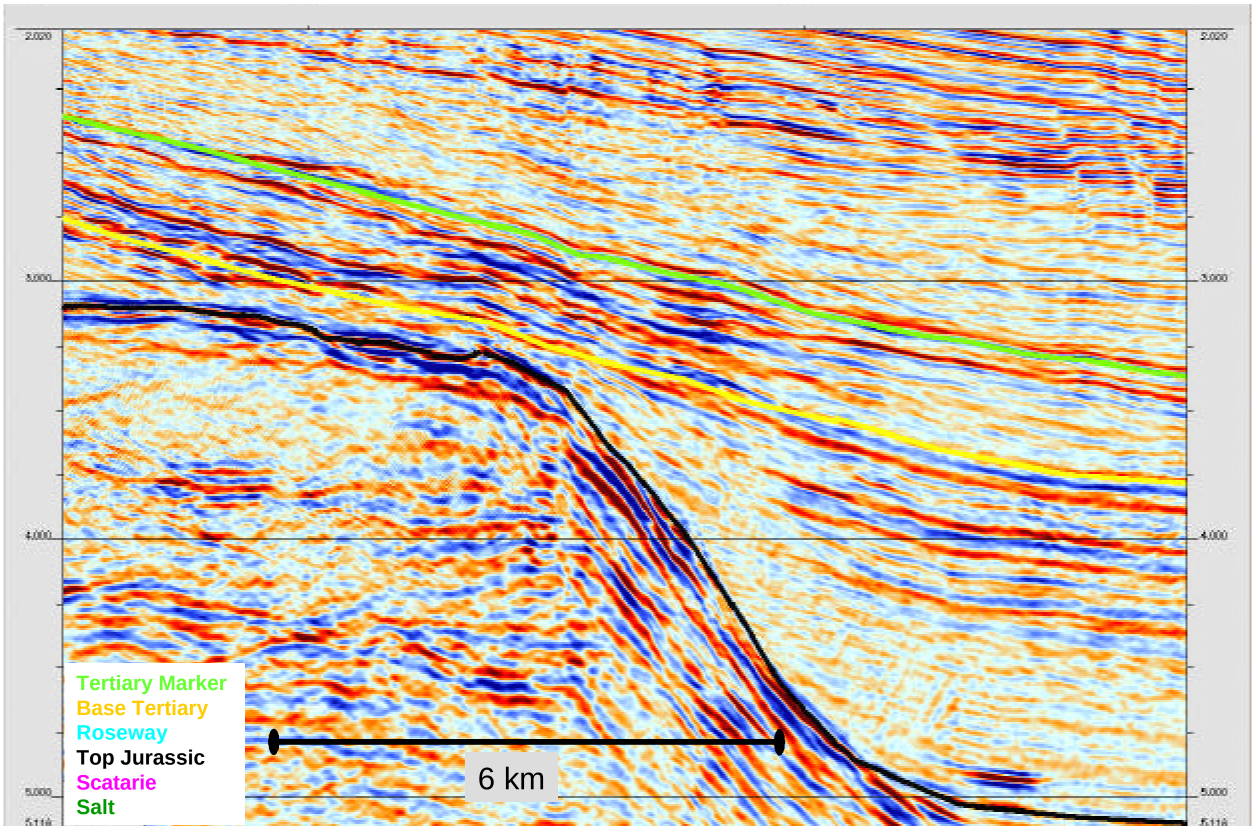


Figure 108. Seismic profile – high relief platform margin with lowstand slope fan/apron complexes east of the Acadia K-62 well. See Figure 4 for location.

Figure 108 is located 10 km east of Acadia K-62 and represents a very high relief bank margin. The bank edge is well preserved but may have been slightly eroded by Tertiary unconformities.

The high amplitude foreslope reflectors may represent cyclic deposition of carbonate high stand foreslope facies.

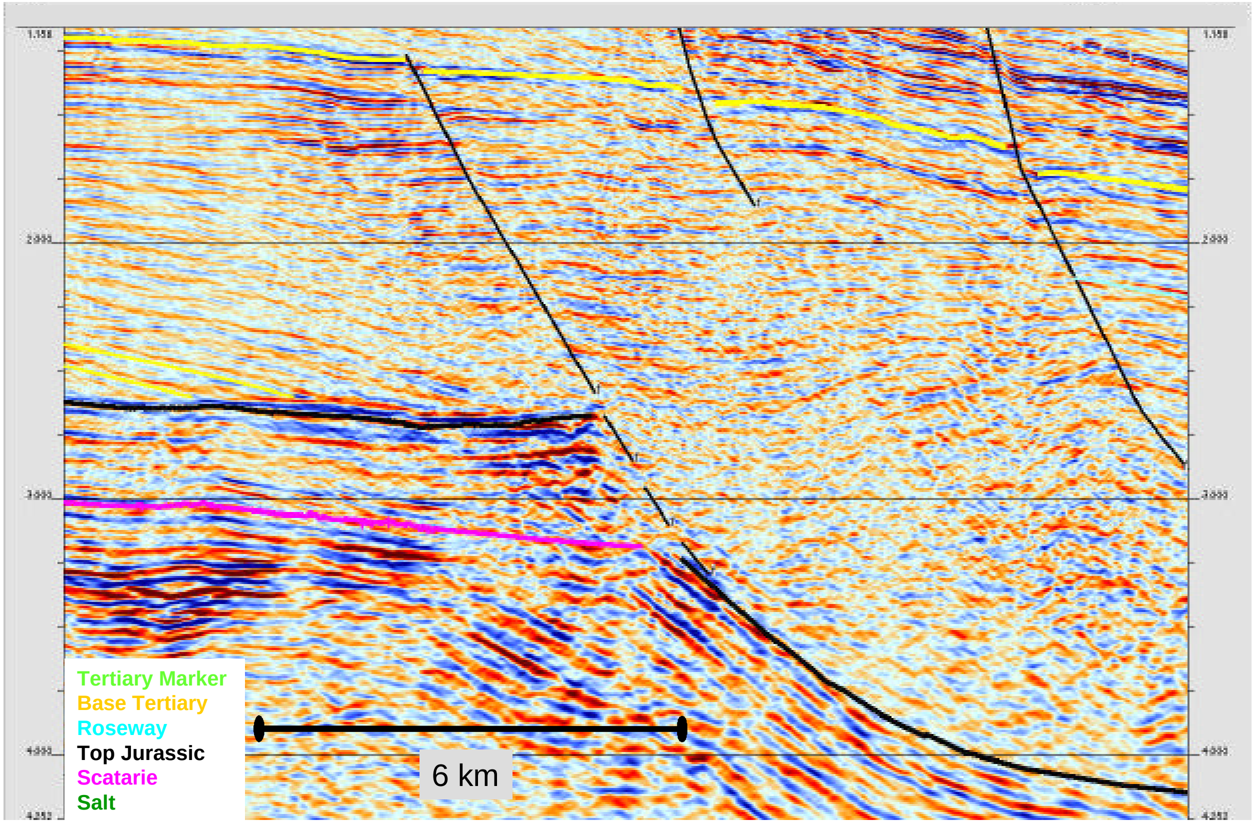


Figure 109. Seismic profile – example of imaging the platform margin near the eastern limit of the TGS survey's Abenaki coverage, north of the Evangeline H-98 well. See Figure 4 for location.

Figure 109 is the easternmost line in this series and lies just north of the Evangeline H-98 well. It displays a rimmed margin profile but the imaging suffers from the convergence of flat-lying and dipping reflectors. Besides not being able to locate the position of the bank edge, the data quality severely limits the interpretation of internal bank edge attributes.

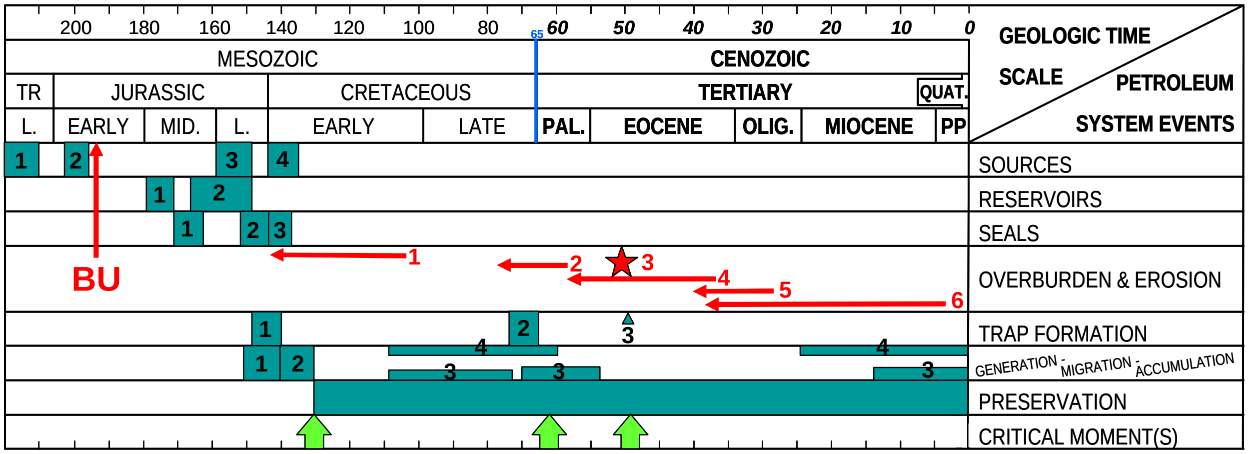
7.3.3 Play Concepts

The play concepts, in general, are the same as the Panuke Segment, i.e. reservoir along the bank edge. However, for the Acadia Segment the previous profiles indicate that there are complicating factors in faulting, erosion and salt disruption and so preservation of the bank edge reefal facies will be a significant risk factor. In areas of interpreted faulting and possible erosion of the Abenaki margin, the potential of the foreslope is enhanced but undoubtedly 3D seismic would be required to refine associated plays. The foreslope along the Acadia segment reflects a similarity to the Tamabra facies of the Golden Lane in Mexico (Figure 66).

The conceptualized petroleum system event timing chart for the Acadia Segment of the Abenaki margin is illustrated (Figure 110). The potential reservoir facies are the same as per the Panuke Segment. However, the Early Eocene Montagnais impact event created a vast region of highly fractured platform interior carbonates heaved as thrust blocks forming the crater walls. 'Regional shaking', analogous to that observed in regions surrounding the Chicxulub crater in Mexico, may be the cause of faulting and partial detachment of adjacent portions of the Abenaki margin underlain by salt. Such deep-seated faults could have acted as conduits for diagenetic fluids to create reservoirs irrespective of original depositional facies. The broad fetch of these extensive faults and fractures along the margin would provide attractive migration pathways for possible hydrocarbons sourced from older, deeper horizons (Late Triassic-Early Jurassic) or younger sequences in the deep water foreslope (Late Jurassic – Early Cretaceous).

EVENT TIMING CHART

ACADIA Segment - Conceptualized Petroleum System



BU = Break-up Unconformity (~mid-late Sinemurian)

SOURCES

1. **Early Synrift (Triassic: Carnian - Norian)**
2. **Late Synrift (Jurassic: Hettangian - Sinemurian)**
3. **Jurassic Verrill Canyon (Oxfordian - Kimmeridgian)**
4. **Cretaceous Verrill Canyon (Berriasian - Valanginian)**

RESERVOIRS

1. **Scatarie / Abenaki 1 (Bajocian – Callovian)**
2. **Baccaro / Abenaki 4, 5 & 6 (Callovian – Kimmeridigian)**

SEALS

1. **Misaine / Abenaki 2 for Scatarie / Abenaki 1**
2. **Top Abenaki 6 for Baccaro / Abenaki 4, 5 & 6**
3. **Lower Cretaceous Shales for Baccaro / Abenaki 4, 5 & 6**

OVERBURDEN

Several periods of significant erosion:

1. **Early Cretaceous (Aptian?)**
2. **Late Paleocene**
3. **Early Eocene (Montagnais Impact Event)**
4. **Late Eocene**
5. **Middle Oligocene**
6. **Pleistocene**

TRAP FORMATION

1. **Diagenetic & Subsidence (L. Jur. – E. Cret.)**
2. **Tectonic & Structural (L. Cret.)**
3. **Montagnais Impact Event (50.5 ±0.76 Ma)**

TIMING

Expulsion periods based on previously modelled deepwater succession (Kidston et al. 2002, Sites 3-5).

Figure 110. Petroleum system events timing chart – – Acadia Segment.

As seen in many of the seismic profiles, specifically on the Acadia and Shelburne Segments, these Cretaceous and Tertiary erosional events removed significant quantities of deepwater slope siliciclastic sediments. However, rarely do the resultant unconformities appear to cut down into the harder Abenaki lithologies and where the unconformities reach the Abenaki they are limited to a very narrow (1-3 km) band at the bank margin. As described by Weissenberger et al. (2000) and Wierzbicki et al. (2002), the main seal for the Abenaki 5 Baccaro reservoirs are the tight, overlying transgressive foreslope facies of the Abenaki 6. Furthermore, the Abenaki 6 is itself overlain by variably porous fluvial and shallow marine sands of the Missisauga Formation. Thus, the removal or sweeping of deepwater fine grained clastic sediments through the action of contour currents and upper slope turbidites probably resulted in modest erosion of the Abenaki 6 top seal and no breeching of potential reservoirs facies in the underlying Abenaki 5. As previously discussed, the post-salt pre-BU Heracles Unit, so far only known in the Mohican Graben area, may provide an additional potential hydrocarbon source.

7.4 Shelburne Segment

The Shelburne Segment of the Abenaki Carbonate Bank Edge (Figure 8) traverses the remaining distance from the eastern edge of the Northeast Channel to the U.S. border. This area has been previously referred to as George's Bank Basin but that term is misleading as the George's Bank is a seafloor physiographic feature while the subsurface geology is part of the overall Scotian Basin and identified in this study as the Shelburne Subbasin. This segment is the most difficult to interpret due to the lack of good seismic data though a regional synthesis was published by the Geological Survey of Canada (Wade, 1990).

7.4.1 Well Control and Seismic Data

There are no wells in the Shelburne Subbasin. An exploration moratorium declared in 1988 pre-dated industry drilling plans and will be in effect to December 31, 2012. Similarly, there has been no new seismic data recorded since 1984. The key seismic data sets are:

- Jebco, 1984
- Western, 1972
- GSI, 1978 Line 106 regional line from the COST G2 well to the ENE across the southern part of the Jebco data and into the deep water. The utility of this line was superceded by the Western regional line DX-1.
- Digicon, 1974

These datasets are limited to paper sections and for this study had to be correlated manually. A digital seismic base was prepared and once the picked values were entered, computer mapping was carried out and merged with the digital maps from the existing TGS dataset.

7.4.2 Interpretation

The structural interpretation shows the distinct nature of the Shelburne Segment. The Yarmouth Arch, bordering the basin to the northwest, is depicted at its shallowest from 0.5 to 1.5 sec in the north to 1.5 to 2.0 sec in the south. The bank edge is not clear due to poor seismic imaging because of the channelized and slumped seafloor topography and coincidence of the bank edge with the present-day continental shelf edge. The position of the bank edge is thus highly speculative and eventually disappears in an enormous salt diapiric feature that obliterates (as visualized seismically) any remnant of the original edge. The paleo-position of the bank edge is thus dashed to link up with the defined margin on the American side of the border.

Northeast of the salt zone is an area of major down-to-the-basin faulting but landward the section is generally unbroken except for several isolated salt piercements and similar listric faults. Within this structural complex were Industry's eight to ten prospects revealed at various conference presentations in the 1980's. Hence, the prospective area is quite limited and constrained by the above features.

Stratigraphic correlations within the Shelburne Segment relied on well ties at the Mohawk B-93 (Canada) and Exxon 975 (USA) wells using the long regional strike line DX-1 (Western, 1972) which intersected both wells. This became the base line from which the suite of Jebco lines was correlated. Picks were obtained from the GSC for Mohawk and the MMS for Exxon 975 wells respectively. This long-distance seismic correlation has inherent shortcomings and can result in lateral reflection assumptions where continuity is affected by faults and/or facies changes. The resulting maps can best be viewed as structural form maps and greatly assist in outlining areas for assessment.

There has been speculation in various papers of the existence of a Middle to Late Jurassic age deltaic complex ('Shelburne Delta') coeval with the Sable Delta in this region (Wade, 1990). This has been invoked indirectly based on interpretation of progradational reflection packages, a 120 degree bend in the regional strike and the presence of salt in the Northeast Channel.

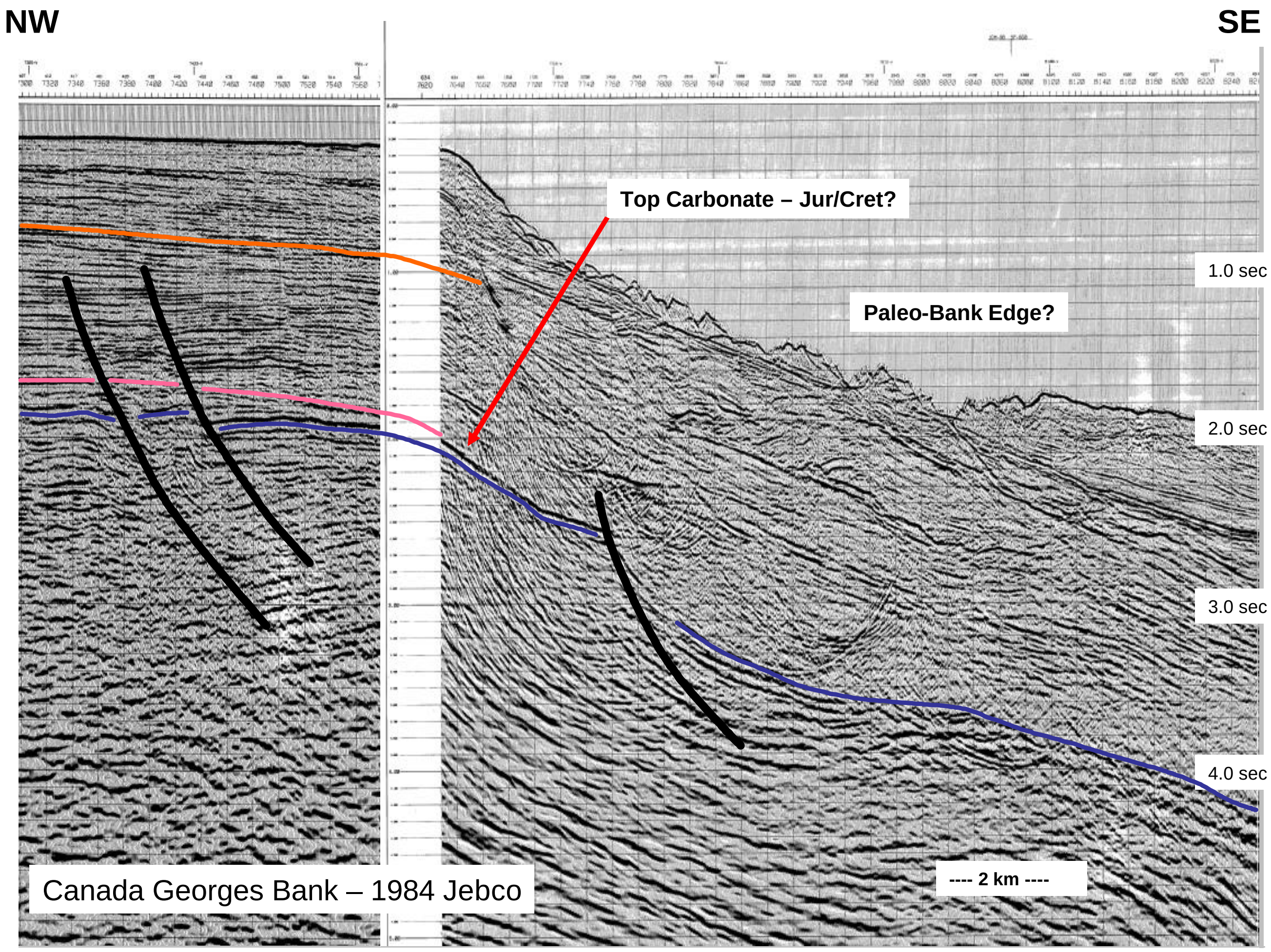


Figure 111. Seismic profile of a faulted sigmoidal bank margin profile. See text for details. See Figure 4 for location.

Figure 111 displays a faulted sigmoidal bank margin where the top carbonate surface is difficult to follow and the internal reflectivity is poor to absent. Seismic stratigraphic markers had to be brought in from the landward side utilizing the well control mentioned above and from the deepwater events used in the TGS interpretation to connect the horizons in a reasonable manner.

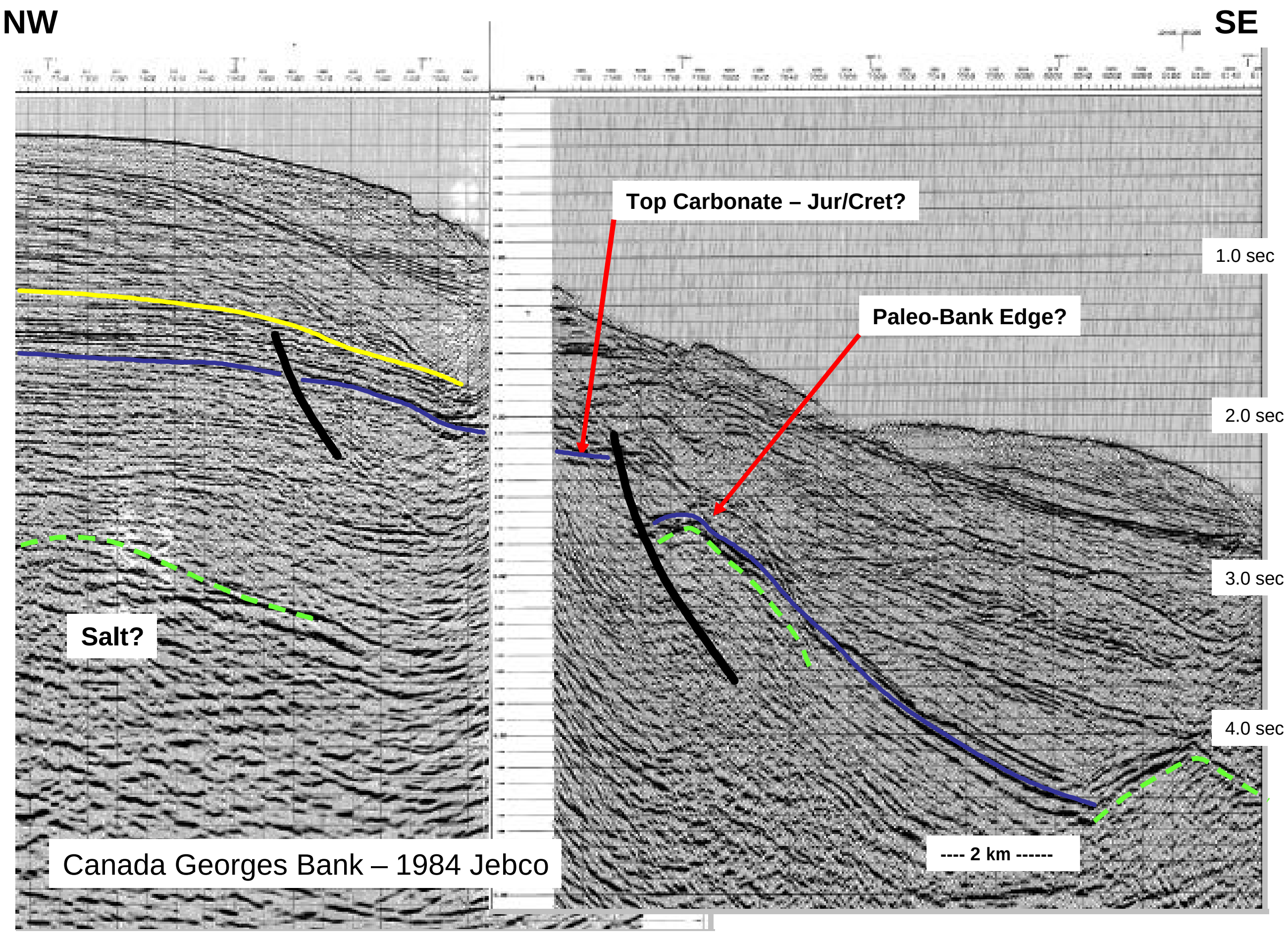


Figure 112 Seismic profile of a faulted bank margin with salt piercement. See text for details. See Figure 4 for location.

Figure 112 illustrates a faulted margin and the large listric growth faults with a piercement salt feature. The bank margin was inferred in the same manner as the previous line and the conclusion is of a faulted margin with only an approximation as to its actual location.

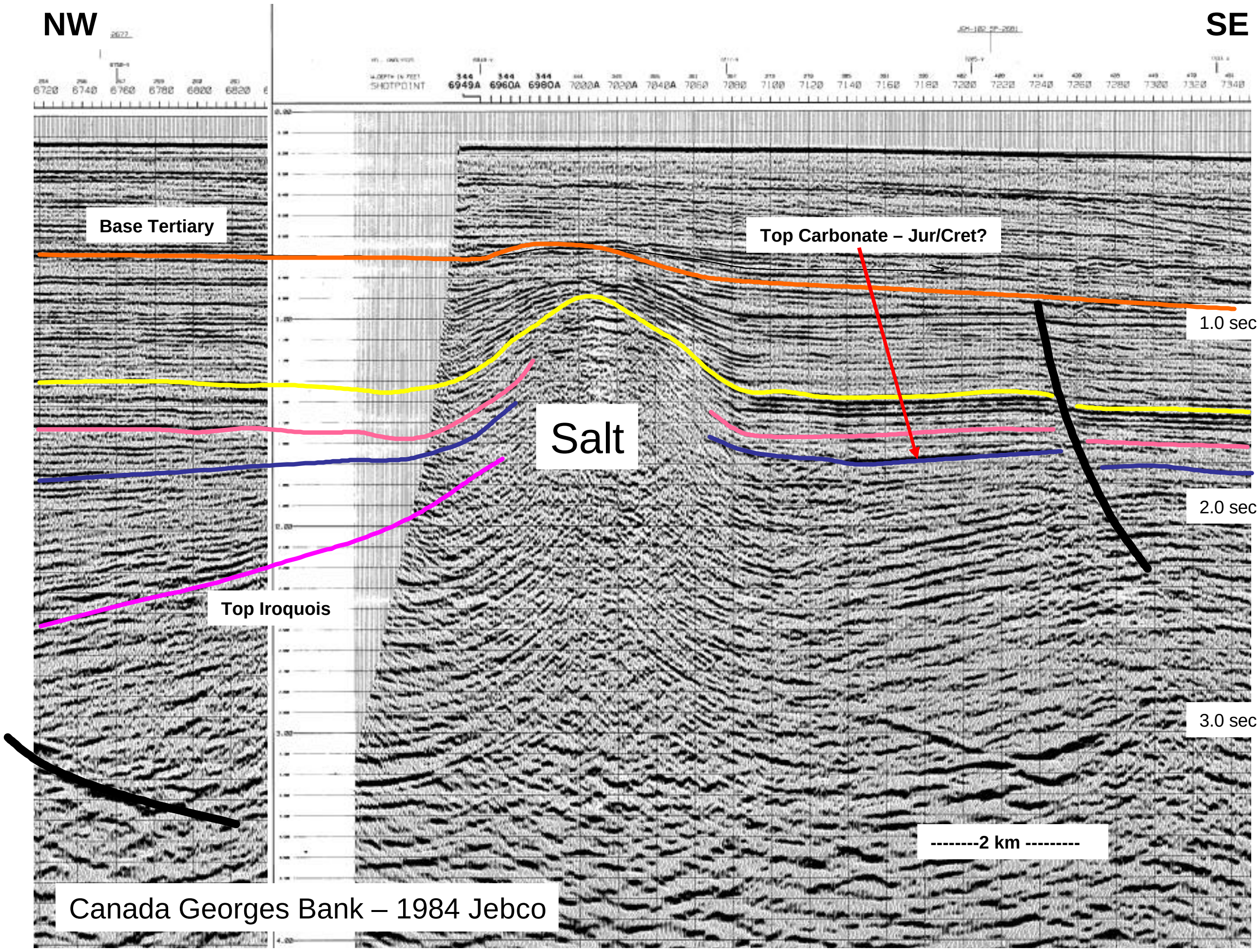


Figure 113. Seismic profile of an interior platform salt piercement. See text for details. See Figure 4 for location.

Figure 113 is located on the platform and reveals a salt piercement feature in front of a major down-to-basin listric fault. This confirms the presence of salt within the shelf in this region with the reflection character of adjacent and overlying strata inferring early syndepositional motion. Motion of this feature appears to have started about the beginning of the Cretaceous.

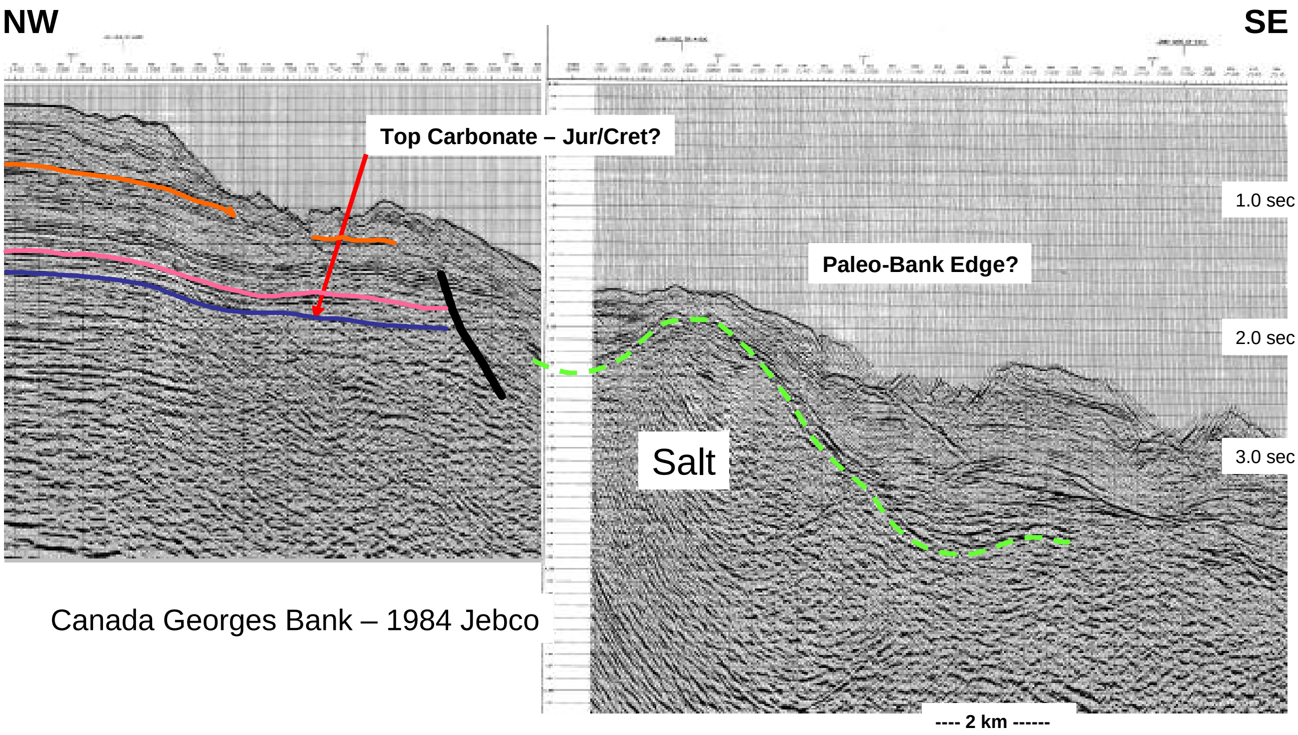


Figure 114. Seismic profile of major disruption by salt tectonism along the edge of the carbonate margin. See text for details. See Figure 4 for location.

Figure 114 confirms the disruption of the bank edge by a massive salt feature. This feature was initially interpreted as a buried seamount but magnetic maps and correlation with the known seamount chain indicates the feature is decidedly salt. This is not a definitive solution, but the main Argo salt province is known to pinch out in this direction towards the southeastern limit of the Scotian Basin. The disruption of the bank removes a considerable portion of acreage from this particular play.

7.4.3 Play Concepts

The traditional bank edge plays are affected by significant post-depositional salt tectonism. On the Shelburne Segment, this bank edge disruption diminishes the prospective area. Until new seismic data is acquired, the bank edge cannot effectively be explored and the carbonate platforms prospectivity will be degraded by analogy to the U.S. George's Bank Basin. The foreslope play is poorly delineated except to assume a band of some unit width, but the lower angle profile seen on seismic contributes to the risk.

7.5 Comparative Summary of Bank Edge

Table 10 summarizes some of the salient observations between the well known Panuke Segment and the lesser known Shelburne Segment. The Acadia Segment lies between these two end members and will benefit from the proposed TGS infill survey and any future work in the Panuke and Acadia Segments.

7.6 Platform Interior

Figure 8 outlines a relatively large area of the back-reef or platform interior and of the nine wells drilled all targeted structural anomalies above basement highs or salt swells but did not encounter hydrocarbons. The Smackover play onshore Gulf of Mexico is very prolific as described in Section 3.6.1, and although its key appears to be the underlying Jurassic source rock that is not present in the equivalent Abenaki, the possibility of underlying upper Triassic/lower Jurassic early synrift basins containing lacustrine source rocks cannot be ruled out in the platform setting (e.g. Mohican Graben).

BETTER KNOWN--LESSER KNOWN		
Panuke	**Acadia**	**Shelburne**
Bank edge preserved from Tertiary erosion	Bank edge variably affected by Tertiary erosion	Bank edge appears not to have been preserved from erosion
Mostly rimmed margin	Mostly rimmed margin	More ramp-like margin
No overlying water-wedge to affect imaging, amplitudes	Overlying water-wedge	Overlying water-wedge
4-way closures on top carbonate	No discernible closures on regional time maps, needs 3D	Poor 2D seismic, 1970s vintage
Non-faulted bank edge	Faulted in areas	Faulted in areas
Underlying salt “swells”?	Mohican Graben, underlying salt features, some salt disrupts bank-edge	Main salt trend intersects bank edge
Regional gas/water contact	Unknown	Unknown
Leached, fractured and dolomitized reefal limestone	Dolomitized back reef oolitic facies; attribute of reef margin unknown	Unknown

Table 10. Comparative Summary of Abenaki Bank Edge Segments

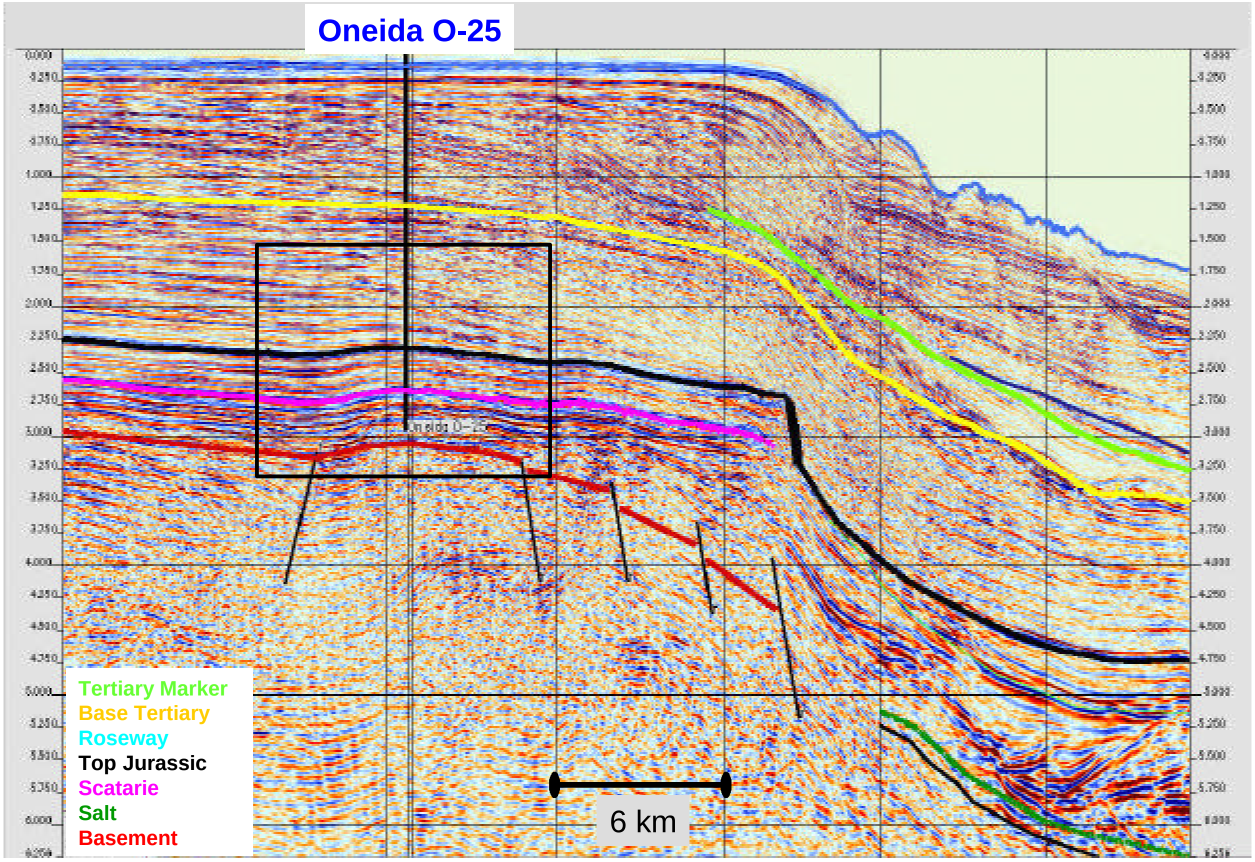


Figure 115. Regional Seismic Line across Oneida O-25 exploration well. See Figure 4 for location. Box outline indicates the area zoomed on in Figure 116.

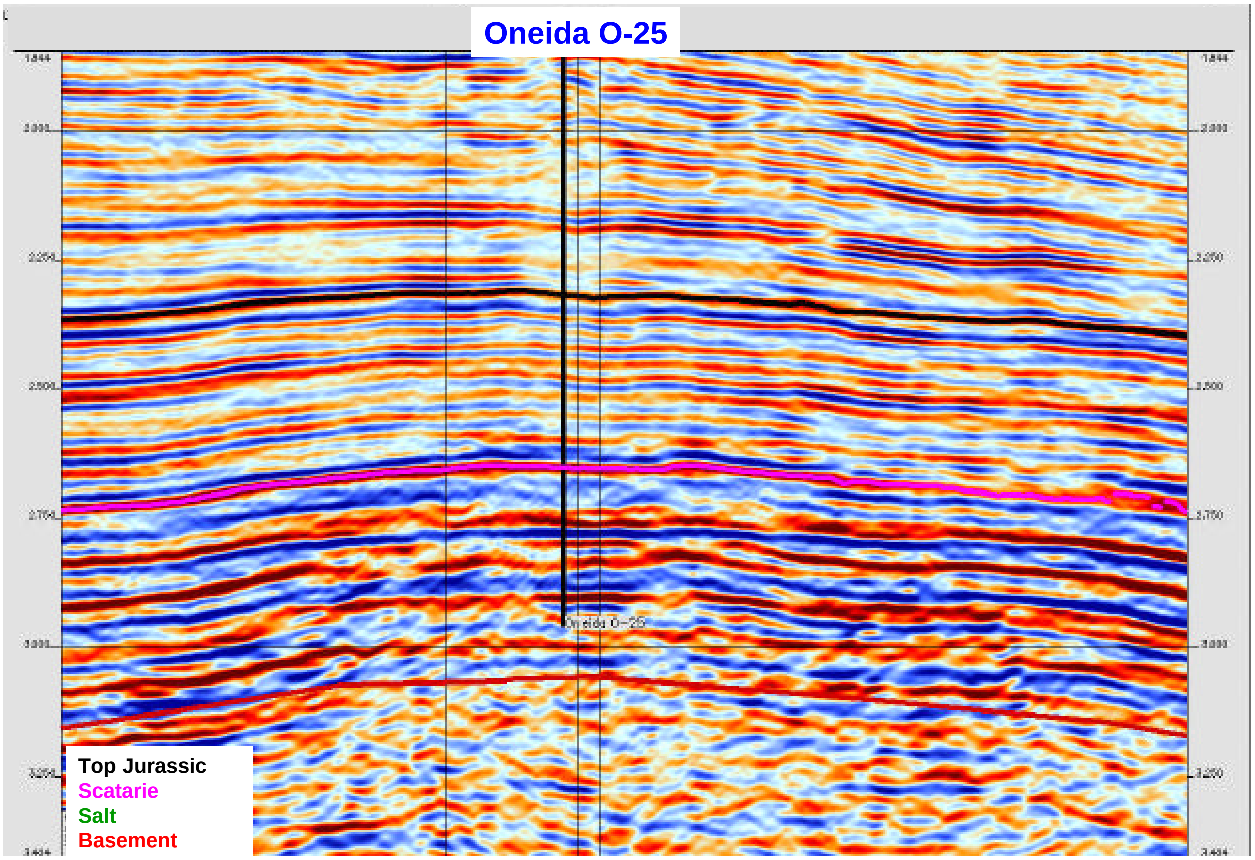


Figure 116. Detailed seismic profile- Oneida O-25 exploration well. See Figure 115 for location.

7.6.1 Outer Platform

The outer high-energy platform is a zone including the Oneida O-25 well and broadest across the platform promontory overlying the Mohican Graben. The demarcation of this zone is from the GSC Scotian Basin Atlas (GSC, 1991). All the wells in this zone were dry and abandoned.

Figure 115 lies across the Oneida O-25 well whose objective was carbonate reefal porosity over a basement high. The parallel reflectors imply a post-depositional flexure or uplift in Early Cretaceous time. An enlargement of the seismic profile through the well location (Figure 116) shows the evenly distributed band of reflections with no apparent anomalous amplitudes, typical of such settings.

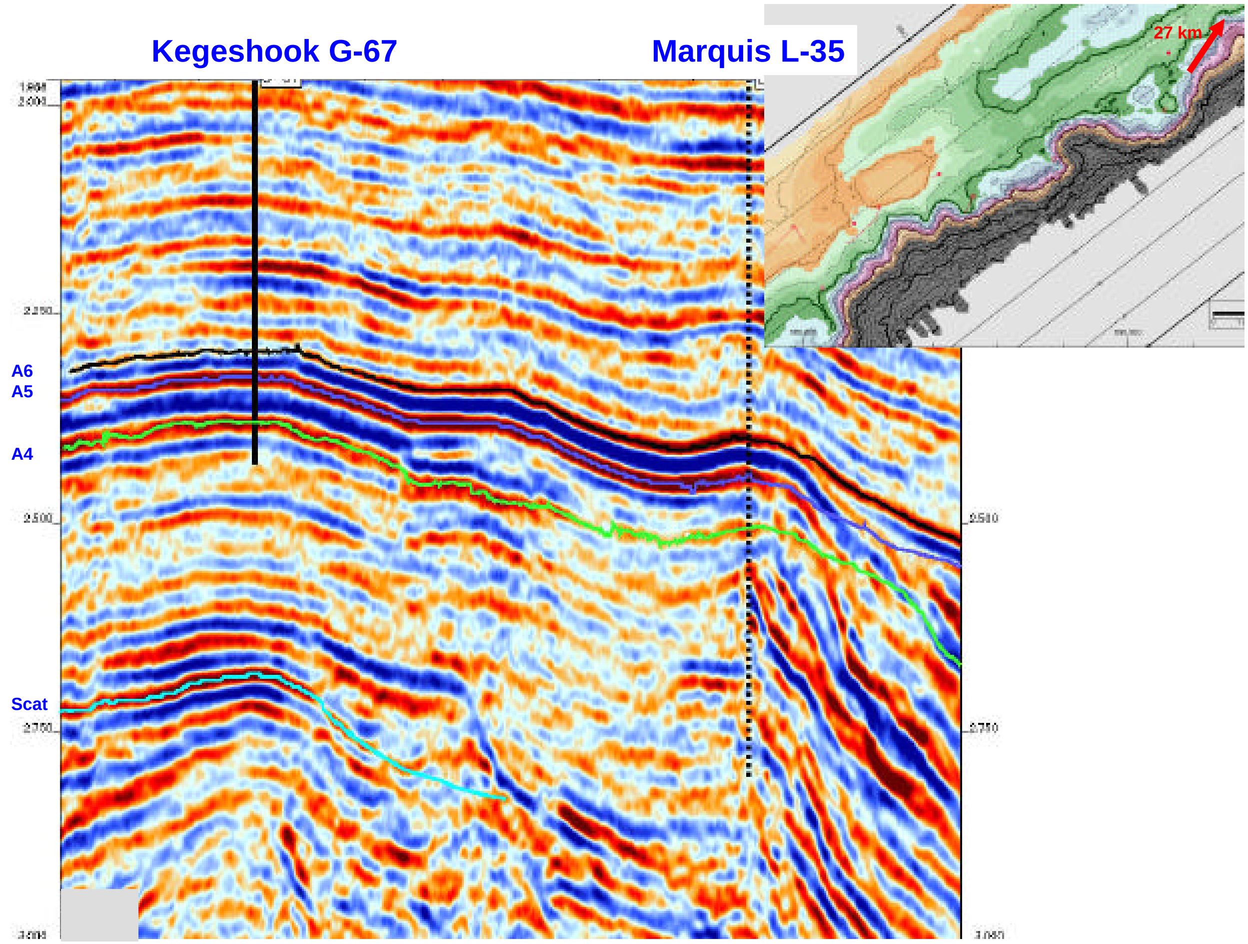


Figure 117. Detailed seismic profile – Kegeshook G-67 exploration well. See Figure 4 for location.

A 3D seismic line across the Kegeshook G-67 (Figure 117) and Marquis L-35 wells reveals a structural high with no apparent amplitude anomalies. The G-47 well was positioned an a feature that was later determined to be a salt ridge with motion that appears to post-date carbonate deposition. A seismic line (Figure 118) across the Abenaki J-56 well shows its salt flank location on the platform.

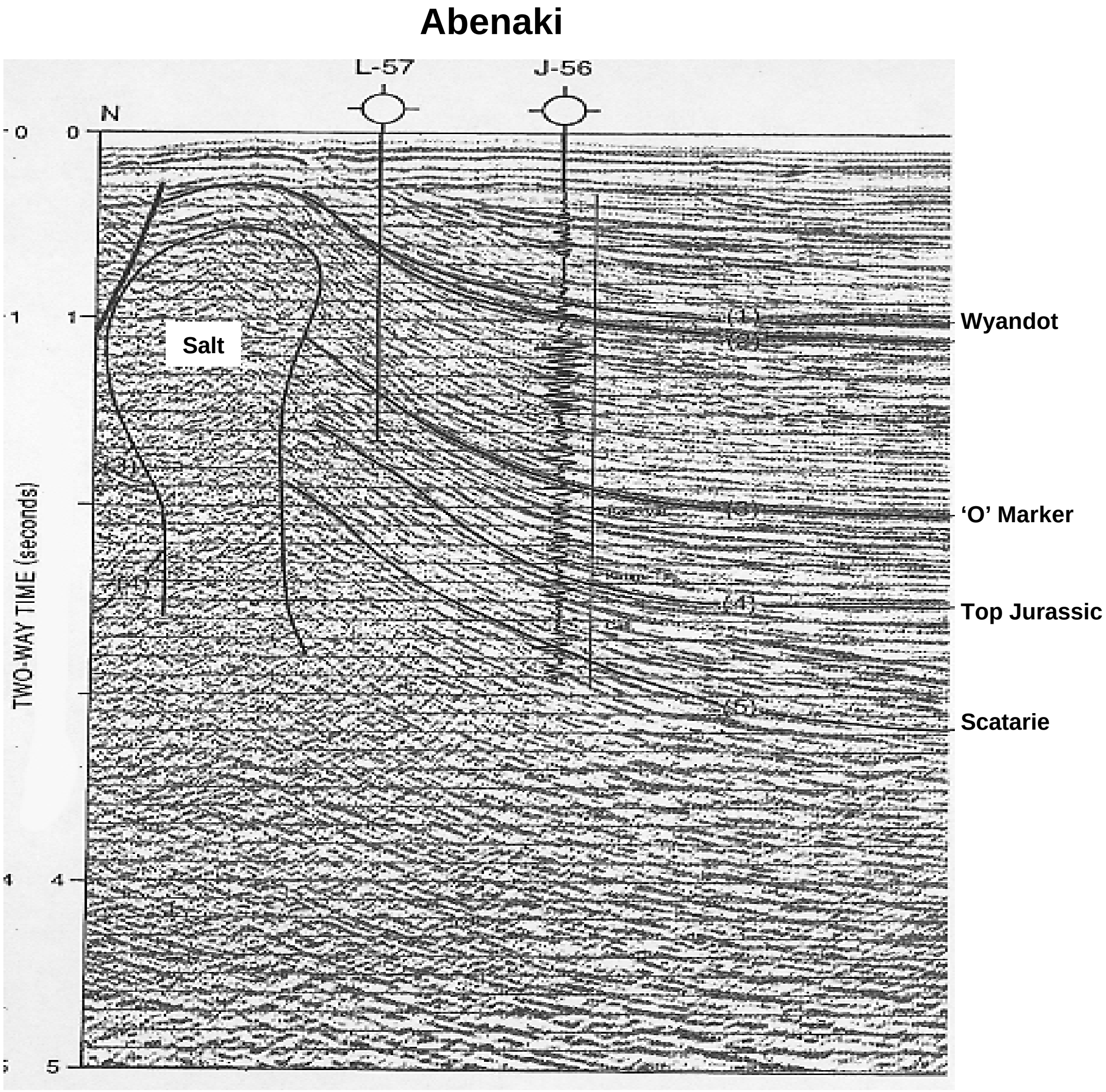


Figure 118. Seismic profile – Abenaki J-56 exploration well. See Figure 4 for location.

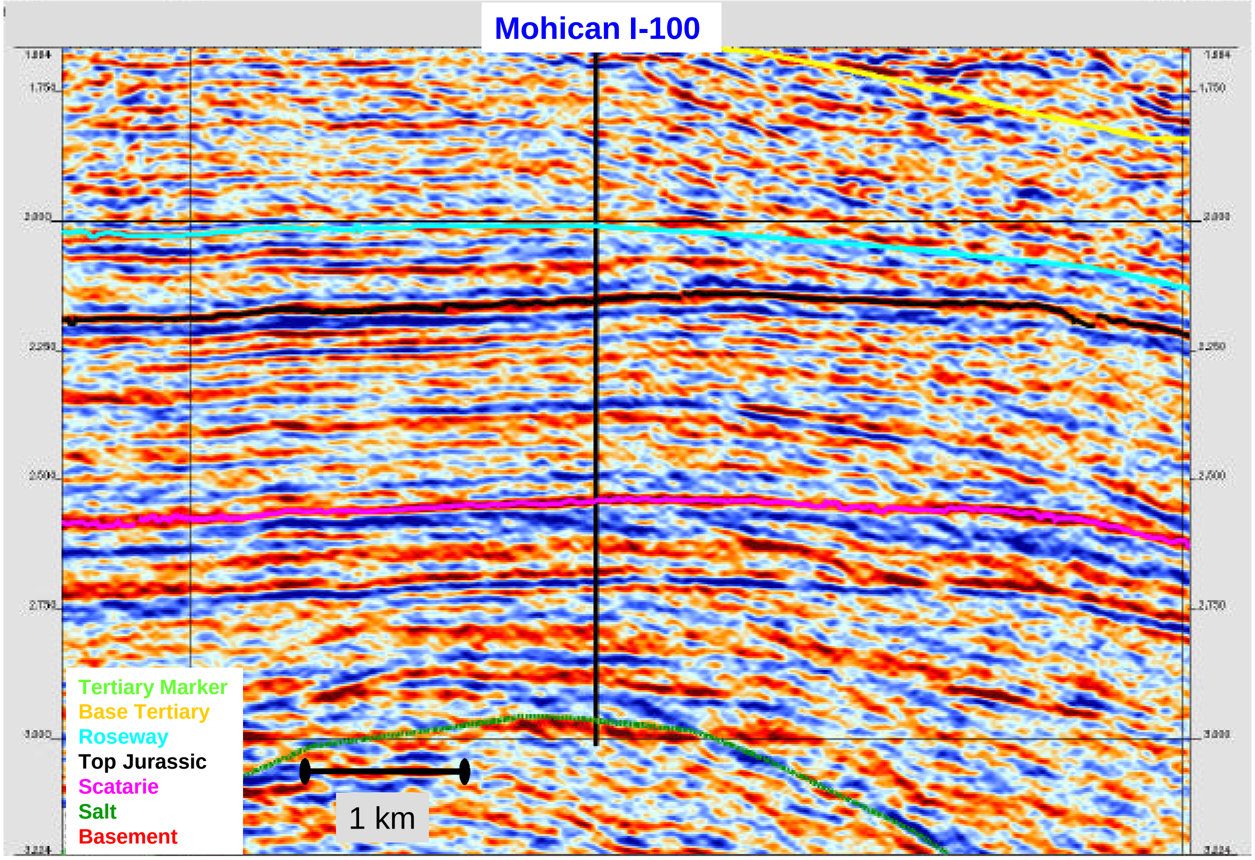


Figure 119. Detailed seismic profile – Mohican I-100 exploration well. See Figure 4 for location.

7.6.2 Inner Platform

The inner, low-energy zone is an extensive area along the entire platform. All wells were dry and abandoned. A magnified seismic profile (Figure 119) of the Mohican I-100 well illustrates the internal seismic response of the feature. The regional profile (Figure 120) infers pre-Abenaki salt motion and post-Abenaki faulting.

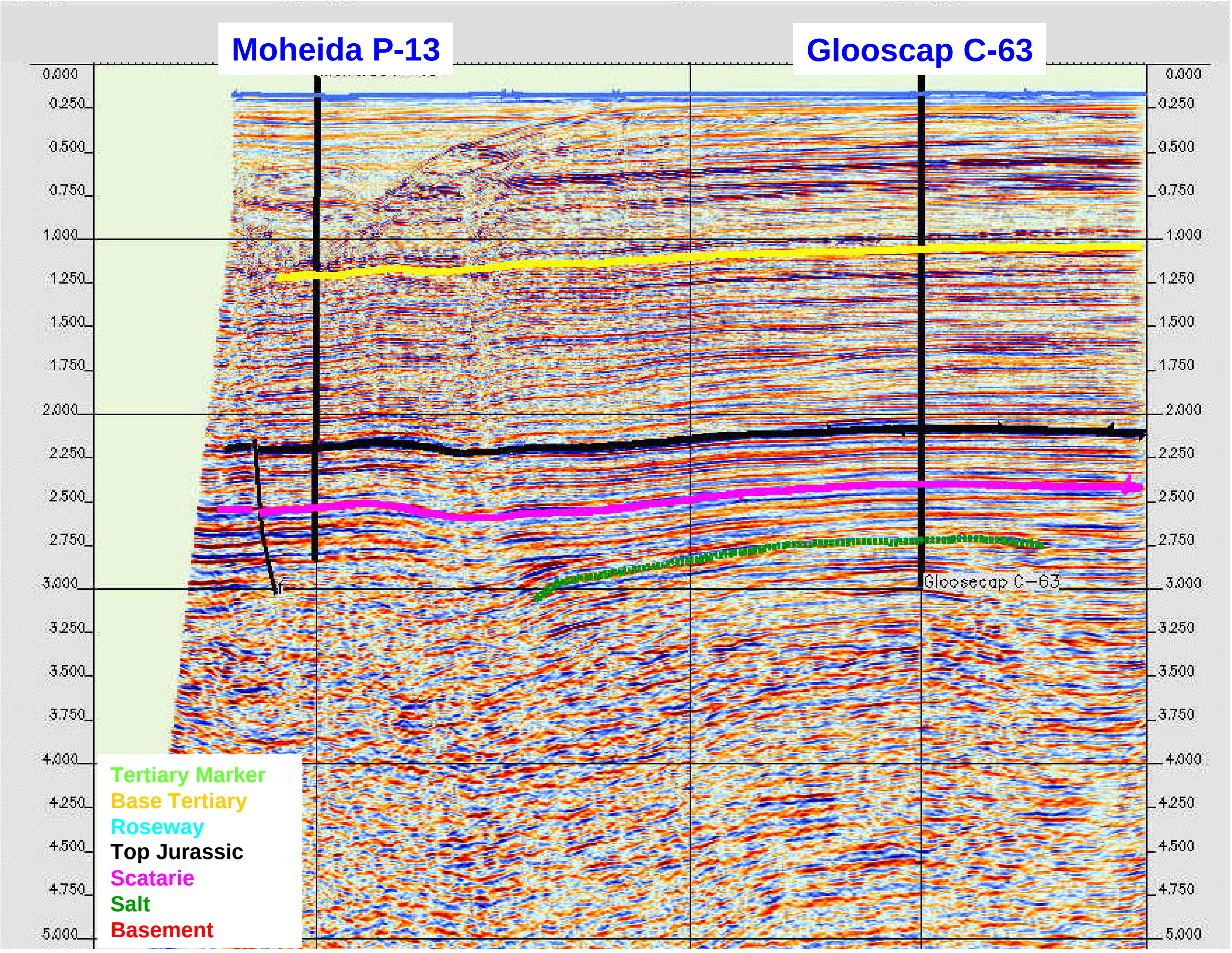


Figure 120. Regional seismic line across Moheida P-13 and Glooscap C-63 exploration wells. See Figure 4 for location.

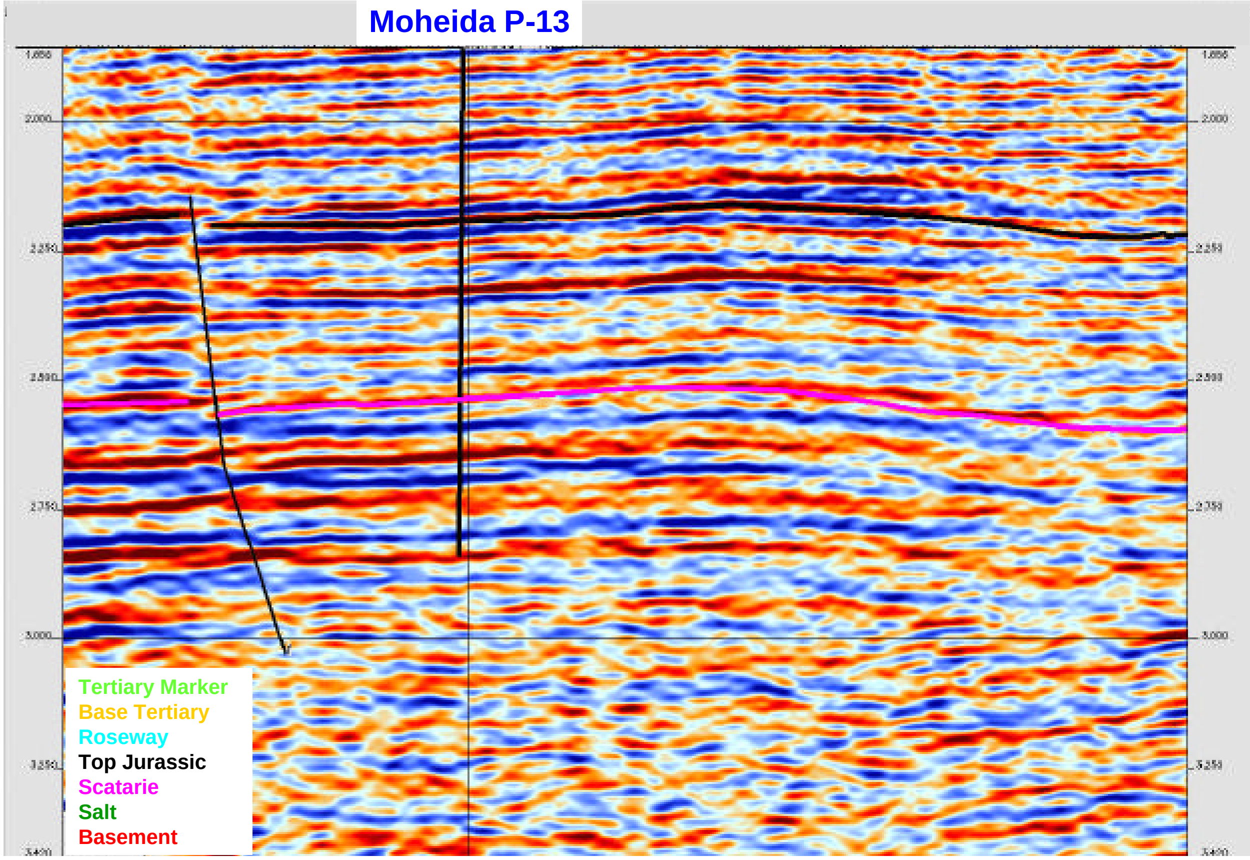


Figure 121. Detailed seismic profile – Moheida P-13 exploration well. See Figure 4 for location.

A regional seismic profile across the Moheida P-13 and Glooscap C-63 well locations (Figure 120) indicates two low relief structures with the former related to a fault. A seismic close-up (Figure 121) of the Moheida P-13 location shows non-eventful seismic character and a similar view (Figure 122) of the Glooscap C-63 well shows very uniform seismic character.

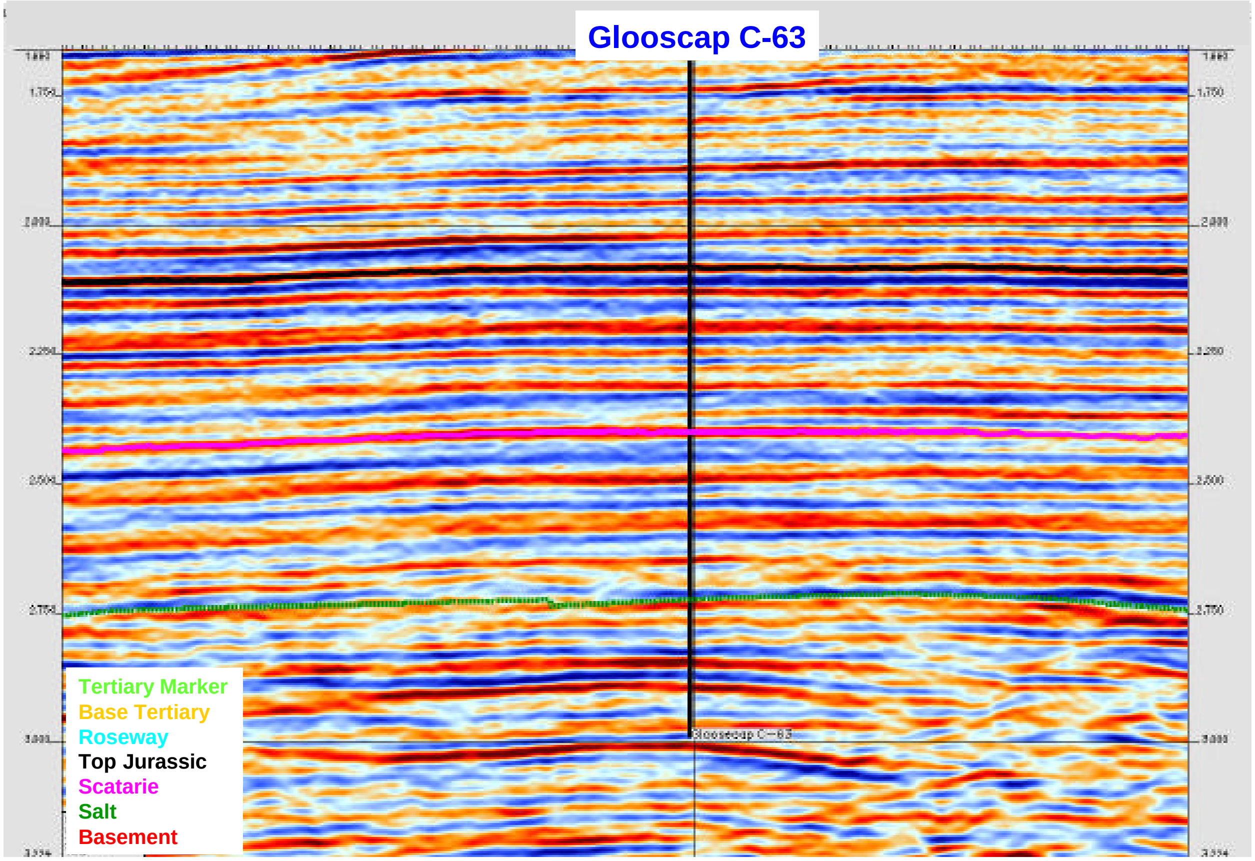


Figure 122. Detailed seismic profile – Glooscap C-63 exploration well. See Figure 4 for location.

Como P-21

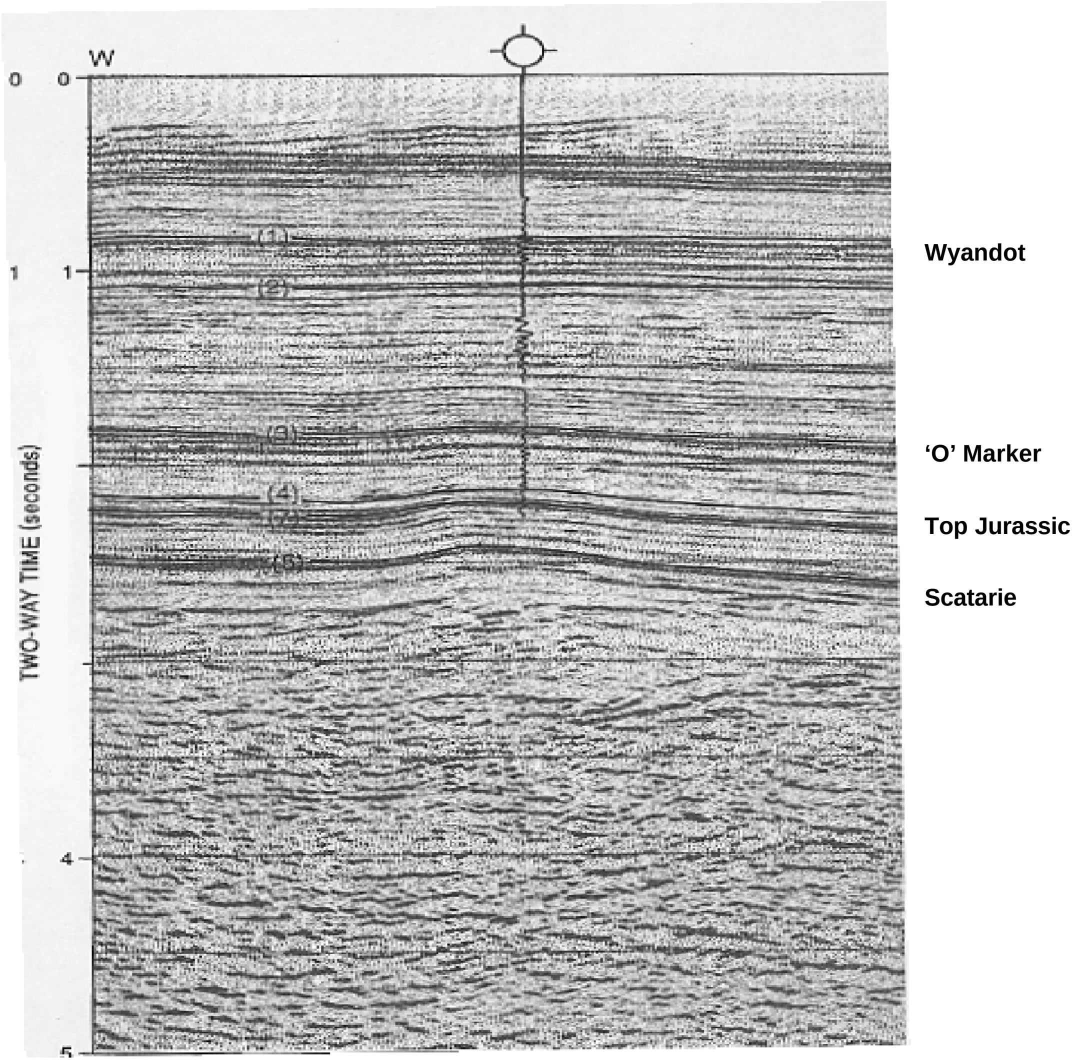


Figure 123. Seismic profile – Como P-21 exploration well. See Figure 4 for location.

In the Panuke Segment the Como P-21 seismic profile (Figure 123) reveals a low relief feature above a basement high. The nearby Dover A-43 well's seismic (Figure 124) confirms the well tested the high side of a tilted fault block.

Dover A-43

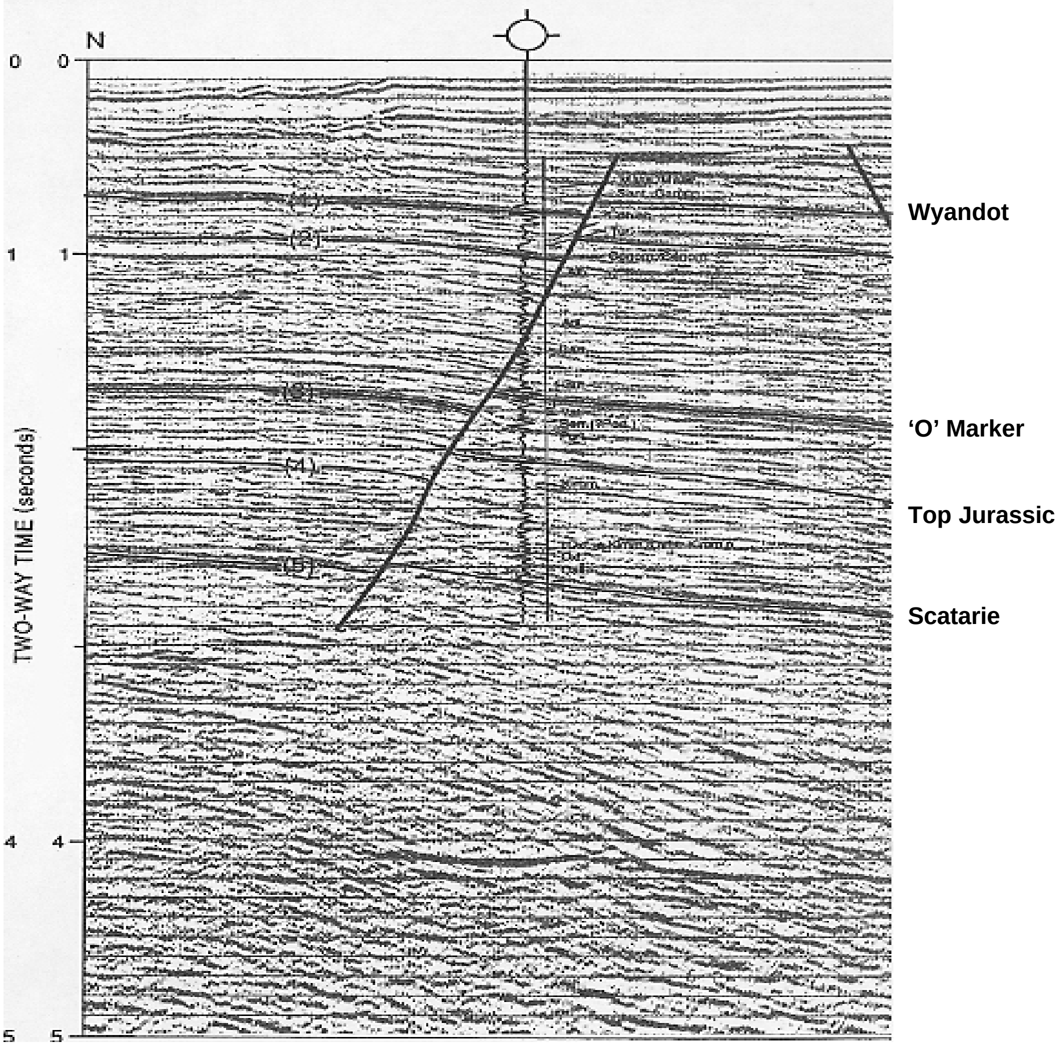


Figure 124. Seismic profile – Dover A-43 exploration well. See Figure 4 for location.

7.7 Play Summary

The Concept Map (Figure 8) shows, on a regional basis, the interpretation and results of this study. Elements of other maps and figures are all assembled to present a singular comprehensive map. The fairways correspond to the plays of Figure 24, i.e. interior platform, margin and foreslope. The zones of faulting, erosion and salt disruption are shown on the map. In summary, the following eight play areas with the dominant play type were defined and are listed below.

1) <u>Panuke Segment Bank Edge</u>

Bank margin reefal facies with combined structural/stratigraphic trap similar to Deep Panuke.

2) <u>Acadia Segment Bank Edge</u>

As above, but with complications due to faulting, salt tectonism and erosion of the bank margin.

3) <u>Shelburne Segment Bank Edge</u>

Possible reefal facies but lower-angle ramp-like margin.

4) Panuke Segment Foreslope

Foreslope reef debris and/or bypass sands are combined into a single stratigraphic trap potential.

5) Acadia Segment Foreslope

As above but more potential for eroded reefal debris.

6) Shelburne Segment Foreslope

As above but less likely part of a rimmed margin profile.

7) Outer Shelf

High energy oolite shoals or patch reefs along promontory built out over Mohican Graben.

8) Inner Shelf

Low energy setting but potential for bioherms and shoals over basement highs.

8. PETROLEUM SYSTEMS

8.1 Cohasset/Panuke Oils

While this report addresses the hydrocarbon potential of the Late Jurassic Abenaki Formation, the known occurrences of liquid hydrocarbons entrapped in younger sediments overlying the Abenaki merit discussion.

High gravity oil (49º - 52º API) was produced at the Cohasset/Panuke/Balmoral Fields from fluvial and shallow marine sand sequences of the Early Cretaceous Logan Canyon and Missisauga Formations respectively (CNSOPB, 2000a). These stacked sand reservoirs are draped over the Baccaro Member carbonate bank edge forming subtle anticlinal features. Combined ultimate production from these fields was 44.445 MMbbls (7.067 x $10^6 m^3$) when production ceased in December 1999 (CNSOPB, 2000b). A similar though minor discovery was made on the northeastern end of the Abenaki bank margin (Panuke Segment) at Penobscot L-30 well, however, the pay intervals are of modest thickness and it remains undeveloped.

The Cohasset/Panuke/Balmoral oils have been typed but have yet to be matched to known source rooks in the Scotian Basin. Analysis of the oils indicates that they are sourced from kerogen Types I and II inferring a lacustrine source (Mukhopadhyay, 1993; Mukhopadhyay et al., 1995). Such source rocks may be localized and though volumetrically small, lacustrine sediments can have high TOC values and the capacity to generate large volumes of hydrocarbons. If present in the Scotian Basin, these sequences would be stratigraphically deeper of early Jurassic or even late Triassic age, and would have to rely upon deep-seated faults for migration into the shallower sequences.

8.2 Deep Panuke Gas

Hydrocarbons in the Abenaki Formation's Deep Panuke field are dominated by a dry and lean gas composed almost entirely of methane (CH_4) with very low gas liquid volumes and low levels of hydrogen sulphide (H_2S) and associated gases. The following information is sourced from PanCanadian's (EnCana) 2002 Deep Panuke Development Plan application.

Gas was successfully flow-tested in four Panuke wells (PP3C, PI1B, H-08 and M-79A) over the Abenaki 5 zone (Baccaro Member) with open flow rates ranging from 51.2 – 61.1 MMcf/d. (1.450 – 1790 $E^6 m^3$/d) Associated gas liquids volumes are quite low ranging from 1.2 - 3.6 bbls per $E^6 ft^3$. (6.9 - 20.0 m^3 per $E^6 m^3$) In all DST and MDT tests, hydrogen sulphide gas was present though in low volumes averaging 0.2% (2000 ppm) H_2S and is considered abiogenic in origin. The Deep Panuke gas is normally-pressured with a common pressure system and a single gas/water contact at about -3505 metres subsea elevation.

8.3 Source Rocks

The source for the gas discovered at Deep Panuke is believed to have been generated from the shales of the Jurassic-Cretaceous Verrill Canyon Formation; the basinal equivalent facies of the Abenaki, MicMac, Missisauga and Logan Canyon Formations (PanCanadian, 2002). The Verrill Canyon is found all along the eastern basinal portion of the Scotian Basin and East Newfoundland basin, covering a geographically large area of about 30,000 km^2 (Klemme, 1994). Thickness of the formation probably exceeds several thousand metres in the regional depocentres (Wade and MacLean, 1990).

Verrill Canyon Formation sediments are known to have varying kerogen types through geologic time (Mukhopadhyay and Wade, 1993; Mukhopadhyay et al., 1995; Mukhopadhyay et al., 2003). Late Jurassic-Early Cretaceous marine sediments are considered oil- and gas-prone with Types II, II-III and III kerogen types. The Middle to Late Cretaceous marine Verrill Canyon contains both terrestrial and marine sediments that are condensate- to gas-prone containing Type II-III and III kerogens. Information on the Early and Middle Jurassic-age Verrill Canyon is unknown due to the lack of well penetrations and its great depth of burial. Event timing charts incorporating all known and speculative source facies have been constructed for the Abenaki formation in general (Figure 26) and two of its Segments: Panuke (Figure 93) and Acadia (Figure 109).

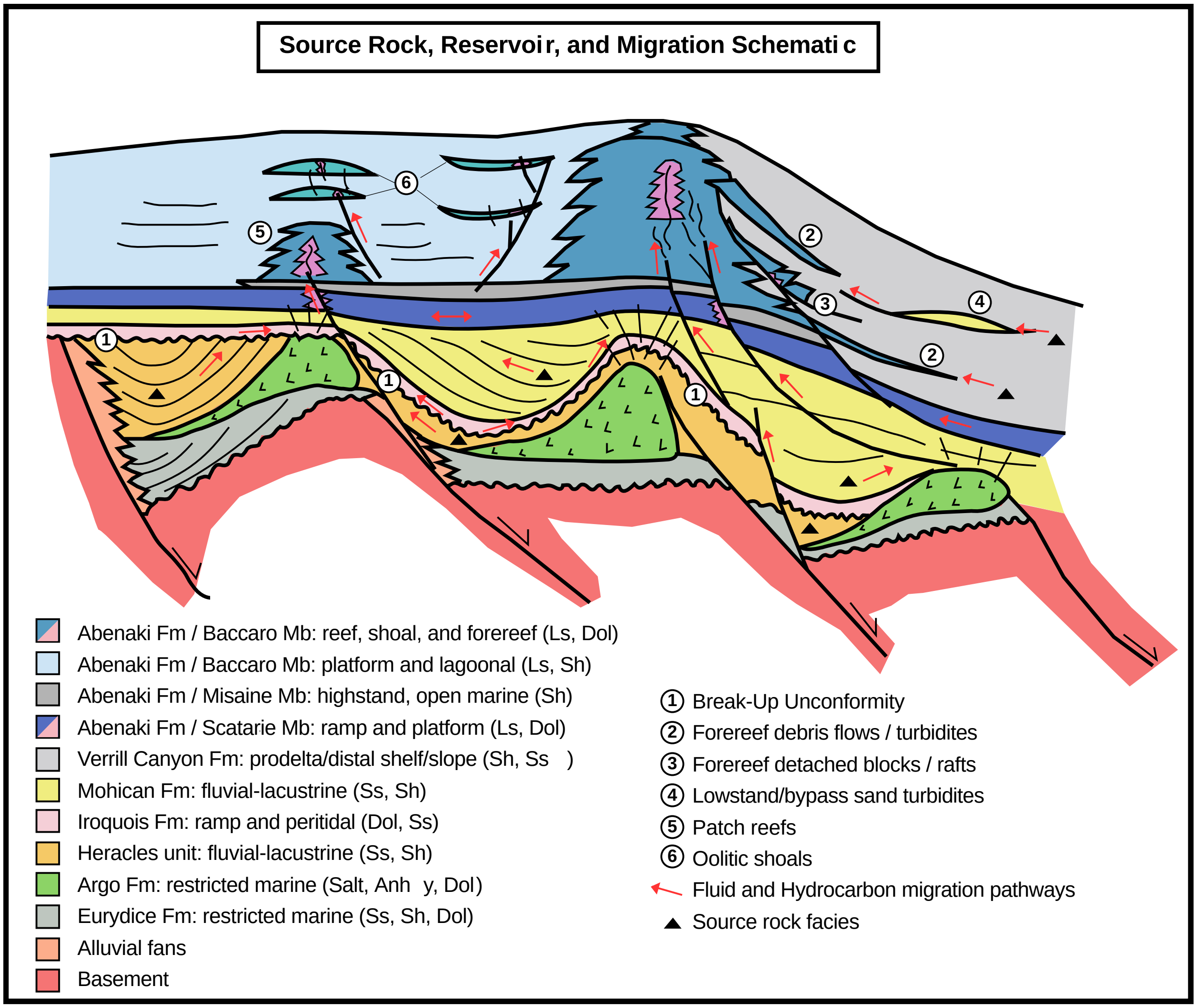


Figure 125. Abenaki Formation petroleum systems schematic drawing. See text for details.

Verrill Canyon sediments probably reached maturity for hydrocarbon generation on the basin margin slope in the Late Cretaceous and Tertiary (Mukhopadhyay, 1993; Mukhopadhyay et al., 1995). However, in those areas with thicker overburden such as the Laurentian, Sable and Shelburne Subbasins, maturation of these sediments occurred earlier in the Early to Middle Cretaceous and Late Cretaceous respectively. Those portions of the Verrill Canyon in proximity to the ancient deltas during Jurassic and Cretaceous times (e.g. Panuke and Shelburne Segments) are inferred to have slightly elevated quantities of terrestrial (gas-prone) organic matter than in those areas dominated by open marine conditions. In the latter, normal open ocean conditions with good circulation patterns prevailed in the Late Jurassic and Cretaceous on the Scotian margin (Gradstein et al., 1990). Darker shales with possible greater organic content may have formed in local settings during the Callovian-Oxfordian and Aptian-Cenomanian but have not been encountered. Organic rich source rocks reflecting deepwater anoxic conditions may have formed in localized bathymetric lows associated with salt structuring on the slope adjacent to the Abenaki Bank margin though would have matured later given the thinner overburden section (e.g., Acadia Segment).

There are other potential sources for hydrocarbons in the Abenaki. As discussed in Sections 4.2 and 5.5, progradational clastic successions of the Early Jurassic Heracles Unit and Middle Jurassic Mohican Formation rapidly loaded underlying Argo salts and created salt ridges and evacuation synclines prior to deposition of the basal Abenaki Scatarie Member. Within the adjacent synclines, lacustrine facies with rich oil-prone Type I and II kerogens may have formed. While their maturation may have occurred in the Late Jurassic (Mukhopadhyay et al., 2003) (Kidston et al, 2002), given their proximity to salt bodies, potential lacustrine source rocks would have been subjected to elevated heat flows causing earlier maturation. Faults and fractures induced by later salt motion would provide pathways into overlying strata. To date, sediments within these synclines have not been drilled and the concept remains speculative, although the lacustrine affinities of the Cohasset/Panuke/Balmoral oils may offer clues supporting this source concept.

The possible migration pathways are shown for various speculative source rock facies into potential Abenaki Formation carbonate facies reservoirs (Figure 125). A common denominator appears to be the presence of underlying salt. Salt motion, its drivers and resultant structural expressions would facilitate creation of pathways for the migration of diagenetic fluids and later hydrocarbons. They influenced the formation of deep basin margin-bounding down-to-the-basin listric faults, fractures systems in overlying strata as a result of salt motion, and formation of structural lows containing possible lacustrine source rock facies. Such linkages may explain the interpreted lacustrine origin of the liquid hydrocarbons produced from the Cohasset/Panuke/Balmoral oil fields overlying the discovered gas at Deep Panuke.

Sub-seismic or buried wrench faults and fractures normal to the bank margin could also be considered as potential pathways for fluids and hydrocarbons. The Early Jurassic plate reconstruction of Welsink et al. (1990) illustrates the left-lateral shear couple with secondary wrenching, normal faulting and folds. Such faults would have formed in response to Jurassic rifting and plate motion, and the secondary features would offer long-lived linkages to both the deepwater and platform successions.

9. RESOURCE ASSESSMENTS

9.1 Historical Assessments

The only previous assessment of the carbonate bank was carried out by the GSC and published in 1989 but based on well results to the end of 1983. The report mentions four wildcats drilled along the bank margin without success although by 1989 three more were drilled but were all dry (Figures 4, 5). Two main play types were immediately recognized; porosity in bank edge reefal buildups and other facies-related reservoir development on the platform interior. Seventeen prospects of the bank edge play were identified, four of which were drilled by the end of 1983. The GSC analysis expected an oil-prone play due to the predominantly marine source rocks of the Verrill Canyon Formation. Their calculations suggested median pool sizes of 53 MMB and 210 Bcf with the overall estimates of the resource potential of the bank edge play in the table below.

	Low (P90)	Median (P50)	High (P10)
Gas (Bcf)	166	1300	3774
Oil (MMB)	30	321	1097
OEB	58	538	1726

Table 11. GSC 1989 Hydrocarbon Assessment: Carbonate Bank Play

The Canadian Gas Potential Committee (CGPC) 2001 Report, while acknowledging EnCana's Deep Panuke discovery, did not have any data to run a numerical assessment. On a geological basis, they divided the Baccaro reef trend into two segments; Panuke and Acadia. The Panuke Segment was constrained to the flank of the Sable Subbasin from Penobscot L-30 to the southwest limit of the sub-basin near the Evangeline H-98 well. The play was treated as 'established' based on the Deep Panuke gas discovery and assigned a recoverable gas value of 929 Bcf (PanCanadian press releases and PanCanadian Development Plan, 2002). Recent (2004, 2005) EnCana press releases have refined this value to 950 Bcf. The Acadia Segment continued from the end of the Panuke Segment southwest to the Northeast Channel and deemed to be a conceptual play and so was discussed but not assessed.

10. CONCLUSIONS

10.1. Basin Evaluation

The Upper Jurassic Abenaki Formation carbonate bank is a generally rimmed margin that extends for 650 km from Sable Island to the U.S. border. It is non-linear, faulted, eroded and, in places, disrupted by salt intrusions. For assessment purposes, it has been subdivided into three segments based on geologic criteria; Panuke, Acadia and Shelburne.

The bank margin of the Panuke Segment is the best preserved, has a major gas discovery and abuts the prolific gas-prone Sable Subbasin. The 3D seismic surveys, in defining and understanding the discovery, have proven indispensable. The bank edge reservoir fairway exists as narrow as 1-3 km wide fairway and future exploration well designs should be prepared for a whipstock.

The Acadia Segment has only three wells over its 400 km length and the bank margin has undergone faulting, erosion and salt disruption. Prospect generation will undoubtedly require 3D seismic surveys.

The Shelburne Segment is unexplored and poorly imaged by the vintage seismic from the 1970's and 1980's. The margin profile is less steep than the other segments and in the vicinity of the Northeast Channel a Jurassic delta may have existed. New seismic, both regional 2D and local 3D will be required for future exploration programs.

The Baccaro Member belongs to a proven petroleum system with the Deep Panuke discovery. Whether its attributes can be extrapolated to the other segments remains uncertain.

Except for the discovery off Nova Scotia, there is only one other significant success in the Upper Jurassic carbonate platforms of the circum-North Atlantic, that being the Cap Juby heavy oil field offshore Morocco.

Productive carbonate petroleum systems from the Upper Jurassic in the U.S. Gulf of Mexico (Smackover Formation), the Lower Cretaceous Pimienta-Tamabra in Mexico (Golden Lane) and the Middle Devonian Slave Point and Swan Hills of the WCSB were useful analogues for this study.

The Abenaki carbonate platform has yielded one discovery to date on the bank edge at Deep Panuke. This single discovery is modest when considering that the 650 km long play fairway is virtually unexplored. Hence, although one play area is proven, the others remain conceptual. Of the remaining 20 exploration wells on the platform, there is evidence of positive indicators in mud gas readings and porosities either drilled or inferred from lost circulation while drilling.

With a single significant commercial hydrocarbon discovery off Nova Scotia, a heavy oil discovery offshore Morocco and none encountered off the U.S. margins, the success factors of this play remain to be determined. The variable quantity and quality of relevant datasets inhibit a comprehensive numerical analysis of the entire platform and margin succession. Additional seismic data, well results and future discoveries are required to better understand and more accurately quantify the resource potential of the Abenaki carbonate margin and equivalent plays offshore Nova Scotia, Northwest Africa and the United States.

GLOSSARY

Aggradational profile: Vertical accretion resulting in a stationary upright margin. Because carbonate accumulation rates on the platform are greater than in the basin, the relief between margin and basin will increase and gullied bypass and erosional margins may develop.

BB: Billion barrels (10^9)

Bcf: Billion cubic feet (10^9)

BOE: Barrels of Oil Equivalent

BOEB: Billion Oil Equivalent Barrels

CGPC: Canadian Gas Potential Committee

CNSOPB: Canada-Nova Scotia Offshore Petroleum Board, “the Board”.

Carbonate ramp: Shallow wave-agitated facies of the nearshore zone which pass downslope, without a marked break in slope, into deeper water low energy deposits. A ramp differs from a rimmed shelf in that continuous reef trends generally are absent, high energy lime sands are located near the shoreline, and deeper water breccias (if present) generally lack clasts of shallow shelf edge facies. Ramps can be subdivided on the basis of profile into homoclinal ramps and distally steepened ramps.

Conceptual play: An exploration play that does not yet have discoveries or reserves but which geological analysis indicates may exist.

Discovery: The term applies to the granting by CNSOPB of a Significant Discovery License (SDL) which means oil and/or gas was tested to surface in significant quantities that have potential for future commercial development.

DSDP: Deep Sea Drilling Project

EMR: Energy, Mines and Resources (Canada)

Escarpment profile: Shelf margin and slope to basin facies are separated by a submarine escarpment. The submarine escarpment may result from faulting, margin collapse, or rapid upbuilding of the margin compared to the basin.

Established play: An exploration play that has been demonstrated to exist by the discovery of one, or more, pools. Commerciality may or may not be a factor in the definition.

EUR: Estimated Ultimate Recovery equals, at any point in time, the sum of produced, proven reserves and undiscovered potential.

GIP: Gas-in-place

GOM: Gulf of Mexico

GSC: Geological Survey of Canada

Isolated platform and oceanic atoll: Shallow water platform detached from continental shelf, normally with steep slopes and surrounded by deep water. Atolls develop above oceanic volcanoes, and isolated platforms develop on nonvolcanic crustal blocks.

Lacustrine: Pertaining to, produced by, or formed in a lake or lakes.

MB: Thousand barrels (10^3)

Mcf: Thousand cubic feet (10^3)

MMB: Million barrels (10^6)

MMcf: Million cubic feet (10^6)

MMS: Minerals Management Service, U.S. Department of the Interior

Mya: million years ago

New Field Wildcat (NFW): The first well on a prospect or geological feature that is testing a new structure or play concept. Such a feature may straddle more than one fault block. As opposed to a delineation well, step-out, development, injector, etc.

NGL: natural gas liquids

ODP: Ocean Drilling Project (now IODP – International Offshore Drilling Program)

OGIP: Original-Gas-In-Place

OIP: Oil-In-Place

ONAREP: Office National de Recherches et d' Explorations Petrolieres, Kingdom of Morocco (now ONHYM)

ONHYM: Office National des Hydrocarbures et des Mines.(ex-ONAREP)

OOIP: Original-Oil-In-Place

Open or unrimmed platform: Shallow water platform with a nearly flat or extremely low angle slope from the shoreline to the break in slope that marks the shelf margin and steeper slope. Elevated rims are absent at the shelf margin, allowing tidal flushing and swells to extend across most of the shelf.

Play: A geological formation, or structural or stratigraphic trend, which has similar lithologic, reservoir or other characteristics extending over some distance or extent.

Potential: Unproven quantities of recoverable hydrocarbons that may exist.

Progradational profile: Lateral and basinward accretion resulting in an offlap geometry. Two extreme cases of progradation profile configuration are recognized: (a) sigmoidal progradation in which the platform margin accretes basinward and upward, and (b) oblique progradation in which the platform margin accretes basinward, resulting in a horizontal basinward shift. Sigmoidal to oblique, sigmoidal-oblique, and complex sigmoidal-oblique are examples that range between case (a) and (b). Basinward-steeping facies shifts characterize progradational geometries.

Prospect: A singular structure or geologic feature that has the necessary attributes to contain hydrocarbons and hence be a drilling target.

Reserves: Quantities of oil, gas and related substances that are proven to exist in known accumulations and are believed recoverable at some point in time.

Resources: The total quantity of oil, gas and related substances that are estimated at a particular time to be contained in, or that have been produced from, known accumulations, plus, those estimated quantities in accumulations yet to be discovered.

Retrogradional profile: Landward shelf margin shift resulting in an onlap geometry and landward-steeping facies. Two cases of onlap profile configuration are recognized: (a) gradual retreat and (b) backstepping or step-wise retreat.

Rimmed carbonate platform: Shallow water platform whose outer wave-agitated edge has a semicontinuous to continuous rim or barrier along the shelf margin which restricts circulation and wave action to form a low energy lagoon. Rims may consist of barrier reefs, skeletal and ooid sands, or islands (eolianite or reefs) from an earlier depositional phase. The platform margin is market by a pronounced increase in slope, commonly a few degrees to 60° or more.

Stochastic calculation: Statistical calculation using Monte Carlo (or other) sampling techniques of input variables to result in a probability output distribution.

Tcf: Trillion cubic feet (10^{12})

TGU: Total gas units as measured from liberated gas in the circulating drilling mud and well cuttings.

USGS: United States Geological Survey

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