CHAPTER 4

PETROLEUM GEOCHEMISTRY

Chapter 4 presents the results of the geochemical study of the Scotian Basin that was undertaken in the PFA project. Numerous previous studies had attempted to identify the source rocks generative of the hydrocarbons discovered in the basin but none of these studies reached conclusive results at the basin scale. The present Petroleum Geochemistry study had the privilege of using the large existing geochemical database acquired through more than 40 years of exploration, the knowledge transmitted by the numerous geochemists who have worked on this basin. The results of the biostratigraphy study provided a strong stratigraphic architecture needed for relating source rocks to an age instead of a lithostratigraphic interval, like Verrill Canyon for instance.

Understanding the generative system is central to assessing the petroleum system(s) of the Nova Scotia margin. The search for the source rocks generative of oil, gas & condensate discovered and yet to be discovered is therefore at the heart of the geochemistry project.

Maturity, of course, is the engine of hydrocarbon generation from these source rocks. Petroleum system modeling, which is a major part of the PLAY FAIRWAY ANALYSIS project, needs source rocks and maturity among many other elements and processes to play with.

Source rock search

Source rock search consists of reviewing all available TOC/Rock. New TOC/Rock Eval data to complement these databases were needed to verify and confirm existing data,.

Source rocks are not so easy to identify because drilling widely used oil-based mud. Other contaminants such as lignite, plastic, asphalt, rubber and paint have also been used. As a consequence, Oil Geochemistry was applied on oil and condensates of the Nova Scotia margin for attempting to identify oil families that would relate them to source rocks by their genetic signatures.

Oil and Condensates characterization

Oil families identify the various types of source rocks they originate from (best case scenario). New GC and GCMS analyses of oil, condensates and hydrocarbon fluid inclusions were carried out focusing on their saturate fractions.

- Hydrocarbon inclusions essentially were used for assessing possible source potential in the Triassic and Lower Jurassic. Source rocks in this interval are not documented because mostly not penetrated in the deep margin or not present (hiatus or unconformity) where penetrated. Triassic or Early Jurassic source rocks are expected to be oil-prone either lacustrine (Type 1; West African offshore Bucomazi analog) in salt or post- salt situation and or marine (Type 2) in the Pliensbachian-Toarcian (Portugal, Morocco and French Schistes-Carton analogs).

In the past, several attempts were made to characterize oil and condensates of the Nova Scotia margin. P. K. Mukhopadhyay (1990, 1991) conducted biomarker analysis on aromatic fractions. The Geological Survey of Canada presented a poster by Fowler and Obermajer (2000) on Nova Scotia oil families based on gasoline range compounds. These various approaches lacked references to genetic signatures capable of relating oil and condensates to source rock type and environment of deposition. The most significant data in a genetic sense remain the "standard" biomarkers of the saturate fraction and stable carbon isotope of oil and gas. Unfortunately there is no gas isotope data available in the various accessible databases and no gas samples are available for carrying out isotope analyses.

- For oil, condensates and bitumen extracts, carbon isotope data were acquired and reported on by Mukhopadhyay (1991). These data are re-examined in this study.
- For "standard" biomarkers (saturates) of the Nova Scotia oil and condensates no database was ever constituted. There is only a few fingerprints, one of which is displayed in the Geological Survey of Canada poster by Fowler and Obermajer (1999). The reason evoked is that oils and condensates are light and therefore they do not contain significant amount of large molecules in the C_{27} to C_{30} range, where these biomarkers are. This gap in data control opened the opportunity to at least check what "standard" biomarkers may bring in order to improve understanding of the Petroleum Systems of the Nova Scotia margin.
- A regional geochemical survey, the confidentiality of which was lifted in April 2011, conducted by TDI-Brooks International, Inc. (Bernard B. B., Allan K. A. and McDonald T; J. 2000) became accessible as a source of data for this study. The geochemical data of this survey consisting of carbon isotopes and molecular compositions (GC-GCMS) of piston-core seeps are also examined and discussed in this study.
- A regional satellite oil slick study was also acquired for the PFA study.

Maturity

Maturity, of course, is the engine of hydrocarbon generation. Existing maturity data are accessible from the on-line GSC database . New Vitrinite Reflectance data were acquired to complement the GSC database where needed , i.e. on the western margin of Nova Scotia.

The main result of the study is the identification of five (5) key source rocks as:

1.Lower Cretaceous – Aptian (deltaic)

- Intra-Aptian MFS (Naskapi)

2.Lower Cretaceous – Valanginian (deltaic)

- Base age 137 Ma

3. Upper Jurassic – Tithonian (transition from carbonate to deltaic environment)

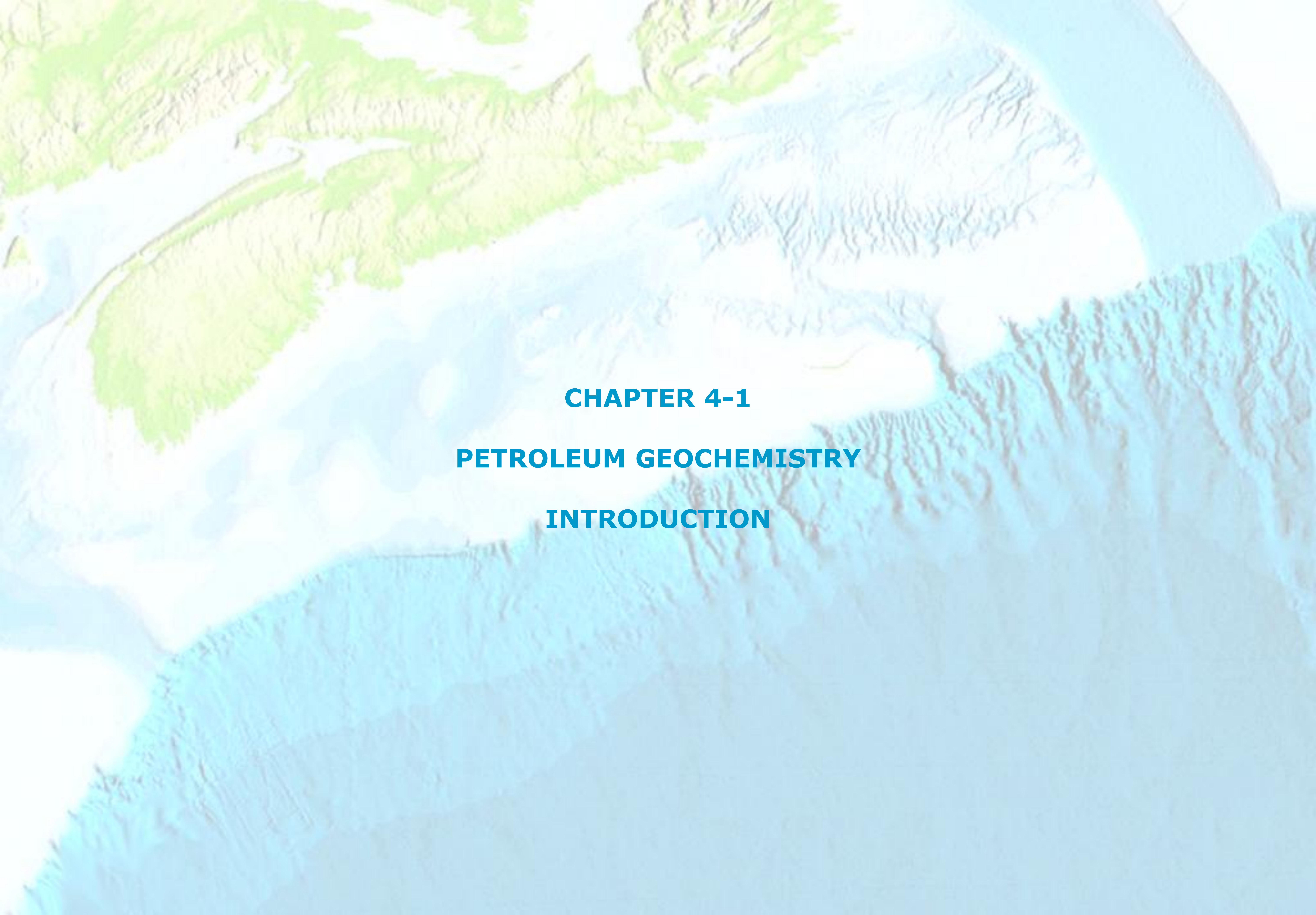
- Tithonian MFS
- The Tithonian source rock is of major importance as it is well defined, organic-rich and mature

4. Middle Jurassic – Callovian

- Callovian MFS –Misaine

5.Early Jurassic source complex– Liassic

- Deposited immediately post-rift, hypersaline (gammacerane) to carbonate marine environment (Sinemurian-Pliensbachian-Toarcian);
- Not penetrated. Inferred from the Moroccan and Portuguese conjugate margins as well as from piston core samples offshore Nova Scotia and wells on the Grand Banks.
- Because not penetrated, these Early Jurassic source rocks are taken as one source complex



CHAPTER 4-1

PETROLEUM GEOCHEMISTRY

INTRODUCTION

Petroleum Geochemistry

Introduction

Understanding the generative system is central to assessing the petroleum system(s) of the Nova Scotia margin. The search for the source rocks generative of oil, gas & condensate discovered and yet to be discovered is therefore at the heart of the geochemistry project.

Maturity, of course, is the engine of hydrocarbon generation from these source rocks. Petroleum system modeling, which is a major part of the PLAY FAIRWAY ANALYSIS project, needs source rocks and maturity among many other elements and processes to play with.

Source rock search

Source rock search consists of reviewing all available TOC/Rock Eval data. Most of these data are stored in the GSC database at the following address: http://basin.gdr.nrcan.gc.ca/index_e.php (open site). Some data not entered in the GSC database were retrieved from the DMC database at the following address: http://ww1.cnsopbdmc.ca/dp/pages/apptab/ITabManager.html (this site requires an authorization).

New TOC/Rock Eval data to complement these databases were needed to verify and confirm existing data, to extend data control toward the western margin and to check the pre-salt sedimentary series only penetrated by wells on the back shelf, where it is accessible at relatively shallow depths.

Source rocks are not so evident to identify because drilling widely used oil-based mud. Other contaminants such as lignite, plastic, asphalt, rubber and paint have also been used. As a consequence, Oil Geochemistry was applied on oil and condensates of the Nova Scotia margin for attempting to identify oil families that would relate them to source rocks by their genetic signatures.

Oil and Condensates characterization

Oil families identify the various types of source rocks they originate from (best case scenario). New GC and GCMS analyses of oil, condensates and hydrocarbon fluid inclusions were carried out focusing on their saturate fractions. A study of fluid inclusion in salt (Argo Salt) was carried out by Y. Kettanah Professor Assistant at Dalhousie University in Halifax as part of the Play Fairway Analysis project. Salt samples with inclusions filled with hydrocarbons were collected by Y. Kettanah and submitted to biomarker analysis in order to complete the dataset of the geochemistry study.

- Hydrocarbon inclusions essentially were used for assessing possible source potential in the Triassic and Lower Jurassic. Source rocks in this interval are not documented because mostly not penetrated in the deep margin or not present (hiatus or unconformity) where penetrated. Triassic or Early Jurassic source rocks are expected to be oil-prone either lacustrine (Type 1; West African offshore Bucomazi analog) in salt or post- salt situation and or marine (Type 2) in the Pliensbachian-Toarcian (Portugal, Morocco and French Schistes-Carton analogs).

In the past, several attempts were made to characterize oil and condensates of the Nova Scotia margin. P. K. Mukhopadhyay (1990, 1991) conducted biomarker analysis on aromatic fractions. The Geological Survey of Canada presented a poster by Fowler and Obermajer (2000) on Nova Scotia oil families based on gasoline range compounds. These various approaches lacked references to genetic signatures capable of relating oil and condensates to source rock type and environment of deposition. The most significant data in a genetic sense remain the "standard" biomarkers of the saturate fraction and stable carbon isotope of oil and gas. Unfortunately there is no gas isotope data available in the various accessible databases and no gas samples are available for carrying out isotope analyses.

- For oil, condensates and bitumen extracts, carbon isotope data were acquired and reported on by Mukhopadhyay (1991). These data are re-examined in this study.
- For "standard" biomarkers (saturates) of the Nova Scotia oil and condensates no database was ever constituted. There is only a few fingerprints, one of which is displayed in the Geological Survey of Canada poster by Fowler and Obermajer (1999). The reason evoked is that oils and condensates are light and therefore they do not contain significant amount of large molecules in the C_{27} to C_{30} range, where these biomarkers are. This gap in data control opened the opportunity to at least check what "standard" biomarkers may bring in order to improve understanding of the Petroleum Systems of the Nova Scotia margin.
- A regional geochemical survey, the confidentiality of which was lifted in April 2011, conducted by TDI-Brooks International, Inc. (Bernard B. B., Allan K. A. and McDonald T; J. 2000) became accessible as a source of data for this study. The geochemical data of this survey consisting of carbon isotopes and molecular compositions (GC-GCMS) of piston-core seeps are also examined and discussed in this study.

Maturity

Maturity, of course, is the engine of hydrocarbon generation. Existing maturity data – Vitrinite Reflectance, SPI and TAI – are accessible from the on-line GSC database (http://basin.gdr.nrcan.gc.ca/index_e.php). New Vitrinite Reflectance data were acquired to complement the GSC database where needed, i.e. on the western margin of Nova Scotia.

Content of the Petroleum Geochemistry Chapter 4 (Plates 4-1-1 to 4-4-16)

Source rock evaluation is also developed in Chapter 6

Source rock summary

Five (5) key source rocks were identified:

1. **Lower Cretaceous – Aptian (deltaic)**
    - Intra-Aptian MFS (Naskapi)
2. **Lower Cretaceous – Valanginian (deltaic)**
    - Base age 137 Ma
3. **Upper Jurassic – Tithonian (transition from carbonate to deltaic environment)**
    - Tithonian MFS
    - The Tithonian source rock is of major importance as it is well defined, organic-rich and mature
4. **Middle Jurassic – Callovian**
    - Callovian MFS –Misaine
5. **Early Jurassic source complex– Liassic**
    - Deposited immediately post-rift, hypersaline (gammacerane) to carbonate marine environment (Sinemurian-Pliensbachian-Toarcian)
    - Not penetrated. Inferred from the Moroccan and Portuguese conjugate margins
    - Because not penetrated, these Early Jurassic source rocks are taken as one source complex

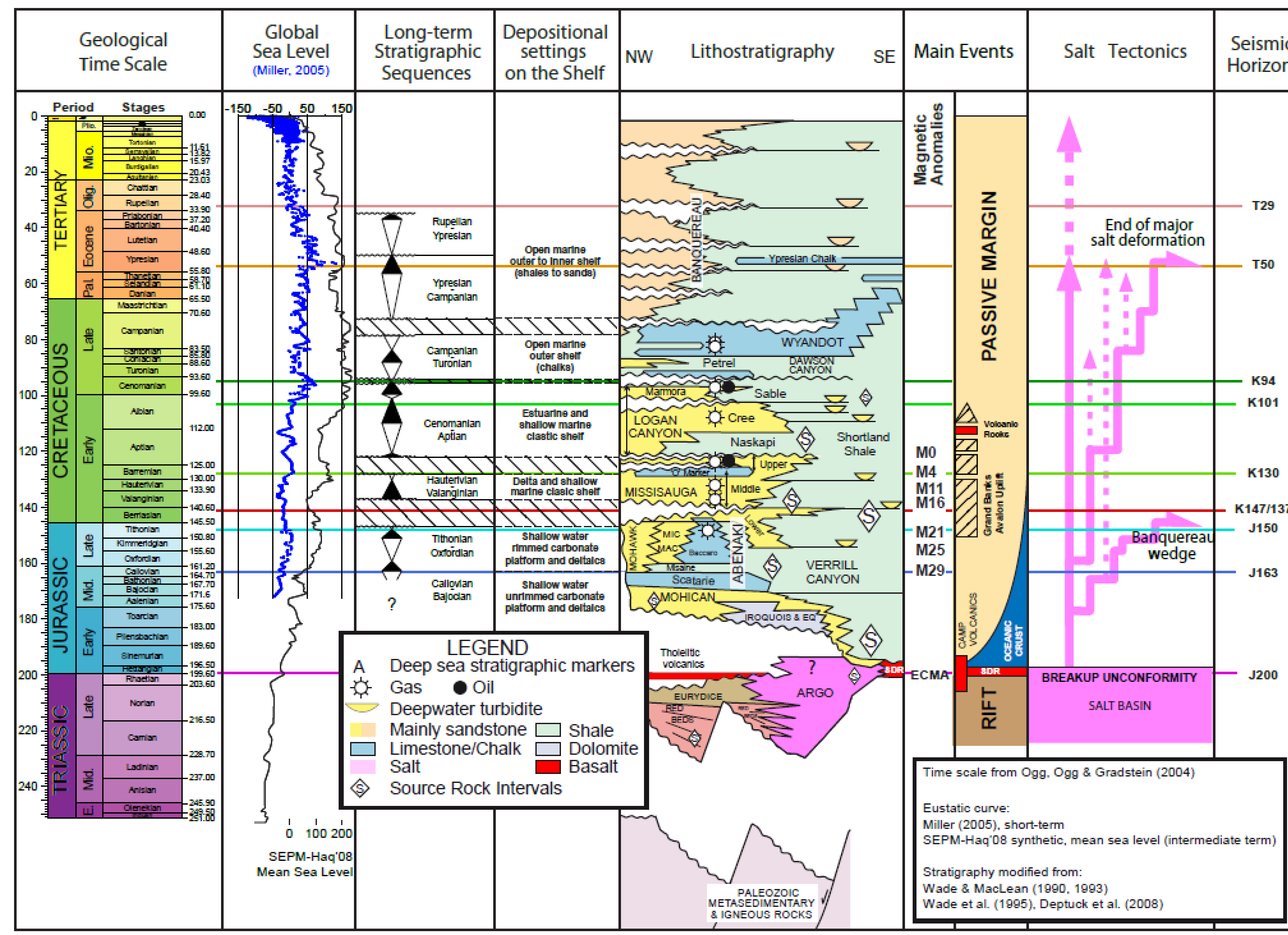
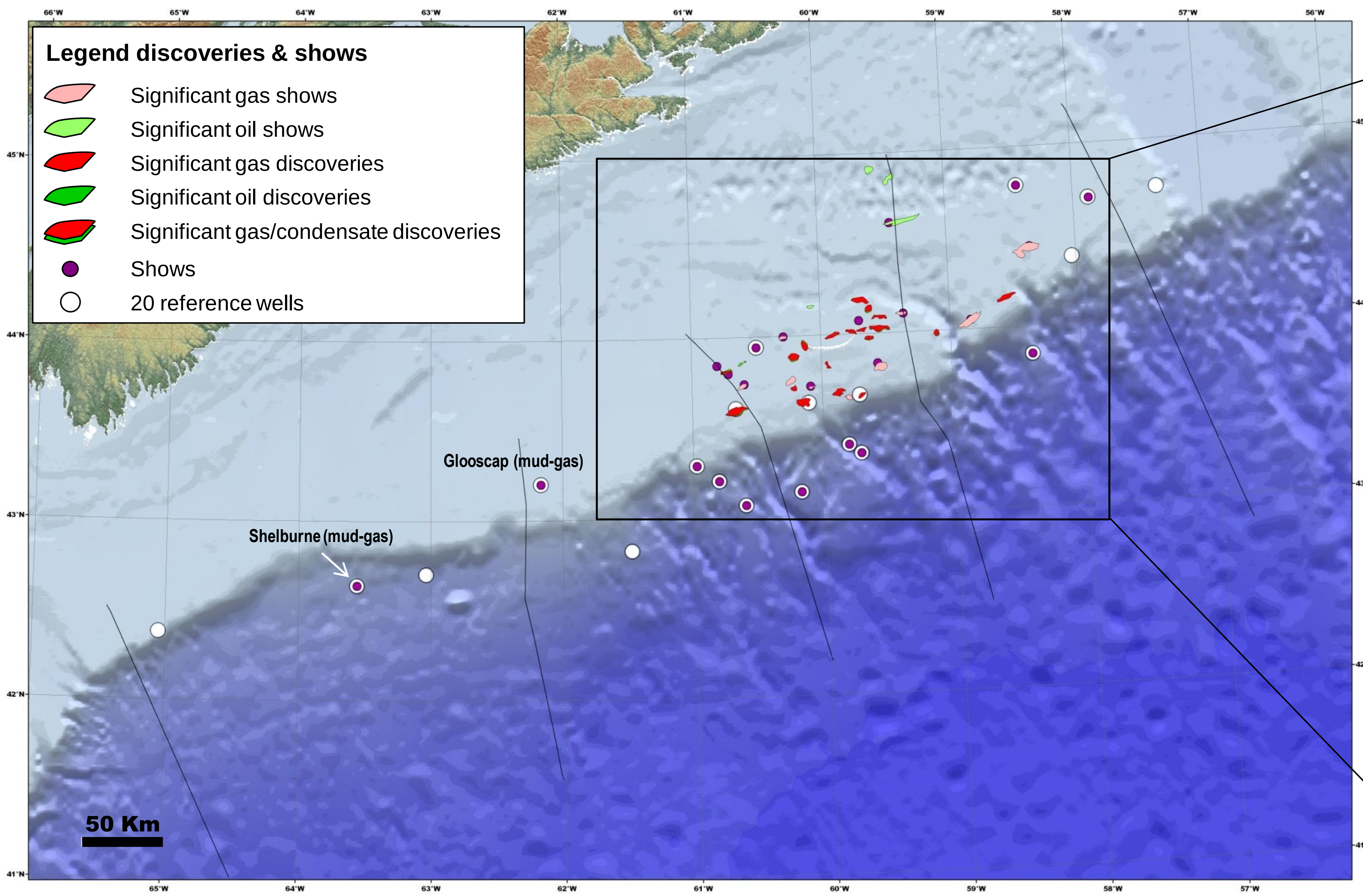


Figure 1: Chronostratigraphic chart developed for the Play Fairway Analysis project. Source rocks are outlined by diamond-shaped boxes including a S for source rock. Large and small diamond boxes indicate major and minor source rocks, respectively. The Aptian (Naskapi) source rock is minor as it is mature only over a limited area of the margin. The Valanginian source rock is considered minor as it is relatively limited in organic matter. However, it reflects and accounts for organic matter present in the Lower Cretaceous (Missisauga). The Tithonian source rock is of major importance as it is well defined, organic-rich and mature. The Misaine source rock is considered because it is a maximum flooding surface well identified where penetrated. It was encountered and documented in two wells only located on the Jurassic carbonate shelf. Spatially limited and poor data support makes it a source rock of minor importance. Yet not penetrated, the Early Jurassic source complex is considered major. Its existence is strongly supported by analogs on the conjugate margins of Portugal and Morocco (see Chapter 4, Plates 4-4-10 to 4-4-12).

CHAPTER 4-2

PETROLEUM GEOCHEMISTRY

HYDROCARBON OCCURENCES



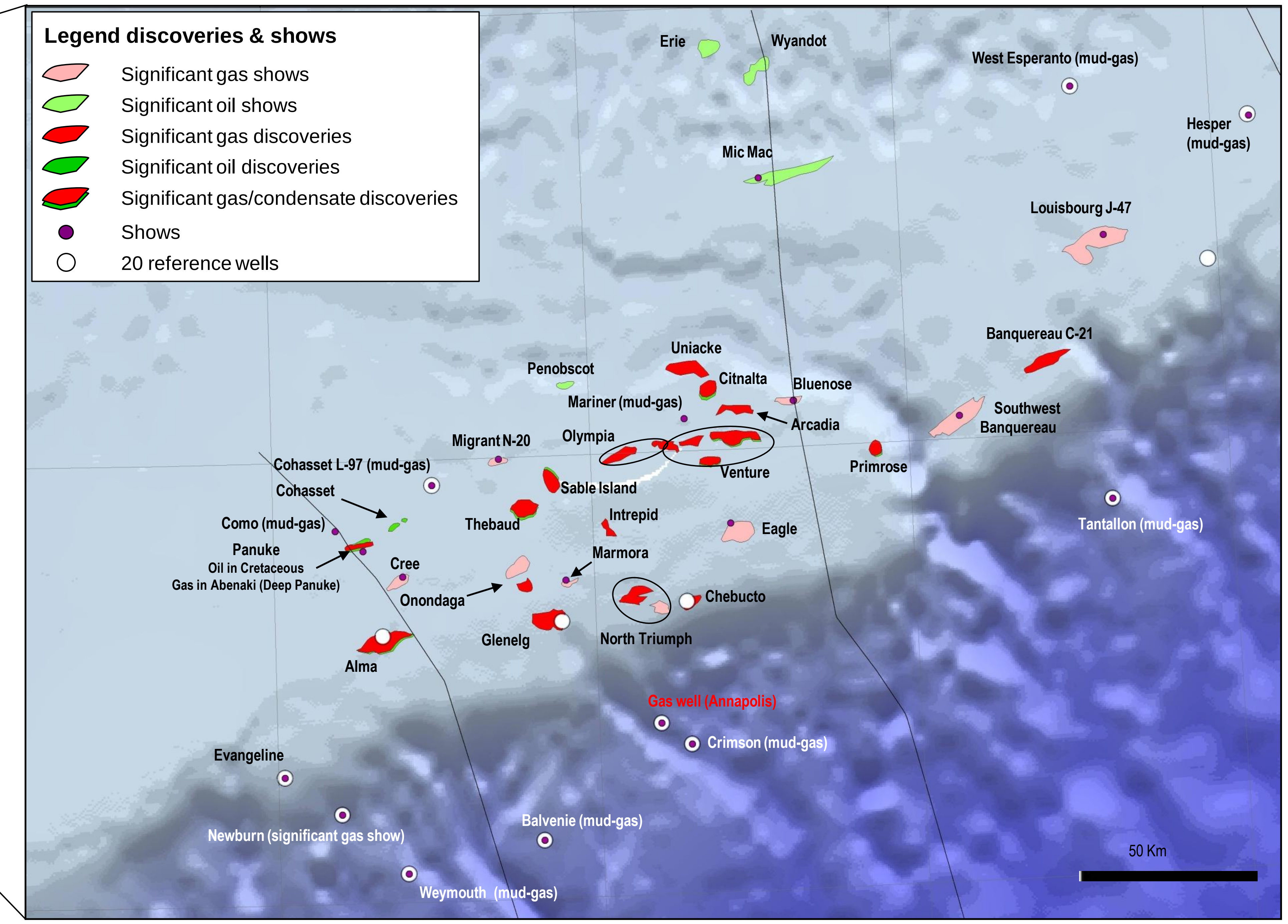


Figure 2: Zoom on the distribution of significant discoveries and shows.

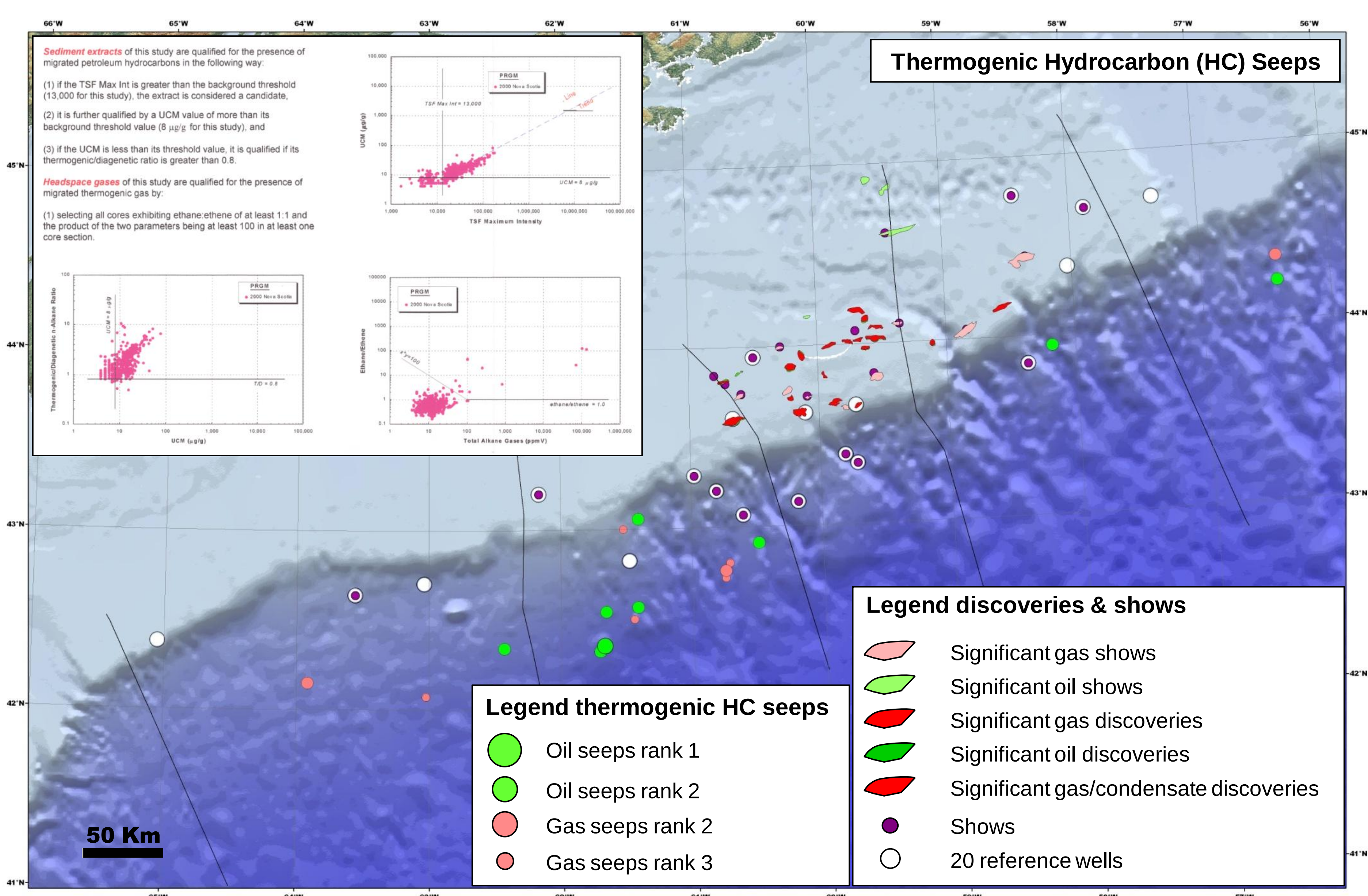


Figure 3: Distribution of significant discoveries, shows, minor mud-gas shows and thermogenic hydrocarbon seeps by Bernard et al. 2000)

Key observations

Figures 1 & 2 display the distribution of significant oil, condensates and gas discoveries as well as of mud-gas shows. Significant oil, condensates and gas discoveries are located in the Sable and the Abenaki sub-basins. Significant gas shows are located in the Sable sub-basin (Cree, Onondaga and Eagle). East of the Sable sub-basin (Southwest Banquereau, Louisbourg) and West of the Sable sub-basin (Evangeline). Significant oil shows are located in the Northeastern part of the Abenaki sub-basin (Penobscot, Erie, Wyandot and Mic Mac).

Figure 3 shows the distribution of oil and gas seeps, identified as thermogenic. Most of these seeps occur on the slope of the western region of the Scotian margin, where the Early Jurassic source rock matured late. Few thermogenic hydrocarbon seeps where identified on the slope of the eastern region, near Tantallon and further east. There are no significant thermogenic seeps in the distal part of the Sable Basin, where the deeply buried Early Jurassic source rock maturing early is overmature and depleted of its hydrocarbon potential. These observations argue in favor of the existence of an Early Jurassic source rock. Details on source rock maturation, hydrocarbon generation, expulsion and timing from the various source rocks identified on the margin are dealt with in Chapter 7.

A regional geochemical survey, the confidentiality of which was lifted in April 2011, conducted by TDI-Brooks International, Inc. (Bernard B. B., Allan K. A. and McDonald T; J. 2000) became accessible as a source of data for this study. The distribution of thermogenic hydrocarbon seeps is shown in Figure 3. The geochemical data of this survey consisting of carbon isotopes and molecular compositions (GC-GCMS) of piston-core seeps are also examined and discussed in this study.

Reference:
Bernard B. B., Allan K. A. and McDonald T; J. (2000) Regional geochemical survey for 2000 Nova Scotia Consortium. SGE Program. TDI-Brooks International, Inc. report, December 2000.

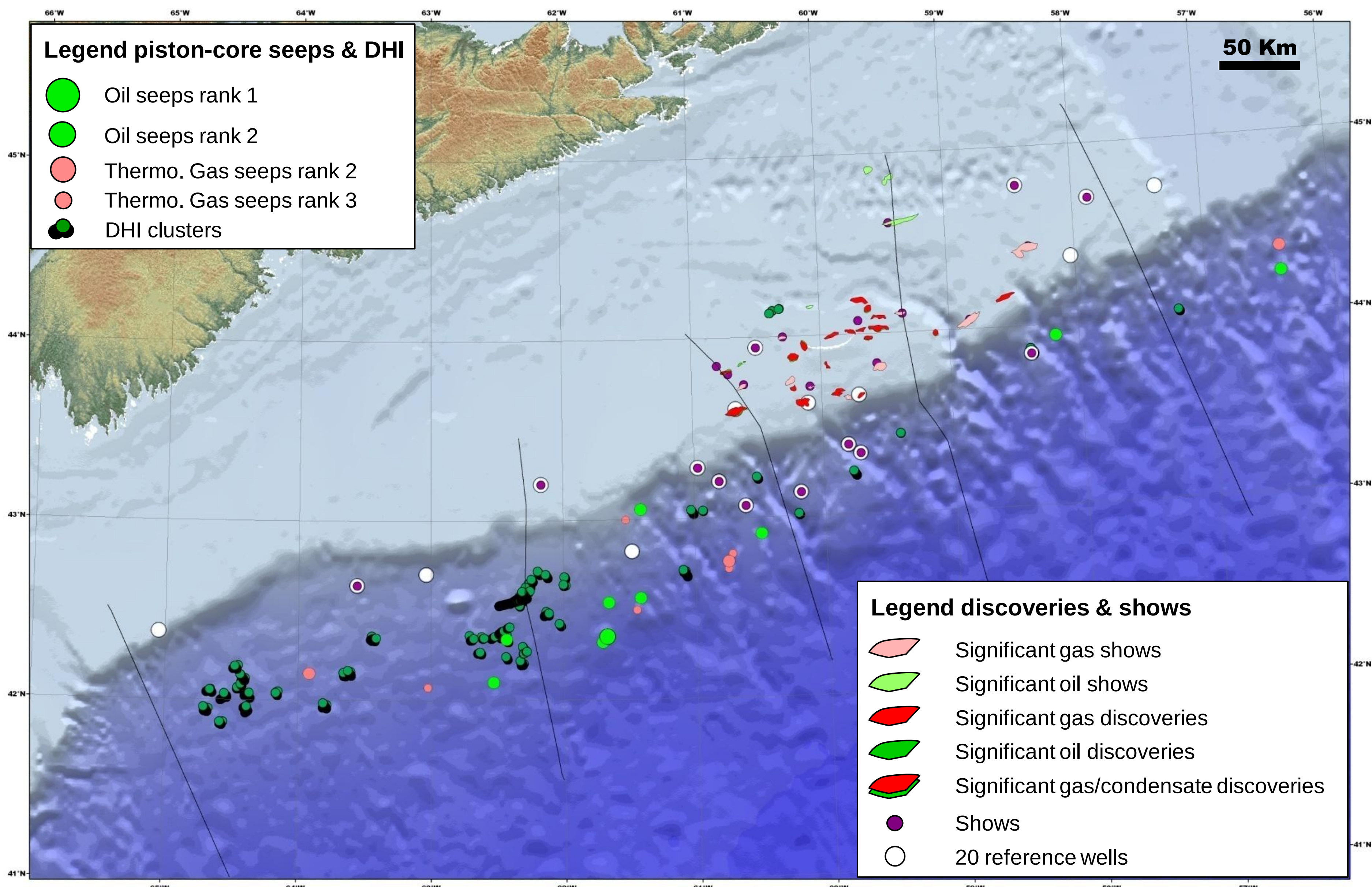


Figure 1: Distribution of significant discoveries, shows, minor mud-gas shows, thermogenic hydrocarbon seeps by Bernard et al. (2000) and Direct Hydrocarbon Indicators (DHI; see Seismic Interpretation)

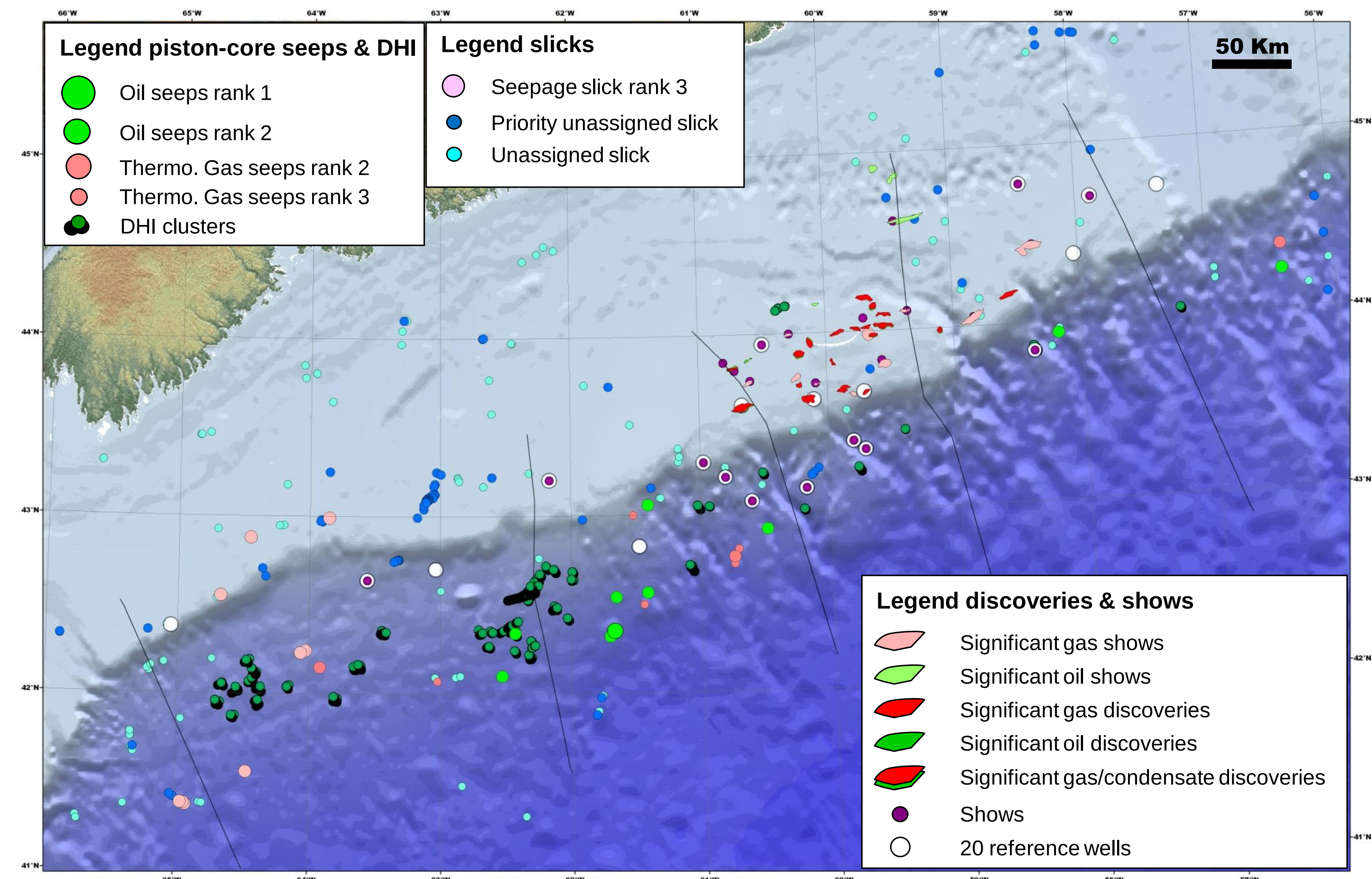


Figure 2: Distribution of significant discoveries, shows, minor mud-gas shows, thermogenic hydrocarbon seeps by Bernard et al. 2000), DHI and satellite oil slicks by (NPA-Fugro).

Key observations

In Figure 1, Direct Hydrocarbons Indicators (DHI) are essentially observed in the western part of the margin slope. Their concentration coincides relatively well with the occurrence of the thermogenic oil and gas seeps. Of course, DHI are observed at shallow depth where biogenic gas accumulations may exist.

In Figure 2, where satellite oil slicks are added, many occurrences of rank 3 slicks also occur in the western part of the margin, on the slope and at the shelf edge.

The superposition of all positive indicators definitely argues in favor the presence of one or several active Petroleum Systems in the western part of the margin.

Figures 1 to 4 of the next Plate (4-2-3) show an example of how satellite oil slicks are identified. One satellite scene of oil slicks as interpreted by NPA-Fugro, provider of the slick study, is shown in the general margin context. Figures 2 displays the slicks and then Figures 3 and 4 show how the interpreter illustrates and ranks the observed slicks. The slick interpretation was made by NPA-Fugro and is presented here as it is. New recent satellite surveys to evaluate the persistence of the slicks through time are available for purchase at NPRA-Fugro.

PETROLEUM GEOCHEMISTRY - HYDROCARBON OCCURENCES

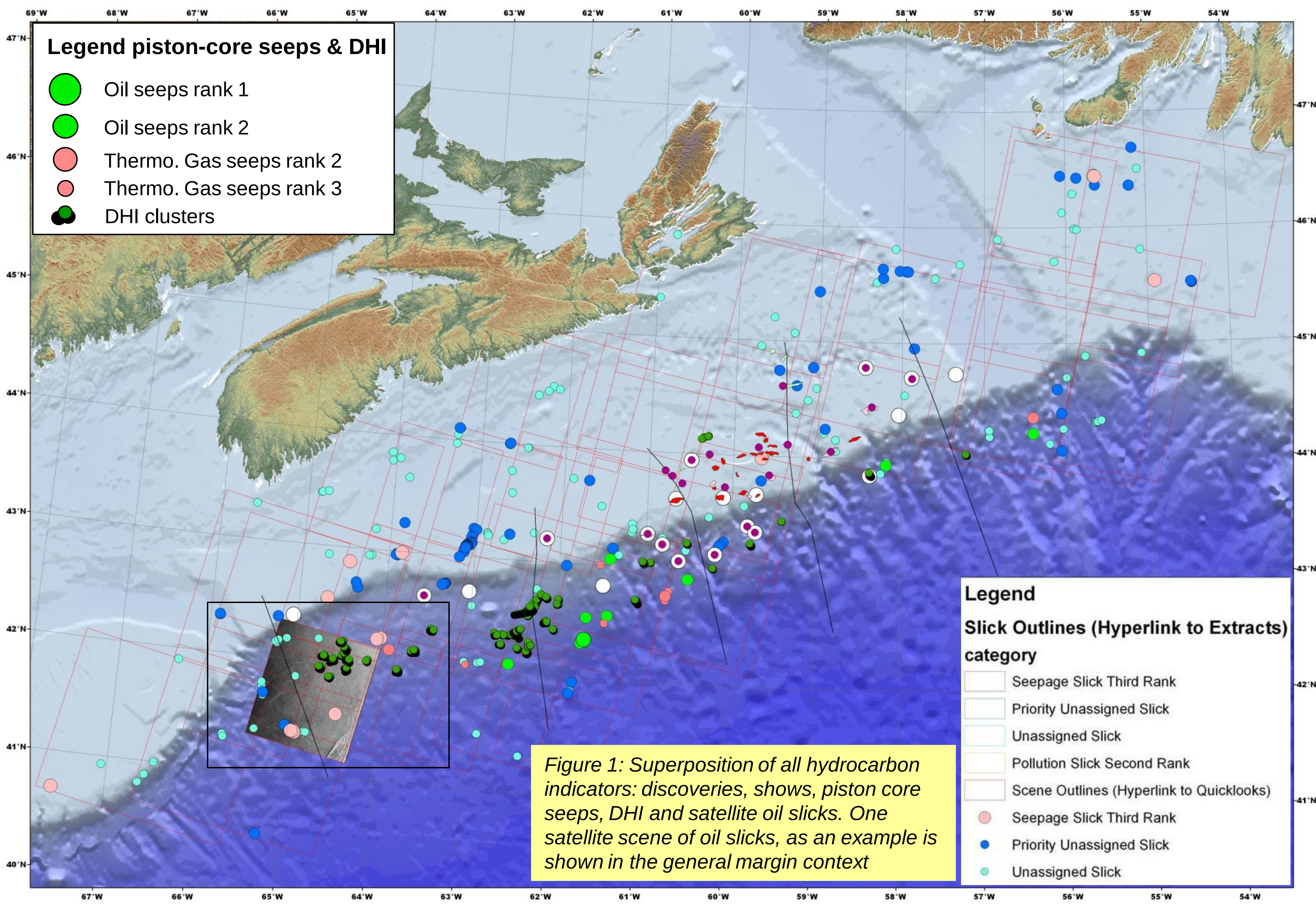


Figure 1: Superposition of all hydrocarbon indicators: discoveries, shows, piston core seeps, DHI and satellite oil slicks. One satellite scene of oil slicks, as an example is shown in the general margin context

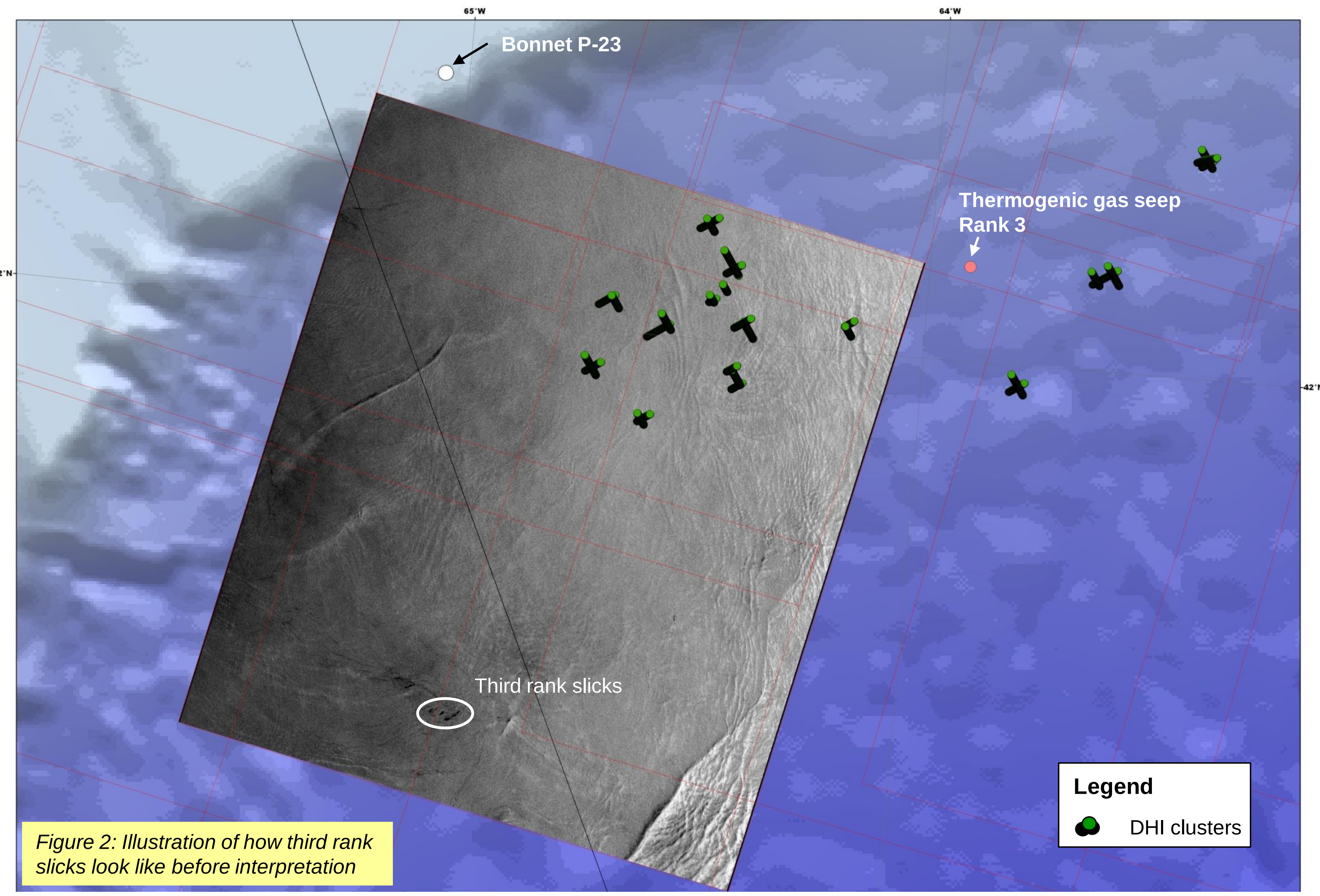


Figure 2: Illustration of how third rank slicks look like before interpretation

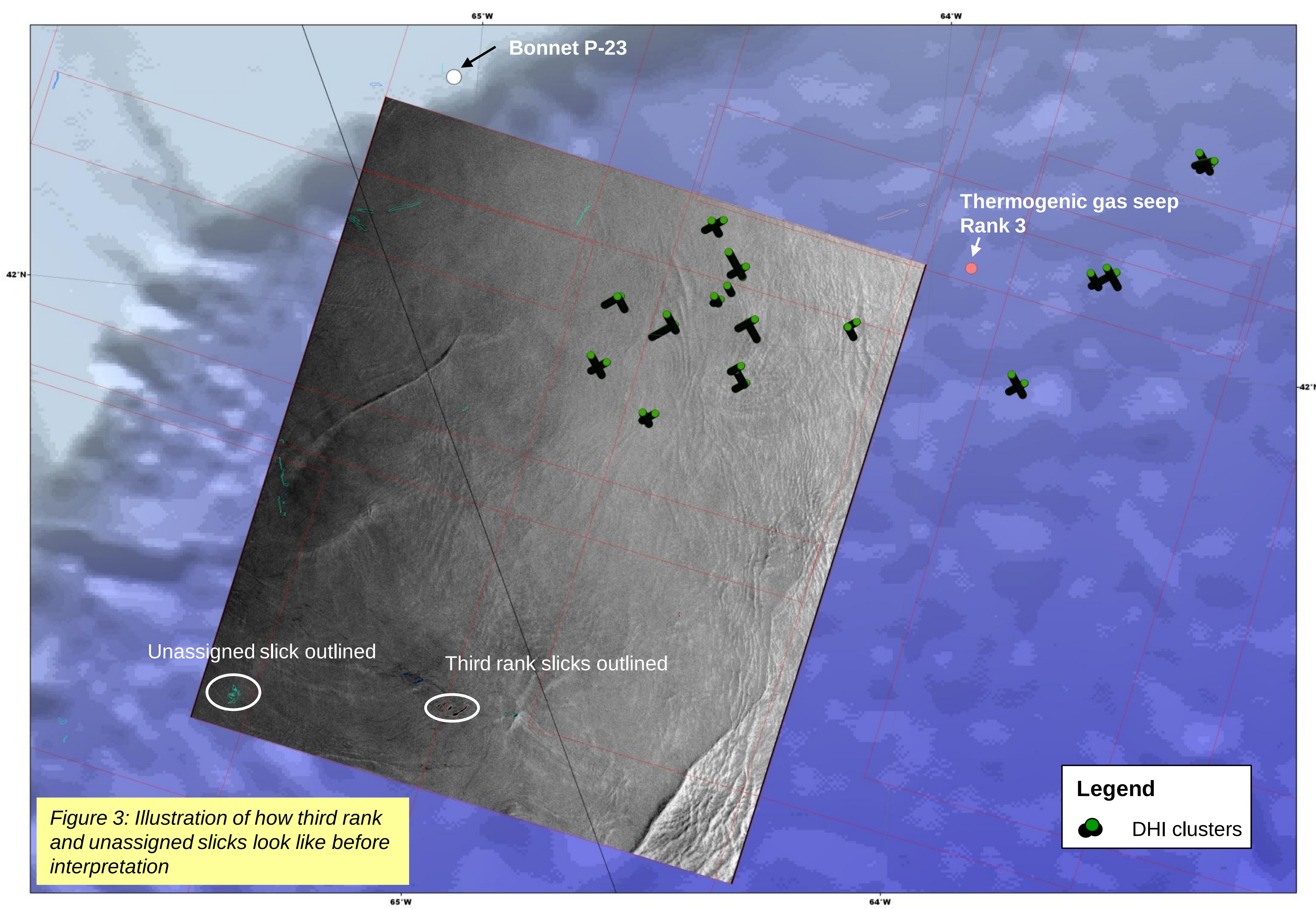


Figure 3: Illustration of how third rank and unassigned slicks look like before interpretation

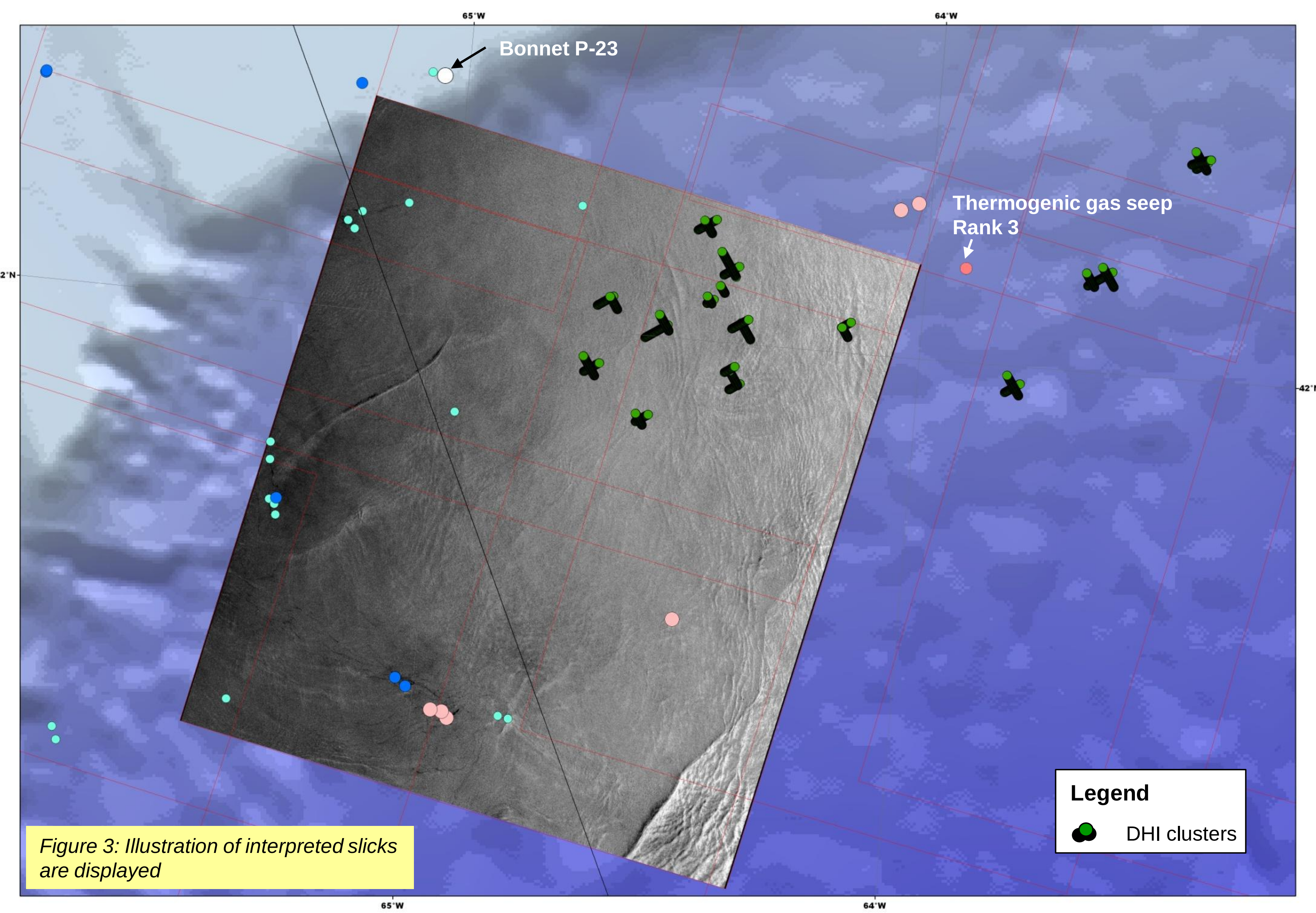


Figure 3: Illustration of interpreted slicks are displayed

Hydrocarbon Occurrences – Satellite Oil Slicks

CHAPTER 4-3

PETROLEUM GEOCHEMISTRY

DATA

ROCK DATA

The basic geochemical data available on line consist of source rock and maturity data for the Scotian Shelf and the Scotian Slope as well as the South Grand Banks. There are TOC and Rock Eval data for 61 shelf & slope wells and maturity data for 88 shelf & slope wells (Plate 4-3-2). New data TOC and Rock Eval data were acquired on 17 wells either not analyzed prior to this study, or repeats to check consistency with existing data (Plate 4-3-2). For maturity, Vitrinite Reflectance was measured on 2 wells (Plate 4-3-2). New TOC/Rock Eval and Vitrinite Reflectance analyses were carried out at the geochemistry laboratory of the GSC-Calgary.

Rock Eval and TOC

The source rock data consist of TOC and Rock Eval analyses characterizing the source rock potential of well cuttings and cores. The TOC is a measure of organic carbon content expressed in weight % of the rock. The TOC analysis may be obtained by different procedures, but also directly from the Rock Eval analysis, depending on the type of analyzer. The analytical results produced by TOC and Rock Eval analyses are as follows:

- TOC: Organic Carbon content
- Free hydrocarbons content in the rock sample: S1 value
- Remaining hydrocarbon potential (HC not realized): S2 value
- Oxidation “potential” contained in the organic matter of the kerogen: S3 value
- Tmax: Maximum pyrolysis temperature, at which the remaining hydrocarbon potential (S2) is generated. Due to its specificity, Tmax is a maturity measurement, which can be correlated to other maturity parameters such as Vitrinite Reflectance, Thermal Alteration Index (TAI), Spore Color Index (SPI) and others.

The Rock Eval data populating the GSC on-line database were generated by various laboratories including the geochemistry laboratory of the GSC-Calgary.

Maceral

Maceral data derived from microscopic analysis of kerogen are available from Mukhopadhyay’s reports (1989, 1990a, 1990b and1991) and Mukhopadhyay et al. publications (1990 and 1995). All unpublished reports are available from CNSOPB DMC database. Over the years, P. K. Mukhopadhyay has defined a maceral description chart specially adapted to the Nova Scotia margin. That chart is displayed in Table 1 (right) to provide the reader with the descriptive code used in the following plates.

Maturity

Maturity data used in this study consist essentially of Vitrinite Reflectance. The GSC online database is populated mainly by data from various laboratories but mainly from Avery and Mukhopadhyay. New Vitrinite Reflectance data were acquired for only two wells, so adding two maturity profiles to the 88 existing ones. For wells with multiple maturity datasets from different sources, there are sometimes conflicting maturity profiles.

OIL & CONDENSATE DATA

Existing accessible oil and condensate data, such as GC traces, aromatic biomarkers, gasoline range GC traces are neither numerous nor that meaningful. Interpretation of these data was tentative not contributing clear cut solutions to understanding the petroleum systems of the Nova Scotia margin. New biomarker data were acquired on 15 oils and condensates samples for this study with a particular focus on the saturate fractions of these samples. Saturate biomarkers of the steranes and hopanes/triterpanes were often discarded as their concentration are low in condensates and light oils.

PISTON-CORE SEEPS DATA

Seeps data from the regional geochemical survey on the slope of the Nova Scotia margin by TDI-Brooks International, Inc. were made available to this study end of March (2011) when confidentiality on the report was released.

Amorphous Organic Matter Related to Kerogen and Hydrocarbon Potential

Kerogen Type	Organic facies: Amorphous Maceral Type (Fluorescence)	Organic facies: Associated Major Macerals	Organic facies: Environment of Deposition	Range of Hydrogen Index (mg HC/g TOC)	Pyrolisis-GC Pattern	Oil/Gas Potential[+]
I	Sapro I* (golden yellow)	Alginite	Lakes or algal mat (shallow marine or freshwater)	Greater than 800	Mainly n-alkanes between C_{10} - C_{30}	Oil + Condensate + Gas[#] (80%)
IIA	Sapro IIA* (yellow brown)	Alginite, Sapro I, Part. Liptinite A & B, Liptodetrinite	Lagoon or lakes (marine or fresh). Upwelling area (shallow or deep marine)	550 - 800	Dominant cyclo- and normal alkanes between C_8 - C_{27}	Oil + Condensate + Gas[#] (60 - 90%)
IIA-IIB	Sapro IIA* + Sapro IIB* (brown or orange)	Part. Liptinite A & B, Liptodetrinite, Sapro-Vitrinite	Upwelling region, prodelta, Lacustrine delta, deep marine anoxia	300 - 600	Mixed cyclo- and normal alkanes and aromatics between C_6 - C_{20}	Oil + Condensate + Gas[#] (50%) (50%)
IIB	Sapro IIB* (brown)	Part. Liptinite A & B, Sapro IIA, Desmocollinite	Deltaic marsh, lagoon, back-barrier, deep marine anoxia	225 - 400	Mixed aromatics and cycloalkanes	Condensate + Gas + Oil (50%) (40%) (10%)
IIB-III	Sapro IIB + Humosapro	Telocollinite, Part. Liptinite B	Partially oxic prodelta or shallow marine, and lagoon	100 - 250	N-alkanes up to C_{12} and Low molecular wt. aromatics, and phenol	Gas + Condensate (70%) (30%)
III	Humosapro* (nonfluorescent to dark brown)	Part. Liptinite B, Telocollinite	Delta swamp, partially oxic. Shallow or deep marine basins	50 - 125	Mainly aromatics and n-alkanes up to C_{14} and phenol	Gas (>80%)
IV	Macrinite (nonfluorescent)	Fusinite, Macrinite, Recycled vitrinite	Oxic swamp, tidal flats or deep marine basins	Less than 50	Minor hydrocarbons	Non source

Sapro I*, Sapro IIA*, Sapro IIB*, Humosapro* = Sapropelinite I, IIA, IIB and Humosapropelinite; Part: Liptinite = Particulate Liptinite A & B

Sapropelinite = Bituminite = Amorphinite. Particulate liptinite A = Lamalginite. Particulate liptinite B = Exinite & Resinite

+ Under normal Eh/Ph condition without diagenetic oxidation; # Generation starts beyond 1.0% Ro

Table 1: P. K; Mukhopadhyay’s maceral description chart

Reference:

P. K. Mukhopadhyay and Wade J. A. 1990. Organic facies and maturation of sediments from three Scotian Shelf wells. Bulletin of Canadian Petroleum Geology, Vol. 38, No. 4, pp. 407-425 (DEC 1990).

DATA QUALITY

Oil-based mud and various additives were used in an estimated 80% of the wells analyzed constitutes a serious problem for interpreting geochemical data and in particular , for identifying source rocks on the Nova Scotia margin. The Table of Figure 1 shows the record of the mud scheme for the Glenelg J-48 well as it is documented in the GSC Basin database. This type of Table is included in this Chapter of this Atlas, wherever this kind of information is critical for the interpretation presented.

Rock Eval and TOC data

Rock extract data are highly susceptible to oil-based mud contamination. Adding oil to the mud obviously distorts Rock Eval data, primarily the S1 peak. Other additives, such as Gilsonite or lignite, to cite only a few, used for drilling wells on the Scotian margin, distort possibly the S1 peak but mainly the S2 peak and the total organic content (TOC). Widely used mud-additives on the Scotian margin appears to be a major problem for identifying source rocks.

Maceral data

Maceral data obtained by microscopic observation offers the advantage that part of the contaminants from the mud can be identified and discarded from the kerogen composition. However, mud additives such as lignite and gilsonite may not always be easily separated from the in-situ sedimentary kerogen.

Oil and Condensate data

Oil and condensate are not subject to too much distortion by mud additives as they are collected from tests. However, in case of doubt, possible contamination must cautiously be examined.

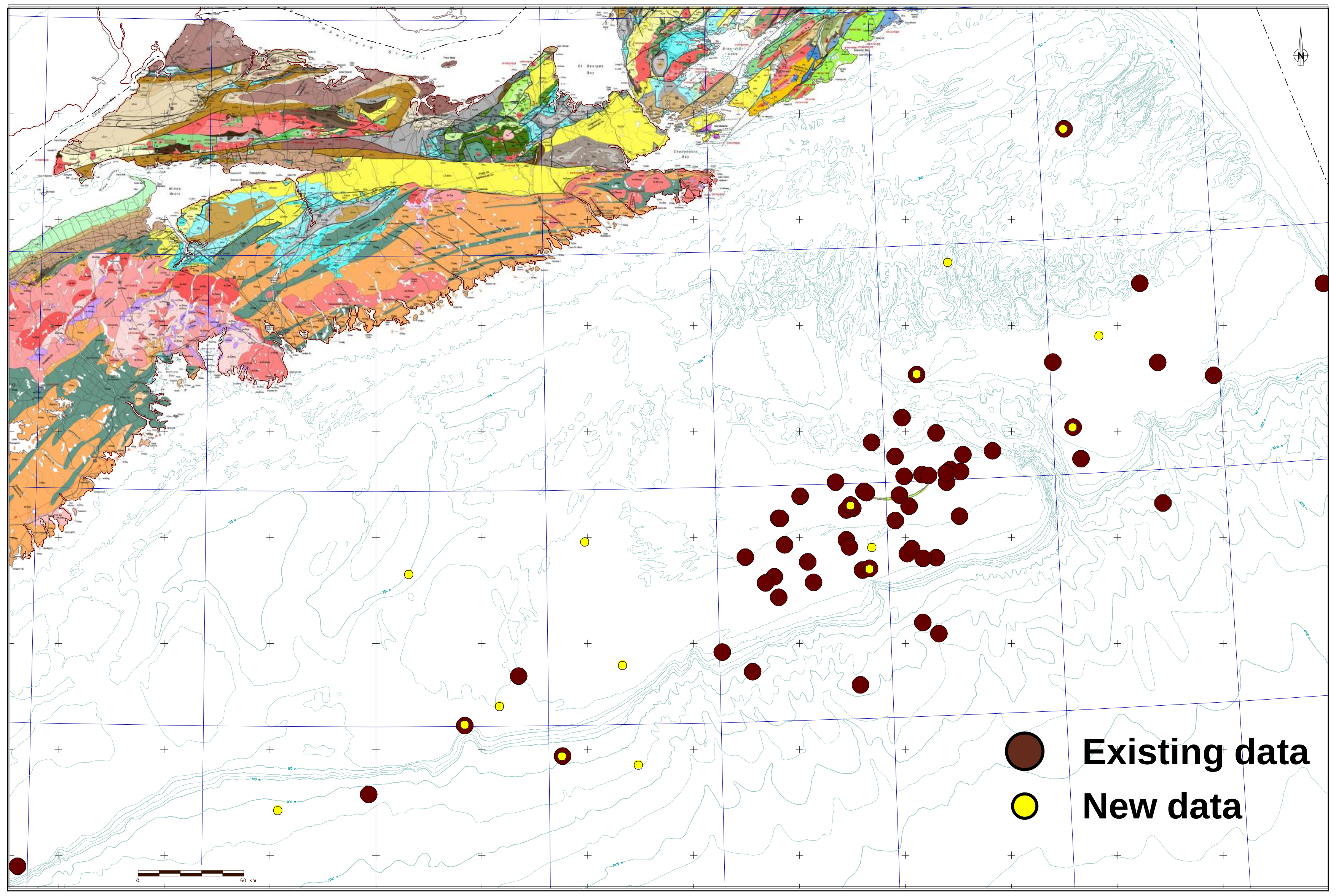
Piston-core seeps data

Seeps data from the regional geochemical survey on the slope of the Nova Scotia margin by TDI-Brooks International, Inc., deserve some careful examination of possible contamination by natural organic material present in the sediments near sea floor collected by piston-coring. This contamination cannot be eliminated, but avoided as much as possible using geochemical methods such as chromatography to select samples containing the least amount of recent natural organic matter and discard the others.

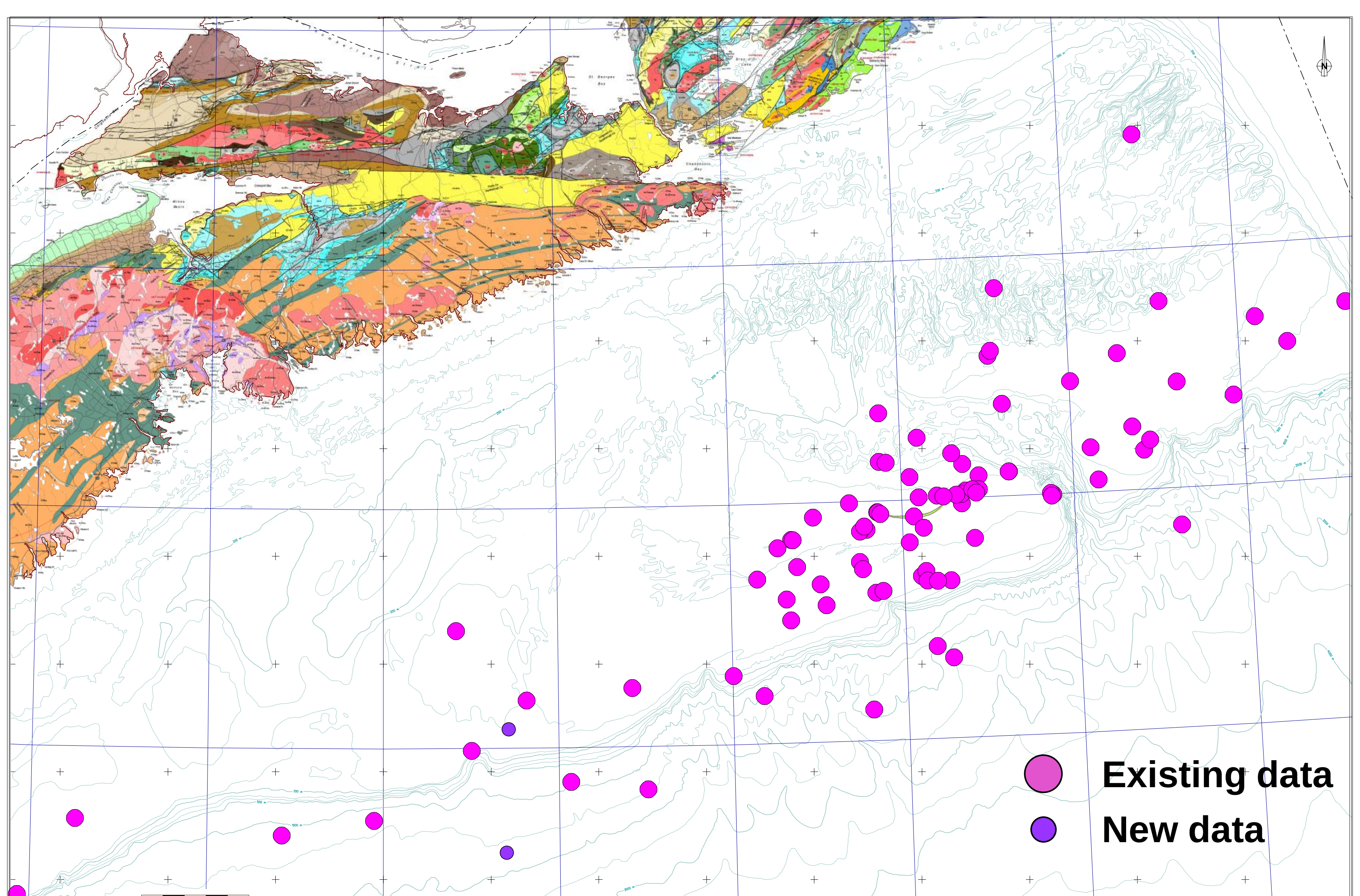
Top	Bottom	Units	Mud	Mud Additives	Event	Comments
3513		M			FISH	SURVEY TOOL LEFT IN THE HOLE - RECOVERED WITH AN OVERSHOT
4119		M				DRILL STRING STUCK IN THE HOLE AS A RESULT OF A WELL KICK - ADDED DIESEL AND WORKED PIPE FREE
5241		M				PIPE STUCK IN THE HOLE - PIPE WAS BACKED-OFF AND CEMENTED IN THE HOLE - WELL WAS SIDETRACKED
4119		M			KICK	POSITIVE FLOW CHECK - MUD WEIGHT RAISED BY 510 KG/M3 (FROM 1140 TO 1650 KG/M3) TO KILL THE WELL
4134		M			LOST CIRC	NO FURTHUR LOST CIRCULATION DATA FOUND IN WELL HISTORY REPORT
5157		M				
5193		M				
108	368	M	SEAWATER - VISCOUS SLUGS		MUD	
368	3261	M	SEAWATER - KCL			
3261	4141	M	FRESHWATER - GEL - LIGNOSULPHONATE	DIESEL (4119 & 4141 M), PIPELAX (4119 M), CHROME LIGNITE (4119 M)		
4141	5253	M	FRESHWATER - GEL - CHROME LIGNITE	CHROME LIGNITE (4141-5253 M), KWIKSEAL & WALNUT (5205 & 5253 M), X-PEL-G (4553, 4735, 4753 & 5081 M)		
4785	5083	M			MUD MOTOR	DYNA-DRILLED INTERVAL
5083	5157	M				TURBO DRILLED INTERVAL
5205	5227	M				
4913	5085	M			MUD MOTOR*	DYNA-DRILLED INTERVAL (DIRECTIONAL DRILLING INTERVAL IN SIDETRACKED HOLE)
5095	5148	M				TURBO DRILLED INTERVAL IN SIDETRACKED HOLE

Figure 1: Glenelg J-48 - Example of a mud scheme used in many drilling operations

TOC/ROCK EVAL DATA



MATURITY DATA



TOC/ROCK EVAL DATA

Online GSC Basin Database

54 shelf wells

Abenaki J-56
Alma F-67
Alma K-85
Arcadia J-16
Argo F-38
Bluenose 2G-47
Chebucto K-90
Citadel H-52
Citnalta I-59
Cohasset A-52
Cohasset D-42
Cohasset L-97
Cree E-35
Dauntless D-35
Demascota G-32
Eagle D-21
Evangeline H-98
Glenelg E-58
Glenelg J-48
Glooscap C-63
Intrepid L-80
Iroquois J-17
Louisbourg J-47
Merigomish C-52
Migrant N-20
Mohican I-100
North Triumph B-52
North Triumph G-43
Olympia A-12
Onondaga B-96
Onondaga E-84
Onondaga B-84
Penobscot L-30
Peskowesk A-99
Sable Island C-67
Sable Island E-48
Sable Island O-47
Saint Paul P-91
South Desbarres O-76
South Griffin J-13
South Sable B-44
South Venture O-59
S.W. Banquereau F-34
Thebaud C-74
Thebaud I-93
Thebaud P-84
Uniacke G-72
Venture B-43
Venture B-52
Wenonah J-75
W. Chebucto K-20
West Olympia O-51
West Venture N-91
Whycocomagh N-90

7 slope wells

Acadia K-62
Albatross B-13
Annapolis G-24
Balvenie B-79
Crimson F-81
Newburn H-23
Tantallon M-41

Wells from the DMC database

2 shelf wells

West Esperanto B-78 (no Excel datasheet)
Bonnet P-23

TOC/Rock Eval & Maturity data newly acquired

TOC/Rock Eval		Nb. of Samples
• Acadia K-62	4000m to TD (~5300m) + (Fluid Inclusion basal carbonates)	69
• Shelburne G-29	3000m to TD (~4000m)	70
• Torbrook C-15	2600m to TD (~3600m)	54
• Shubenacadie H-100	3200m to TD (~4200m)	41
• Oneida O-25	3100m to TD (~4100m)	102
• Sambro I-29	1000m to 1600m	21
• Ojibwa E-07	1400m to TD (~2300m)	69
• Glenelg J-48	4500m to TD (~5100m)	39
• Marmora C-34	3800m-3900m	22
• Chippewa L-75	5900'-6972'	23
• Citadel H-52	5500'-5666'	12
• Emerillon C-56	9250'-10750'	48
• Erie D-26	5500'-7995'	57
• Moheida P-15	3300m-3900m	53
• Mohican I-100	4200m-4300m	13
• Argo F-38	10000'-11110' (TD) OK	7
• Iroquois J-17	4485'-5890' (17) and 6650'-6845' (9) oil stains anhydrite	80
Vitrinite Reflectance		
• Torbrook C-15	2835m-3600m	23
• Moheida P-15	10810'-12860'	27

MATURITY DATA

Online GSC Basin Database

79 shelf wells

Abenaki J-56
Alma F-67
Arcadia J-16
Banquereau C-21
Bluenose 2G-47
Bluenose G-47
Bonnet P-23
Chebucto K-90
Chippewa L-75
Citadel H-52
Citnalta I-59
Cohasset A-52
Cohasset D-42
Cohasset L-97
Cree E-35
Dauntless D-35
Demascota G-32
Dover A-13
Eagle D-21
Evangeline H-98
Glenelg J-48
Glooscap C-63
Hesper I-52
Intrepid L-80
Merigomish C-52
Jason C-20
Louisbourg J-47
Mic Mac H-86
Mic Mac J-77
Migrant N-20
Missisauga H-54
Mohawk B-93
Mohican I-100
Naskapi N-30
North Banquereau I-13
North Triumph B-52
North Triumph G-43
Olympia A-12
Oneida A-12
Onondaga B-96
Onondaga E-84
Panucke B-90
Penobscot B-41
Penobscot L-30
Primrose 1A A-41
Primrose A-41
Primrose F-41
Primrose N-50
Sable Island 3H-58
Sable Island 4H-58
Sable Island C-67
Sachem D-76
Sable Island E-48
Sable Island O-47
Saint Paul P-91
Sauk A-57
South Desbarres O-76
South Griffin J-13
South Sable B-44
South Venture O-59
S.W. Banquereau F-34
Thebaud C-74
Thebaud I-93
Thebaud P-84
Triumph P-50
Uniacke G-72
Venture B-13
Venture B-43
Venture B-52
Venture D-23
Venture H-22
Wenonah J-75
West Chebucto K-20
West Esperanto B-78
West Olympia O-51
West Venture C-62
West Venture N-91
Whycocomagh N-90
Wyandot E-53

9 slope wells

Acadia K-62
Albatross B-13
Annapolis G-24
Balvenie B-79
Crimson F-81
Newburn H-23
Shelburne G-29
Shubenacadie H-100
Tantallon M-41

MATURITY DATA (continued)

Distribution of Vitrinite Reflectance data versus burial depth for the 20 reference wells

The diagram of Figure 1 displays Vitrinite Reflectance data per well for the 20 wells of reference. The analyst name is provided In the inset list. In cases, wells were analyzed by several laboratories that are identified by more than one analysts names. Sometimes, only the laboratory is known and therefore listed.

This selection of data, as an example, shows that there is a relatively narrow spread of the maturity gradient throughout the Nova Scotia margin. In wells with several maturity datasets measured by different analysts, there is sometimes convergence of the maturity gradients, which is a confirmation of the validity of the data. Cases of divergence between datasets also exist weakening confidence in either of the datasets. Modeling with the suites of constraints imposed by temperature, pressure, overburden and rifting history inducing the thermal development at the various modeled locations helps with distinguishing which one of the maturity gradients applies.

Detailed maturity of each well is neither presented nor discussed in the Petroleum Geochemistry part of the Atlas except for the wells, which serve in identifying the source rocks of the margin in Plates 4-4-1 to 4-4-8 below.

Maturity, however, is used extensively in the modeling part of the study for maturity calibration of the basin models Themis 1D,- 2D and -3D.

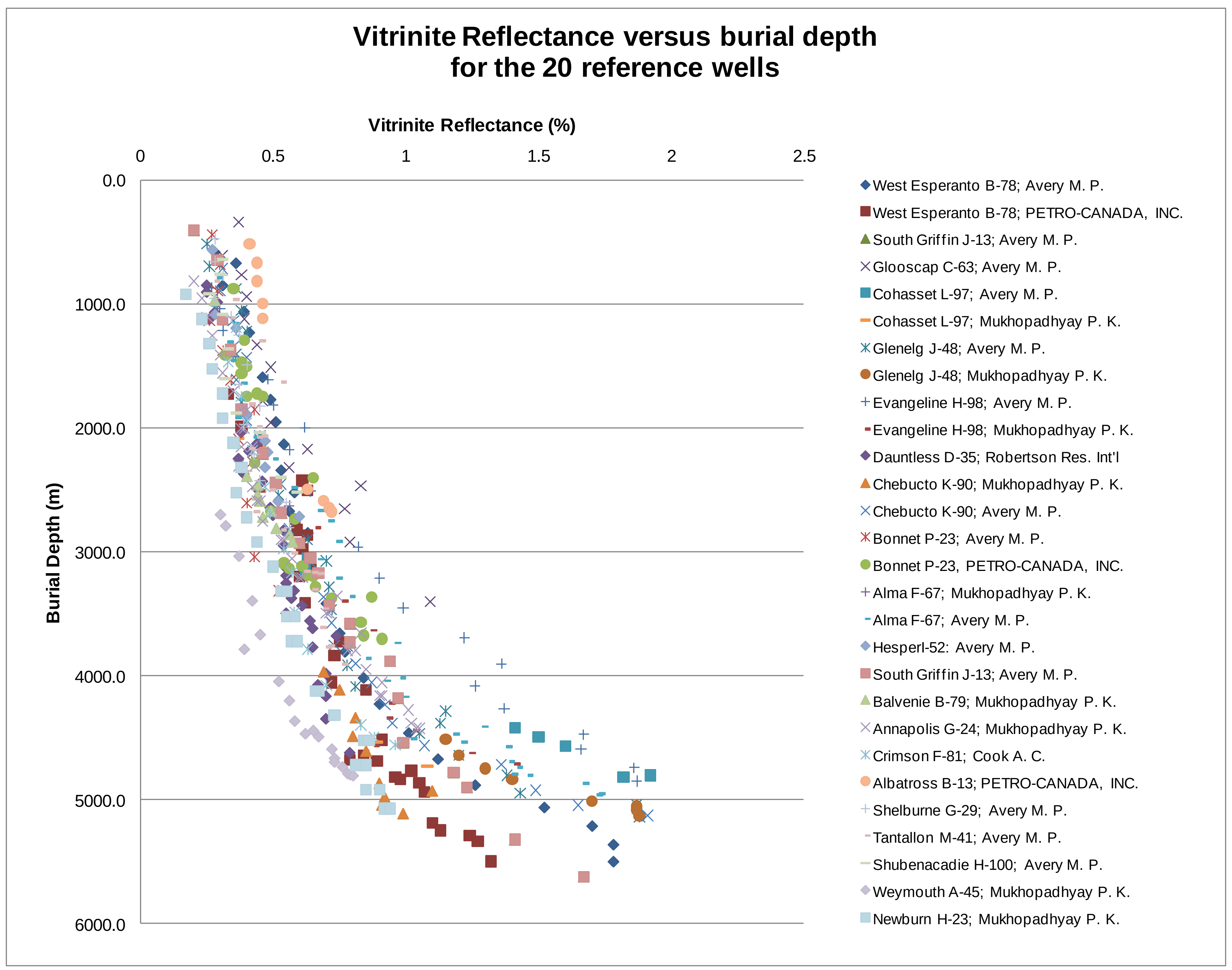
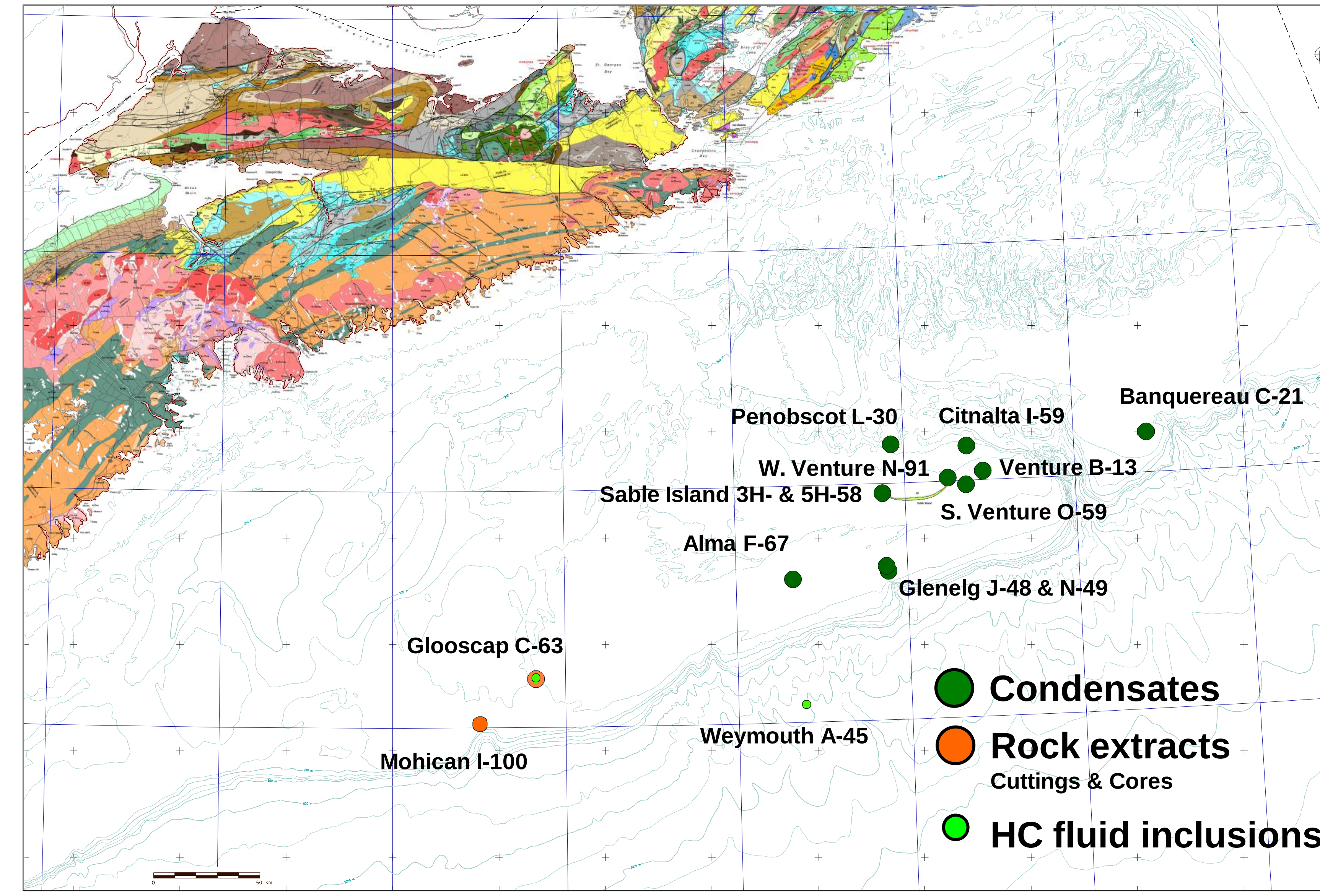


Figure 1: Vitrinite Reflectance for the 20 key wells

OIL, CONDENSATES, ROCK EXTRACTS and FLUID INCLUSIONS DATA



Biomarker analyses of oil and condensates from the following wells:

1. **PENOBSCOT L-30,** RFT#5 2643.00 – 2643.00m, GSC group 1
2. **SABLE 3H-58,** PT#4 1632.20 – 1633.42m, GSC group 3a
3. **SABLE 5H-58E,** DST#4 1639.82 – 1641.65m, GSC not grouped
4. **BANQUEREAU C-21,** DST#2 3585.00 – 3596.00m, GSC group 2
5. **GLENELG J-48,** DST#8 3491.00 – 3495.00m, GSC group 3b
6. **GLENELG N-49,** DST#2 3476.00 – 3485.00m, GSC group 2
7. **GLENELG N-49,** DST#1 3597.00 – 3602.00m, GSC group 2
8. **ALMA F-67,** DST#2 3026.00 – 3032.00 m, GSC not grouped
9. **SOUTH VENTURE O-59,** DST#11 4209.00 – 4217.00 m, Above OP, GSC group 3b
10. **WEST VENTURE C-62,** DST#3 4741.00 – 4743.00 m, Within OP, GSC group 3a
11. **VENTURE B-13,** DST#6 4572.00 – 4579.00 m, Below top OP, Basal Missisauga, GSC group 3b
12. **CITNALTA I-59,** PT#3 12393'-12407' (3777.4-3781.7m), Basal Missisauga
13. **CITNALTA I-59,** PT#2 12964'-12985' (3951.4-3957.8m), Basal Missisauga
14. **CITNALTA I-59,** PT#1 13301'-13317' (4054-4059m), Basal Missisauga
15. **HERON H-73,** DST#6 2294.00 – 2306.00m (South Whale Basin)

Glooscap C-63, cutting extracts from shales interlayered near the top of the Argo Salt at depths:

- Cutting sample 4320-40m
- Cutting sample 4490m

Mohican I-100, extracts of core samples

- Sample 4095.75 m displays a very weak trace
- Sample 4098.14 m displaying oleanane is contaminated

Weymouth A-45. Biomarker analyses of hydrocarbon fluid inclusion from salt canopy:

- Top salt
- Middle salt
- Bottom mix
- Bottom salt

Biomarkers of Oils and Condensates (Hopanes m/z 191)

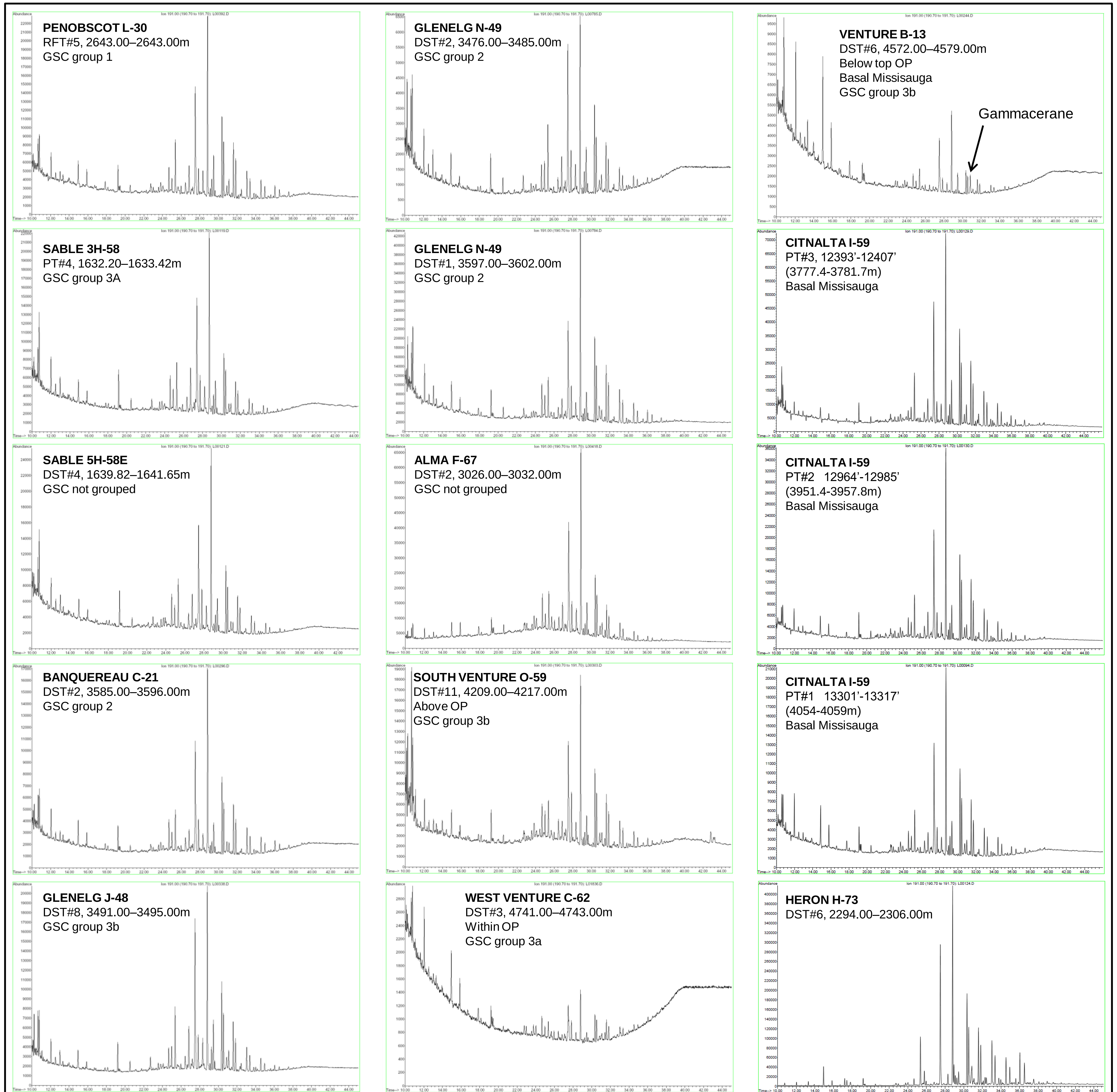


Figure 1: Hopane traces (m/z 191) of 14 condensates and oils from the Nova Scotia margin and 1 from Heron H-73 located in the South Whale Basin of Newfoundland. Among these traces the condensate from DST#6 at Venture B-13 displays a significant Gammacerane anomaly compared to the other oils and condensates. Heron H-73 oil I the South Whale Basin exhibits a slightly improved Gammacerane.

Biomarkers of Cutting Extracts from Venture B-13 (Hopanes m/z 191)

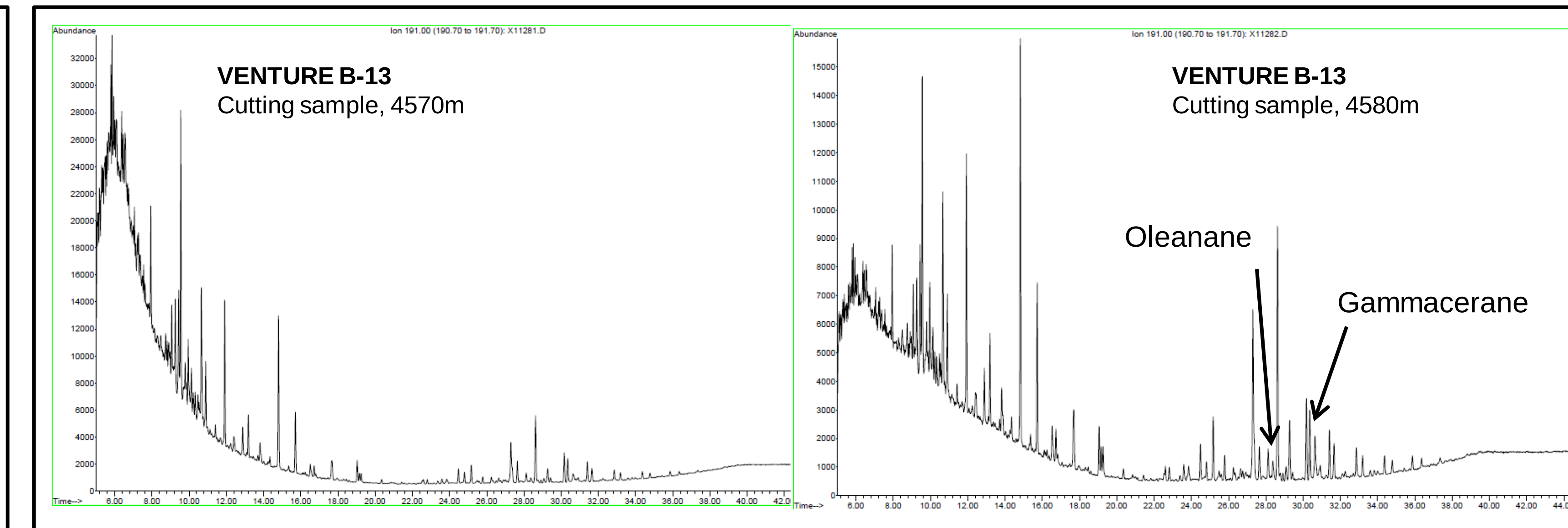


Figure 2: Hopane traces (m/z 191) of 2 cutting samples at 4570 and 4580m from the Venture B-13 well. At 4580m there is a Gammacerane anomaly not observed at 4570m.

Top	Bottom	Units	Mud	Mud Additives	Event	Comments
236		M				STRING STUCK IN THE HOLE - AN OUTSIDE STRING WAS RUN AND CLEANED OUT 21 M OF FILL ON TOP OF BIT
3058		M			FISH	PIPE PARTED AT 1112 M - FISH RECOVERED WITH AN OVERSHOT
5368		M				DRILL PIPE STUCK AFTER CONTROLLING KICK - FISH BACKED OFF & LEFT IN THE HOLE - WELL WAS SUSPENDED
5368		M			KICK	MUD WEIGHT INCREASED TO 2160 KG/M3 TO KILL THE WELL
4673		M			LOST CIRC	RETURNS LOST WHILE CIRCULATING AFTER RUNNING 244 MM CASING
58.5	1295.4	M	SEAWATER - BENTONITE PILLS			
1295.4	2992.4	M	SEAWATER - POLYMER		MUD	
2992.4	5368	M	FRESHWATER - LIGNOSULFONATE			

Figure 3: Mud-scheme used in the Venture B-13. Lignosulfonate was added to the mud 2992 to 5368m. In other well drilled with lignosulfonate mud-additive, there was no Gammacerane contamination but oleanane, which is the case here.

Gammacerane occurrence in Venture B-13, DST#6 4572-4579m

The surprise from Venture B-13 is the occurrence of Gammacerane in the condensate of DST#6 (4972-4979m). Gammacerane often interpreted as reflecting a source rock deposited in a hypersaline environment would support an Early Jurassic or Triassic (Argo Salt) source rock on the Nova Scotia margin. The arguments for this are:

- Oils from Morocco known to originate from the Toarcian source rock contain Gammacerane (see Plate 4-4-11).
- Pliensbachian shale of the Peniche Basin of Portugal contains Gammacerane (see Figure 4 Plate 4-4-10).
- Also, deposition of a source rock in a hypersaline environment on the Nova Scotia margin most likely develops in Triassic or Early Jurassic time during or soon after Argo Salt deposition.

These arguments support Early Jurassic sourcing.

Because Gammacerane in the Venture B-13 condensate of DST#6 could also be contamination by gilsonite added to the mud, yet it is unlikely in DST, cutting samples at 4570m and 4580m were extracted and analyzed for biomarkers. The m/z 191 traces of the saturates is shown in Figure 2 of this Plate (above). At 4570m, the trace displays background Gammacerane, whereas at 4580m the trace exhibits improved Gammacerane. This distribution between the 2 samples suggests that at 4570m, that is just before testing, there was no excess of Gammacerane meaning neither contamination nor indigenous anomaly. Excess of Gammacerane occurs only in the sample at the bottom or below the tested interval. This observation argues in favor of indigenous Gammacerane in the condensate of Venture B-13 DST#6.

Cutting samples from shales interlayered in the Argo Salt (Triassic) in the Glooscap C-63 well were analyzed by Rock Eval pyrolysis to test the hypothesis of Triassic sourcing. The Glooscap C-63 well is the only one penetrating the Argo salt sufficiently and in "autochthonous" position of the Argo salt to carry out that test. High TOC and high S1 values in the depth range from 4320m to 4410m are the result of contamination by mud-additive. GCMS analysis of 2 of these samples shown in Figure 1 of the next Plate 4-3-5 strongly suggest the presence of mud contaminant.

Oleanane - age specific biomarker not present in sediments before the occurrence of angiosperms on earth (~100Ma) - observed in the sample at 4580m is likely part of the lignosulfonate mud-additive used for drilling at these depths.

Glooscap C-63 – Biomarkers of rock extracts

- Shale interlayered in Argo salt
- No Gammacerane
- Mud-additive contamination

Biomarker traces (m/z 191) - Saturates

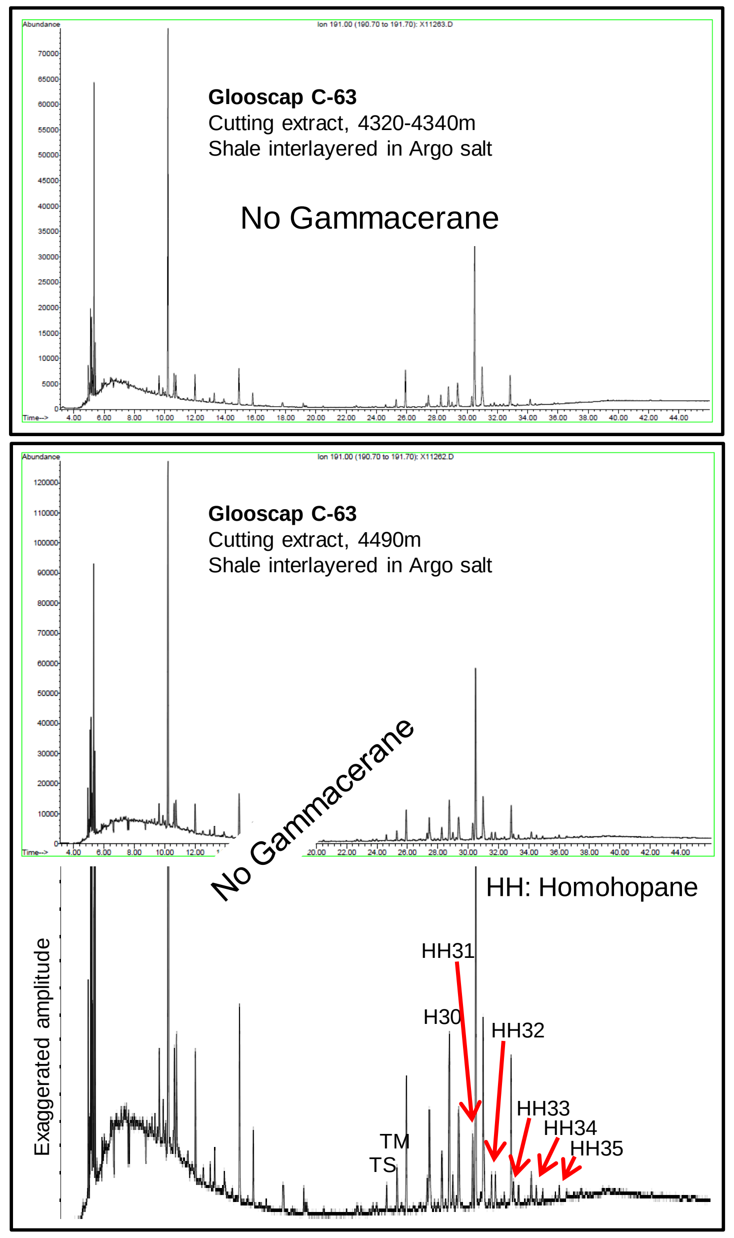


Figure 1: Mud-scheme used in the Glooscap C-63 well. Lignosulphonate was added to the mud 2653 to 4542m.

Top	Bottom	Units	Mud	Mud Additives	Event	Comments
2501.5		M			FISH (1)	PIPE STUCK IN THE HOLE - PUMPED DIESEL, PIPELAX, NUTPLUG - WELL WAS SIDETRACKED (#1) AROUND FISH
2513.7		M			FISH (2)	WELL WAS SIDETRACKED (#2) AROUND FISH
2663.3		M			FISH (3)	DRILL STRING PARTED - BHA RECOVERED WITH AN OVERSHOT
4437		M			FISH (4)	
4541.2		M			FISH (5)	DRILL STRING PARTED - BHA RECOVERED WITH AN OVERSHOT - CONES LEFT ON BOTTOM
4541.2		M			FISH (6)	STRING PARTED WHILE ATTEMPTING TO RECOVER CONES - BHA RECOVERED WITH OVERSHOT
4541.2		M			FISH (7)	STRING PARTED WHILE ATTEMPTING TO RECOVER JUNK - MAGNET LEFT ON BOTTOM & WELL WAS ABANDONED
122	309.7	M	SEAWATER - GEL SWEEPS		MUD	
309.7	847.6	M	SEAWATER WITH BENTONITE	NUTPLUG		
847.6	2653	M	FRESHWATER KCL - POLYMER	NUTPLUG, LIGNOSOL CF, CROMEX, PIPELAX		
2653	4542	M	FRESHWATER - POLYMER - LIGNOSULPHONATE	CROMEX, NUTPLUG, LIGNOSOL, RESINEX, PIPELAX		
2850	3250	M			MUD MOTOR	TURBO DRILLED INTERVAL

Figure 2: Mud-scheme used in the Glooscap C-63 well. Lignosulphonate was added to the mud 2653 to 4542m (Obtained from the on-line GSC Basin Database).

Mohican I-100 – Biomarkers of rock extracts

Mud- additive

Top	Bottom	Units	Mud	Mud Additives	Event	Comments
601	1265	FT	TREATED GEL		MUD	
1265	14410		DLS	SPERSENE, CROMEX		
DLS = Dispersed Lignosulphonate						

Biomarker traces (m/z 191) - Saturates

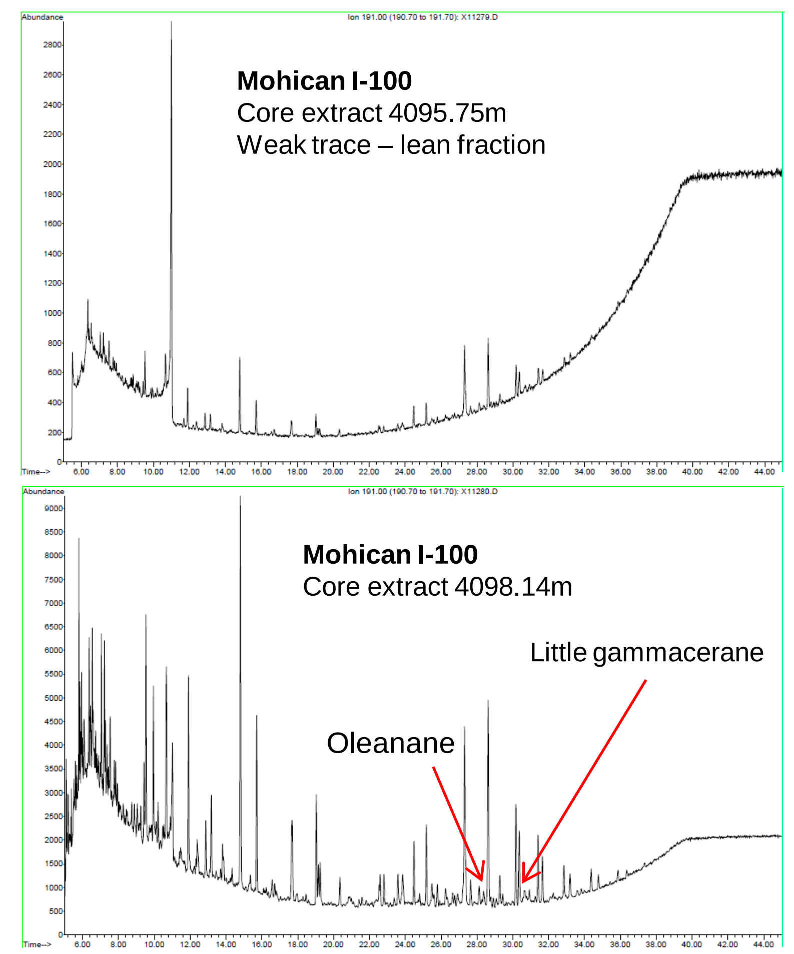
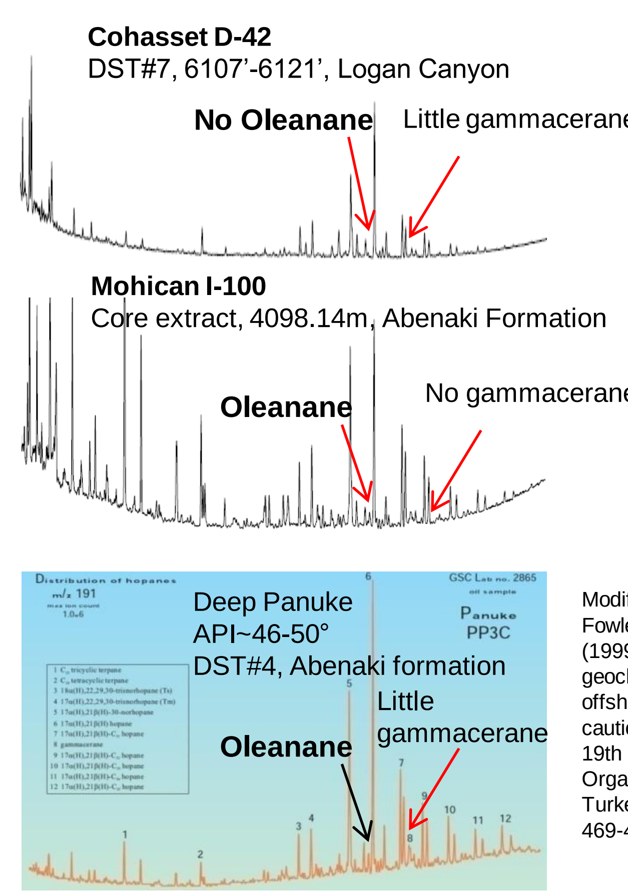


Figure 3: In Mohican I-100, sample from 4095.75 m displays a very weak trace, sample from 4098.14 m displaying oleanane is contaminated



Modified from:
Fowler, M. G. and Obermajer, M. (1999) Reassessing the petroleum geochemistry of the Scotian Shelf, offshore eastern Canada - a cautionary tale for geochemists. 19th International Meeting on Organic Geochemistry, Istanbul, Turkey, September 6-10, 1999, 469-470.

Figure 4: In Cohasset D-42, Mohican I-100 and Deep Panuke (Panuke PP3C), oleanane is present in Jurassic Abenaki oil and stained core extract but absent from Logan Canyon oil. This observation suggests that oleanane - age specific biomarker not present in sediments before the occurrence of angiosperms on earth (~100Ma) – is a mud contaminant. Gammacerane in these samples is absent or not abundant.

Biomarker analyses of extracts from the Toarcian source rock, offshore Morocco (IODP Leg 79, Site 547)

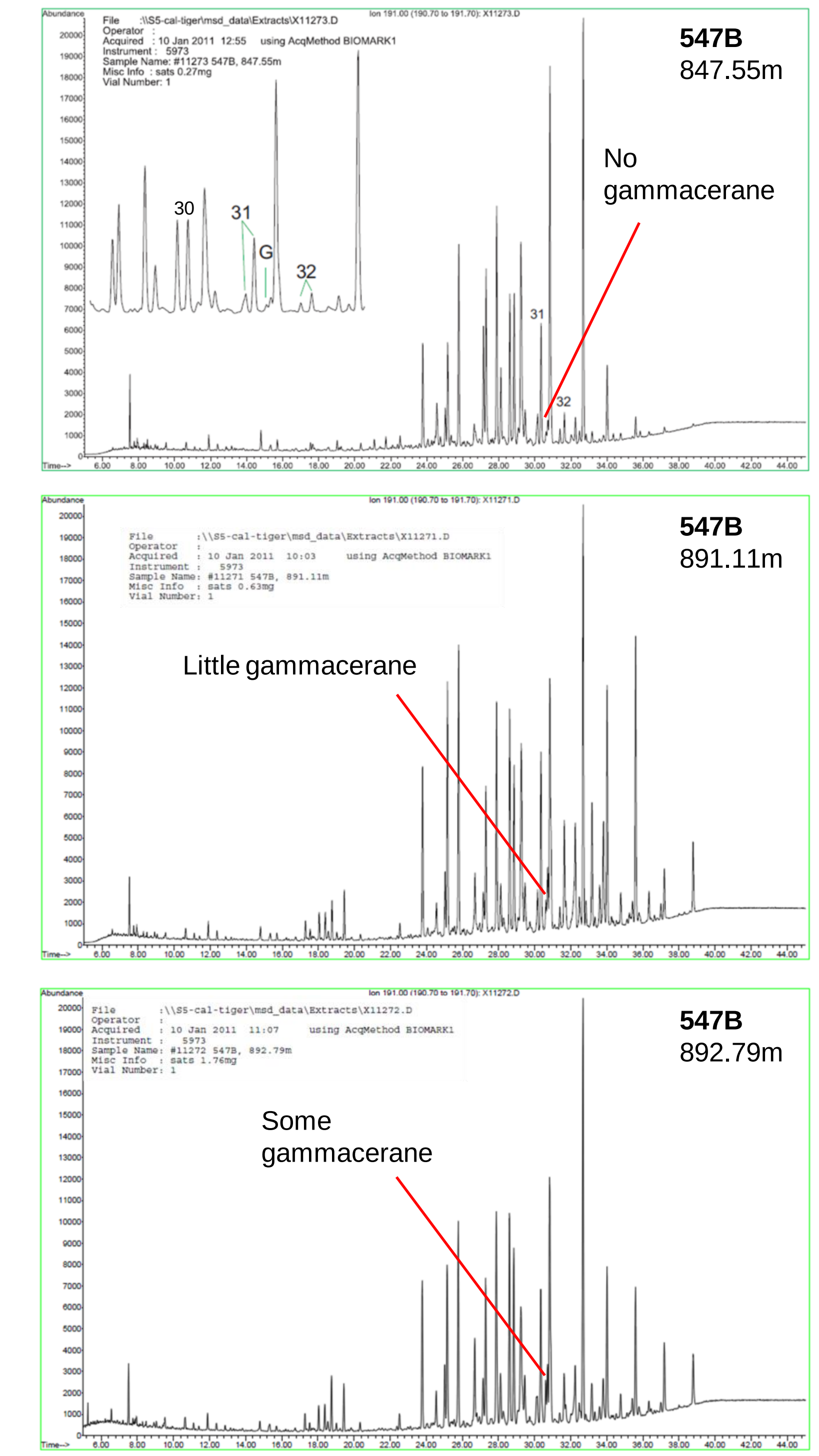


Figure 5: Ion 191 traces of three samples of Toarcian black shales from DSDP Leg 79 Site 547, well 547B. These traces display no or background abundance of gammacerane. The shallow depth of these samples explains their immaturity and unusual signature.

Comments on these data

- ✓ Cutting samples from shales interlayered in the Argo Salt (Triassic) in the Glooscap C-63 well were analyzed by Rock Eval pyrolysis to test the hypothesis of Triassic sourcing. The Glooscap C-63 well is the only one penetrating the Argo salt sufficiently and in "autochthonous" position to carry out that test. High TOC and high S1 values in the depth range from 4320m to 4410m are the result of contamination by mud-additive. GCMS analysis of 2 of these samples shown in Figure 1 strongly suggest the presence of mud contaminant.
- ✓ No or lean amount of Gammacerane in the condensates shown in Plate 4-3-4 except for Venture B-13 (DST#6 4572-4579m) and in Figure 4 (This Plate), indicates that they were not generated by source rocks deposited under hypersaline (or stratified water) anoxic conditions. For the extracts from Glooscap C-63 (Figure 1) and Mohican I-100 (Figure 3), the absence or lean presence of Gammacerane indicates that the source intervals extracted were not deposited under hypersaline (or stratified water) anoxic conditions. That is the case in DSDP Leg 79 Site 547, well 547B located offshore Morocco (Figure 5). Note that DSDP well 547 penetrated a rich Toarcian source rock.
- ✓ Oleanane - age specific biomarker not present in sediments before the occurrence of angiosperms on earth (~100Ma) - observed in the Deep Panuke condensate (Abenaki reservoir), Mohican I-100 (Abenaki core extract) shown in Figure 4, likely reflects contamination by lignosulfonate mud-additive used for drilling at these depths. In the Logan Canyon reservoir of the Cohasset D-42 well, oleanane could be derived from the Naskapi source rock or grabbed by leaching along the migration path.

Fluid Inclusions

Biomarker traces (m/z 191) - Saturates

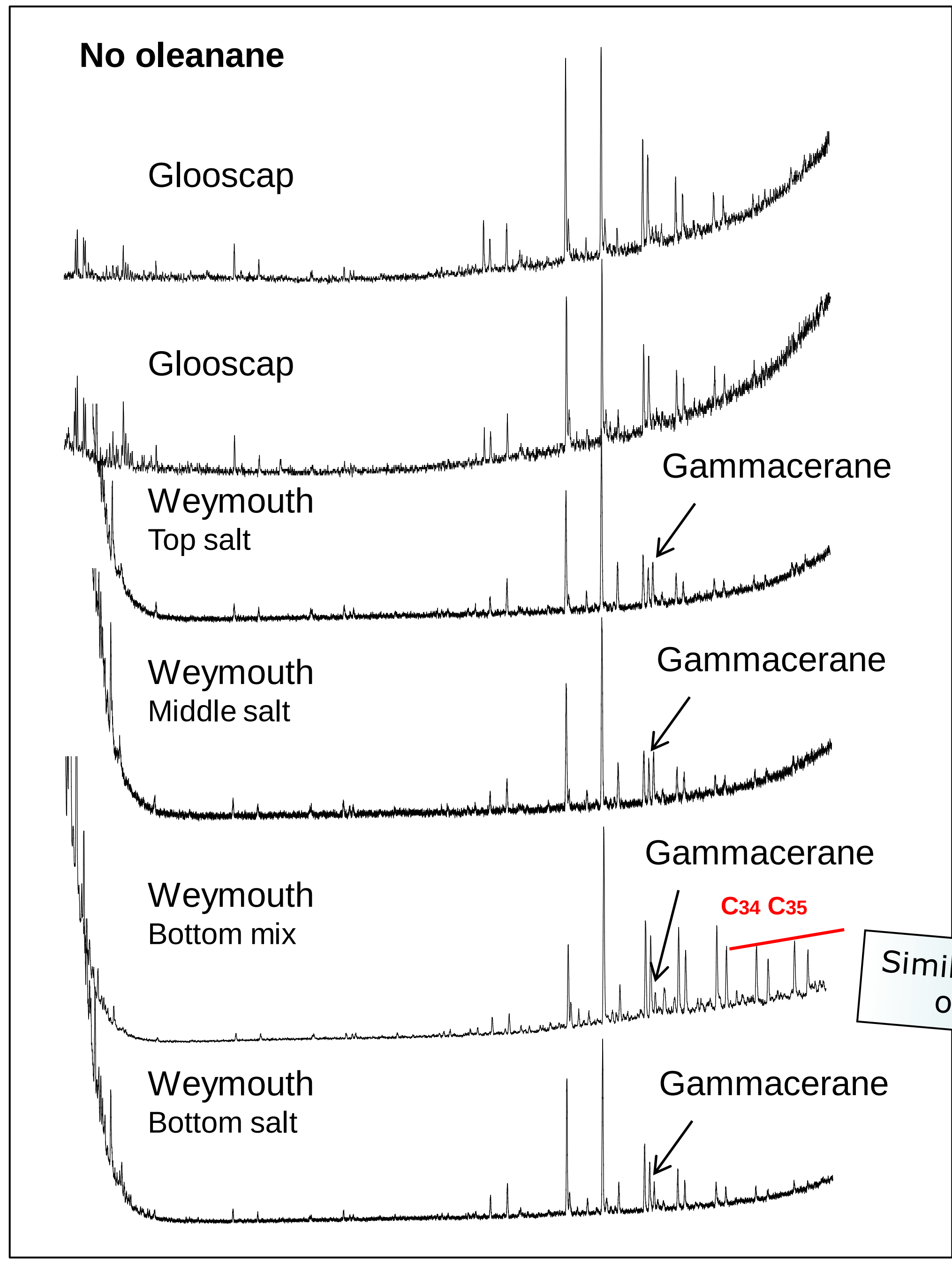
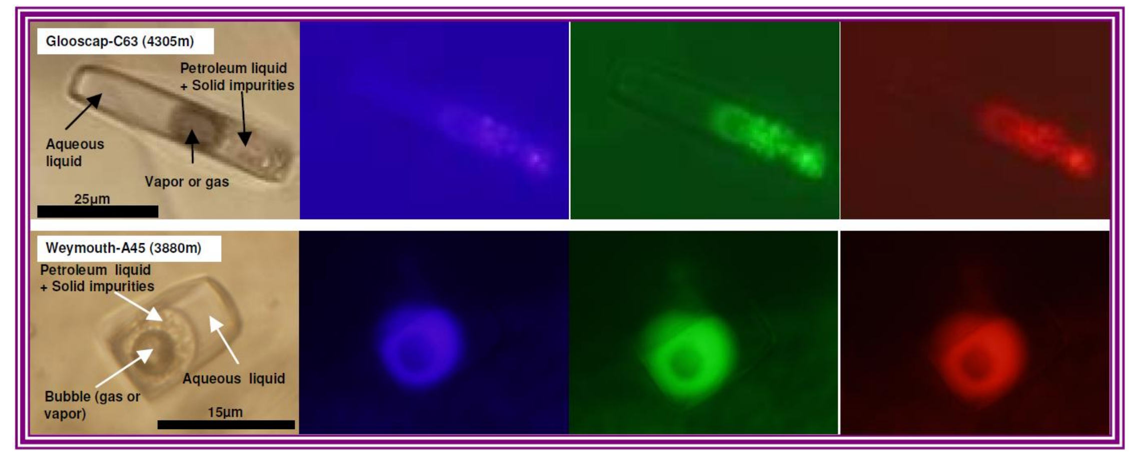
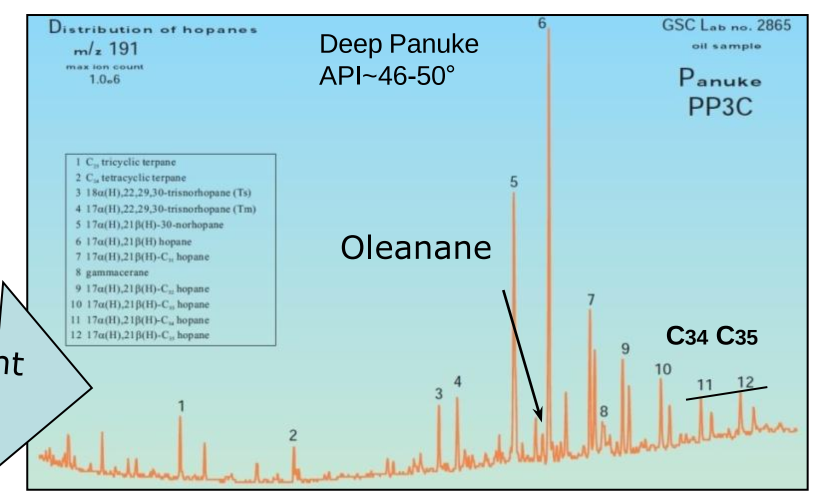


Figure 1: Hopane traces (m/z 191) of hydrocarbon (HC) fluid from inclusions in salt show significant amount of Gammacerane in the salt canopy at Weymouth A-45. In the autochthonous salt at Glooscap C-63, there is no particular Gammacerane anomaly. In addition, in the Weymouth A-45 bottom mix gathering several samples from the basal part of the canopy, the homohopane ratio C_{35} to C_{34} equal to 1 suggests that the source rock of these HC inclusions deposited in a carbonate environment.



Reference:
Yawooz Kettanah (2010) Hydrocarbon fluid inclusion study in the Argo Salt of Glooscap C-63 and Weymouth A-45 wells, offshore Scotian margin. Study report to OETR.

Figure 2: Example of hydrocarbon fluid inclusions from Kettanah (2010)



Reference:
Fowler, M. G. and Obermajer, M. (1999) Reassessing the petroleum geochemistry of the Scotian Shelf, offshore eastern Canada - a cautionary tale for geochemists. 19th International Meeting on Organic Geochemistry, Istanbul, Turkey, September 6-10, 1999, 469-470.

Figure 3: In Jurassic Abenaki condensate at "deep Panuke" (Panuke PP3C), homohopane ratio C_{35} to C_{34} is equal to 1. Such a ratio is indicative of a source rock deposited in a carbonate environment. Oleanane - age specific biomarker not present in sediments before the occurrence of angiosperms on earth (~100Ma) – is also present in this condensate, suggesting contamination by oil-based mud or, but improbably, leaching of Upper Cretaceous organic matter along the migration path.

Biomarkers – Conclusions

- Gammacerane in Weymouth salt fluid inclusion and in Venture B-213 DST#6 indicate the presence of a generative source rock deposited in a hypersaline (or water stratified) environment. The sporadic presence of Gammacerane may indicate that the hypersaline (or water stratified) environment is not uniformly distributed.
- Homohopane ratio C35 to C34 equal to or greater than 1 is indicative of a source rock deposited in a carbonate environment. This is the case for hydrocarbon fluid inclusions in Weymouth A-45 bottom mix sample and in condensate at the "deep Panuke" PP3C well. This environment is compatible with or without hypersaline conditions suggested by a presence of Gammacerane.
- Oleanane in "deep Panuke" condensate, suggests either contamination (oil-based mud) or leaching of Upper Cretaceous organic matter along the migration path. In the structural position of the Panuke PP3C well, the latter is very unlikely. Oleanane in Glooscap C-63 and Mohican I-100 extracts of stained Jurassic rocks also indicates contamination.

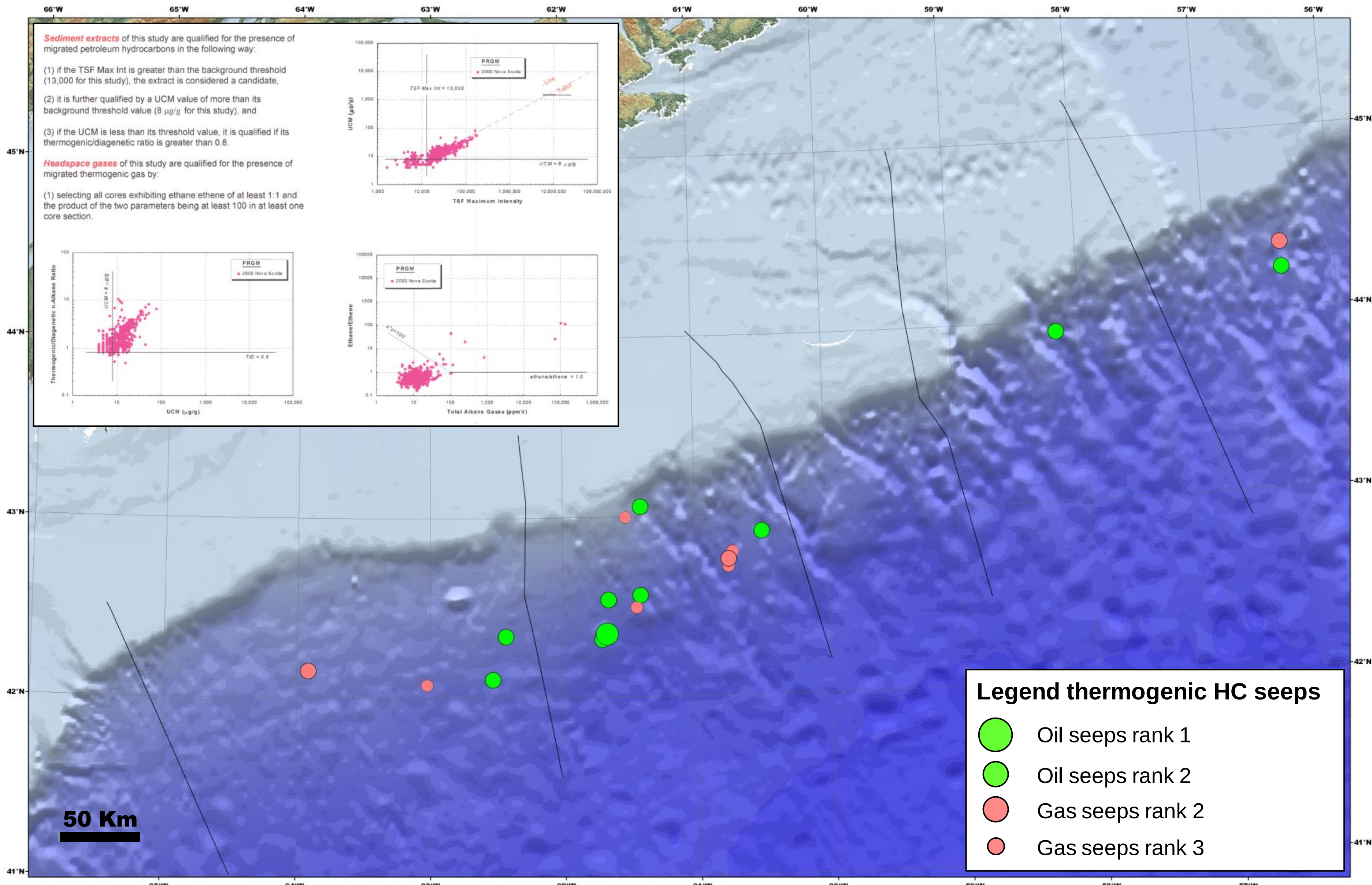


Figure 1: Location of piston-cores seeps displaying thermogenic hydrocarbons in order of importance. Map modified from TDI Brooks Int'l report (2000)

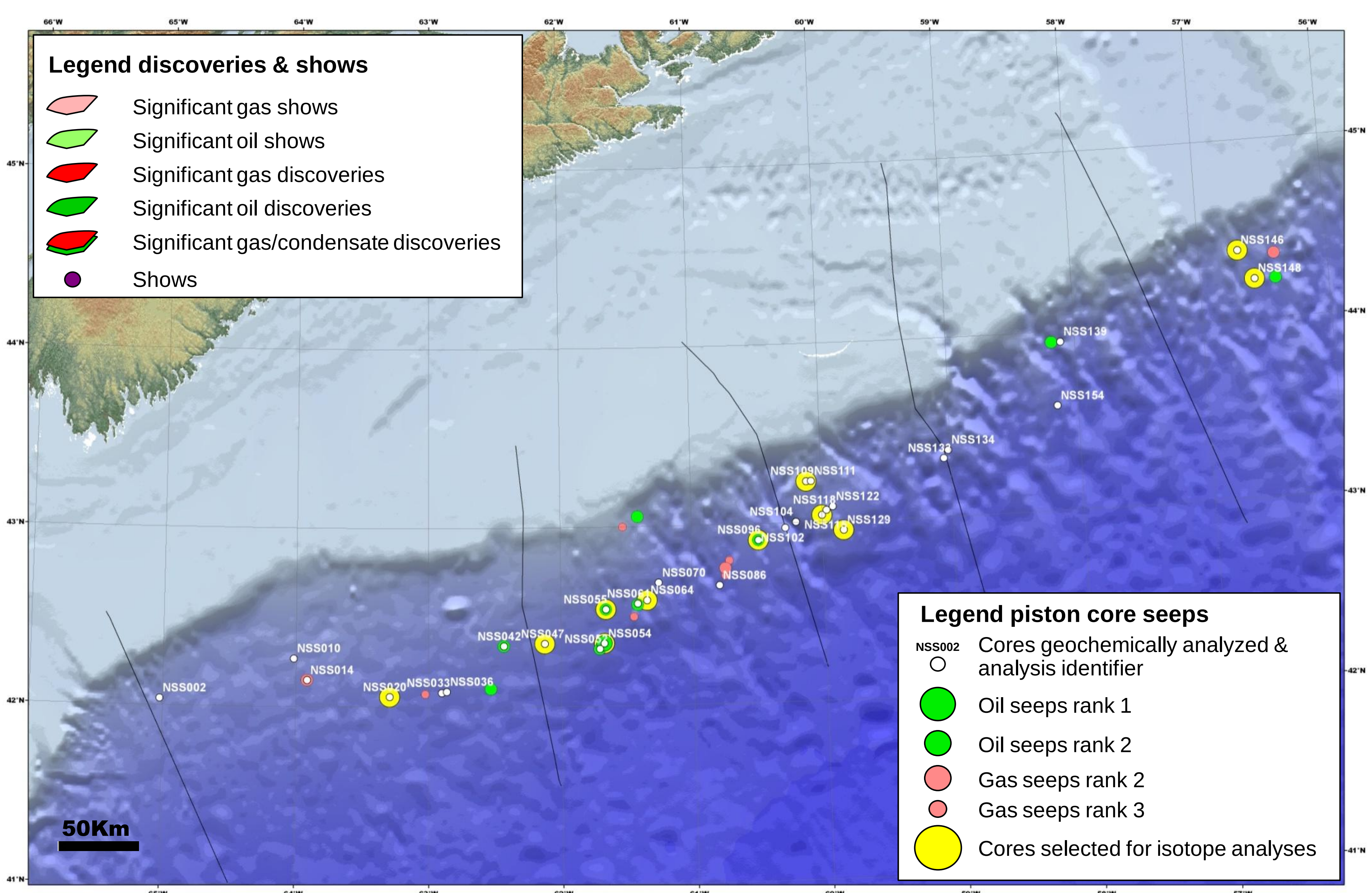


Figure 2: Piston-cores seeps displaying thermogenic hydrocarbons in order of importance and piston-cores geochemically analyzed (numbered). Piston-cores selected for carbon isotopes analyses are the yellow dot. Sample numbering for Map modified from TDI Brooks Int'l report (2000).

REGIONAL GEOCHEMICAL SURVEY for 2000 Nova Scotia Consortium SGE PROGRAM by TDI-Brooks International, Inc.

The report describes first the field and laboratory procedures of surface geochemical exploration using piston cores. Methodology and objectives of surface geochemical exploration using piston cores are presented in Peters et al. (2005)

The results of standard analyses of surface geochemical exploration analyses consist of the following:

- Total Scanning Fluorescence;
- C_{15+} hydrocarbons and UCM (Unresolved Complex Mixture);
- Headspace gas; and
- Carbon isotopic composition of gas.

Figure 1 shows distribution and rank of significant thermogenic hydrocarbon seeps based on the above mentioned analyses.

Carbon isotopic composition of headspace gas on 2 cores only produced $\delta^{13}C_1$ results. They are:

- Core# NSS014 - 2 sections of the core had enough headspace gas for performing the analyses. Methane $\delta^{13}C_1$ values of -92.50 and 87.66 per mil indicate a biogenic origin of the gas; and
- Core# NSS057 - 1 section only was measurable producing a $\delta^{13}C_1$ =-28.25 per mil, which falls in the range of thermogenic non-associated gas.

Both seeps did not reach the rank of significant occurrence according to the ranking criteria.

A second part of the report consists of a detailed geochemical study carried out by Geomark Research, Inc. on 30 piston-core samples for TDI-Brooks International, Inc.. Sample preparation and analyses are the followings :

- Bitumen extraction;
- Fraction separation by liquid chromatography;
- GC analysis of the saturate and aromatic fractions;
- GC-MS analysis of the saturate and aromatic fractions; and
- Carbon isotope analyses of the saturate and aromatic fractions.

The data are listed in the Table 1 (below).

Only the isotope data listed in Table 1 are reinterpreted because the opportunity arose to integrate them with isotope data from Morocco. The biomarker data, in particular the m/z 191 traces do not show any significant abundance of Gammacerane, which suggests that the seeps must originate from a "normal" marine source rock. The other biomarker data of Table 1 are not subject to reinterpretation because they are not compatible with the other data used in this study. Also, the biomarker interpretation made in the TDI-Brooks International, Inc. report consists only of general comments with no attempt to envisage the possibilities of an Early Jurassic sourcing of the seeps.

												Terpanes				Steranes Steranes abb mz 218					
#	Sample ID	Core	Lat	Long	Section	TSFmax	EOM ppm	δ13Csat	δ13Caro	Pr/Ph	C19/C23	C24/C23	C29/H	S/T	%C27	%C28	%C29	C28/C29	C27Ts/Tm	C29Ts/Tm	TAS3
1	NSCP0006	NSS002	42.0372	-65.0222	20	2l.815	50	n/a	-27.40		0.04	0.65	0.63	0.27	29.7	25.70	44.60	0.58	0.42	0.25	
2	NSCP0029	NSS010	42.2693	-64.0159	20	27.965	105	-29.68	-28.25												0.14
3	NSCP0040	NSS014	42.1484	-63.9154	11	58.240	110	-29.85	-28.11		0.11	0.53	0.64	0.20	30.8	19.20	50.00	0.38	0.33	0.20	0.05
4	NSCP0059	NSS020	42.0564	-63.2919	16	93.820	90	-30.47	-29.87	1.42	0.10	0.54	0.57	0.41	28.7	20.2	51.10	0.40	0.71	0.37	0.18
5	NSCP0098	NSS033	42.0796	-62.9019	15	48.020	126	-30.20	-29.75		0.08	0.49	0.56	0.38	29.6	20	50.40	0.40	0.5	0.28	0.18
6	NSCP0108	NSS036	42.0858	-62.8644	18	40.070	114	-30.66	-29.55		0.05	0.56	0.56	0.34	28.3	18.90	52.80	0.36	0.51	0.27	0.15
7	NSCP0126	NSS042	42.3388	-62.4321	23	50.380	48	-28.36	-28.74		0.03	0.62	0.55	0.34	27.1	20.60	52.30	0.39	0.46	0.32	
8	NSCP0141	NSS047	42.3511	-62.1239	26	112.340	78	-30.08	-29.46	1.47	0.05	0.55	0.57	0.45	29.5	20.20	50.40	0.40	0.63	0.36	0.11
9	NSCP0156	NSS052	42.3189	-61.7066	27	82.420	70	-29.78	-28.20		0.02	0.57	0.61	0.38	26.5	24.20	49.30	0.49	0.48	0.29	0.09
10	NSCP0162	NSS054	42.3498	-62.6721	12	144.750	88	-30.44	-29.72	1.55	0.10	0.49	0.67	0.43	32.4	17.60	50.00	0.35	0.77	0.38	0.09
11	NSCP0165	NSS055	42.5395	-61.6573	25	124.710	78	-30.26	-29.66	1.42	0.10	0.49	0.57	0.43	28.2	18.40	53.40	0.34	0.73	0.34	0.10
12	NSCP0182	NSS061	42.5693	-61.4155	20	43.260	60	n/a	-29.26	1.56	0.03	0.62	0.62	0.34	24.5	10.4	55.10	0.19	0.51	0.21	
13	NSCP0191	NSS064	42.5883	-61.3455	16	105.600	70	-30.23	-29.42	l.47	0.02	0.53	0.58	0.45	28.1	20.2	51.80	0.39	0.74	0.39	0.07
14	NSCP0208	NSS070	42.6844	-61.2547	6	67.650	68	-30.09	-29.62		0.07	0.38	0.53	0.42	30.6	21	48.40	0.43	0.64	0.35	0.05
15	NSCP0257	NSS086	42.6625	-60.7927	20	60.120	38	-29.20	-28.66		0.02	0.60	0.63	0.39	26.8	25.00	48.20	0.52	0.52	0.30	0.09
16	NSCP0302	NSS096	42.909438	-60.489672	8	109.620	175	-30.50	-29.68	1.39	0.11	0.54	0.57	0.48	27.1	21.1	51.70	0.41	0.63	0.37	0.11
17	NSCP0320	NSS102	42.973267	-60.282017	20	68.130	102	-30.48	-29.57		0.04	0.66	0.61	0.40	24.4	28.1	47.50	0.59	0.47	0.29	0 13
18	NSCP0326	NSS104	43.004593	-60.199075	20	51.380	93	-30.11	-29.17		0.03	0.62	0.62	0.34	23.8	27.9	48.30	0.58	0.37	0.28	0 12
19	NSCP0341	NSS109	43.230265	-60.113157	11	76.860	120	-30.47	-29.52	1.50	0.09	0.53	0.55	0.52	27.2	19.90	52.90	0.38	0.57	0.38	0.11
20	NSCP0348	NSS111	43.230945	-60.07698	28	54.200	120	-30.23	-29.27		0.10	0.52	0.58	0.39	27.2	22.20	50.60	0.44	0.49	0.32	0.10
21	NSCP0359	NSS115	43.038225	-59.999515	16	82.400	220	-30.57	-29.90	1.35	0.1	0.55	0.54	0.48	27.4	20.60	52.10	0.40	0.81	0.42	0.14
22	NSCP0369	NSS118	43.065698	-59.96357	26	53.640	85	-30.23	-29.68		0.06	0.61	0.58	0.35	24.4	26.70	48.90	0.55	0.39	0.29	0.11
23	NSCP0381	NSS122	43.084255	-59.91686	23	76.960	100	-30.41	-29.76		0.08	0.59	0.58	0.39	23.1	26.7	50.10	0.53	0.51	0.32	0.12
24	NSCP0402	NSS129	42.950465	-59.83766	25	166.350	328	-30.57	-30.04	1.45	0.15	0.56	0.57	0.49	28.5	18.90	52.70	0.36	0.77	0.43	0.14
25	NSCP0414	NSS133	43.3277	-59.051572	26	63.710	102	-30.37	-29.44		0.03	0.53	0.63	0.37	24.3	26.00	49.70	0.52	0.46	0.30	0.07
26	NSCP0417	NSS134	43.37268	-59.015608	20	47.220	95	-30.05	-28.88		0.06	0.58	0.71	0.28	25.8	27.00	47.30	0.57	0.32	0.26	0.12
27	NSCP0429	NSS139	43.942128	-58.11025	15	73.960	135	-30.32	-29.22		0.06	0.53	0.58	0.47	26.7	22.20	51.10	0.43	0.57	0.34	0.11
28	NSCP0448	NSS146	44.385383	-56.691885	11	29.465	42	-29.93	-29.05	1.31	0.05	0.57	0.61	0.67	28.1	23.70	48.20	0.49	0.72	0.39	0.12
29	NSCP0453	NSS148	44.221647	-56.576188	2	28.885	78	-30.63	-29.87	1.23	0.04	0.60	0.62	0.58	30.4	25.80	43.80	0.59	0.69	0.36	0.18
30	NSCP0472	NSS154	43.588087	-58.159307	25	61.020	93	-30.20	-29.90		0.04	0.50	0.66	0.37	24.4	27.00	48.60	0.56	0.42	0.28	0.14

S/T= Steranes/Terpanes
TAS3=(C20+C21)/(ΣC20-C28) m/z=231
ROM=Immature Recent organic matter

Table 1: List of the piston-core samples geochemically analyzed (White dots in Figure 2, left).

Reference:
Bernard B. B., Allan K. A. and McDonald T; J. (2000) Regional geochemical survey for 2000 Nova Scotia Consortium. SGE Program. TDI-Brooks International, Inc. report, December 2000.
Peters K. E., Walters C. C. and Moldowan J. M. (2005) The biomarker guide; Biomarkers and isotopes in the environment and human history. Cambridge University Press, Volume 1.

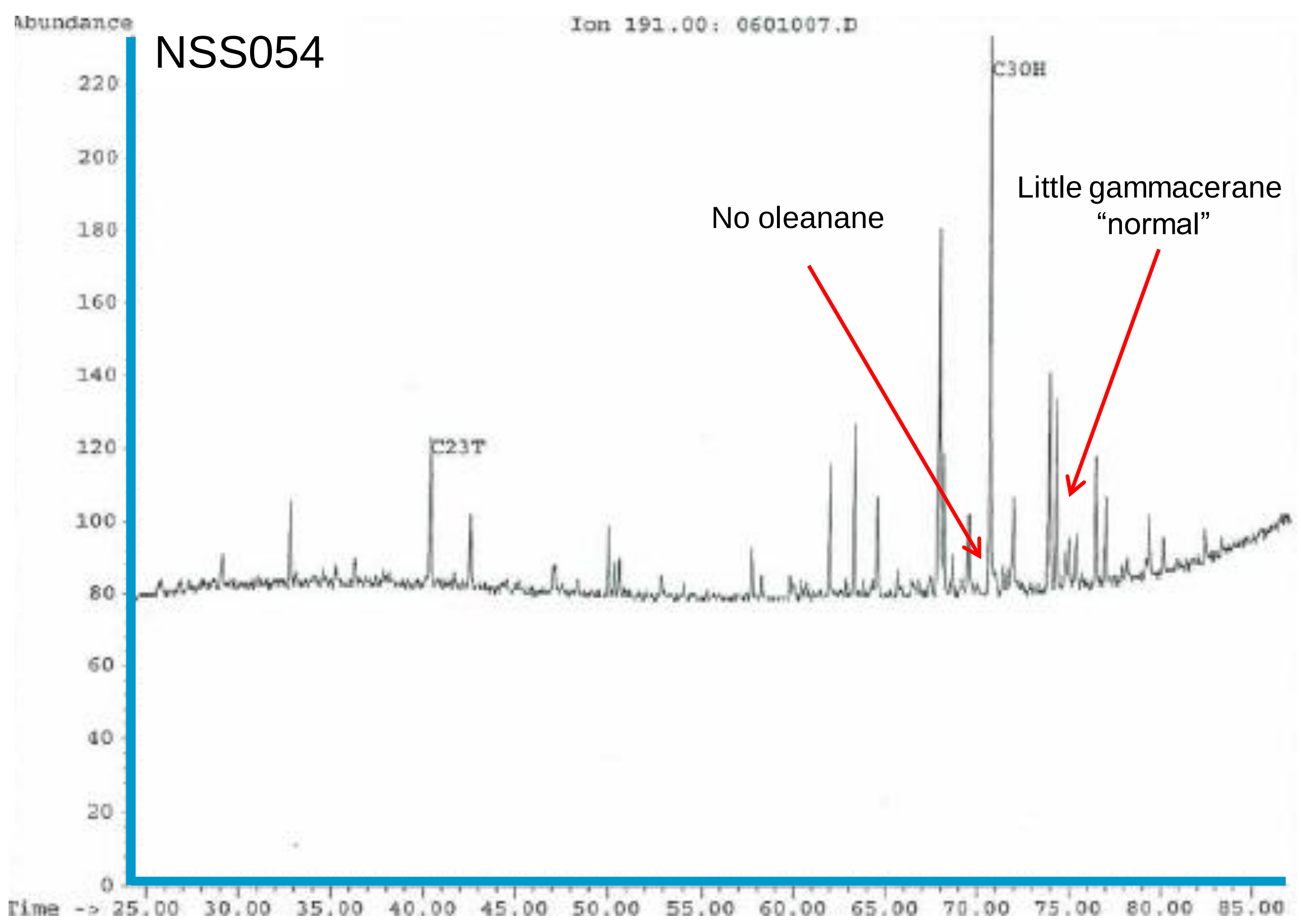


Figure 1: Low Gammacerane abundance in piston-core seeps

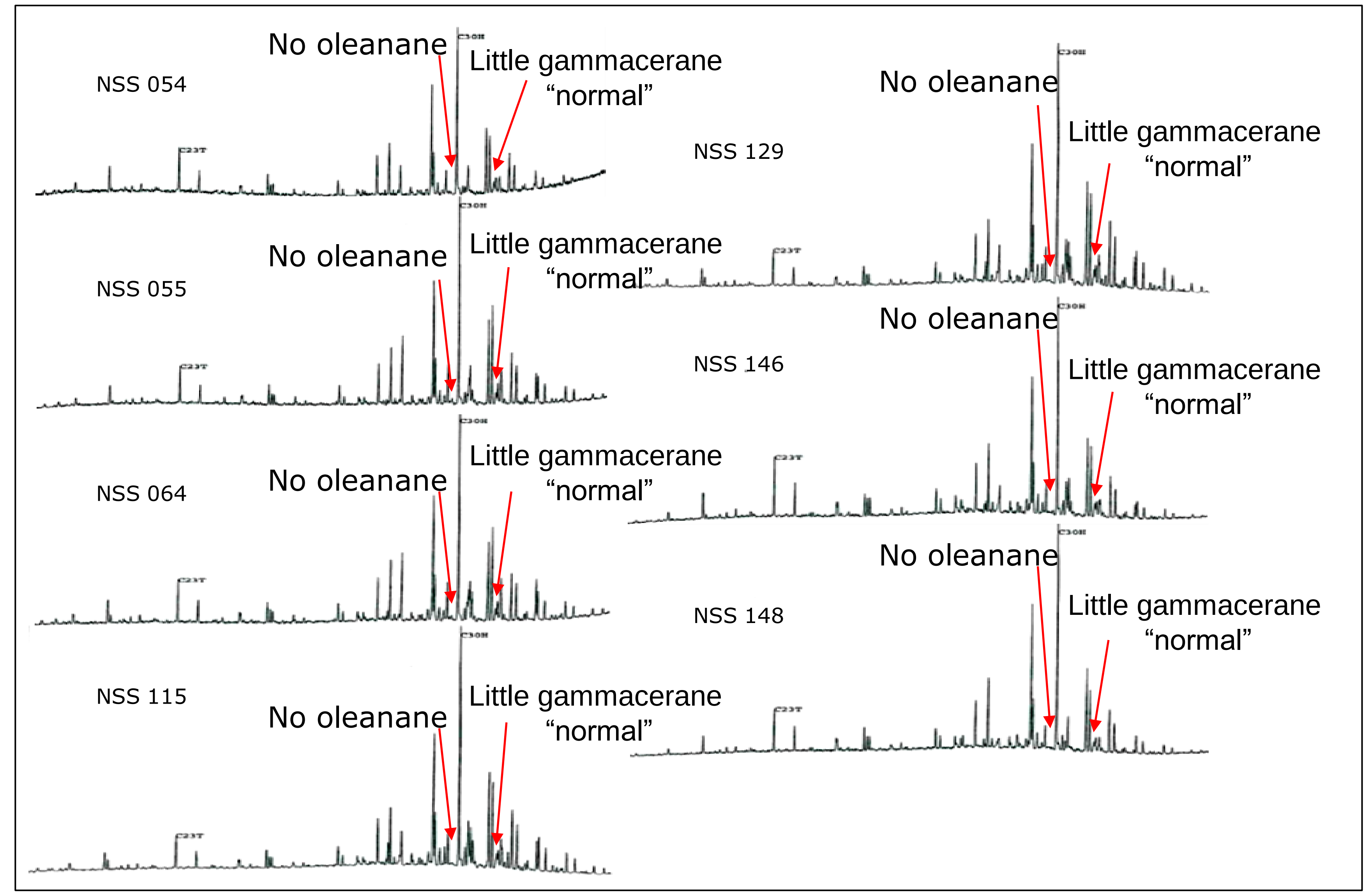


Figure 2: Low Gammacerane abundance and absence of Oleanane in all piston-core seeps analyzed for stable carbon isotopes.

Summary and Conclusions

Results from biomarker analyses of oil, condensates and source rock extracts indicate that there are three types of source facies as follows:

- Gammacerane in Weymouth salt fluid inclusion and in Venture B-213 DST#6 indicate the presence of a generative source rock deposited in a hypersaline (or water stratified) environment. and supports the presence of an Early Jurassic source rock. The sporadic presence of Gammacerane may indicate that the hypersaline (or water stratified) environment is not uniformly distributed.
- Homohopane ratio C35 to C34 equal to or greater than 1 is indicative of a source rock deposited in a carbonate environment. This is the case for hydrocarbon fluid inclusions in Weymouth A-45 bottom mix sample and in condensate at the "deep Panuke" PP3C well. This environment is compatible with or without hypersaline conditions suggested by a presence of Gammacerane.
- Oleanane in "deep Panuke" condensate, suggests either contamination (oil-based mud) or leaching of Upper Cretaceous organic matter along the migration path. In the structural position of the Panuke PP3C well, the latter is very unlikely. Oleanane in Glooscap C-63 and Mohican I-100 extracts of stained Jurassic rocks also indicates contamination.

The analysis of piston core data leads to the following conclusions:

- The tight isotope group (Figure 2, Plate 4-3-8) formed by the piston core samples separates them clearly from the condensates of the Shelf gas discoveries and suggest that they are all originated from the same source rock
- Good match of the isotopic signatures with the Sidi Rhalem oil of Morocco sourced by an Early Jurassic (Toarcian) source rock (Figure 2, Plate 4-3-8) suggests and supports the presence of an Early Jurassic source rock on the Nova Scotia margin.
- Low abundance of Gammacerane in the seeps displayed in Figure 2 suggests that their source rock was not deposited under water stratified or hypersaline conditions. The Toarcian source rock in the IODP well 547B exemplifies such a case as it is bare of Gammacerane (see Figure 5, Plate 4-3-5) but nonetheless a source rock.
- Absence of Oleanane precludes any Late Cretaceous sourcing (Figures 1 and 2, this Plate).

THESE ARGUMENTS SPEAK IN FAVOR OF PRESENCE OF AN EARLY JURASSIC SOURCE ROCK

- On the western part of the margin, down slope off the Jurassic carbonate platform, the Early Jurassic source rock is the only one mature.
- Going east, other source rocks become mature up to at least the Tithonian one, which could also feed the seeps.
- The effect should be to spread the tight isotope seep group toward the discovered oil/condensates group but this does not happen as if the Early Jurassic source rock was the only one feeding the seeps.

CHAPTER 4-4

PETROLEUM GEOCHEMISTRY

SOURCE ROCKS

PETROLEUM GEOCHEMISTRY - SOURCE ROCKS

Introduction

The assessment of a Petroleum System requires:

1. Understanding the generative system, which is central to assessing the petroleum system of any sedimentary basin therefore also of the Nova Scotia margin. The search for the source rocks generative of oil, gas & condensates discovered and yet to be discovered is therefore at the heart of the geochemistry project.
2. Maturity, of course, is the engine of hydrocarbon generation from these source rocks.
3. Petroleum system modeling, which is a major part of the PLAY FAIRWAY assessment, needs to account for source rocks and maturity among many other elements and processes.

Source rock and maturity evaluations lie with the Geochemist and are based on the examination of data such as TOC, Rock Eval (see intro) and Vitrinite Reflectance, Tmax to cite only the main types available for this study.

The identification of source rocks may be achieved by the characterization of oils, condensates and fluid inclusions based on biomarkers, isotopes and light molecular composition (gasoline range). This approach may provide distinct genetic signatures of oils reflecting distinct source rocks they originate from but it does not quantify generative potential of the source rocks.

Plates 4-4-2 to 4-4-9 display a selection of wells from the Scotian margin, where the source rocks identified are best developed. Examples of the various plots, diagrams and Tables used for source rock identification are provided here, as templates, to help reading the Plates of this Chapter 4-4:

- Figure 1 displays the typical depth plots for TOC/Rock Eval and maturity data also often called Geochemical Logs. This plot contains a gamma-ray curve and a column of stratigraphic markers to provide a framework to the variation of the
- TOC/Rock Eval parameters. Vitrinite Reflectance data are added to the TOC/Rock Eval depth plot (Figure 1). On occasion, a more detailed TOC plot exemplified in Figure 2 is provided.
- Figures 3 and 4 display the typical diagrams used for assessing the different types of source rocks, whether terrestrial (Type III), marine (Type II) or lacustrine (Type I). The HIxOI diagram of Figure 4 is also called a Pseudo Van Krevelen diagram.
- The majority of Maceral analyses on the Scotian margin were performed by P. K. Mukhopadhyay. Table 1 displays a typical description of microscopic organic facies by P. K. Mukhopadhyay in his reports who performed the majority of these analyses for the Scotian margin.
- Contamination by mud-additives, which is a significant source of problem for interpreting geochemical data on the Scotian margin is presented in Table 2. This type of Tables indicating the mud scheme used during drilling operation are available from the online GSC Basin database for each well of the Scotian margin.

Plates 4-4-10 to 4-4-14 display the characteristics of Early Jurassic source rocks located on the Nova Scotia conjugate margins of Portugal and Morocco.

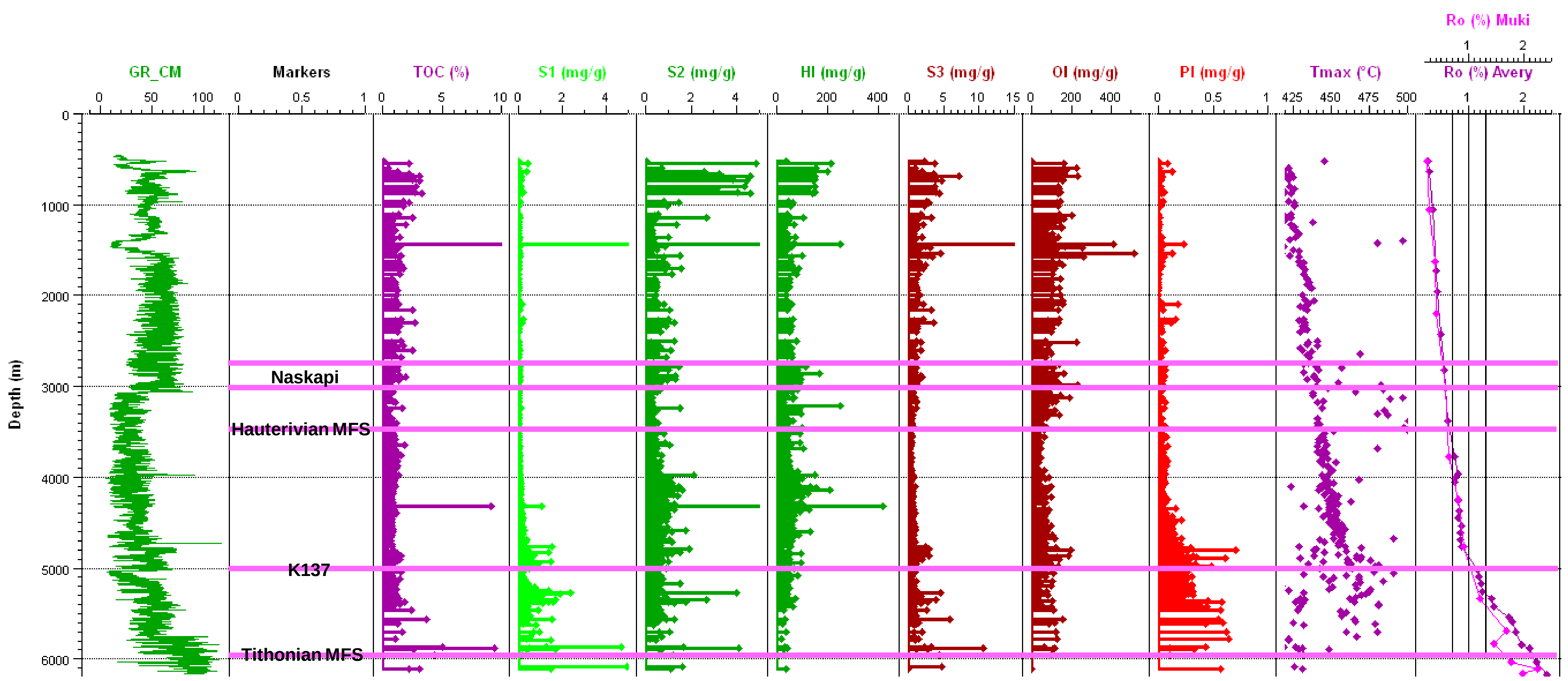


Figure 1: Typical depth plot for TOC/Rock Eval and maturity data also often called Geochemical Log. This plot contains a gamma-ray curve and a column of stratigraphic markers to provide a framework to the variation of the TOC/Rock Eval parameters. Vitrinite Reflectance data are added to the TOC/Rock Eval depth plot

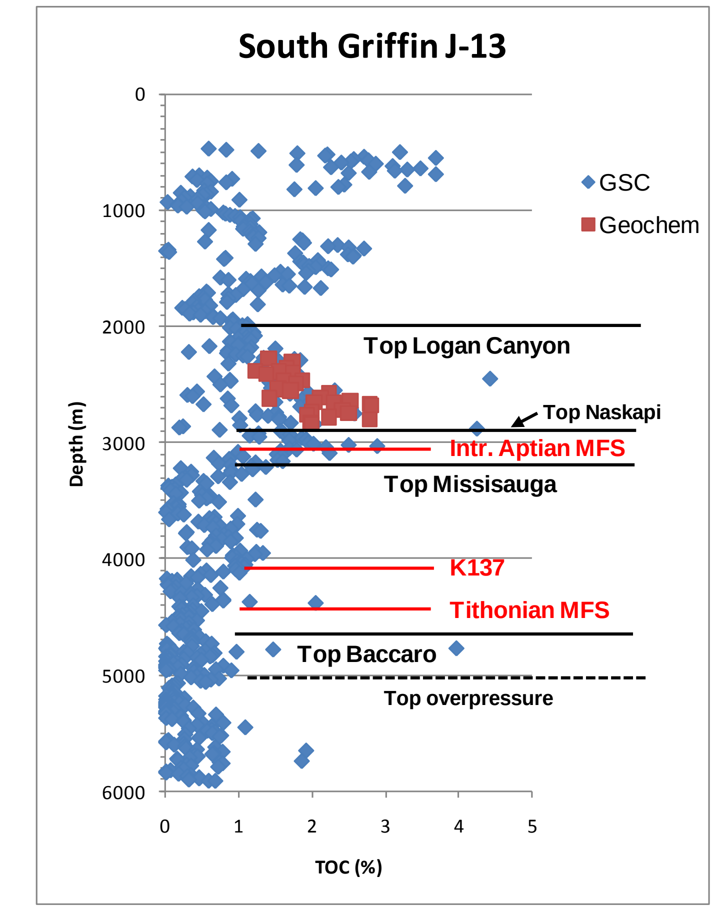


Figure 2: Typical depth plot for displaying TOC alone

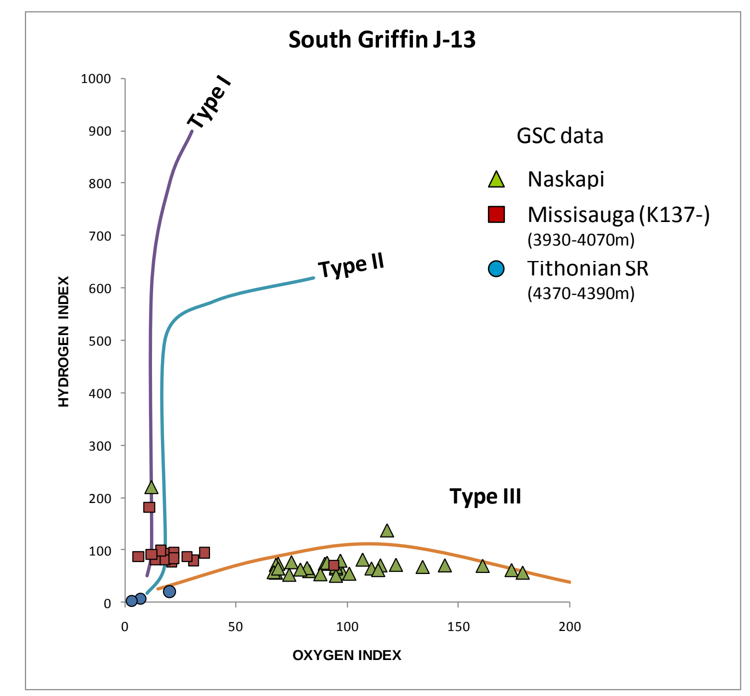


Figure 3: Typical HI x OI diagram also called called Pseudo Van Krevelen diagram defining the various organic matter types, whether terrestrial (Type III), marine (Type II) or lacustrine (Type I) or mixed for various intervals

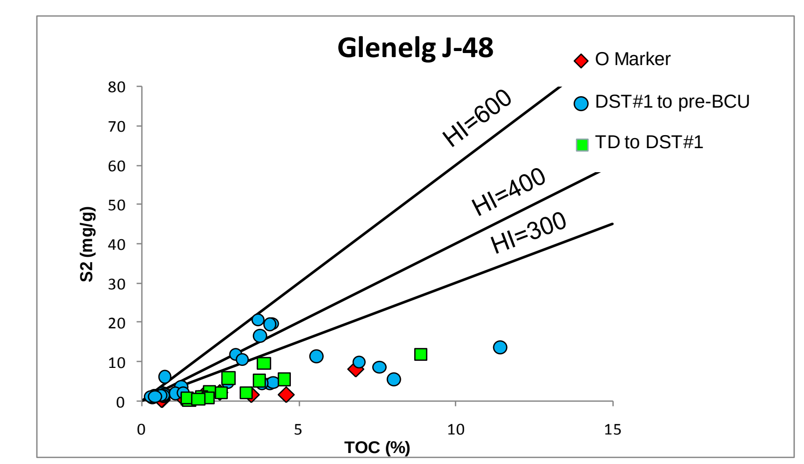


Figure 4: Typical S2 x TOC diagram showing the Hydrogen Indices (HI) range for various intervals

Table 1: Typical description of microscopic organic facies by P. K. Mukhopadhyay.

Organic facies in the interval TD to ~K137

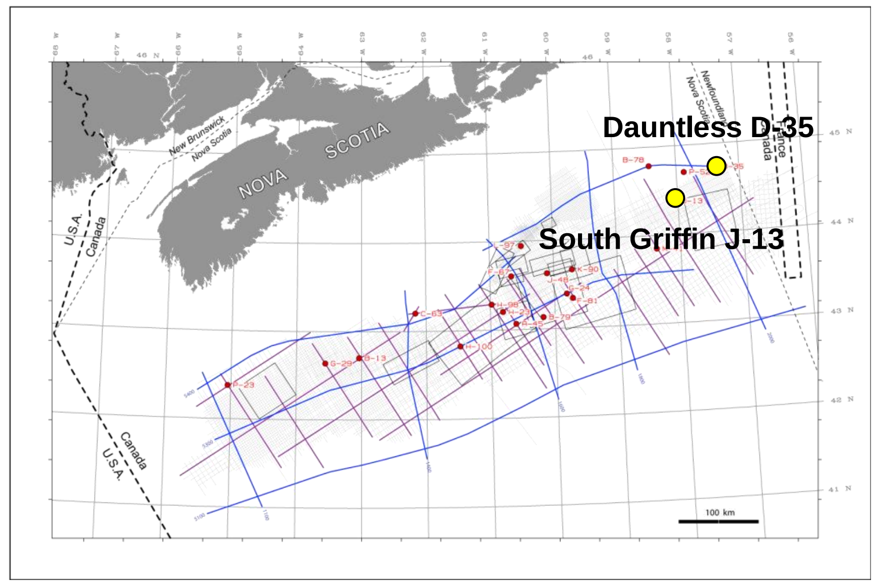
	DEPTH (m)	TOC (%)	VR Ro (%)	OXIDATION LEVEL	ENVIRONMENT	ORGANIC INPUT	KEROGEN TYPE	OIL/GAS POTENTIAL
	4940	0.63	1.05	Anoxic (partially)	Inner neritic - marginal marine	Mixed	IIA-IIB	Oil/Condensate
	4980	0.52	1.12	Anoxic (partially)	Inner neritic - marginal marine	Mixed	IIA-IIB	Oil/Condensate
	5175	n/a	1.22	Mildly anoxic	Inner neritic - marginal marine	Terrestrial	IIB	Cond.-Gas/Oil
	5255	n/a	1.25	Mildly anoxic	Inner neritic - marginal marine	Terrestrial	IIB	Cond.-Gas/Oil
	5420	0.83	1.45	Anoxic (partially)	Inner neritic - marginal marine	Mixed	IIA-IIB	Gas/Cond.
	5590	n/a	1.78	Mildly oxic	Inner/outer neritic - marg. marine	Mixed	IIB	Gas/Cond.
Tithonian	5700	1.66	1.85	Mildly oxic	Inner/outer neritic - marg. marine	Mixed	IIB-III	Gas/Cond.
Tithonian	5865	4.83	2.13	Mildly anoxic	Inner/outer neritic - marg. marine	Mixed	IIB	Cond.-Gas/Oil
Tithonian	6080	n/a	2.2	Mildly anoxic	Inner/outer neritic - marg. marine	Mixed	IIB	Cond.-Gas/Oil
Tithonian	6115	3.07	2.25	Anoxic (partially)	Inner/outer neritic - marg. marine	Mixed	IIA-IIB	Oil/Condensate
Tithonian	6170	n/a	2.42	Mildly anoxic	Inner/outer neritic - marg. marine	Mixed	IIB	Cond.-Gas/Oil

Reference:
P. K. Mukhopadhyay & Wade J. A. 1990. Organic facies and maturation of sediments from three Scotian Shelf wells. Bulletin of Canadian Petroleum Geology, Vol. 38, No. 4, pp. 407-425

Top	Bottom	Units	Mud	Mud Additives	Event	Comments
924.5		M			FISH	DRILL STRING PARTED - FISH RECOVERED WITH AN OVERSHOT
3115.4		M				
4027.7		M				TWO BIT CONES LOST - MILLED ON JUNK & RECOVERED SAME WITH A JUNK BASKET
4034.7		M				DRILL STRING PARTED - FISH RECOVERED WITH AN OVERSHOT
4120		M				THREE BIT CONES LOST - MILLED ON JUNK & RECOVERED SAME WITH A JUNK BASKET
103	342.9	M	SEAWATER		MUD	
342.9	917.5	M	SEAWATER - XCD			
917.5	3115.1	M	SEAWATER - KCL POLYMER			
3115.1	5911.1	M	FRESHWATER - LIGNOSULFONATE	LIGNITE, LIGNOSULFONATE		
3215.9	3258.9	M			MUD MOTOR	TURBO DRILLED INTERVAL
3332.1	3450	M				
4178.5	4181.6	M				
4340	4356.2	M				

Table 2: This type of Tables indicating the mud scheme used during drilling operation are available from the online GSC Basin database for each well of the Scotian margin

South Griffin J-13

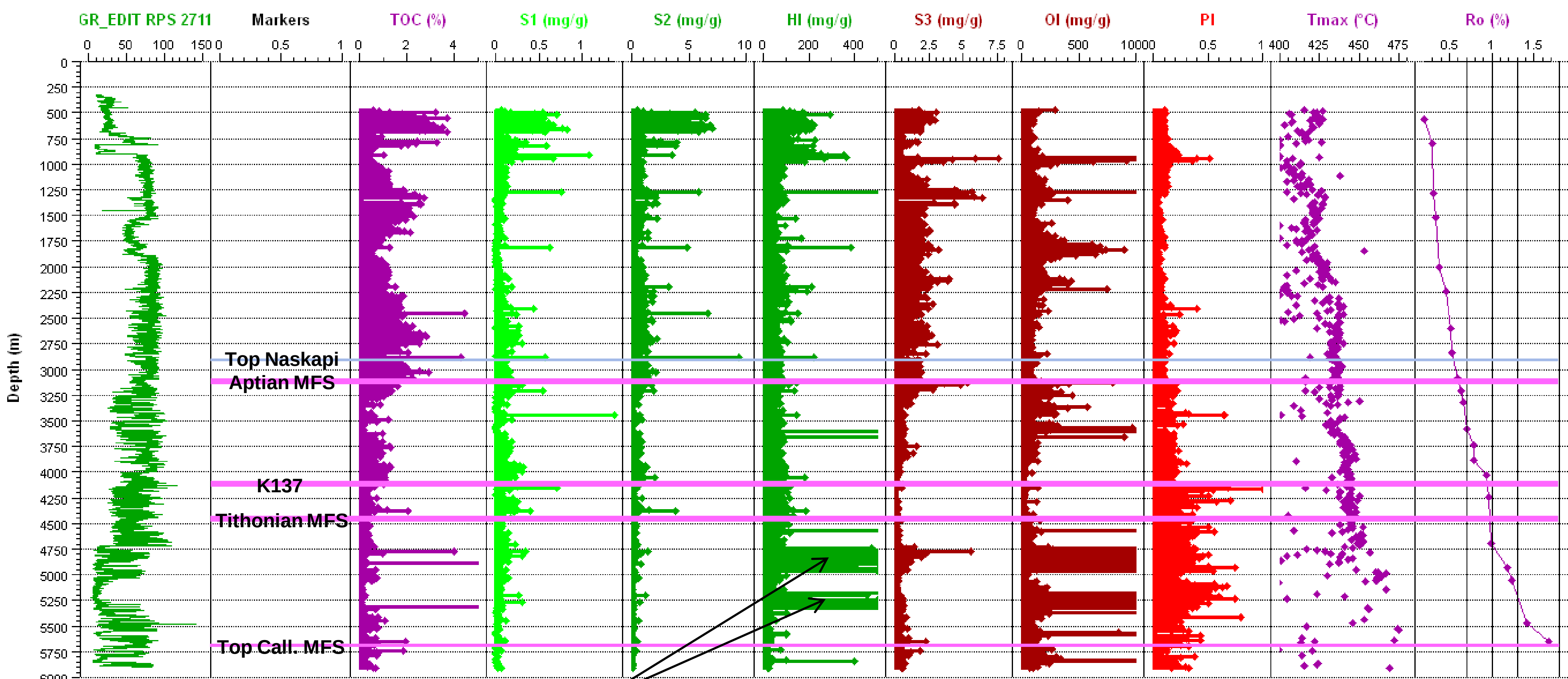


Top	Bottom	Units	Mud	Mud Additives	Event	Comments
924.5		M			FISH	DRILL STRING PARTED - FISH RECOVERED WITH AN OVERSHOT
3115.4		M				
4027.7		M				TWO BIT CONES LOST - MILLED ON JUNK & RECOVERED SAME WITH A JUNK BASKET
4034.7		M				DRILL STRING PARTED - FISH RECOVERED WITH AN OVERSHOT
4120		M				THREE BIT CONES LOST - MILLED ON JUNK & RECOVERED SAME WITH A JUNK BASKET
103	342.9	M	SEAWATER		MUD	
342.9	917.5	M	SEAWATER - XCD			
917.5	3115.1	M	SEAWATER - KCL POLYMER			
3115.1	5911.1	M	FRESHWATER - LIGNOSULFONATE	LIGNITE, LIGNOSULFONATE		
3215.9	3258.9	M			MUD MOTOR	TURBO DRILLED INTERVAL
3332.1	3450	M				
4178.5	4181.6	M				
4340	4356.2	M				

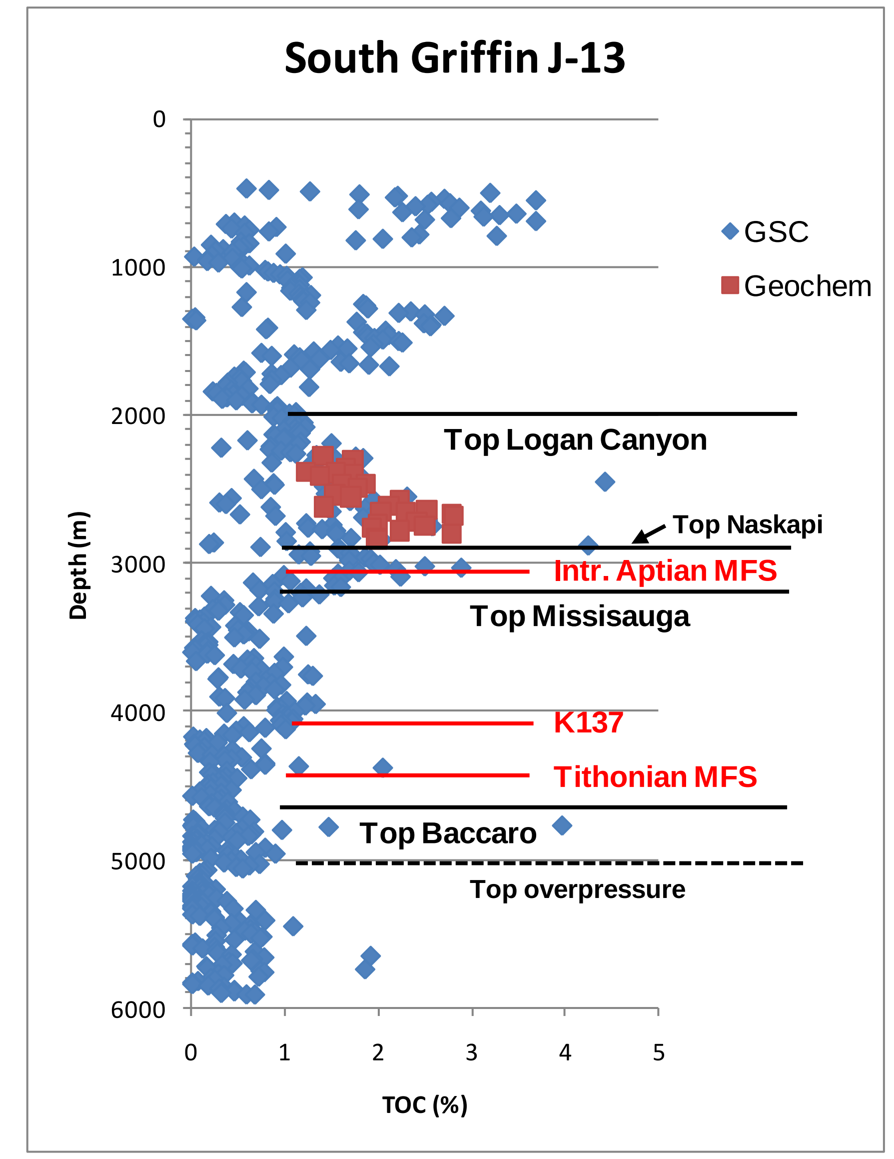
Dauntless D-35

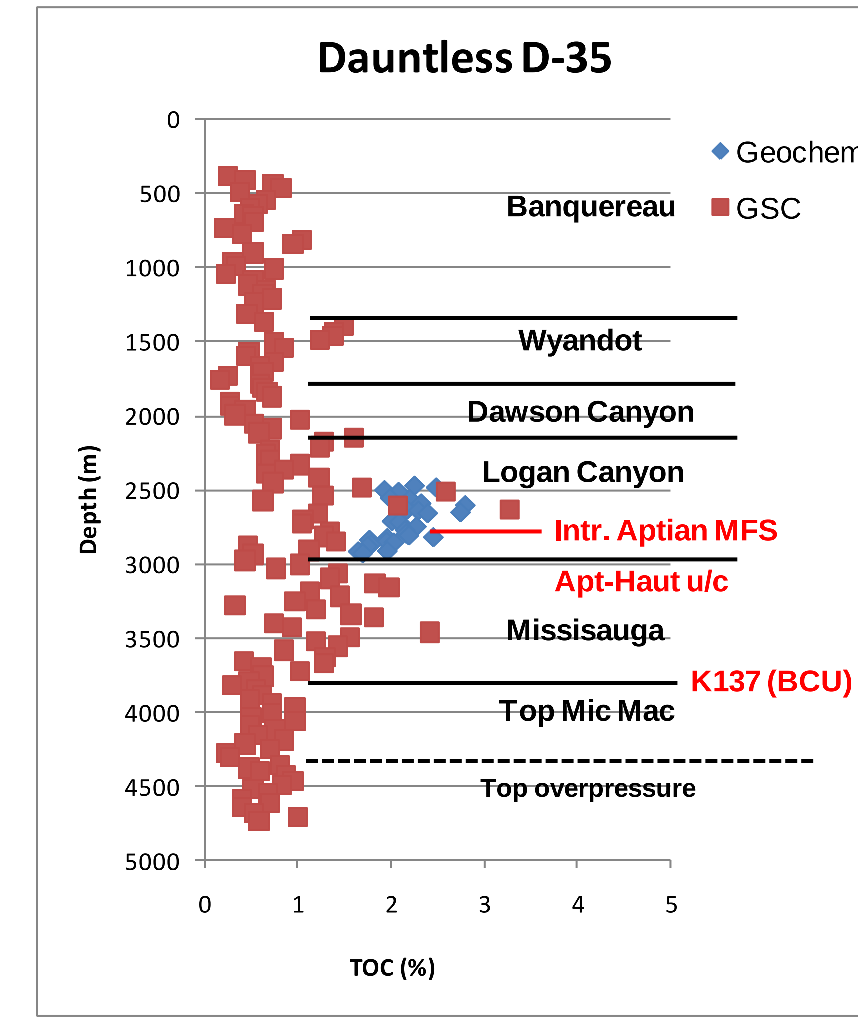
Top	Bottom	Units	Mud	Mud Additives	Event	Comments
2830		FT		STUCK CASING PULLED FREE	FISH	
330	1001		TREATED GEL		MUD	
1001	15555		DLS	SPERSENE, CROMEX, DIESEL, PIPELAX		

DLS = Dispersed Lignosulphonate

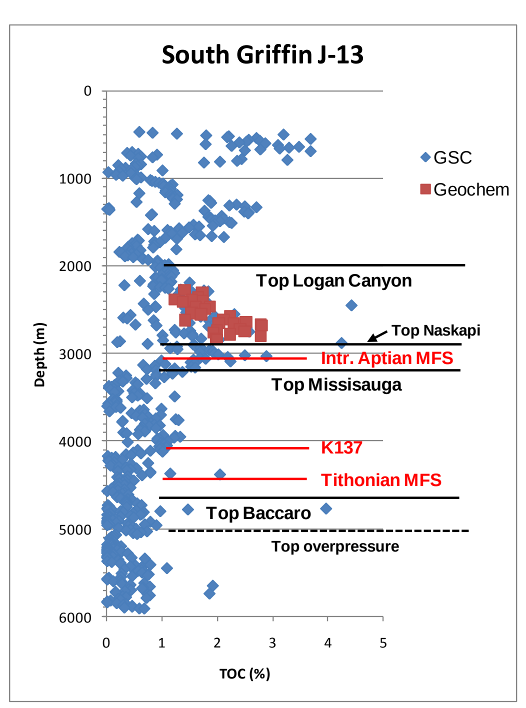


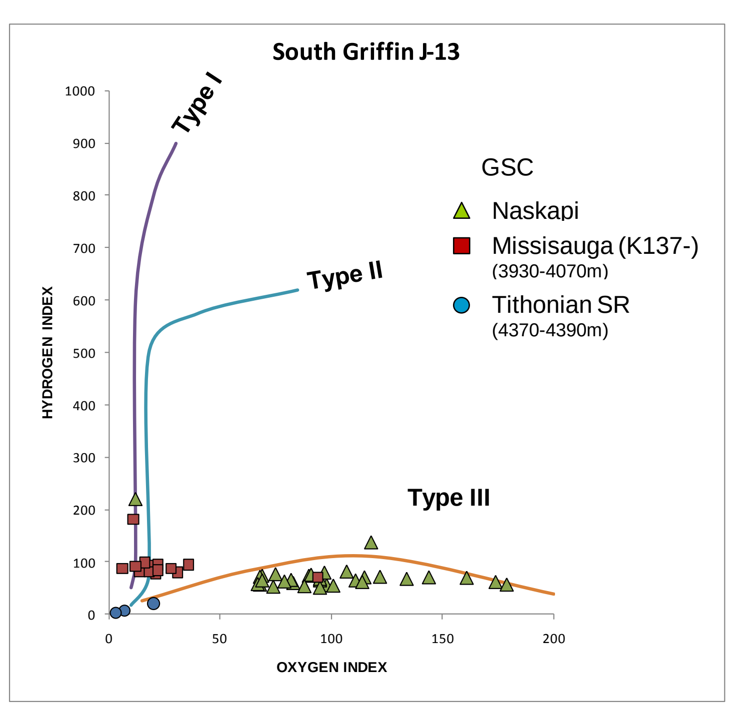
The large Hydrogen and Oxygen Indices below 3115m down to TD reflect contamination by mud additive (Lignosulfonate). Below the Tithonian MFS, HI values are too high for the elevate level maturity of that section of the well.





Like South Griffin J-13, Dauntless D-35 was drilled using Lignosulfonate added to the mud



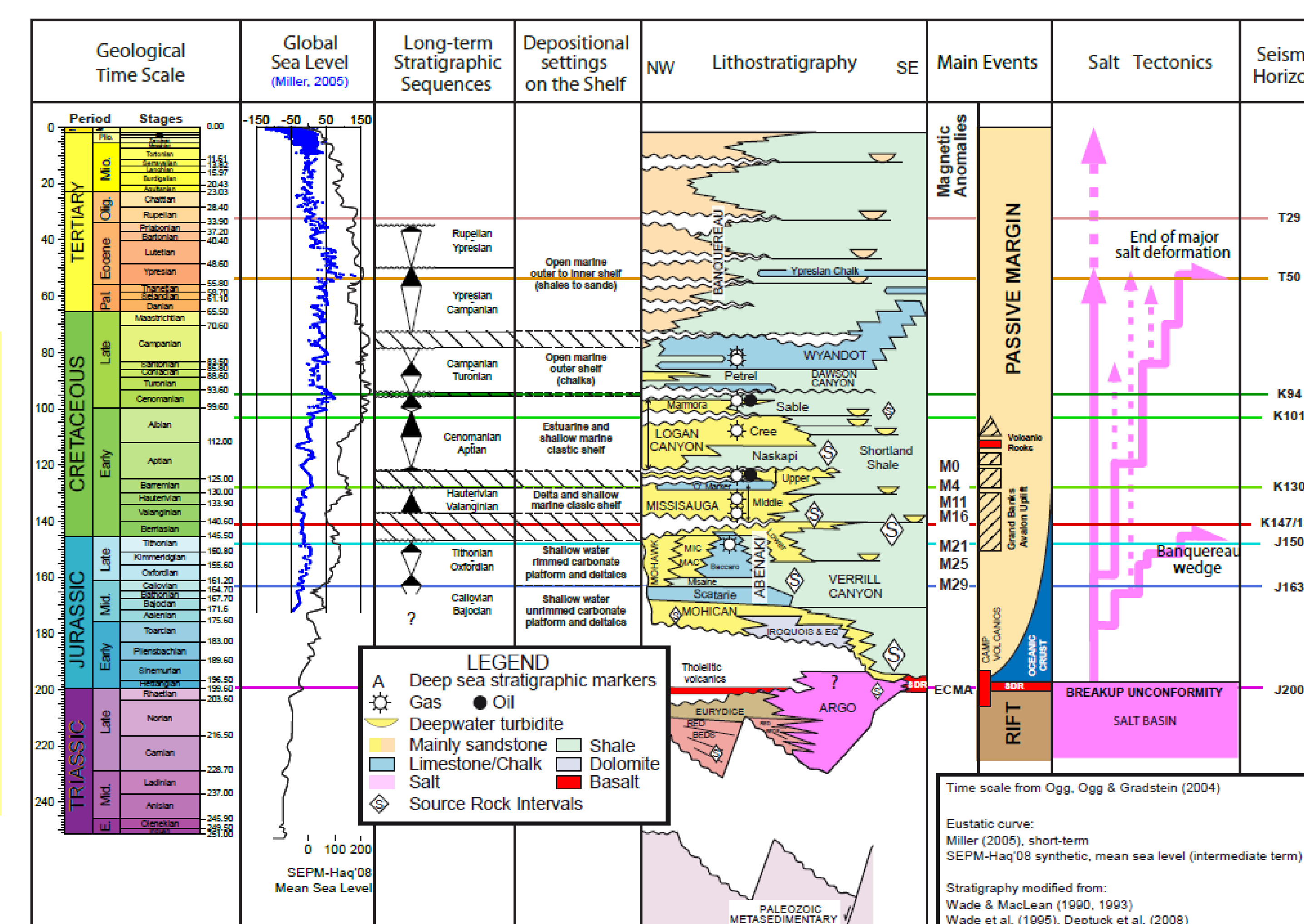


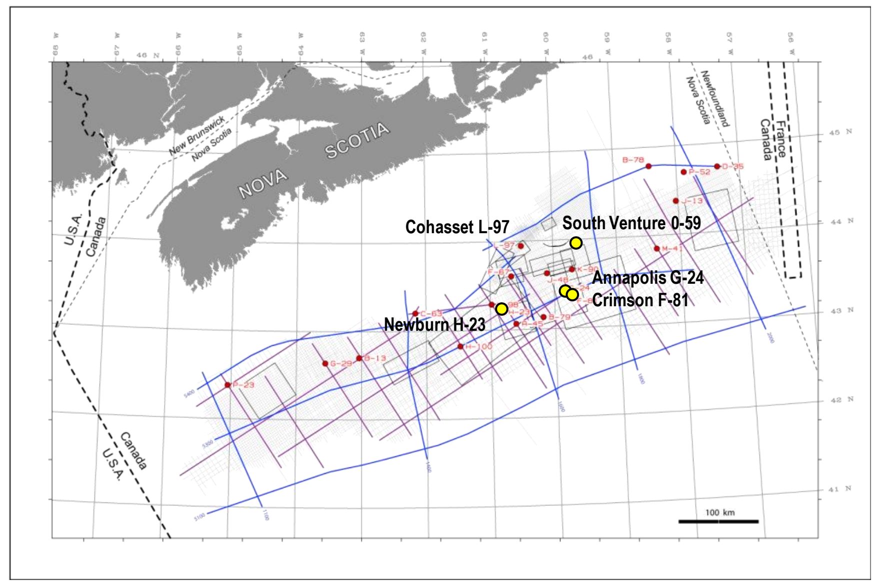
The Naskapi source rock is well developed in South Griffin J-13

- ✓ Maximum TOC are slightly greater than 2%
- ✓ Hydrogen and Oxygen Indices (HI & OI, respectively) indicate a Type III kerogen at best (see HI x OI diagram, left)
- ✓ Vitrinite Reflectance Ro=0.5 to 0.6% indicate incipient maturity only
- ✓ Eastward, the Naskapi source rock is present in Dauntless D-35

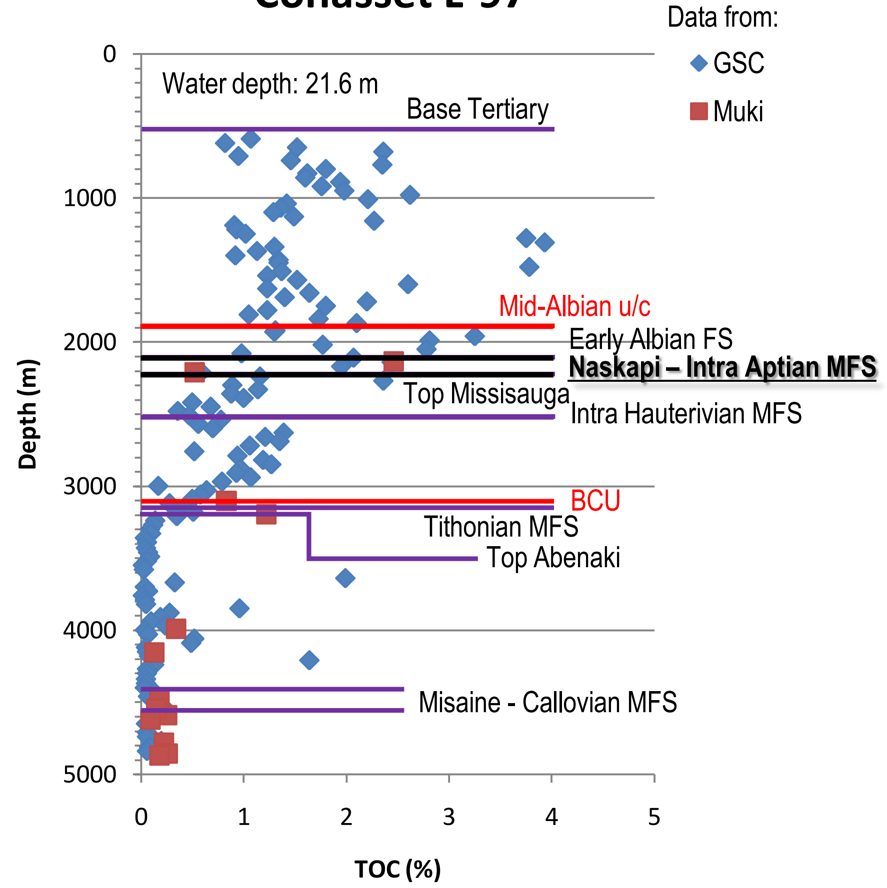
NOTE:

- ✓ TOC=2% at the level of the Tithonian MFS with HI and OI values indicating an exhausted source rock
- ✓ TOC=2% at the level of the Callovian MFS
- ✓ The Missisauga formation above the BCU unconformity displays TOC averaging less than1% in South Griffin J-13 and 1.5% in Dauntless D-35
- ✓ The Logan Canyon formation is also organic-rich in both South Griffin J-13 and Dauntless D-35 but remains immature in these two wells and throughout the margin

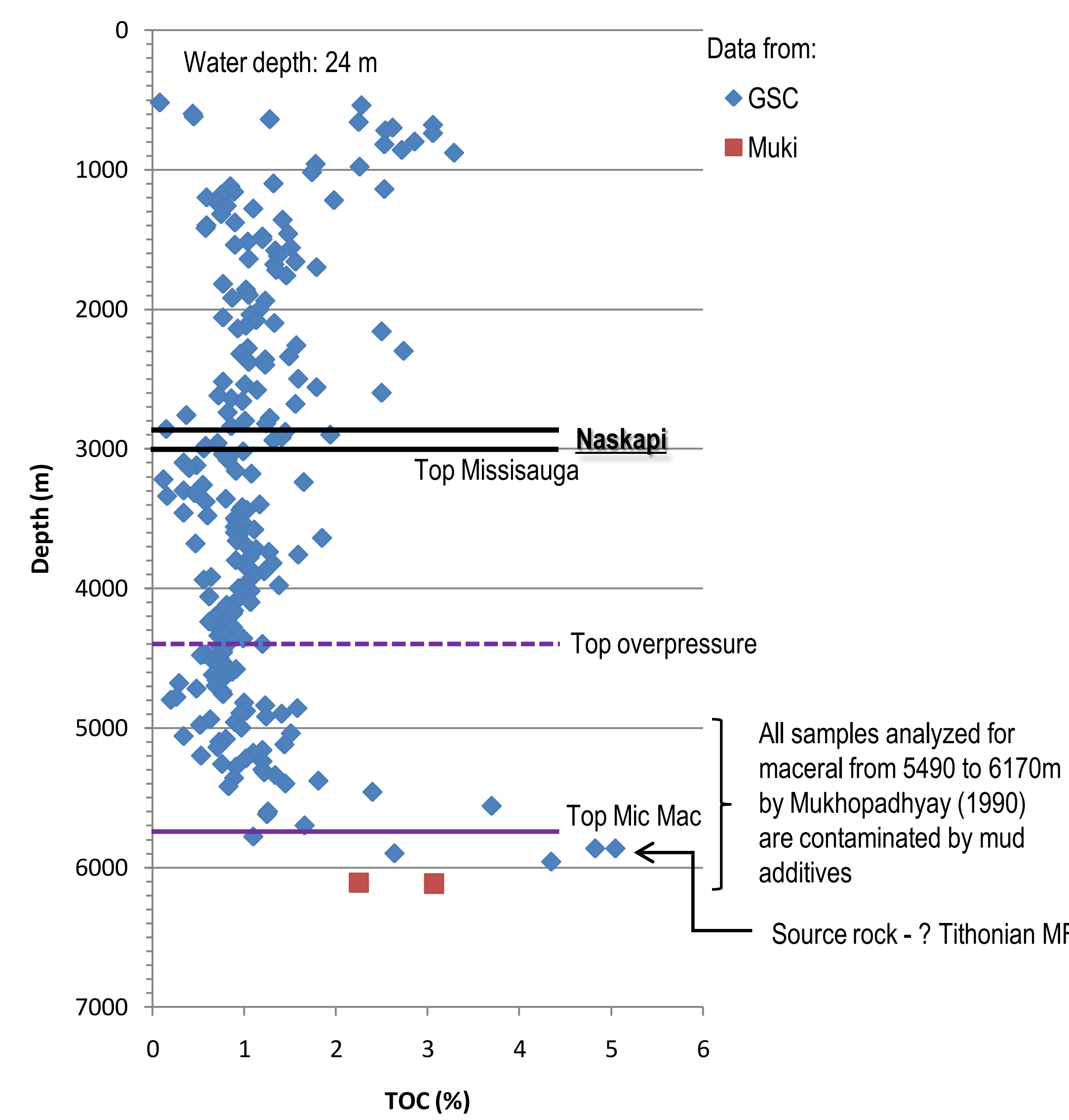




Cohasset L-97



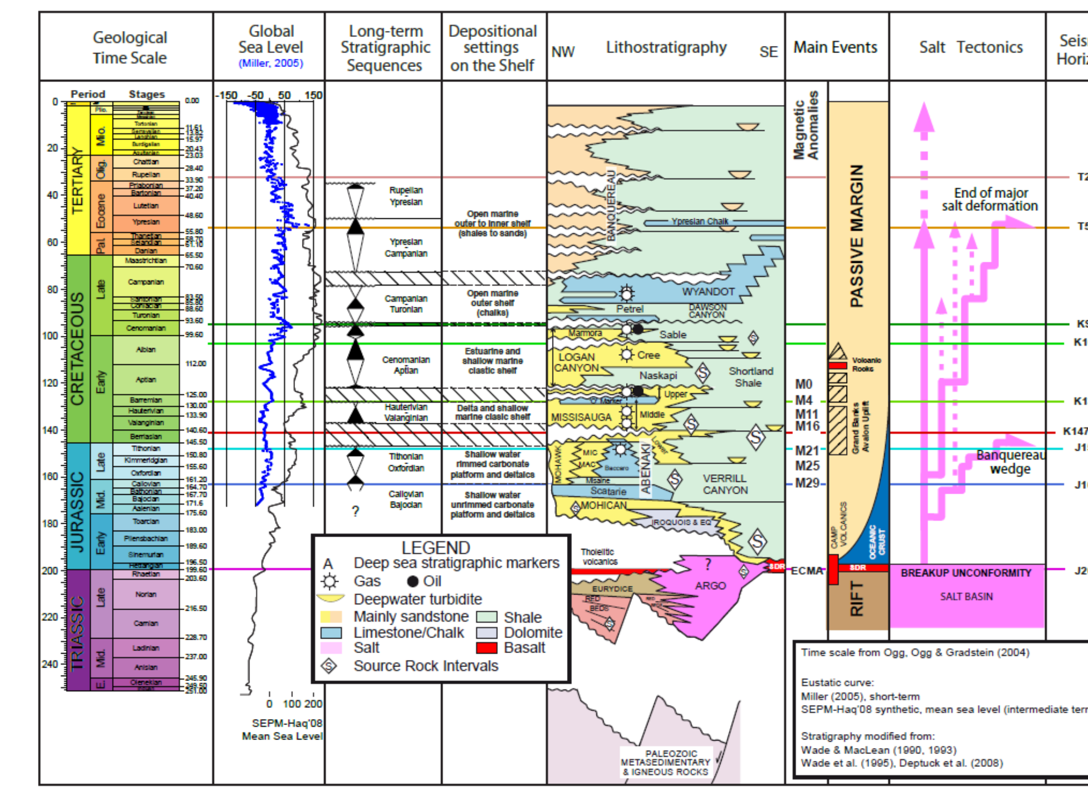
South Venture O-59



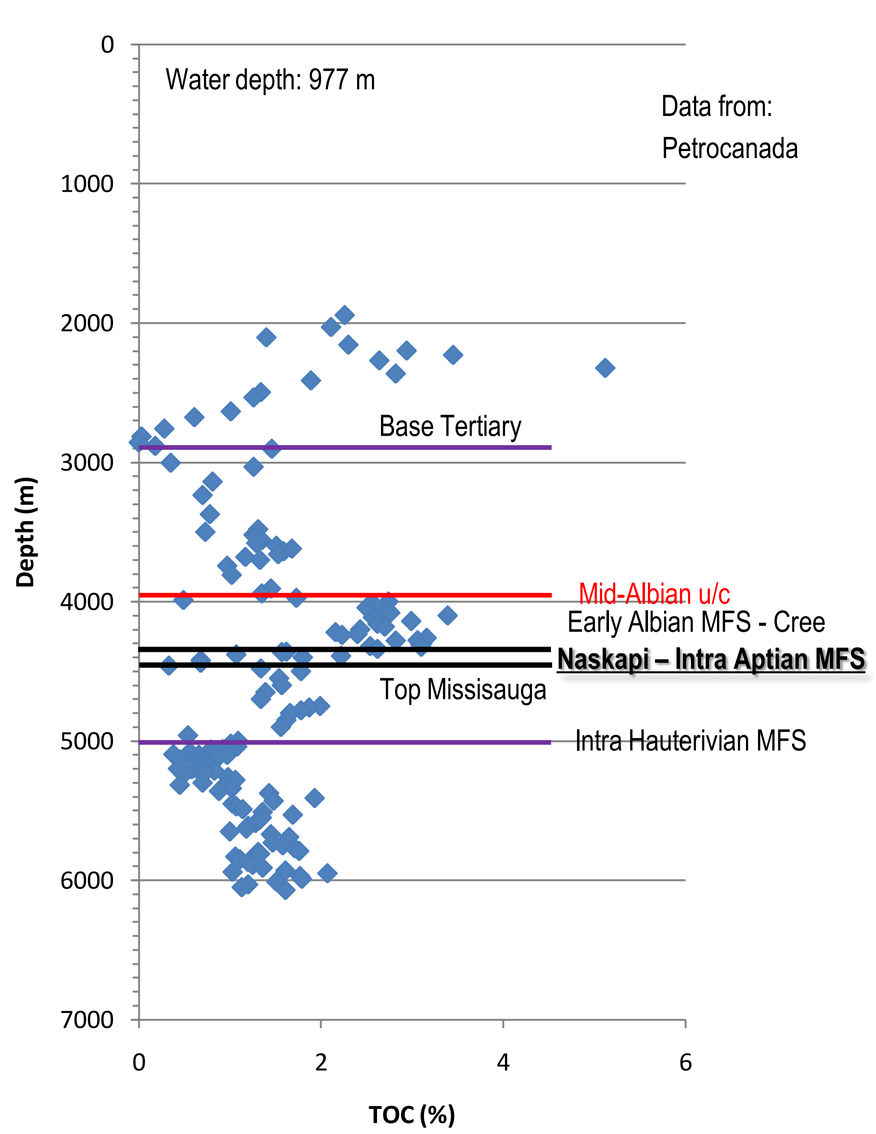
Naskapi (Intra Aptian MFS) source rock throughout the "Sable Basin"

BASIC CHARACTERISTICS:

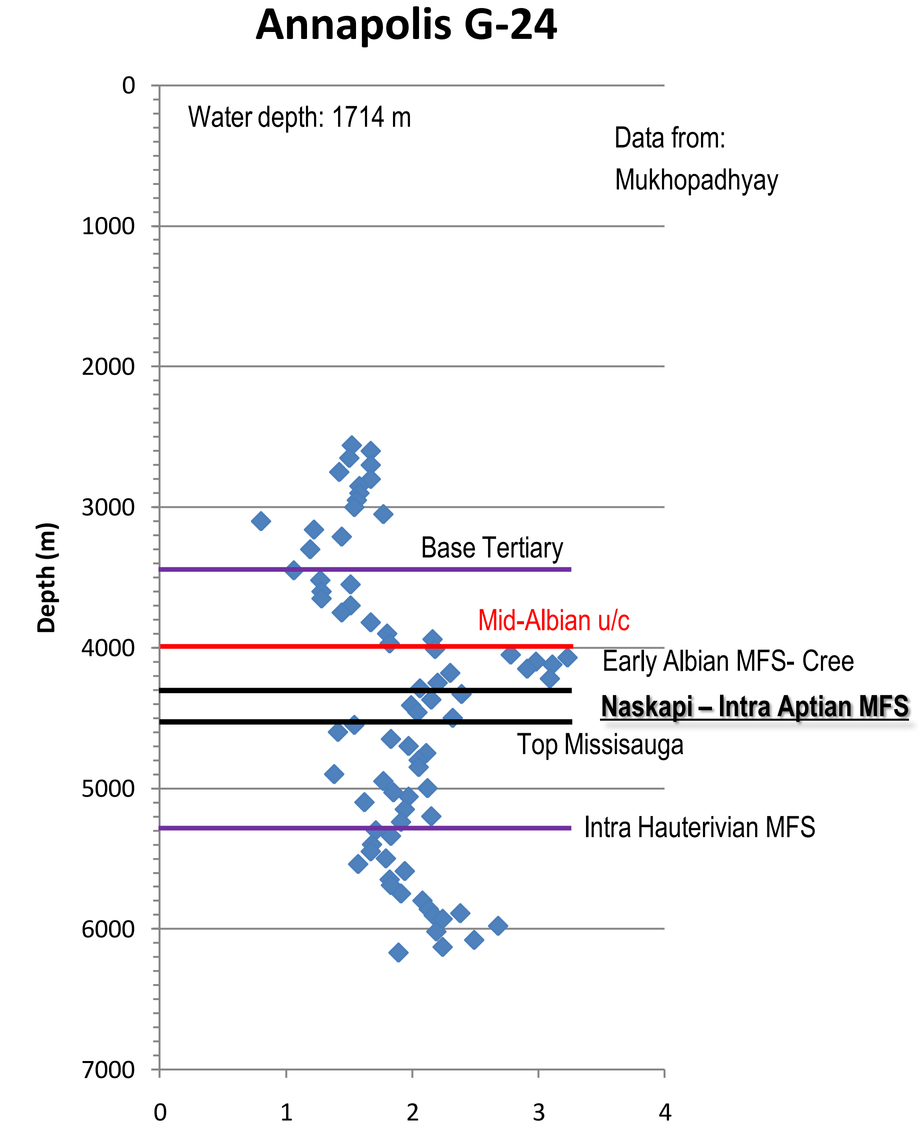
- TOC=2%
- Kerogen Type III
- Marginally mature locally only (see Modeling), the Naskapi source rock is considered minor
- For modeling purpose, the following characteristics were retained:
  - TOC=2%
  - Kerogen Type III



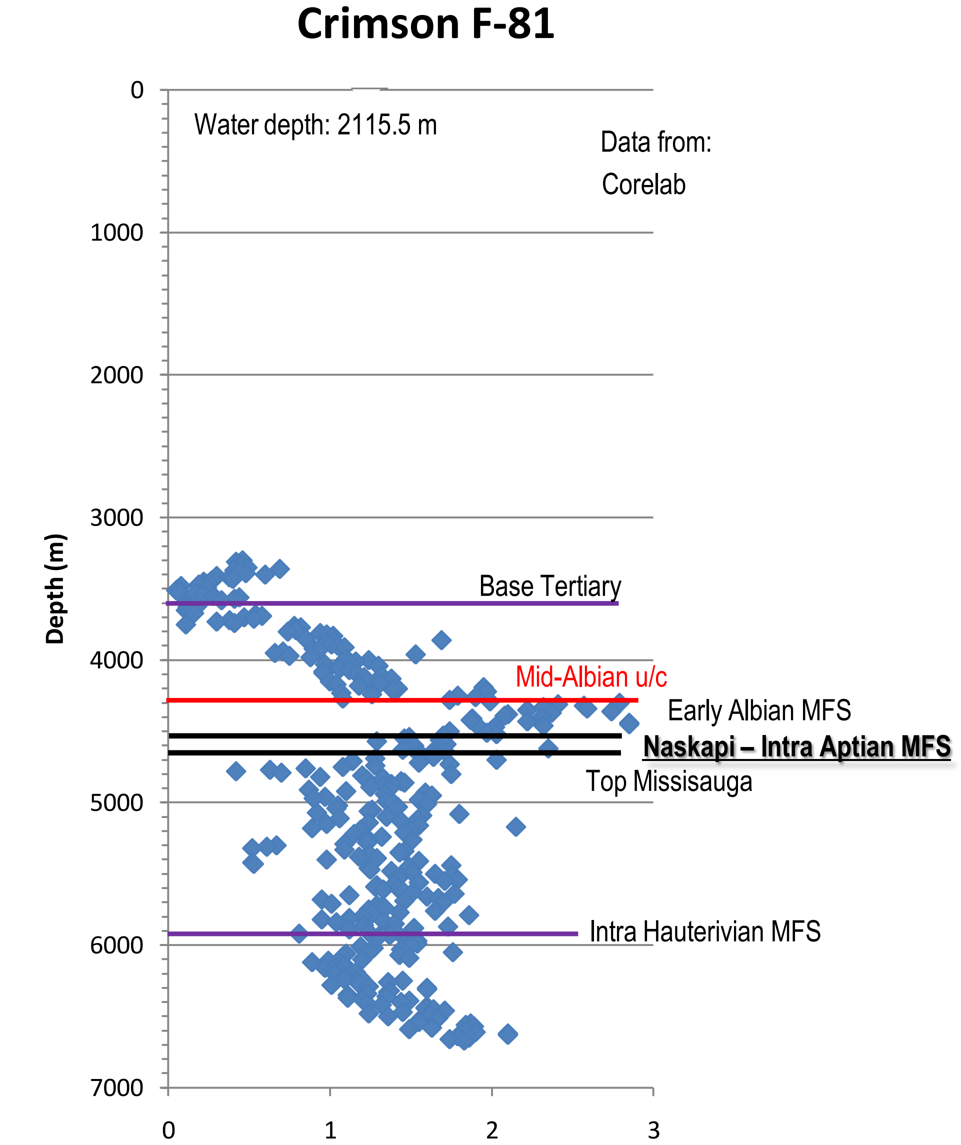
Newburn H-23



Annapolis G-24

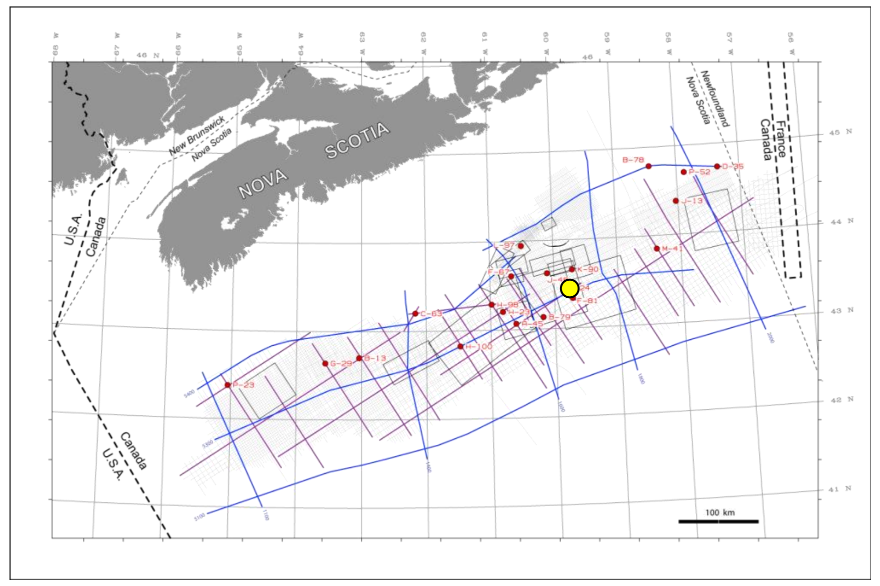


Crimson F-81



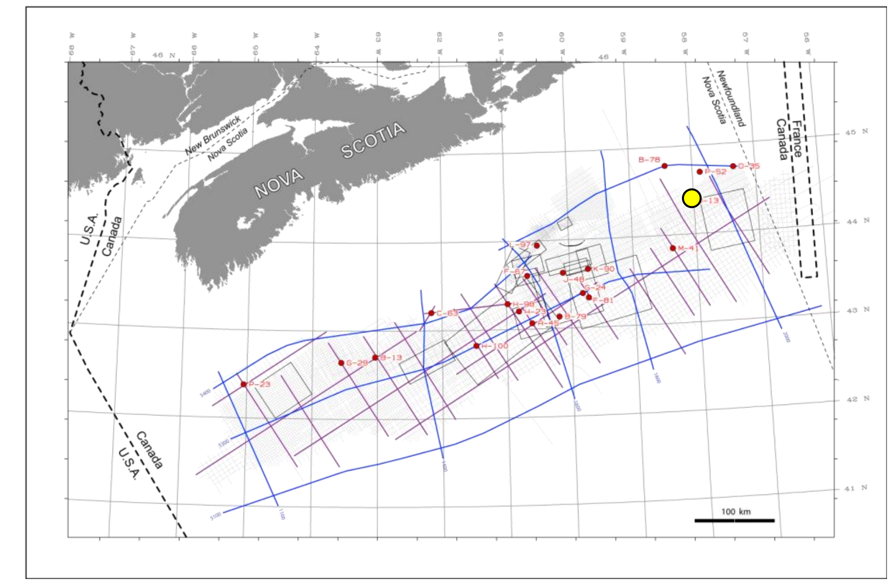
PETROLEUM GEOCHEMISTRY - SOURCE ROCKS

Annapolis G-24

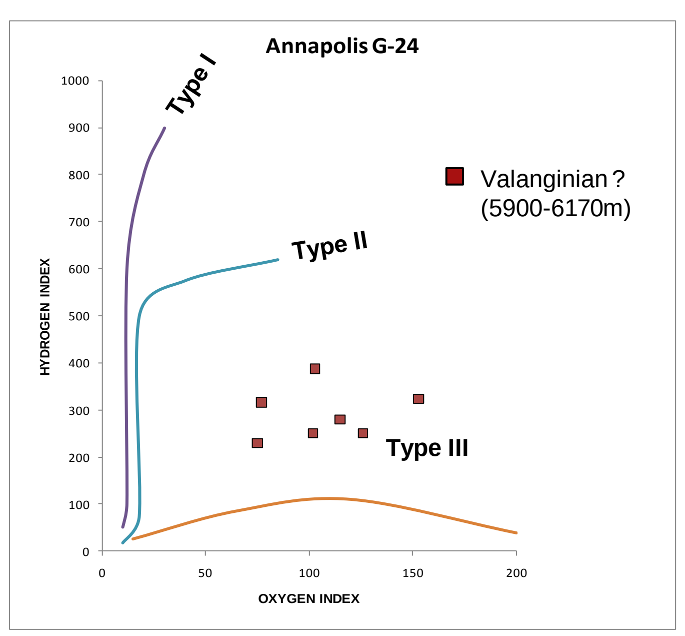


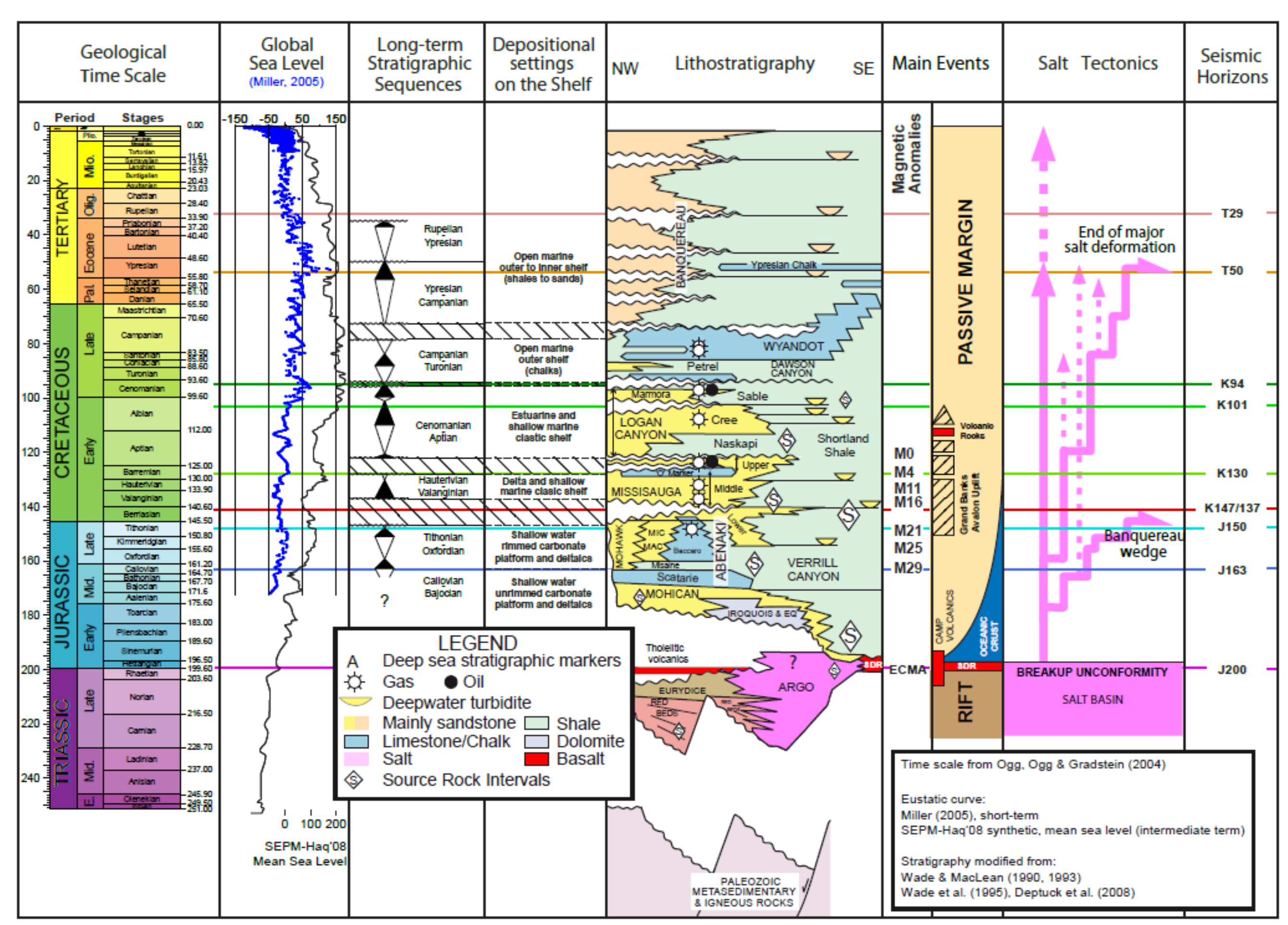
Top	Bottom	Units	Mud	Mud Additives	Event	Comments
5525	5525	M			FISH	MDT TOOL STUCK AT 5525 M - RECOVERED WITH OVERSHOT
5058	5058	M			KICK	3.0 M3 INFLUX WHILE CIRCULATING - MUD WEIGHT WAS MAINTAINED - INFLUX WAS CIRCULATED TO SURFACE
5508	5508	M				4.5 M3 KICK WHILE DRILLING - MUD WEIGHT INCREASED FROM 1582 TO 1654 KG/M3
5508	5508	M			LOST CIRC	77 M3 OF MUD WAS LOST WHEN MUD WEIGHT INCREASED TO 1726 KG/M3 AFTER KICK WAS CIRCULATED OUT
1714	2532	M	SEAWATER - PHG SWEEPS		MUD	
2532	6182	M	PARADRIL IA			SYNTHETIC OIL-BASED MUD
4450	4865	M			MUD MOTOR	INTERVAL DRILLED WITH DOWNHOLE MOTOR
4998	5058	M				

South Griffin J-13

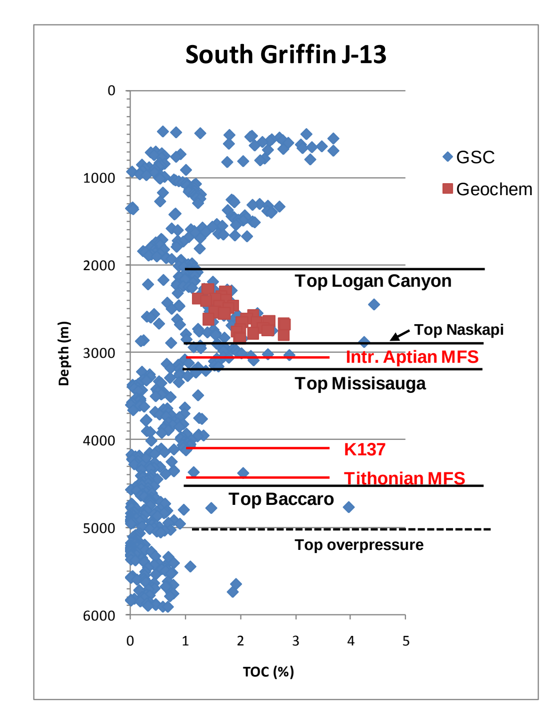


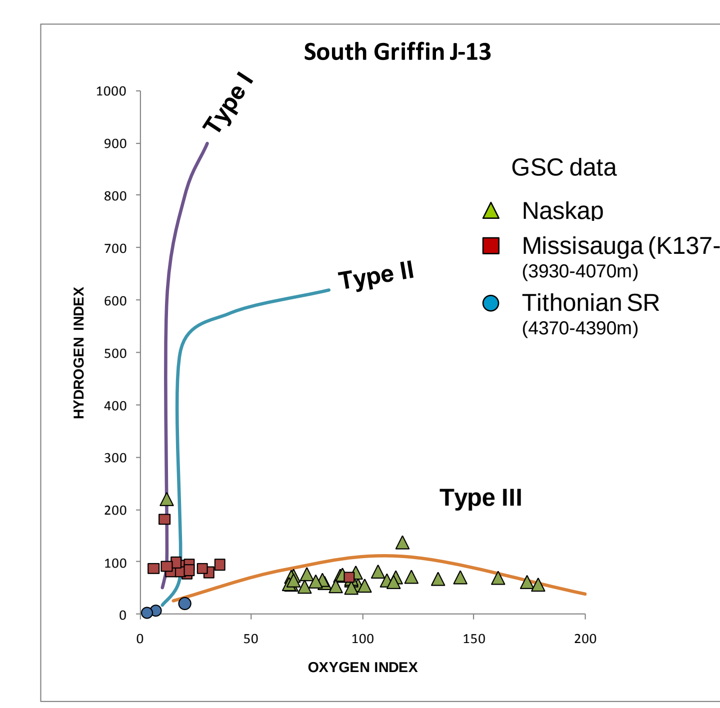
Top	Bottom	Units	Mud	Mud Additives	Event	Comments
924.5		M			FISH	DRILL STRING PARTED - FISH RECOVERED WITH AN OVERSHOT
3115.4		M				
4027.7		M				TWO BIT CONES LOST - MILLED ON JUNK & RECOVERED SAME WITH A JUNK BASKET
4034.7		M				DRILL STRING PARTED - FISH RECOVERED WITH AN OVERSHOT
4120		M				THREE BIT CONES LOST - MILLED ON JUNK & RECOVERED SAME WITH A JUNK BASKET
103	342.9	M	SEAWATER		MUD	
342.9	917.5	M	SEAWATER - XCD			
917.5	3115.1	M	SEAWATER - KCL POLYMER			
3115.1	5911.1	M	FRESHWATER - LIGNOSULFONATE	LIGNITE, LIGNOSULFONATE		
3215.9	3258.9	M			MUD MOTOR	TURBO DRILLED INTERVAL
3332.1	3450	M				
4178.5	4181.6	M				
4340	4356.2	M				





The large Hydrogen and Oxygen Indices below 3115m down to TD reflect contamination by mud additive (Lignosulfonate). Below the Tithonian MFS, HI values are too high for the elevate level maturity of that section of the well.



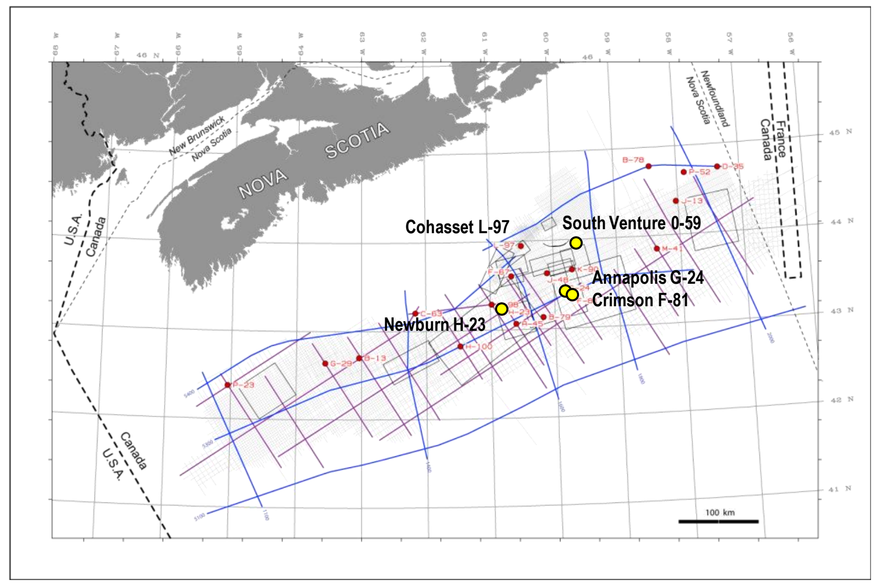


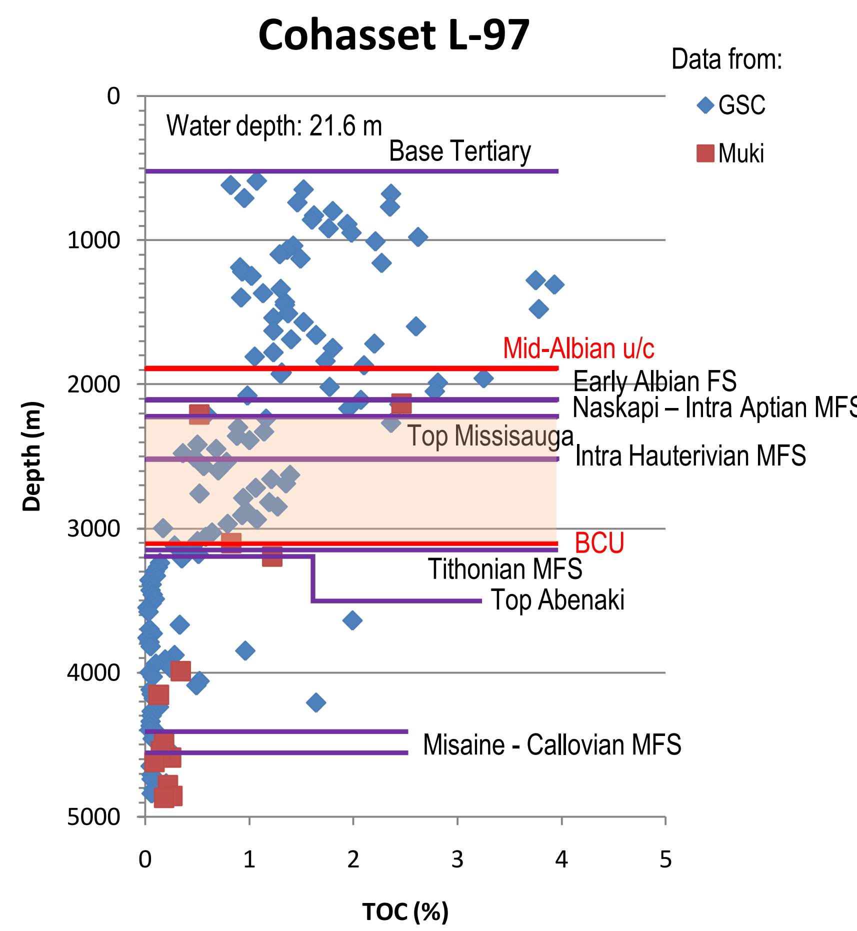
BASIC CHARACTERISTICS:

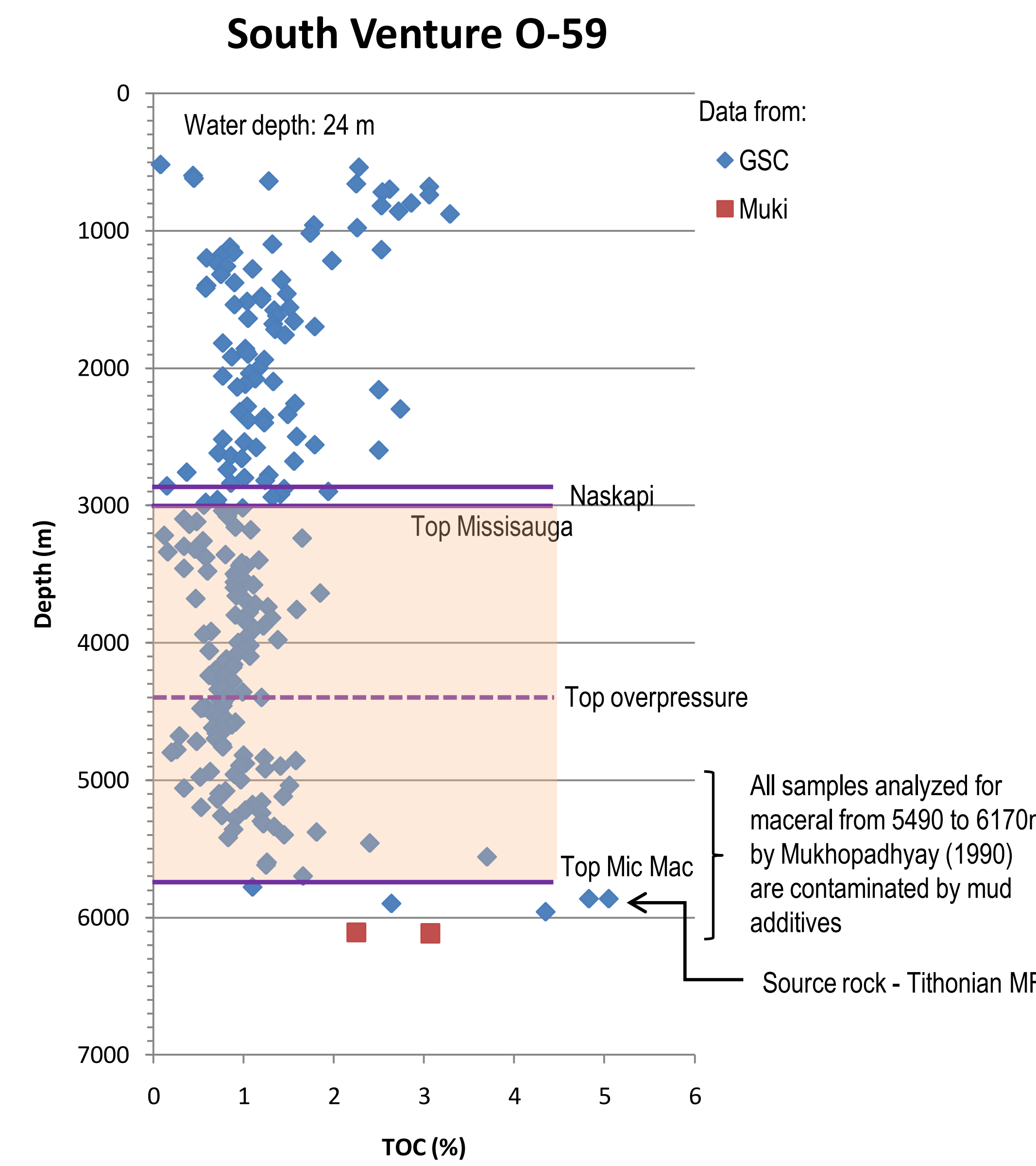
- TOC comprised between 1 and 2%
- Kerogen Type III
- The Berriasian/Valanginian source rock is considered minor but it honors the presence of the background source potential contained in the Missisauga that needs to be accounted for in Petroleum System modeling
- For modeling purpose, the following characteristics were retained:
  - TOC=1% (conservative)
  - Kerogen Type III

Source Rock –Valanginian

PETROLEUM GEOCHEMISTRY - SOURCE ROCKS



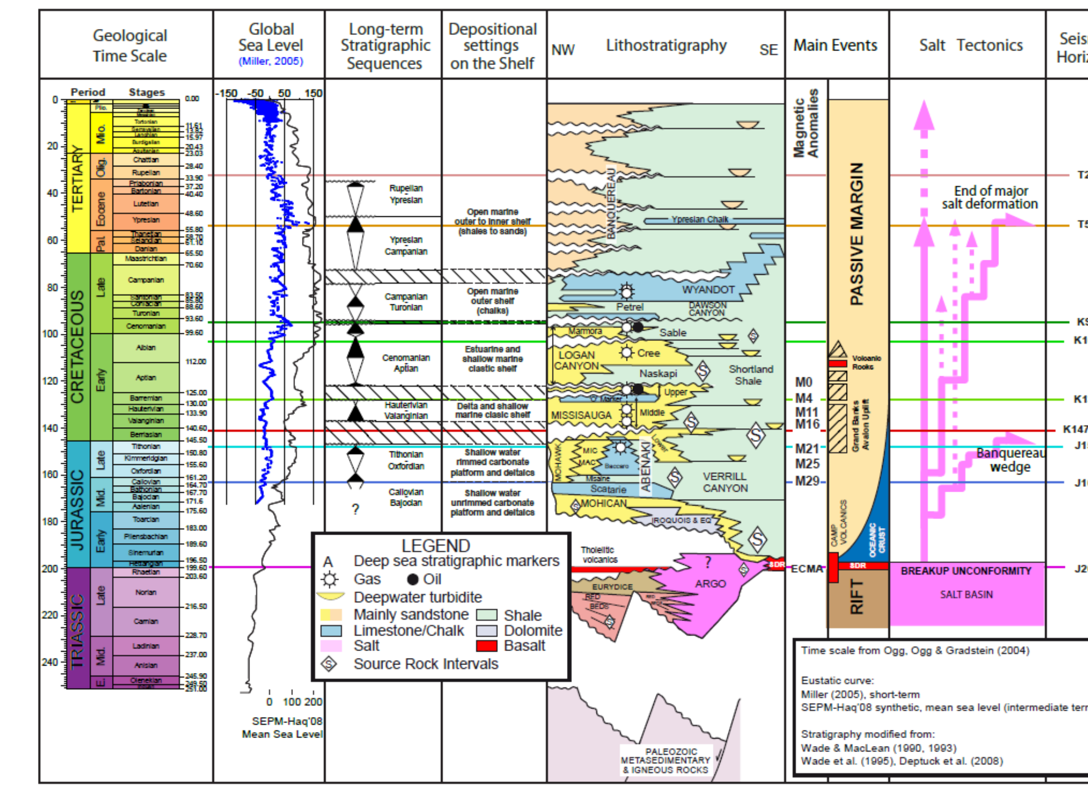


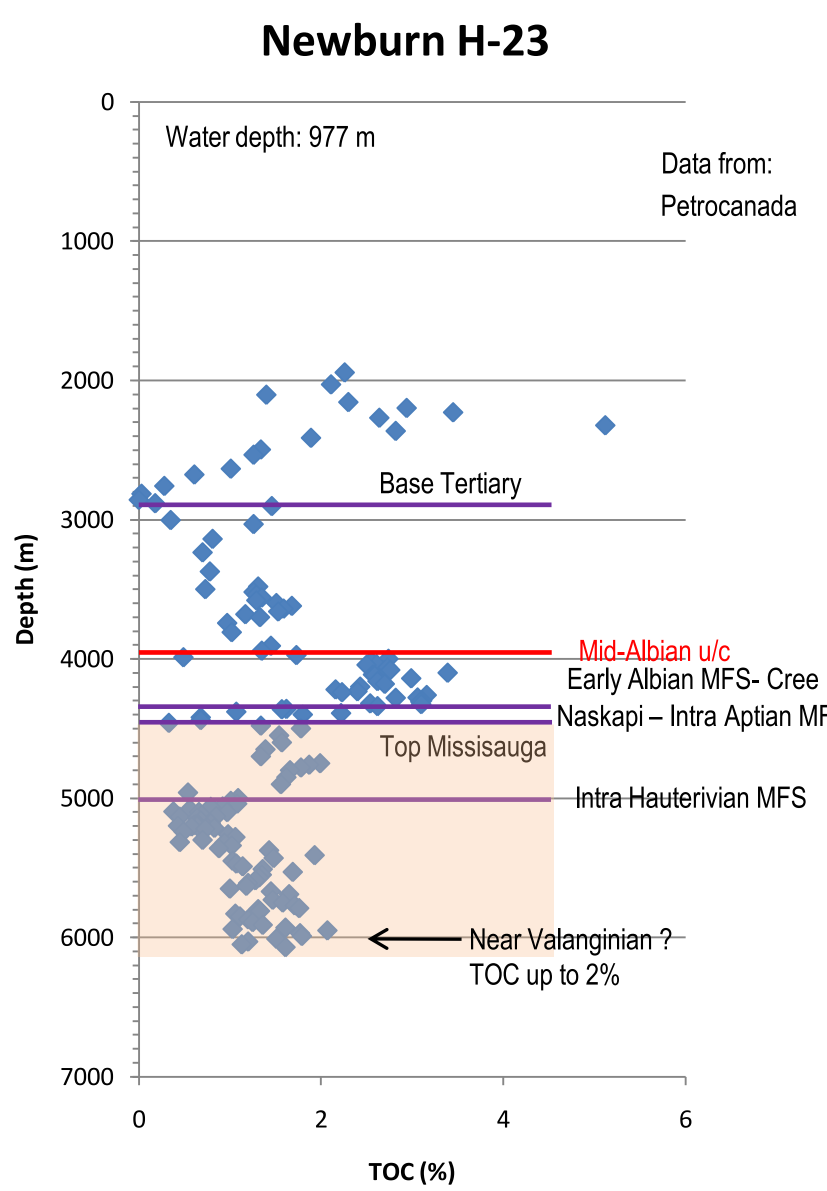


Berriasian/Valanginian source rocks throughout the "Sable Basin"

BASIC CHARACTERISTICS:

- TOC comprised between 1 and 2.5%
- Kerogen Type III
- The Berriasian/Valanginian source rock is considered minor but it honors the presence of the background source potential contained in the Missisauga that needs to be accounted for in Petroleum System modeling
- For modeling purpose, the following characteristics were retained:
  - TOC=1% (conservative)
  - Kerogen Type III

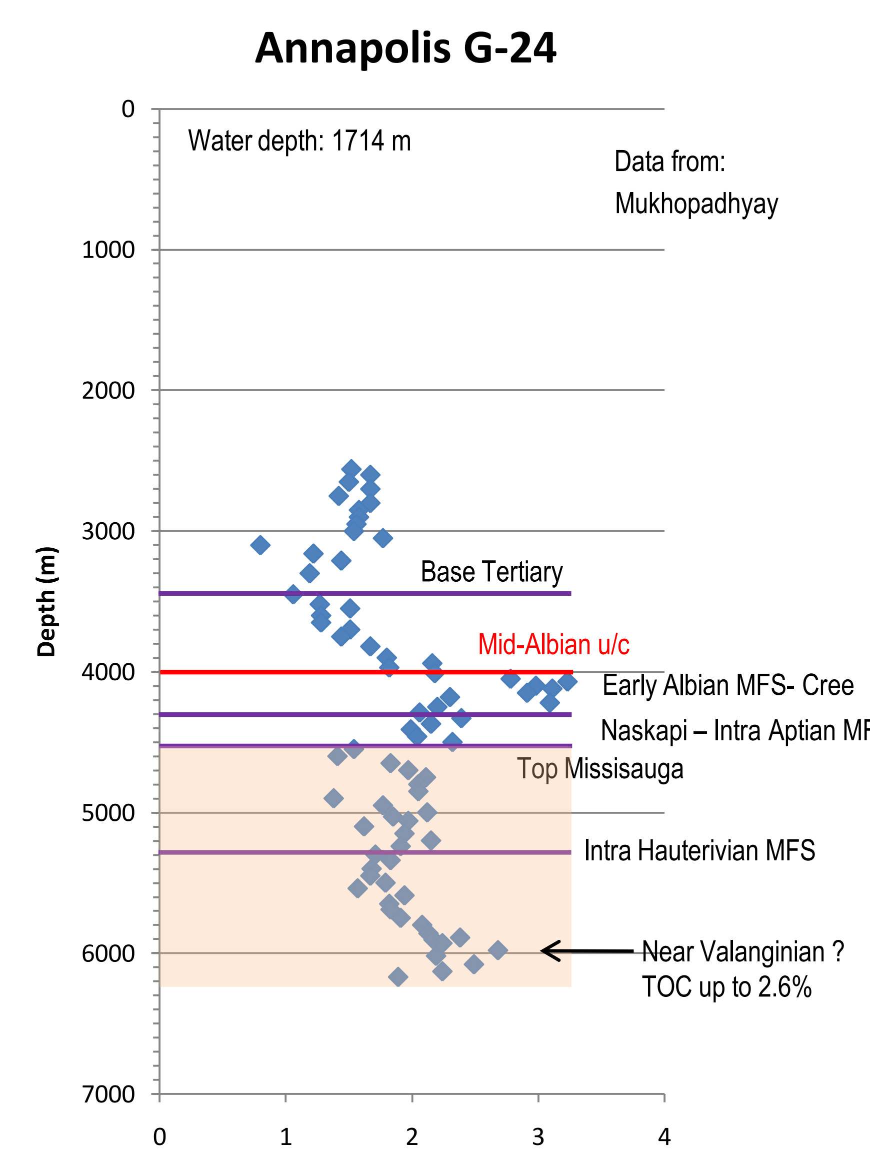


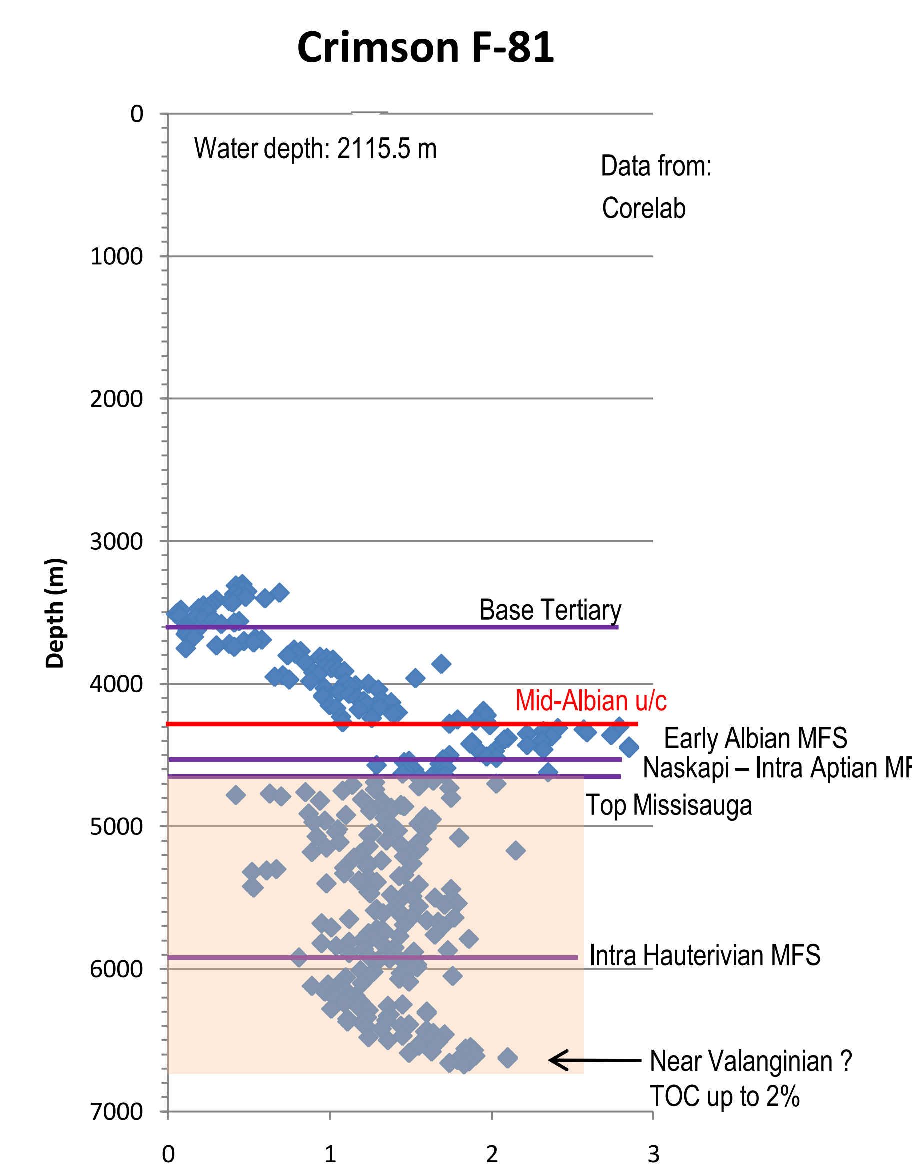


IN DISTAL POSITION:

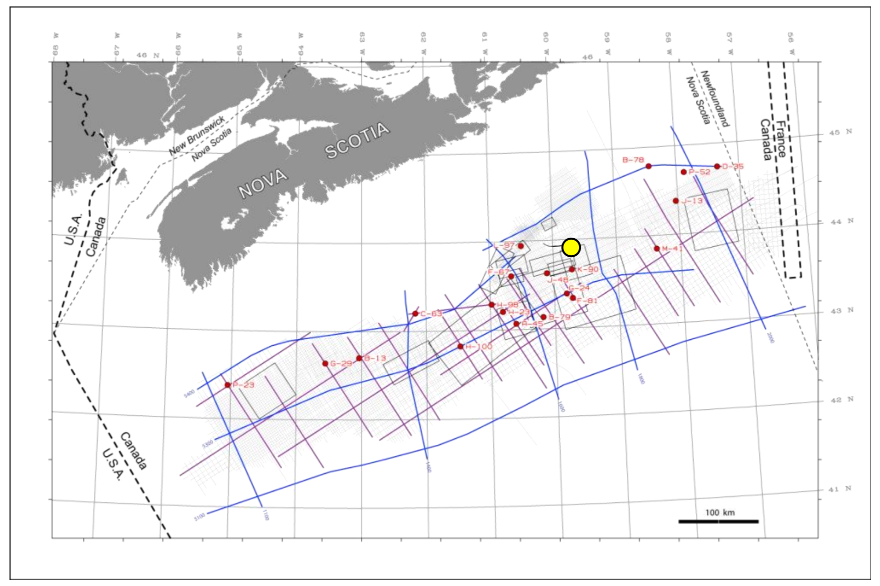
The TOC of the basal Cretaceous source interval improves:

- TOC comprised between 1.5% and 2.5%
- Kerogen Type III
- The whole Missisauga Formation is sufficiently organic-rich in Annapolis and Crimson to charge the surrounding Missisauga reservoirs if mature, which is the case.

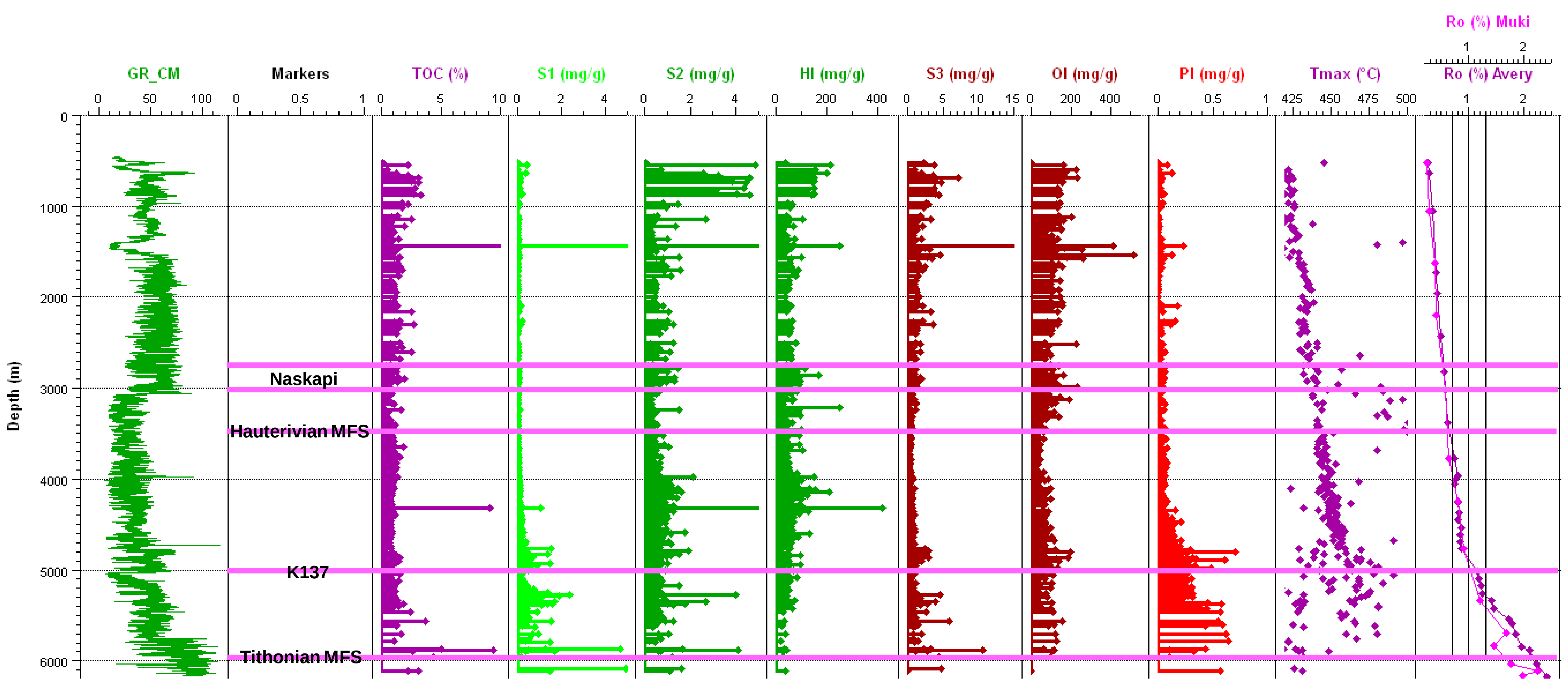




South Venture O-59



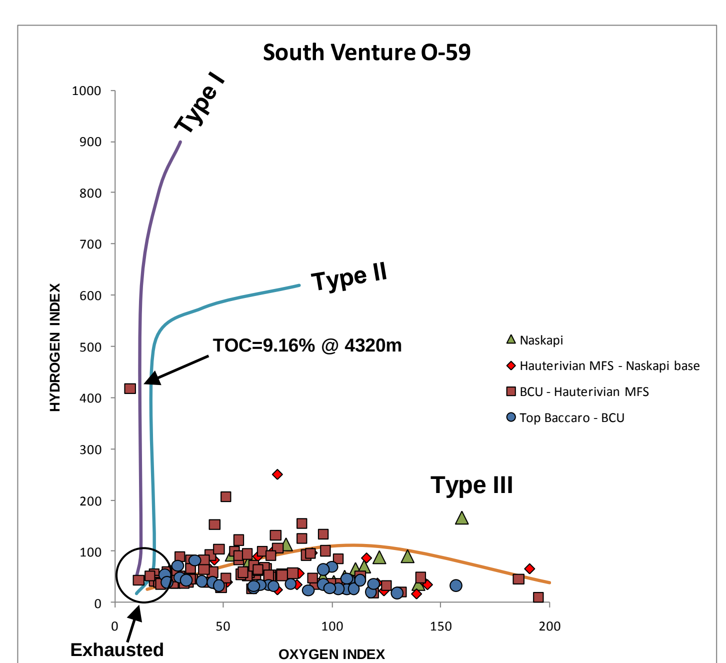
Top	Bottom	Units	Mud	Mud Additives	Event	Comments
513		M			FISH	ONE ARM FROM A REAMER LOST - EVENTUALLY RECOVERED WITH A JUNK BASKET
4766		M				RFT TOOL STUCK AT 3657 METRES - FISH RECOVERED WITH AN OVERSHOT
5756		M				SEVERAL SIDEWALL CORE BULLETS LEFT IN THE HOLE AFTER A SWC RUN - RECOVERED WITH A JUNK BASKET
4766		M			KICK	GAS LEVELS ROSE WHILE TRIPPING OUT OF THE HOLE - MUD WEIGHT RAISED BY 0.5 PPG (FROM 13 TO 13.5 PPG)
5036		M				GAS LEVELS ROSE WHILE DRILLING - MUD WEIGHT RAISED BY 2.5 PPG (FROM 14.4 TO 16.9 PPG)
3083		M			LOST CIRC	MUD LOSSES OF 3.5 BBLS/HOUR REDUCED WITH THE PLACEMENT OF AN LCM PILL
3530		M				MUD LOSSES OF 10-15 BBLS/HOUR REDUCED WITH THE PLACEMENT OF AN LCM PILL
4343		M				MUD LOSSES REDUCED FROM 25 TO 8 BBLS/HOUR WITH THE PLACEMENT OF A 25 PPG MICA PILL & KILL MUD
59	189	M	SEAWATER - BENTONITE PILLS		MUD	
189	3085	M	SEAWATER - POLYMER			
3085	6176	M	FRESHWATER - POLYMER			
3696	3817	M			MUD MOTOR	TURBO DRILLED INTERVAL
4852	4854	M				
4910	4980	M				
4999	5047	M				
5176	5236	M				
5422	5753	M				
5771	6176	M				DYNA-DRILLED INTERVAL



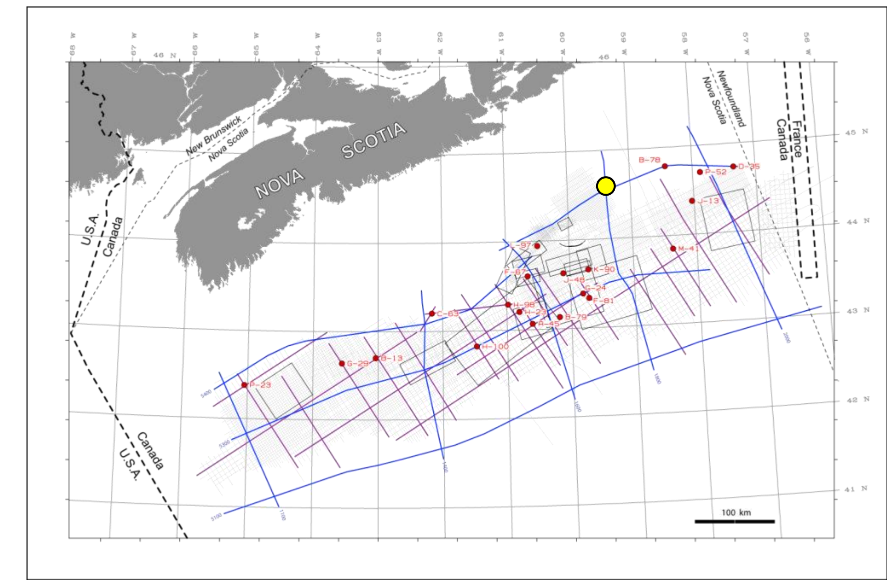
Organic facies in the interval TD to ~K137

	DEPTH (m)	TOC (%)	VR Ro (%)	OXIDATION LEVEL	ENVIRONMENT	ORGANIC INPUT	KEROGEN TYPE	OIL/GAS POTENTIAL
	4940	0.63	1.05	Anoxic (partially)	Inner neritic - marginal marine	Mixed	IIA-IIB	Oil/Condensate
	4980	0.52	1.12	Anoxic (partially)	Inner neritic - marginal marine	Mixed	IIA-IIB	Oil/Condensate
	5175	n/a	1.22	Mildly anoxic	Inner neritic - marginal marine	Terrestrial	IIB	Cond.-Gas/Oil
	5255	n/a	1.25	Mildly anoxic	Inner neritic - marginal marine	Terrestrial	IIB	Cond.-Gas/Oil
	5420	0.83	1.45	Anoxic (partially)	Inner neritic - marginal marine	Mixed	IIA-IIB	Gas/Cond.
	5590	n/a	1.78	Mildly oxic	Inner/outer neritic - marg. marine	Mixed	IIB	Gas/Cond.
Tithonian	5700	1.66	1.85	Mildly oxic	Inner/outer neritic - marg. marine	Mixed	IIB-III	Gas/Cond.
Tithonian	5865	4.83	2.13	Mildly anoxic	Inner/outer neritic - marg. marine	Mixed	IIB	Cond.-Gas/Oil
Tithonian	6080	n/a	2.2	Mildly anoxic	Inner/outer neritic - marg. marine	Mixed	IIB	Cond.-Gas/Oil
Tithonian	6115	3.07	2.25	Anoxic (partially)	Inner/outer neritic - marg. marine	Mixed	IIA-IIB	Oil/Condensate
Tithonian	6170	n/a	2.42	Mildly anoxic	Inner/outer neritic - marg. marine	Mixed	IIB	Cond.-Gas/Oil

Reference:
P. K. Mukhopadhyay & Wade J. A. 1990. Organic facies and maturation of sediments from three Scotian Shelf wells. Bulletin of Canadian Petroleum Geology, Vol. 38, No. 4, pp. 407-425

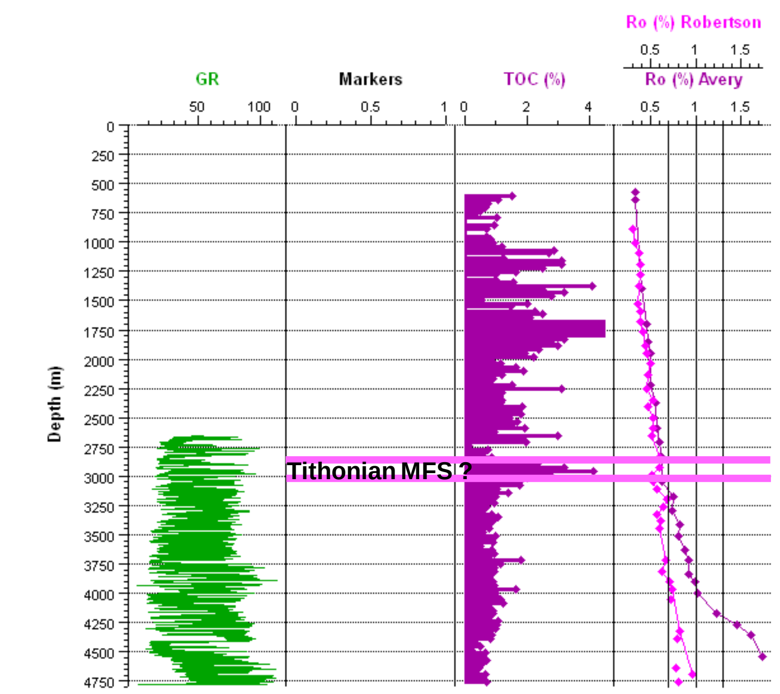


Mic Mac H-86



Top	Bottom	Units	Mud	Mud Additives	Event	Comments
13707		FT			FISH	PIPE STUCK IN HOLE - CIRCULATED 45 BARRELS OF DIESEL & 40 BARRELS OF PIPELAX - WORKED PIPE FREE
263	964		TREATED GEL		MUD	
964	15700		DLS	FIBRE, NUTPLUG, CELLOSEAL, SPERSENE, CROMEX, PIPELAX, DIESEL		

DLS = Dispersed Lignosulphonate

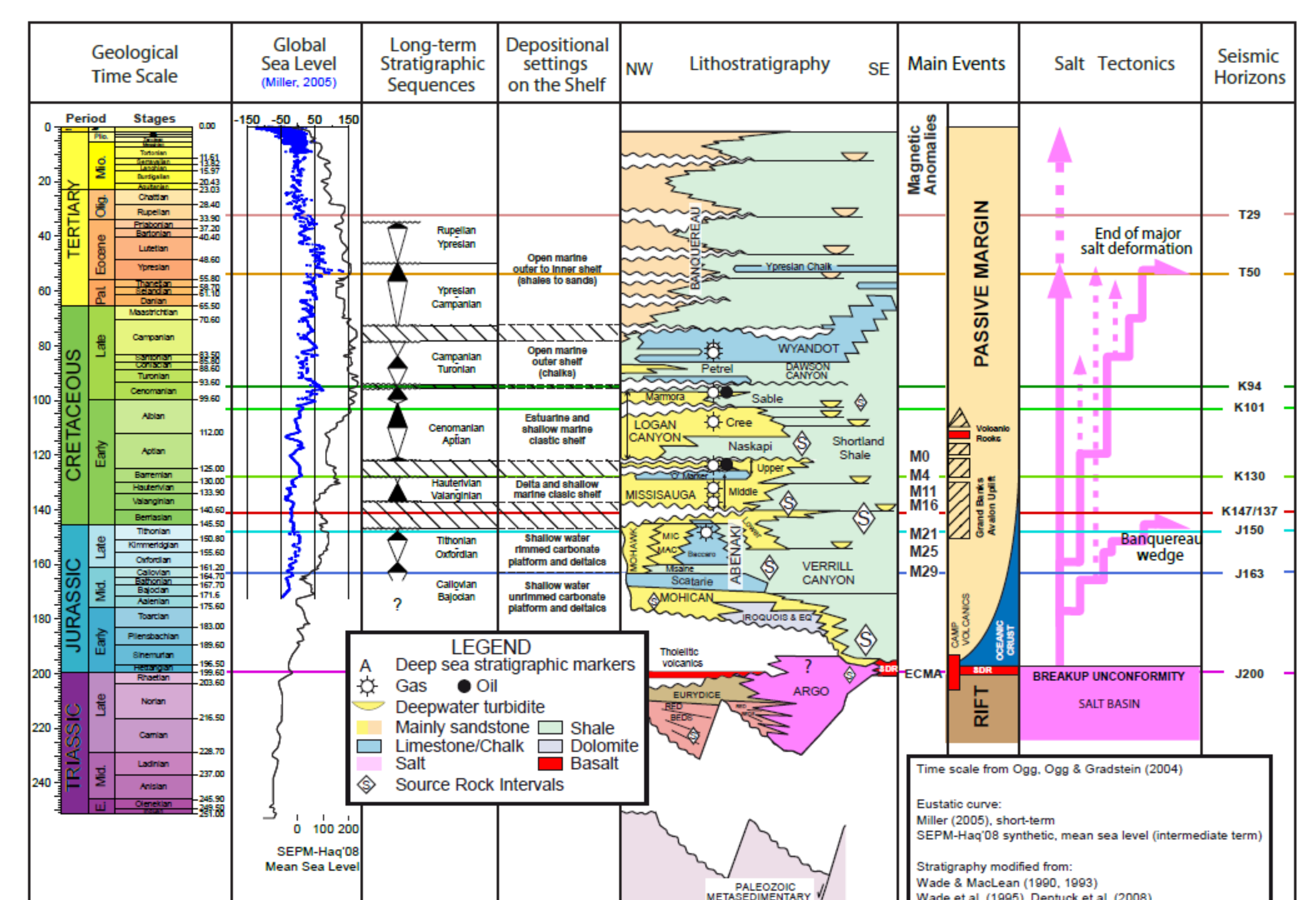


The Tithonian source rock in South Venture O-59

- ✓ South Venture O-59 is not contaminated by any mud additives.
- ✓ Kerogen microscopy (Maceral) indicates Type IIA-IIB, Gas-Condensate/Oil prone (see Organic facies Table from Mukhopadhyay 1990, left)
- ✓ Below 5000m, where is located the Tithonian MFS, maturity is high (Ro>1.22%), Tmax reaching 460°C tends to disappear by lack of remaining generative potential (Rock Eval S2 peak).
- ✓ HI x OI diagram indicates a Tithonian source rock (SR) depleted in generative potential, consistent with a level of maturity Ro>1.8%

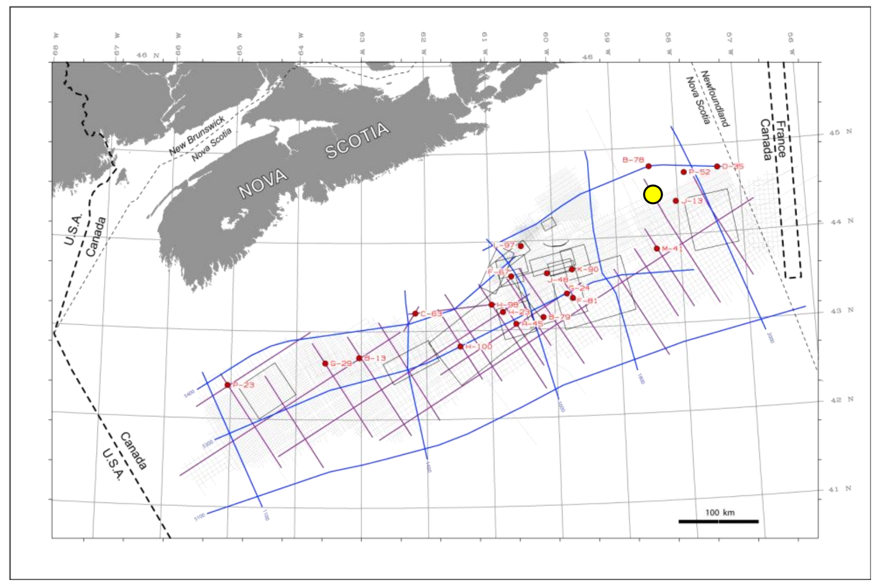
The Tithonian source rock in Mic Mac H-86

- ✓ Mic Mac H-86 is contaminated by mud additive Dispersed Ligno-Sulfonate: DLS)
- ✓ Data are limited to TOC and maturity
- ✓ TOC reaches values of 2 to 4% at the level of the Tithonian MFS as derived from structural maps Top Baccaro and BCU (This Study)
- ✓ Ro=0.6% at the level of the Tithonian MFS indicates incipient maturity only or onset of the oil window

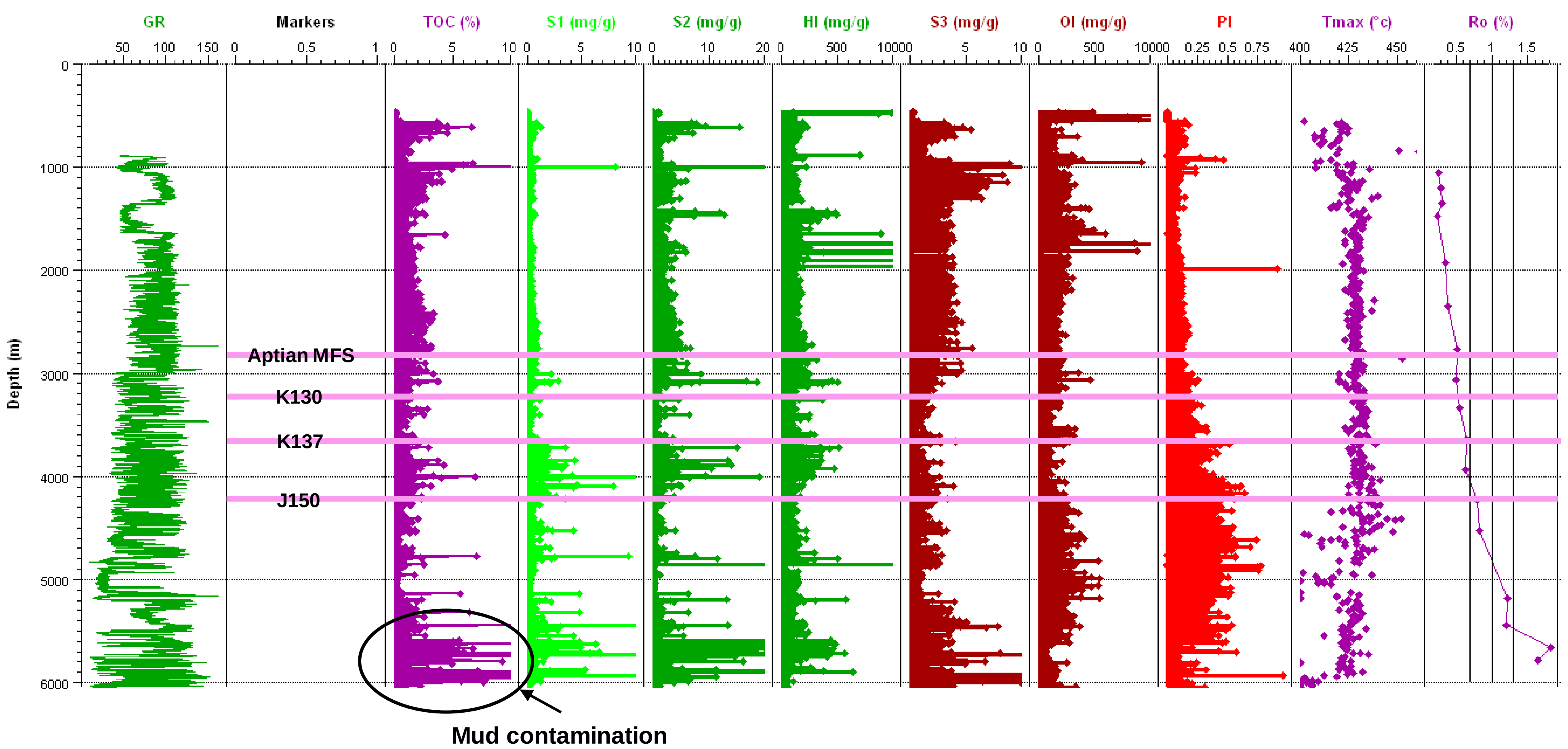


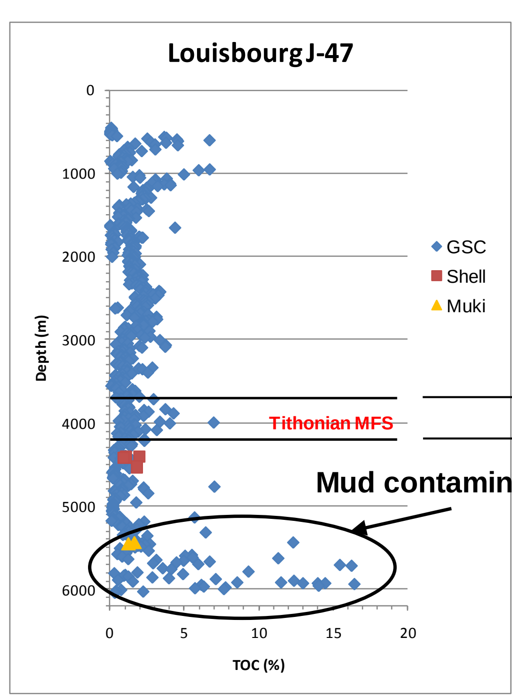
PETROLEUM GEOCHEMISTRY - SOURCE ROCKS

Louisbourg J-17

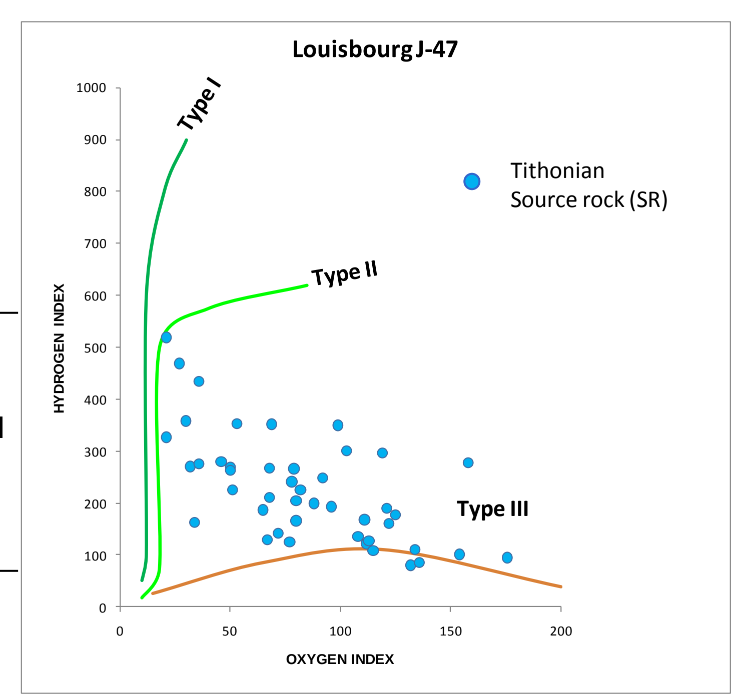


Top	Bottom	Units	Mud	Mud Additives	Event	Comments
370		M			FISH	660 MM HOLE OPENER STUCK - FISH RECOVERED
5386.5		M				DRILL COLLARS DROPPED IN HOLE - FISH RECOVERED
5475		M				BOTTOM HOLE TOOLS & TEST STRING STUCK IN HOLE AT 5475 M - TEST STRING RECOVERED - TOOLS LEFT IN HOLE
5838.5		M				LOGGING TOOL STUCK IN HOLE - FISH NOT RECOVERED
5840		M				PERFORATING ASSEMBLY STUCK IN HOLE AT 5752 - FISH PUSHED TO 5840 M WITH DRILL STRING - NOT RECOVERED
6511		M			KICK	INCREASED MUD WEIGHT BY 97 KG/M3 (FROM 2096 TO 2193 KG/M3)
101	262.4	M	SEAWATER - GEL-POLYMER SWEEPS		MUD	
262.4	898.2	M	GEL-POLYMER			
898.2	6042.4	M	KCL			
5455.1	5538.9	M			MUD MOTOR	TURBO DRILLED INTERVAL
5696.2	5738.5	M				
5847.4	5869.1	M				

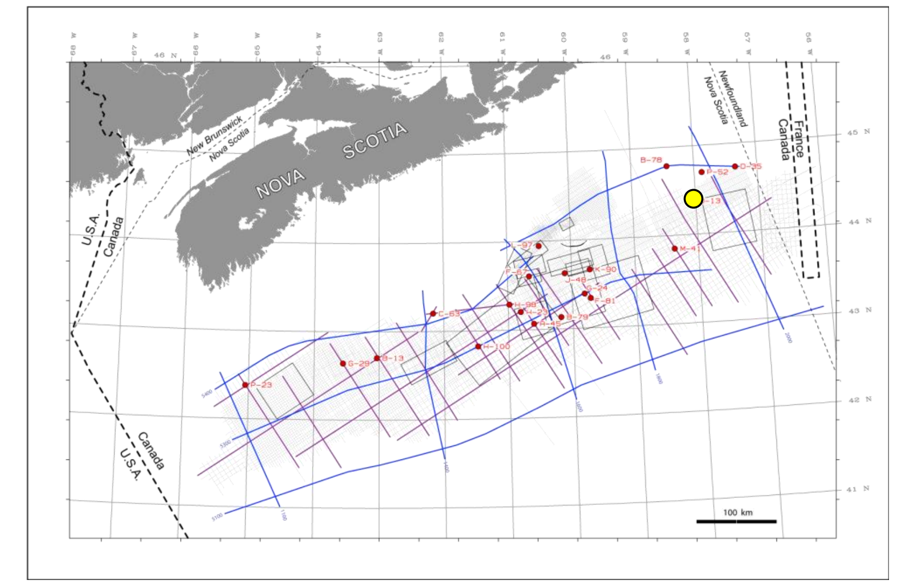




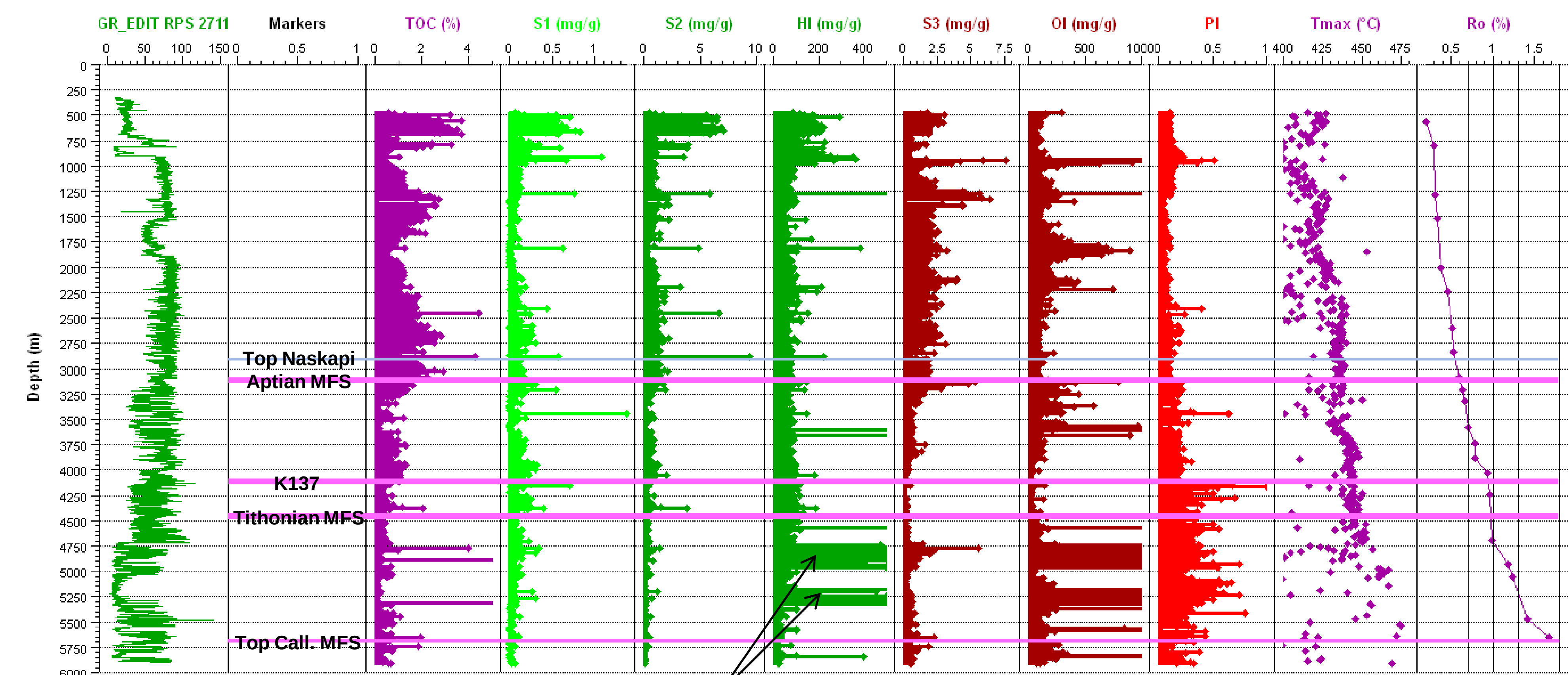
All data from the Tithonian MFS interval are plotted in the HIxOI diagram

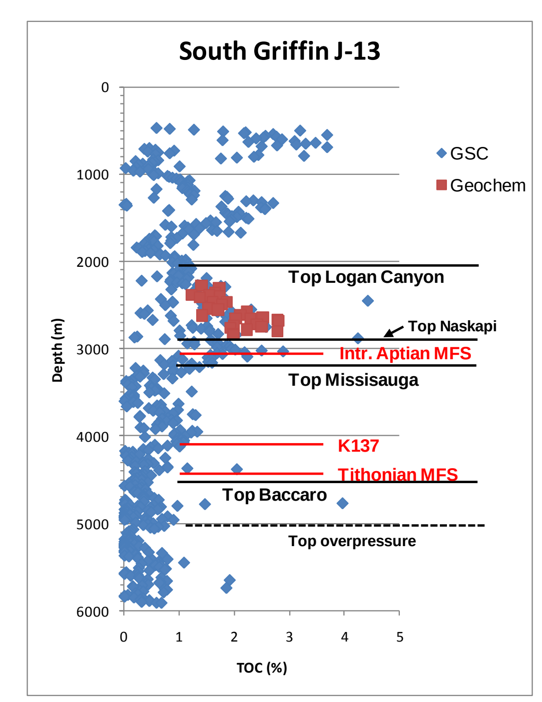


South Griffin J-13

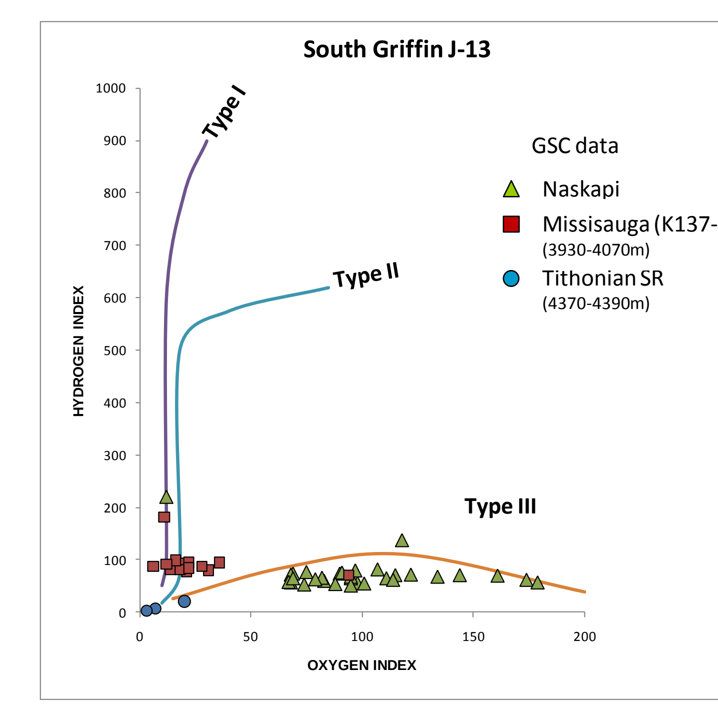


Top	Bottom	Units	Mud	Mud Additives	Event	Comments
924.5		M			FISH	DRILL STRING PARTED - FISH RECOVERED WITH AN OVERSHOT
3115.4		M				
4027.7		M				TWO BIT CONES LOST - MILLED ON JUNK & RECOVERED SAME WITH A JUNK BASKET
4034.7		M				DRILL STRING PARTED - FISH RECOVERED WITH AN OVERSHOT
4120		M				THREE BIT CONES LOST - MILLED ON JUNK & RECOVERED SAME WITH A JUNK BASKET
103	342.9	M	SEAWATER		MUD	
342.9	917.5	M	SEAWATER - XCD			
917.5	3115.1	M	SEAWATER - KCL POLYMER			
3115.1	5911.1	M	FRESHWATER - LIGNOSULFONATE	LIGNITE, LIGNOSULFONATE		
3215.9	3258.9	M			MUD MOTOR	TURBO DRILLED INTERVAL
3332.1	3450	M				
4178.5	4181.6	M				
4340	4356.2	M				





The large Hydrogen and Oxygen Indices below 3115m down to TD reflect contamination by mud additive (Lignosulfonate). Below the Tithonian MFS, HI values are too high for the elevate level maturity of that section of the well.



Organic facies in the interval J150 to K137 (Tithonian)

DEPTH (m)	TOC (%)	VR Ro (%)	OXIDATION LEVEL	ORGANIC INPUT	KEROGEN TYPE	OIL/GAS POTENTIAL
3995	3.36	0.7	mildly anoxic (shallow marine)	Terrestrial	IIB-III	Gas/Cond.
4005	1.71	0.7	mildly oxic (shallow marine)	Terrestrial	III	Gas

Organic facies in the interval TD to J150 (Mic Mac Oxfordian?)

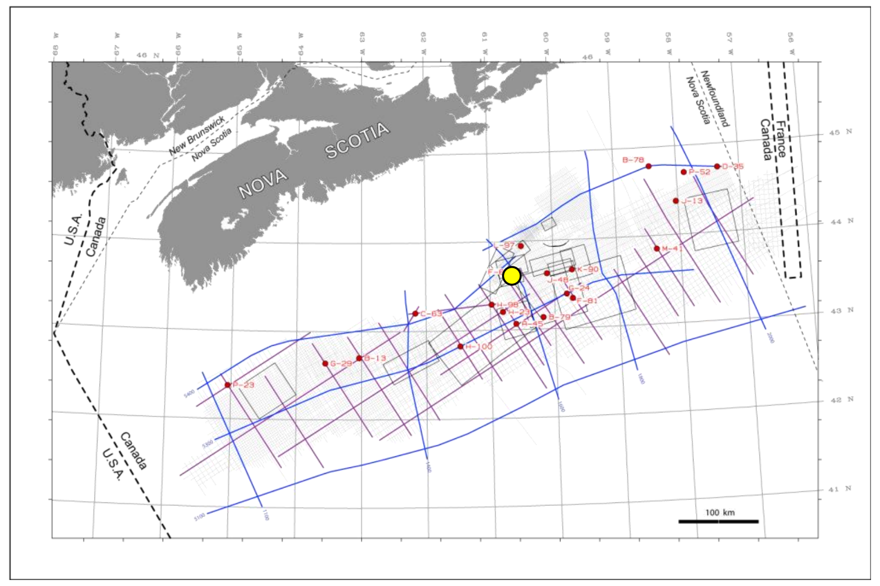
DEPTH (m)	TOC (%)	VR Ro (%)	OXIDATION LEVEL	ORGANIC INPUT	KEROGEN TYPE	OIL/GAS POTENTIAL
5455	2.15	~1.3	mildly anoxic (shallow marine)	Mixed	IIB	Cond./Oil/Gas
5580	0.49	~1.6	mildly anoxic (shallow marine)	Terrestrial	IIB	Gas/Cond.
5655	3.12	1.81	mildly anoxic (shallow marine)	Mixed	IIB	Cond./Gas

Reference:
P. K. Mukhopadhyay & Wade J. A. 1990. Organic facies and maturation of sediments from three Scotian Shelf wells. Bulletin of Canadian Petroleum Geology, Vol. 38, No. 4, pp. 407-425

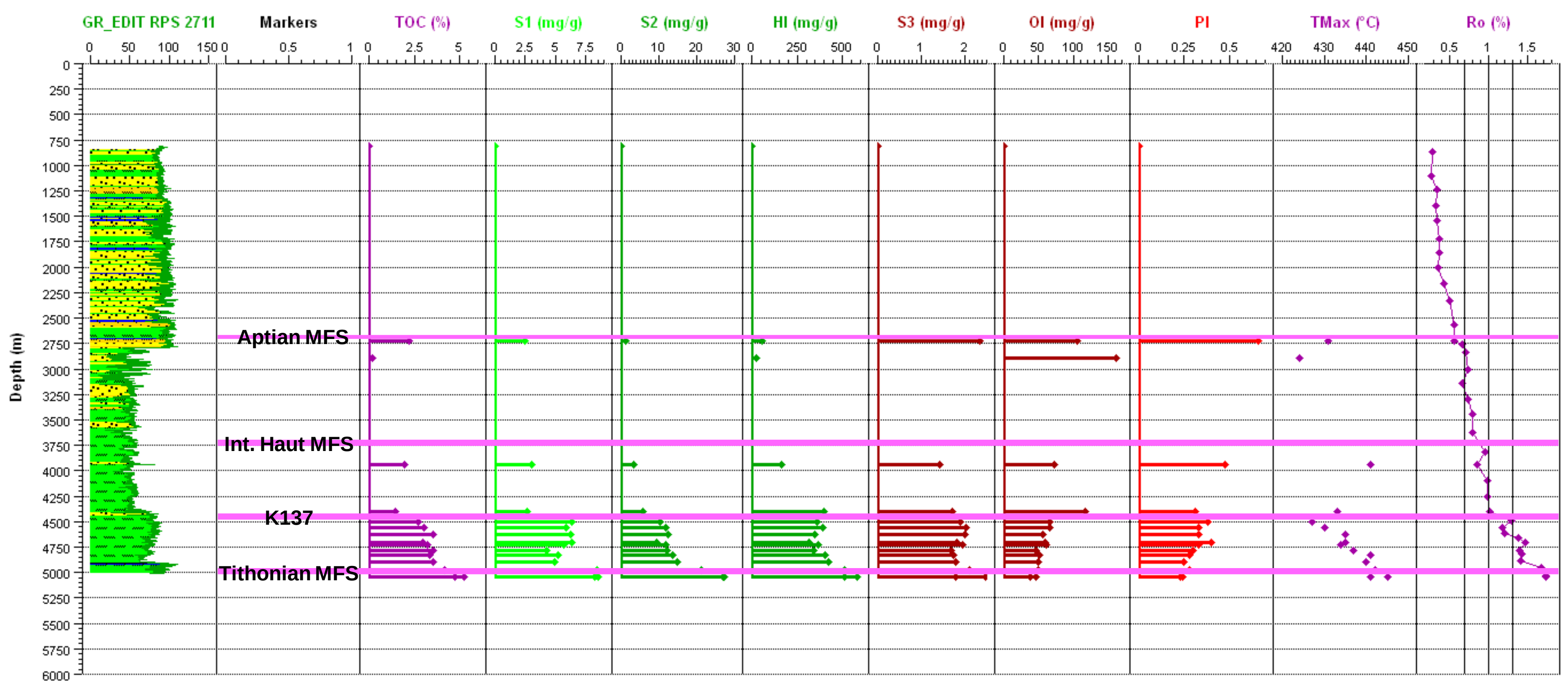
The Tithonian source rock is well developed in Louisbourg J-47 and South Griffin J-13

- ✓ Maximum TOC reaches up to 7%, averaging 3% in Louisbourg J-47 at a
- ✓ Moderate level of maturity of Ro=0.7%
- ✓ Hydrogen and Oxygen Indices (HI & OI, respectively) indicate a mix Type II-III kerogen (see HI x OI diagram, left)
- ✓ In South Griffin J-13, the Tithonian source rock is deeper buried but quite more mature with HI x OI values showing a generative potential exhausted

Alma F-67



Top	Bottom	Units	Mud	Mud Additives	Event	Comments
3655		M			FISH	STUCK PIPE WAS JARRED FREE
4018		M				STUCK PIPE WAS BACKED OFF & RECOVERED WITH FISHING JARS
4380		M				PIPE WAS CEMENTED TO CASING - BACKED OFF, MILLED & RECOVERED
4412		M			KICK	MUD WEIGHT RAISED BY 418 KG/M3 (FROM 1617 TO 2035 KG/M3) TO KILL THE WELL
4841		M				MUD WEIGHT RAISED BY 35 KG/M3 (FROM 2110 TO 2145 KG/M3)
110	830	M	SEAWATER - VISCOUS PILLS		MUD	
830	2811	M	KCL POLYMER			
2811	5054	M	BIOVERT			OIL-BASED MUD
3907	3947	M			MUD MOTOR	NAVI-DRILLED INTERVAL (DIRECTIONAL DRILLING)
4408	4446	M				TURBO DRILLED INTERVAL
4966	5054	M				DYNA-DRILLED INTERVAL



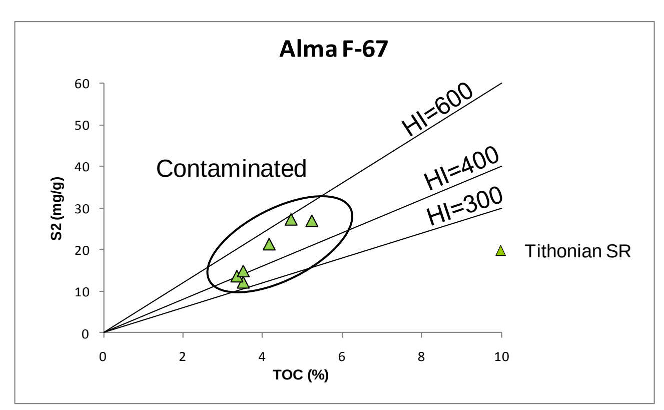
Organic facies in the interval J150 to K147/137 (Tithonian)

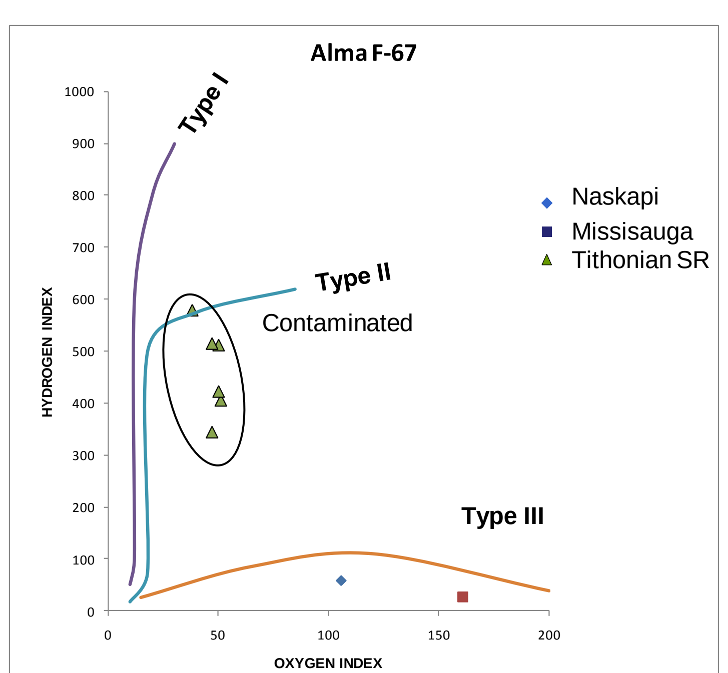
DEPTH (m)	TOC (%)	VR Ro (%)	OXIDATION LEVEL	ORGANIC INPUT	KEROGEN TYPE	HYDROCARBON POTENTIAL
4500 - 4725	3.2*	1.1 to 1.5	Partly anoxic	Mainly marine	IIA-IIB mix (IIA dominated)	Oil-Gas/Condensate
4785 - TD	3.5*	1.5 to 1.7	Partly anoxic	Shallow marine	IIA-IIB mix (IIB dominated)	Oil-Gas/Condensate

Samples # 4975m & 5040m exhibit contamination by lignite observed under the microscope (Mukhopadhyay 1990)

Reference :

Mukhopadhyay P. K. 1990. Evaluation of organic facies of the Verrill Canyon Formation. Sable Basin, Scotian Shelf wells. Report from Global Geoenergy Research Ltd. GGRL file No. 390, March 30, 1990.





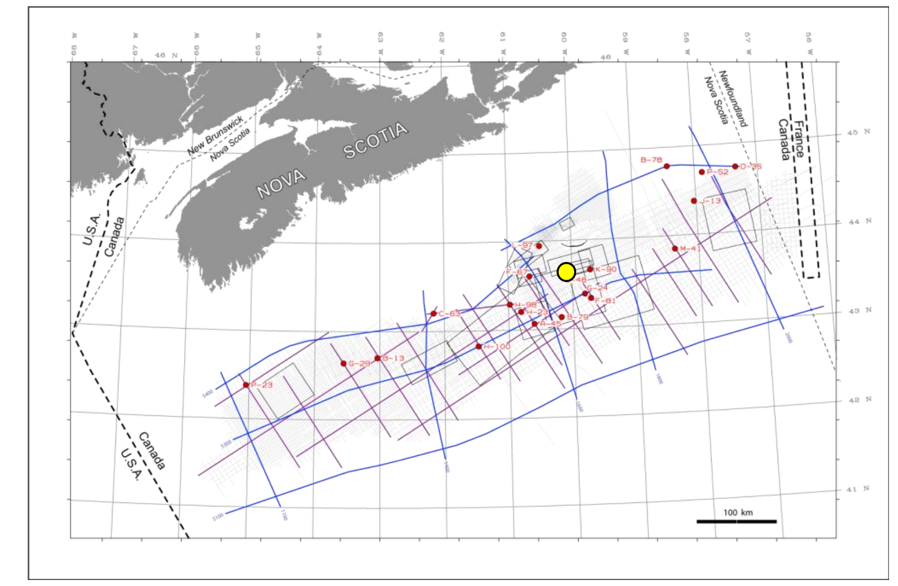
The Tithonian source rock in Alma F-67

- ✓ Alma F-67 is severely contaminated by mud additives. All samples from the Tithonian MFS level are contaminated (see HI x OI diagram, left)
- ✓ All Rock Eval S1 peaks (free hydrocarbons) are high due contamination
- ✓ Kerogen microscopy (Maceral) indicates Type IIA-IIB, Oil-Gas/Condensate prone (see Organic facies Table from Mukhopadhyay 1990, above)

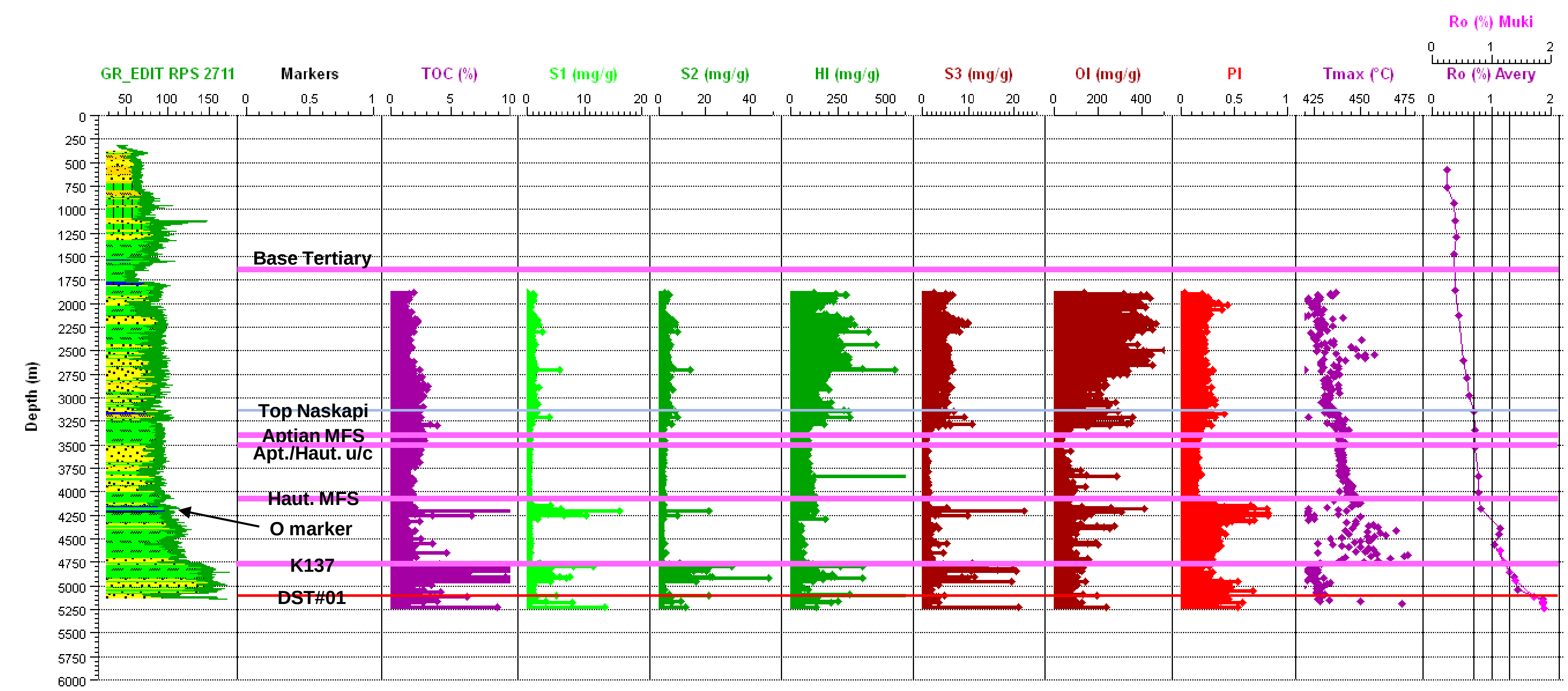
The Tithonian source rock in Glenelg J-48

- ✓ Glenelg J-48 is also severely contaminated by mud additive but the Tithonian from TD to DST#1 displays TOC values comprised between 1.79 and 2.10% from core samples (see also Organic facies Table)
- ✓ HI x OI diagram indicates a Tithonian source rock (SR) depleted in generative potential, consistent with a level of maturity Ro>1.8%
- ✓ Kerogen microscopy (Maceral) indicates Type IIB, Gas/Condensate prone (see Organic facies Table from Mukhopadhyay (1990), right)

Glenelg J-48



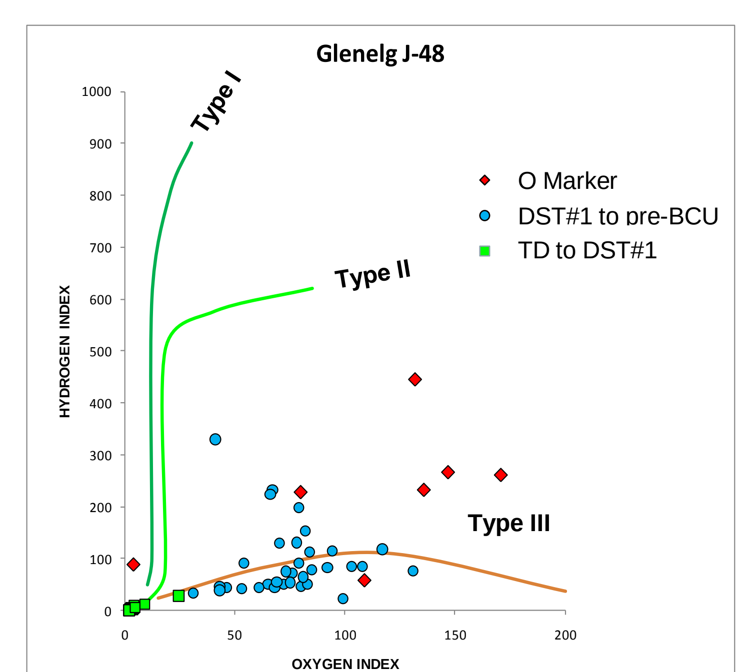
Top	Bottom	Units	Mud	Mud Additives	Event	Comments
3513		M			FISH	SURVEY TOOL LEFT IN THE HOLE - RECOVERED WITH AN OVERSHOT
4119		M				DRILL STRING STUCK IN THE HOLE AS A RESULT OF A WELL KICK - ADDED DIESEL AND WORKED PIPE FREE
5241		M				PIPE STUCK IN THE HOLE - PIPE WAS BACKED-OFF AND CEMENTED IN THE HOLE - WELL WAS SIDETRACKED
4119		M			KICK	POSITIVE FLOW CHECK - MUD WEIGHT RAISED BY 510 KG/M3 (FROM 1140 TO 1650 KG/M3) TO KILL THE WELL
4134		M			LOST CIRC	NO FURTHUR LOST CIRCULATION DATA FOUND IN WELL HISTORY REPORT
5157		M				
5193		M				
108	368	M	SEAWATER - VISCOUS SLUGS		MUD	
368	3261	M	SEAWATER - KCL			
3261	4141	M	FRESHWATER - GEL - LIGNOSULPHONATE	DIESEL (4119 & 4141 M), PIPELAX (4119 M), CHROME LIGNITE (4119 M)		
4141	5253	M	FRESHWATER - GEL - CHROME LIGNITE	CHROME LIGNITE (4141-5253 M), KWIKSEAL & WALNUT (5205 & 5253 M), X-PEL-G (4553, 4735, 4753 & 5081 M)		
4785	5083	M			MUD MOTOR	DYNA-DRILLED INTERVAL
5083	5157	M				TURBO DRILLED INTERVAL
5205	5227	M				
4913	5085	M			MUD MOTOR*	DYNA-DRILLED INTERVAL (DIRECTIONAL DRILLING INTERVAL IN SIDETRACKED HOLE)
5095	5148	M				TURBO DRILLED INTERVAL IN SIDETRACKED HOLE

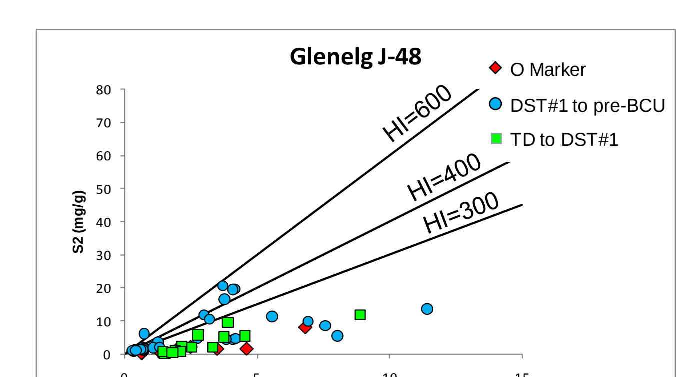


DEPTH (m)	TOC (%)	VR Ro (%)	OXIDATION LEVEL	ORGANIC INPUT	KEROGEN TYPE	HYDROCARBON POTENTIAL
4620	1.34	1.15	Partly oxic	Terrestrial	III	Gas
4655	1.92		Partly oxic	Terrestrial	III	Gas
4745	1.64	1.2	Partly oxic	Terrestrial	III	Gas
4855	8.35	1.3	Partly anoxic	Marine	IIA	Oil
4940	3.43	1.4	Partly anoxic	Marine	IIA	Oil
5115	2.52	1.7	Partly oxic	Terrestrial	III	Gas
5115	24.43	1.7	Partly oxic	Terrestrial	III	Gas
5160	2.14	1.87	Partly oxic	Terrestrial	III	Gas
5180.8 (core)	1.88	1.87	Partly anoxic	Mixed	IIB	Gas/Condensate
5166.7 (core)	2.1	1.87	Partly anoxic	Mixed	IIB	Gas/Condensate
5167 (core)	1.79	1.87	Partly anoxic	Mixed	IIB	Gas/Condensate
5235	4.54	1.88	Partly oxic	Mixed	III	Gas

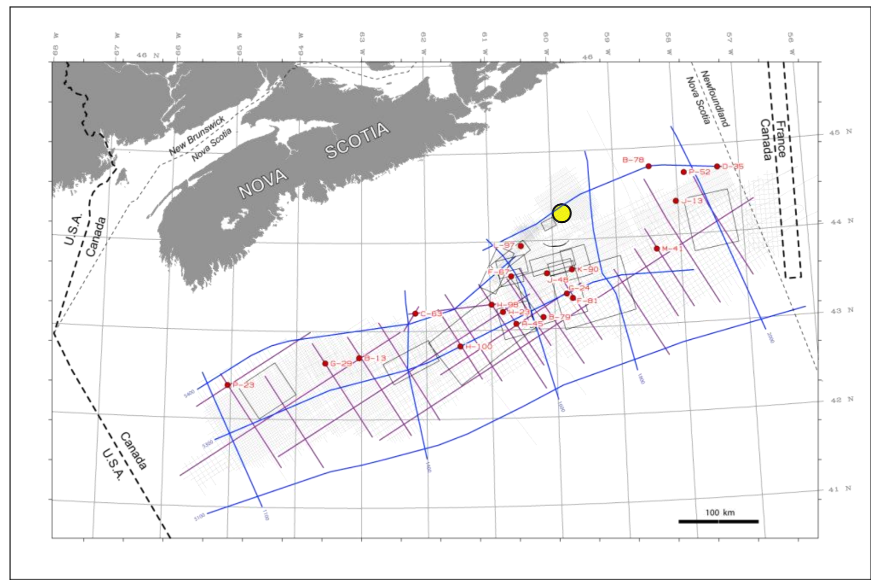
Reference :

P. K. Mukhopadhyay 1990. Evaluation of organic facies of the Verrill Canyon Formation. Sable Basin, Scotian Shelf wells. Report from Global Geoenergy Research Ltd. GGRL file No. 390, March 30, 1990.





Abenaki J-56

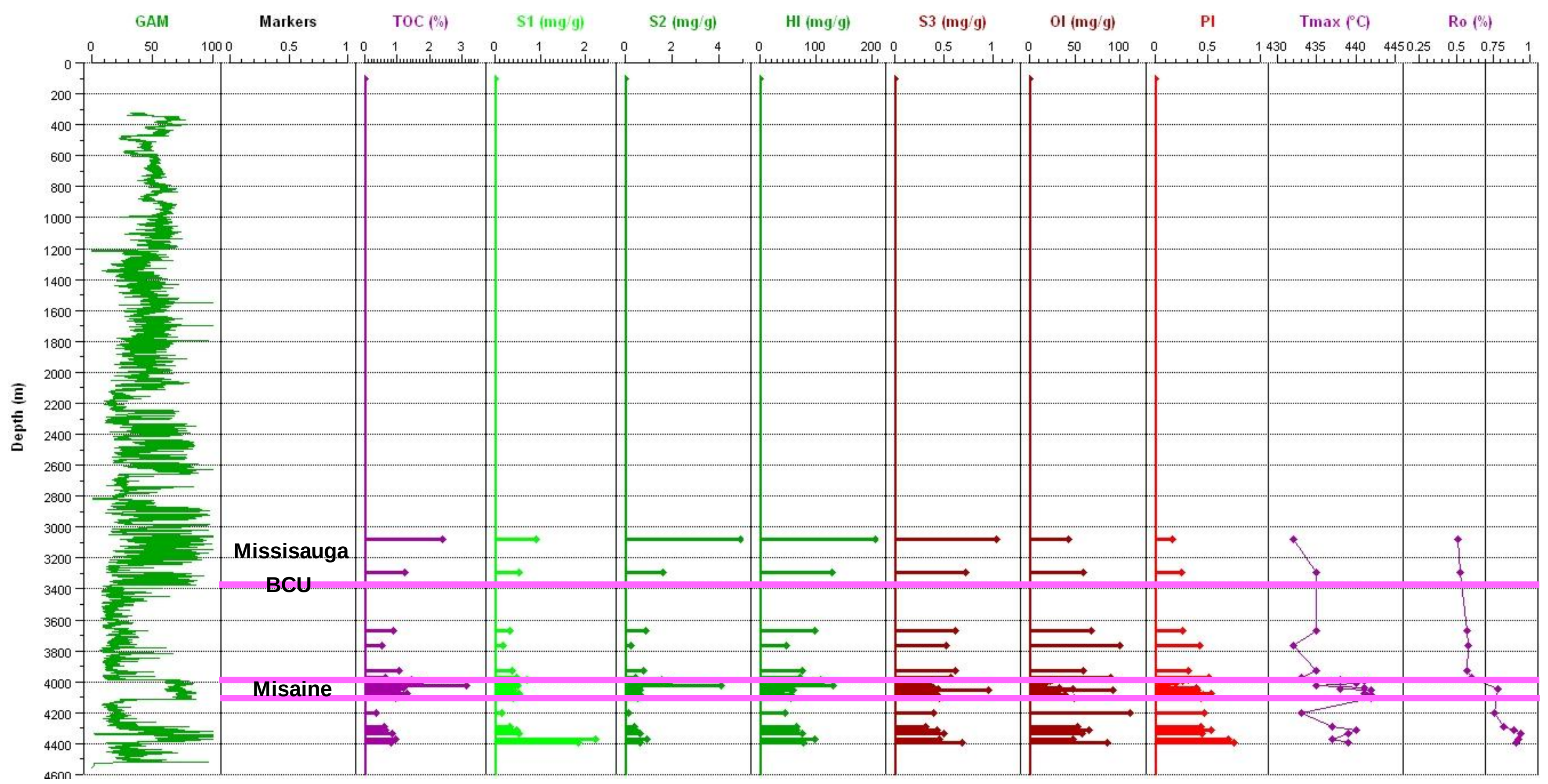


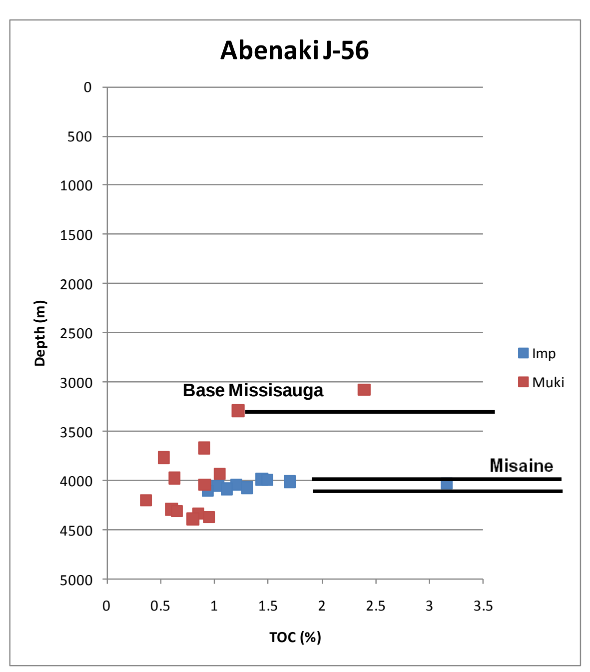
Top	Bottom	Units	Mud	Mud Additives	Event	Comments
8725	9300	FT			LOST CIRC	LOST CIRCULATION MATERIAL ADDED: MICA, NUTPLUG & CELLOSEAL
435	1130	FT	TREATED GEL		MUD	
1130	14991	FT	DLS	DIESEL (9312 & 14650 FT), SPERSENE, CROMEX, CELLOSEAL, NUTPLUG, PIPELAX	MUD	

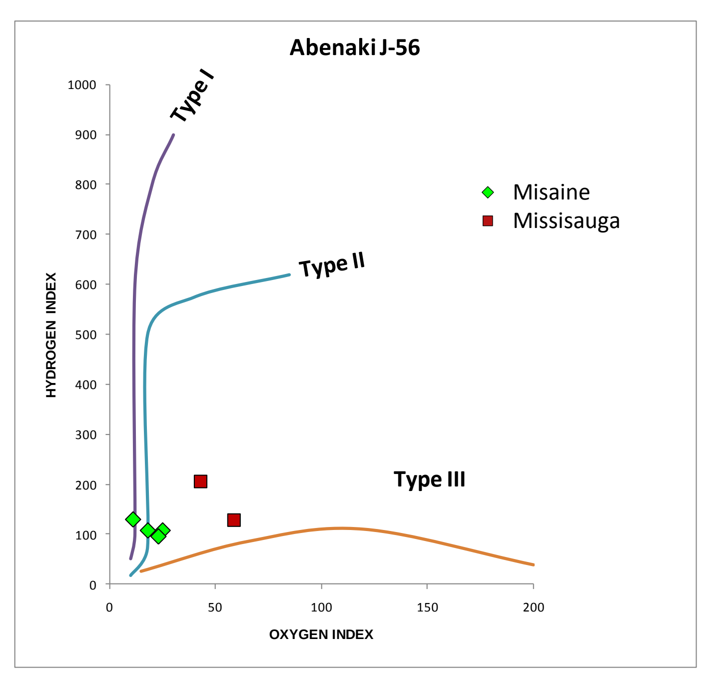
DLS = Dispersed Lignosulphonate

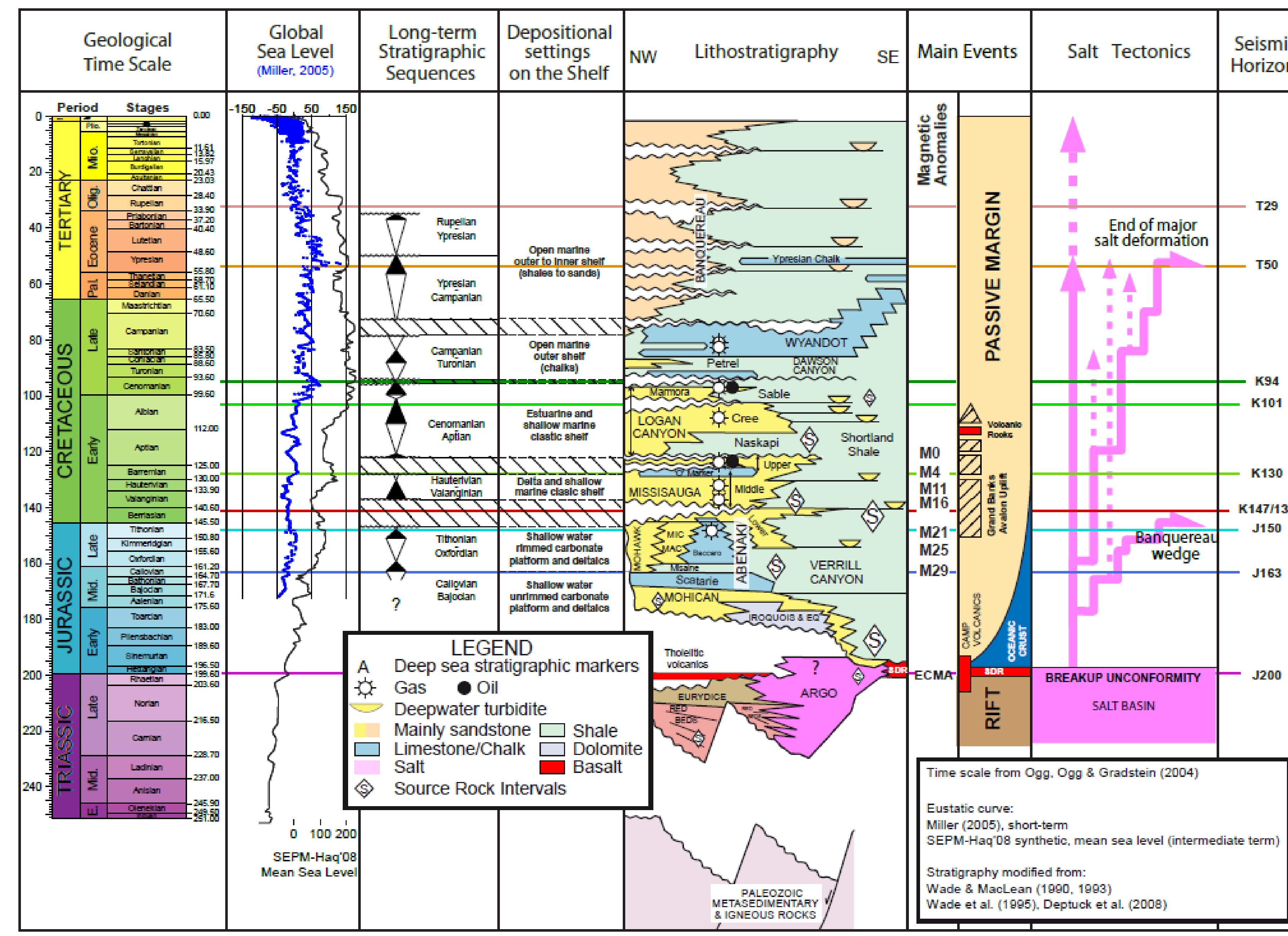
The Misaine source rock in Abenaki J-56

- ✓ Abenaki J-56 is contaminated by Dispersed Ligno-Sulfonate (DLS). However, low Rock Eval S1 peak (free hydrocarbons) suggest that the contamination is minimal if any.
- ✓ HI x OI diagram indicates a Misaine source rock partly depleted in generative potential (HI=100), consistent with a level of maturity Tmax=441°C and a Ro=0.8% applied to a type II kerogen
- ✓ The Misaine source rock is honoring the fact that it corresponds to maximum flooding surfaces of the Callovian but it is considered minor as it is substantiated by only one well – Abenaki J-56
- ✓ For modeling purpose, the following characteristics were retained:
  - TOC=2%
  - Kerogen Type II-III







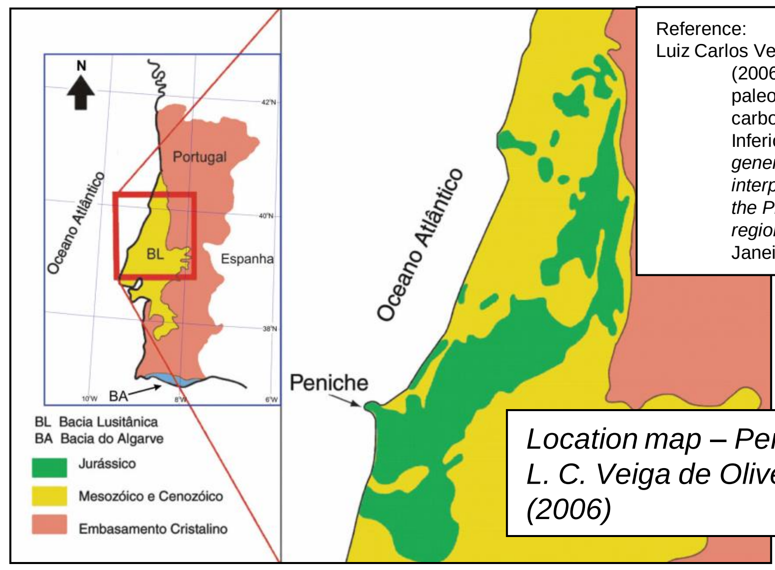


The Early Jurassic source complex

- ✓ Liassic sediments are missing in all wells drilled down to the Triassic, except for Uniacke G-72, located down slope of the shelf edge prevailing at the time. Uniacke G-72 encountered remobilized Liassic clastics. Further out, Liassic sedimentation is expected to have taken place in the subsiding part of the basin.
- ✓ On the Portugal side of the opening proto-Atlantic ocean, Sinemurian, Pliensbachian and Toarcian source rocks are known to exist. There is therefore a strong possibility that their equivalent be present on the Nova Scotian margin.
- ✓ On the Morocco margin, Toarcian source rocks are proven.

In Portugal

Luiz Carlos Veiga de Oliveira et al. (2006) publication reports the following :



Location map – Peniche Basin
L. C. Veiga de Oliveira et al. (2006)

Reference:
Luiz Carlos Veiga de Oliveira, Rodrigues R., Duarte L. V. Lemos V. B. (2006). Avaliação do potencial gerador de petróleo e interpretação paleoambiental com base em biomarcadores e isótopos estáveis de carbono da seção Pliensbaquiano - Toarciano inferior (Jurássico Inferior) da região de Peniche (Bacia Lusitânica, Portugal). *Oil generation potential assessment and paleoenvironmental interpretation based on biomarkers and stable carbon isotopes of the Pliensbachian - Lower Toarcian (Lower Jurassic) of the Peniche region (Lusitanian Basin, Portugal)*. B. Geoci. Petrobras, Rio de Janeiro, v. 14, n. 2, p. 207-234, maio/nov. 2006

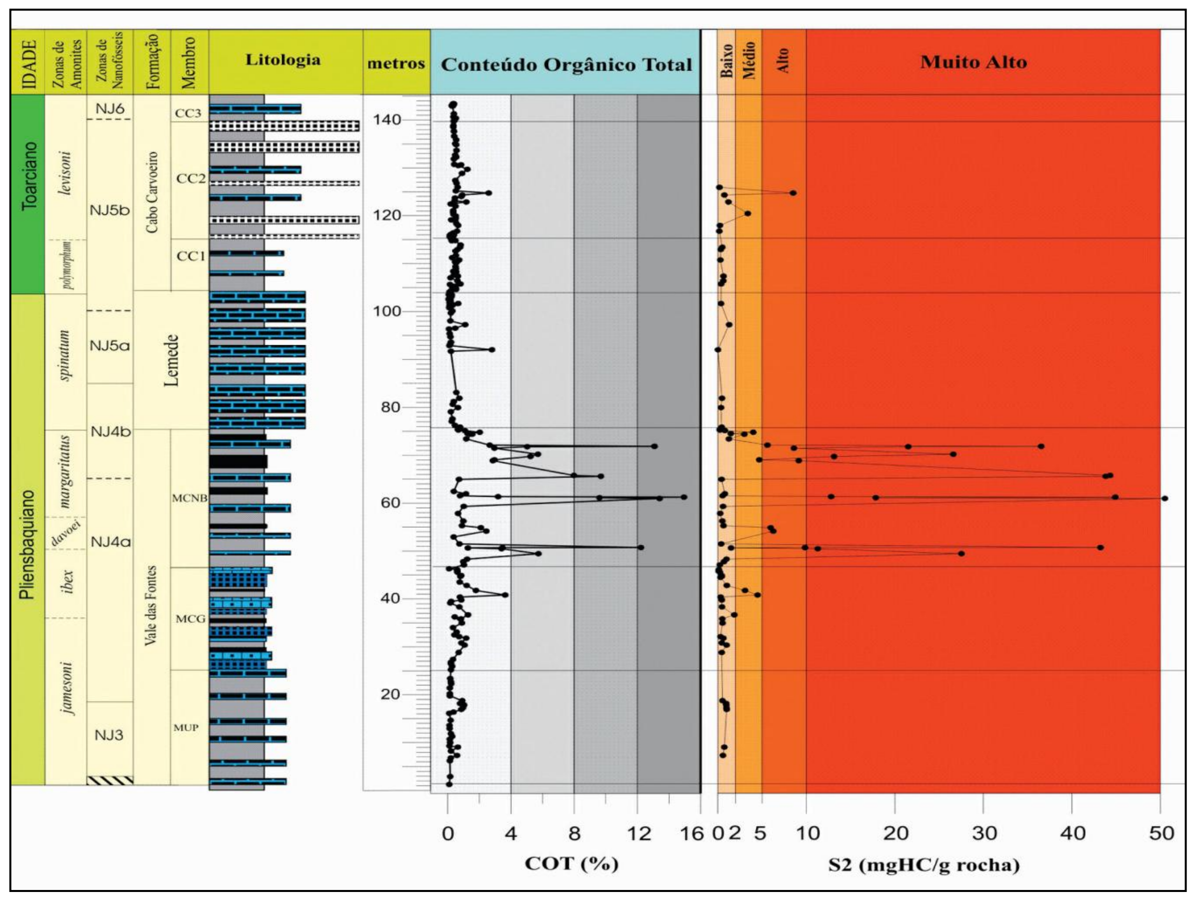
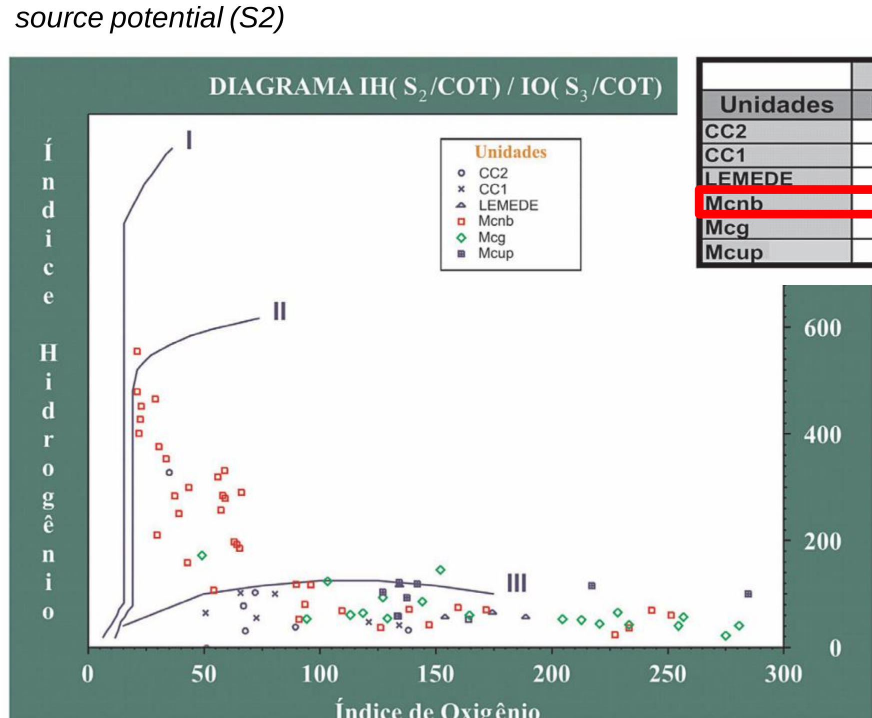


Figure 1: Stratigraphy, Lithology and Rock Eval Total Organic Carbon content (TOC) & source potential (S2)



Unidades	IH Média	IH Máx.	IO Média	IO Máx.
CC2	101,28	327,69	78,22	138,09
CC1	68,16	101,56	87,46	134,24
LEMEDE	58,58	116,22	176,15	354,45
Mcnb	210,16	555,26	89,04	251,39
Mcg	67,17	172,63	185,3	344,26
Mcup	101,55	121,52	168,04	284,74

Figure 2: Diagram of Hydrogen Index x Oxygen index (HI x OI) for samples of Peniche Basin

Peniche Basin (Luiz Carlos Veiga de Oliveira et al., 2006)

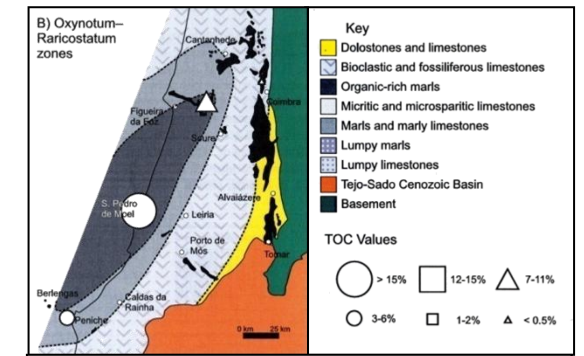
- ✓ The Mncb Member (MLOF* Mbr. in L. V. Duarte, 2010; see Figure 3 on the right) of the Vale das Fontes Formation of Pliensbachian age is definitely an organic-rich source rock with TOC up to in excess of 14%, averaging 3.8% over the Mncb interval 28m thick (see Figure 2).
- ✓ An bitumen extract from the sample at 72.12m analyzed by Gas Chromatography – Mass Spectrometry (Figure 4) displays a large Gammacerane peak on the m/z 191 trace shown below. It compares closely with the trace of a condensate from DST#6 of the Venture B-13 discovery well offshore Nova Scotia also shown in Figure 4 below.

* MLOF = Marly Limestones with Organic-rich Facies

Lusitanian Basin (L. V. Duarte, 2010)

- ✓ In addition to the Pliensbachian source rock, Duarte et al. (2010) reports a very rich source rocks of Sinemurian age in San Pedro de Moel area (see location map & Figure 3) exhibiting maximum TOC in excess of 20% for two samples, otherwise of richness comparable to the Pliensbachian described by Luiz Carlos Veiga de Oliveira et al. (2006) over a similar thickness.

Reference:
L.V. Duarte, R.L. Silva, L.C.V. Oliveira, M.J. Comas-Rengifo, F. Silva (2010). Organic-Rich Facies in the Sinemurian and Pliensbachian of the Lusitanian Basin, Portugal: Total organic carbon distribution and relation to transgressive-regressive facies cycles . Geologica Acta, Vol. 8, No. 3, pp. 325-340.



Location map and TOC distribution in the Sinemurian of the Lusitanian Basin (L. V. Duarte, 2010)

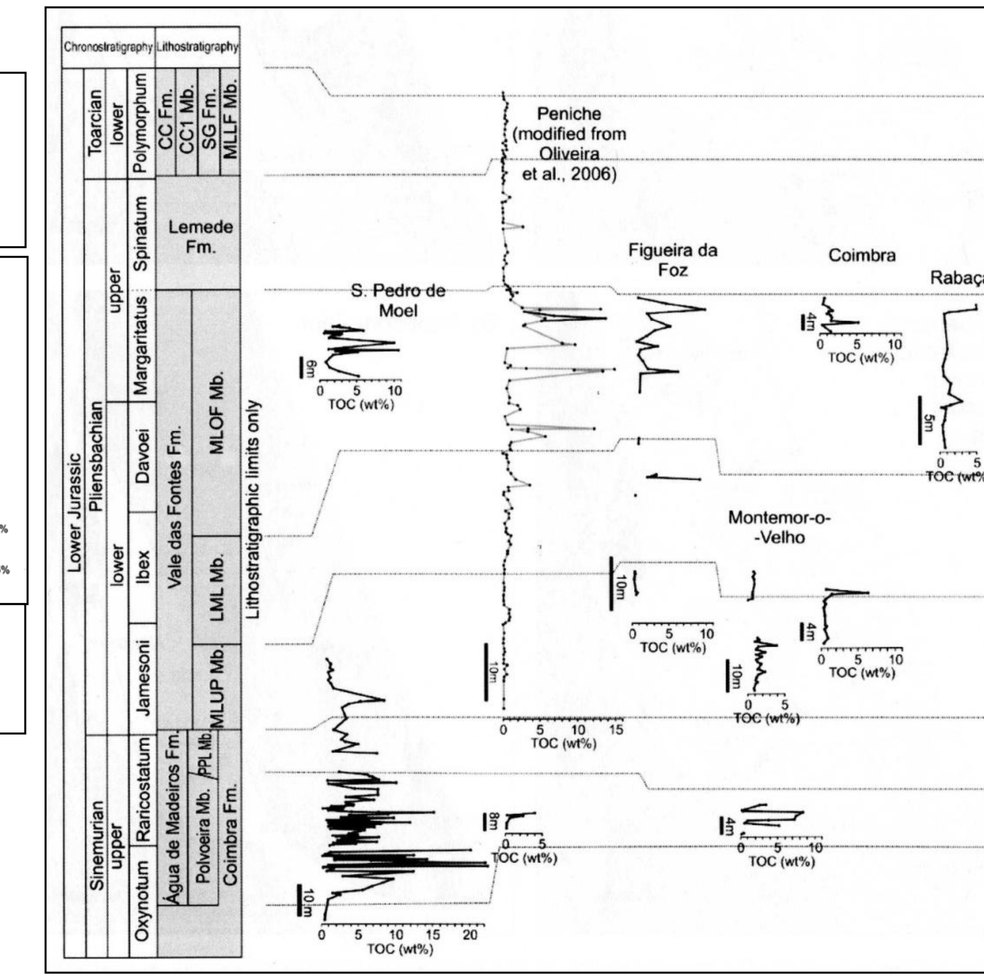


Figure 3: TOC distribution in the uppermost Sinemurian-Pliensbachian of the Lusitanian Basin (L. V. Duarte, 2010)

Gammacerane in Venture B-13 DST#6 condensate

- ✓ Gammacerane found in the Venture B-13 condensate of DST# 6 sample compared to the extract from an organic-rich Pliensbachian sample (see Figure 4 below) strengthen the simple analogy with the Peniche Basin, providing a direct argument in favor of the presence of potential Liassic source rock on the Nova Scotiann margin
- ✓ Of course, due to largely generalized use of mud additive during drilling operations on the Nova Scotian margin, contamination in the Venture B-13 well needed to be checked
- ✓ In normal circumstances DSTs should not be affected by mud contaminants. However, if the reservoir tested was invaded by mud fluids prior to testing, it may give back contaminant in the test

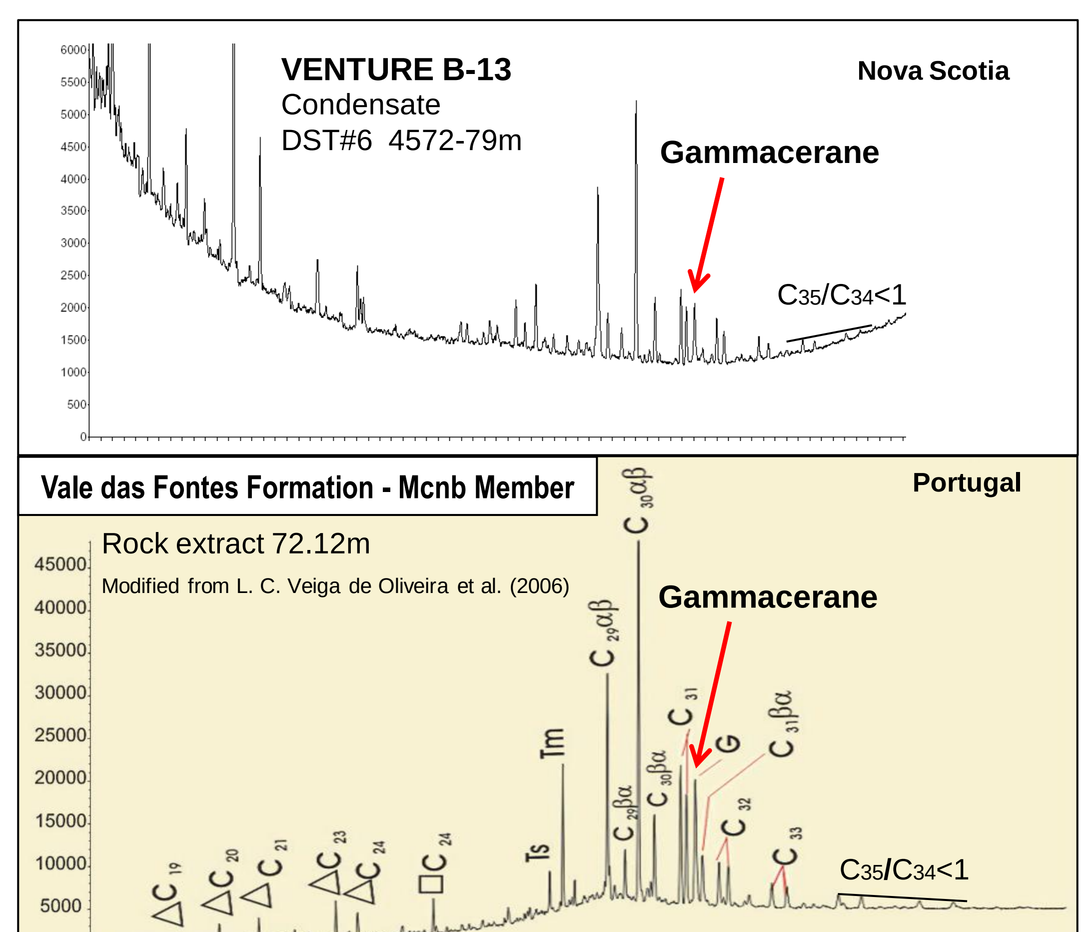


Figure 4: Biomarker traces (m/z 191). Gammacerane is present in the condensate of Venture B-13 DST#6 and in an extract from the Mncb Member of the Pliensbachian Vale das Fontes Formation

Gammacerane – contaminant or indigenous?

- ✓ Cutting extracts were analyzed for Gammacerane based on the principle that cuttings would be most affected by a gilsonite type of mud additive containing Gammacerane.
- ✓ Results shown in Figure 5 are that Gammacerane in the 4570m cuttings, just above the tested interval is not anomalously abundant, whereas it is in the 4580m cutting below DST#6
- ✓ This distribution of Gammacerane in the cuttings tends to demonstrate that Gammacerane in DST#6 condensate is not contamination by mud additive

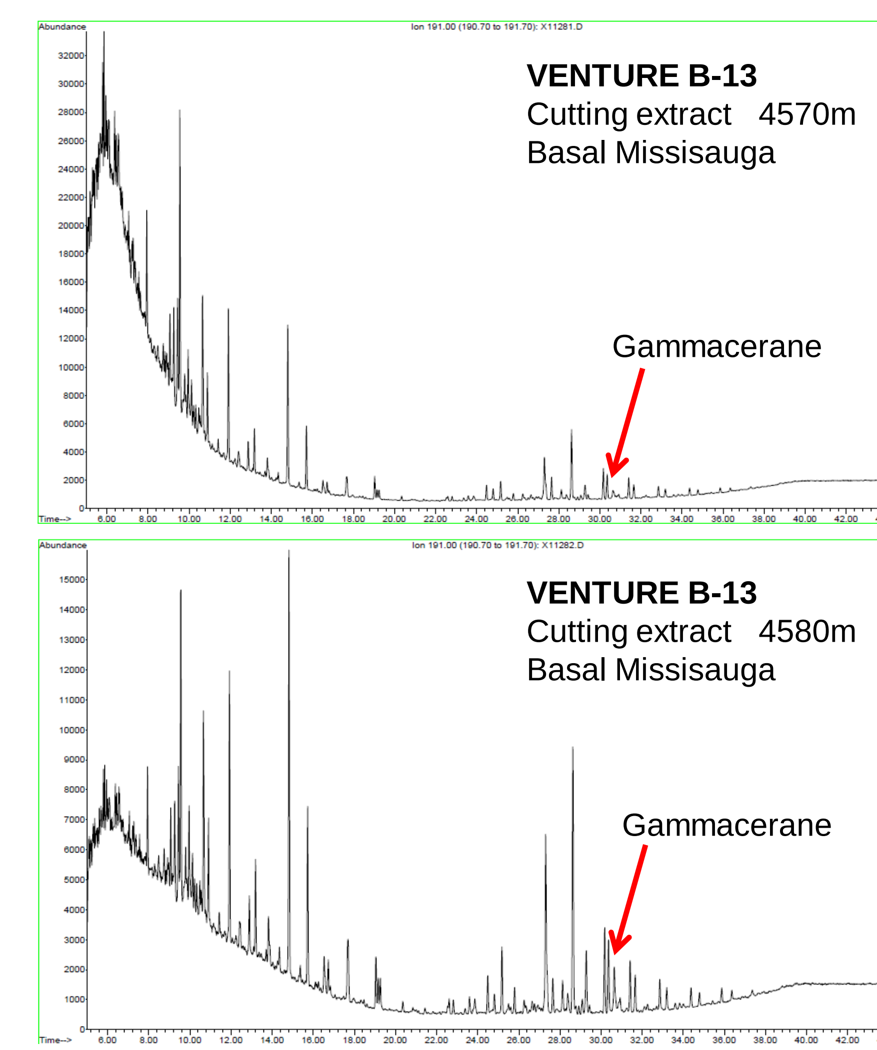
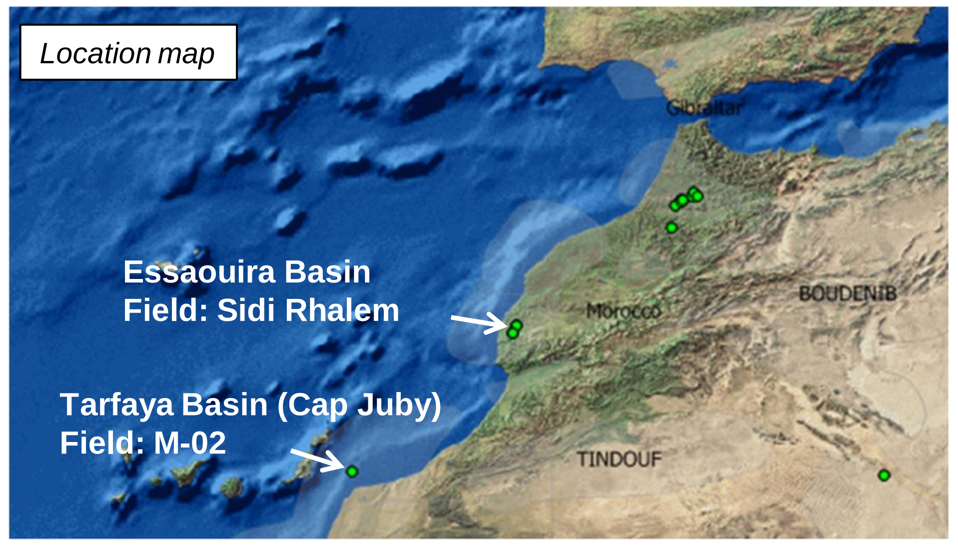


Figure 5: Biomarker traces (m/z 191) of cutting extracts from Venture B-13. Gammacerane is not anomalously abundant at the depth just above DST#6 (4570m) but well developed at 4580 m, just below the tested interval

In Morocco

Based on data graciously provided by Geomark Research Inc.:



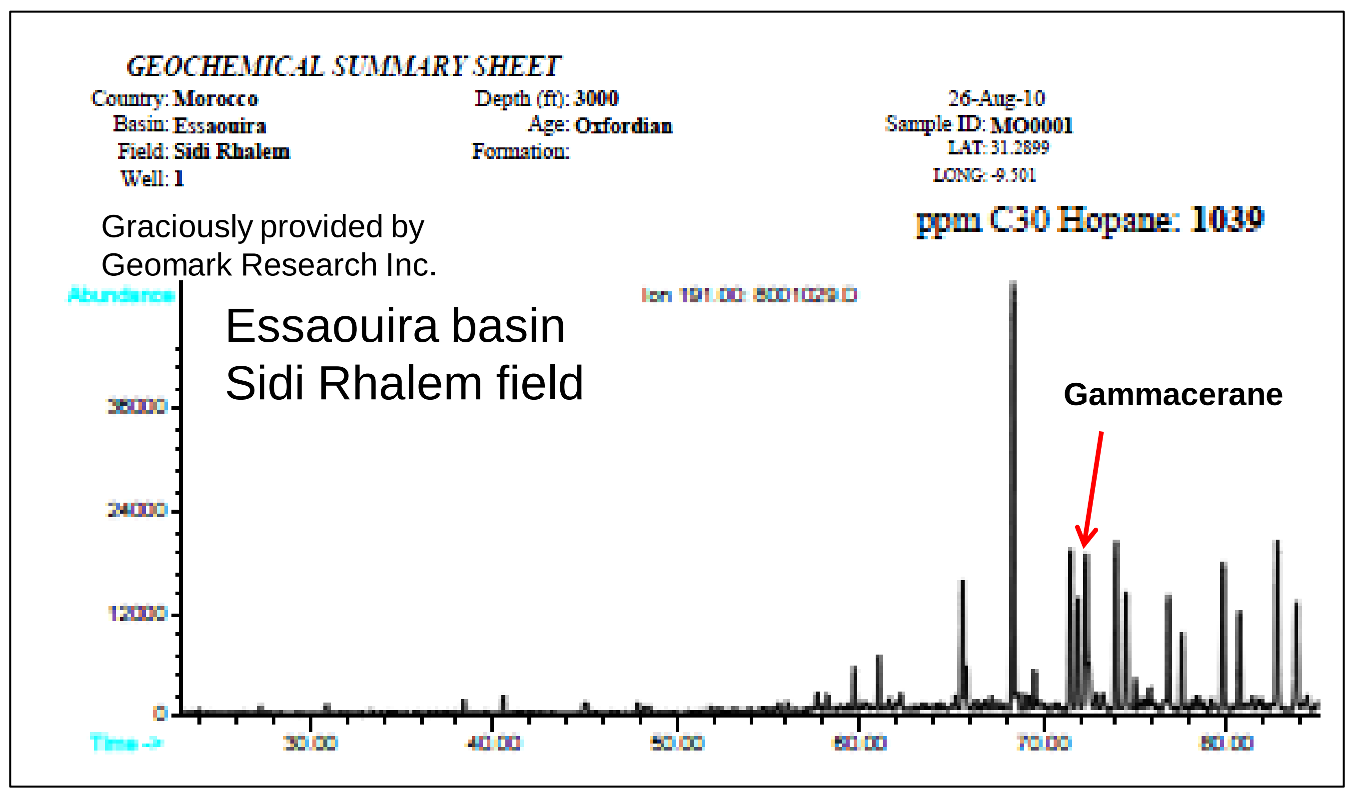


Figure 1: Biomarker traces (m/z 191). Gammacerane is present in the oil of the Sidi Rhalem field, Essaouira Basin, Morocco

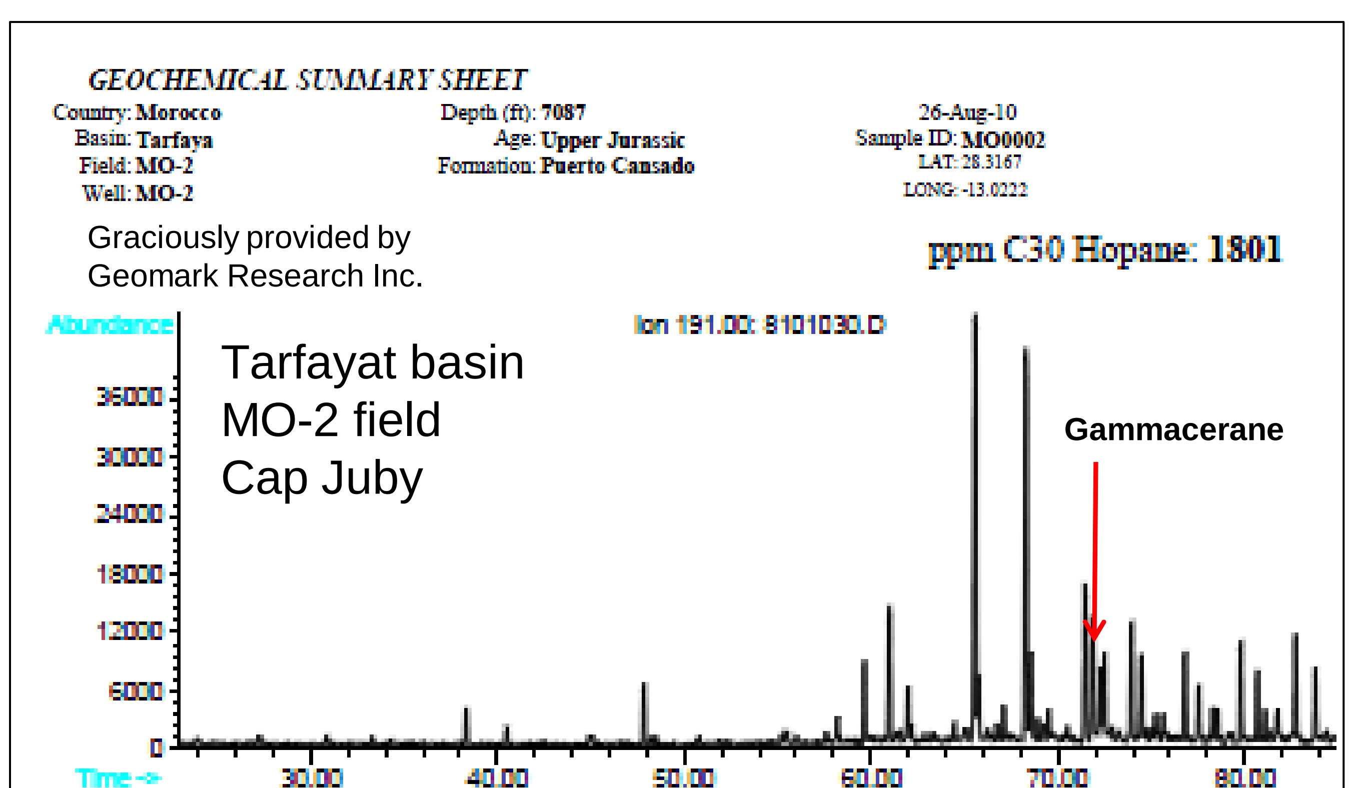


Figure 2: Biomarker traces (m/z 191). Gammacerane is present in the oil of the MO-2 field, Tarfayat Basin, Cap Juby, offshore Morocco

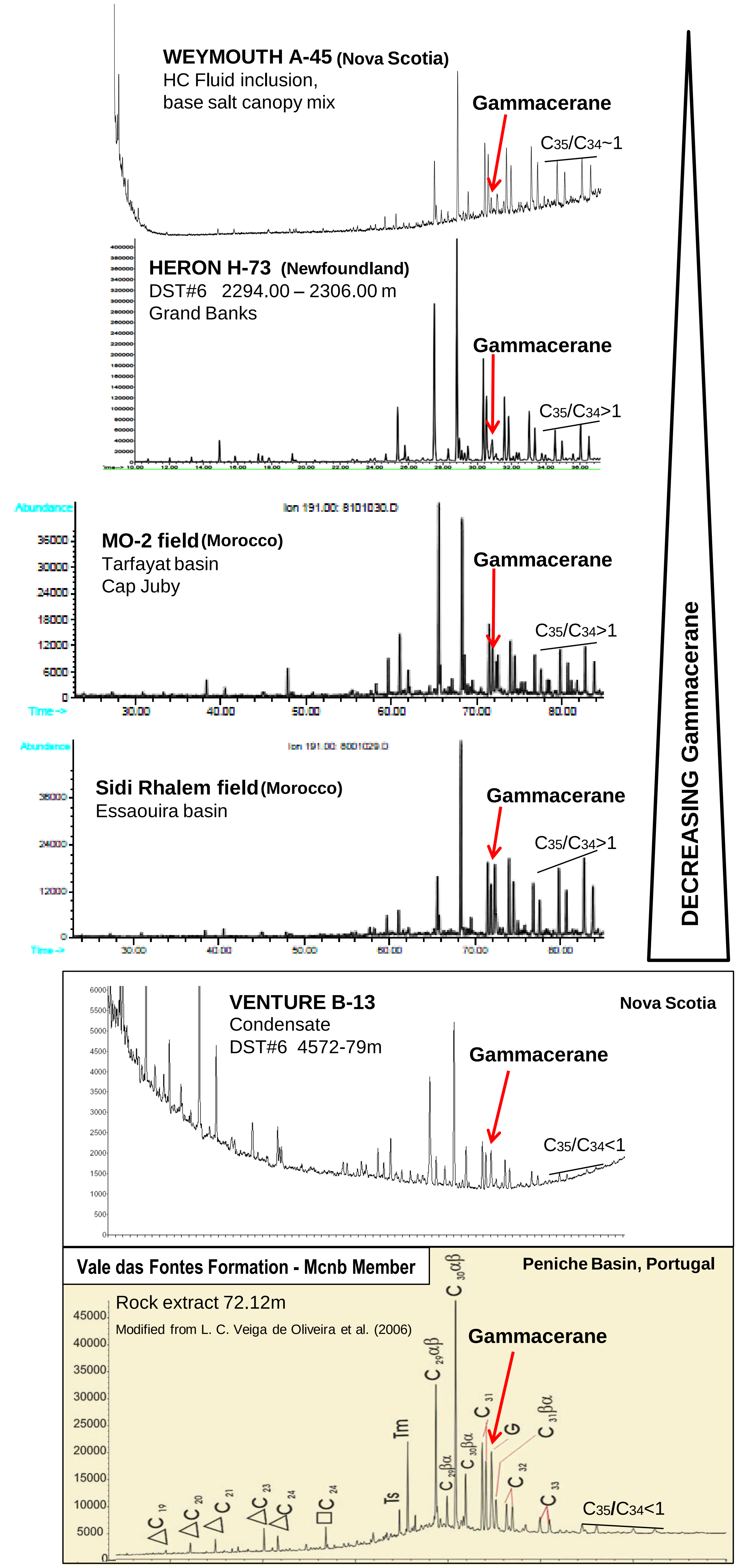


Figure 3: Biomarker traces (m/z 191) of various oils, condensate, extracts and HC fluid inclusion all exhibiting Gammacerane and a homohopane C_{35}/C_{34} ratio. A high C_{35}/C_{34} ratio >1 is commonly associated with marine carbonates and evaporites. It is at least a general indicator of highly reducing marine conditions during deposition (Peters and Moldowan, 1991)

Gammacerane & depositional environments

- ✓ Gammacerane forms by reduction of tetrahymanol. The source of tetrahymanol appears to be bacterivorous ciliates, which occur at the interface between oxic and anoxic zones of stratified water columns.
- ✓ Abundant Gammacerane is believed to indicate the presence of stratified water column.
- ✓ Although stratified water column can result from both hypersality at depth (halocline) and temperature (thermocline), high abundance of Gammacerane is mostly found in high salinity environments and evaporites.
- ✓ The most likely environments for a source of Gammacerane on the Nova Scotian margin would be:
  - Early Jurassic (Liassic), post-rift with high salinity at the end of the Argo salt deposition changing progressively to carbonate and more open marine environments, or
  - Triassic.

Homopane C35/C34 ratio & depositional environments

- ✓ High C_{35}-homopane compared to C_{34}-homohopane (see Figure 3) is commonly associated with marine carbonates and evaporites. It is at least a general indicator of highly reducing marine conditions during deposition (Peters and Moldowan, 1991) providing a highly favorable environment for source rock deposition and preservation.

Gammacerane & Homopane C35/C34 ratio

- ✓ C_{35}/C_{34} homohopane ratios in oils and Gammacerane abundance in oils, condensates and fluid inclusion oil presented here (Figure 3) do not show a direct relationship. The source rock portion of the Pliensbachian Vale das Fontes Formation of Portugal displays Gammacerane but the C_{35}/C_{34} homohopane ratio does not exhibit any sign of highly reducing conditions, yet it is associated to an organic-rich source rock well preserved, the facies of which is marly rather than pure carbonates (Duarte et al., 2010).
- ✓ Taking Gammacerane and the C_{35}/C_{34} homohopane ratio as indicators of salinity and, reducing and/or carbonate deposition conditions, respectively, supports the environments foreseen for the Early Jurassic source rock complex based on the Moroccan and Portuguese margins.
- ✓ In addition, organic-rich Toarcian offshore Morocco, DSDP Leg 79 Site 547, consist of black shale is associated to a carbonate environment of deposition without any sign of hypersalinity. Accordingly, the hopane trace (ion 191) of extracts from several black shale samples collected and analyzed for this study display very lean Gammacerane content only, nothing more than a usual background (see below Figure 4).

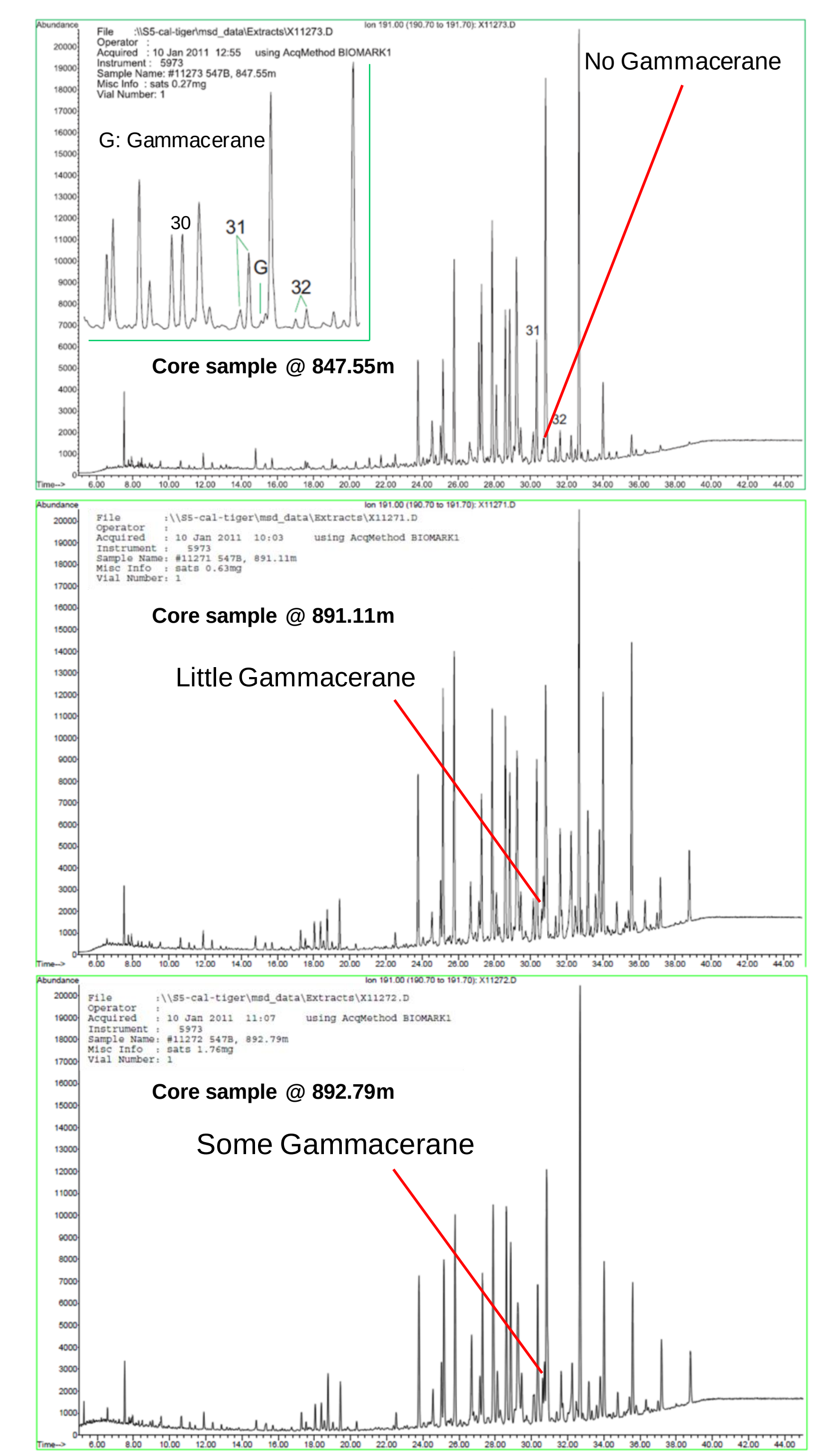


Figure 4: Ion 191 traces of three samples of Toarcian black shales from DSDP Leg 79 Site 547, well 547B. These traces display no or background abundance of Gammacerane. The shallow depth of these samples explains their immaturity and unusual signature. Location, analytical results and geological context are discussed in the next Plate

In Morocco (continued)

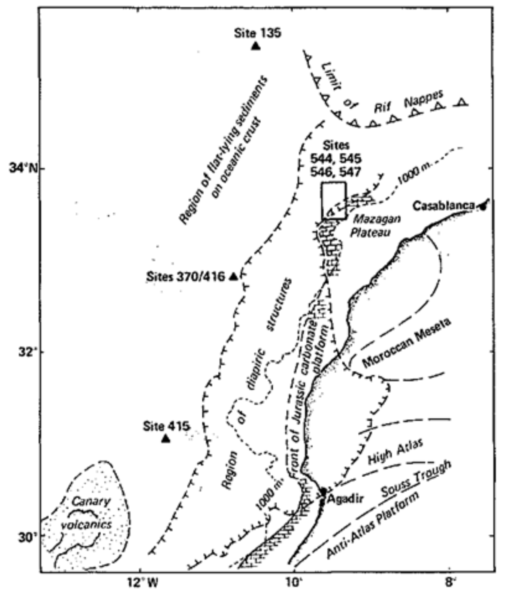


Figure 1: Location of DSDP drill sites Leg 79, Site 547 (within rectangle) on the Morocco margin (modified from Rullkotter et al. 1984).

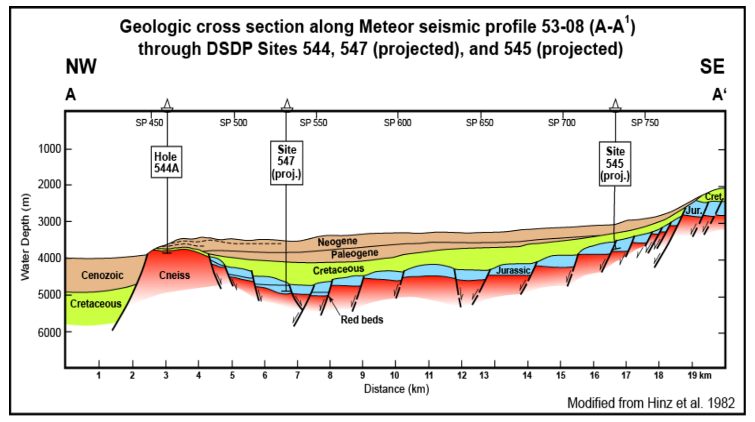


Figure 2: Cross section showing well locations of DSDP Leg 79, Sites 544, 545 and 547

Absence of Gammacerane in the Early Jurassic of DSDP well 547B

- ✓ The Early Jurassic offshore Morocco, DSDP Leg 79 Site 547, consist of black shale associated to a carbonate environment of deposition without signs of hypersalinity (Figures 2 & 4).
- ✓ The Triassic section of the well 547B consists of red beds as shown in Figure 2 and Map in Figure 7 (Eurydice equivalent on the Nova Scotia margin).
- ✓ Consistently, the hopane traces (ion 191) of extracts from several black shale samples collected and analyzed for this study display very lean Gammacerane content only, nothing more than a usual background (see below Figure 6).
- ✓ Gammacerane is a proof of the existence of an Early Jurassic source rock. Its absence does not indicate the absence of an Early Jurassic source rock but the absence of hypersaline (or water stratified) environment of deposition.

References:

J. Rullkotter, P. A. Mukhopadhyay, R. G. Schaffer, D. H. Welte (1984). Geochemistry and petrography of organic matter in sediments from Deep Sea Drilling project Sites 545 and 547, Mazagan Escarpment.

Hinz K., Winter E. L., Baugartner P. O., Bradshaw M. J., Channel J. E. T., Jaffrezo M., Jansa L. F., Leckie R. M., Moore J.N., Rullkotter J., Schaftenaar C., Steiger T. H., Vuchev V. and Wiegand G. E. (1982). Preliminary results from DSDP Leg 79, seaward of the Mazagan Plateau off Morocco. *In* von Rad U., Hinz K., Sarnthein M. and Siebold E. (eds.), *Geology of the Northwest African Continental Margin:* Berlin-Heidelberg (Springer-Verlag), pp. 23-33.

Sibuet J.-C. Rouzo S. and Srivastava S. (2011). Plate tectonic reconstructions and paleo-geographic maps of the central and north Atlantic oceans. Final report to OETR (February 28, 2011).

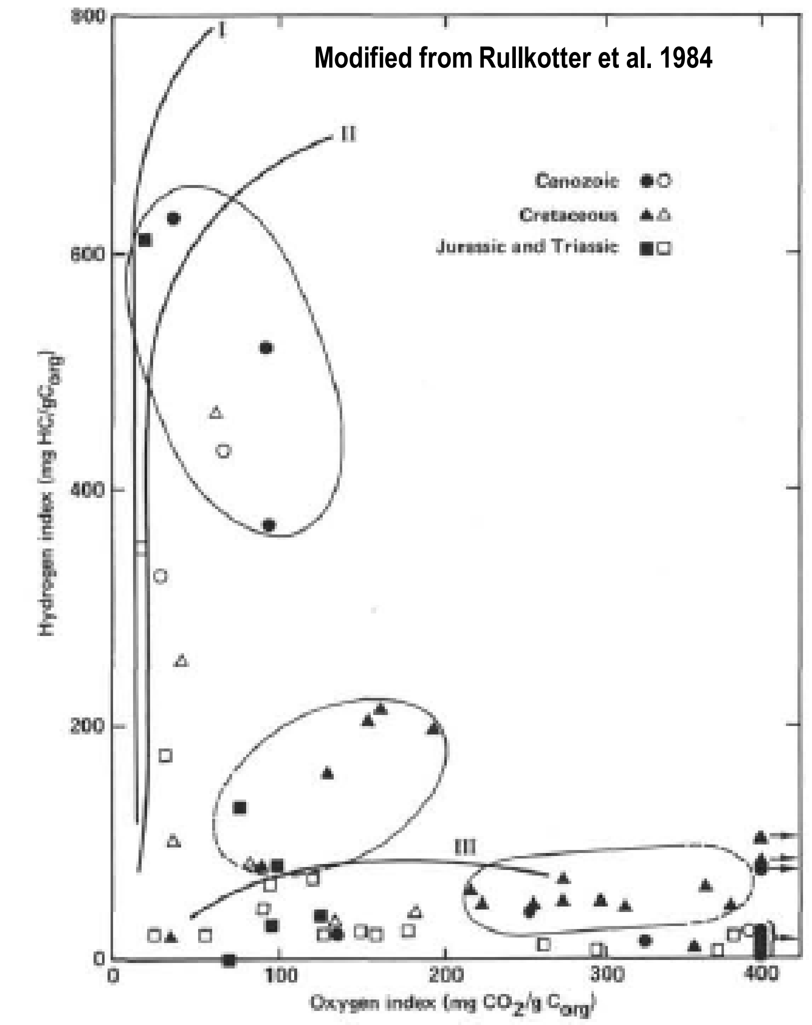


Figure 3: Hydrogen versus Oxygen indices from Early Jurassic rocks in DSDP well 547B

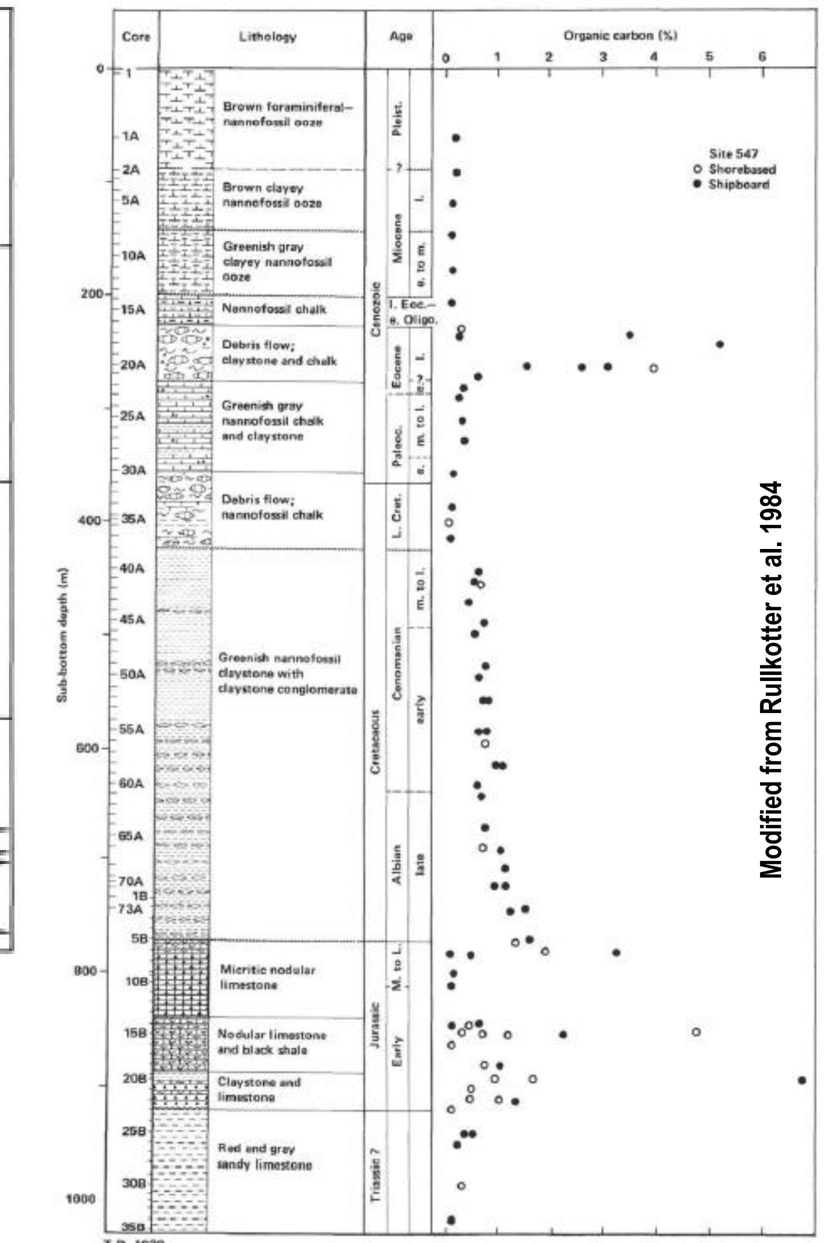


Figure 4: Total Organic Carbon measurements in DSDP well 547B

EXPEDITION (Leg)	SITE	HOLE	CORE	SECTION	SAMPLE	LOCATION	SECTION_ID	TOP_DEPTH	BOTTOM_DEPTH	ANALYST	REQUEST	EQUEST_PAR	TYPE	VOLUME	SAMPLE_DATE	REMARKS	HALF	MBSF_TOP	MCD_TOP
79	547	B	15	2	4421954	BCR	970576	5	9	WH	22219	A	---	5	11/25/2010 10:35:56 AM		W	847.55	847.55
79	547	B	20	1	4421955	BCR	970671	11	18	WH	22219	A	---	5	11/25/2010 10:40:45 AM		W	891.11	891.11
79	547	B	20	1	4421956	BCR	970671	130	133	WH	22219	A	---	7	11/25/2010 10:48:27 AM		W	892.3	892.3
79	547	B	20	2	4421957	BCR	970666	29	32	WH	22219	A	---	8	11/25/2010 10:51:49 AM		W	892.79	892.79
79	547	B	20	2	4421958	BCR	970666	51	66	WH	22219	A	---	7	11/25/2010 10:55:23 AM		W	893.01	893.01
79	547	B	20	2	4421959	BCR	970666	89	96	WH	22219	A	---	10	11/25/2010 10:57:46 AM		W	893.39	893.39
79	547	B	22	1	4421960	BCR	970706	20	30	WH	22219	A	---	10	11/25/2010 11:00:59 AM		W	905.2	905.2

Table 1: List of the core samples collected from DSDP well 547B for analyses.

Depth	Sample	Qty	Tmax	S1	S2	S3	PI	S2/S3	PC(%)	TOC(%)	HI	OI
0	9107	70.7	442	0.74	12.21	0.55	0.06	22.20	1.11	5.05	242	11
847.55	4421954	70.0	423	0.10	4.04	2.87	0.02	1.41	0.47	2.70	150	106
891.11	4421955	70.9	423	0.13	8.82	1.94	0.01	4.55	0.82	2.38	371	82
892.3	4421956	70.3	423	0.03	0.25	1.56	0.10	0.16	0.08	0.59	42	264
892.79	4421957	70.6	425	0.10	6.31	1.71	0.02	3.69	0.61	2.92	216	59
893.01	4421958	70.1	425	0.04	0.63	1.80	0.05	0.35	0.12	0.87	72	207
893.39	4421959	70.3	491	0.00	0.01	1.78	0.21	0.01	0.07	1.16	1	153
905.2	4421960	70.6	425	0.05	0.53	1.61	0.08	0.33	0.11	0.93	57	173
0	9107	70.4	442	0.72	12.18	0.63	0.06	19.33	1.11	5.09	239	12

Table 2: TOC/Rock Eval data acquired on the cores samples collected from DSDP well 547B. (Yellow outline: TOC/Rock Eval standard; Red outline: source rock samples (see Biomarker traces in Figure 6)

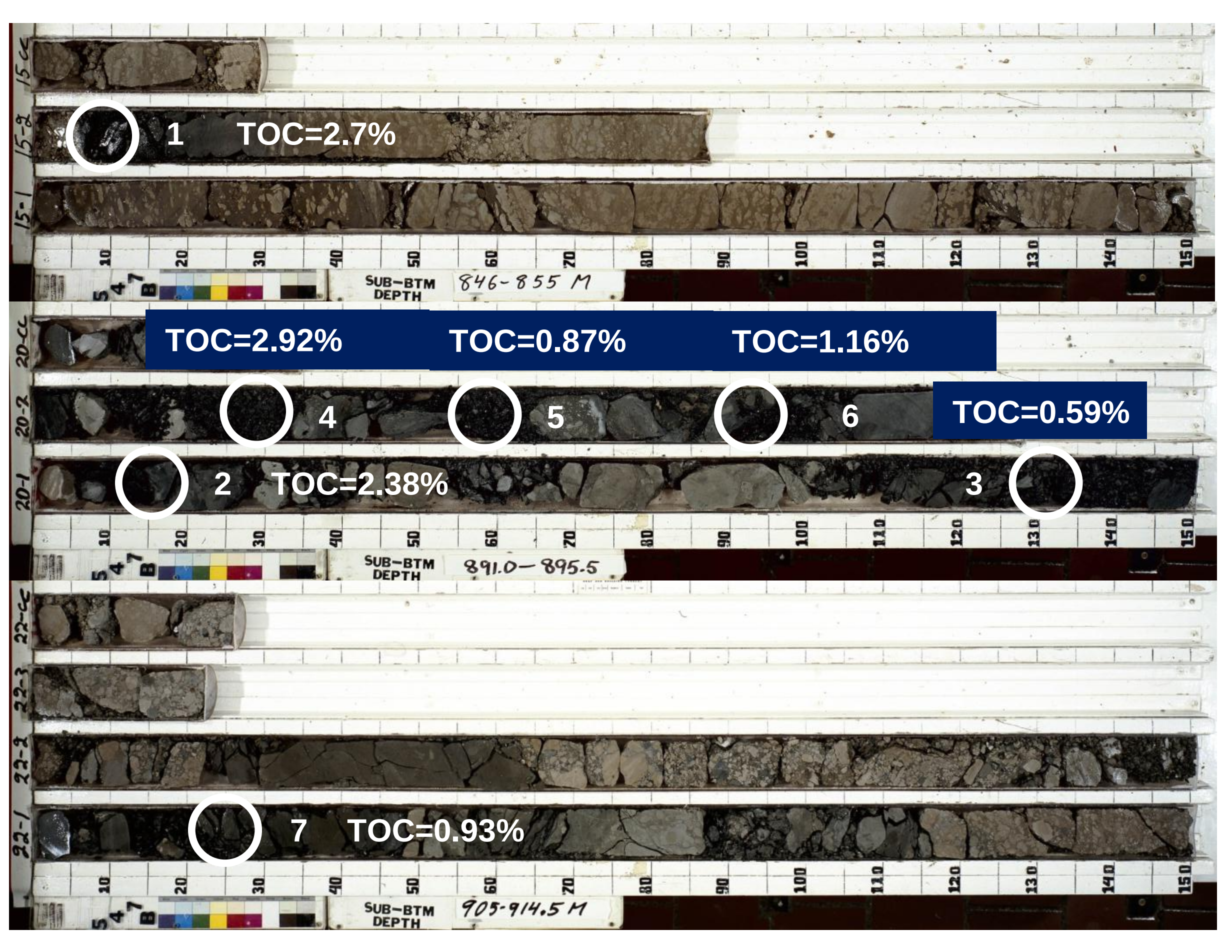


Figure 5: Picture of the cores from DSDP well 547B. The spots where the samples were collected from are outlined by circles. TOC are from the data listed in Table 2

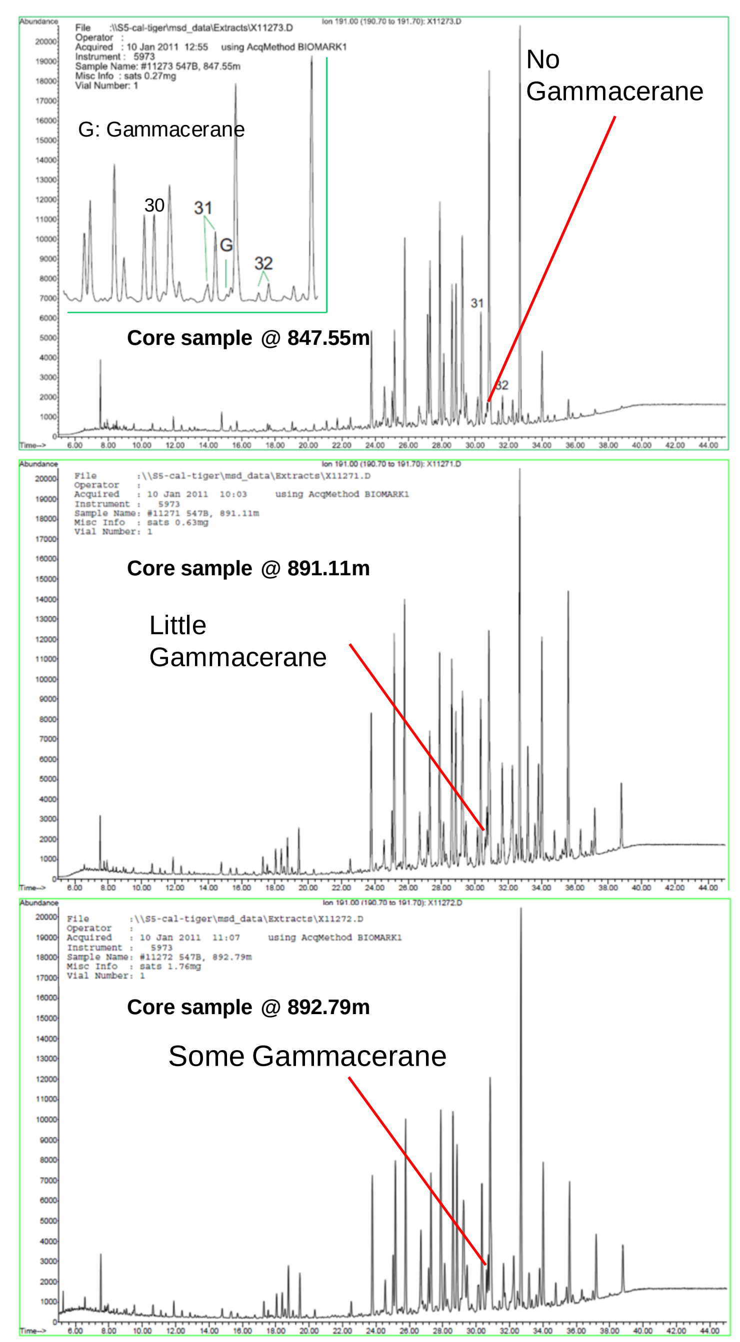


Figure 6: Ion 191 traces of three samples of Toarcian black shales from DSDP Leg 79 Site 547, well 547B. These traces display no or background abundance of Gammacerane. The shallow depth of these samples explains their immaturity and unusual signatures. Location, analytical results and geological context is presented in Figures 1, 2, 3, 4 and 5.

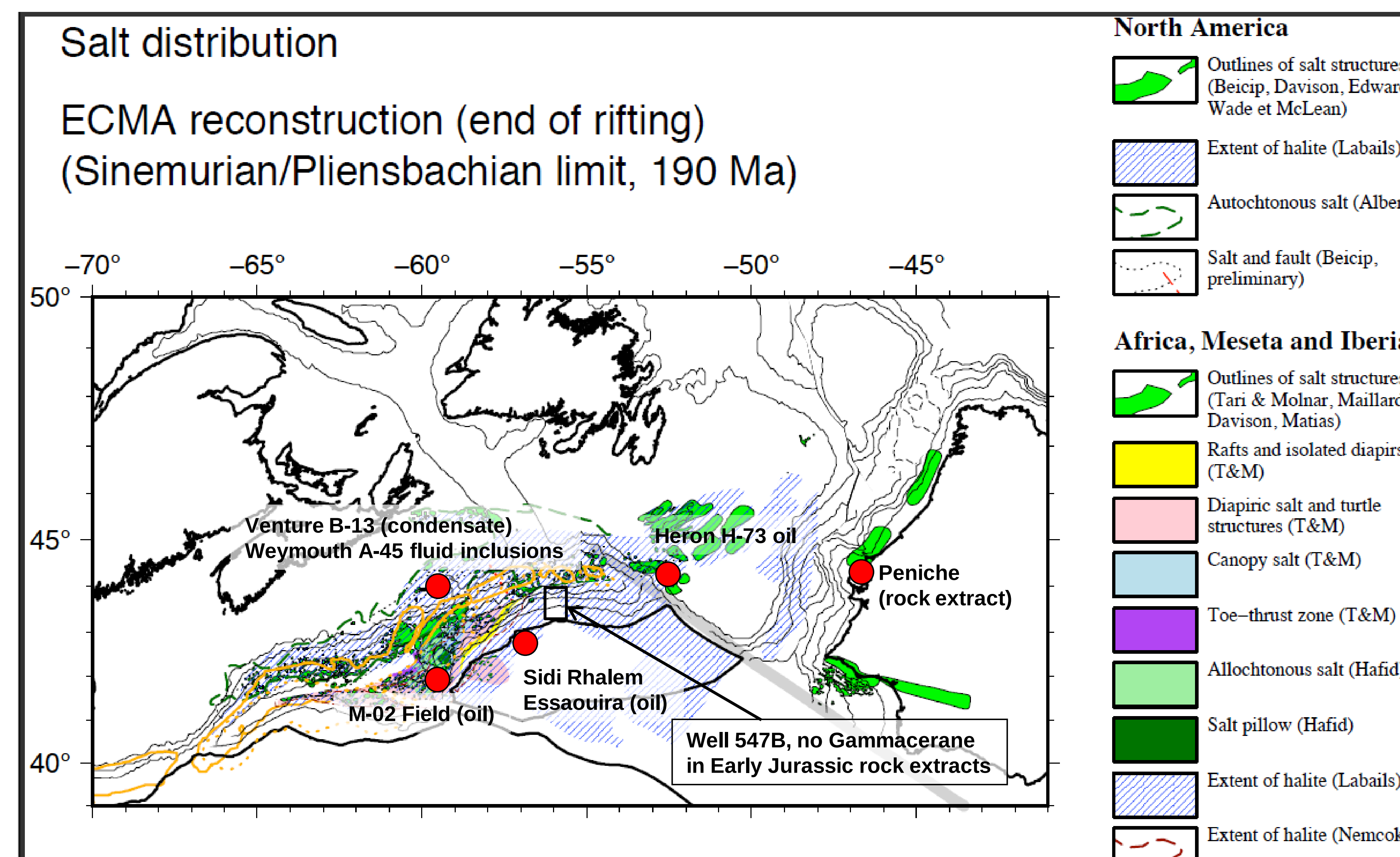


Figure 7: Rift reconstruction 190 Ma and salt distribution by Sibuet et al. (2011). Red dots show locations of Gammacerane occurrences in oils, condensates, rock extracts and hydrocarbon fluid inclusions. Gammacerane is absent or in very low abundance in Early Jurassic organic-rich intervals of DSDP wells 547B. Also, there is no salt deposited in the Triassic/Jurassic interval of well 547B (Figures 2, 3, 4 and 5).

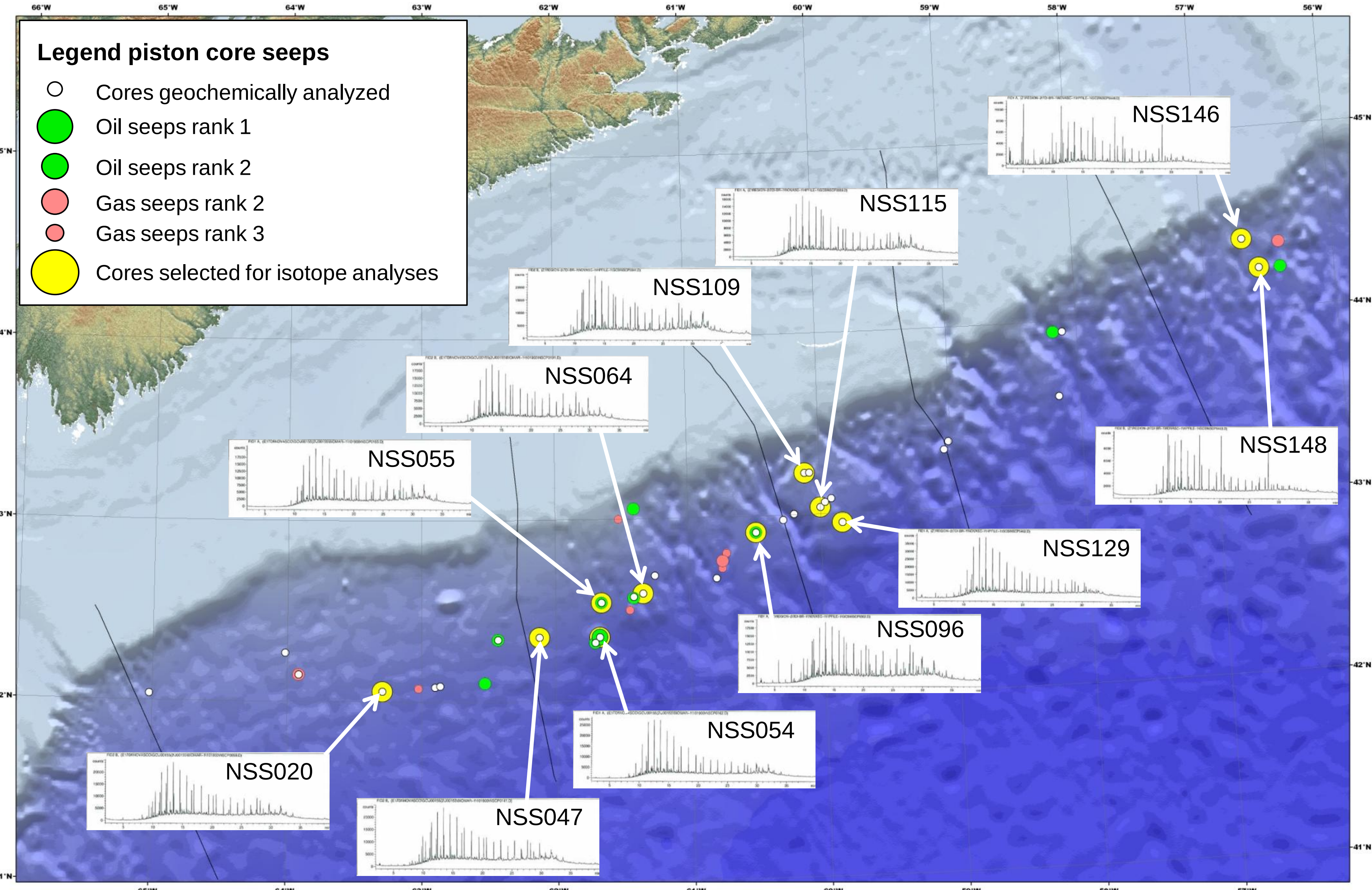


Figure 1: Location of the piston-cores analyzed for carbon isotopes (yellow dots). The gas-chromatograms show that the samples extracted from the piston-cores are as little as possible contaminated by recent indigenous organic material.

Re-interpretation of the "REGIONAL GEOCHEMICAL SURVEY for 2000 Nova Scotia Consortium SGE PROGRAM by TDI-Brooks International, Inc.

Carbon isotope data

This interpretation integrates carbon isotope data of oil/condensate and source rock extracts from Mukhopadhyay (1989 & 1990), and TDI-Brooks data (2000) on seeps from piston-cores and data from Morocco margin graciously provided by Geomark Research, Inc.. Yet many of the extracts (shown separately in Figure 4) do not qualify as source rock for the oil and condensates from the Nova Scotia margin (see Sofer diagram Figure 2), some do. Along the Sofer line (Sofer 1984), $\delta^{13}C$ of the source extracts lighter than oil/condensates suggest a lower maturity of the source samples analyzed.

Figure 1 shows the location of the piston-core seeps analyzed for isotopes. The gas-chromatograms show that the samples extracted from the piston-cores are as little as possible contaminated by recent indigenous organic material. In Figure 2, the piston-core seeps displaying $\delta^{13}C$ ranging in the -30 to -31 per mil for the saturate fraction and -29 to -30 per mil for the aromatic fraction are isotopically lighter than the oil/condensate and their qualifying source rocks, indicating a different source rock for these oil-seeps.

Comparison with Morocco oils (see location Figure 3) known to originate from the Toarcian source rock suggests that the piston-core seeps could originate from an Early Jurassic source rock possibly present on the Nova Scotia margin:

- The oil from the Essaouira field of Sidi Rhalem is isotopically compatible with the piston-core seeps (Figure 3)
- The MO-002 oil from the Tarfayat Basin (Cap Juby; see location Figure 3) known to originate from the Toarcian source rock displays isotopic values apparently compatible with the bulk of the Nova Scotia oils and condensates yet its biomarkers present characteristics of hypersalinity (gammacerane) of an Early Jurassic (Toarcian) source rock (see Figure 2 of Plate 4-4-11). However, the MO-002 oil is severely biodegraded (Figure 4), which may be the reason for the drift of its isotopic composition toward heavier values.

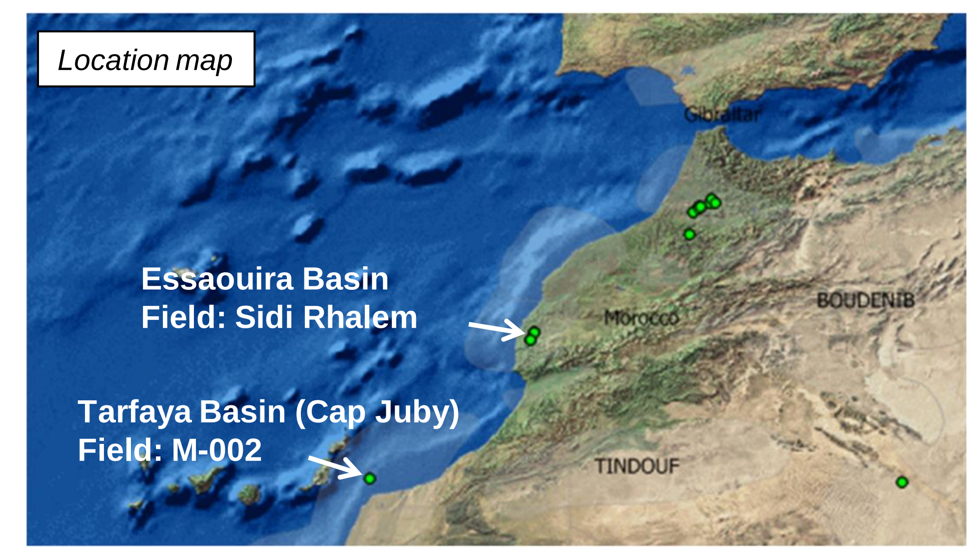


Figure 3: Location of the Morocco oil samples used for comparison of oils and condensates across the Atlantic ocean with the Nova Scotia conjugate margin

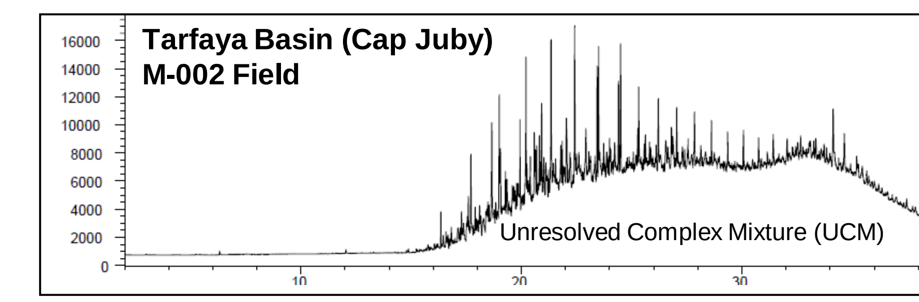


Figure 4: Gas-chromatographic trace of the MO-002 oil (Cap Juby, Tarfayat Basin) showing biodegradation of the oil.

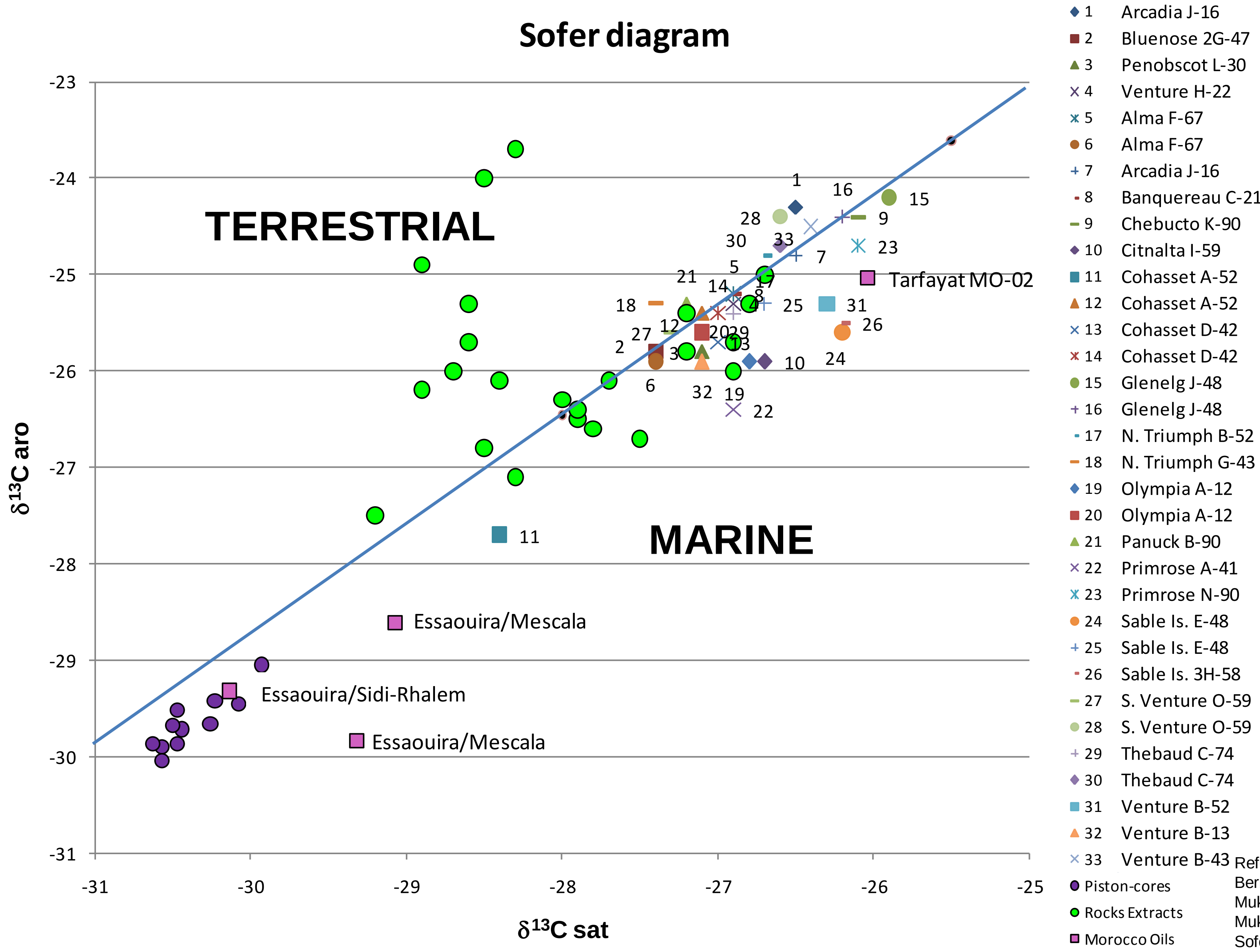


Figure 2: Sofer diagram (Sofer, 1984) displaying carbon isotopes (saturates & aromatics) of oils, condensates (numbered samples) and bitumen extracts from rock samples (green dots) from the Nova Scotia margin reported by Mukhopadyay (1990). Piston-cores seeps (dark blue dots) from TDI-Brooks Int'l, Inc. study (2000) and Morocco oils) communicated graciously by Geomark Research are also included in the diagram. The Many Nova Scotia oils and condensates are located near the separation line between terrestrial and marine source origin. The bitumen extracts located near the line are candidates for sourcing the oils and condensates. Other extract located deep in the Terrestrial domain of the diagram can be discarded as source of the Nova Scotia oils and condensates. The piston-core seeps originate from a very distinct source rock. The isotope correlation of the piston-cores with Morocco Sidi Rhalem oil known to be sourced from the Toarcian source rock supports the presence of an Early Jurassic source rock on the Nova Scotia margin (conjugate to the Morocco margin).

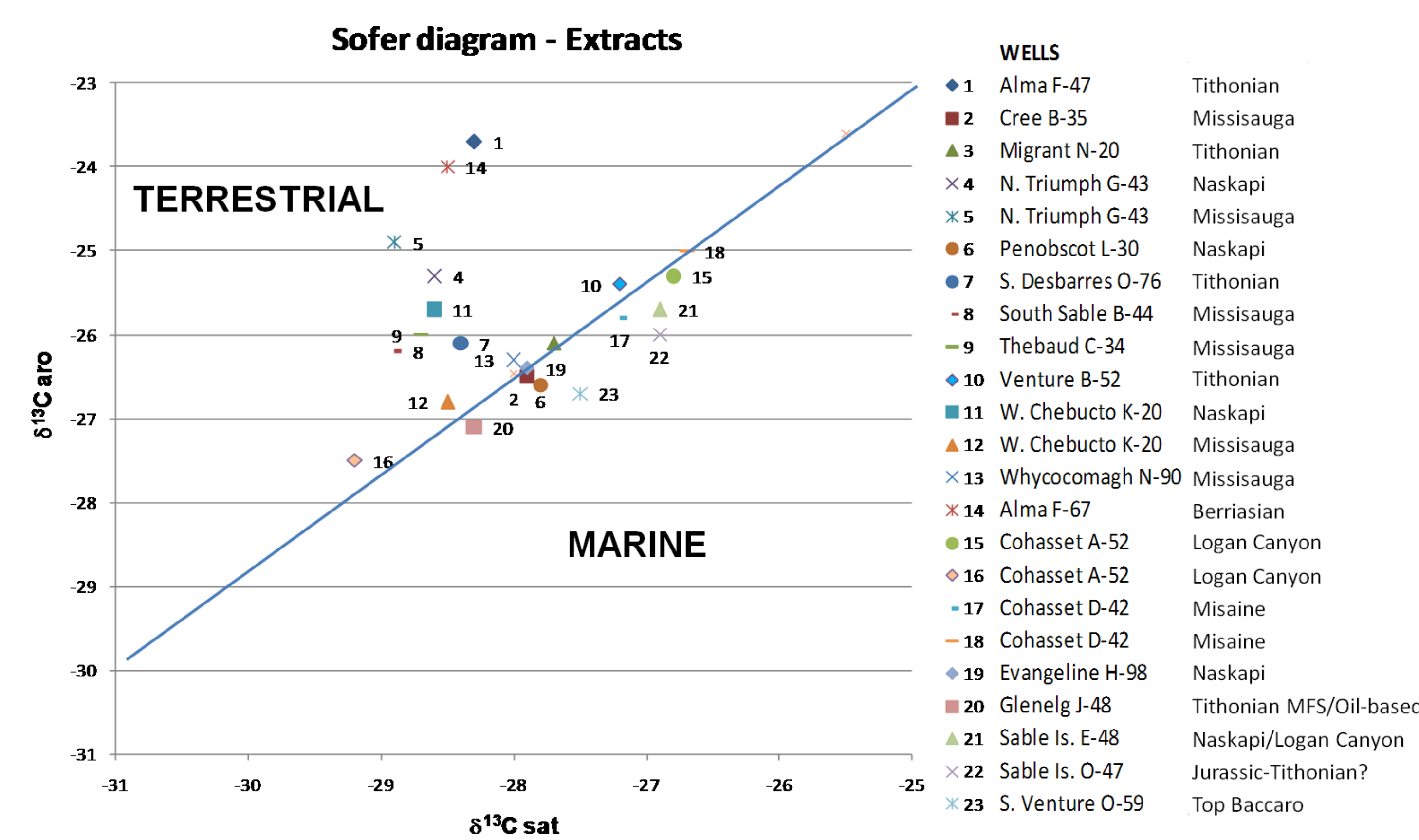


Figure 4: Sofer diagram (Sofer, 1984) displaying carbon isotopes (saturates & aromatics) of bitumen extracts from rock samples (green dots of Figure 2) selected from various wells and stratigraphic intervals. Only the bitumen extracts located near the line are candidates for sourcing the oils and condensates of the Nova Scotia margin.

References:
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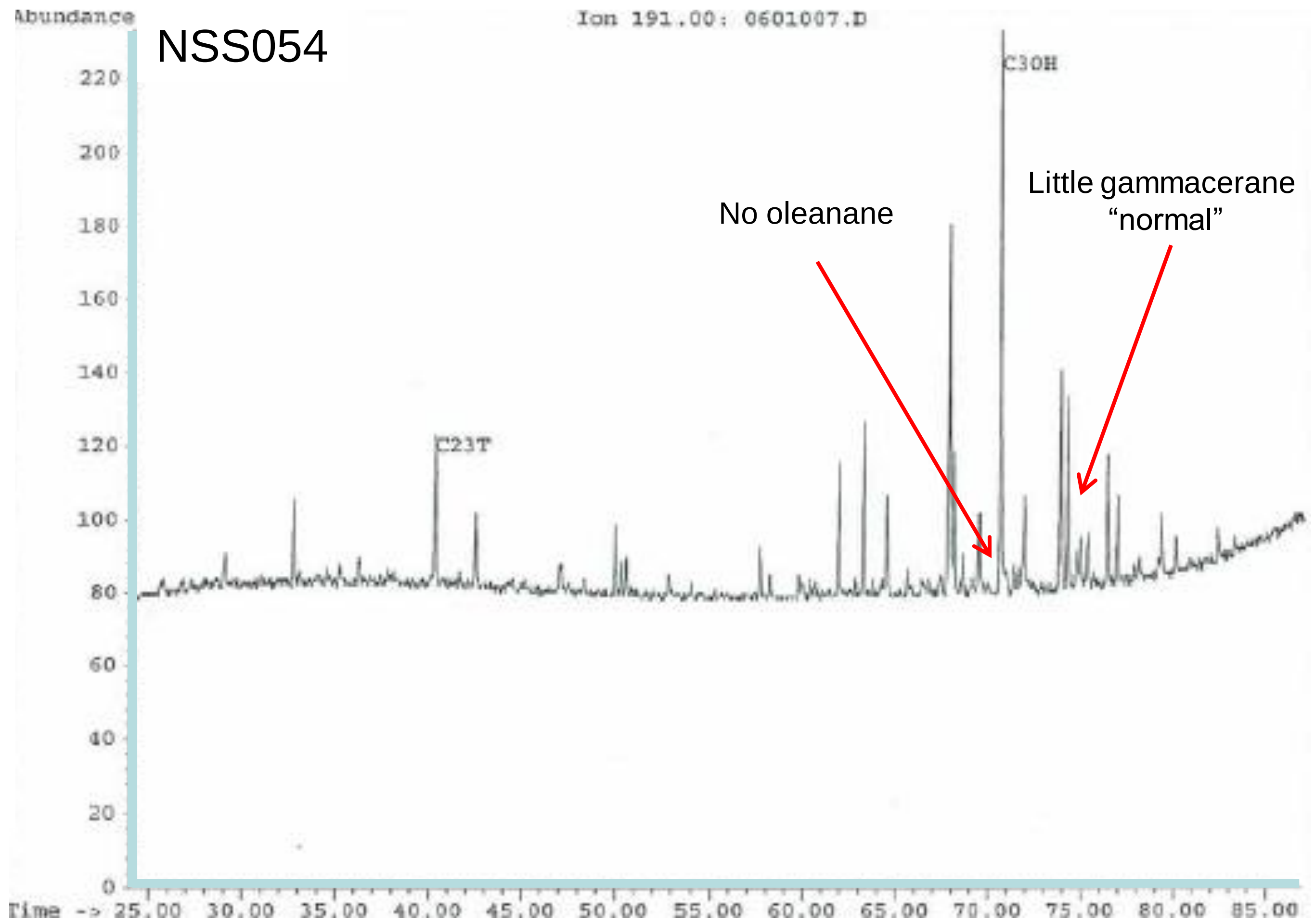

Figure 1: Low Gammacerane abundance in piston-core seeps

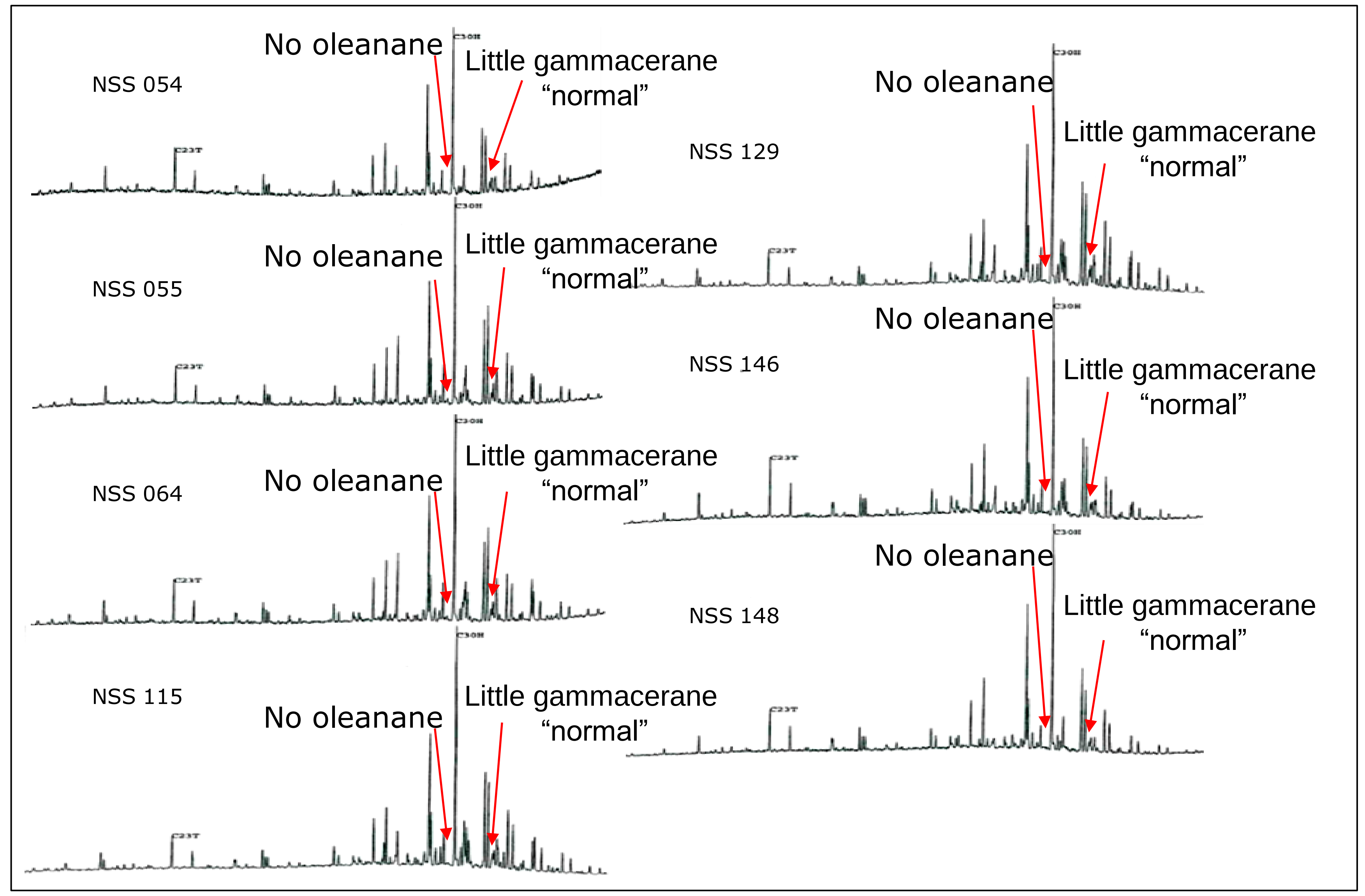

Figure 2: Low Gammacerane abundance and absence of Oleanane in all piston-core seeps analyzed for stable carbon isotopes.

Piston core conclusions

- The tight isotope group (Figure 2, Plate 4-3-8) formed by the piston core samples separates them clearly from the condensates of the Shelf gas discoveries and suggest that they are all originated from the same source rock;
- Good match of the isotopic signatures with the Sidi Rhalem oil of Morocco sourced by an Early Jurassic (Toarcian) source rock (Figure 2, Plate 4-3-8) suggests and supports the presence of an Early Jurassic source rock on the Nova Scotia margin.
- Low abundance of Gammacerane in the seeps displayed in Figure 2 suggests that their source rock was not deposited under water stratified or hypersaline conditions. The Toarcian source rock in the IODP well 547B exemplifies such a case as it is bare of Gammacerane (see Figure 5, Plate 4-3-5) but nonetheless a source rock.
- Absence of Oleanane precludes any Late Cretaceous sourcing (Figures 1 and 2, this Plate).

THESE ARGUMENTS SPEAK IN FAVOR OF PRESENCE OF AN EARLY JURASSIC SOURCE ROCK

- On the western part of the margin, down slope off the Jurassic carbonate platform, the Early Jurassic source rock is the only one mature.
- Going east, other source rocks become mature up to at least the Tithonian one, which could also feed the seeps.
- The effect should be to spread the tight isotope seep group toward the discovered oil/condensates group but this does not happen as if the Early Jurassic source rock was the only one feeding the seeps.

Source rocks

Lower Cretaceous – Aptian – Naskapi (deltaic)

This source rock was deposited during the Intra-Aptian flooding event as a prodeltaic facies of the incipient Logan Canyon/Cree deltaic development. The source interval coincides reasonably well with the Naskapi shale of the lithostratigraphic nomenclature. TOC/Rock Eval data defining the characteristics of this source rock are shown in Figures in Plates 4-4-2 and 4-4-3 for various wells from the Scotian Shelf and Slope. Organic richness is only fair with TOC averaging 2%. The organic matter composing this source rock is of a terrestrially derived Type III as is suggested by microscopic kerogen analyses and Hydrogen Index – Oxygen index cross plot shown in Plate 4-4-2.

The hydrocarbon kitchen applying to the Lower Cretaceous – Aptian source rock is limited to a restricted area of the shelf (see maturity Map in Plate 7-3-2-2). The maturity data (Vitrinite Reflectance) for various well locations indicate mostly immaturity except for wells located at present day shelf edge, e.g. Chebucto K-90. A map of present day maturity produced by the Temis 3D model of the margin on the Naskapi source rock shown in Plate 7-3-2-2 displays extent and intensity of the limited hydrocarbon kitchen applying to the Naskapi source rock. As a consequence of the limited kitchen, the Naskapi source rock does not appear to be a large contributor to the petroleum system of the Nova Scotia margin.

For modeling purpose, the Naskapi source rock is defined as follows:

- TOC=2%
- Kerogen Type III, using default Type III from Temis.

Lower Cretaceous –Valanginian (deltaic)

The age of this source interval is Berriasian-Valanginian (from K137 up) depositing as prodeltaic and paralic facies of the "middle" Missisauga delta. The Lower Cretaceous source rock is absent on the Jurassic carbonate shelf edge. That source interval is diffuse. Organic richness is mostly limited to TOC<1.5% and the kerogen is of a Type III.. Plates 4-4-3 and 4-4-4 display the characteristics of the Berriasian-Valanginian source rock.

The main reason for defining this interval as a source rock is to test its effect on the petroleum system modeled with Temis.

For Temis petroleum system modeling, the following characteristics are applied:

- TOC=1%
- Kerogen Type III, using default Type III from Temis.

Upper Jurassic – Tithonian MFS (carbonate transition to deltaic)

The Upper Jurassic source rock is present beyond the Jurassic carbonate bank edge. It was deposited at the transition from carbonate to deltaic environments of deposition during the Tithonian maximum flooding event. The source rock of the Tithonian MFS defined here corresponds to the lower part of the Verrill Canyon formation cited as source interval in P. K. Mukhopadhyay reports and publications. This Upper Jurassic source rock was difficult to identify due to drilling with oil-based mud (Lignosulphonate, Gilsonite and others) at the approach of overpressures, which is almost always coincidentally with approaching the Jurassic. Oil-based mud contamination strongly affects TOC/Rock Eval data usually by improving the response of these measurements to anomalously high values. The best and only way to overcome the distortion on Rock Eval analyses in defining source rock characteristics is to rely on kerogen microscopy, which allows for discriminating at least solid contaminants. In that regard, Mukhopadhyay's work through the years is key for defining the Tithonian MFS as a prominent source rock of the deltaic region of the Nova Scotia margin.

Figures in Plates 4-4-5 to 4-4-7 display the characteristics of the Tithonian source rock in various wells of the margin. Some wells shown on the Plates were not been screened by kerogen microscopy, e.g. South Griffin J-13 (Plate 4-4-6).

For Temis petroleum system modeling, the following characteristics are applied:

- TOC=3%
- Kerogen Type II-III.

Middle Jurassic – Misaine - Callovian MFS

Evidence for a Callovian source rock is limited to one well - Abenaki J-56 - located at the edge of the Jurassic platform. The extension of this source rock beyond the carbonate platform edge is unknown. In lithostratigraphic terms, this source rock corresponds to the Misaine Member. The Misaine is a shale dominated layer deposited during the Callovian flooding event. After Mukhopadhyay (1989), the Misaine in the Cohasset D-42 well is of Type III to IIB . In the new stratigraphic framework of this study, the source rock interval coinciding to the Callovian MFS is restricted to the part showing a kerogen Type IIB that is condensate/gas prone in Mukhopadhyay classification. Plate 4-4-8 displays the characteristics of the Callovian source rock in one well only of the margin, where it was penetrated and showed significant source potential.

For Temis petroleum system modeling, the following characteristics were applied:

- TOC=2%
- Kerogen Type IIB (II-III; standard)

Early Jurassic Source Complex - Sinemurian-Pliensbachian-Toarcian

A Sinemurian-Pliensbachian-Toarcian source complex is inferred by analogy to source rocks recognized on the conjugate margins of Newfoundland and Nova Scotia, in Portugal and Morocco. The Sinemurian immediately overlaying the Argo salt would offer a confined hypersaline environment, where source rocks are known to have deposited in rift basins. These confined environments are often prone to the development of ciliate bacteria, which are precursors of the Gammacerane molecule. Gammacerane was seen in the Pliensbachian source rock of Portugal (Peniche Basin) and in Moroccan oils. On the Scotian Shelf, one condensate from DST#6 of the Venture B-13 well and hydrocarbon fluids from salt inclusions in the Weymouth A-45 well display the presence of Gammacerane. Usually, DST hydrocarbon fluids are clean from mud contamination. However, if mud with Gilsonite additive was used and the formation tested was partly invaded by mud before testing, there is a chance that the DST fluids be contaminated. On the other hand, in the case of fluid inclusions in salt from the Weymouth well, the presence of Gammacerane is to be trusted as sample cleaning is drastic before crushing the inclusions for gas-chromatography (GC) and GC/mass-spectrometry (GCMS) analyses. The Toarcian penetrated in the 547B well of IODP Leg 79, Site 547 did not display any Gammacerane leading to the conclusion that Gammacerane is not necessarily a criterion for defining the contribution of a Toarcian source rock. Depending on the environment whether hypersaline or not, Gammacerane may or may not be present. Along the Nova Scotia margin, Gammacerane may be associated to a source rock depositing at the end or immediately after the salt of the Argo Formation. At Pliensbachian and Toarcian time, the environment has possibly evolved into a carbonate environment no longer hypersaline or presenting any other water stratification of any type. This would be the case of the 547B well off Morocco, which penetrated the Liassic section down to a crystalline basement without penetrating any salt and not displaying any Gammacerane. In the Nova Scotia margin, the extension of a hypersaline source rock would be limited to the rift area occupied by the autochthonous salt of the Argo Formation.

Later, once spreading had started, restricted conditions and hypersalinity ceased as the basin opened. Sediments could deposit further, beyond the autochthonous salt area, over the ECMA volcanics. Source rocks depositing then would no longer contain Gammacerane by lack of water stratification (halocline in this instance). In time succession, the hypersaline source rock would preferably be Sinemurian deposited approximately just before spreading. Then, source rocks depositing later during early spreading may lose hypersaline characteristics, these would be Pliensbachian – Toarcian in age. To summarize, one or more Early Jurassic source rocks may exist. Their presence is unproven but is worth considering based on the conjugate Moroccan margin.

For Temis petroleum system modeling, one source rock only is defined for the Sinemurian to Toarcian source complex, named *Pliensbachian source rock* in the 3D modeling Chapter, Plate 7-3-1-3a. The estimated characteristics of this source rock are as follows:

- TOC=5%
- Kerogen Type II

Source thickness and lateral extent

The thickness of a source rock is as important as its organic richness for determining the amount of hydrocarbons that can potentially be produced by it. The lateral extent of a source rock is also important as oil accumulations have a tendency to occur at the shortest lateral distance from the generative kitchen of the source rock. Both thickness and lateral extent of the source rocks clearly identified in few wells only, cannot not clearly be defined with the well control at hand. Also the lateral extent out of the well control is undetermined. Therefore, these two variables of the petroleum systems had to be estimated for feeding the 3 dimensional petroleum system model presented in Chapter 7. The maps of source rock thickness and lateral extent that are accounted for in the Scotian Basin model are shown in Plate 7-3-1-3a (Chapter 7).

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