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 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.

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 rift, Kupferschiefer analog) in salt or post-salt situation and or marine (Type 2) in the Pliensbachian-Triassic (Portugal, Morocco and French Schistes Carbonates 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 conducted a regional satellite oil slick study was also acquired for the PFA study.

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. For oil, condensates and bitumen extracts, carbon isotope data were acquired and reported by Mukhopadhyay (1991). These data are re-examined in this study.

For "standard" biomarkers (saturates) of the Nova Scotia oil and bitumen extracts 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 C11 to C40 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-DCIMS) 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
   - Deposition immediately post-rift, hypersaline (gammacerane) to carbonate marine environment (Sinemurian-Pliensbachian-Triassic);
   - 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

PENDLETON GEOCHEMISTRY
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 and the mechanisms driving their generation is a major component of the play forum project. The study includes the impact of hydrocarbon generation from these source rocks on the petroleum system and on the evolution of the Nova Scotia margin.

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 like 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 inclusions 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 but mostly preferring to penetrate in the deep margin or not present (hastur or unconformities) where penetrated. Triassic or Lower Jurassic source rocks are expected to be oil-prone without a lutiniferous (Type 1; West African Oil, Paaschau) analagous in salt or post salt situation and or marine (Type 2) in the Pliensbacbian-Toarcian (Portugal, Monaco and French Schiloo-Carbon 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 gas chromatography and mass spectrometry. These various approaches lacked references to genetic signatures capable of relating oil and condensates to specific source rock types and environment of deposition. The most significant data in a genetic sense remain the “standard” biomarkers of the saturated 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 gasotope 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 constructed. 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 C15 to C35 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 TD-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 gas and carbon compounds 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](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)

1. Introduction – Content - Source rock summary
2. Hydrocarbon occurrences
   - Significant discoveries and shows
   - Significant seeps on the Nova Scotia margin slope (TD-Brooks regional geochemical survey)
   - New GC and GCMS analyses of oil, condensates and hydrocarbon fluid inclusions
3. Data
   - Oil sticks (NPA-Fugo satellite sticks)
   - Oil sticks (NPA-Fugo satellite sticks)
4. Source Rock
   - Introduction
   - Lithology
   - Geochemical data
   - New TOC/Rock Eval data
5. Source Rock summary
   - Five (5) key source rocks were identified:
     1. Lower Cretaceous – Aptian (deltaic)
     2. Lower Cretaceous – Valanginian (deltaic)
     3. Upper Jurassic – Tithonian (transition from carbonate to deltaic environment)
     4. Middle Jurassic – Callovian
     5. Early Jurassic source complex – Liassic

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 major as it is relatively limited in organic matter. However, it reflects and accounts for organic matter present in the Lower Cretaceous (Mississauga). The Tithonian source rock is of major importance as it is well defined, organic-rich and mature. The Liassic source rock is considered major 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).

Source rock evaluation is also developed in Chapter 6

PL. 4-1-1

Introduction – Content – Source Rock Summary
CHAPTER 4-2
PETROLEUM GEOCHEMISTRY
HYDROCARBON OCCURRENCES
**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**

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 NPA-Fugro.
Hydrocarbon Occurrences – Satellite Oil Slicks

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 4: Illustration of interpreted slicks are displayed.

Legend piston-core seeps & DHI
- Oil seeps rank 1
- Oil seeps rank 2
- Thermo. Gas seeps rank 2
- Thermo. Gas seeps rank 3
- DHI clusters

Legend Slick Outlines (Hyperlink to Extracts)
category
- Swampy Slick Third Rank
- Privately Unassigned Slick
- Unassigned Slick
- Pollution Slick Second Rank
- Source Outlines Important to Quantitative
  - Swampy Slick First Rank
- Privately Unassigned Slick
- Unassigned Slick
ROCK DATA
The basic geochemical data available on line consist of source rock and maturity data for the Scotian Shelf and the Slocan Slope as well as the South Grand Banks. There are TOC and Rock Eval data for 61 shales & slope wells and maturity data for 88 shales & 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 repeated 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 and 1991) 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 essentially assimilate of Vitrinite Reflectance. The GSC on-line database is populated mainly by data from various laboratories but mainly from Avery and Mukhopadhyay. New Vitrinite Reflectance data were acquired on 88 existing wells, in order to add 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 and 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 stearanes and hopanes/stereanes were often discarded as their concentration are low in condensates and light oils.

PISTON-CORE SEEPS DATA
See data from the regional geological 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.

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 shows the advantage that part of the contaminants from the mud can be identified and discarded from the kerogen composition. However, mud additives such as light oils and bitumens may not always be easily separated from the in-situ sedimentary kerogen.

Oil and Condensate data
Oil and condensate data 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 see data
See data from the regional geological survey on the slope of the Nova Scotia margin by TDI-Brooks International, Inc. are made available to this study end of March (2011) when confidentiality on the report was released.
### TOC/ROCK EVAL DATA

**Online GSC Basin Database**

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<th>54 shelf wells</th>
<th>Wells from the DMC database</th>
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<td>Alma F-67</td>
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<td>Whyoomagham N-90</td>
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### MATURITY DATA

**Online GSC Basin Database**

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<tr>
<td>North Triumph B-52</td>
<td>Whyoomagham N-90</td>
</tr>
</tbody>
</table>

### Vitrinite Reflectance

- **Acadia K-62**: 400 to TD (~5300 m) + Fluid Inclusion basal carbonates
- **Shelburne B-29**: 3000 to TD (~4000 m)
- **Torbrosk C-15**: 2600 to TD (~3600 m)
- **Shubenacadie B-100**: 32000 to TD (~4200 m)
- **Onondaga A-25**: 3100 to TD (~4100 m)
- **Sambro I-29**: 1000 to 1600 m
- **Objaws E-07**: 1400 to TD (~2300 m)
- **Glenelg J-48**: 4500 to TD (~5100 m)
- **Marmora C-34**: 3800 to 3900 m
- **Chippewa L-75**: 5900' - 6000'
- **Cohasset D-47**: 5500' - 5600'
- **Migrant N-20**: 920' - 1075'
- **Ersk D-26**: 5700' - 5900'
- **Mohican P-15**: 3300 to 3900 m
- **Gold P-38**: 10000 - 11100 TD
- **Irroquois J-17**: 4450' - 5850' (17') and 6650' - 6845' (9) oil stains anhydrite

### TOC, Rock Eval and Maturity

- **Torbrosk C-15**: 2835m - 3600m
- **Mohican P-15**: 10810' - 12860'
Maturity, however, is used extensively in the modeling part of the study for maturity calibration of the basin models. Maturity is typically determined from vitrinite reflectance data, which is a measure of the degree of thermal maturation of organic matter in sedimentary rocks. The vitrinite reflectance data are used to estimate the temperature and pressure conditions under which the organic matter was deposited and the thermal history of the basin.

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 basin. Detailed maturity of each well is neither presented nor discussed in the Petroleum Geochemistry part of the Atlas except for modeled locations helps with distinguishing which one of the maturity gradients applies.

Maturity, however, is used extensively in the modeling part of the study for maturity calibration of the basin models. Maturity is typically determined from vitrinite reflectance data, which is a measure of the degree of thermal maturation of organic matter in sedimentary rocks. The vitrinite reflectance data are used to estimate the temperature and pressure conditions under which the organic matter was deposited and the thermal history of the basin.
The expectation is that a DST at 4572m is the condensate of Venture B well. The two 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 is the occurrence of Gammacerane in the condensate of DST#6. DST#6 well is the only one penetrating both the upper and lower Trenches of the Argo Salt. Cutting samples from depths transferred in the Argo Salt (3567m) in the Oblique C, DST #6 well were analyzed by Oleanane of 2 of these samples shown in Figure 1 of the next Plate 4.

**Figure 2:** Hopane traces (m/z 191) of 2 cutting samples at 4570 and 4580m from the Venture B.

Oleanane of 2 of these samples shown in Figure 1 of the next Plate 4.

**Figure 3:** Mud sample, 4580m.
**Glooscap C-63 – Biomarkers of rock extracts**

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

**Biomarker traces (m/z 191) - Saturates**

- Glooscap C-63 Cutting extract, 4340-4344m Shale interlayered in Argo salt
  - No Gammacerane

**Mohican I-100 – Biomarkers of rock extracts**

**Mud - additive**

<table>
<thead>
<tr>
<th>Top</th>
<th>Bottom</th>
<th>Unit</th>
<th>Mud</th>
<th>Mud Additives</th>
<th>Event</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>DLS</td>
<td>1540</td>
<td>FT</td>
<td>TREATED-DEL</td>
<td>SPERSE, CROMEX</td>
<td>MUD</td>
<td>-</td>
</tr>
</tbody>
</table>

**Biomarker traces (m/z 191) - Saturates**

- Mohican I-100 Core extract 4096.75m Weak trace - lean fraction
  - Little gammacerane

**Figure 3:** In Mohican I-100, sample from 4096.75m displays a very weak trace, sample from 4098.14m displaying oleanane is contaminated

- Mohican I-100 Core extract 4098.14m
  - Oleanane
  - Little gammacerane

**Figure 4:** In Cohasset D-42, Mohican I-100 and Deep Panuke (Panuke PPZ), 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.

**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 4572-4573m) 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 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 those 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**

- Glooscap
- Weymouth Top salt
- Weymouth Middle salt
- Weymouth Bottom mix
- Weymouth Bottom salt

**Gammacerane**

**Oleanane**

- No oleanane

---

**Biomarkers – Conclusions**

- Gammacerane in Weymouth salt fluid inclusion and in Venture B-213 DST 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:** Hopane traces (m/z 191) of hydrocarbon 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 C35 to C34 equal to 1 suggests that the source rock of these HC inclusions deposited in a carbonate environment.

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

**Figure 3:** In Jurassic Abenaki condensates at “Deep Panuke” (Panuke PP3C), homohopane ratio C35 to C34 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, improbably, leaching of Upper Cretaceous organic matter along the migration path.

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;
- C1-C6 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 δ13C results. They are:

- Core# NSS014-2 sections of the core had enough headspace gas for performing the analyses. Methane δ13C 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 δ13C = -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:

- Blumen 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 isotopic data listed in Table 1 are reinterpreted because the opportunity arose to integrate them with isotopic 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 seepage of the seeps.

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

<table>
<thead>
<tr>
<th>Location</th>
<th>Sample ID</th>
<th>Depth (m)</th>
<th>Oil saturation (vol%)</th>
<th>Gas saturation (vol%)</th>
<th>ROM (per mil)</th>
<th>13C (per mil)</th>
<th>TAS3</th>
<th>Steranes</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDI-Brooks International, Inc. report consists only of genera Brooks International, Inc. 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 seepage of the seeps.</td>
<td></td>
<td></td>
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</tbody>
</table>
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. The 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. The 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
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 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 I), 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 4-10 to 4-4-14 display the characteristics of Early Jurassic source rocks located on the Nova Scotia conjugate margins of Portugal and Morocco.
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 than 1% 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.

**Like South Griffin J-13, Dauntless D-35 was drilled using Lignosulfonate added to the mud.**
Source Rock – Naskapi (Intra Aptian MFS) - Sable Sub-basin

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

All samples analyzed for maceral from 5490 to 6770m by Mukhopadhyay (1990) are contaminated by mud additives.

Source rock - T Tithonian MFS

Data from: Petrocanada

Data from: Muki

Data from: Corelab

Data from: Mukhopadhyay

Data from: Muki

Data from: Corelab

Data from: Muki

TOC (%)

Depth (m)

Cohasset L-97

Newburn H-23

South Venture O-59

Annapolis G-24

Crimson F-81

Source Rock - Naskapi (Intra Aptian MFS) - Sable Sub-basin
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 elevated 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
PETROLEUM GEOCHEMISTRY - SOURCE ROCKS

BERRIASIAN/VALANGINIAN SOURCE ROCKS THROUGHOUT THE “SABLE BASIN”

- 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.
The Tithonian source rock in South Venture O-59
- South Venture O-59 is not contaminated by any mud additives.
- Kerogenous microscopic (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.

Reference:
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.
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 IIB, 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 TDC 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).
**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 purposes, the following characteristics were retained:
  - TOC=2%
  - Kerogen Type II–III
The Early Jurassic source complex
- Liasic 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 Liasic clastics. Further out, Liasic 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.

In Portugal
Luiz Carlos Veiga de Oliveira et al. (2006) publication reports the following:
- The Mnb Member (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 Mnb 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.

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 Liasic source rock on the Nova Scotian 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.

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.
PETROLEUM GEOCHEMISTRY - SOURCE ROCKS

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, Tarfaya Basin, Cap Juby, offshore Morocco

Figure 3: Biomarker traces (m/z 191) of various oils, condensate, extracts and HC fluids. Some 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.

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.

Source Rock – Early Jurassic Source Complex - Sinemurian/Pliensbachian/Toarcian

PL. 4-4-11

Gammacerane & depositional environments

- Gammacerane forms by reduction of tetrahymanol. The source of tetrahymanol appears to be bacteriaceous diatoms, which occur at the interface betweenoxic and anoxic zones of stratifiedwater columns.
- Abundant Gammacerane is believed to indicate the presence of stratified water column.
- Although stratified water column can result from both hypersalinity 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), postrift with high salinity at the end of the Argo salt deposition changing progressively to carbonate and more open marine environments, or
  - Triassic.

Homohopane C35/C34 ratio & depositional environments

- High C35/C34 homohopane compared to C29 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

- C35/C34 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 C35/C34 homohopane ratio does not exhibit any sign of highly reducing conditions, yet it is associated to an organic-rich source rock well rock preserved, the facies of which is marly rather than pure carbonates (Quarta et al., 2010).
- Taking Gammacerane and the C35/C34 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 Gammacerane (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).

Source Rock – Early Jurassic Source Complex - Sinemurian/Pliensbachian/Toarcian

PL. 4-4-11
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 (Zunzane 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:


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

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).

Gammacerane

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

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

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

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 shallower 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).

Carbon isotope data

This interpretation integrates carbon isotope data of oil/condensate and source rock extracts from Mahopadhyay (1989 and 1993), 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), δ13C of the source extracts lighter than oils/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 δ13C ranging in the -30 to -31 per mil for the aromatic fraction and -29 to -30 per mil for the aliphatic fraction are isotopically lighter than the oil/condensates and their qualifying source rocks, indicating a different source rock for these oils.

Comparison with Morocco oils (see location Figure 3) known to originate from the Taurian 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 Rhalam is isotopically compatible with the piston-core seeps (Figure 3).
- The MO-002 oil from the Tarfaya Basin (Cap Juby) sea location Figure 3) known to originate from the Taurian source rock displays isotopic values apparently compatible with the bulk of the Nova Scotia oils and condensates yet its biomarkers present characteristics of hypersalinity (gamaeracene) of an Early Jurassic (Toarcian) source rock (see Figure 2 of Plate 4A-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 4: Gas-chromatographic trace of the MO-002 oil (Cap Juby, Tarfaya Basin) showing biodegradation of the oil.

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 2: Sofer diagram (Sofer, 1984) displaying carbon isotope (saturates & aromatics) of oils, condensates (numbered samples) and bitumen extracts from rock samples (green dots) from the Nova Scotia margin reported by Mahopadhyay (1993). Piston-core seeps (pink blue dots) from TDI-Brooks Inc. (inc. study 2000) and Morocco oil (blue dots) were graciously provided by Geomark Research. 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 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 Rhalam oil is known to be sourced from the Taurian source rock supports the presence of an Early Jurassic source rock on the Nova Scotia margin (conjugate to the Morocco margin).

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.

Source Rock – Early Jurassic Source Complex - Sinemurian/Pliensbachian/Toarcian

PL. 4-4-13
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.
Conclusions

PL. 4-4-15

PETROLEUM GEOCHEMISTRY - SOURCE ROCKS

PLAY FAIRWAY ANALYSIS - OFFSHORE NOVA SCOTIA - CANADA - JUNE 2011

Source rocks

Lower Cretaceous – Aptian – Naskapi (deltaic)

This source rock was deposited during the intra-Aptian flooding event as a progradational facies of the incipient Loggan Canyon/One deltaic development. The source interval coincides reasonably well with the Naskapi shale of the lithostratigraphic nomenclature. TOC/RockEval 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 terrestrial 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 (Winite反射率) for various well locations indicate mostly immaturity except for wells located at present day shelf edge, e.g. Chubucto 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 Ventil 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 (Liignosulphonate, Gallocitrone and others) at the approach of overpressures, which is almost always coincidently 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 at carboniferous. 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 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 III.

Middle Jurassic – Missaia – Callovian MFS

Evidence for a Callovian source rock is limited to one well - Abenaki J-58 - 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 Missaia Member. The Missaia is a shallow doman dominated layer deposited during the Callovian flooding event. After Mukhopadhyay (1989), the Missaia 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 a 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 are applied:
- TOC<2%
- Kerogen Type IIb (IIb-III; standard)

Early Jurassic Source Complex – Sinemurian-Plenuschbian-Toarcian

A Sinemurian-Plenuschbian-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 overlying the Argo salt would offer a confined hypersaline environment, where source rocks are known to have been deposited in rift basins. These confined environments are often prone to the development of diatate bacteria, which are precursors of the Gammaceranaceae molecule. Gammaceranaceae was seen in the Plienschbian 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 Gammaceranaceae. Usually, DST hydrocarbon fluids are clean from mud contamination. However, if mud with Gallowane additive was used and the formation tested was partially 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 Gammaceranaceae is to be trusted as sample cleaning is drastic before crushing the inclusions for gas chromatography and GC/mass-spectrometry (GC/MS) analyses. The Toarcian penetrated in the 5478 well of IOOP Leg 79, Site 547 did not display any Gammaceranaceae leading to the conclusion that Gammaceranaceae is not necessarily a criterion for defining the contribution of a Toarcian source rock. Depending on the environment whether hypersaline or not, Gammaceranaceae may or may not be present. Along the Nova Scotia margin, Gammaceranaceae may be limited to a source rock deposited at the end or immediately after the salt of the Argo Formation. At Plenuschbian and Toarcian time, the environment has possibly evolved into a carbonates framework no longer hypersaline nor preserving the salt wall contact. This would be the case of the 4548 well off Morocco, which penetrated the Liasic section down to a crystalline basement without penetrating any salt and not displaying any Gammaceranaceae. 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.
References


