Abstract

The Early Paleozoic fold and thrust belt on the west coast of Newfoundland hosts a frontier petroleum system that has minor production and several shallow wells with light oil shows. The basin sits at the structural front of the northeastern Canadian Appalachians, recording the complex tectonic history of Ordovician to Devonian shortening events. During the Taconian (Ordovician) and Acadian (Devonian) orogenies, westward thrusting imbricated continental slope and rise deposits, creating thrust sheets that repeat Lower Paleozoic strata. We present two-dimensional (2-D) basin models to assess the thermal evolution, transformation, migration, and accumulation of hydrocarbons.

Two viable source rocks for this petroleum system have been identified in the Cow Head Group hosted in distal continental slope and rise deposits, with TOC concentrations of up to 10.35 wt.% and a type I/II kerogen with high hydrogen index (HI) values of over 840 [mg HC/g TOC]. This initial investigation presents a 2D petroleum basin model approach including a structural restoration of the fold and thrust belt. The model is calibrated with petrophysical property logs collected from two well, Seamus #1 and Finnegan #1 drilled in 2010. Geochemical data from outcrop samples and oil seeps were used to characterize the source rock quality. Maturity data from pyrolysis analysis are used as additional calibration data.

Our 2-D model for the area shows that kerogen transformation starts prior to the Acadian reverse faulting. Maturity data from outcrop samples indicates that a substantial amount of overburden (approximately 2 km) was present after the Acadian orogeny.
This 2D model gives an in-depth understanding of the evolution of the petroleum system in western Newfoundland and contributes to a better understanding of hydrocarbon generation and migration in fold and thrust belts in general. Understanding these critical elements in a petroleum system context can in turn provide proper risk assessment for future exploration efforts in fold and thrust belts.

References Cited


STRUCTURAL RESTORATION AND 2-D BASIN MODELING IN FOLD AND THRUST BELTS – A CASE STUDY FROM WESTERN NEWFOUNDLAND

Martin Schwangler, Nicholas B. Harris, John F. Waldron

[Diagram showing structural restoration and 2-D basin modeling in fold and thrust belts with labels for basement, continental slope and rise, accretionary wedge, and platform.]
Regional Geology & Tectonic Evolution

No geologic information available after the Acadian (Devonian) Orogeny

(modified after Waldron and van Staal, 2001)
Parsons Pond Area

- Major reverse fault (evidence from seismic and mapping)
- Imbricated continental slope and rise above platform
### Petroleum System

#### Source
- Late Cambrian Cooks Brook/Green Point Fm.
- Middle Ordovician Middle Arm Point/Shallow Bay Fm

#### Reservoir
- St. George Group
- Interformational Cow Head Group

#### Seal
- Goose Tickle Group
- Western Brook Pond Group

#### Trap
- Structural traps
- Stratigraphic traps

#### Maturation
- ??

#### Migration/Accumulation
- ??

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### Platform Stratigraphy vs. Humber Arm Allochthon Stratigraphy

<table>
<thead>
<tr>
<th>Period</th>
<th>Series</th>
<th>Stage</th>
<th>Platform Stratigraphy</th>
<th>Humber Arm Allochthon Stratigraphy</th>
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</thead>
<tbody>
<tr>
<td>DEVONIAN</td>
<td>Lower</td>
<td></td>
<td>Red Island Road</td>
<td>Clam Bank</td>
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<td></td>
<td></td>
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<tr>
<td>SILURIAN</td>
<td>Pridoli</td>
<td>W</td>
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<tr>
<td></td>
<td></td>
<td>LI</td>
<td></td>
<td></td>
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<tr>
<td>ORDOVICAN</td>
<td>Upper</td>
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<td>Series 2</td>
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</table>

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**PETROLEUM SYSTEM**
QUESTIONS WE WOULD LIKE TO ANSWER
- Maturity development within the basin
- Timing of oil generation and migration
- Impact of the fold and thrust-belt geometry on maturity development
- Geometry of migration pathways

UNCERTAINTIES
- Amount of erosion
- Paleo Water Deoth (PWD)
- Sediment Water Interface Temperature (SWIT)
Apatite fission tracks are a result of $^{238}$U decay destroying the crystal lattice along their flight paths.

- Initial track length is $\sim 15\mu m$.
- Tracks heal with increasing temperature.
- Tracks disappear when temperature increases over $110^\circ C$.
- Annealing temperature and annealing rates dependent on Cl content in apatite.

Gleadow et al. 2002
APATITE FISSION TRACK – APPLICATION

- Thermal history framework
- Timing and magnitude of paleo-thermal events
- Paleo-geothermal gradients
- Constraints on the thermal maximum and therefore the maturity of sediments in the basin
- Reconstruction of uplift and erosion history where there are gaps in the geologic record

Seamus-Lower Head FW

<table>
<thead>
<tr>
<th>Proterozoic</th>
<th>Cambrian</th>
<th>Ordovician</th>
<th>Silurian</th>
<th>Devonian</th>
<th>Carboniferous</th>
<th>Permian</th>
<th>Triassic</th>
<th>Jurassic</th>
<th>Cretaceous</th>
<th>Tertiary</th>
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<td></td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Late</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>Early</td>
<td>Late</td>
<td>Early</td>
<td>Late</td>
<td>Early</td>
<td>Late</td>
</tr>
</tbody>
</table>

??

- 100 km

mod modified after Enachescu, 2005

N100 km

NEWFOUNDLAND

Anticosti Basin

Port au Port Peninsula

Maritimes Basin

Deer Lake Basin

Jeanne d’Arc Basin

Hibernia

Laurentian Basin

Carson Basin

Whale Basin

Orphan Basin

Anticosti Basin

St. Anthony Basin

Orpheus Graben

100 km
Apatite Fission Track Results – St. Paul’s Inlet

(modified after Waldron et al., 2003)
Buryal History Calibration

Parsons Pond

Cow Head

St. Paul's Inlet

Apatite Fission Tracks

Track Age: 235.7 ± 14 Ma

GC1219-5 (SM093): outcrop
Lower Head Formation

Deposition of the Lower Head Formation

>115°C
303 to 246 Ma

74-98°C
263 to 109 Ma

36-67°C
75 to 3 Ma

Present temperature 5°C
THermal Maturity Through Time

Seamus-Lower Head FW

340 Ma

Sweeney & Burnham (1990). EASY%Ro [%Ro]

- Immature (0 - 0.55)
- Early Oil (0.55 - 0.70)
- Main Oil (0.70 - 1.00)
- Late Oil (1.00 - 1.30)
- Wet Gas (1.30 - 2.00)
- Dry Gas (2.00 - 4.00)
- Overmature (4.00 - 5.00)

Present day
Gouville Oil (Thrust Sheet)
Western Brook Pond
Table Head
Sitit George Dr.
Port au Port Dr.
Labrador Dr.
Grenville Basement
THERMAL MATURITY THROUGH TIME

300 Ma
THERMAL MATURITY THROUGH TIME

Seamus-Lower Head FW

240 Ma

Sweeney & BllTharr (1990)_EASY%Ro [%Ro]
- Immature (0 - 0.55)
- Early Oil (0.55 - 0.70)
- Main Oil (0.70 - 1.00)
- Late Oil (1.00 - 1.30)
- Wet Gas (1.30 - 2.00)
- Dry Gas (2.00 - 4.00)
- Overmature (4.00 - 5.00)
THERMAL MATURITY THROUGH TIME

200 Ma

Sweeney & Burnham (1990) EASY%Ro [%Ro]
- Immature (0 - 0.55)
- Early Oil (0.55 - 0.70)
- Main Oil (0.70 - 1.00)
- Late Oil (1.00 - 1.30)
- Wet Gas (1.30 - 2.00)
- Dry Gas (2.00 - 4.00)
- Overmature (4.00 - 5.00)
THERMAL MATURITY THROUGH TIME

Seamus-Lower Head FW

Sweeney & Blithe (1990) EASY%Ro [%Ro]
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- Late Oil (1.00 - 1.30)
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- Dry Gas (2.00 - 4.00)
- Overmature (4.00 - 5.00)

90 Ma
Thermal maturity of the source rock is dependent on its structural position.

Thermal maturity increases during the Acadian Orogeny and Carboniferous sedimentation.
TRANSFORMATION RATIO THROUGH TIME

300 Ma
TRANSFORMATION RATIO THROUGH TIME

Seamus-Lower Head FW

200 Ma
TRANSFORMATION RATIO THROUGH TIME

90 Ma

Depth Subsurface (m)

600 550 500 500 450 400 400 350 300 300 250 200 200 150 150 100 100 50 50 0 0

Ages (my)

Present day

Grenville Basement

90 Ma

TR (all) [%]

0 to 10.00

10.00 to 20.00

20.00 to 30.00

30.00 to 40.00

40.00 to 50.00

50.00 to 60.00

60.00 to 70.00

70.00 to 80.00

80.00 to 90.00

90.00 to 100.00

Seamus-Lower Head FW
Transformation ratio through time

- Transformation ratio dependent on the structural position of the source rock.
- Transformation ratio is linked to the major burial events.

0 Ma

Diagram showing depth and time correlation with transformation ratio. The diagram includes depth markers at 200 m, 1000 m, and 1800 m, indicating transformation ratios at these depths.
430 Ma

Strong increase during the Silurian and Early Devonian
Marginal generation during the Early Carboniferous
300 Ma

Strong increase during the Carboniferous
### Generation & Migration Through Time

**Seamus-Lower Head FW**

<table>
<thead>
<tr>
<th>Era</th>
<th>Precambrian</th>
<th>Paleozoic</th>
<th>Mesozoic</th>
<th>Cenozoic</th>
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</thead>
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<tr>
<td>Period</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
</tr>
<tr>
<td>Time intervals</td>
<td>Early</td>
<td>Late</td>
<td>Early</td>
<td>Late</td>
</tr>
</tbody>
</table>

**Depth-Surface (km)**

| Age (My) | 0 | 50 | 100 | 150 | 200 | 250 | 300 | 350 | 400 | 450 | 500 | 550 | 600 |
|----------|---|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Present  | D | C  | B   | A   | B   | A   | B   | A   | B   | A   | B   | A   | B   |

**240 Ma**

- **Generation plateaus**
- **Migration during uplift**

**Generation & Migration Through Time**

- **Present day**
- **Grenville Basement**
- **Western Brook Pond**
- **Table Head**
- **St George Dr**
- **Port au Port Dr**
- **Labrador Dr**

**Generation plateaus**

**Migration during uplift**
Generation & Migration Through Time

Seamus-Lower Head FW

200 Ma

Migration during Jurassic burial

Generation plateaus
**Generation & Migration Through Time**

Seamus-Lower Head FW

<table>
<thead>
<tr>
<th>Precambrian</th>
<th>Paleozoic</th>
<th>Mesozoic</th>
<th>Cenozoic</th>
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<tbody>
<tr>
<td>Cambrian</td>
<td>Ordovician</td>
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<td>Carboniferous</td>
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<td>Silurian</td>
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<tr>
<td>Jurassic</td>
<td>Cretaceous</td>
<td>Eocene</td>
<td>Cretaceous</td>
</tr>
</tbody>
</table>

**90 Ma**

- Some migration during Cretaceous burial

**Generation plateaus**
Generation & Migration Through Time

Some migration at present day

Generation plateaus
- No oil generation at present day
- Accumulation mostly in isolated conglomerate lenses (1 to 20 m; 3 to 66 ft) within the accretionary wedge
- Present day oil shows could be explained by along bed and along fault migration
Three distinct tectonic events (detected by AFTA) have a significant impact on the oil generation and migration history of the basin:

- Alleghanian Orogeny
- Opening of the Atlantic Ocean
- Opening of the Labrador Sea

Carboniferous basin extended over most of western Newfoundland with sediment thicknesses ranging from 2.5 km (South) to 1 km (North).

Substantial cooling since mid-Cenozoic in western Newfoundland suggests denudation of up to 1 km overburden with deposition into adjacent sedimentary basins.
• Oil generation started before the Acadian Orogeny around 445 Ma.
• The main oil generation occurred during the Acadian Orogeny and Carboniferous sedimentation.
• Later burial and uplift events possibly reactivated faults and provided migration conduits for oil.
• Present day thermal maturity of the source rocks is dependent on the structural position within the imbricated stack.
• Accumulations can be found in isolated conglomerate lenses within the Cambrian and Ordovician continental slope and rise sediments.
• No oil generation at present day.
• Present day oil shows could be explained by along bed and along fault migration.
ACKNOWLEDGEMENT

• Ian Duddy (Geotrack)
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