Shale Oil Potential of the Paris Basin, France*

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Search and Discovery Article #10384 (2012)
Posted January 9, 2012

*Adapted from oral presentation at AAPG International Conference and Exhibition, Milan, Italy, October 23-26, 2011

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Abstract

In the French Paris Basin, most of hydrocarbons are generated in the Liassic Shale interval. Among these Liassic deposits, three source rock intervals are identified in the basin: the Lower Toarcian organic-rich interval (“Schistes Carton”); the Pliensbachian (“Amaltheus Shale”); and the Sinemurian-Hettangian. All are marine shales, with type II kerogen.

Numerous similarities exist between the North American Bakken Shale play, that locally is intensively developed for Shale Oil production, and the Paris Liassic Shale: the high source rock potential with favorable maturation (within the oil window), a very close contact and proximity between the source beds and a potential low porosity tight fractured reservoir, and both basins being cratonic.

Multi-2D basin modeling over the main depocenter of Liassic Shale (east of Paris) helped to understand the source rock maturity evolution through time. Where most deeply buried, maturation started during Lower Cretaceous for Sinemurian source rock, and around mid-Cretaceous for Schistes Carton. Maturity increased until the end of Cretaceous and uplift/erosion of the basin; since then, maturity evolved very little.

Hydrocarbon generation and expulsion history from the source rocks was modeled. HC migration (starting at the end of Cretaceous) is developed upward (Dogger reservoirs) and downward (Triassic reservoirs), faults are important pathways. An evaluation of the amount of hydrocarbons still possibly trapped in source rocks (Shale Oil) was performed. A big part of the generated HC was subsequently expelled; the remaining HC vary from one source rock to another, and also geographically, but is generally in the average of 20-30% of the generated HC.
Based on 2D modeling results, tentative 3D volumetric estimates have been made. The main results taken from 2D modeling were the maturity level of the three source rocks at present day, especially their Transformation Ratio. TR was extrapolated to maps, based on the burial, thickness and structure of each source layer. Then total generated HC were estimated for each of the three source rocks. In total, around 95 bn bbls were generated by the Liassic Shales (Toarcian Schistes Carton being the most prolific source rock).

The use of basin modeling tools supported the new play concept that the Paris Basin is clearly a major area for Shale Oil potential. An exploration strategy is currently developed by Toreador for a proof of play of this unconventional resource.

References


THEME VI: SHALE OIL & GAS CASE STUDIES: THE TOOLBOX ASSETS II (AAPG/EMD)

BASIN MODELING STUDY WITH TEMIS®

SHALE OIL POTENTIAL OF THE PARIS BASIN, FRANCE

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Milano, October 26th, 2011
INTRODUCTION

In 2009 Toreador Energy France asked Beicip Franlab to run an evaluation of HC “generated in” and “expelled from” Liassic shales in the Paris Basin.

This talk sums up the workflow that was used to estimate from 2D data HC volumes in unconventional resources.

It illustrates how Basin Modelling is helpful in HC exploration of unconventional oil resources – even in areas with old available data only.
Overview of the Paris Basin
Geology

Is there any shale oil potential in the Paris Basin?
TOTAL OIL Produced (1958 – 2000)
33.5 * 10^9 kg \rightarrow \sim 0.25 \text{ Bbbl}
Oil represents 93% of produced HC, from conventional reservoir only, at present day.

Liassic Shale = SR interval

Petroleum systems interval

Liassic = Lower Jurassic in W. Europe
Unconventional Resources
New Objectives in SR Layers

How much HCs remain in the SR interval?

% of Produced Oil

- Neocomian ~ 10%
- Dogger ~ 45%
- Keuper ~ 45%

Liassic SRs

Schistes Carton SR

Domerian SR (eq. Amaltheus Shale SR)

Lotharingian – Sinemurian SR

IFP Report, 2002
Focus on the « Schistes Carton »
eq. « Posidonia Shale » (2009)

From Goy, 1979

From Frimmel, 2004

Quarry of Lantenne Vertière
(Eastern Paris Basin)
Analogy with the Bakken Shale

- Both Williston and Paris Basins are intracratonic basins, with a rough circular shape (Williston Basin larger and deeper)

- TOC lower in the Paris Basin (/ 3)

- SR thicker in the Paris Basin (x 2-4)

- Similar organic matter (Type II restricted marine)

- Similar maturity (Tmax = 435 C)

- Overpressure not proven in Liassic SRs

- Both basins have an unconventional oil potential (producing in the Williston Basin)
Available Data for the Temis 2D Study

Only old data is available for the Basin Modelling / Petroleum System Modelling in the Paris Basin.
About 11,000 km² in the central and deep part of the Paris Basin.

Largest conventional oil fields are enclosed in the study area.
Available Data for the Definition of Unconventional Resources

- Old regional seismic lines (reprocessed in 2007).
- Digitalized and slightly corrected.
- Time to Depth conversion done.
- 6 SECTIONS:

Stratigraphic model in Temis 2D

20 km
Available Data for the Definition of Unconventional Resources

- BRGM and IFP Atlases, academic publications
  - Structural maps (depth and/or thickness maps – regional scale)
  - Sedimentological model and lithology/facies maps (regional scale)
  - Source rocks characteristics (RockEval, kinetics, distribution)
  - Concepts on petroleum systems

- Well Data
  - Stratigraphy and lithology
  - Petrophysical data
  - Calibration data (temperature, pressure,... more than 20 wells used)
Focus on SR maps (effective thickness and TOC)

- **Data on Source Rocks (IFP Atlas)**

  - **Schistes Carton SR**
    - SR thickness (m)
      - 50-60 m
    - Data on SR layers is highly reliable
      - hundreds of wells have been used as control points

  - **Domerian SR**
    - SR thickness (m)
      - 10-40 m

  - **Sinemurian – Lotharingian SR**
    - SR thickness (m)
      - 30-60 m

  - **Liassic SRs thickness**

  - **Liassic SRs TOC**
    - Data on SR layers is highly reliable
      - hundreds of wells have been used as control points

  - **IFP Atlas, 2002**
    - Study Area
    - Paris

  - **IFP Atlas, 1996**
    - Study Zone
    - Paris
Temis 2D Study Paris Basin

Building of 2D Basin Models
Workflow with Temis 2D®

Geological Environment
- Tectonic evolution
- Paleobathymetry
- Surface paleo temperature
- Bottom paleo heat flow

Structure and Stratigraphy
(2D seismic lines)

Facies Distribution
(“Lithologies”)

Source Rocks and Kerogen
(Geochemistry and PVT behavior)

Petrophysical Behavior
- Petrophysical properties
- Source rock maturity
- HC expulsion and migration
- Evolution through time / timing

Numerical Simulations

Calibration data
- Well Temperature
- Well Pressure
- HCs Volumes
- etc.
HC Expulsion Modelling
Darcy Law

\[ U_i = - \frac{K k r_i}{\mu_i} \left( \text{grad}(P - \rho_w g z) + \text{grad}(P_c) \right) - (\rho_w - \rho_i) g \text{grad}(Z) \]

Intrinsic permeability \( K \)
Relative permeability phase \( i \)
Viscosity phase \( i \)

**Relates the flow rate \( U_i \) of phase \( i \) to the different driving forces.**

(calculation of HCs and water movements within the porous media)

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**Capillarity**
**Buoyancy**
**Hydrodynamism**

How Temis calculates the amount of generated HCs that migrate out of SRs layers?...
Temis 2D results

SR Maturity Modelling
HC Expulsion Modelling
Source Rock Maturity (TR)  
Section EW-1

Modeling Results

Transformation Ratio in %
- below 1E-3
- 1E-3 - 10
- 10 - 20
- 20 - 30
- 30 - 40
- 40 - 50
- 50 - 60
- 60 - 70
- 70 - 80
- 80 - 90
- 90 - 100
- above 100

Zoom on Liassic SR

70-80%  
50-60%
Evolution of the TR through time

- Maturity started around 150 Ma
- Peak Oil at 90 – 70 Ma

Burial Curve with TR

Modelling Results

- Schistes Carton
- Amaltheus
- Sinemurian
TR maps updated with 2D modeling results

**Interpolation of Modeling Results**

- **Schistes Carton SR**
- **Amaltheus Shale SR**
- **Sinemurian SR**
Generated HC Mass
Section EW-1

Modeling Results
In Place HC
Section EW-1

Saturation %

Schistes Carton: 49%
Amaltheus: 30%
Sinemurian: 37%

Ratio « Remaining HC in SR / Generated HC » in SR:

Modeling Results
Calculation of HC Volumes

Evaluation of remaining HC resources (at basin scale – 3D) in SR layers with:

- Source Rock thickness maps
- TOC maps
- Transformation Ratio maps (from Temis 2D)
- Average ratio « remaining HC / generated HC » (from Temis 2D)
Calculation of HC Resources Workflow (1/2)

For each SR layer...

SR Bulk Thickness (m)

"Effective" Thickness (m)

Rock Mass (kg_rock)

Initial TOC (% - kg_C/kg_rock)

Modified from IFP Atlas, 1996

Maximum S2 (kg_HC/kg_rock)

Modified from IFP Atlas, 1996

Maximum Potential HC Mass (kg_HC)

x 0.8 = (20% average total micro porosity)

x 0.6 kg_HC/kg_C = (HI = 600 mg_HC/g_C)

x 2645 kg/m³ = (average mineral density)

x 1000000 m² (cell surface)

From well data and Temis 2D
Calculation of HC Resources Workflow (2/2)

For each SR layer...

Maximum Potential HC Mass (kg)

\[
\text{Maximum Potential HC Mass (kg)} / 840 \text{ kg/m}^3 \text{ (average oil density at surface condition)} / 0.15897 \text{ (conversion in bbl)}
\]

Maximum Potential HC Volume (bbl) (surf. cond.)

Transformation Ratio (%)

\[\text{Transformation Ratio (\%)} \rightarrow \text{From Temis 2D}\]

Generated HC Volume (bbl) (surf. cond.)

Generated HC Volume (bbl) (surf. cond.)

Average Ratio « Remaining HC / Generated HC »

Residual HC Resource (bbl) (surf. cond.)
Non-Expelled HC Resources in Source Rocks of the Paris Basin

<table>
<thead>
<tr>
<th></th>
<th>Generated HC volume (calculated with TR) Bbbl</th>
<th>Residual HC resource in SR layers Bbbl</th>
<th>TR average</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCHISTES CARTON SR</td>
<td>45</td>
<td>9</td>
<td>32%</td>
</tr>
<tr>
<td>AMALTEUS SR (Domerian)</td>
<td>11</td>
<td>2</td>
<td>43%</td>
</tr>
<tr>
<td>SINEMURIAN SR (Lotharingian)</td>
<td>24</td>
<td>5</td>
<td>58%</td>
</tr>
<tr>
<td><strong>TOTAL Bbbl</strong></td>
<td><strong>81</strong></td>
<td><strong>16</strong></td>
<td></td>
</tr>
</tbody>
</table>

Volume calculated on 9521 km².

Residual HC resource in SR layers

- SCHISTES CARTON SR
- AMALTEUS SR (Domerian)
- SINEMURIAN SR (Lotharingian)

Bbbl - % total

- SCHISTES CARTON SR: 9 56%
- AMALTEUS SR (Domerian): 2 14%
- SINEMURIAN SR (Lotharingian): 5 30%
CONCLUSIONS

1. **The dataset on the Paris Basin available in 2009 was abundant but old:**
   - 6 regional seismic lines (BRGM)
   - Source rock maps from geological atlases (IFP and BRGM)
   - Well data

   → We integrated all for an evaluation at basin scale

2. A methodology based on **TEMIS 2D** models was developed for estimating HC volumes remaining in SR layers.

3. The 3 Liassic source rocks **GENERATED** large volumes of HC in the Paris Basin, about **80 Bbbl** in the study area (9 500 km²).
   (0.25 Bbbl produced in conventional reservoirs)

4. **REMAINING** volumes in SRs = **16 Bbbl** (>50% in the Schistes Carton).
TEMIS basin modeling is a good tool to estimate HC volumes in Unconventional Plays.

A big thank you to Toreador Energy France for allowing the release of the study, and for the fruitful cooperation.

That’s all folks