Education Days Moscow 2013

**Basin and Petroleum Systems Modelling:**
Applications for Conventional and Unconventional Petroleum Exploration Risk and Resource Assessments

By Dr Bjorn Wygrala
Schlumberger

21-22 November 2013

7. Shale Gas/Oil
1. Opening Session: Industry Challenges and Opportunities

**Conventional Petroleum Systems**

2. Deepwater and Salt
3. Structural Complexity
4. Reservoir in Petroleum Systems Modeling

**Theoretical Aspects**

5. Temperature and Pressure
6. Petroleum Generation and Migration

**Unconventional Petroleum Systems**

7. Shale Gas/Oil
8. Gas Hydrates

In conventional petroleum systems, we are interested in the hydrocarbons that have been expelled from the source rocks.

**Conventional Petroleum Systems and Processes**

**Source System**
- source unit
- carrier
- expulsion

**Carrier System**
- loss

**Reservoir System**
- loss

**Basic processes:**
- generation
- expulsion
- migration
- containment (accumulation/loss)
In unconventional petroleum systems, we are interested in the hydrocarbons that have been retained in the source rocks.

Basic processes:
- generation
- retention
- secondary cracking of oil to gas
- containment (accumulation/loss)
In **unconventional** petroleum systems, we are interested in the hydrocarbons that have been **retained** in the source rocks ... *or migrated into juxtaposed, continuous organic-lean intervals*
Shale Gas or Shale Oil?

Burial until oil is generated in source rock

Further burial until retained oil in source rock is cracked to gas

Uplift and erosion to move source rocks to shallower depths to improve drilling economics

The oil can be expelled and/or retained

Burial until oil is generated in source rock

The oil can be expelled and/or retained

Uplift and erosion to move source rocks to shallower depths to improve drilling economics

Shale Gas

Shale Oil

Controlling factors for shale gas or shale oil:
- thermal histories (temperature vs. time)
- type of organic matter

... assessed with Petroleum Systems Modeling!
Contents

- Alaska North Slope 3D Petroleum Systems Model
  - Conventional Exploration Risk and Resource Assessment
  - Geological Evolution
  - Maturation History
  - Petroleum Migration History

- Unconventionals: Shale Gas/Oil Assessment
  - Workflow and Application

- Summary and Conclusions
Alaska North Slope - Schlumberger/USGS 3D Petroleum Systems Study

3D Model covers ~275,000 km²
Well database with > 400 wells
Alaska North Slope - 3D Petroleum Systems Model

U.S. Geological Survey Energy Group experts for the project include:

Kenneth J. Bird, Leslie B. Magoon, and Zenon C. Valin
New interpretation of Brookian sequence to take time-stratigraphic instead of litho-stratigraphic development into account
Petroleum Systems Modeling

Alaska North Slope Geology and Petroleum Systems through geologic time …
Alaska North Slope - 3D Petroleum Systems Model

120 Ma
Alaska North Slope - 3D Petroleum Systems Model

115 Ma
Alaska North Slope - 3D Petroleum Systems Model

110 Ma
Alaska North Slope - 3D Petroleum Systems Model

105 Ma
Alaska North Slope - 3D Petroleum Systems Model

97 Ma
Alaska North Slope - 3D Petroleum Systems Model

85 Ma
Alaska North Slope - 3D Petroleum Systems Model

75 Ma
Alaska North Slope - 3D Petroleum Systems Model

65 Ma
Alaska North Slope - 3D Petroleum Systems Model

After first Tertiary uplift

60 Ma
Alaska North Slope - 3D Petroleum Systems Model

41 Ma
Alaska North Slope - 3D Petroleum Systems Model

After second Tertiary uplift

40 Ma
Alaska North Slope - 3D Petroleum Systems Model
After third Tertiary uplift

24 Ma
Alaska North Slope - 3D Petroleum Systems Model

10 Ma
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PetroMod Special Functions and Output for Unconventionals

Special Functions for shale oil and gas modeling:

Langmuir adsorption model:
• all parameters can be edited with user-defined values; included in PetroMod 2011.1
• adsorption modeling takes both pressure and temperature effects into account

Organic porosity modeling:
• can be simulated as a function of organic matter maturation in PetroMod 2011.1
• porosity overlay includes organic porosity
• separate organic porosity overlay available in Q1, 2010

Geomechanics modeling:
• Current stress regime
• Stress history

Special Results for shale oil and gas evaluations:

Resource (oil/gas) properties:
• Maturity (%Ro)
• Petroleum type (oil vs. gas)
• Petroleum volumes (oil/gas in place)
• Expulsion vs. retention
• Saturations
• PT and phase!
• Adsorbed vs. free phase gas

Reservoir properties:
• Porosity/Permeability history
• Stress/Strain history
Workflows and Tools

Original G&G Data: includes measured, interpreted, estimated and conceptual data used to construct data models:
- Petrel (data assembly)
- Petrel (data integration and analysis)

Results of Process-Based Analysis: data which is calculated from models and is the result of processes through geologic time
- PetroMod (process simulation)
- Petroleum Systems 3D

Play to Prospect Risk
- Play Chance Mapping
- Prospect Assessment
Play Chance Mapping - Megaregional Screening with Basic Criteria

Central North Slope tracts

Central Foothills tracts

TAPS
# Typical Geologic Criteria for Shale Gas Assessments

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Description</th>
<th>Value Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOC</td>
<td>Total organic carbon (weight %)</td>
<td>&gt; 2%</td>
</tr>
<tr>
<td>Thermal Maturity</td>
<td>Thermal maturation measure/calculated by vitrinite reflectance (%Ro)</td>
<td>&gt; 1.2 %Ro (gas)</td>
</tr>
<tr>
<td>Thickness</td>
<td>'Continuous' thickness of source/reservoir</td>
<td>&gt; 50-100 ft</td>
</tr>
<tr>
<td>Depth</td>
<td>'Deep' enough for pressure support, shallow enough for economics … uplift/erosion!</td>
<td>&gt; 3000 ft, &lt; 10,000 ft</td>
</tr>
<tr>
<td>Fracability</td>
<td>High quartz and/or carbonate, low clay mineral content</td>
<td>&gt; 50% quartz and/or carbonate</td>
</tr>
<tr>
<td>Containment</td>
<td>Seal or confining elements to trap oil/gas and limit fracing range</td>
<td></td>
</tr>
<tr>
<td>…</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Conversion of Organic Matter by Type

Note:
- Unique samples! Not universal for all Type I, II or III kerogens!
Play to Prospect Risk plugin

Make Play Chance Map Window for **Shublik Source Properties** in Petrel:

Selected criteria
Play to Prospect Risk plugin

Make Play Chance Map for **Shublik Source Properties** in Petrel:

- **COS** = Chance of Success

Select either a [**simple transform**](#) or a [**transform function**](#) to convert criteria value (for example source rock thickness) to Chance of Success (COS*) values:

- 1 = good
- 0 = bad

* COS = Chance of Success
**Play Chance Mapping - Megaregional Screening with Basic Criteria**

* Depth map from 3D petroleum systems model; simple transform of depth values to COS*

* COS = Chance of Success  
  1 = good  
  0 = bad
Play Chance Mapping - Megaregional Screening with Basic Criteria

Maturation (%Ro) map from 3D petroleum systems model; transform function to COS

* COS = Chance of Success
1 = good
0 = bad
Play Chance Mapping - Megaregional Screening with Basic Criteria

Total Play Chance Map!
for Shublik Shale Oil Resources

Combine all Source Risk Maps

* COS = Chance of Success
1 = good
0 = bad
Play Chance Mapping - Local Area Screening with Refined Data

- Central North Slope tracts
- Central Foothills tracts
- TAPS

local area play chance maps
Play to Prospect Risk plugin
Make Play Chance Map for **Shublik Source Properties** in Petrel:

User-defined list of criteria, in this example factors which can have an effect on *shale oil* prospectivity:

1. Oil generation
2. Oil properties
3. Oil retention
4. Oil volumetrics
5. Target location and access
Play Chance Mapping for Shale Oil

Total Play Chance Map!
for shale oil potential in Shublik target

note rescaled COS
Shale Oil Exploration: Alaska

Alaska North Slope

- Great Bear leased shale oil play acreage based on Schlumberger/USGS PetroMod 3D petroleum systems model

- Favourable maturation 'windows' for two source units (Hue/GRZ and Shublik/Kingak) from Peters et al. 2006

- Areas available in 7th December 2011 lease sale (purple colour)
Shale Oil Exploration: Alaska … next steps

Note favourable location next to TAPS pipeline

Full field development fanning out from initial development corridor
Announcement of first results from Alcor No. 1 shale oil test well:

- "where we thought we would find oil in these source rocks, we found oil"
- "… we determined what leases to purchase and where to drill test wells using a model of the North Slope petroleum system …"
- "that model had proved very successful in explaining the mix of oils found in the (conventional) North Slope oil fields. The model had predicted the locations of 'liquids fairways' in the source rocks, and the results so far of Great Bear's drilling have substantiated those predictions"

Summary and Conclusions

3D Petroleum Systems Model and rapid analysis and decisions enabled explorer to recognize shale oil potential in a new play and be the first mover.

As a result, initial drilling has now (technically) proven the first shale oil play in Alaska.

Image courtesy akbizmag.com
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■ Summary and Conclusions
Petroleum Resource Assessment Workflow
for conventionals and unconventionals

G&G Data into Model
Petroleum Systems
Analysis and Mapping
Statistical Analysis
Risks and Resources
Petroleum Resource Assessment Workflow for conventionals and unconventionals

G&G Data into Model

Petroleum Systems

Analysis and Mapping

Statistical Analysis

Risks and Resources

Interpretation, mapping of Gross Depositional Environments and model construction

Petroleum Systems Modeling of maturation, expulsion vs. retention, migration and accumulation

Risk Mapping and definition of Assessment Units (ASU)

Statistical assessment of conventional and unconventional hydrocarbon resources

Resource Mapping and Reporting
U.S. Geological Survey Energy Group experts for the project include:

Kenneth J. Bird, Leslie B. Magoon, and Zenon C. Valin
Alaska North Slope - 3D Petroleum Systems Model

Present-day
HC Masses in Place

The total oil and gas masses show the hydrocarbon in place. Here, most of the oil is adsorbed while most gas is in the free phase.
Expelled vs. Retained

The primary generated oil and gas mass reduced by the secondary cracking losses is compared with total oil/gas in place.

The effect of asphaltenes (not in H!!) has to be treated separately when using SARA kinetics.
Volumes in Place

Total Oil Volumes per Rock Mass (0...1 bbl/ton)

Total Gas Volumes per Rock Mass (0...300 scf/ton)

Use Overlay Calculator for Volumetrics (and “Corrected” Saturations)

Total Gas Volume per Rock Mass =
((Petroleum Mass: Methane [megatons])+(Adsorption Mass: Methane [megatons])) * 10^9 / 0.717 / ((Density: Bulk [kg/m^3]) - (Porosity [percent]) * 0.01 * 1040) * ElementVolume * 10^9)
Assessment Units (AU) Definition – USGS Bakken Example

Using a geology-based assessment methodology, the U.S. Geological Survey estimated mean undiscovered volumes of 7.4 billion barrels of oil, 6.7 trillion cubic feet of associated/dissolved natural gas, and 0.53 billion barrels of natural gas liquids in the Bakken and Three Forks Formations in the Williston Basin Province of Montana, North Dakota, and South Dakota.

<table>
<thead>
<tr>
<th>Assessment Units (AU)</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>- USGS Bakken Example</td>
<td></td>
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</table>

**Figure 1.** Map showing the Williston Basin Province, Bakken Total Petroleum System (TPS), and the Bakken Formation Assessment Units (AUs). Major structural features are also shown. Inset map shows location of the Bakken TPS (pink).
Definition of Segments = Assessment Units (AU)

Assessment Unit Criteria:
Shale Characteristics, e.g. Facies, Thickness
Maturity e.g. TR, VR, Oil vs Gas

Tools:
Petrel Exploration Geology

Depositional boundary

Depositional boundary

Gas window

Gas window
Definition of Segments = Assessment Units (AU)

Assessment Unit Criteria:
Shale Characteristics, e.g. Facies, Thickness
Maturity e.g. TR, VR, Oil vs Gas

Tools:
Petrel Exploration Geology

Shaly
Gas window
Erosion

Depositional boundary

Offshore

TR=5-15%
TR=<5%
TR=>15%

Depositional boundary

0 Chance of Success 1
Refined Source Rock Model - Shale Layer and Facies Preparation

Zone A: (Up to 30m)
- N: Glauconitic Sandstone
- M: Carbonate Grainstone/Packstones
- S: Black Shale

Zone B: (Up to 15m)
- N: Phosphatic Sand/Shale/Limestones
- M: Lime Packstone/Grainstone
- S: Black Shale

Zone C: (Up to 40m)
- N: Phosphatic Carbonate
- M: Phosphatic Silt
- S: Pebbley/Nodular Phosphorites

Zone D: (Up to 7m)
- N: Non-Phosphatic Sandstone
- M: Massive Phosphatic Sandstone
- S: Offshore Clay/Silt
Selected AU: Shale Porosities and Saturations in each Shublik Zone

Porosity
15 %

Oil Saturation
100%

Zone A

Zone B

Zone C

Zone D
Selected AU: Shale Porosities and Saturations in each Shublik Zone

Porosity: 15%

Zone A

Oil Saturation: 100%

Zone B

Zone C

Zone D
Resources in Segment = Assessment Unit (AU)

Exploration Model (Shublik)

Area [km2]

- Reservoir Thickness [m]
- Net/gross ratio [decimal]
- Porosity [decimal]
- Oil Saturation [decimal]
- Formation volume factor (Bo) [m3/Sm3]

In-Place Oil Resources - STOIIP in AU [MM Sm3]
Resources in Segment = Assessment Unit (AU)

**Exploration Model (Shublik)**
- Area [km²]
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**Analog Model (Eagle Ford)**
- Area [km²]
- Oil well spacing [/km²]
- Segment Number of Oil Wells [n]
- Well Success Rate [decimal]
- Segment Number of Successful Oil Wells [n]
- EUR per oil well [MM Sm³]

**In-Place Oil Resources - STOIIP**
- in AU [MM Sm³]

**Recoverable Oil Resources**
- in AU [MM Sm³]

**Recovery Factor**
- in AU [decimal]
## Table 1 - Summary of Ultimate Recovery Study by County

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**EUR/well (Eagle Ford)**

- Central: 115,282 bbl, 0.018 MM Sm3
- EUR/well (adapted)
  - Central: 100,000 bbl, 0.0159 MM Sm3

---

### Resources in Segment = Assessment Unit (AU)

**Exploration Model (Shublik)**
- **Area [km²]**
- **Reservoir Thickness [m]**
- **Net/gross ratio [decimal]**
- **Porosity [decimal]**
- **Oil Saturation [decimal]**
- **Formation volume factor (Bo) [m³/Sm³]**

**Analog Model (Eagle Ford)**
- **Area [km²]**
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**In-Place Oil Resources - STOIIP**
- **In AU [MM Sm³]**

**Recoverable Oil Resources in AU [MM Sm³]**

**Recovery Factor in AU [decimal]**
### Eagle Ford Analog – Ultimate Recoverable Resources (EUR)

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#### EUR/well (Eagle Ford) vs. EUR/well (adapted)

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<td>Max</td>
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<td>0.0415 MM Sm3</td>
<td>600,000 bbl</td>
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Resources in Segment = Assessment Unit (AU)

In-Place Oil Resources - STOIIP in AU [MM Sm3]

Recoverable Oil Resources in AU [MM Sm3]

Segment = AU Recovery Factor [decimal]
Petroleum Resource Assessment Workflow
for conventionals and unconventionals

G&G Data into Model

Petroleum Systems

Analysis and Mapping

Statistical Analysis

Risks and Resources

Interpretation, mapping of Gross Depositional Environments and model construction

Petroleum Systems Modeling of maturation, expulsion vs. retention, migration and accumulation

Risk Mapping and definition of Assessment Units (ASU)

Statistical assessment of conventional and unconventional hydrocarbon resources

Resource Mapping and Reporting

Statistical Analysis

Risk and Resources
Petroleum Resource Assessment Workflow
for conventionals and unconventionals

G&G Data into Model → Petroleum Systems → Analysis and Mapping → Statistical Analysis → Risks and Resources

Benefits:

- Single software platform with industry-standard software tools
- Petroleum Systems Modeling can handle all conventional and unconventional hydrocarbons
- Unique geology based and fully auditable resource assessment methodology which supports unbiased portfolio management