North GOM Petroleum Systems: Modeling the Burial and Thermal History, Organic Maturation, and Hydrocarbon Generation and Expulsion

Roger J. Barnaby
2006 GCAGS MEETING
Objectives

- Evaluate source rock hydrocarbon potential and maturity
  - Smackover geochemistry (TOC, kerogen)
  - Model burial history
  - Model thermal history
- Model hydrocarbon maturation, generation and expulsion
  - Key controls
  - Timing and burial depths
  - Volumes of oil and gas
- Assess secondary hydrocarbon migration

Previous studies of northern GOM crude oils: composition, $^{13}$C, document Type II algal kerogen in Smackover major source
Primary control for basin modeling
140 key wells (red)
44 sample wells (blue)
30 additional wells being analyzed
### Burial History: Depositional and Erosion Events

#### Geological time scale:
- Berggren et al. 1995
- Salvador 1991
- Galloway et al. 2000
- Mancini and Puckett 2002; 2003
- Mancini et al. 2004

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Burial History

- Reconstructed from present-day sediment thickness after correcting for compaction
- Compaction due to sediment loading
- Maximum paleo water depths < few 100 meters, no correction for water loading
  - Paleobathymetry
  - Sea level through time
Porosity-Depth Relationships

Limestone

Sandstone

Shale

Exponential Compaction

\[ \phi = \phi_0 \exp(-Kz) \]

Where:
- \( \phi \): porosity
- \( \phi_0 \): Initial porosity
- \( K \): compaction factor
- \( z \): depth
Burial History: Decompaction

Present-day depths

Remove 2 & 3
Decompress 1

Partially compact 1

Add 3
Compact 2 and 1

Add 2

Depth (ft)

Porosity

Present-day depths
Burial History: Compacted vs Non-compacted
Lithology (Wilcox)

CALCULATE DECOMPACTION
-lithology from digital logs
-End member lithologies
-SS, SH, LS, ANH
-Log-derived lithology
-mixture of end members
-Compaction parameters for mixed lithology – weighted arithmetic average
Lithology (Upper Glen Rose)
Burial History

- **Depth Subsea (feet)**
  - 20000 to 28000

- **Age (my)**
  - 0 to 200

- **Fm**
  - Miocene
  - Oligocene
  - Jackson
  - Cockfield
  - Coop Mountain
  - Cane River
  - Wilcox
  - Midway
  - Upper Cretaceous
  - Austin (TOKIO)
  - Tuscaloosa
  - Fredericksburg_Was
  - Paluxy
  - Upper Glen Rose
  - Moorningsport
  - Bosassa
  - Bice Island
  - Sligo
  - Hosston
  - Cotton Valley
  - Smackover
  - Base Smackover

- **t= 0**
Modeling formation temperature
- Heat flow approach: temperature function of basement heat flow, thermal conductivity overlying sediment

Present-day heat flow
- Well BHTs
- Surface temp = 20°C
- Thermal conductivity
  - Porosity and lithology are major variables controlling thermal conductivity
  - *In-situ* thermal conductivity computed by BasinMod
Heat Flow Calculation

\[
\frac{W}{\text{meters}^2} = \frac{T_2 - T_1 \cdot (10^3 \cdot \text{deg K})}{y_2 - y_1 \text{ (meters)}} \times \frac{W}{\text{meter} \cdot (10^3 \cdot \text{deg K})}
\]

Heat Flow Calculation

\(T_1, y_1\)

\(T_2, y_2\)
Calculated Heat Flow = 50 mW/m$^2$
Thermal History: Paleoheat Flow

- Constant vs. rift model

\[ \beta = 2.0 \]
\[ \beta = 1.75 \]
\[ \beta = 1.5 \]
\[ \beta = 1.25 \]
\[ \beta = 1.0 \]

N. LA Beta
\[ 1.25 \leq \beta \leq 2.0 \]

Nunn et al 1984
Dunbar & Sawyer 1987
Thermal History: Lithospheric Stretching

\[ \beta = 1.25 \]

\[ \beta = 1.5 \]

\[ \beta = 1.75 \]

\[ \beta = 2.0 \]

Dunbar and Sawyer 1987
Thermal History
Late K Igneous Event

Depth (ft)
%Ro (measured)

Surface %Ro (expected)

Trend B
Trend A

50 mi
Optimum match between BHTs and %Ro and modeled values using rift model with Late Cretaceous thermal event.
Heat Flow: 170 Ma
Heat Flow: 95 Ma
Maturity Modeling

- Thermal maturity (%Ro) calculated using kinetic model from LLNL
- Standard type II kerogen
- 1D steady-state heat flow at model base, heat transfer from conduction
Thermal History: Paleoheat Flow

- Thermal maturity constrained by %Ro

48 mW/m², rift model, modeled maturity reasonably matches TAI and %Ro
Calculated %Ro vs. Measured

%Ro (meas)
%Ro (calc)

\[ y = 1.0162x \]
\[ R^2 = 0.7036 \]
Smackover Maturity

Present-day

95 Ma

Present-day
Hydrocarbon Generation & Expulsion

Smackover: oil-prone
Type II kerogen

TOC data updip wells only
Extrapolated downdip

Ran models with range TOC
OIL-WATER SYSTEM
WATER-WET LITHOLOGIES

RELATIVE PERMEABILITY: OIL/WATER

OIL
INCREASINGLY
MOBILE

WATER
INCREASINGLY
MOBILE

Typical Reservoirs

Ex: saturation threshold = 0.20

Pepper (1991)
Oil Expulsion Volumetrics

Expelled Volume for Rock Unit/Smackover/1D Grid Output=MWell Grid @ 0 (my)
Expulsed Oil Volumetrics

Constant heat flow (present-day)

Rift heat flow model

peak expulsion (108 to 103 my) (late Early Cretaceous)

TOC = 2 x RKZ
Saturation Threshold = 0.15
Gas Generation and Expulsion

Average GOR, North Louisiana = 12,500, up to 500,000 or more
Expelled Gas (Primary + Secondary)

ToC = 2%, saturation threshold = 0.2, rift heat flow w/ K event
Timing of gas expulsion

Saturation threshold = 0.2
TOC = 1%
Heat flow model with rifting and late K event

Cumulative Expulsed Gas Fraction

M.a.
N. LA Petroleum System

N. LA Petroleum System Map

- **Jurassic**
  - E
  - M
  - L

- **Cretaceous**
  - E
  - M
  - L

- **Tertiary**

<table>
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<tr>
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<th>Petroleum Systems Events</th>
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Conclusions

• Geochemical data and basin modeling indicate that Smackover mature for oil and gas
• Peak oil expulsion late Early Cretaceous, persisted into Late Cretaceous
• Most gas is secondary
• Peak gas expulsion early to middle Tertiary
• Cumulative production accounts for less than 1.0% of total expelled volumes of oil and gas
  – Estimates in published literature 1-3%