Geochemical Assessment of Unconventional Shale Resource Systems for Exploration and Production Characteristics

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Energy Institute at TCU
Topics for Talk

• Background
• Total organic carbon (TOC)
  – Importance
  – Description
• Organoporosity
• Thermal Maturity
• Kerogen Type
• Oil and Gas Generation
• Tests for Commercial Shale Gas Production
Background
Where is the most likely place in any sedimentary basin to find hydrocarbons?

The Source Rock

What is the most difficult horizons to produce hydrocarbons?

The Source Rock
Unconventional Shale Resource System

A continuous system having an organic-rich source rock with or without juxtaposed tight, organic lean lithofacies requiring high energy stimulation

What is unconventional? Atypical
Shale Resource Systems: definitions

• Sedimentary Rock
• Shale (mudstone)
  – Particle size
  – Mineralogy
• Stores oil in
  – Organoporosity
  – Matrix porosity
  – Fracture porosity
• Typically is very tight (ultra low permeability)
Eagle Ford Shale

- It is a sedimentary rock (not metamorphic).
- It is a mudstone based on particle size.
- It contains 60% carbonate.
Shale-Gas Resource Systems

High Thermal Maturity
Hybrid System

High Thermal Maturity
Source Rock System

Biogenic Gas
and low thermal maturity
source rocks
Shale System Overlap and Production Potential

- Tight Shale: Barnett Shale, Tuscaloosa Marine Shale, New Albany Shale
- Hybrid Shale: Eagle Ford Shale, Bakken Formation, Montney Shale
- Fractured Shale: Monterey Shale, Some Bakken, Niobrara, Pierre shales

Also note circle sizes (EUR) and overlap.
Denver Basin:

Hybrid Shale Resource System
Total Organic Carbon (TOC)
Distribution of Organic Matter in Rock Sample (low maturity)

Organic Matter: the “source” of oil + assoc. gas

\[ \Sigma \text{wt.\% TOC} = \text{TOC (wt.\%)} \]

Total Organic Carbon (T.O.C.)

e.g., 1 g of TOC per 100 g rock = 1% TOC
Diagrammatic Illustration of TOC for a given kerogen type, e.g., Type II

- **Generative Organic Carbon (wt.%)**
  - Responsible for generation of hydrocarbons
  - Accounts for development of organic porosity

- **Non-Generative Organic Carbon (wt.%)**
  - Does not generate any appreciable amount of petroleum
  - Does account for storage by adsorption
What happens with thermal maturation and expulsion to, e.g., 50% transformation ratio (50% conversion of GOC)?

<table>
<thead>
<tr>
<th>Generative Organic Carbon (wt.%)</th>
<th>Non-Generative Organic Carbon (wt.%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon in expelled petroleum (wt.%)</td>
<td></td>
</tr>
</tbody>
</table>

TOC (wt.%)
TOC_{\text{present-day}} \text{ is now reduced from } TOC_{\text{original}} \text{ as a result of generation and expulsion}

<table>
<thead>
<tr>
<th>TOC_{PD} (wt.%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generative Organic Carbon (GOC_{PD})</td>
</tr>
</tbody>
</table>

Notes:

- with 50% TR, TOC is \textbf{not} reduced 50%; only GOC is reduced 50%

- NGOC increases slightly due to hydrogen shortage in kerogen and bitumen
Why is TOC important?
Generative Portion of TOC at Full Conversion
(assumes Hlo of 400 (38% convertibility))

Total Organic Carbon (wt.%)

1
2
3
4
5
6
7
8
9
10

Total Petroleum Generation Potential (boe/section/200 ft)
Variability in TOC: 
Cuttings vs. Core TOC Values

\[ y = 2.3611x - 0.3906 \]
\[ R^2 = 0.7307 \]

E.g., 2.00% cuttings approximates 4.33% on core samples.
Importance of Relative Hydrogen Content of Source Rocks
Two Source Rocks with the Same TOC but different Hydrogen contents
Their Total Petroleum Generation Potential in boe/section/100 ft

TOC=7%; HI=400

TOC=7%; HI=700

Total Petroleum Generation Potential (boe/section/100 ft)
Development of Organoporosity
Conversion of TOC in wt.% to vol.%

TOC is 7 weight percent

which is about 14 volume percent
Assumptions:

- 7.00 wt.% TOC_o
- 14.00 vol.% TOC_o
- TOC_o is 37% GOC
- Kerogen density is:
  - 1.1 g/cc GOC
  - 1.4 g/cc NGOC

```
Assumptions:

Formation of Organic Porosity
from Generative Organic Carbon

80% conversion of kerogen
3.92%

100% conversion of kerogen
4.90%

Potential Organic Porosity Development (%)
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Pores and C-rich Areas: Barnett Shale

Areas of higher TOC

Reed, Loucks, and Jarvie, 2008
Organic Porosity Development

Loucks et al., 2009
TOC and Total Generation Potential are also indicative of potential for organoporosity development.
Adsorption by TOC
Adsorption: Retention of Bitumen

Longjiang and Barker 1989 from Hunt 1995

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Typical Distribution of Products in Extractable Organic Matter (EOM)

Source Rock Extract Fractions

- Saturates: 35%
- Aromatics: 20%
- Resins: 15%
- Asphaltenes: 30%

Oil Fractional Fractions

- Saturates: 48%
- Aromatics: 40%
- Resins: 7%
- Asphaltenes: 5%
Fort Worth Basin Model without Adsorption of Oil

Barnett Shale

Jarvie et al., 2007a
Barnett Basin Model with Adsorption of Oil

Jarvie et al., 2007a

Barnett Shale
Kerogen Type (Quality)
or
Relative amount of Hydrogen
Worldwide Collection of Immature Petroleum Source Rocks

- Immature Type I: 700-1200
- Immature Type II: 300-700
- Immature Type III: 200-350
- Immature Type IV: <50

Rock-Eval Tmax (°C)

Maturation Pathway

Hydrogen Index (mg kerogen/g TOC)

0.60%Roe
1.00%Roe
1.40%Roe

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Interpretations only apply to immature organic matter.

A source rock does not go from being a marine shale to mixed to terrestrial to inertinite; it simply loses [H] and [C] as hydrocarbons.
Visual Kerogen Assessment of Generation Potential and Products

- Excellent
- Strongly Oil Prone
- Oil Prone
- Mixed Oil-Gas
- Gas Prone
- Dry Gas Prone

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Thermal Maturity
Vitrinite Reflectance: always reported as a single value, but almost always a distribution of values.

Average $%R_o = 0.48$
Std. Dev. = 0.07
No. Pts. = 31

- Solid bitumen
- Recycled Vitrinite
- Inertinite
Experimental Conversion of Barnett Shale

<table>
<thead>
<tr>
<th>Tmax (°C)</th>
<th>TOC</th>
<th>S2</th>
<th>HI</th>
<th>TR</th>
</tr>
</thead>
<tbody>
<tr>
<td>432</td>
<td>5.21</td>
<td>19.8</td>
<td>380</td>
<td>12%</td>
</tr>
<tr>
<td>435</td>
<td>4.53</td>
<td>13.45</td>
<td>297</td>
<td>32%</td>
</tr>
<tr>
<td>437</td>
<td>4.11</td>
<td>10.27</td>
<td>250</td>
<td>42%</td>
</tr>
<tr>
<td>443</td>
<td>3.77</td>
<td>5.88</td>
<td>156</td>
<td>64%</td>
</tr>
<tr>
<td>455</td>
<td>3.41</td>
<td>1.81</td>
<td>53</td>
<td>88%</td>
</tr>
<tr>
<td>470</td>
<td>3.32</td>
<td>1.36</td>
<td>41</td>
<td>91%</td>
</tr>
</tbody>
</table>

Converting the Barnett Shale to oil and gas reveals decreasing remaining potential as Tmax increases. Experimental results by Jarvie and Lundell, 1991.
Type of Gas from Boonesville and Barnett Reservoirs based on gas composition and carbon isotopes

Ref: Jarvie et al., 2003; Hill et al., 2007

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Predicted Maturity of Boonesville and Barnett Shale Gases

Boonesville gases are expelled, oil-associated Barnett Shale generated gas
Mapping transformation ratio (i.e., the extent of kerogen conversion) in Barnett Shale

Jarvie et al., 2007a
# Thermal Maturity Indicators

<table>
<thead>
<tr>
<th>DGR (C1/C1..C4) (%)</th>
<th>LGR C6+/C1..C6) (%)</th>
<th>Gas-to Oil Ratio (GOR) (scf/bbl)</th>
<th>Oil Yield (bbls/mmcf)</th>
<th>Mole % C7+</th>
<th>Vitrinite Reflectance (%Roe)</th>
<th>Tmax (°C)</th>
<th>PI</th>
<th>Interpreted Maturity Window</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 50</td>
<td>&gt; 50</td>
<td>0 - 1999</td>
<td>&gt; 500</td>
<td>&gt; 20.0</td>
<td>&lt; 0.55</td>
<td>&lt;427</td>
<td>&lt; 0.10</td>
<td>Immature</td>
</tr>
<tr>
<td>50 - 74</td>
<td>19.9 - 49.9</td>
<td>2000 - 3499</td>
<td>300 - 499</td>
<td>12.5 - 20.0</td>
<td>0.75 - 0.99</td>
<td>440</td>
<td>0.75</td>
<td>Black</td>
</tr>
<tr>
<td>75 - 84</td>
<td>5.0 - 19.9</td>
<td>3500 - 49999</td>
<td>20 - 299</td>
<td>&lt; 12.5</td>
<td>&lt; 0.10</td>
<td>454</td>
<td>1.00</td>
<td>Volatile Oil</td>
</tr>
<tr>
<td>80 - 90</td>
<td>1.0 - 4.9</td>
<td>50,000 - 99,999</td>
<td>10 - 19</td>
<td>&lt; 12.5</td>
<td>1.00 - 1.19</td>
<td>465</td>
<td>1.20</td>
<td>Condensate-Wet Gas</td>
</tr>
<tr>
<td>&gt; 90</td>
<td>&lt; 1</td>
<td>&gt;100,000</td>
<td>&lt; 10</td>
<td>&lt; 12.5</td>
<td>1.20 - 1.39</td>
<td>&gt; 475</td>
<td>1.40</td>
<td>Wet Gas</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&gt; 140</td>
<td></td>
<td></td>
<td>Dry Gas</td>
</tr>
</tbody>
</table>

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Basic Shale Gas Risk Assessment
Well and Sample Locations: Rocks

- **Ft. Worth Basin**
- **Well and Sample Locations**
  - Well Sample Locations
  - Basin Model Well Locations
  - Outcrop Sample Locations
  - Oil Sample Locations

**Maps and Locations**
- **Oryx Grant #1**
- **MEDC Sims #2**
- Ft. Worth Basin
- Bend Arch
- Llano Uplift
- Ouachita Structural Belt
- Muenster Arch

**Scale in Miles**

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Geologic Maturation Series from the Barnett Shale

**Diagram:***
- **Tmax (°C):** 330, 380, 430, 480, 530, 580
- **Hydrogen Index (mg OIL/g TOC):** 0
- **Type I Oil Prone (usu. lacustrine):** ~0.55% Ro
- **Type II Oil Prone (usu. marine):** ~1.00% Ro
- **Mixed Type II / III Oil / Gas Prone:**
- **Oryx Grant #1**
- **MEDC Sims #2**
- **Gage #1**
- **Heirs #1**
- **Young #1**
- **Oliver #1**
- **Oliver #2**

**Legend:**
- **Oil Window**
- **Condensate Gas Window**
- **Dry Gas Window**

**Notes:**
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Oryx Grant #1, Montague County Texas: Geochemical Log
Select Geochemical Shale-Gas Risk Factors

- TOC (wt%) [0-10]
- %Ro [0.2-2.2]
- Tmax © [420-520]
- TR [0-100]
- Gas Dryness [0-100]

T.P. Sims #2

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Range of Understanding Needed for shale resource play assessment

Modified from King, 2010, SPE-133456
Synopsis

- TOC is a fundamental property of a shale resource system measuring quantity
- Kerogen type is an indication of the quality of the organic matter in terms of oil and gas potential
- Thermal maturity results in generation of organoporosity in organic matter
- Risk involves assessment of a number of organic, inorganic, and many other factors
Gracias !