Geochemical Characteristics of the Devonian Woodford Shale

Dan Jarvie
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Outline

• Background
• Woodford Shale Geochemistry
• Woodford Shale-Gas
  – Oklahoma
    • Arkoma Basin
    • Anadarko Basin
    • Ardmore Basin
  – Texas
    • Permian Basin
• Woodford Shale Oil
• Summary
Reserves per Well Declining but offset by drilling more wells

Reserves per well added, 1973-2015 est.

Where is the most likely place in a sedimentary basin to find hydrocarbons?

*The source rock*
North American Shale Resource Plays

Geochemical Data on various shale resource play types

<table>
<thead>
<tr>
<th>Shale Type</th>
<th>Interpreted Thermal Maturity Window</th>
<th>TOC (wt %)</th>
<th>TOC calculated from maturity (%)</th>
<th>HI (mg HC/g TOC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barnett</td>
<td>Immature to early oil</td>
<td>5.27</td>
<td>5.35</td>
<td>432</td>
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<tr>
<td></td>
<td>Oil</td>
<td>7.06</td>
<td>7.28</td>
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<td>Oil</td>
<td>9.23</td>
<td>9.61</td>
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<td></td>
<td>Dry gas</td>
<td>3.37</td>
<td>5.27</td>
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<td>6.20</td>
<td>299</td>
</tr>
</tbody>
</table>

All values are average values from the Humble database and may include variable thermal maturities.

TOC: total organic carbon, original value
HI: hydrogen index (S2/TOC x 100; mg HC/g TOC)
TR: transformation ratio (HIo / HIpd) where HIo is original HI and HIpd is present-day HI value
\( \%R_e \): vitrinite reflectance equivalent, calculated from Rock-Eval Tmax value
\( \%R_v \): vitrinite reflectance in oil submersion
ppt: parts per thousand or parts per mil

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### Shale Composition

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<thead>
<tr>
<th>Age</th>
<th>Count</th>
<th>Clay Minerals</th>
<th>Potassium Feldspar</th>
<th>Plagioclase Feldspar</th>
<th>Calcite</th>
<th>Dolomite</th>
<th>Siderite</th>
<th>Pyrite</th>
<th>Other</th>
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<td>29.9</td>
<td>42.3</td>
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<td>1.6</td>
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<td>2.9</td>
<td>7.9</td>
<td>0.1</td>
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<td>34.7</td>
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<td>4.4</td>
<td>14.6</td>
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<td>10.9</td>
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<td>29.4</td>
<td>45.9</td>
<td>10.7</td>
<td>9.7</td>
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<td>4.1</td>
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<td>2.1</td>
<td>3.4</td>
<td>3.5</td>
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<td>Mississippian</td>
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<td>0.0</td>
<td>0.6</td>
<td>5.1</td>
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<td>Devonian</td>
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<td>41.8</td>
<td>47.3</td>
<td>3.6</td>
<td>0.0</td>
<td>2.0</td>
<td>1.3</td>
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<td>3.3</td>
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<tr>
<td>Misc. ages</td>
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<td>47.8</td>
<td>33.1</td>
<td>1.0</td>
<td>5.5</td>
<td>5.2</td>
<td>2.3</td>
<td>0.8</td>
<td>3.1</td>
</tr>
</tbody>
</table>

Average Clay: 38%
Average Quartz: 36%

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**Woodford Shale, Delaware Basin, Texas: abundance of low reflecting desmocollinite**

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**Changes**

- **RGS ID:** 04-2884-103341
- **Country:** USA
- **Company:** Superior
- **Well:** #1 El Paso State
- **Depth:** 8310’
- **Unit:** Feet
- **Sample type:** Cutting
- **Analyst:** W.K.
- **Date:** May-05
- **Comments:** Yellow/orange - orange spore fluorescence in mineral matter.

**Vitrinite Reflectance**

**LEGEND**

- Liptinite
- Desmocollinite
- Telocollinite
- Oxidised telocollinite
- Reworked telocollinite
- Sphagnum
- Sterile
- Inertinite
- Cavings/Contamination

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Diamondoids allow for recognition of oil cracking and mixing

- **Low Maturity No Cracking**
- **High Maturity No Cracking**
- **Slightly Cracked**
- **Intensely Cracked**

**Mixed Oils High & Low Maturity oils**

**Barnett Shale Gas Data**

*Slide provided courtesy GeoMark Research*

- **Shale Gases**
- **Tight Sand Gases**

**Nor**

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Thermal Decomposition

Kerogen → Oil → Gas → Dry Gas

Catalytic Decomposition

Kerogen → Dry Gas

Catalytic Activity in Shales

A/TOC = 2.6 ± 0.89

R² = 0.88
Catalytic Activity is related to Hydrogen Index

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  – Texas
    • Permian Basin
• Woodford Shale Oil
• Summary
Comparison of Resource Potentials of Mississippian and Devonian Shales

<table>
<thead>
<tr>
<th>Geochemical Data</th>
<th>Barnett Shale</th>
<th>Caney Shale</th>
<th>Fayetteville Shale</th>
<th>Floyd Shale</th>
<th>Woodford Shale</th>
<th>New Albany Shale</th>
<th>Ohio Shale</th>
<th>Chattanooga Shale</th>
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</thead>
<tbody>
<tr>
<td>Estimated average original TOC (mg/g)</td>
<td>5.84</td>
<td>5.01</td>
<td>5.51</td>
<td>5.65</td>
<td>15.45</td>
<td>13.54</td>
<td>8.34</td>
<td>11.47</td>
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<tr>
<td>Estimated average original generation potential (mg/g)</td>
<td>29.75</td>
<td>19.6</td>
<td>23.9</td>
<td>21.98</td>
<td>59.66</td>
<td>73.81</td>
<td>38.52</td>
<td>42.32</td>
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<tr>
<td>Estimated average total generation potential (bo/af)</td>
<td>651</td>
<td>433</td>
<td>523</td>
<td>481</td>
<td>1306</td>
<td>1616</td>
<td>843</td>
<td>926</td>
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<tr>
<td>Estimated average total generation potential (mcft/af)</td>
<td>3607</td>
<td>2601</td>
<td>3139</td>
<td>2887</td>
<td>7838</td>
<td>9694</td>
<td>5059</td>
<td>5558</td>
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<tr>
<td>Thickness (feet)</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Total generation potential (bcf/section)</td>
<td>38</td>
<td>25</td>
<td>30</td>
<td>28</td>
<td>75</td>
<td>93</td>
<td>49</td>
<td>53</td>
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<tr>
<td>Estimated GIP with 15% retained hydrocarbons</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(comparison made assuming all are 100 ft. thick)

* Ardmore Basin low maturity Woodford Shale outcrops

Comparison of TOC Values: Chert vs. Shale

![Graph comparing Chert vs. Shale TOC values](image)

Data from Comer and Hinch, 1987
Oil and Gas Decomposition Profiles
low sulfur marine shales

Primary Cracking of Organic Matter in Woodford Shale: Compositional Kinetics
Woodford Shale: Sample A
Oil and Gas Yields upon total decomposition

Woodford Shale: Sample A
Oil and Gas Yields upon total decomposition

Woodford Mineralogy: Example

Average Quartz: 37%
Average Illite: 26%
Average kerogen: 15%

Abousleiman et al., 2008
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Woodford Shale Plays:
Arkoma, Anadarko, Ardmore, and Permian Basins
Woodford Shale Basins, Oklahoma

Comparison of early wells in Arkoma Basin: Vertical vs. Horizontal
Select Wells: Arkoma Basin (Oklahoma)

Outline

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        – Midland Basin
        – Central Basin Platform
        – Delaware Basin
  • Woodford Shale Oil
• Summary
Thermal Maturity, Anadarko Basin: focus on Canadian County area

Woodford Shale, Canadian County
Anadarko Basin

Cardott, 1989
Anadarko Basin

Canadian County, Woodford Shale:
Extent of conversion and Thermal Maturity

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Woodford Shale, Ardmore Basin

- Highly oil prone
- Oil prone with some gas
- Mixed oil & gas prone
- Primarily gas prone
- Dry gas prone

**Woodford Shale**

- High remaining potential
- Low to moderate thermal maturity

**Ardmore Basin**
Outline

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    • Permian Basin
• Woodford Shale Oil
• Summary

Distribution of TOC in Permian Basin

- Wolfcamp
- Atoka
- Barnett
- Woodford

TOC (wt.%)

Count

0 5 10 15 20 25 30 35 40 45

0-1 1-2 2-3 3-4 4-5 5-6 6-7 7-8 8-9 9-10
Woodford Shale, Permian Basin:
Decrease in Hydrogen Index with increasing thermal maturity

Predicted Temperature of Earliest Generated Woodford Shale Oil

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Permian Basin: oil and gas windows

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- Summary
Fractures in Bakken Shale

Bakken Shale Database
Williston Basin, USA
Residual Oil Saturation from geochemical analyses

Free Oil Content at Low Level Conversion of Woodford Shale
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Summary

• Woodford Shale geochemistry is variable in terms of
  – Organic richness
  – Original generation potential
  – Thermal maturity
  – And hence... Gas contents, GIP, and EURs
• Make use of all available samples and analytical techniques to optimize exploration and production impact
Thank you!

Peace be with you!
(Shalom)
(Salam Alakum)

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