Woodford Gas-Shale Plays of Oklahoma

Brian J. Cardott
Oklahoma Geological Survey
Application of Advanced Completion Technology in 2004

Caney/Woodford included with Caney

Updated 4/24/2009
Oklahoma Gas-Shale Wells
Completed 1939-2009

Oklahoma Gas Shale Completions (1939-2009)

1,166 Wells
86 Caney Shale
1,077 Woodford Shale

Updated 4/24/2009
Isopach Map of Woodford Shale

From Comer, 1992
# Woodford Mineralogy

<table>
<thead>
<tr>
<th>[grab samples]</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>63-68%</td>
<td>29-87%</td>
<td>30-60%</td>
<td>9-61%</td>
<td>27-53%</td>
</tr>
<tr>
<td>K-Feldspar</td>
<td>4%</td>
<td>0-2%</td>
<td>2-10%</td>
<td>2-42%</td>
<td>0-2%</td>
</tr>
<tr>
<td>Plagioclase</td>
<td>3%</td>
<td></td>
<td></td>
<td>1-4%</td>
<td></td>
</tr>
<tr>
<td>Calcite</td>
<td>10%</td>
<td></td>
<td>5-25%</td>
<td>0-7%</td>
<td>0-11%</td>
</tr>
<tr>
<td>Dolomite</td>
<td>6-9%</td>
<td>0-56%</td>
<td>0-5%</td>
<td>0-10%</td>
<td>0-6%</td>
</tr>
<tr>
<td>Pyrite</td>
<td>5-7%</td>
<td>0-1%</td>
<td>0-5%</td>
<td>2-30%</td>
<td>1-13%</td>
</tr>
<tr>
<td>Total Clays</td>
<td>12-14%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Illite</td>
<td></td>
<td>8-35%</td>
<td>2-5%</td>
<td>7-53%</td>
<td>13-40%</td>
</tr>
<tr>
<td>Illite/Smectite</td>
<td></td>
<td></td>
<td>2-20%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kaolinite</td>
<td>1-7%</td>
<td>2-5%</td>
<td>0-2%</td>
<td>0-5%</td>
<td></td>
</tr>
<tr>
<td>Chlorite</td>
<td></td>
<td>2-5%</td>
<td>0-40%</td>
<td>0-5%</td>
<td></td>
</tr>
</tbody>
</table>

A. O’Brien & Slatt, 1990; B. Kirkland et al., 1992; C. Greiser, 2006; D. Branch, 2007; E. Abousleiman et al., 2008
Example of ECS & CMR Log Data, Woodford Shale

- Higher silica content in upper portion of Woodford (above 120 ft)
- Very high porosity (unlike that found under reservoir conditions)

Mineralogy by Elemental Capture Spectroscopy

From Buckner, 2007

Section of Wyche #1 Shale Gas Montage (ECS & CMR output) created by Rick Lewis, Schlumberger
Woodford Gas-Shale Wells
Completed 1939-2009

1,090 Woodford Wells

Completed 1939-2009

15,310 ft (2005) directional;
(IP 234 Mcf;
7BO 42° API;
GOR 33,429)

422 ft (2008)

1,090 Woodford Wells

Updated 4/24/2009
Woodford Gas-Shale Wells
Completed 2003–2009

1,065 Wells
13 Caney/Woodford
8 Sycamore/Woodford
259 Vertical Woodford
784 Horizontal/Directional Woodford (74%)
1 Sylvan/Woodford
Geologic Provinces of Oklahoma

Northcutt and Campbell, 1995

MAJOR FAULTS

Surface faults

Subsurface faults

Normal faults identified by hachures on relatively downthrown block.

Thrust faults identified with solid barbs on hanging wall block.
Woodford Gas-Shale Wells
Completed 2003–2009

- Caney/Woodford
- Sycamore/Woodford
- Woodford
- Horizontal/Directional
- Sylvan/Woodford
Woodford Shale-Only Wells Completed 2004-2008

970 wells 2004-2008; “Horizontal” includes 10 directional wells
Woodford Shale-Only Wells Completed 2008

- Horizontal
- Vertical
Woodford Shale Gas Wells, 2004-2009

995 Woodford-only wells: 245 vertical (includes directional): depth 430-15,310 ft; IP: 1-2,681 Mcfd;
750 horizontal wells: depth 1,700-14,153 ft TVD; IP 3-11,875 Mcfd
Woodford Shale Horizontal Wells

751 wells
Woodford Shale Produced Water

943 wells (excluding two wells, 11,644 & 16,338 bwpd)
Woodford IP >1 MMcfd
Completed 2004–2009

- Caney/Woodford
- Sycamore/Woodford
- Woodford
- Cny/Wdf IP>1MMcfd
- Woodford IP>1MMcfd
- Syl/Wdf IP>1MMcfd
Woodford Shale Discovery Wells
Completed 2004–2008
156 Woodford-only discovery wells during 2008
PEAK OIL GENERATION

PEAK WET GAS GENERATION

PEAK DRY GAS GENERATION

Modified from Dow (1977), Houseknecht and Spötl (1993), and Taylor and others (1998)
# Guidelines for the Barnett Shale (Based on Rock-Eval Pyrolysis)

<table>
<thead>
<tr>
<th>VRo Values</th>
<th>Maturity</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.55%</td>
<td>Immature</td>
</tr>
<tr>
<td>0.55-1.15%</td>
<td>Oil Window (peak oil at 0.90% VRo)</td>
</tr>
<tr>
<td>1.15-1.40%</td>
<td>Condensate–Wet-Gas Window</td>
</tr>
<tr>
<td>&gt;1.40%</td>
<td>Dry-Gas Window</td>
</tr>
</tbody>
</table>

*From Jarvie and others, 2005*
Isoreflectance Map of the Woodford Shale in Eastern Oklahoma

Map prepared by R. Vance Hall using Petra

Cardott, in preparation
Woodford Gas Shale Wells (2004-2009) by Major Operator

- Antero (99)
- Chesapeake (72)
- Continental (69)
- Coronado (75)
- Devon (118)
- Newfield (225)
- Pablo (42)
- Petroquest (30)
- St. Mary (29)
- WCT (59)
- XTO (45)
Woodford IP >1 MMcfd on Isoreflectance Map
Woodford Gas-Shale Play is primarily in eastern Oklahoma (western Arkoma Basin) where the shale is:

(1) in the gas window (pushing the lower thermal maturity limits to the west and upper thermal maturity limits to the east)

(2) greater than 100 ft thick

(3) relatively shallow (<12,000 ft)
Anadarko Basin

Woodford Shale Isoreflectance Map (Cardott, 1989)
Structure and Vitrinite Reflectance of Woodford Shale, Southern Oklahoma

Cardott, in preparation
Woodford Shale Production (2004-2008 wells)

Cumulative Production
283,672,521 Mcf gas,
597,527 BBLS oil/condensate
from 808 Woodford-only wells
(excludes OWWO, D&A)

(Gas production data supplied by PI/Dwrights LLC, © 2009, IHS Energy Group)
Woodford Shale Only Oil/Condensate Production (135 of 1,042 wells; 2004-2009)
Woodford Shale Only Oil/Condensate Production (135 of 1,042 wells; 2004-2009)
SUMMARY OF WOODFORD GAS SHALE PLAY

- Woodford Shale contains Type II (oil generative) Kerogen with adequate TOC
- Woodford Shale is silica rich (e.g., fracture-able)
- Main Woodford Shale gas play is in eastern Oklahoma at >1.1% Ro
- Woodford Shale gas play in Anadarko Basin shelf @1.2-1.5% Ro
- Some Woodford Shale gas potential is in southern and northeastern Oklahoma at <1.1% Ro
For more information, please visit the Oklahoma Geological Survey Web Site

Oklahoma Hydrocarbon Source Rocks and Gas Shales

References

Presentations & Reports
Including October 2008 Gas Shales Workshop Presentations!

Oklahoma Gas Shale Completions Histogram

Oklahoma Gas-Shale Completions Map, 1939-2009

Woodford Shale Gas Well Completions Map, 1939-2008

Woodford Shale Gas Well Completions Map, 2003-2008

Gas Shales Database

Shale Shaker Articles
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Oklahoma: The Ultimate Oil Opportunity

"New 2008 Drilling Highlights"