Overview of Woodford Gas-Shale Play in Oklahoma, 2008 Update

Brian J. Cardott
Oklahoma Geological Survey
Oklahoma Shale-Gas Well History
650 Wells, 1939–2008

- Caney
- Woodford

Application of Advanced Completion Technology in 2004

Caney/Woodford included with Caney

Updated 8/4/2008
Oklahoma Gas-Shale Wells
Completed 1939-2008

650 Wells
73 Caney Shale
577 Woodford Shale

Updated 8/4/2008
Oklahoma Gas-Shale Wells by Year (1939-2008)

Layered with 2008 Prevalent

Updated 8/4/2008
Based on conodonts, Hass and Huddle (1965) determined a Late Devonian (Frasnian) age for most of the formation; uppermost part is Early Mississippian (Kinderhookian).
Three informal members based on palynomorphs (Urban, 1960; Von Almen, 1970), geochemistry (Sullivan, 1985), log signatures (Hester and others, 1990; Lambert, 1993)

From Hester and others (1990) [Anadarko Basin]
Geologic Provinces of Oklahoma

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.

Northcutt and Campbell, 1995
Isopach Map of Woodford Shale

From Comer, 1992
Woodford Shale

From Comer, 1992
# Woodford Mineralogy

<table>
<thead>
<tr>
<th></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>1-4%</td>
<td></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>8-35%</td>
<td></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></td>
<td>2-5%</td>
<td>0-2%</td>
<td>0-5%</td>
</tr>
<tr>
<td>Chlorite</td>
<td></td>
<td></td>
<td>2-5%</td>
<td>0-40%</td>
<td>0-5%</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
Woodford Gas-Shale Wells

Completed 2003–2008

561 Wells

- 6 Caney/Woodford
- 4 Sycamore/Woodford
- 123 Vertical Woodford
- 428 Horizontal/Directional Woodford (76%)
Woodford Shale-Only Wells Completed 2004-2008

546 wells; “Horizontal” includes 5 directional wells

Number of Wells

Year

Horizontal
Vertical

2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010

242 (89%)
Woodford Shale Gas Wells, 2003-2007

528 Woodford-only wells:
112 vertical: depth 570-15,310 ft; IP: 1-2,681 Mcfd; 416 horizontal wells: depth 1,700-13,105 TVD; IP 3-11,200 Mcfd
Woodford Shale Horizontal Wells

416 wells

Initial Potential (Mcfd) vs. Lateral Length (feet)

- The graph displays a scatter plot of 416 wells, showing the relationship between lateral length (in feet) and initial potential (in Mcfd).
- The x-axis represents the lateral length, while the y-axis represents the initial potential.
- The data points are spread across the graph, indicating a range of values for both lateral length and initial potential.
Woodford IP >1 MMcfd
Completed 2004–2008

- Caney/Woodford
- Sycamore/Woodford
- Woodford
- Woodford IP >1 MMcfd
Woodford Shale Discovery Wells (New Field or Extension)

546 Woodford-only Wells

Year

53% 145
38% 45
17% 7
22% 2
50
100
200
300
Number of Wells

2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010

Updated 8/4/2008
Woodford Shale Discovery Wells

Completed 2004–2008

238 discovery wells
<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
Vitrinite Reflectance of Woodford Shale, Eastern Oklahoma

VRo mean based on minimum of 20 measurements from whole-rock pellets

Cardott, in preparation
Isoreflectance Map of the Woodford Shale in Eastern Oklahoma

Map prepared by R. Vance Hall using Petra

Cardott, in preparation
Woodford Gas Shale Wells (2004-2008) by Major Operator
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 limits to the west and upper limits to the east)

(2) greater than 100 ft thick

(3) relatively shallow (<12,000 ft)
Structure and Vitrinite Reflectance of Woodford Shale, Southern Oklahoma

Location of vitrinite sample, top number is vitrinite reflectance (%), lower number is vitrinite reflectance equivalent (%).

1Surface sample, 2above fault, 3below fault

Outcrop of Woodford Shale

Woodford absent

Fault; solid where known, dashed where approximately located

Structure contour, interval—1,000 feet

Cardott, in preparation
Southern Oklahoma VRo vs Depth

Vitrinite Reflectance (%Ro)

Depth (feet)
Woodford Gas Shales

1939-1996

21 Wells
1 Sycamore/Woodford
Cimarex Energy 3 Griffin-Olmstead
(Marshall CO, 16-5S-5E; IP 747 Mcfd; 4,052-4,135 ft)

Average Monthly Production (Mcf)

Cumulative Gas Production
1,803,733 Mcf

Completed as OIL well in McLish 6,536-6,544 ft on 11/4/55;
OIL-WO well in McLish and Bromide 5,664-5,696 ft on 5/18/56;
GAS-WO to Woodford on 3/21/92

(Gas production data supplied by Petroleum Information/Dwights LLC dba IHS Energy Group, © 2007, IHS Energy Group)
3 Griffin-Olmstead well

Structure contour map of the top of the Viola Group (Ordovician) in the North Madill field (from Huffman and others, 1987)
Verdad Oil & Gas 1 Mary Haynie
(Bryan CO, 22-6S-7E; IP 962 Mcfd; 3,710-4,054 ft)

Completed as GAS well in Misener 4,192-4,227 ft on 6/27/58; GAS-WO (plugback) in Woodford on 11/22/74

Cumulative Production 2,337,532 Mcf

(Gas production data supplied by Petroleum Information/Dwights LLC dba IHS Energy Group, © 2007, IHS Energy Group)
Structure contour map of the top of the Viola Group (Ordovician) in the Aylesworth and SE Aylesworth District fields (from Huffman and others, 1987)
Woodford Shale Production (2004-2008 wells)

Cumulative Production
122,729,596 Mcf gas,
158,238 BBLS oil/condensate
from 440 Woodford-only wells
(excludes OWWO, D&A)

(Gas production data supplied by PI/Dwights LLC, © 2007, IHS Energy Group)
Woodford Shale Only Oil/Condensate Production (67 of 440 wells; 2004-2008)
Woodford Shale Only Oil/Condensate Production (67 of 440 wells; 2004-2008)

- Caney/Woodford
- Sycamore/Woodford
- Woodford
- Woodford Oil/Condensate

- @0.6% Ro
- 40° API oil
- GOR 22,776

- @0.6% Ro
- Condensate
- GOR 41,210

- @1.4% Ro
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
- Some Woodford Shale gas potential is in southern Oklahoma at <1.1% Ro
http://www.ogs.ou.edu

For more information, please visit the Oklahoma Geological Survey Web Site

Oklahoma Geological Survey

Oil and Gas
- About Oil & Gas
- Commonly Asked Questions
- Sources of OK Data
- OGS Oil and Gas Related Publications
- Type Logs
- Oklahoma Stratigraphic Columns
- Field Discovery Wells (Excel format)
- Links
- Available Publications
- Milestones in the Oklahoma Oil and Gas Industry

Oklahoma Hydrocarbon Source Rocks and Gas Shales
- References
- Presentations & Reports
  - Oklahoma Gas-Shale Completions Map, 1939-2007
  - Woodford Shale Gas Well Completions Map, 1939-2007
- Gas Shales Database

Oklahoma Oil and Gas Management Inc., Kiker #1, Sec 30-8N-9E, Wewoka District, Seminole County, OK. Photo by Dan Boyd.

References

Brian J. Cardott
Oklahoma Geological Survey

Bibliography of Caney Shale
Bibliography of Excello Shale
Bibliography of Woodford Shale
Bibliography of Oklahoma Asphalt
Bibliography of Oklahoma Rock-Eval
Bibliography of Oklahoma Solid Hydrocarbons
Bibliography of Oklahoma Gas Shales
Bibliography of Oklahoma Hydrocarbon Source Rocks
Oil and Gas Presentations and Reports

Woodford Gas-Shale Play Update (2008 AAPG Poster)

Conventional Wisdom Applied to Oklahoma Gas Shales

Overview of Woodford Gas Shale Play (2007 Conference)

Oklahoma Gas Shales (2006 CBM Symposium)

Woodford Shale and Caney Shale Reservoir Property Analysis Report
<table>
<thead>
<tr>
<th>Record</th>
<th>API Number</th>
<th>Operator</th>
<th>Completion Date</th>
<th>Well Name</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>412</td>
<td>35-063-24000</td>
<td>Newfield Exploration</td>
<td>3H-22 Tollett</td>
<td></td>
<td></td>
</tr>
<tr>
<td>284</td>
<td>35-121-23817</td>
<td>Newfield Exploration</td>
<td>4H-22 Ellis Sherman</td>
<td>Pine Hill</td>
<td></td>
</tr>
<tr>
<td>443</td>
<td>35-029-20907</td>
<td>Newfield Exploration</td>
<td>3H-31 Patterson</td>
<td></td>
<td></td>
</tr>
<tr>
<td>287</td>
<td>35-063-23816</td>
<td>Newfield Exploration</td>
<td>1H-13 Stuart</td>
<td></td>
<td></td>
</tr>
<tr>
<td>221</td>
<td>35-063-23801</td>
<td>Newfield Exploration</td>
<td>1H-22 Tollett</td>
<td></td>
<td></td>
</tr>
<tr>
<td>245</td>
<td>35-063-23826</td>
<td>Newfield Exploration</td>
<td>2H-31 Patterson</td>
<td></td>
<td></td>
</tr>
<tr>
<td>526</td>
<td>35-029-20908</td>
<td>Newfield Exploration</td>
<td>3H-36 Parker</td>
<td></td>
<td></td>
</tr>
<tr>
<td>442</td>
<td>35-063-23936</td>
<td>Newfield Exploration</td>
<td>2H-28 Sanford</td>
<td></td>
<td></td>
</tr>
<tr>
<td>222</td>
<td>35-063-23785</td>
<td>Newfield Exploration</td>
<td>1H-23 Tipton</td>
<td></td>
<td></td>
</tr>
<tr>
<td>184</td>
<td>35-005-20301</td>
<td>Antero Resources</td>
<td>19-1H Pettigrew</td>
<td></td>
<td></td>
</tr>
<tr>
<td>362</td>
<td>35-063-23843</td>
<td>Newfield Exploration</td>
<td>1H-28 Smith</td>
<td></td>
<td></td>
</tr>
<tr>
<td>592</td>
<td>35-063-24040</td>
<td>Chesapeake Operating</td>
<td>1-3H Cypert</td>
<td>Hill Top</td>
<td></td>
</tr>
<tr>
<td>427</td>
<td>35-063-23915</td>
<td>Newfield Exploration</td>
<td>2H-27 Whitlow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>99</td>
<td>35-063-23749</td>
<td>Newfield Exploration</td>
<td>1H-36 Parker</td>
<td></td>
<td></td>
</tr>
<tr>
<td>305</td>
<td>35-121-23792</td>
<td>Antero Resources</td>
<td>20-1H Silva</td>
<td></td>
<td></td>
</tr>
<tr>
<td>256</td>
<td>35-063-23825</td>
<td>Newfield Exploration</td>
<td>1H-20 Melvin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>243</td>
<td>35-029-20805</td>
<td>Pablo Energy II LLC</td>
<td>1H-28 Lemons</td>
<td>Coalgas</td>
<td></td>
</tr>
<tr>
<td>229</td>
<td>35-121-23742</td>
<td>Newfield Exploration</td>
<td>1H-4 Elms</td>
<td>Pine Hill</td>
<td></td>
</tr>
<tr>
<td>246</td>
<td>35-121-23797</td>
<td>Newfield Exploration</td>
<td>1H-6 Grant</td>
<td>Pine Hill</td>
<td></td>
</tr>
<tr>
<td>251</td>
<td>35-063-23819</td>
<td>Newfield Exploration</td>
<td>1H-32 Gockel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>270</td>
<td>35-063-23803</td>
<td>Newfield Exploration</td>
<td>1H-35 Turpin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>495</td>
<td>35-029-20817</td>
<td>Pablo Energy II LLC</td>
<td>1H-29 Ables</td>
<td>Central</td>
<td></td>
</tr>
<tr>
<td>532</td>
<td>35-063-24006</td>
<td>Newfield Exploration</td>
<td>2H-17 Burton</td>
<td>Ashland</td>
<td></td>
</tr>
<tr>
<td>273</td>
<td>35-029-20820</td>
<td>Devon Energy</td>
<td>1-15H Sprague</td>
<td></td>
<td></td>
</tr>
<tr>
<td>444</td>
<td>35-029-20862</td>
<td>Antero Resources</td>
<td>33-1H Brown</td>
<td></td>
<td>Ashland</td>
</tr>
<tr>
<td>288</td>
<td>35-121-23749</td>
<td>Newfield Exploration</td>
<td>2H-23 McWilliams</td>
<td></td>
<td>Pine Hill</td>
</tr>
<tr>
<td>475</td>
<td>35-029-20921</td>
<td>XTO Energy</td>
<td>12-25H Lemons</td>
<td></td>
<td>Ashland</td>
</tr>
</tbody>
</table>
Typical Calf Creek point of Woodford chert found in Haskell County, Oklahoma

(Norman Transcript, March 11, 2007, p. E1)