Application of Organic Petrology to the Woodford Gas-Shale Play, Oklahoma, U.S.A.

Brian J. Cardott
Oklahoma Geological Survey
Outline

- Background on Gas Shales
- Oklahoma Woodford Shale
- Oklahoma Woodford Gas-Shale Play
Non-Negotiable Parameters Necessary for Gas Shales

- Fractures (permeability)
- Gas Source Rock (Gas Generation, Storage, and Preservation)

[similar to coalbed methane]
Fractures

- Lithology must be fracture-able (e.g., silica rich)
- Fractures must stay in-zone (e.g., need fracture barriers; stay away from faults)
- Natural vs. induced fractures
Example of Poor Gas Shale

Weathered Clay-Rich Sylvan Shale ("Thud")
Example of Good Gas Shale

Fractured, Silica-Rich Woodford Shale (“Ping”)

- **Organic Matter Type:** Type II Kerogen
- **Organic Matter Quantity:** minimum of 2% TOC (depends on thermal maturity)
- **Thermal Maturity** (highest gas rates in gas window)
Figure 2: Volume of hydrocarbon gas (C₁-C₅) generated by hydrous pyrolysis from thermally immature source rocks bearing different kerogen types (Lewan and Henry, 2001).

From Lewan, 2002
Zones of Petroleum Generation and Destruction

Organic Matter Type:
- Amorphous (Oil) Liptinitic
- Mixed
- Coal (Gas) Humic

Coal Rank:
- Peat
- Lignite
- \( s_b \)
- \( h_v C_b \)
- \( h_v B_b \)
- \( h_v A_b \)
- \( m_v \)
- \( l_v \)
- \( s_a \)
- \( m_a \)

Random Reflectance of Vitrinite (R\(_{v}\)\%):
- 0.2
- 0.3
- 0.4
- 0.5
- 0.6
- 0.7
- 0.8
- 0.9
- 1.0
- 1.20
- 1.35
- 2.0
- 3.0
- 4.0
- 5.0

Peak Oil Generation
PEAK WET GAS GENERATION
PEAK DRY GAS GENERATION

Oil Floor
Wet Gas Floor
Dry Gas Generation Limit
Dry Gas Preservation Limit

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
Figure 1: Generation of oil and gas from an 80-Ma source rock with Type-II kerogen and associated crude oil. Curves are based on kinetic parameters determined by hydrous and hydrothermal pyrolysis and EASY%Ro (Swweeney and Burnham, 1990).

From Lewan, 2002
Based on conodonts, Hass and Huddle (1965) determined a Late Devonian (Frasnian) age for most of the formation; uppermost part is Early Mississippian (Kinderhookian) unconformity.
Paleogeography and Facies Distribution in the Late Devonian

From Kirkland and others, 1992
Geologic Provinces of Oklahoma

- Northern Shelf Areas
  - Anadarko Basin
  - Arbuckle Mountain Uplift
  - Wichita Mountain Uplift
  - Hollis Basin
  - Marietta Basin
  - Ardmore Basin
  - Gulf Coastal Plain
  - Arkoma Basin
  - Ouachita Mountain Uplift
  - Ozark Uplift
Isopach Map of Woodford Shale

EXPLANATION

- Ouachita Province Boundary (thrust fault)
- Upper Devonian shale missing
- Cretaceous overlap
- Erosional limit of Sylamore Ss. (basal ss. of Chattanooga)
- Covered boundary
- Isopach contours

From Comer, 1992
Woodford Shale Gas Wells

206 Wells, 1939–2007

Application of Advanced Completion Technology
Woodford Gas Shales

1939-2007

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

553 ft
(IP 122 Mcf)
Woodford Gas Shales
2003–2007
Why is the Woodford Shale Gas Play where it is?

185 Wells
4 Caney/Woodford
3 Sycamore/Woodford
95 Horizontal Woodford
Generalized Structure Map of Woodford Shale, Eastern Oklahoma

Map prepared by R. Vance Hall using Petra
Woodford Shale is the oldest rock in Oklahoma that contained wood (vitrinite) from the progymnosperm *Archaeopteris* (organ genus *Callixylon*)
Vitrinite Reflectance of Woodford Shale, Eastern Oklahoma

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

Cardott, in preparation
Amoco 1 Devils Backbone well, 31-5N-24E, D&A
Woodford Shale at 17,854 ft
VRo = 6.36%, n=57

6.84% Ro
500X, field width 140 µ
Isoreflectance Map of the Woodford Shale in Eastern Oklahoma

Map prepared by R. Vance Hall using Petra

Cardott, in preparation
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)
(2) greater than 100 ft thick
(3) relatively shallow (<12,000 ft)
Structure and Vitrinite Reflectance of Woodford Shale, Southern Oklahoma

Cardott, in preparation
Woodford Gas Shales
1939-1996

21 Wells
1 Sycamore/Woodford

Sycamore; Woodford
Woodford

<1MMcf/mo
steep decline

Madill
Aylesworth

oil
oil
Cimarex Energy 3 Griffin-Olmstead
(Marshall CO, 16-5S-5E; IP 747 Mcfd; 4,052-4,135 ft)

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

Cumulative Gas Production 1,776,752 Mcf

Madill Field

(Gas production data supplied by Petroleum Information/Dwights LLC dba IHS Energy Group, © 2007, IHS Energy Group)
Verdad Oil & Gas 1 Mary Haynie
(Bryan CO, 22-6S-7E; IP 962 Mcfd; 3,710-4,054 ft)

Average Annual Production (Mcf)


10,000 100,000 1,000,000

346 MMcf

75 MMcf

Aylesworth Field

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 2,298,658 Mcf

(Gas production data supplied by Petroleum Information/Dwights LLC dba IHS Energy Group, © 2007, IHS Energy Group)
Woodford Shale Production (2004-2007 wells)

Cumulative Production
19,333,211 Mcf gas,
21,187 BBLs oil/condensate
from 134 wells (excludes 10 OWWO)

(Gas production data supplied by PI/Dwights LLC,
© 2007, IHS Energy Group)
Woodford Shale Oil/Condensate Production
(25 of 152 wells; 2003-2007)

- Caney/Woodford
- Sycamore/Woodford
- Woodford
- Horizontal Woodford
- Oil or Condensate

Oil: 10-48° API
Condensate: >49° API
Gas well: GOR >15,000
Oil well: GOR <10,000

@1.0% Ro
40° API oil
GOR 22,776

@0.6% Ro
55° API condensate
GOR 87,555

@1.3% Ro
41,210

@0.6% Ro
55° API condensate
GOR 87,555
Gas Storage and Production

- Production decline curves suggest initial gas production is as free gas in fractures.
- Gas production depends on fracture connectivity with gas storage sites (free and sorbed gas).

Devon Energy 1-26 Edwards horizontal Woodford well (2005)

![Graph showing average monthly production](image)
Solid bitumen network may be important for gas storage and migration by diffusion.
ORGANIC NETWORK IN WOODFORD
(AOM; SOLID HYDROCARBON)

0.94% VRo

Solid hydrocarbon network visible by 0.9% VRo
ORGANIC NETWORK IN WOODFORD
(AOM; SOLID HYDROCARBON)

Solid hydrocarbon network noticeable at high thermal maturity

7.28% VRo
Woodford Shale Gas Wells, 2003-2007

All 175 wells: depth 570-15,310 ft; IP: 3-8,930 Mcfd
93 horizontal wells: depth 5,450-11,867 TVD; IP 125-8,930 Mcfd
SUMMARY OF WOODFORD GAS SHALE PLAY

- Woodford Shale contains Type II Kerogen with adequate TOC
- Woodford Shale is silica rich (e.g., fracture-able)
- Most 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
- Organic network may be important for gas diffusion in shales
Typical Calf Creek point of Woodford chert found in Haskell County, Oklahoma
(Norman Transcript, March 11, 2007, p. E1)