Conventional Wisdom
Applied to Oklahoma Gas Shales

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Oklahoma Geological Survey
Outline

- Conventional Wisdom of Gas Shales
- Oklahoma Woodford Shale
- Oklahoma Woodford Gas-Shale Play
Conventional Wisdom
[Non-Negotiable Parameters]
Necessary for Gas Shales
(summarized from others working on the Barnett Shale)

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

- Lithology must be fracture-able (e.g., silica-rich shale)
- Fractures must stay in-zone (e.g., need fracture barriers; stay away from faults)
- Natural vs. induced fractures (gas-filled; not water-, oil-, or mineral-filled fractures)
Example of Poor Gas Shale

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

Fractured, Silica-Rich Woodford Shale ("Ping")
Gas Generation: Organic-Rich Black Shale/Siltstone

- **Organic Matter Type:**
  Type II (oil generative) Kerogen

- **Organic Matter Quantity:** minimum of 2% TOC (depends on thermal maturity)

- **Thermal Maturity** (highest gas rates in gas window, >1.4% VRo)
Gas Generation by Kerogen Type

At 350°C for 72 h, Type-I and -II kerogens generate 1.8 times as much thermogenic gas as Type-III kerogen.

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).
## Guidelines for the Barnett Shale (Based on Rock-Eval Pyrolysis)

<table>
<thead>
<tr>
<th>VRo Values</th>
<th>Maturity</th>
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</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).
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
  - Arkoma Basin
  - Ouachita Mountain Uplift
  - Gulf Coastal Plain

- Ozark Uplift
Isopach Map of Woodford Shale

From Comer, 1992
Woodford Shale

From Comer, 1992
Oklahoma Shale-Gas Wells

275 Wells, 1939–2007

Application of Advanced Completion Technology

Caney
Woodford

Number of Wells

Year

Woodford Gas Shales

1939-2007

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

553 ft (IP 122 Mcf)

Sycamore/Woodford
Caney/Woodford
Woodford
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 progynmosperm *Archaeopteris* (organ genus *Callixylon*)
Vitrinite Reflectance of Woodford Shale, Eastern Oklahoma

Cardott, in preparation

VRo mean based on minimum of 20 measurements from whole-rock pellets
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
Cimarex Energy 3 Griffin-Olmstead (Marshall CO, 16-5S-5E; IP 747 Mcfd; 4,052-4,135 ft)

Madill Field

Cumulative Gas Production 1,776,752 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)
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 2,298,658 Mcf

Gas production data supplied by Petroleum Information/Dwights LLC dba IHS Energy Group, © 2007, IHS Energy Group
Woodford Shale Production (2003-2007 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

- @1.3% Ro
- @1.0% Ro
- @0.6% Ro 40° API oil GOR 22,776
- @0.6% Ro GOR 41,210
- @1.3% Ro 55° API condensate GOR 87,555

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

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

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

<table>
<thead>
<tr>
<th>Date</th>
<th>Average Monthly Production (Mcf)</th>
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<tbody>
<tr>
<td>Jan-05</td>
<td>59,764 Mcf</td>
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Note: The graph shows the average monthly production from January 2005 to May 2007, with a peak value of 59,764 Mcf in January 2005.
Taylor and others (1998)

KEROGEN NETWORK
(SOLID BITUMEN; IMPSONITE)

Solid bitumen network may be important for gas storage and migration by diffusion

Taylor and others (1998)
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)