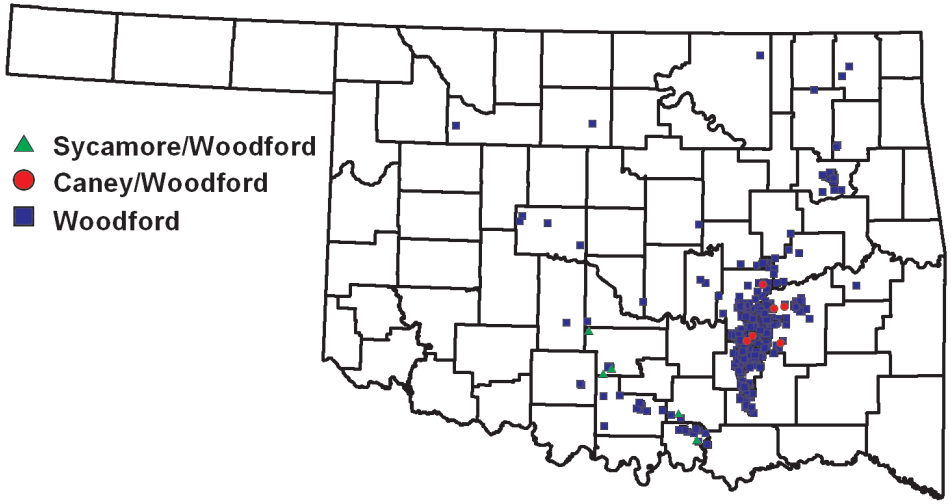
Thermal Maturity of the Woodford Shale in Oklahoma Applied to the Gas-Shale Play

Brian J. Cardott

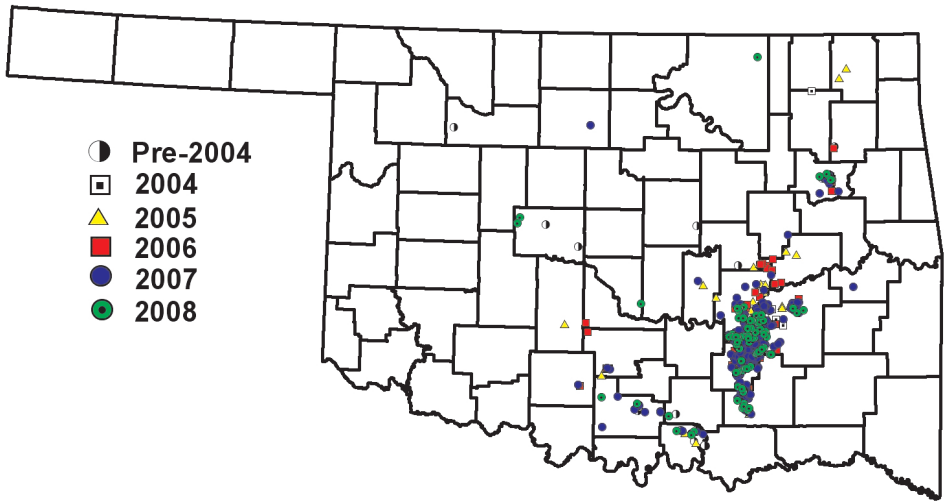
Abstract

The Woodford Shale (Late Devonian-Early Mississippian), an important hydrocarbon source rock in Oklahoma, is age-equivalent to Late Devonian gas shales in the United States (e.g., New Albany, Antrim, Ohio). It exceeds the minimum non-negotiable parameters necessary for an economic gas shale: gas source rock and fracture-able lithology. Abundant oil-generative organic matter (e.g.., Type II kerogen; 2-14% total organic carbon) in the Woodford Shale is the source of thermogenic methane and a bitumen network, beginning in the late oil window, that are sites for gas storage and migration. Abundant natural fractures in silica-rich (30-87% quartz) lithologies of the Woodford Shale in southern Oklahoma exposures illustrate lithologies that develop induced fractures, required to produce gas from shales in the subsurface.

Since 2004, more than 550 Woodford Shale gas wells have been completed in eastern, southern and western Oklahoma by using advanced completion techniques (e.g., frac technology, horizontal drilling). Most interest is where the Woodford Shale is in the condensate or dry-gas window (>1.15% vitrinite reflectance, VRo), greater than 50 ft thick, and at relatively shallow depth (<12,000 ft) in the western part of the Arkoma Basin where initial potential gas rates up to 11 million cubic ft per day have been realized. Thermal maturity of the Woodford Shale in the Arkoma Basin covers a range of issues from possibly lower gas rates and oil handling in the oil window (<1.15% VRo) to the west to gas composition changes (dilution with CO_2) at high thermal maturity (>3% VRo) to the east. Additional Woodford Shale gas plays in south-central and northeast Oklahoma are primarily in the oil window at relatively shallow depth (<7,000 ft). A Woodford gas-shale play in the Anadarko Basin shelf in Canadian County is at the boundary of the condensate and dry gas (thermogenic methane) windows.

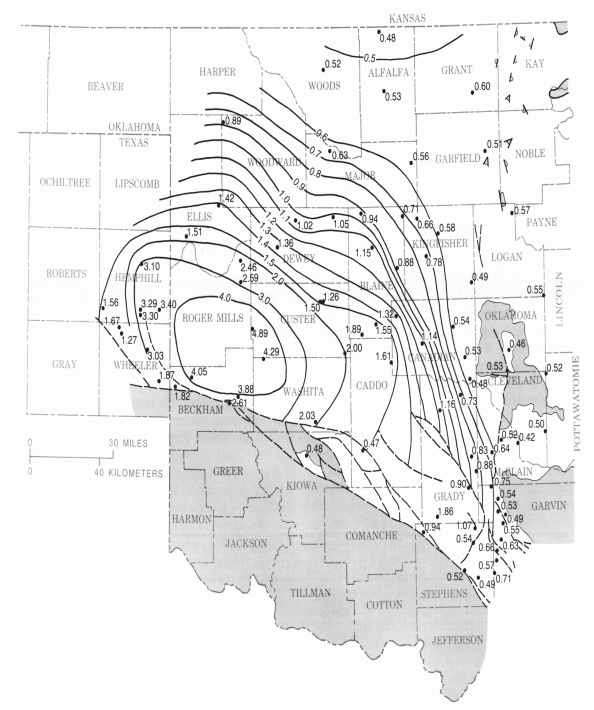


Map of Woodford Shale gas-well completions (1939-2008). Woodford gas plays since 2004 are in western Arkoma Basin, northeast Oklahoma shelf, southern Oklahoma, and Anadarko Basin shelf.



Map of Woodford Shale gas-well completions by year (1939-2008; 577 wells)

ANADARKO BASIN

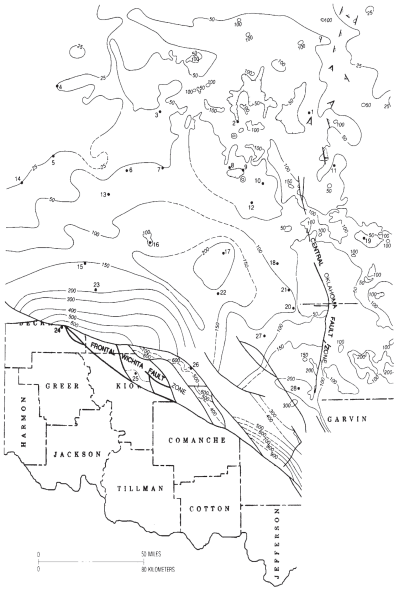


Isoreflectance map of Woodford Shale in the Anadarko Basin (from Cardott, 1989, OGS Circular 90)

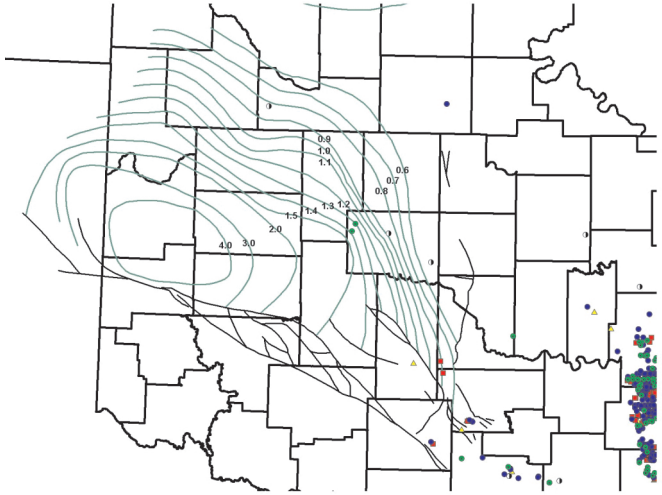
Vitrinite Reflectance Introduction

Vitrinite is a coal maceral derived from the lignin and cellulose of vascular plant cell walls and fillings from the Devonian to Recent. Vitrinite reflectance (%Ro) is a measurement of the percentage of light reflected off the vitrinite maceral at high (500X) magnification in oil immersion.

The mean random vitrinite reflectance values are based on an average of a minimum of 20 measurements (to be statistically valid) from whole-rock preparation (to eliminate any influence from caving contamination).



Woodford Shale isopach map in Anadarko Basin (modified from Amsden, 1975, OGS Bulletin 121)



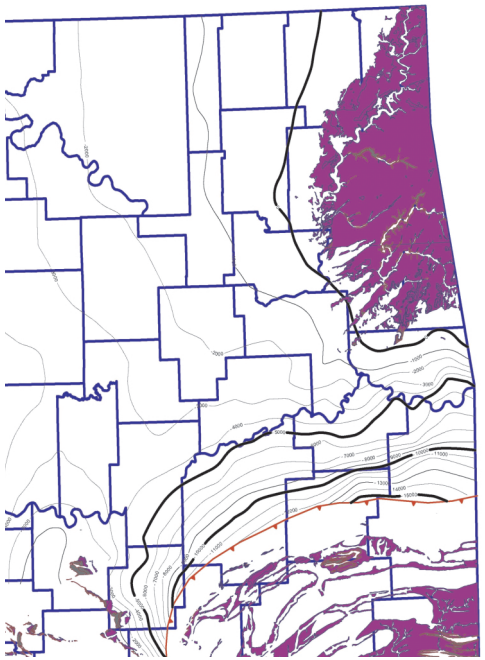
Woodford Shale gas-well completions (1939-2008) on isoreflectance map of Woodford Shale in the Anadarko Basin.

Vitrinite Reflectance Guidelines for the Barnett Shale (Based on Rock-Eval Pyrolysis; from Jarvie and others, 2005, OGS Circular 110)

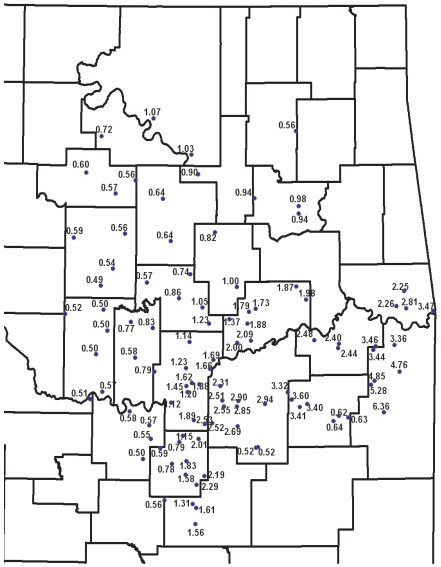
VRo Values	Maturity
<0.55%	Immature
0.55-1.15%	Oil Window (peak oil at 0.90%VRo)
1.15- 1.40%	Condensate – Wet-Gas Window
>1.40%	Dry-Gas Window

The thickest Woodford Shale in Oklahoma occurs in the Anadarko Basin depocenter. The great depth would require expensive wells. The recent Woodford Shale well completions in the basin shelf in western Canadian County are at the boundary of the condensate and dry gas windows (@1.4% Ro).

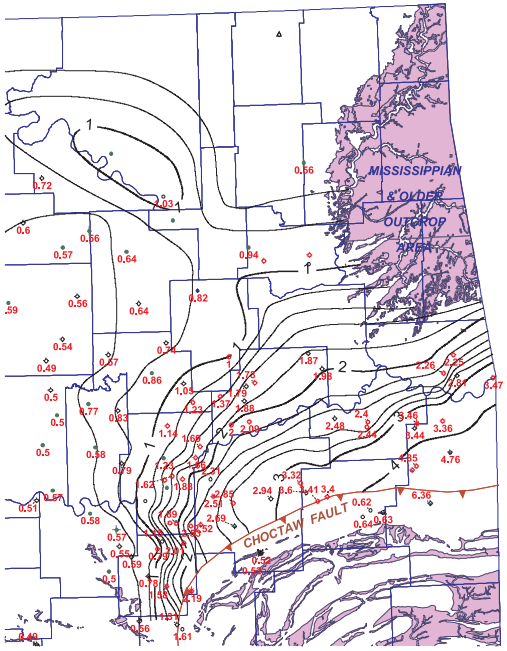
EASTERN OKLAHOMA



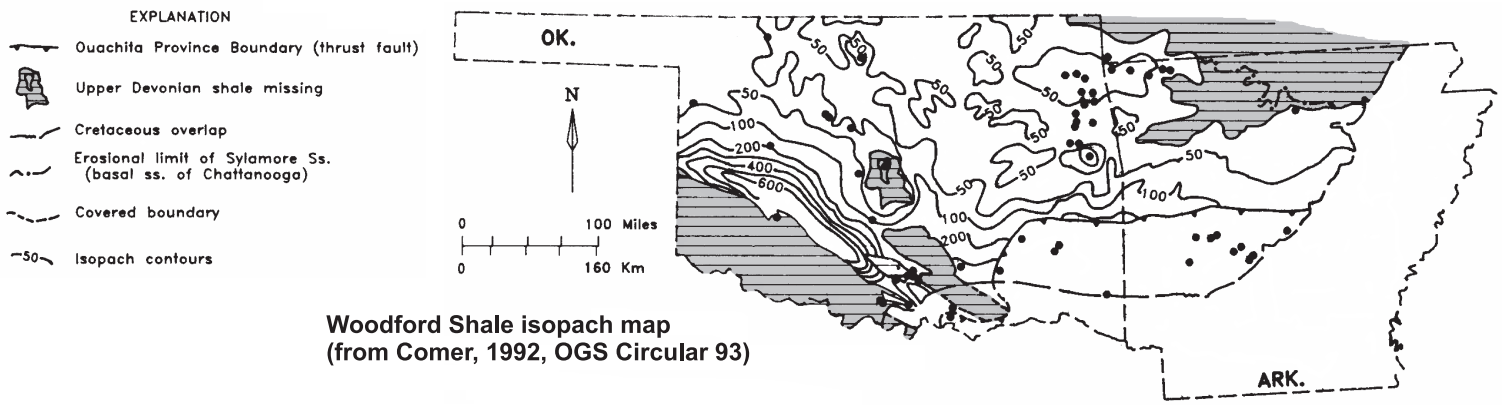
Generalized structure map of Woodford Shale in eastern Oklahoma (prepared by R. Vance Hall).



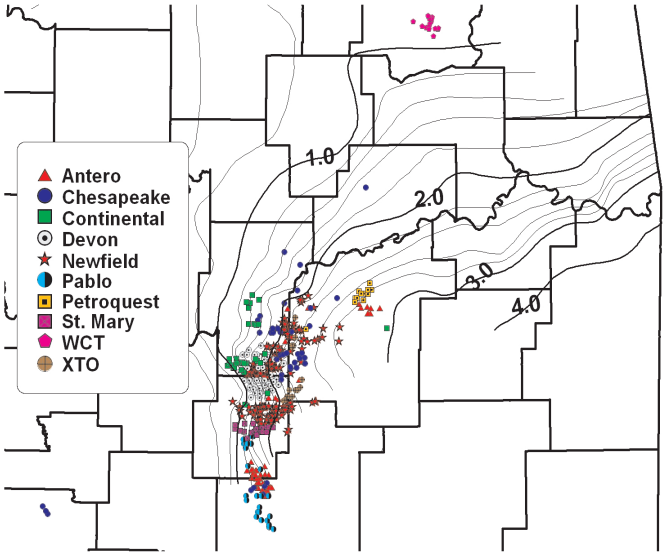
Map of mean random vitrinite reflectance data of Woodford Shale in eastern Oklahoma based on an average of a minimum of 20 measurements (Cardott, 2008, in preparation).



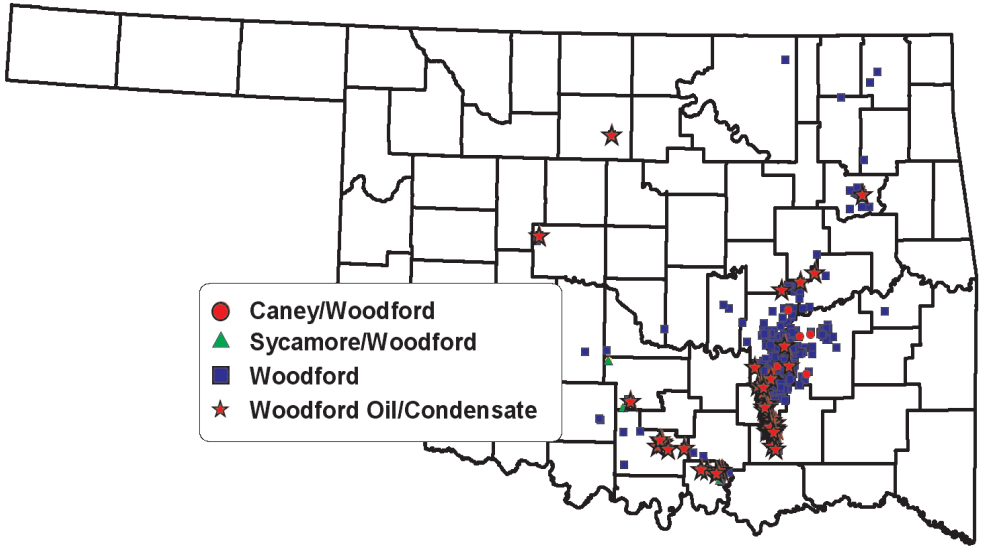
Vitrinite isoreflectance map of Woodford Shale in eastern Oklahoma (contoured by R. Vance Hall from data by B.J. Cardott)



Woodford Shale isopach map
(from Comer, 1992, OGS Circular 93)

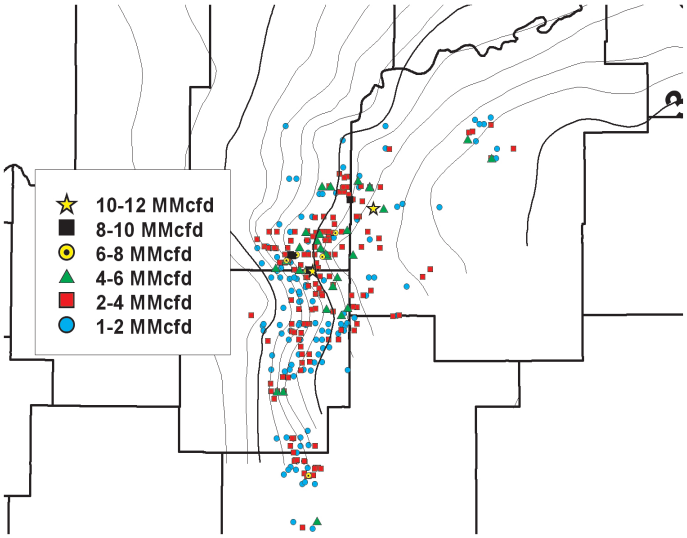


Map of Woodford Shale gas-well completions (2004-2008) by top 10 major operators (451 wells) on isoreflectance map.

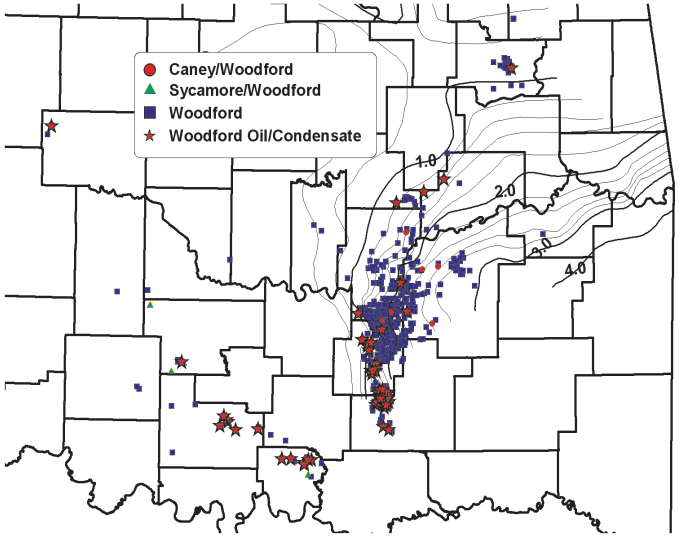


Woodford Shale oil/condensate producing wells (67 of 440 wells; 2004-2008).

The primary Woodford Shale gas play is in the western part of the Arkoma Basin where thick shale occurs in the condensate to dry gas windows at relatively shallow depths (compared to the Anadarko Basin). The Woodford Shale gas play in northeast Oklahoma includes thermogenic and biogenic methane where the shale is thinner, shallower, and in the oil window.

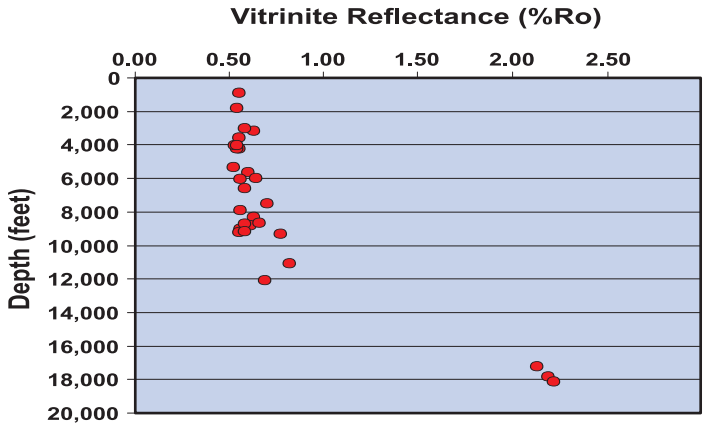


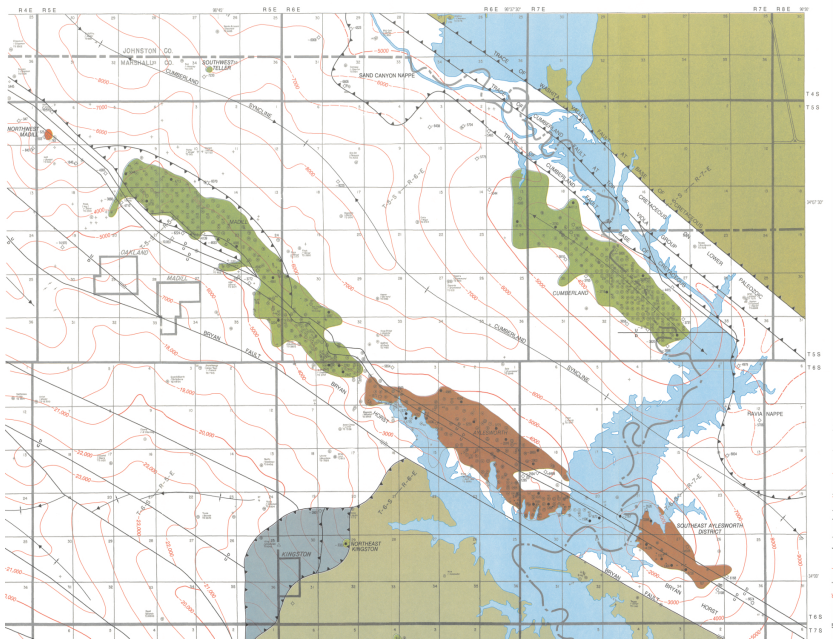
Map of Woodford Shale gas-well completions (2004-2008) with Initial Potential gas rates >1 MMcfd (340 wells) on isoreflectance map.



Woodford Shale wells (2004-2008) on isoreflectance map showing condensate production into the gas window (>1.4% Ro).

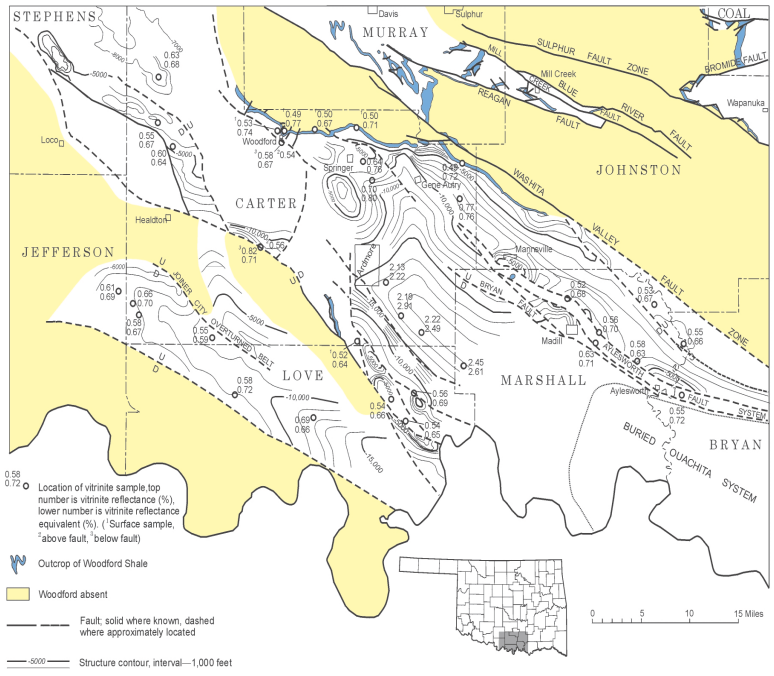
SOUTHERN OKLAHOMA



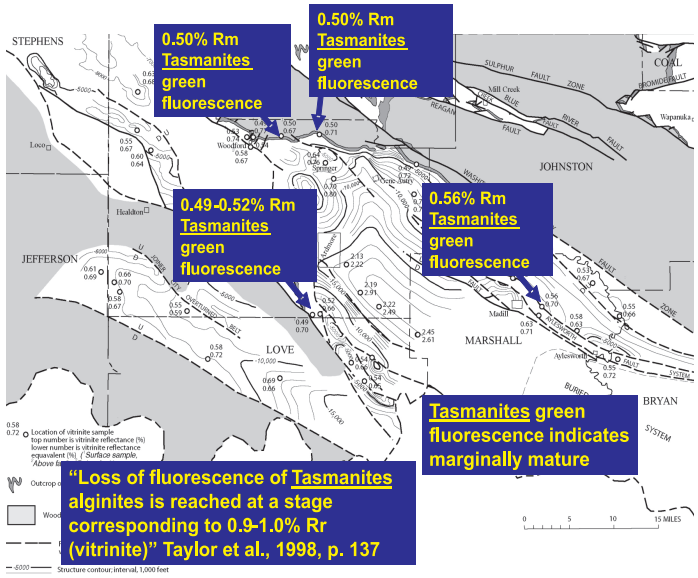


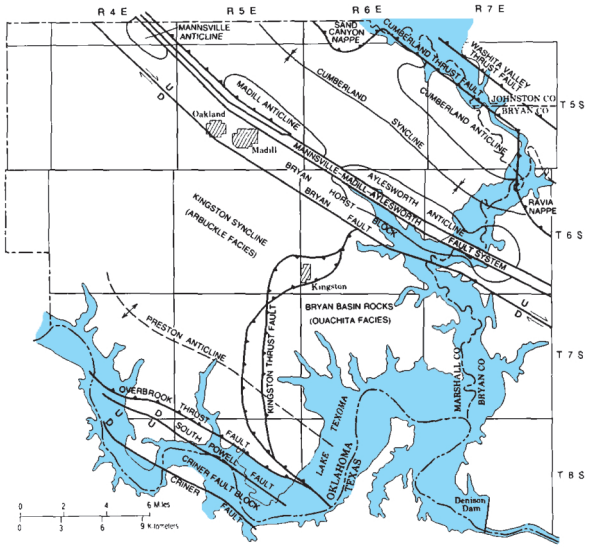
Portion of subsurface structure map of Marshall County, OK (modified from Huffman, 1987). Structure contours drawn on top of Viola Group (ft below mean sea level).

THERMAL MATURITY AND STRUCTURE



Vitrinite reflectance of Woodford Shale in southern Oklahoma on Woodford Shale structure map (Woodford Shale structure map prepared by Carlyle Hinshaw in 1999; vitrinite-reflectance data by Cardott, in preparation).



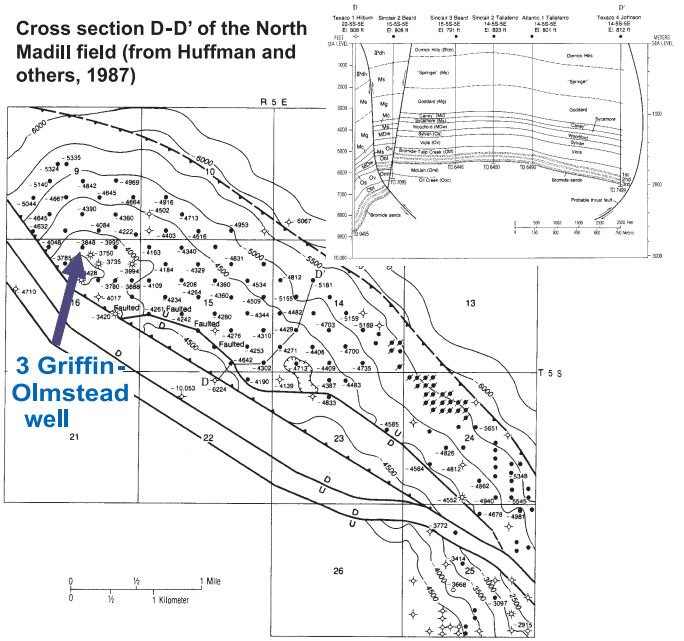


Principal subsurface structural features in Marshall County (from Huffman and others, 1987)

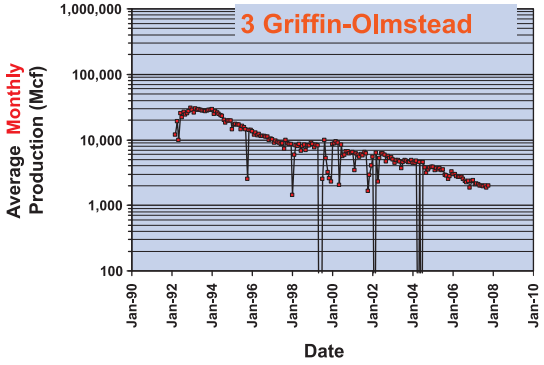
GAS PRODUCTION IN OIL WINDOW

Two examples of gas production from naturally-fractured Woodford Shale in the Madill and Aylesworth anticlines in the Ardmore Basin demonstrate gas production with little or no reported oil production at relatively shallow depths (e.g., @4,000 ft) where the Woodford Shale is in the oil window (@0.6% Ro). Even though Type II Kerogen is capable of generating about 75% of source-rock thermogenic methane by 1.1% Ro (Lewan, 2002), these examples may be special cases where thermogenic gas migrated into the fractured Woodford Shale from deeper in the Ardmore Basin. Gas isotope data from these wells are not available.

Cross section D-D' of the North Madill field (from Huffman and others, 1987)

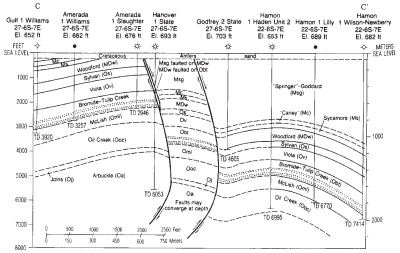


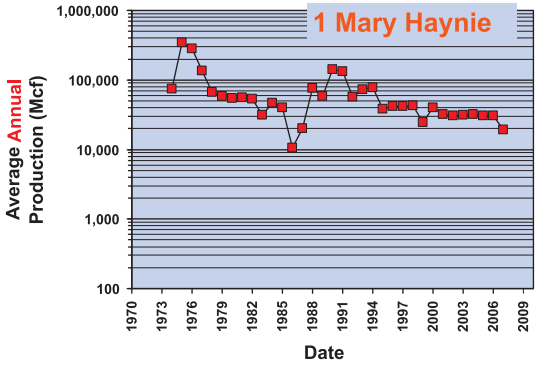
Structure contour map of the top of the Viola Group (Ordovician) in the North Madill field (from Huffman and others, 1987)



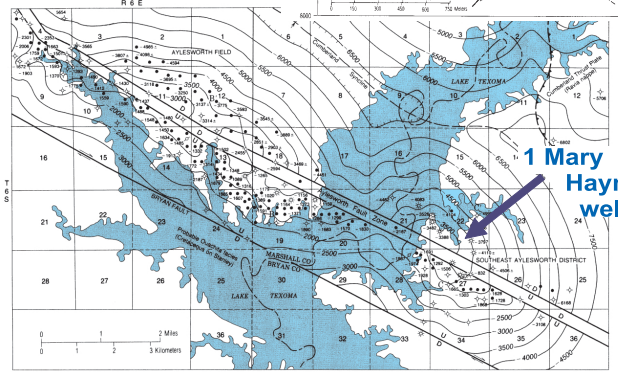
MADILL FIELD
Cimarex Energy of Colorado 3 Griffin-Olmstead well Marshall Co.; NW¼ NW¼ NE¼ 16-5S-5E Originally completed as oil well in McLlish (6,536-6,544 ft) in 1955, oil workover well in McLish and Bromide (5,664-5,696 ft) in 1956, and gas workover well in Woodford Shale (4,052-4,135 ft) in 1992. IP 747 Mcfd; Cumulative Woodford Shale gas production of 1,792,734 Mcf from March 1992 to October 2007 (data from IHS Energy)

Cross section C-C' of the Aylesworth District field Huffman and others, (from SE1987)





SE AYLESWORTH DISTRICT FIELD
Verdad Oil & Gas Corp. 1 Mary Haynie well Bryan Co.; NW¼ SE¼ SW¼ SE¼ 22-6S-7E Originally completed as gas well in Misener sand (4,192-4,227 ft) in 1956 and plugged back to Woodford Shale (3,710-4,054 ft) in 1974. IP 962 Mcfd; Cumulative Woodford Shale gas production of 2,330,605 Mcf from November 1974 to August 2007. Produced 178 bbls oil in 1995 (data from IHS Energy)



Structure contour map of the top of the Viola Group (Ordovician) in the Aylesworth and SE Aylesworth District fields (from Huffman and others, 1987)