Osage Oil & Gas Summit November 5, 2015

Woodford Shale Thermal Anomaly in Osage County, Oklahoma

Brian J. Cardott

Oklahoma Geological Survey

Outline of Presentation

- Basic Parameters Needed for Oil Production from Shale Resource Plays
- Woodford Shale thermal anomaly in Osage County
- Evaluation of Woodford Shale (Late Devonian-Early Mississippian) as a Liquid Hydrocarbon Reservoir

Conventional Wisdom [Non-Negotiable Parameters] Necessary for Shale Gas and Oil

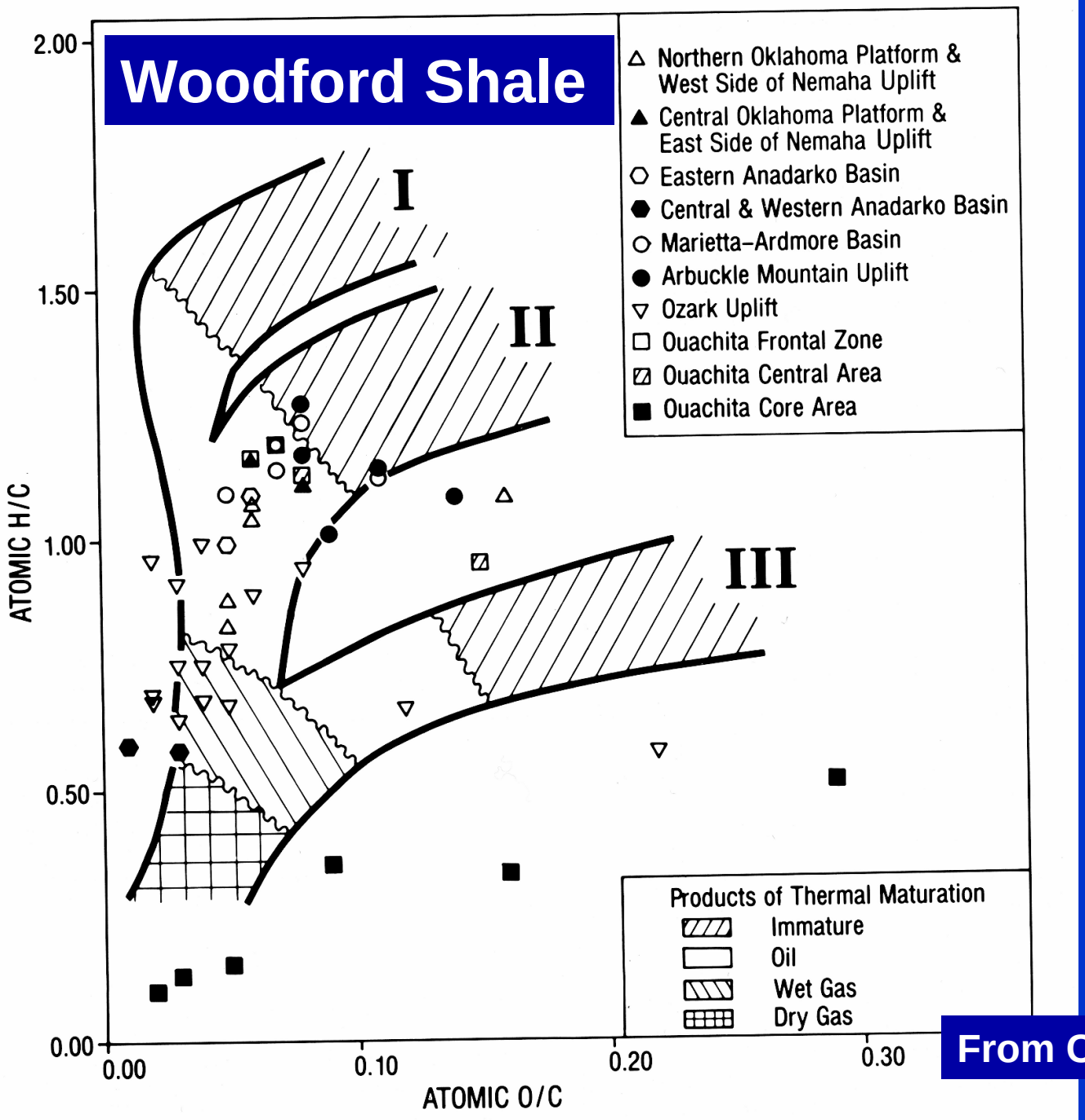
- Hydrocarbon Source Rock (Hydrocarbon Generation, Storage, and Preservation)
- Brittle lithology to generate fractures (permeability) or "conventional" reservoir lithology

Hydrocarbon Generation: Organic-Rich Black Shale

- **Organic Matter Type**:

  Type II (oil generative) Kerogen

  [All gas shales have Type II Kerogen]
- **Organic Matter Quantity**: minimum of 2% TOC (Total Organic Carbon content depends on thermal maturity since TOC decreases with increasing thermal maturity)
- **Thermal Maturity**: oil, condensate, or dry gas windows

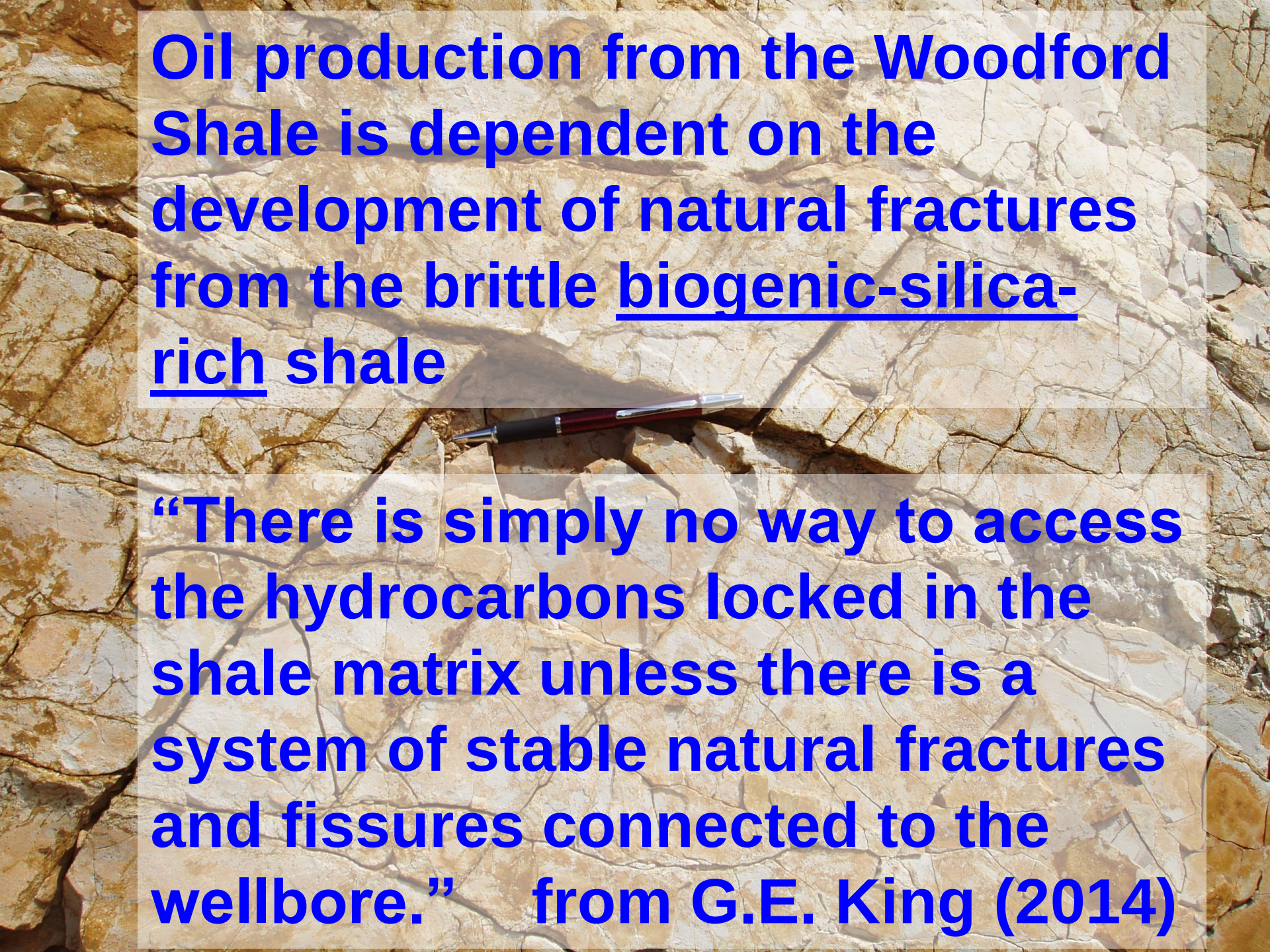


From Comer, 1992

Woodford Mineralogy

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

A. O'Brien & Slatt, 1990; B. Kirkland et al., 1992; C. Greiser, 2006; D. Branch, 2007; E. Abousleiman et al., 2008



Oil production from the Woodford Shale is dependent on the development of natural fractures from the brittle biogenic-silica-rich shale

"There is simply no way to access the hydrocarbons locked in the shale matrix unless there is a system of stable natural fractures and fissures connected to the wellbore." from G.E. King (2014)

Useful Background Information on Vitrinite Reflectance is Available in AAPG Search and Discovery Article #40928

http://www.searchanddiscovery.com

Introduction to Vitrinite Reflectance as a Thermal Maturity Indicator*

Brian J. Cardott[1]

Search and Discovery Article #40928 (2012)
Posted May 21, 2012

Cardott, 2012a

*Adapted from presentation at Tulsa Geological Society luncheon, May 8, 2012

[1]Oklahoma Geological Survey, Norman Oklahoma (bcardott@ou.edu)

Abstract

Thermal maturity is one of the most important parameters used in the evaluation of gas-shale and shale-oil plays. Vitrinite reflectance (VRo) is a commonly used thermal maturity indicator. Many operators use the vitrinite-reflectance value without knowing what it is or how it is derived. Conventional wisdom of the Barnett Shale gas play in the Fort Worth Basin indicates the highest gas rates occur at >1.4% VRo. Knowledge of the oil and condensate windows is essential for liquid hydrocarbon production. This presentation answers the questions: what is vitrinite; what is vitrinite reflectance; how is vitrinite reflectance measured; what are some sources of error; and how does one tell good data from bad data?

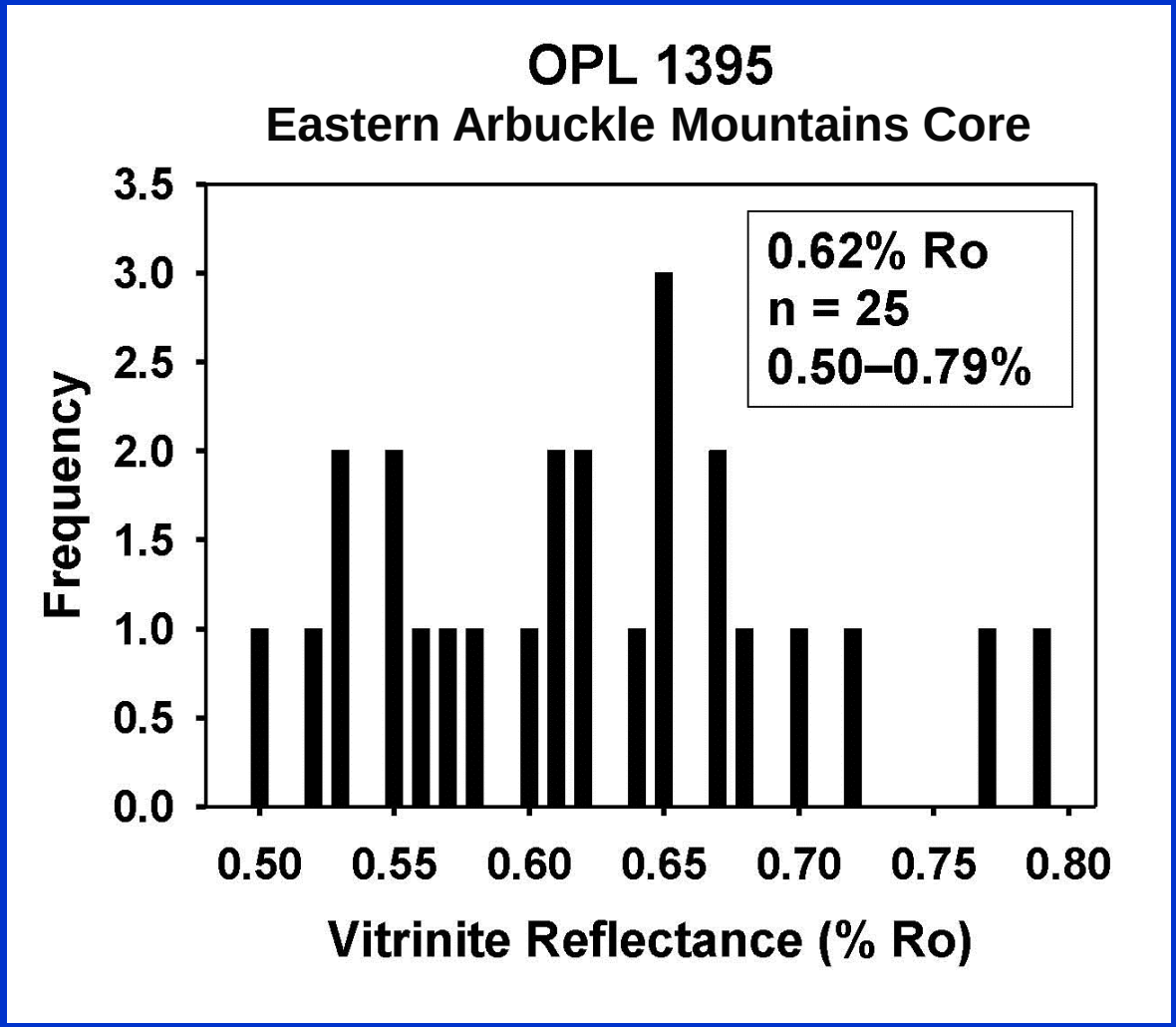
References

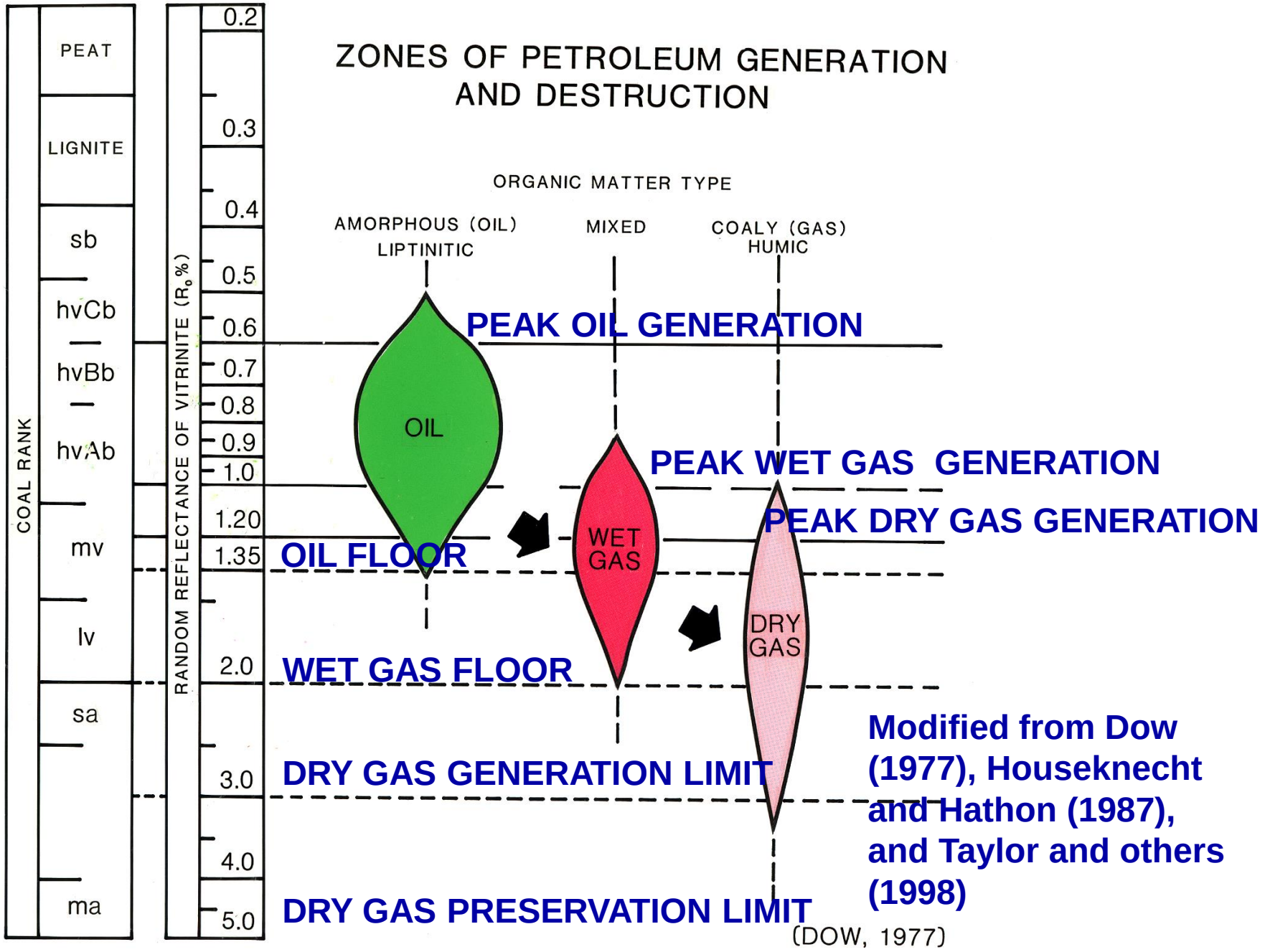
Abdelmalak, M.M., C. Aubourg, L. Geoffroy, and F. Laggoun-Défarge, 2012, A new oil-window indicator? The magnetic assemblage of claystones from the Baffin Bay volcanic margin (Greenland): AAPG Bulletin, v. 96, p. 205-215.

American Society for Testing and Materials (ASTM), 2011, Standard test method for microscopical determination of the reflectance

Vitrinite Reflectance Summary

Vitrinite is derived from woody organic matter. The vitrinite-reflectance value is an average of >20 measurements typically following a normalized distribution over a range of ~0.3% Ro.




ZONES OF PETROLEUM GENERATION AND DESTRUCTION
ORGANIC MATTER TYPE
AMORPHOUS (OIL) LIPTINITIC
MIXED
COALY (GAS) HUMIC
COAL RANK
PEAT
LIGNITE
sb
hvCb
hvBb
hvAb
mv
lv
sa
ma
RANDOM REFLECTANCE OF VITRINITE (R_o%)
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
OIL
WET GAS
DRY GAS
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 Hathon (1987), and Taylor and others (1998)
(DOW, 1977)

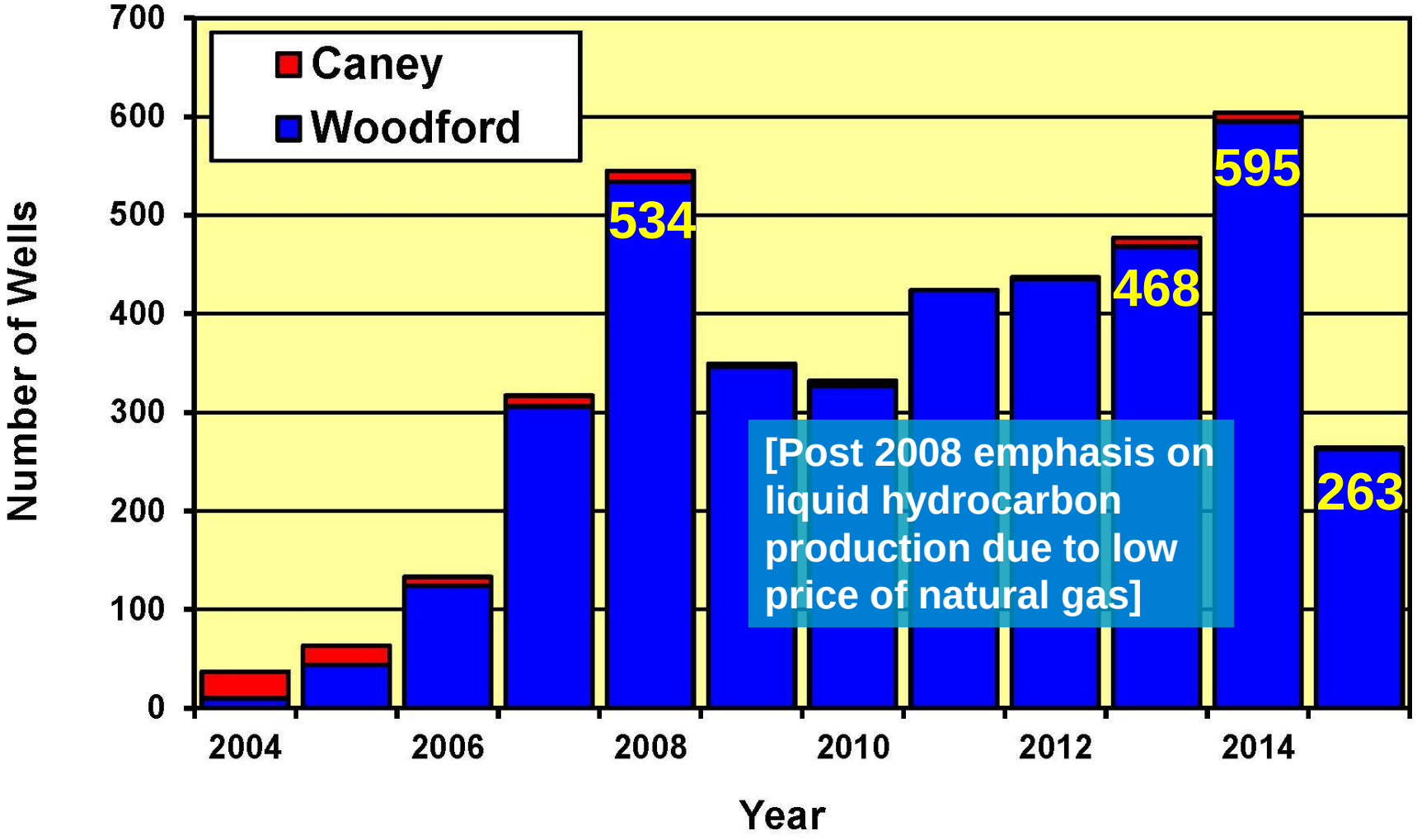
Guidelines for the Barnett Shale (applied to Woodford Shale)

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 (methane) Window

From Jarvie and others, 2005

Woodford Shale Well History

3,876 Woodford Wells, 2004–2015

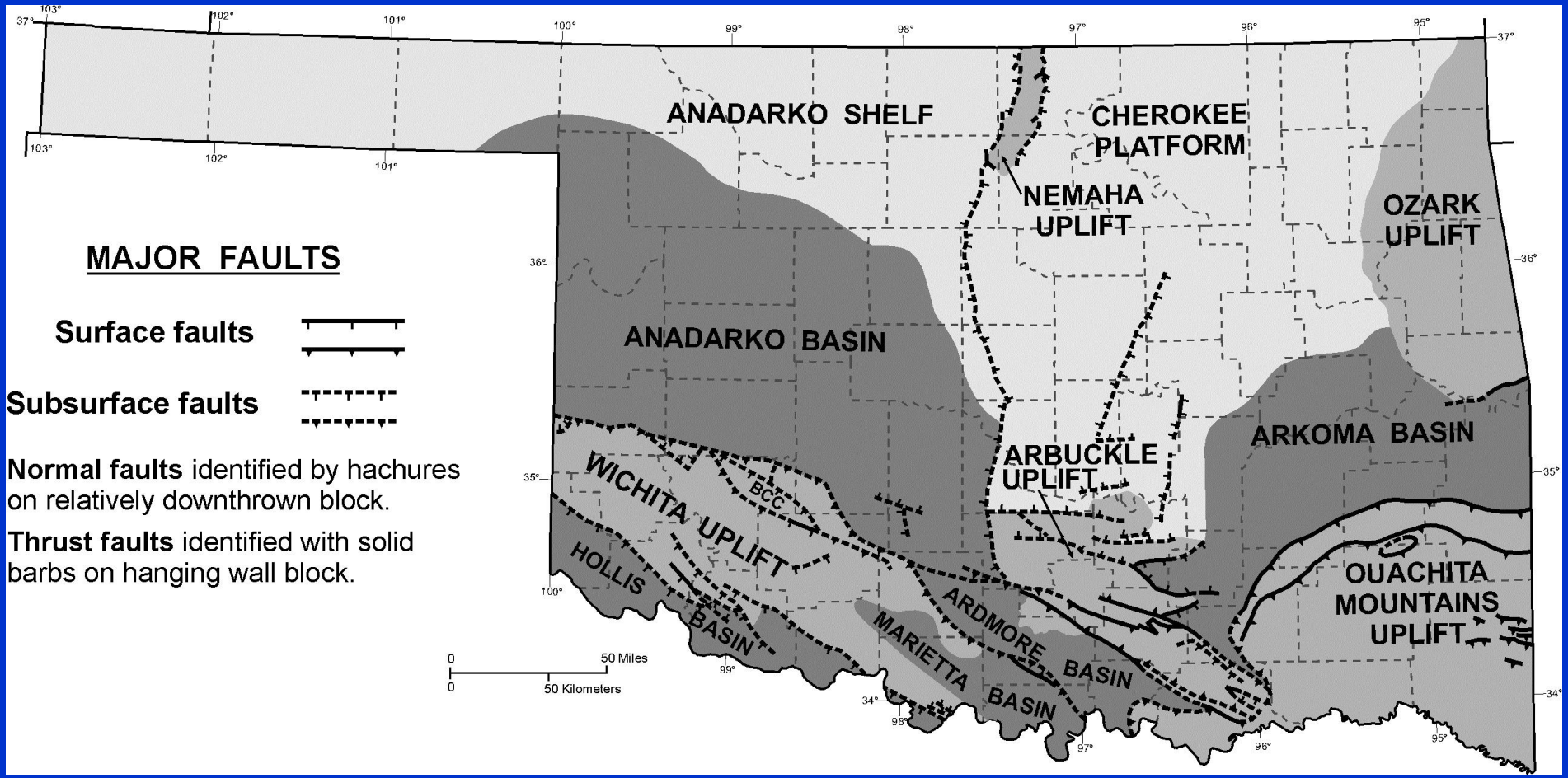


Oklahoma Oil/Condensate/Gas Production Caveat

- **Gas** production is reported by the Oklahoma Corporation Commission by **WELL**.
- **Oil/condensate** production is reported by the Oklahoma Tax Commission by **LEASE** [production by well is only on single-well leases]. **Use of Initial Potential (IP) on Maps.**

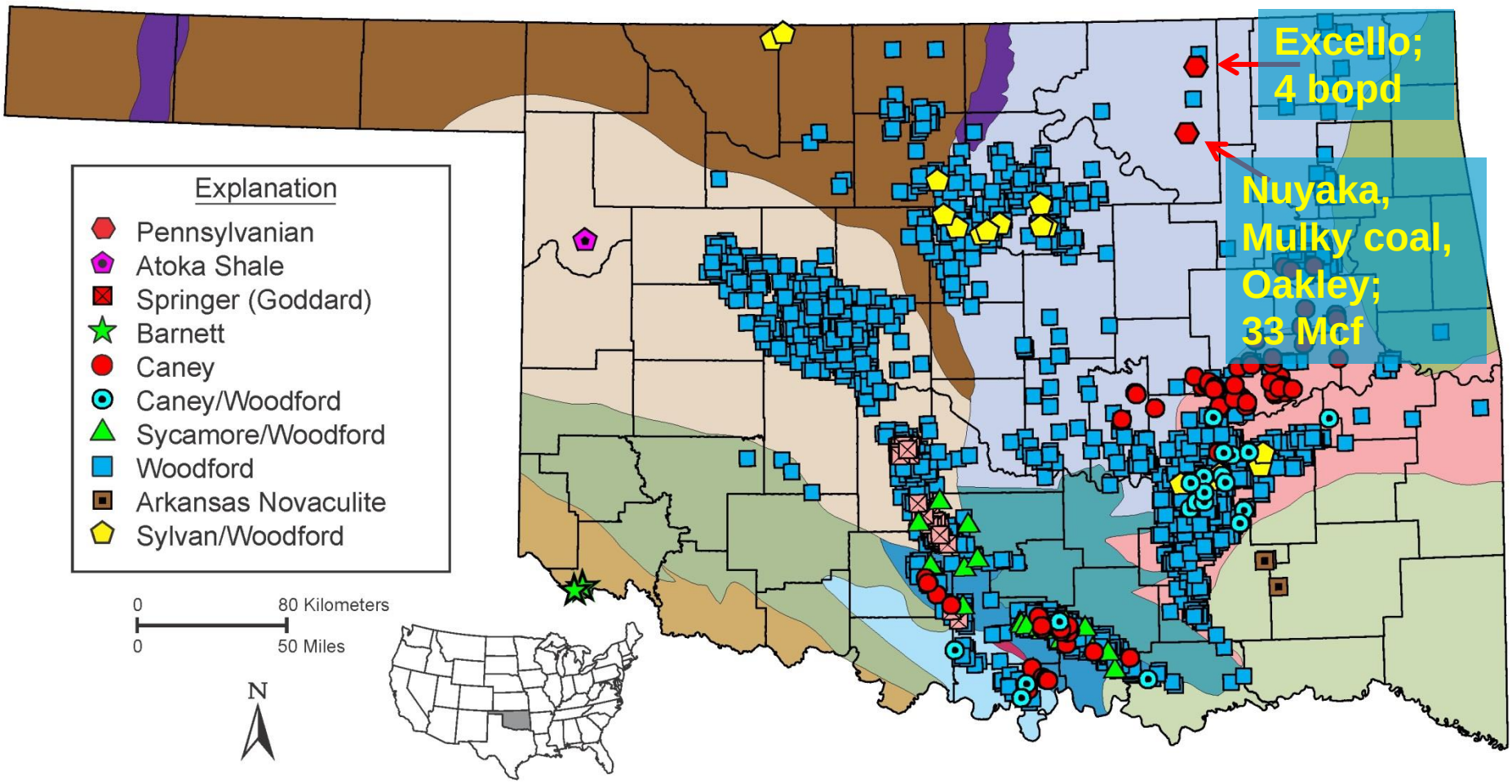
(Production data supplied by PI/Dwights LLC, © 2014, IHS Energy Group)

Oklahoma Geologic Provinces



Geologic provinces from Northcutt and Campbell, 1995

Oklahoma Gas/Tight Oil Shales (4,123 well completions, 1939-2015)



Oklahoma CBM article was published in the 2010 Oklahoma Geology Notes (v. 70, p. 4-14)

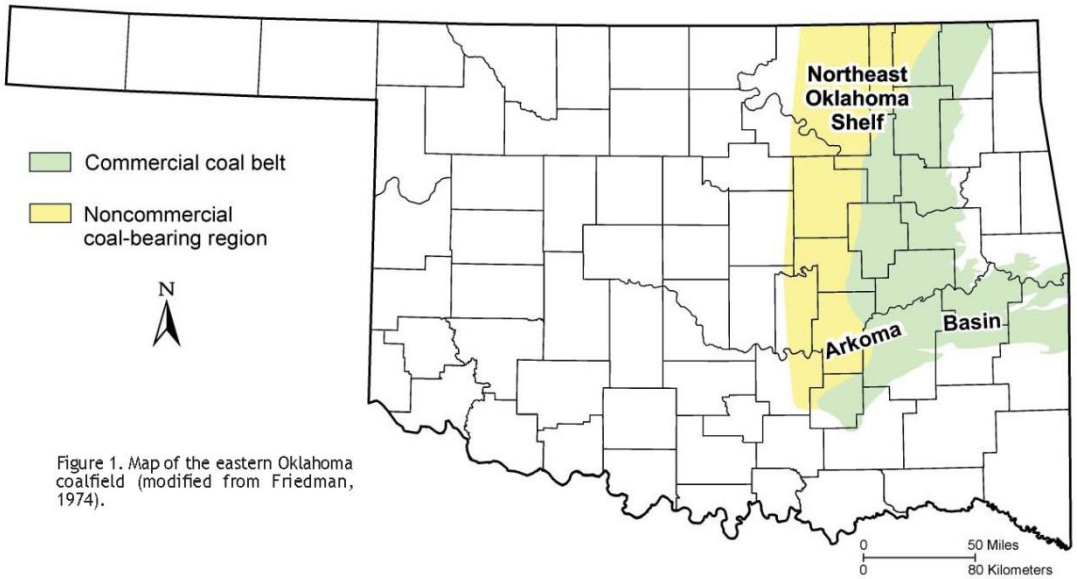


Figure 1. Map of the eastern Oklahoma coalfield (modified from Friedman, 1974).

Issues Related to Oklahoma Coalbed-Methane Activity, 1988–2008

Brian J. Cardott
Oklahoma Geological Survey

INTRODUCTION

Numerous studies and tax incentives led to the development of coalbed methane (CBM) in Oklahoma

Alabama in 1980. The United States Internal Revenue Service (IRS) § 29 income tax credit further stimulated interest in CBM (Phase I from 1980 through 1992, Phase II from 1993

coal-bearing region (area containing coal beds too thin or deep for mining; **Figure 1**). There are CBM wells in both areas. The coalfield is further divided into the northeast Oklaho- shelf ("shelf") and the Arkoma n ("basin"). Coal beds on the strike north-northeast and dip to the west; CBM wells occur of the outcrop belt. The coal in the basin are highly folded faulted (Cardott, 2002).

sin of Colorado and New Mexico in 1977 and the Black Warrior Basin of

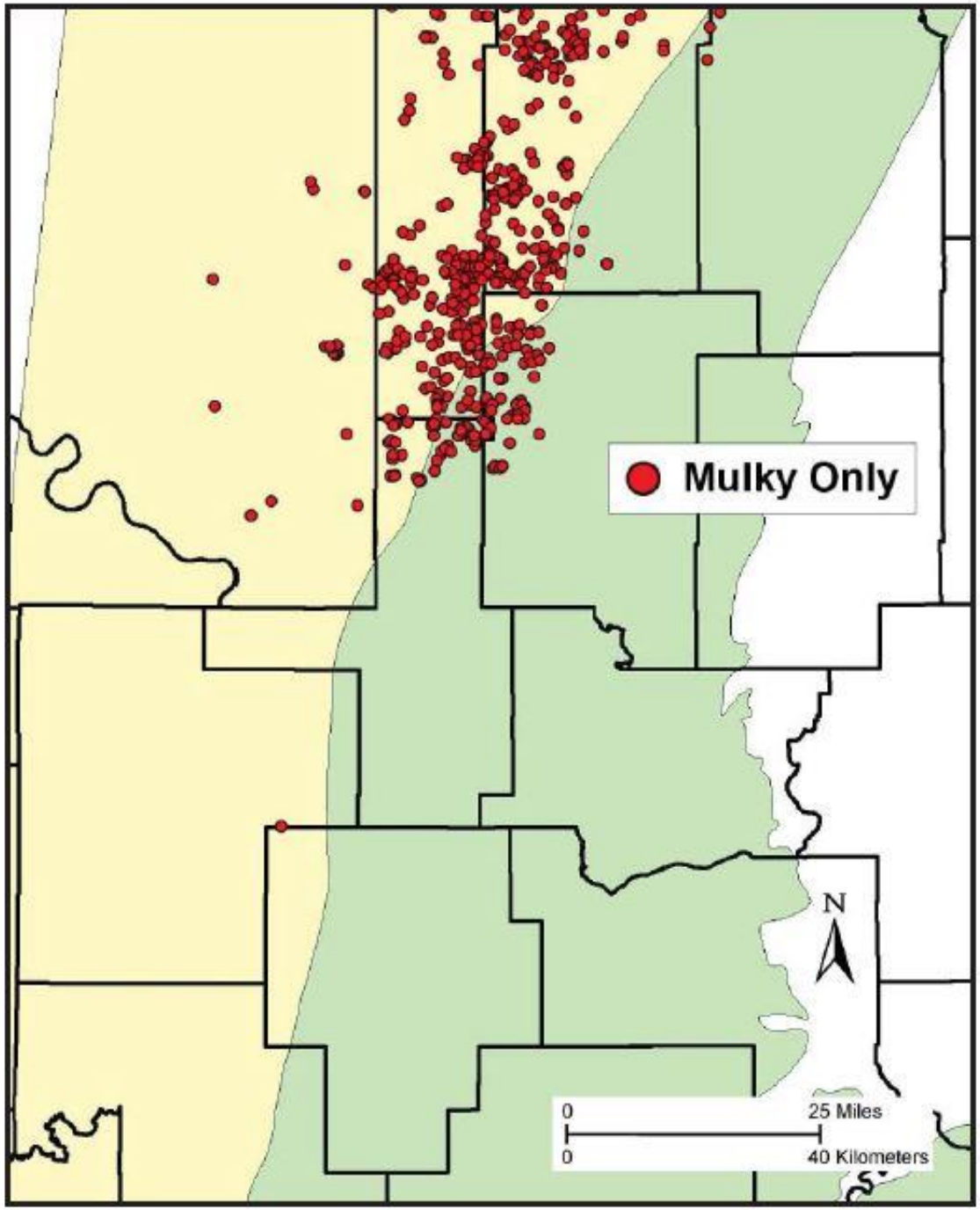
coal beds of commercial value for coal mining) and the noncommercial

first CBM wells in eastern Okla- a were drilled in 1988 to the Hartshorne coal (middle Pennsylvanian) in Haskell County. From 1988

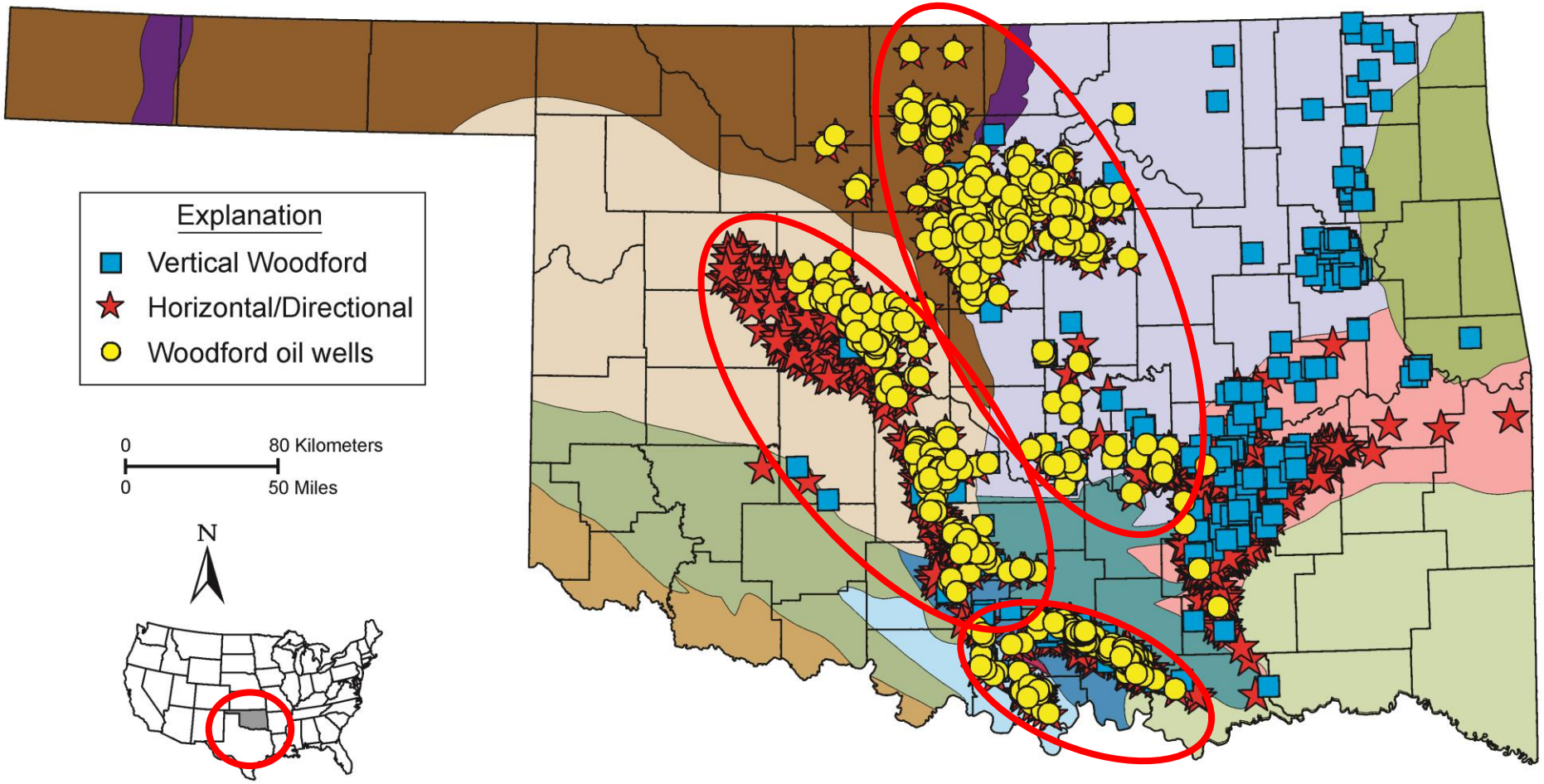
1. Horizontal CBM
2. Gas fields by county
3. Recompletions (OWWO)
4. Mulky coal problem
5. CBM with noncoal
6. "Pennsylvanian" CBM
7. Commingled CBM

Figure 7. Map showing Mulky-only coal-bed-methane (CBM) wells in Oklahoma (1994-2008).

Cardott (2010) concluded that the Mulky only wells in Oklahoma were completed in the Excello Shale



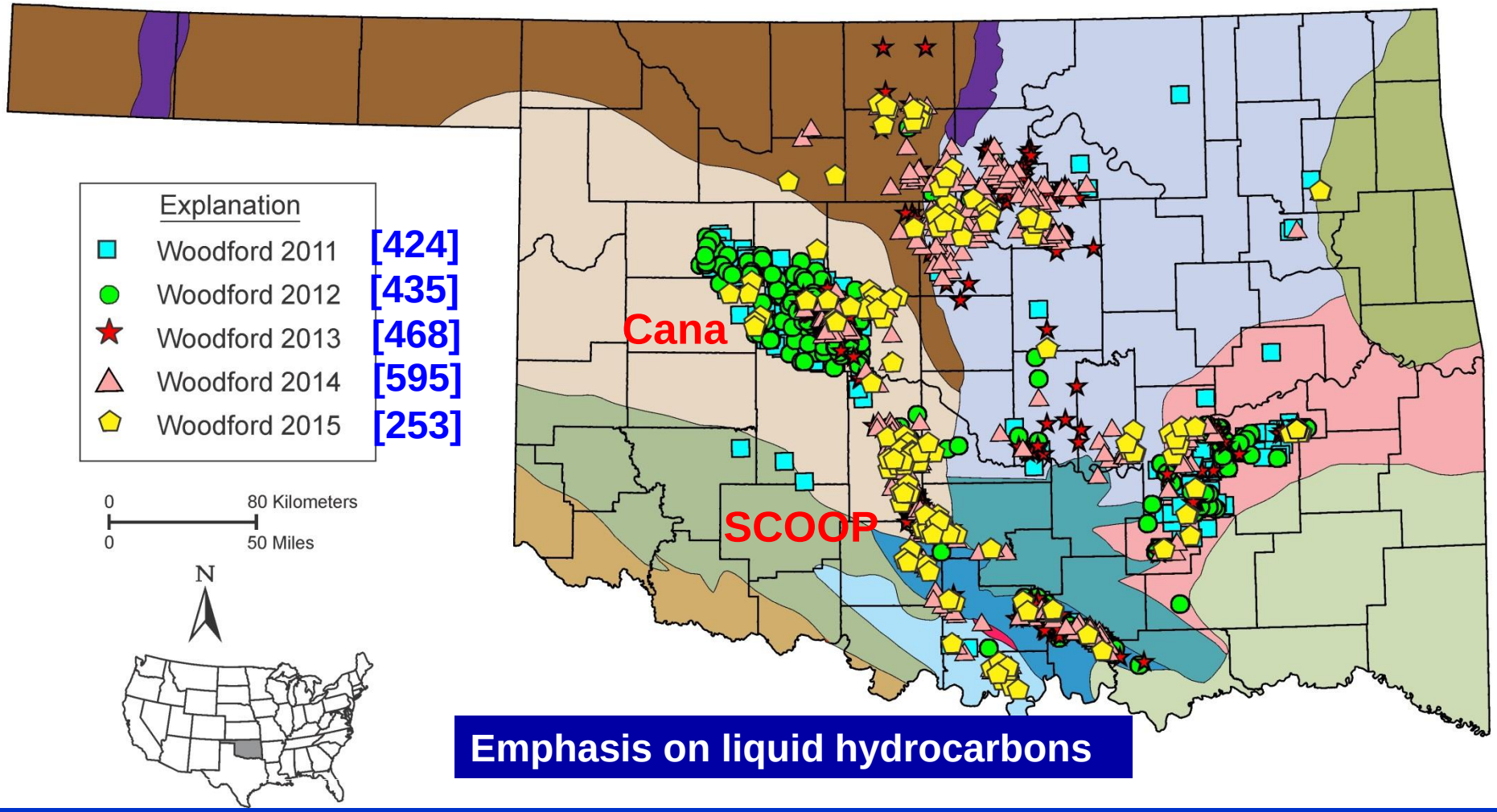
Woodford Shale Wells (2004-2015)



3,865 Woodford wells

Most Woodford "oil wells" (based on GOR <17,000) have low IP gas.

Woodford Shale (2011-2015)



Emphasis on liquid hydrocarbons

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Thermal maturity of Woodford Shale gas and oil plays, Oklahoma, USA

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Thermal maturity

ABSTRACT

Being a hydrocarbon source rock and having a brittle (silica-rich) lithologic character makes the Woodford Shale (Late Devonian to Early Mississippian) an important oil and gas shale in Oklahoma. Since 2004, Woodford Shale plays have expanded from producing primarily thermogenic methane in one geologic province to producing thermogenic methane, condensate, oil and biogenic methane in four geologic provinces at thermal maturities from mature (>0.5% vitrinite reflectance, Ro) to post mature (2% to 3% Ro). Condensate is produced at a thermal maturity up to 1.67% Ro. Oil is produced from naturally-fractured, silica-rich shale. Biogenic methane is produced in shallow (<2000 ft, 610 m) reservoirs down dip from the outcrop in northeast Oklahoma.

1. Introduction

The Woodford Shale (Late Devonian to Early Mississippian) is an important hydrocarbon source rock in Oklahoma (Comer and Hinch, 1987; Johnson and Cardott, 1992). It is a black to dark-gray, marine, carbona-

potential (e.g., high total organic carbon content with Type II kerogen), one advantage of the marine Woodford Shale as a gas shale is its quartz-rich composition, specifically rich
primarily from Radiolaria and sponge spicul
Kuuskraa et al. (2011) indicated that marine shales (common deposi-

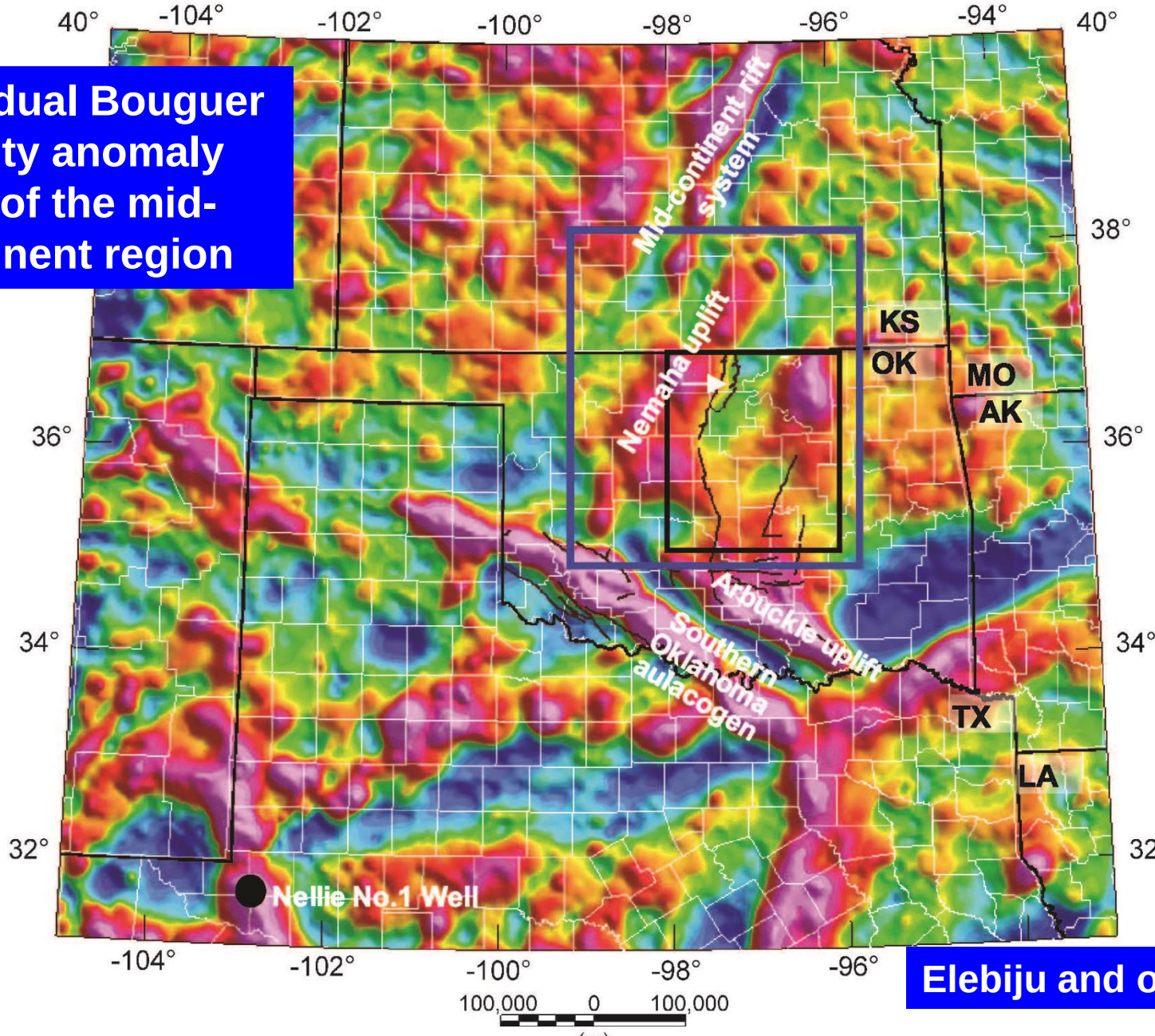
Cardott, 2012b

Due to a number of variables, Woodford Shale vitrinite isoreflectance maps should be used as a qualitative thermal maturity indicator (e.g., start, middle, end of oil window; condensate window; gas window) and not as a "drill here" indicator because of the following factors:

- **Vitrinite reflectance is an average of many values and has some internal variation.**
- **Woodford Shale vitrinite reflectance was originally determined to estimate the general hydrocarbon source rock potential.**
- **The Woodford Shale is divided into three informal members: the lower member was deposited more near-shore marine and is where the most and largest vitrinite and petrified wood is found.**
- **The vitrinite reflectance value is extrapolated to the entire thickness even though the Woodford Shale may be up to 700 ft thick.**

Osage County Basement Anomaly

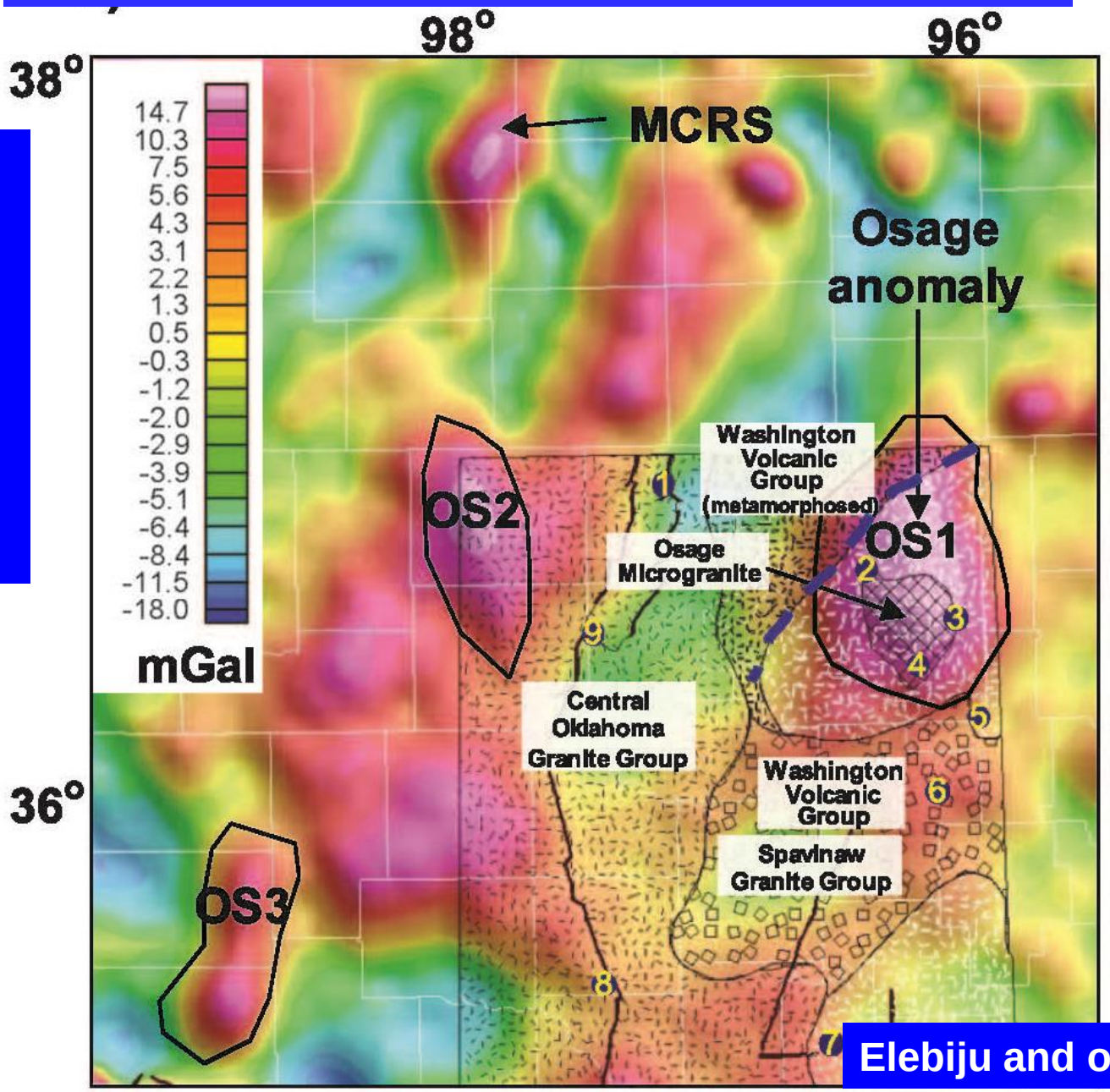
Residual Bouguer gravity anomaly map of the mid-continent region



Elebiju and others, 2011

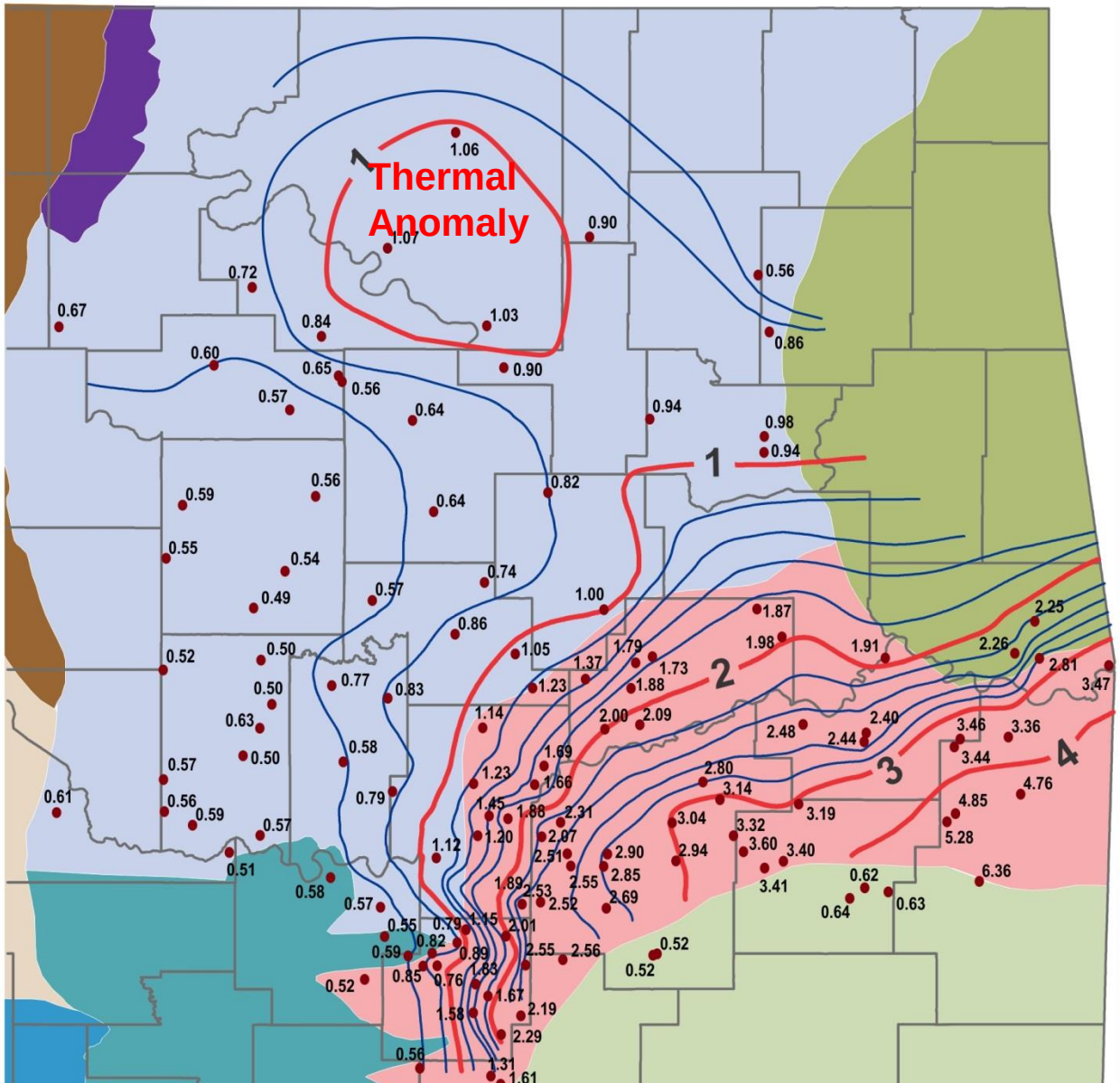
Osage County Basement Anomaly

Residual Bouguer gravity anomaly map showing Osage anomaly



Elebiju and others, 2011

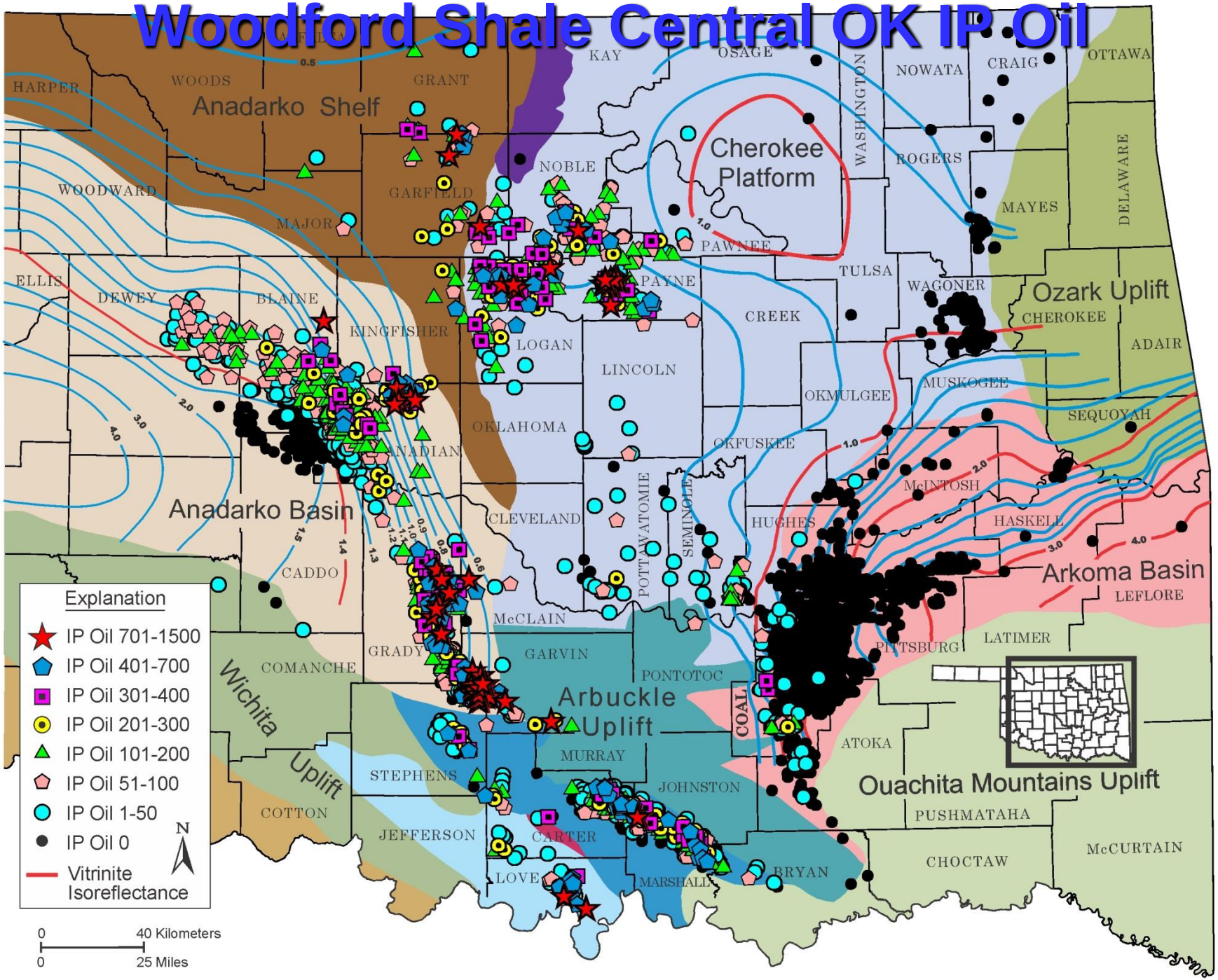
Isoreflectance Map of the Woodford Shale in Eastern Oklahoma (Updated September 2015)



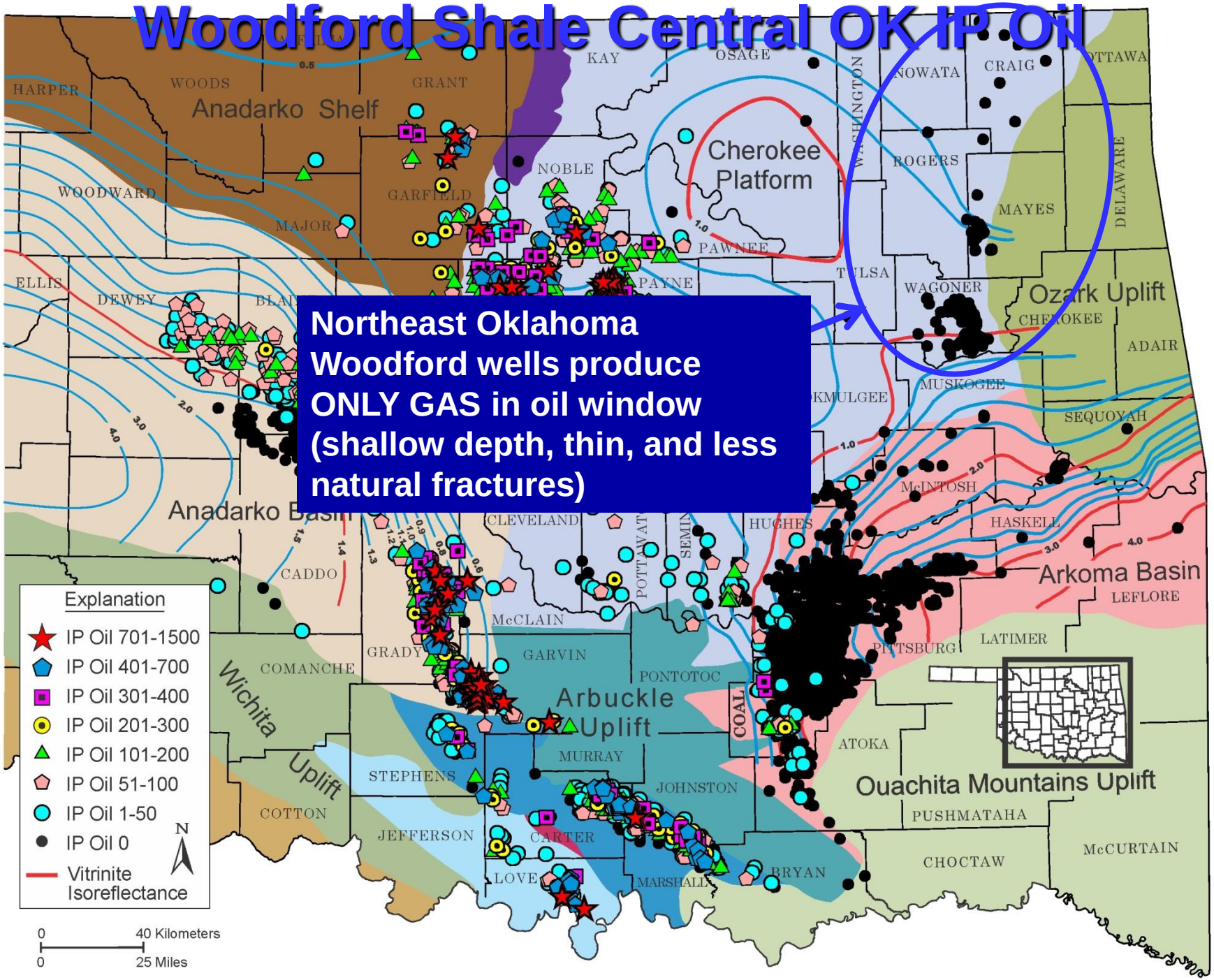
Distribution of 120 Woodford Shale samples with vitrinite-reflectance data (n ≥20; whole-rock pellets)

Modified from Cardott, 2012

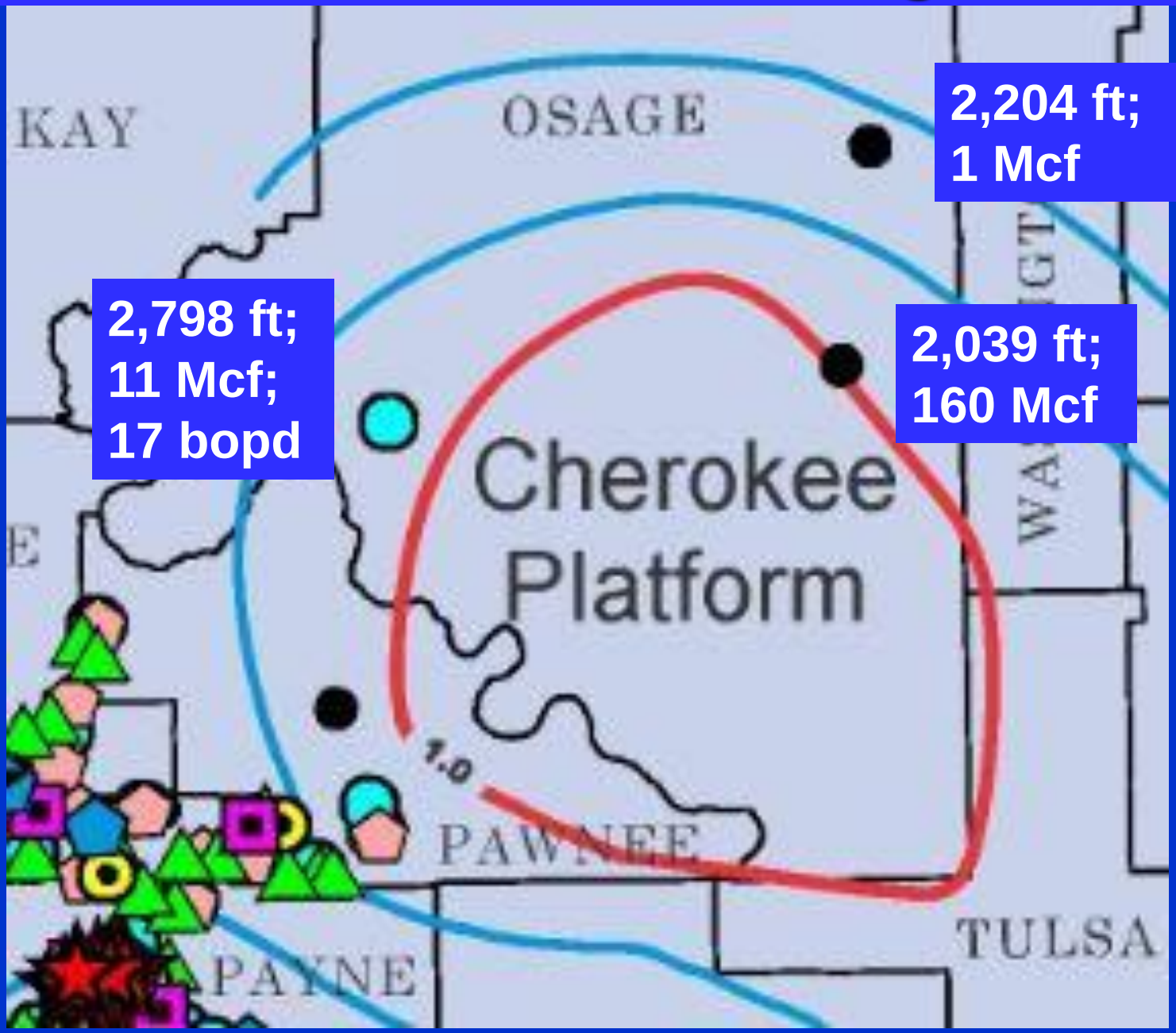
Woodford Shale Central OK IP Oil



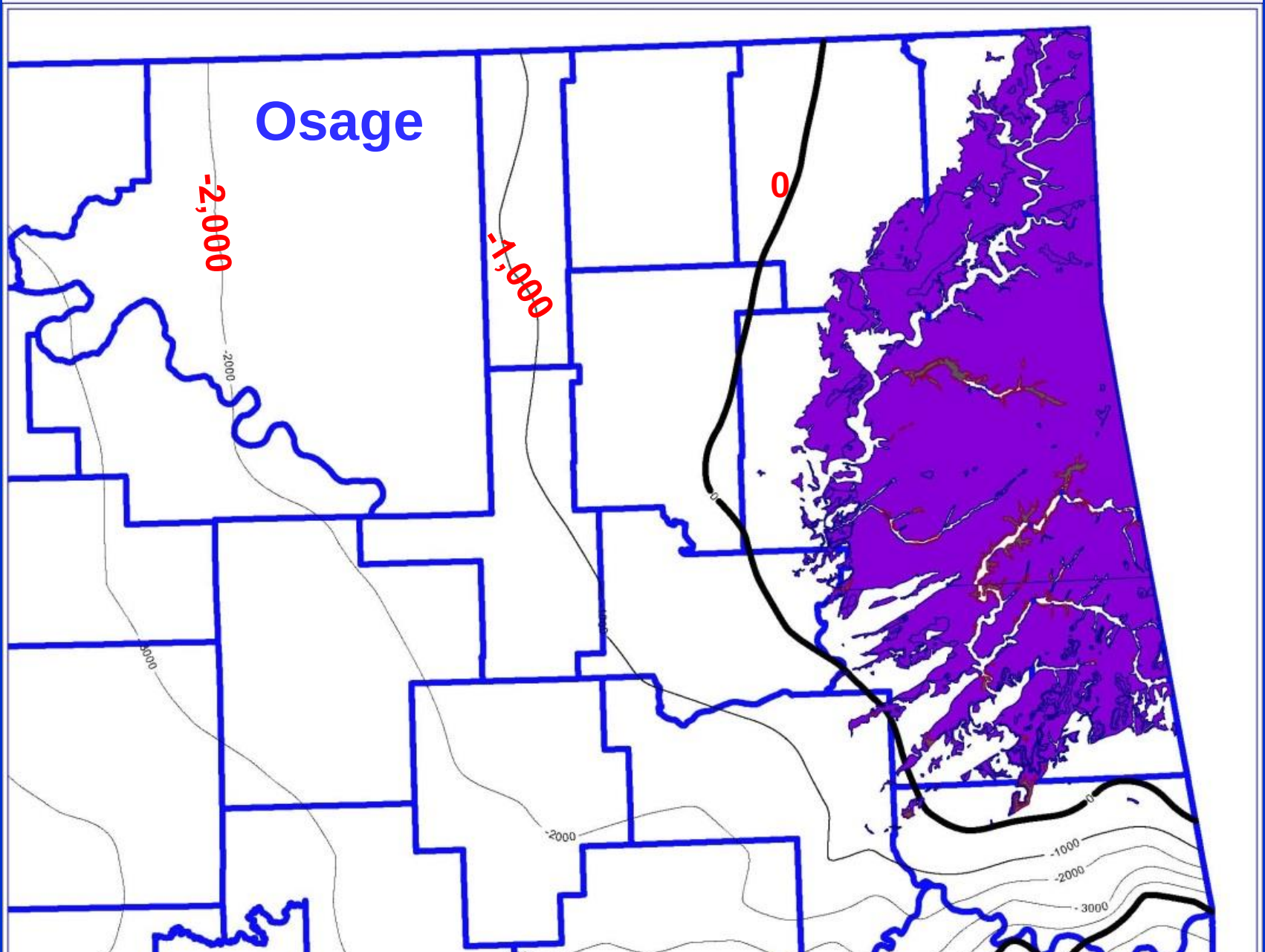
Woodford Shale Central OK IP Oil



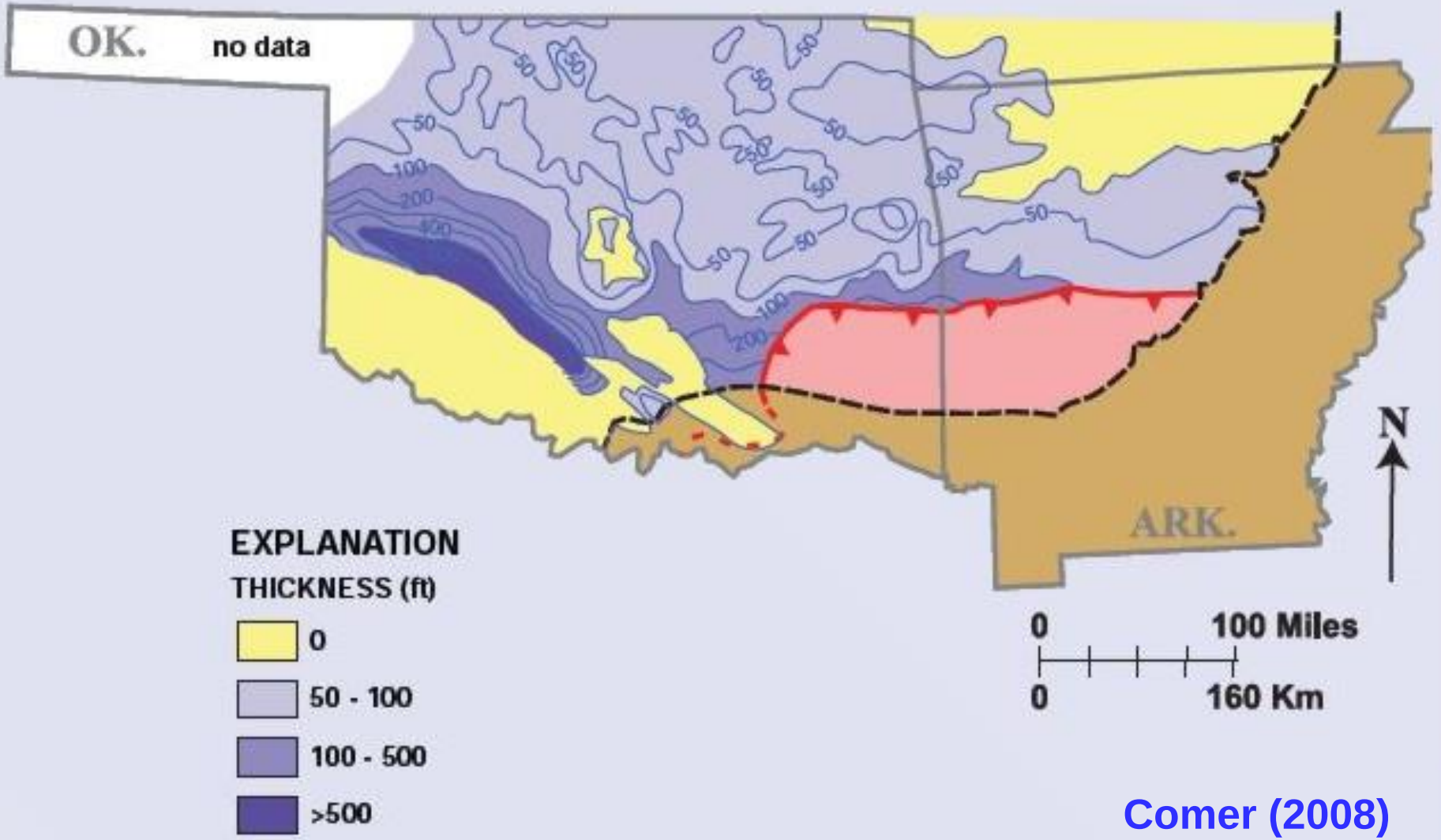
Woodford Shale Wells in Osage County



Woodford Shale Structure

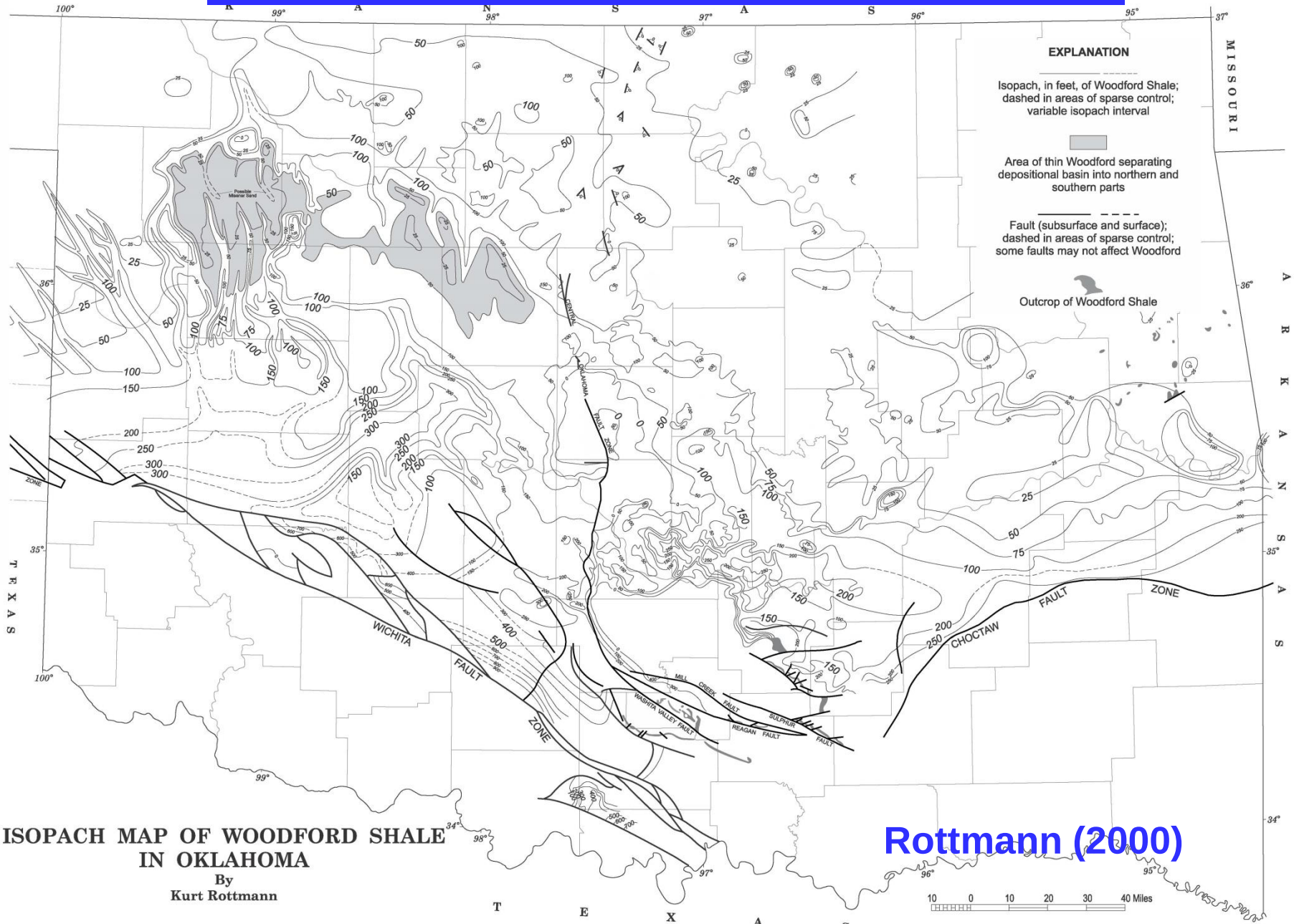


Woodford Shale Isopach

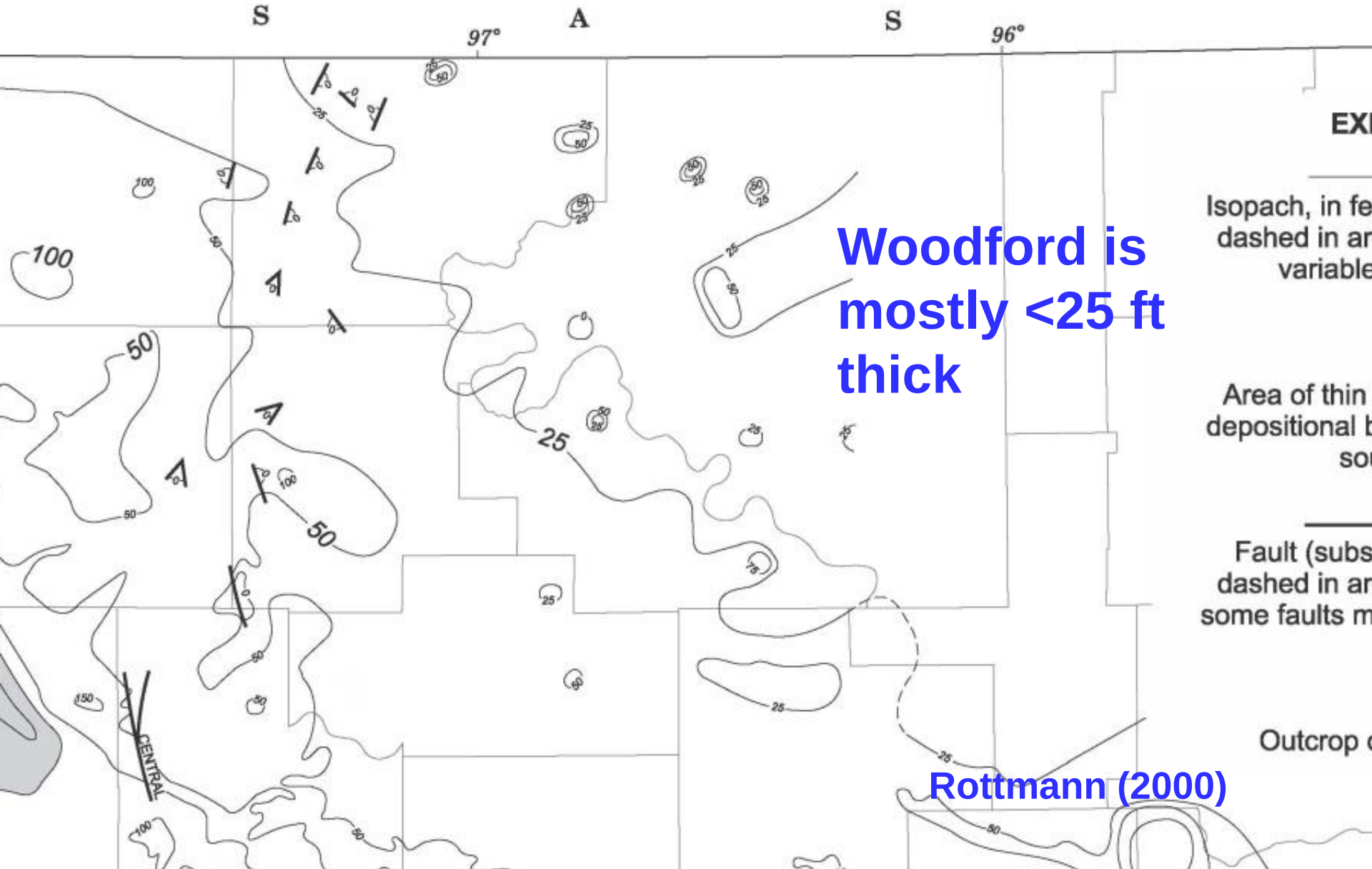


Comer (2008)

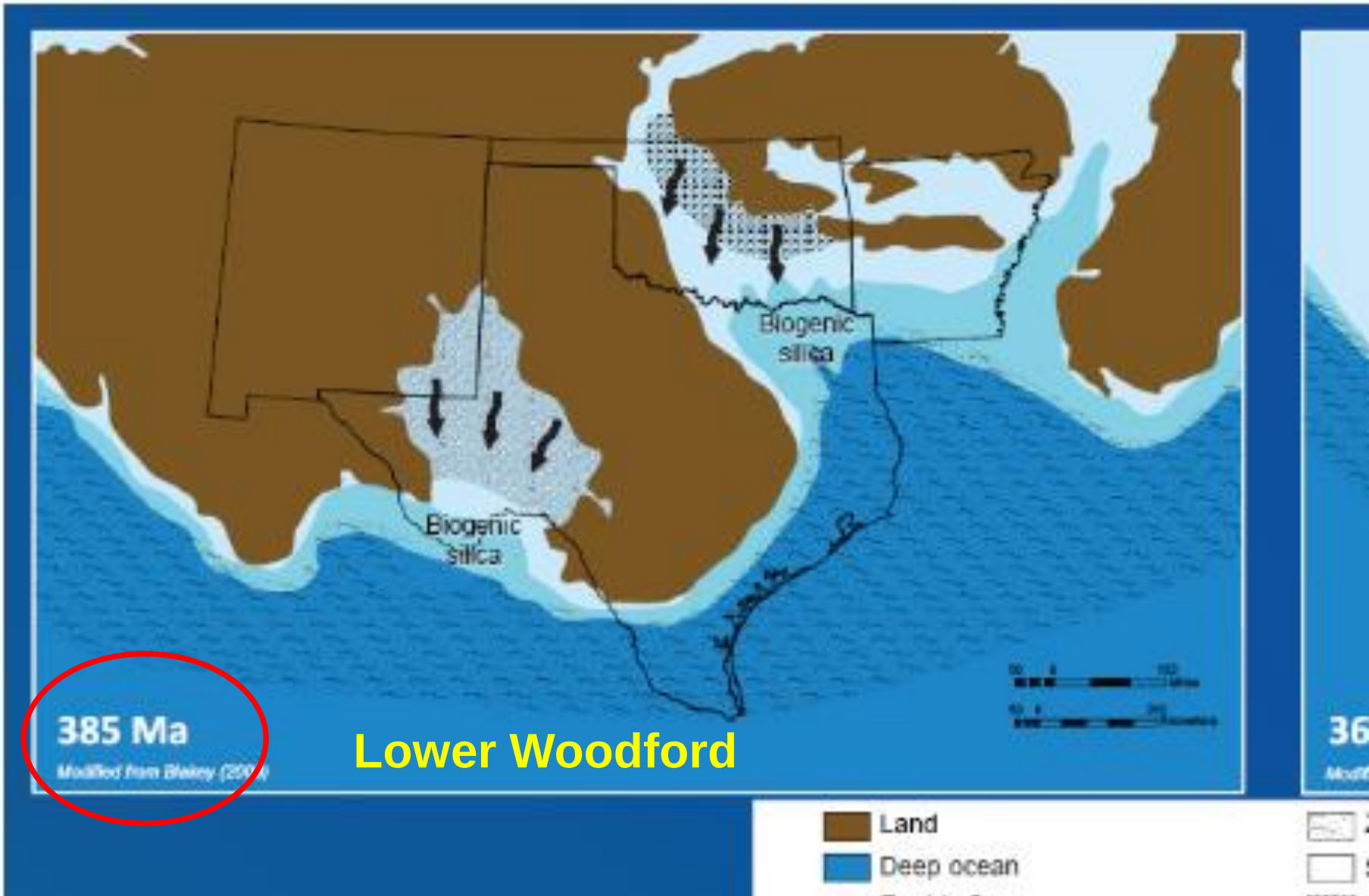
Woodford Shale Isopach



Woodford Shale Isopach



Biogenic Silica Extent in the Woodford Shale (Comer poster, 2008)



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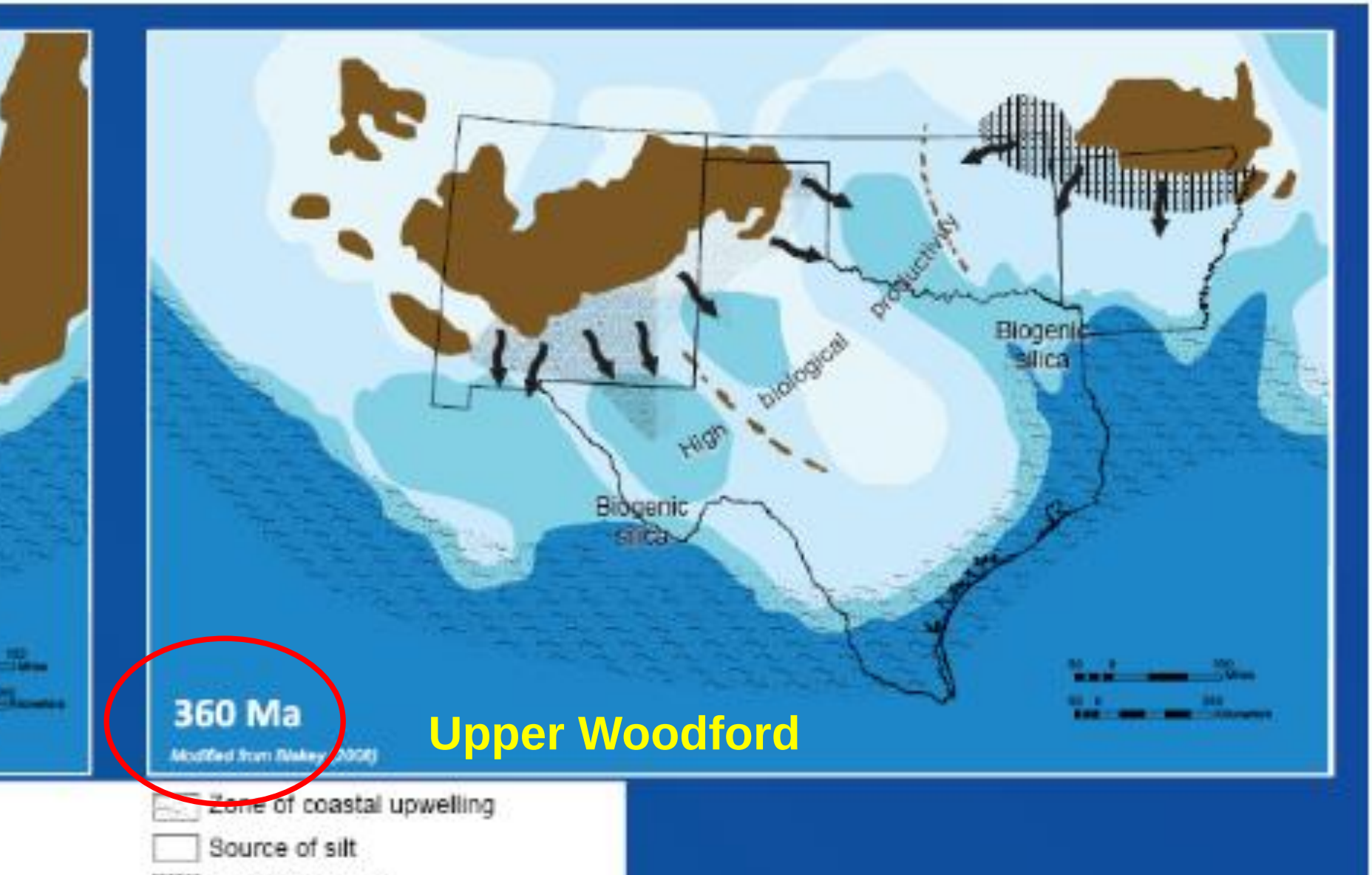
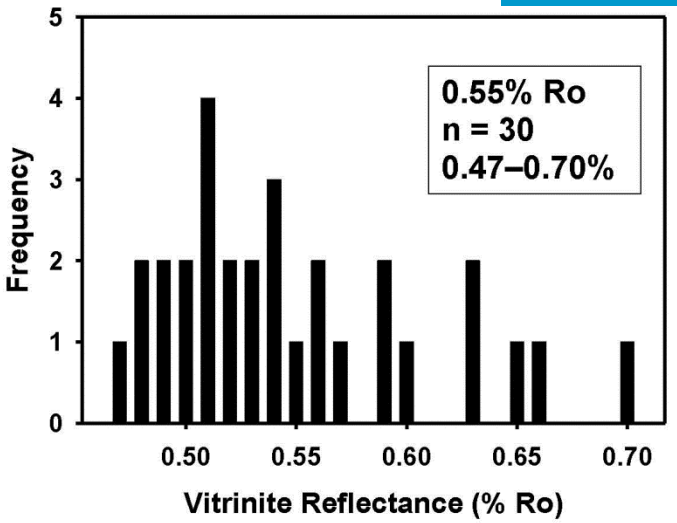


Lack of chert beds in No Head Hollow Chattanooga Shale Outcrop near Tahlequah

Anadarko Basin



Woodford Shale Isoreflectance Map based on 81 wells (Cardott, 1989)

0.67%

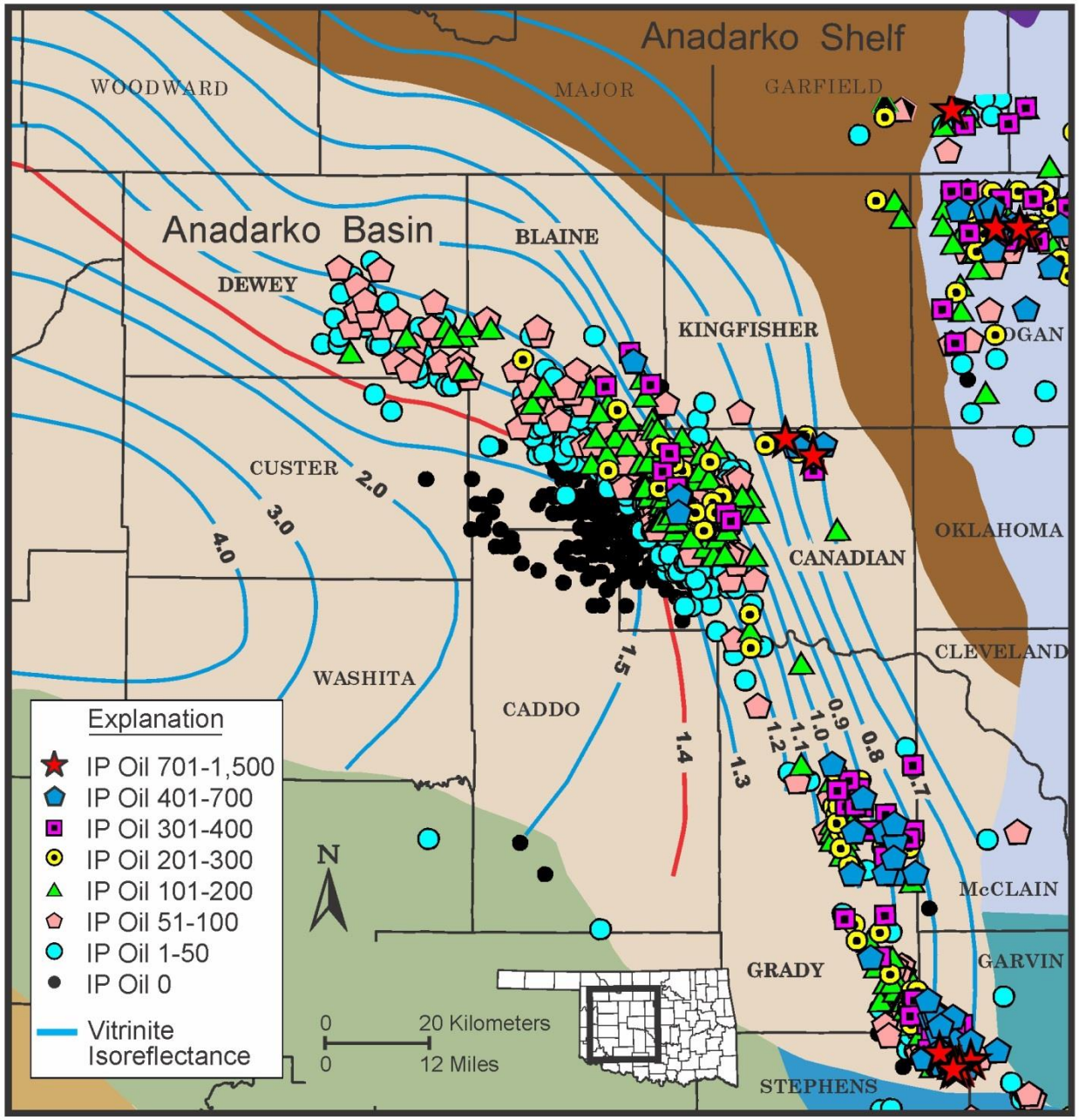
0.77%

0.55% GF

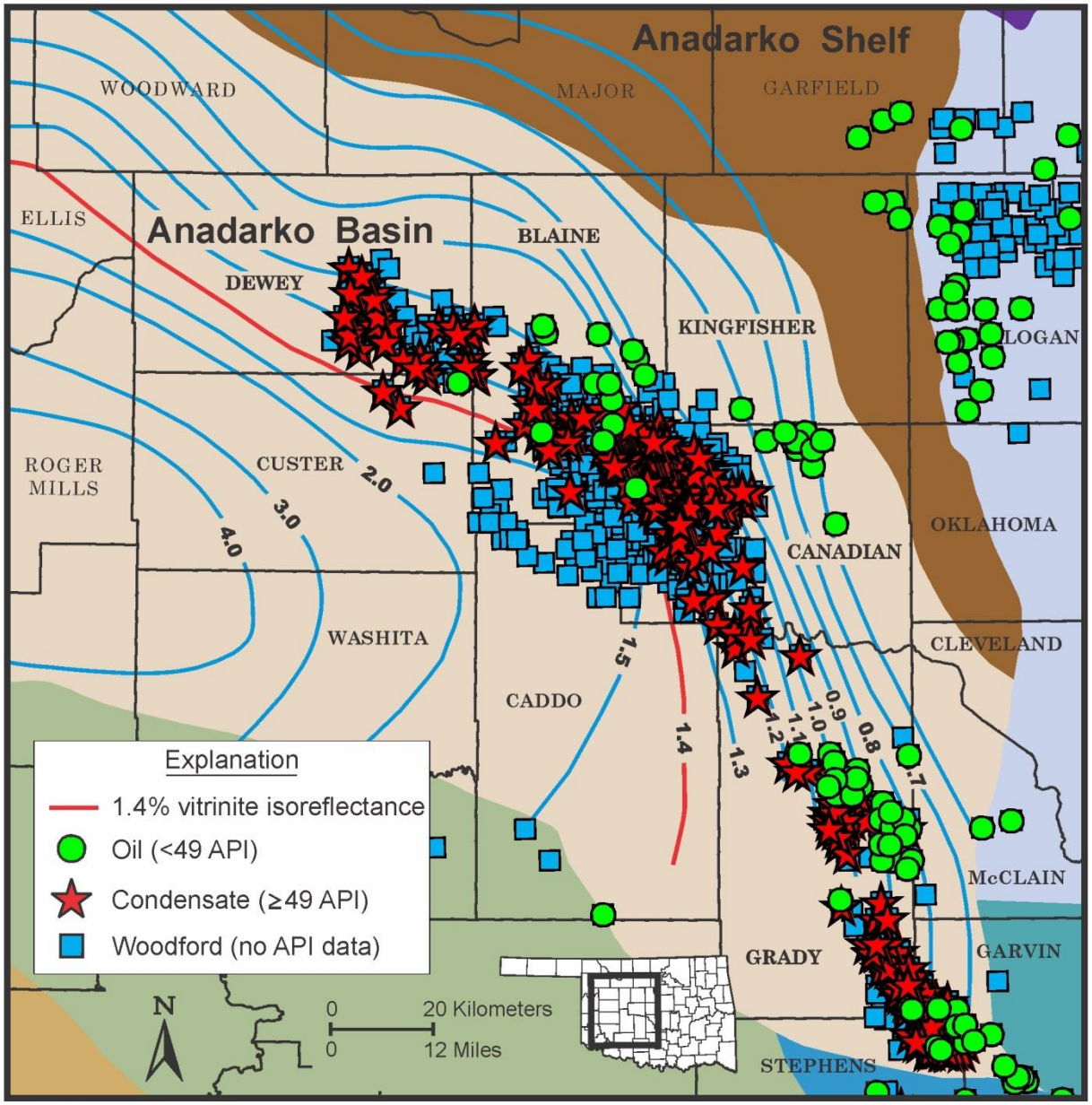
0.49% GF

OPL 153
0.77%

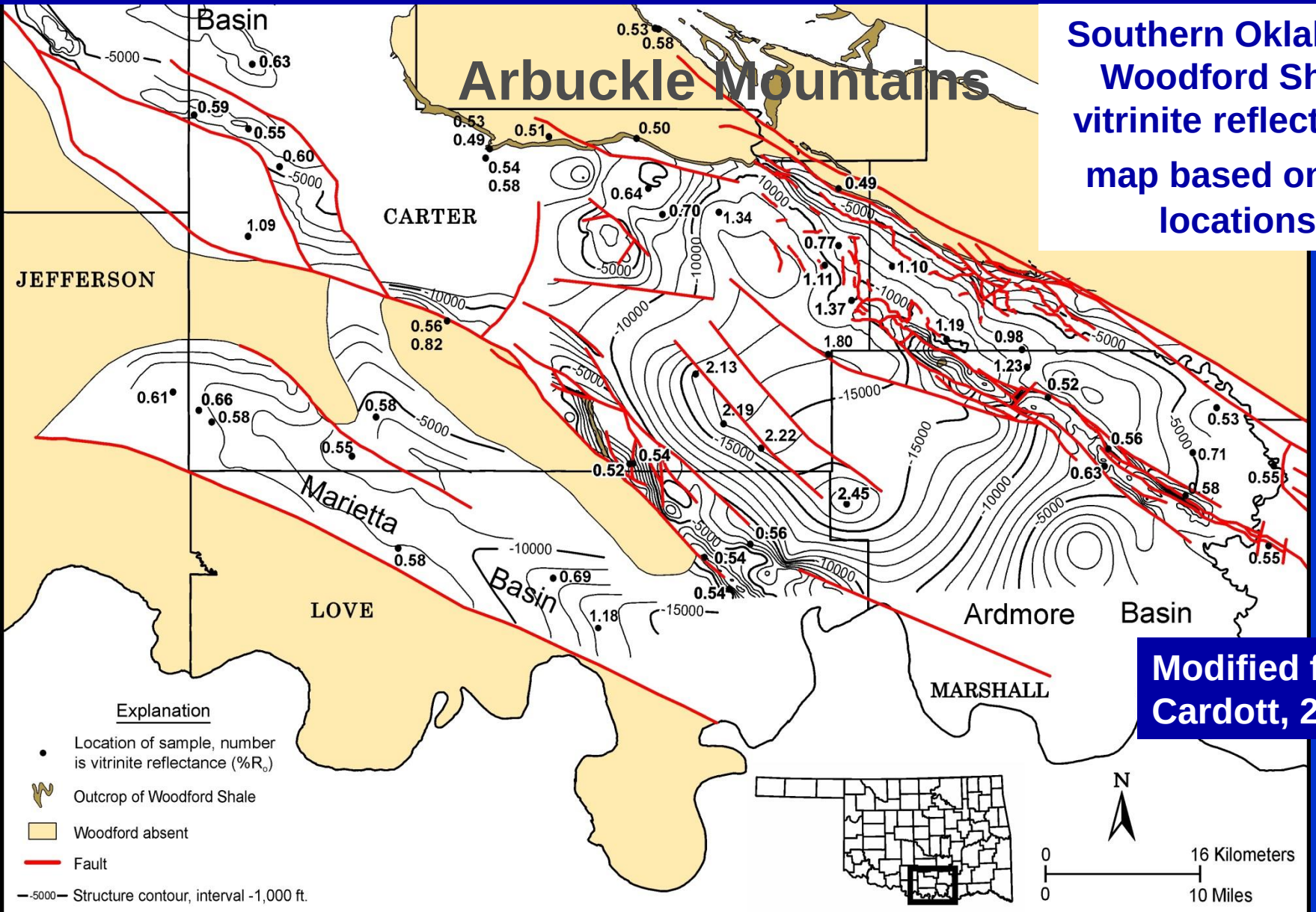
Woodford Shale Anadarko Basin IP Oil



Woodford Anadarko Basin API Gravity



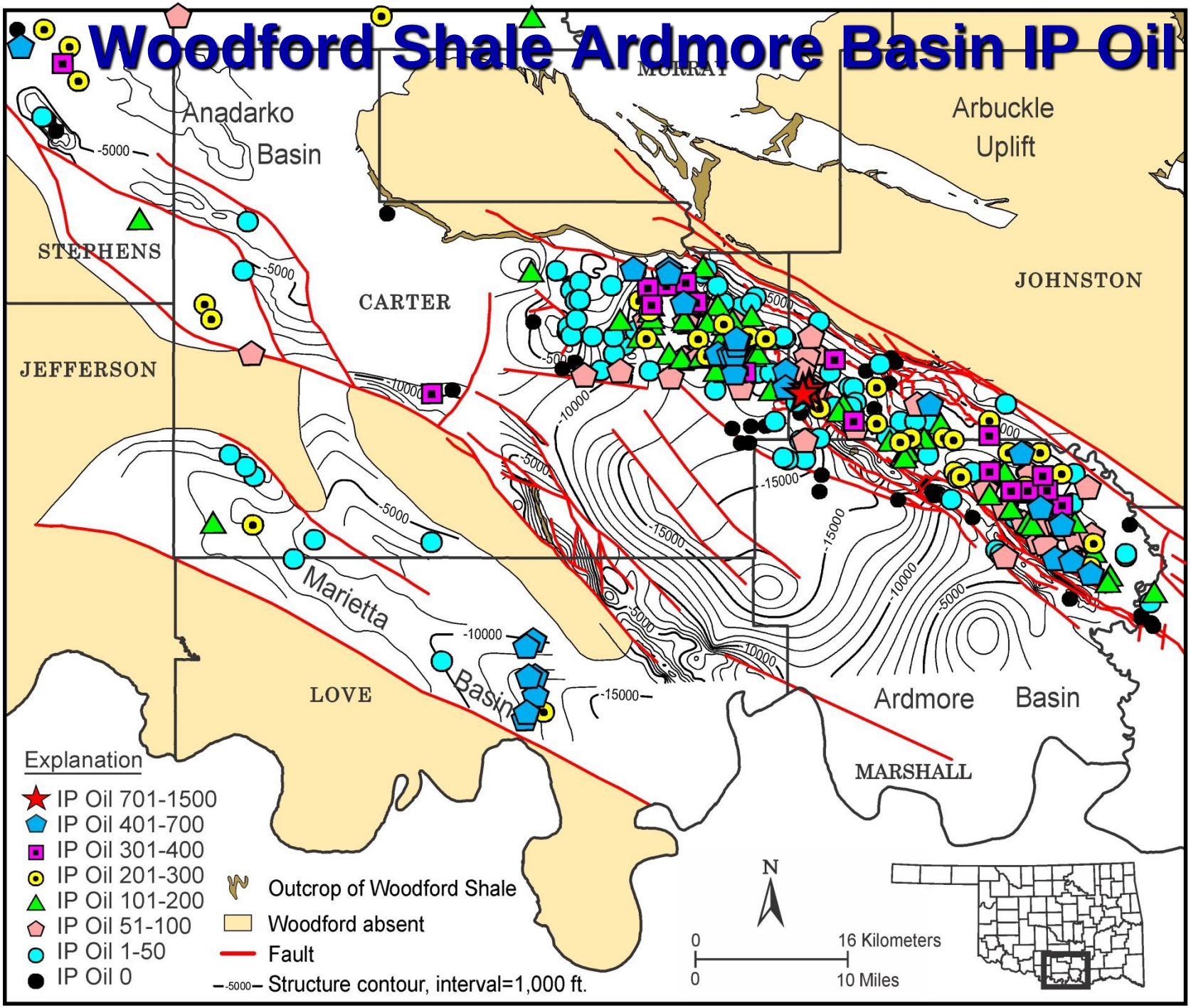
Woodford Shale Vitrinite Reflectance Data in Southern Oklahoma (Updated October 2013)



Southern Oklahoma Woodford Shale vitrinite reflectance map based on 51 locations

Modified from Cardott, 2012

Woodford Shale Ardmore Basin IP Oil



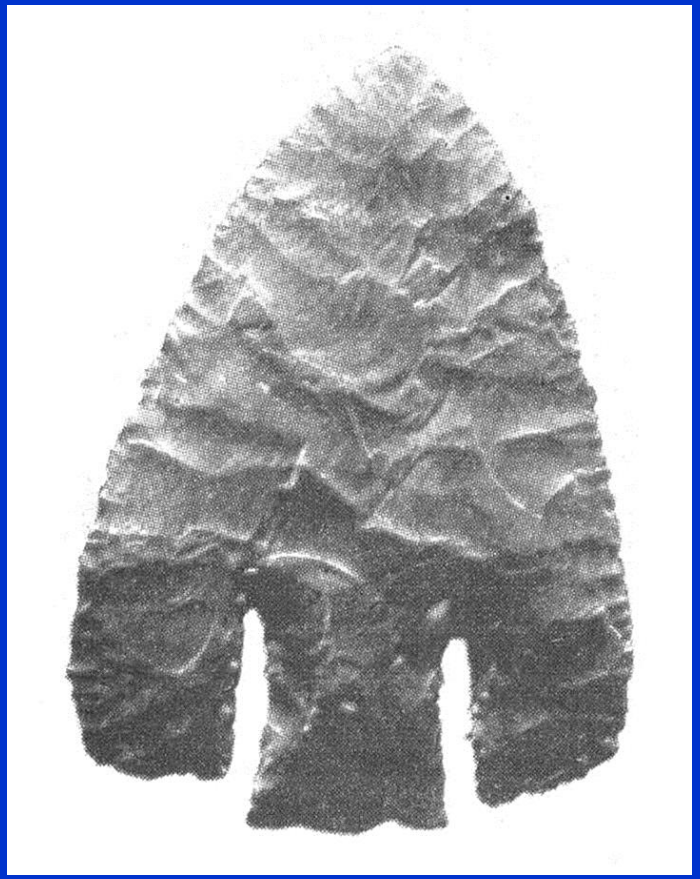
Conclusions

Vitrinite reflectance values >1.0% Ro occur in the Woodford Shale in Osage County indicating a thermal anomaly at present-day depths of <3,000 ft.

The Woodford Shale in Osage County is <50 ft thick and does not contain biogenic silica.

Shallow depth, thin bed, and lack of fractures have precluded oil production from the Woodford Shale in Osage County.

THANK YOU



Typical Calf Creek point of Woodford chert found in Haskell County, Oklahoma (Norman Transcript, March 11, 2007, p. E1)

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