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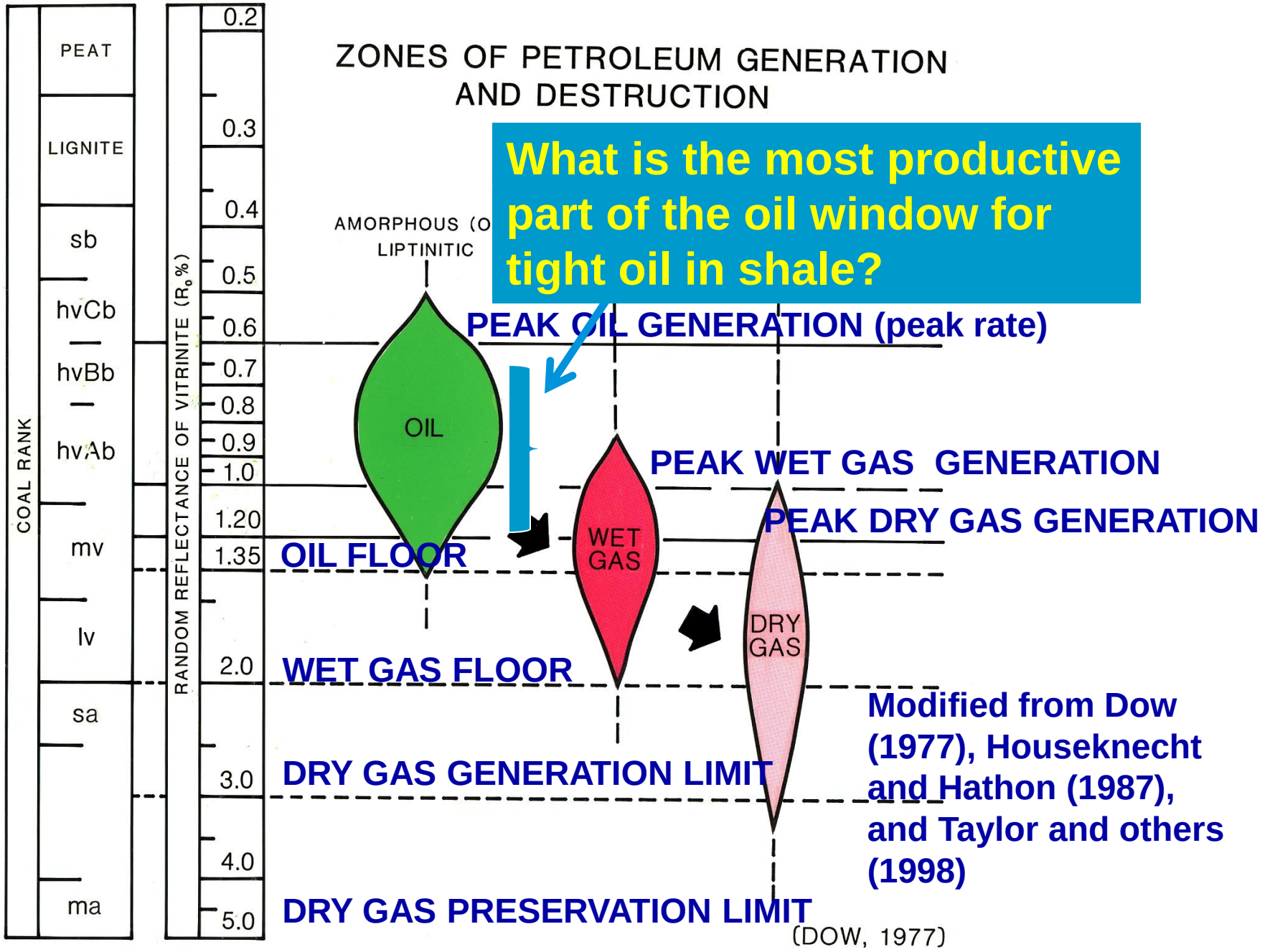
Using Thermal Maturity to Identify the Most Productive Part of the Oil Window to Target in the Woodford Shale

Brian J. Cardott

Oklahoma Geological Survey

Outline of Presentation

- Define the Oil Window
- Evaluate Woodford Shale (Late Devonian-Early Mississippian) well completion maps based on thermal maturity and production rates.


ZONES OF PETROLEUM GENERATION AND DESTRUCTION
What is the most productive part of the oil window for tight oil in shale?
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
AMORPHOUS (O
LIPTINITIC
OIL
WET GAS
DRY GAS
PEAK OIL GENERATION (peak rate)
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)

Most petroleum geochemists use 0.6% Ro as the onset of oil generation (e.g., Peters and Cassa, 1994, Applied source rock geochemistry: AAPG Memoir 60, p. 93-117)

Table 5.3. Geochemical Parameters Describing Level of Thermal Maturation

Stage of Thermal Maturity for Oil	Maturation			Generation		
	R_o (%)	T_{max} (°C)	TAI[a]	Bitumen/ TOC[b]	Bitumen (mg/g rock)	PI[c] $[S_1/(S_1 + S_2)]$
Immature	0.2–0.6	<435	1.5–2.6	<0.05	<50	<0.10
Mature						
Early	0.6–0.65	435–445	2.6–2.7	0.05–0.10	50–100	0.10–0.15
Peak	0.65–0.9	445–450	2.7–2.9	0.15–0.25	150–250	0.25–0.40
Late	0.9–1.35	450–470	2.9–3.3	—	—	>0.40
Postmature	>1.35	>470	>3.3	—	—	—

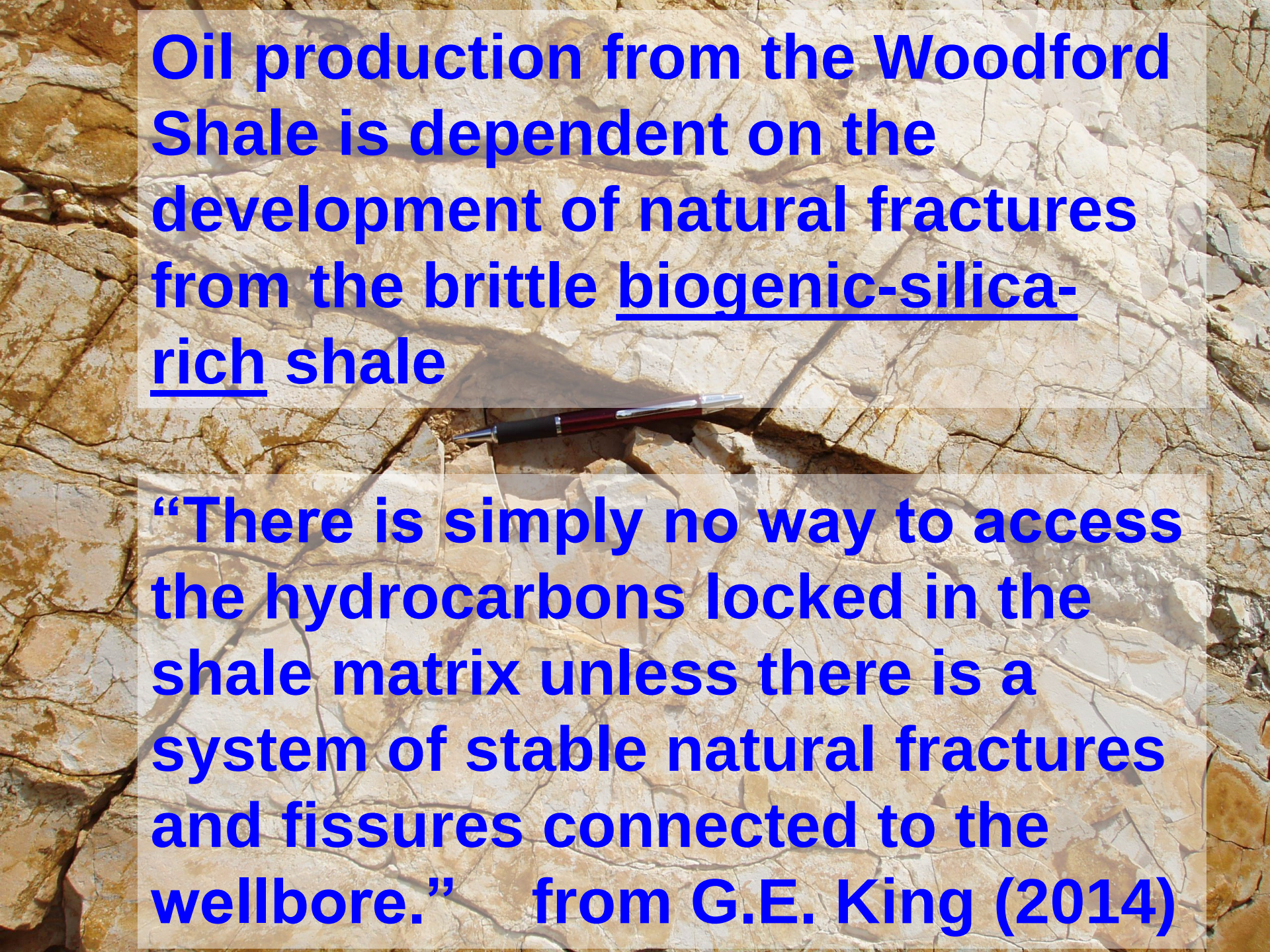
[a]TAI, thermal alteration index.

[b]Mature oil–prone source rocks with type I or II kerogen commonly show bitumen/TOC ratios in the range 0.05–0.25. Caution should be applied when interpreting extract yields from coals. For example, many gas–prone coals show high extract yields suggesting oil–prone character, but extract yield normalized to TOC is low (<30 mg HC/g TOC). Bitumen/TOC ratios over 0.25 can indicate contamination or migrated oil or can be artifacts caused by ratios of small, inaccurate numbers.

[c]PI, production index.

Jarvie (2012, p. 91):
"…thermal maturity values from about 0.60 to 1.40% Ro are the most likely values significant for petroleum liquid generation. Regardless of thermal maturity, there must be sufficient oil saturation to allow the possibility of commercial production of oil".

Jarvie (2012, p. 91):
"Although an organic-rich source rock in the oil window with good oil saturation is the most likely place to have oil, it is also the most difficult to produce, unless it has open fractures or an organic-lean facies closely associated with it."



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)

Guidelines for the Barnett 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 Window

From Jarvie and others, 2005

Consider:

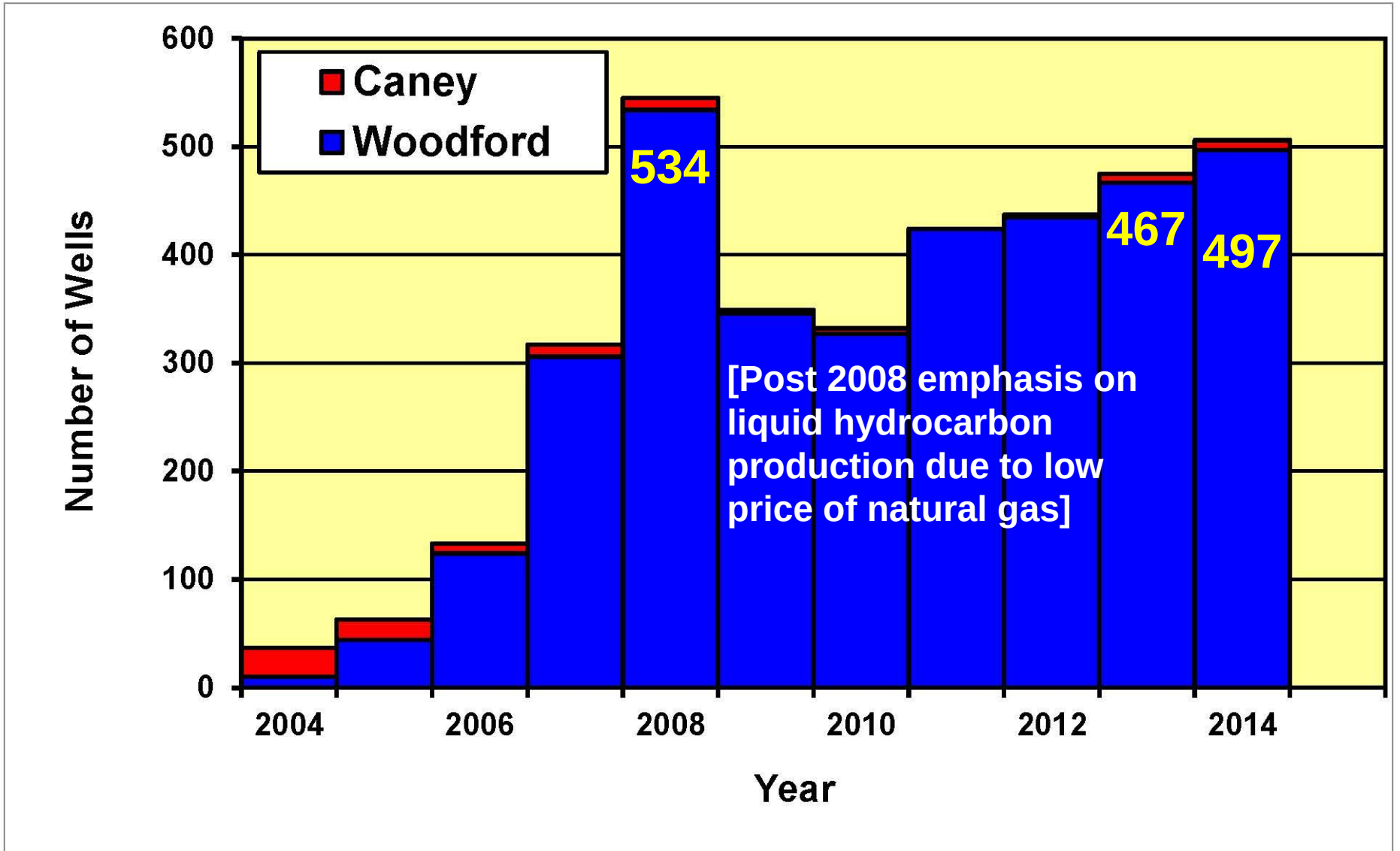
Much of the generated oil does not migrate out of the rock. Meyer (2012, p. 72) indicated that “for every barrel of crude oil in conventional reservoirs…there are 8 bbl of potentially producible oil equivalents remaining in the source rock” and “Speculative estimates of just how much generated oil remains in shale source rocks range between 45% and 95% depending on the geology of the formation and the quality of the estimate.”

Consider:

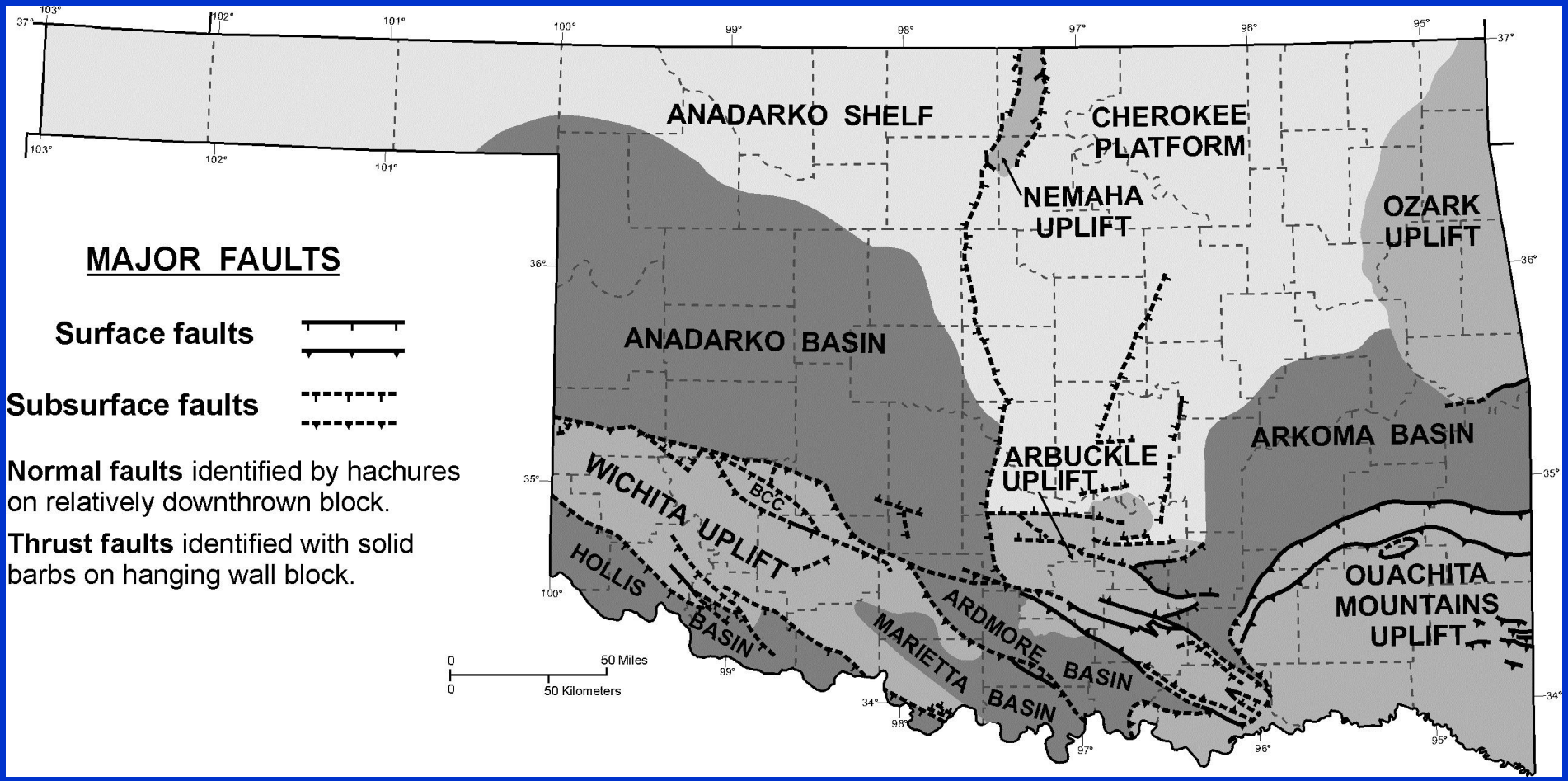
- **Saturation, beginning at ~0.6% VRo, suggests beginning of oil migration.**
- **Peak oil generation is at ~0.90% VRo.**
- **Migration pathways within shale (e.g., microfractures) are required for oil migration and storage.**
- **Condensate behaves as a gas in the reservoir.**
- **Barring oil migration, the best thermal maturity for tight oil production is peak to late mature (0.7-1.2% VRo) in a naturally-fractured reservoir.**

Woodford Shale Well History

3,515 Woodford Wells, 2004–2014

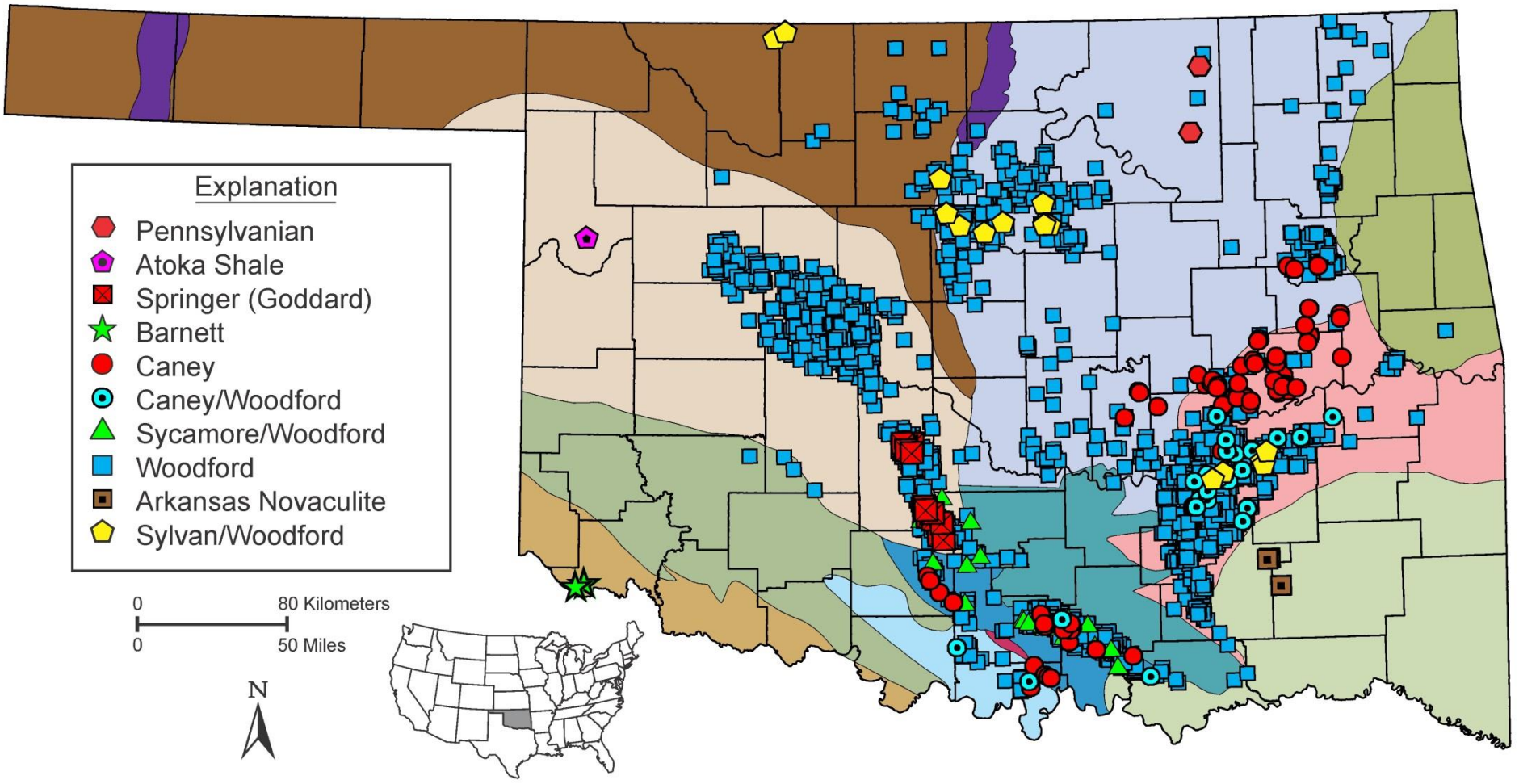


Oklahoma Geologic Provinces

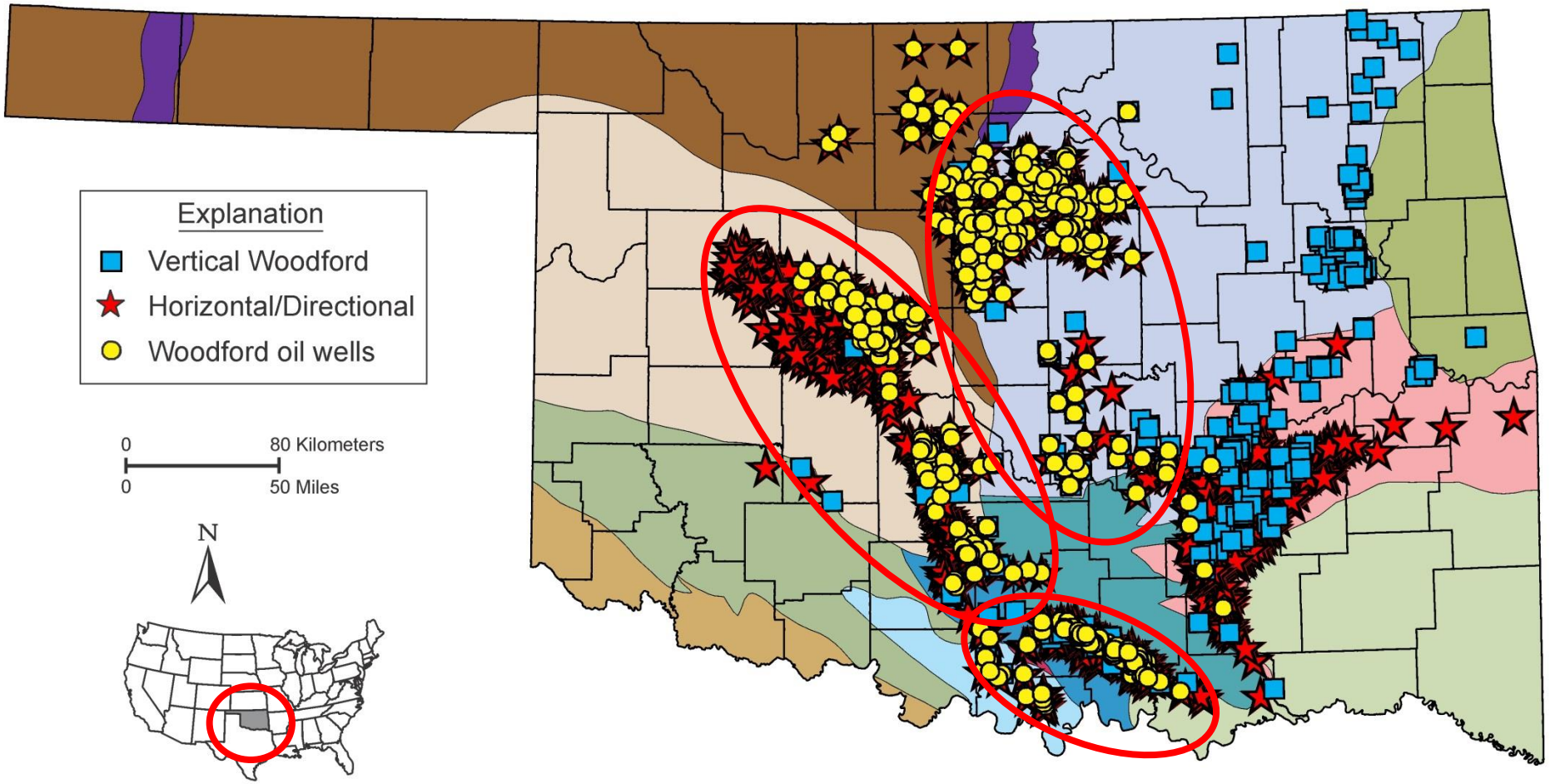


Geologic provinces from Northcutt and Campbell, 1995

Oklahoma Gas/Tight Oil Shales (3,727 well completions, 1939-2014)



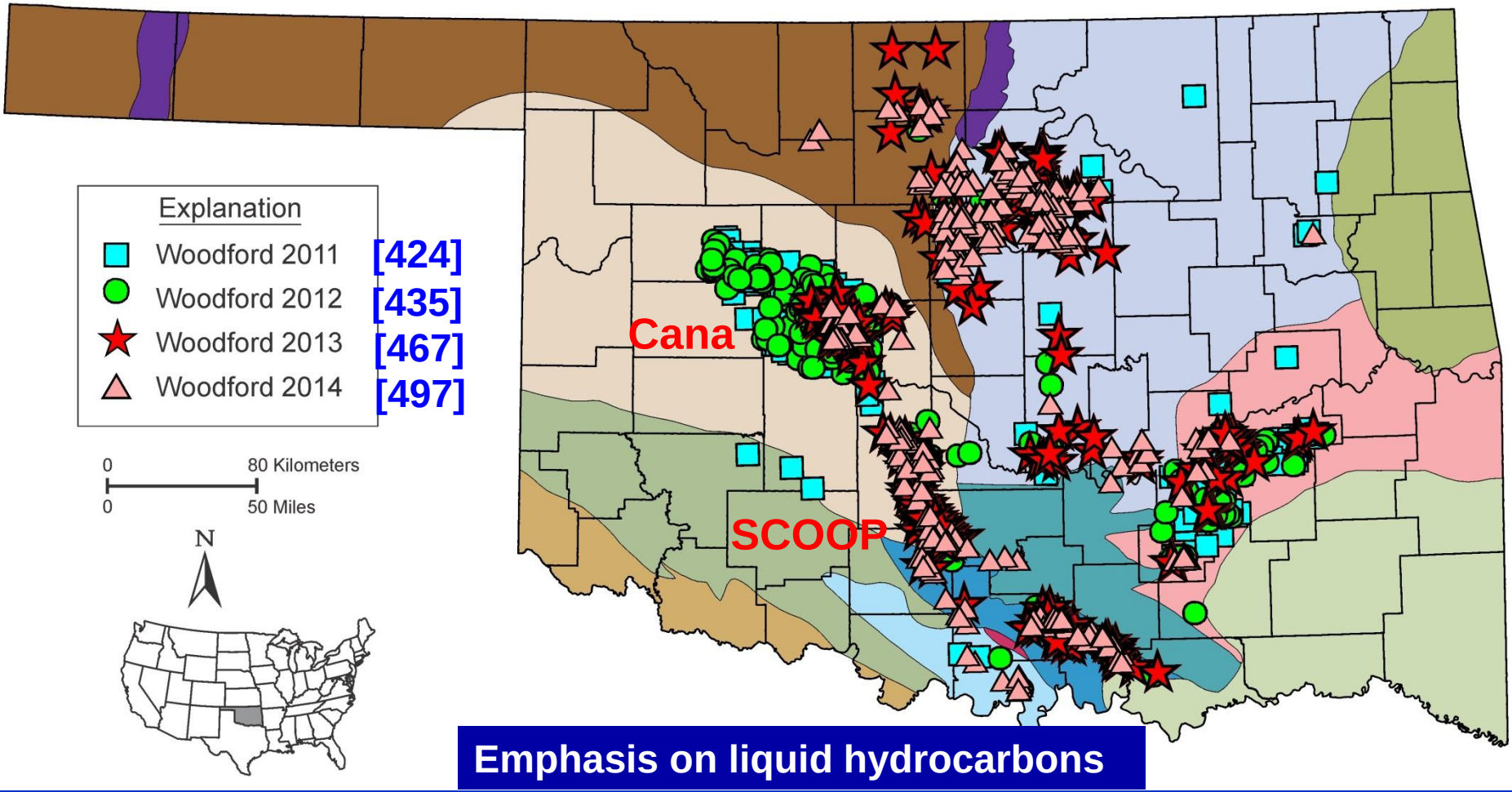
Woodford Shale Wells (2004-2014)



3,511 Woodford wells

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

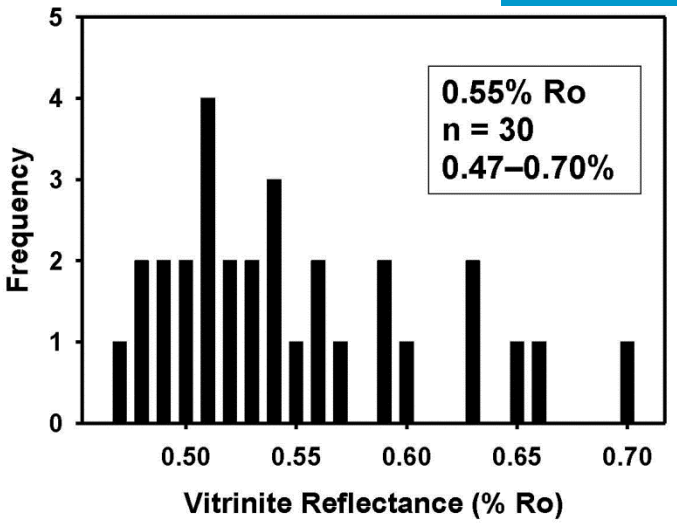
Woodford Shale (2011-2014)



Emphasis on liquid hydrocarbons

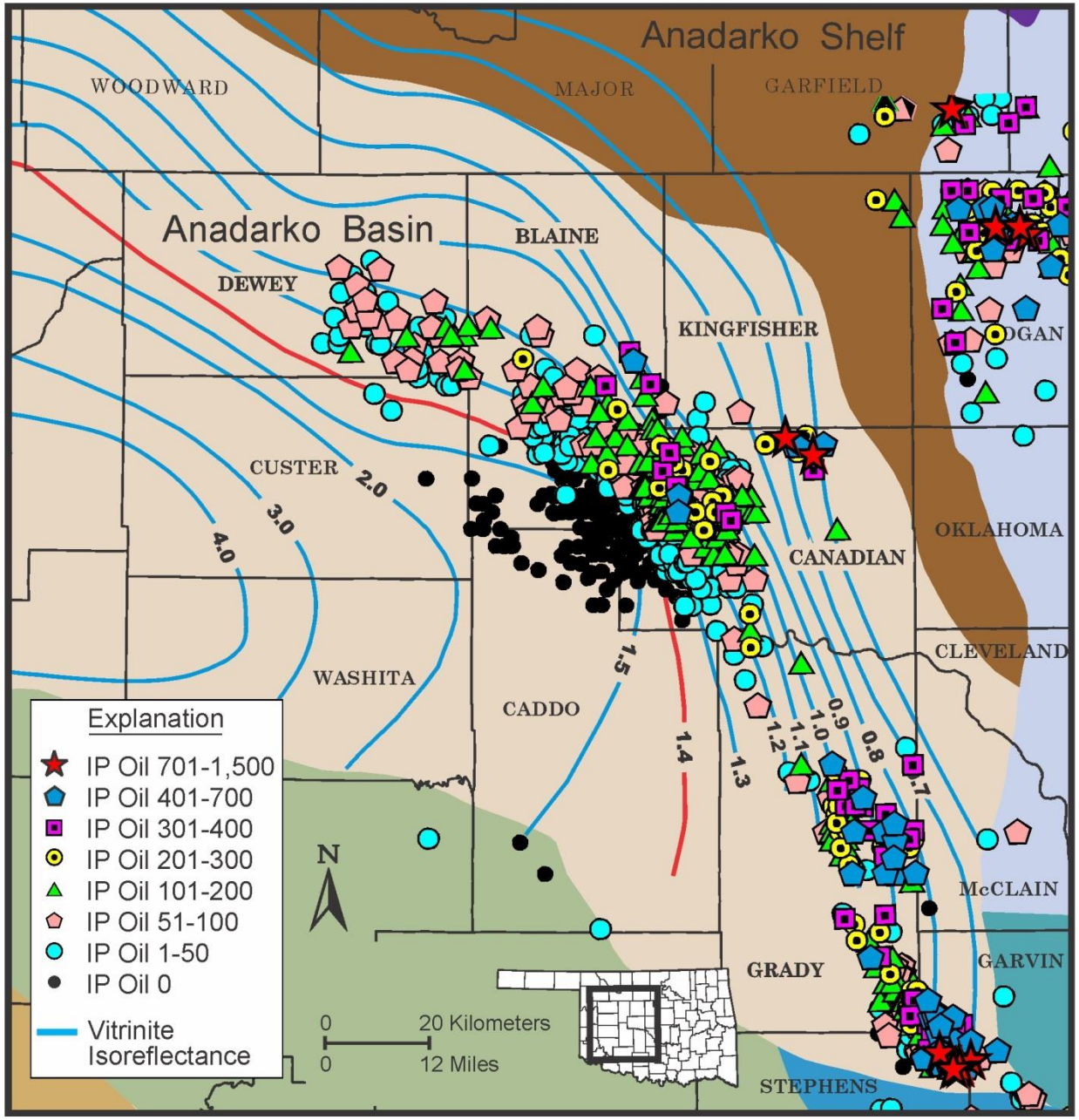
Anadarko Basin

OPL 1414

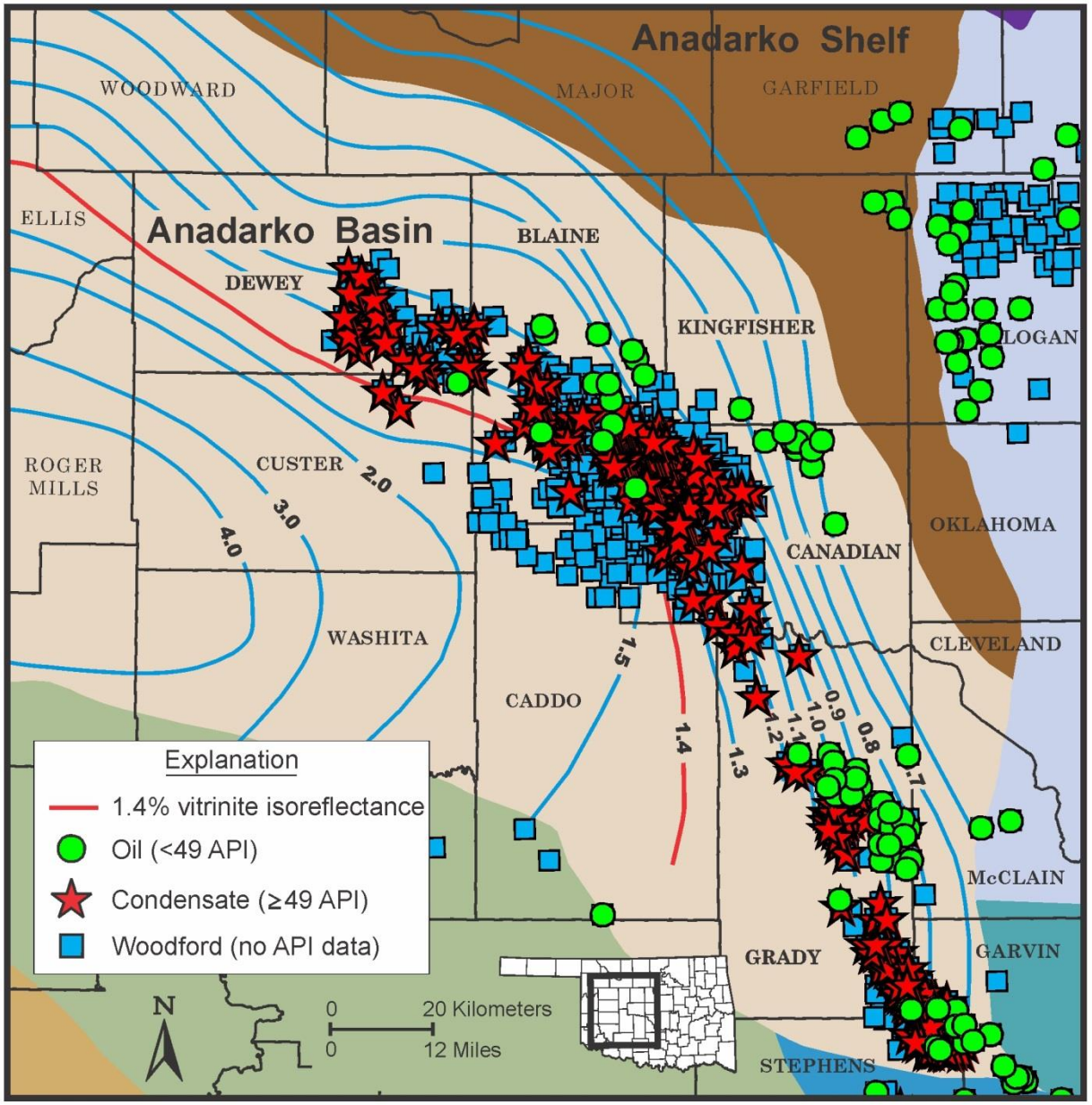


Woodford Shale Isoreflectance Map based on 81 wells (Cardott, 1989)

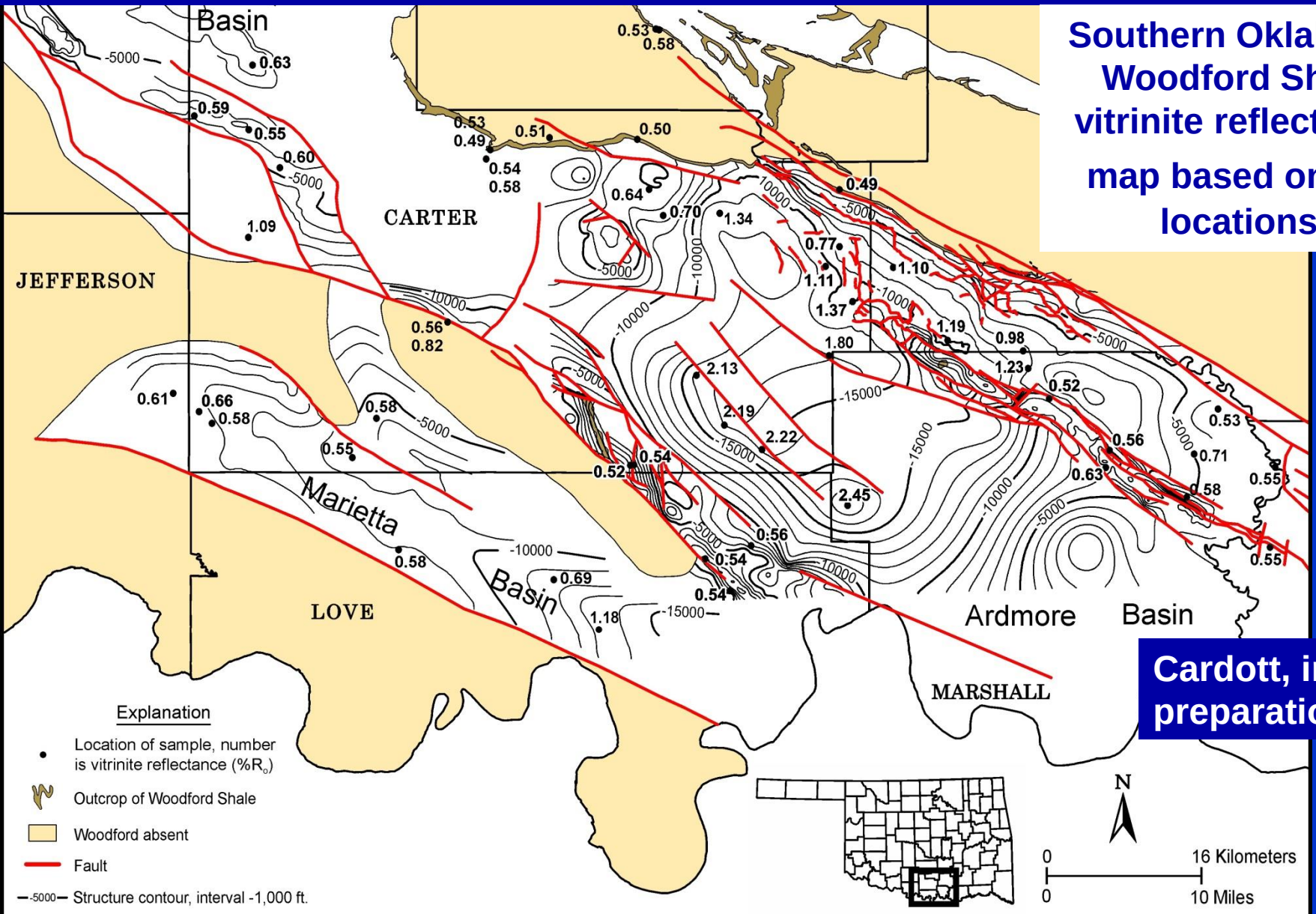
Woodford Shale Anadarko Basin IP Oil



Woodford Anadarko Basin API Gravity



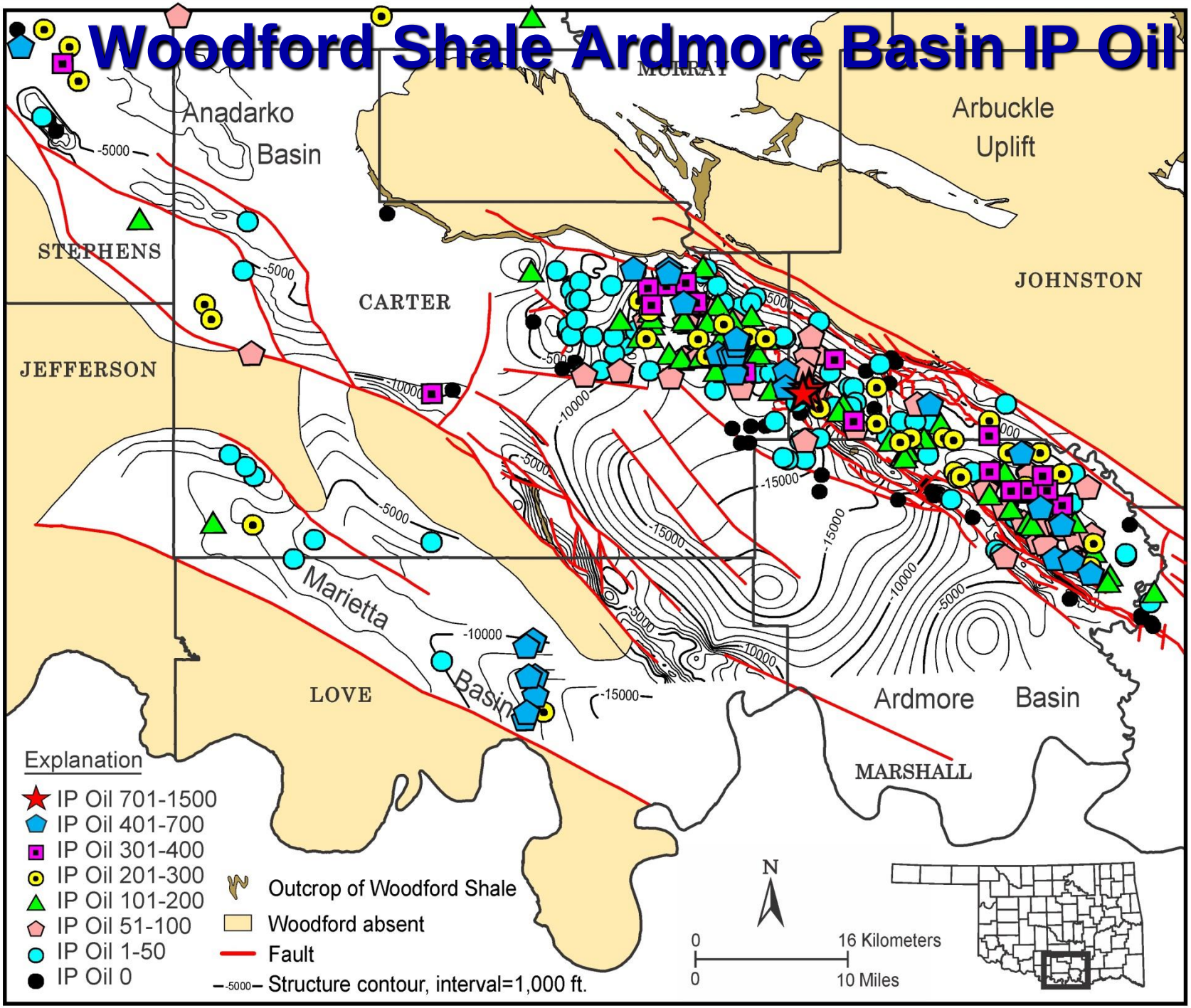
Woodford Shale Vitrinite Reflectance Data in Southern Oklahoma (Updated October 2013)



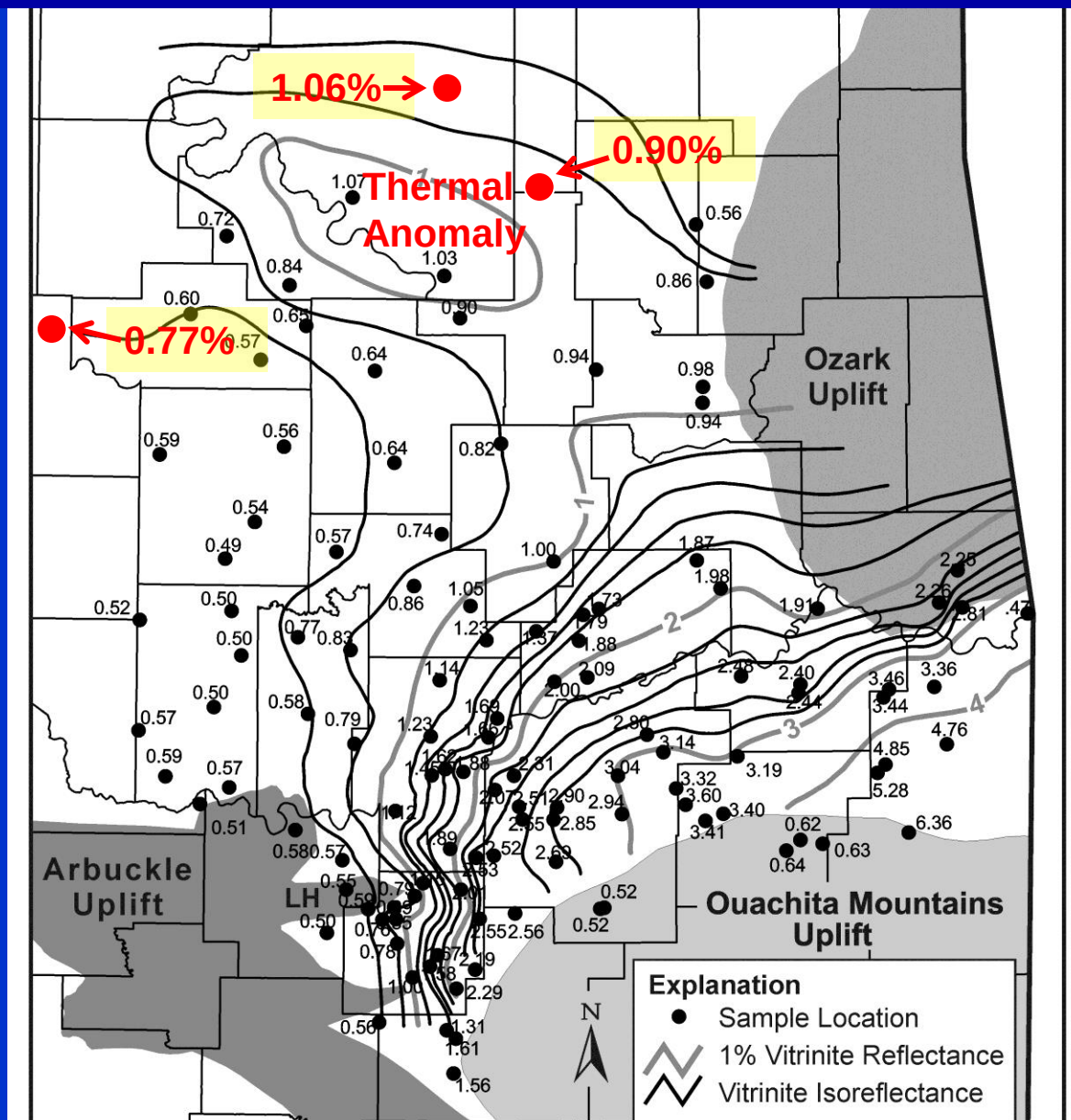
Southern Oklahoma Woodford Shale vitrinite reflectance map based on 51 locations

Cardott, in preparation

Woodford Shale Ardmore Basin IP Oil

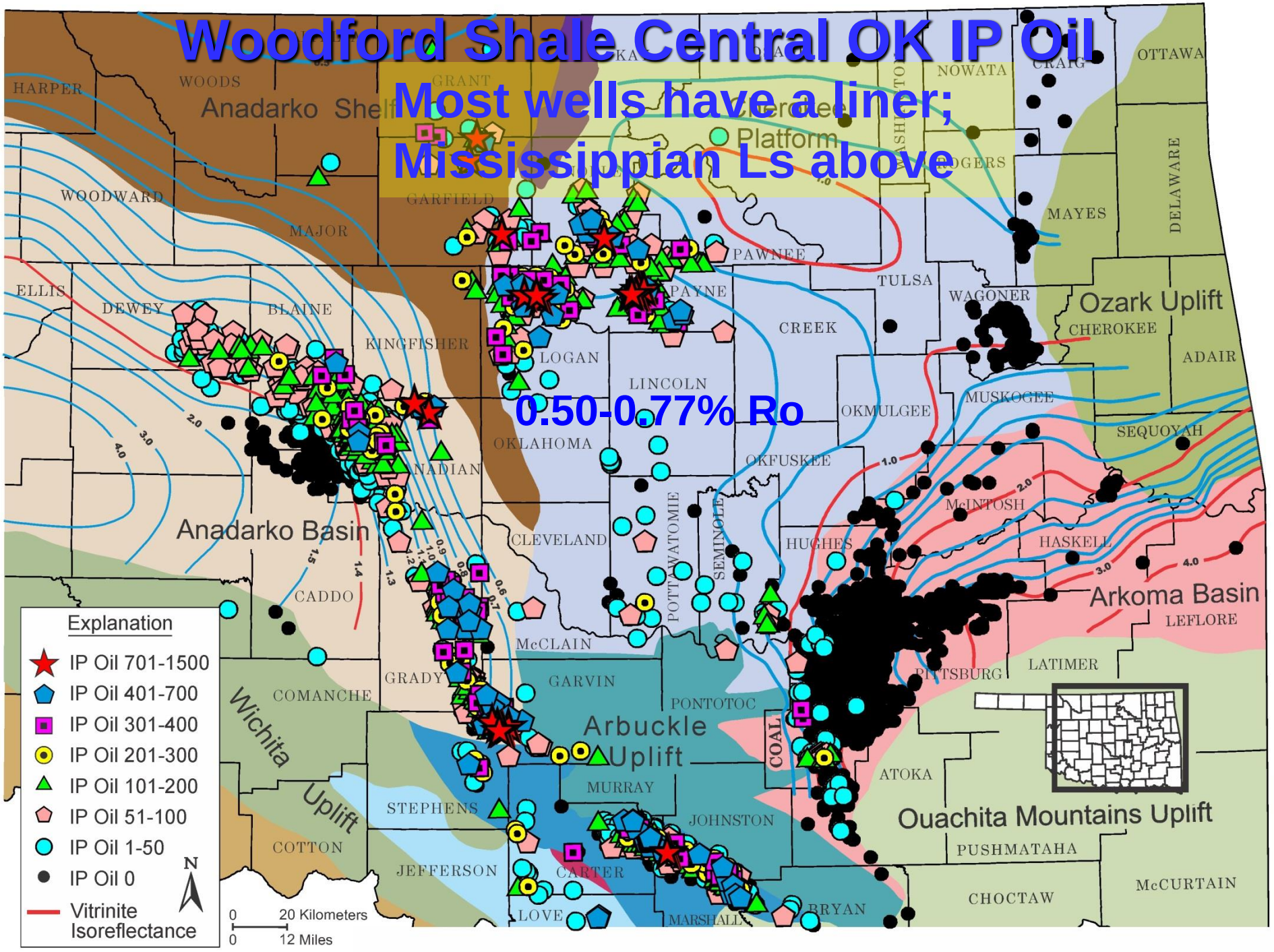


Isoreflectance Map of the Woodford Shale in Eastern Oklahoma (Updated November 2011)



Distribution of 117 Woodford Shale samples with vitrinite-reflectance data (n ≥20; whole-rock pellets)

Cardott, in preparation


Woodford Shale Central OK IP Oil
Most wells have a liner;
Mississippian Ls above
0.50-0.77% Ro
Anadarko Basin
Arkoma Basin
Ozark Uplift
Ouachita Mountains Uplift
Arbuckle Uplift
Wichita Uplift
Anadarko Shelf
Cherokee Platform
Explanation
IP Oil 701-1500
IP Oil 401-700
IP Oil 301-400
IP Oil 201-300
IP Oil 101-200
IP Oil 51-100
IP Oil 1-50
IP Oil 0
Vitrinite Isoreflectance
N
0 20 Kilometers
0 12 Miles

Conclusions

Lower oil production rates occur at <0.60% Ro (dependent on oil saturation).

Oil production ranges from thermal maturities of ~0.59-1.18% Ro in the Anadarko, Ardmore, and Arkoma Basins and shelf areas (dependent on oil saturation). Higher initial production rates and higher cumulative production occurs at higher thermal maturities.

Condensate production ranges from thermal maturities of ~1.15-1.67% Ro in the Anadarko, Ardmore, and Arkoma Basins.