Oklahoma Corporation Commission

March 21, 2012

Oklahoma Woodford Shale Oil and Gas Plays, 2012 Update

Brian J. Cardott

Oklahoma Geological Survey

Goals of the presentation:

- Where are the Woodford Shale plays in Oklahoma?
- Why are the plays where they are?
- What types of hydrocarbons are produced?

Three Basic Factors Necessary for a Successful Gas Shale Play

- **Hydrocarbon Source Rock:**
  Organic Matter TYPE, QUANTITY, AND THERMAL MATURITY.
- **Mineralogy:** quartz and carbonate vs. clays. Mineralogy and rock fabric influence porosity and mechanical strength (**brittleness vs. ductile**)
- **Stress:** rock is difficult to break and fractures may close in high stress; low stress regions result in better stimulation.

Modified from Norton and Tushingham, 2011

All gas shales have marine Type II Kerogen bulk composition

(Jarvie and others, 2007; Zumberge and others, 2012)

'Magnificent Seven' Gas Shale Basins of the U.S. and Canada

UNITED STATES

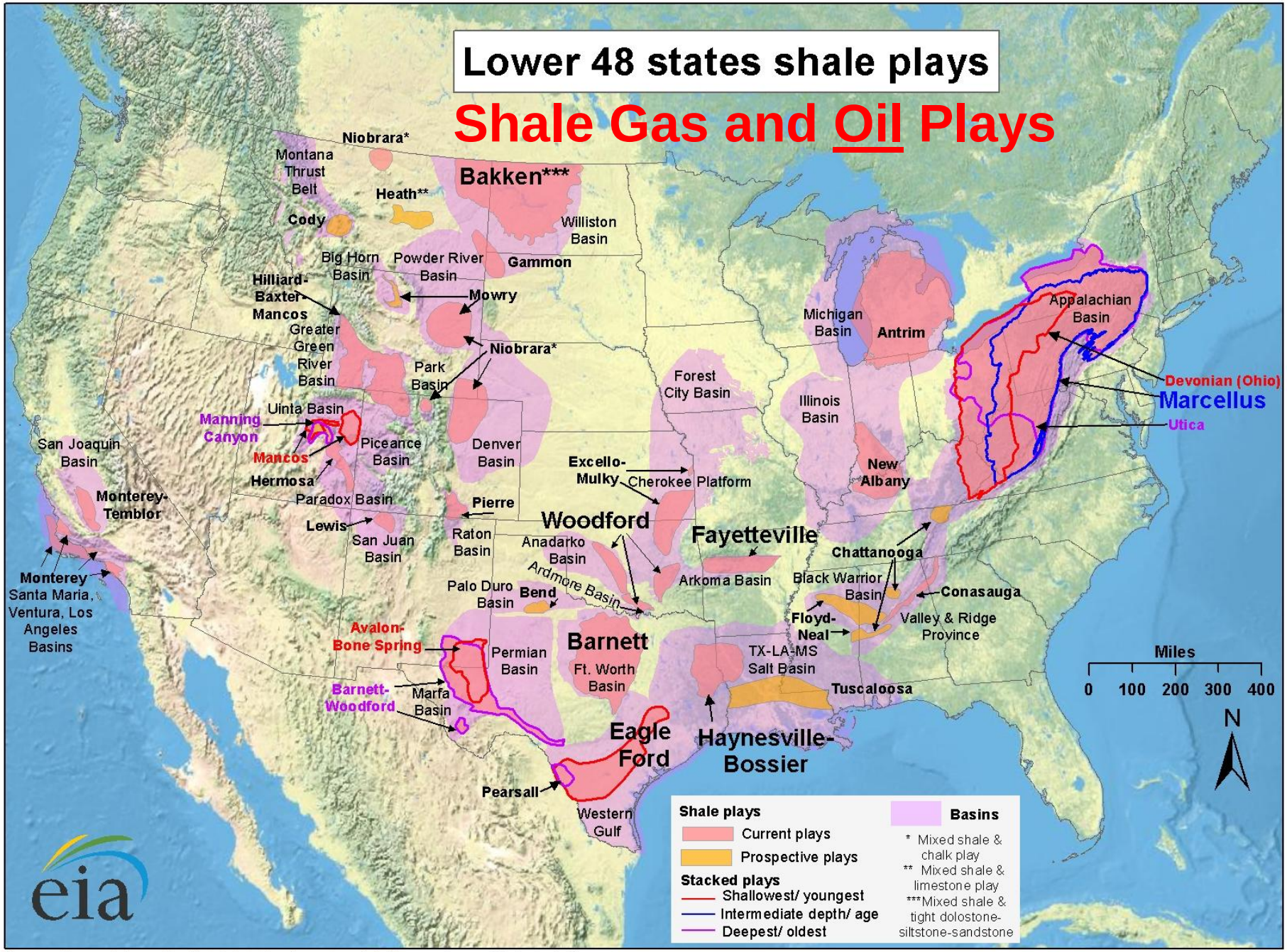
- Barnett
- Fayetteville
- Haynesville
- Marcellus
- Woodford (Late Devonian-Early Mississippian)

CANADA

Horn River

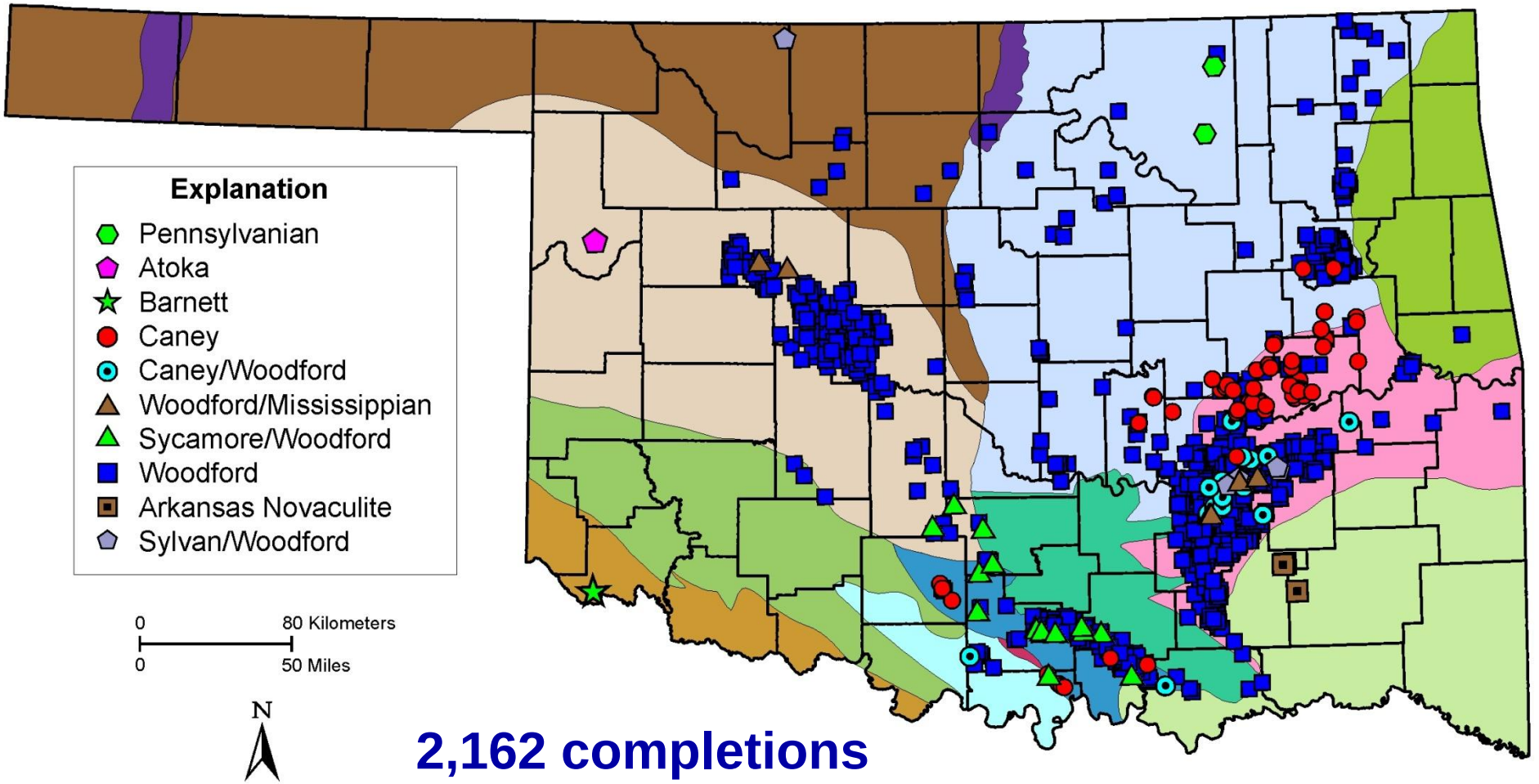
Montney

From Kuuskraa, 2011



Source: Energy Information Administration based on data from various published studies.
Updated: May 9, 2011

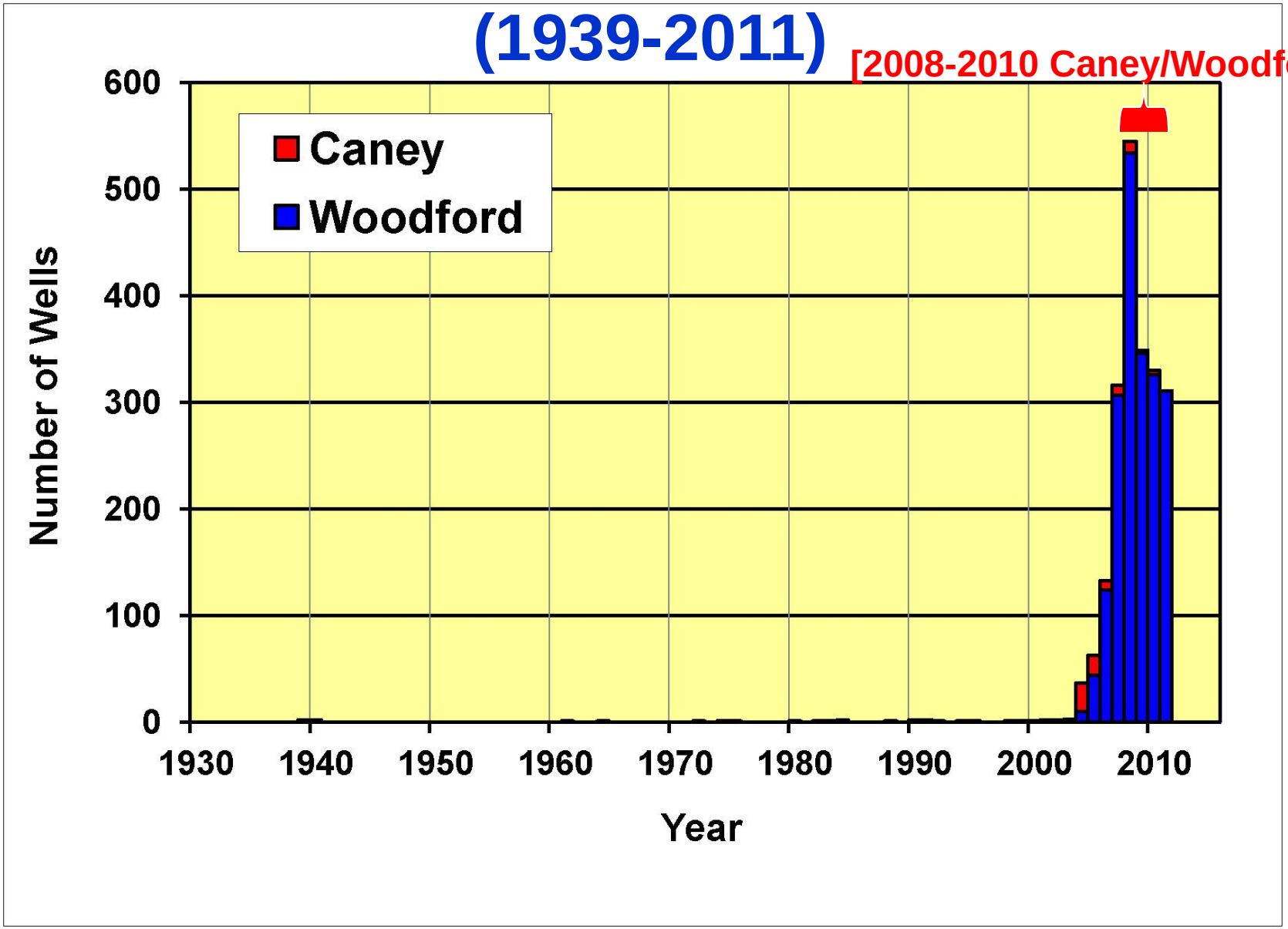
Oklahoma Shale Gas/Oil Completions (1939-2011)



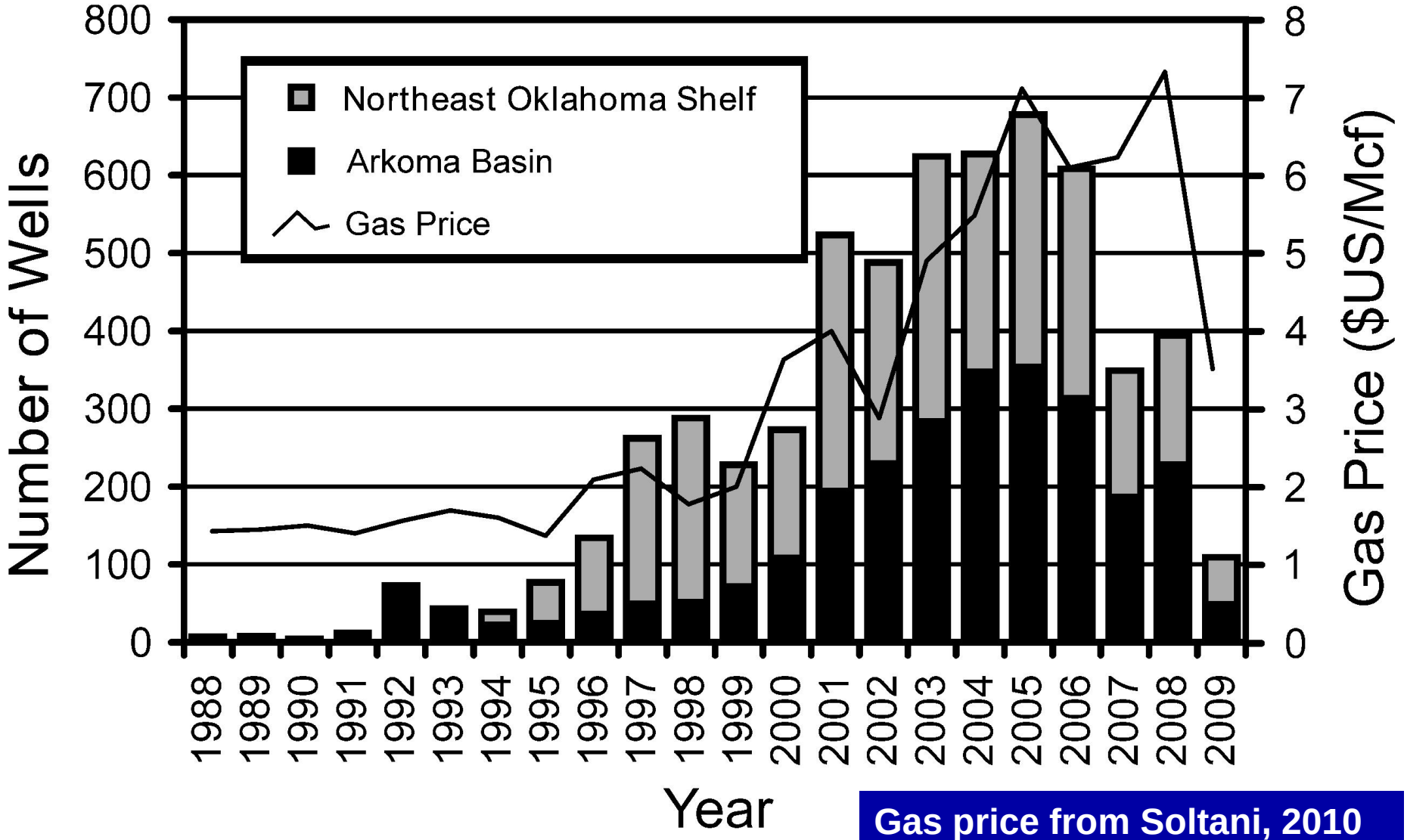
2,162 completions

Woodford/Caney Shale Completions (1939-2011)

[2008-2010 Caney/Woodford]

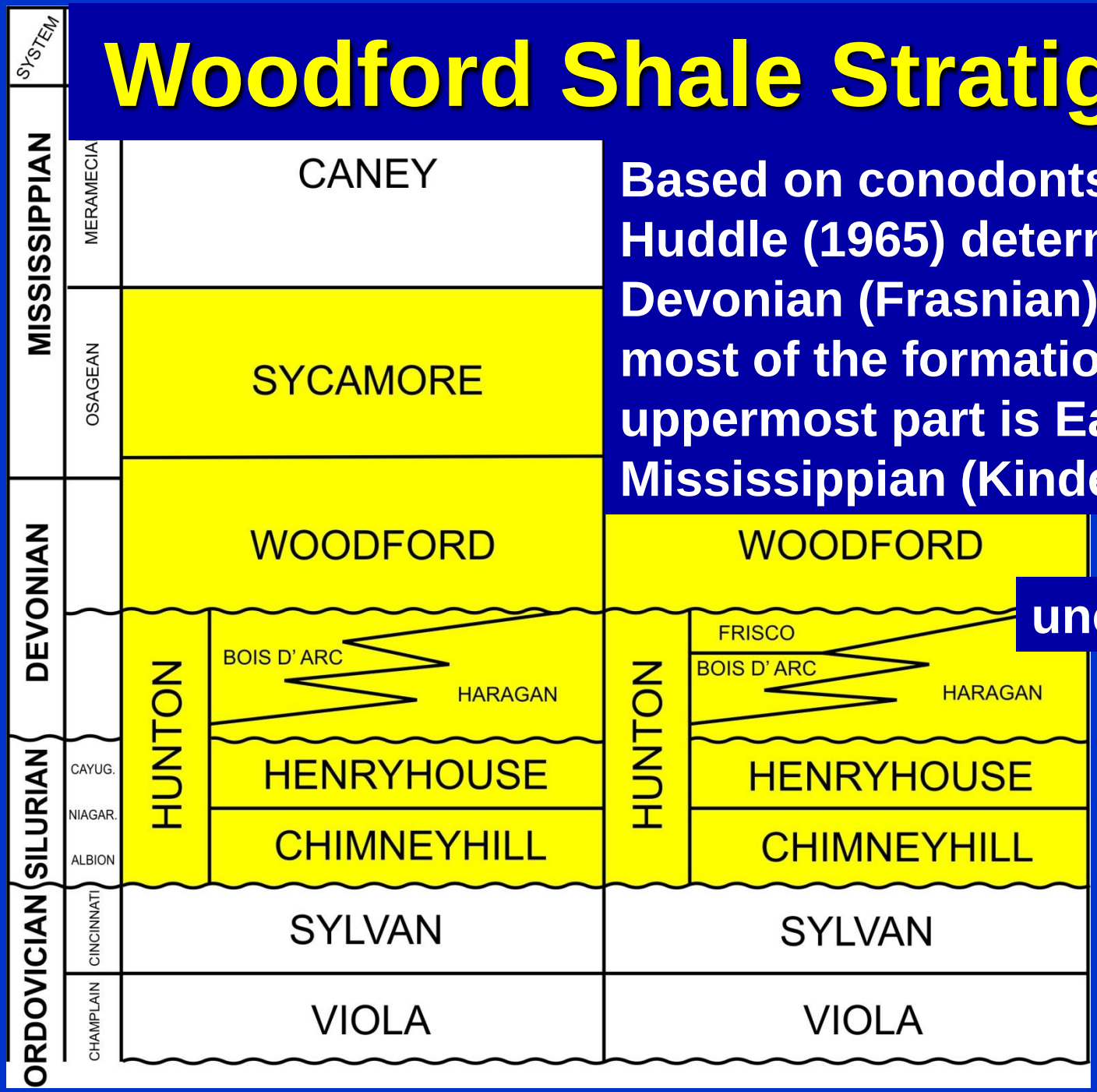


Oklahoma CBM Gas Price (1988-2009)



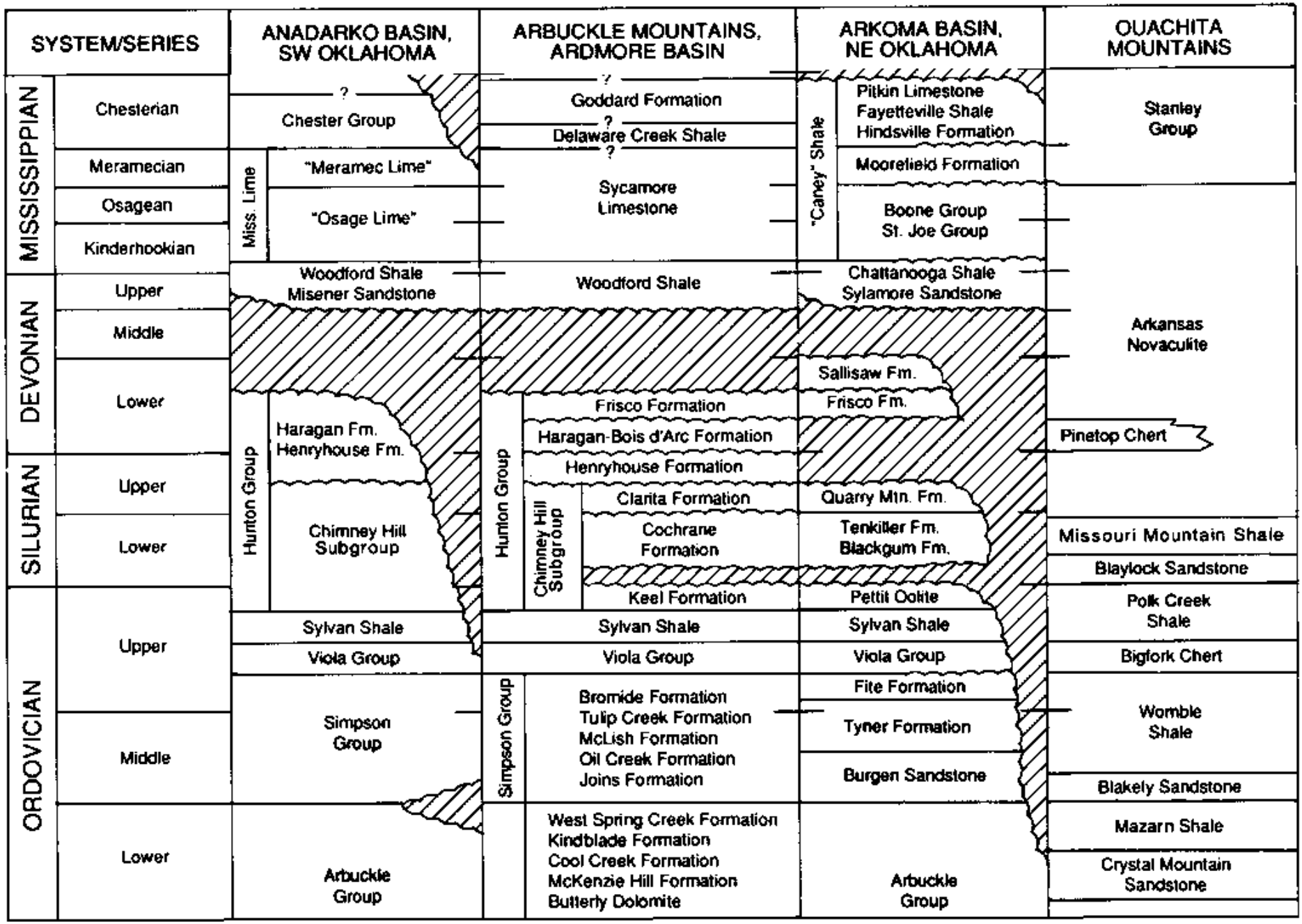
Gas price from Soltani, 2010

Woodford Shale Stratigraphy



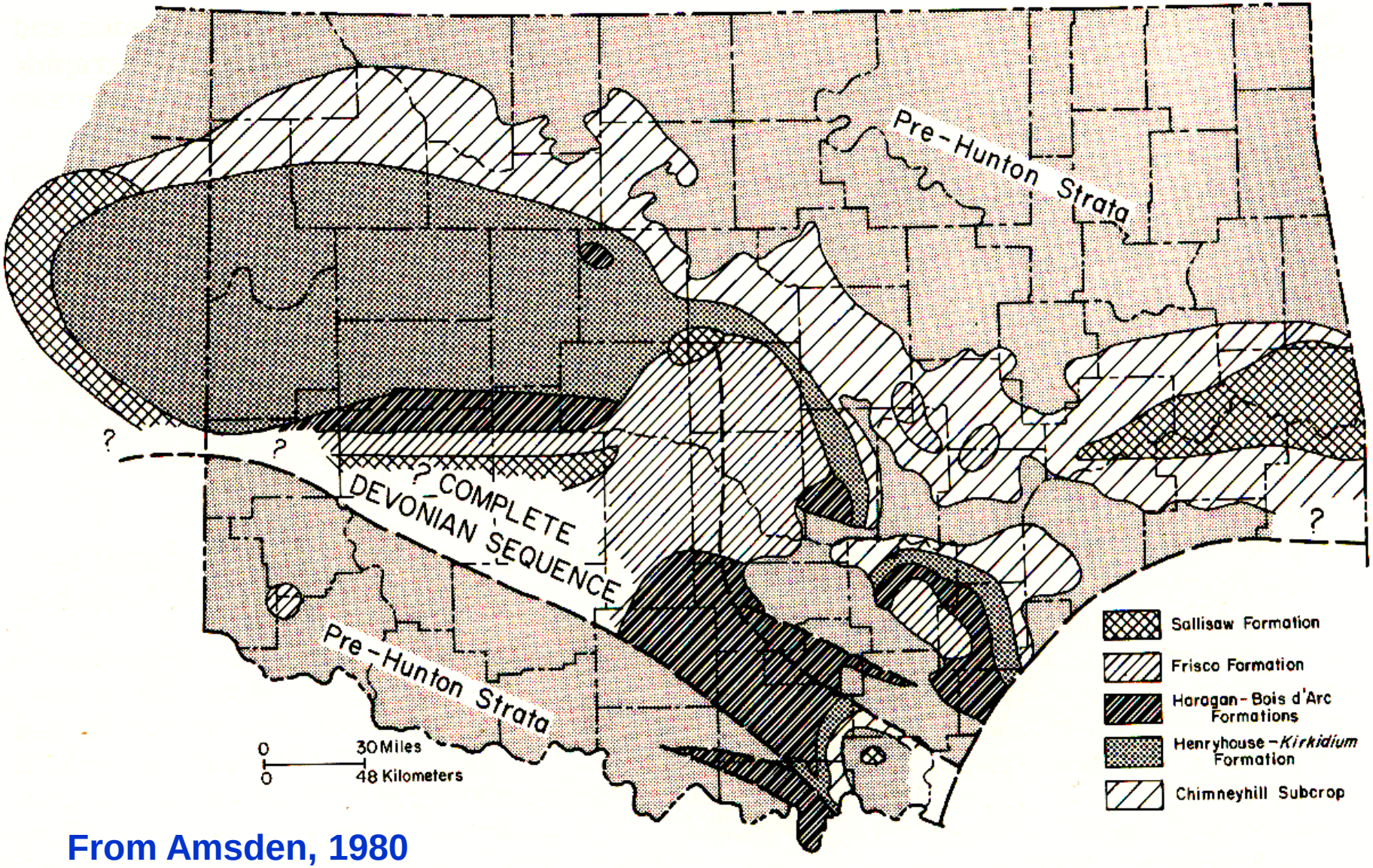
Based on conodonts, Hass and Huddle (1965) determined a Late Devonian (Frasnian) age for most of the formation; uppermost part is Early Mississippian (Kinderhookian)

unconformity



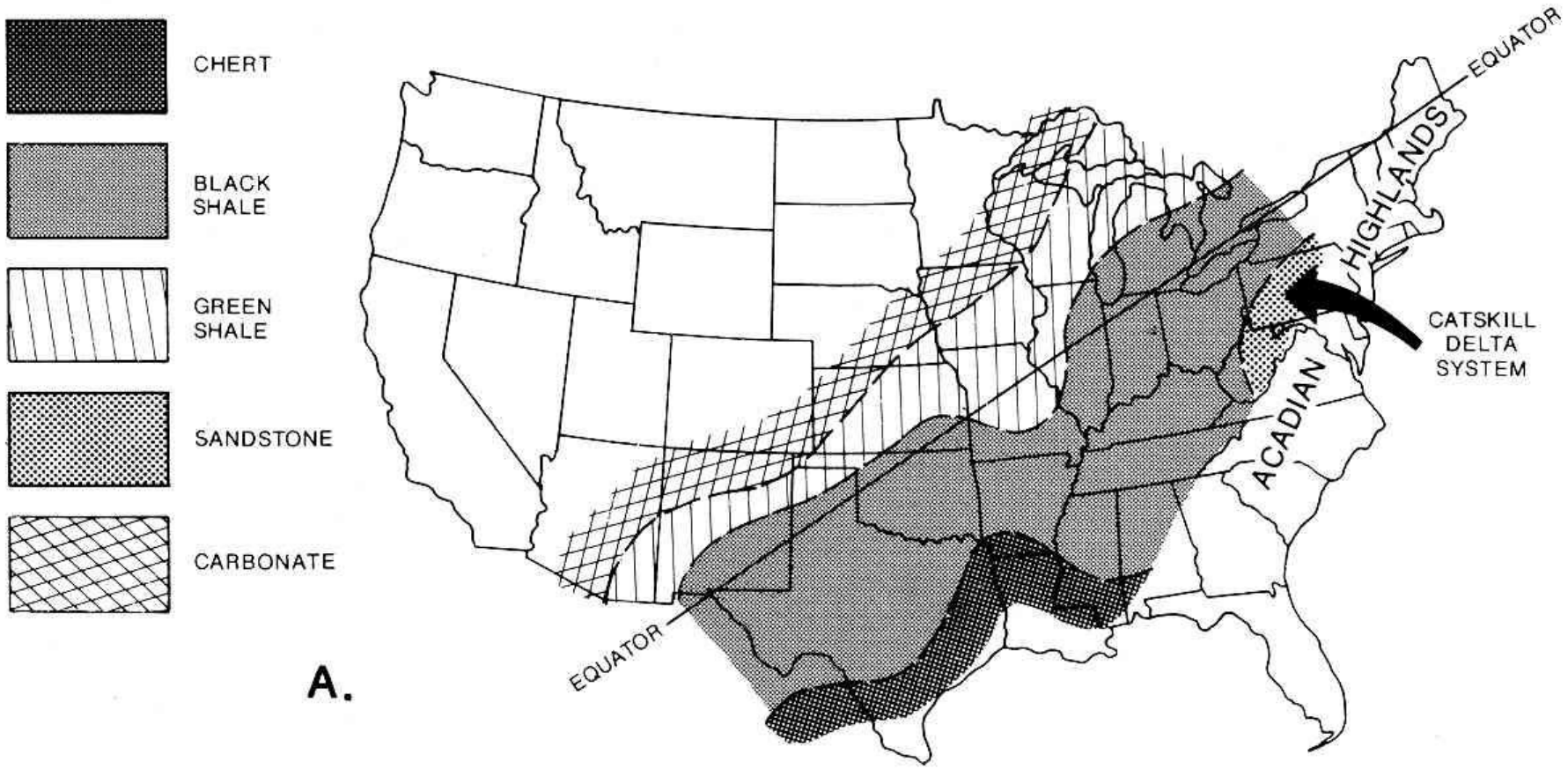
Modified from Johnson and Cardott, 1992

Pre-Woodford Geologic Map



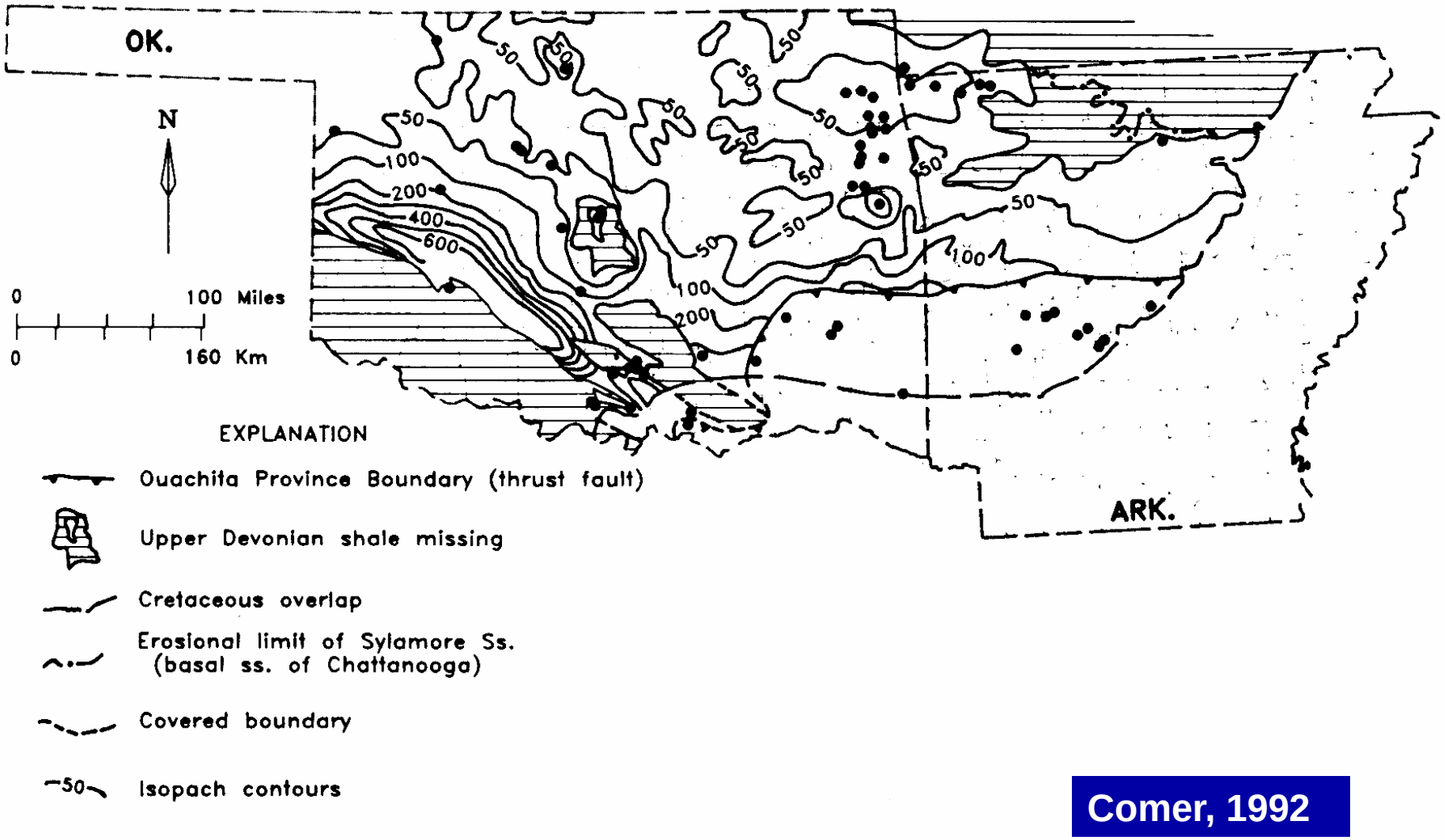
From Amsden, 1980

Paleogeography and Facies Distribution in the Late Devonian



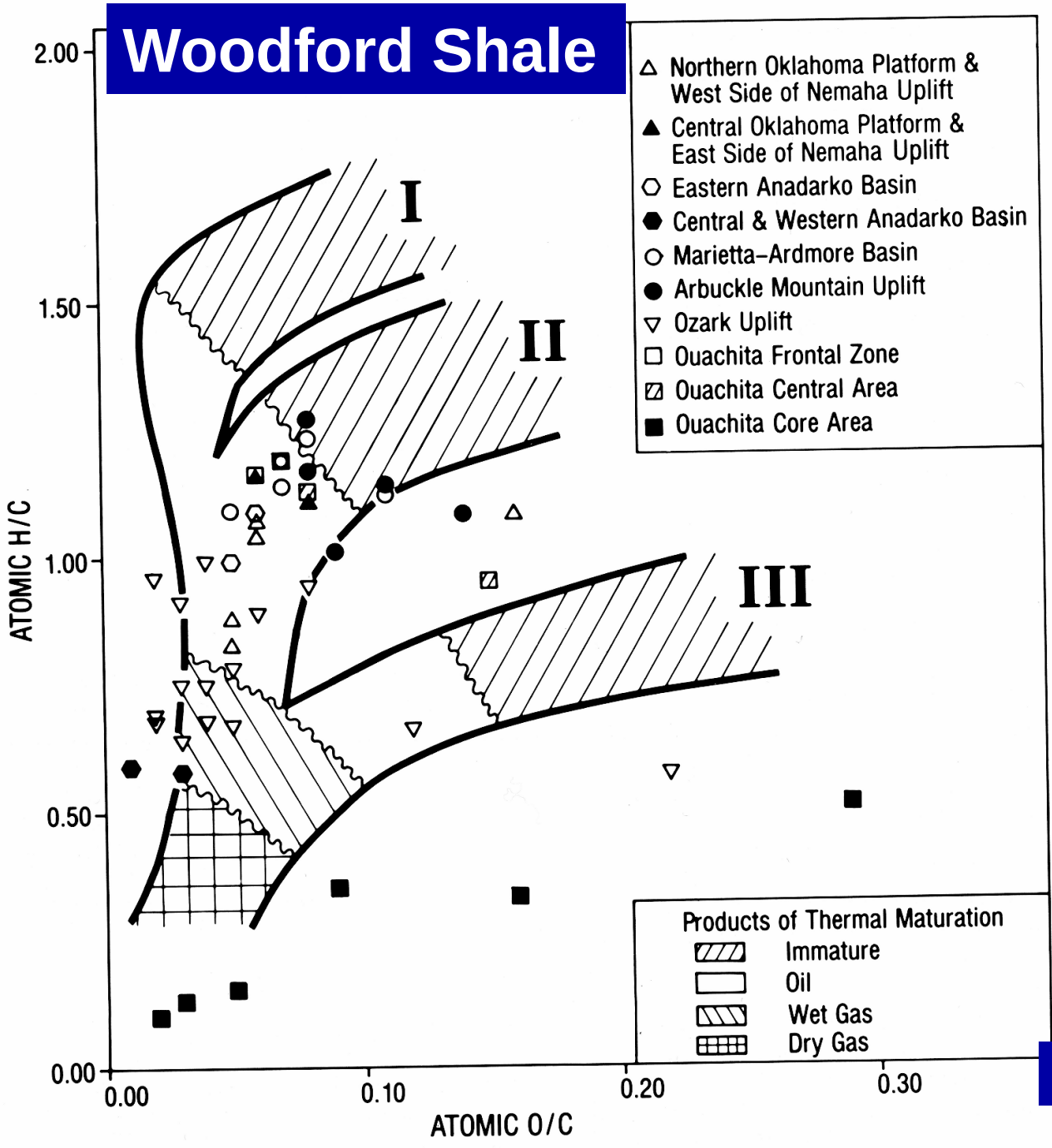
Kirkland and others, 1992

Isopach Map of Woodford Shale



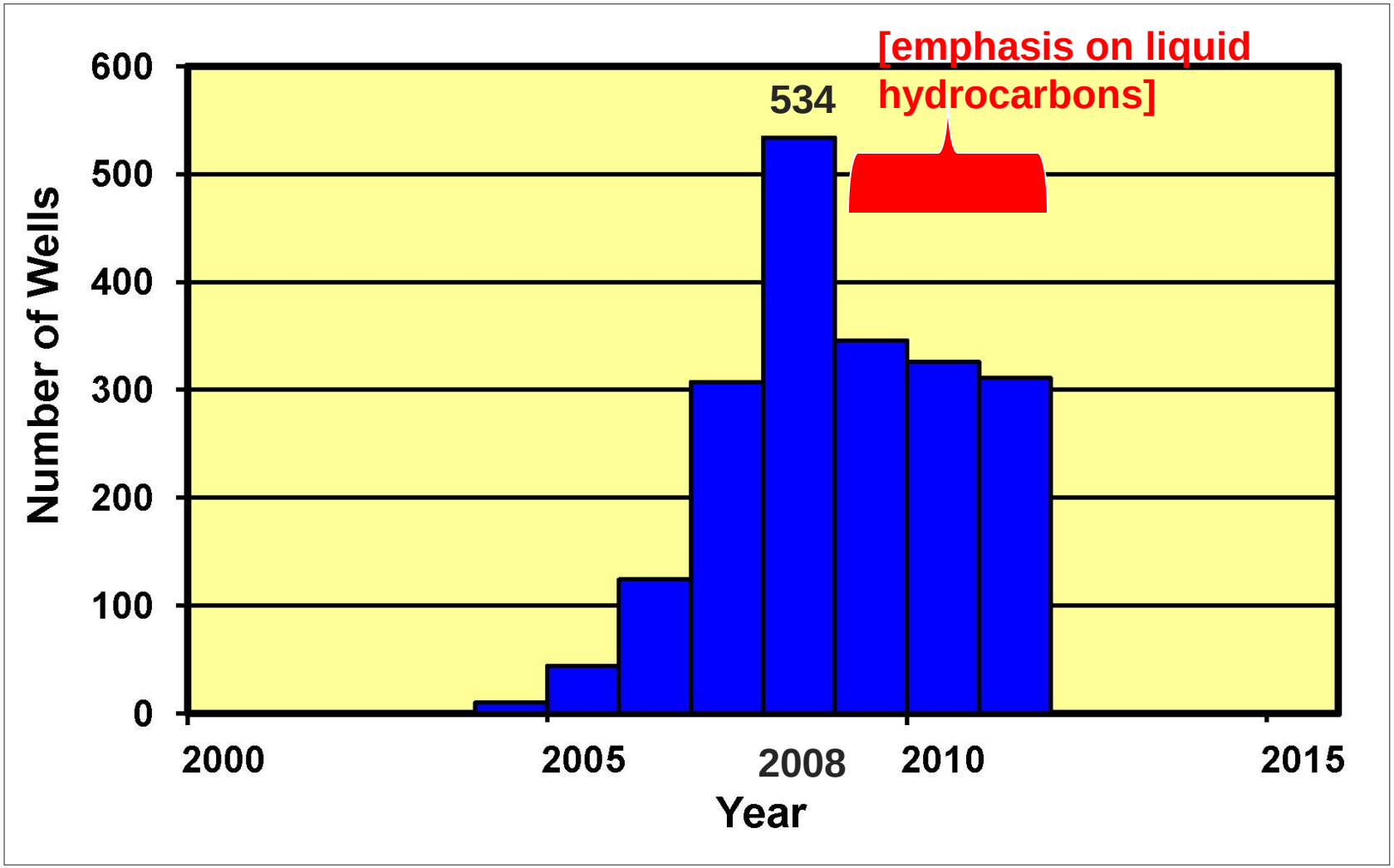
Comer, 1992

Woodford Shale

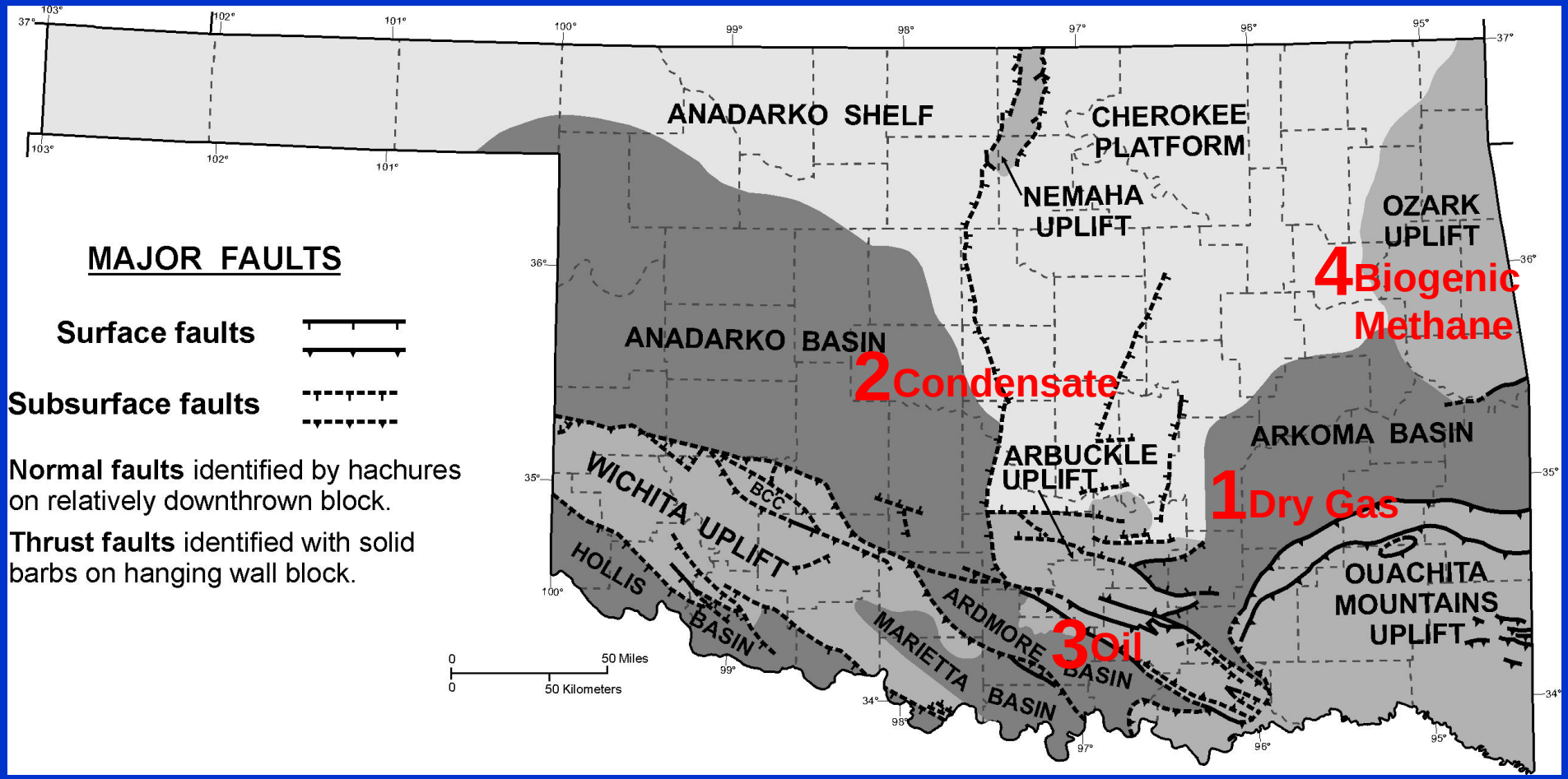


Comer (1992)

Woodford Shale Completions (2004-2011)

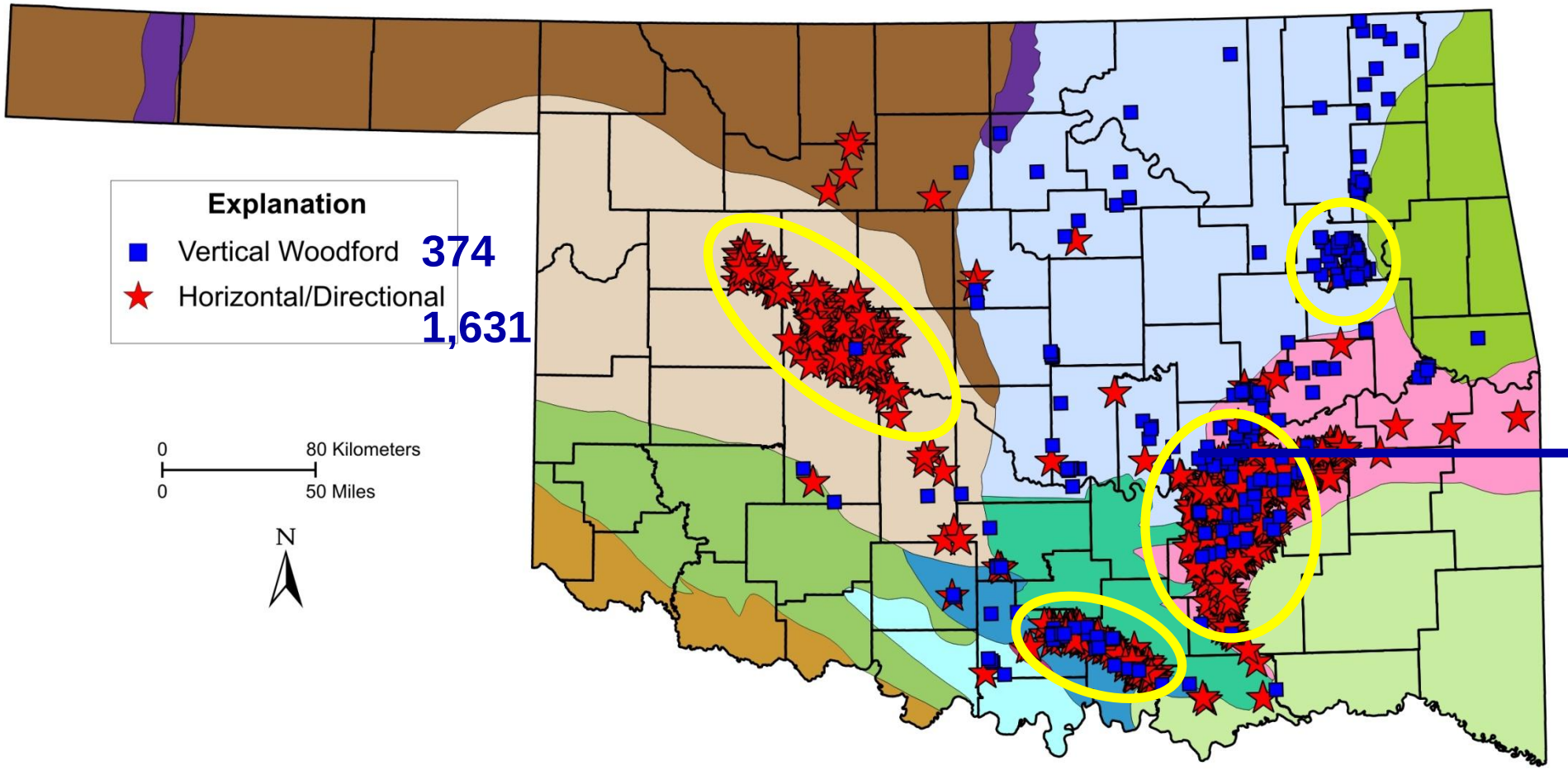


Woodford Shale Plays

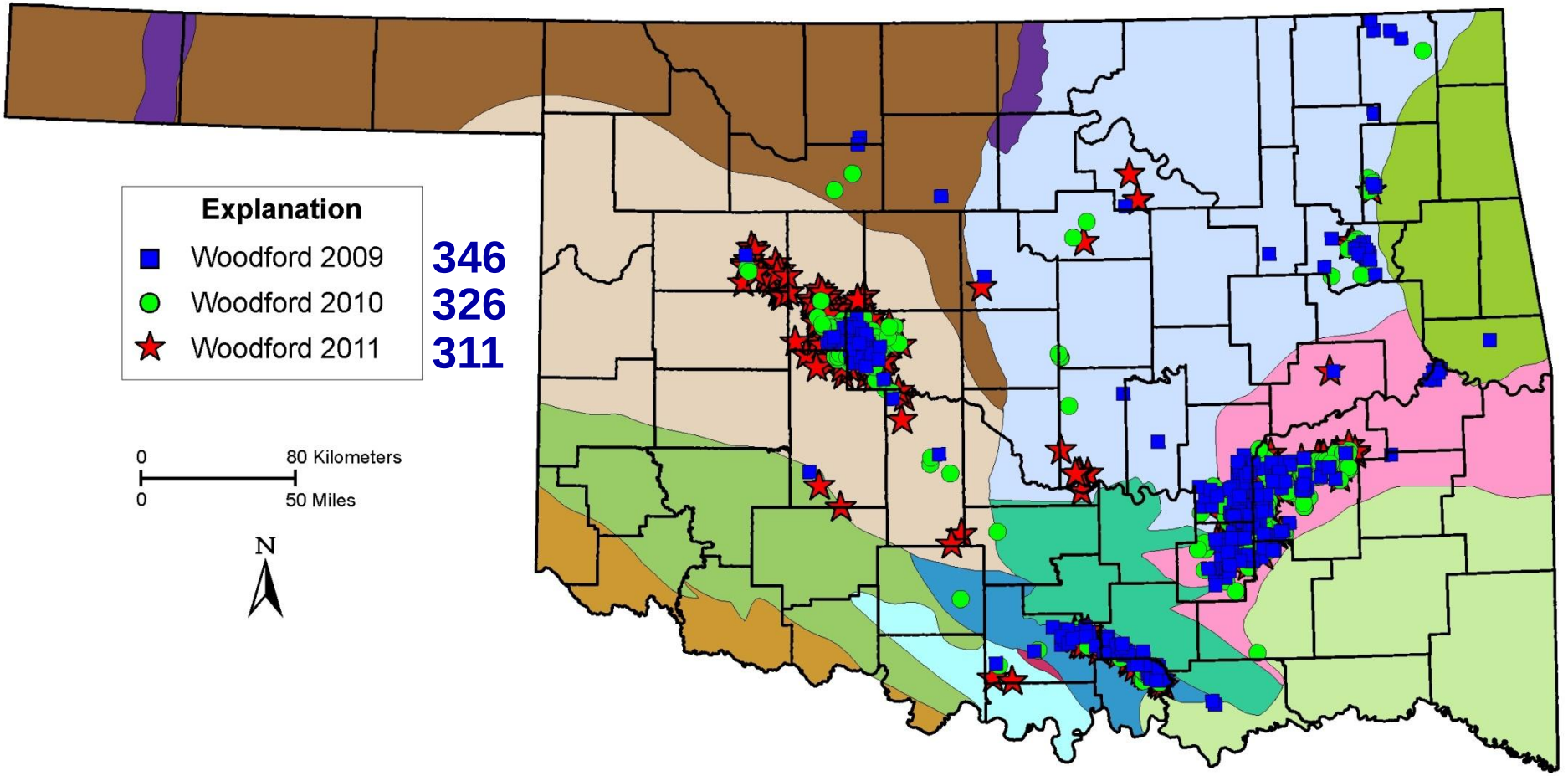


Geologic provinces from Northcutt and Campbell, 1995

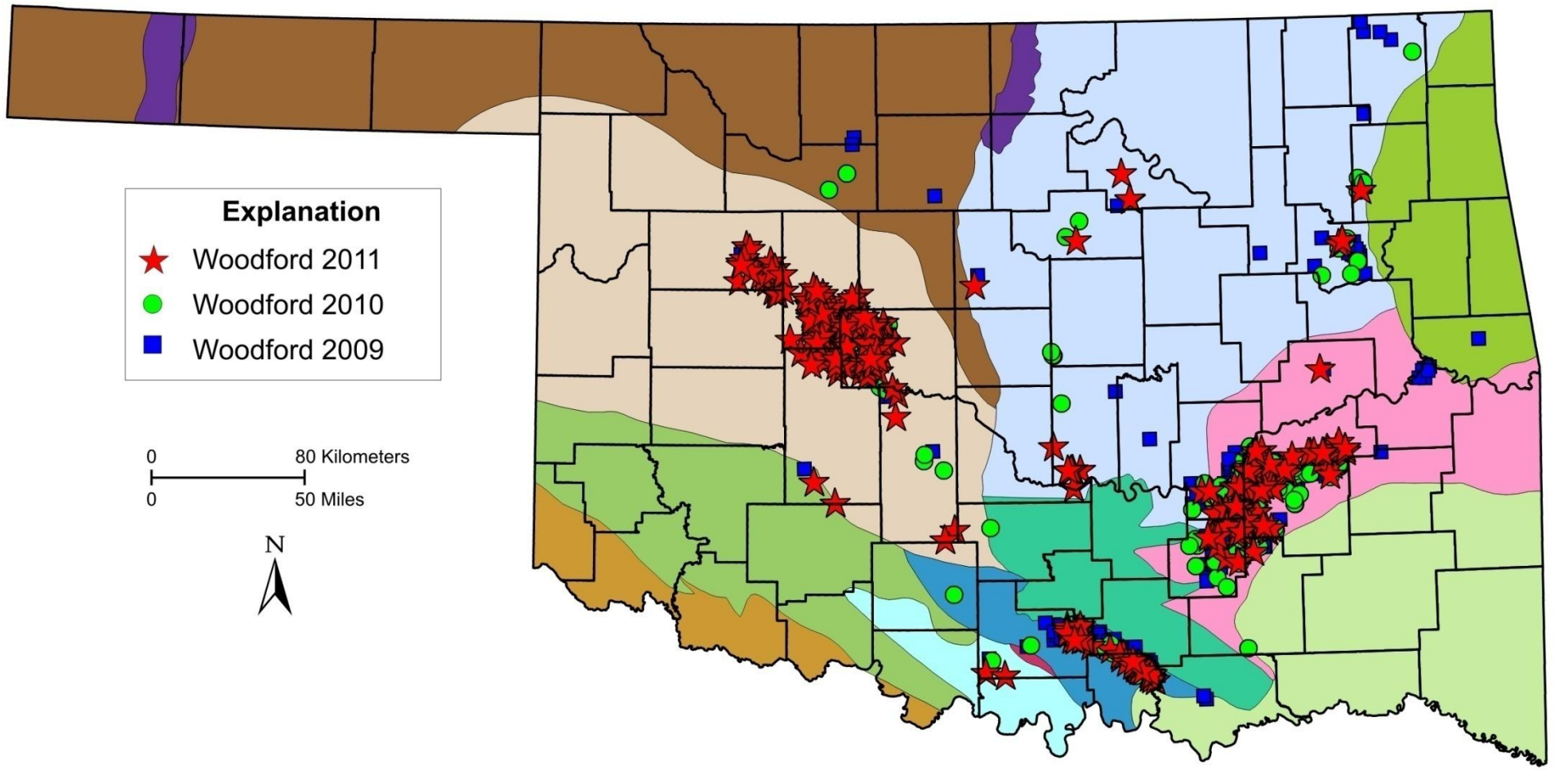
2,005 Woodford Shale Wells (2004-2011)



Woodford Shale Wells (2009-2011)



Woodford Shale Wells (2011-2009)



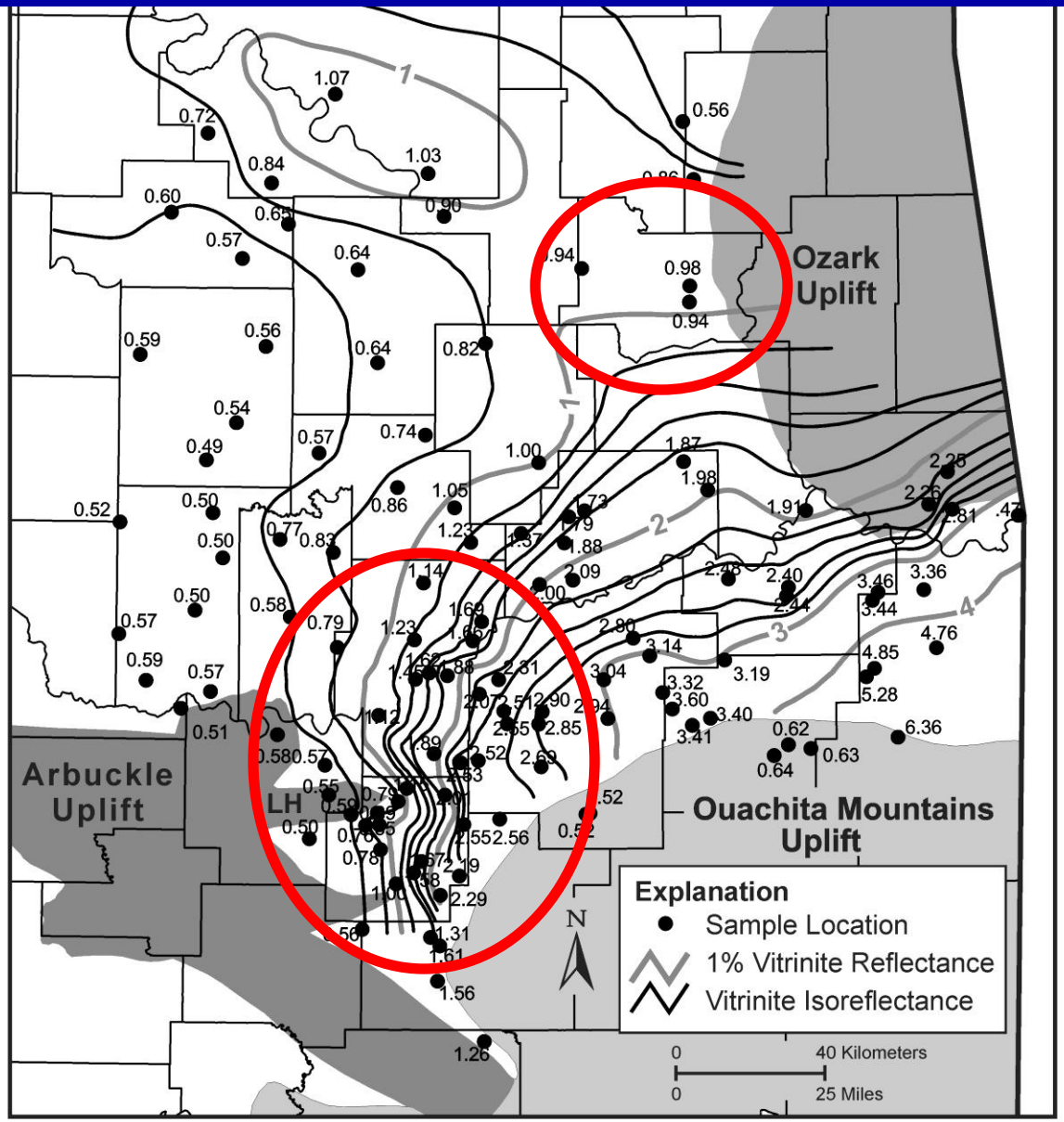
Emphasis of presentation on importance of thermal maturity (by vitrinite reflectance) on the Woodford Shale oil and gas plays.

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

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

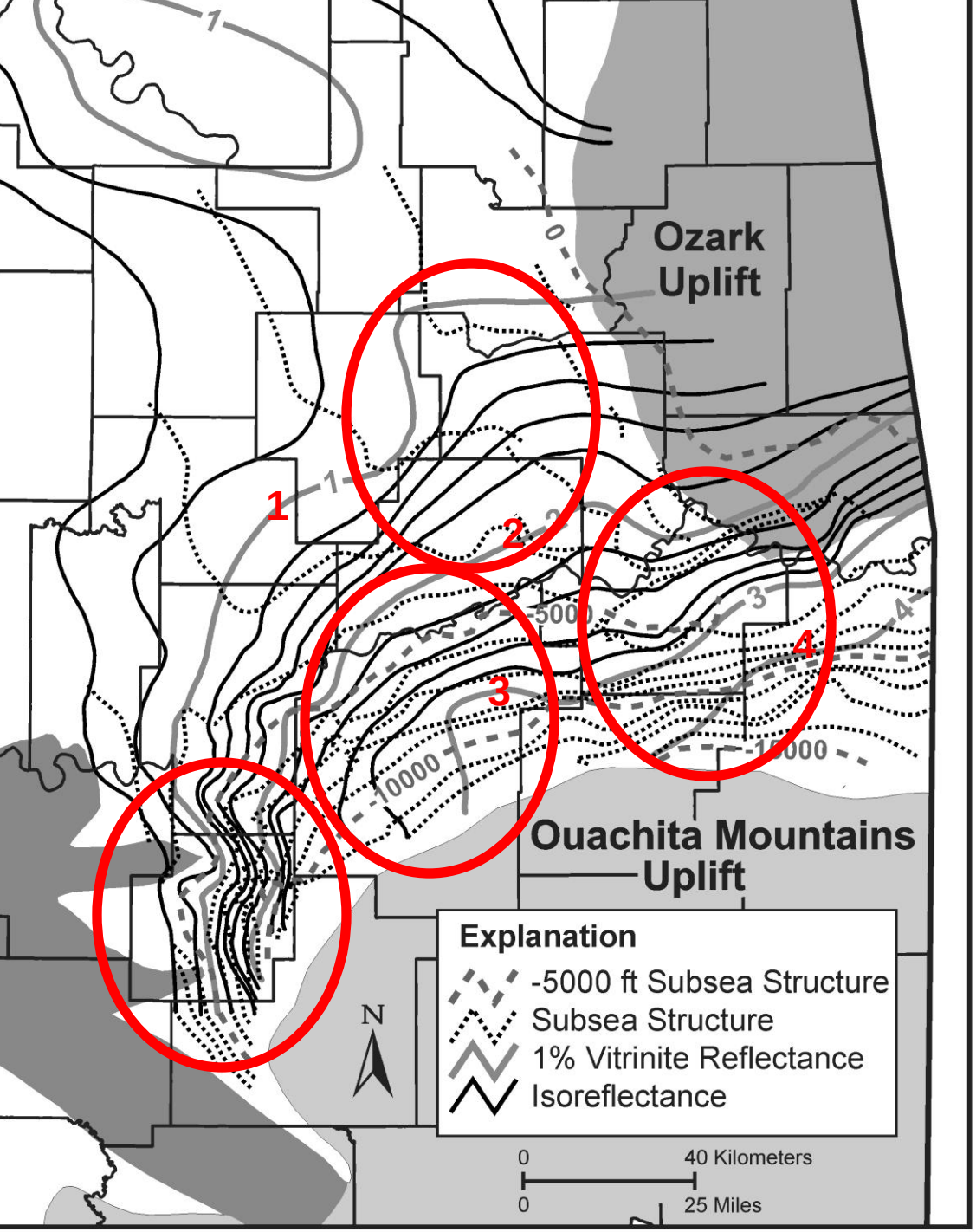
From Jarvie and others, 2005

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

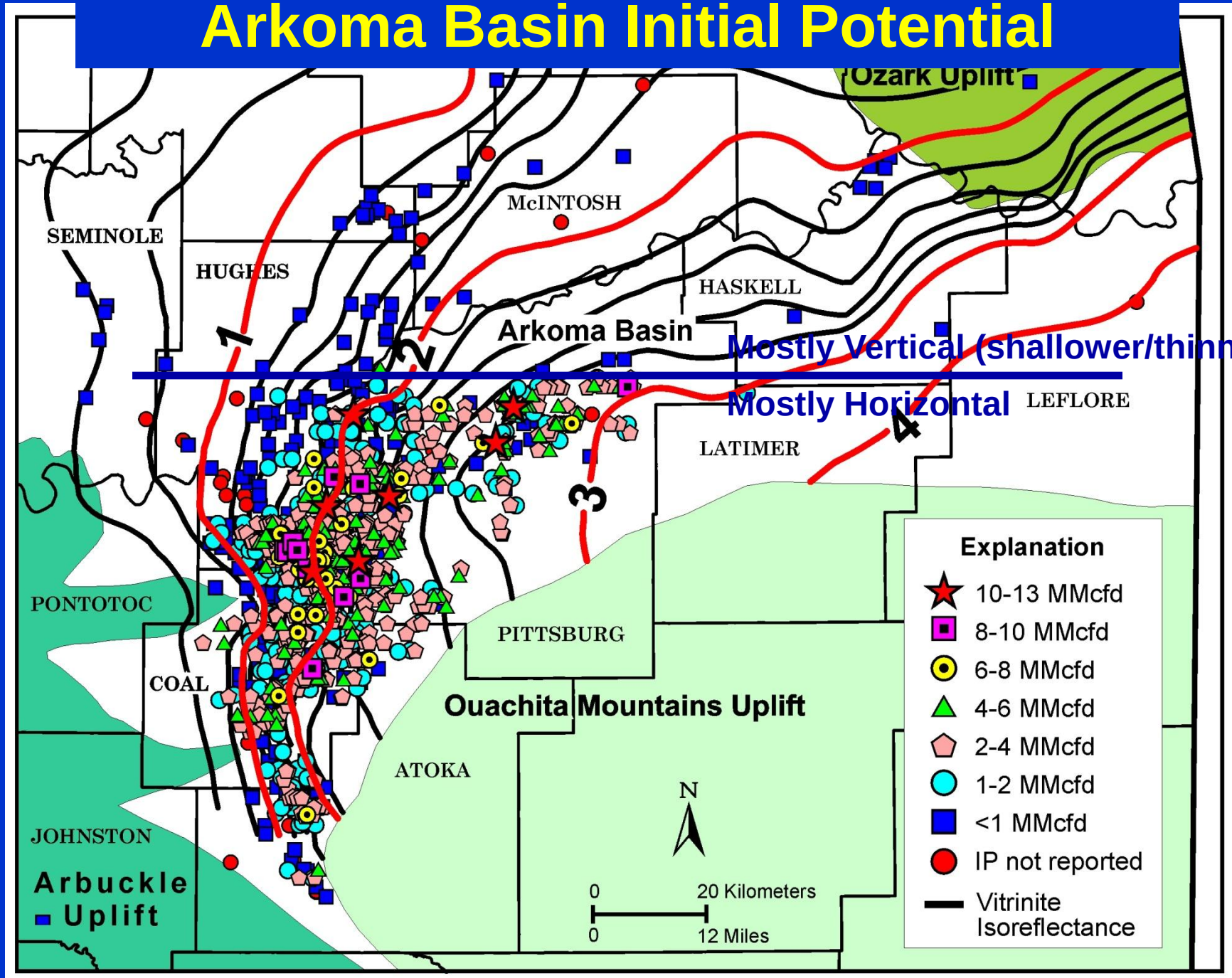


Woodford Shale Structure & Vitrinite Isoreflectance Map

Maps prepared by
R. Vance Hall
using Petra

The following maps are from an August 2011 presentation and have not been updated.

Arkoma Basin Initial Potential



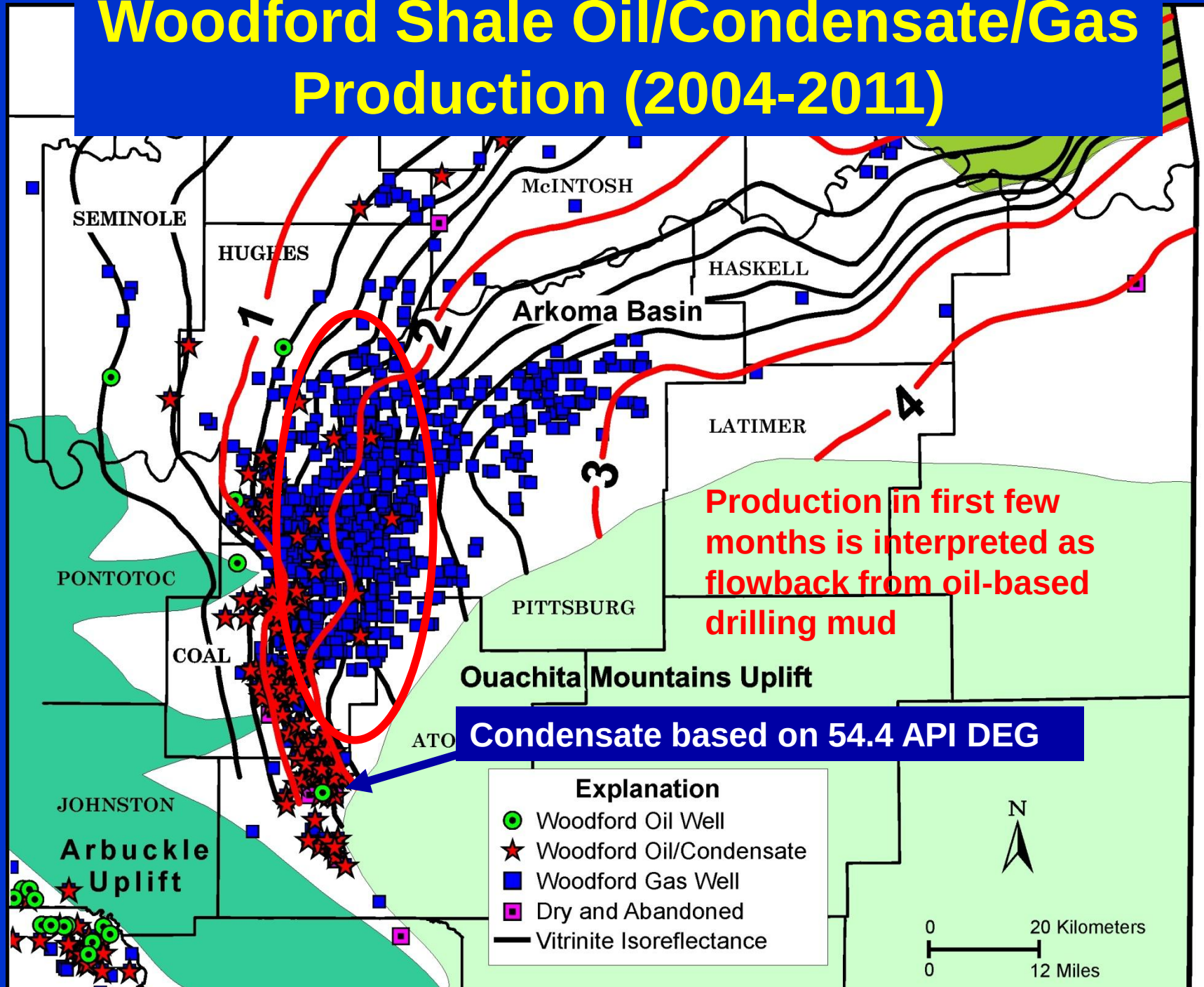
Woodford Oil/Condensate/Gas Production Caveat

- **Gas** production is reported by the Oklahoma Corporation Commission by **WELL**.

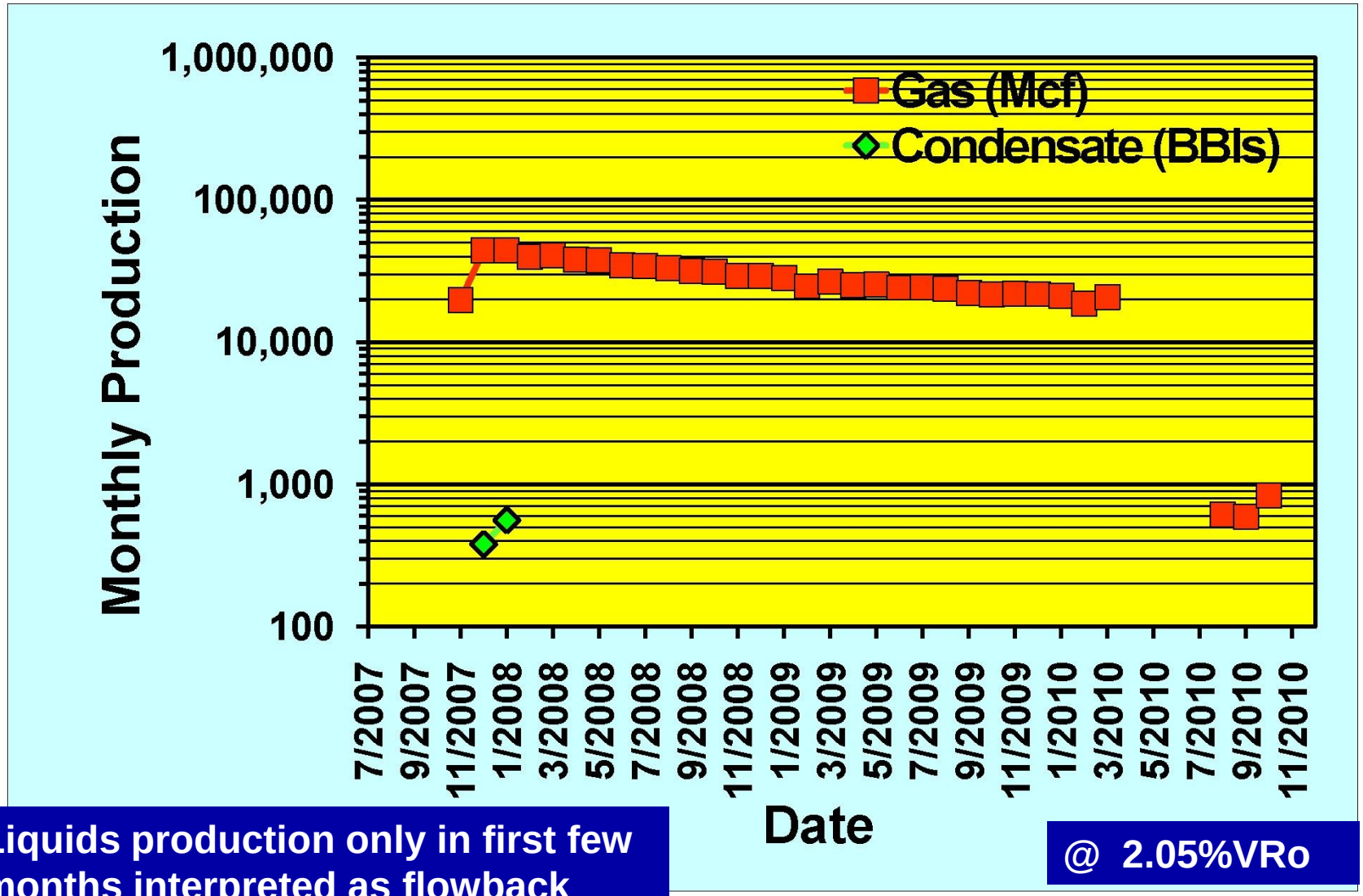
- **Oil/condensate** production is reported by the Oklahoma Tax Commission by **LEASE** [production by well is only on single-well leases]

(Production data supplied by PI/Dwights LLC, © 2011, IHS Energy Group)

Woodford Shale Oil/Condensate/Gas Production (2004-2011)



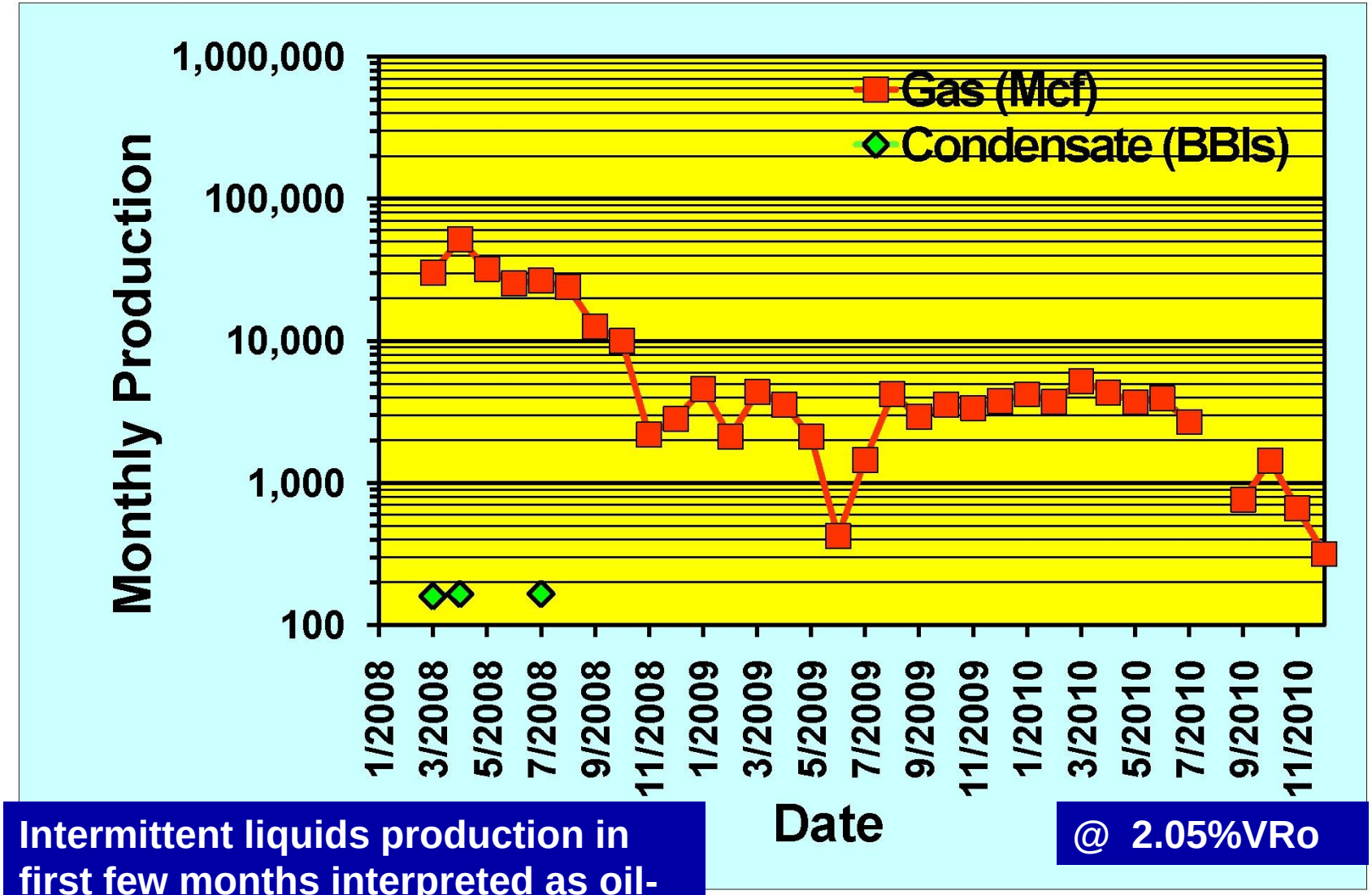
(1) Newfield 3H-36 Genevieve (36-6N-11E; Hughes Co.; IP 2,118 Mcfd)



Liquids production only in first few months interpreted as flowback

@ 2.05%VRo

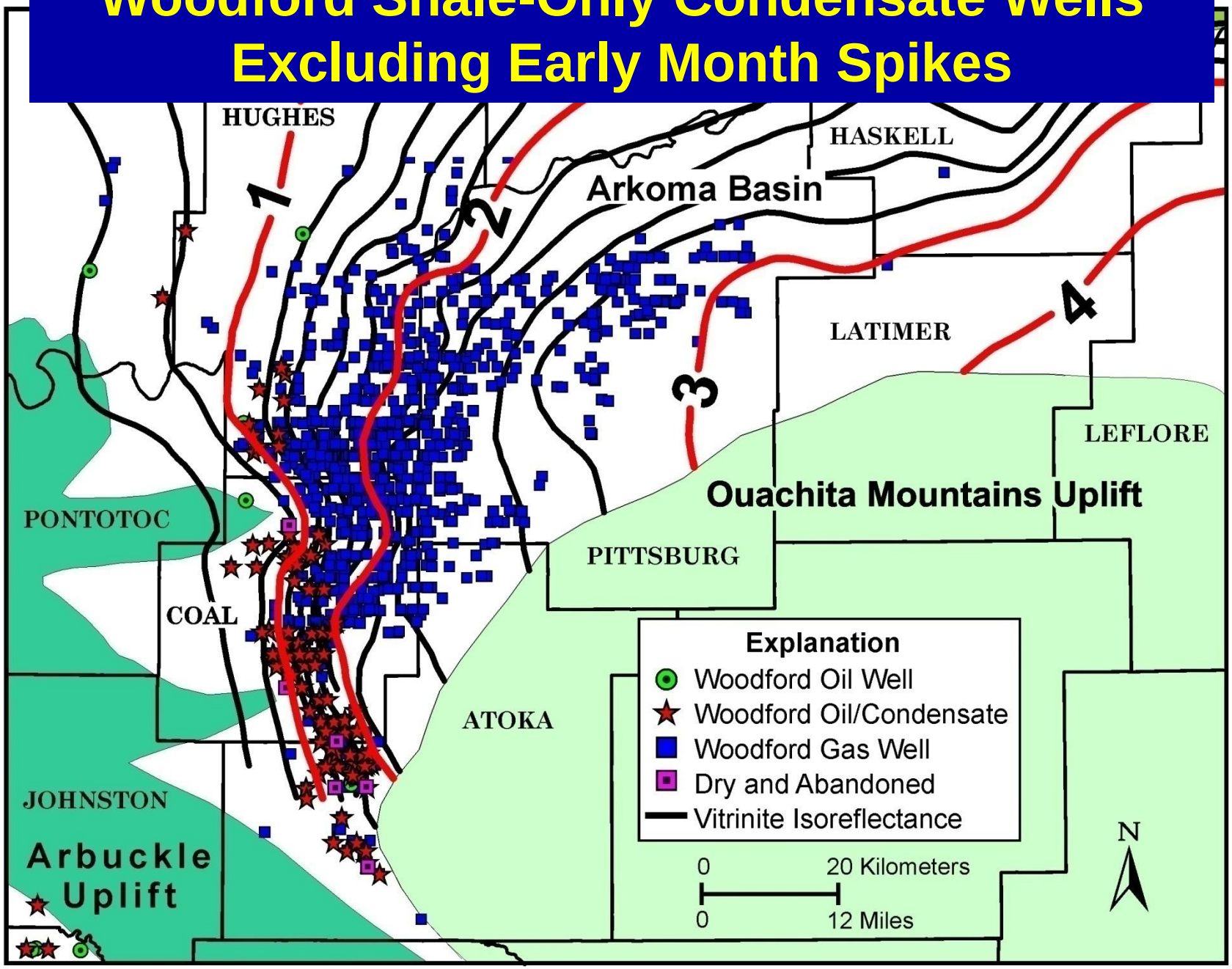
(2) Cimarex 3-34H Hall (34-3N-11E; Coal Co.; IP 1,740 Mcfd)

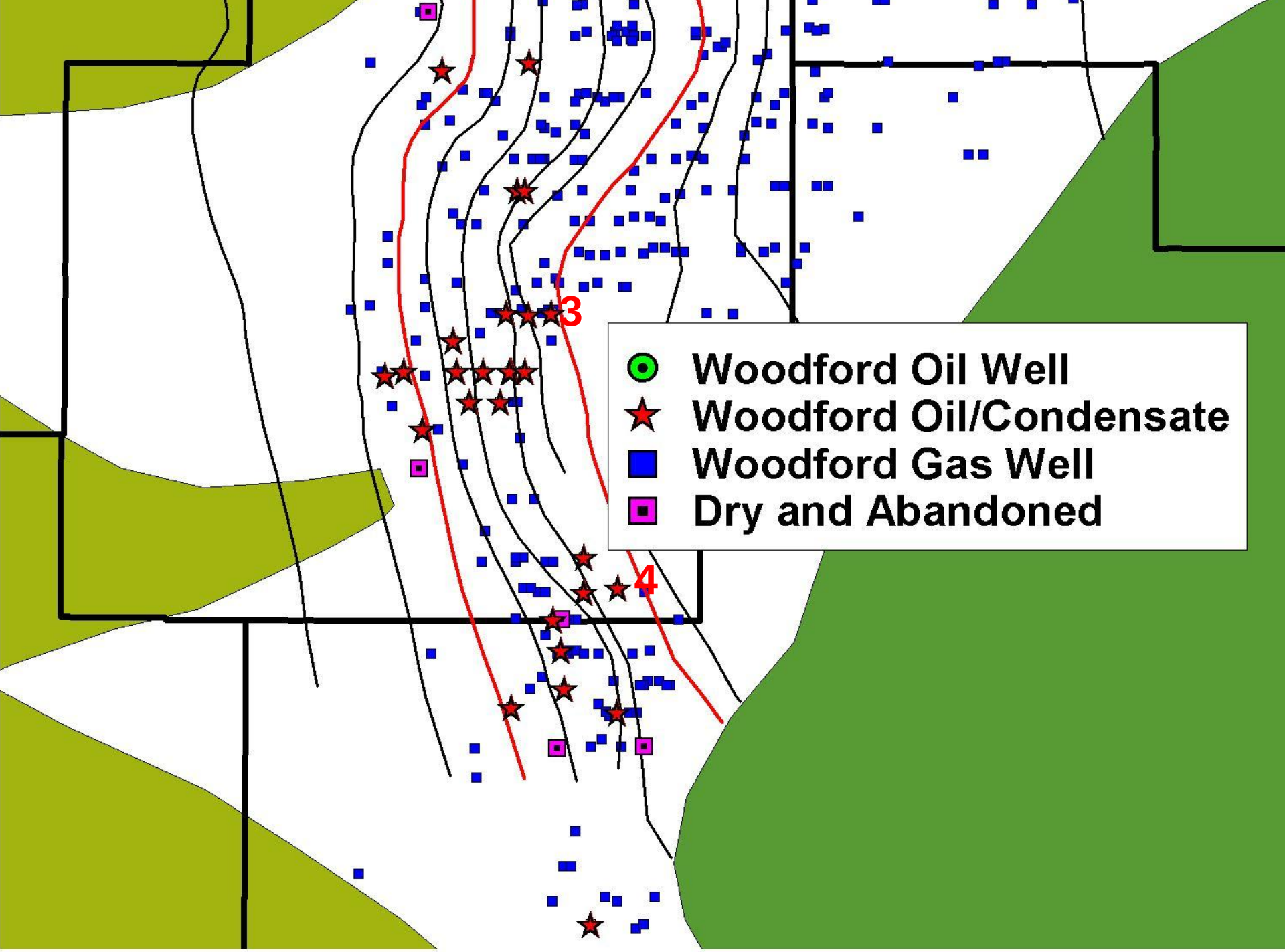


Intermittent liquids production in first few months interpreted as oil-based drilling mud flowback

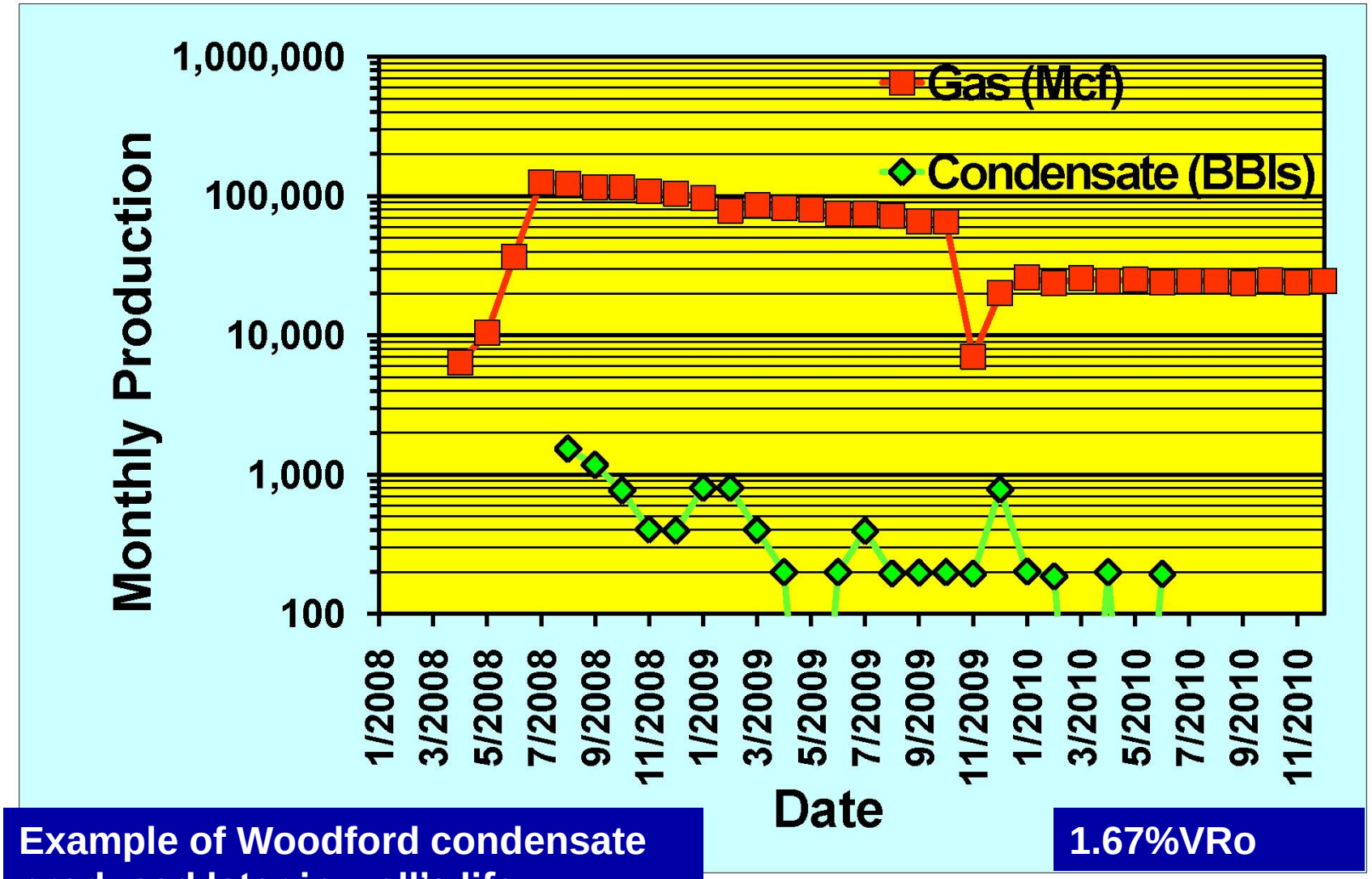
@ 2.05%VRo

Woodford Shale-Only Condensate Wells Excluding Early Month Spikes




3
4
Woodford Oil Well
Woodford Oil/Condensate
Woodford Gas Well
Dry and Abandoned

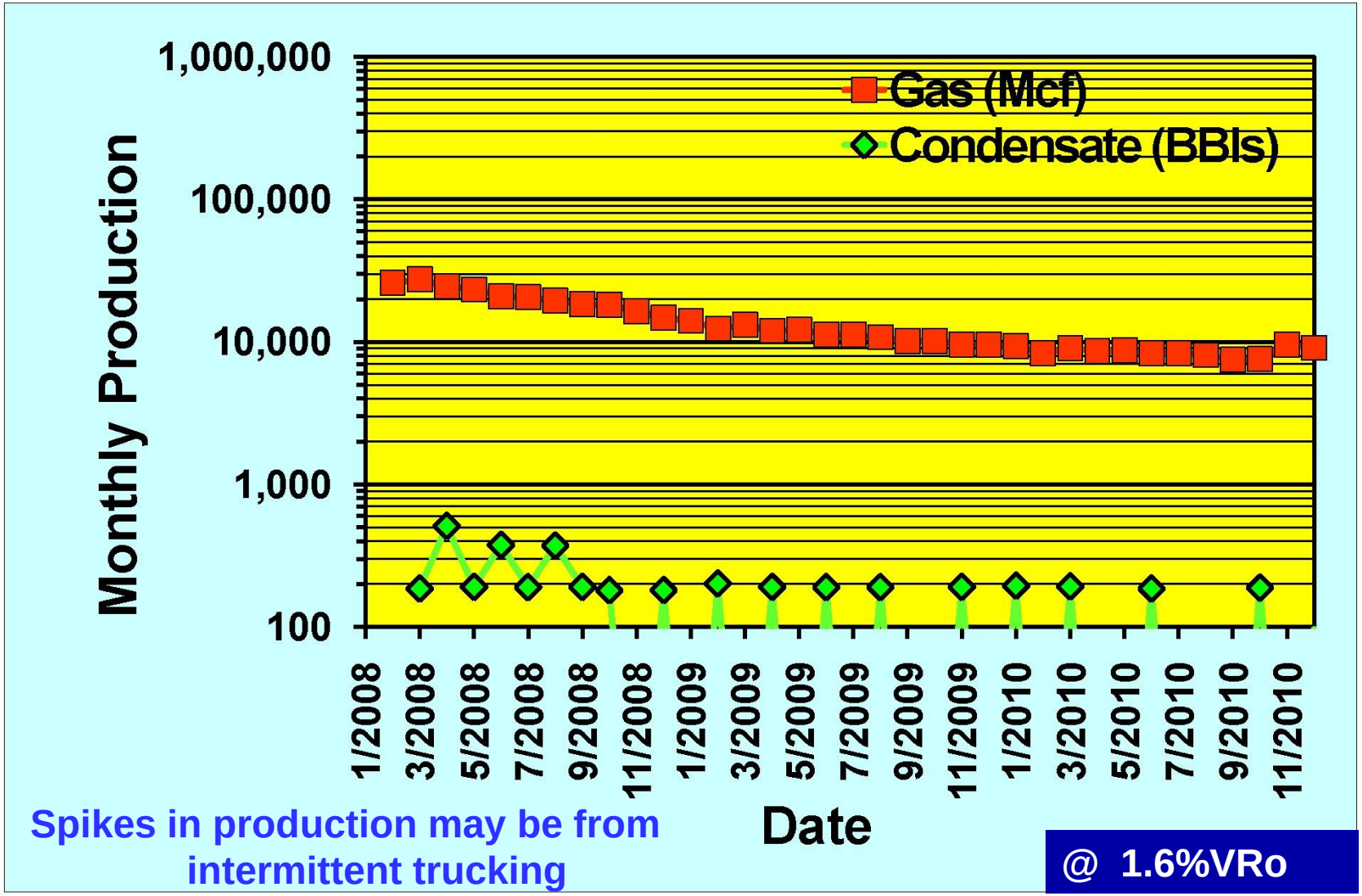
(3) St. Mary Land & Exploration 3-14 Marvin (14-1N-10E; Coal Co.; IP 3,125 Mcfd)



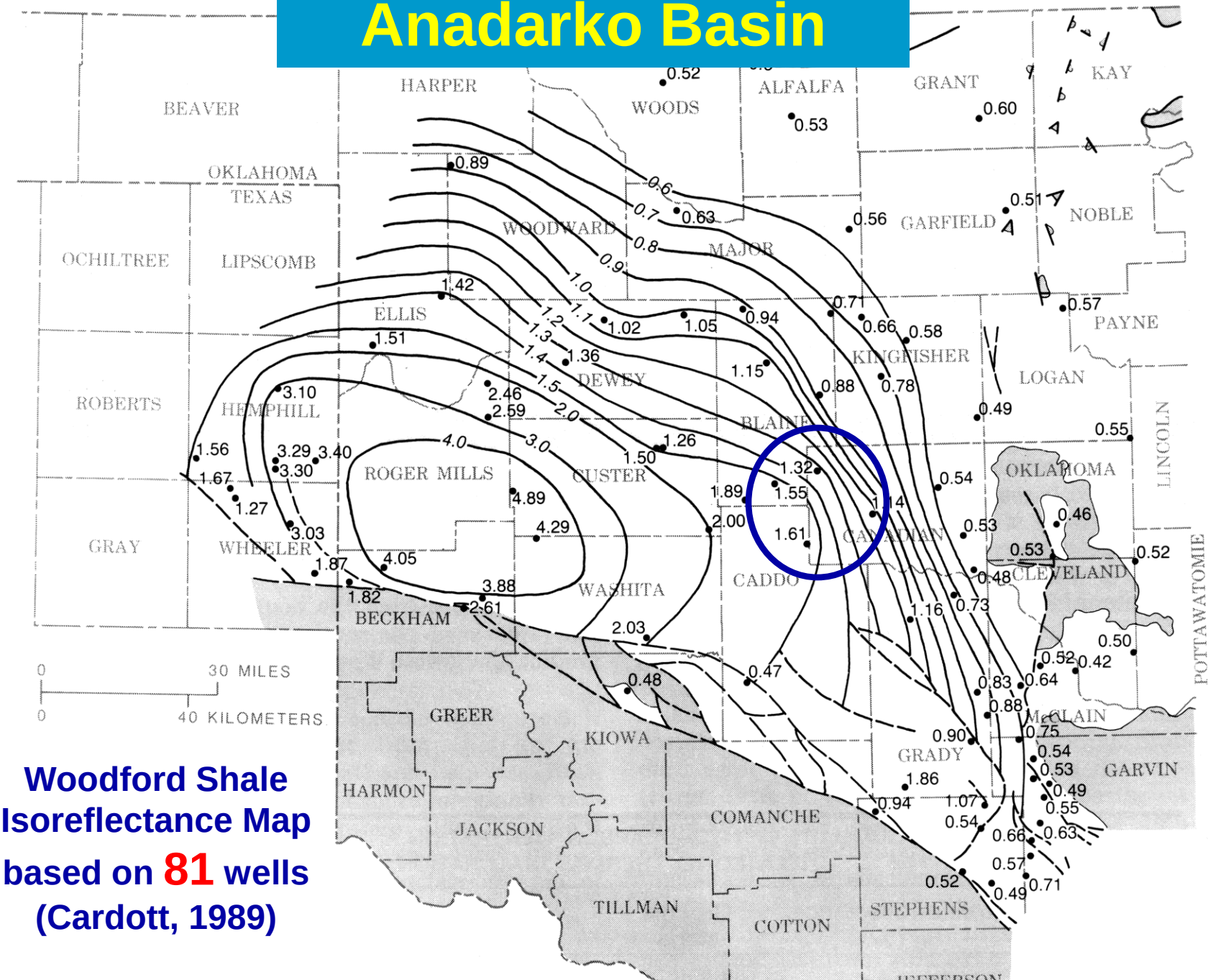
Example of Woodford condensate produced later in well's life

1.67%VRo

(4) Antero 30-1H Harris (30-1S-11E; Coal Co.; IP 1,334 Mcfd)

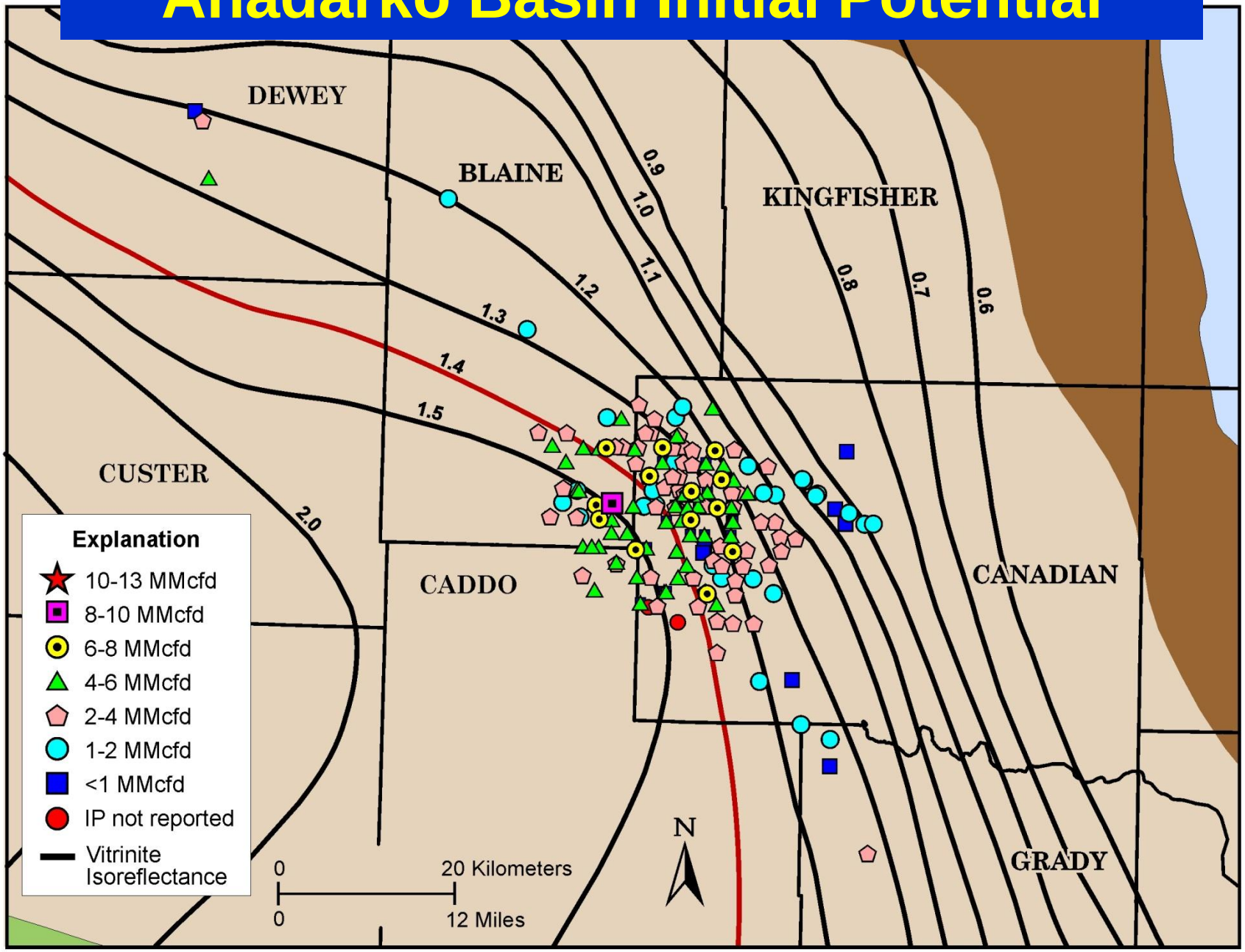


Anadarko Basin

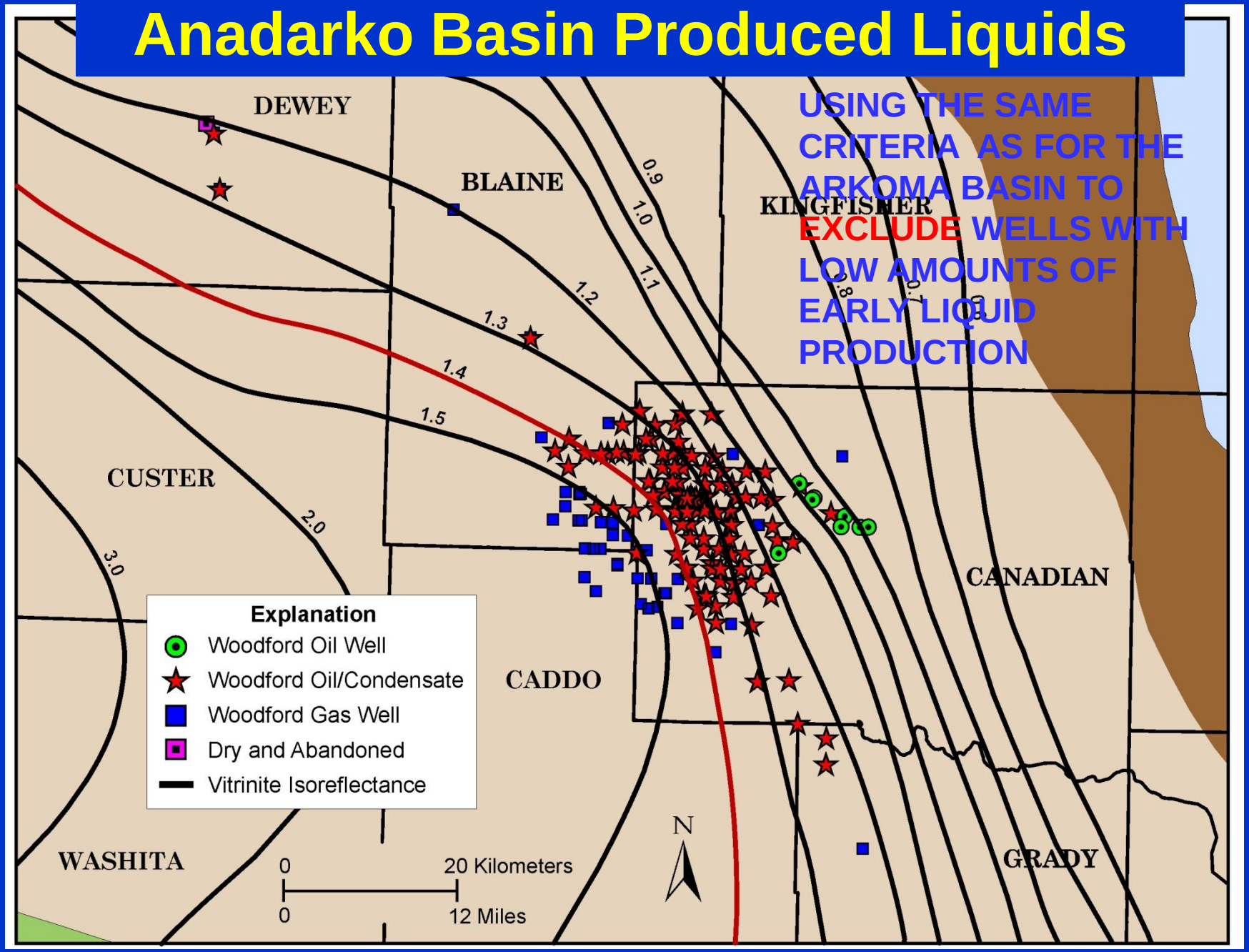


Woodford Shale Isoreflectance Map based on 81 wells (Cardott, 1989)

Anadarko Basin Initial Potential

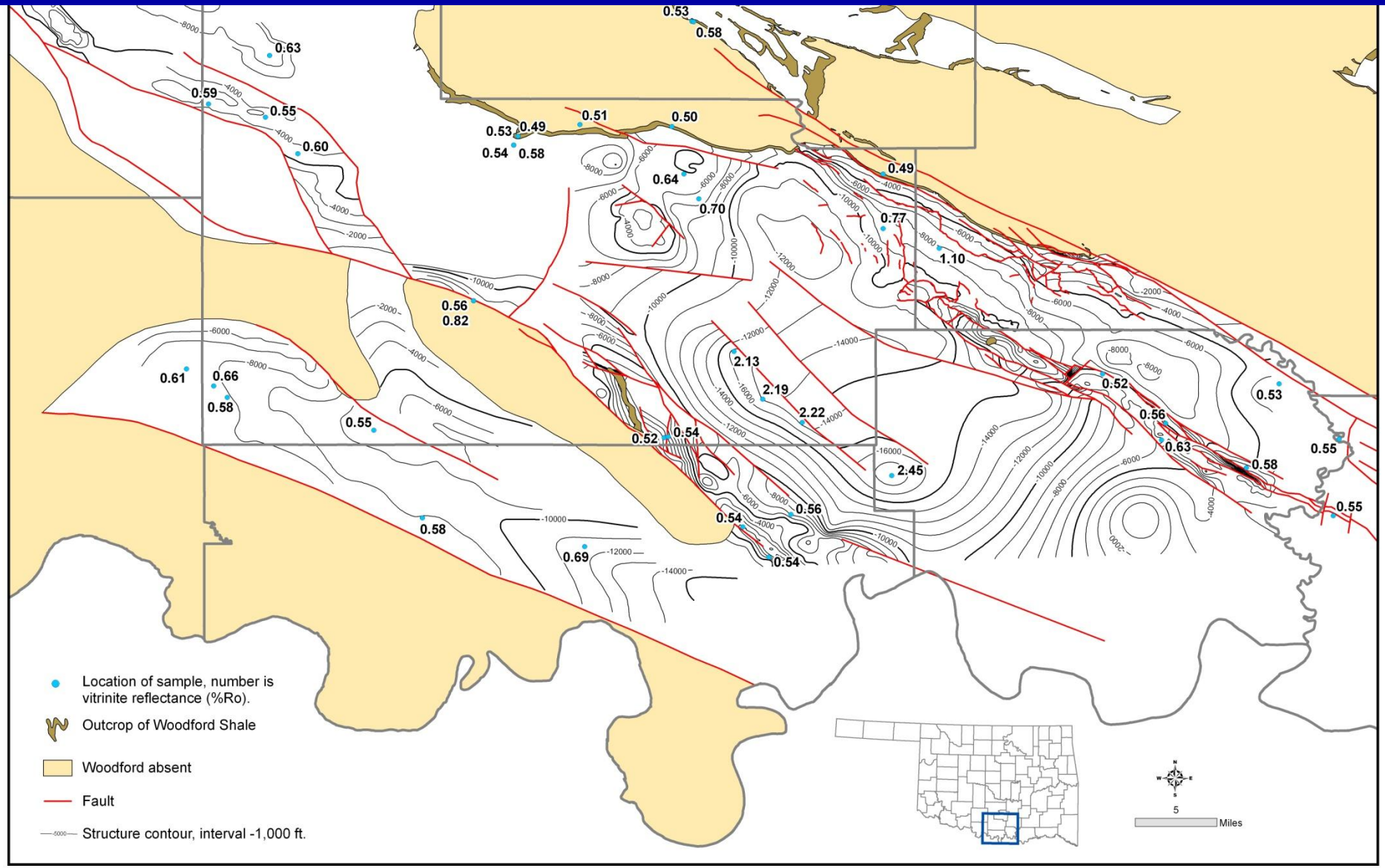


Anadarko Basin Produced Liquids



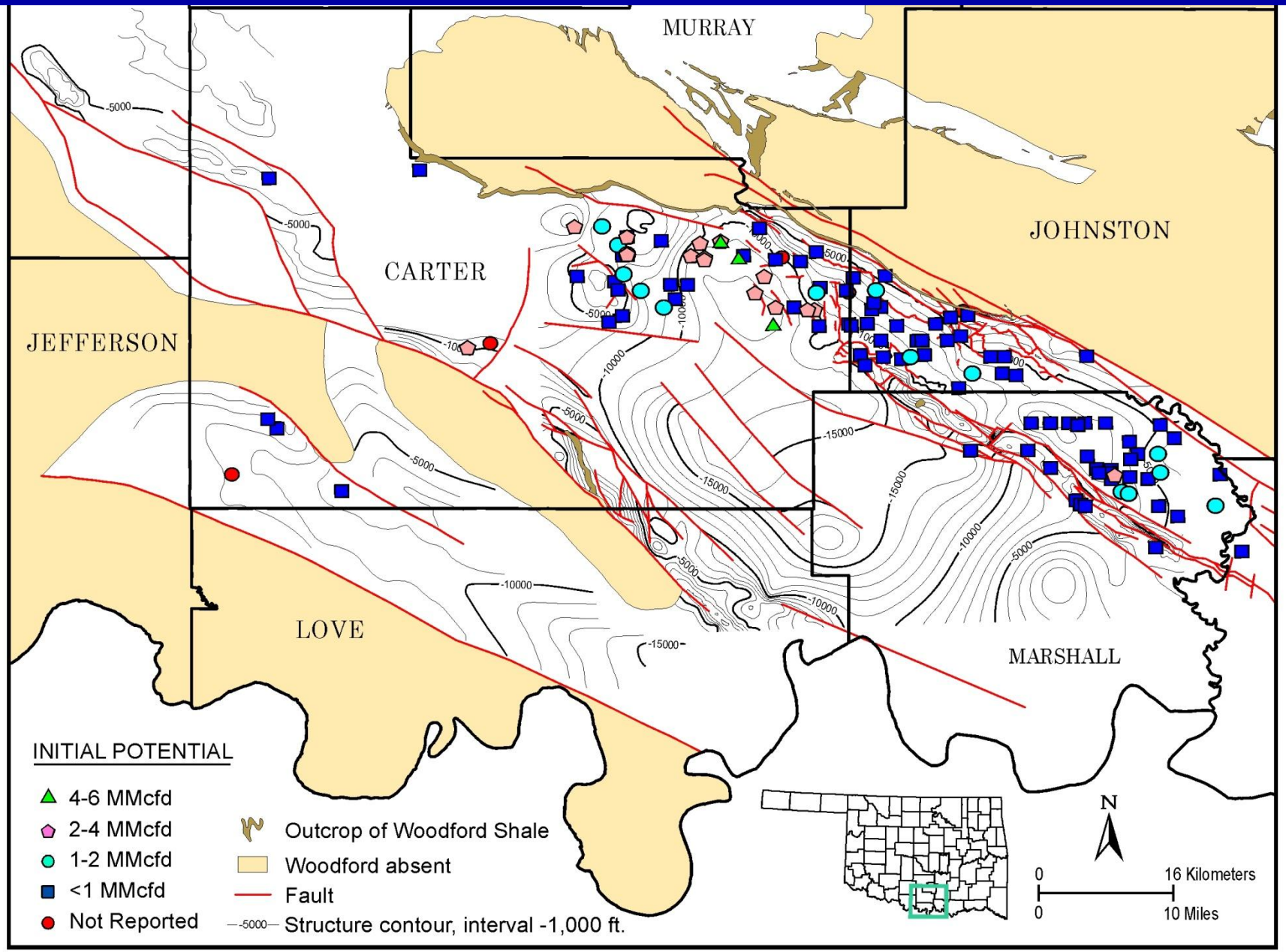
USING THE SAME CRITERIA AS FOR THE ARKOMA BASIN TO EXCLUDE WELLS WITH LOW AMOUNTS OF EARLY LIQUID PRODUCTION

Woodford Shale VRo on Structure



Vitrinite reflectance of Woodford Shale in southern Oklahoma on Woodford Shale structure map (structure modified from Carlyle Hinshaw (1999) and Wagner & Brown (2010); VRo data by Cardott).

Woodford Shale IPs on Structure



Shale Oil Plays

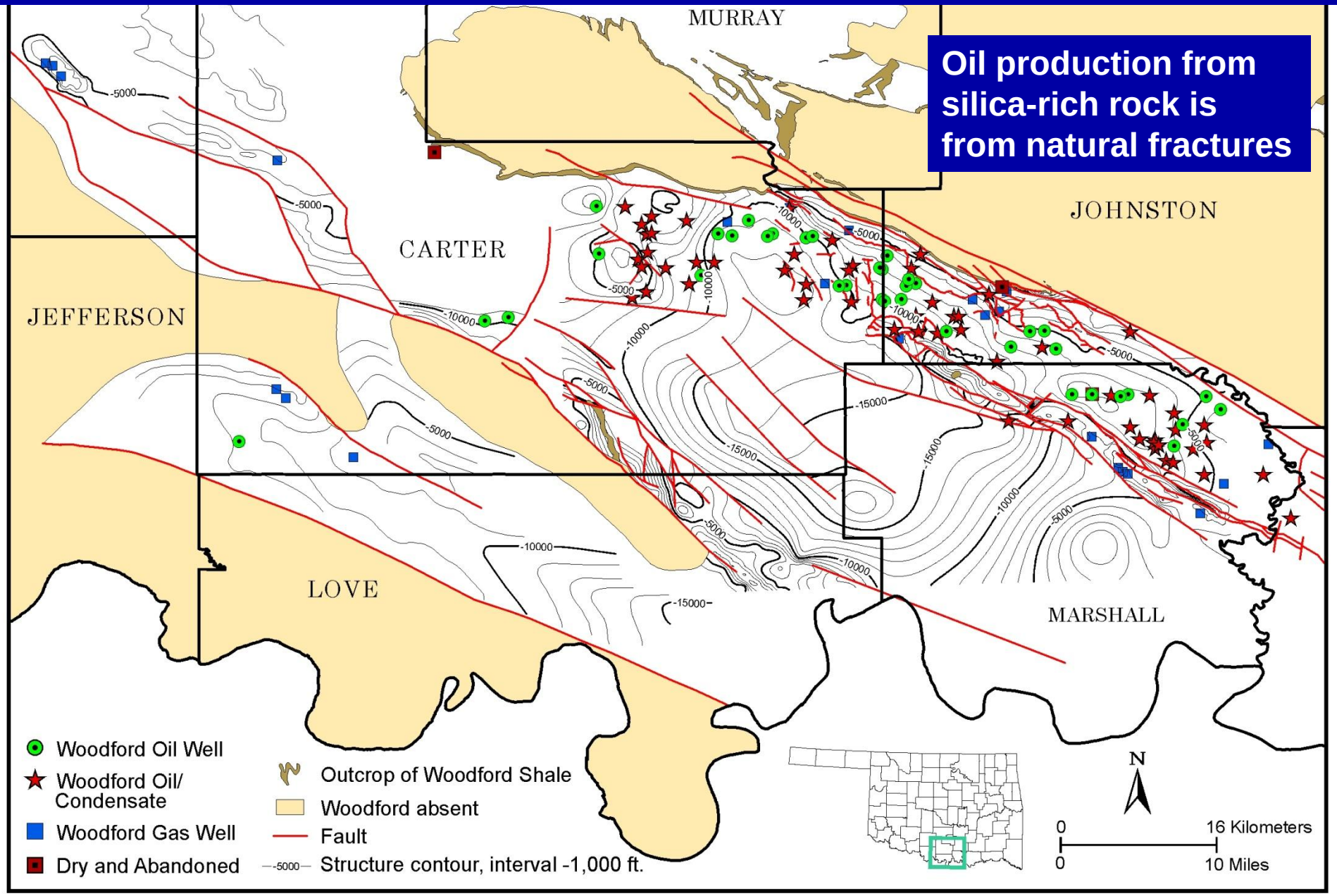
The Bakken Shale (Late Devonian-Early Mississippian; North Dakota & Montana) is the analog for shale oil plays. However, the reservoir of the Bakken is a permeable, non-shale middle member.

Other formations considered shale oil plays (mostly carbonates) are the Eagle Ford Shale (Late Cretaceous; Texas) and Niobrara Shale (Late Cretaceous; Rocky Mountains).

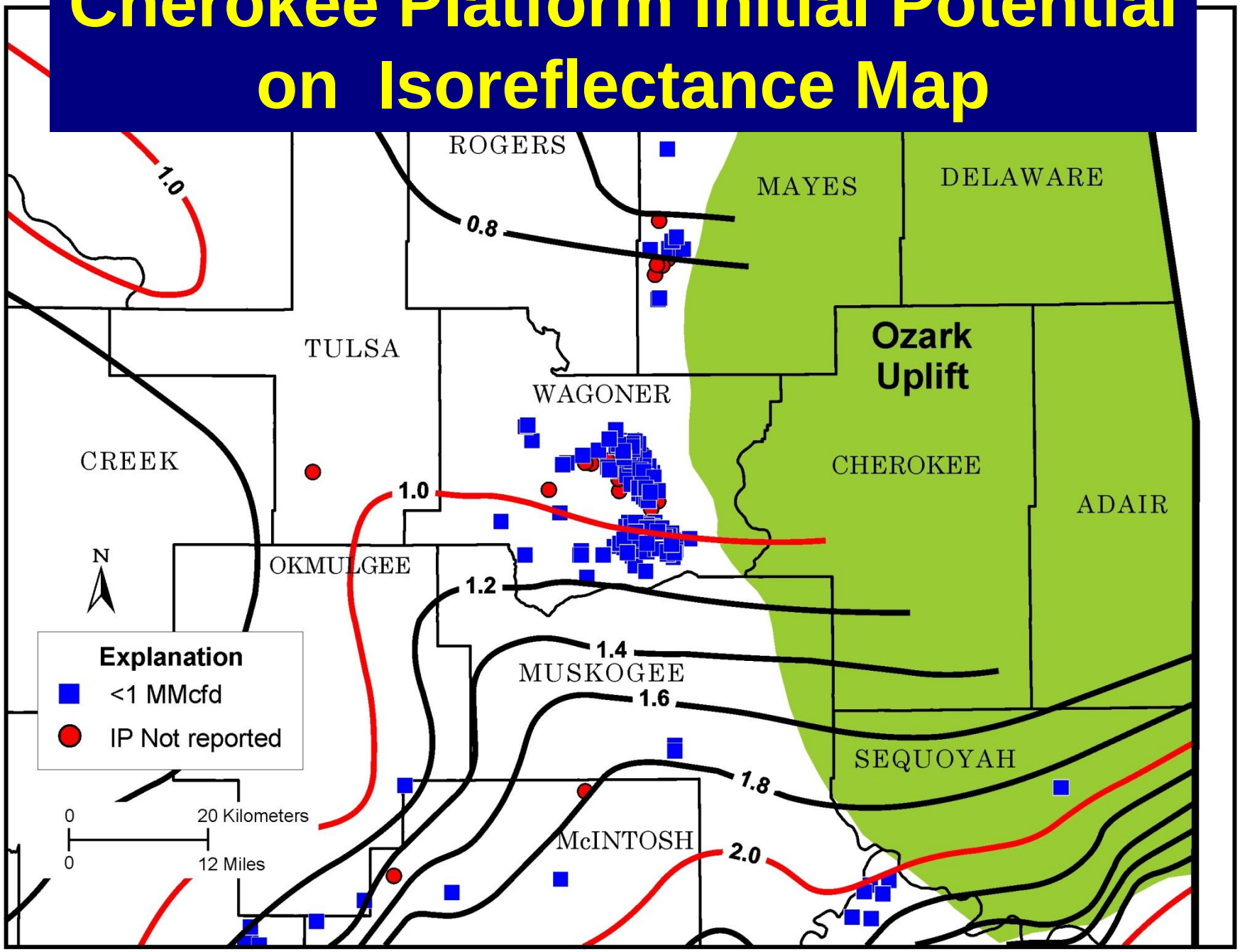
"The preferred rock type for a shale-oil play is a hybrid—that is, a formation with a good mix of non-shale lithologies, particularly carbonates"

(Darbonne, 2011)

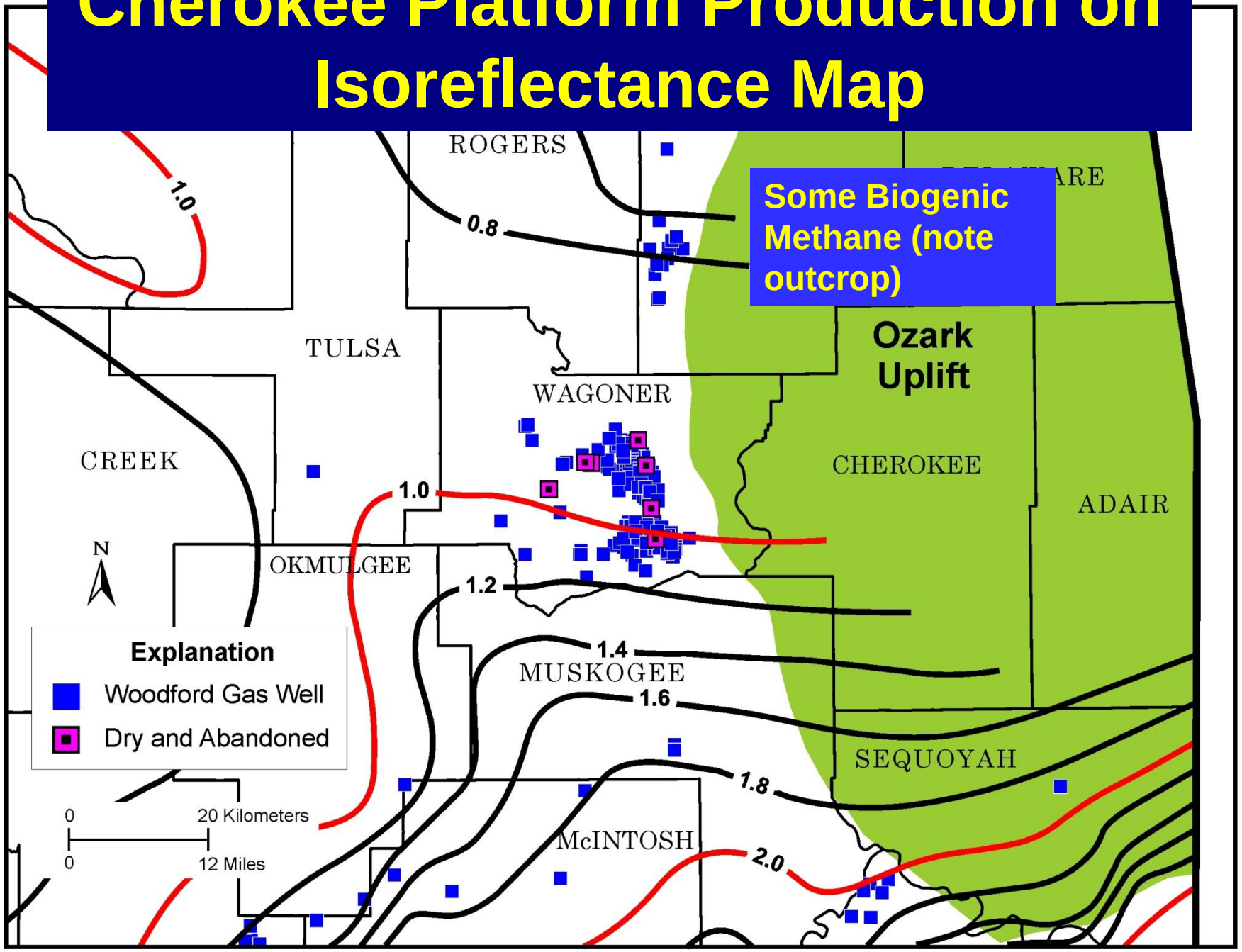
Woodford Production on Structure



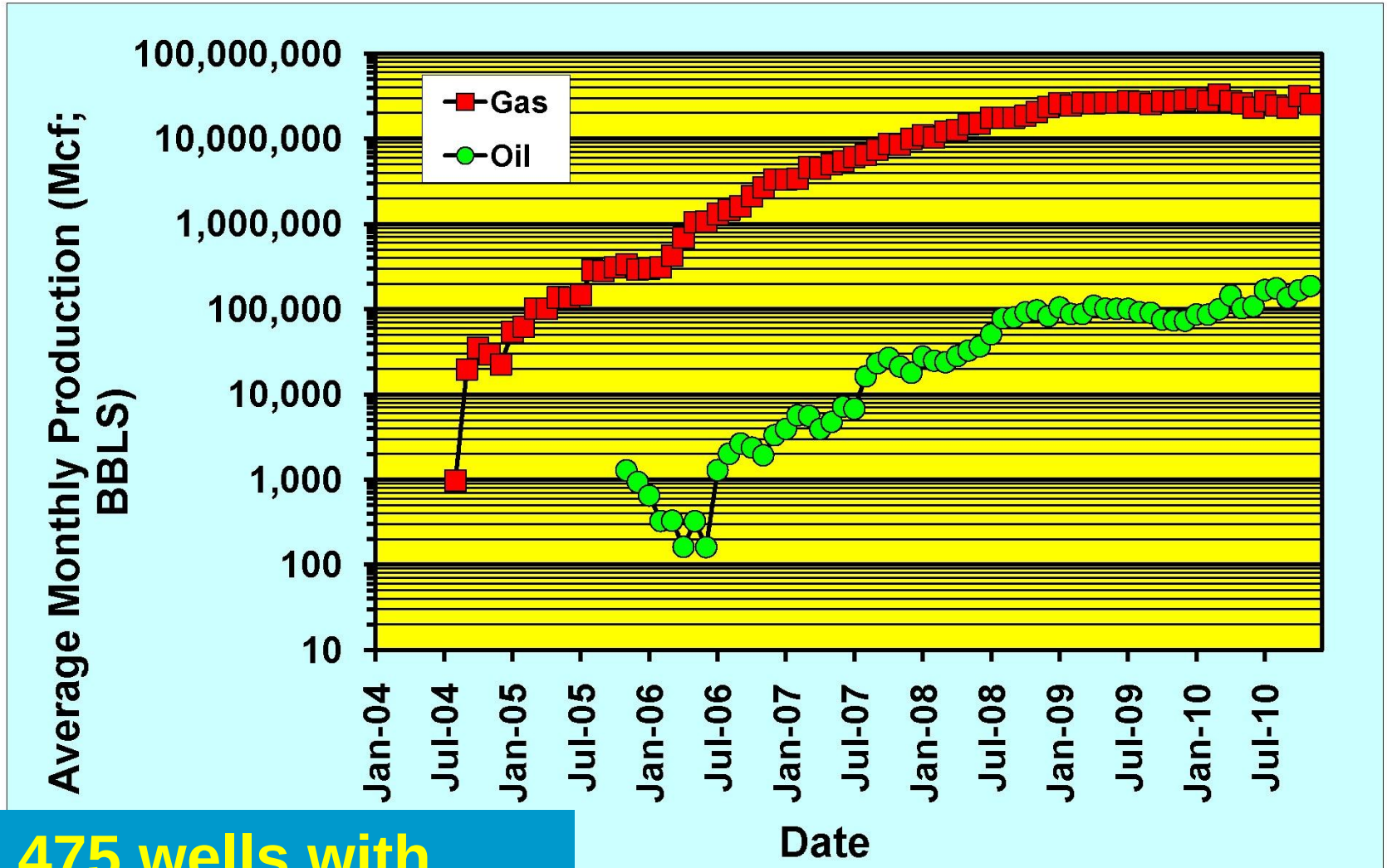
Cherokee Platform Initial Potential on Isoreflectance Map



Cherokee Platform Production on Isoreflectance Map



Woodford-Only Production

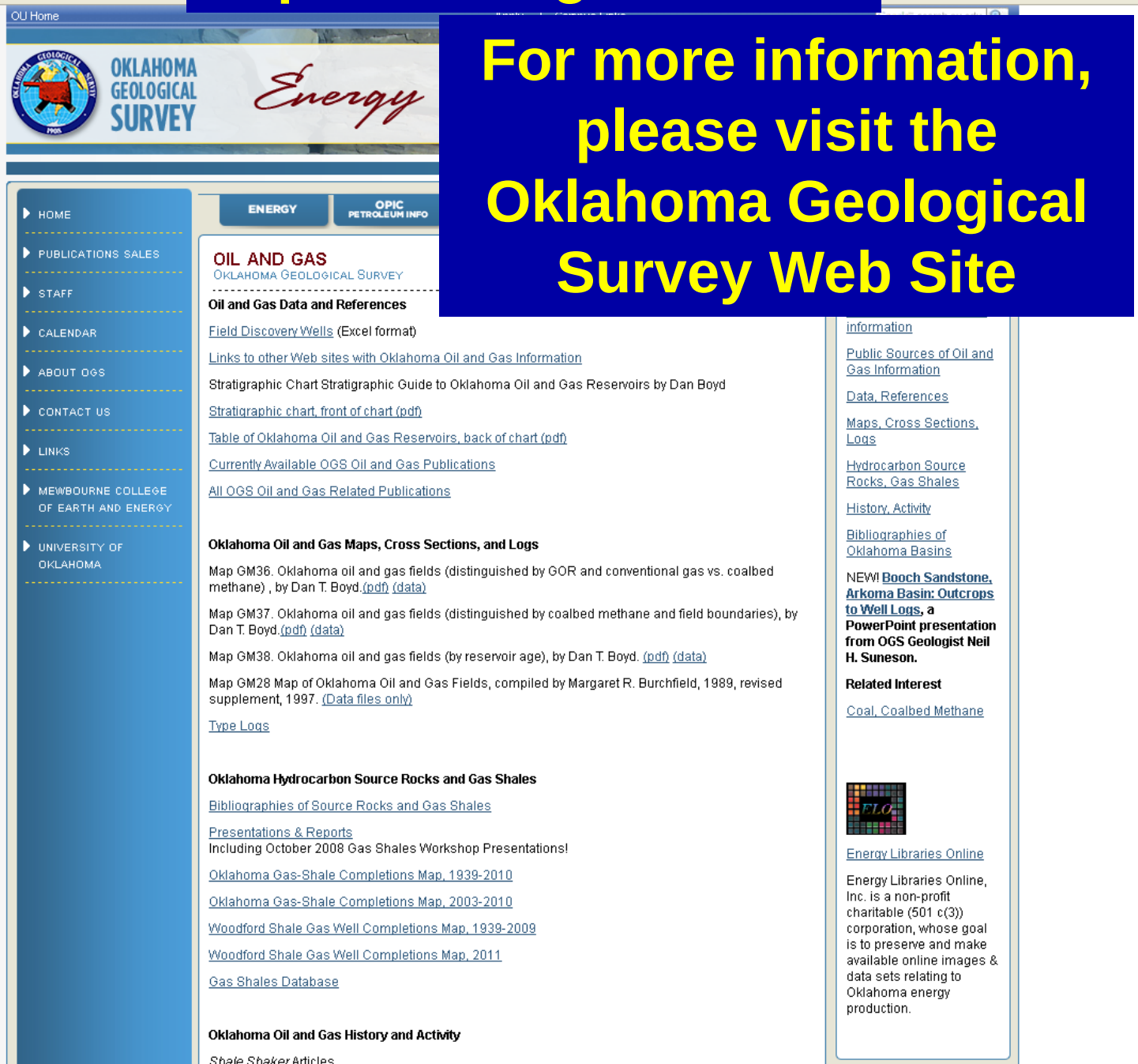


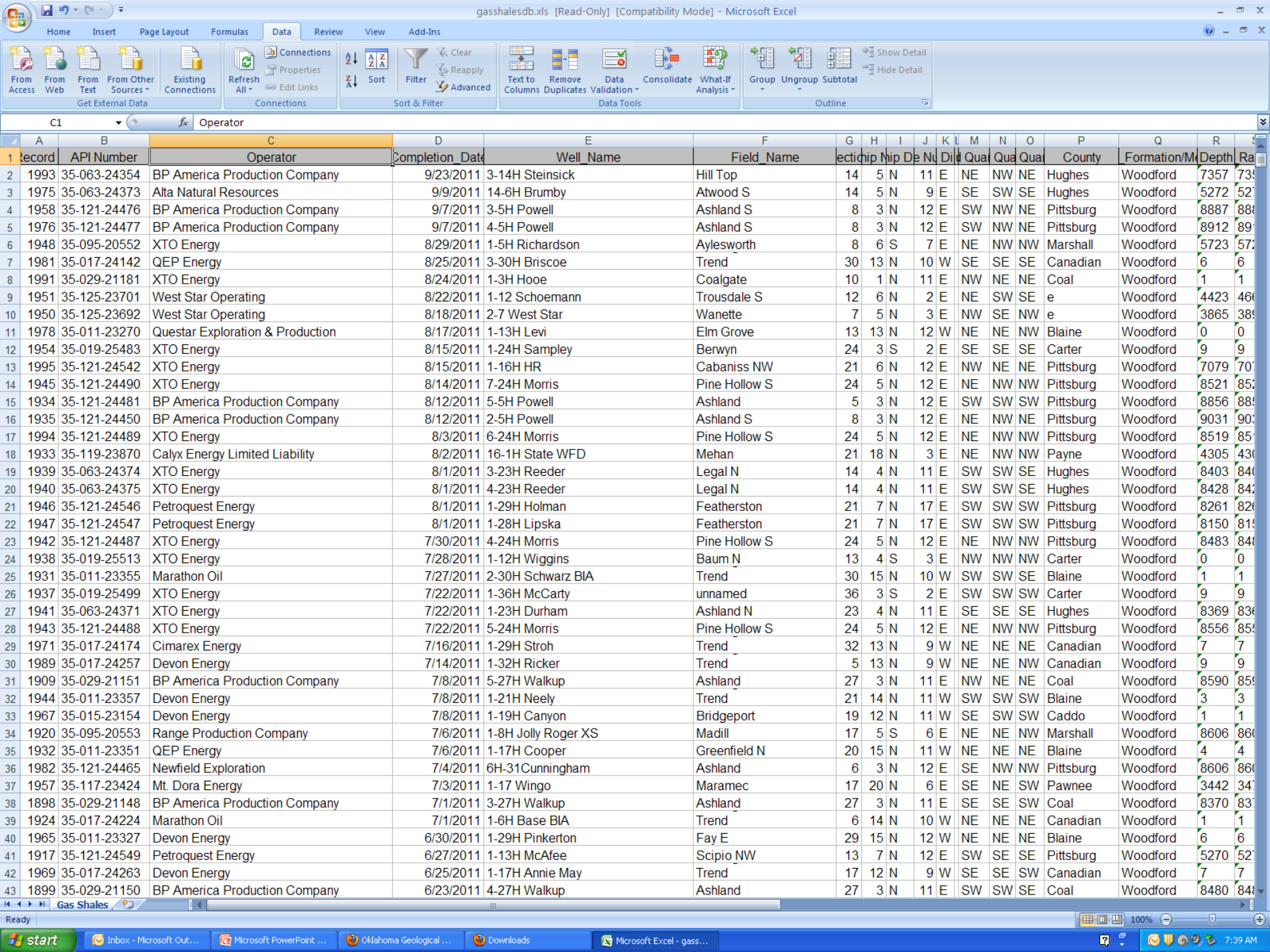
1,475 wells with production data; excludes 55 OWWO

Cumulative: 932 Bcf, 3,701,330 Bo

http://www.ogs.ou.edu

For more information, please visit the Oklahoma Geological Survey Web Site





A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
ecord	API Number	Operator	ompletion_Date	Well_Name	Field_Name	ectio	hip	Nip	De	Nu	Dir	Qua	Qua	Qua	County	Formation/M	Depth	Ra
1993	35-063-24354	BP America Production Company	9/23/2011	3-14H Steinsick	Hill Top	14	5	N	11	E		NE	NW	NE	Hughes	Woodford	7357	73
1975	35-063-24373	Alta Natural Resources	9/9/2011	14-6H Brumby	Atwood S	14	5	N	9	E		SE	SW	SE	Hughes	Woodford	5272	52
1958	35-121-24476	BP America Production Company	9/7/2011	3-5H Powell	Ashland S	8	3	N	12	E		SW	NW	NE	Pittsburg	Woodford	8887	88
1976	35-121-24477	BP America Production Company	9/7/2011	4-5H Powell	Ashland S	8	3	N	12	E		SW	NW	NE	Pittsburg	Woodford	8912	89
1948	35-095-20552	XTO Energy	8/29/2011	1-5H Richardson	Aylesworth	8	6	S	7	E		NE	NW	NW	Marshall	Woodford	5723	57
1981	35-017-24142	QEP Energy	8/25/2011	3-30H Briscoe	Trend	30	13	N	10	W		SE	SE	SE	Canadian	Woodford	6	6
1991	35-029-21181	XTO Energy	8/24/2011	1-3H Hooe	Coalgate	10	1	N	11	E		NW	NE	NE	Coal	Woodford	1	1
1951	35-125-23701	West Star Operating	8/22/2011	1-12 Schoemann	Trousdale S	12	6	N	2	E		NE	SW	SE	e	Woodford	4423	46
1950	35-125-23692	West Star Operating	8/18/2011	2-7 West Star	Wanette	7	5	N	3	E		NW	SE	NW	e	Woodford	3865	38
1978	35-011-23270	Questar Exploration & Production	8/17/2011	1-13H Levi	Elm Grove	13	13	N	12	W		NE	NE	NW	Blaine	Woodford	0	0
1954	35-019-25483	XTO Energy	8/15/2011	1-24H Sampley	Berwyn	24	3	S	2	E		SE	SE	SE	Carter	Woodford	9	9
1995	35-121-24542	XTO Energy	8/15/2011	1-16H HR	Cabaniss NW	21	6	N	12	E		NW	NE	NE	Pittsburg	Woodford	7079	70
1945	35-121-24490	XTO Energy	8/14/2011	7-24H Morris	Pine Hollow S	24	5	N	12	E		NE	NW	NW	Pittsburg	Woodford	8521	85
1934	35-121-24481	BP America Production Company	8/12/2011	5-5H Powell	Ashland	5	3	N	12	E		SW	SW	SW	Pittsburg	Woodford	8856	88
1935	35-121-24450	BP America Production Company	8/12/2011	2-5H Powell	Ashland S	8	3	N	12	E		NE	NW	NE	Pittsburg	Woodford	9031	90
1994	35-121-24489	XTO Energy	8/3/2011	6-24H Morris	Pine Hollow S	24	5	N	12	E		NE	NW	NW	Pittsburg	Woodford	8519	85
1933	35-119-23870	Calyx Energy Limited Liability	8/2/2011	16-1H State WFD	Mehan	21	18	N	3	E		NE	NW	NW	Payne	Woodford	4305	43
1939	35-063-24374	XTO Energy	8/1/2011	3-23H Reeder	Legal N	14	4	N	11	E		SW	SW	SE	Hughes	Woodford	8403	84
1940	35-063-24375	XTO Energy	8/1/2011	4-23H Reeder	Legal N	14	4	N	11	E		SW	SW	SE	Hughes	Woodford	8428	84
1946	35-121-24546	Petroquest Energy	8/1/2011	1-29H Holman	Featherston	21	7	N	17	E		SW	SW	SW	Pittsburg	Woodford	8261	82
1947	35-121-24547	Petroquest Energy	8/1/2011	1-28H Lipska	Featherston	21	7	N	17	E		SW	SW	SW	Pittsburg	Woodford	8150	81
1942	35-121-24487	XTO Energy	7/30/2011	4-24H Morris	Pine Hollow S	24	5	N	12	E		NE	NW	NW	Pittsburg	Woodford	8483	84
1938	35-019-25513	XTO Energy	7/28/2011	1-12H Wiggins	Baum N	13	4	S	3	E		NW	NW	NW	Carter	Woodford	0	0
1931	35-011-23355	Marathon Oil	7/27/2011	2-30H Schwarz BIA	Trend	30	15	N	10	W		SW	SW	SE	Blaine	Woodford	1	1
1937	35-019-25499	XTO Energy	7/22/2011	1-36H McCarty	unnamed	36	3	S	2	E		SW	SW	SW	Carter	Woodford	9	9
1941	35-063-24371	XTO Energy	7/22/2011	1-23H Durham	Ashland N	23	4	N	11	E		SE	SE	SE	Hughes	Woodford	8369	83
1943	35-121-24488	XTO Energy	7/22/2011	5-24H Morris	Pine Hollow S	24	5	N	12	E		NE	NW	NW	Pittsburg	Woodford	8556	85
1971	35-017-24174	Cimarex Energy	7/16/2011	1-29H Stroh	Trend	32	13	N	9	W		NE	NE	NE	Canadian	Woodford	7	7
1989	35-017-24257	Devon Energy	7/14/2011	1-32H Ricker	Trend	5	13	N	9	W		NE	NE	NW	Canadian	Woodford	9	9
1909	35-029-21151	BP America Production Company	7/8/2011	5-27H Walkup	Ashland	27	3	N	11	E		NW	NE	NE	Coal	Woodford	8590	85
1944	35-011-23357	Devon Energy	7/8/2011	1-21H Neely	Trend	21	14	N	11	W		SW	SW	SW	Blaine	Woodford	3	3
1967	35-015-23154	Devon Energy	7/8/2011	1-19H Canyon	Bridgeport	19	12	N	11	W		SE	SW	SW	Caddo	Woodford	1	1
1920	35-095-20553	Range Production Company	7/6/2011	1-8H Jolly Roger XS	Madill	17	5	S	6	E		NE	NE	NW	Marshall	Woodford	8606	86
1932	35-011-23351	QEP Energy	7/6/2011	1-17H Cooper	Greenfield N	20	15	N	11	W		NE	NE	NE	Blaine	Woodford	4	4
1982	35-121-24465	Newfield Exploration	7/4/2011	6H-31Cunningham	Ashland	6	3	N	12	E		SE	NW	NW	Pittsburg	Woodford	8606	86
1957	35-117-23424	Mt. Dora Energy	7/3/2011	1-17 Wingo	Maramec	17	20	N	6	E		SE	NE	SW	Pawnee	Woodford	3442	34
1898	35-029-21148	BP America Production Company	7/1/2011	3-27H Walkup	Ashland	27	3	N	11	E		SE	SE	SW	Coal	Woodford	8370	83
1924	35-017-24224	Marathon Oil	7/1/2011	1-6H Base BIA	Trend	6	14	N	10	W		NE	NE	NE	Canadian	Woodford	1	1
1965	35-011-23327	Devon Energy	6/30/2011	1-29H Pinkerton	Fay E	29	15	N	12	W		NE	NE	NE	Blaine	Woodford	6	6
1917	35-121-24549	Petroquest Energy	6/27/2011	1-13H McAfee	Scipio NW	13	7	N	12	E		SW	SE	SE	Pittsburg	Woodford	5270	52
1969	35-017-24263	Devon Energy	6/25/2011	1-17H Annie May	Trend	17	12	N	9	W		SE	SE	SW	Canadian	Woodford	7	7
1899	35-029-21150	BP America Production Company	6/23/2011	4-27H Walkup	Ashland	27	3	N	11	E		SW	SW	SE	Coal	Woodford	8480	84