Oklahoma Shale Gas and Oil Workshop

November 20, 2013

Overview of Oklahoma Shale Resource Plays

Brian J. Cardott

Oklahoma Geological Survey

Outline of Presentation

- Basic parameters needed for shale resource plays
- Known hydrocarbon source rocks of Oklahoma
- Oklahoma Shale Gas and Oil Wells
- Evaluation (oldest to youngest) of Sylvan, Arkansas Novaculite, Woodford, Caney, Barnett, Atoka, and Pennsylvanian shales

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

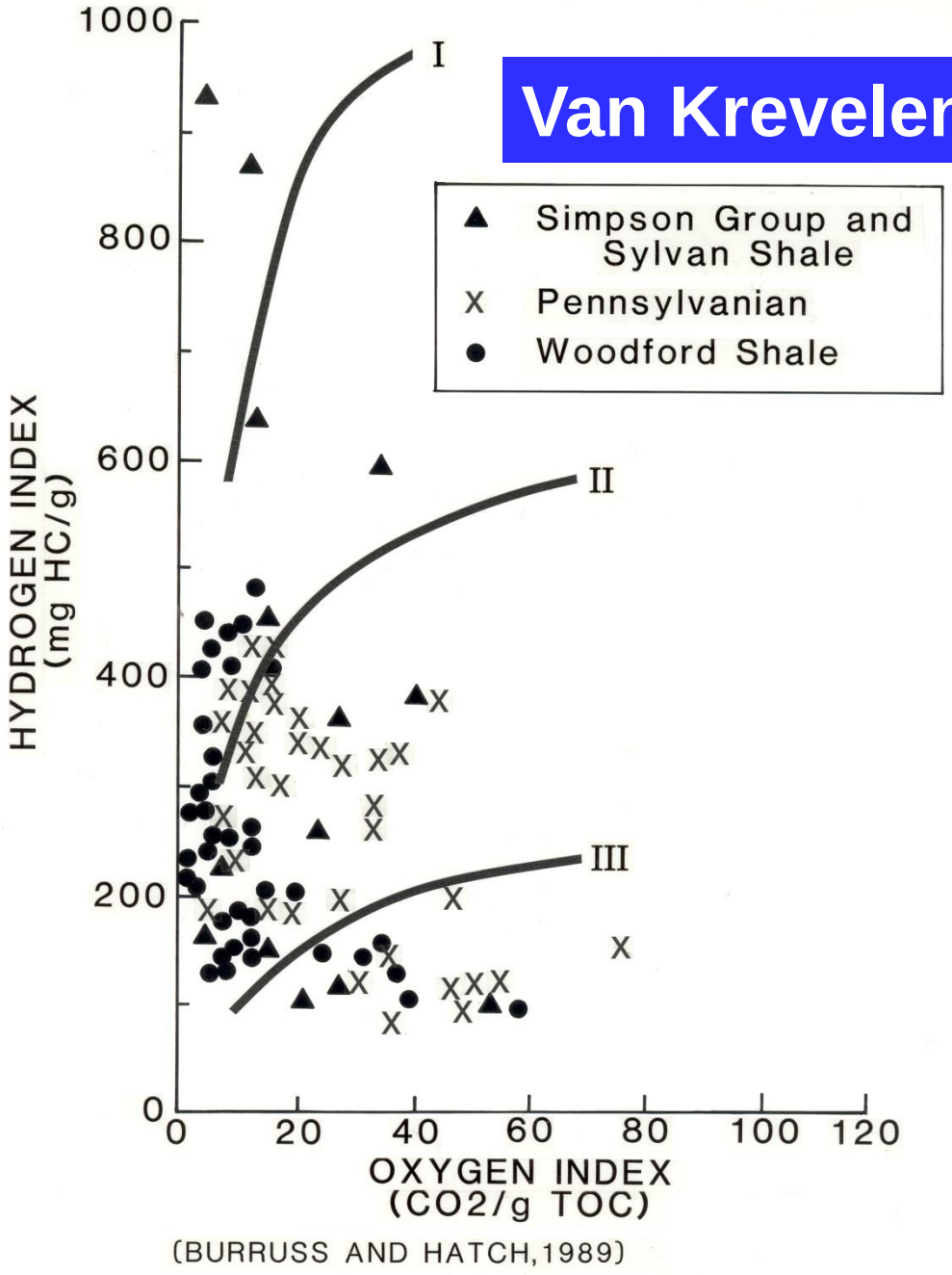
Known Hydrocarbon Source Rocks of Oklahoma

SYSTEM	PRODUCING INTERVAL	HYDROCARBON-SOURCE ROCK	KEROGEN TYPE	TOC %
PERMIAN	PERMIAN (UNDIFFERENTIATED)			
PENNSYLVANIAN	VIRGILIAN	UPPER AND MIDDLE PENNSYLVANIAN	II III	<1-25
	DESMOINESIAN			
	ATOKAN			
	MORROWAN	MORROWAN	III	0.5-3.4
MISSISSIPPIAN	SPRINGER FORMATION	SPRINGER FORMATION	III	
		Caney	II	1-8
	PRE-CHESTER MISSISSIPPIAN (UNDIFFERENTIATED)	WOODFORD SHALE	II III	<1-14
DEVONIAN	HUNTON GROUP			
SILURIAN				
ORDOVICIAN	SIMPSON GROUP	SYLVAN SIMPSON GROUP	II I II	<1-9
UPPER CAMBRIAN	ARBUCKLE GROUP			

Best Ordovician samples are from Kansas

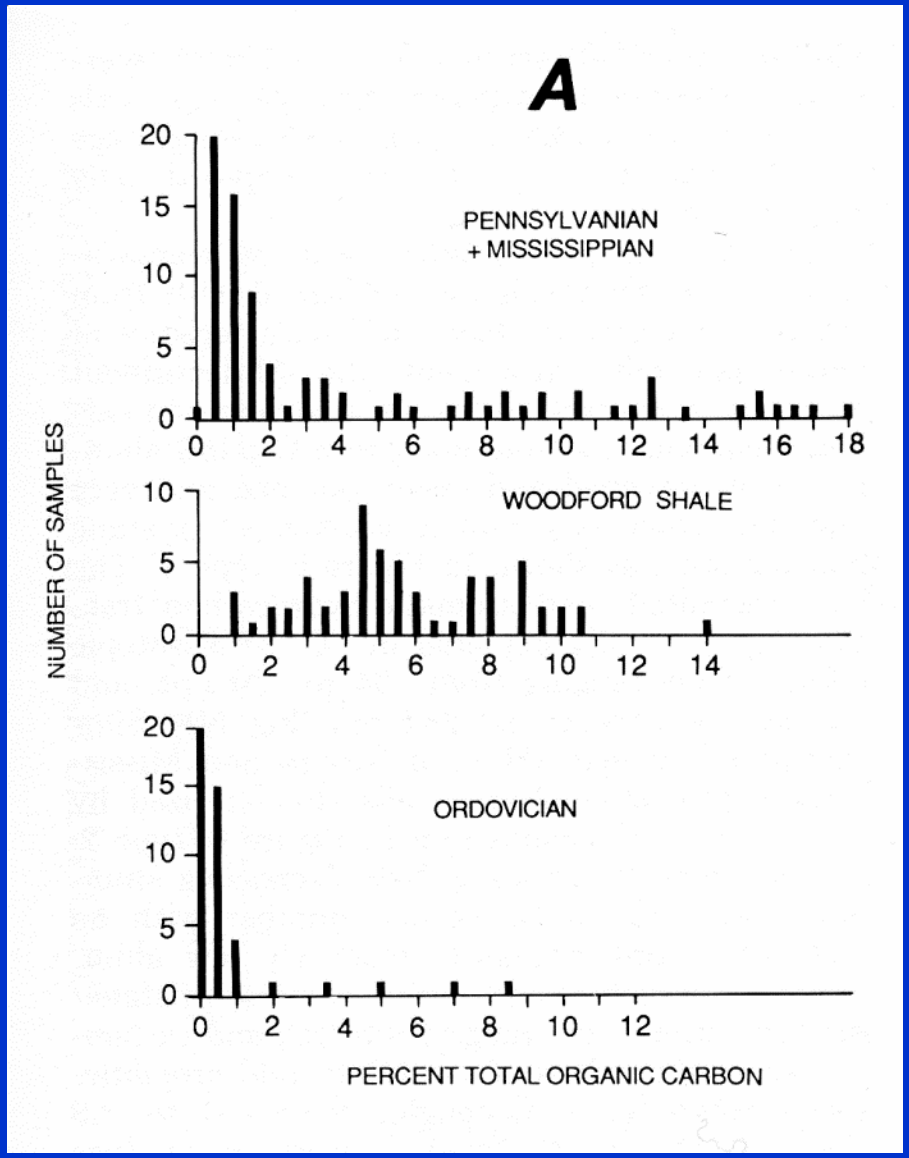
Modified from Johnson and Cardott, 1992

Van Krevelen Type Diagram



Anadarko Basin oil and hydrocarbon source-rock study by Burruss and Hatch, 1989

Anadarko Basin Source-Rock TOC



Burruss and Hatch, 1989

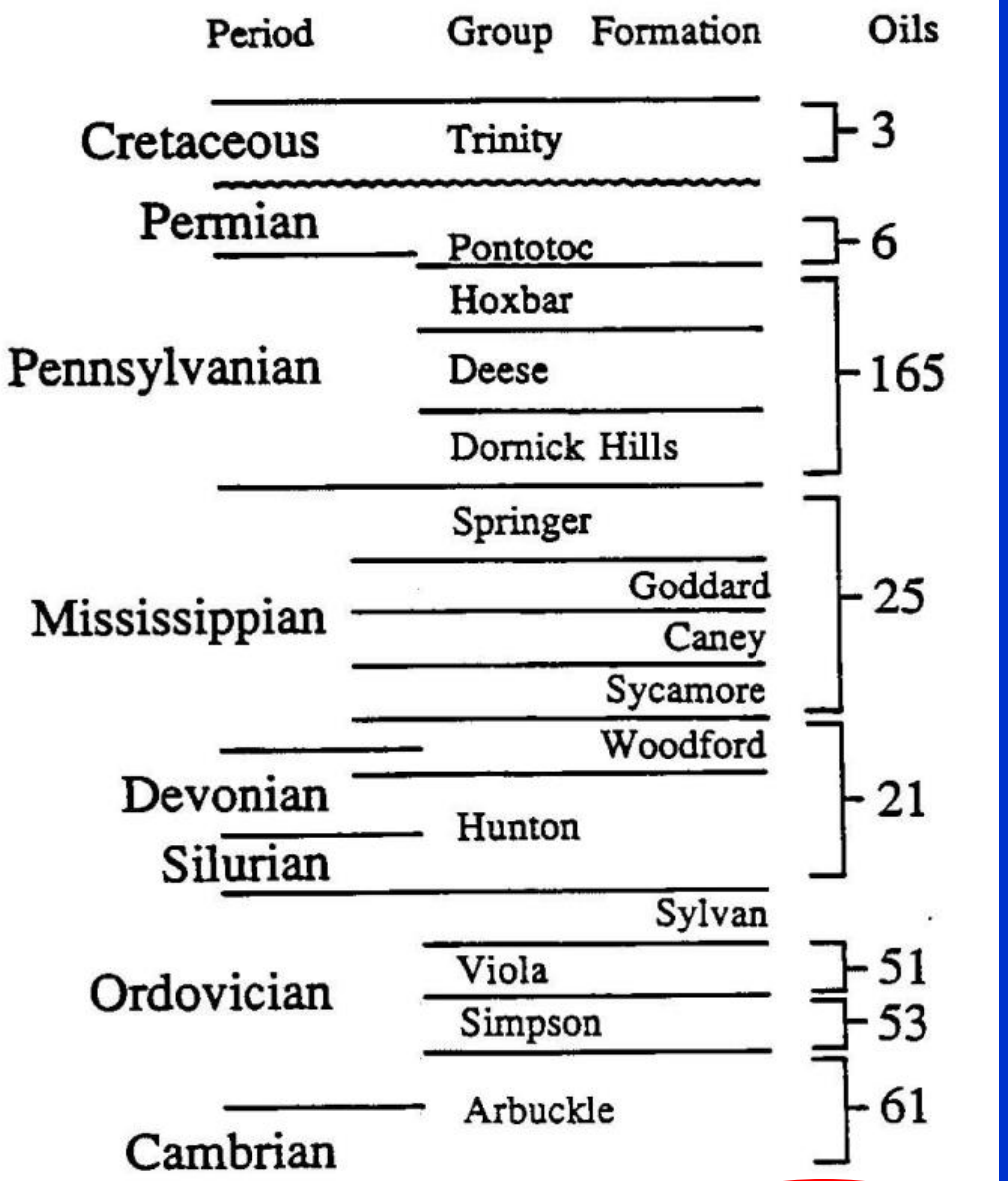


Figure 2. Stratigraphic distribution of 385 oil samples.

Wavrek, D.A., 1992, Characterization of oil types in the Ardmore and Marietta Basins, southern Oklahoma aulacogen: OGS Circular 93, p. 185-195.

Wavrek, 1992

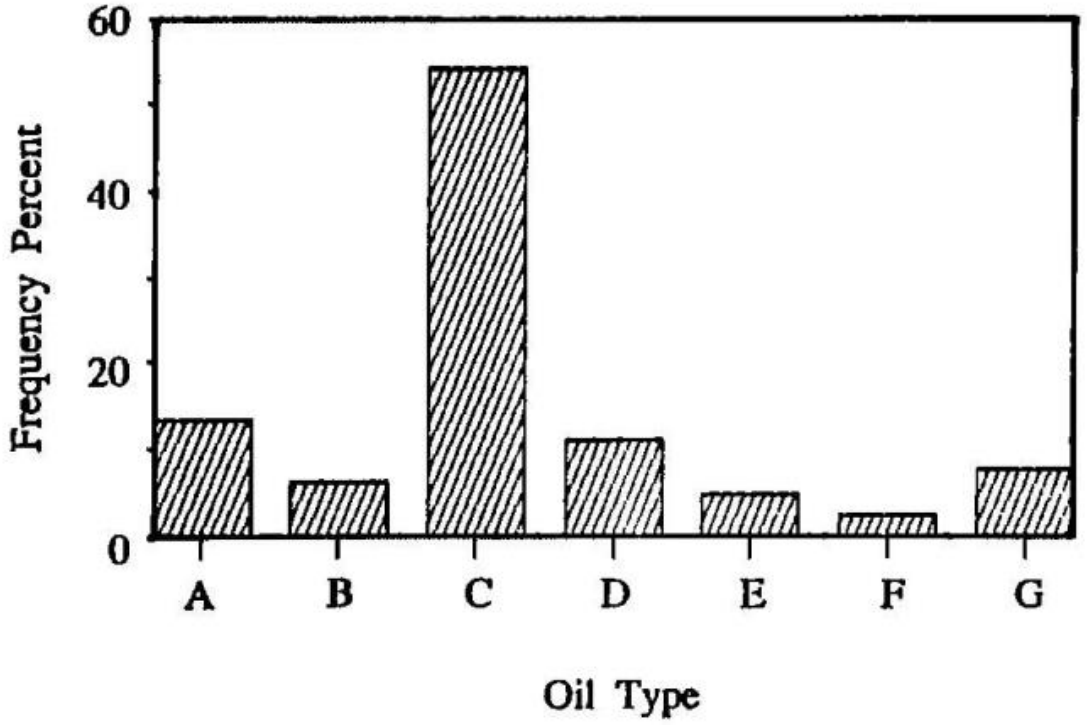


Figure 11. Frequency distribution of oil types reservoired in the Ardmore and Marietta basins.

Source Facies:

A	Pennsylvanian (Atoka?)
B	Mississippian (Goddard, Caney, Sycamore)
C	Devonian-Mississippian (Woodford)
D	Upper Ordovician (Viola Group)
E	Middle Ordovician (Simpson Group)
F & G	Mixed

Wavrek, 1992

Anadarko Basin Source Rock and Oil Study (Wang and Philp, 1997)

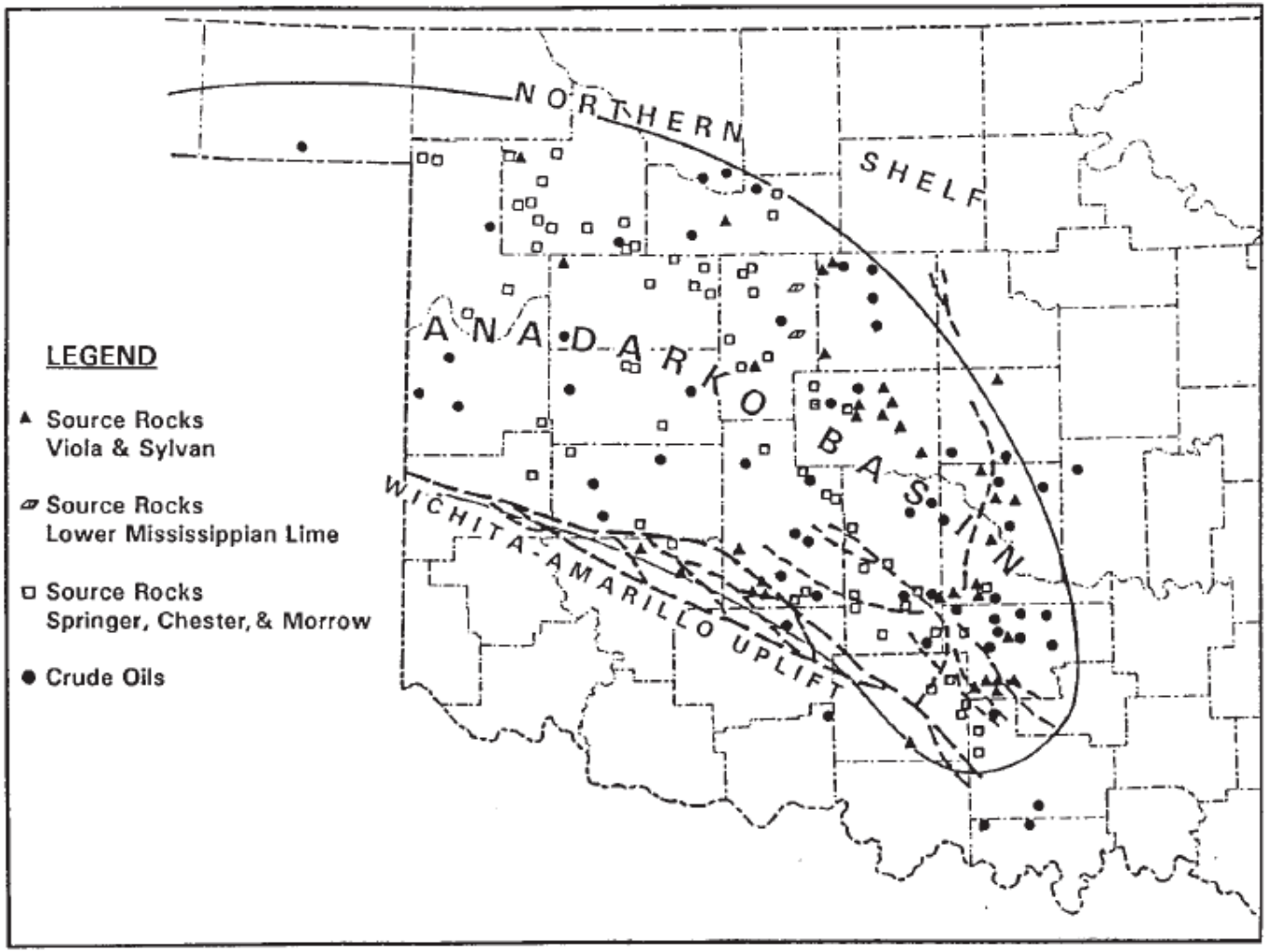


Figure 3—Map of the Anadarko basin within the state of Oklahoma showing the locations of source rock and oil samples collected for this study.

Anadarko Basin Source Rock Samples (Wang and Philp, 1997)

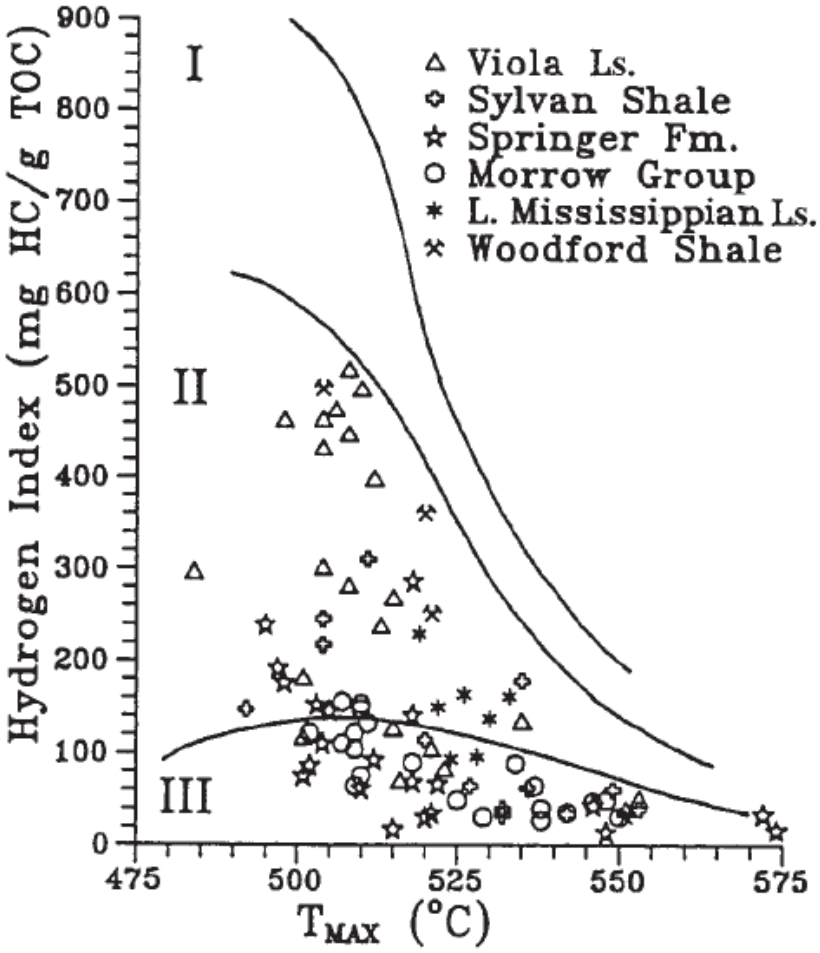


Figure 4—Kerogen typing using HI vs. T_{max} of Pyran Level-I pyrolysis system. The T_{max} value of Pyran is systematically 85°C higher than that of Rock-Eval pyrolysis, but the principles are the same.

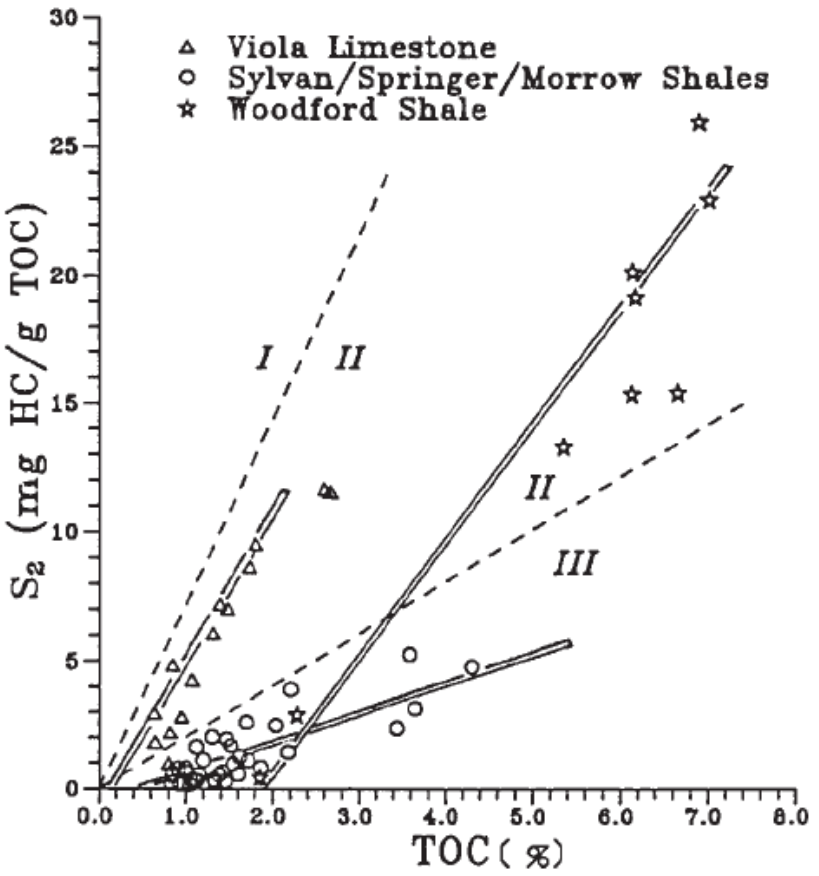


Figure 5—S_2 vs. TOC (total organic carbon) plot for five formations or groups. The Sylvan, Springer, and Morrow shales have similar slopes and their data are plotted together.

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]

(Production data supplied by PI/Dwights LLC, © 2013, IHS Energy Group)

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"

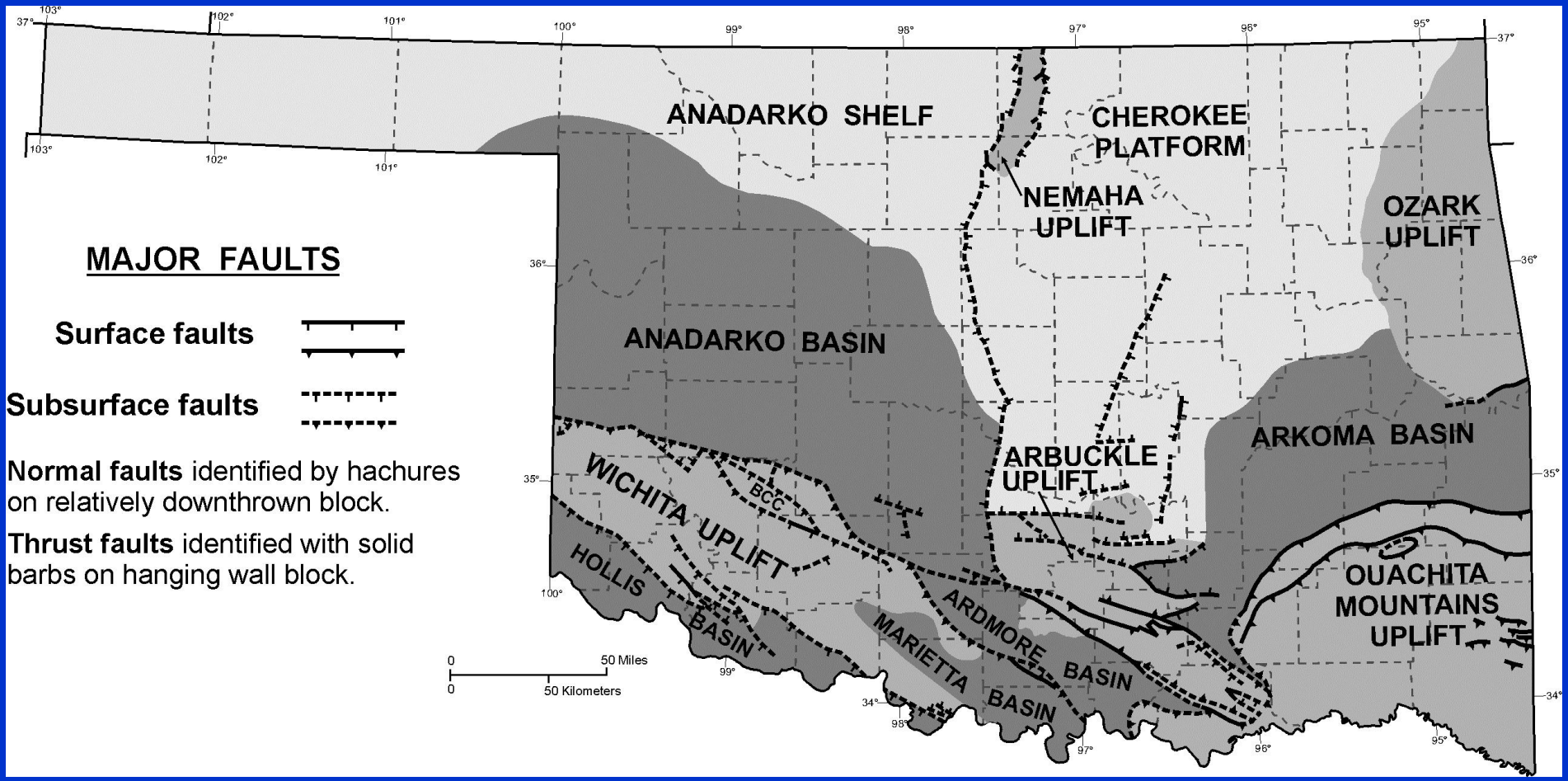
(Darbonne, 2011)

Eagle Ford Shale Porosity and Permeability

"The greater connectivity of interparticle pores in limestones is important to higher hydrocarbon producibility in these rocks relative to mudstones, which is why the limestones are critical components of overall hydrocarbon fluid transmissivity system in the formation. Furthermore, the abundant authigenic calcite in the limestones provided the overall brittle mechanical nature of the limestones compared to the more TOC-rich and ductile mudstones."

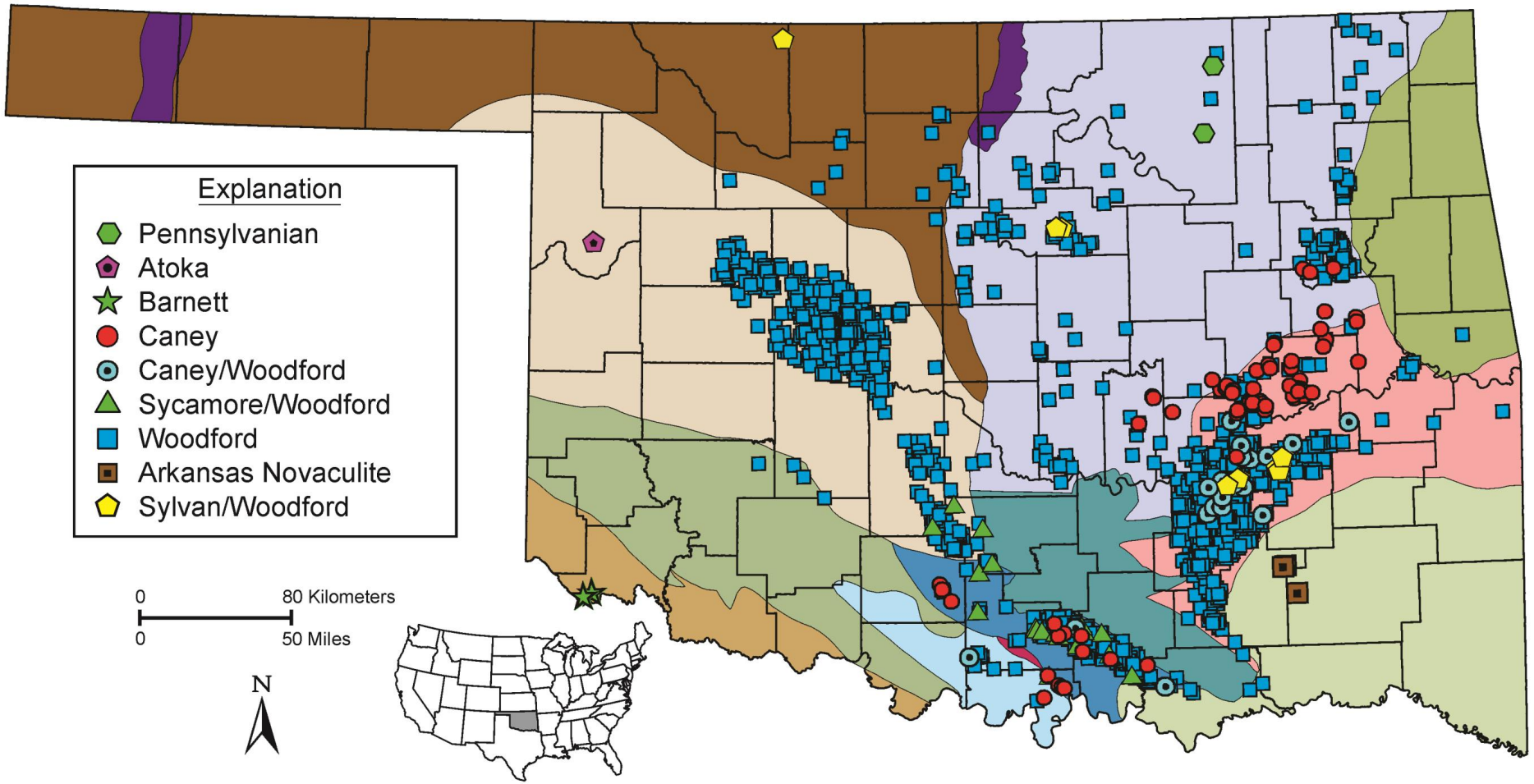
Fishman and others, 2013

Oklahoma Geologic Provinces



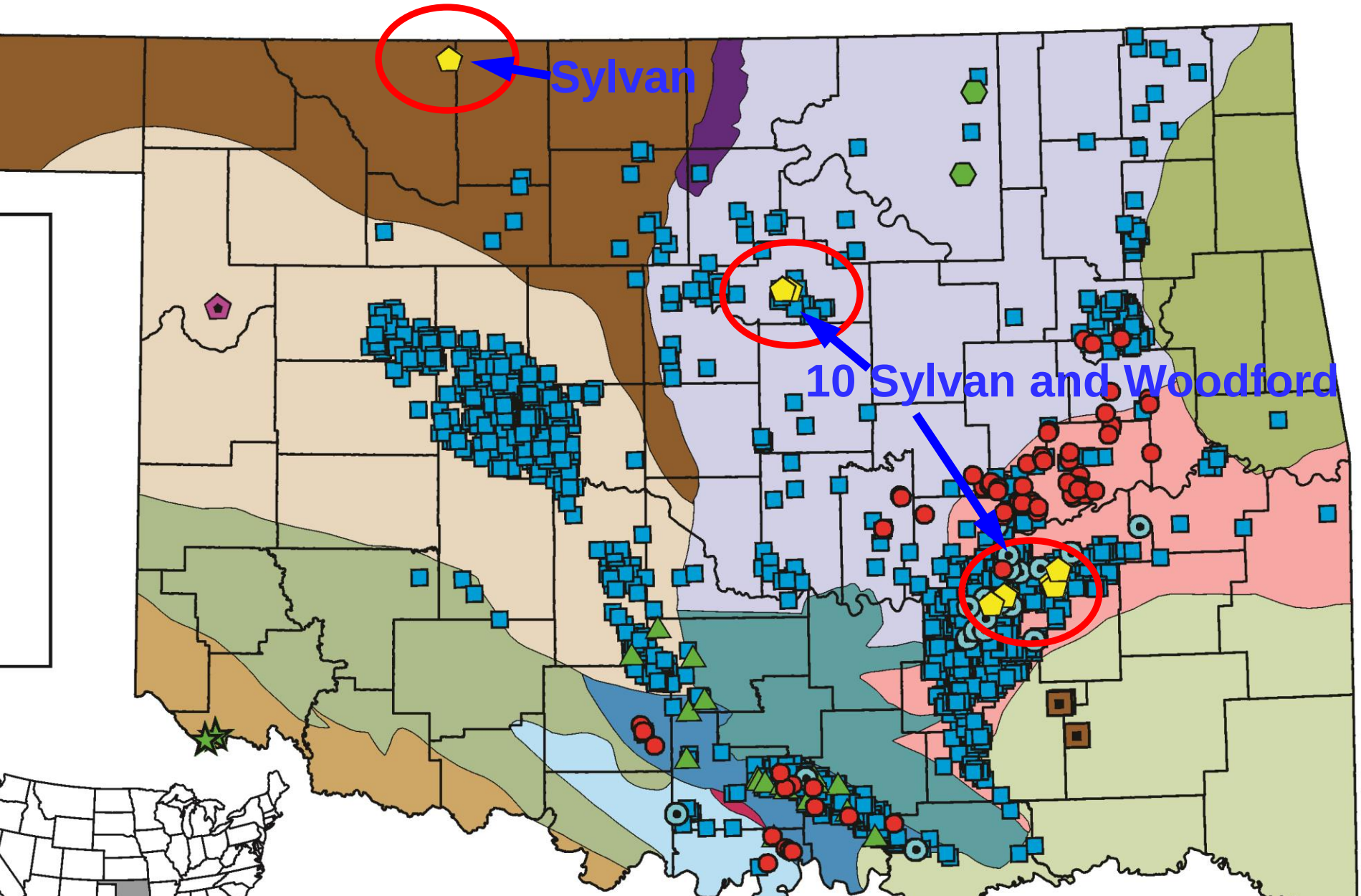
Geologic provinces from Northcutt and Campbell, 1995

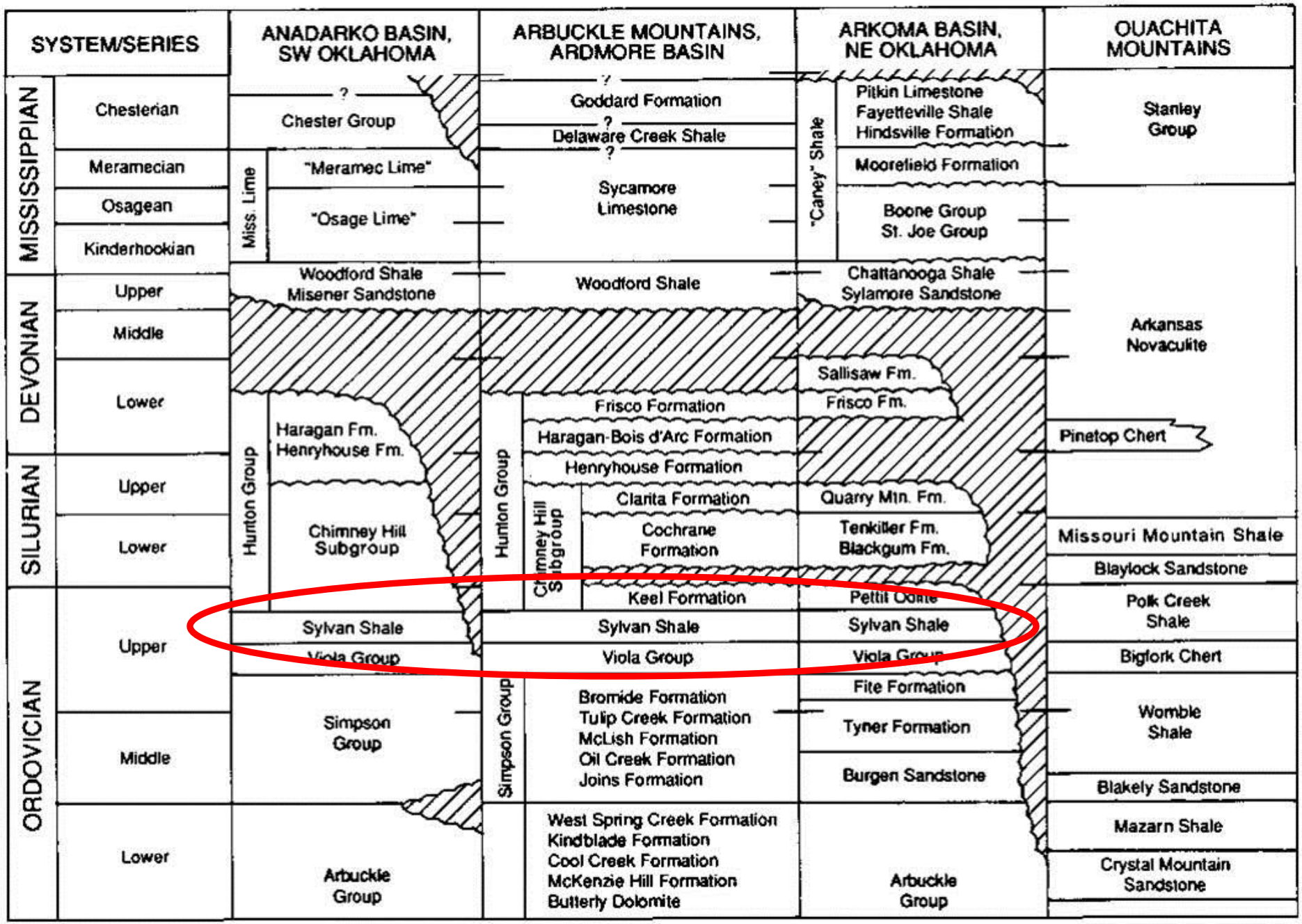
Oklahoma Shale Gas/Oil Completions (1939-2013)



2,996 completions

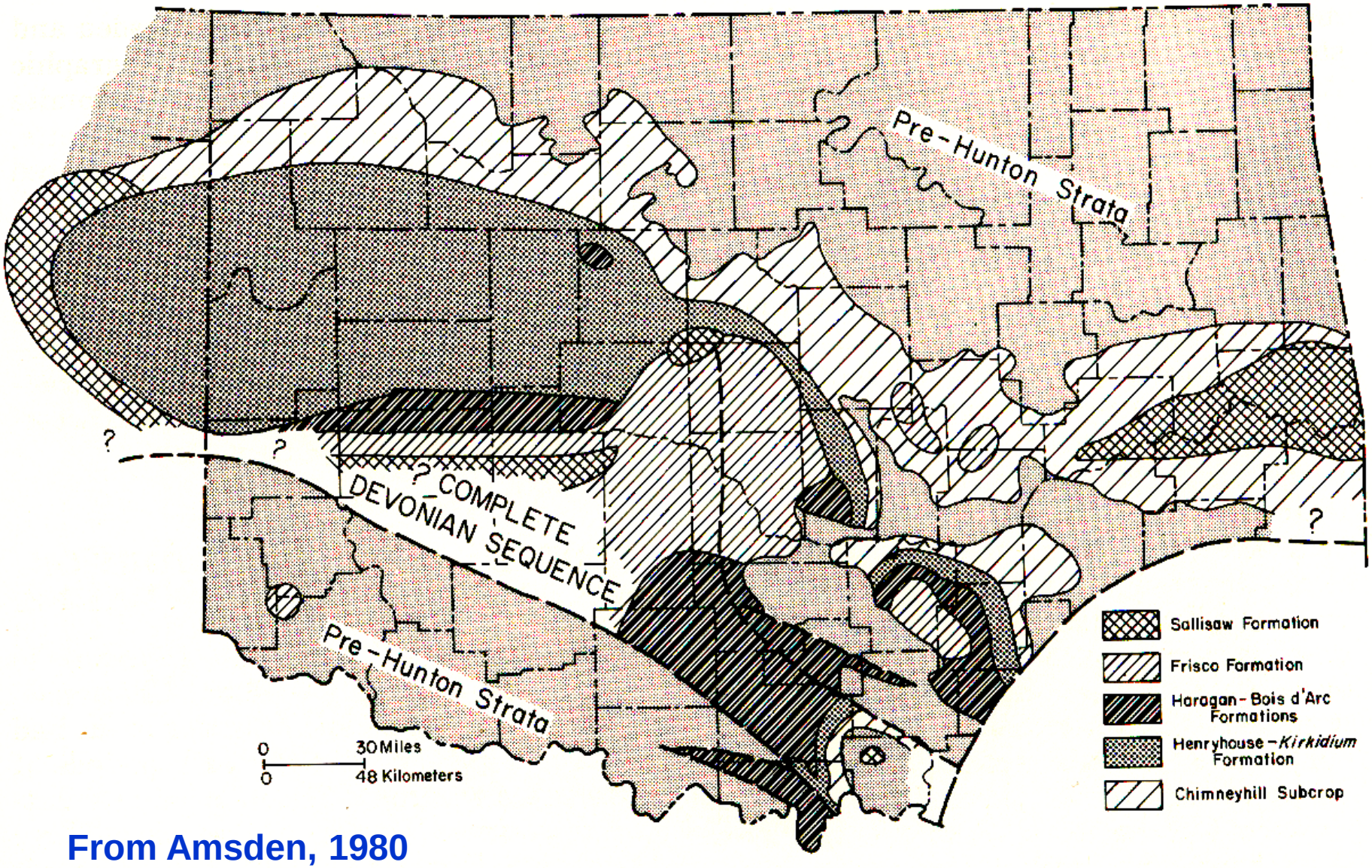
Sylvan Shale (Ordovician) [2008-2013]



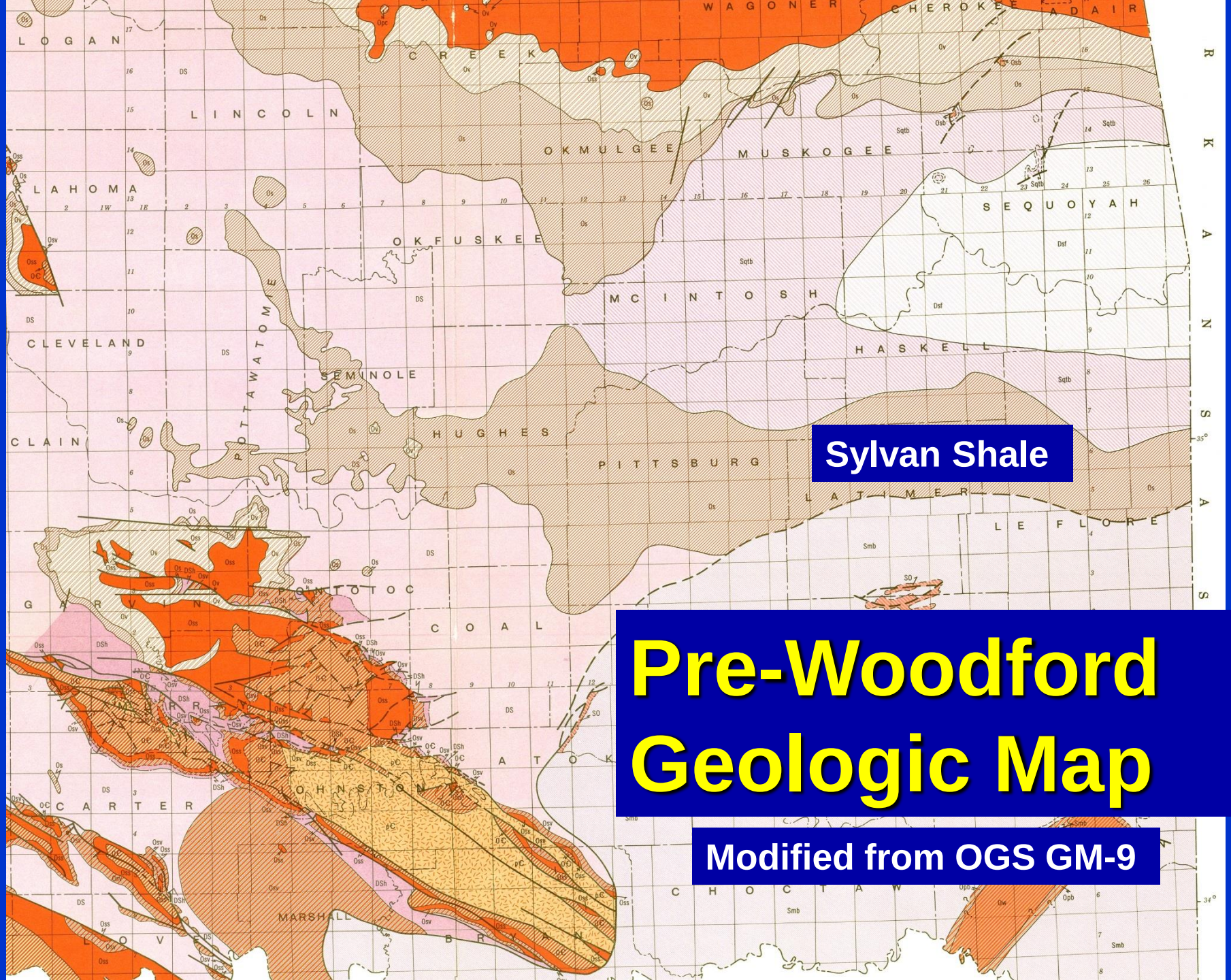


Modified from Johnson and Cardott, 1992

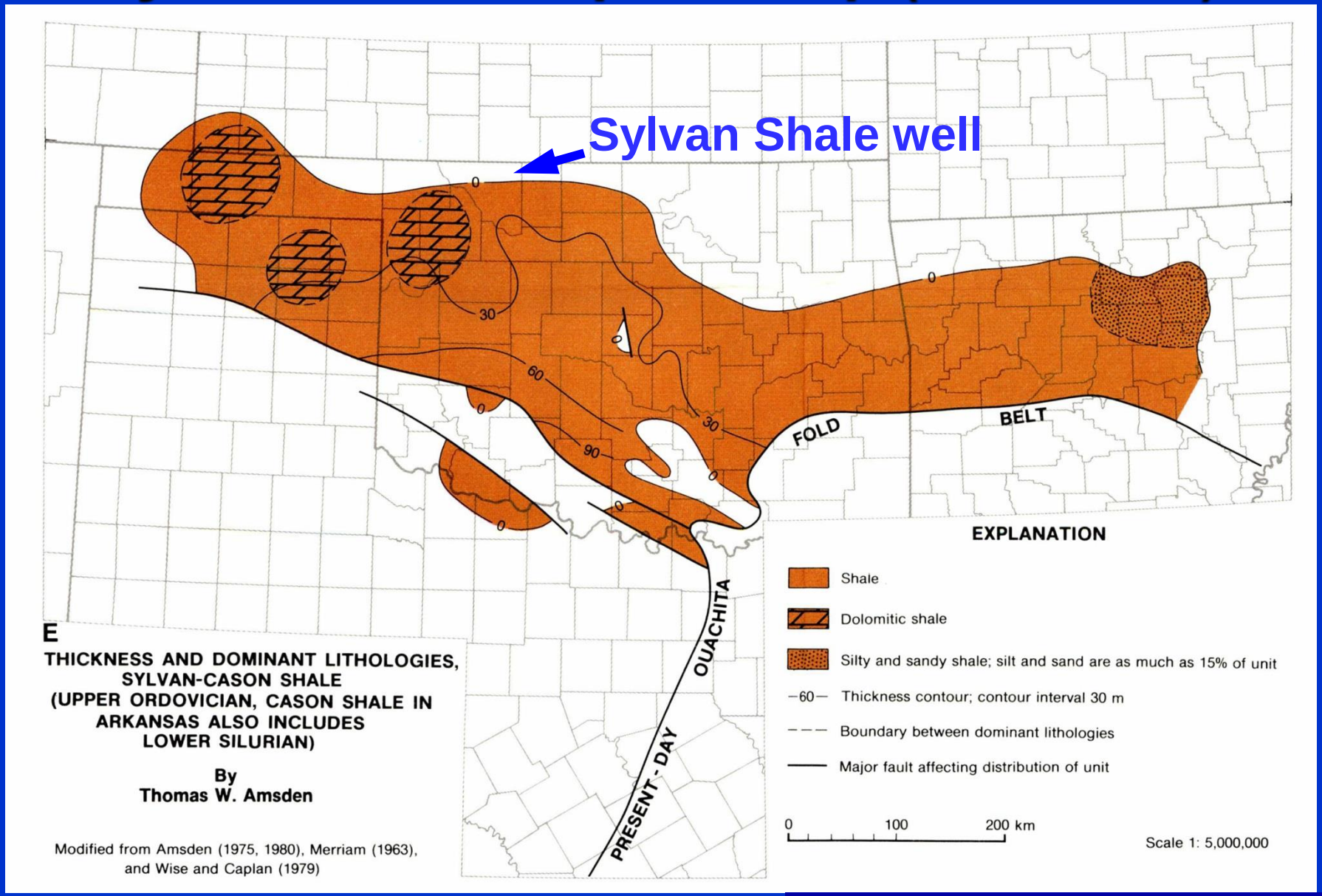
Pre-Woodford Geologic Map



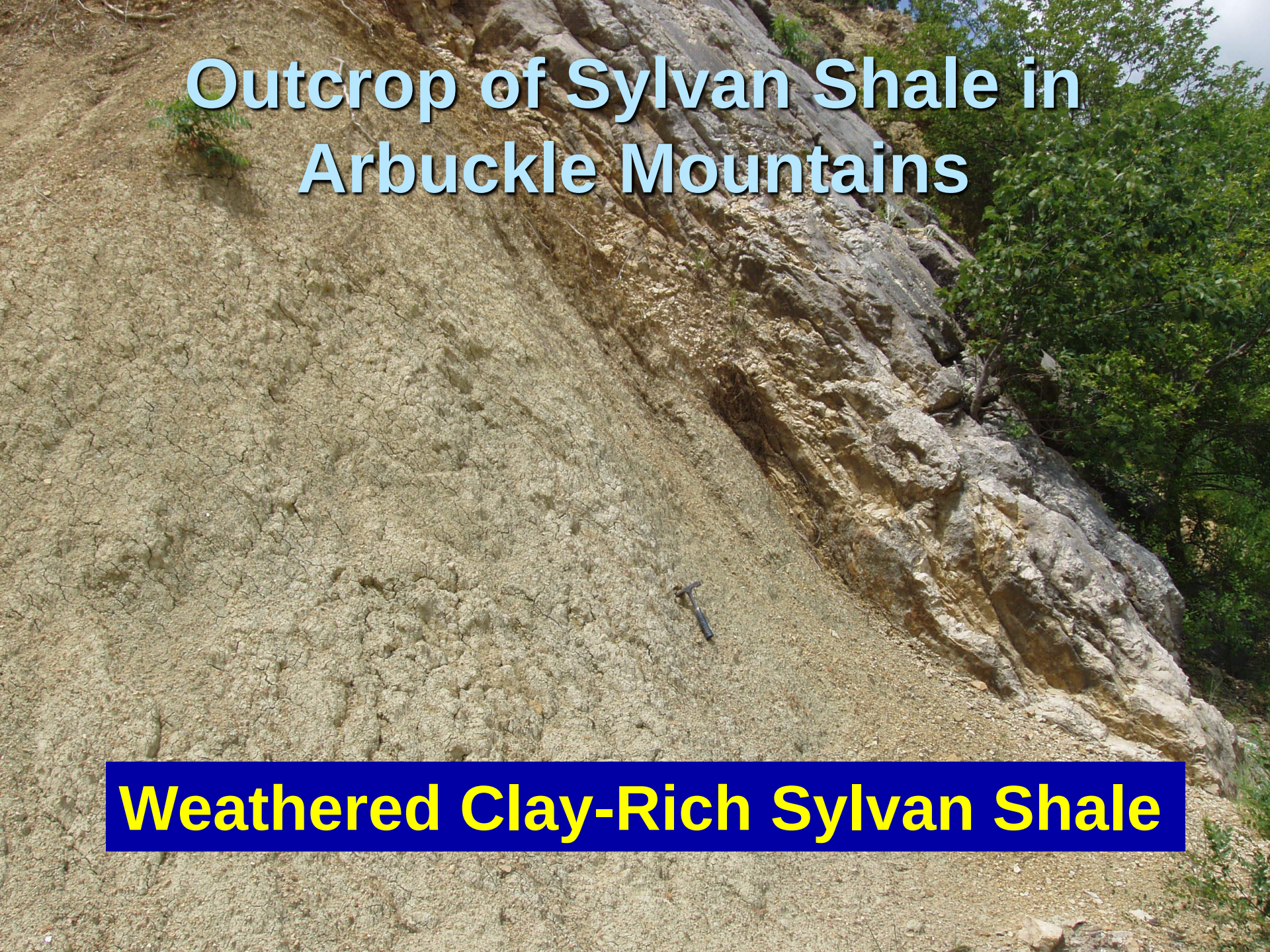
From Amsden, 1980


Sylvan Shale
Pre-Woodford Geologic Map
Modified from OGS GM-9

Sylvan Shale Isopach Map (in meters)

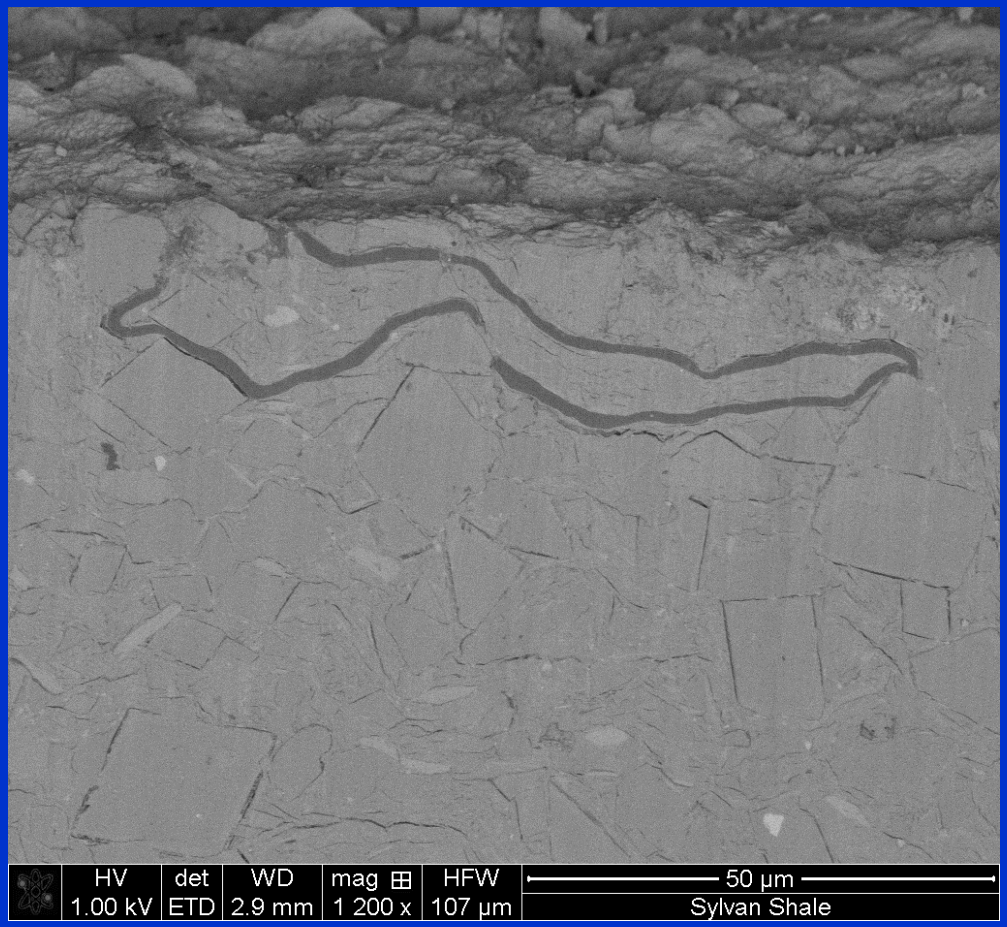


From Johnson and others, 1989


Outcrop of Sylvan Shale in Arbuckle Mountains
Weathered Clay-Rich Sylvan Shale

Example of Poor Gas Shale (but Good Frac Barrier)

Abundant dolomite; organic matter type?



Organic-Walled Fossils of the Sylvan Shale

Acritarchs
Chitinozoa
Conodonts
Graptolites
Scolecodonts

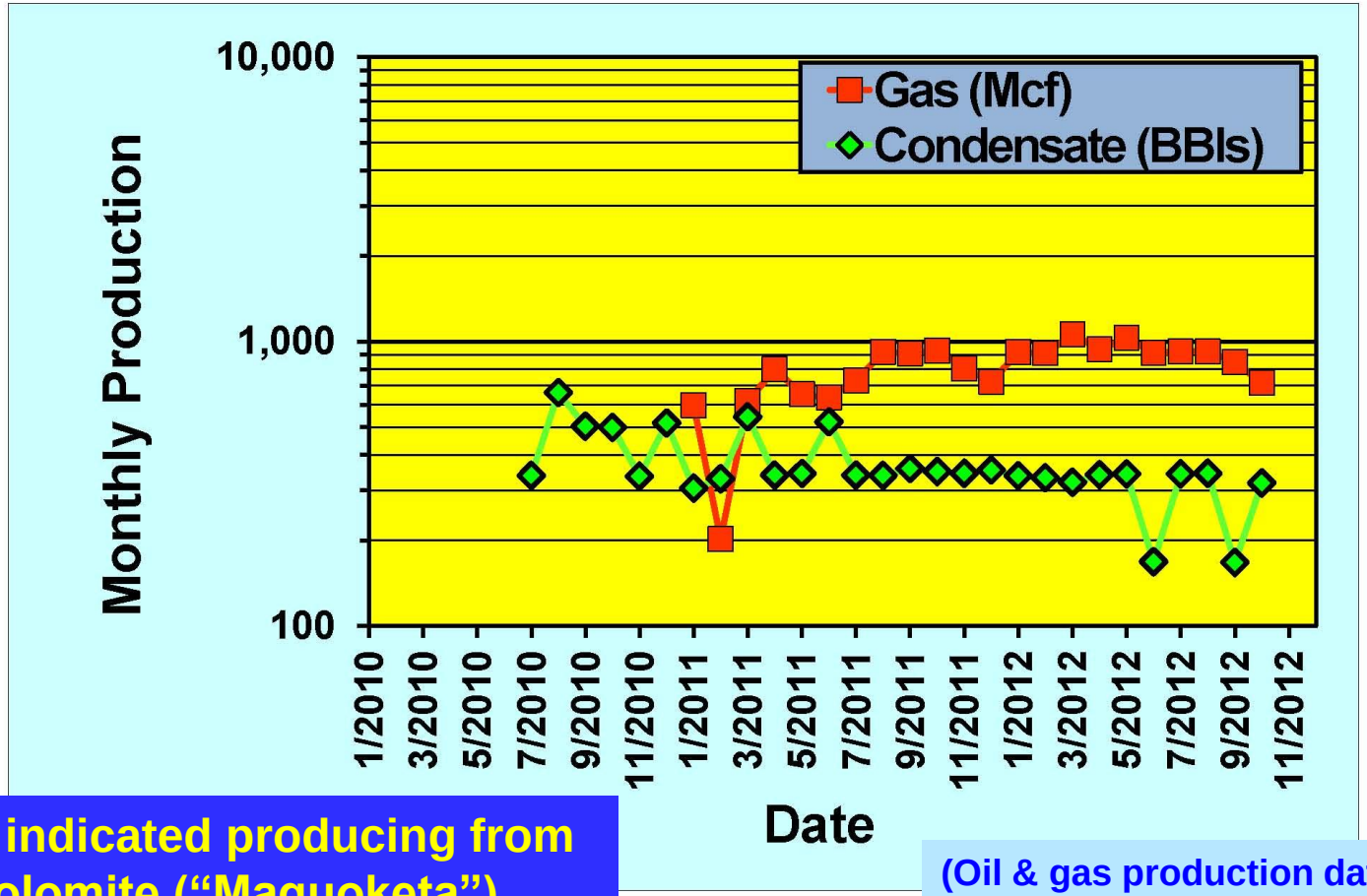
Sylvan Shale (Ordovician)

Wang (1993): Sylvan Shale is generally organic lean (<1% TOC); mainly Type III kerogen.

Wang and Philp (1997):
"The Sylvan Shale is thin and organically lean in the Anadarko Basin, and probably NOT a source rock in the basin."

There are 10 horizontal Woodford/Sylvan wells in Hughes, Pittsburg, and Payne counties;

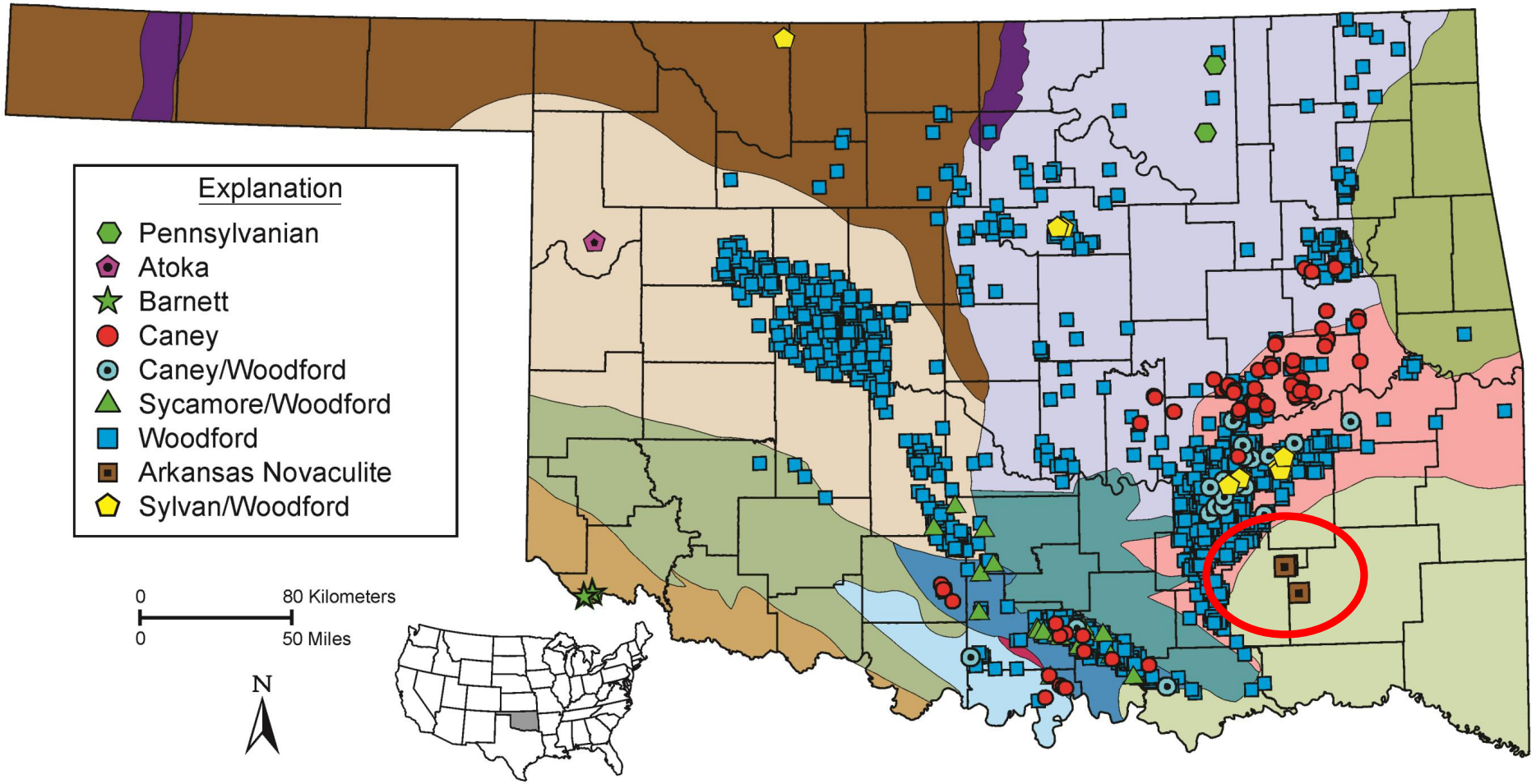
One Sylvan-Shale-only vertical well in Woods County:
Chesapeake Operating 1-2 RK Farms (2-28N-13W):
completed 8/15/2010 from 5,411-5,460 ft; IP 28 MCFD, 20 BOPD.



Operator indicated producing from Sylvan Dolomite ("Maquoketa")

Cum: 17.7 MMcf; 10,326 BO

Arkansas Novaculite/Bigfork Chert wells (2009-2010)



Arkansas Novaculite
(Scratch Hill Section, Atoka, OK)

Exploration for the Arkansas Novaculite Reservoir, in the Southern Ouachita Mountains, Arkansas*

Theodore J. Godo[1], Peng Li[2], and Michael E. Ratchford[2]

Search and Discovery Article #10337 (2011)
Posted July 12, 2011

*Adapted from oral presentation at AAPG Annual Convention and Exhibition, Houston, Texas, USA, April 10-13, 2011

[1]Shell Exploration and Production Company, Houston, TX (ted.godo@shell.com)
[2]Arkansas Geological Survey, Little Rock, AR.

Abstract

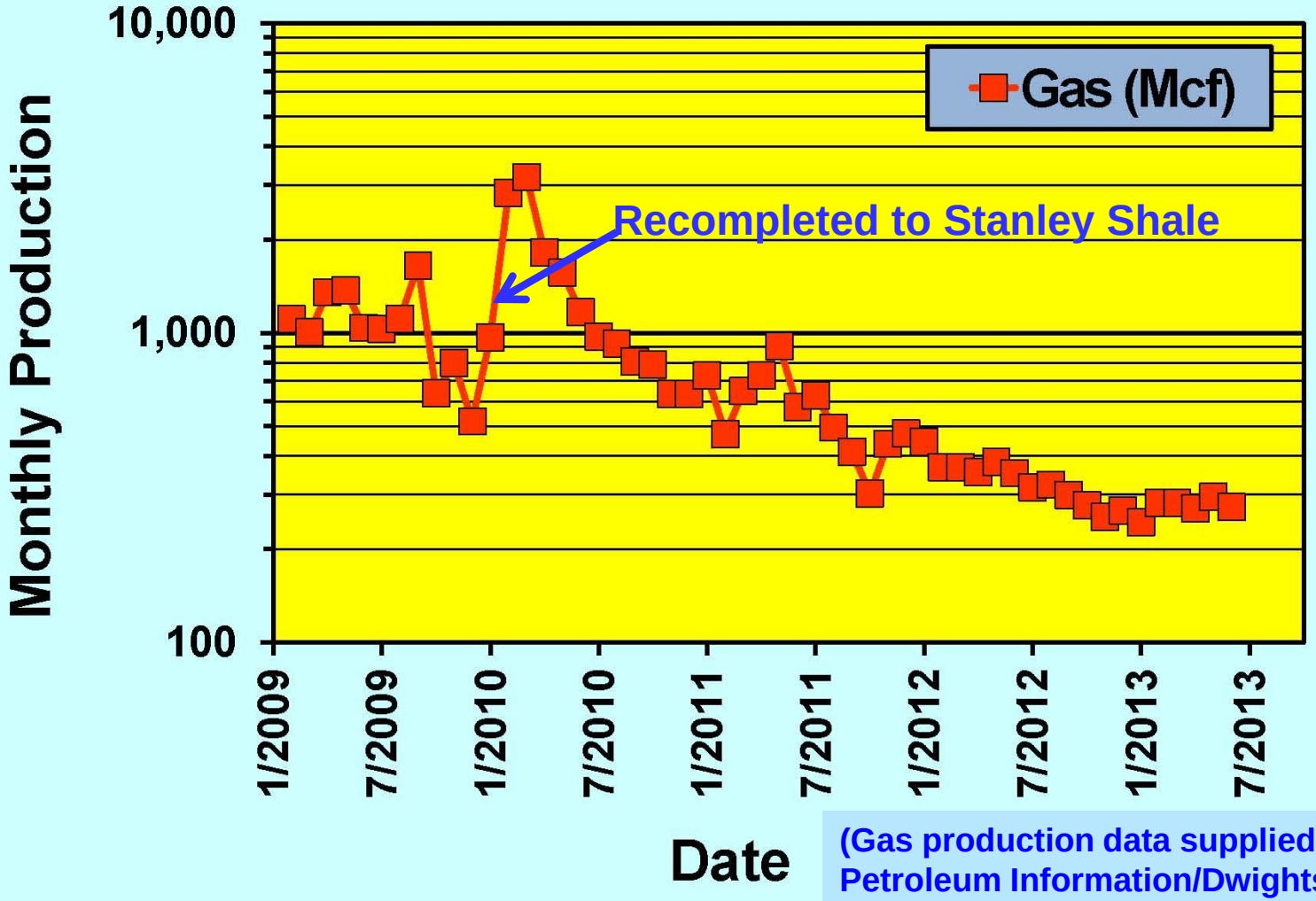
The Arkansas Novaculite, famous for its whetstone characteristic, is also an oil and gas reservoir in the Ouachita overthrust belt of Oklahoma and Texas (Caballos Novaculite). Oil and gas fields such as Isom Springs in Oklahoma and McKay Creek, Pinion and Thistle fields in West Texas found reservoirs in this chert section some 30 years ago. The chert reservoir has shown to be productive when it is highly fractured in complex thrust faults. In Arkansas, outcrops of this chert present along the southern side of the Benton uplift often contain a considerable amount of carbonate. The carbonate can be identified at times as highly abraded fossil fragments but otherwise are found as individual calcium carbonate concretion-like masses and also single dolomite rhombs. When leached, it is referred to tripolitic chert and can have porosity measurements ranging to over 50% percent. Assuming the carbonate is leached in the subsurface, the Arkansas Novaculite would have matrix porosity with fractures, which was the concept for the Shell exploration well that drilled Prospect Rattler.

Prospect Rattler was drilled by Shell with the well named the 1-26 Arivett and is located in Pike County, Arkansas. The Arivett 1-26 well spudded in the Mississippian Stanley Shale and reached a total depth of 10,570 in the Silurian Blaylock Sandstone. The well penetrated a complete section of all three members of the Arkansas Novaculite, as described in the type section at Caddo Gap, Arkansas. This formation has very low dips in an otherwise non-internally faulted section. The well was air/mist drilled and flared several gas shows in sands and novaculite. The upper member of the Arkansas Novaculite contains an unleached carbonate-rich chert section based on cuttings, core analysis, and wireline logging. The results reveal little matrix porosity in the Arkansas Novaculite. However, small amounts of thermally “dead” oil residues or anthraxolite is present in some fractures and some micropores of leached carbonate material. This indicates that a hydrocarbon charge migrated through the Arkansas Novaculite but never accumulated. The vitrinite equivalent reflectance of the Arkansas Novaculite is 3.5%. Even at this high thermal maturity, the middle member shale has up to 4% total organic carbon content and is considered a major source rock. The failure mechanism was most likely a poor reservoir and a poor charge/timing as peak charge occurred before the trap was formed.

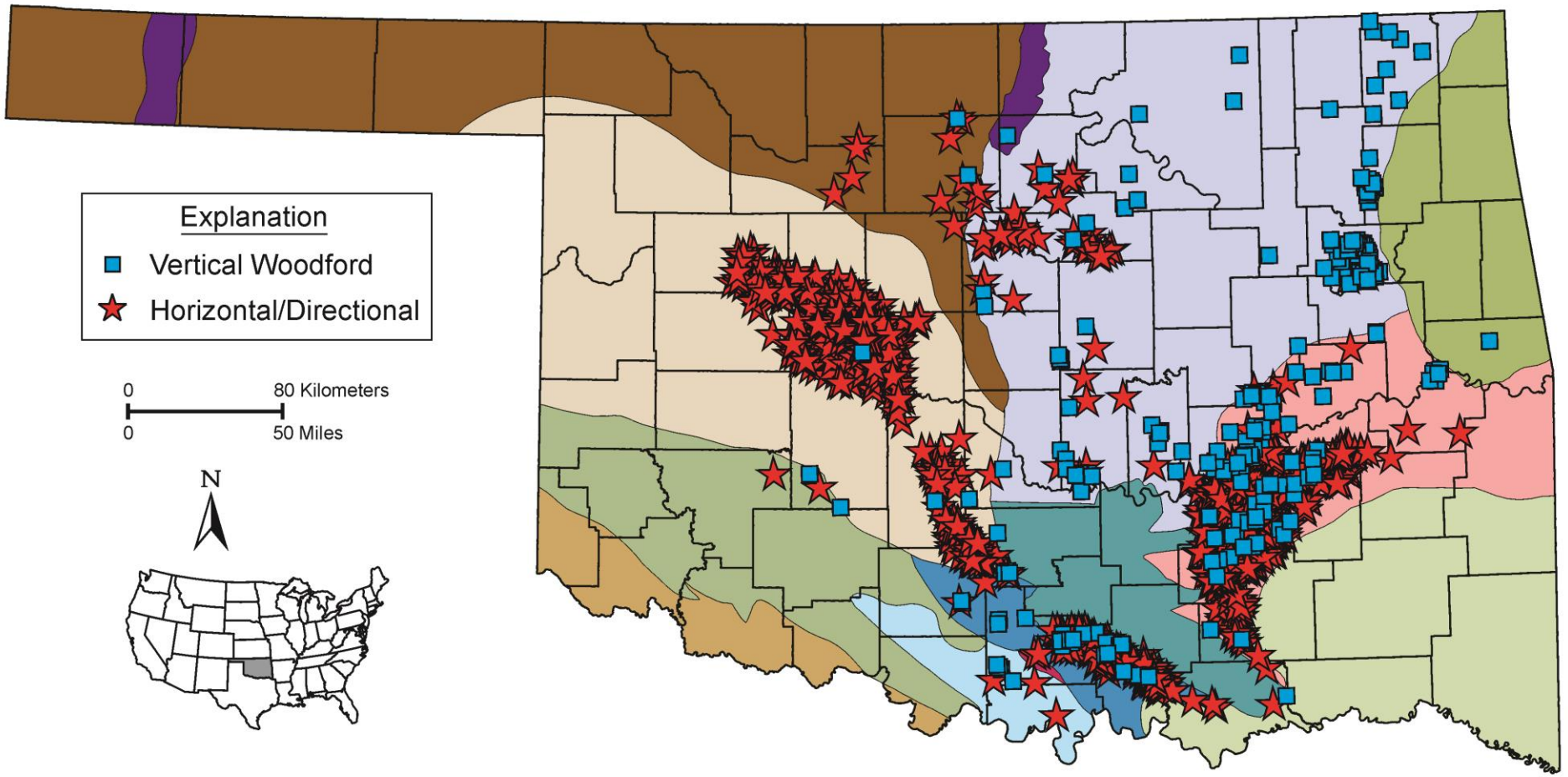
Arkansas Novaculite (AN)/Bigfork Chert (BC) wells

- RKI E&P 2-9 Denton-Perrin (1/2009; 9-2S-15E; 6,250 ft; IP 243 Mcf) [AN]
- Longfellow Energy LP 26-3 Wyrick (2/2010; 26-1N-14E; 8,104 ft; IP 2,926 Mcf; cum 1,109 MMcf) [AN/BC]
- Longfellow Energy LP 35-3 Ertman Unit (4/2010; 35-1N-14E; 8,890 ft; IP 2,762 Mcf; cum 282 MMcf) [AN/BC]

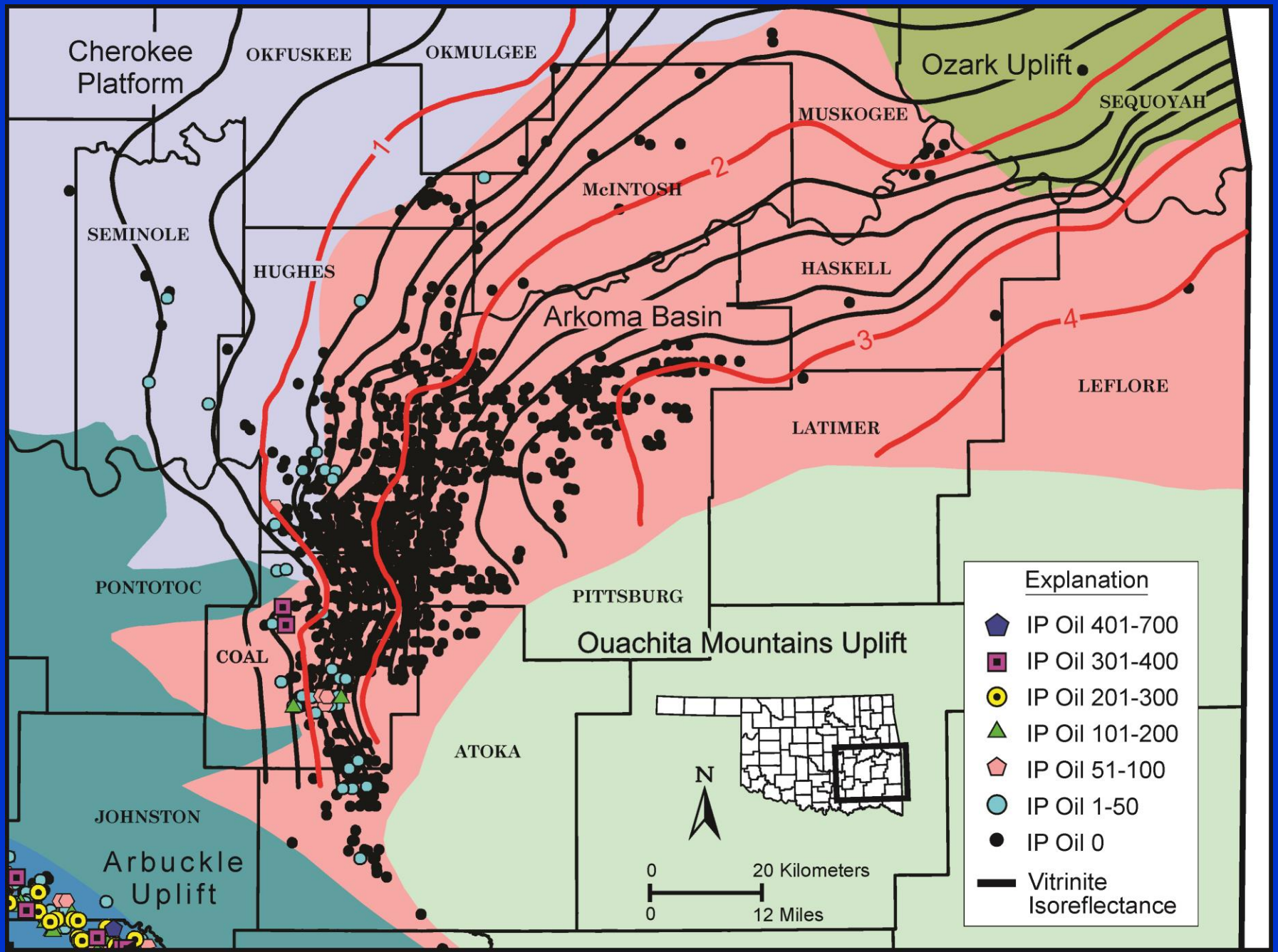
Arkansas Novaculite gas well:
RKI E&P 2-9 Denton-Perrin (Pushmataha Co.; 9-2S-15E): completed 5/2009 from 6,250-6,311 ft; IP 243 MCFD; recompleted to Stanley Shale in 3/2010



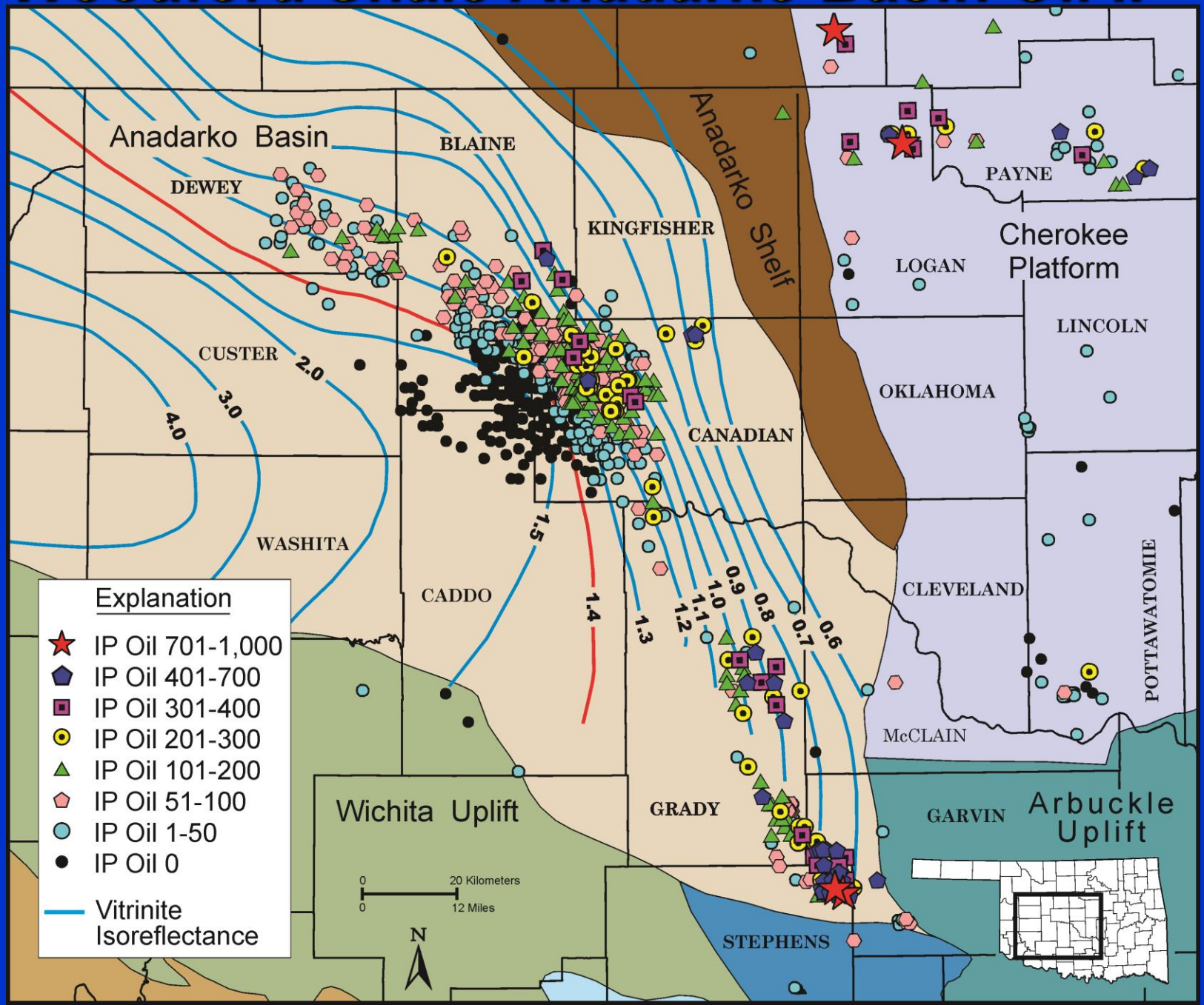
Woodford Shale (2004-2013)

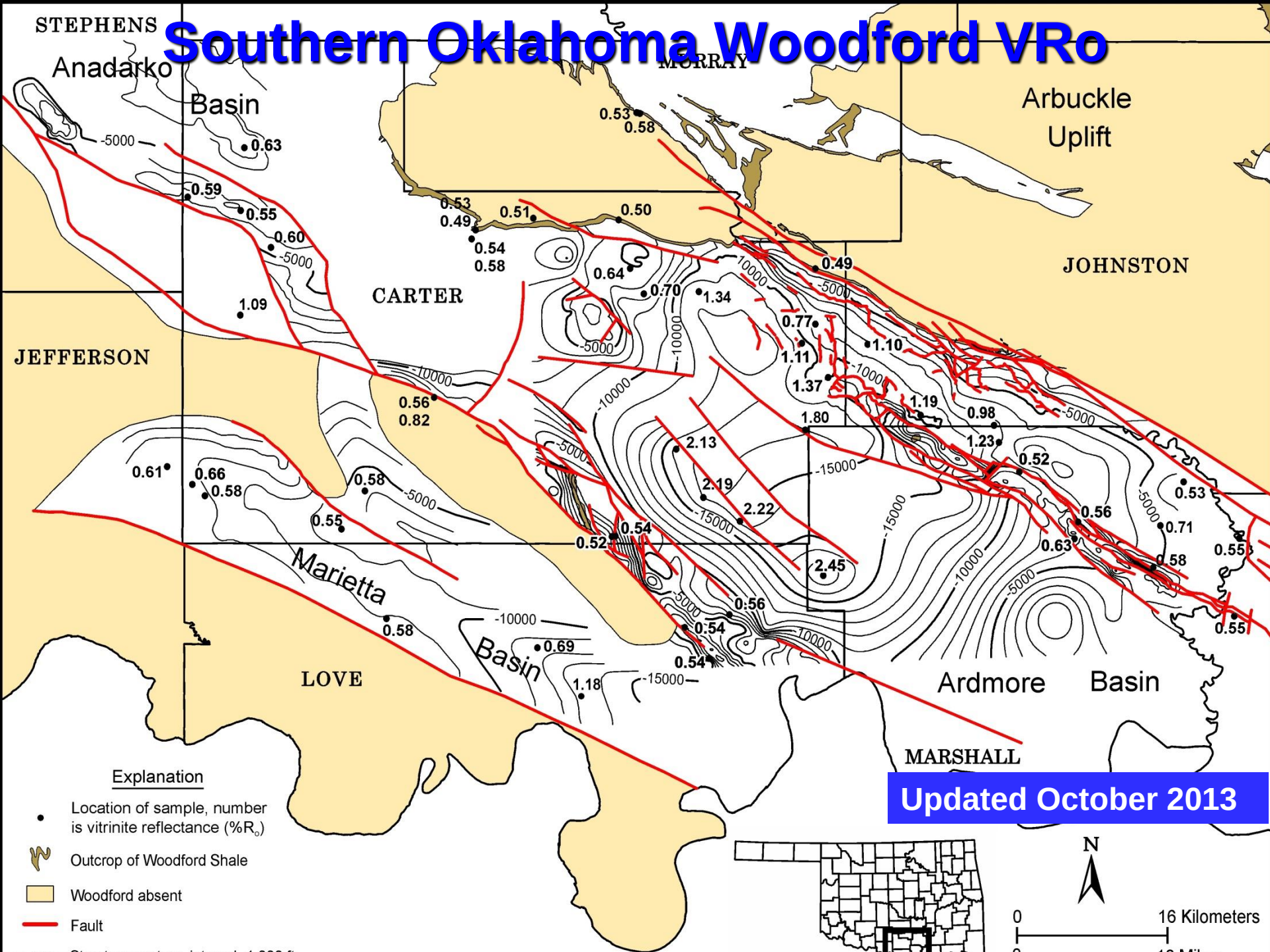


Woodford Shale Arkoma Basin Oil IP

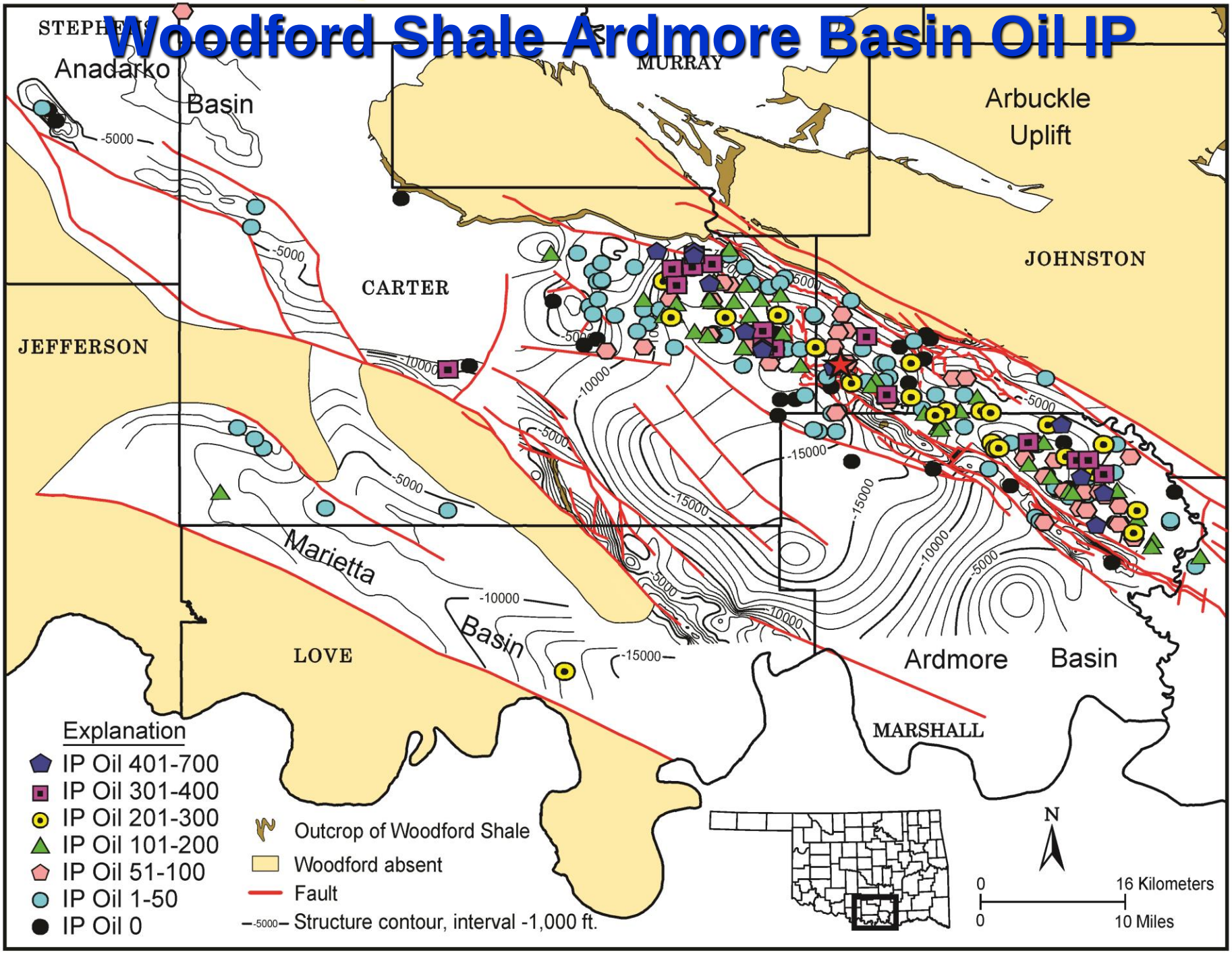


Woodford Shale Anadarko Basin Oil IP




Southern Oklahoma Woodford VRo
STEPHENS
Anadarko
Basin
MURRAY
Arbuckle
Uplift
JOHNSTON
CARTER
JEFFERSON
LOVE
Marietta
Basin
Ardmore
Basin
MARSHALL
Updated October 2013
Explanation
Location of sample, number is vitrinite reflectance (%Ro)
Outcrop of Woodford Shale
Woodford absent
Fault
N
0
16 Kilometers

Woodford Shale Ardmore Basin Oil IP



Woodford Shale: From Hydrocarbon Source Rock to Reservoir*

Brian J. Cardott[1]

Search and Discovery Article #50817 (2013)**
Posted July 22, 2013

*Adapted from oral presentation given at AAPG Education Directorate Woodford Shale Forum, Oklahoma City, Oklahoma, April 11, 2013.

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

International Journal of Coal Geology 103 (2012) 109–119

Contents lists available at SciVerse ScienceDirect

International Journal of Coal Geology

journal homepage: www.elsevier.com/locate/ijcoalgeo

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

Brian J. Cardott *

Oklahoma Geological Survey, Norman, OK, USA

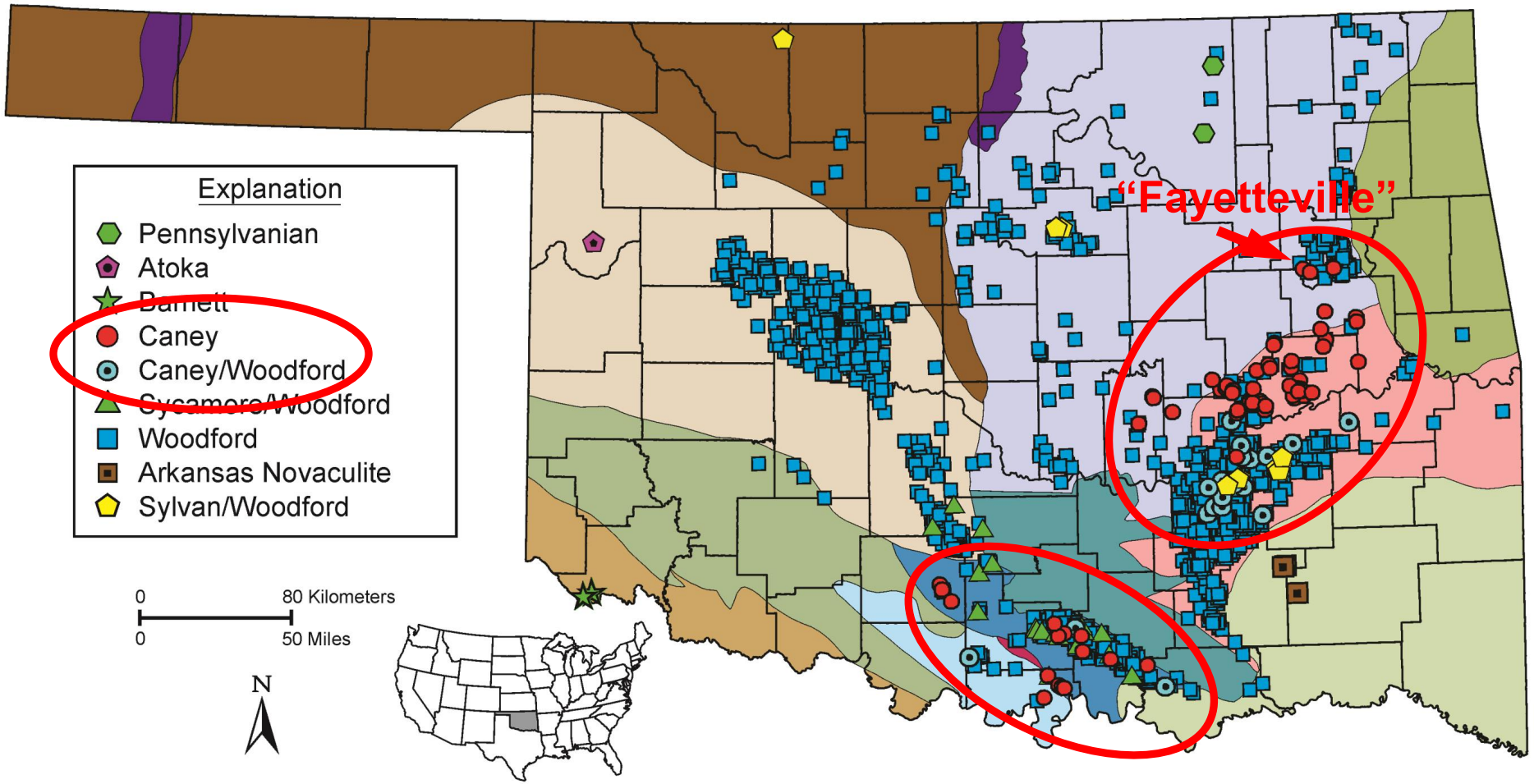
ARTICLE INFO

Article history:
Received 8 December 2011
Received in revised form 15 June 2012
Accepted 16 June 2012

ABSTRACT

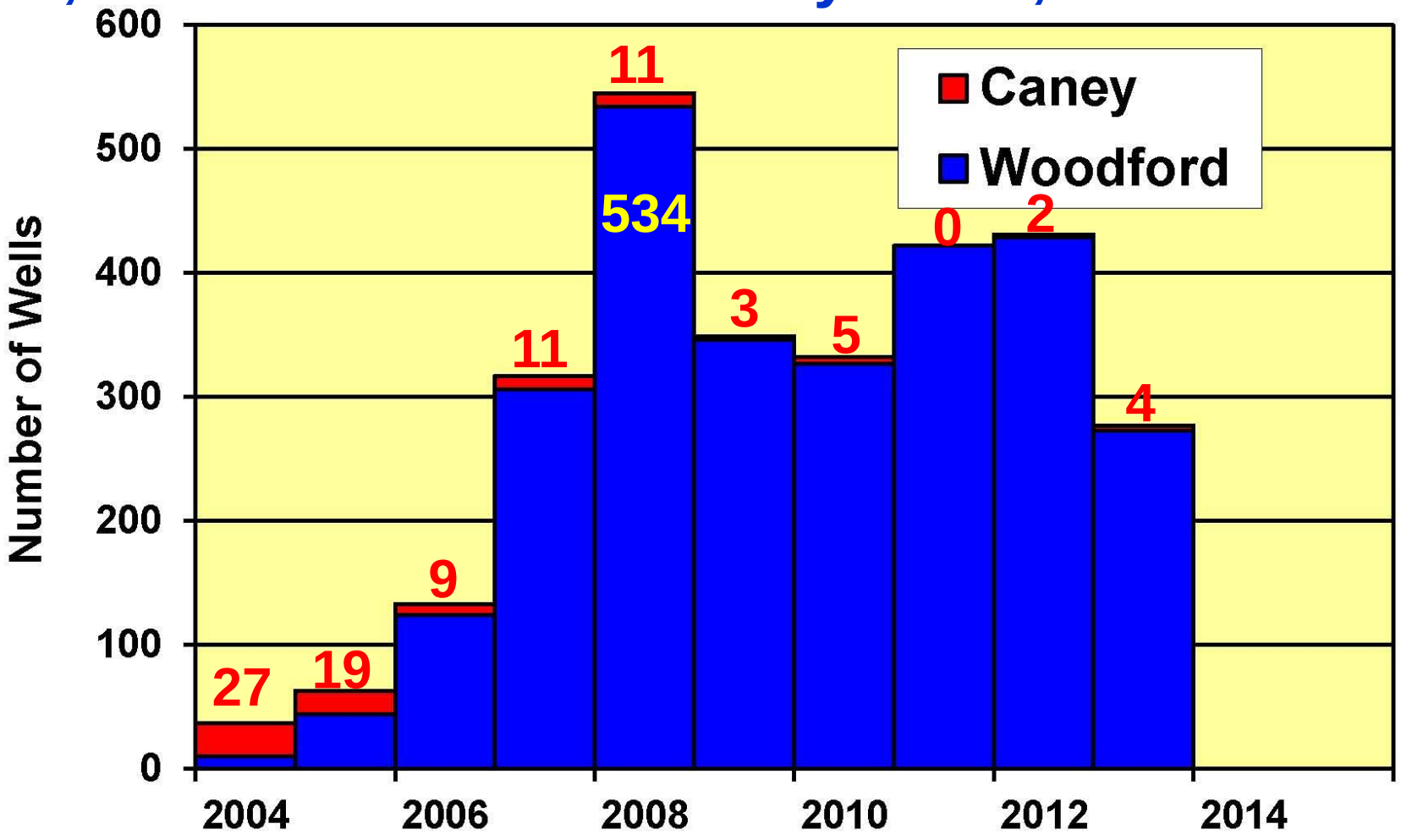
Being a hydrocarbon source rock and having a brittle (silica-rich) lithologic character makes the Woodford Shale (Late Devonian to Early Mississippian) an important oil and gas shale in Oklahoma. Since 2004 Woodford Shale plays have expanded from producing primarily thermogenic methane in one geologic prov

Caney Shale (1982 to 2013) [age equivalent to the Barnett Shale and Fayetteville Shale]



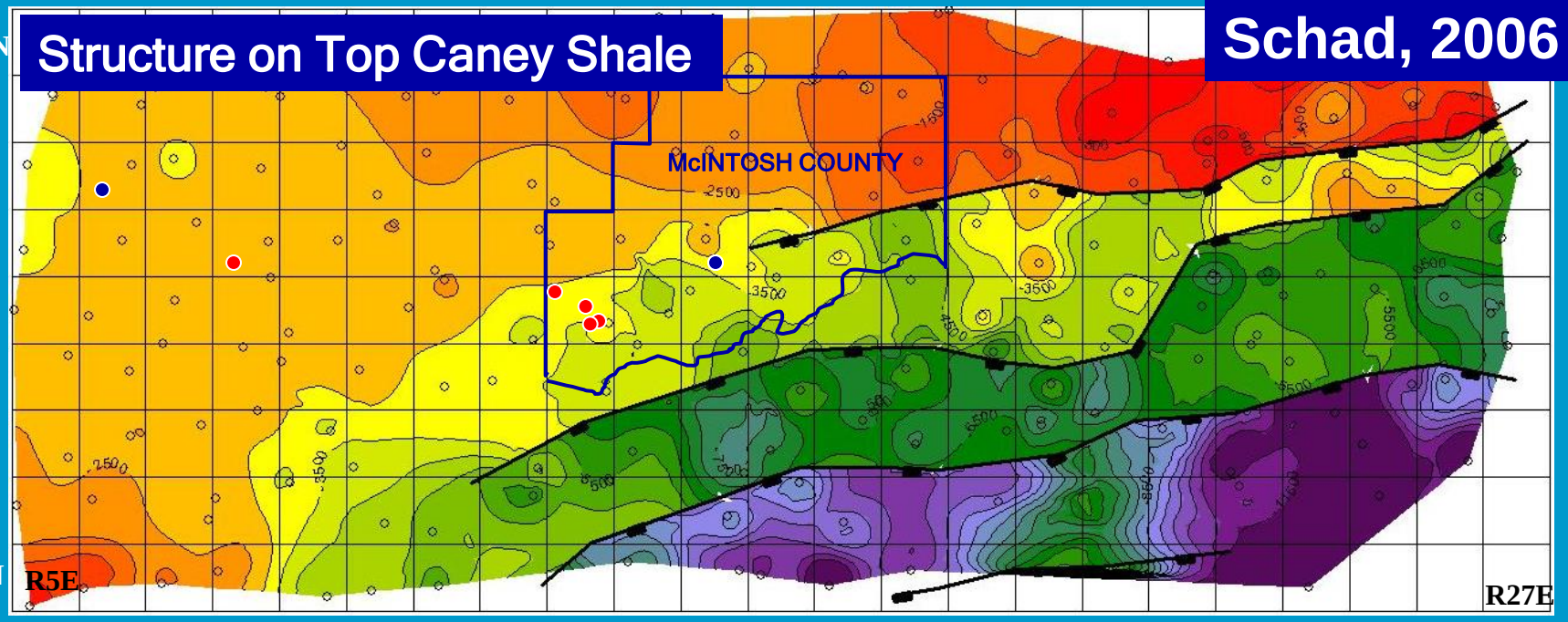
Oklahoma Shale-Gas Well History

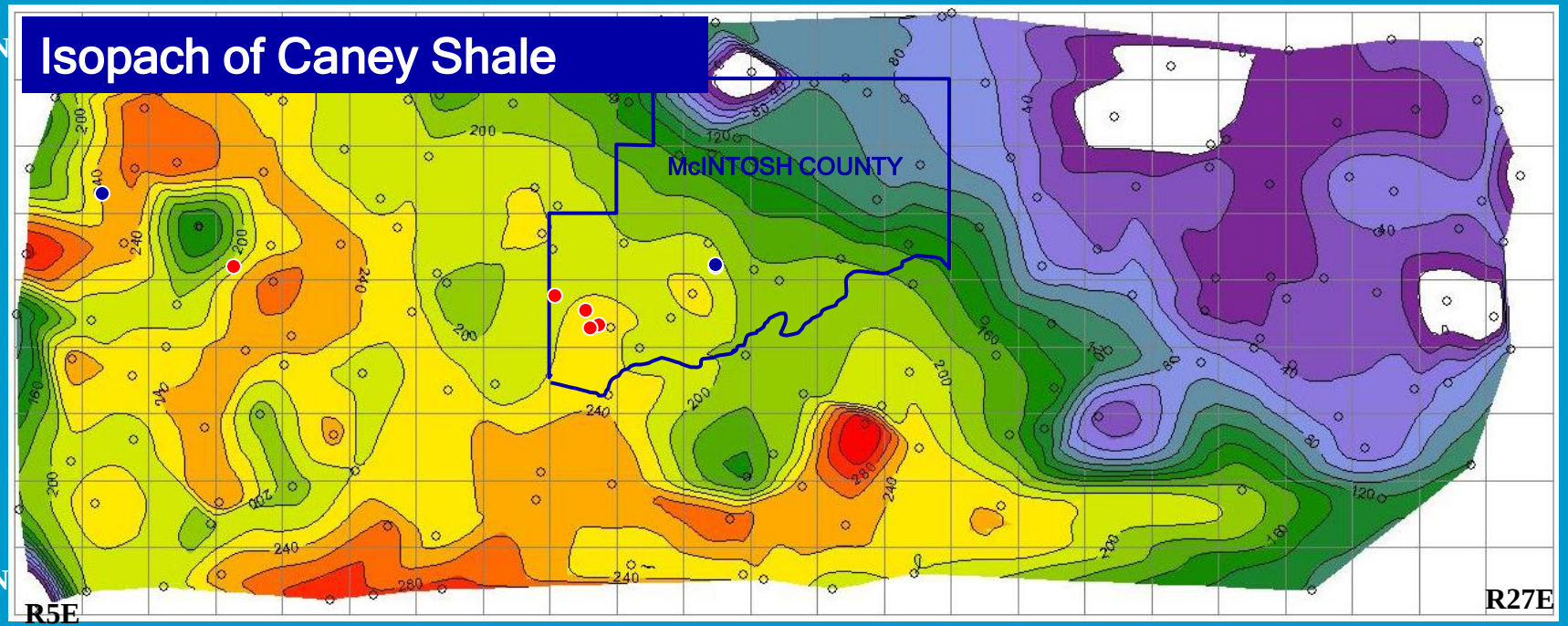
2,815 Woodford + 91 Caney Wells, 2004–2013



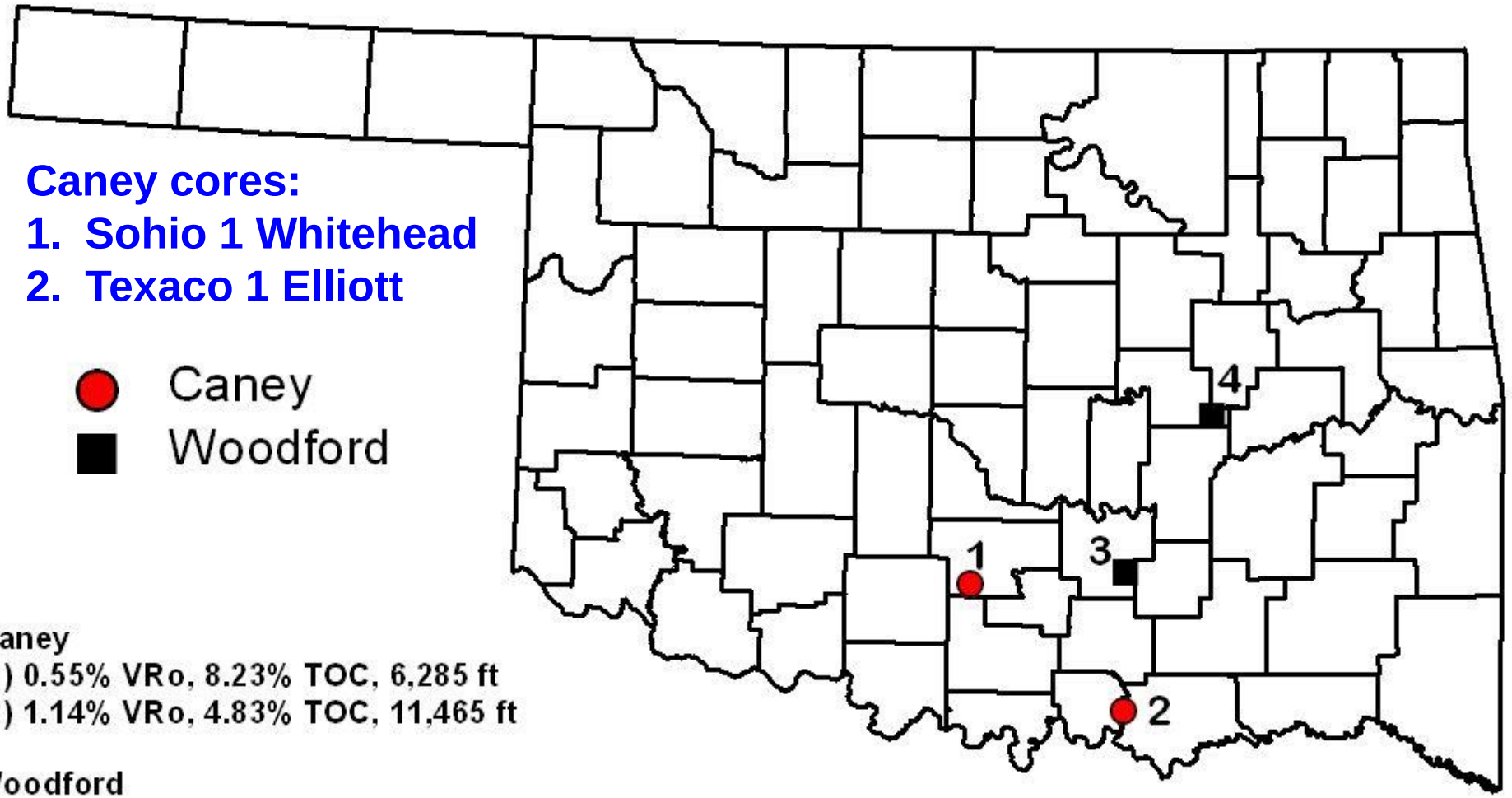
Caney/Woodford included with Caney

2012 & 2013 Caney wells in Carter, Johnston, Love, and Marshall Cos


Structure on Top Caney Shale
Schad, 2006
T13N
T5N
R5E
R27E
McINTOSH COUNTY
-2500
-3500
-4500
-5500


Isopach of Caney Shale
T13N
T5N
R5E
R27E
McINTOSH COUNTY
200
240
280
160
120
80
40

Rock-Eval Pyrolysis Data from OPIC Cores

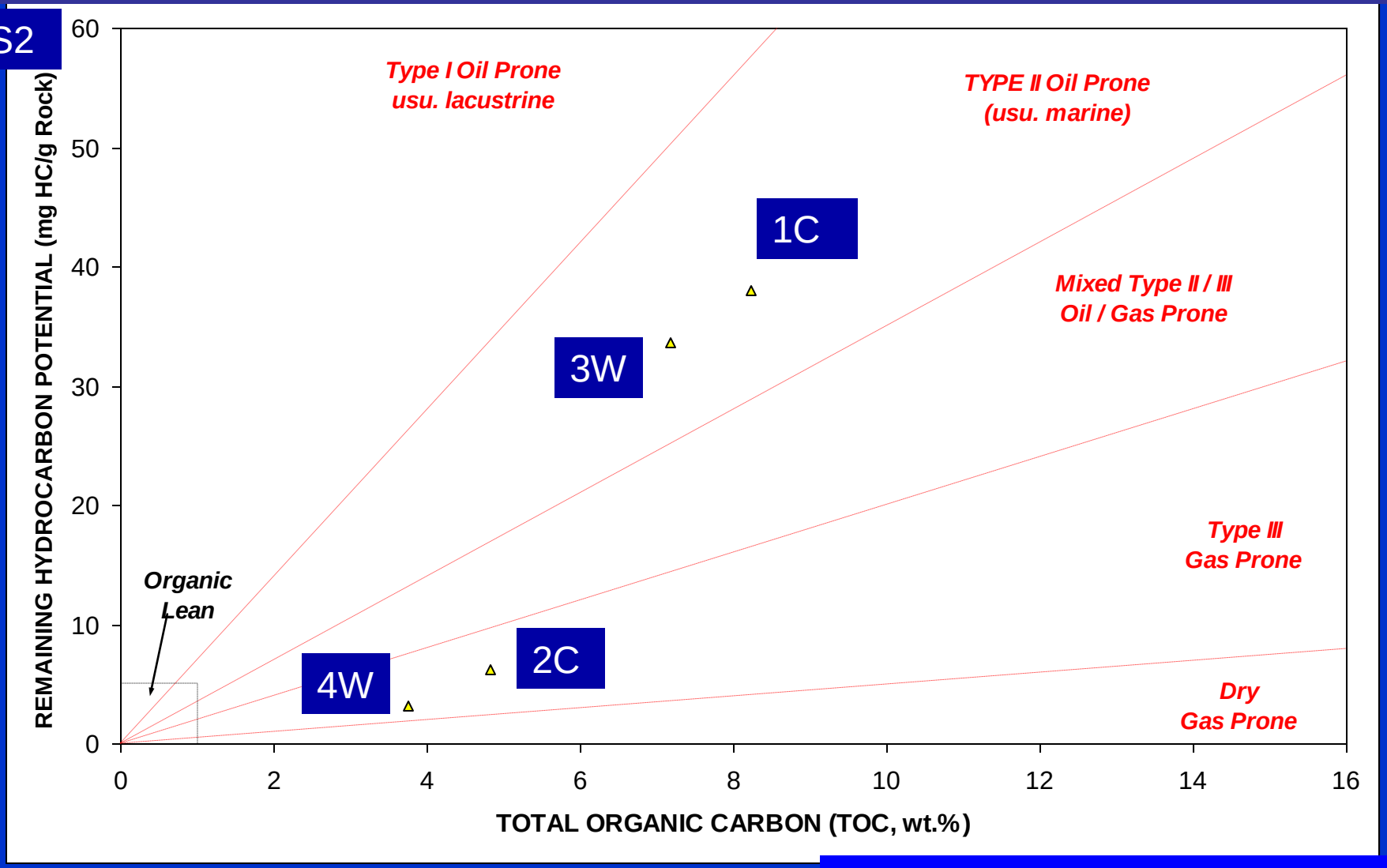


Caney
(1) 0.55% VRo, 8.23% TOC, 6,285 ft
(2) 1.14% VRo, 4.83% TOC, 11,465 ft

Woodford
(3) 0.50% VRo, 7.18% TOC, 3,266 ft
(4) 1.23% VRo, 3.76% TOC, 3,709 ft

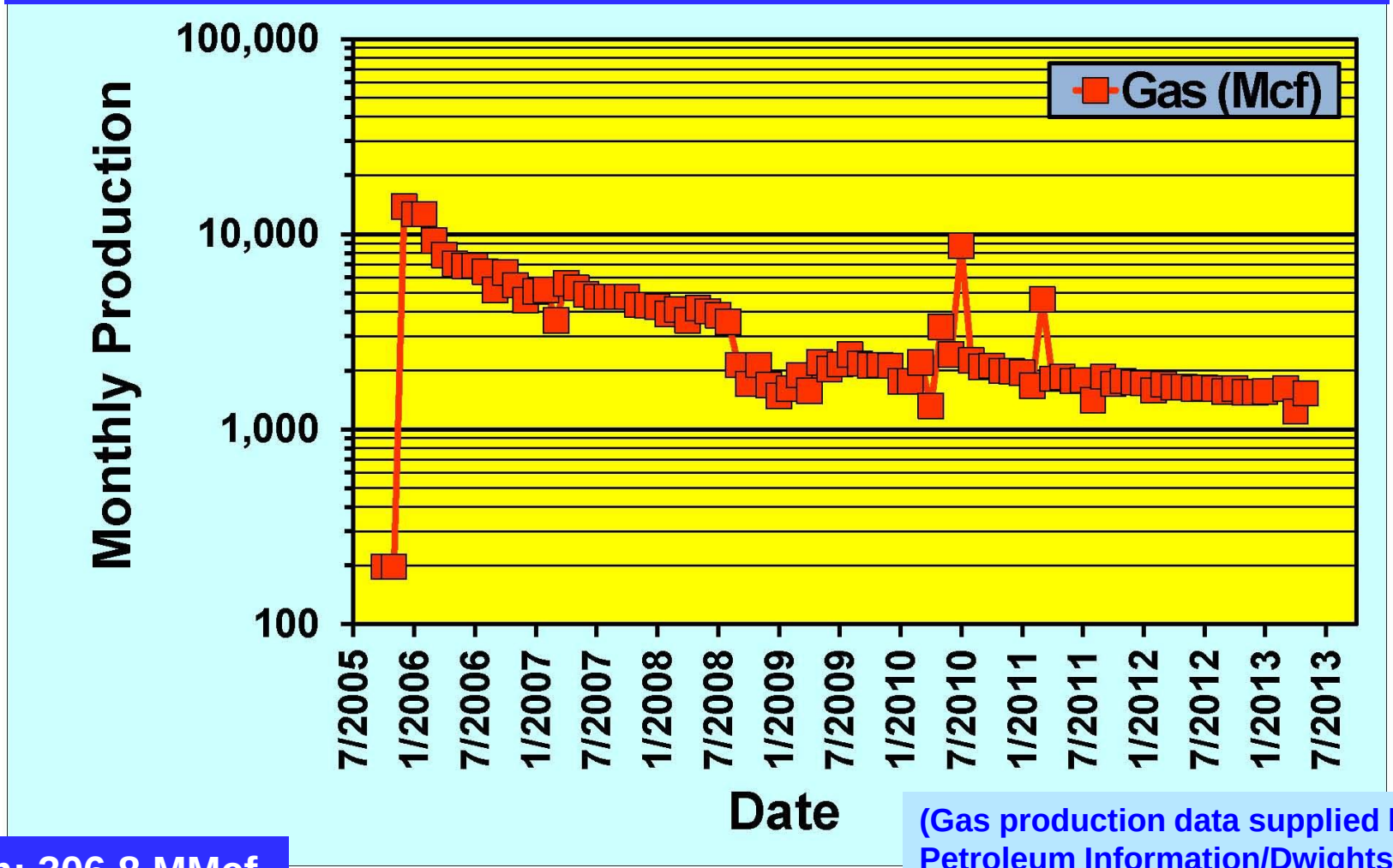
Rock-Eval data compliments of Humble Geochemical Services

Rock-Eval Pyrolysis Data from OPIC Cores



Rock-Eval data compliments of Humble Geochemical Services

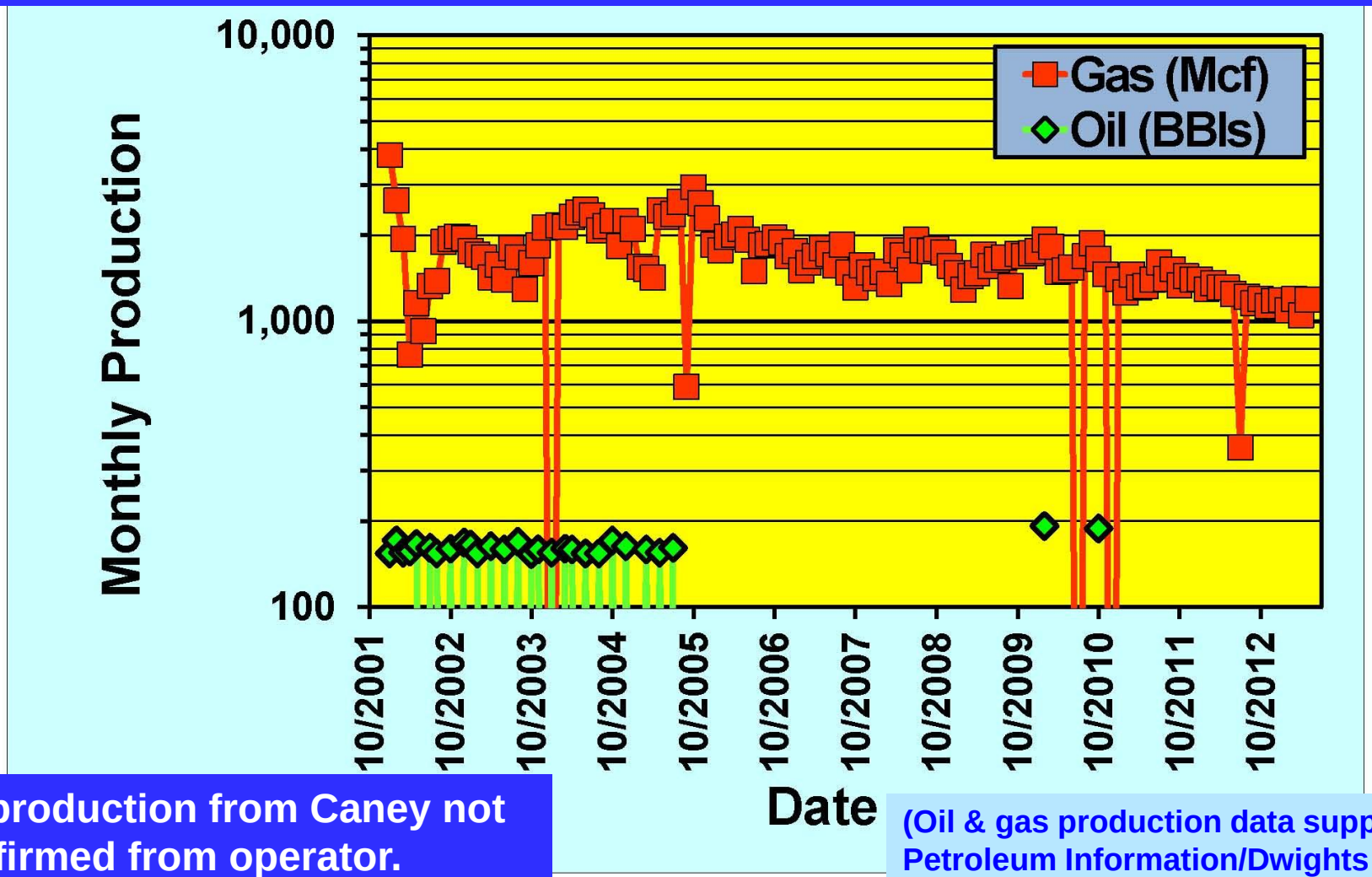
Southern Oklahoma Vertical Caney Gas Well: Newfield Exploration 4D F.M. Wood (Stephens Co.; 26-1S-5W): recompleted to Caney 9/2005 from 2,766-2,830 ft; IP 743 MCFD



Cum: 306.8 MMcf

(Gas production data supplied by Petroleum Information/Dwights LLC dba IHS Energy Group, © 2013)

Southern Oklahoma Vertical Caney Well: Star Resources LLC 3-8 Terri Twin (Love Co.; 8-6S-2E): recompleted to Caney 12/2001 from 4,471-4,498 ft; IP 180 MCFD

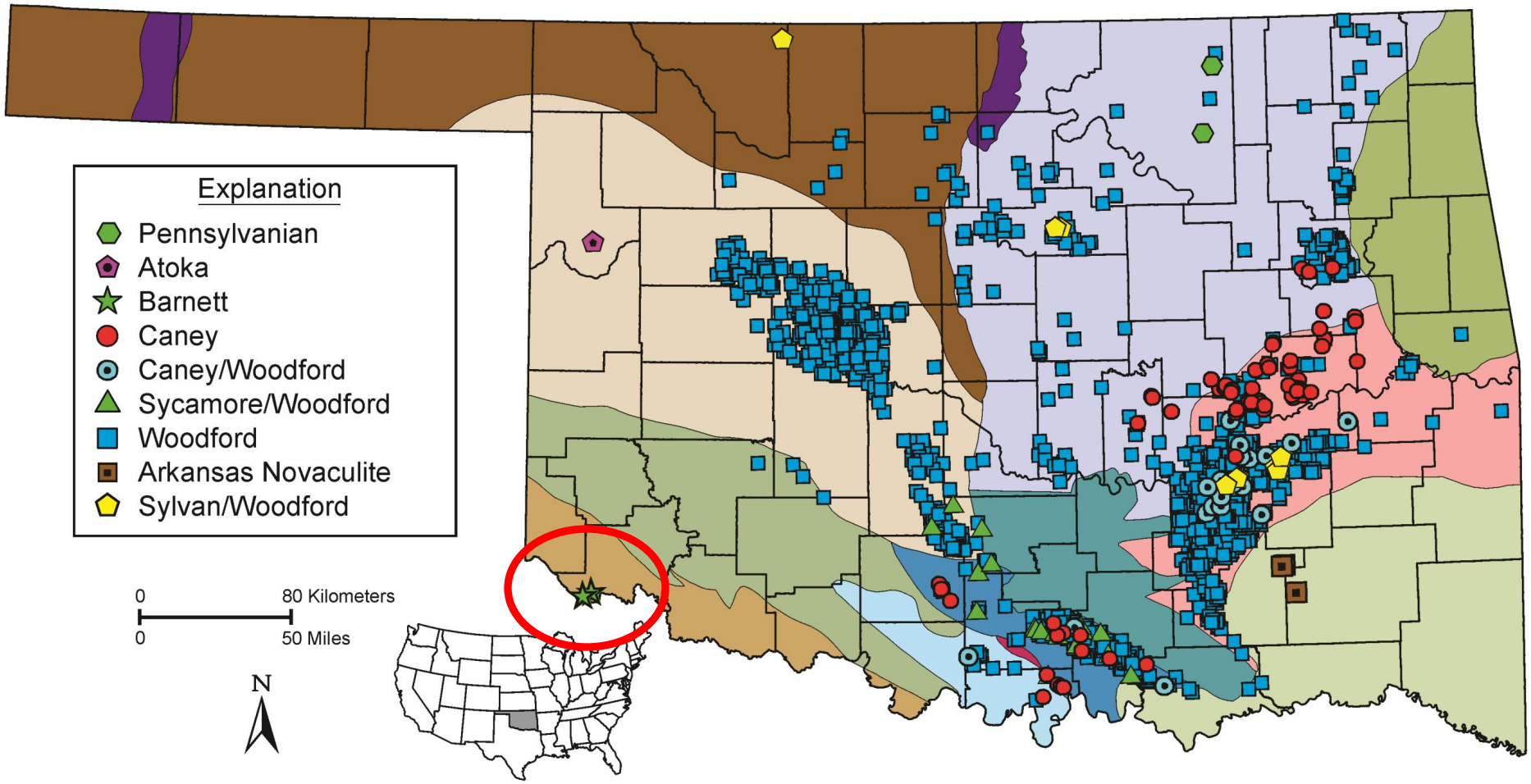


Oil production from Caney not confirmed from operator.
Cum: 224.2 MMcf; 4,538 BO

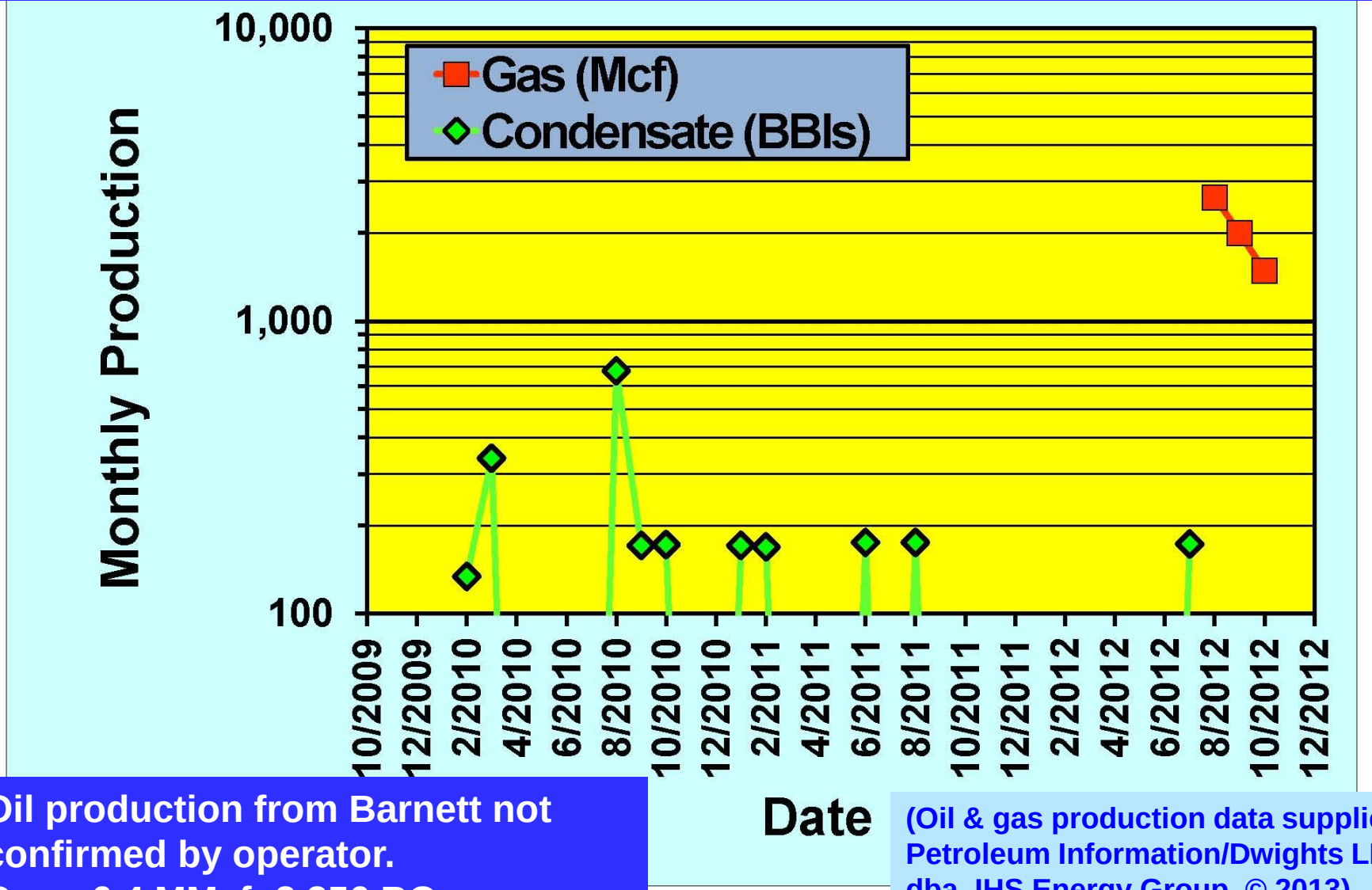
Barnett Shale

(1) GLB Exploration 1-29 Hatch well; 29-1S-23W; Jackson Co.; 7,966 TVD; 4/17/2010

(2) Texas Energy Operations 1 Lane well; 2-2S-24W; Jackson Co.; 7,830 TVD; recompleted 4/20/2012



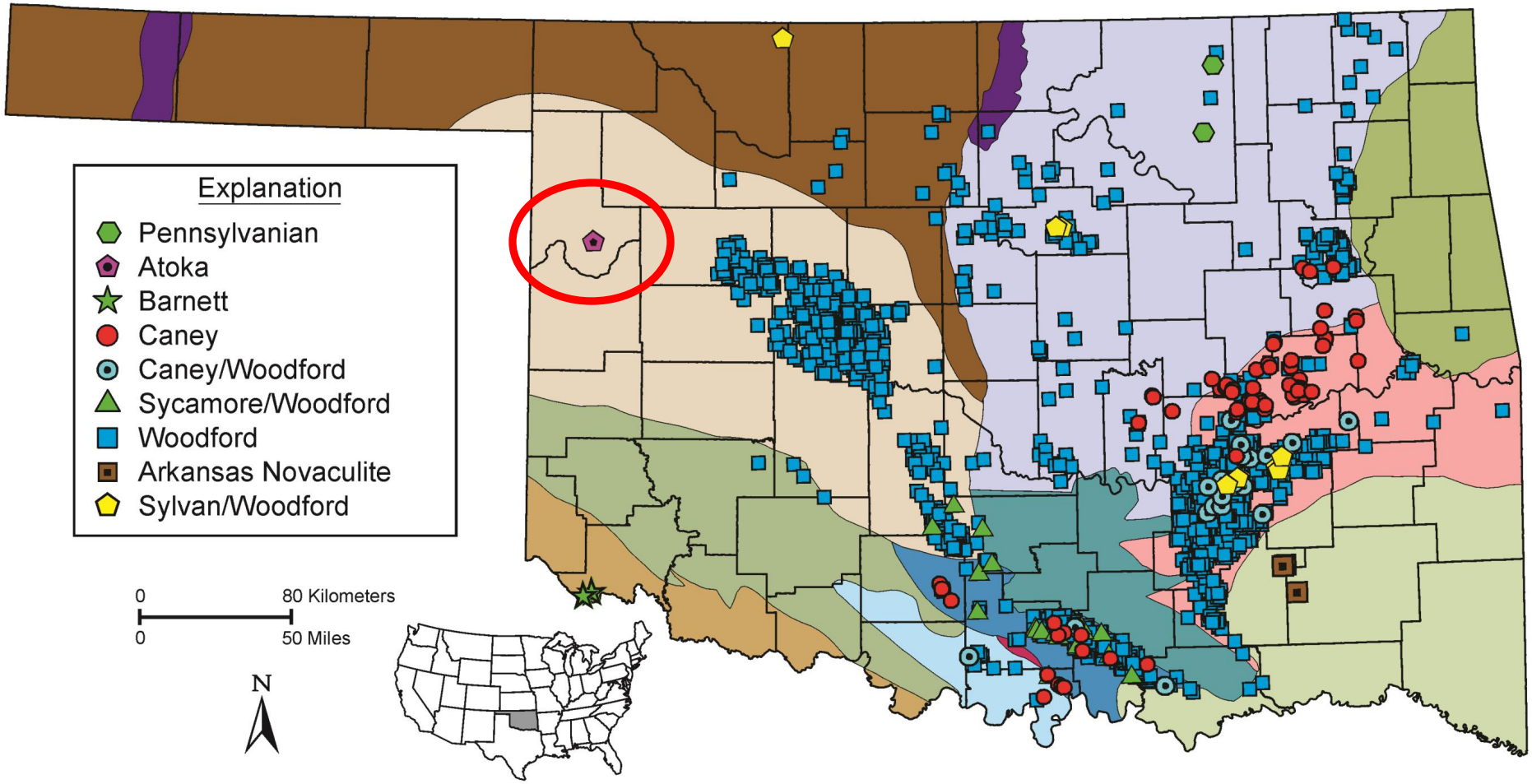
Horizontal Barnett Shale Oil Well
GLB Exploration 1-29 Hatch (Jackson Co.; 29-1S-23W): completed 4/17/2010 to 7,966 TVD; IP 1.1 MMcfd; 216 BO



Oil production from Barnett not confirmed by operator.
Cum: 6.4 MMcf; 2,356 BO

Atokan Series

Continental Resources 1-22H Shrewder well; 22-18N-23W; Ellis Co.; "Atoka Shale"; 10,926 TVD

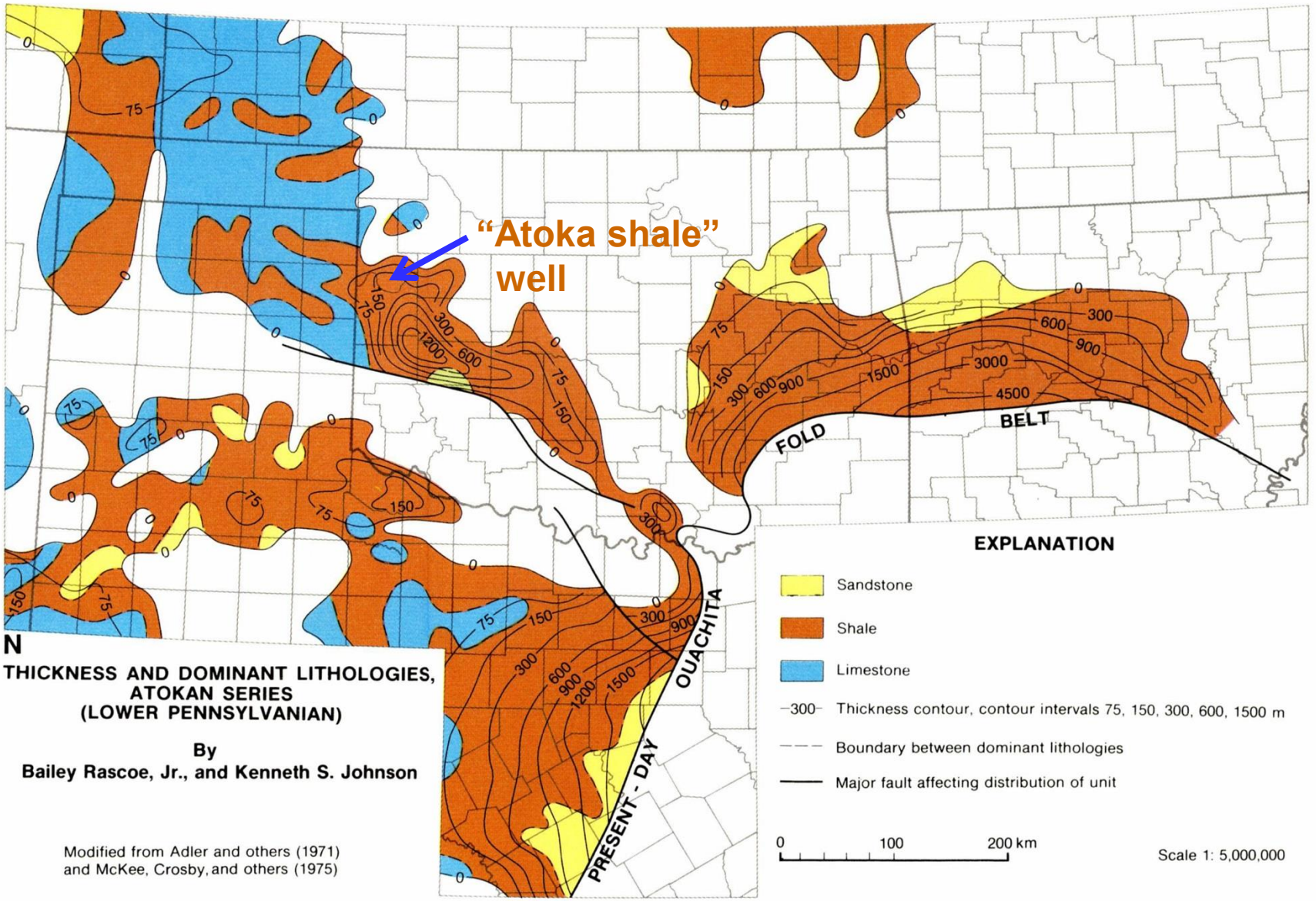


IHS Energy News

An unconventional gas resource play in **Pennsylvanian Atoka shale** is emerging in the **Anadarko** basin in the Texas Panhandle and far western **Oklahoma. Continental Resources Inc.**, Enid, Okla., says it has 34,000 net acres in the play as of mid-December 2008. The play stretches about 85 miles from Peek Field in Ellis County, Okla., west to Lipscomb, Ochiltree, eastern Hansford, northeastern Roberts, and northernmost Hemphill counties in the Texas Panhandle. Continental says **EOG Resources Inc.**, Houston, has completed 26 horizontal wells at as much as 7 MMcf/d per well and attributed 400 Bcf of Atoka recovery potential to its 60,000 net acres. **January 7, 2009**

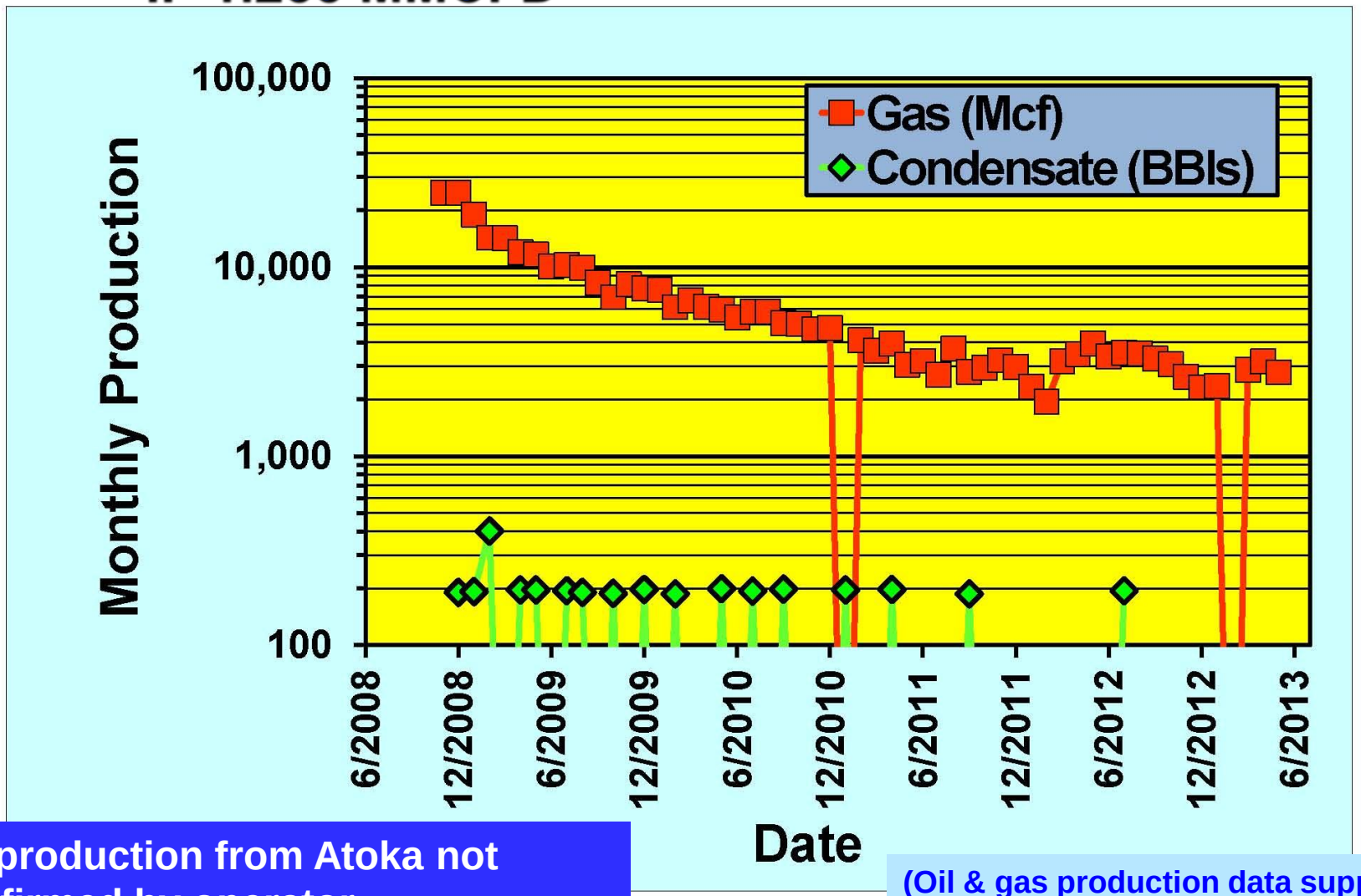
A geologist at Continental Resources indicated the well was completed in the Novi, a dolomite-rich member in the Atoka.

Atokan Isopach Map (in meters)



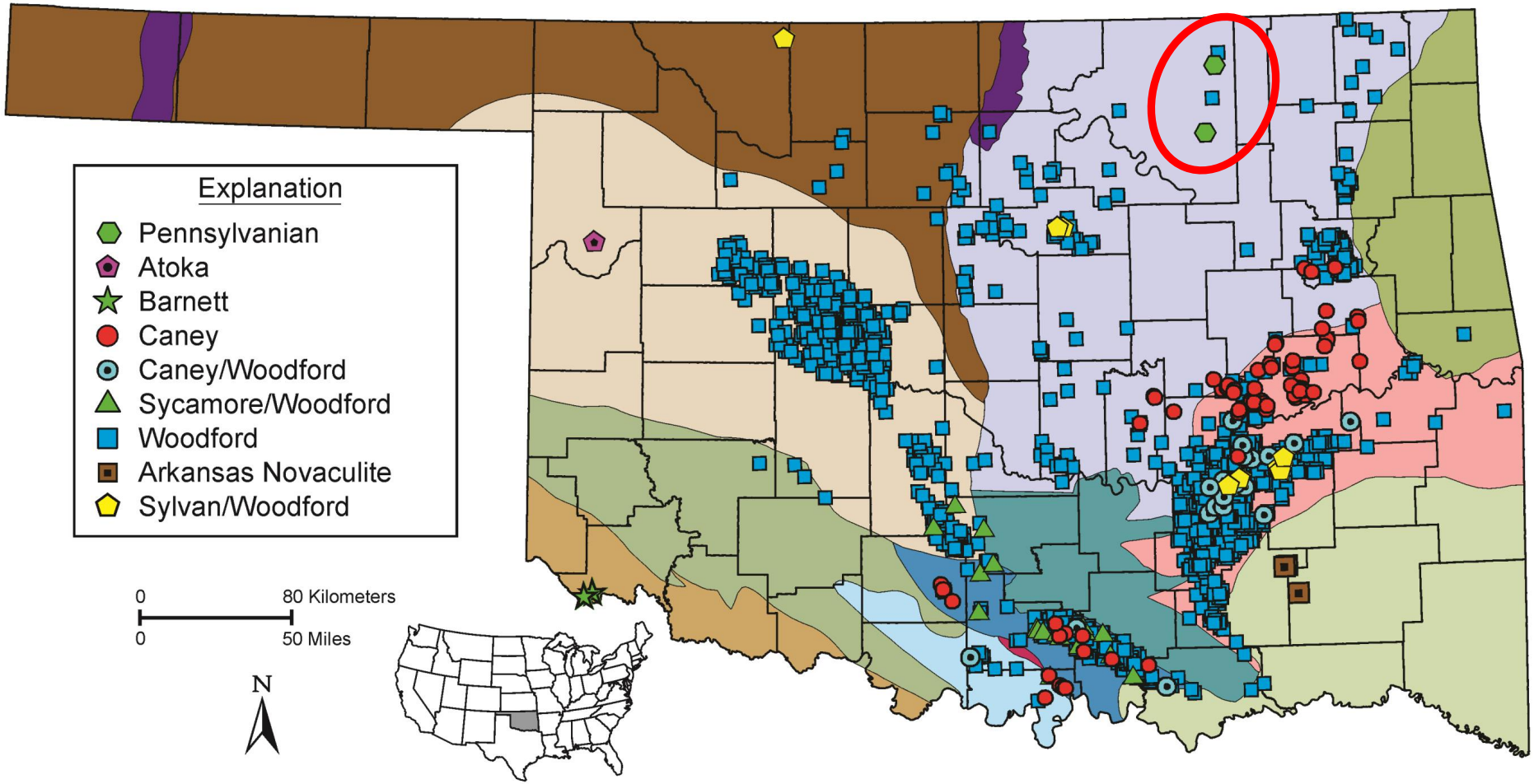
From Johnson and others, 1989

Continental Resources 1-22H Shrewder well; 22-18N-23W; Ellis Co.; "Atoka Shale"; 10,926 TVD; IP 1.255 MMCFD



Oil production from Atoka not confirmed by operator.
Cum: 334 MMcf; 3,495 BO

Pennsylvanian Shales (NE OK)



Osage County

OPER: PERFORMANCE OPERATING CO LLC; WELL: 10-32 EDMUNDSON WEST; API: 35-113-44046;	S-T-R: 28-27N-11E; SPOT: SE SW SE; FOOTAGE: 330 FSL 990 FWL SE;	FIELD: DOMES-POND CREEK; PROJ DEPTH: 1950; PROJ FM: CHAT; (PMT APP'D 20101012) (FR:20101112 OKC NAO/MER) LEASE TYPE:FEE TARGET OBJ: OIL; OPER ADD: P O BOX 628, BARNSDALL, OK 74002--0628, (918)847-2531 EL: 858 GR; ;VERTICAL; L&L Surf: 36.782523131 -96.12146808; PREV OPER: PERFORMANCE ENERGY R PREV LEASE: EDMUNDSON W	DO STATUS: OIL;

CONTR: THORNTON AIR, SPUD:20101027 CSG: 8 5/8 IN @ 42 W/8 SACK,4 1/2 IN @ 1761 W/230 SACK;LOG TOPS: JONES /SD/ 966-981, WAYSIDE 1040-1056, BIG LIME

1167-1194, OSWEGO 1331, SUMMIT 1362-1368, EXCELLO 1388; TD: 1820; (EXCELLO) (TD REACHED:20101029) PRODUCING INTERVALS DATA: # 01 PERF (EXCELLO) 1650-1654 W/ 8 SHOTS 1656-1660 W/ 8 SHOTS 1664-1672 W/ 16 SHOTS ; ACID (1650-1672) W/ 400 GAL ACID 15%; FRACTURING (1650-1672) W/ 390 BBL WATER 20000 LB MIXED SAND DETAILS: 1 GAL INH, 18 GAL, 300#, 2000# 20/40, 18000# 12/20 SD ADDITIVE: GELA, KCL OIL: 4 BPD WTR: 50 BBL DTD: 1820; COMPDATE: 20101113; (EST); # 01 IPP OIL: 4 BPD WTR: 50 BBL PROD ZONE: PERF (EXCELLO) 1650-1672 (GROSS) W/ 32 ; $$

Completion reported as Cherokee completion; NO PRODUCTION

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

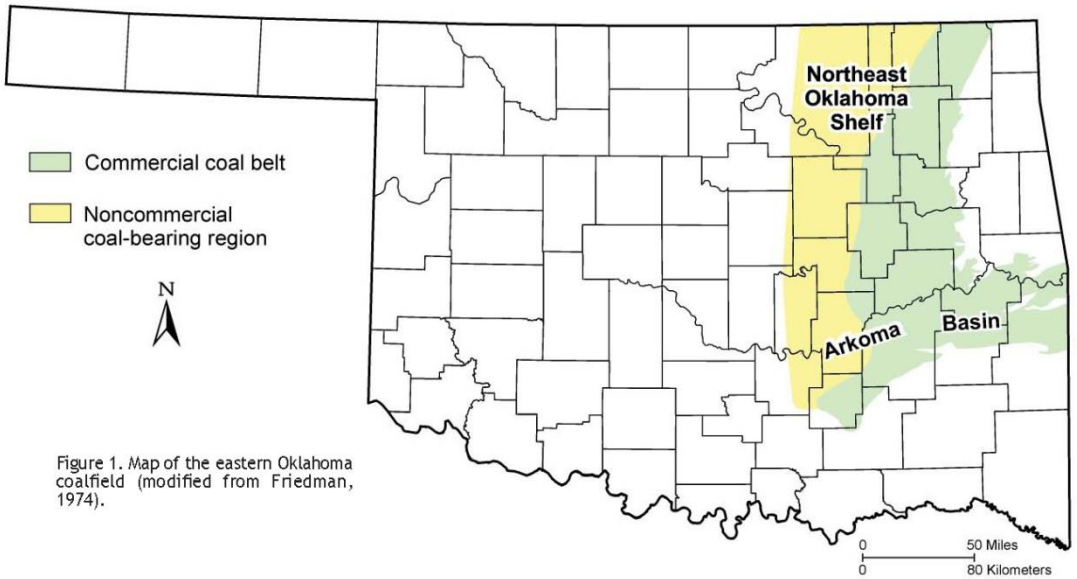


Figure 1. Map of the eastern Oklahoma coalfield (modified from Friedman, 1974).

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).

of CBM began in the San Juan Basin 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

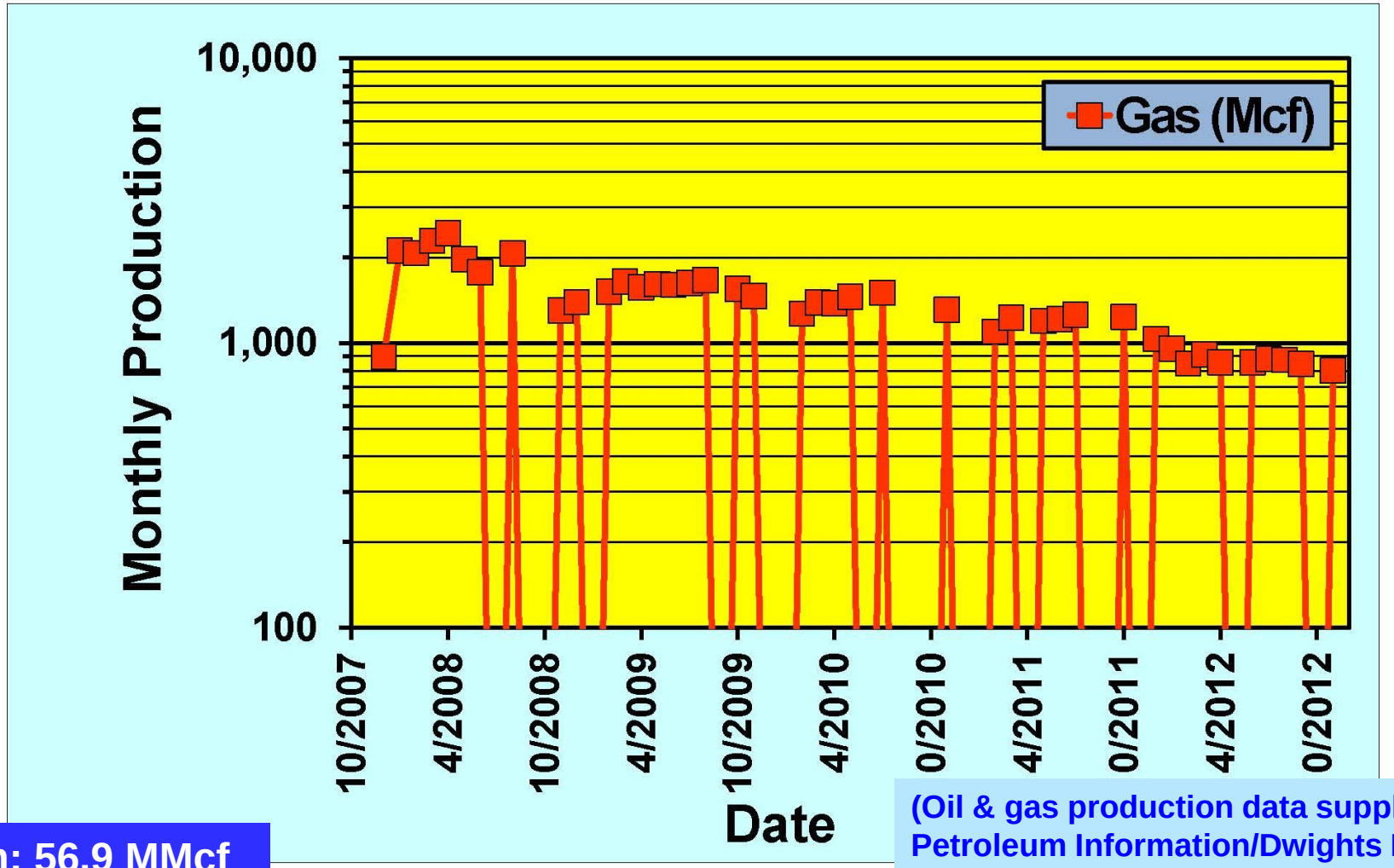
Excello Shale

Osage County

OPER: CEP MID-CONTINENT LIMITED LIABILITY CORP; WELL: 977 MARSHALL; API: 35-113-42654;	S-T-R: 12-23N-10E; SPOT: NW SW SE; FOOTAGE: 1177 FSL 2335 FEL SE;	FIELD: OSAGE COUNTY CBM GAS AREA; PROJ DEPTH: 2100; PROJ FM: MISSISSIPPIAN; (PMT APP'D 20070725) (FR:20070806 OKC RES) TARGET OBJ: METH; OPER ADD: 1440 SOUTH HAYNIE, P O BOX 970, SKIATOOK, OK 74070, (918)396-0817 EL: 929 GR; ;VERTICAL; L&L Surf: 36.480474465 -96.181909434; PREV OPER: AMVEST OSAGE INC PREV LEASE: OSAGE	DG STATUS: GAS-CB;

CONTR: PENSE BROTHERS DRILLING, SPUD:20070912 CSG: 7 IN @ 531,4 1/2 IN @ 1722;LOG TOPS: CLEVELAND UPPER 1085, NUYAKA 1148, DAWSON UPPER 1153, CLEVELAND LOWER 1160, LITTLE OSAGE 1477, OSWEGO 1480, MULKY 1520, IRON POST 1533, VERDIGRIS 1587, OAKLEY COAL 1594, CROWEBERG 1599, MINERAL COAL 1652; TD: 1735; (MINERAL COAL) (TD REACHED:20070919) 1722 PBTD PRODUCING INTERVALS DATA: # 01 PERF (NUYAKA) 1150-1154 PERF (MULKY) 1522-1524 1531-1533 PERF (OAKLEY COAL) 1596-1599; ACID (1150-1154) W/ 500 GAL ACID 7 1/2% ADDITIVE: HCL; ACID (1522-1533) W/ 500 GAL ACID 7 1/2% ADDITIVE: HCL; ACID (1596-1599) W/ 500 GAL ACID 7 1/2% ADDITIVE: HCL; FRACTURING (1150-1154) W/ 145000 CF FOAM 10170 LB SAND DETAILS: 12837 GAL MAVFOAM C70 ADDITIVE: NTGN; FRACTURING (1522-1533) W/ 150000 CF FOAM 10000 LB SAND DETAILS 9740 GAL MAVFOAM C70 ADDITIVE: NTGN; FRACTURING (1596-1599) W/ 107000 CF FOAM 52000 LB SAND DETAILS: 7907 GAL MAVFOAM C70 ADDITIVE: NTGN GAS: 33 MCFD WTR: 160 BBL DTD: 1735; 1722 PB COMPDATE: 20080110; # 01 IPP GAS: 33 MCFD WTR: 160 BBL PROD ZONE: PERF (NUYAKA) 1150-1154 PERF (MULKY) 1522-1533 (GROSS) PERF (OAKLEY COAL) 1596-1599 COMMINGLED; $$

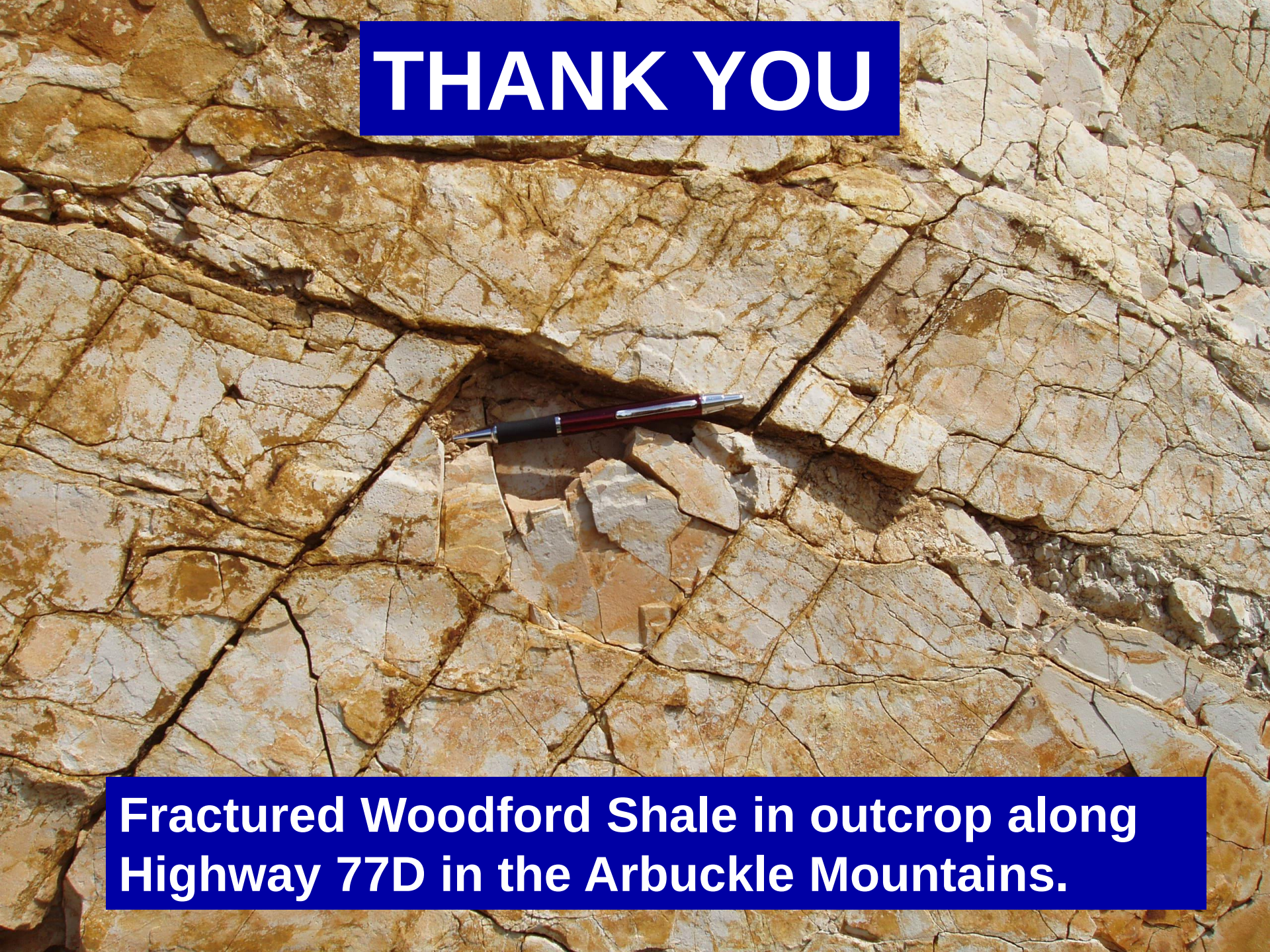
Pennsylvanian shale gas well:
CEP Mid-Continent 977 Marshall (Osage Co.; 12-23N-10E): perforated Nuyaka shale, Mulky coal (Excello Shale), and Oakley shale on 1/10/2008; IP 33 Mcfd



Cum: 56.9 MMcf

(Oil & gas production data supplied by Petroleum Information/Dwights LLC dba IHS Energy Group, © 2013)

THANK YOU



Fractured Woodford Shale in outcrop along Highway 77D in the Arbuckle Mountains.