Application of Organic Petrology to the Woodford Gas-Shale Play, Oklahoma, U.S.A.

Brian J. Cardott

Oklahoma Geological Survey

Outline

- Background on Gas Shales
- Oklahoma Woodford Shale
- Oklahoma Woodford Gas-Shale Play

Non-Negotiable Parameters Necessary for Gas Shales

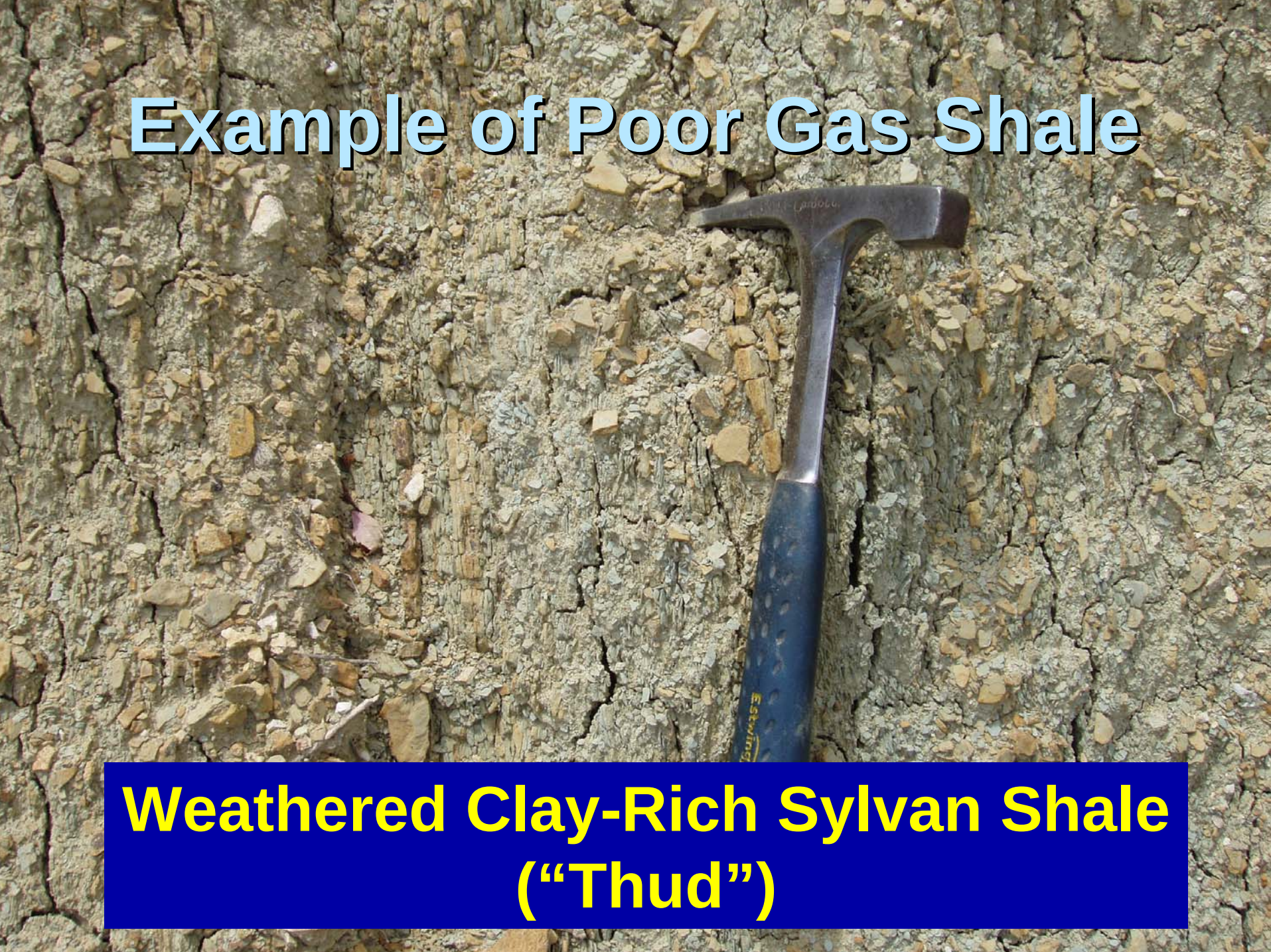
- Fractures (permeability)
- Gas Source Rock (Gas Generation, Storage, and Preservation)

  [similar to coalbed methane]

Fractures

- Lithology must be fracture-able (e.g., silica rich)
- Fractures must stay in-zone (e.g., need fracture barriers; stay away from faults)
- Natural vs. induced fractures

Example of Poor Gas Shale



Weathered Clay-Rich Sylvan Shale ("Thud")

Example of Good Gas Shale

Fractured, Silica-Rich Woodford Shale (“Ping”)

Gas Generation (Application of Organic Petrology): Organic-Rich Black Shale/Siltstone

- Organic Matter Type:

  Type II Kerogen
- Organic Matter Quantity: minimum of 2% TOC (depends on thermal maturity)
- Thermal Maturity (highest gas rates in gas window)

Gas Generation by Kerogen Type

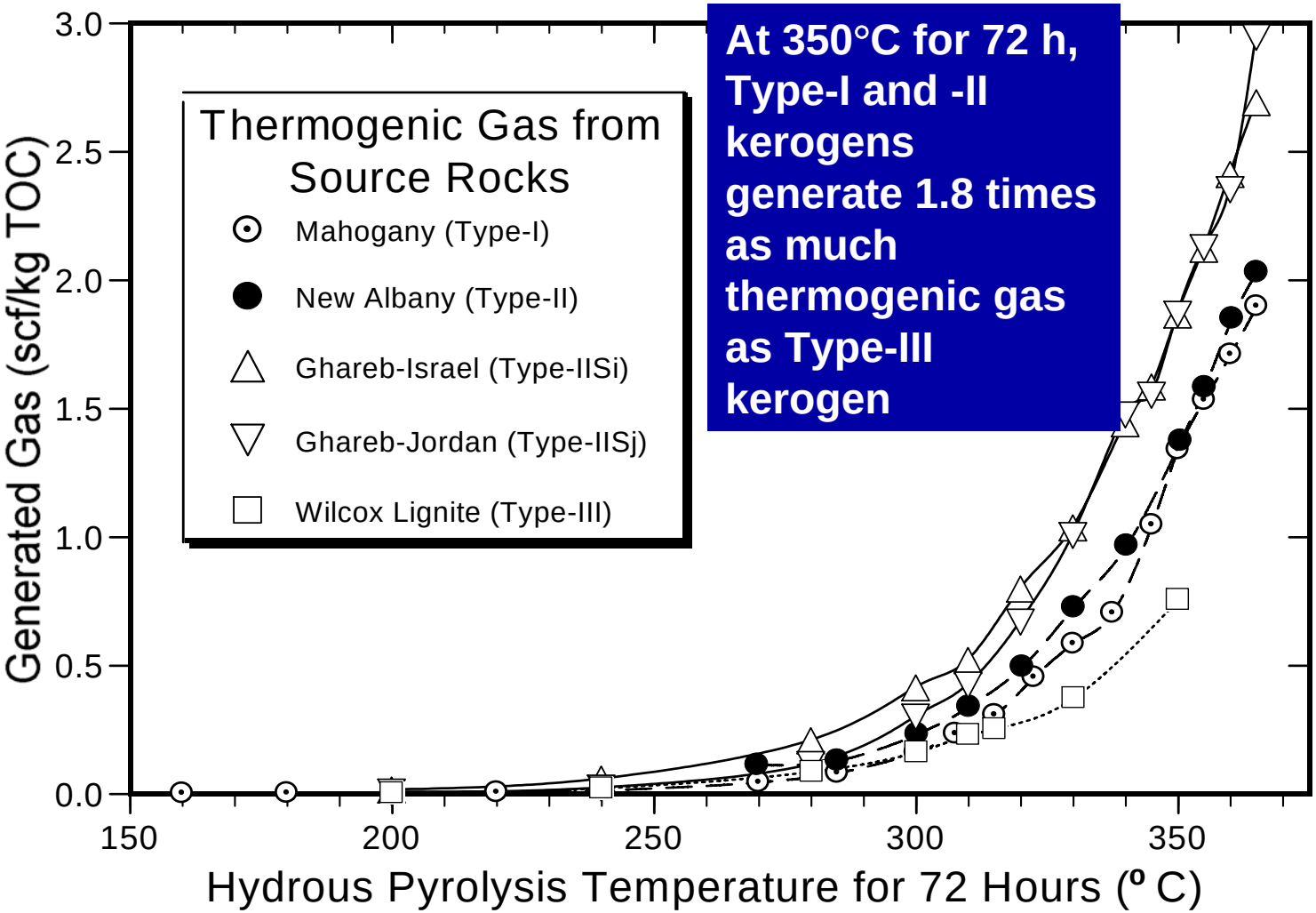
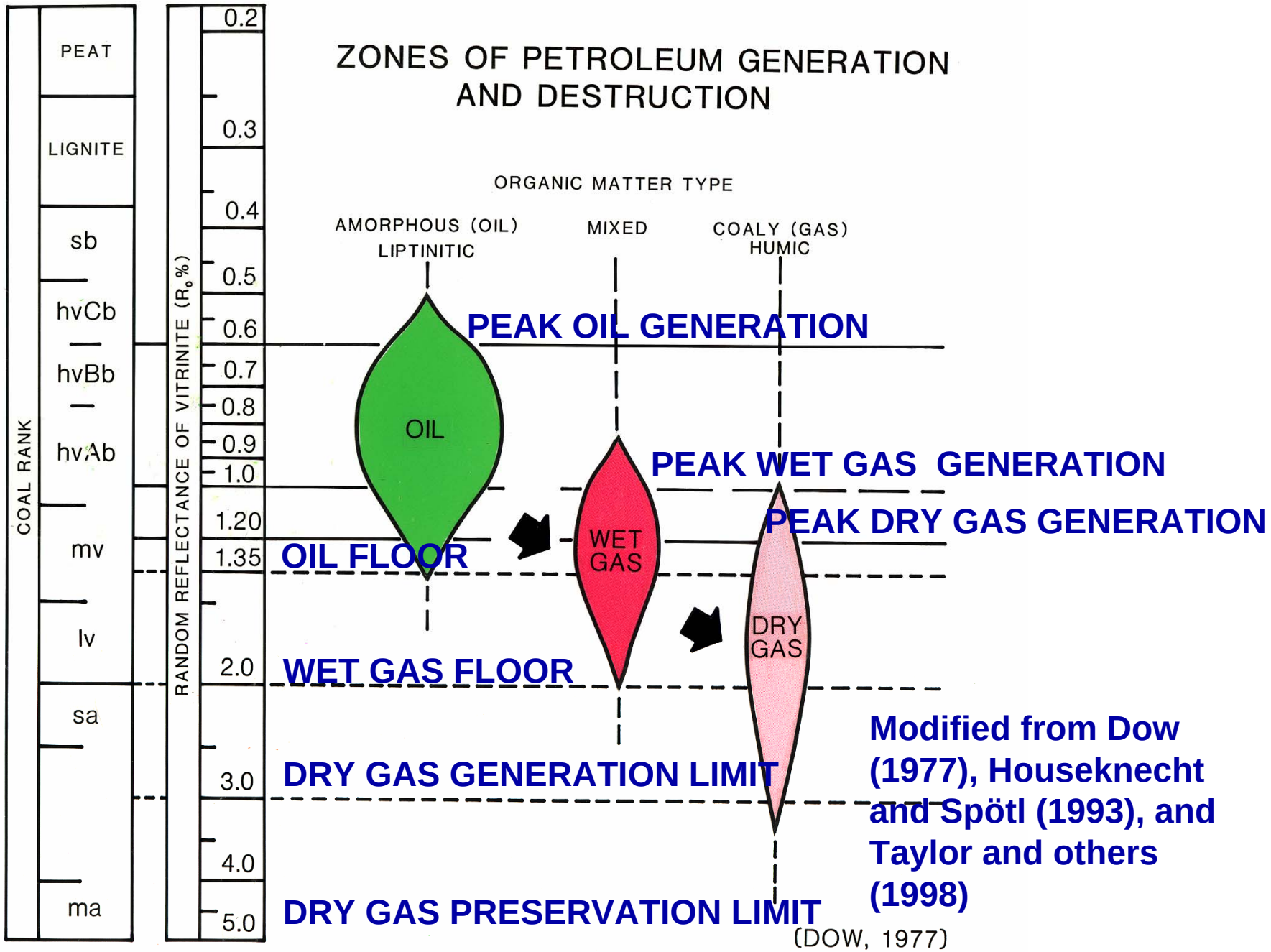


Figure 2: Volume of hydrocarbon gas (C_1-C_5) generated by hydrous pyrolysis from thermally immature source rocks bearing different kerogen types (Lewan and Henry, 2001).

From Lewan, 2002


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 Spötl (1993), and Taylor and others (1998)
(DOW, 1977)

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

Type II Kerogen Gas Generation (Hydrous Pyrolysis)

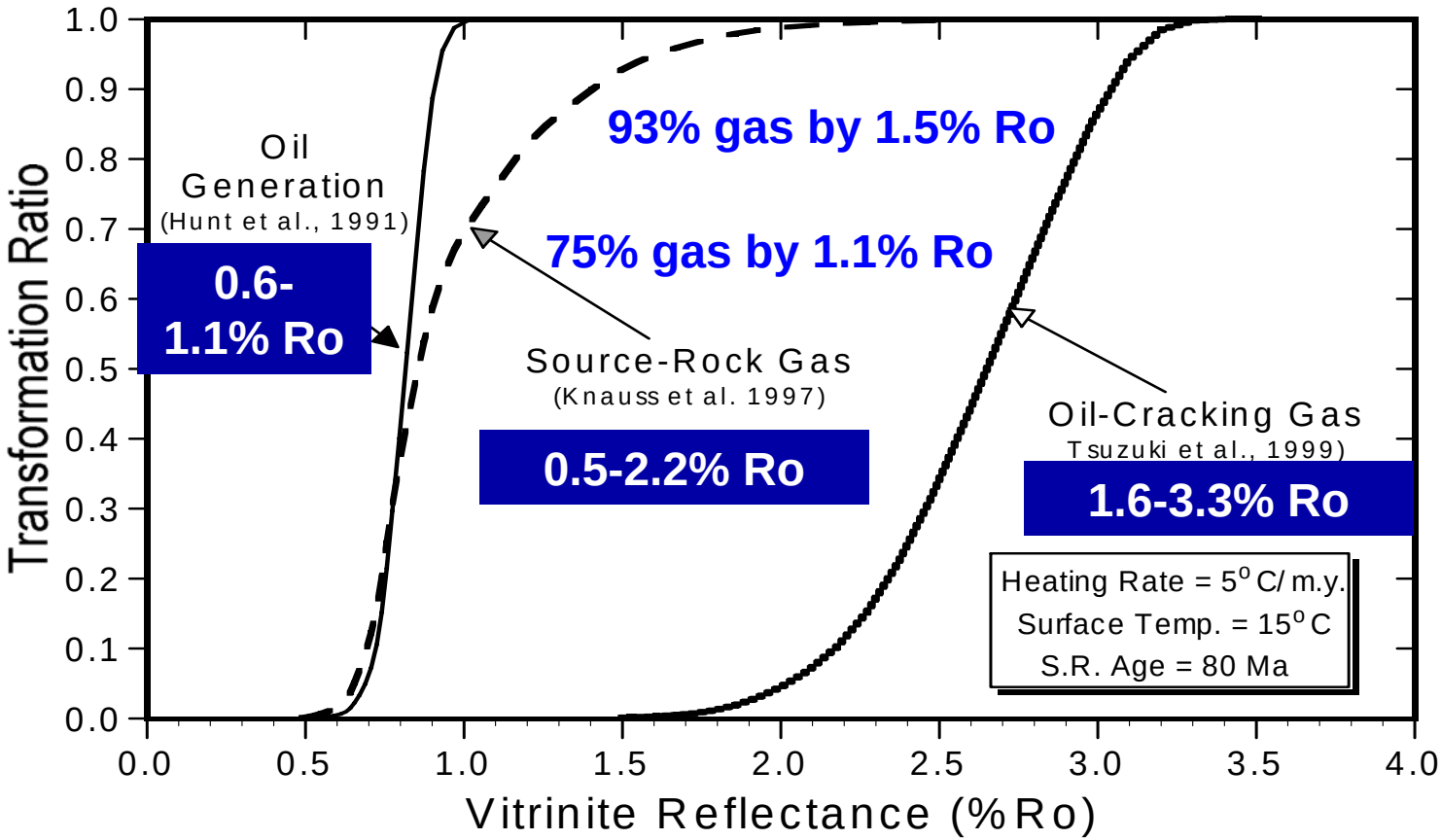
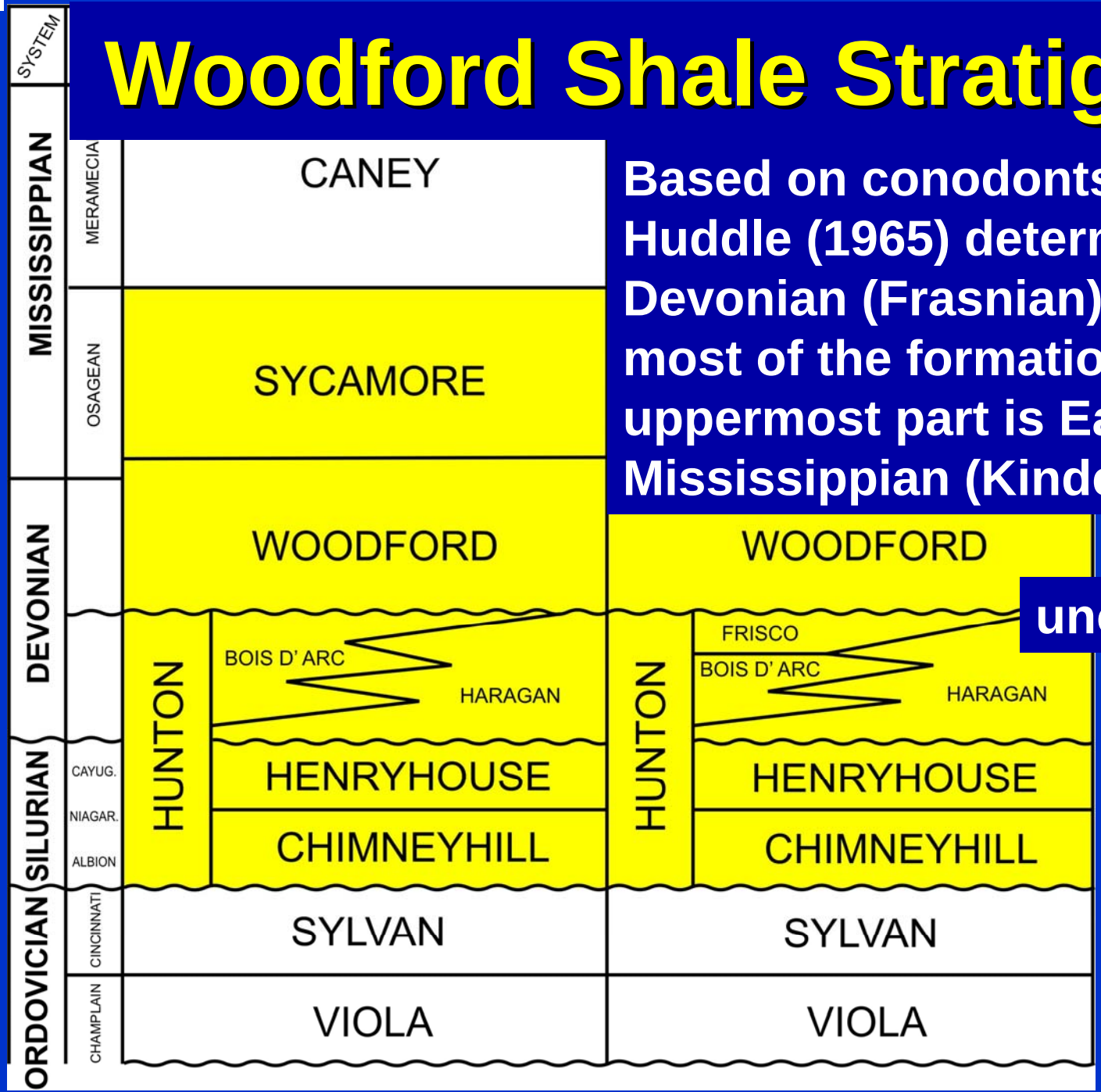


Figure 1: Generation of oil and gas from an 80-Ma source rock with Type-II kerogen and associated crude oil. Curves are based on kinetic parameters determined by hydrous and hydrothermal pyrolysis and EASY%Ro (Swweeney and Burnham, 1990).

From Lewan, 2002

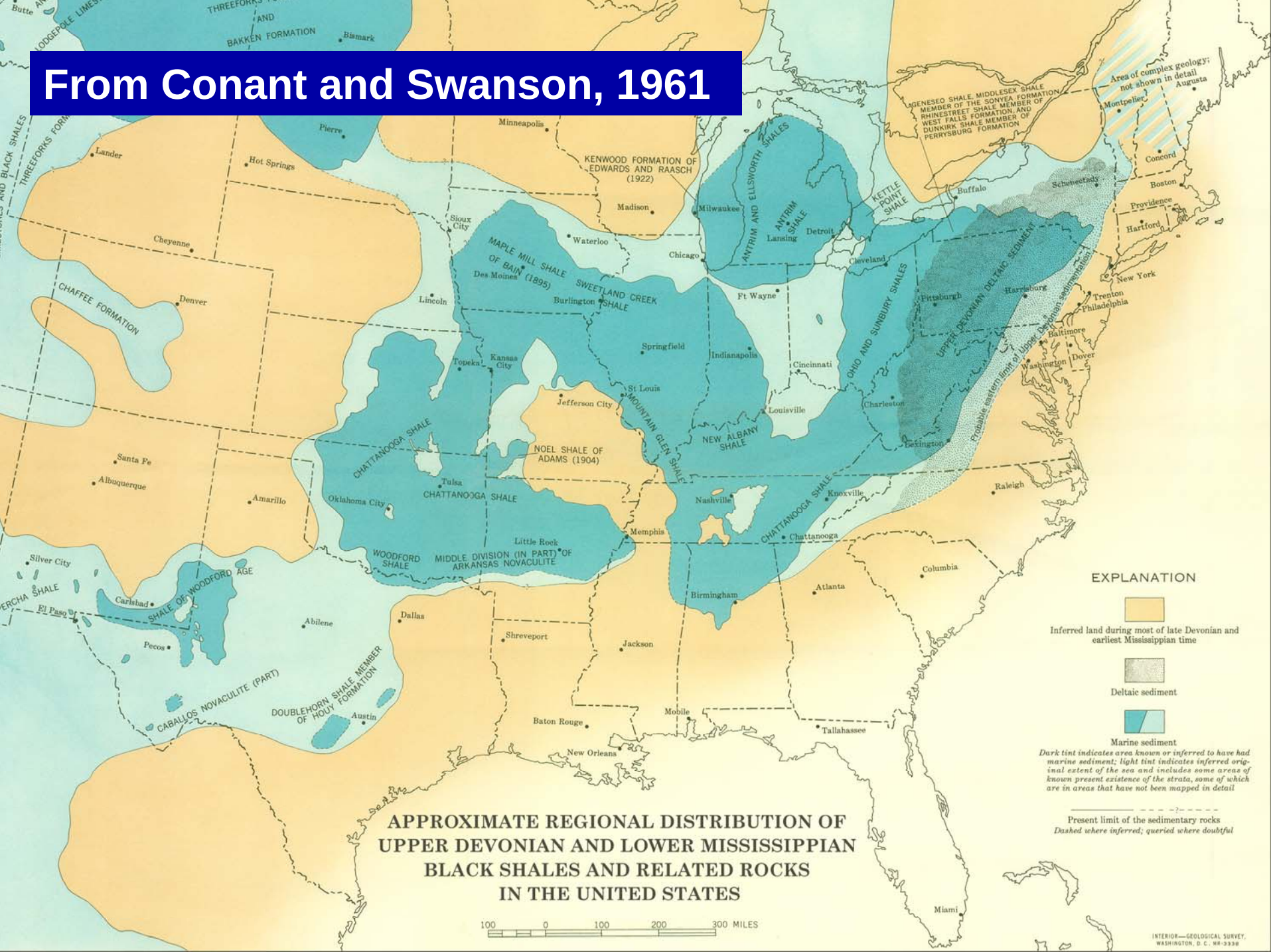
Woodford Shale Stratigraphy



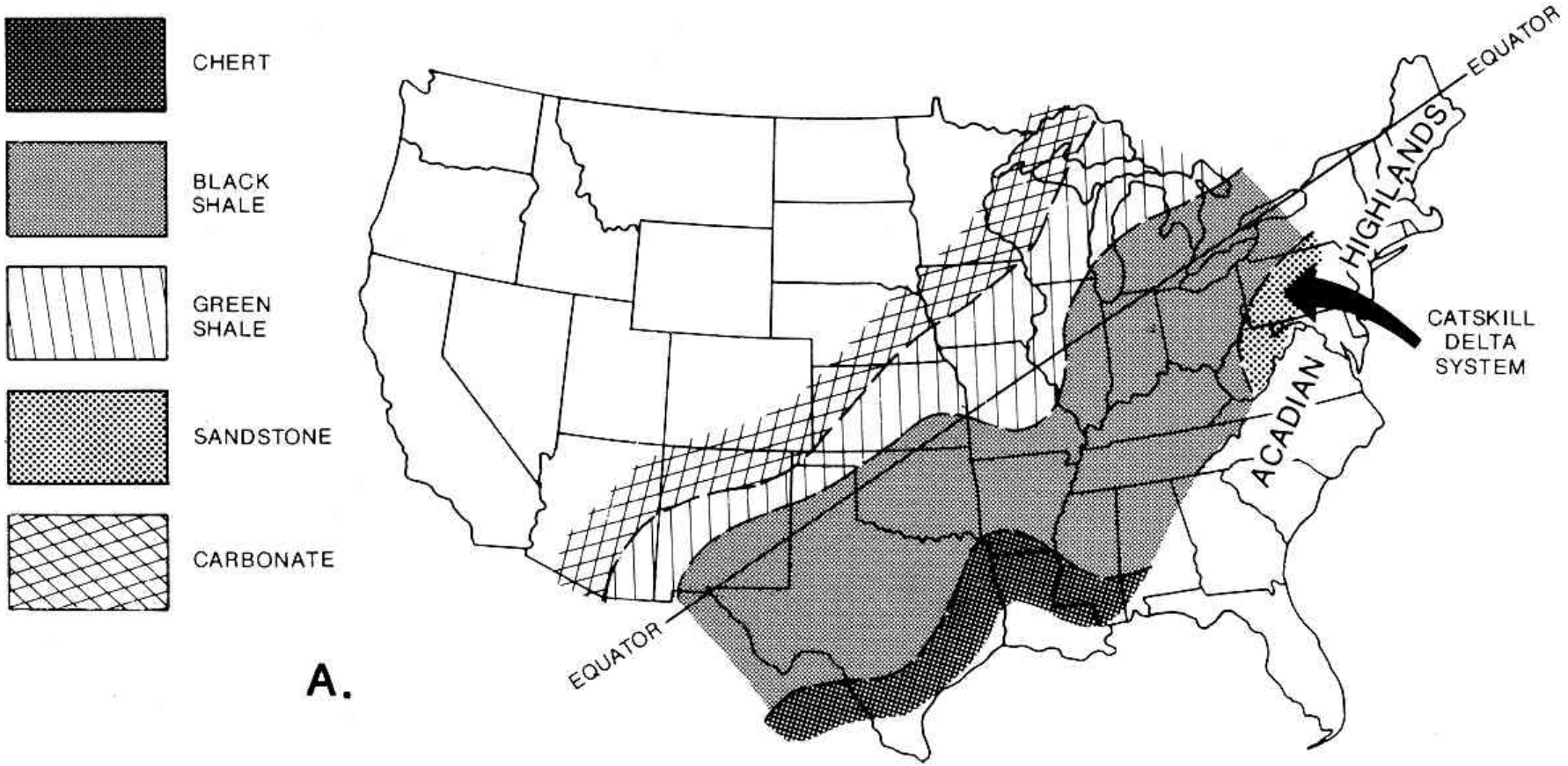
Based on conodonts, Hass and Huddle (1965) determined a Late Devonian (Frasnian) age for most of the formation; uppermost part is Early Mississippian (Kinderhookian)

unconformity

From Conant and Swanson, 1961

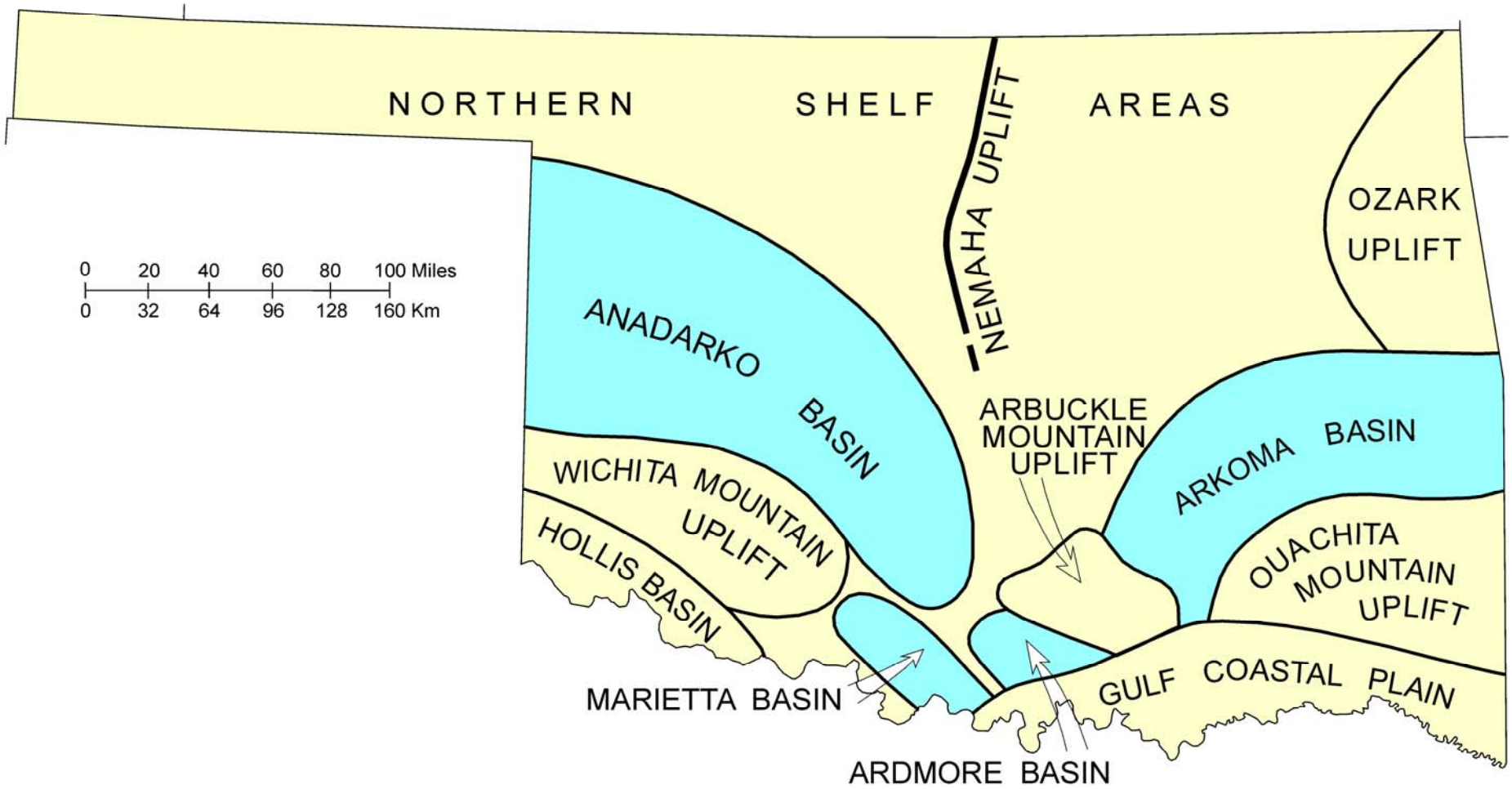


Paleogeography and Facies Distribution in the Late Devonian

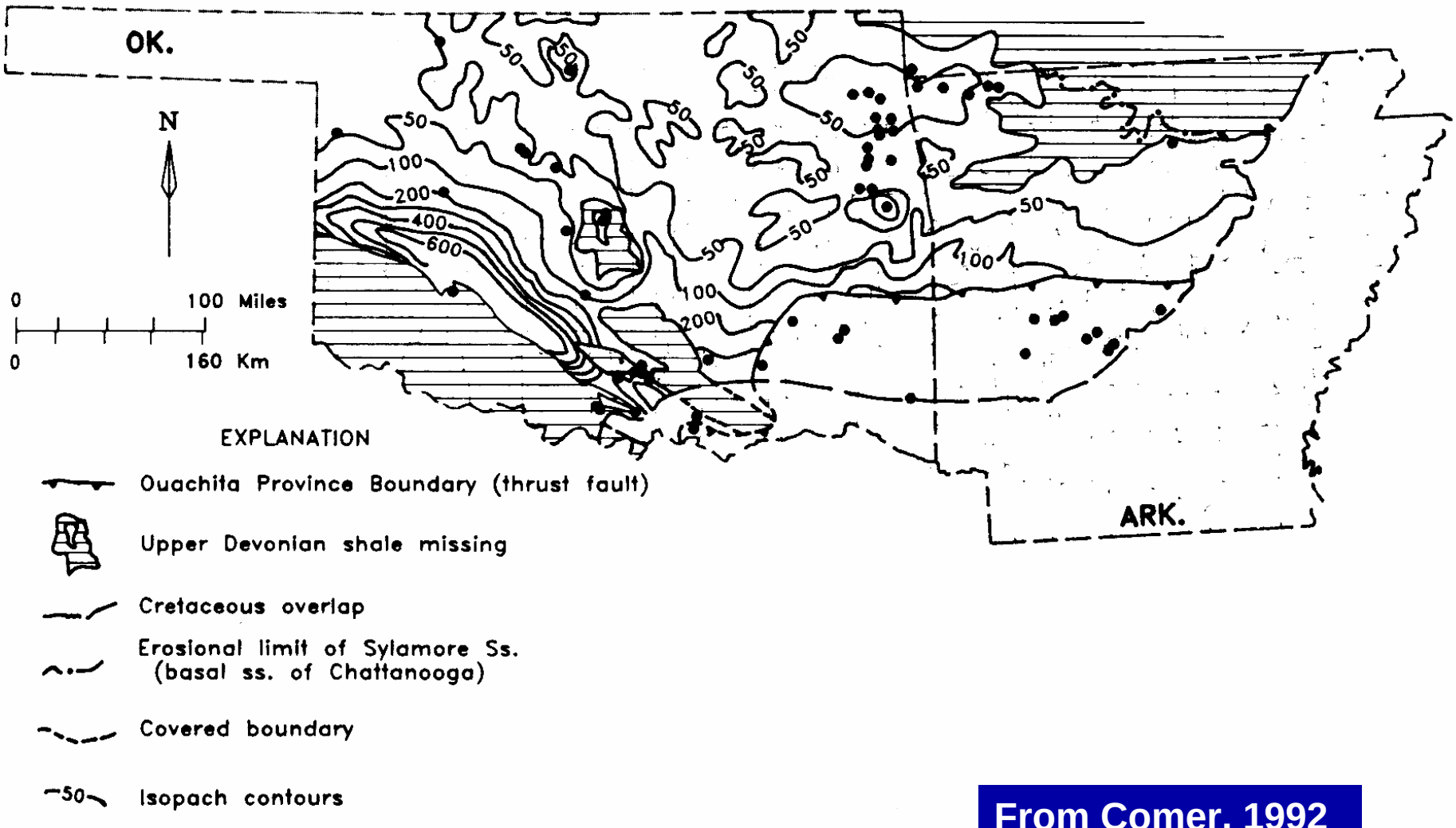


From Kirkland and others, 1992

Geologic Provinces of Oklahoma

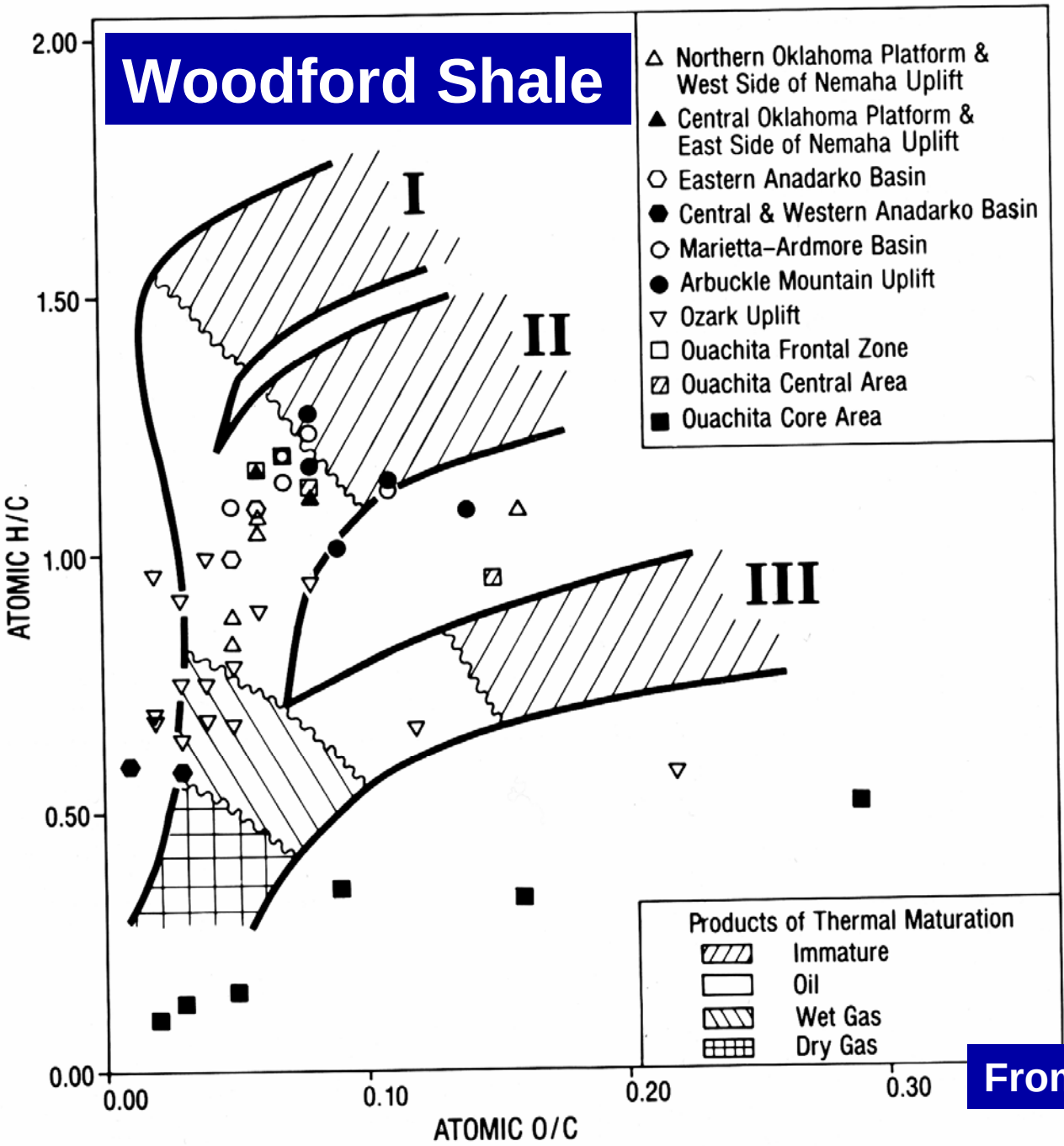


Isopach Map of Woodford Shale



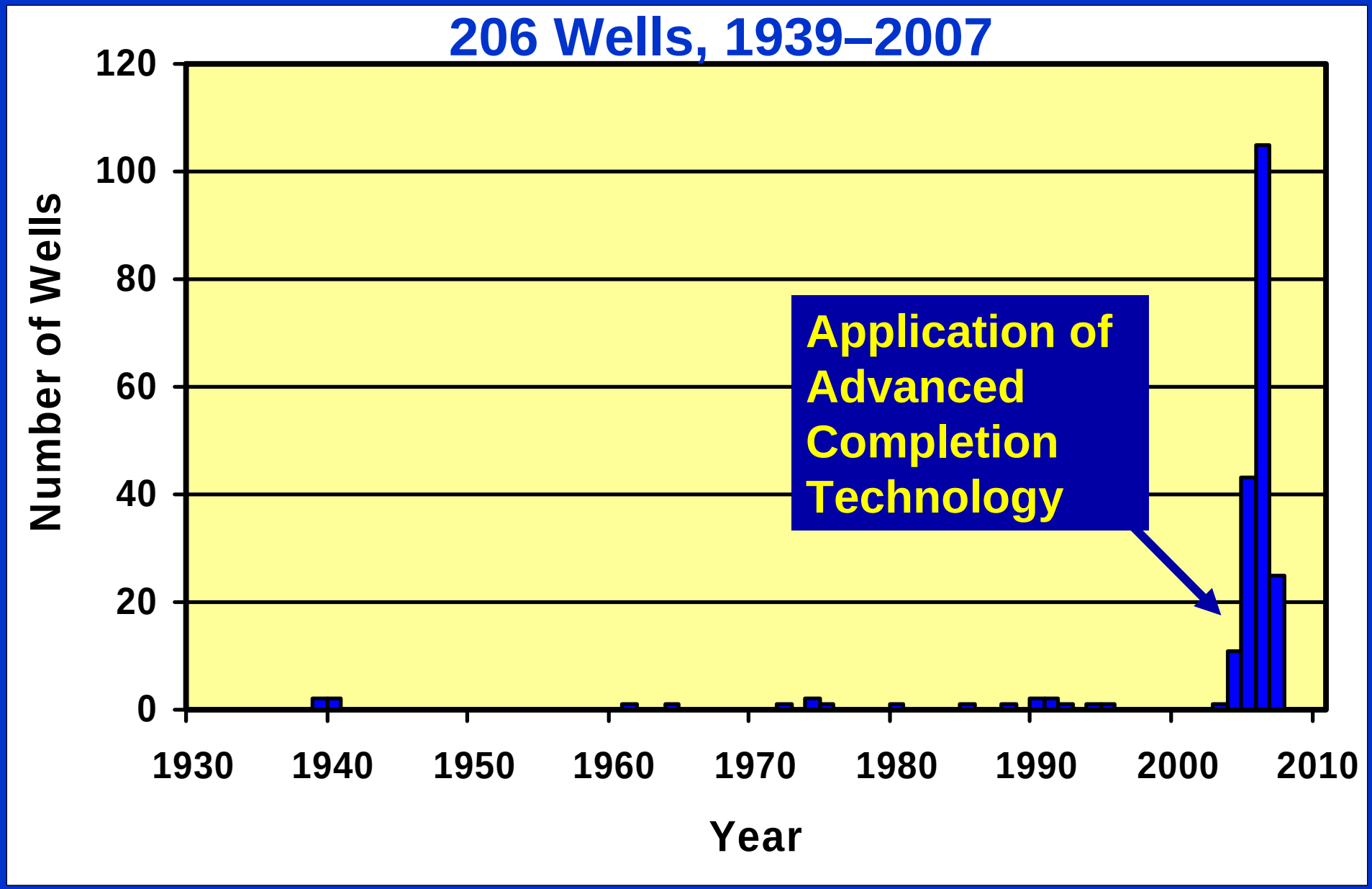
From Comer, 1992

Woodford Shale



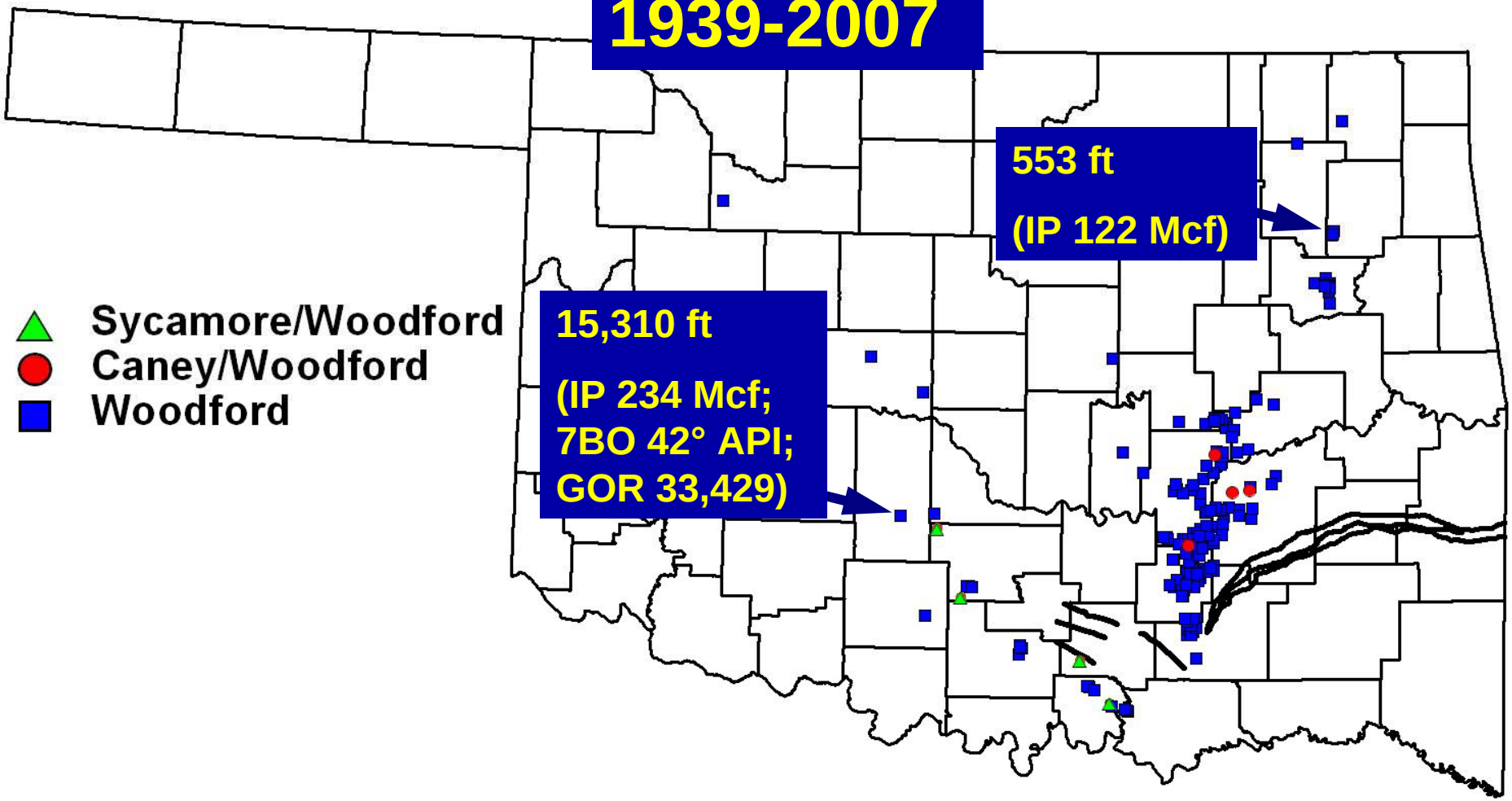
From Comer, 1992

Woodford Shale Gas Wells



Woodford Gas Shales

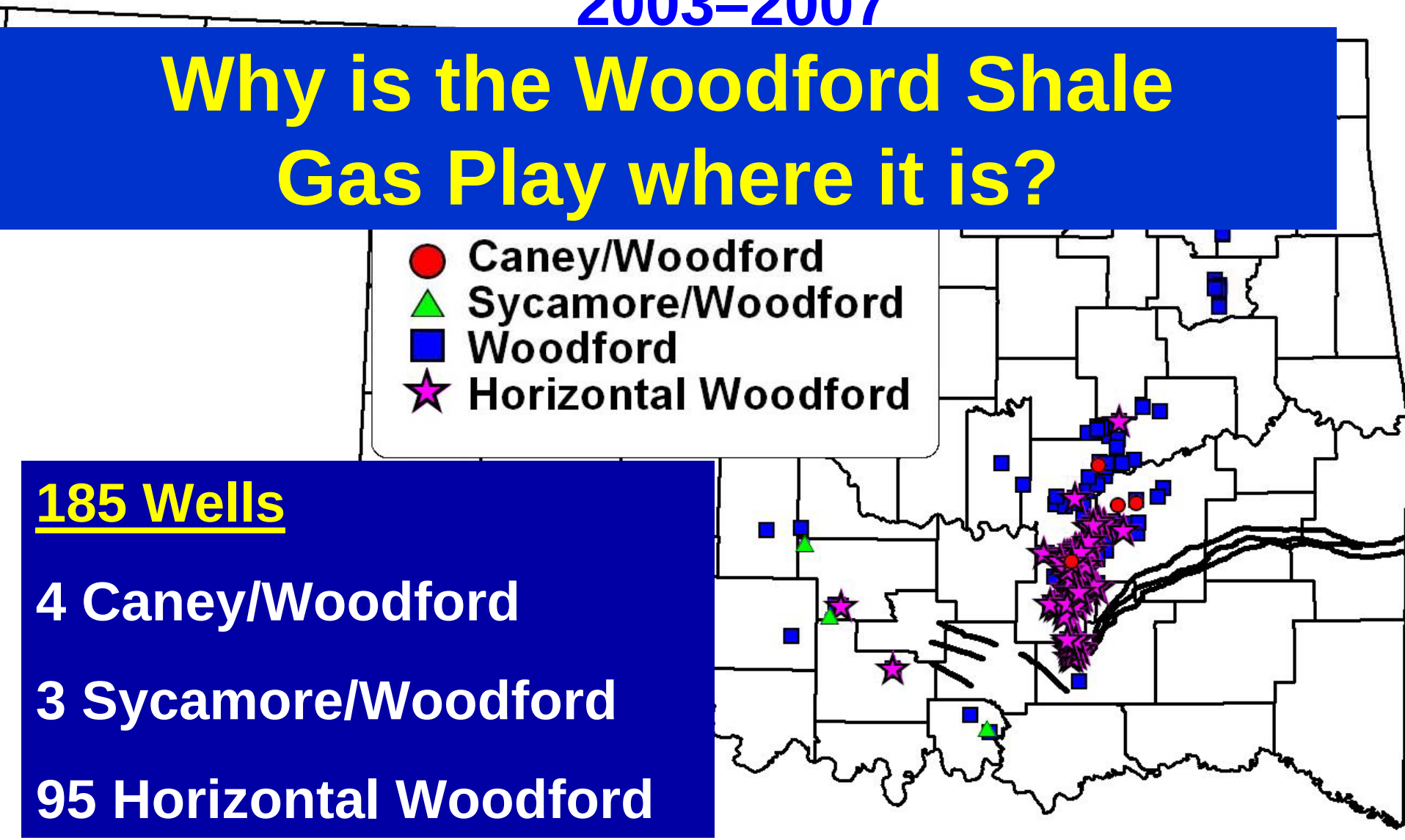
1939-2007



Woodford Gas Shales

2003–2007

Why is the Woodford Shale Gas Play where it is?

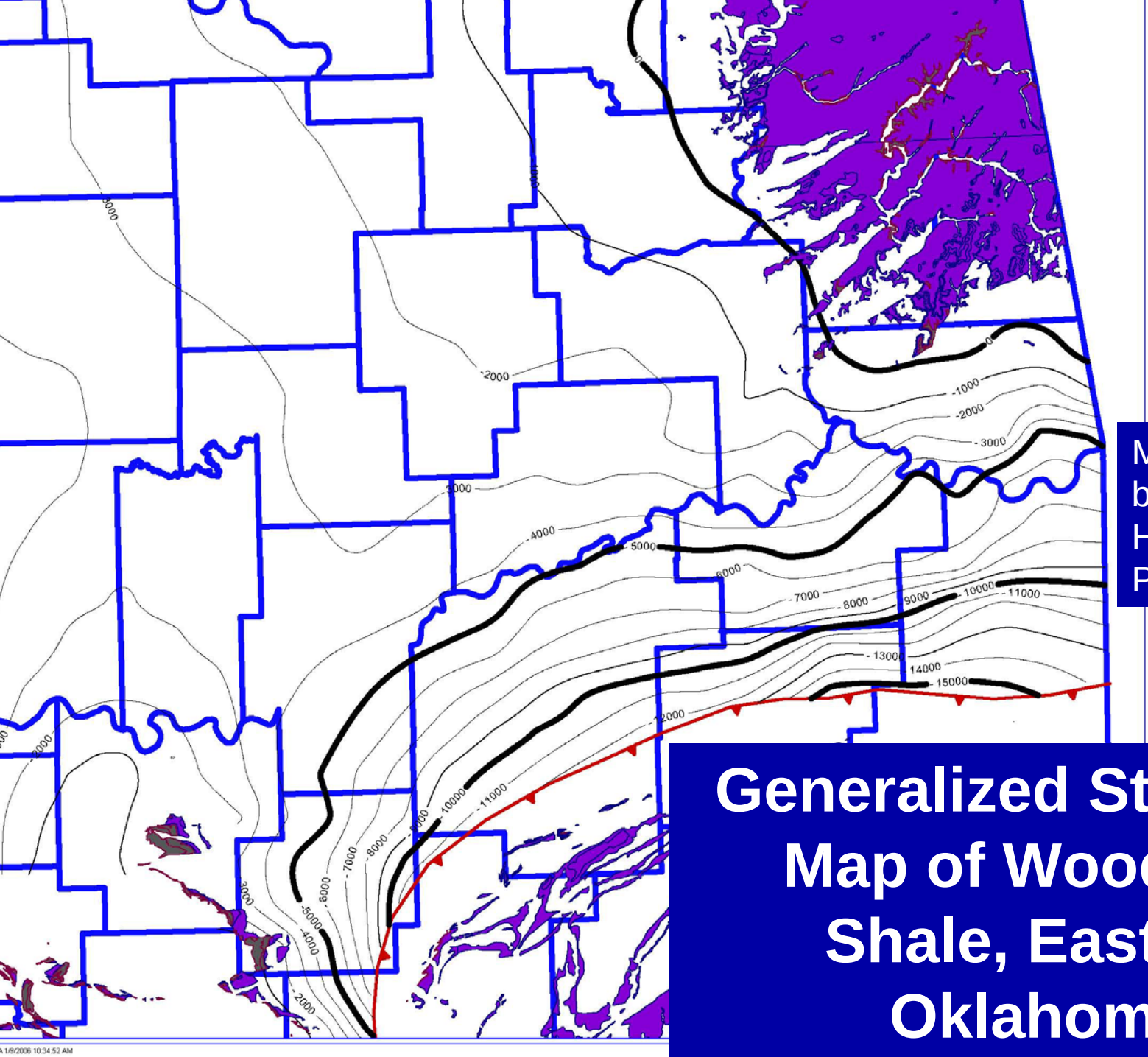


185 Wells

4 Caney/Woodford

3 Sycamore/Woodford

95 Horizontal Woodford

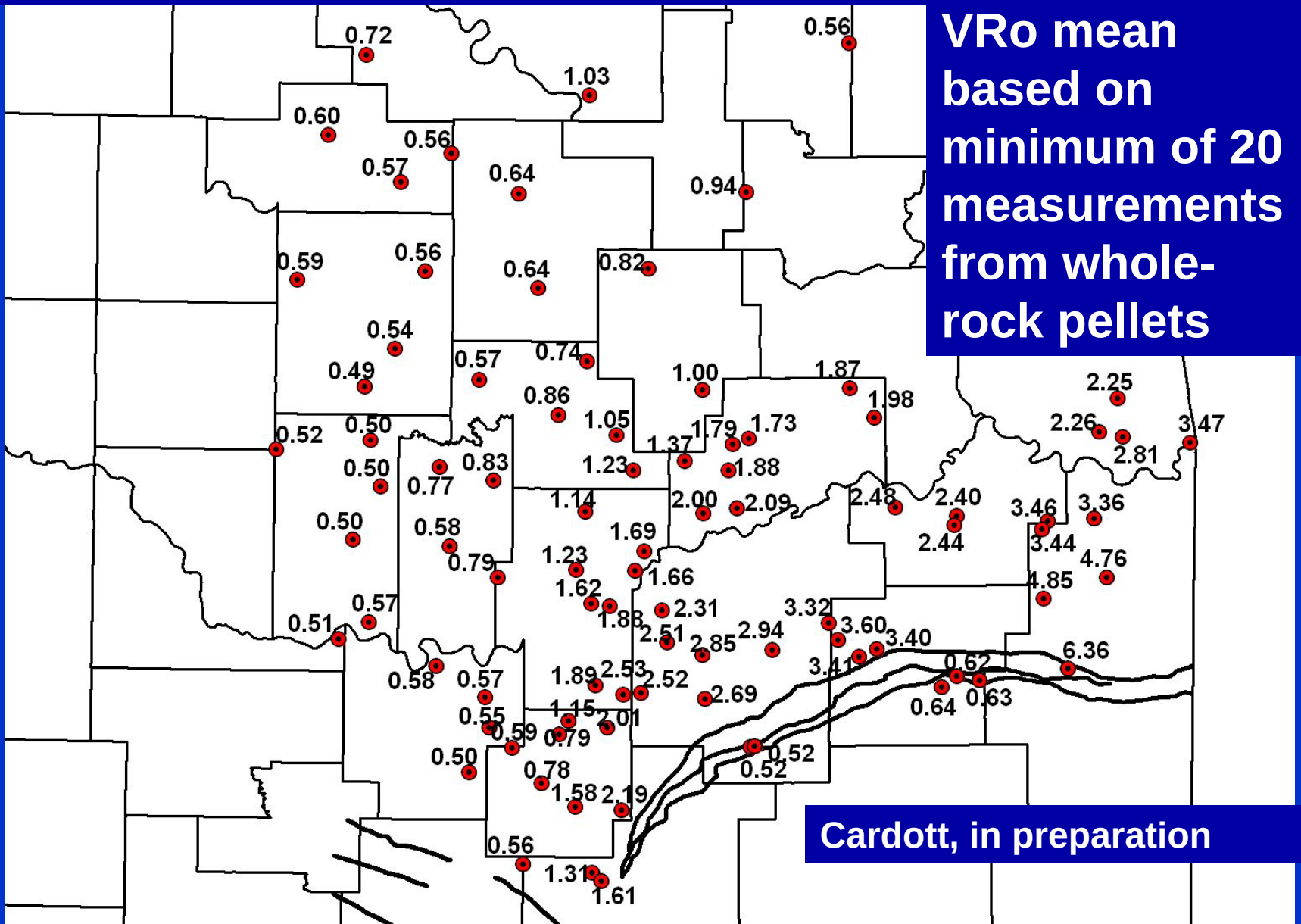


Map prepared by R. Vance Hall using Petra

Generalized Structure Map of Woodford Shale, Eastern Oklahoma

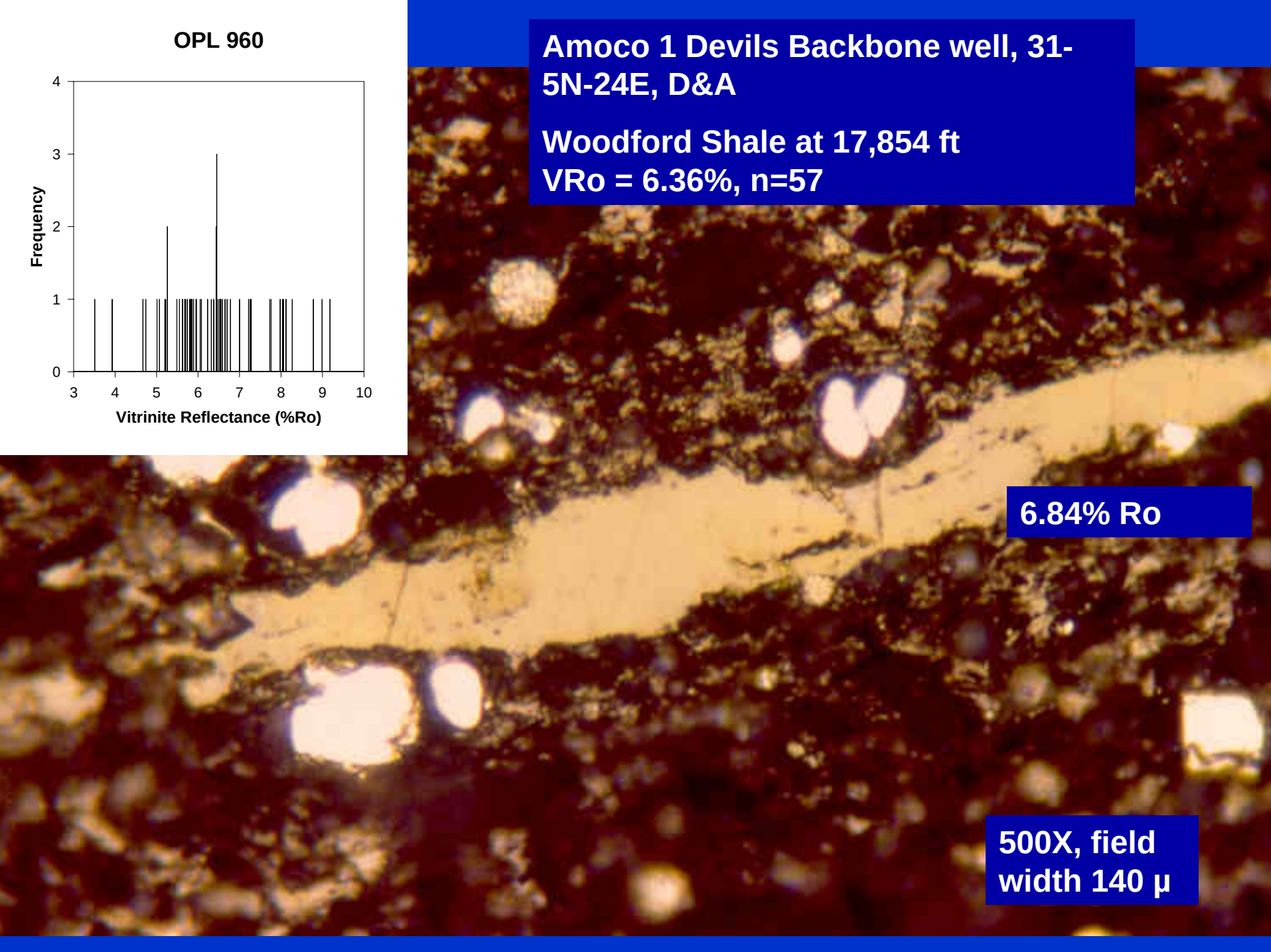
Woodford Shale is the oldest rock in Oklahoma that contained wood (vitrinite) from the progymnosperm *Archaeopteris* (organ genus *Callixylon*)

Vitrinite Reflectance of Woodford Shale, Eastern Oklahoma

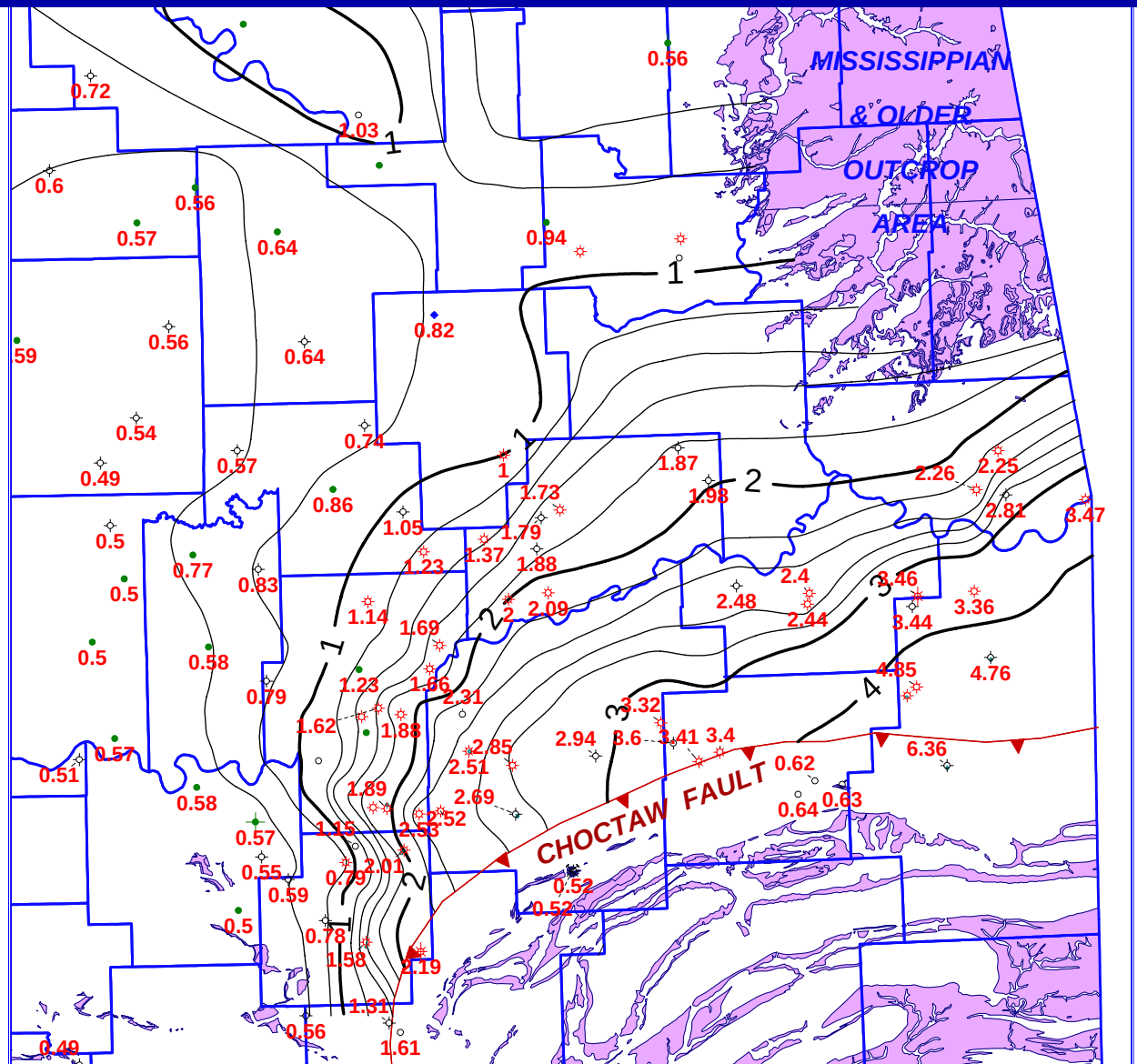


VRo mean based on minimum of 20 measurements from whole-rock pellets

Cardott, in preparation


OPL 960
Frequency
0
1
2
3
4
3
4
5
6
7
8
9
10
Vitrinite Reflectance (%Ro)
Amoco 1 Devils Backbone well, 31-5N-24E, D&A
Woodford Shale at 17,854 ft
VRo = 6.36%, n=57
6.84% Ro
500X, field width 140 µ

Isoreflectance Map of the Woodford Shale in Eastern Oklahoma



Map prepared by R. Vance Hall using Petra

Cardott, in preparation

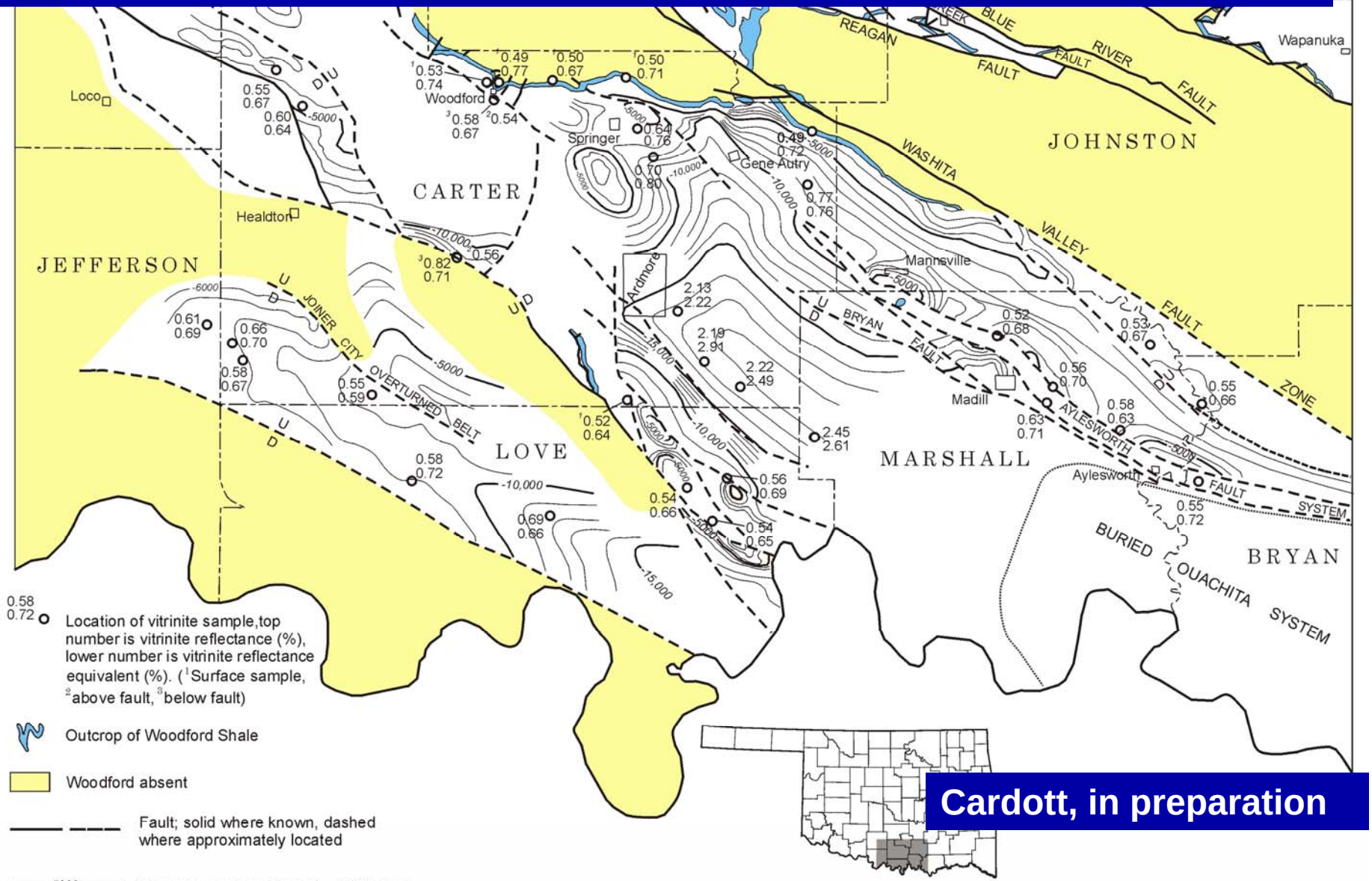
Woodford Gas-Shale Play is primarily in eastern Oklahoma (western Arkoma Basin) where the shale is:

(1) in the gas window (pushing the lower limits to the west)

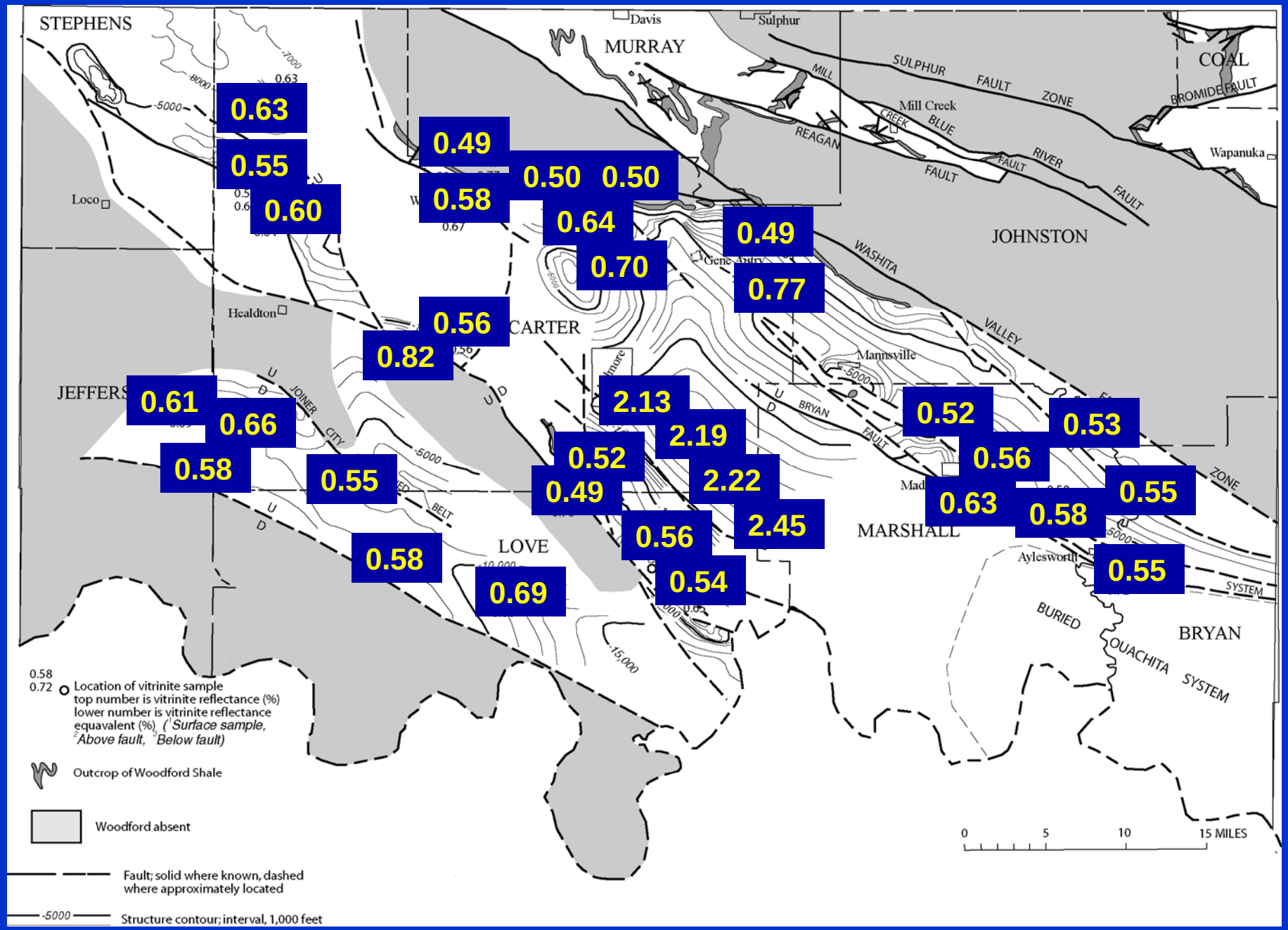
(2) greater than 100 ft thick

(3) relatively shallow (<12,000 ft)

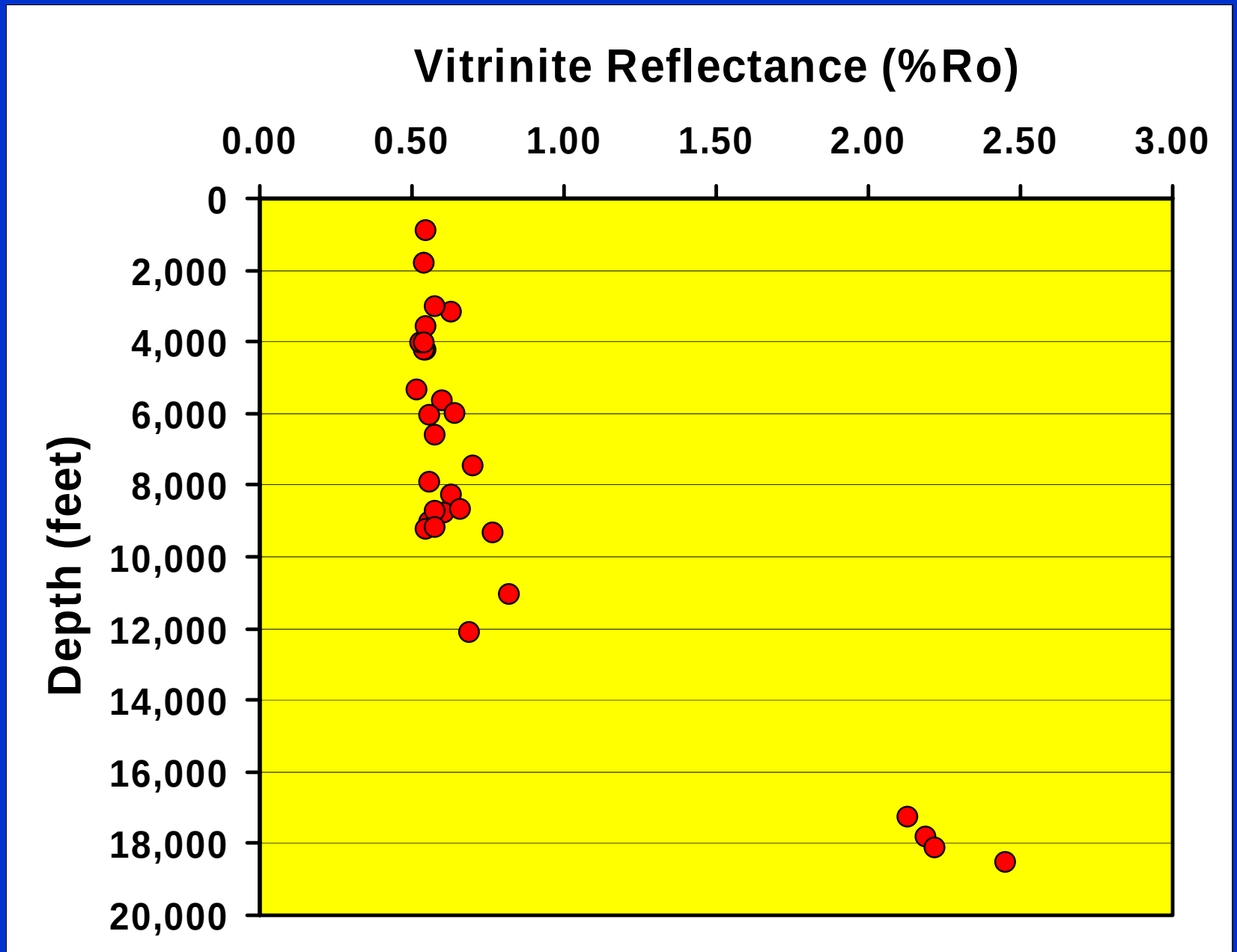
Structure and Vitrinite Reflectance of Woodford Shale, Southern Oklahoma



Cardott, in preparation


STEPHENS
Davis
Sulphur
MURRAY
COAL
SULPHUR FAULT ZONE
BROMIDE FAULT
MILL CREEK BLUE REAGAN FAULT
Mill Creek
RIVER FAULT
Wapanuka
Loco
JOHNSTON
WASHITA VALLEY FAULT
Healdton
CARTER
Mannsville
JEFFERS
JOINER CITY
BRYAN FAULT
MARSHALL
Aylesworth
LOVE
BELT
BURIED ARBUCKLE SYSTEM
BRYAN
0.63
0.55
0.60
0.49
0.50
0.50
0.58
0.64
0.70
0.49
0.77
0.56
0.82
0.61
0.66
0.58
0.55
2.13
2.19
0.52
0.49
2.22
2.45
0.56
0.58
0.69
0.54
0.52
0.53
0.56
0.63
0.58
0.55
0.55
0.58
0.72 Location of vitrinite sample top number is vitrinite reflectance (%) lower number is vitrinite reflectance equavalent (%) (1 Surface sample, 2 Above fault, 3 Below fault)
Outcrop of Woodford Shale
Woodford absent
Fault; solid where known, dashed where approximately located
-5000 Structure contour; interval, 1,000 feet
0 5 10 15 MILES

Southern Oklahoma VRo vs Depth



Woodford Gas Shales

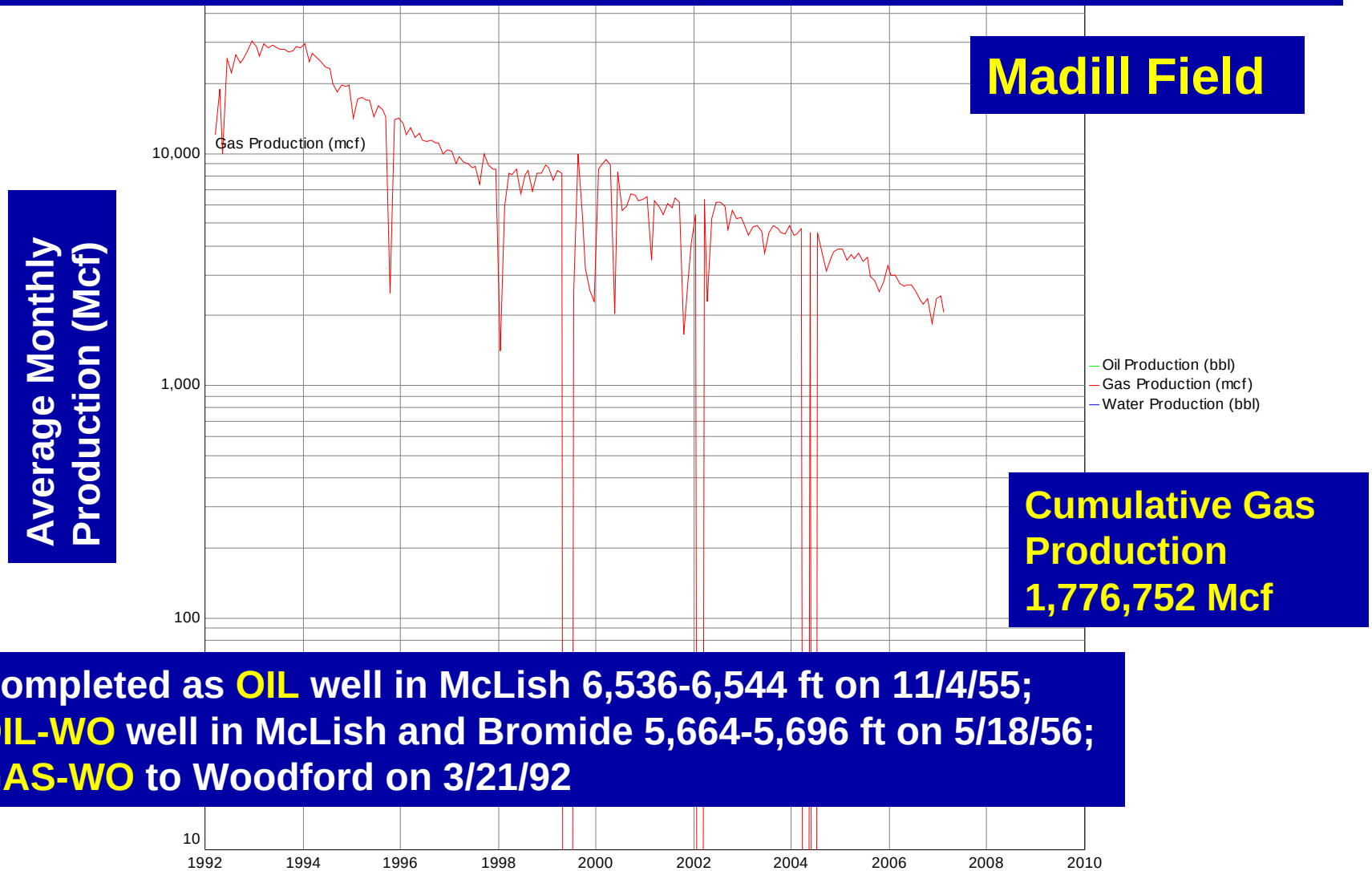
1939-1996

21 Wells

1 Sycamore/Woodford

Cimarex Energy 3 Griffin-Olmstead
(Marshall CO, 16-5S-5E; IP 747 Mcfd; 4,052-4,135 ft)

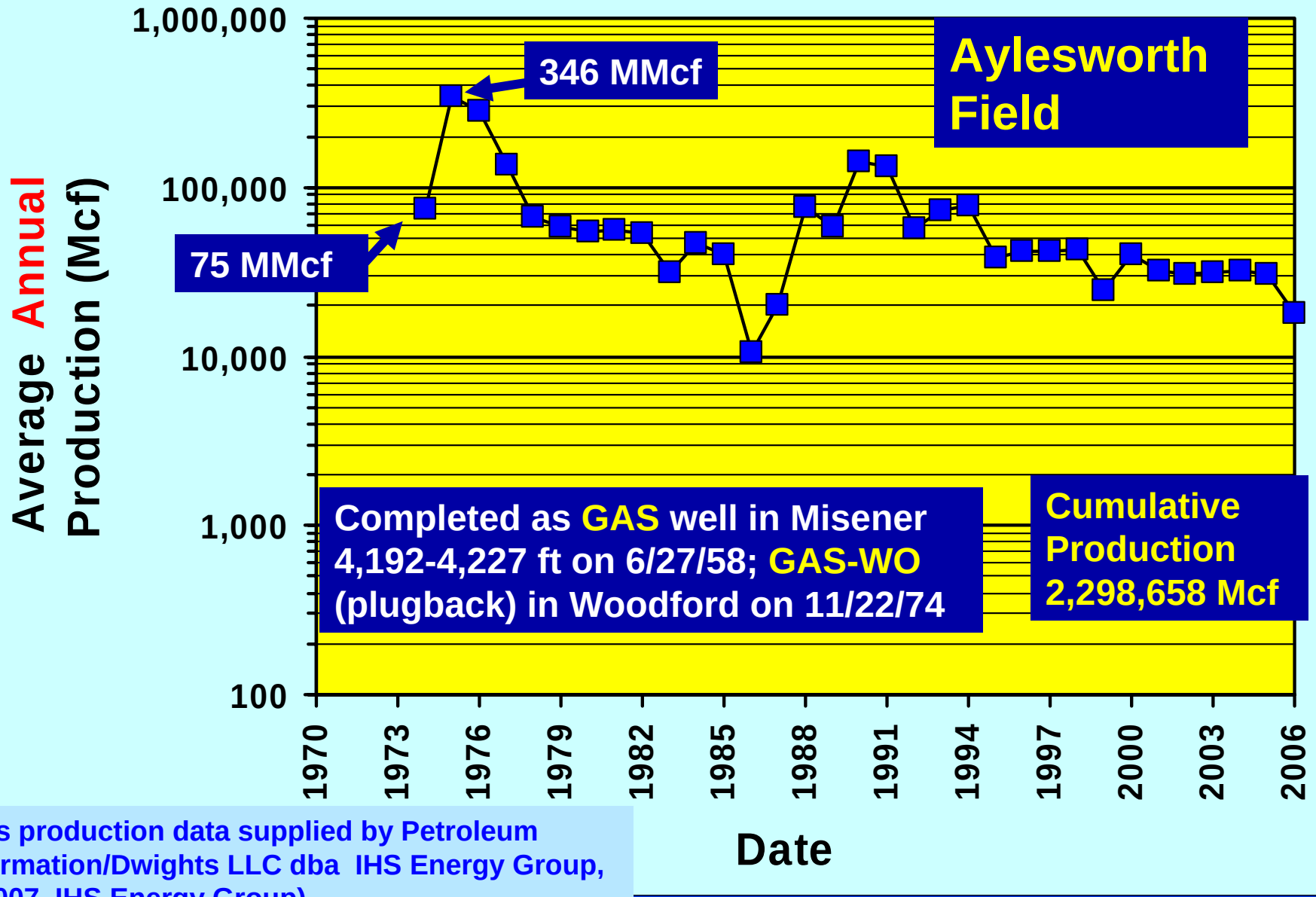
Madill Field



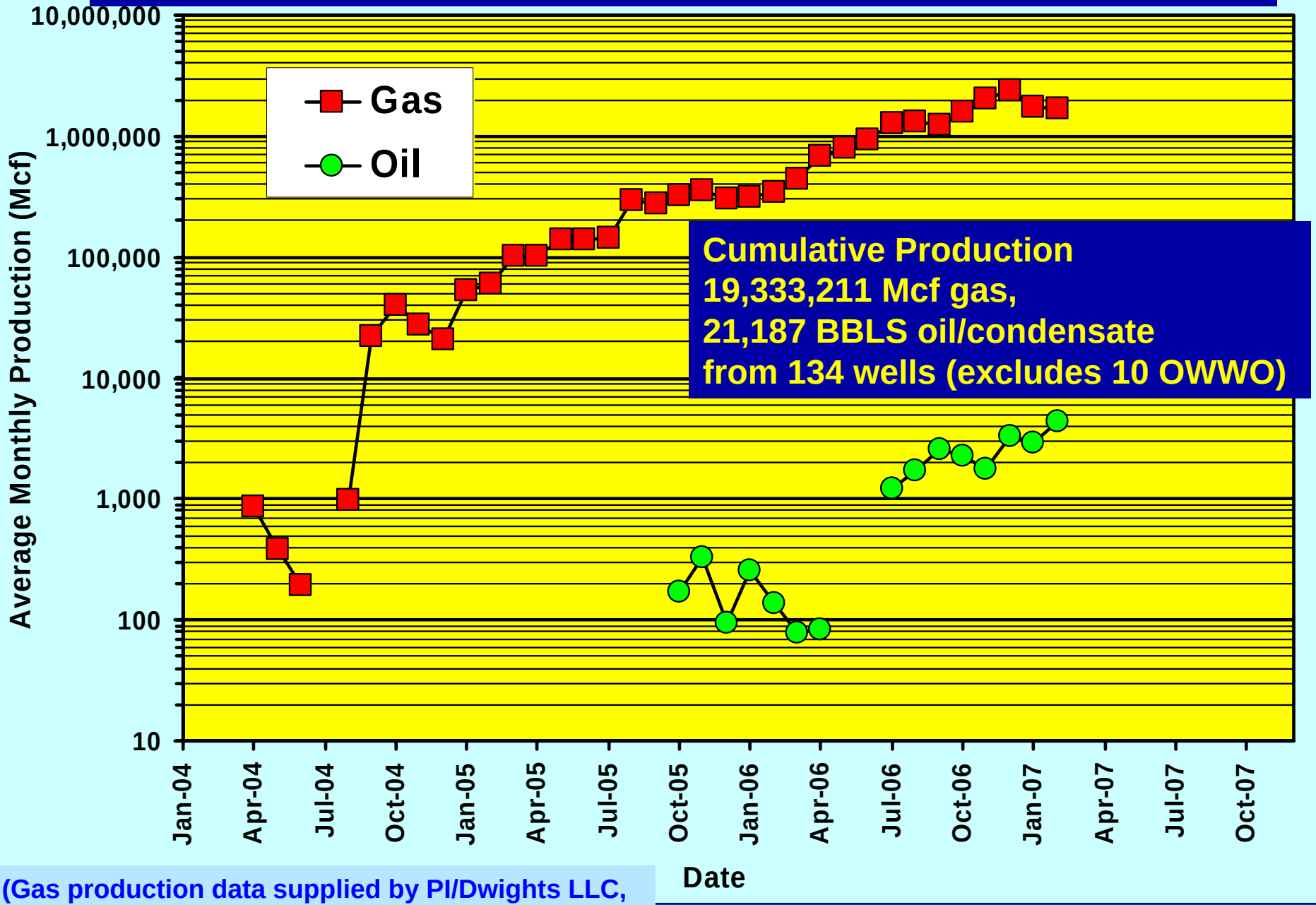
Cumulative Gas Production 1,776,752 Mcf

**Completed as OIL well in McLish 6,536-6,544 ft on 11/4/55;
OIL-WO well in McLish and Bromide 5,664-5,696 ft on 5/18/56;
GAS-WO to Woodford on 3/21/92**

Verdad Oil & Gas 1 Mary Haynie
(Bryan CO, 22-6S-7E; IP 962 Mcfd; 3,710-4,054 ft)

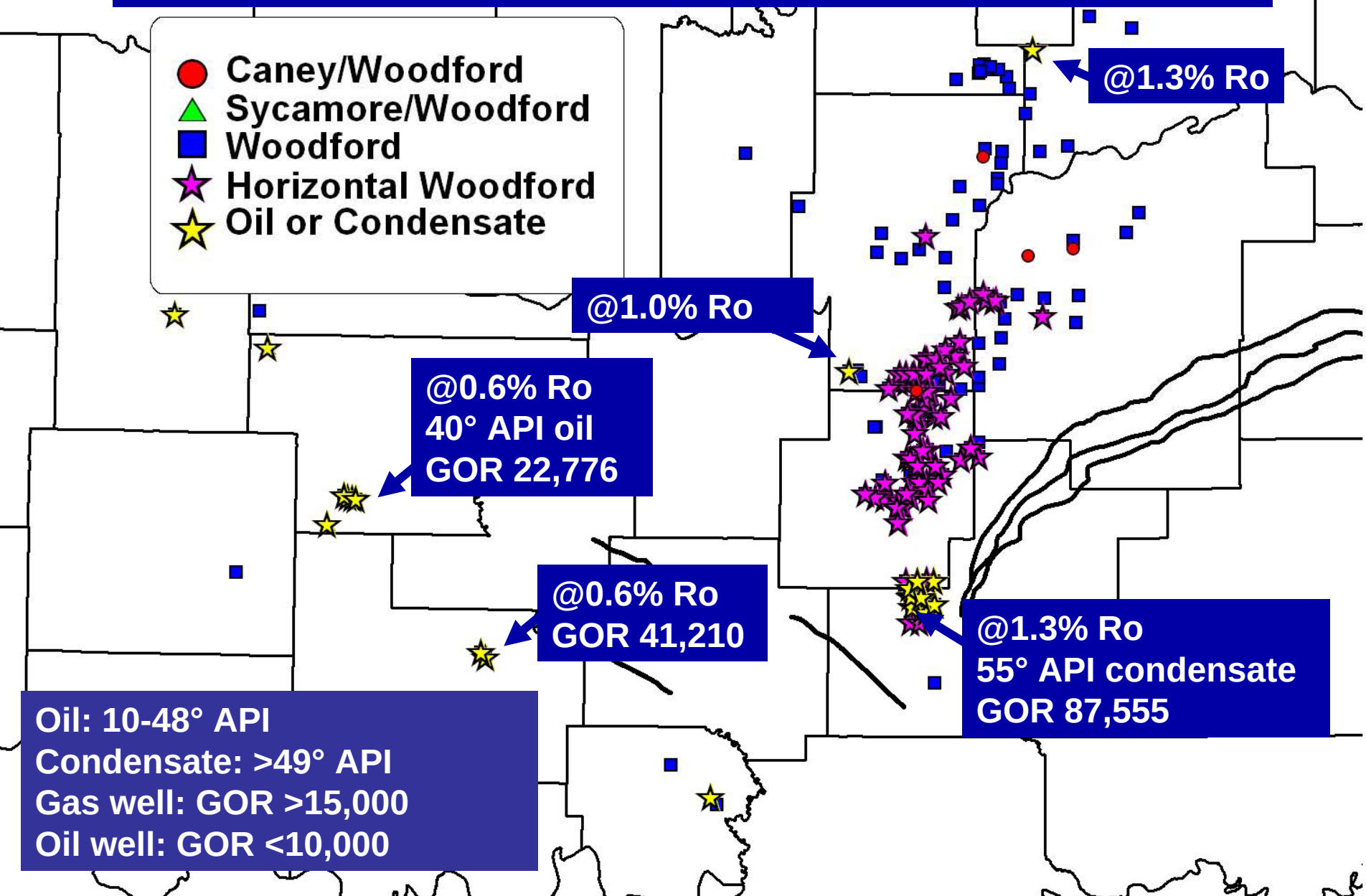


Woodford Shale Production (2004-2007 wells)



(Gas production data supplied by PI/Dwights LLC,

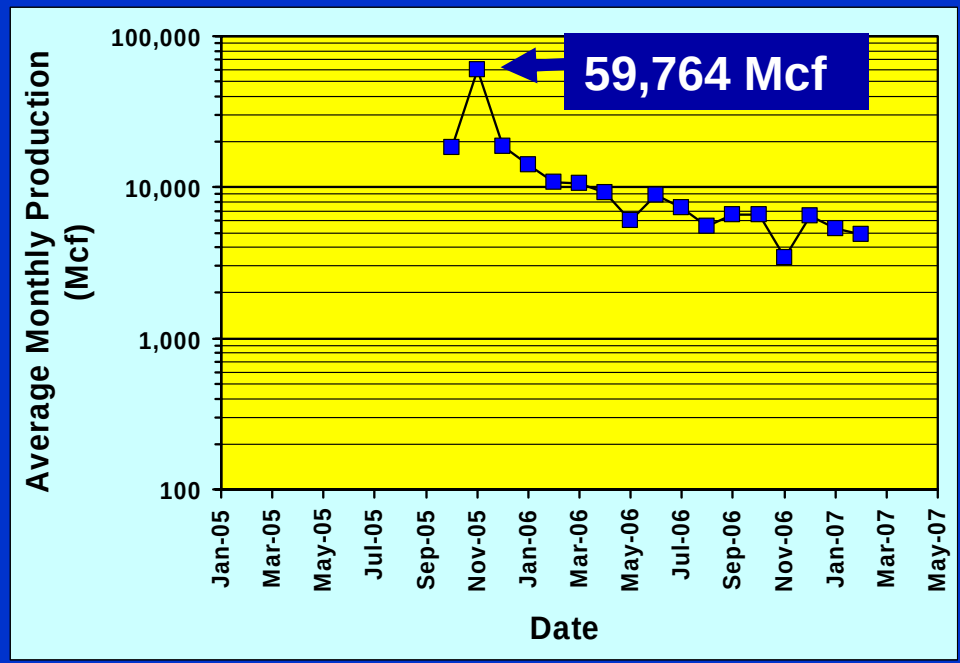
Woodford Shale Oil/Condensate Production (25 of 152 wells; 2003-2007)



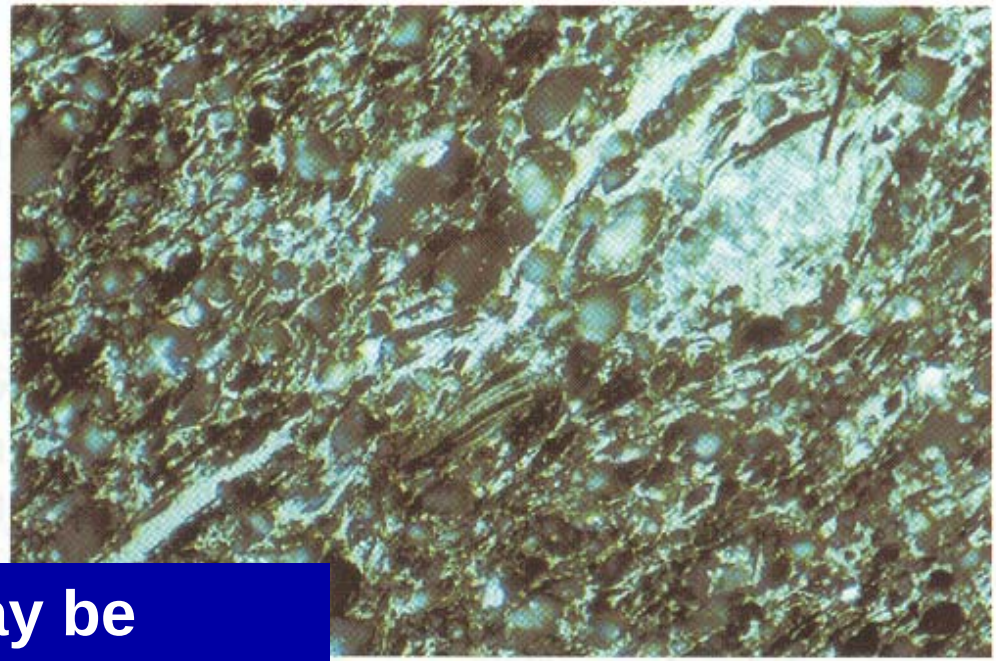
Gas Storage and Production

- Production decline curves suggest initial gas production is as **free gas** in fractures
- Gas Production depends on fracture connectivity with gas storage sites (**free and sorbed gas**)

Devon Energy 1-26 Edwards horizontal Woodford well (2005)



KEROGEN NETWORK (SOLID BITUMEN; IMPSONITE)

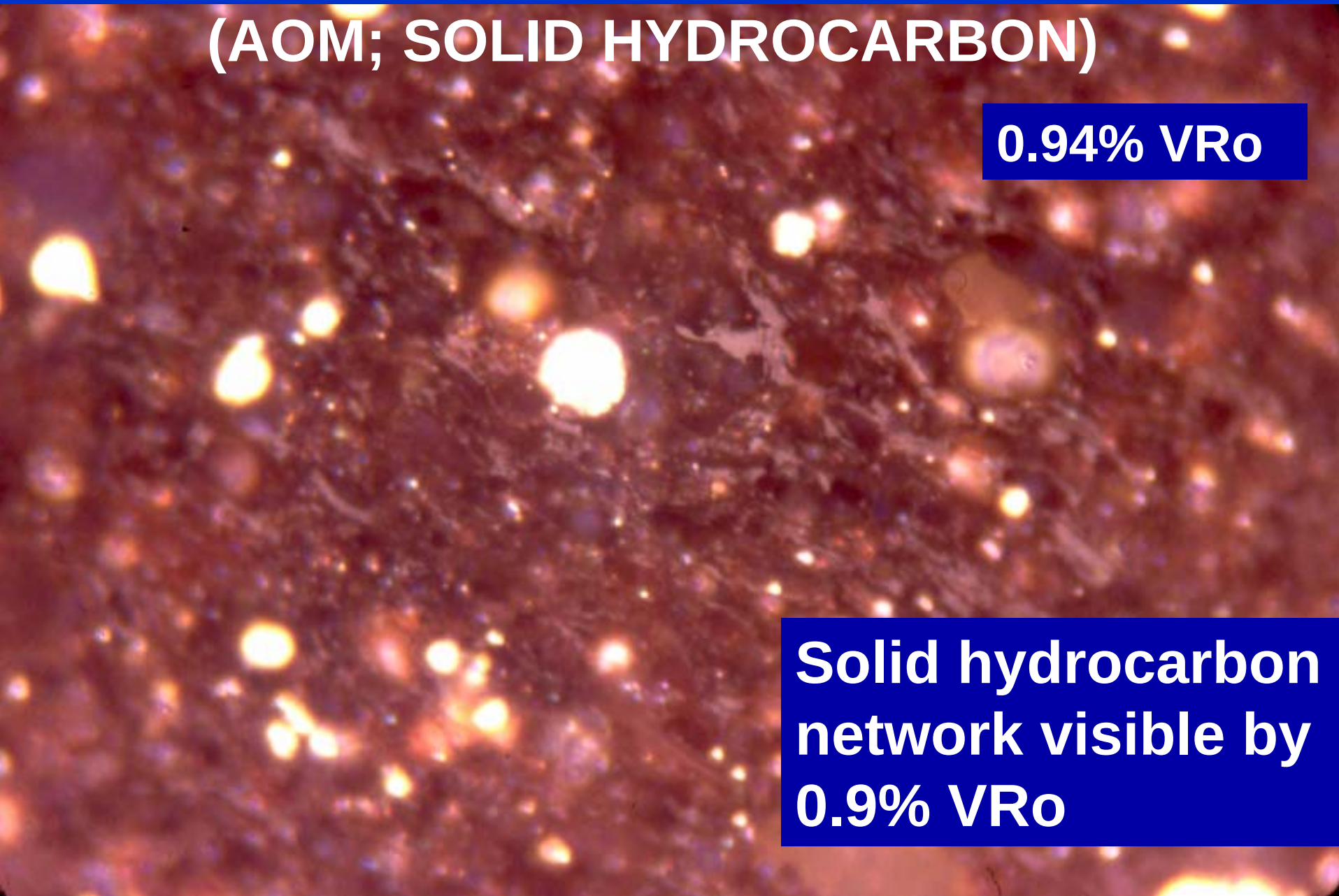


A

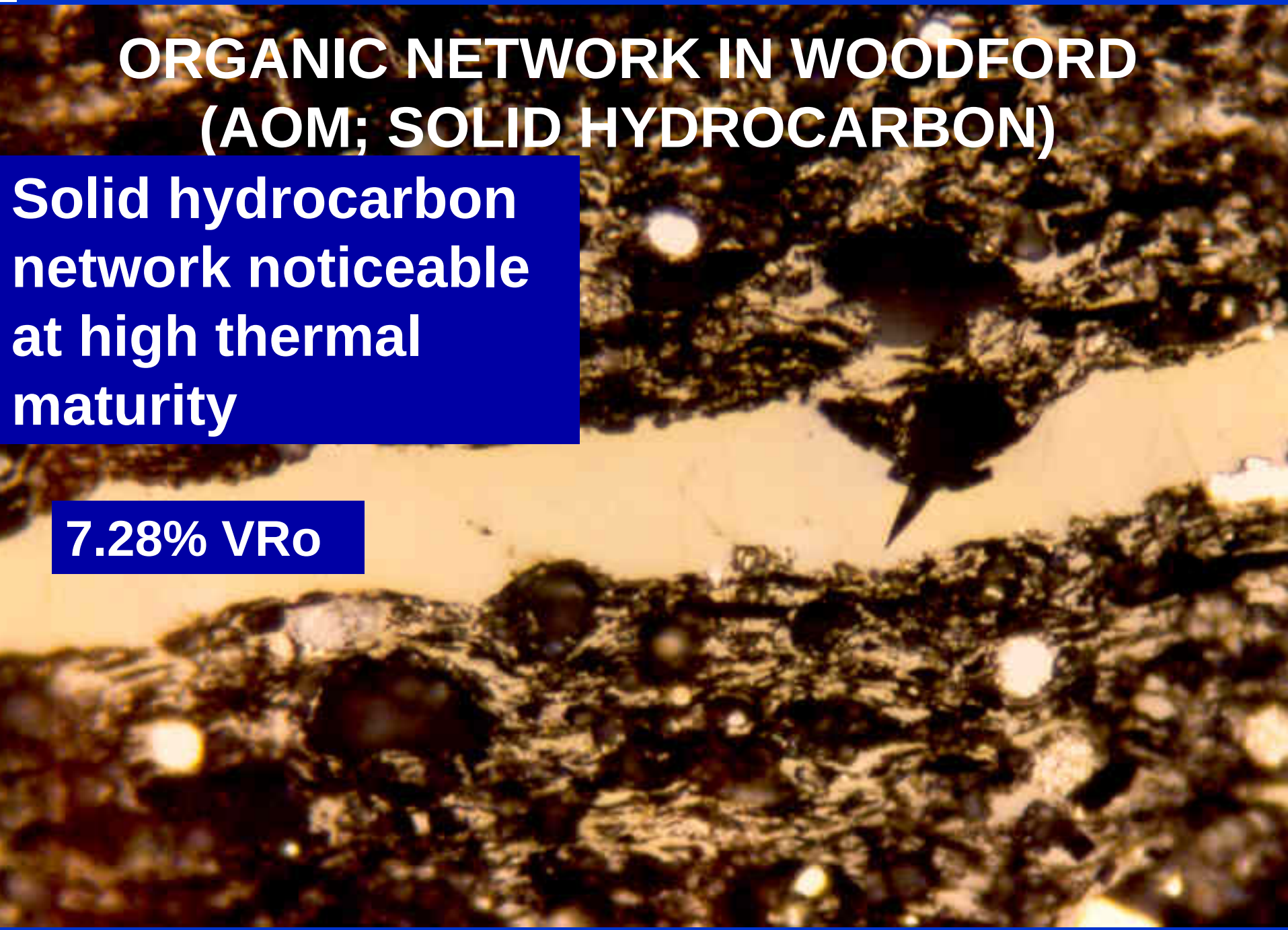
Solid bitumen network may be important for gas storage and migration by diffusion

Taylor and others (1998)

ORGANIC NETWORK IN WOODFORD (AOM; SOLID HYDROCARBON)



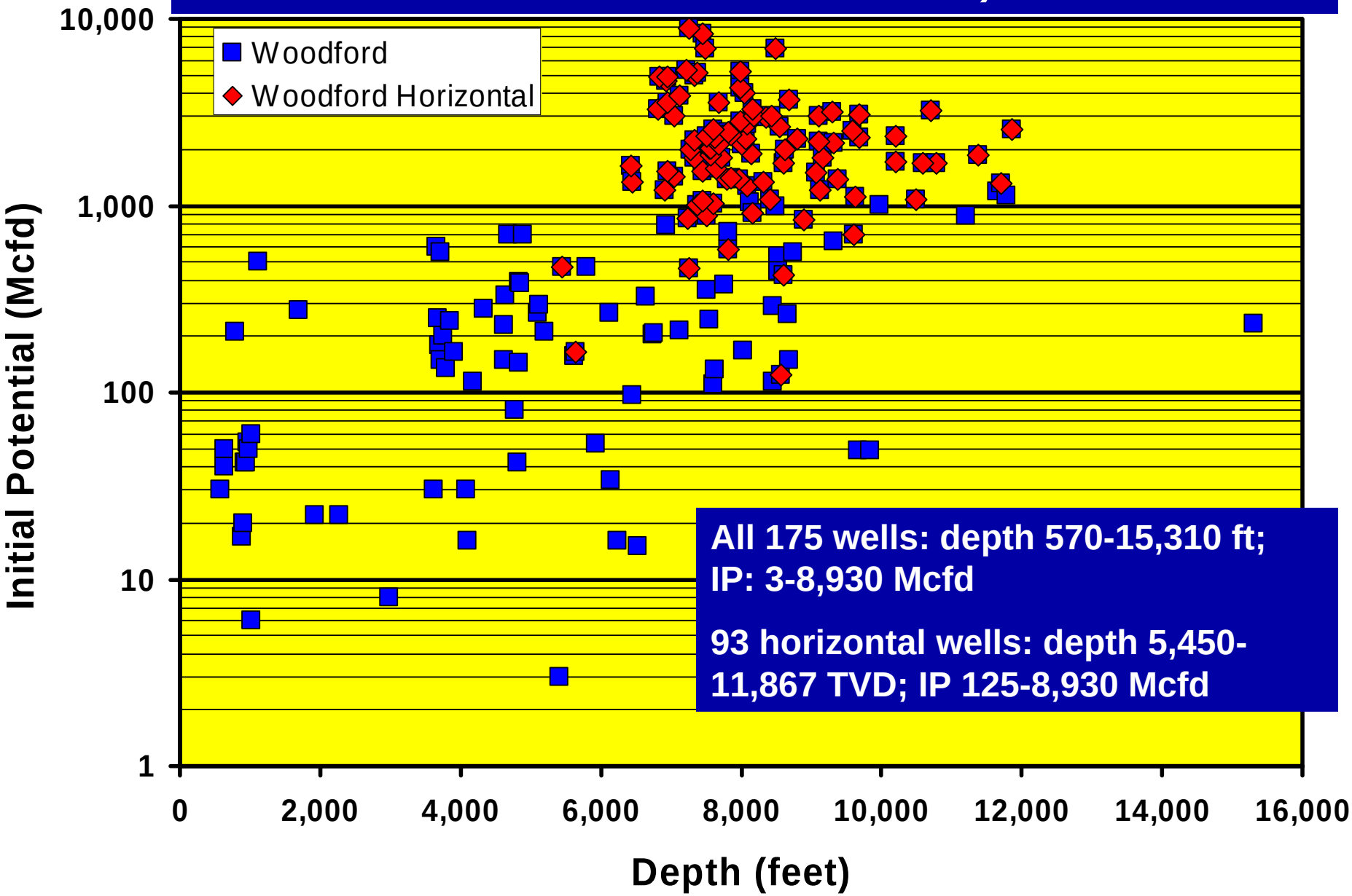
ORGANIC NETWORK IN WOODFORD (AOM; SOLID HYDROCARBON)



Solid hydrocarbon network noticeable at high thermal maturity

7.28% VRo

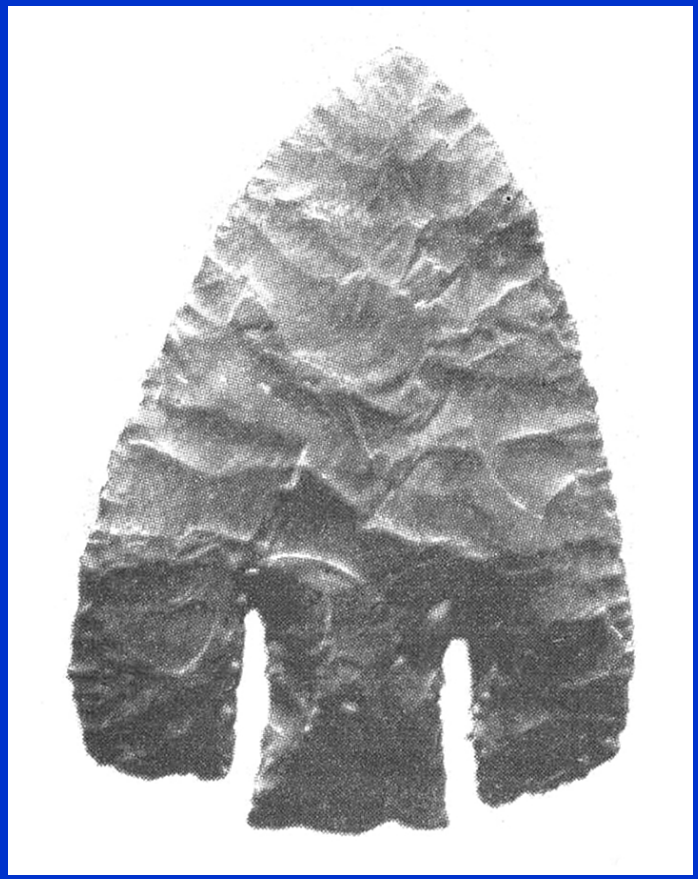
Woodford Shale Gas Wells, 2003-2007



SUMMARY OF WOODFORD GAS SHALE PLAY

- Woodford Shale contains Type II Kerogen with adequate TOC
- Woodford Shale is silica rich (e.g., fracture-able)
- Most Woodford Shale gas play is in eastern Oklahoma at >1.1% Ro
- Some Woodford Shale gas potential is in southern Oklahoma at <1.1% Ro
- Organic network may be important for gas diffusion in shales

THANK YOU



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