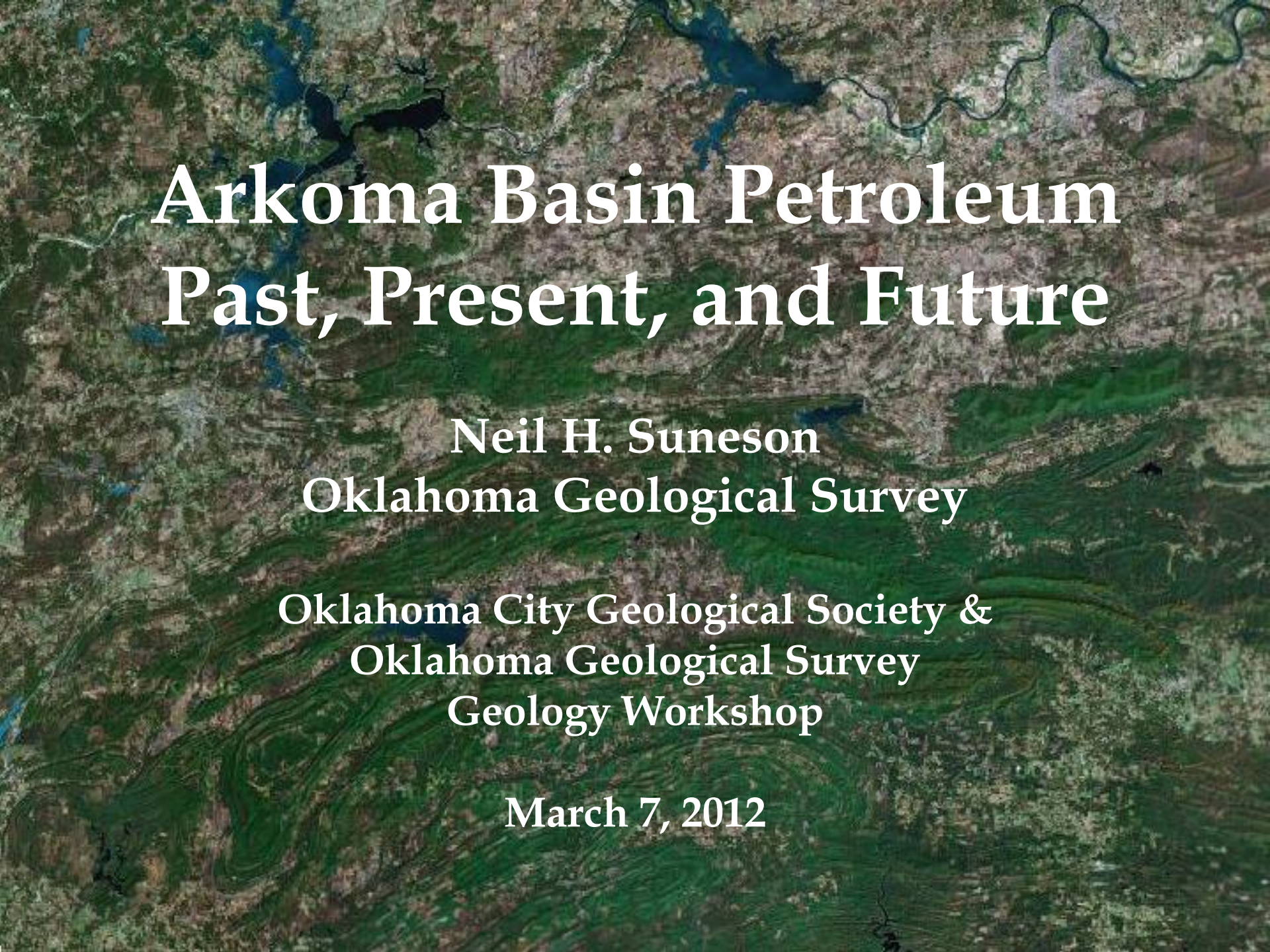


Arkoma Basin Petroleum Past, Present, and Future

Neil H. Suneson
Oklahoma Geological Survey

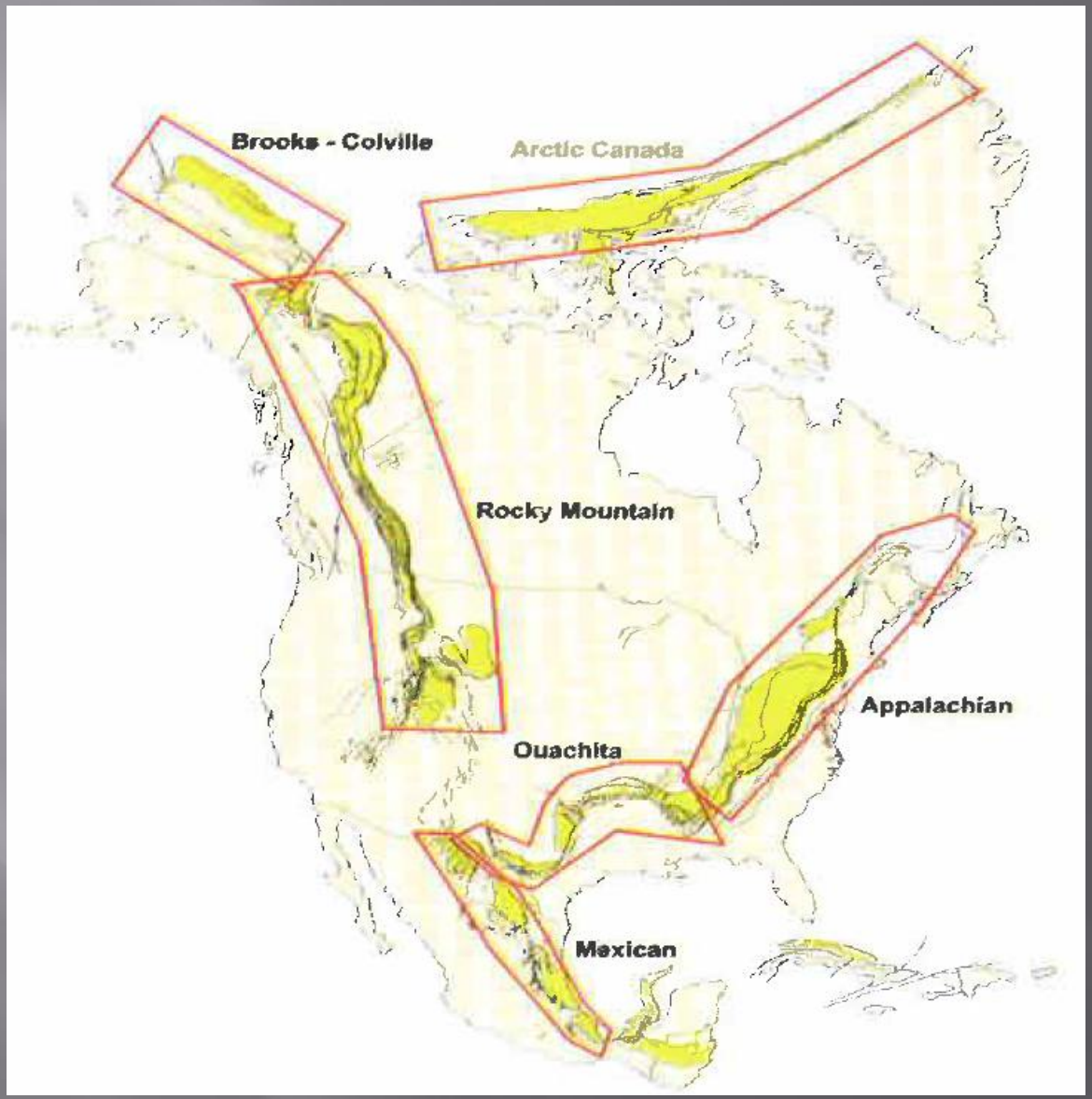
Oklahoma City Geological Society &
Oklahoma Geological Survey
Geology Workshop

March 7, 2012

Have shamelessly taken other peoples' slides from all over the internet, so special thanks to:

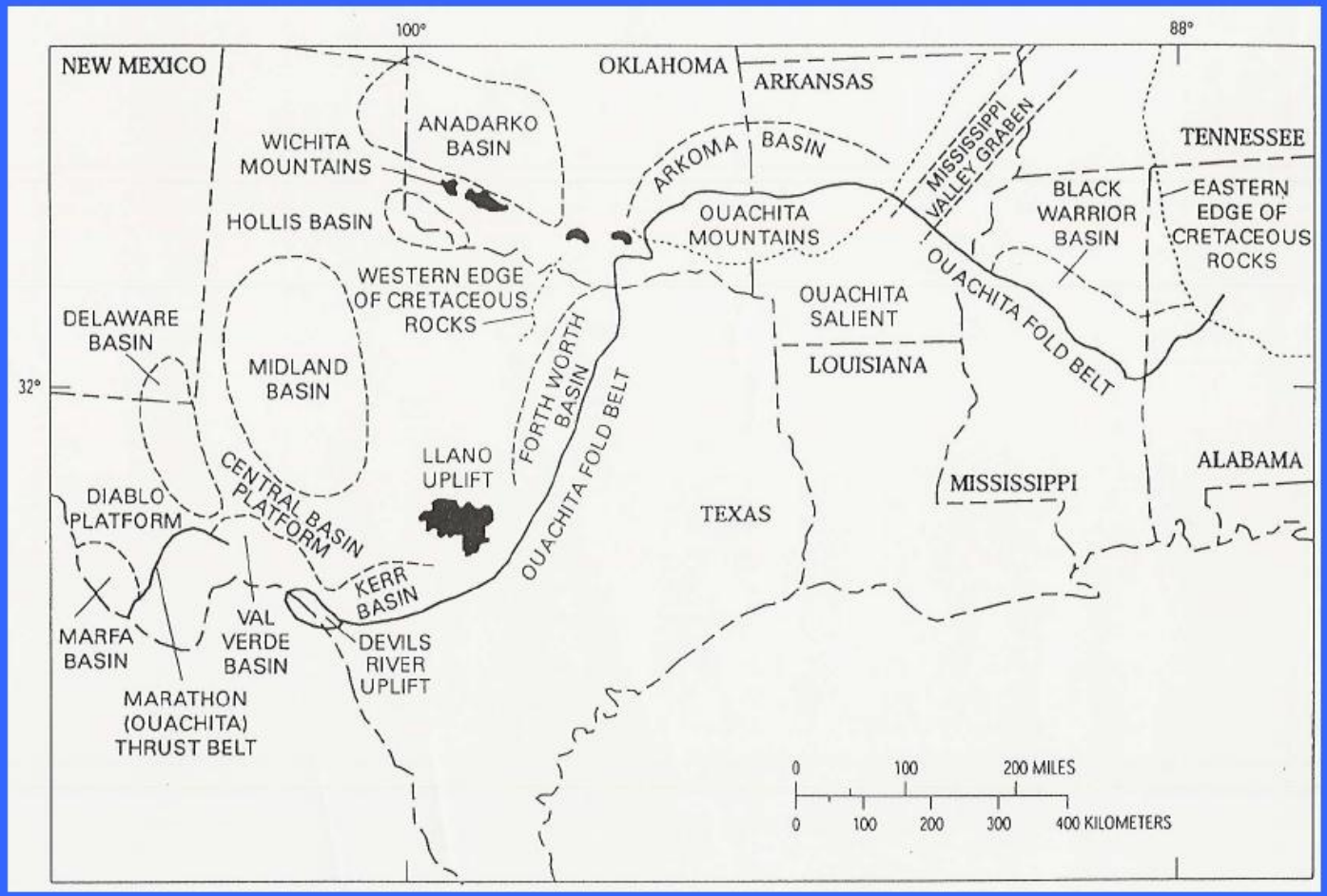
OGS colleagues Dan Boyd, Rick Andrews, Brian Cardott
USGS geologists for posting powerpoints
AAPG for having Bulletin online
OGS for having publications online
Bill Gates for Print Screen

Note: This presentation will be posted on OGS website



Thrust belts and foreland basins of North America

Present day Mid-Continent Tectonic Features.

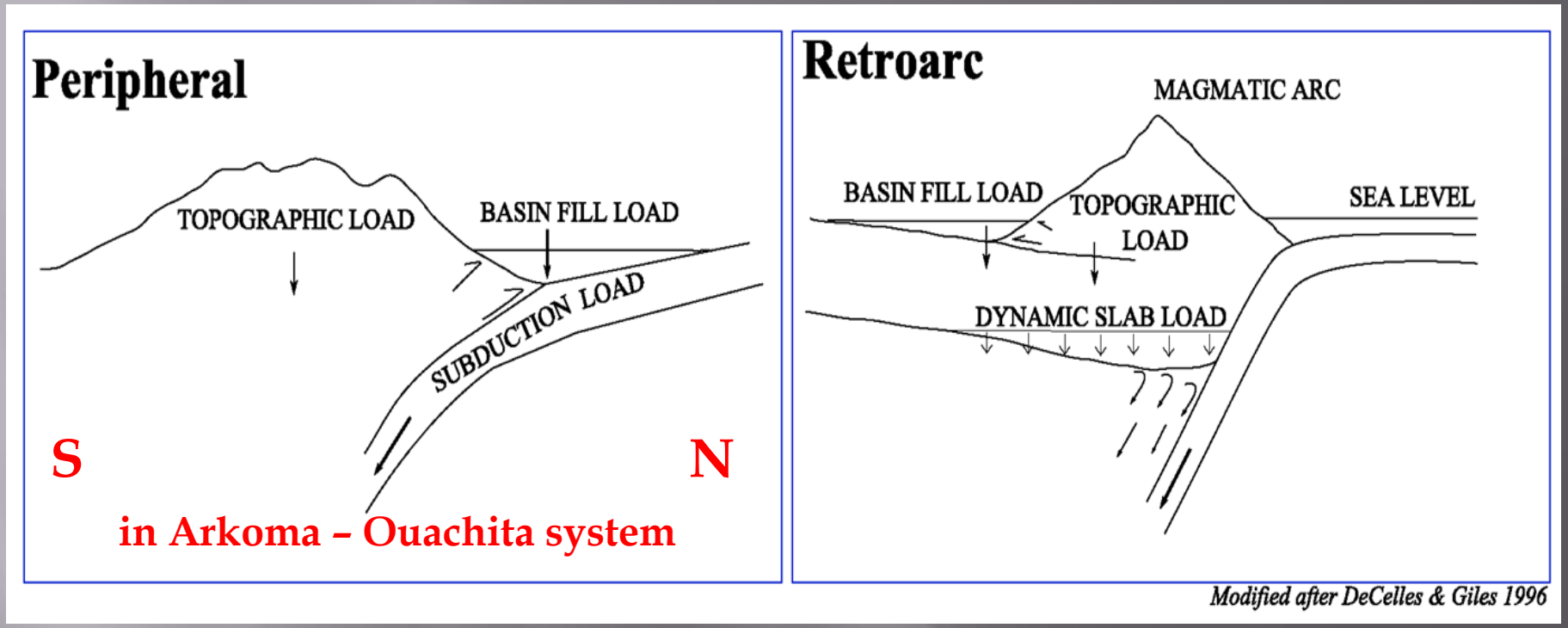


(Perry, 1986).

Arkoma Basin – one of many (Black Warrior, Fort Worth, Kerr) petroleum-bearing foreland basins.

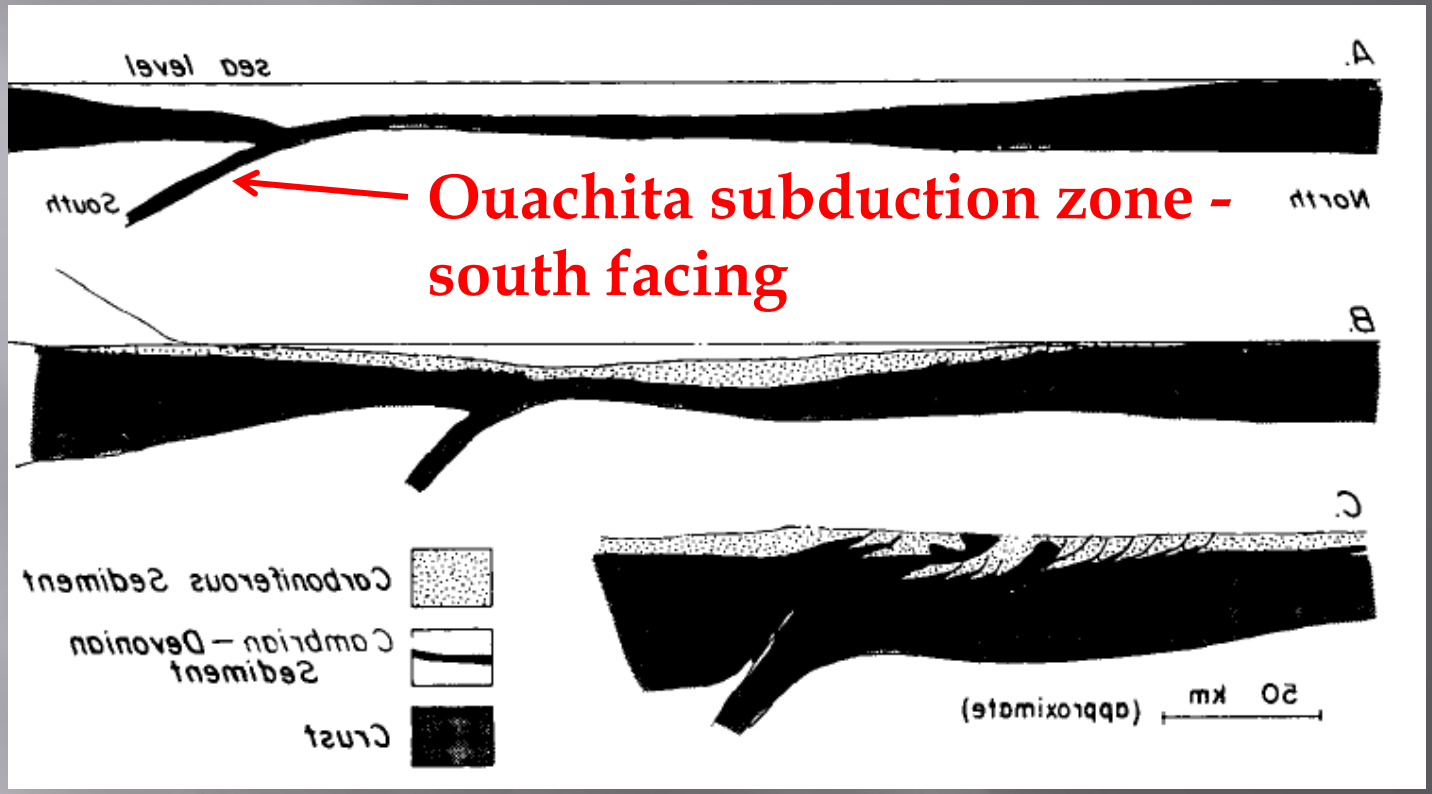
But what exactly is a "foreland basin" (aka "foredeep")? Features/characteristics:

1. Elongate basin, adjacent and parallel to compressional orogenic belt
2. Forms between orogenic belt and craton
3. Site of potential sediment accumulation
4. Two types:
    - Peripheral forms on subducted/underthrust plate
    - Retroarc forms on overriding plate behind magmatic arc
5. Consists of four discrete depozones:
    - Wedge-top
    - Foredeep
    - Forebulge
    - Backbulge

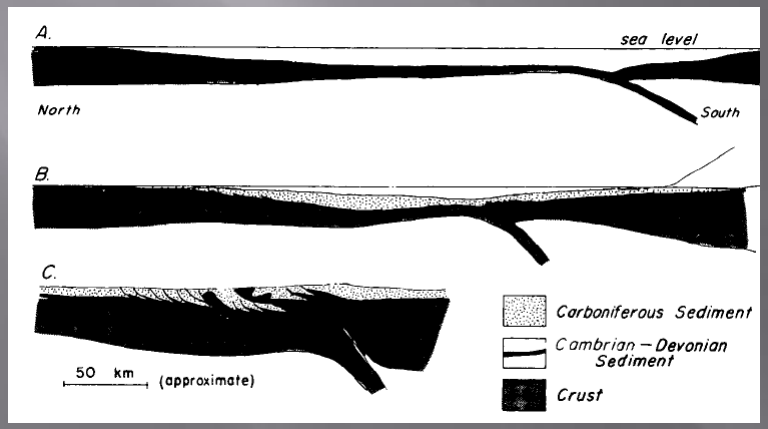


Arkoma Basin – Ouachita orogenic belt is a peripheral foreland basin. There is no identified magmatic arc, basin developed on subducted plate.

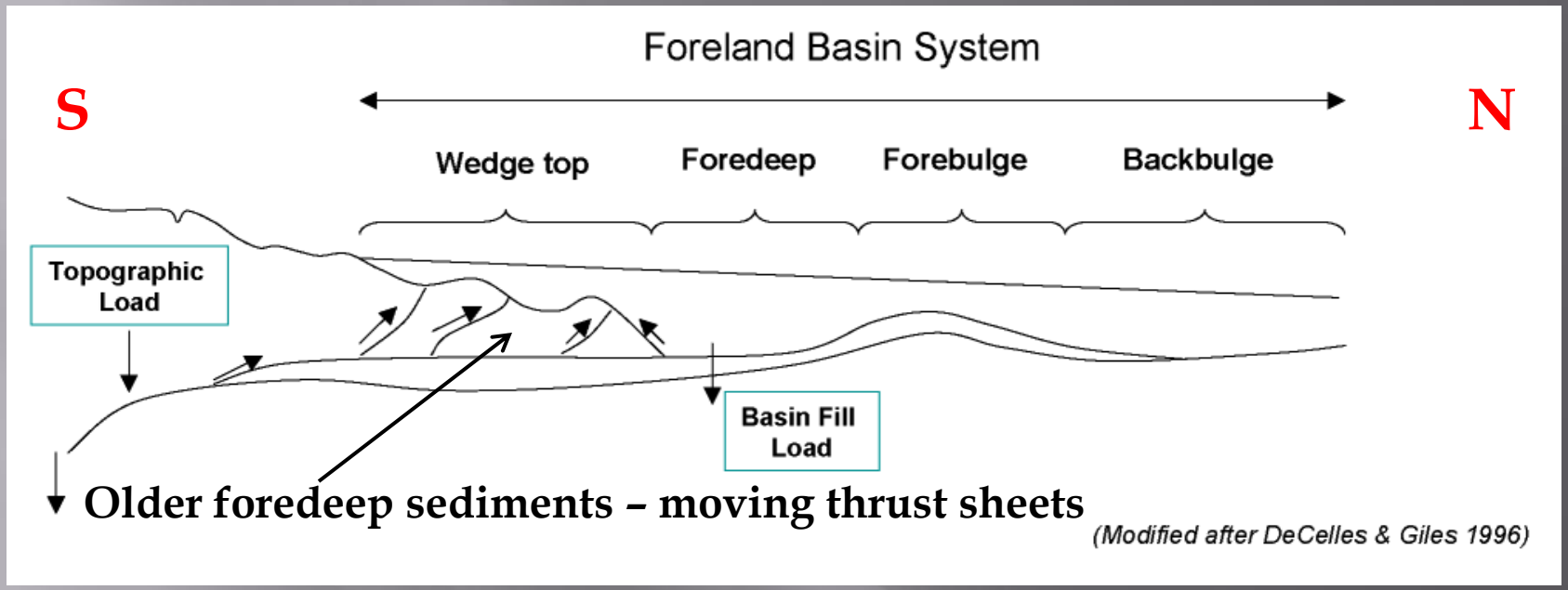
But note that orogenic belt (topographic load) does not necessarily have to be above sea level.



Ouachita subduction zone - south facing

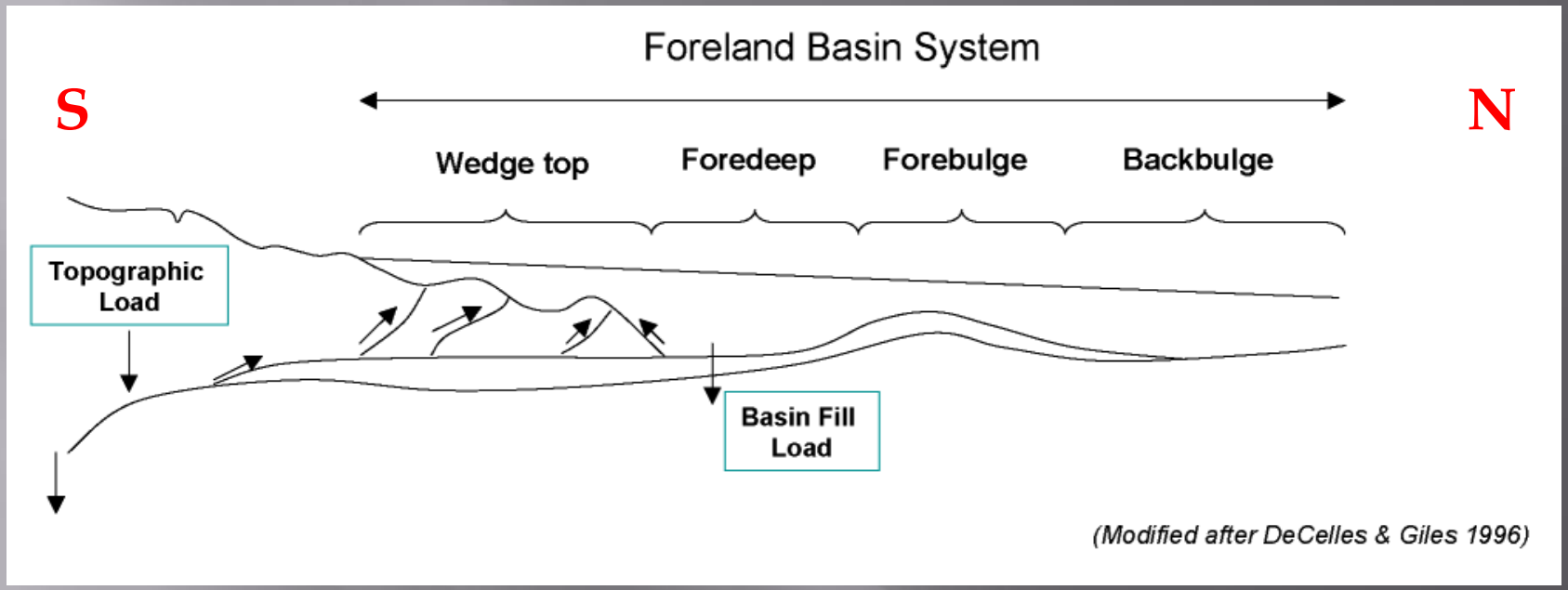


published version



Carboniferous strata in Ouachitas record a south-to-north migration of the orogenic wedge and foredeep, with foredeep strata becoming progressively incorporated into the wedge.

"High" to south only locally breaks sea level, and topography on wedge top traps most of what little sediment comes from south.



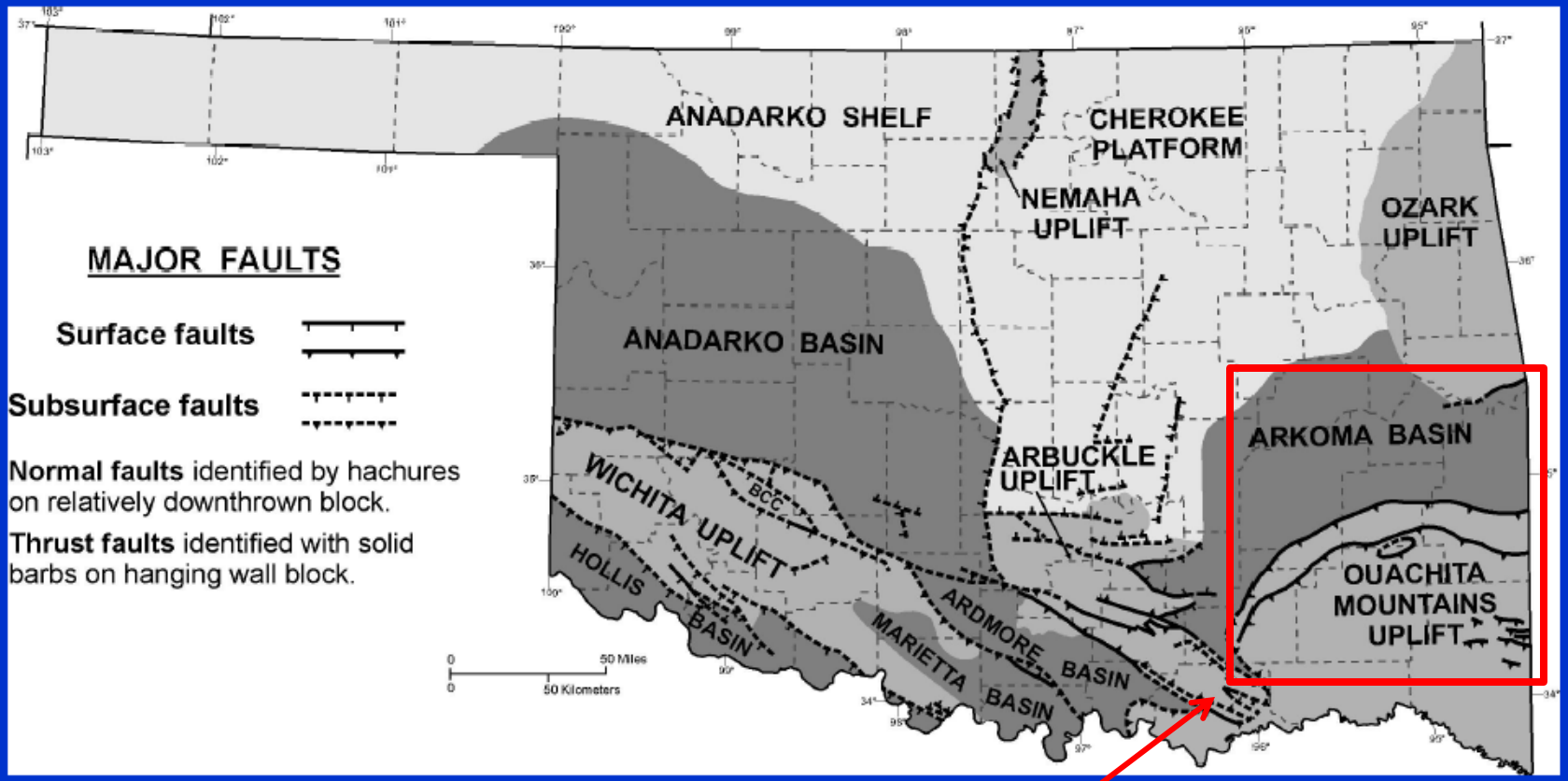
The result:

Strata in the wedge (thrust sheets of turbidite strata – Stanley, Jackfork, Atoka in Ouachita orogenic belt) should be similar to those in the foredeep (turbidite strata in Arkoma Basin -Atoka Fm.)

This is, in fact, what we see.

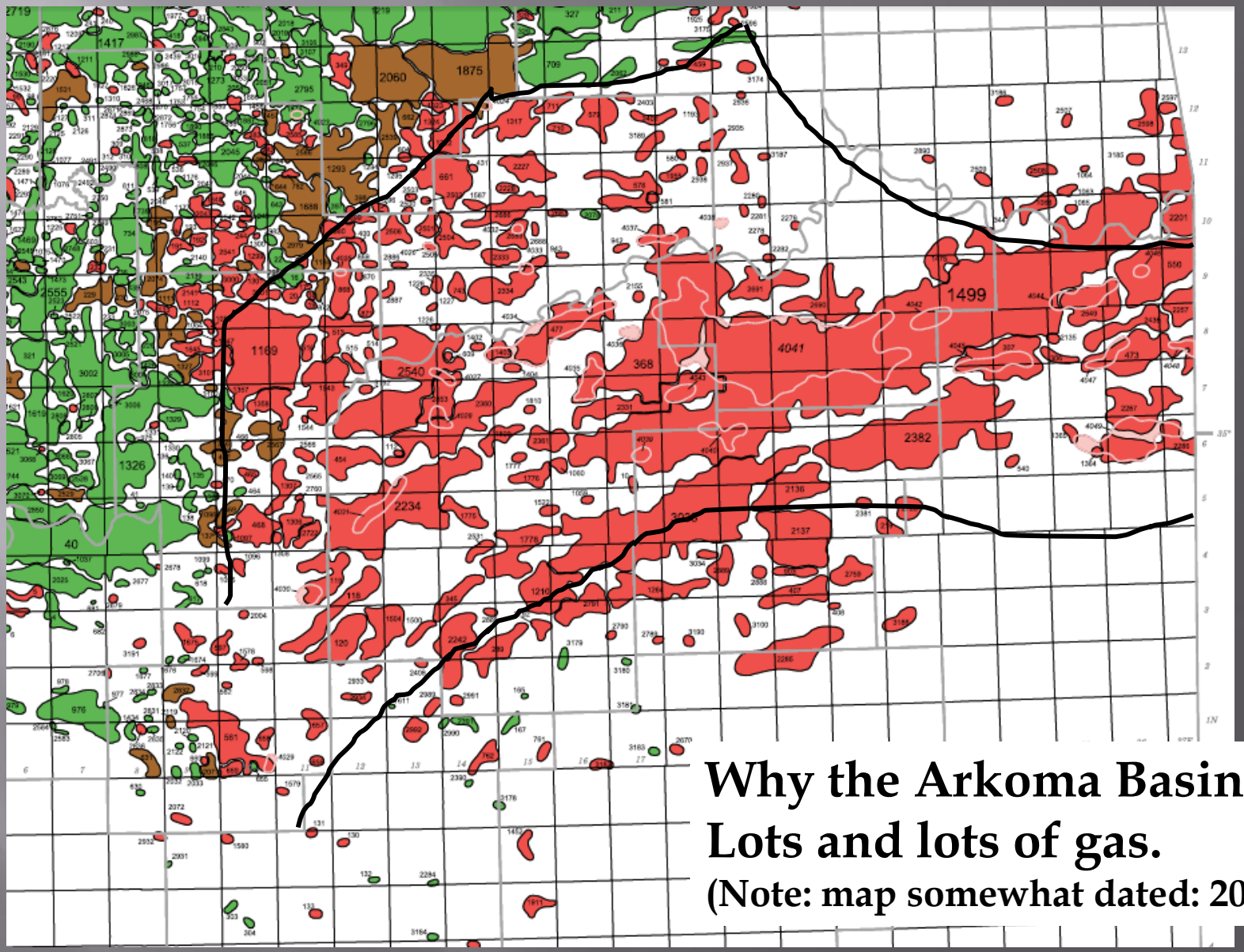
So stratigraphic traps in Arkoma Basin should be present in Ouachitas, albeit with more structure.

Geologic Provinces of Oklahoma

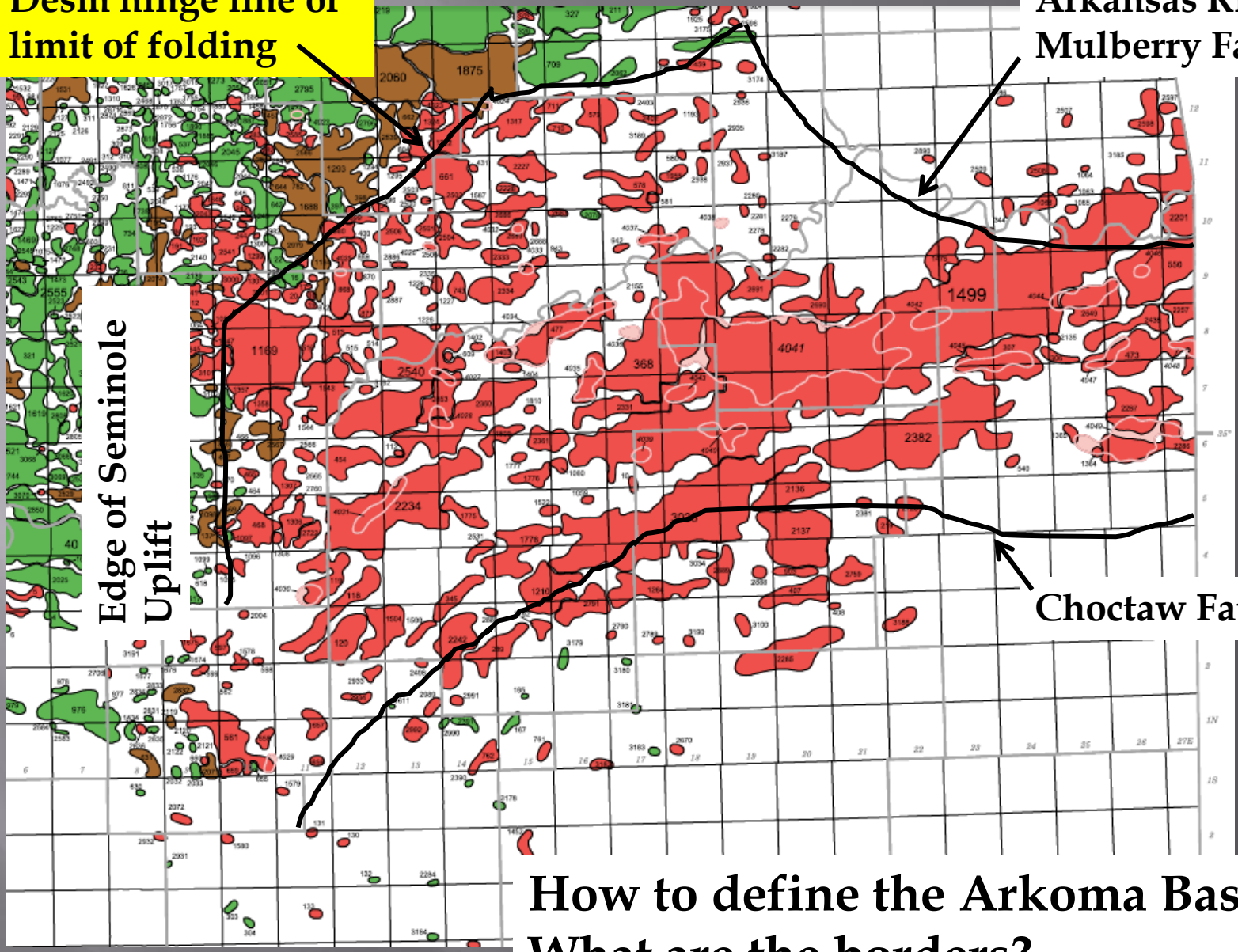


Northcutt and Campbell, 1995

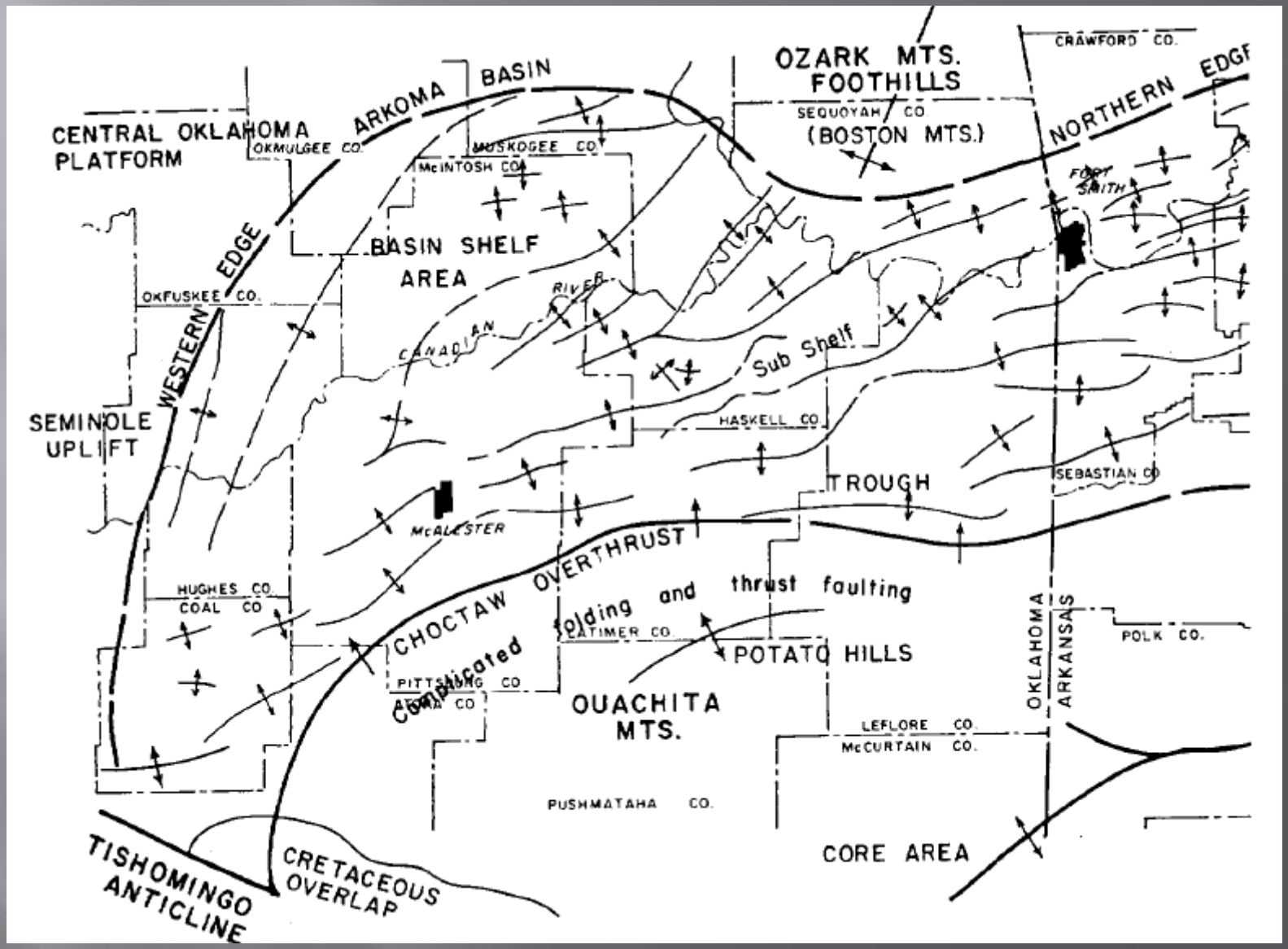
So ……. My area of interest



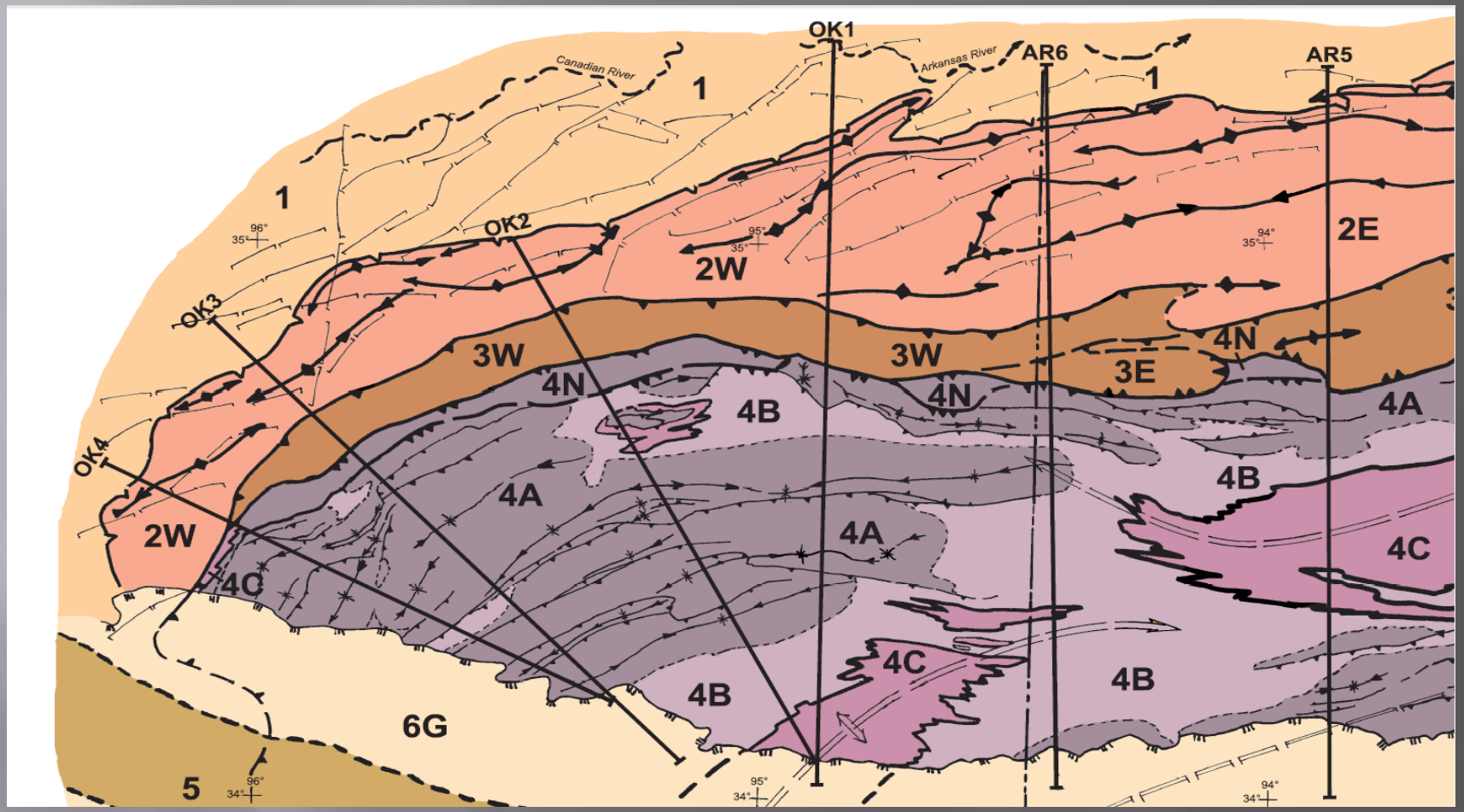
Why the Arkoma Basin?
Lots and lots of gas.
(Note: map somewhat dated: 2002)



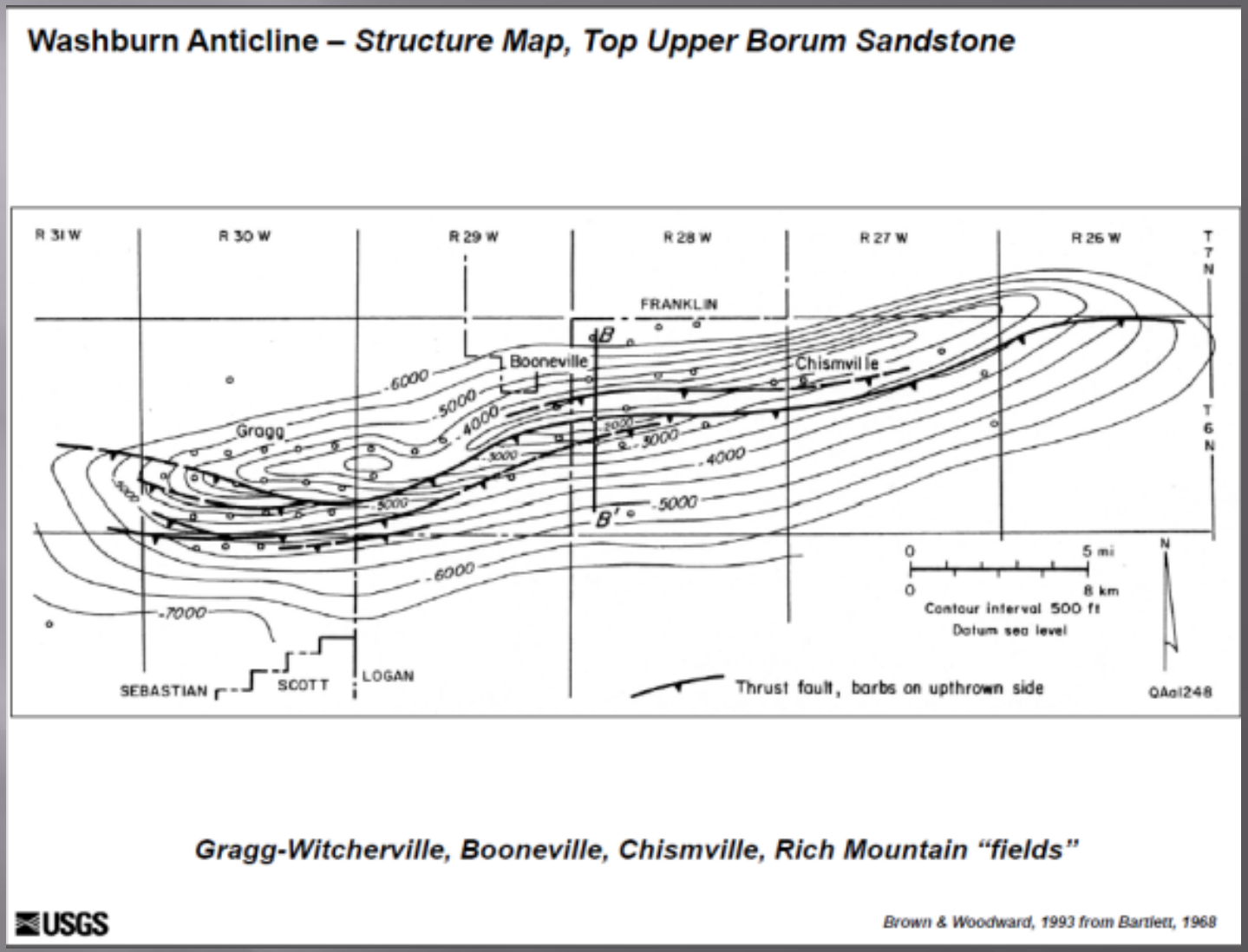
How to define the Arkoma Basin? What are the borders?



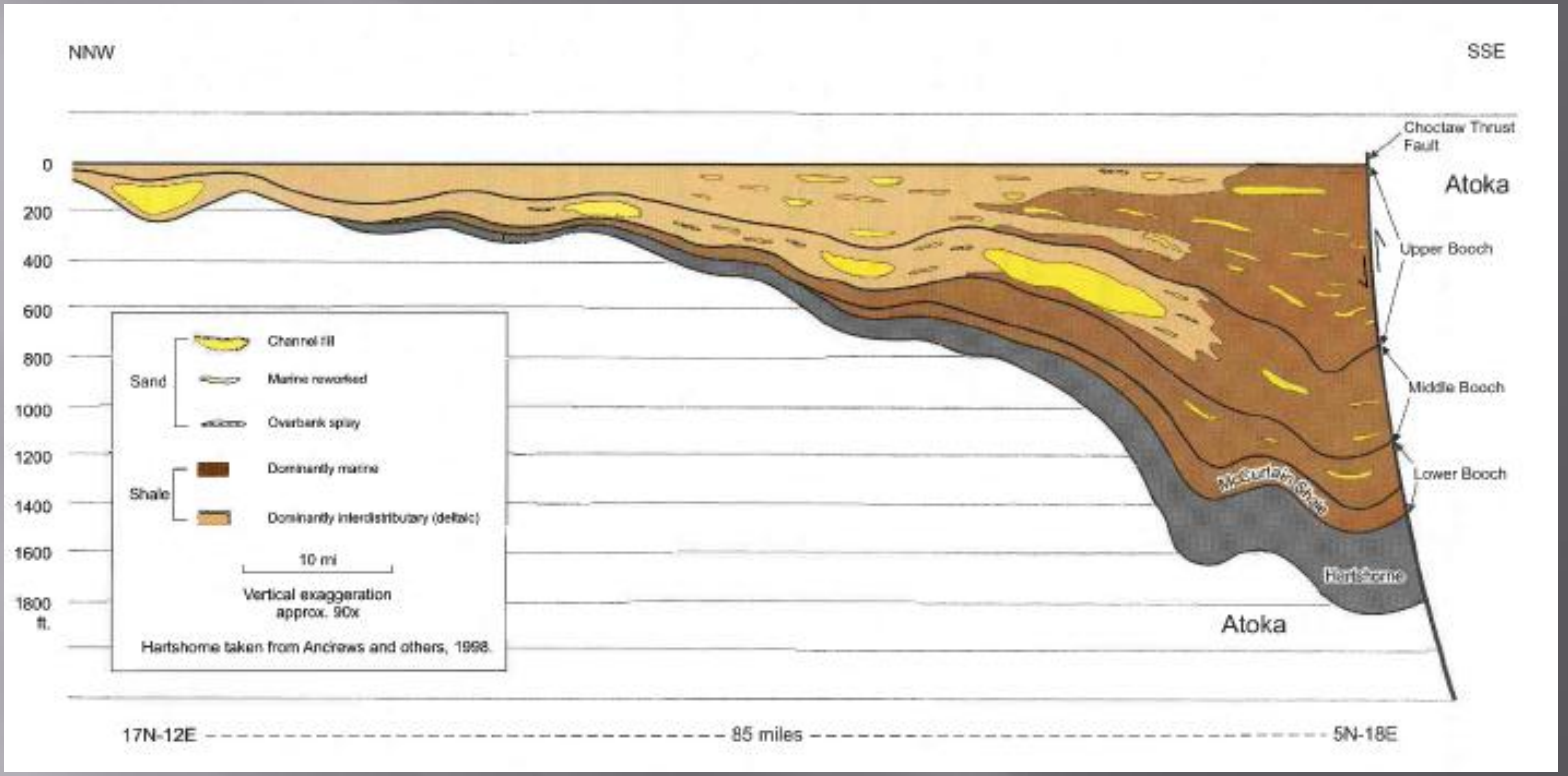
"Structural" boundary of Arkoma Basin (from 1968 AAPG Memoir showing folds in the Arkoma Basin)



Folds in Arkoma Basin from Arbenz (2008). Area 1 – Folds are drapes over mostly S-side-down normal faults. Area 2W – Folds are thin-skinned compressional structures. Both types of folds form traps.

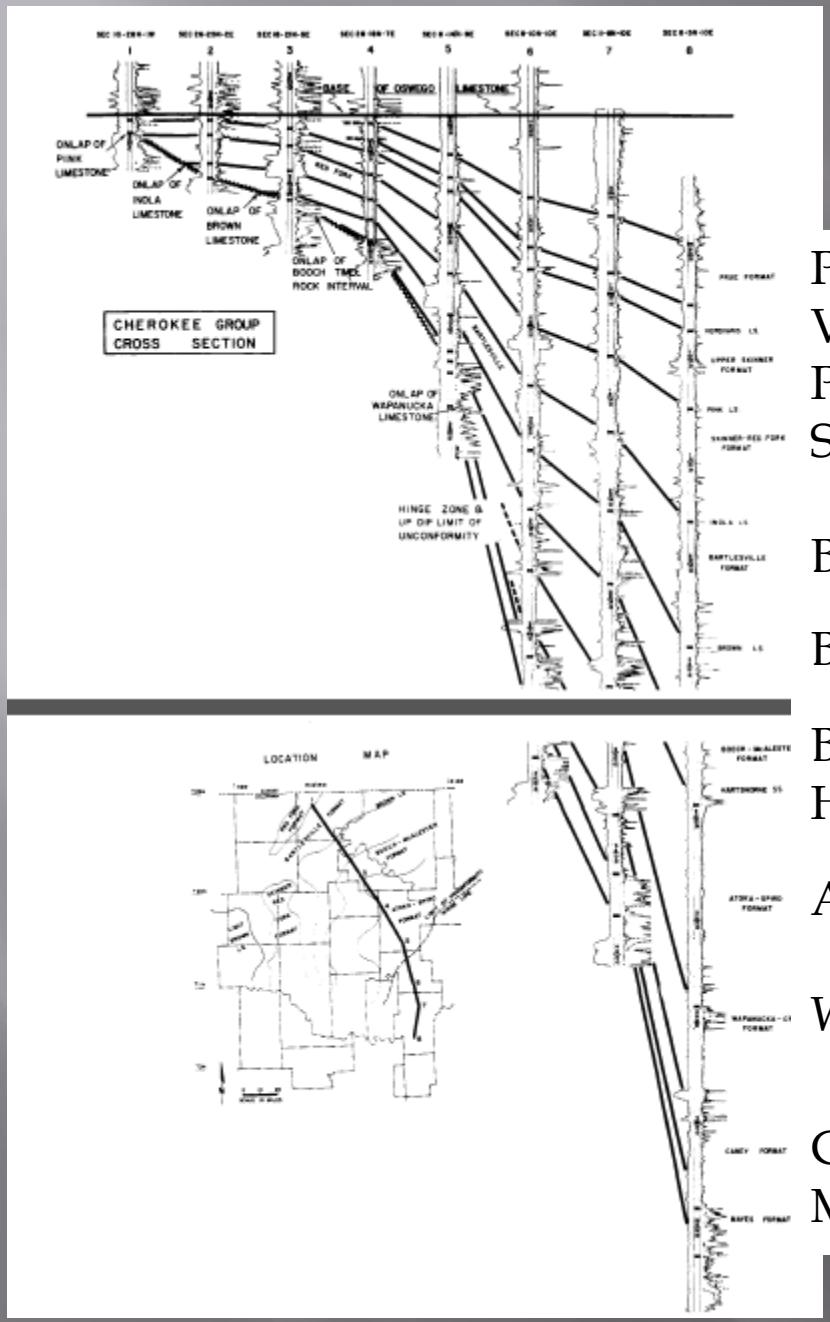


Ideal (simple) Arkoma Basin compressional structure. Asymmetric (steep north limb), thrust-cored, closed.



Another definition of the northern boundary of the Arkoma Basin – Desmoinesian hinge zone.

Note thickening of Booch (middle and lower McAlester Fm.) and Hartshorne Fm. south into basin.



Prue
Verdigris
Pink
Skinner-RF

Bartlesville

Brown

Booch-McAl
Hartshorne

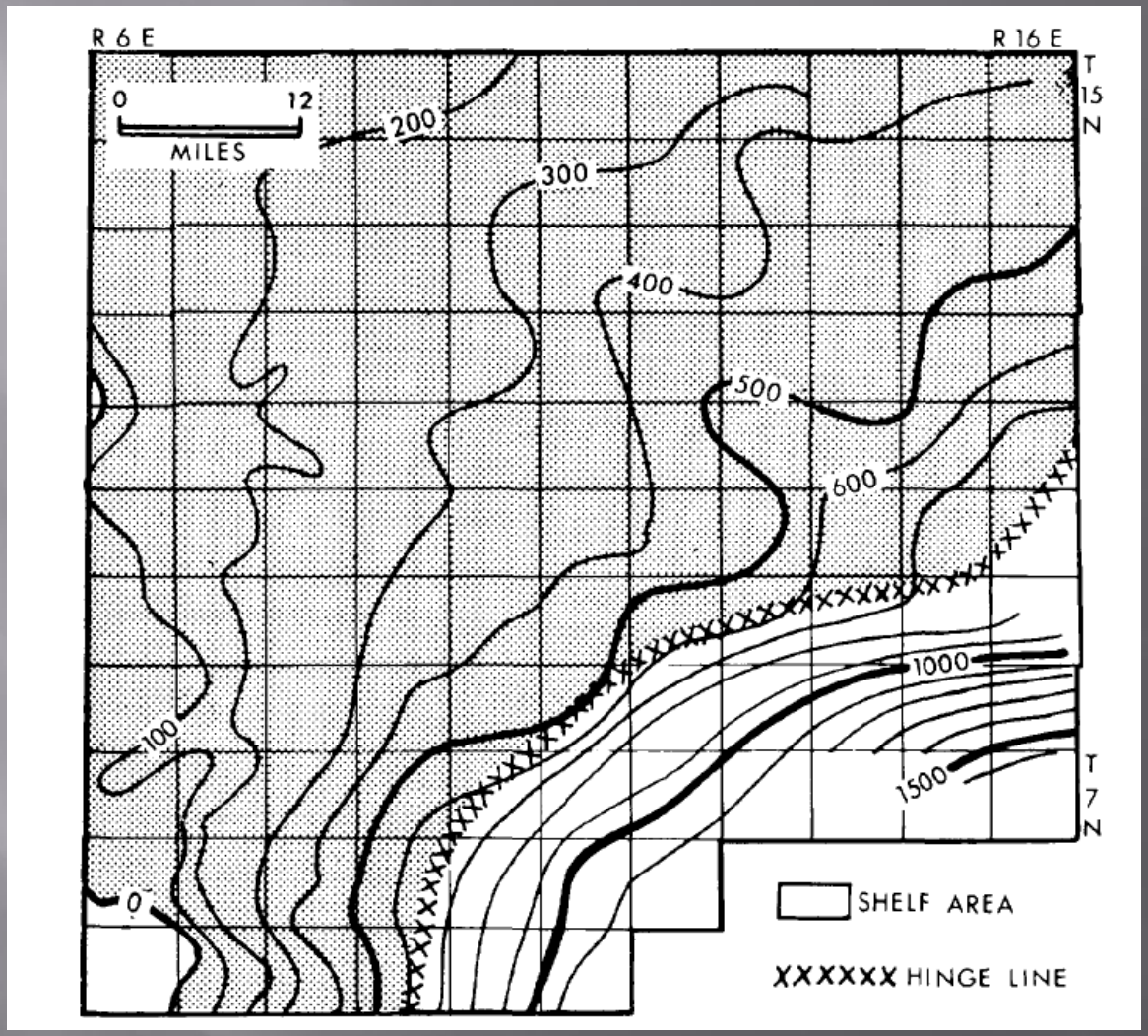
Atoka-Spiro

Wap-Crom

Caney
Mayes

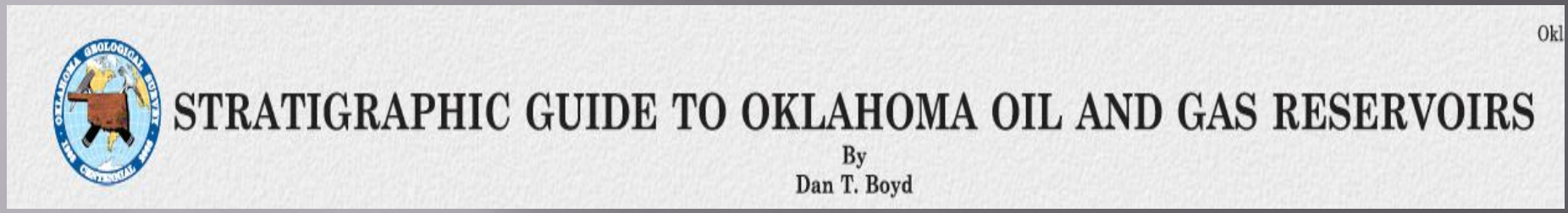
NNW-SSE strat section hung on B/Oswego showing thickening of Atokan through Cherokee strata off of platform and into Arkoma Basin. (from Visher et al., 1971)

RF – Red Fork
McAl – McAlester
Wap – Wapanucka
Crom - Cromwell



Isopach map of McAlester Fm., showing hinge line along northwestern edge of Arkoma Basin, and abrupt thickening into the basin (from Busch, 1974)

My source for OK reservoir strata:



ARKOMA BASIN COMPLETIONS (>100)

Calvin*
Allen*
Senora*
Thurman*
Red Fork*/Earlsboro*
Bartlesville*/Salt*
Savanna
Booch*/McAlester
Hartshorne
Atoka Lime*
Atoka*

Fanshawe
Gilcrease*/Morris*
Red Oak
Panola
Brazil
Cecil
Spiro
Wapanucka*
Union Valley*
Cromwell*
Jefferson*

Caney*
Woodford*
Hunton*
Viola*
Simpson*
Arbuckle*

(*other provinces, too)

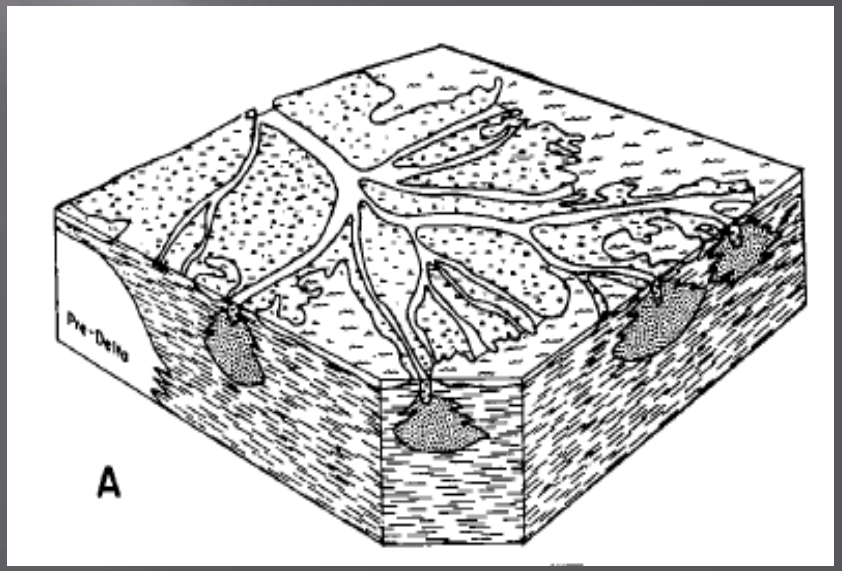
SYSTEM	SERIES	GROUP	FORMAL SURFACE NAMES OF FORMATIONS OR MEMBERS		FORMAL & INFORMAL SUBSURFACE NAMES	
PENNSYLVANIAN	DESMOINESIAN	Marmaton	Ft. Scott Limestone	Higginsville Limestone	Oswego lime	"Wheeler sand"
				Little Osage Shale		
				Blackjack Creek Ls.		
		Cabaniss	Senora Formation	Excello Shale		
				Breezy Hill Ls.		
				Lagonda Sandstone	Cherokee group	Prue sand
				Verdigris Limestone		Verdigris Limestone
				Croweburg coal		Henryetta coal
				Oowala Sandstone		Upper Skinner sand
				Mineral coal		Morris coal
				Chelsea Sandstone		Middle Skinner sand Lower Skinner sand
				Tiawah Limestone		Pink lime
		Krebs	Boggy Formation	Taft Sandstone		Red Fork sand Burbank sand Earlsboro sand
				Inola Limestone		Inola Limestone
				Bluejacket Sandstone		Bartlesville sand Glenn sand Salt sand
			Savanna Fm.	Doneley Limestone		Brown lime
				Sam Creek Ls.		
				Spaniard Limestone		
			McAlester Formation	Keota Sandstone		Upper Booch sand Taneha sand Tucker sand Lower Booch sand
				Tamaha Sandstone		
				Cameron Sandstone		
				Lequire Sandstone		
				Warner Sandstone		
				McCurtain Shale		
			Hartshorne Formation	Hartshorne Sandstone		Hartshorne sand

Principal reservoirs in northern part of Arkoma Basin.

Most of these in most places are fluvial-dominated deltaic.

Allen
Senora

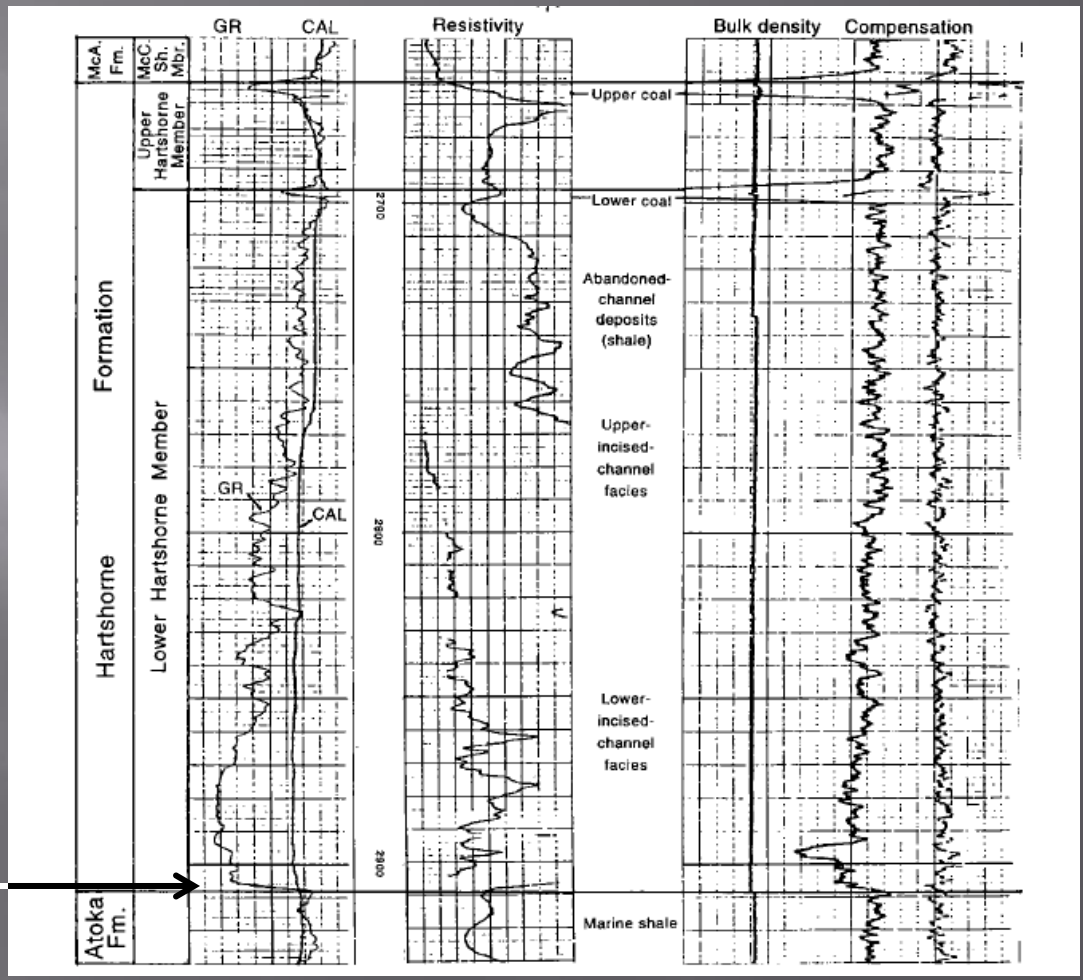
Stuart, Thurman



Hartshorne Ss.

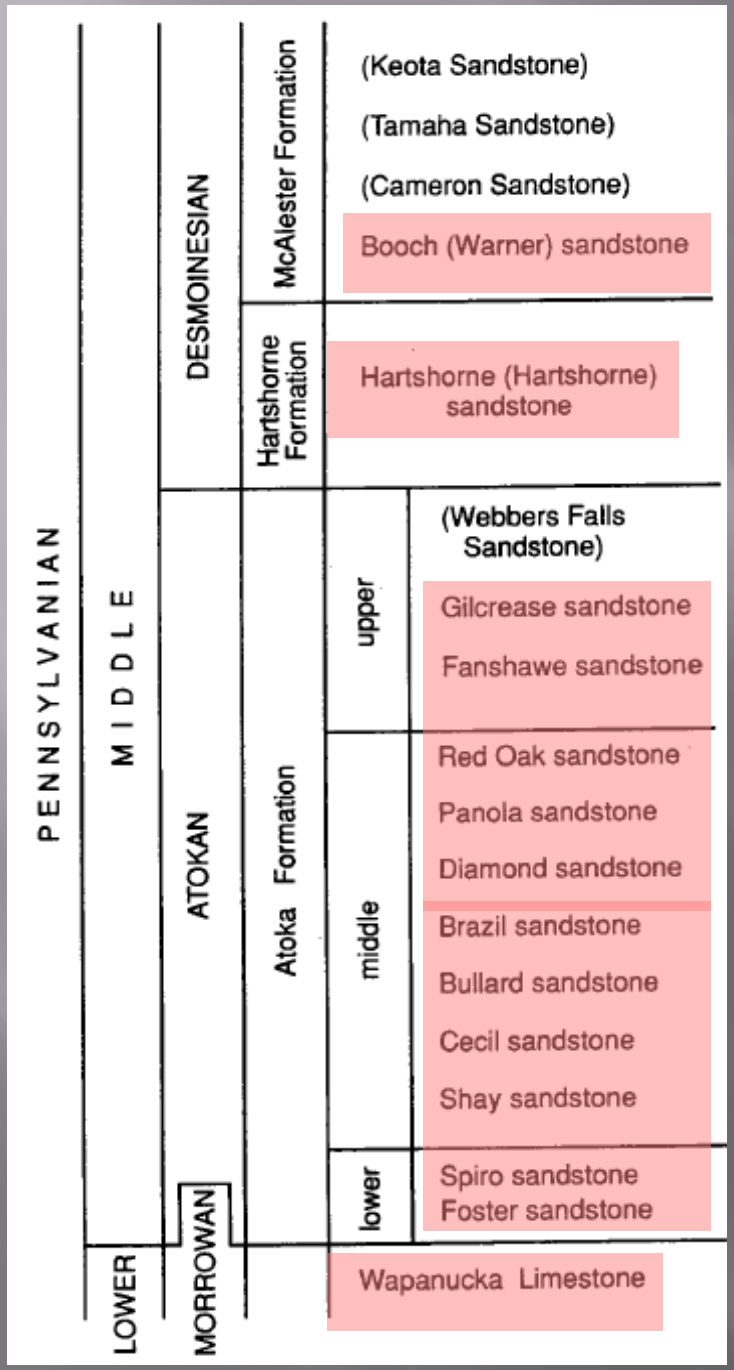
TXO 1 Gallagher NWNW 26/6N/21E

Abrupt base, uniform sand development typical of channel fills



Log character of incised channel-fill sandstone in Hartshorne Fm. Characteristics: thick, typically linear, best reservoir quality.

Hartshorne incised channel-fill sandstone outcrop, Red Oak Ridge.



Principal reservoir units in southern part of Arkoma Basin

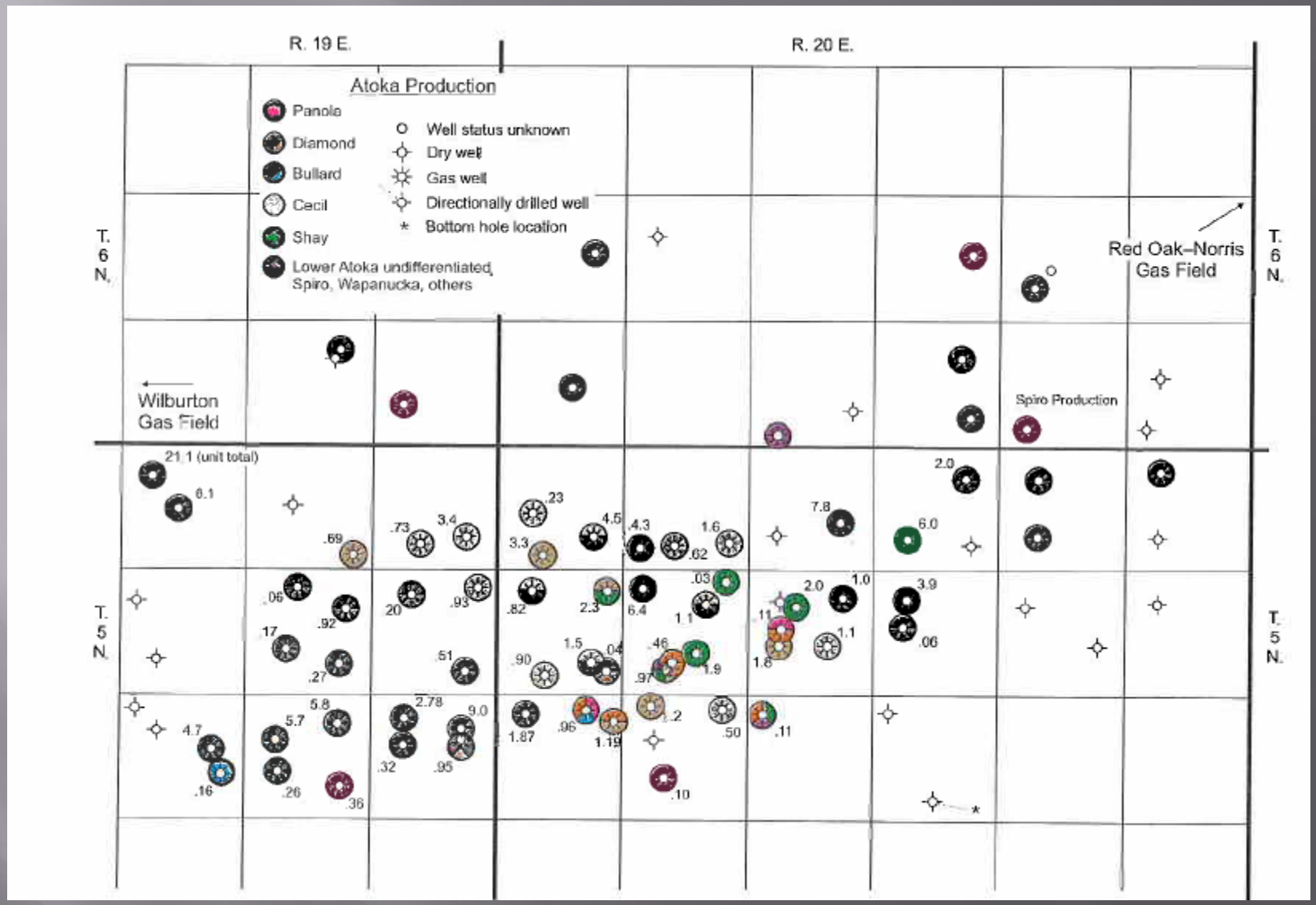
Desmoinesian units are mostly fluvial-deltaic.

Upper Atokan units are shallow marine.

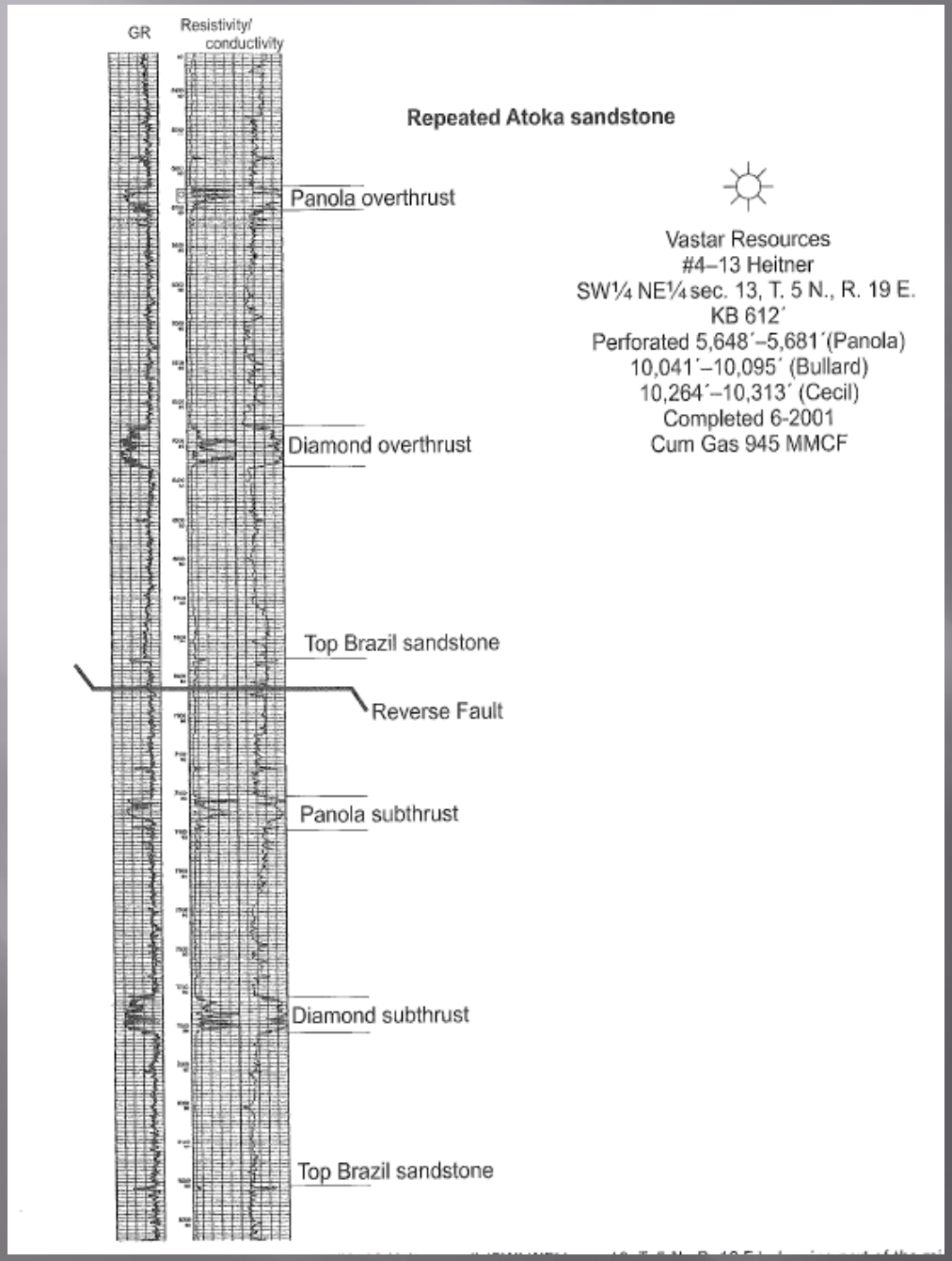
Middle Atokan units are mostly deep-water.

Lower Atokan and Morrowan units are shallow marine.

Remember this slide



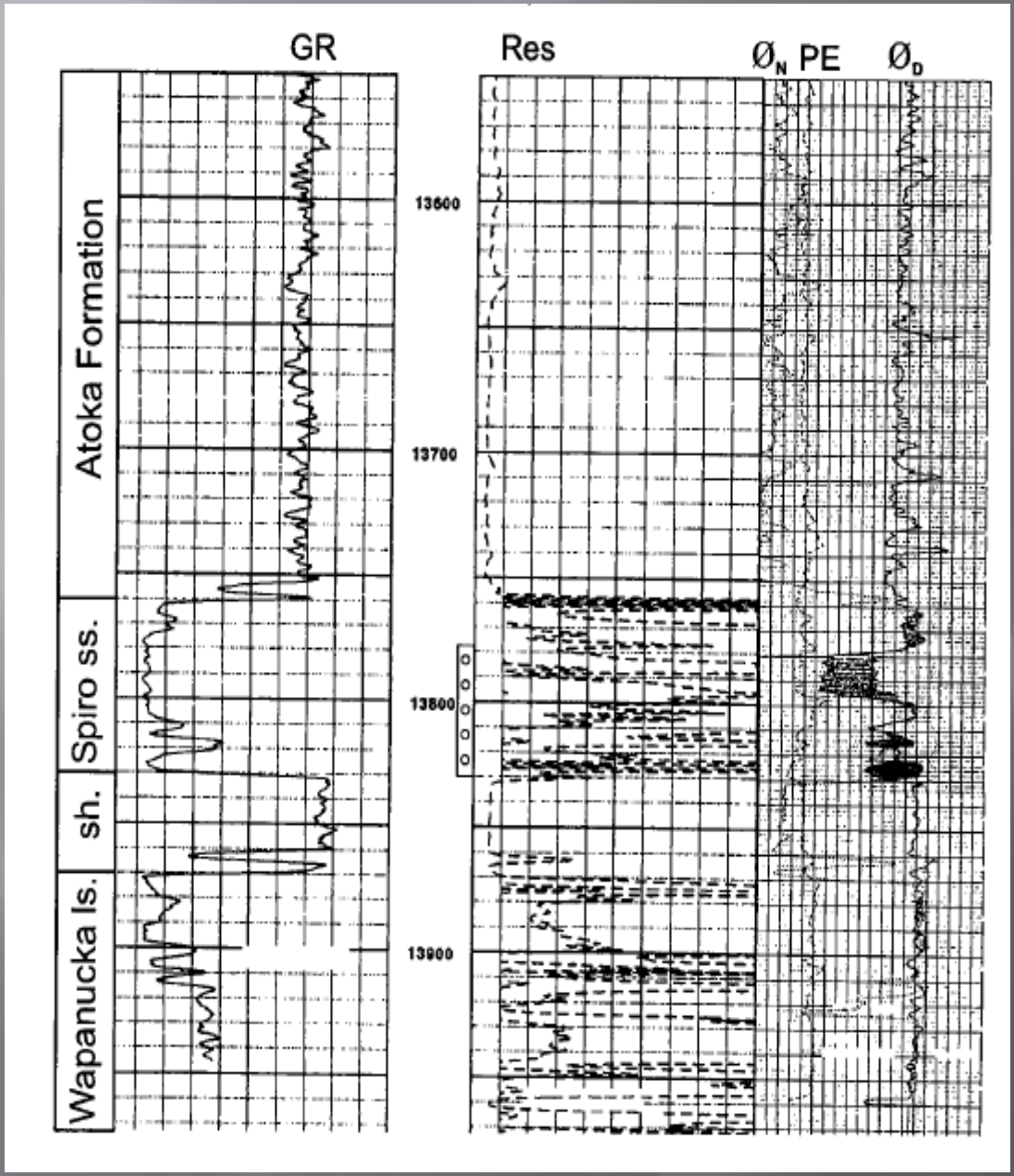
Production map of part of Panola Field, showing production from Panola, Diamond, Bullard, Cecil, Shay, and undivided lower Atoka sandstones plus Wapanucka



Vastar
4-13 Heitner
SWNE 13/5N/19E

Repeated section of deep-water Atoka turbidites in Panola Field, Latimer County.

Key to further exploration – restore thrust plates to original position, then look at reservoir facies.



BTA No. 2-24 JV-P Amason, Veterans Colony West Field

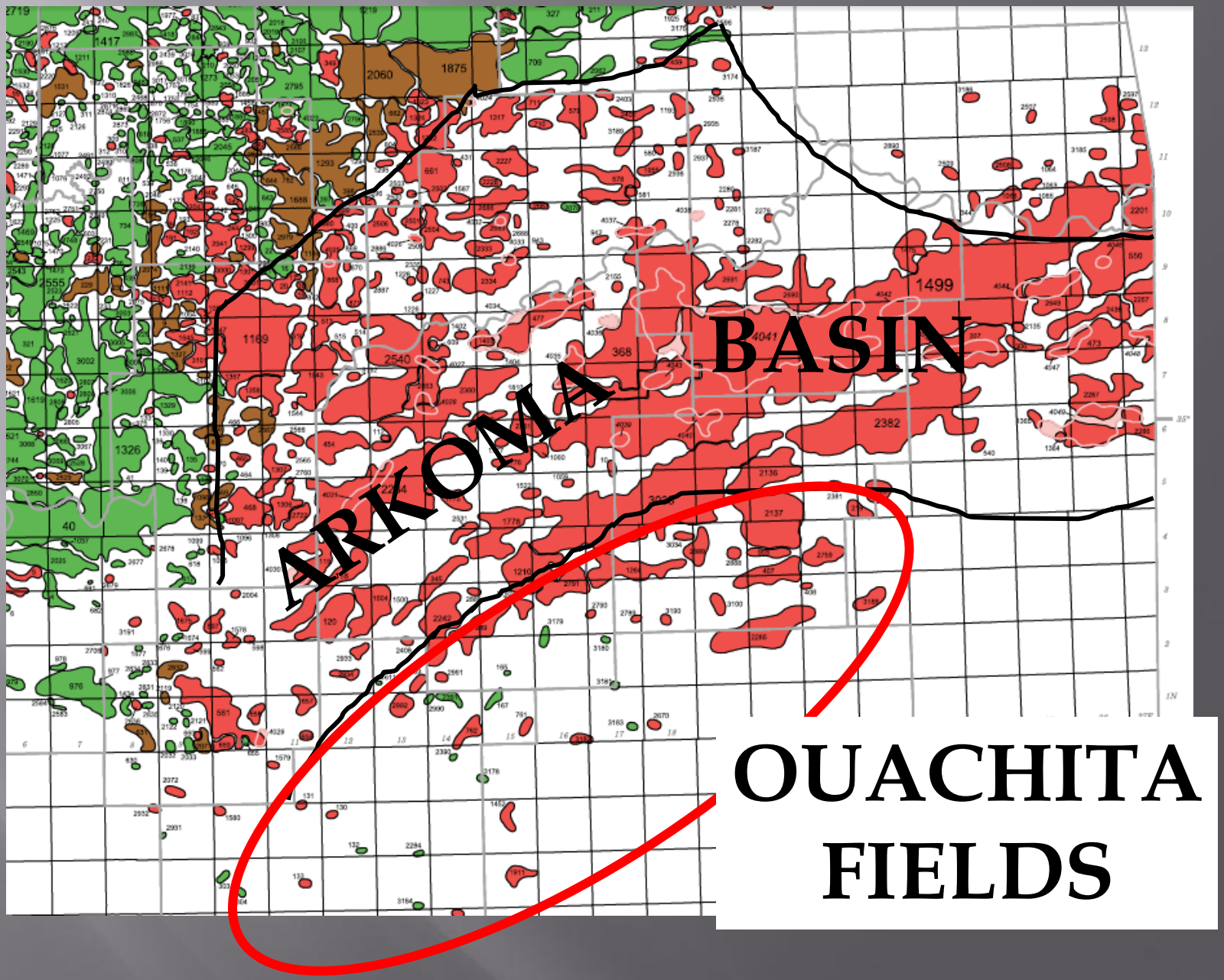
Typical log character of Spiro sandstone. Note conspicuous "sub-Spiro shale" (Atokan – Morrowan boundary) separating Spiro and Wapanucka Limestone.

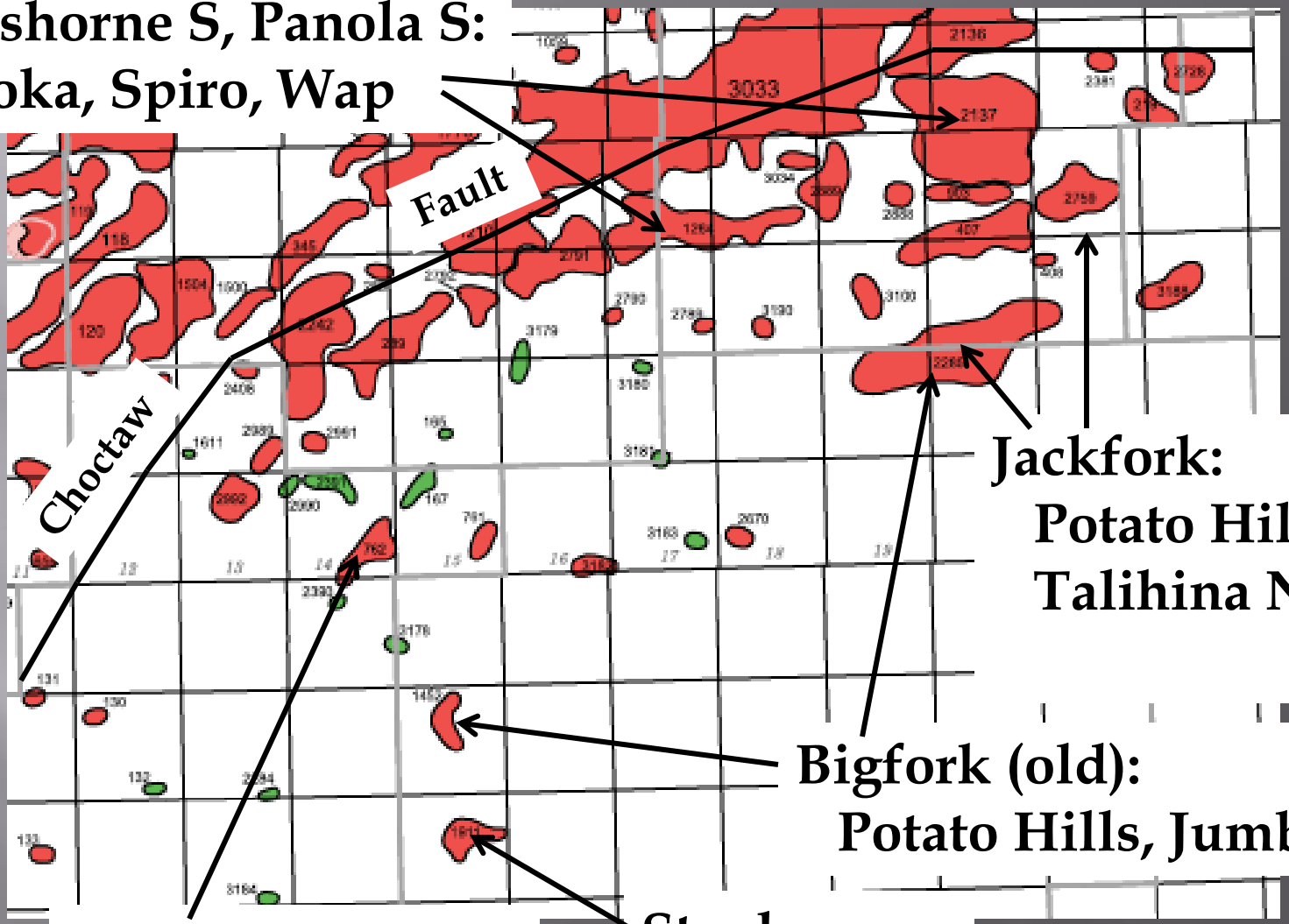
STRATIGRAPHIC GUIDE TO OKLAHOMA OIL AND GAS RESERVOIRS

By
Dan T. Boyd

OUACHITA OROGENIC BELT COMPLETIONS

Spiro/Wapanucka
Jackfork
Stanley
Arkansas Novaculite
Bigfork


ARKOMA
BASIN
OUACHITA
FIELDS


Hartshorne S, Panola S:
Atoka, Spiro, Wap
Fault
Choctaw
Jackfork:
Potato Hills,
Talihina NW
Bigfork (old):
Potato Hills, Jumbo S
Stanley:
Moyers SW
Ark. Novaculite:
Daisy W,
Isom Sprs.
Remember this slide

Channel sandstone in Jackfork Group, McKinley Rocks
Not all turbidites are created equal

HISTORY OF HYDROCARBON EXPLORATION AND DEVELOPMENT IN THE ARKOMA BASIN AND OUACHITA MOUNTAINS

Exploration periods:

- **Solids Are Good period (pre-1910)**
- **Anticlines Are Good period (1910 – 1935)**
- **Geologic Maps Are Good period (1935 – 1950)**
- **Drilling Deeper Is Good period (1950 – 1980)**
- **Thrust Plates Are Good period (1980 - ~1990)**
- **Horizontal Wells Are Good period (~1990 – present)**
- **The Future**

SOLIDS ARE GOOD
PRE- 1910 EARLY HISTORY

Prehistory. Native Americans used asphaltites to bind arrowheads to shafts

1812. Asphaltite (called coal) noted by explorer John Maley

Civil War years. Gas seep near Chilli (probably along Carbon Fault) used by soldiers

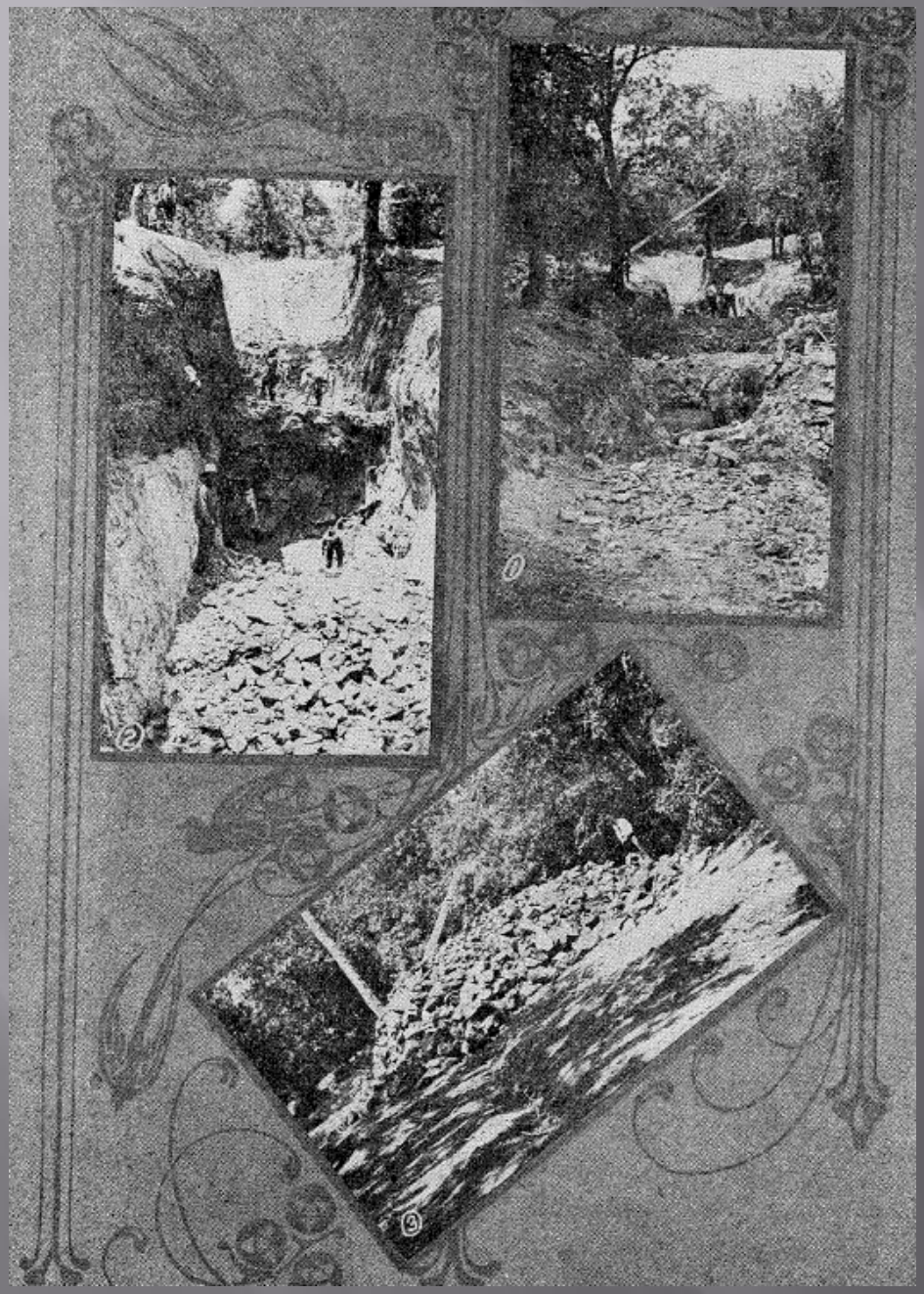
1890. Asphaltite vein discovered near Jumbo. Mined from 1892 to 1924

1899. First scientific report on asphaltites by Taff

1907. Asphaltite vein discovered near Sardis

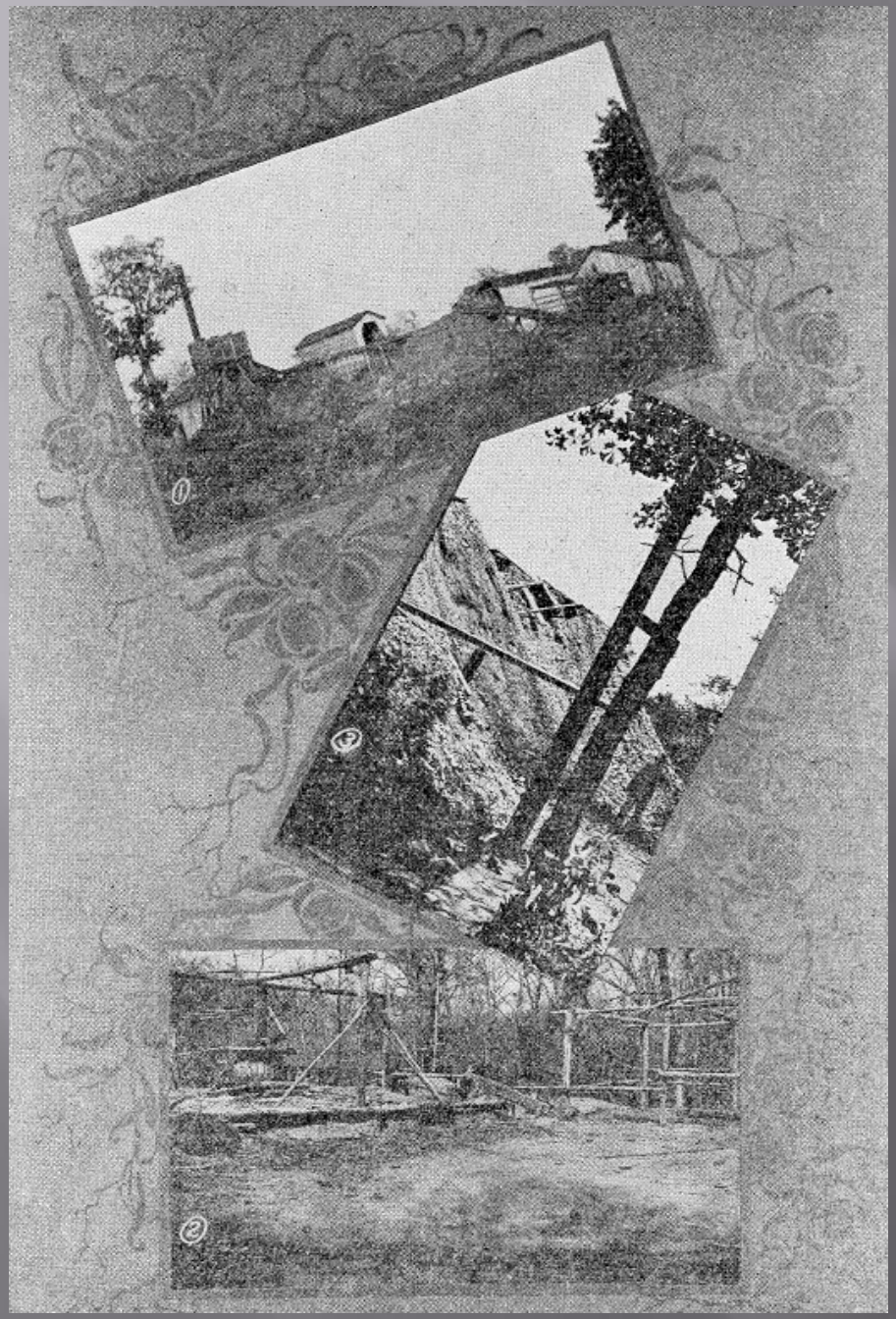
1910. Explosion at Jumbo Mine, several killed.

WWI. Impsonite mined at Page for vanadium



Early asphalt and asphaltite pits and mines in western Ouachita Mtns., Arkoma Basin, and Cretaceous overlap (from 1911 OGS Bulletin 2).

Upper photos – asphalt pits (location not given). Lower photo – pile of gypsonite (sic) (gilsonite?)



Top – asphalt mine, Tuskahoma.

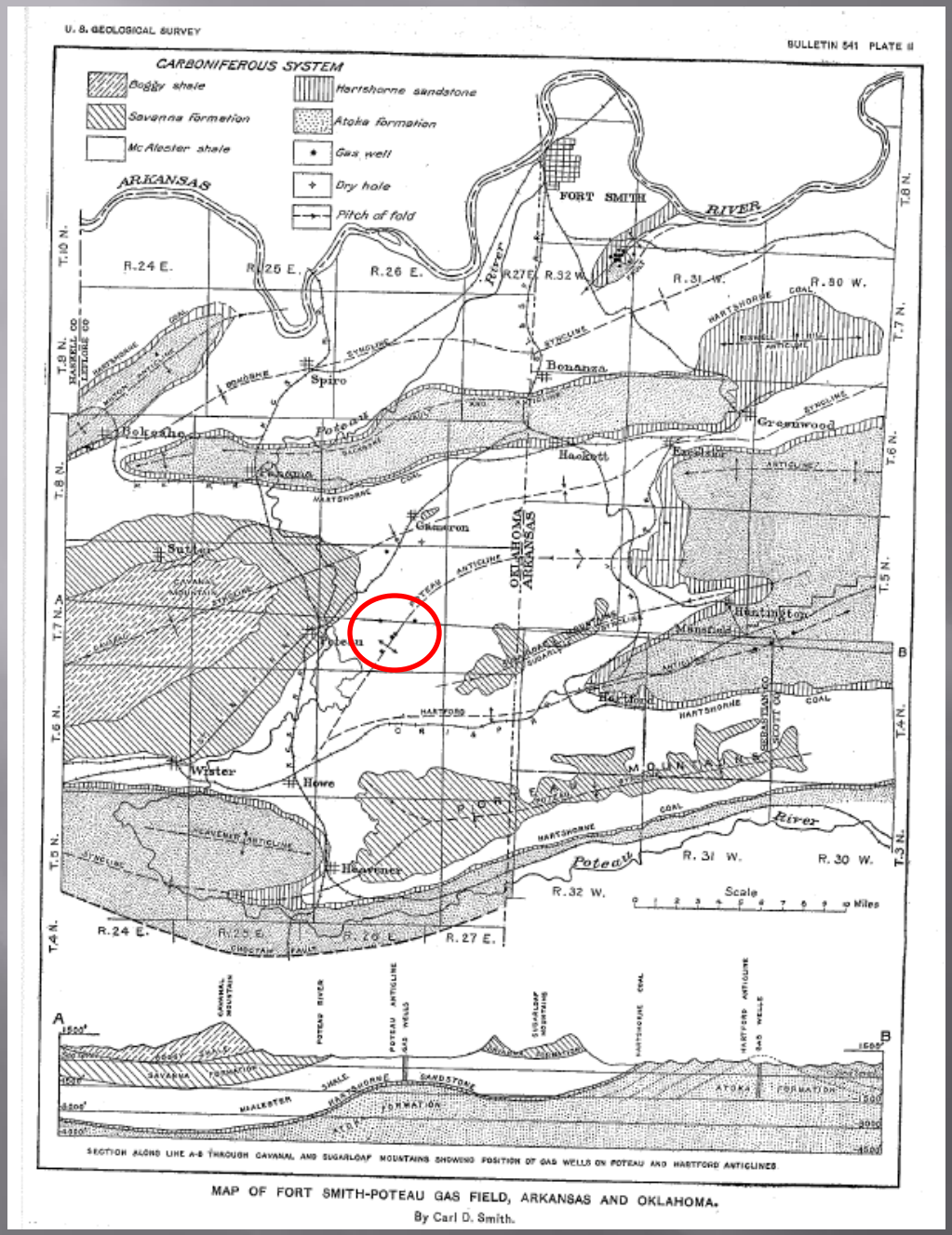
Middle – dump of asphalt mine.

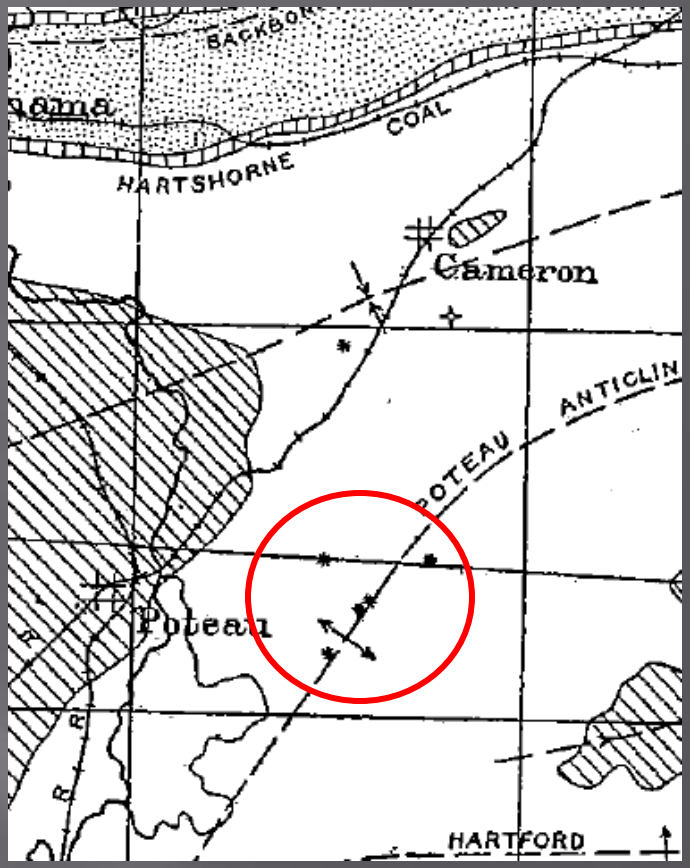
Bottom – asphalt mine near Atoka.

(from 1911 OGS Bull. 2)

ANTICLINES ARE GOOD (1910 – 1935)

1902. First natural gas discovered in Arkoma Basin near Mansfield, Arkansas.
1910. Poteau Gas Field discovered. Le Flore County Gas and Electric No. 1 Hill in Hartshorne Ss on Poteau Anticline.
1912. Red Oak Gas Field discovered. Gladys Belle O&G Co. in Hartshorne Ss on Brazil Anticline.
1914. Word "structure" first used in Cushing Field.
1914. Redden Oil Field discovered.
1921. Dake first suggests Ouachitas result of thrust faulting.
1929. Wilburton Gas Field discovered. Limestone O&G No. 1 Nettie McCurray in Hartshorne Ss on Wilburton Anticline.
1932. Peak of drilling activity in McGee Valley.



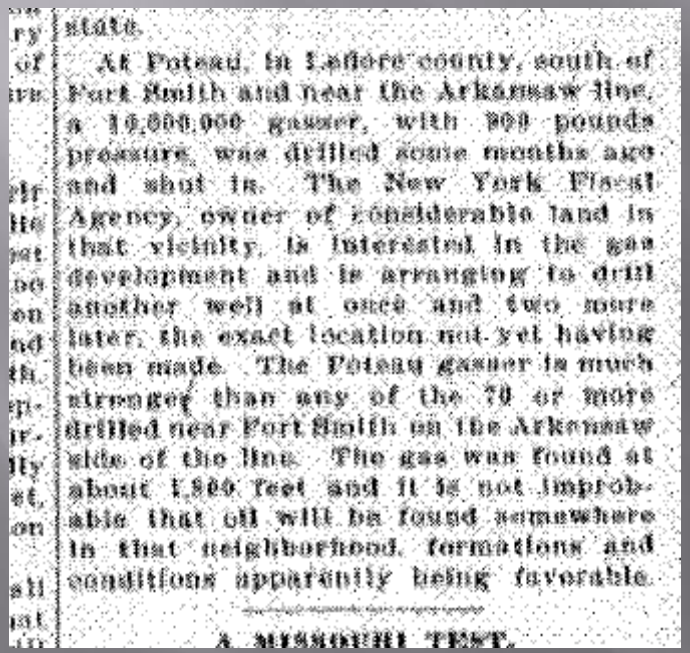


1912 map (USGS Bulletin 541) showing location of Poteau Gas Field on Poteau Anticline.

September 22, 1910

MID-CONTINENT FIELDS

OKLAHOMA, KANSAS, NORTHWESTERN LOUISIANA, NORTH TEXAS

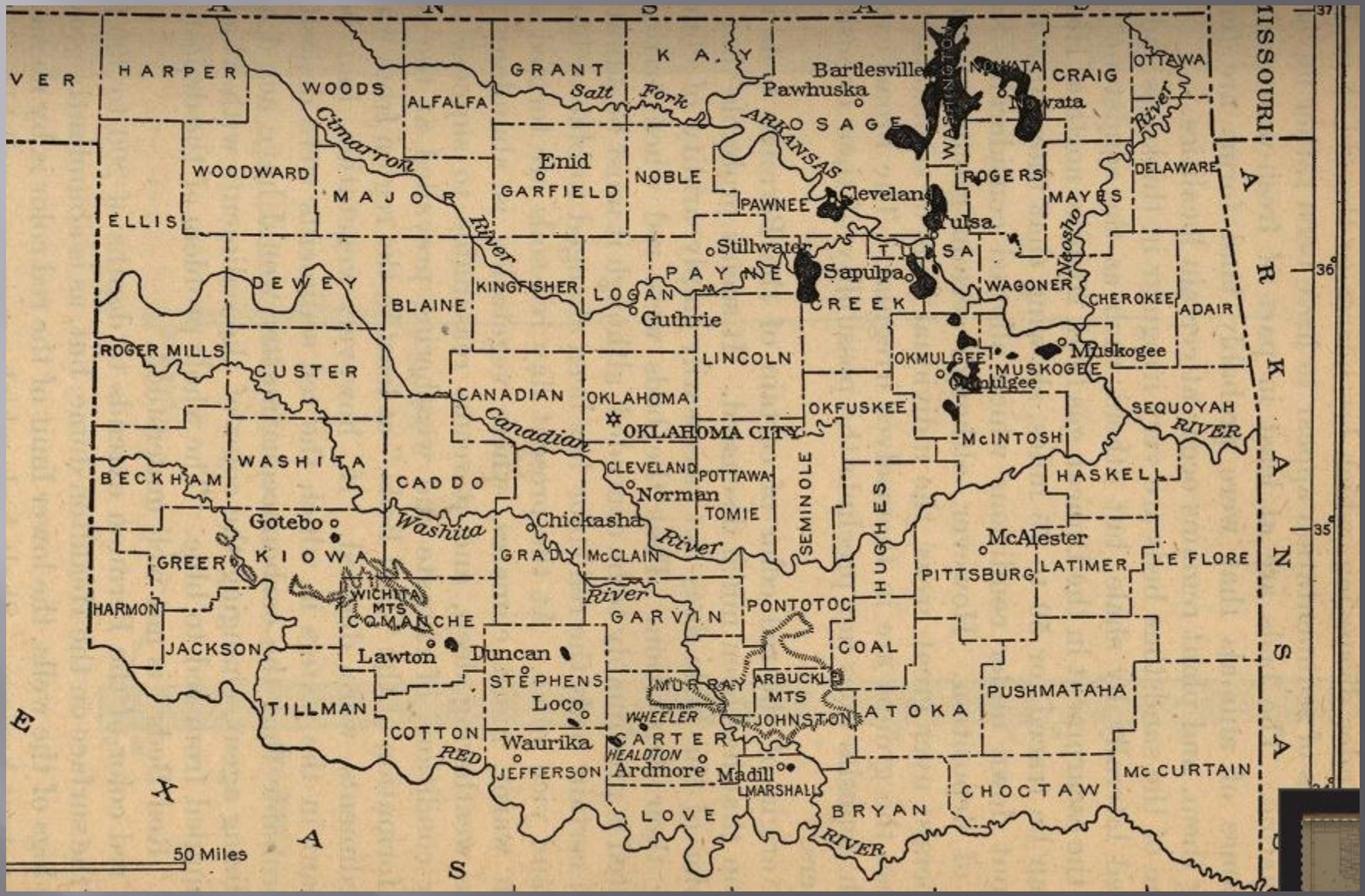


state.

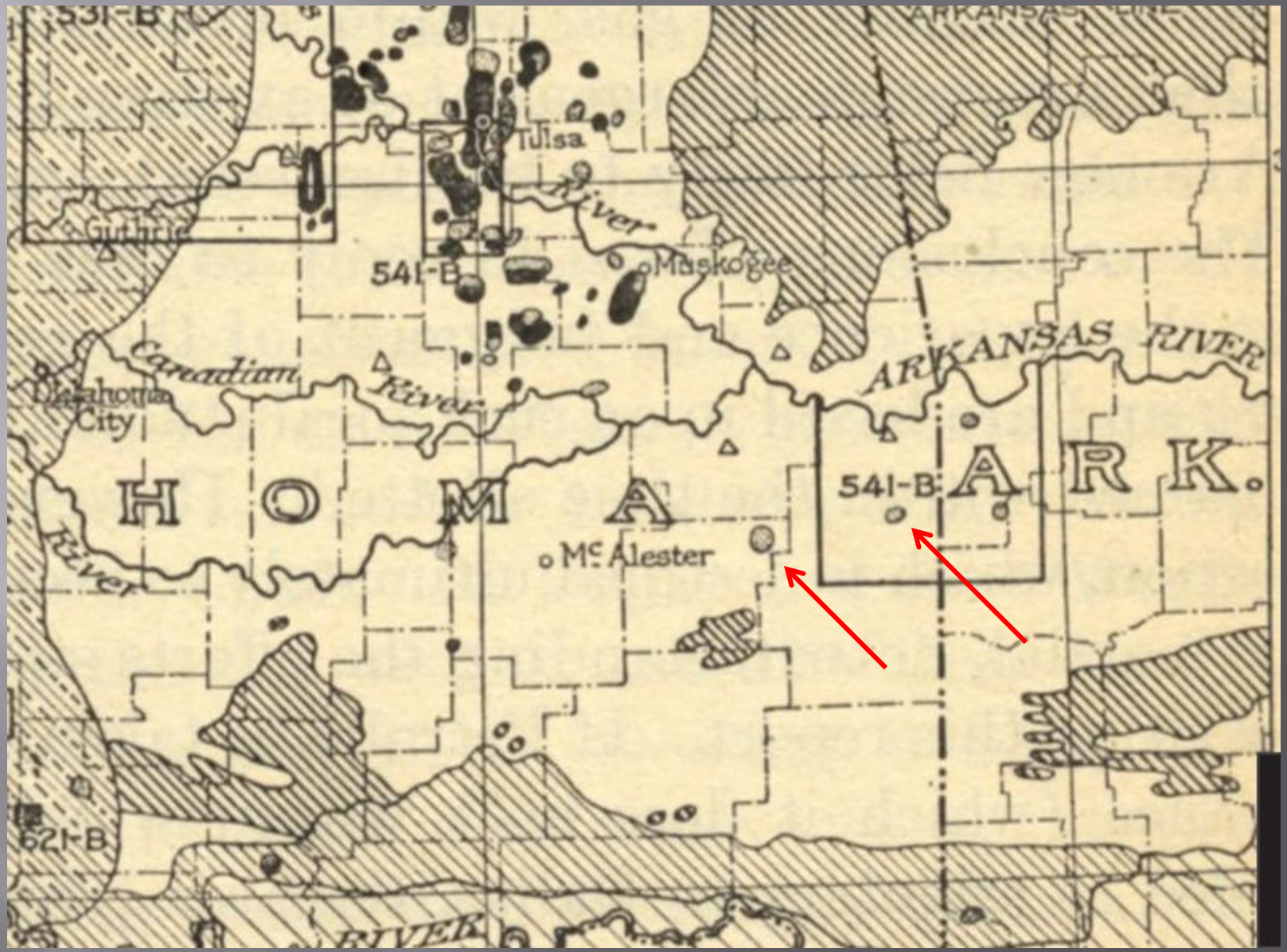
At Poteau, in Leflore county, south of Fort Smith and near the Arkansaw line, a 10,000,000 gasser, with 900 pounds pressure, was drilled some months ago and shut in. The New York Fiscal Agency, owner of considerable land in that vicinity, is interested in the gas development and is arranging to drill another well at once and two more later, the exact location not yet having been made. The Poteau gasser is much stronger than any of the 70 or more drilled near Fort Smith on the Arkansaw side of the line. The gas was found at about 1,000 feet and it is not improbable that oil will be found somewhere in that neighborhood, formations and conditions apparently being favorable.

A MISSOURI TEST.

At Poteau, ……. a 10,000,000 gasser, with 100 pounds of pressure, was drilled some months ago and shut in. The New York Fiscal Agency, owner of considerable land in that vicinity, is interested in the gas development and is arranging to drill another well at once and two more later ……. The Poteau gasser is much stronger than any of the 70 or more drilled near Forth Smith on the Arkansas side of the line. The gas was found at about 1,000 feet and it is not improbable that oil will be found somewhere in that neighborhood, formations and conditions apparently being favorable.



But interestingly, the Poteau Field did not make it on to this 1915 map of Oklahoma oil and gas fields.



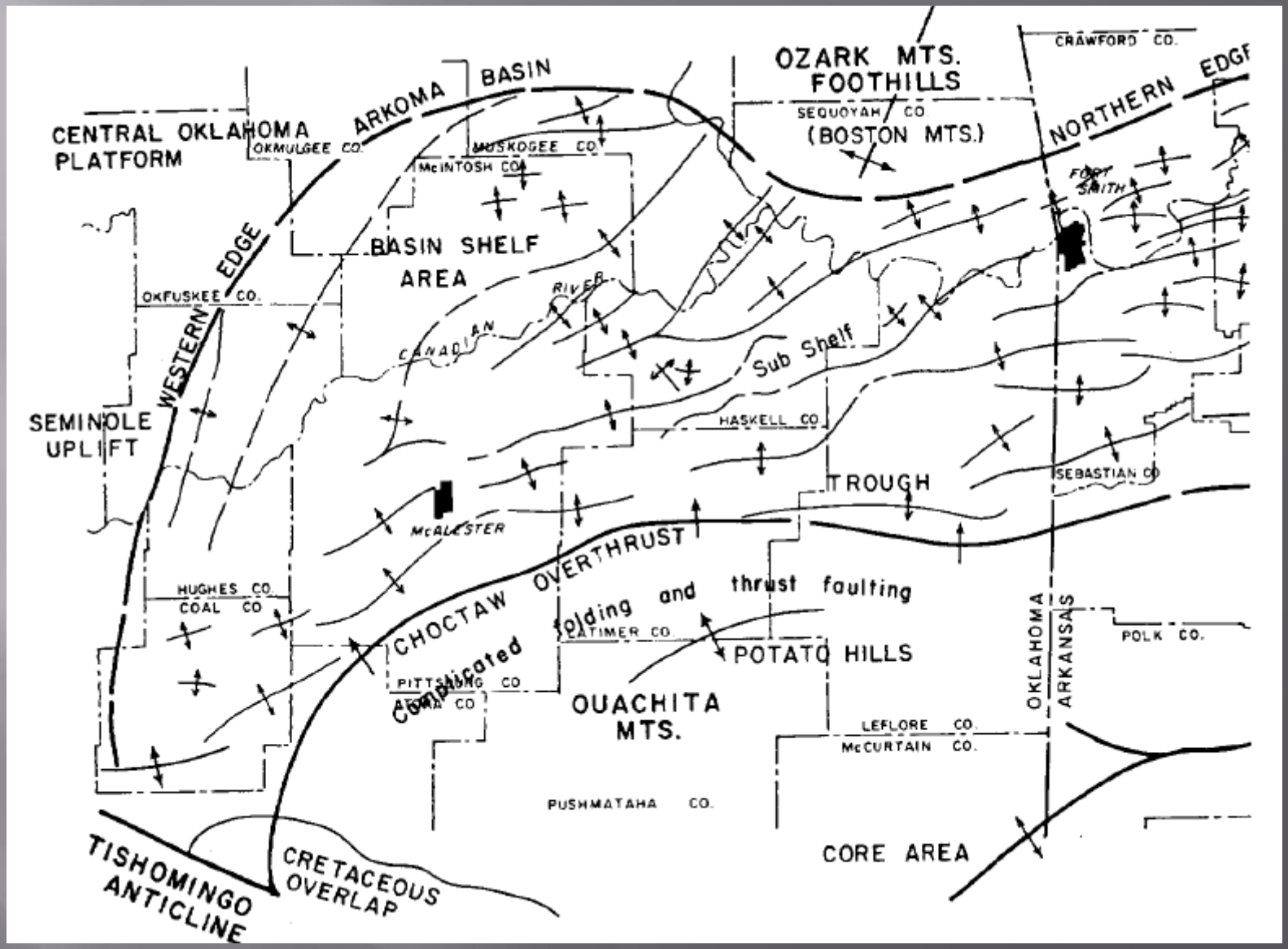
But Poteau and Red Oak Fields are on this 1916 USGS map.

Cable-tool rig at Redden Oil Field (photo taken in 2000)

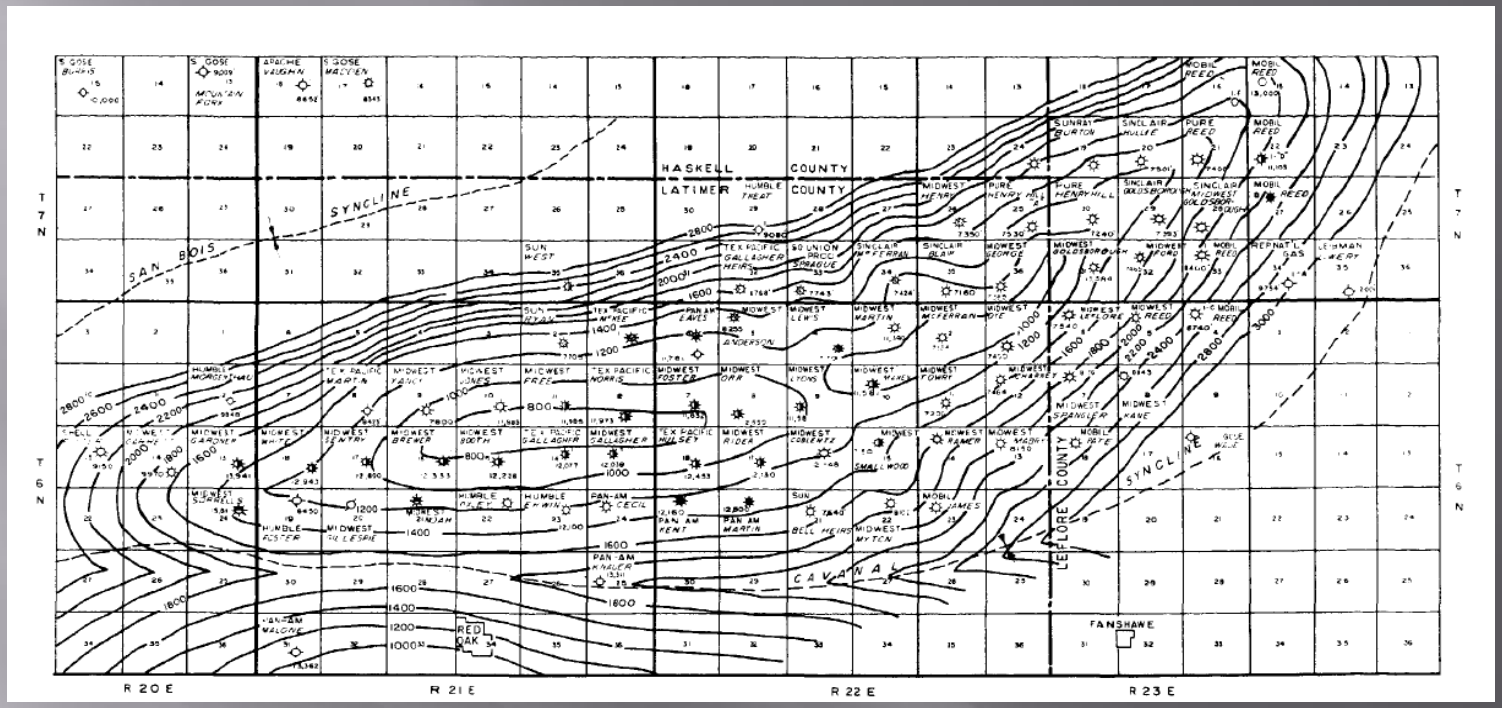
Is there anything down there?

Sampling old oil well at Redden Field.

Reservoir at Redden: Sandstone in Stanley – at least some dipdown from tar sand at surface (trap)



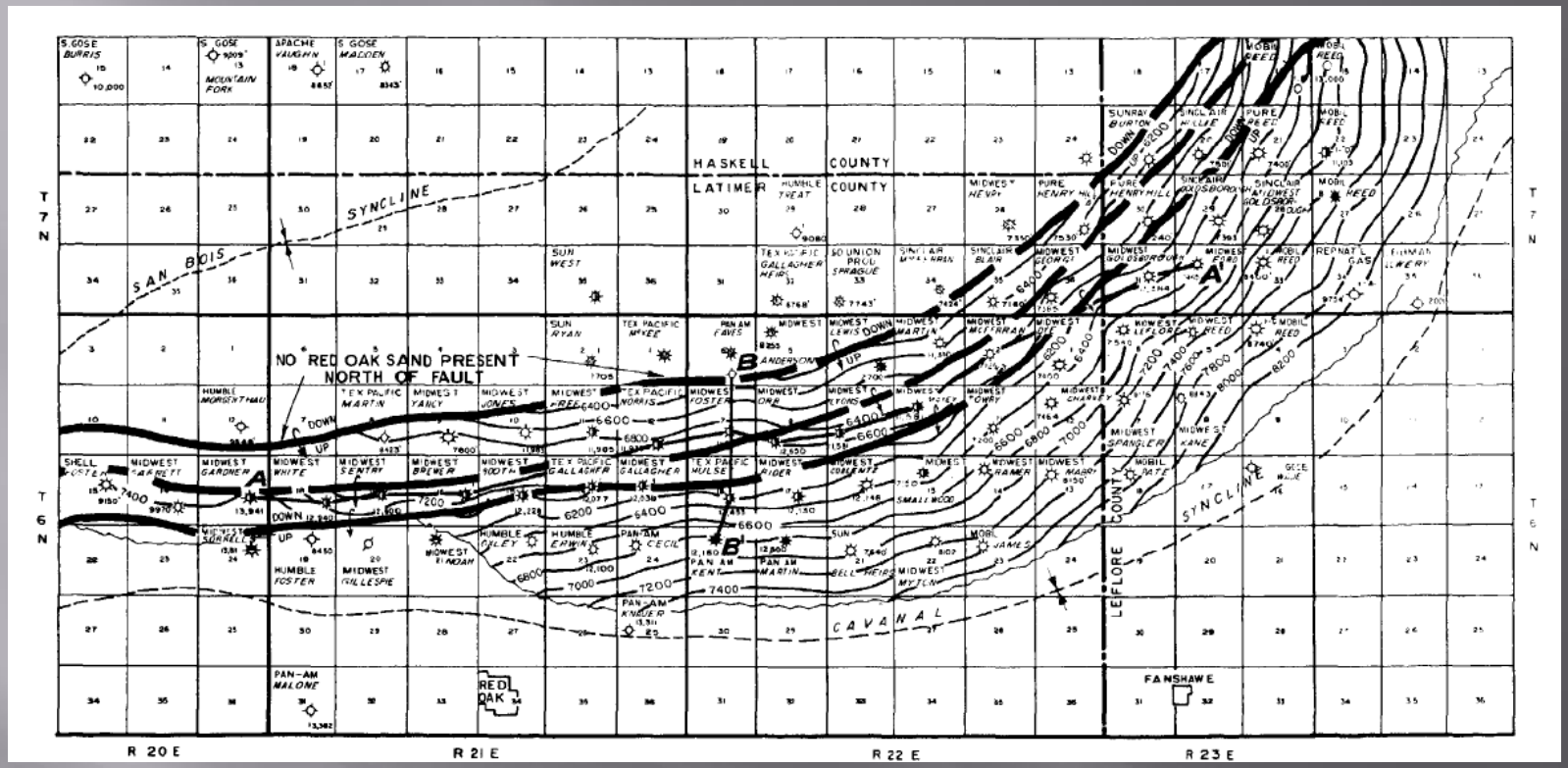
The Poteau and Red Oak Fields proved the success of drilling anticlines (first used at Cushing in 1914).



Structure contour map of Brazil Anticline (Red Oak – Norris Field, 1968) on Hartshorne Ss (relatively shallow)

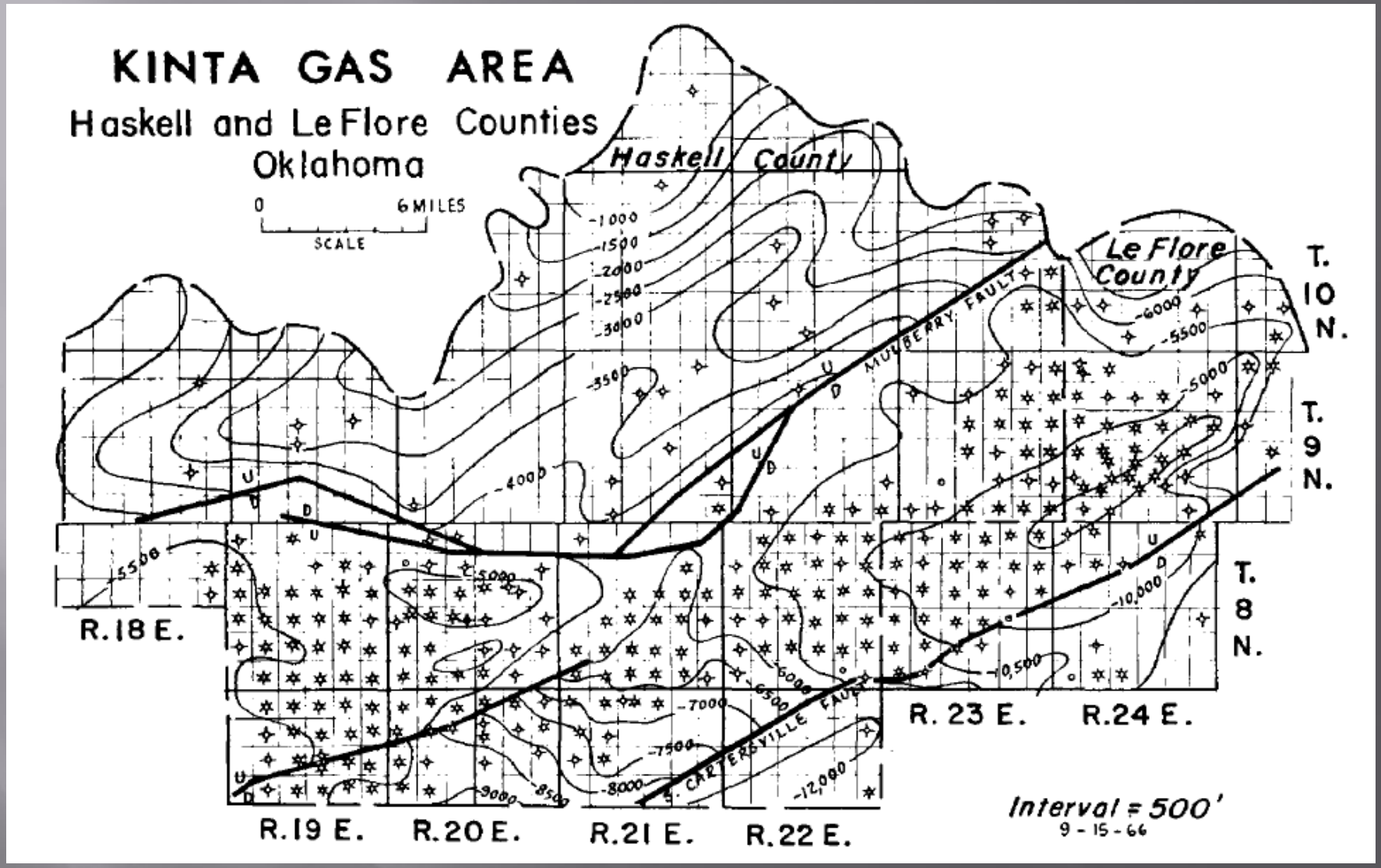
Note anticline is asymmetric (steep north limb)

(Note also shape of Cavanal Syncline – totally bogus)

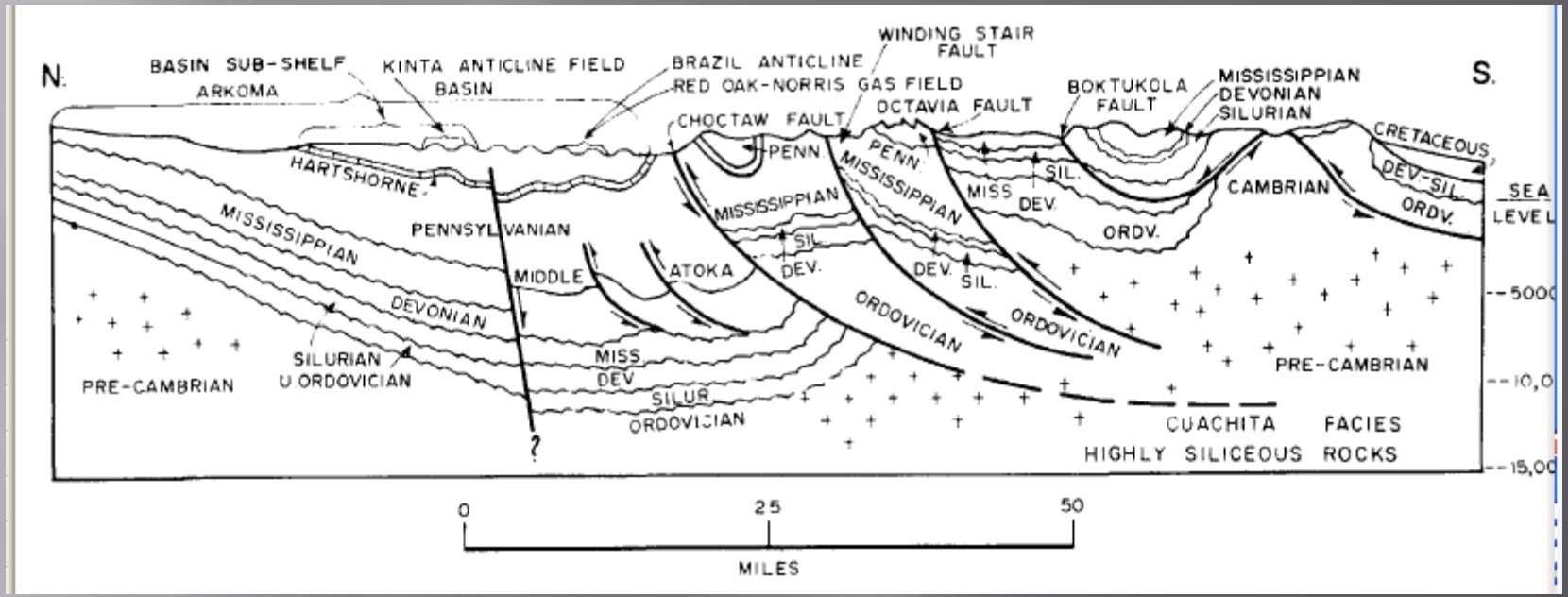


Structure contour map of Brazil Anticline (Red Oak – Norris Field, 1968) on Red Oak Ss (moderately deep)

North-vergent thrust faults present; explain asymmetric fold at Hartshorne level. Really beginning to understand structure of Arkoma Basin folds.



Beginning to recognize the COMPLEXITY of anticlinal structures.



Still some very fundamental flaws in understanding the deep structure in the Arkoma Basin and the shallower structure in the Ouachita Mountains. E.g., involvement of basement.

1968 cross section through Red Oak – Norris field.

GEOLOGIC MAPS ARE GOOD PERIOD (1935 – 1950)

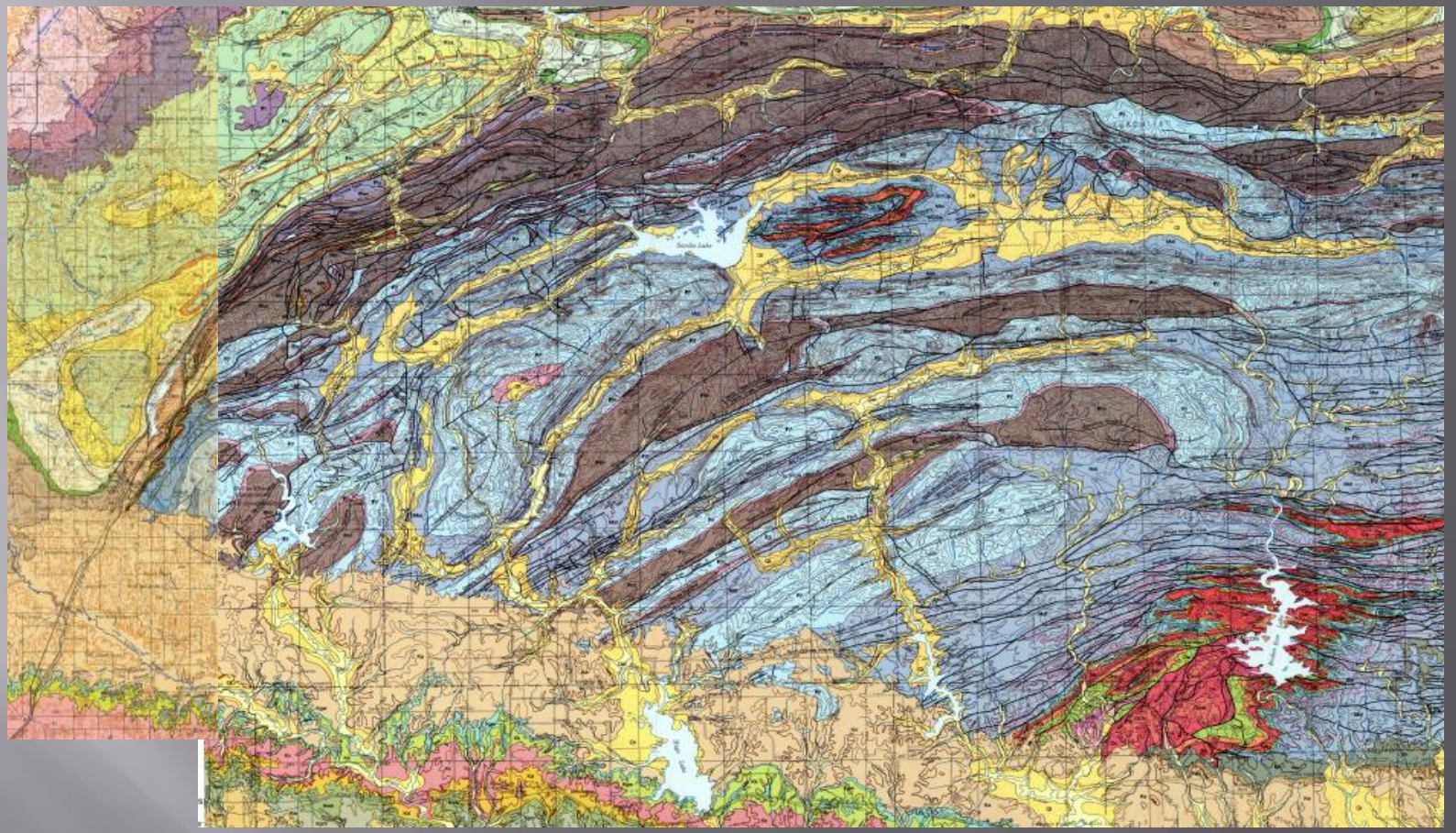
1937. USGS Bulletin by Knechtel on resources of the Lehigh coal district

1937. USGS Bulletin by Hendricks on resources of the McAlester coal district

1938. USGS Bulletin by Dane et al. on resources of the Quinton-Scipio coal district

1939. USGS Bulletin by Hendricks on resources of the Howe-Wilburton coal district

1947. Geologic map on western part of Ouachita Mountains by Hendricks et al.



Surface geologic map of Ouachita Mountains. Most of western part and all of Arkoma Basin (to the north) mapped by USGS. Even to present, these maps are little improved upon.

DEEPER DRILLING IS GOOD PERIOD (and new sed-strat concepts) (1950 - 1980)

1959. Discovery of Red Oak, Spiro Sss at Red Oak Field by Midwest and Frankfort No. 1 Orr

1959. Paper by Dan Busch on Pennsylvanian delta deposits, inc. Booch in Arkoma Basin

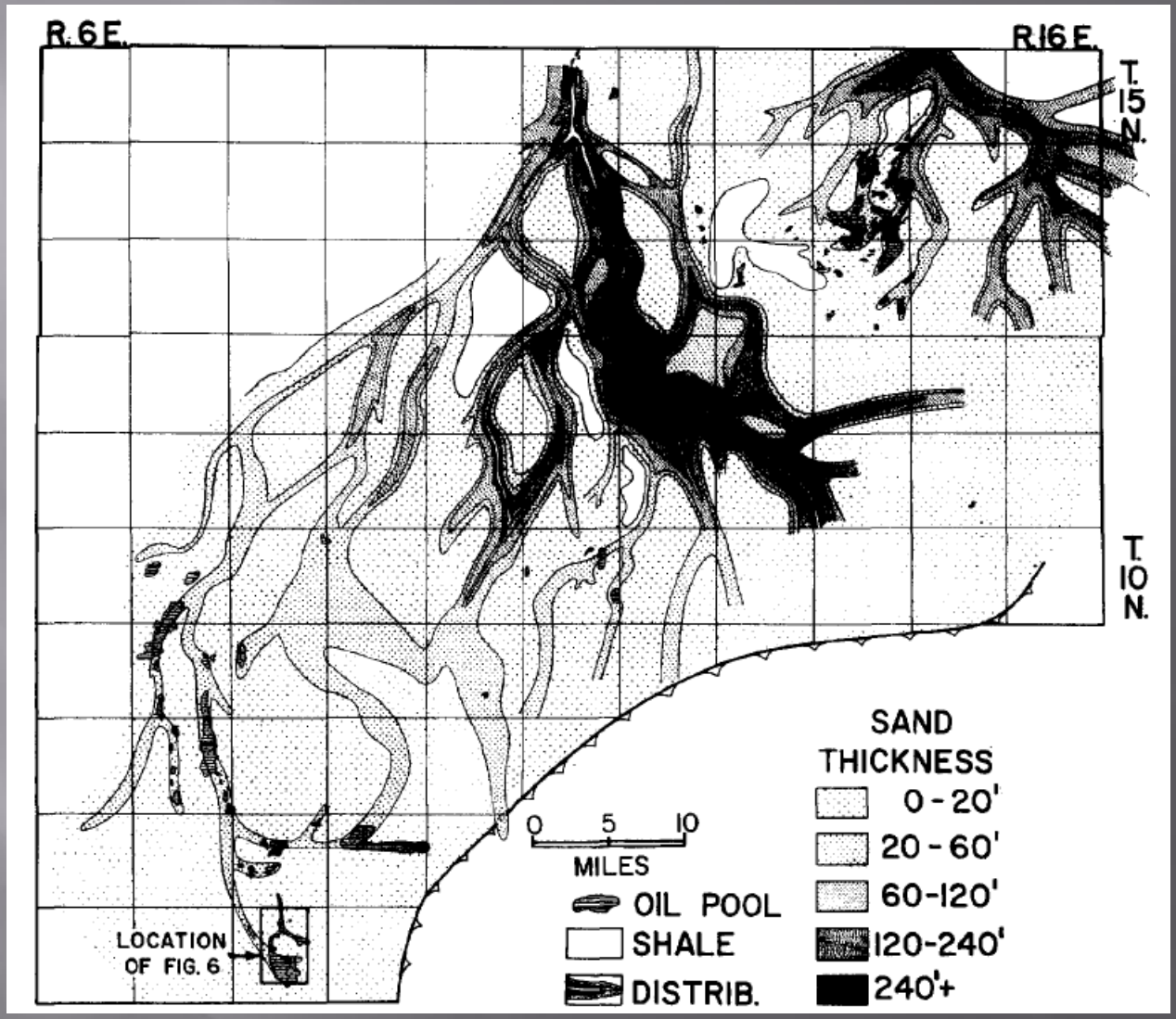
1960. Paper by Lewis Cline on deep-water deposits (turbidites, flysch) of Ouachita Mountains

1960. Potato Hills Gas Field discovered by Sinclair No. 1 Reneau in Bigfork Chert

1960. Wilburton Gas Field "rediscovered" by Ambassador No. 1 Williams in Spiro

1977. Isom Springs Oil Field discovered by Westheimer-Neustadt No. 1 Wallace in Arkansas Novaculite

1978. Pittsburg Gas Field discovered by Hamilton Bros. No. 1 Chitty-Scott in Wapanucka, Cromwell

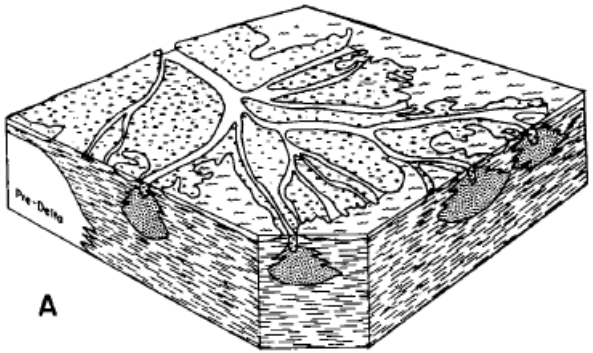


Classic paper by Dan Busch on Pennsylvanian delta systems in Arkoma Basin. Explained reservoir distribution and heterogeneity.

SYSTEM	SERIES	GROUP	FORMATION	SURFACE NAMES (Members & Fms.)	PRIMARY SUBSURFACE NAMES	SECONDARY SUBSURFACE NAMES
PENNSYLVANIAN	DESMOINESIAN	MARMATON	FT. SCOTT	Ft. Scott Limestone (Wetumka Shale in Arkoma basin)	Oswego lime	Oswego lime
		"CHEROKEE"	SENORA	Lagonda Sandstone (Calvin Fm. in Arkoma Basin)	Prue sand	Squirrel, Perryman, Gibson, Bixler, 2nd & 3rd Deese, Wanette
		CABANISS		Verdigris Limestone	Verdigris Limestone	Ardmore lime
				Croweburg coal	Henryetta coal (Senora lime)	Croweburg coal (Senora lime)
				Oowala Sandstone	Upper Skinner sand (Cherokee Platform)	Verdigris, Senora, Allen sand, Cattleman sandstone
				Mineral coal	Morris coal	Morris coal
					Middle skinner sand	Allen, Olympic, Senora sand
				Chelsea Sandstone	Lower Skinner sand	Upper Hart zone (?), Senora Thurman, Fourth deese sand
				Tiawah Limestone	Pink lime	Pink lime, lower Senora lime
				-Weir-Pittsburg coal bed- (Senora base when Stuart & Thurman are absent)		
			STUART	Stuart Shale only present in Arkoma basin	Stuart Shale only present in Arkoma basin	Stuart Shale only present in Arkoma basin
			THURMAN	Thurman Ss. only present in Arkoma basin	Thurman Ss. only present in Arkoma basin	Thurman Ss. only present in Arkoma basin
		KREBS	BOGGY	Taft Sandstone	Red Fork sand	Earlsboro, Burbank, Dora Osborn Peach Orchard, Chicken Farm sand
				Inola Limestone	Inola Limestone	Inola Limestone
				Bluejacket Sandstone	Bartlesville sand	Glenn sand, Burgess sand
			SAVANNA	Doneley Limestone	Upper Brown lime	Brown lime
				Sam Creek Limestone	Middle Brown lime	Brown lime
				Spaniard Limestone	Lower Brown lime	Brown lime
			McALESTER	Tamaha Limestone	Upper Booch sand	
				Upper Warner (Lequire) Ss.		Booch sand
				Lower Warner Sandstone	Lower Booch sand	

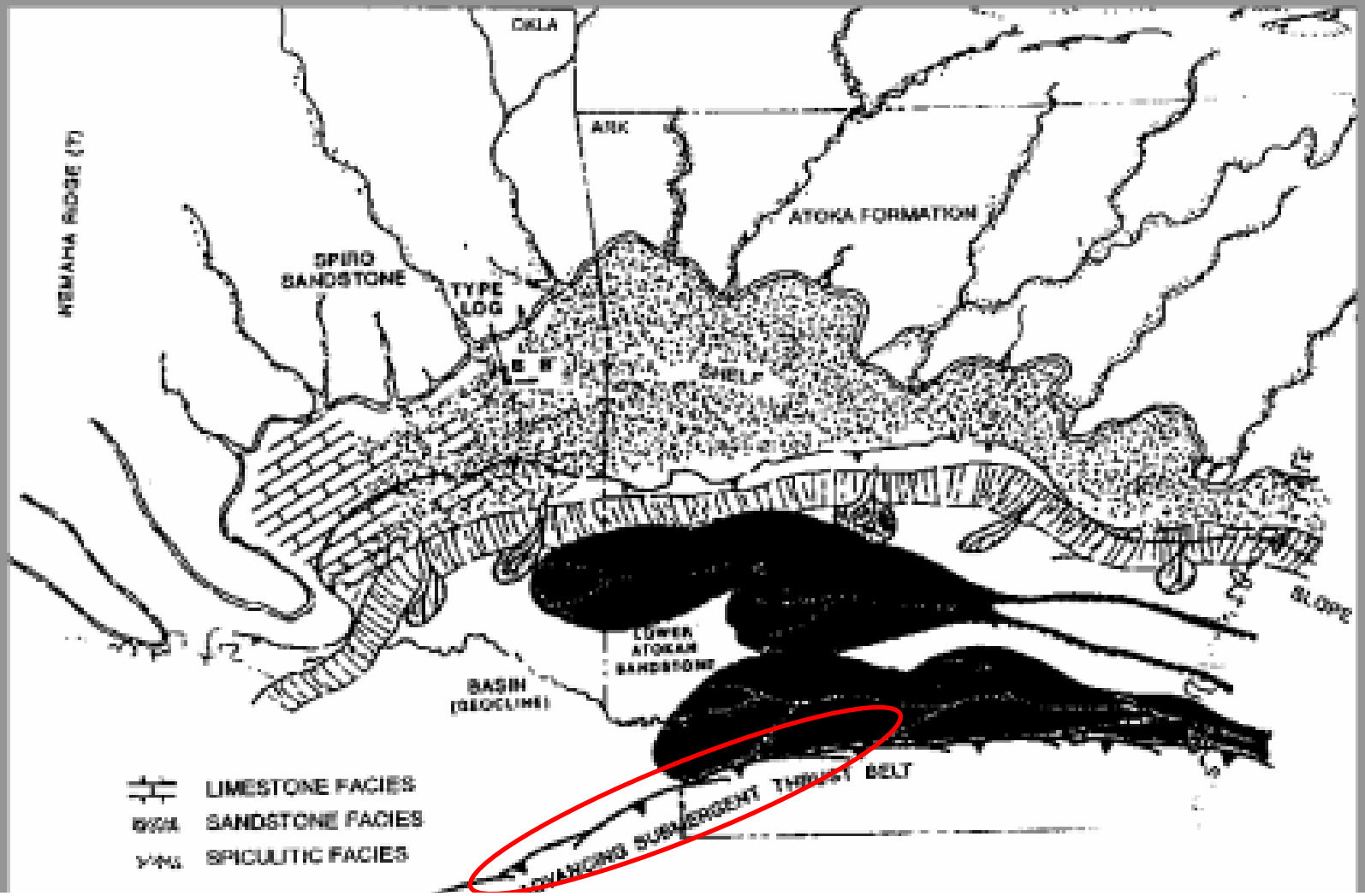
Principal reservoirs in northern part of Arkoma Basin.

Most of these in most places are fluvial-dominated deltaic.

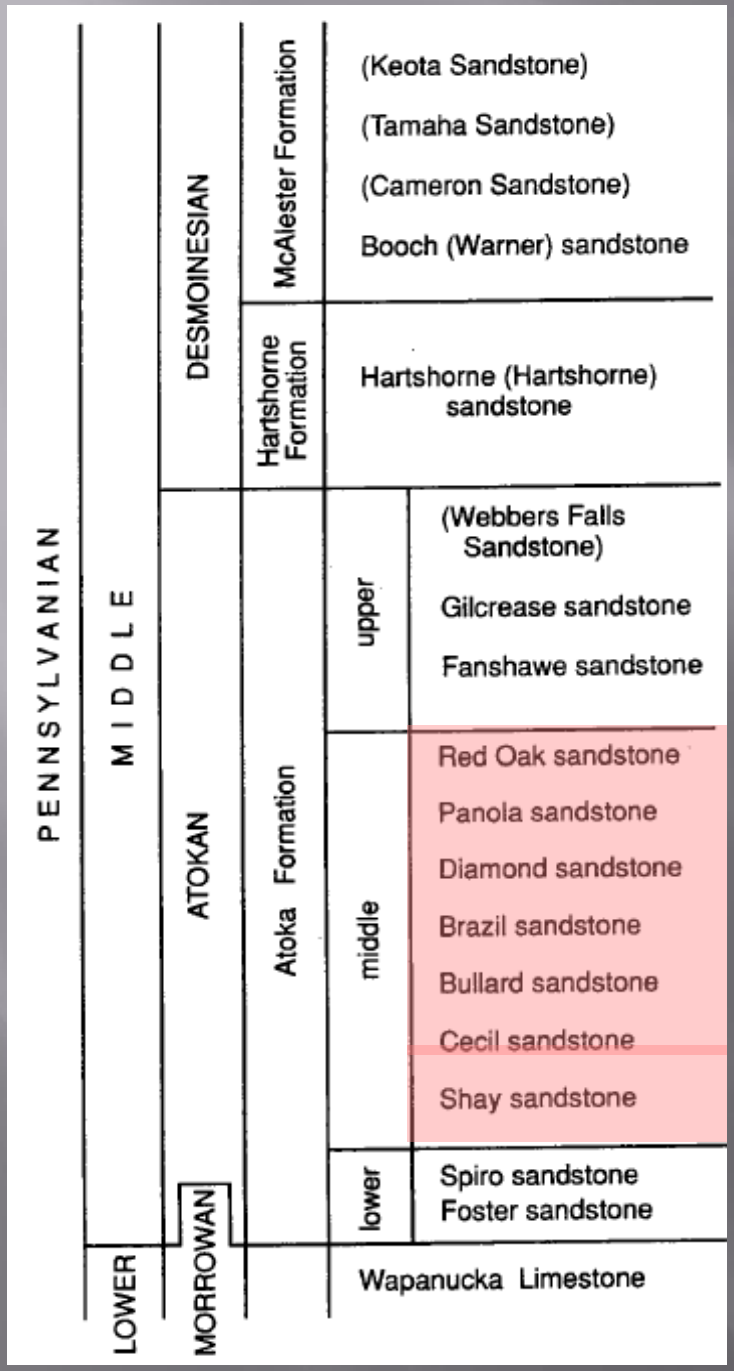


Red Fork, Bartlesville, Booch

Contrasting Atokan paleogeographic setting in the western Arkoma Basin



Advancing thrust front high enough to funnel turbidite fans but not high enough to contribute sediment.



Principal reservoir units in southern part of Arkoma Basin and thrust-faulted part of Ouachita Mountains

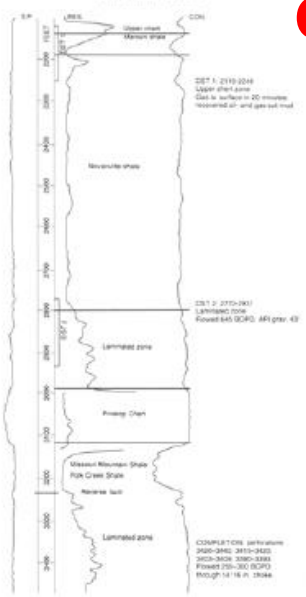
Middle Atokan units are mostly deep-water and are named in Arkoma Basin.

Atoka sandstones in Ouachitas are deep-water and mostly unnamed (Atoka only).

(excludes shallow-water Spiro, Wapanucka)

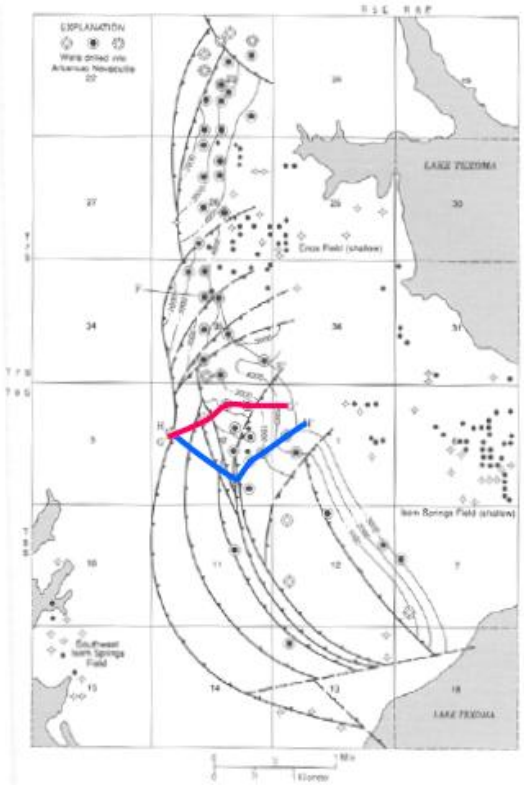
Oil in fractured chert. Don't forget the …

Isom Springs Field



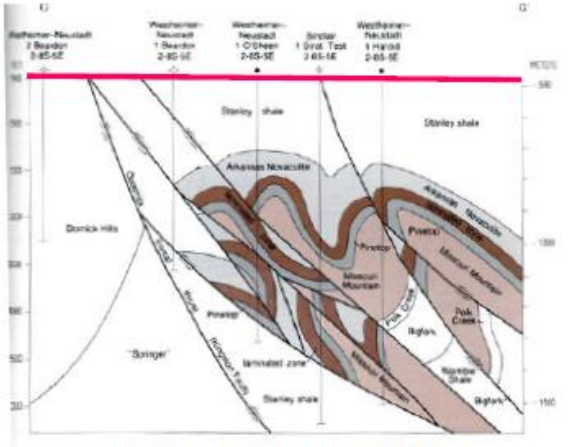
Westheimer-Neustadt #1 Wallace
Isom Springs Field
Marshall Co., OK

USGS

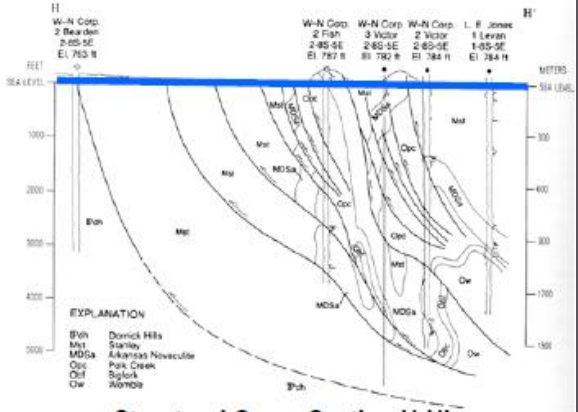


Structure contour map,
Top Arkansas Novaculite,
Isom Springs Field
Marshall Co., OK

(illustrations modified from Huffman and others, 1987)



Structural Cross Section G-G',
Isom Springs – Enos Fields
Marshall Co., OK



Structural Cross Section H-H',
Isom Springs Field,
Marshall Co., OK

MORRISON, LAWRENCE S., Lamima Corp., Ardmore, OK

Oil Production from Fractured Cherts of Woodford and Arkansas Novaculite Formations, Oklahoma

The chert section of the Woodford Formation has been known to be productive of oil and gas for at least 30 years. However, little was known about the chert as a reservoir until 1969 when Jones and Pellow Oil Co. and Westheimer-Neustadt Corp. jointly developed the Northeast Alden pool extension in T7N, R13W, Caddo County, Oklahoma. Cores, thin sections, X-ray analyses, and combustion tube studies indicate that the Woodford Chert is a prime source bed for hydrocarbons, and when fractured is an excellent reservoir.

In February 1977, Westheimer-Neustadt Corp. drilled the No. 1 Wallace in Sec. 2, T8S, R5E, to test the Arkansas Novaculite, which is similar to the Woodford Chert, and completed the well for a potential flow of more than 1,000 bbl of oil per day. The significance of the discovery has not been fully realized by industry in that it may have opened a new petroleum province in the Ouachita facies that extends from southeastern Oklahoma in a broad arch for over 600 mi (966 km) to the Marathon Mountains near the Mexican border.

A reminder ……..
from 1980 …….

of the similarities of the Woodford Chert and the Arkansas Novaculite.

…"a new petroleum province in the Ouachita facies …"

Remember this slide

THRUST PLATES ARE GOOD PERIOD 1980 - ~1990

1982. Publication of Alberta thrust-front geometry paper by Jones; recognition of triangle zone

1982. South Blanco Gas Field discovered by Hamilton Bros. 1-30 Indian Nations from Wapanucka and repeated Wapanucka

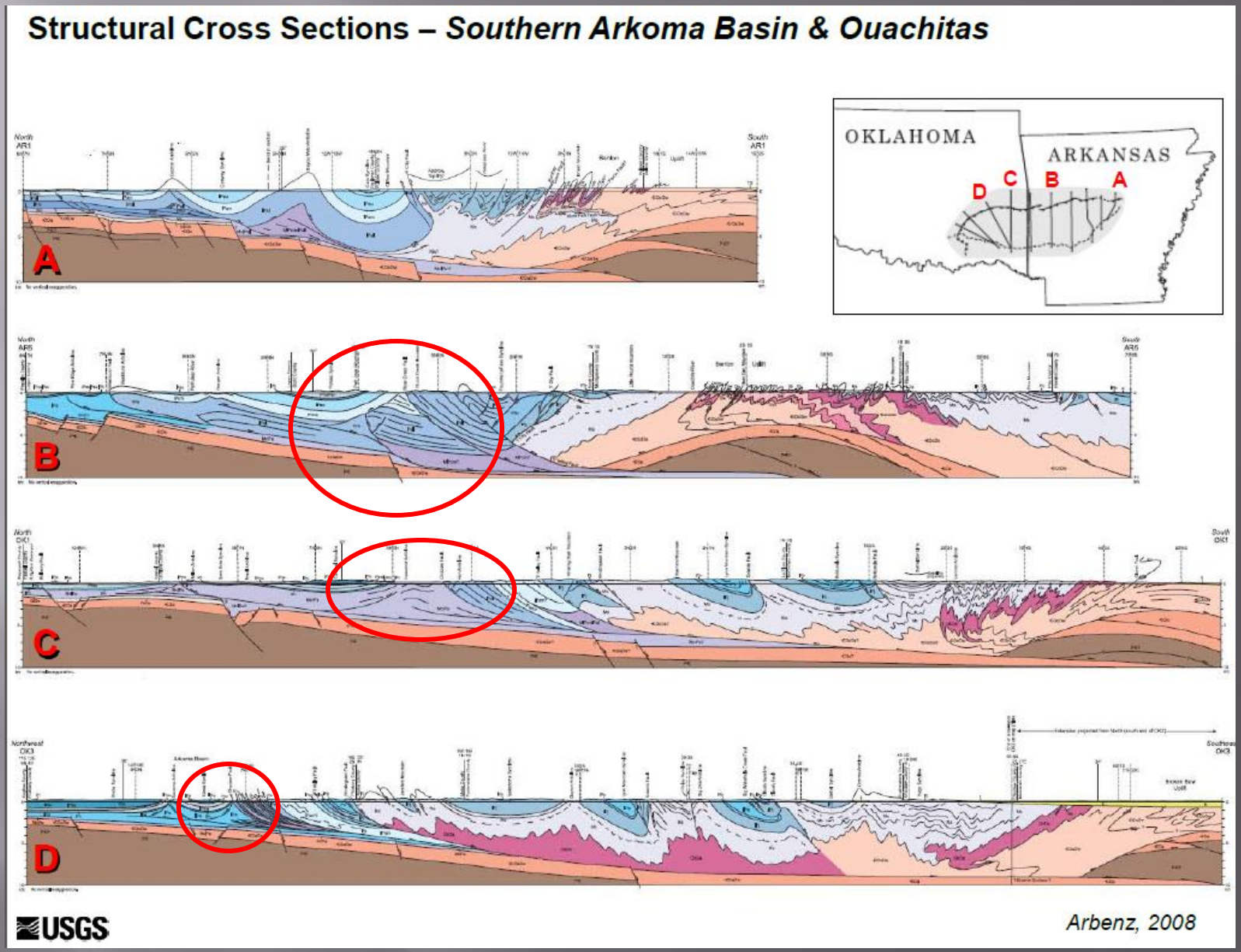
1985 – 1988. Infill drilling of Red Oak Field by Amoco.

1987. Wilburton "Deep" discovered by Arco 2 Yourman in Arbuckle horst block

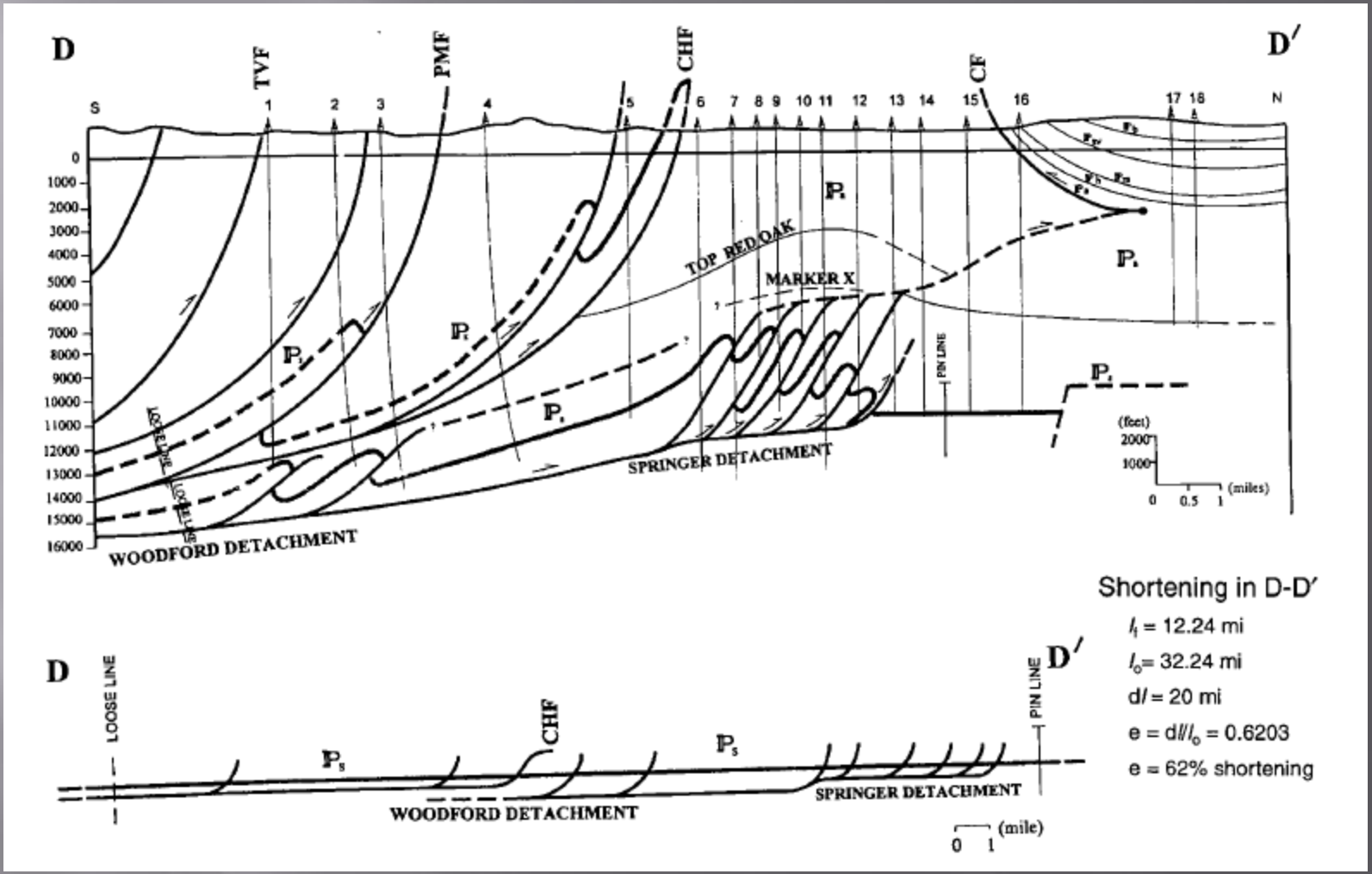
1987. SOPC 1-22 Weyerhaeuser well drilled on crest of Broken Bow Uplift. TD ~19,000 ft

1988. SW Haileyville Gas Field discovered by Amoco 2 Zipperer from overturned Spiro/Wapanucka

1988. Publication of Arkoma Basin depositional history by Sutherland – changing source terranes

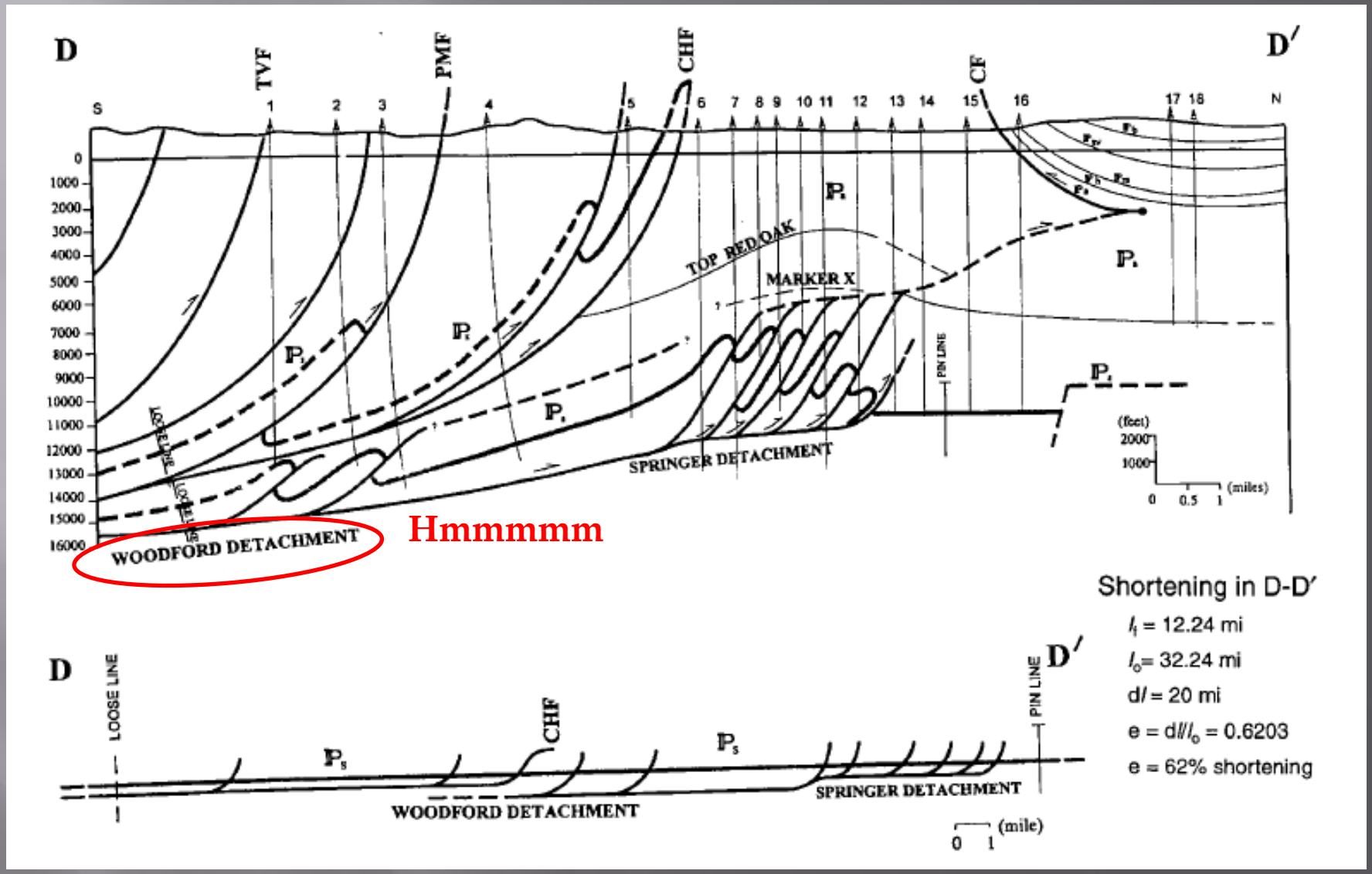


Triangle zone geometry explains Arkoma Basin – Ouachita fold-and-thrust belt transition.



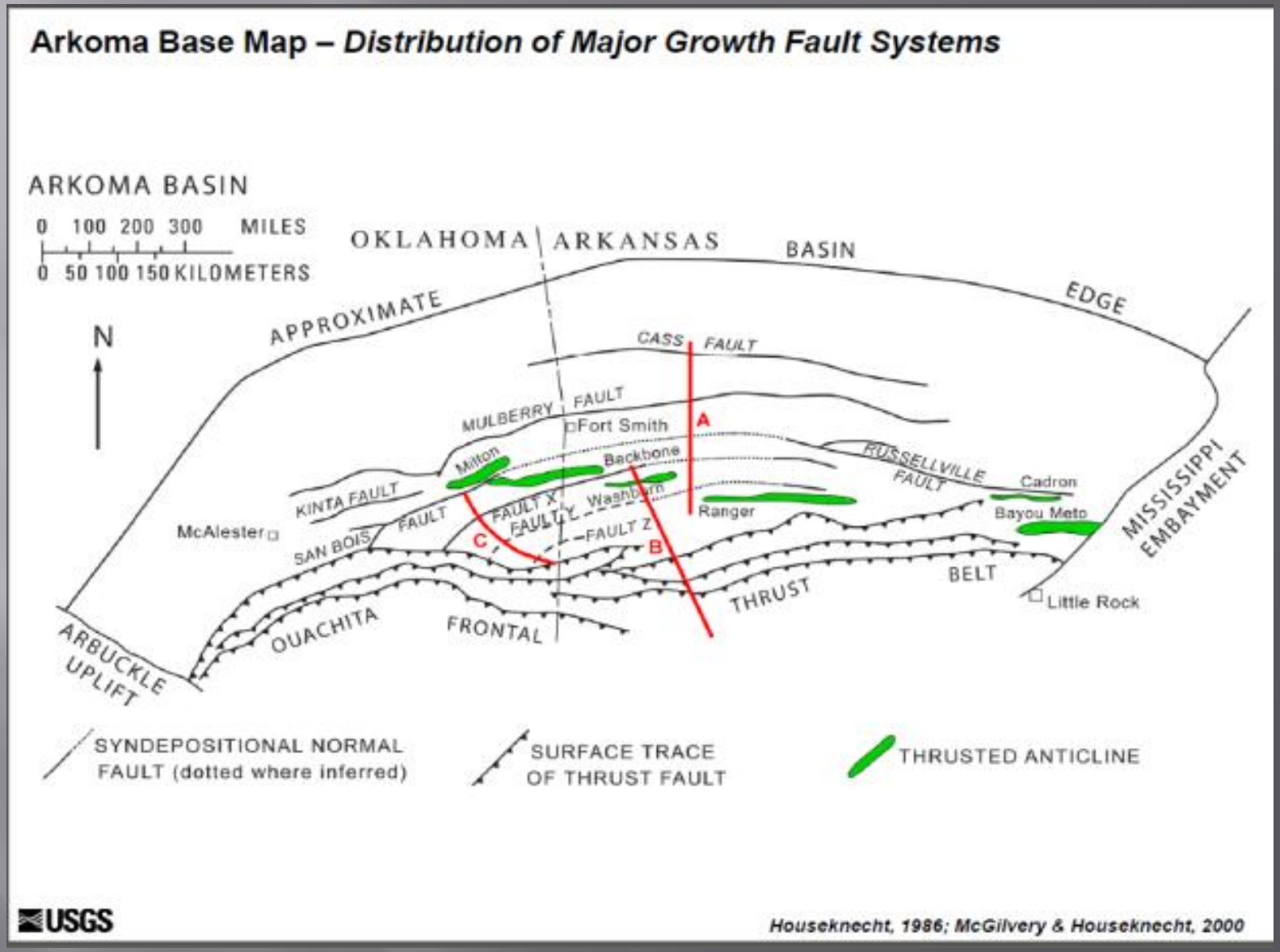
Triangle zone typically floored by duplex structure with floor and roof detachments. Explains repeated, overturned reservoirs in Arkoma – Ouachita transition zone.

Remember this slide



How far south does the Woodford extend? Certainly a source rock; possibly reservoir?

Woodford Shale near Bengal in Ouachita Mountains - What is it doing there and where did it come from and is there more?



Removing movement on thrusts ➡ better understanding of the Atokan growth faults that formed Arkoma Basin

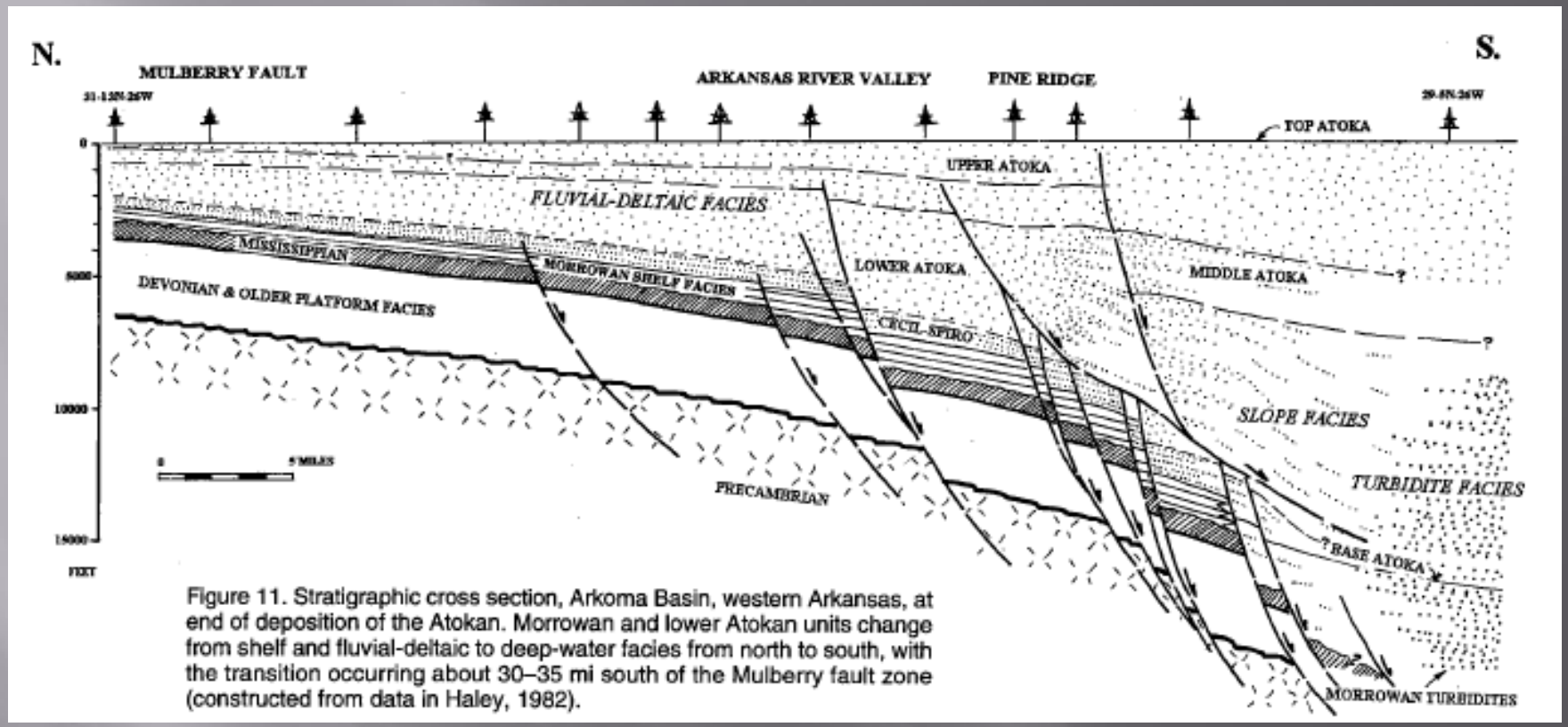
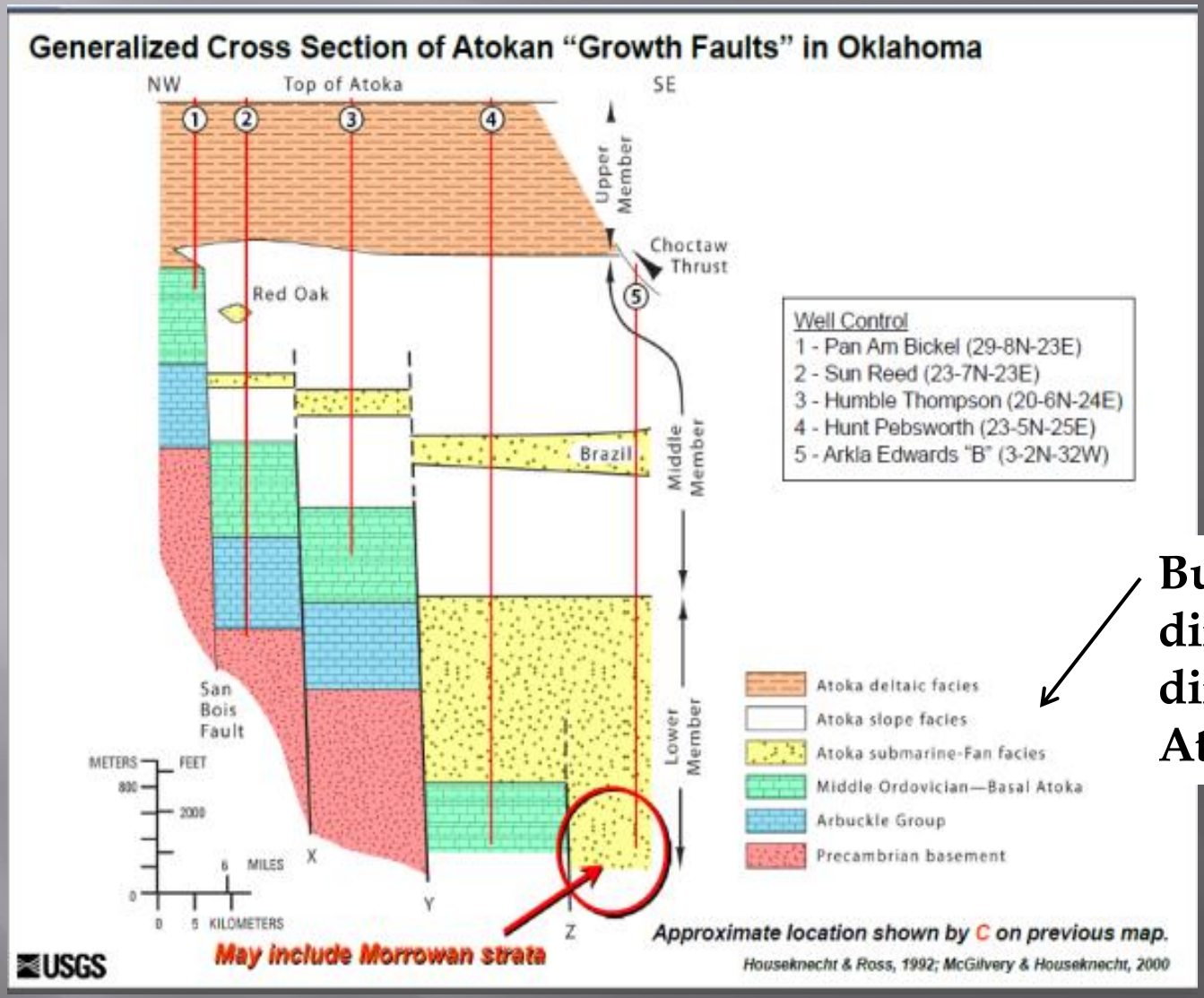


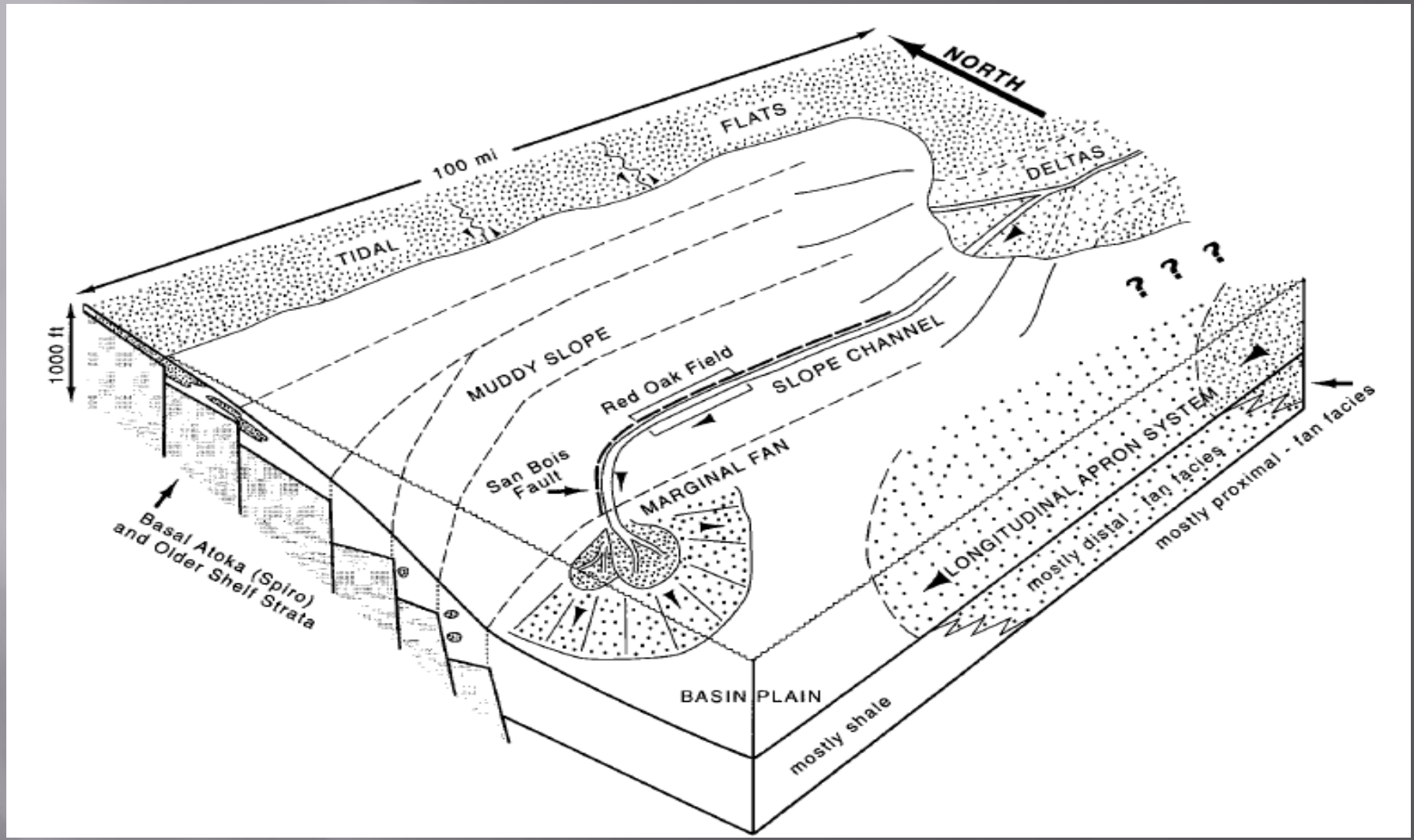
Figure 11. Stratigraphic cross section, Arkoma Basin, western Arkansas, at end of deposition of the Atokan. Morrowan and lower Atokan units change from shelf and fluvial-deltaic to deep-water facies from north to south, with the transition occurring about 30–35 mi south of the Mulberry fault zone (constructed from data in Haley, 1982).

- Middle Atoka thickens across S-side-down growth faults
- Middle Atoka dominantly fluvial-deltaic to N; deeper water (turbidites) to S
- Recognition of different deep-water facies in middle Atoka reservoirs

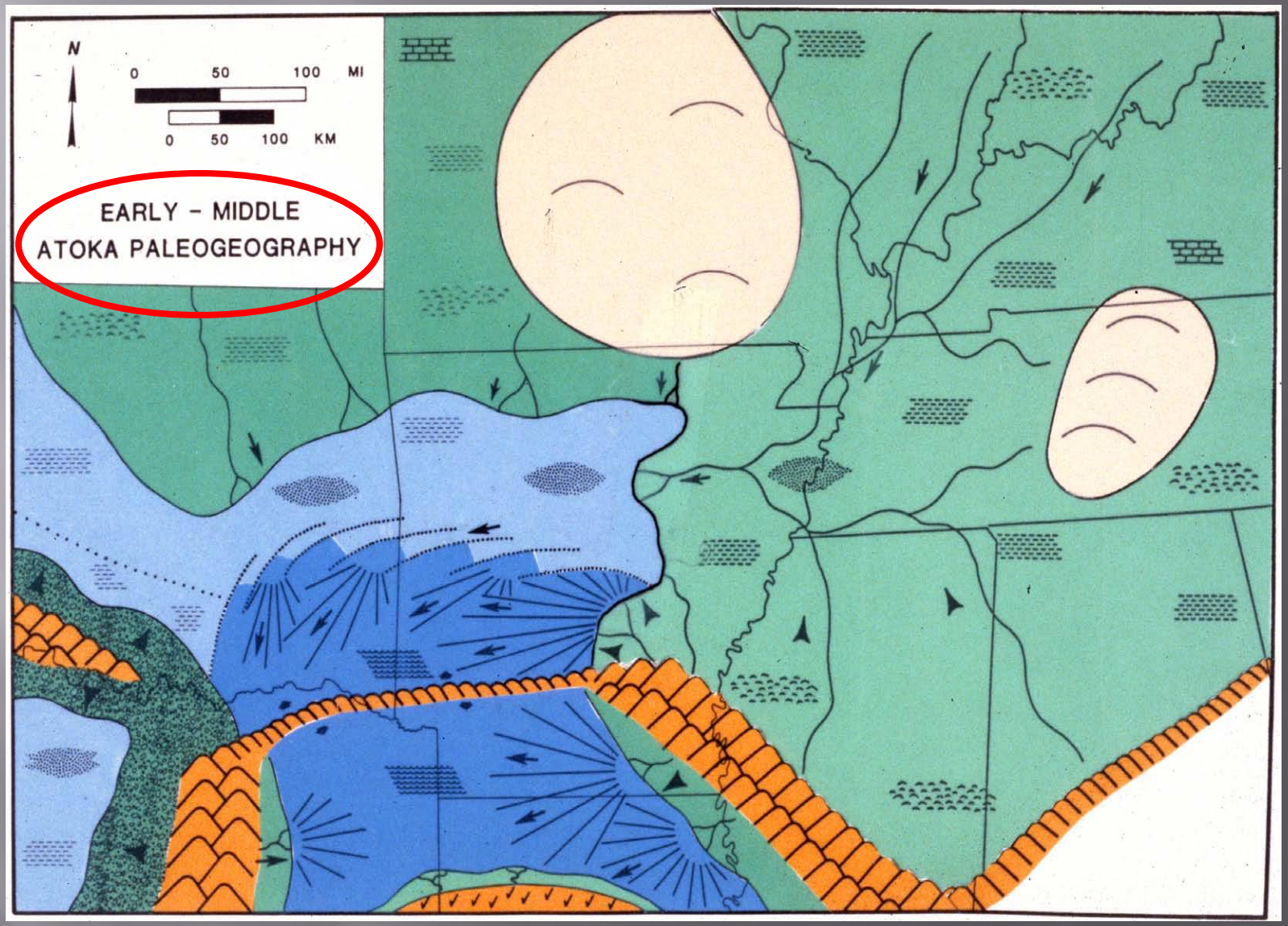


But does recognize different facies in different parts of the Atoka

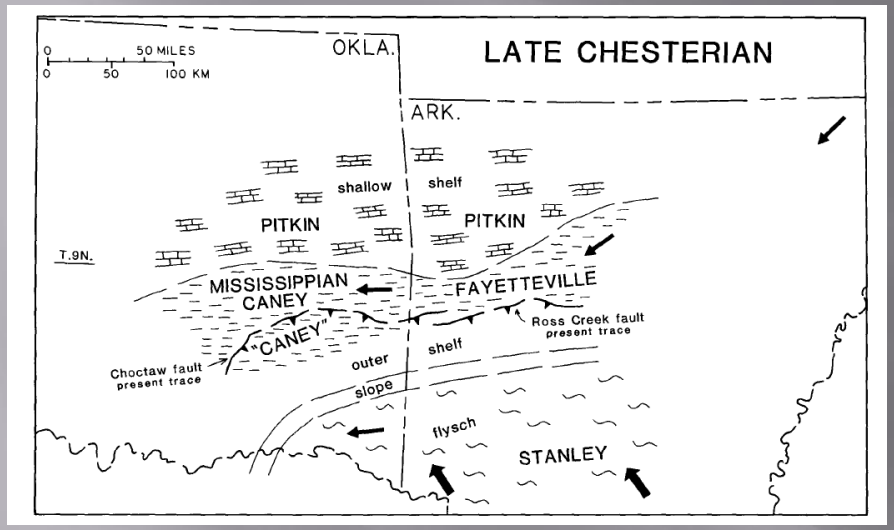
Tremendously over-simplified sketch of facies relations across growth faults.

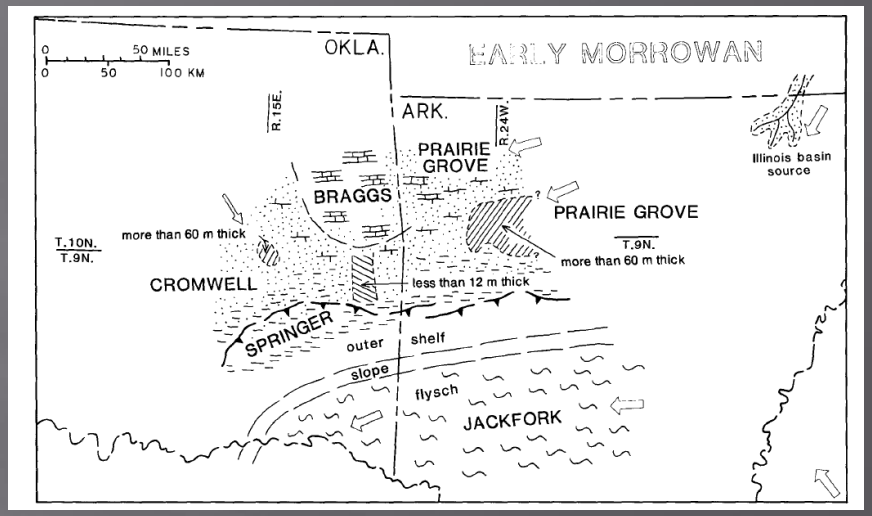


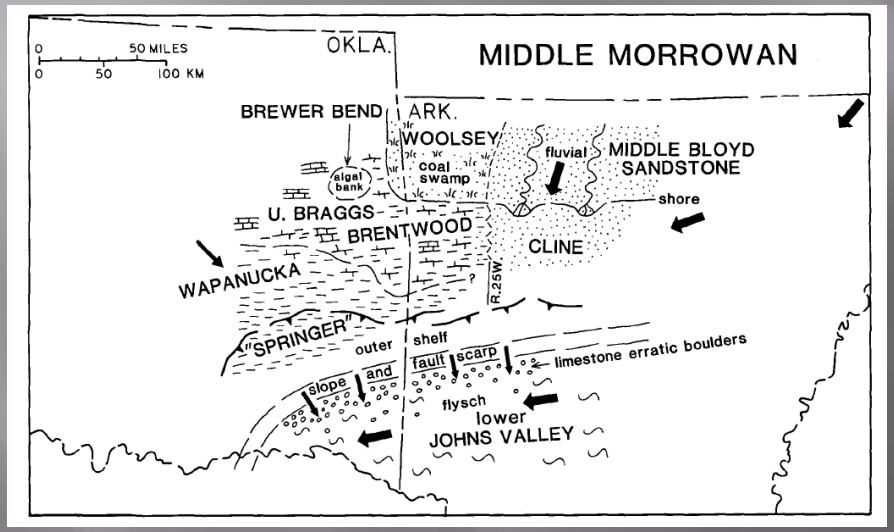
One of the facies models for one of the Atoka reservoir sandstones – the Red Oak Ss. Question: Does this work for any of the other Atoka sandstone reservoirs?

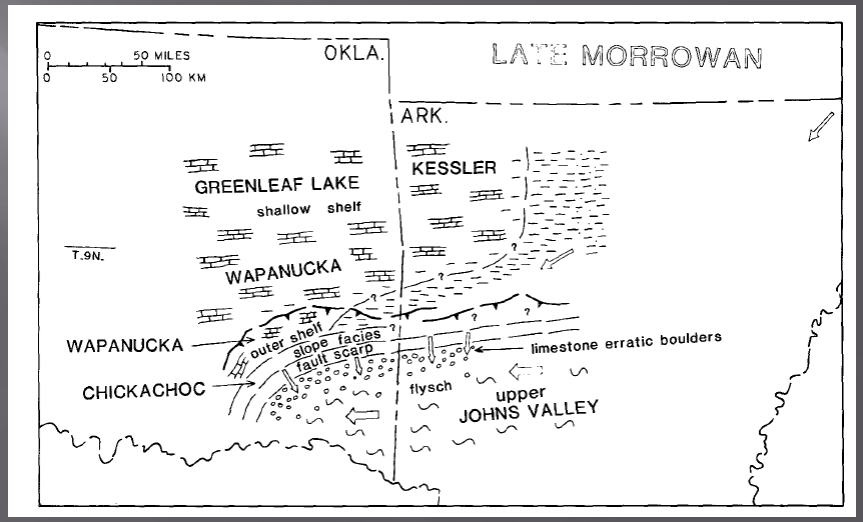


Details of distribution and facies ⟹ regional picture of sedimentary history of entire basin

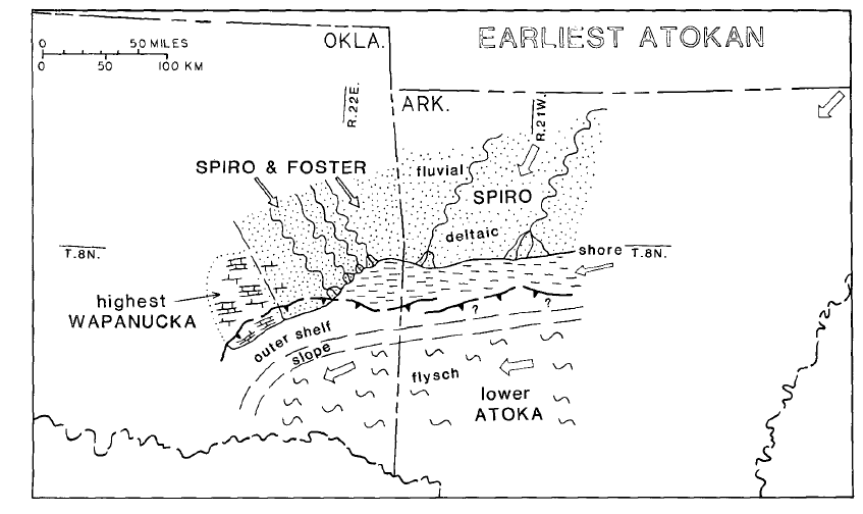


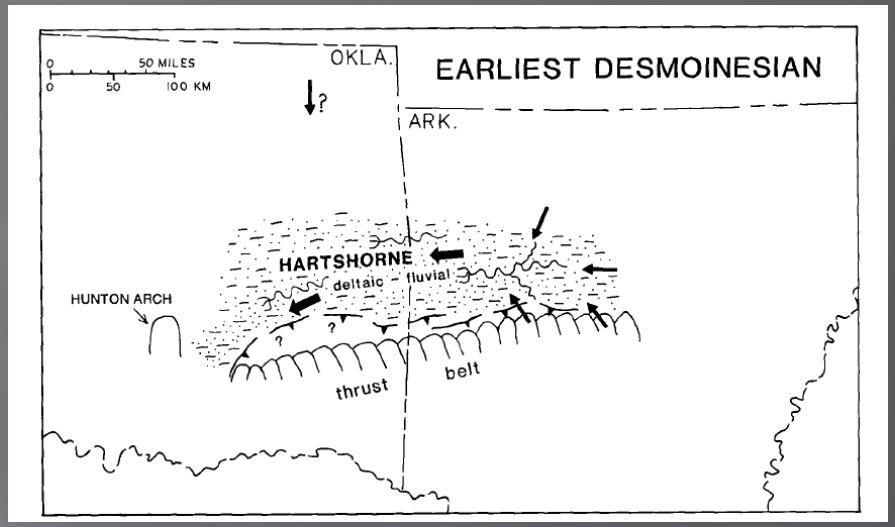


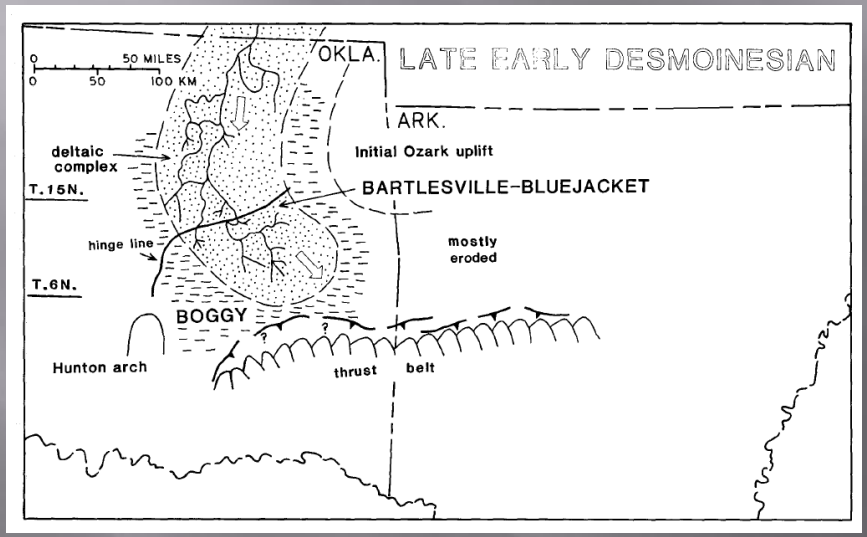


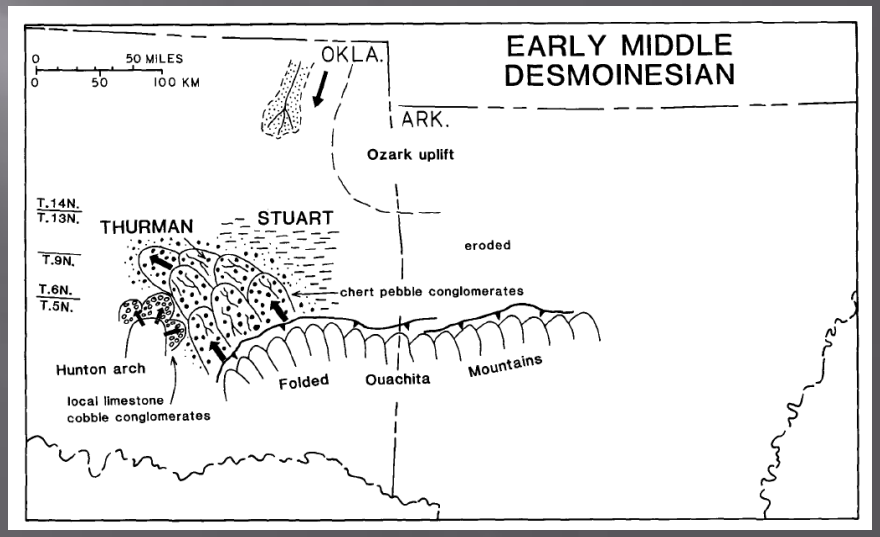


Shelf sedimentation, development of basin, advancing submarine tectonic wedge, turbidites and deep-water facies

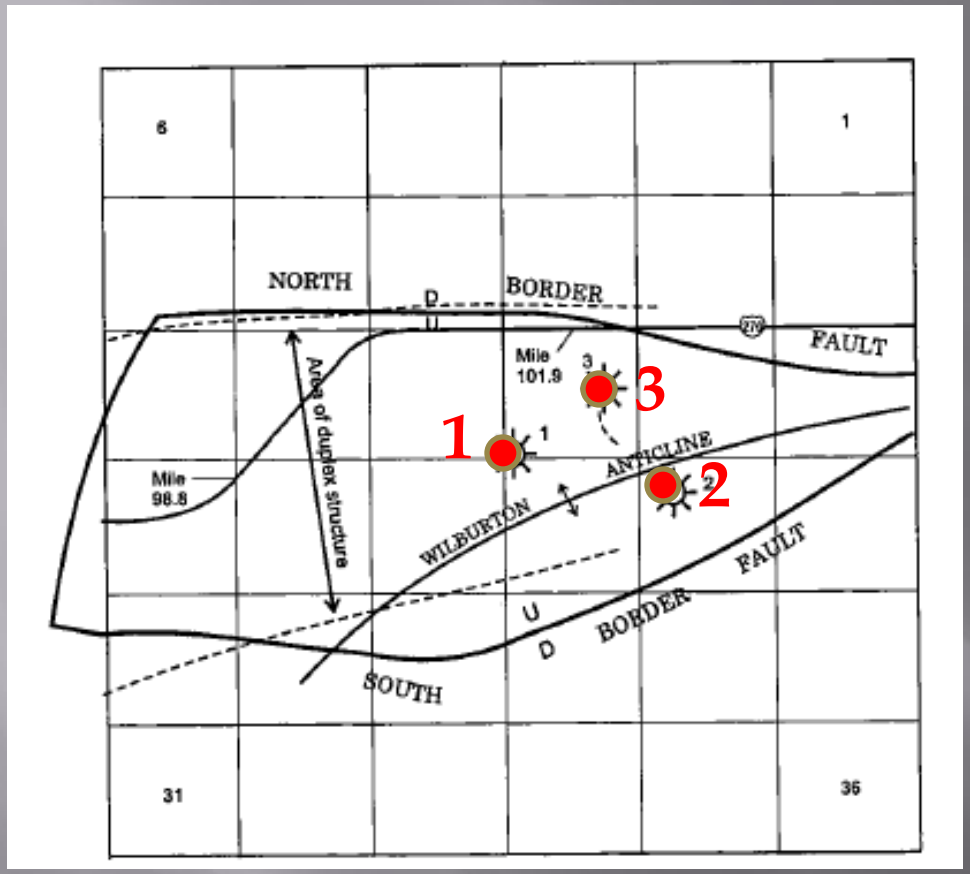








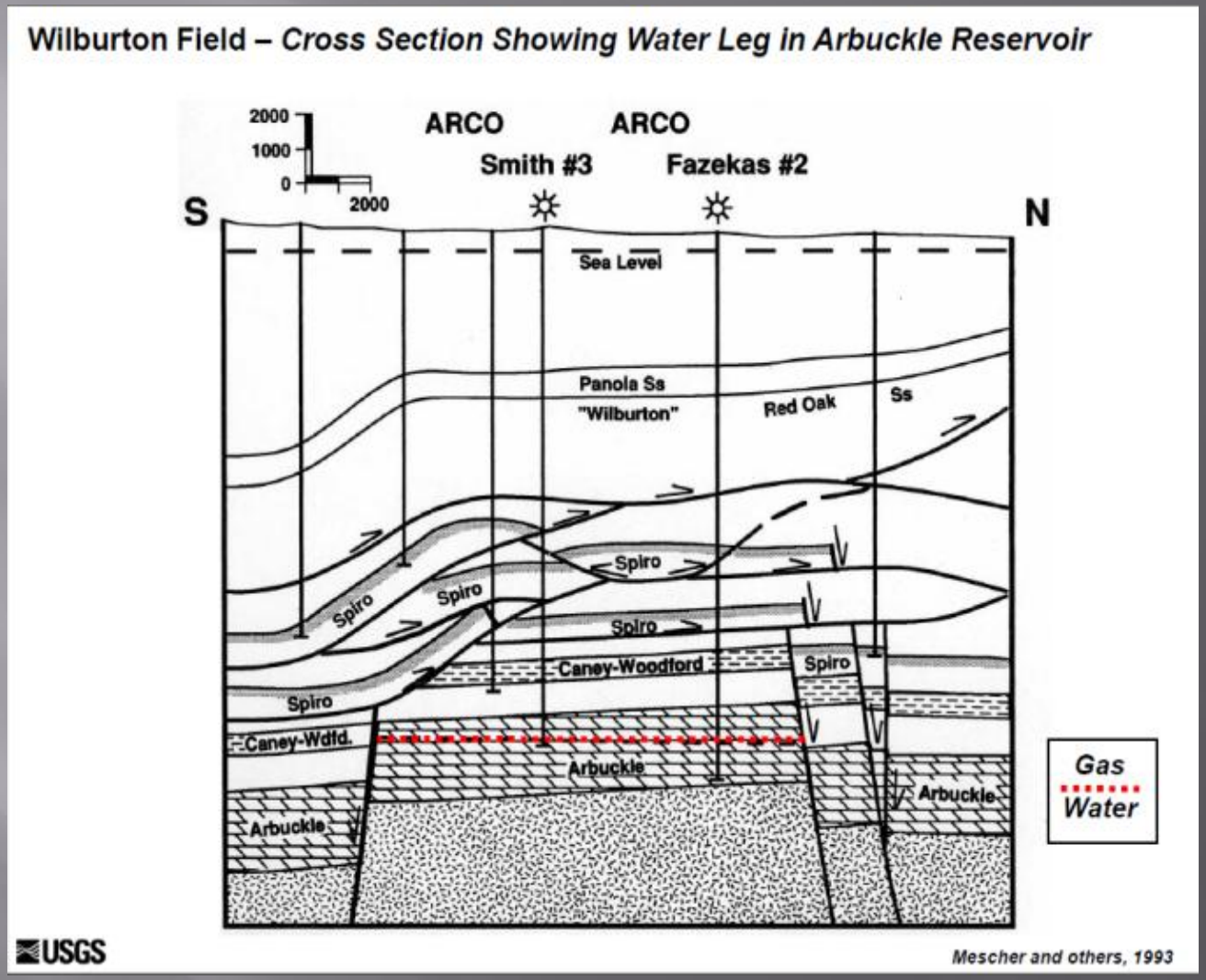
Advancing thrust sheets, filling of basin from east then north, uplift and erosion of Ouachitas



Wilburton "Deep"

The impact of sub-thrust structure on overlying structures. Wilburton "original", Wilburton "rediscovery", and Wilburton "Deep" discovery wells all located within a mile of each other.

1. Limestone No. 1 McCurray, 1929, in Hartshorne on Wilburton Anticline
2. Ambassador No. 1 Williams, 1960, in Spiro in thrust sheet
3. Arco No. 2 Yourman, 1987, in Arbuckle in horst block



Arbuckle horst block (Arbuckle juxtaposed against Woodford); higher thrust-faulted Spiro; higher still Atoka reservoirs.

HORIZONTAL WELLS ARE GOOD PERIOD ~1990 - PRESENT

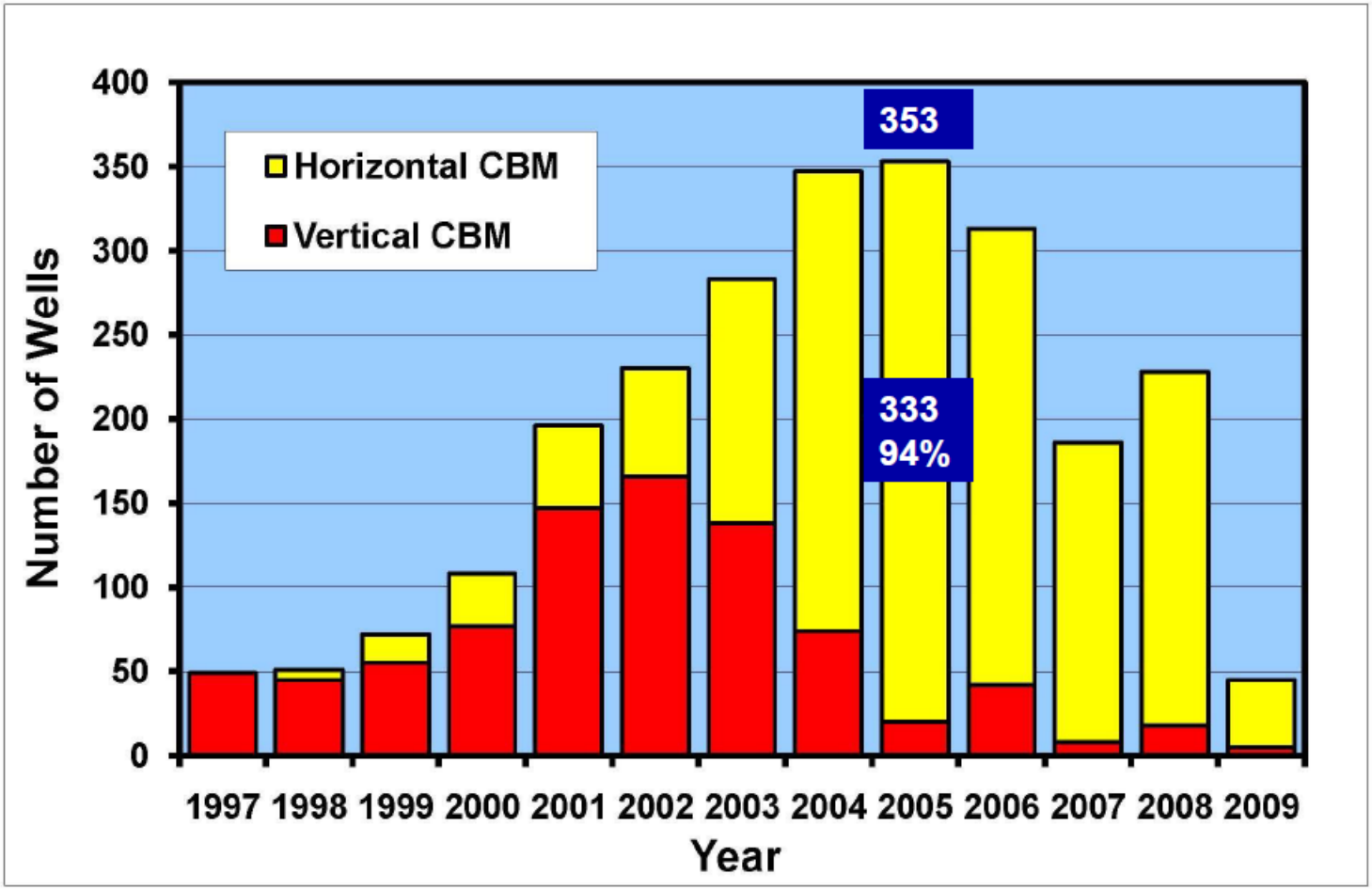
1988. First production of CBM. Hartshorne coal, Kinta Field

1996. Potato Hills Gas Field "rediscovered" by GHK No. 1-33 Ratcliff in sub- (mid-level) thrust Jackfork Ss.

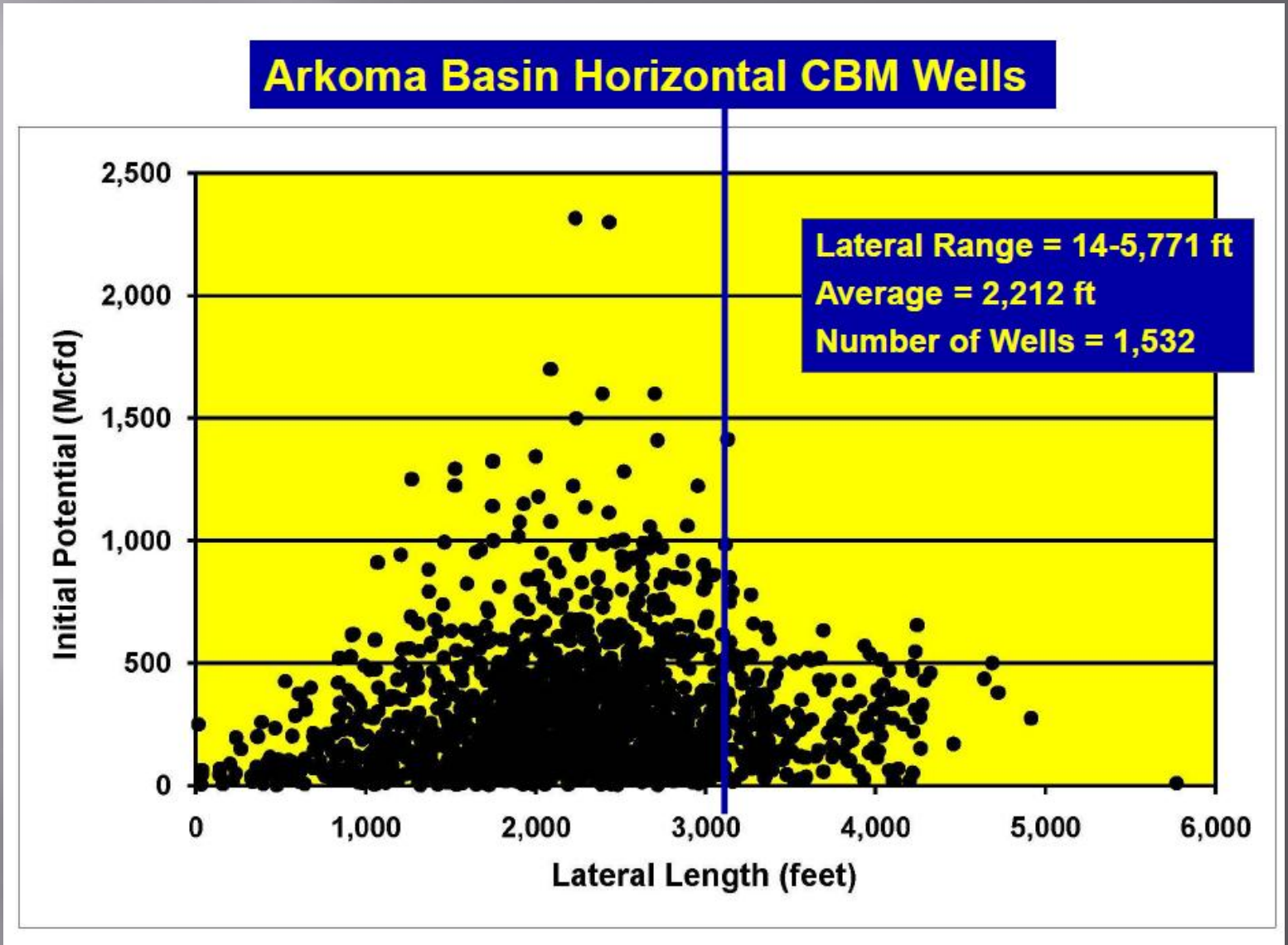
2004. First shale gas development from Woodford Sh in Pittsburg, Hughes Counties

2012. This Meeting

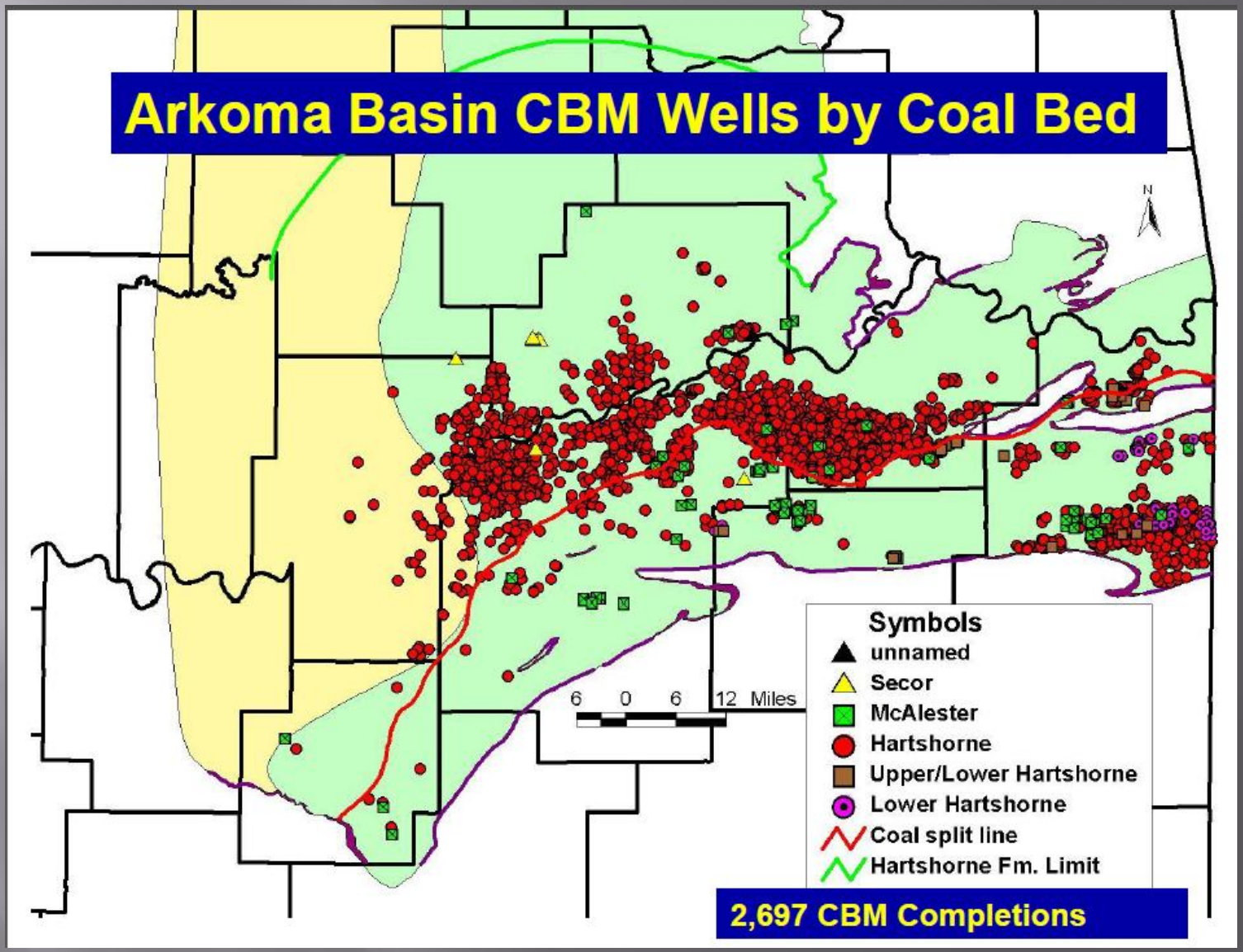
Arkoma Basin



Coalbed methane drilling in Arkoma Basin. Peak activity 2004-2006, immediately before gas shale boom.

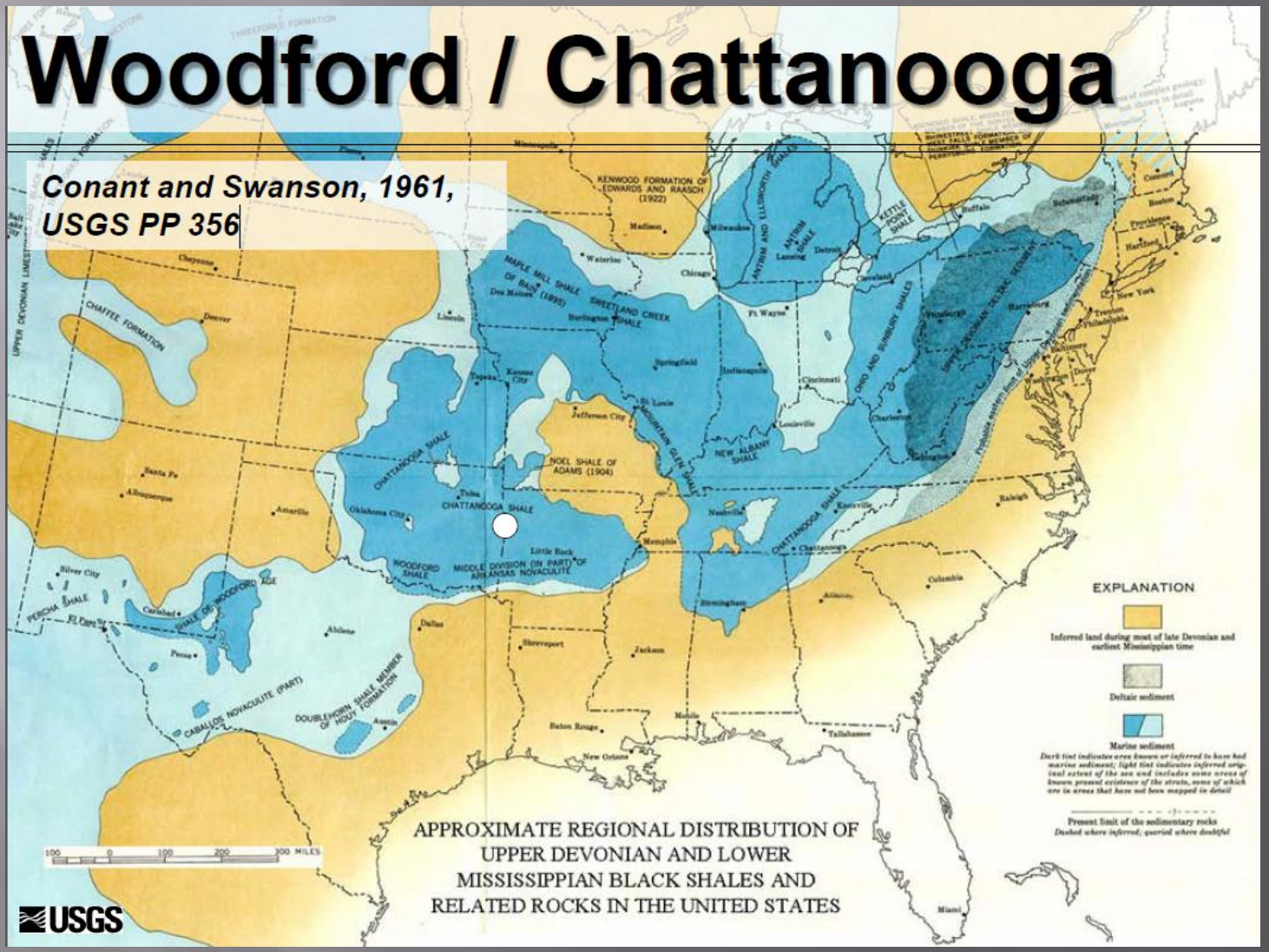


Continued effort to determine what makes a good CBM well. Here, relation of lateral length to IP (2010 report).



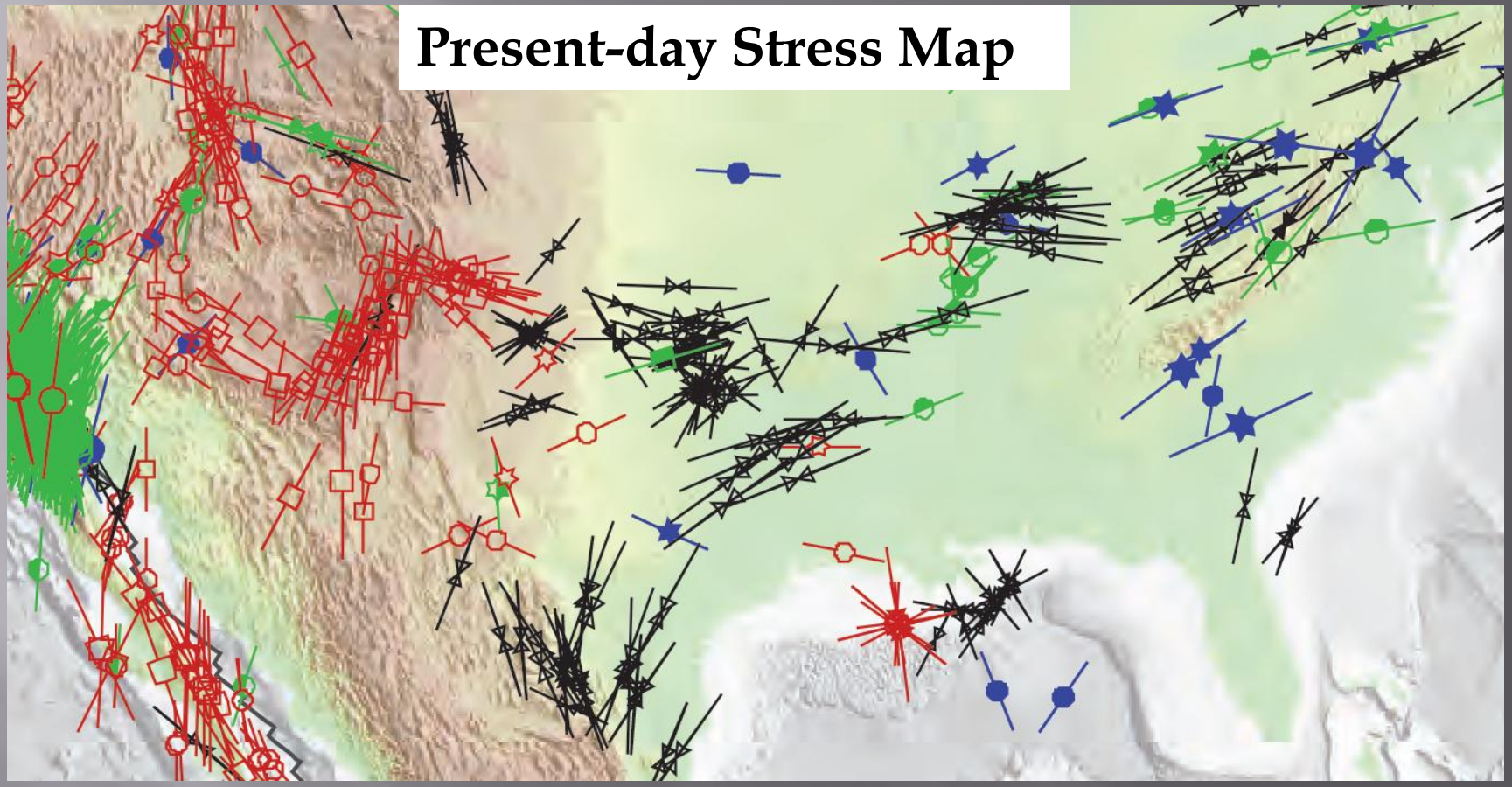
Most Arkoma Basin CBM wells are in Hartshorne, and most are north of coal split line where coal is thickest.

Woodford / Chattanooga



Woodford Shale gas play - part of much larger shale gas play. Largely result of better horizontal drilling and multi-stage hydraulic fracturing techniques.

Present-day Stress Map



In OK, max compressive stress ~N75E-S75W, so best lateral direction N15W-S15E. But most are N-S due to land. (Close enough for gov't work)

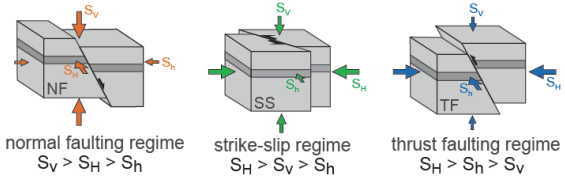
The stress maps display the maximum horizontal compressional stress S_H

Method
- focal mechanism
- breakouts
- drill. induced frac.
- overcoring
- hydro. fractures
- geol. indicators

Data depth range
0-40 km

Quality
- A — S_H is within ± 15°
- B — S_H is within ± 20°
- C — S_H is within ± 25°

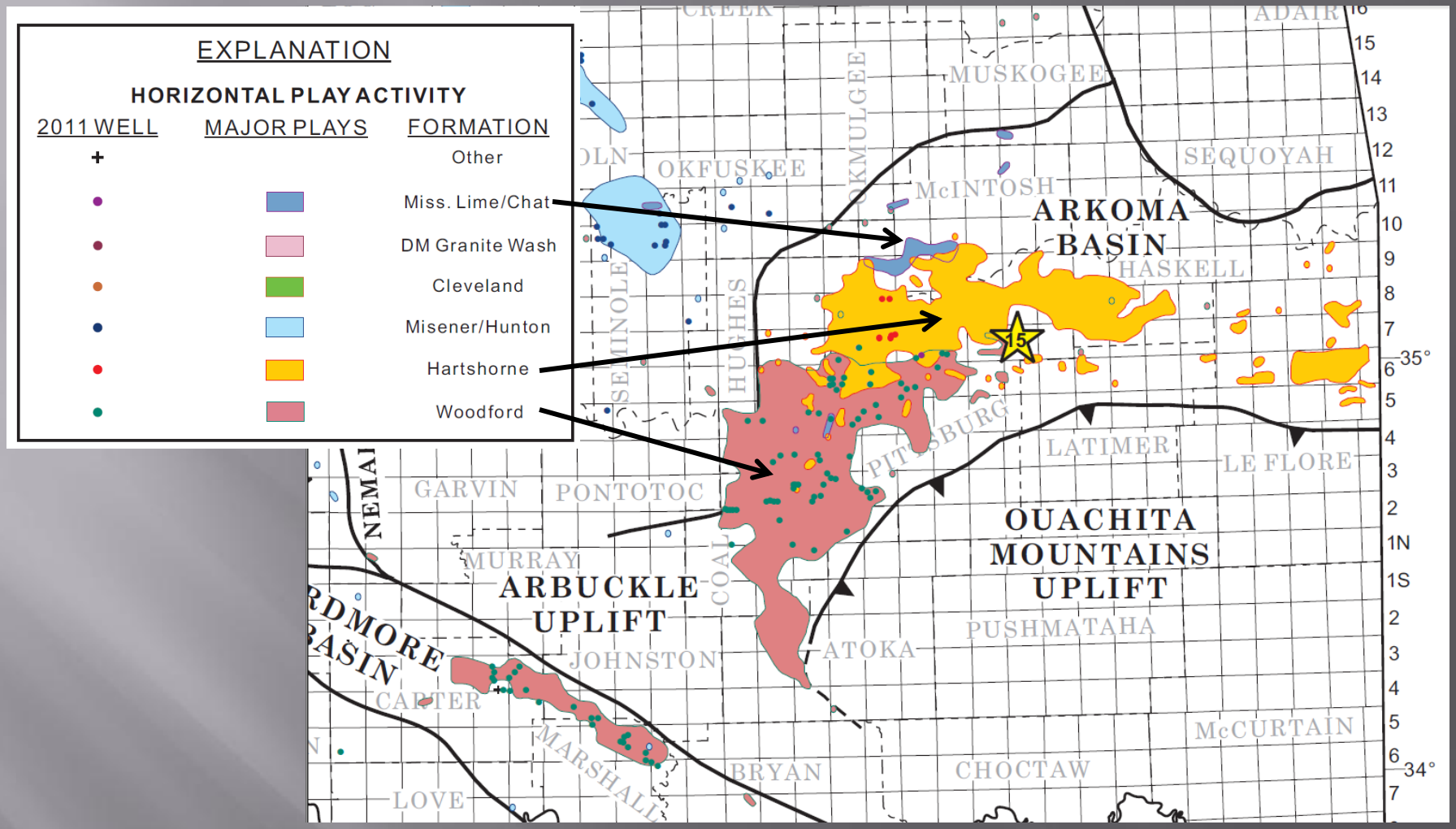
Stress Regime
- Normal faulting
- Strike-slip faulting
- Thrust faulting
- Unknown regime



normal faulting regime
$S_V > S_H > S_h$

strike-slip regime
$S_H > S_V > S_h$

thrust faulting regime
$S_H > S_h > S_V$



The present. 2011 OK Drilling Highlights (Boyd, Mar-Apr 2012 Shale Shaker). Hartshorne CBM basically dead; minor Miss. Chat; most activity is Woodford

THE FUTURE

of Arkoma Basin and Ouachita Mountains Petroleum Exploration

To ignore the two killers:

- **Awful gas prices (currently)**
- **No infrastructure (how long?)**

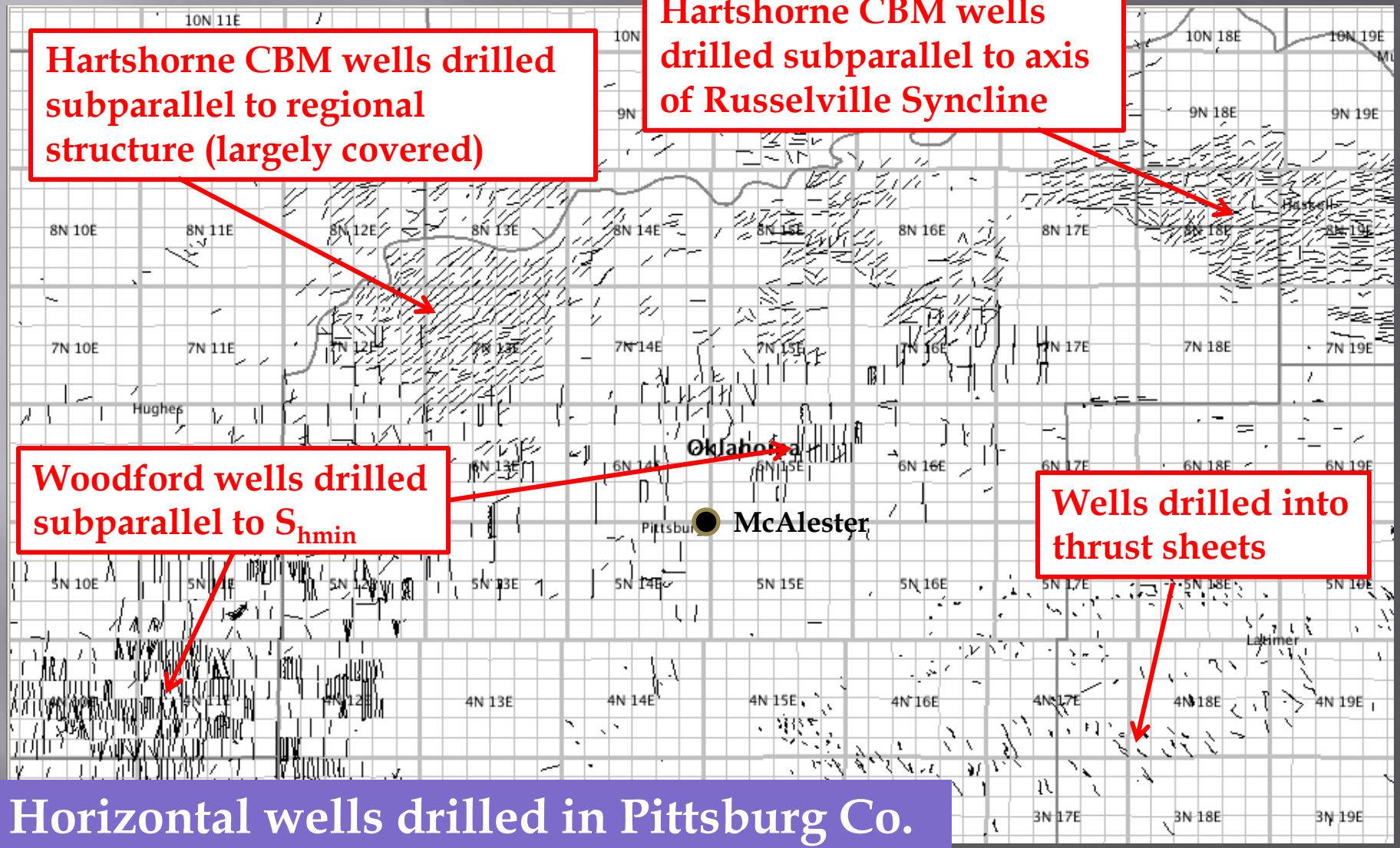
Plays, concepts, and unknowns:

Arkoma Basin:

- more Woodford Shale development* (okay okay)
- middle Atoka Fm. sandstone facies
- transition-zone structure to east
- organic shales in middle Atoka Fm.*

Ouachita Mountains:

- Woodford Shale – how far to S beneath thrusts?
- early – middle Paleozoic shelf edge
- organic shales in Atoka Fm.*
- structure/fractured Atoka Fm. sandstones in frontal belt*
- anticlines
- Jackfork – another Potato Hills?
- Stanley – hints from old fields
- Arkansas Novaculite – remember Isom Springs
- Bigfork Chert*



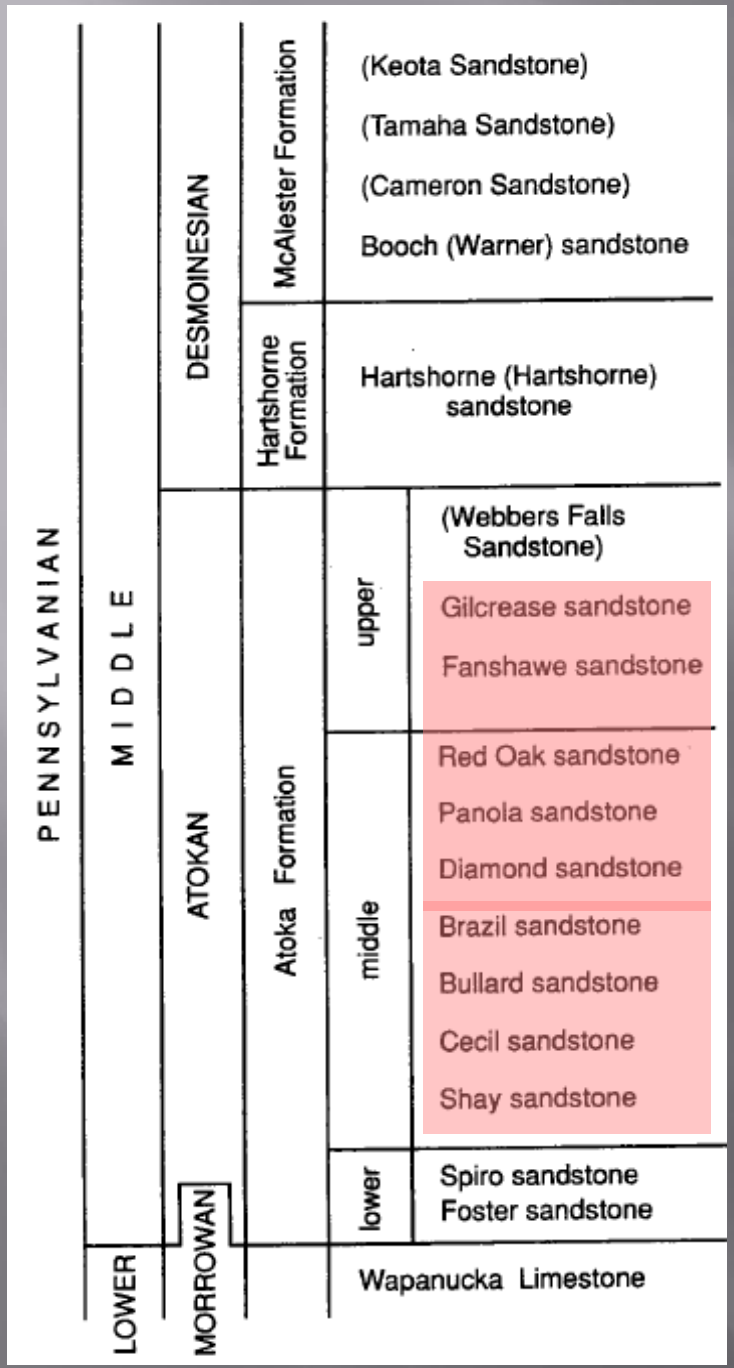
Horizontal wells drilled in Pittsburg Co.

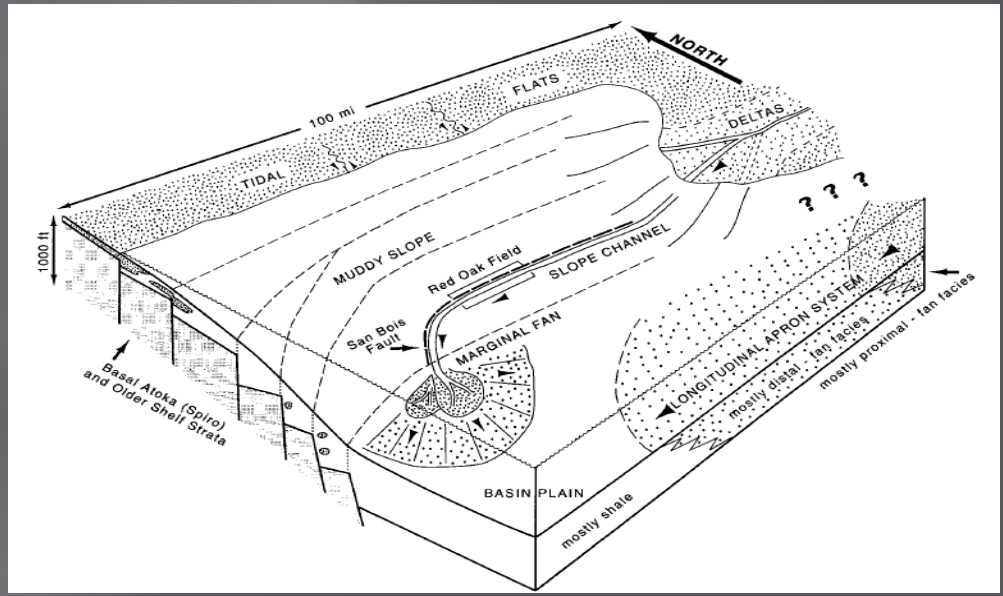
CBM – subparallel to Penn^n regional structure; thrust sheets – perpendicular to Penn^n regional structure; gas shale – subparallel to present-day minimum horiz. stress direction

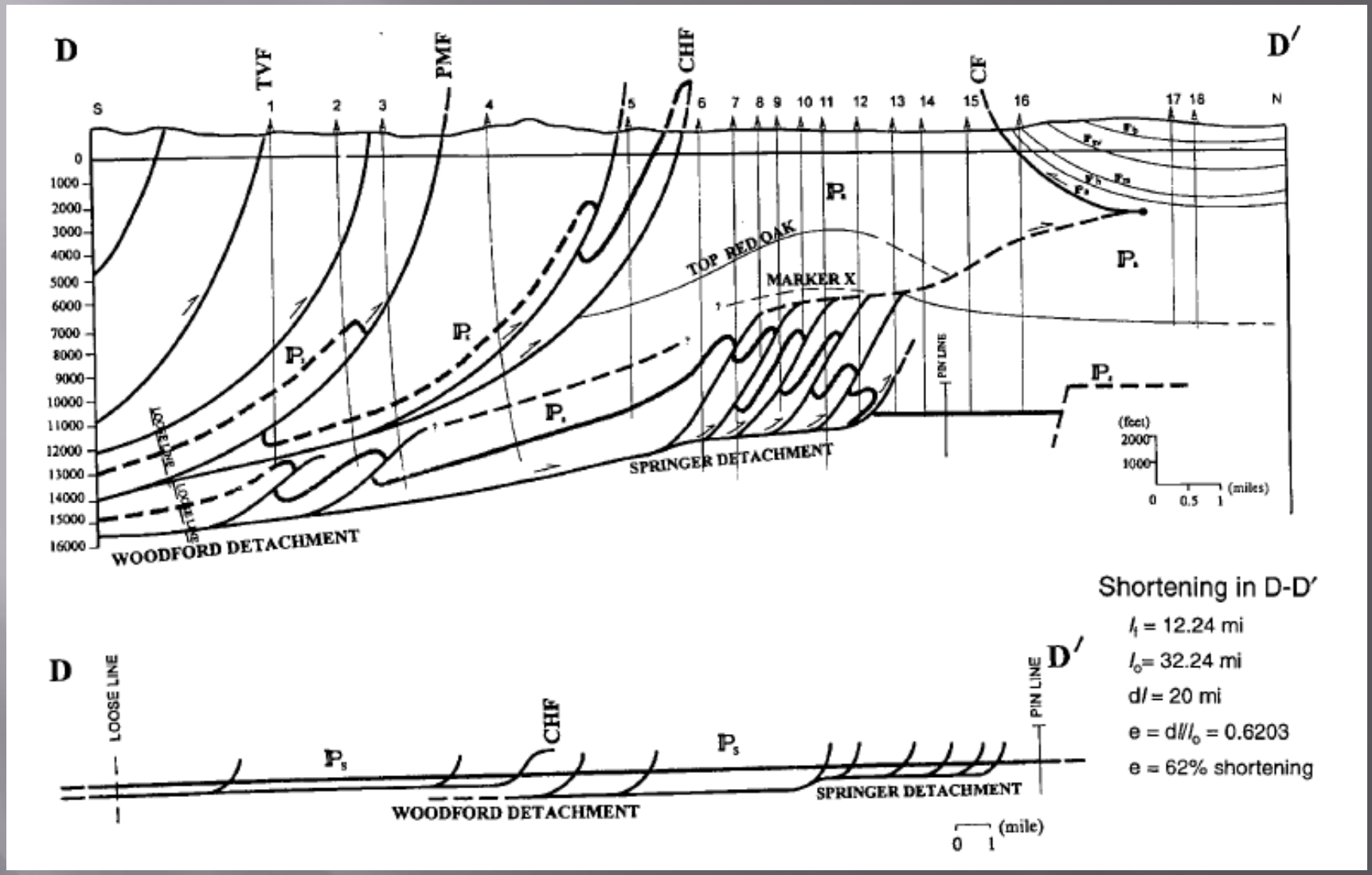
Principal reservoir units in southern part of Arkoma Basin

"Middle Atokan units are mostly deep-water."

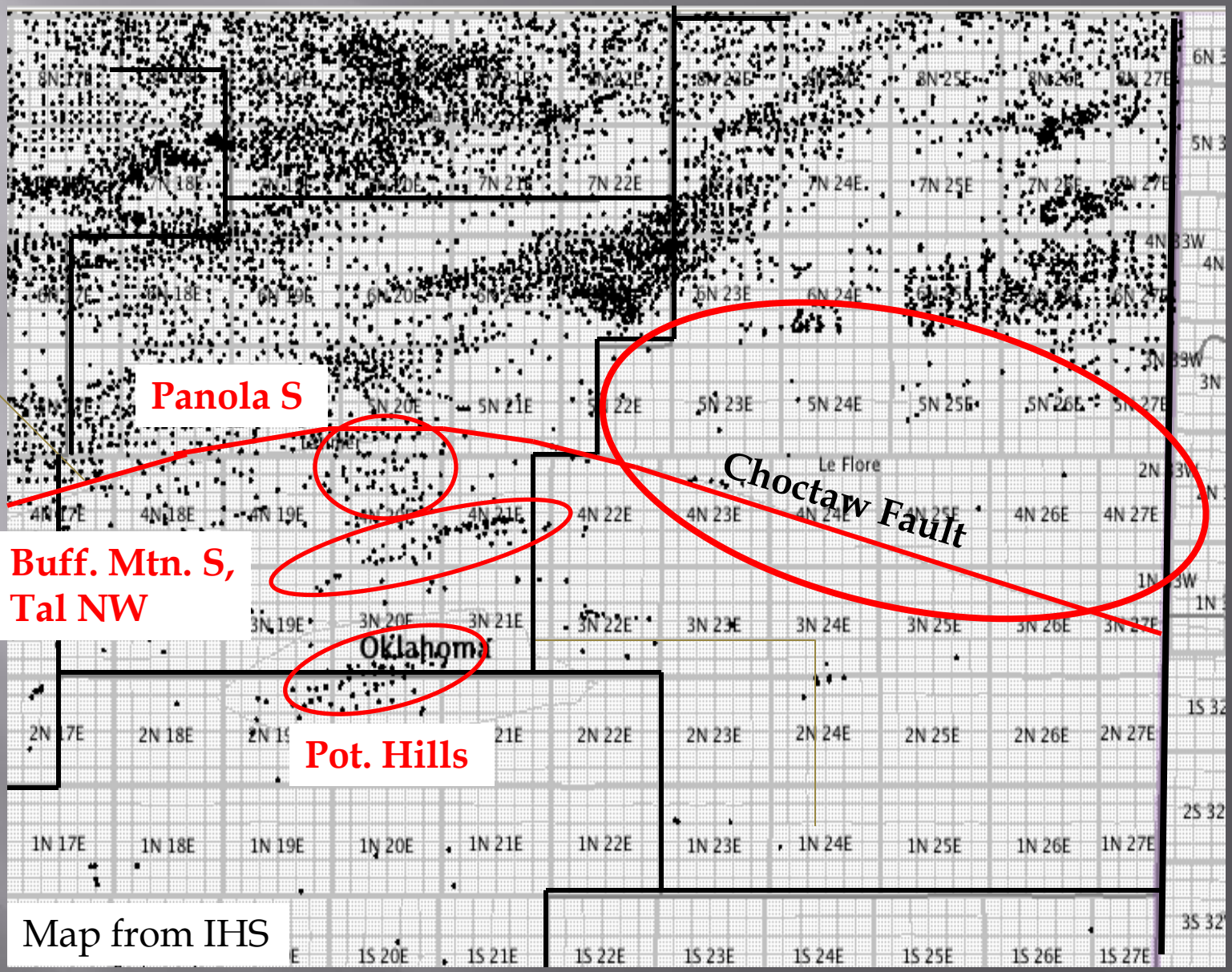
Can we identify facies relations and distributions of these like we've done for the Red Oak?



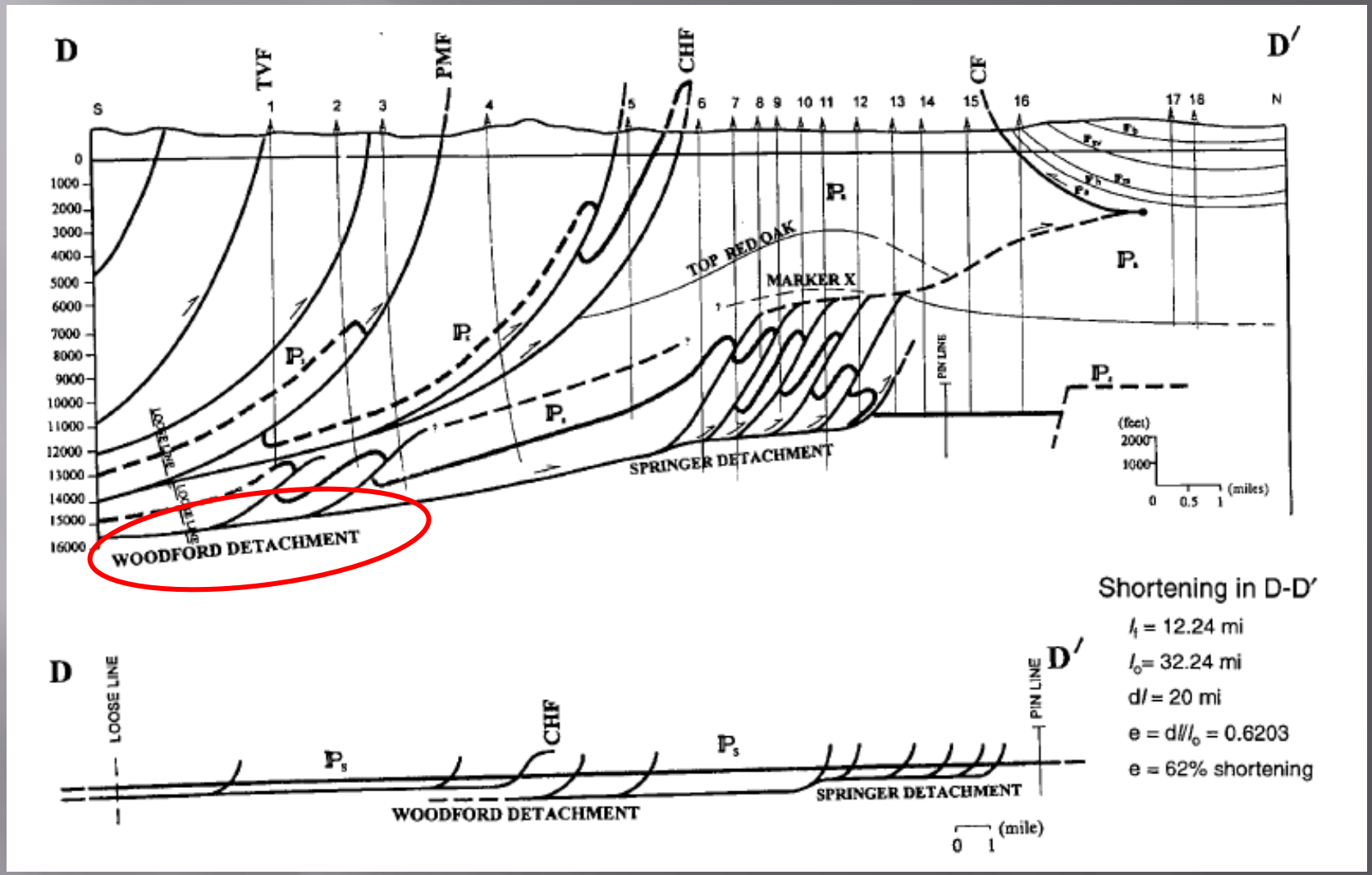




Have fair handle on structural geology of transition zone in Red Oak area and to west, but not as well to east. Same picture to east? Probably not.



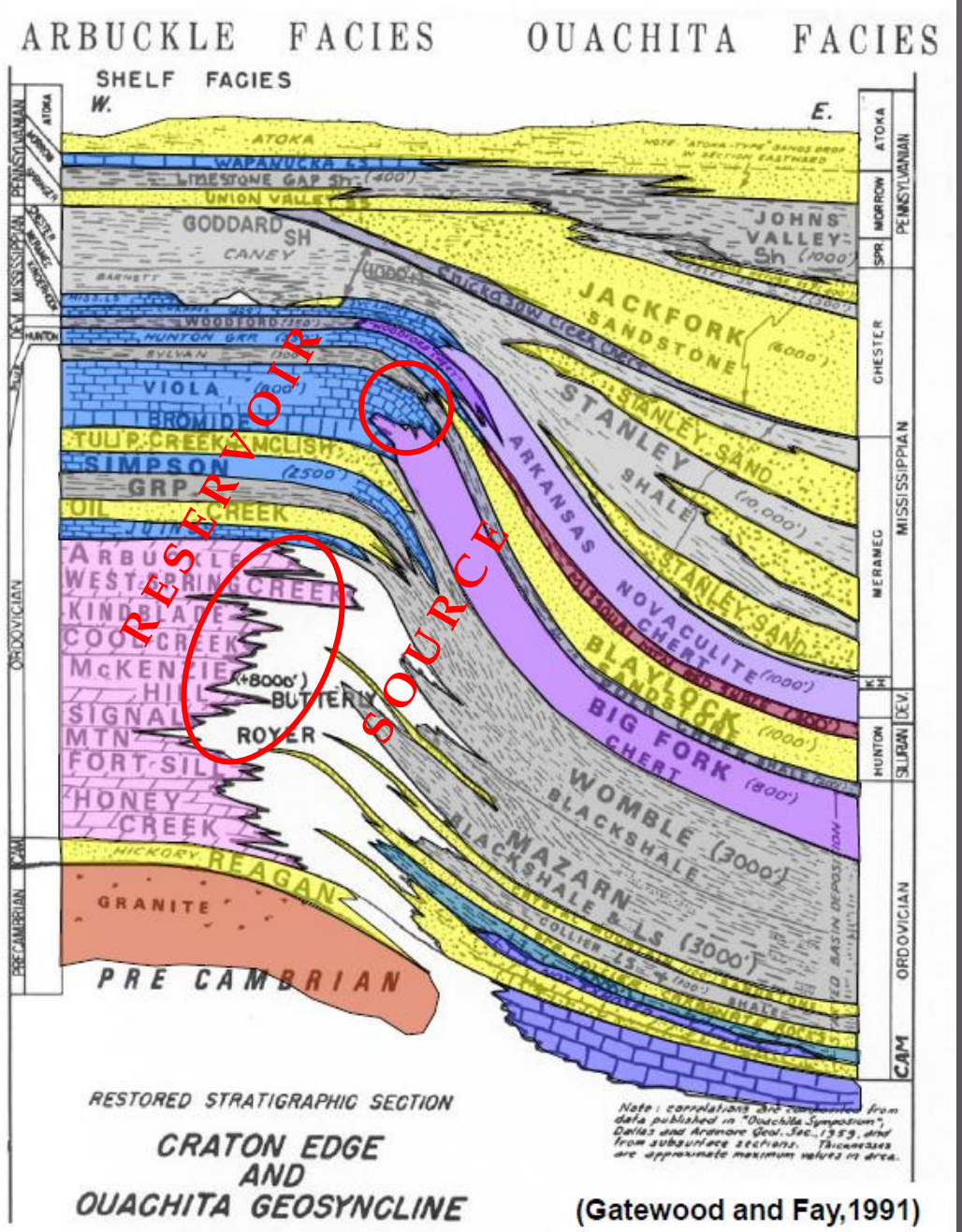
Why is Le Flore County being dissed? Thermal maturity? Are there enough wells +/- data to really know?



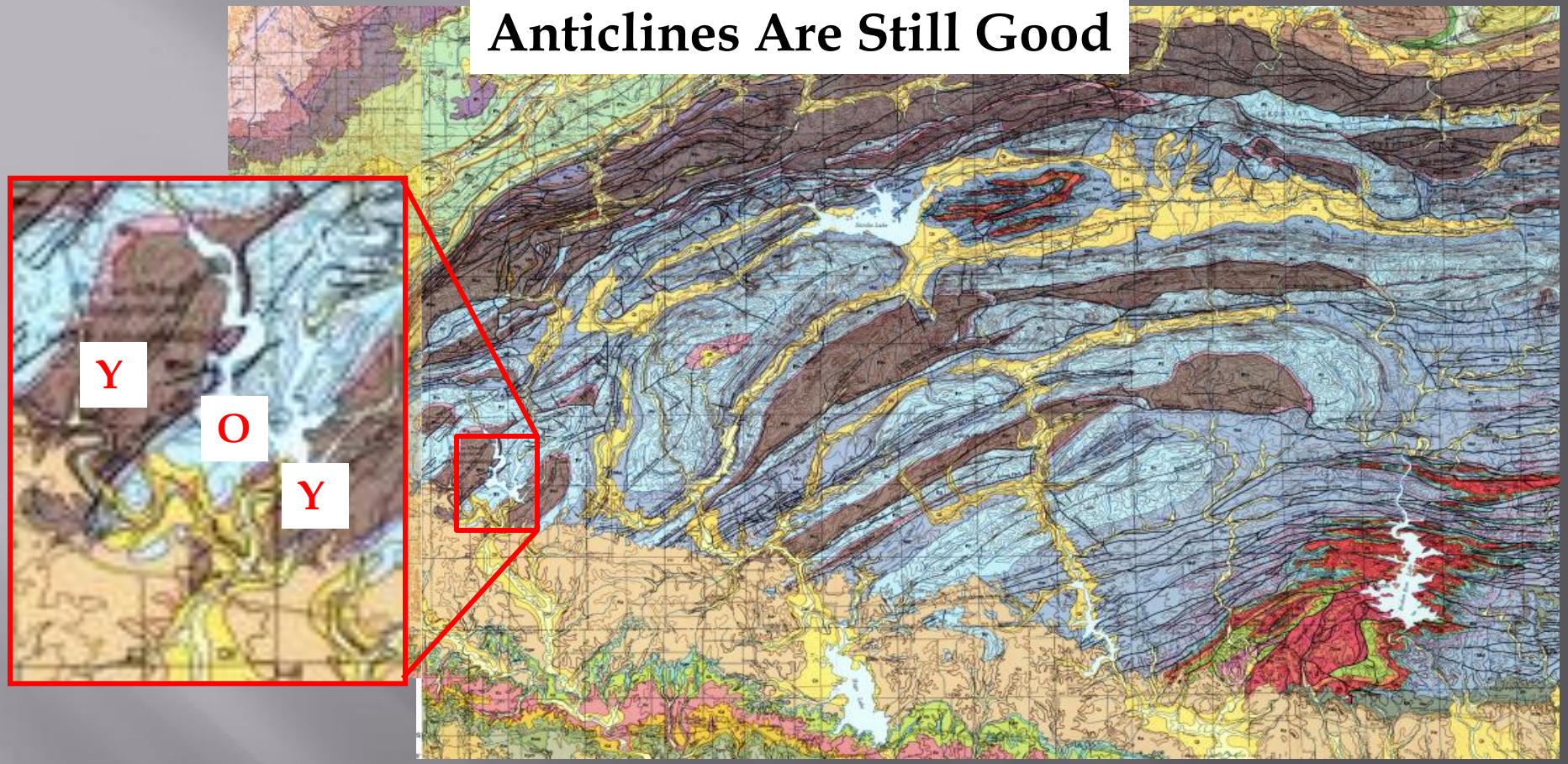
How far beneath Ouachita thrust faults does Woodford extend? Where might it be reservoir-quality, and where might it serve as source rock for overlying units?

A related question –

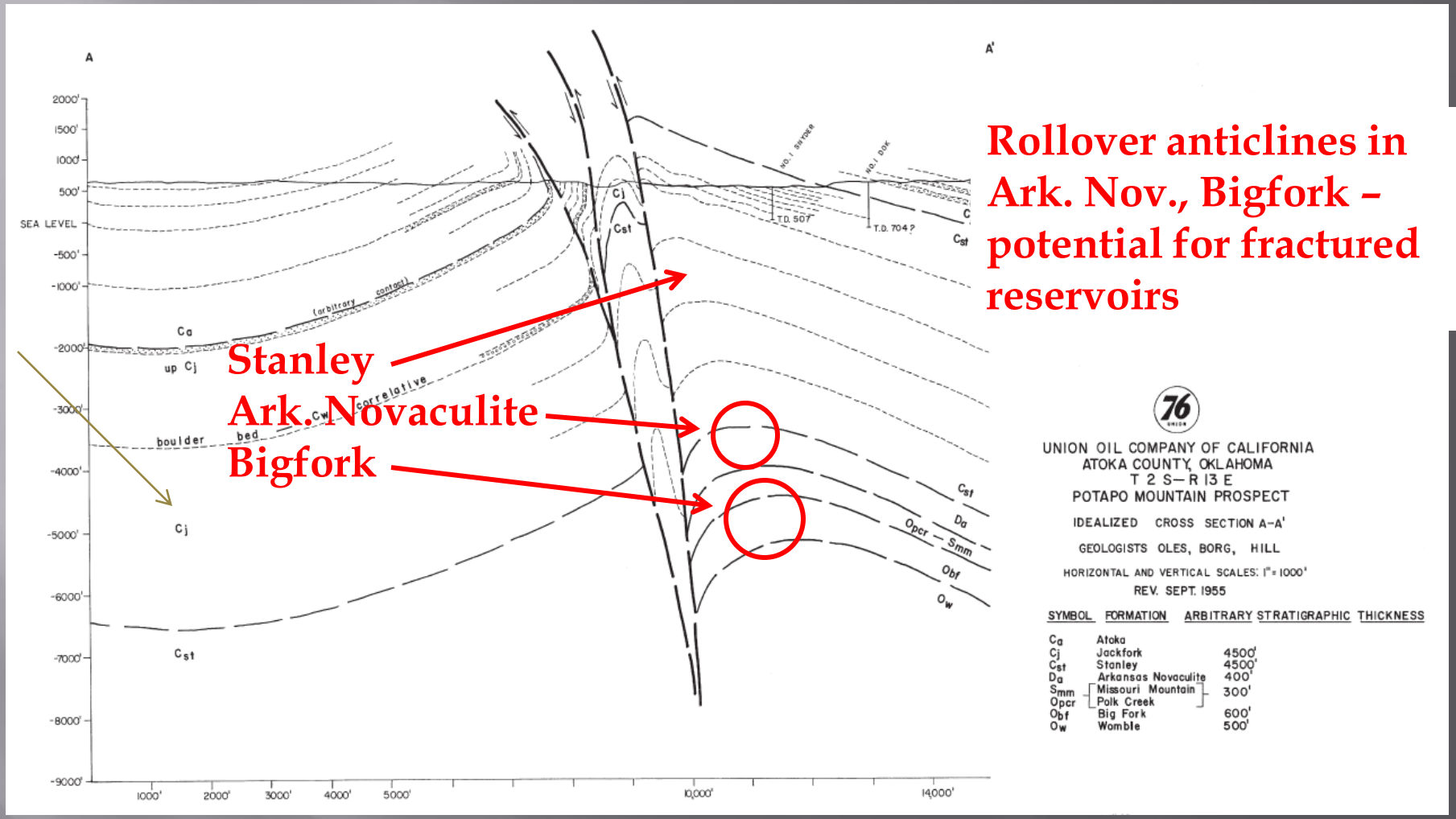
Where is the Morrowan and pre-Morrowan shelf edge beneath the thrusts, and where is the juxtaposition of source rock in the basin (to the south) against reservoir rock on the shelf (to the north)?



Anticlines Are Still Good



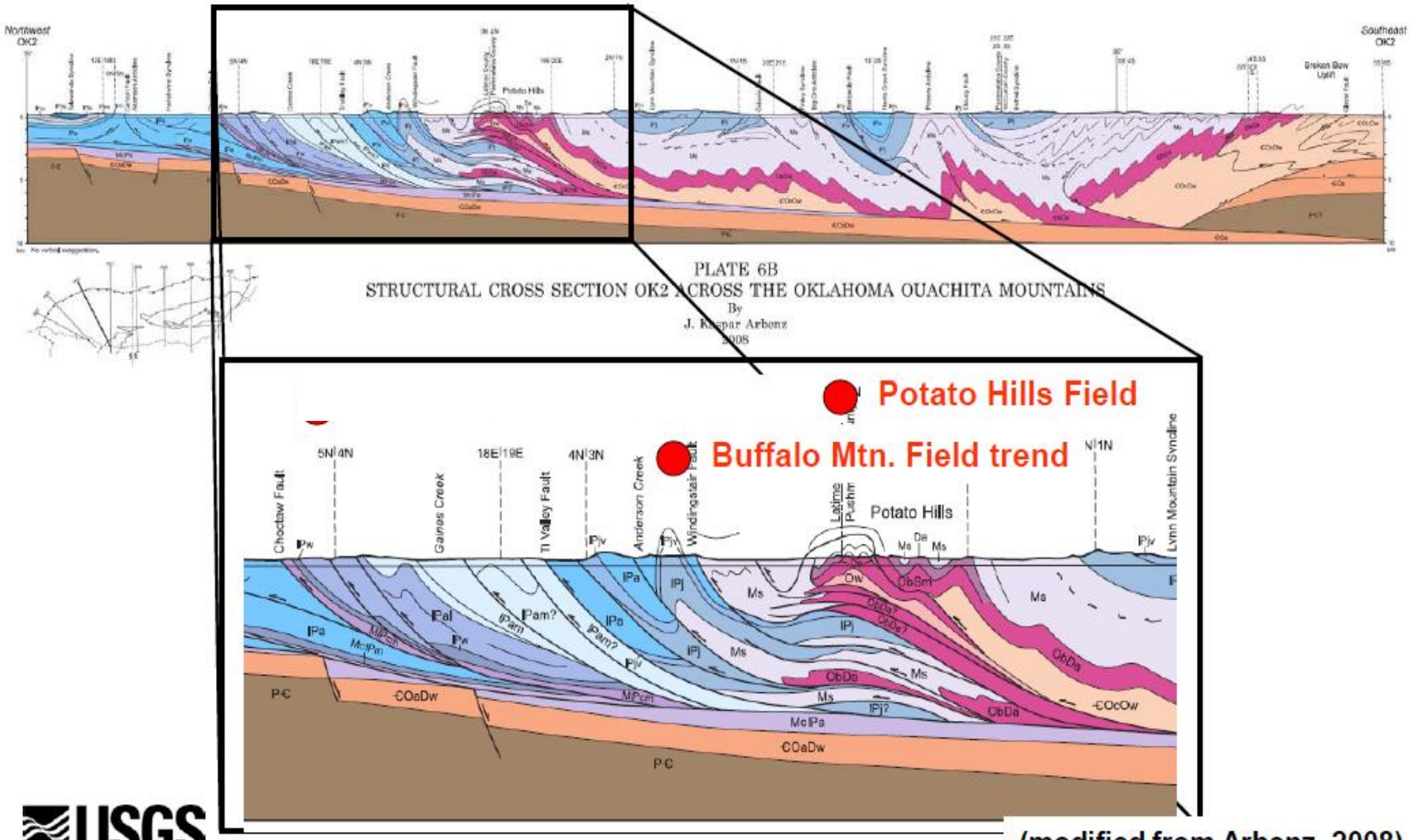
Potapo Creek Anticline prospect, originally documented by Misch and Oles as part of Union of California Ouachita exploration project. Small, now abandoned oil field, but ……..



Rollover anticlines in Ark. Nov., Bigfork – potential for fractured reservoirs

Union's cross section from 1955. We now know the fault is listric and that a fault-bend fold (anticline) probably occurs in the overriding plate. These structures are common throughout the Ouachitas.

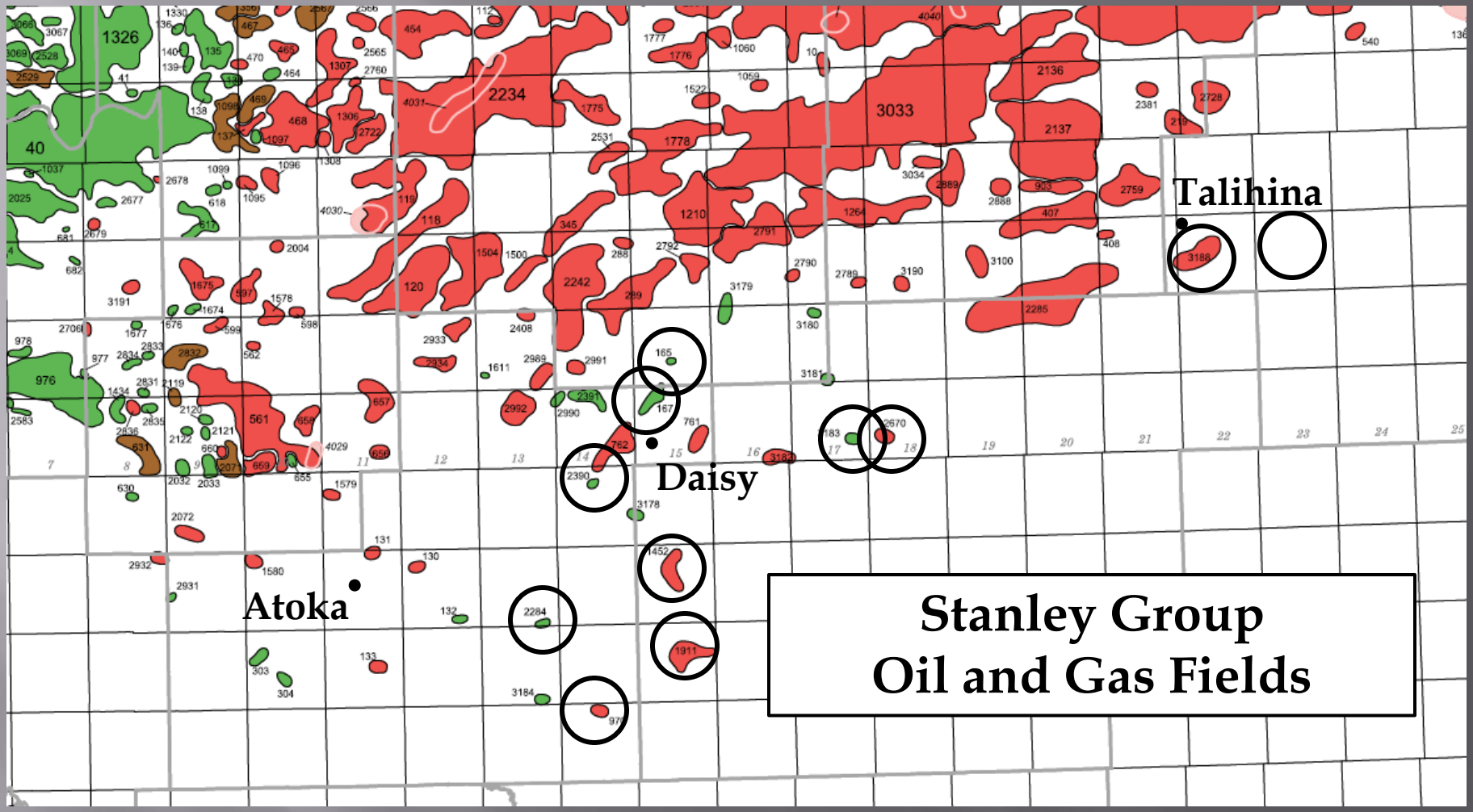
Jackfork fields in northern Ouachitas – production from fractured/tight sandstones, anticlinal crests, and ...



USGS

(modified from Arbenz, 2008)

Stratigraphic (channel sands) traps throughout Ouachitas



Stanley produces dribs and drabs of oil and gas throughout Ouachitas. Poor reservoir? Are we treating it right? More modern completion techniques required?

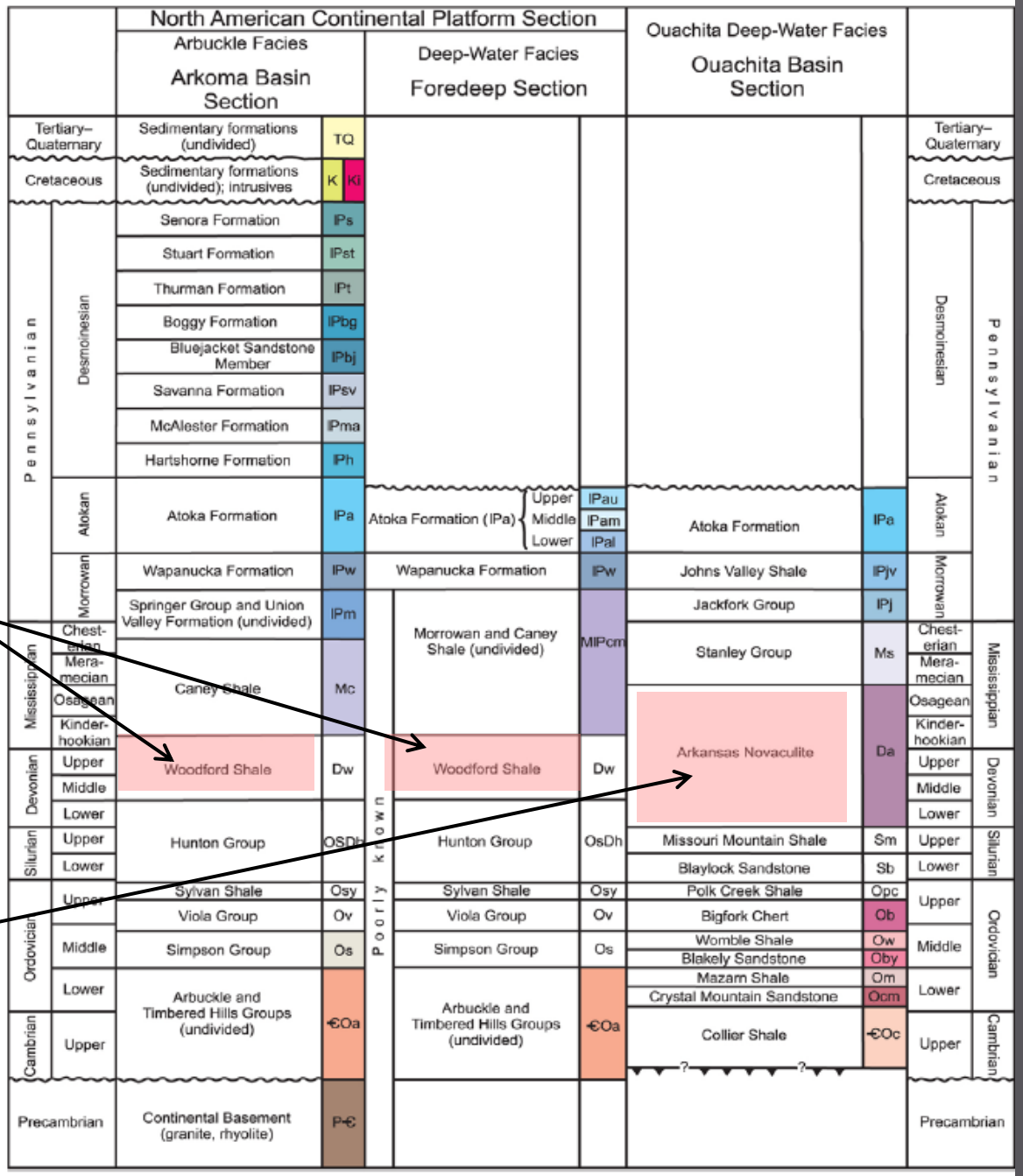
Chronostratigraphy

Oklahoma Nomenclature

The Elephant in the Room

Woodford Shale

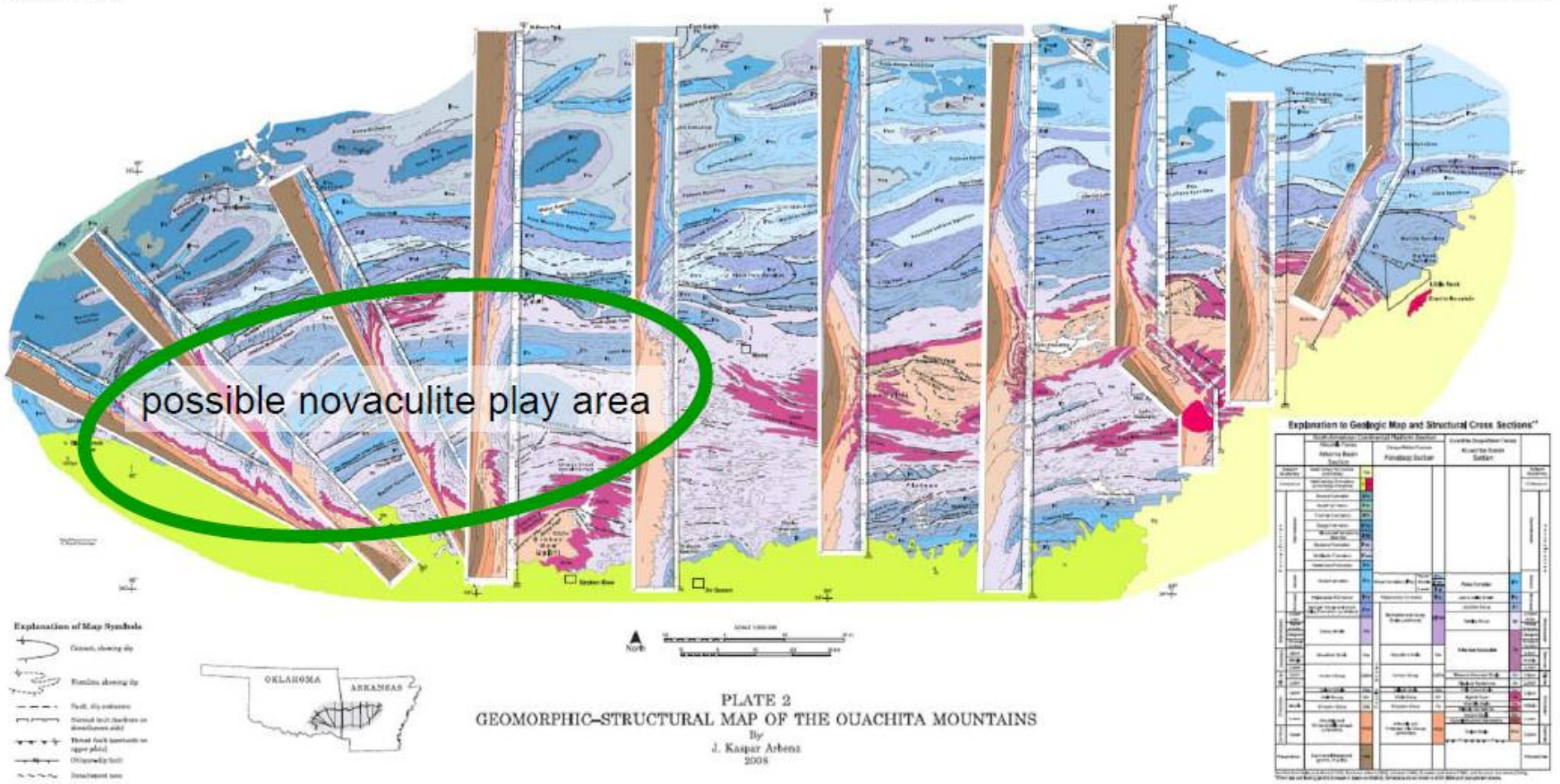
Arkansas Novaculite



USGS

Arbenz, 2008

Geomorphic – Structural Map of the Ouachita Mountains



(modified from Arbenz, 2008)

USGS