[AV]Mississippi Lime Play: From Outcrop to Subsurface - The Evolution of a Play*

Shane E. Matson[1]

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Conclusions

- A confluence of events is at play.
- Structural trends inform reservoir character.
- This play is about water.
- Thoughtful stimulation.
- Standing on the shoulders of giants.
- Much of the acreage is emerging.
    - Hundreds of new wells will be coming on line in 2013.

Selected References

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AAPG Discovery Thinking Forum

May 20, 2013

Pittsburgh, PA

Mississippi Lime Play

From Outcrop to Subsurface: The Evolution of a Play

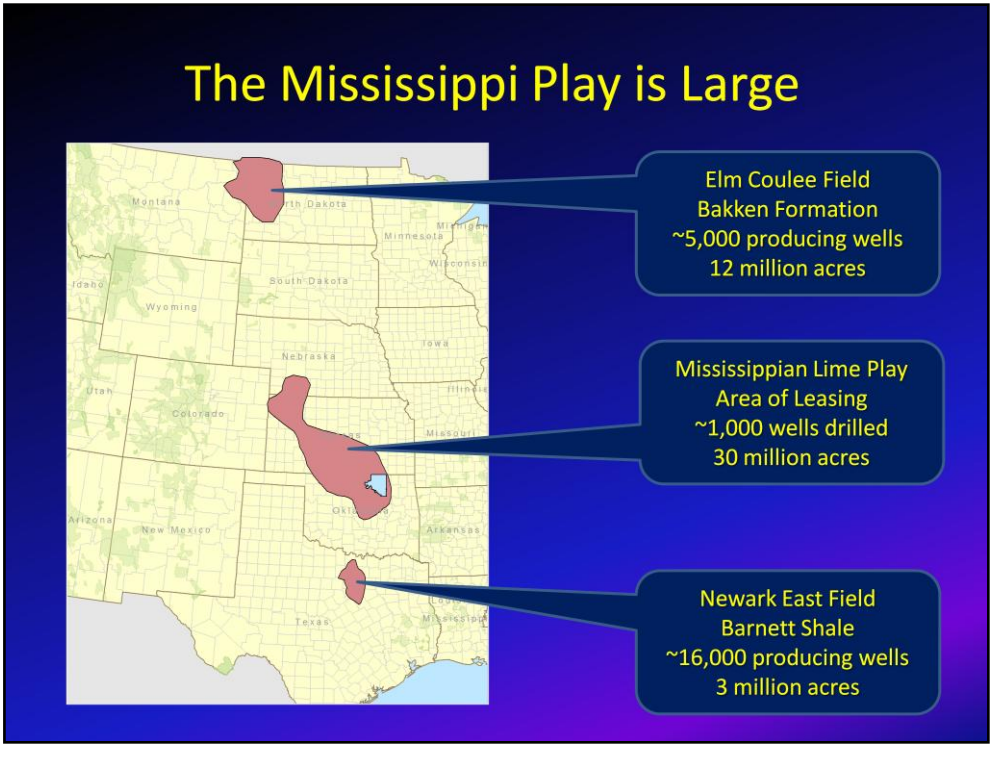
Shane E. Matson
Independent Geologist

When this Association began, more than 25 years ago, the objective of the few petroleum geologists then in existence was to find oil fields.

A. I. Levorsen
Discovery Thinking
The Bulletin of the American Association of Petroleum Geologists
Vol 27, No. 7, July, 1943

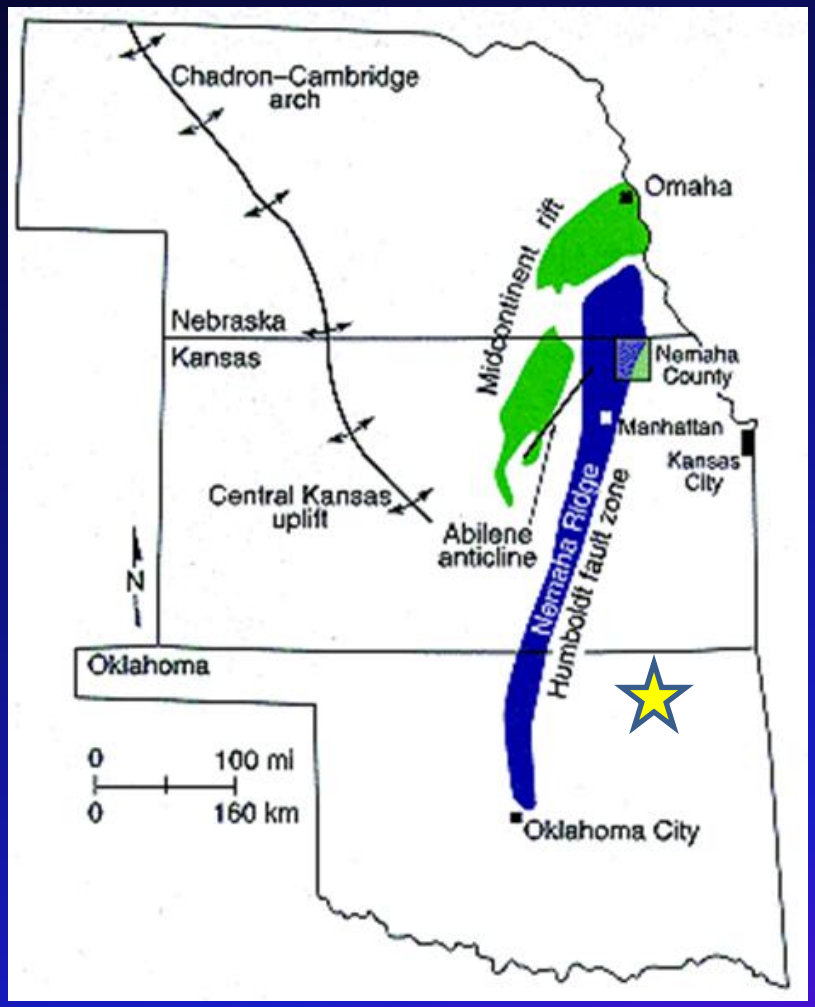
Presentation

- Modern History
- State of Play
- Three Pretty Pictures
- Geologic History
- Reservoir Definition, Stimulation and Production
- Geological Observations
- Architecture of the Reservoir
- Conclusions - Description in Nature



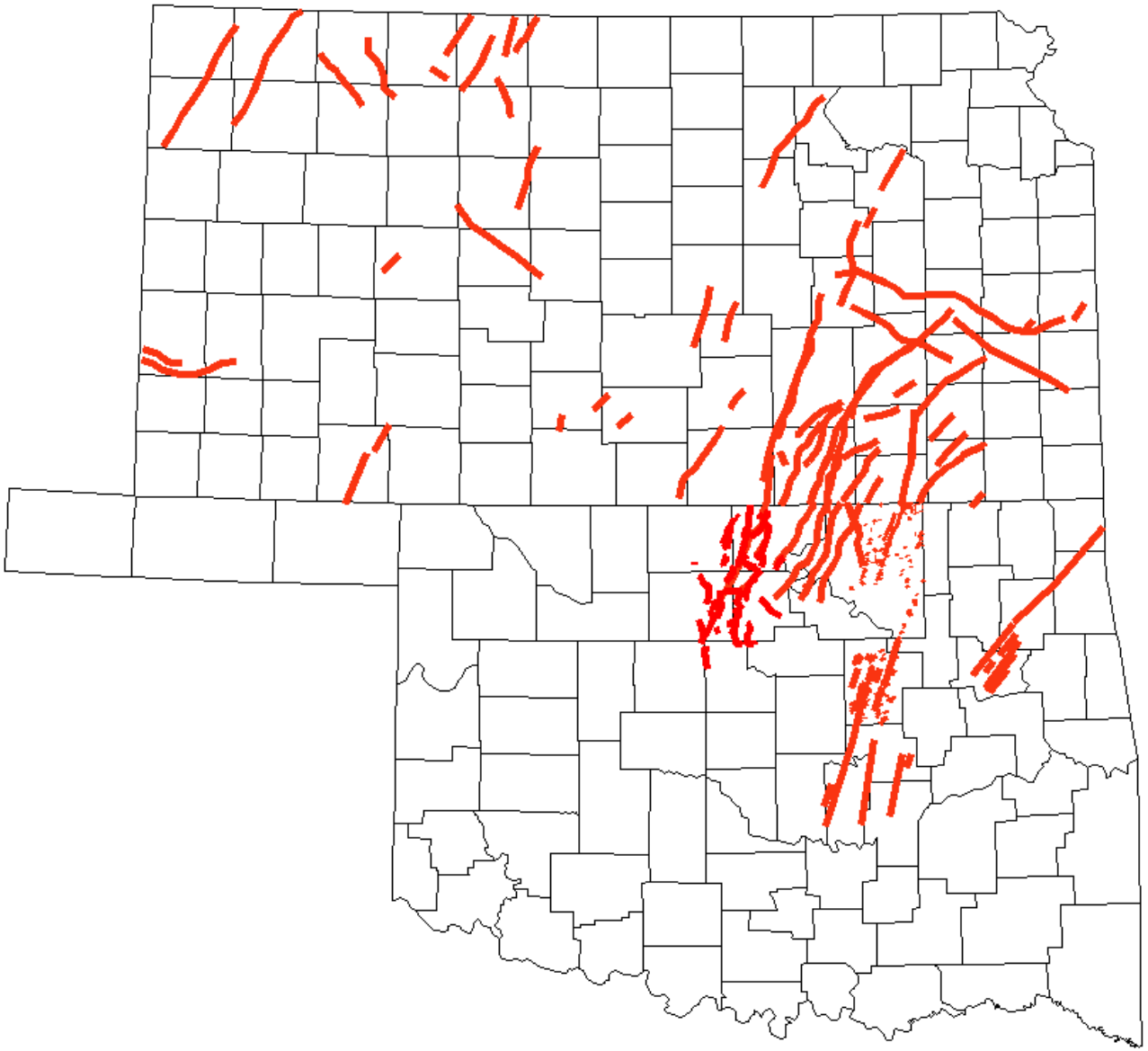
Presenter's notes: Each play exhibits a unique dynamic. In this play there are many. The Mississippi Lime Play is the first regionally extensive high-fluid-volume play.

What and where is the Nemaha Ridge?



The Nemaha Ridge is a continental-scale structural feature that runs north-south from Omaha to Oklahoma City. It bisects the Mississippian Lime Play into two major provinces.

Tectonic Lineaments – Surface and Subsurface



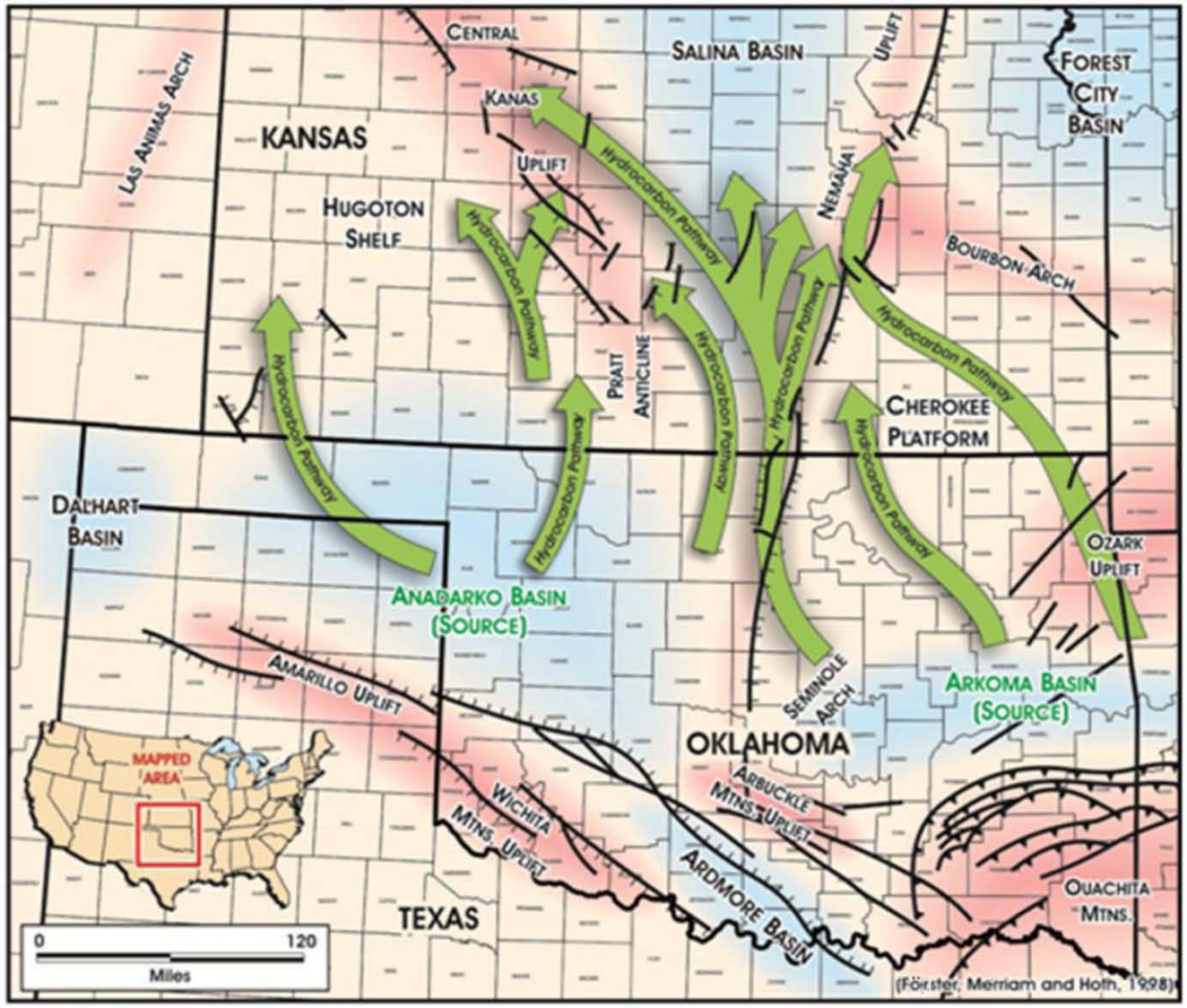
Multiple Sources – OGS Bulletin 40, KGS, Proprietary Magnetic and Shallow Surface

Mississippian Overview – Oil Migration and Distribution

The Woodford Shale was the source for much of the hydrocarbons produced in the Anadarko and Arkoma basins.

- The deep Anadarko basin produced gas-weighted hydrocarbons
- The Arkoma Basin was shallower and produced oil-weighted volumes

Woodford Shale - Migration Paths



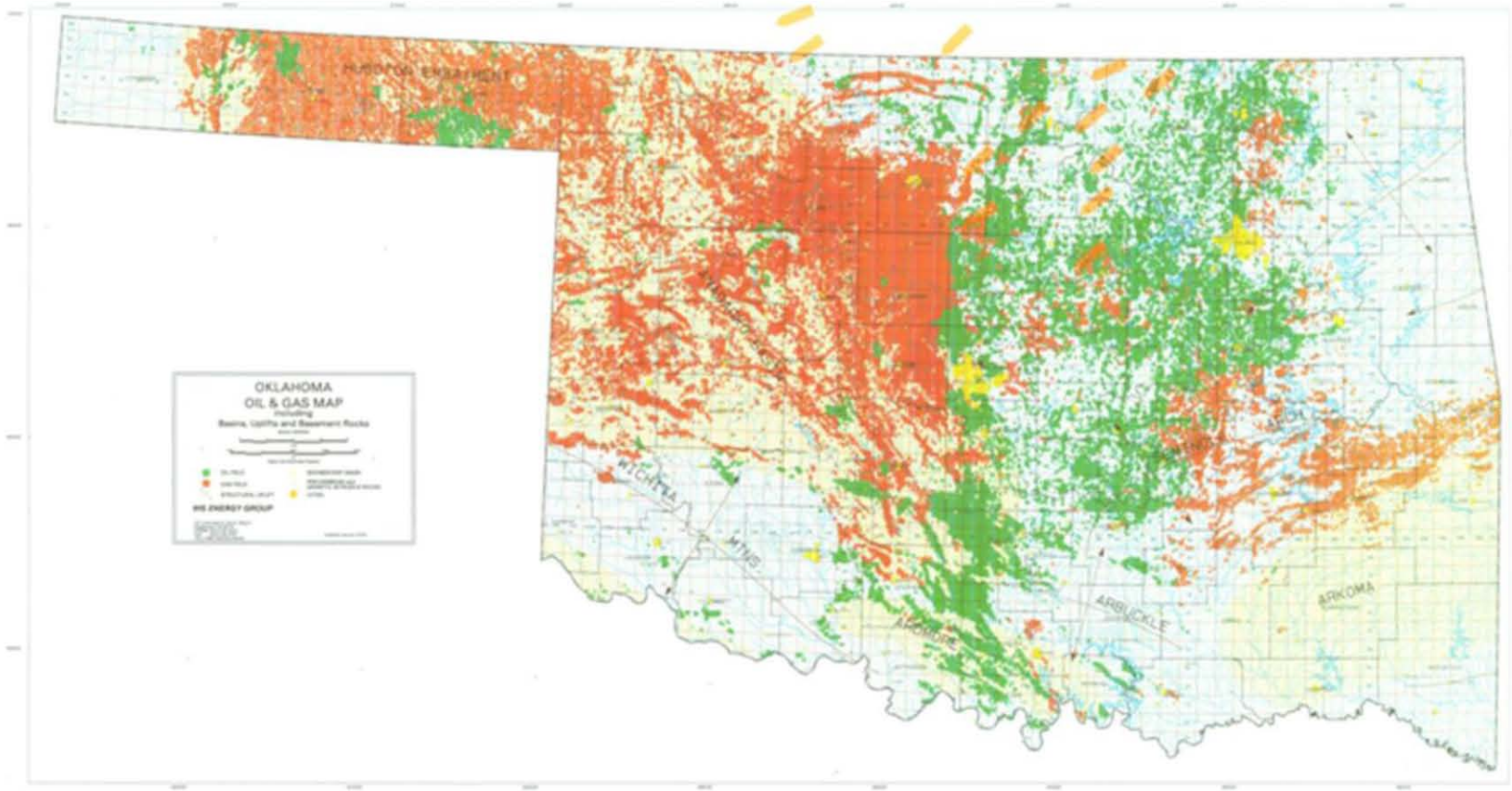
Modified from Gerhard, L. KGS Bull 250

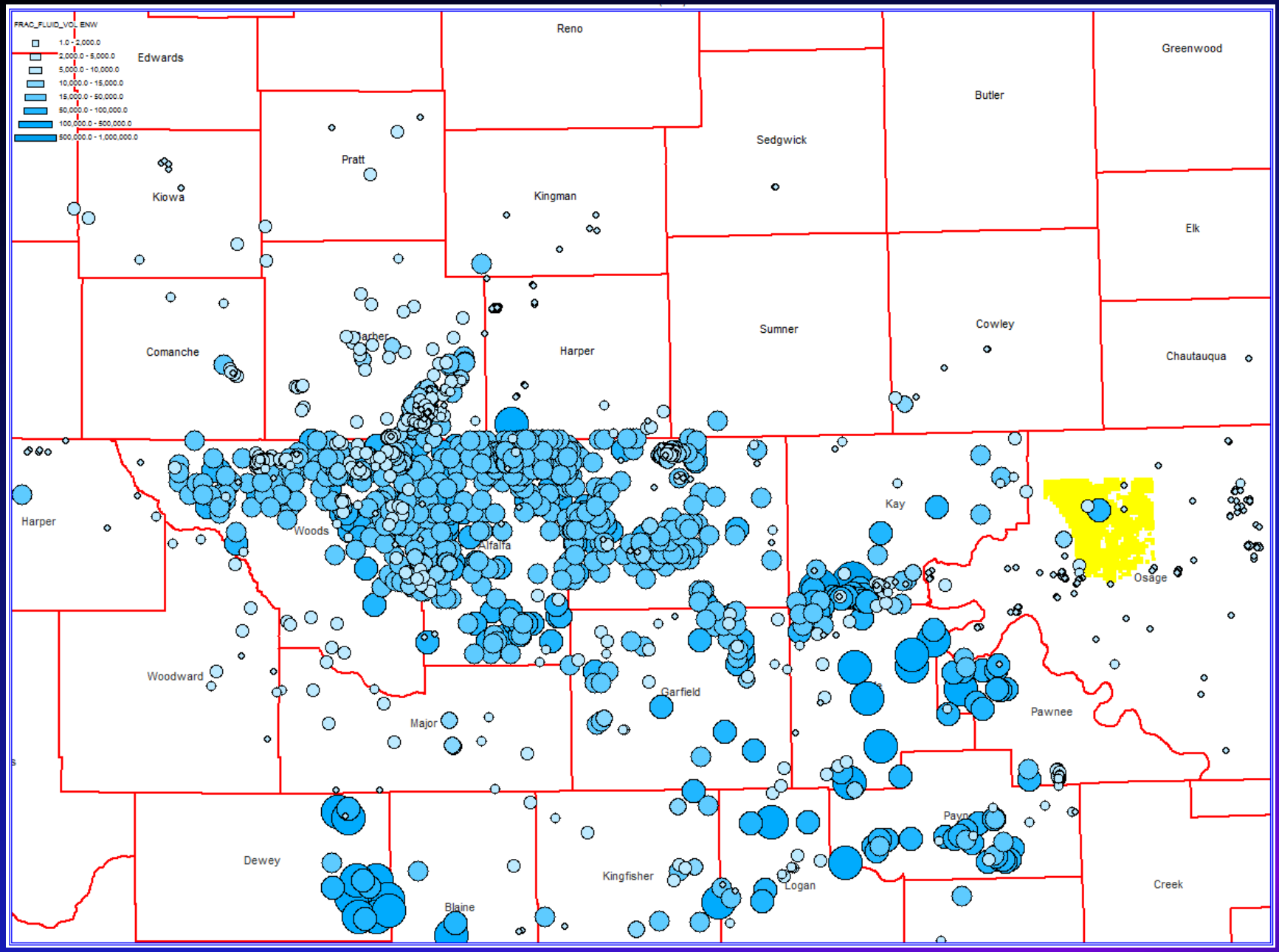
Structure: Control of HC in Reservoir

Mississippian Overview – Oil Migration and Distribution

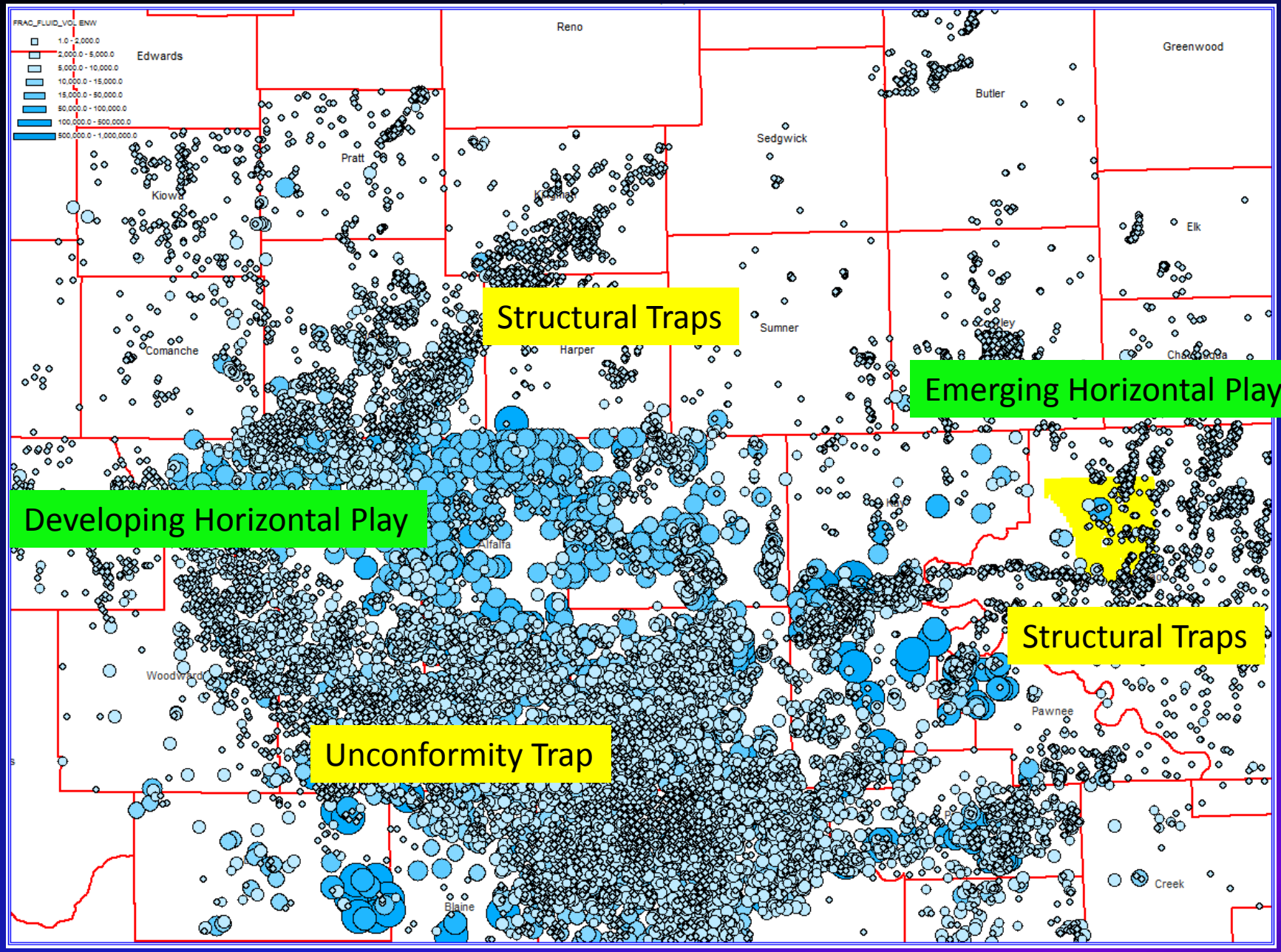
This production distribution map shows that western Oklahoma fields are pervasively gassy, with hydrocarbon sources in the Anadarko Basin; while fields in the eastern portion of the state tend to be more oily.

State of Oklahoma Gas and Oil Distribution





Completed Mississippi - 2009 - Present



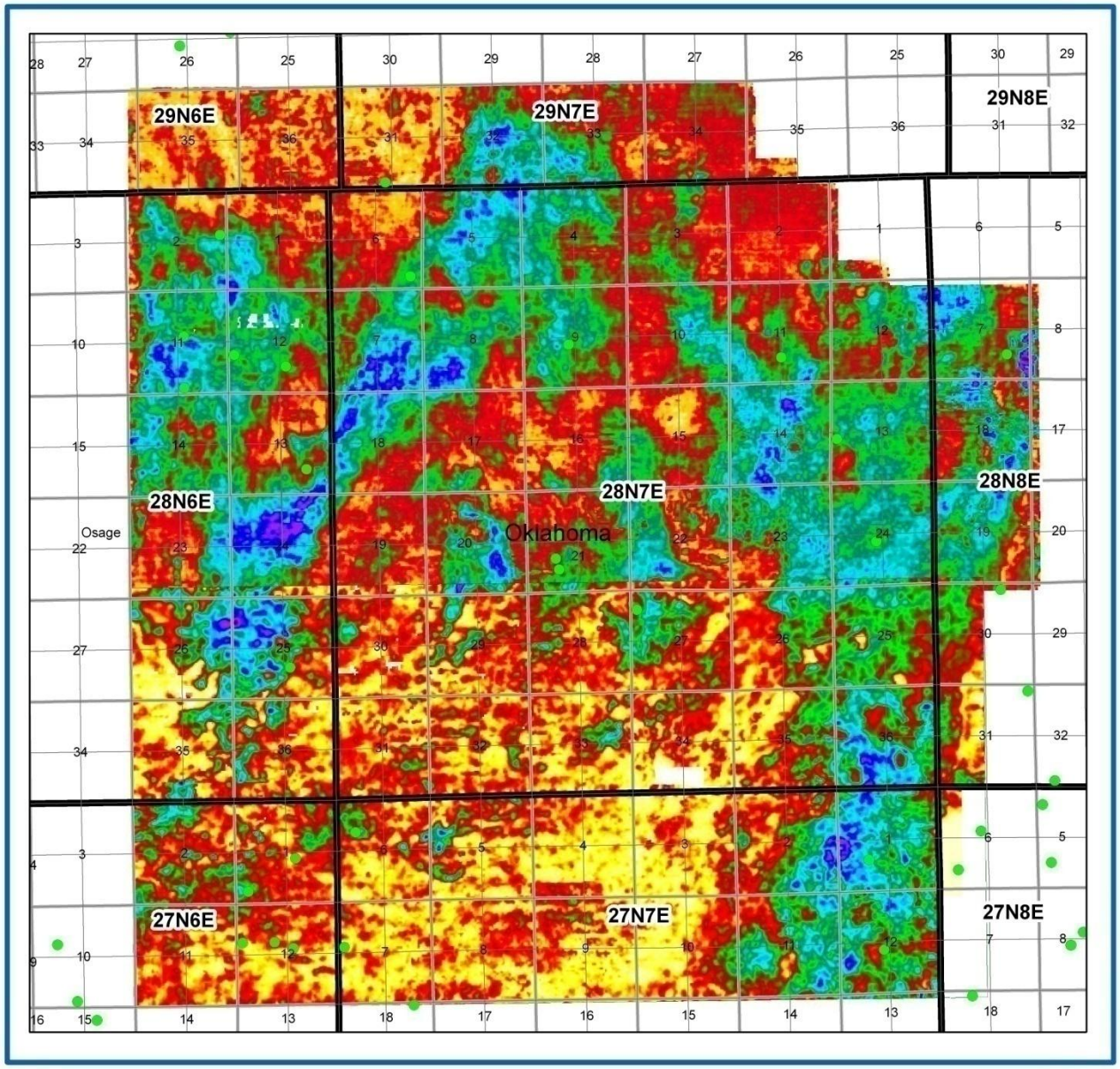
All Completions

Three Pretty Pictures

1. Seismic Attribute of 55 sq. mi. of 3D Seismic

2. Map of Tri-State Mining District

3. Merged Image of Above


29N6E
29N7E
29N8E
28N6E
28N7E
28N8E
27N6E
27N7E
27N8E
Osage
Oklahoma

Geological Survey Professional Paper 588

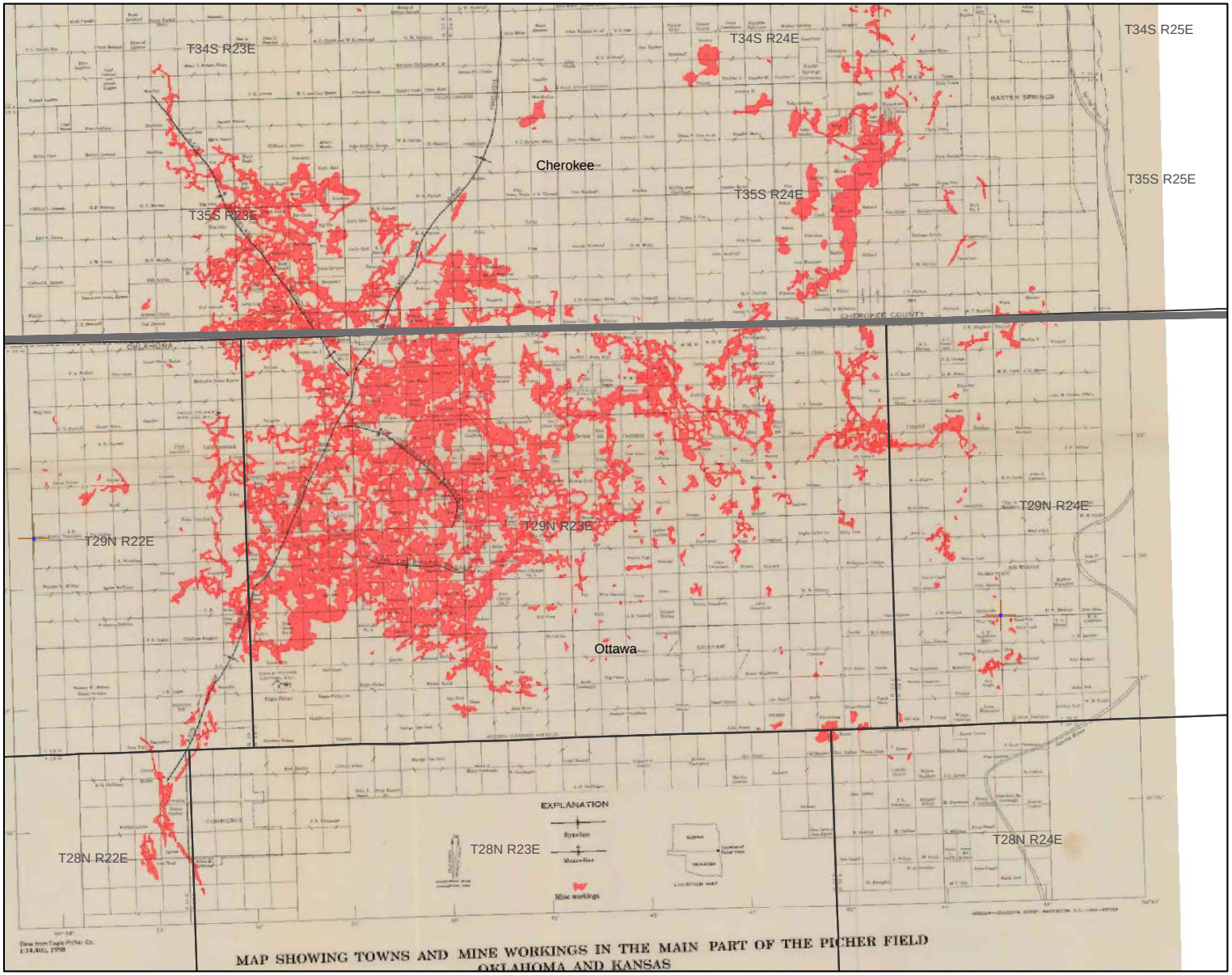
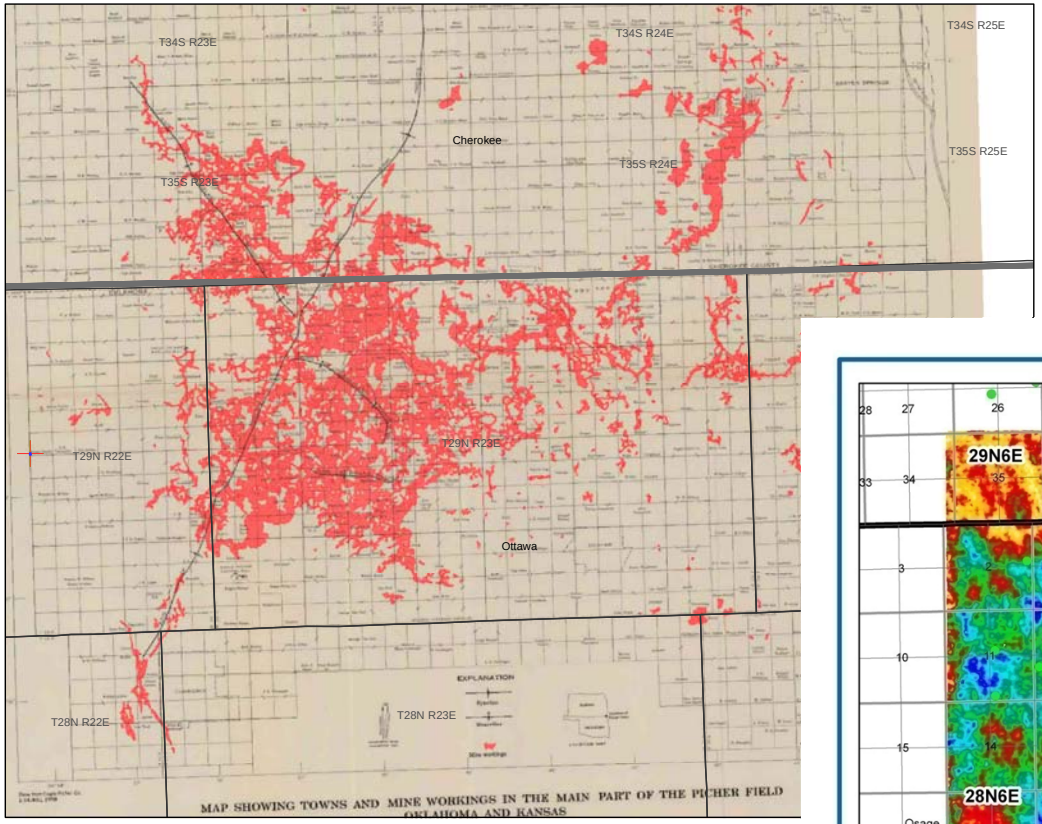
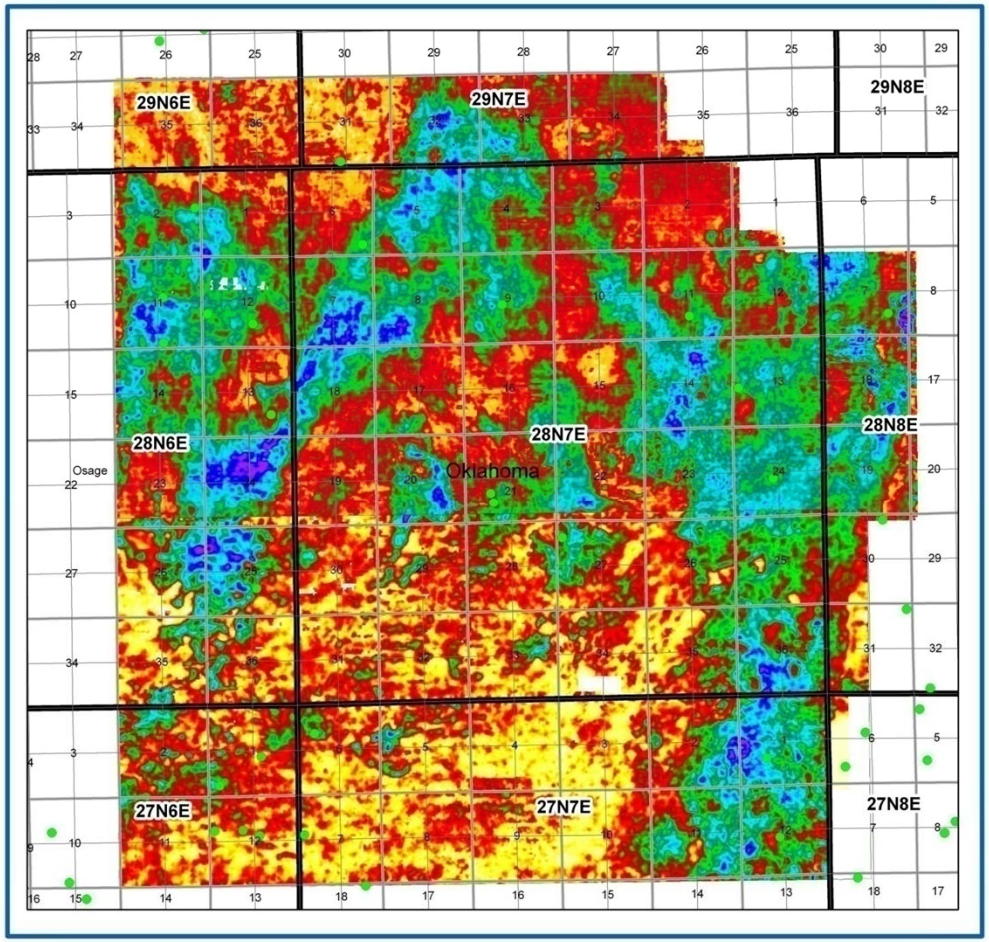


Plate 11 - Mine Workings of the Picher Field



120 miles apart!!!!

WOW!!!!



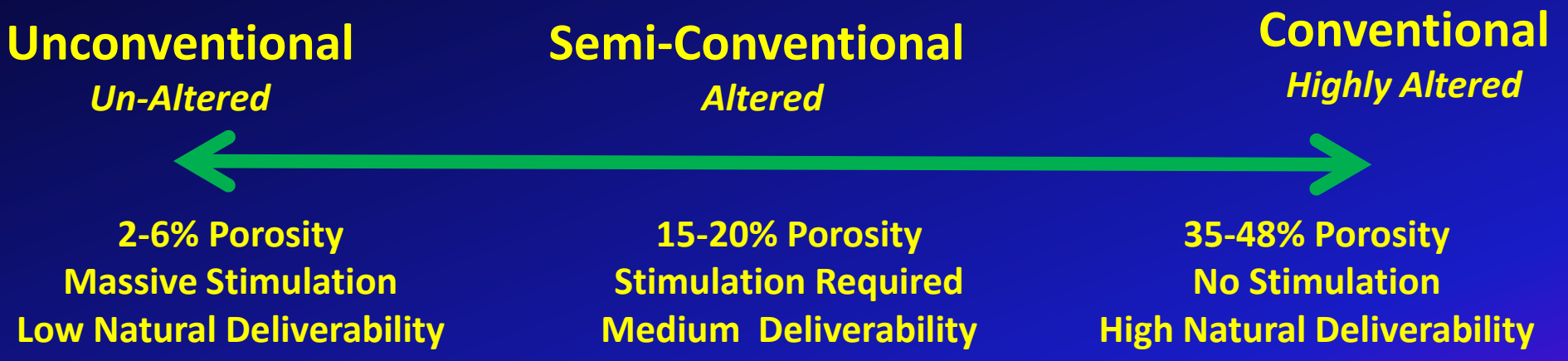
Geologic History of the Reservoir

- **Deposition**
- **Transpressive tectonics**
- **Meteoric diagenesis during exposure of the Mississippi**
- **Burial**
- **Cracking of the brittle section**
- **Hydrocarbon filling of traps**
- **Hydrothermal fluid movement along vertical faults**
- **Hydrocarbon filling of traps**
- **Ozark uplift**
- **Hydrocarbon refill of traps**
- **Breaching of the reservoir**
- **Extensional faulting and fracturing**
- **Water sweeps higher porosity units**

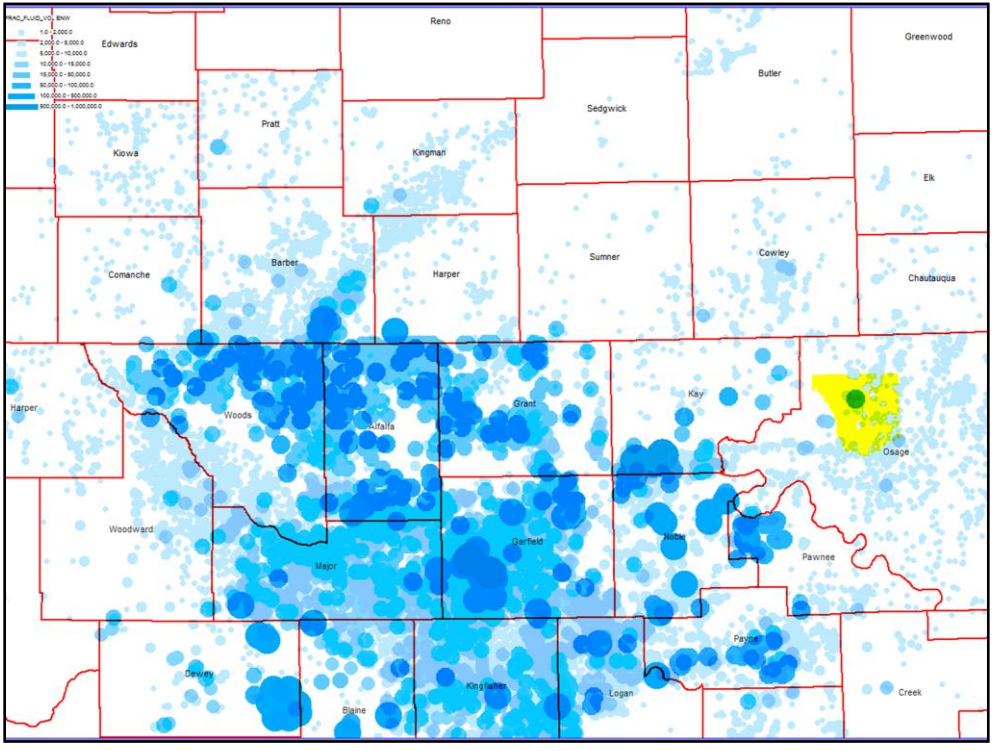
Reservoir Definition

Multiple Reservoir Systems

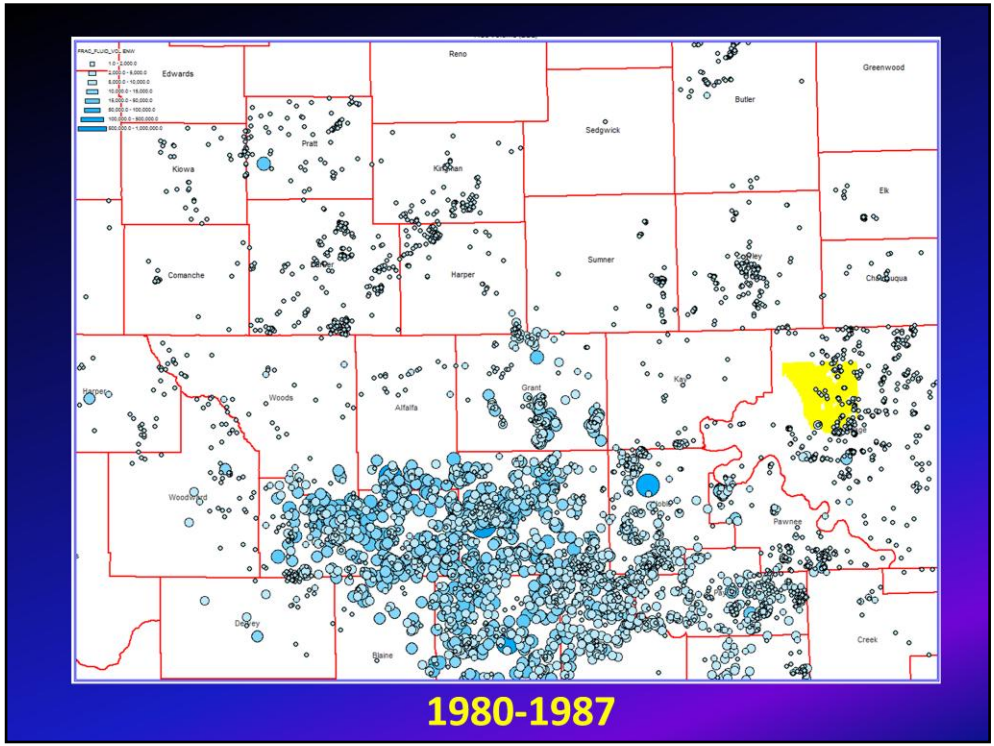
Conventional – Semi-Conventional - Unconventional



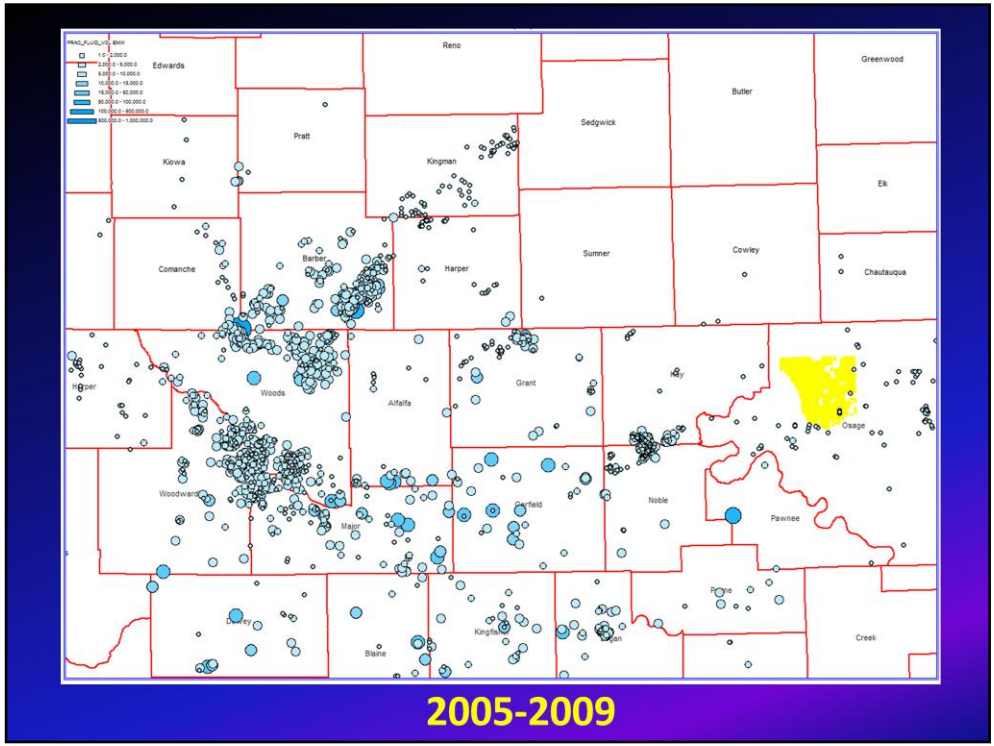
Sweep Efficiency of Hydrological System Increases with Porosity



Presenter's notes: All decades of stimulated wells; shading and bubble size according to fluid volume.



Presenter's notes: Shading and bubble size according to stimulating fluid volume.



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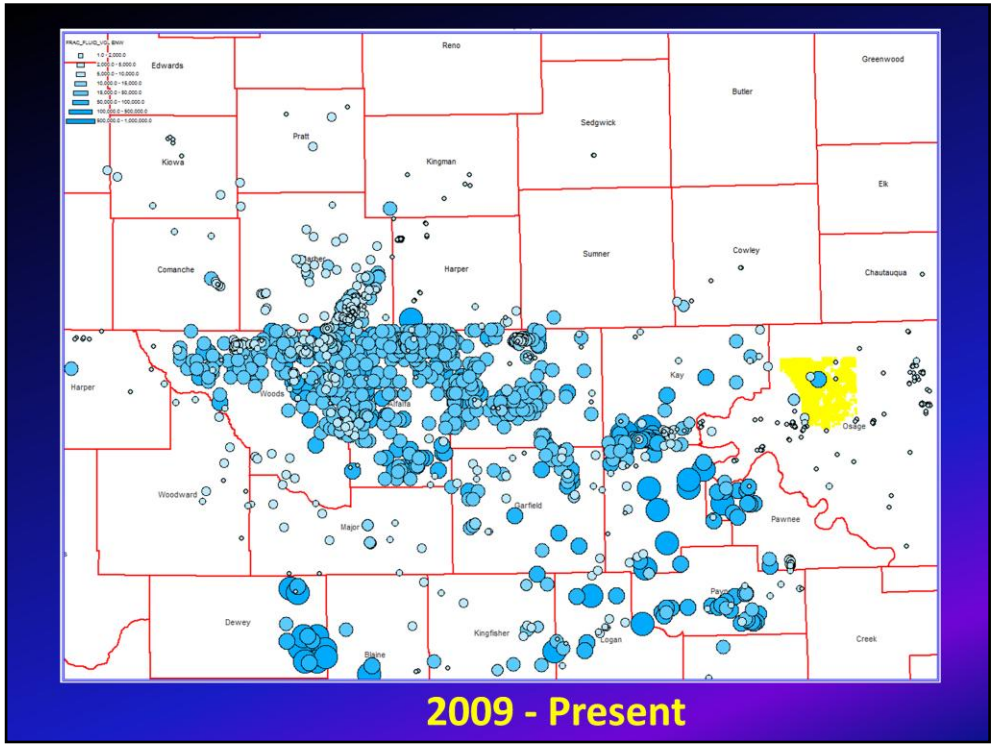

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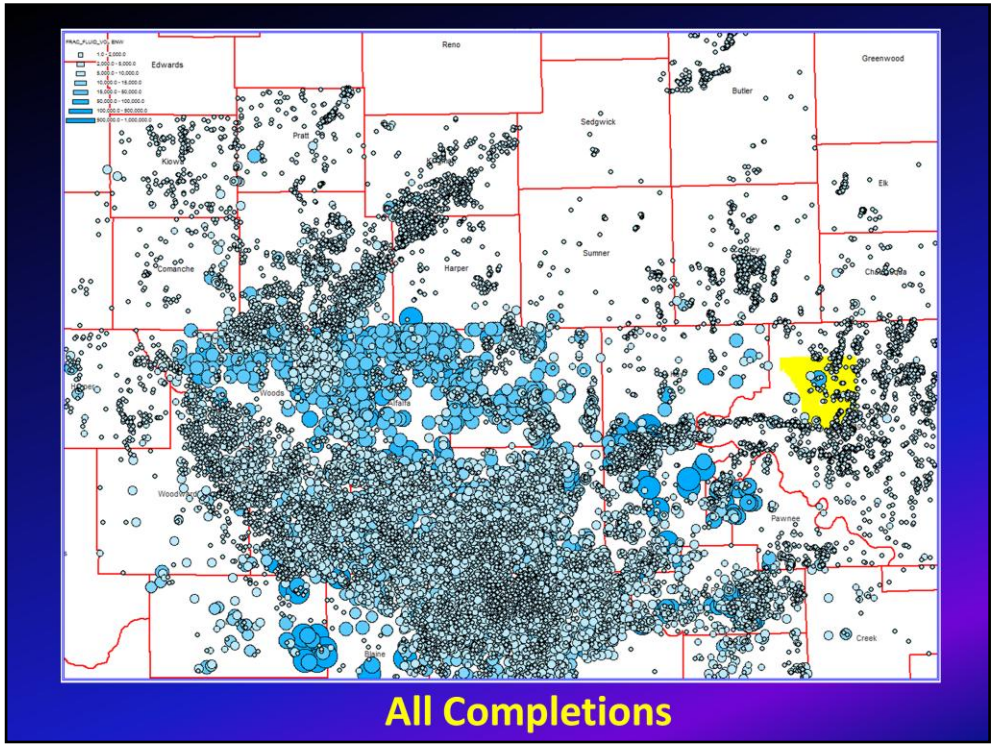
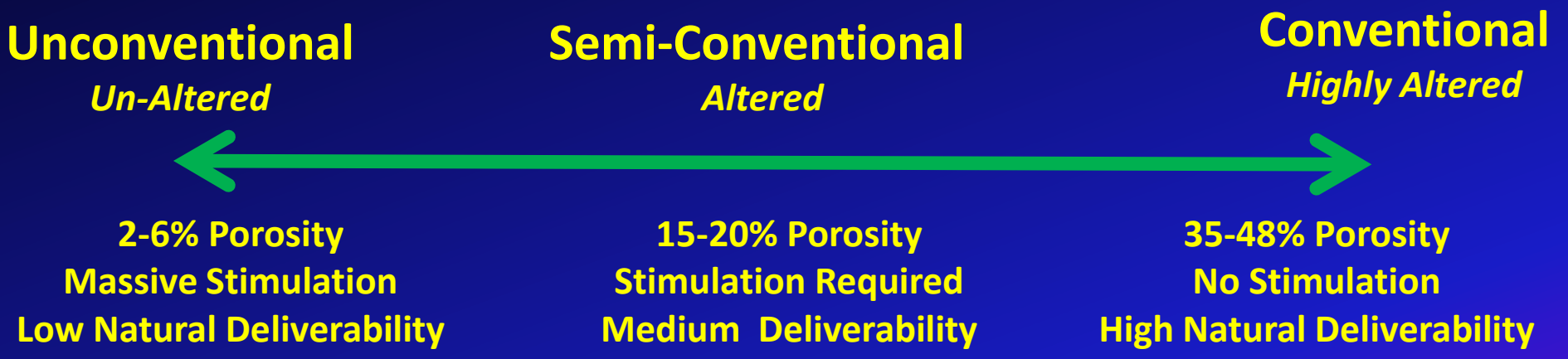


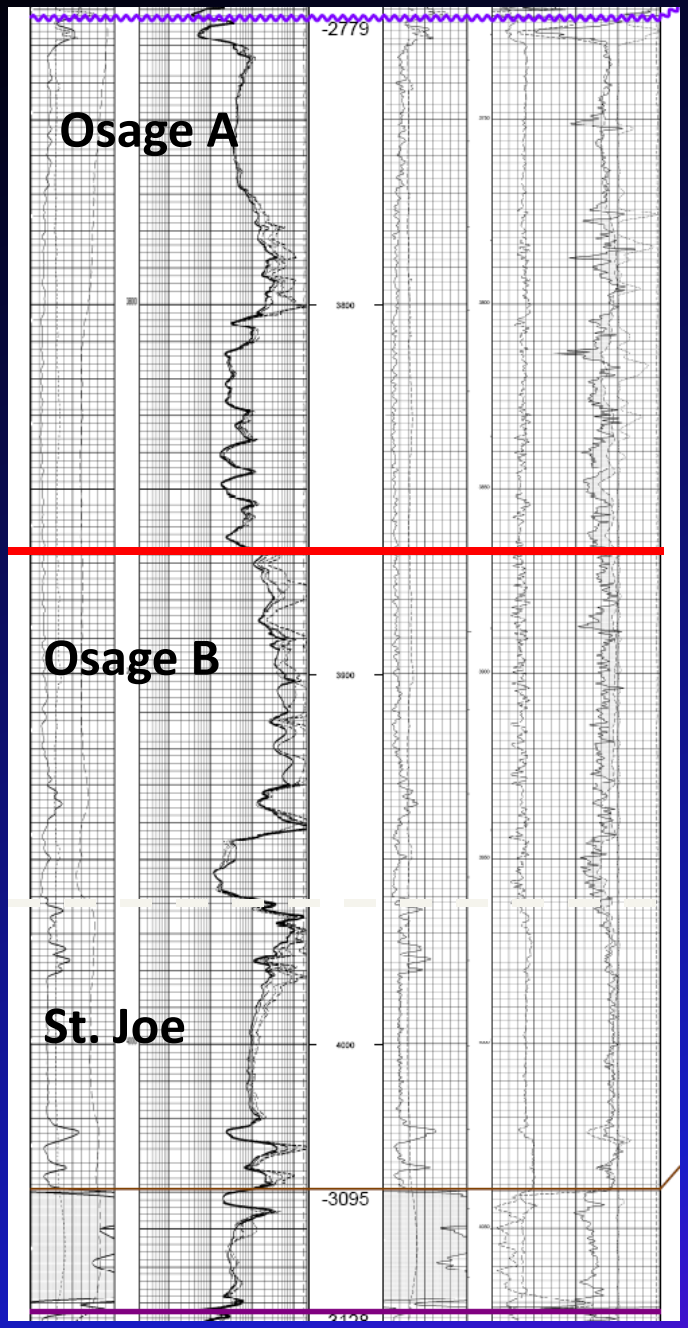
Presenter's notes: Shading and bubble size according to stimulating fluid volume.

Reservoir Definition

Multiple Reservoir Systems
Conventional – Semi-Conventional - Unconventional



Sweep Efficiency of Hydrological System Increases with Porosity

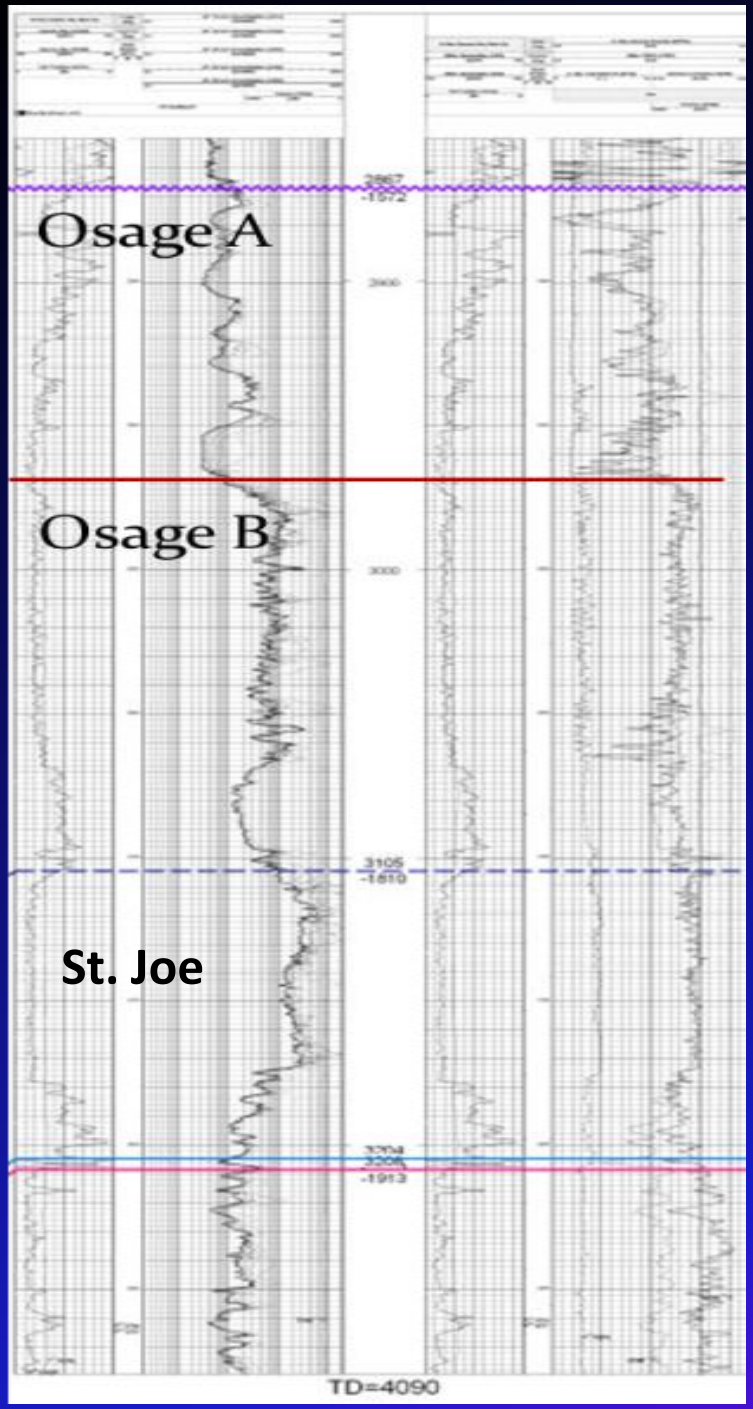


Reservoir Geology

Osage A – Unaltered
Silicified Limestone
High Diagenetic Susceptibility

Osage B – Unaltered
Interbedded Chert and Lime
Low Diagenetic Susceptibility

Kinderhook Limestone



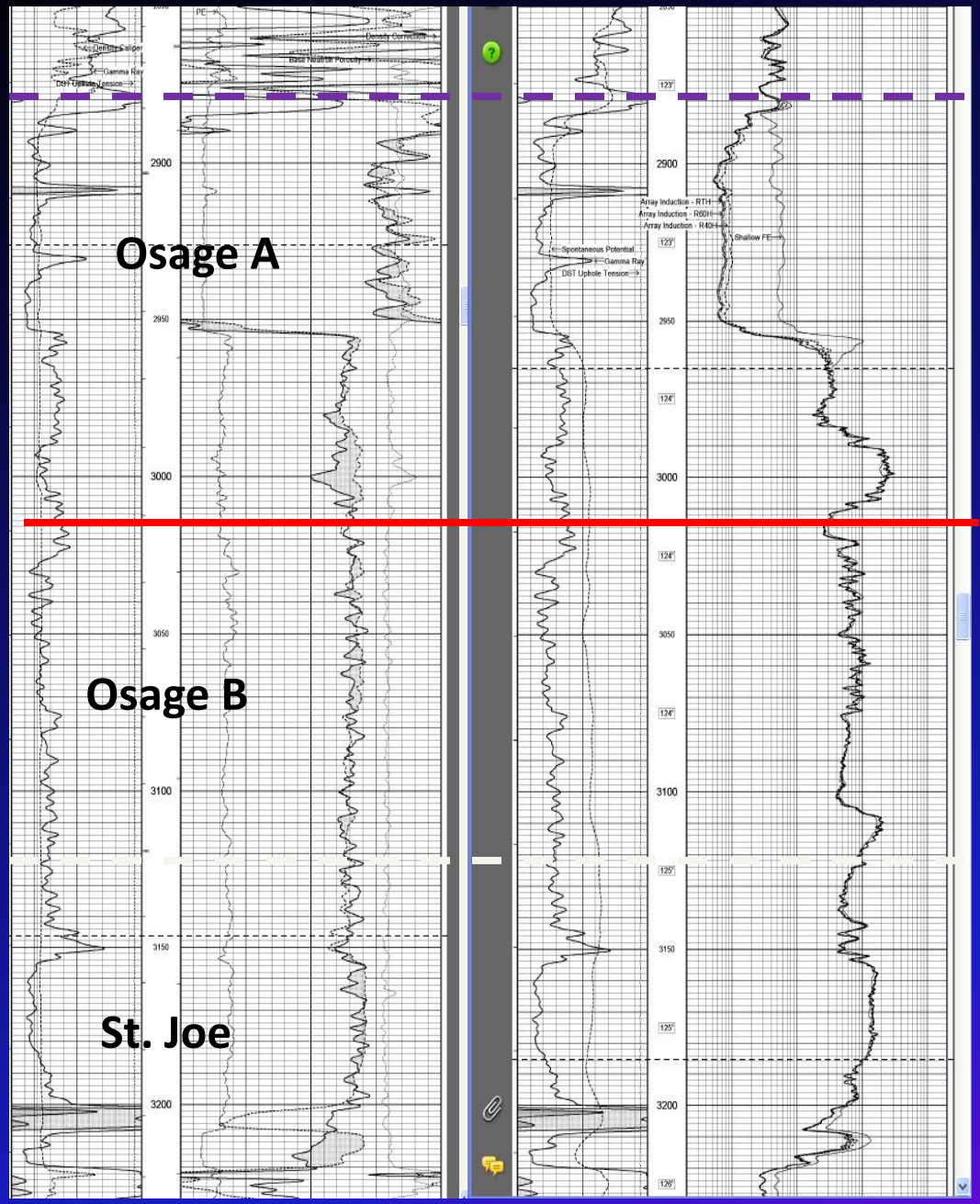
Reservoir Geology

Osage A – Altered

Osage B – Unaltered

Kinderhook Limestone

Reservoir Geology

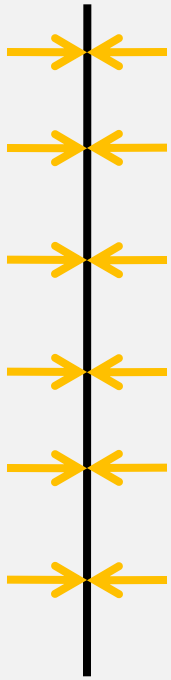


Osage A – Highly Altered

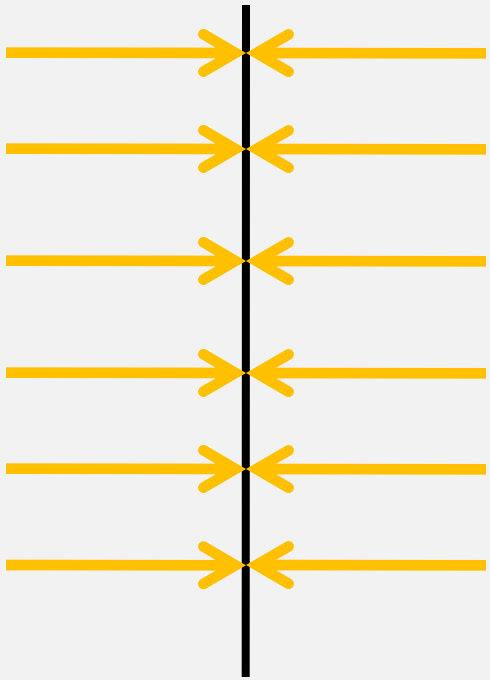
Osage B – Unaltered

Kinderhook Limestone

Natural Deliverability

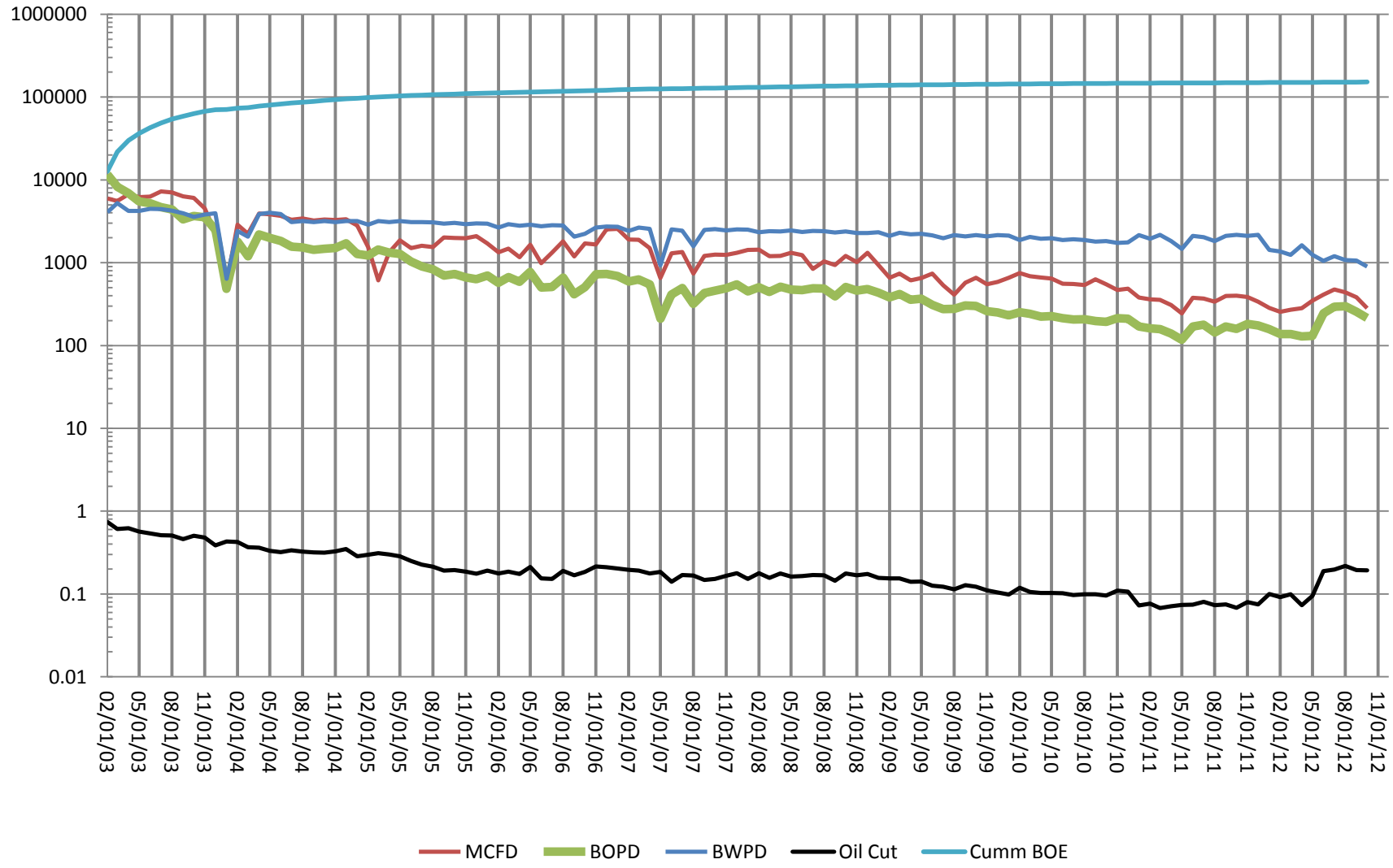


Unconventional
Low Deliverability

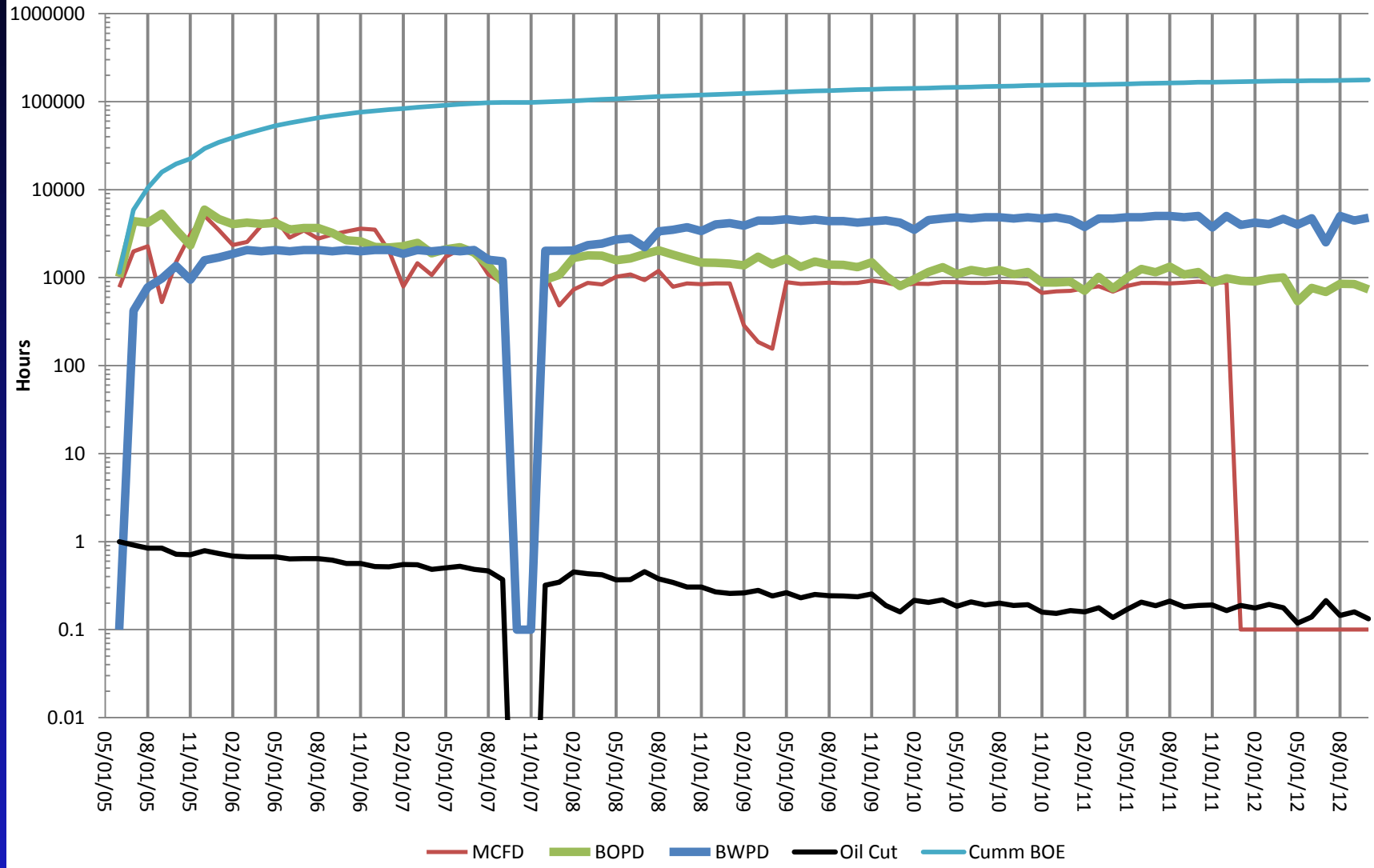


Conventional
High Deliverability

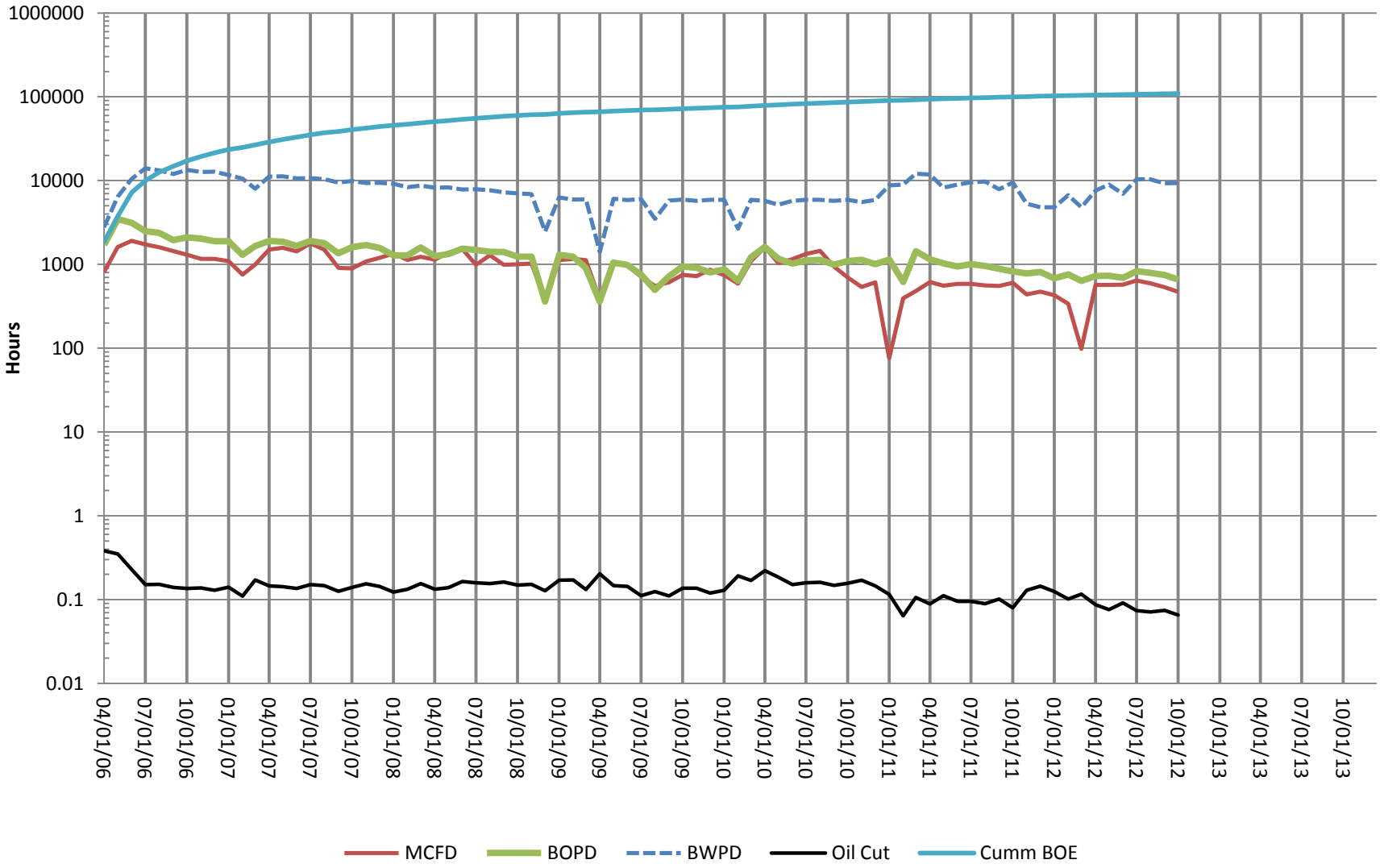
Conventional Reservoir
First Production February 2003
Cumulative Production 152,00 BOE (89% Oil)
EUR 183,000 BOE

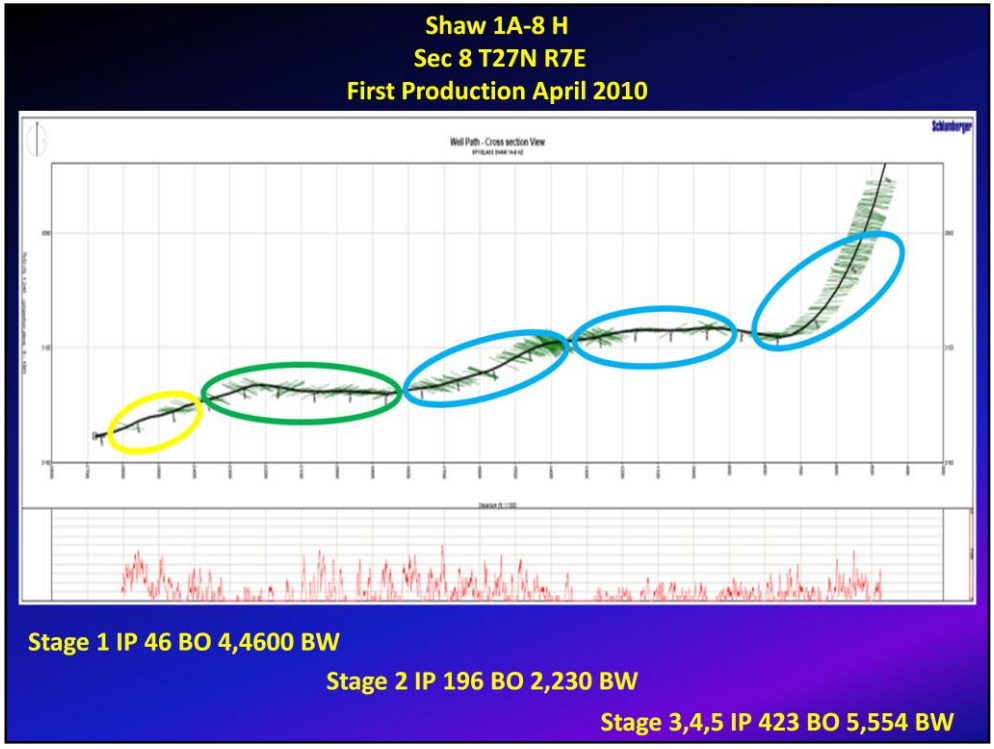


Conventional Reservoir
First Production June 2006
Cumulative Production 176,200 BOE (89% Oil)
EUR 257,000 BOE



Conventional Reservoir
First Production April 2006
Cumulative Oil Production 110,000 BOE (88% Oil)
EUR > 200,000 BOE



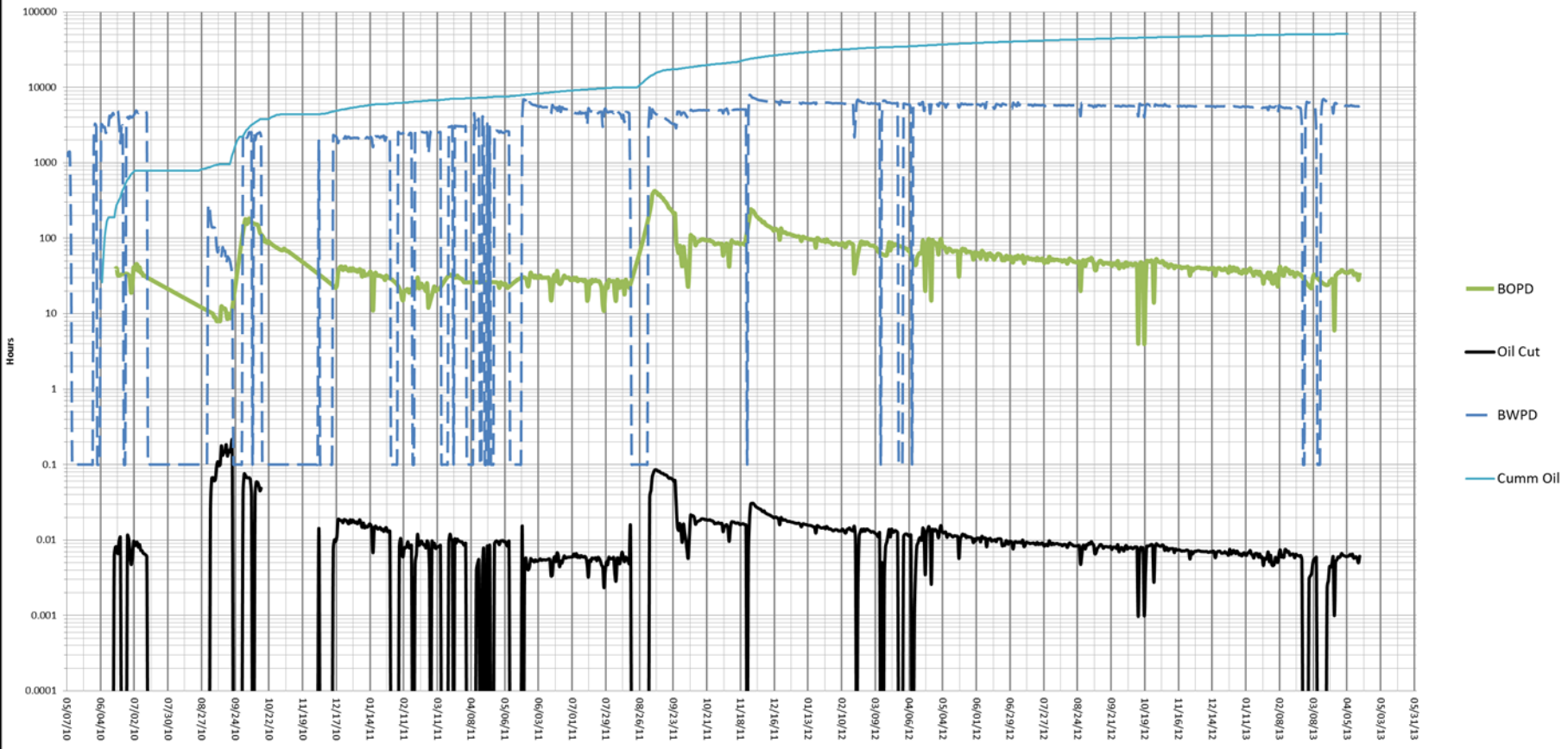


Presenter's notes: Shaw 1A-8H, drilled to ~3,100 feet TVD, has since been completed with a two-stage frac:

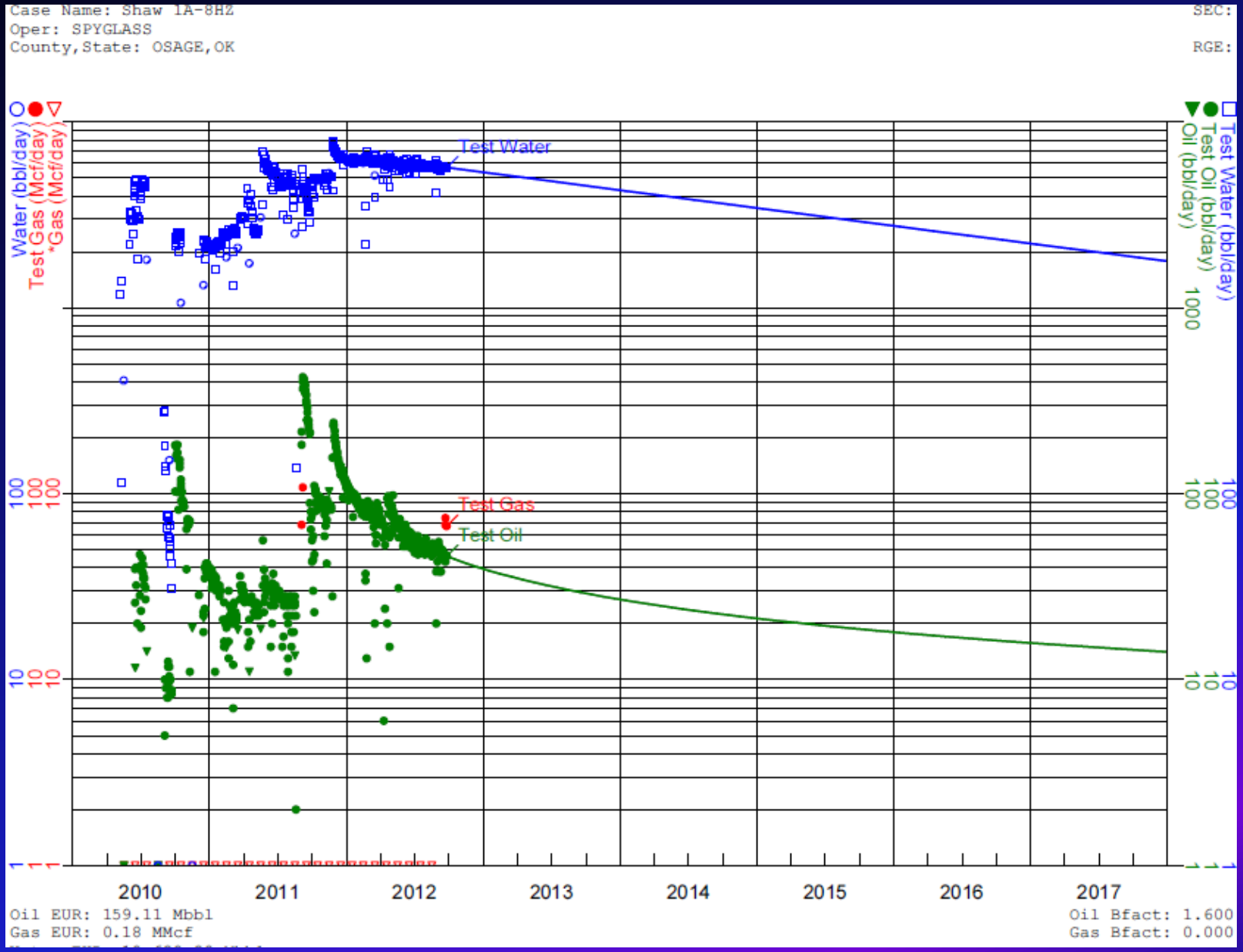
- Frac Stage 1:
  - Fracture stimulation: injected 5,600 bbl water and 50,000 lbs 20/40 sand at 60 BPM in three 5' perf clusters (2 spf).
  - IP: 50 bbl/day oil and 4,500 bbl/day water.
- Frac Stage 2:
  - Perf three 5' intervals (2 spf), light acid and swab produced 100 bbl/day fluid (20% oil cut).
  - Fracture stimulation: injected 10,000 bbl water and 21,000 lbs 20/40 sand at 45 BPM in nine 5' perf clusters (2 spf).
  - IP: ~200 bbl/day oil and 3,400 bbl/day water.
- Frac Stage 3, 4, 5
  - Four 400' Stages, Four 5' Perf Clusters, 6 SPF (120 shots), 10K BF, 50-60 BPM, 60k # 20/40 Sand, Bio-Ball Sealers.
  - IP 420 BOPD; 200' from base of Penn.

Fractures per foot from image log.

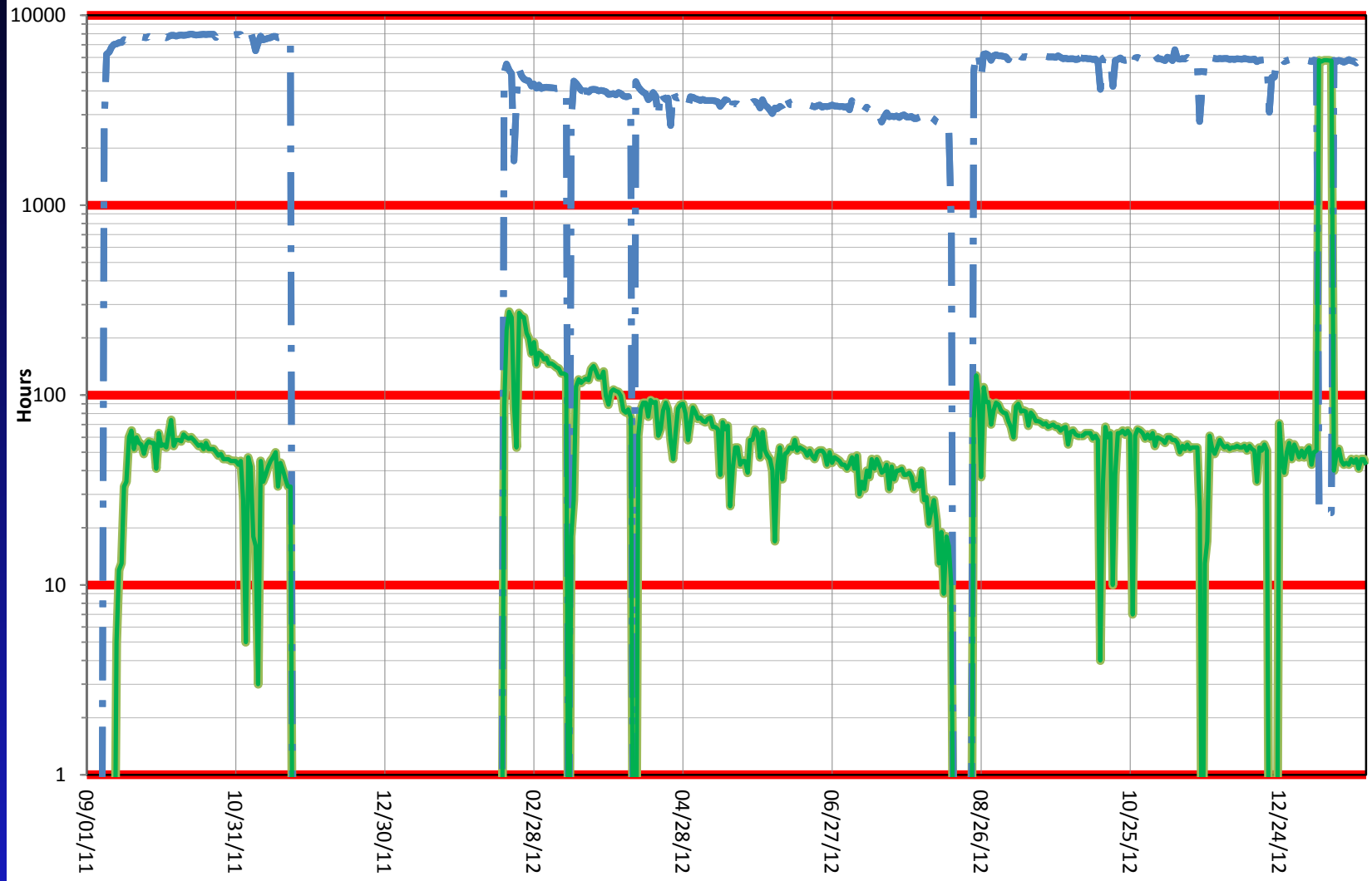
Unconventional Reservoir
First Production April 2010
Cumulative Production 52,000 BO (100% Oil)
EUR 159,000 BO (100% Oil)



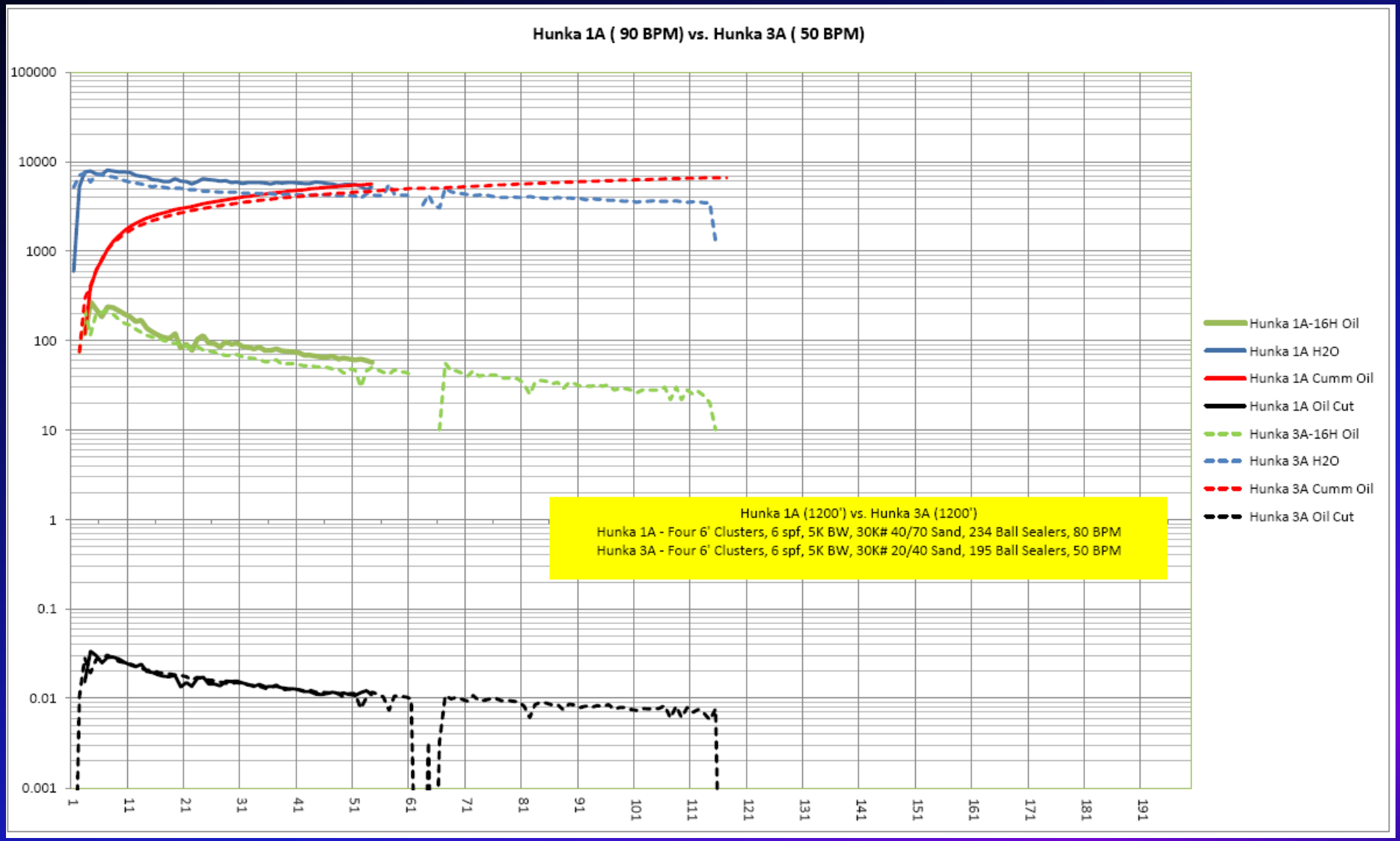
EUR 159,000 BO – 1200’ Lateral



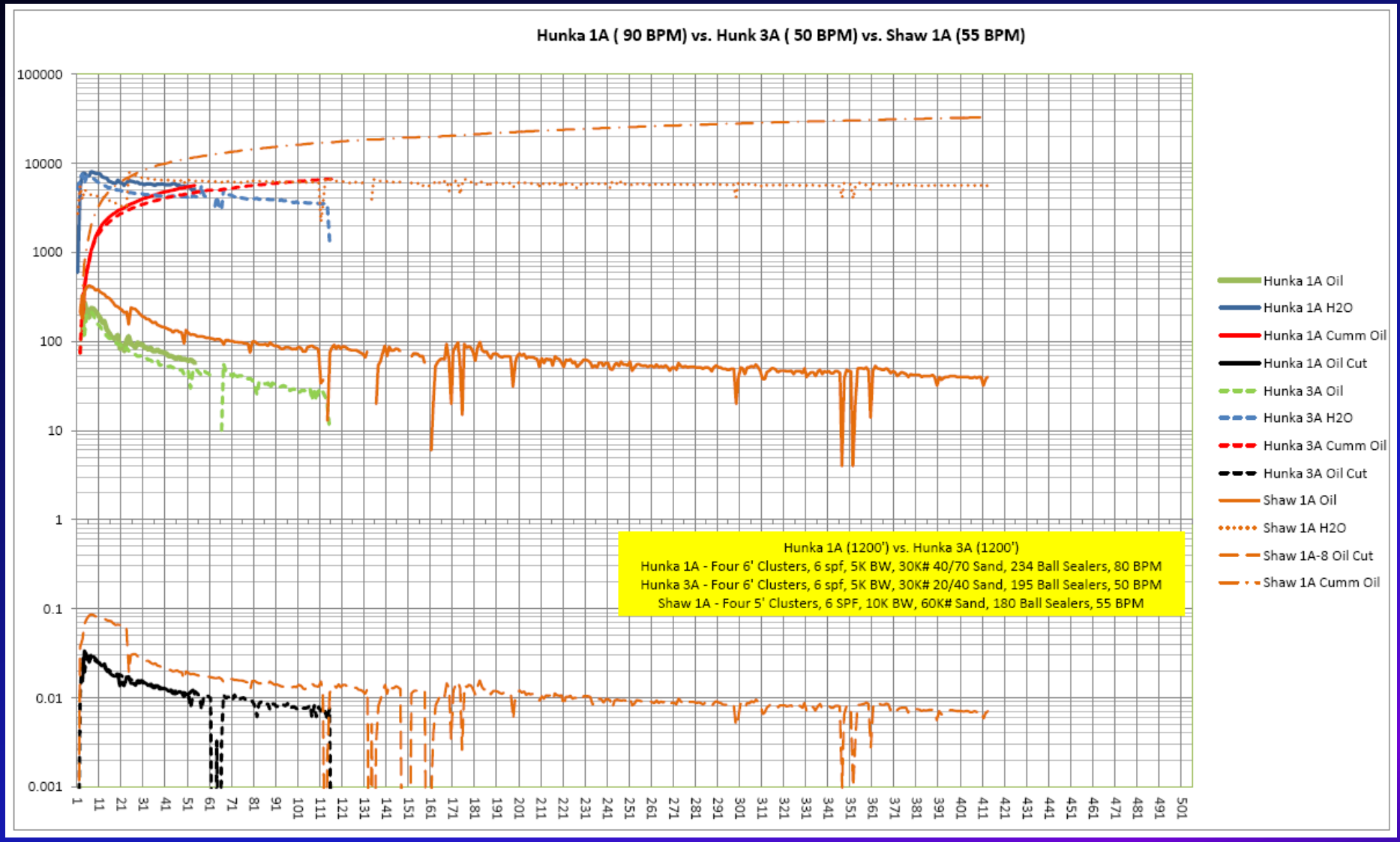
Unconventional Reservoir
Cumulative: 30,500 BO
EUR 133,00 BO (1900’ lateral)



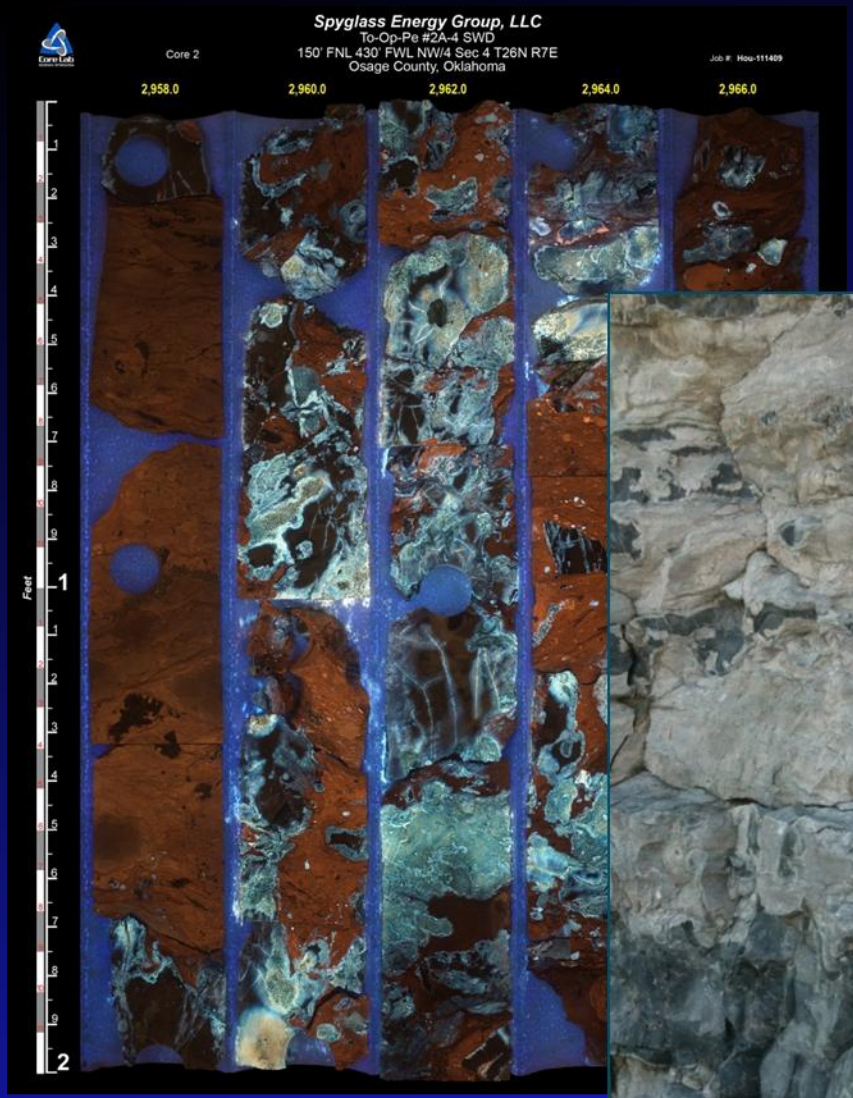
Osage B Unaltered – 50 BPM vs. 80 BPM

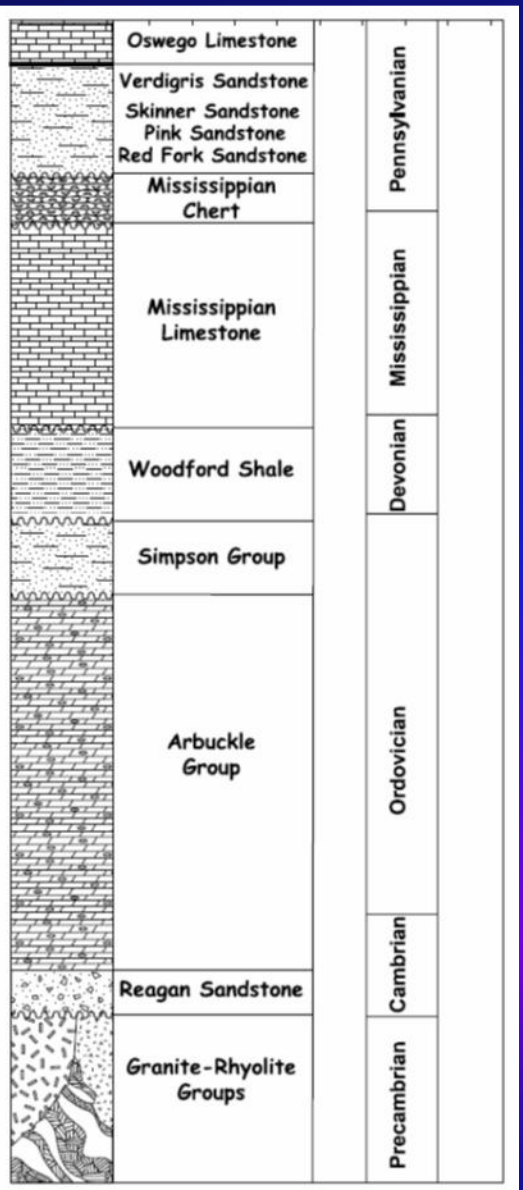


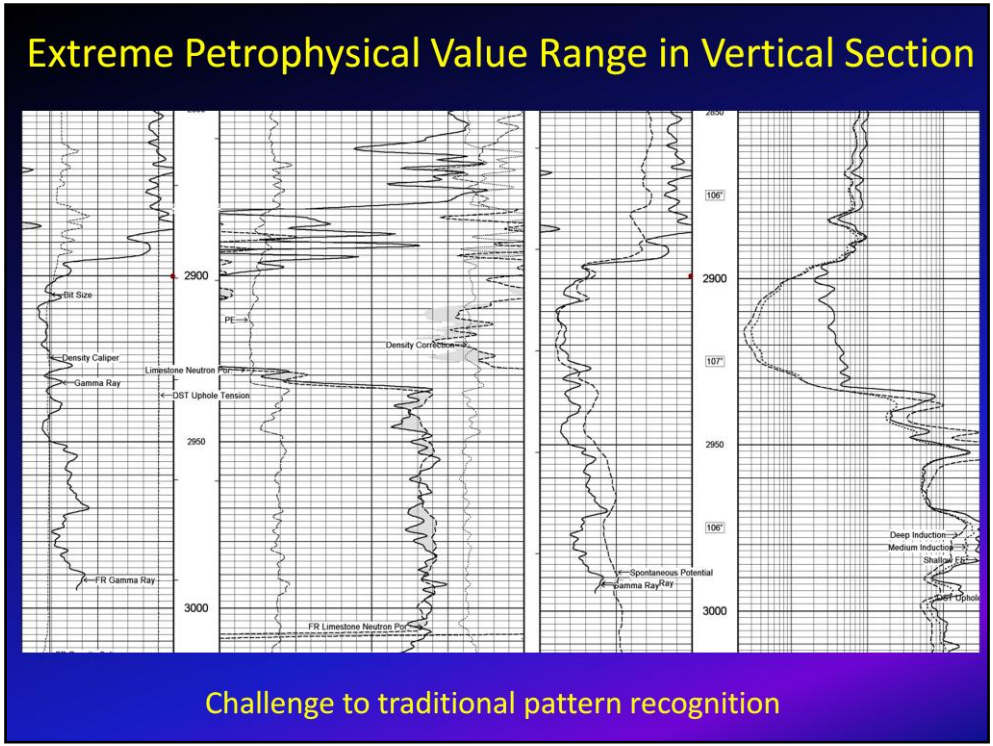
Osage B – Unaltered – 5K BW vs. 10K BW (3X improvement)



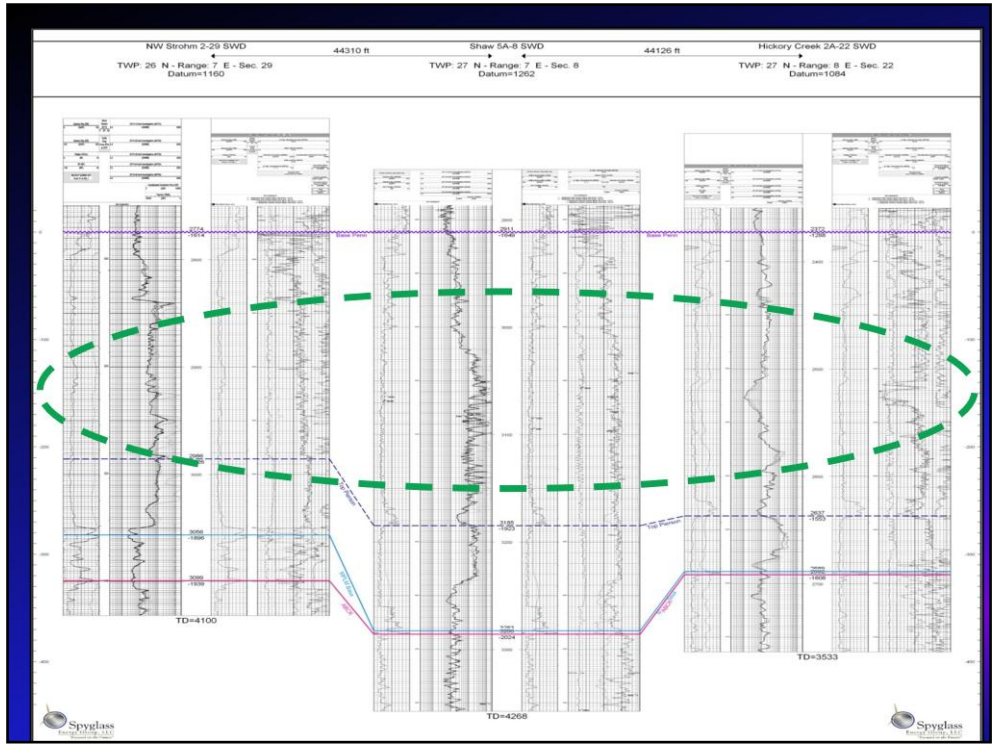
Geological Observations



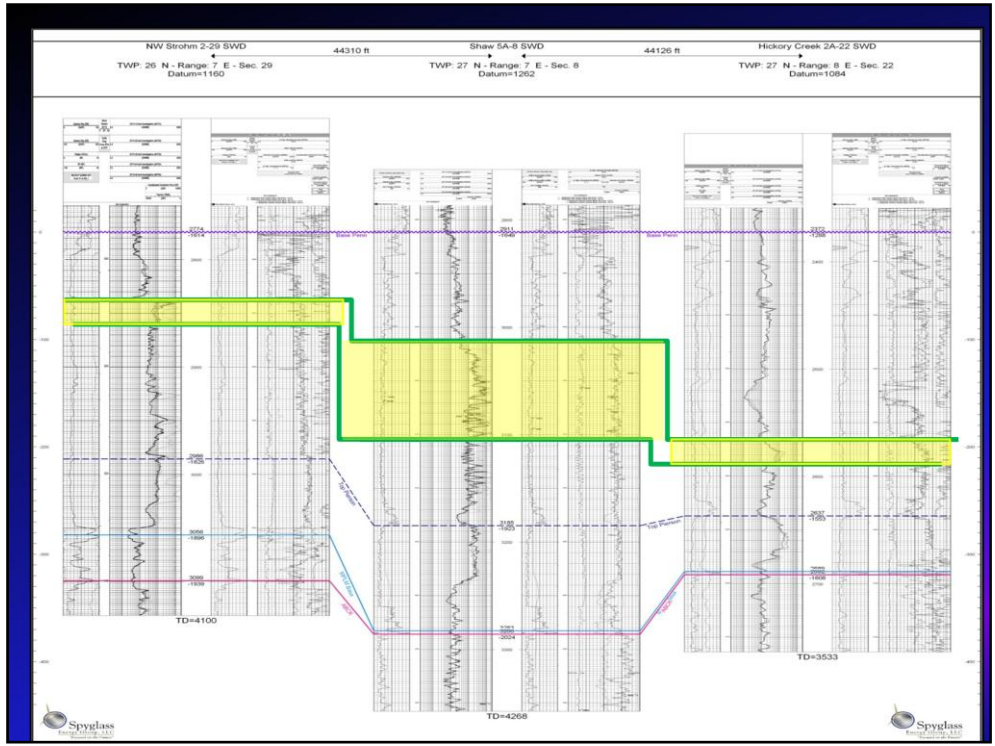




Presenter's notes: In 2003 Charles Wickstrom, then Exploration Manager of Ceja Corporation, put 200,000 acres together for a large 3D seismic program to hunt the HW 60 Tripolite subcrop play. Between 2003 and 2007 seventeen hz wells were drilled and completed. In the process a great deal was learned about the internal trapping of the high-porosity system. A great deal was also re-learned by a new generation of geologists.



Presenter's notes: For 100 years geologists have isopached and structure-mapped the Miss. What we have yet to accomplish is a meaningful inter-Mississippian diagenetic/facies map.



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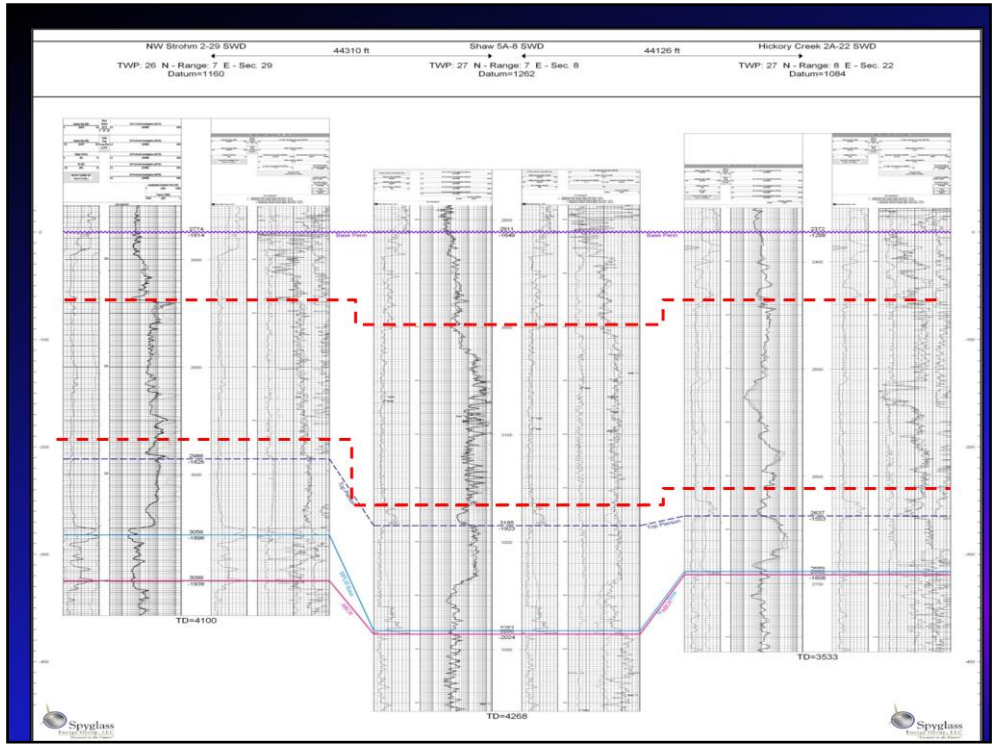

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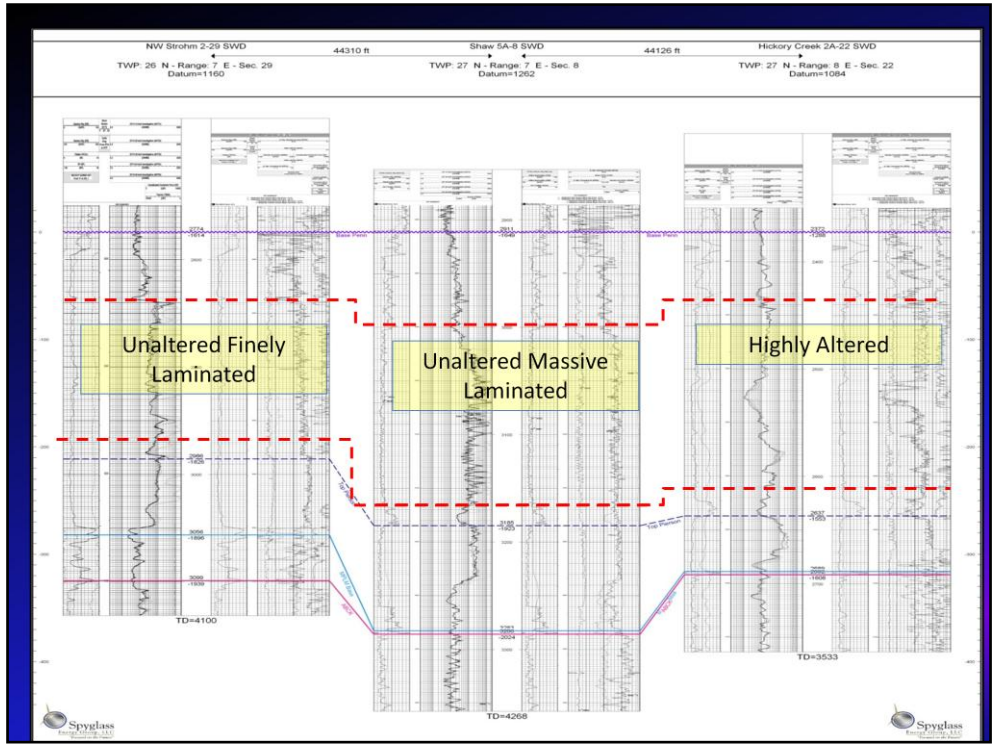

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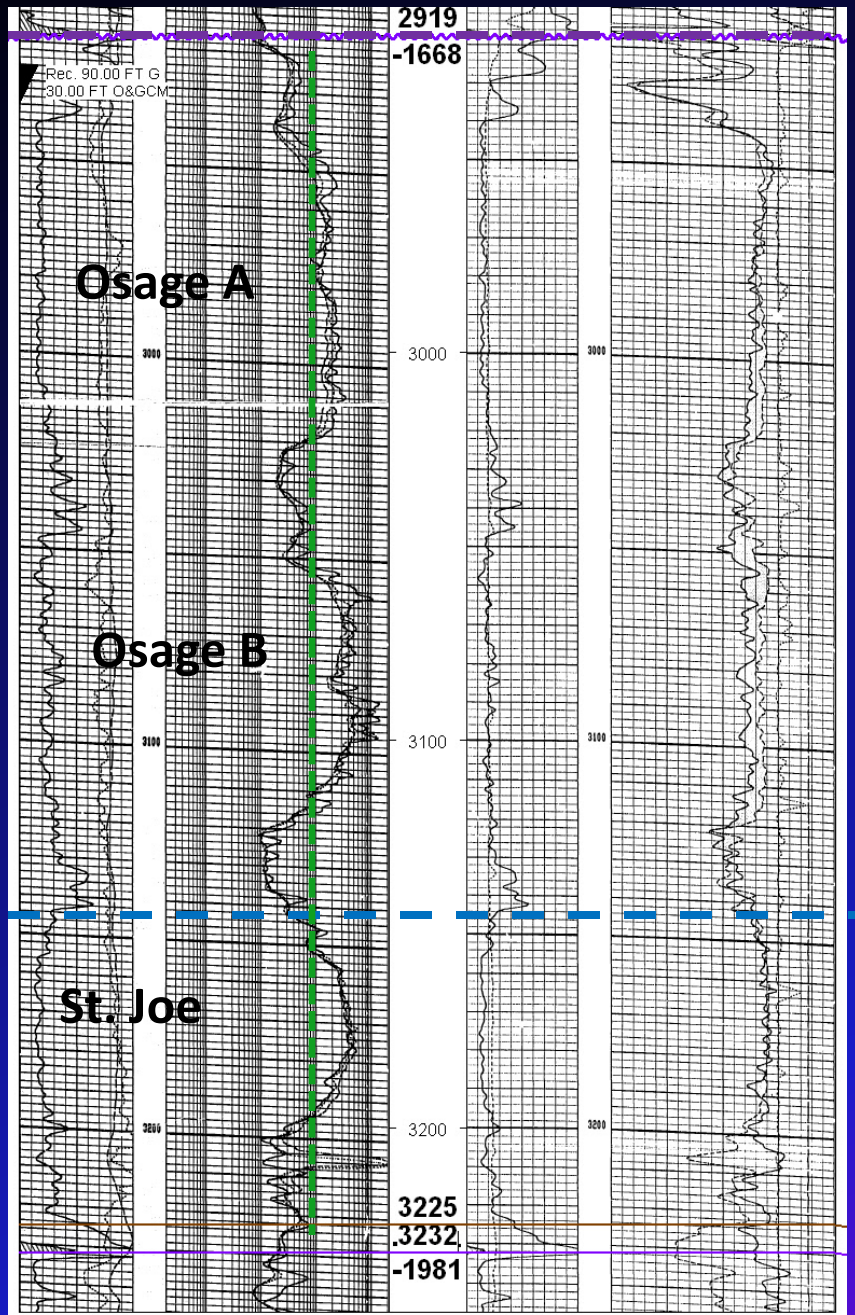
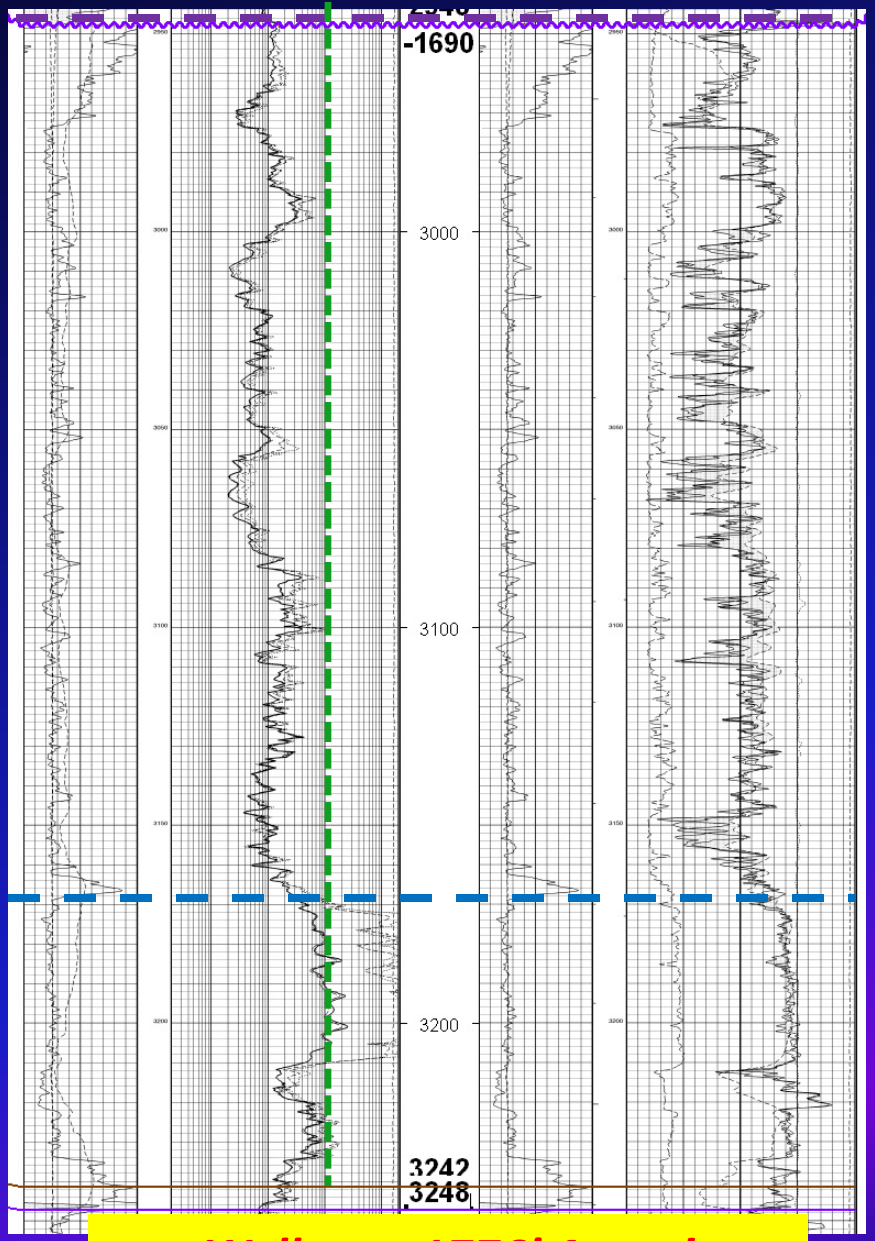
Architecture of the Reservoir





Wells are 1776' Apart!

Historical Perspective

A special problem that we have been dealing with in the last few years is the one where we are concerned about the variation in the fluid levels within what we identify as a single reservoir. What I am referring to is the fact that we can have the following fluid levels in a particular well –

Gas, Oil, Water;
Then just Oil;

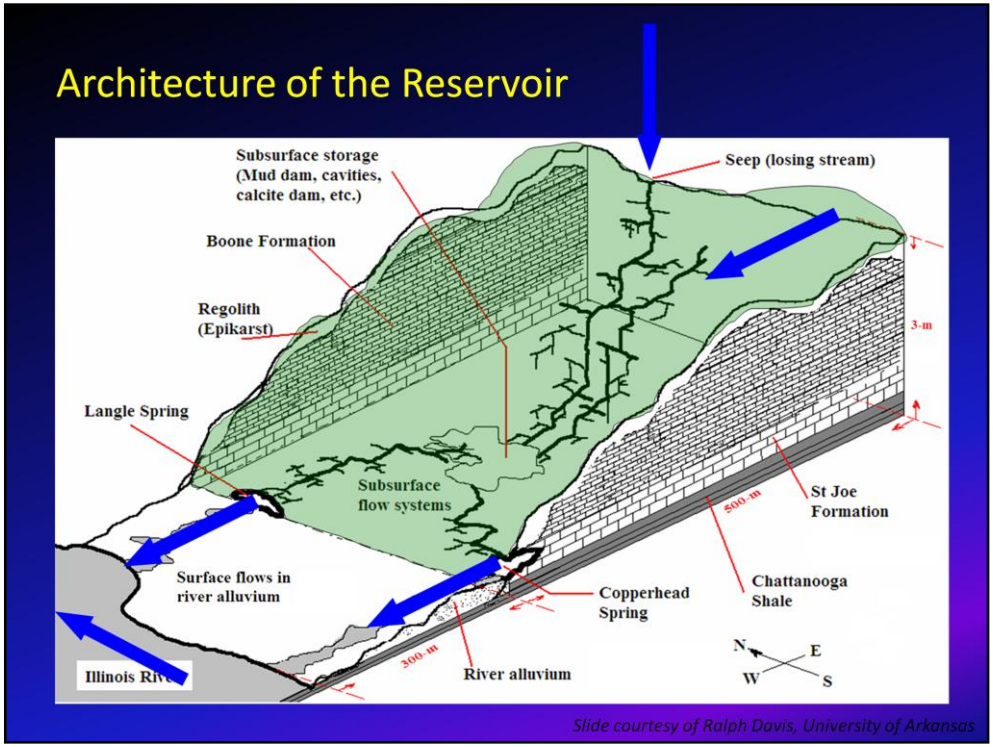
Then just Gas and Water;
Then just Gas;

Then Oil , Water;
And then just Water;

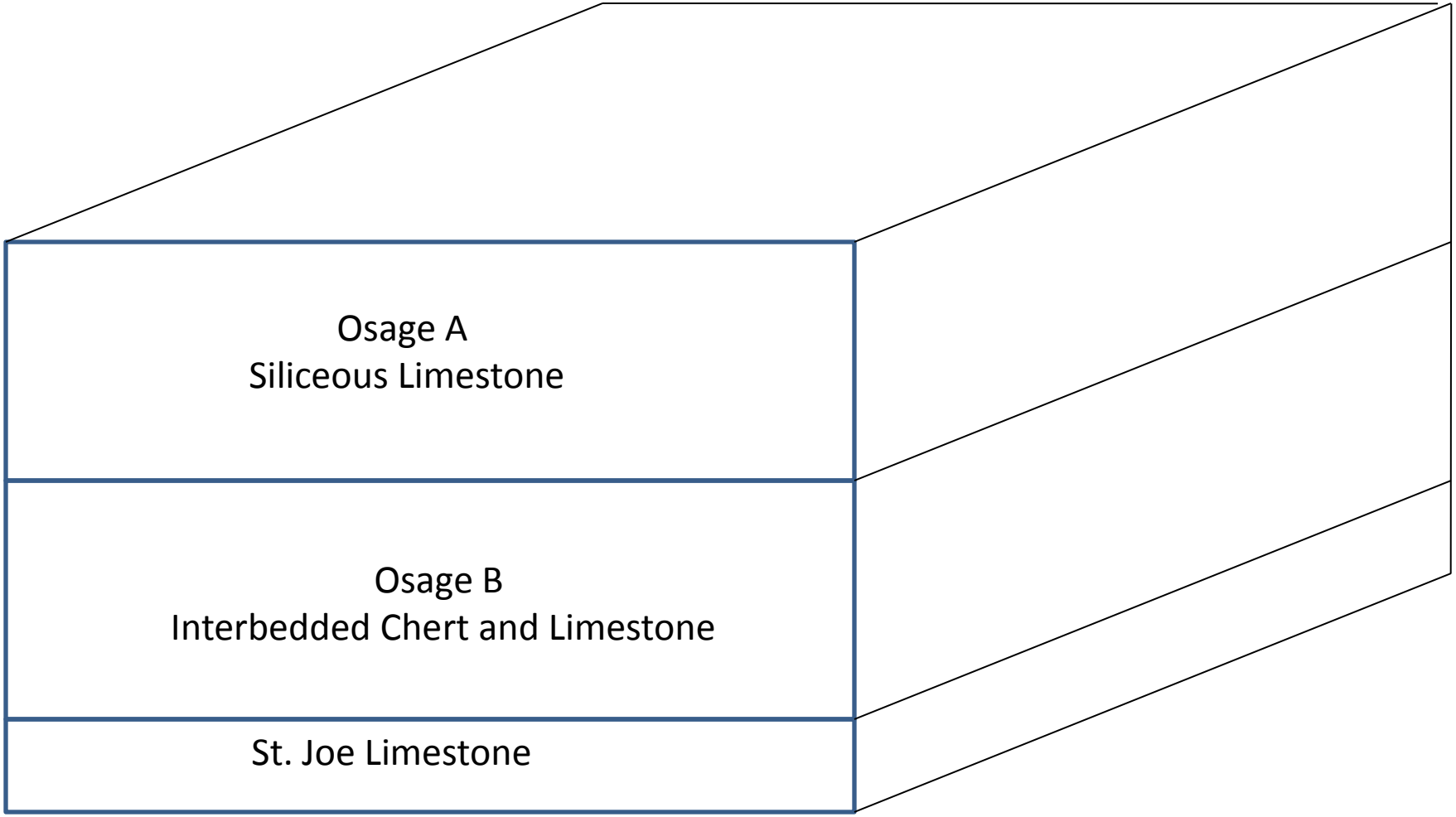
then another zone back to Oil or Gas. We may not have this particular sequence in any one well but we may have any kind of sequence such as this one.

Rick P. Clinton
Symposium of the Mississippian of Oklahoma and Kansas
TGS Digest, Volume 27, 1959

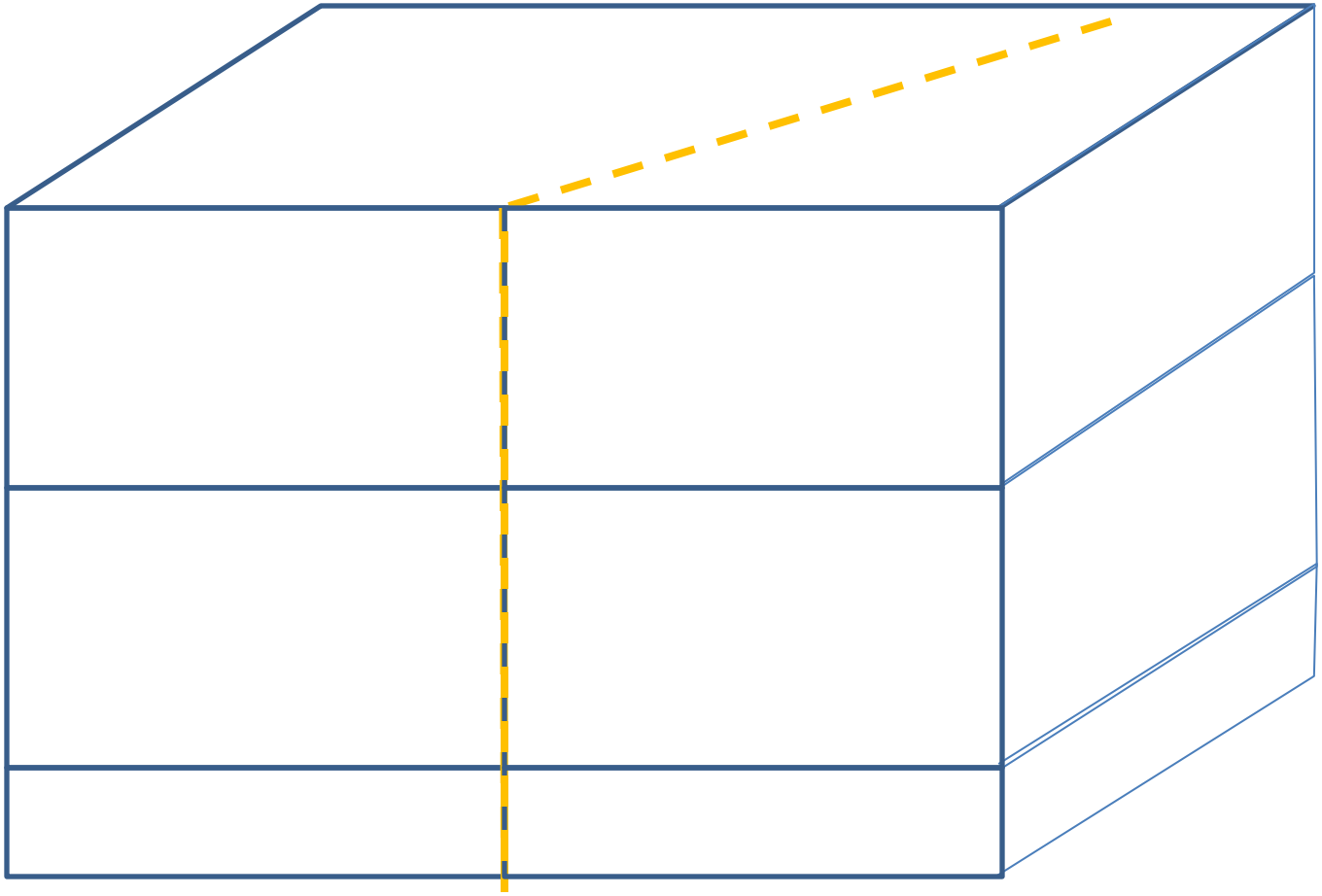
Presenter's notes: Left: Bella Vista road cut on Hwy 540; right: Jane Missouri road cut on hwy 540.



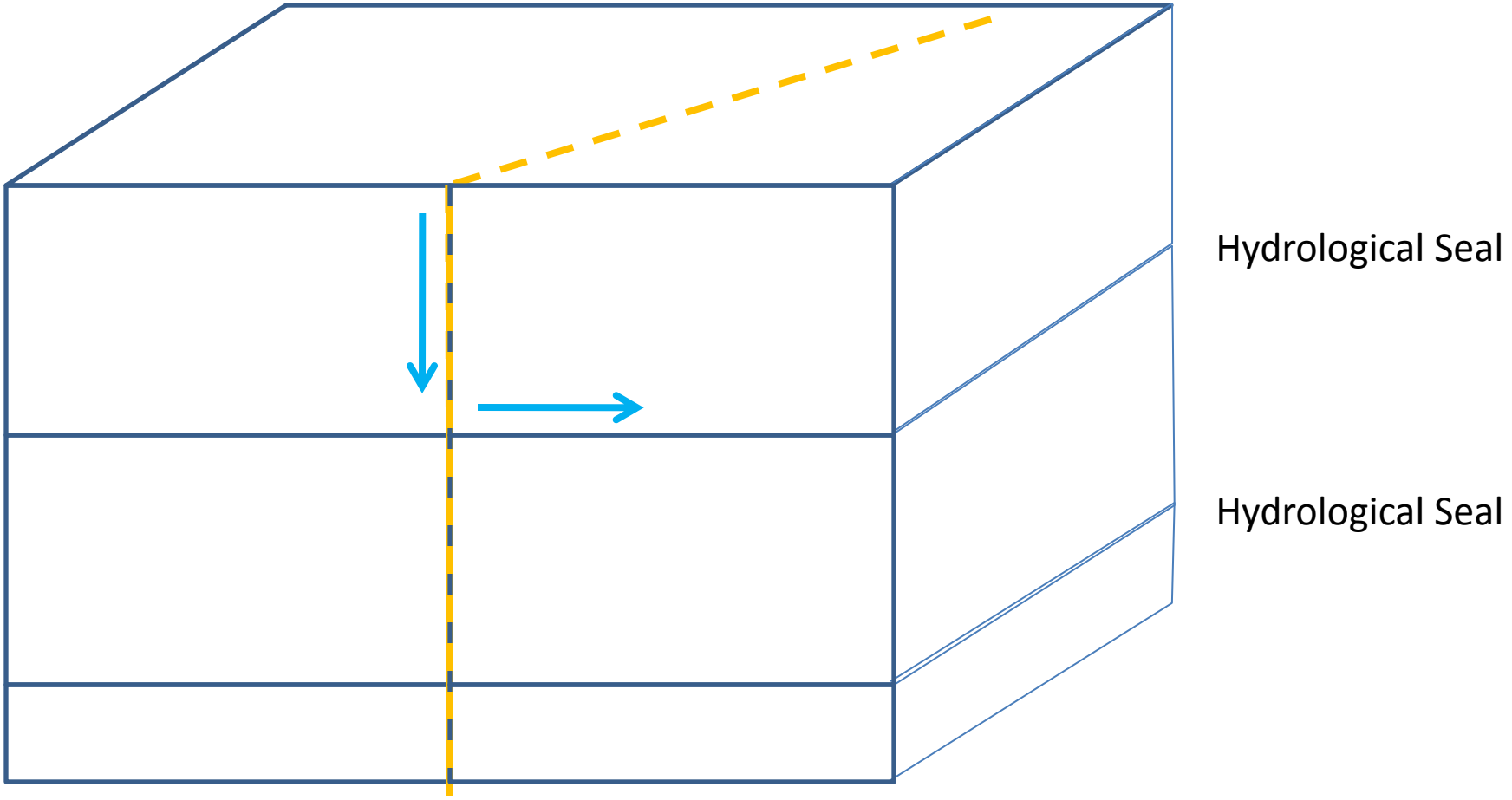
Presenter's notes: Fine-grained carbonate sands deposited on ramp.
Early diagenetic chert--Preferential replacement based on depositional facies (even low-energy deposition is differentiated by grain size across a spectrum).
Proto-Ouachita Transpressional Tectonics
Mississippian – Pennsylvanian Unconformity--Meteoric impact greatest on pre-existing tectonic weakened lineaments.
Deposition of Penn Shales
Continued wrenching of NE Oklahoma – Cracking of the brittle section
Hydrothermal fluids of unknown origin move laterally through section.
Tripolization by dissolution of lime
Hydrocarbon filling of traps – world's largest stratigraphic trap?
Ozark Uplift--Reversal of dip from west to the east
Leak-off of hydrocarbons in high porosity traps
Hydrocarbon Refill of traps
Breaching of the reservoir
Extensional faulting and fracturing due to removal of overburden.
Water moves through the system sweeping higher porosity lithologies.



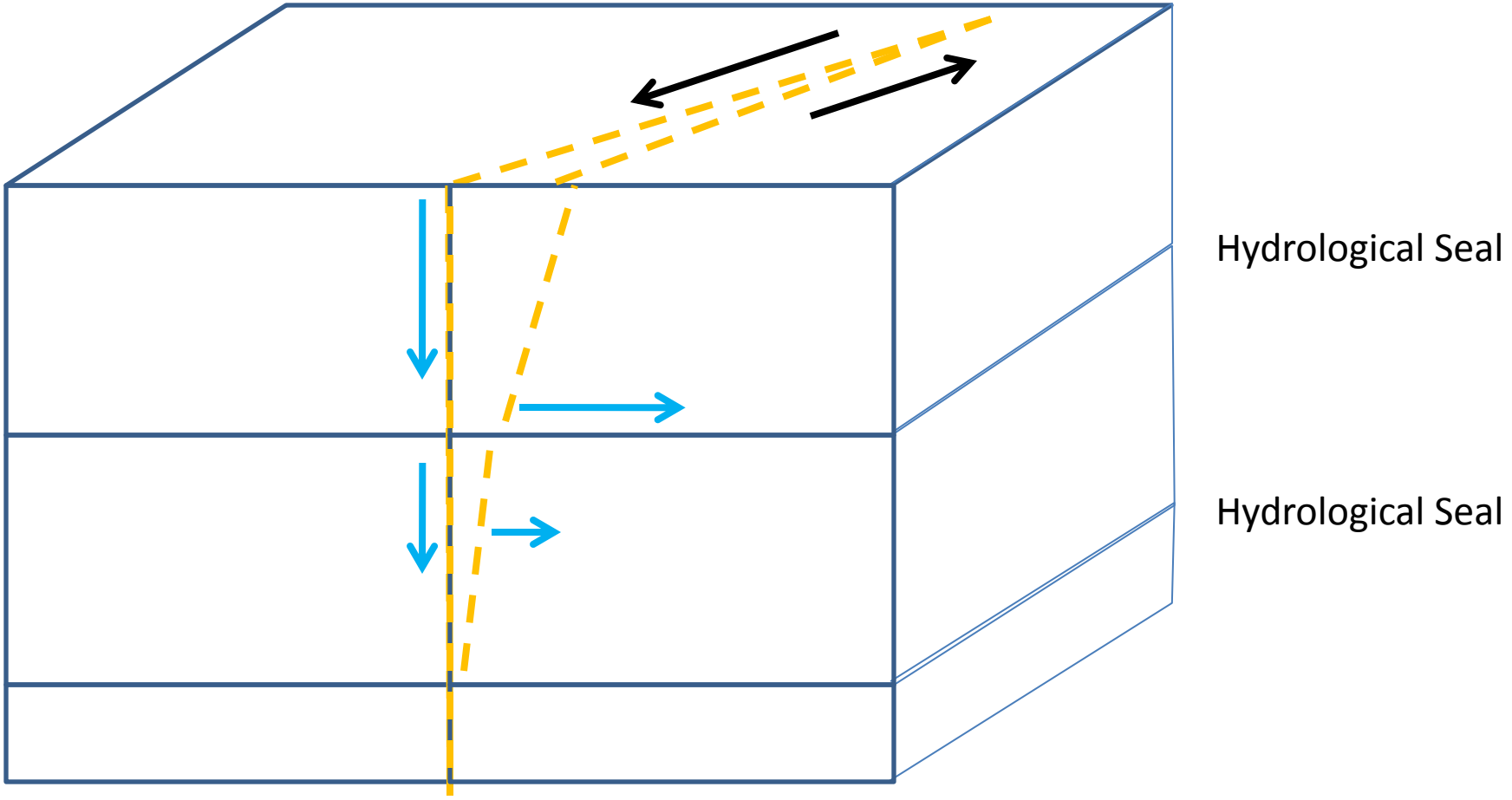
Deposition of system



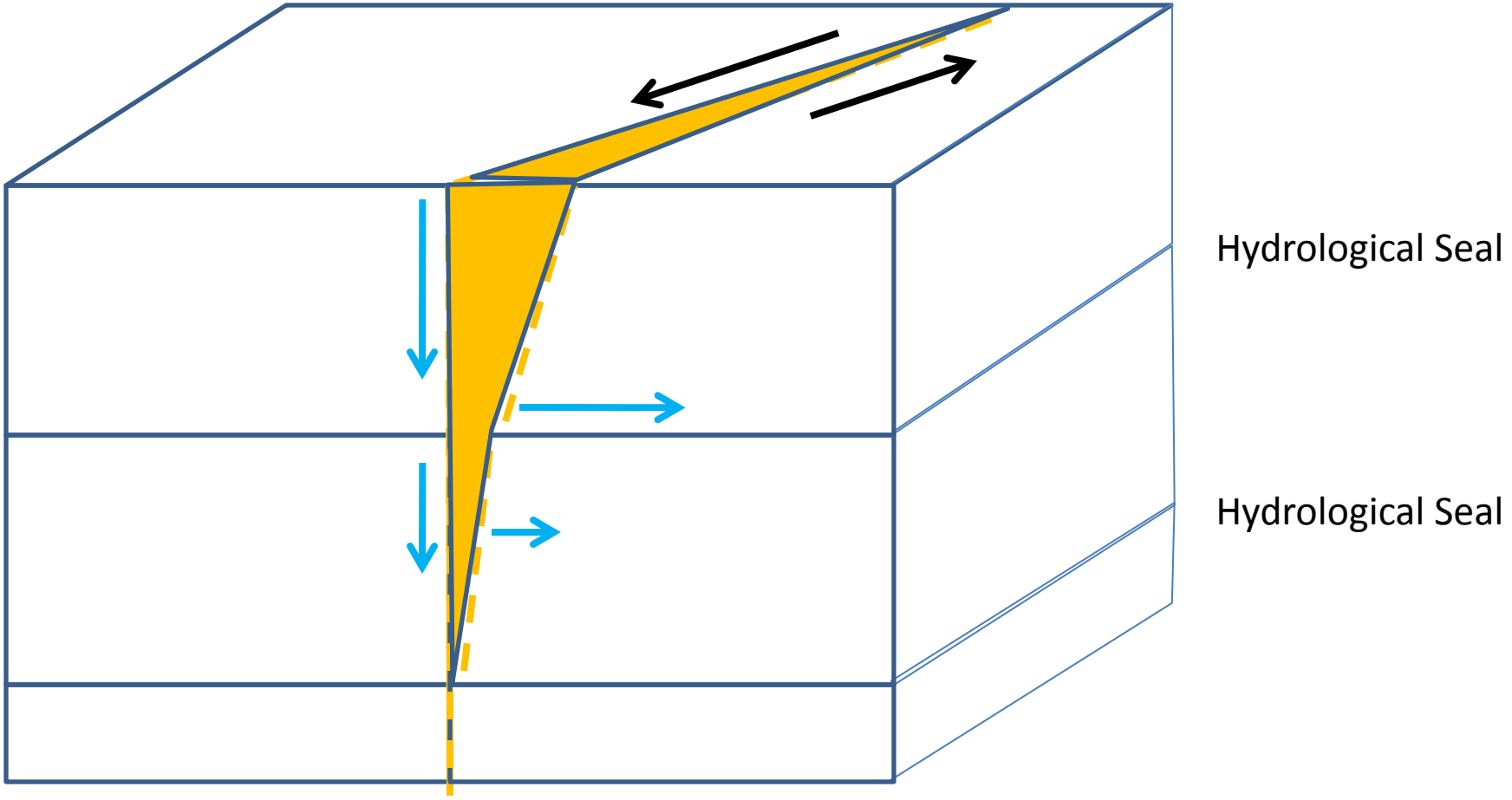
Meteoric processes effect Surface for a really long time



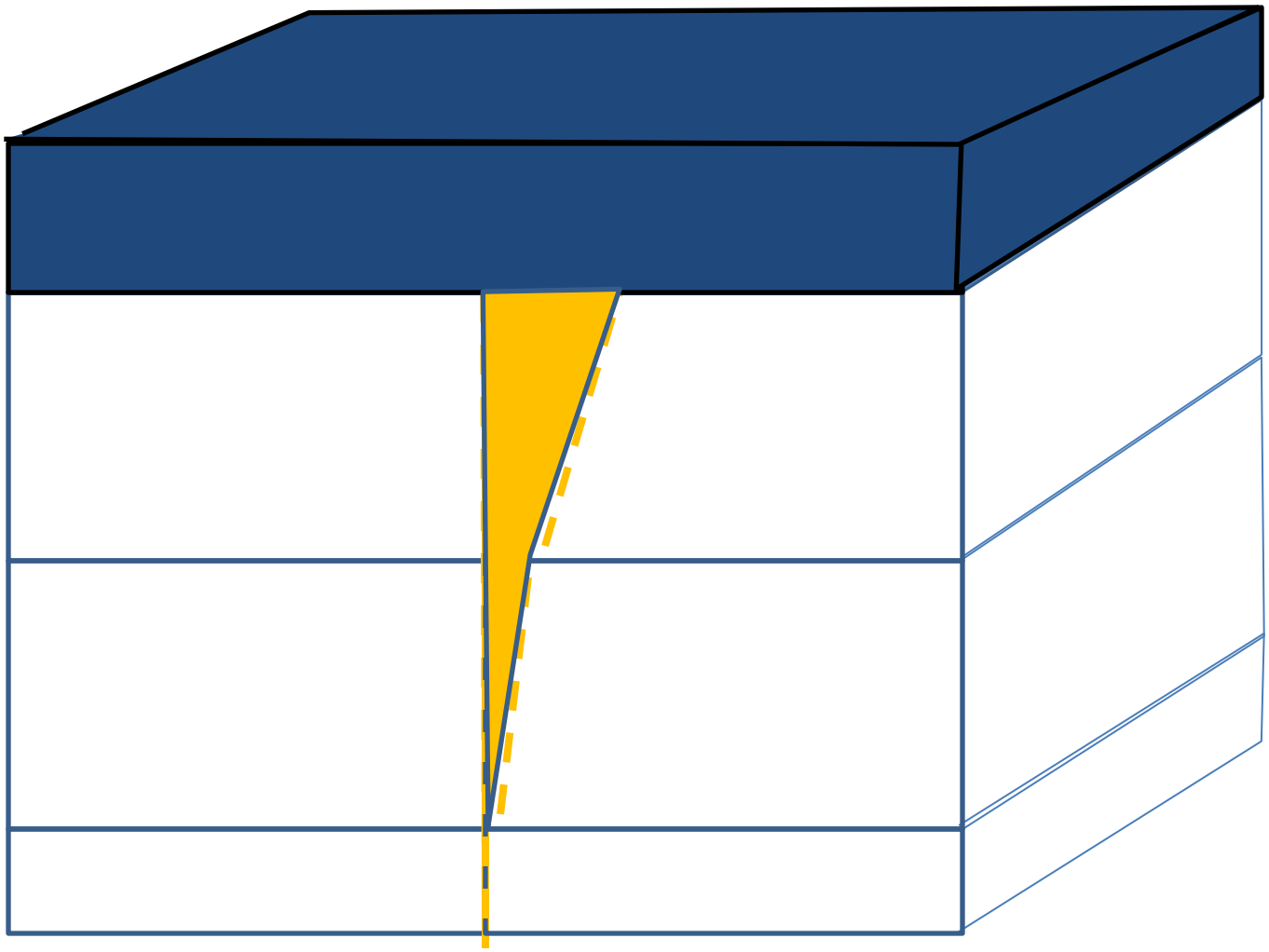
Osage A is affected most significantly by meteoric process



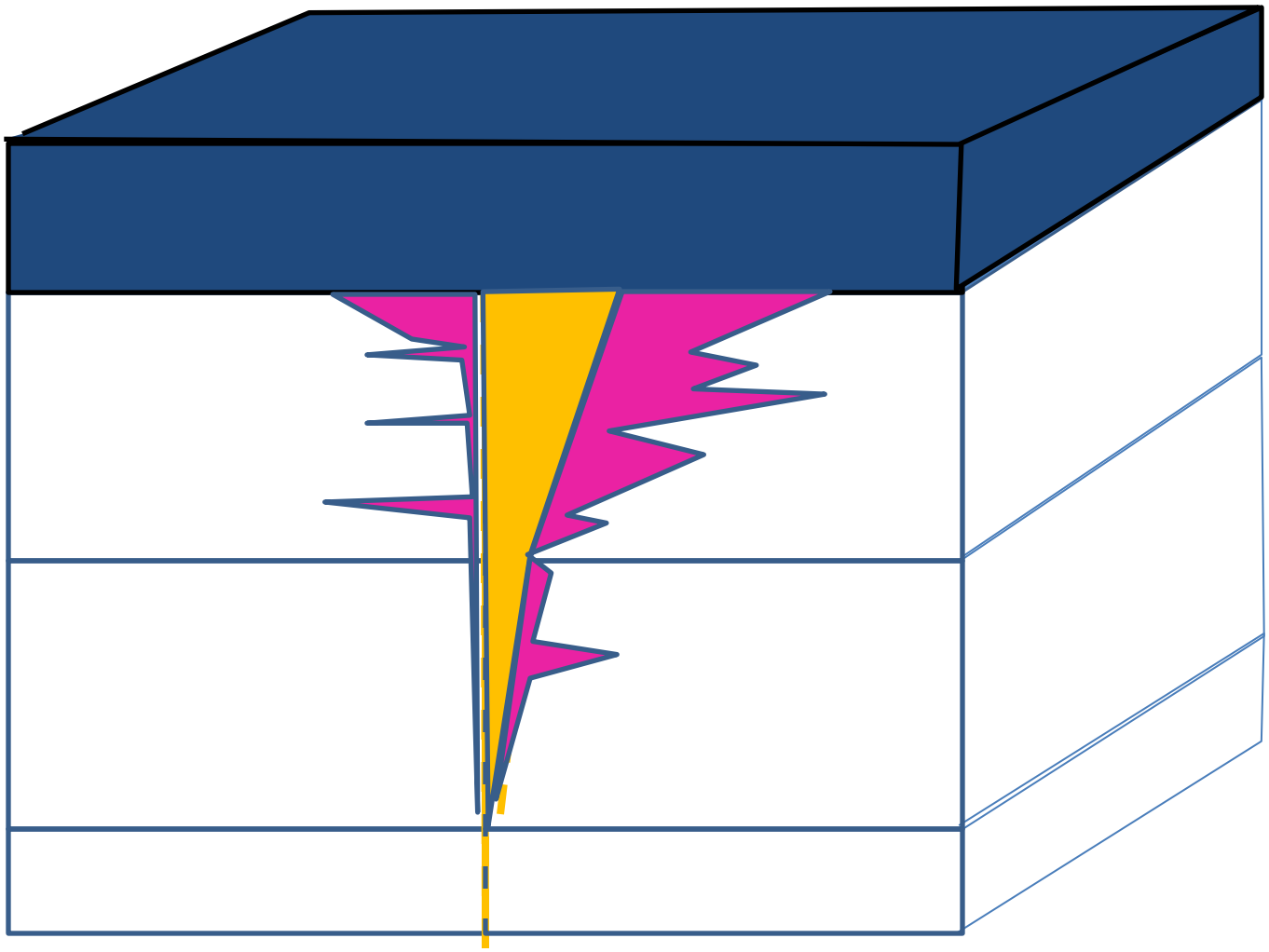
Proto-Ouachita Tectonics induce wrenching of Cherokee Platform



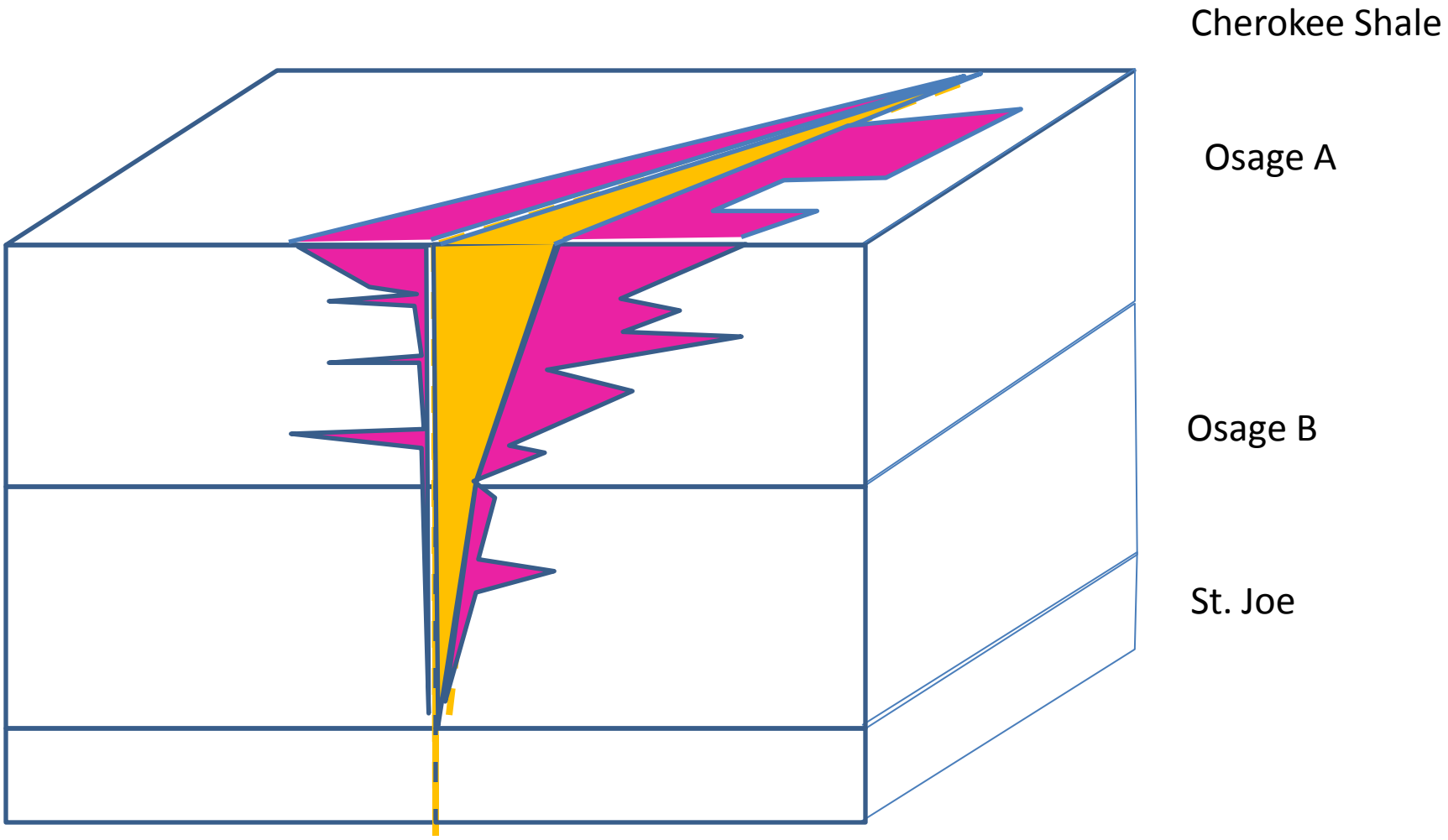
Osage A is affected most significantly



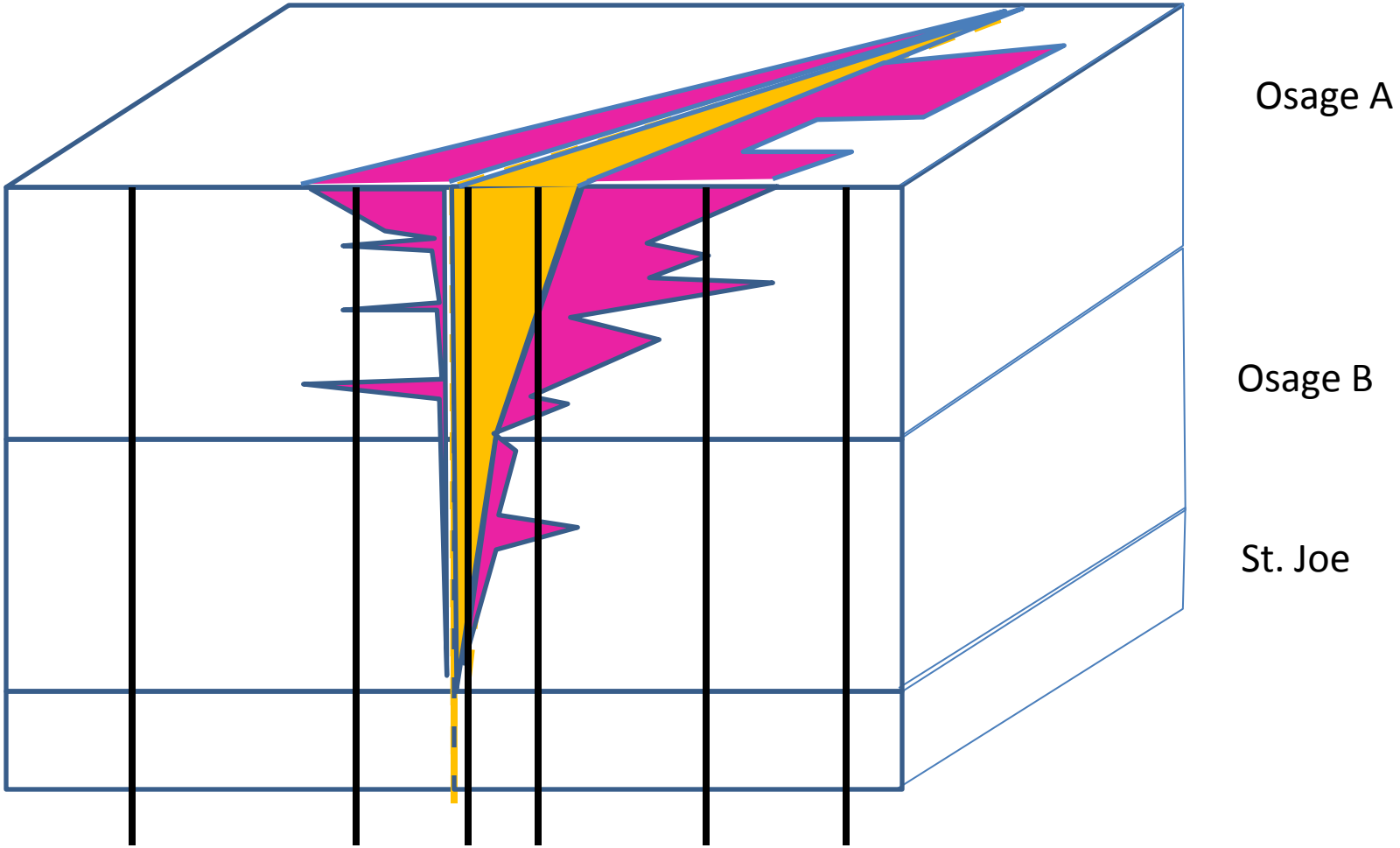
Cherokee transgression and burial



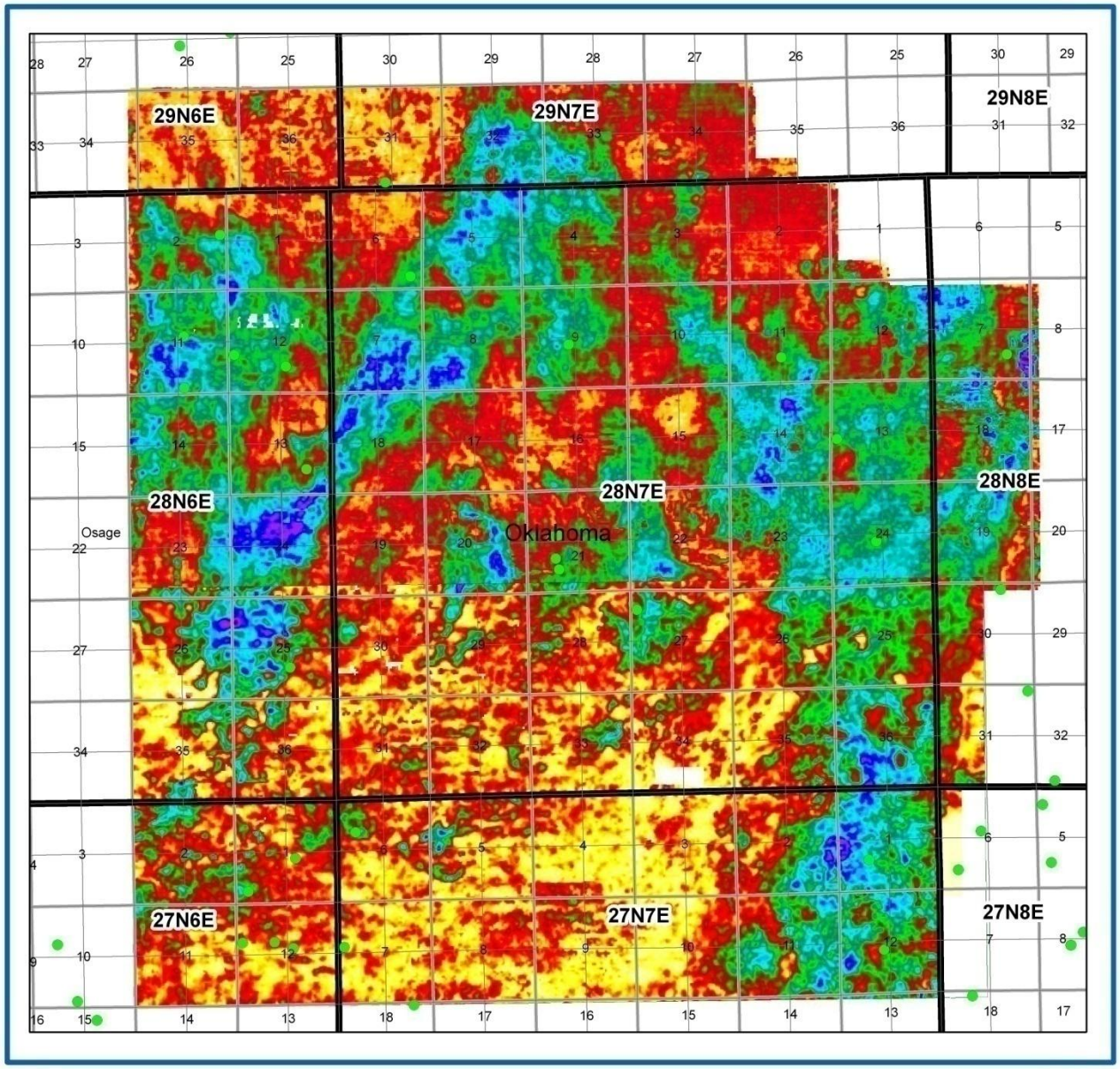
Hydrothermal fluids preferentially migrate through Osagean lithologies due to brittleness of rock and meteorically enhanced lineaments



Map view of tripolite development - post-hydrothermal alteration


Osage A
Osage B
St. Joe

MississippSeismic “Chat” Stratigraphy



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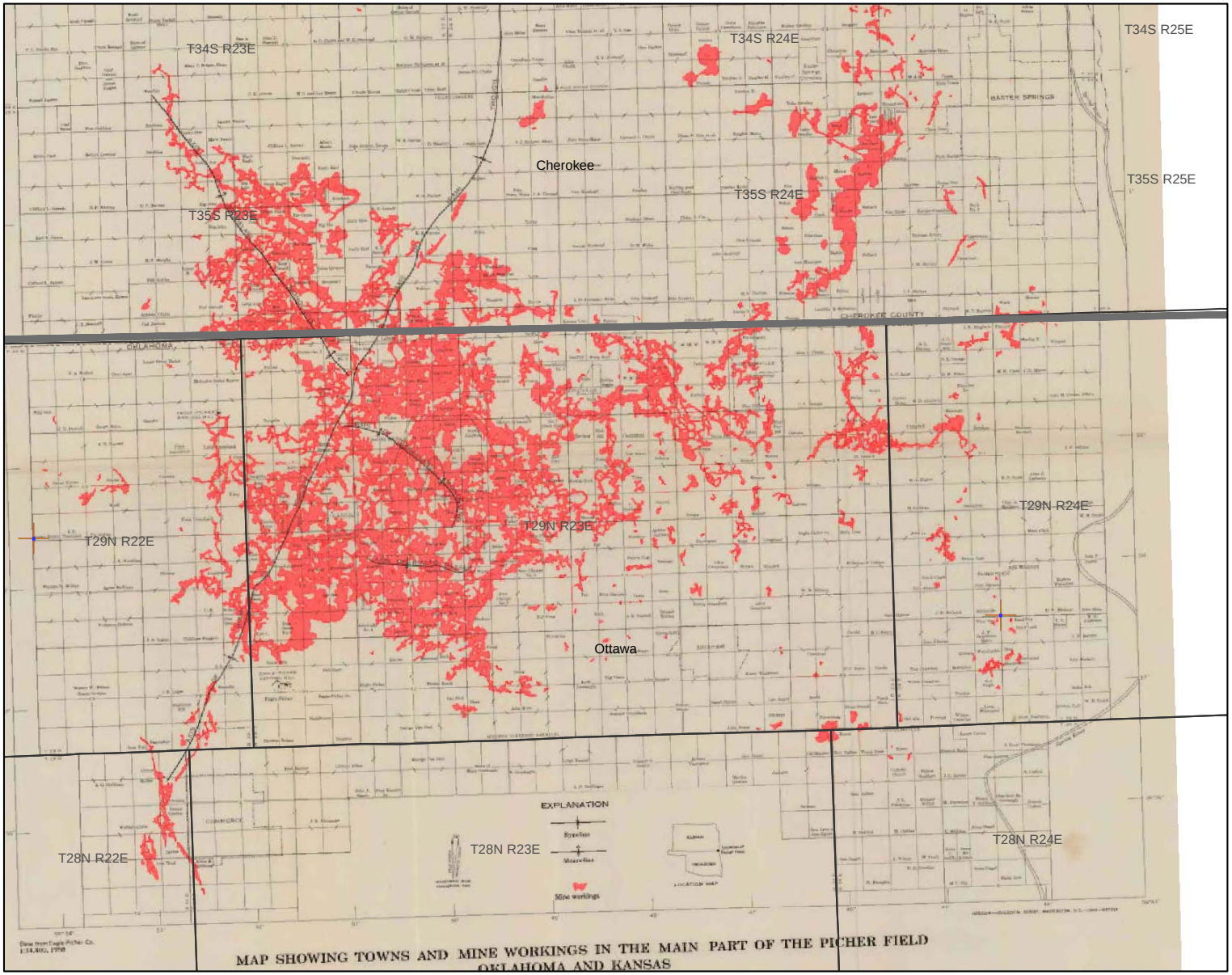
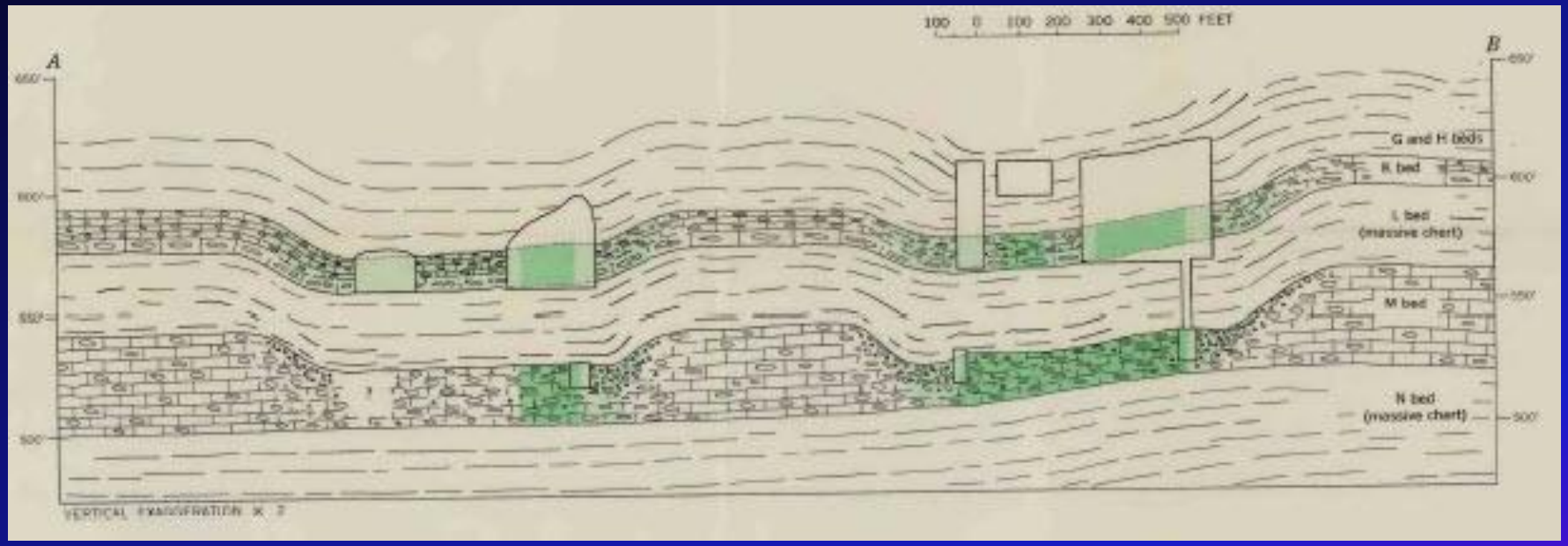


Plate 11 - Mine Workings of the Picher Field

The Tri-State host rock is Mississippian chert breccias and tripolites in a horst and graben terrain



3500’

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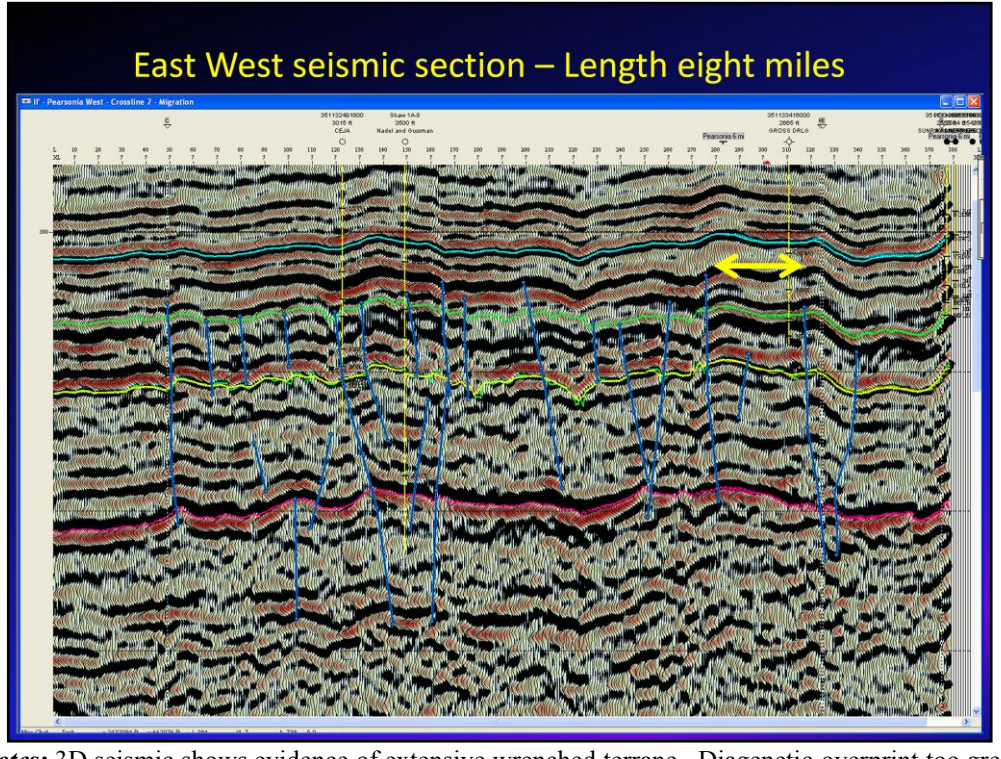
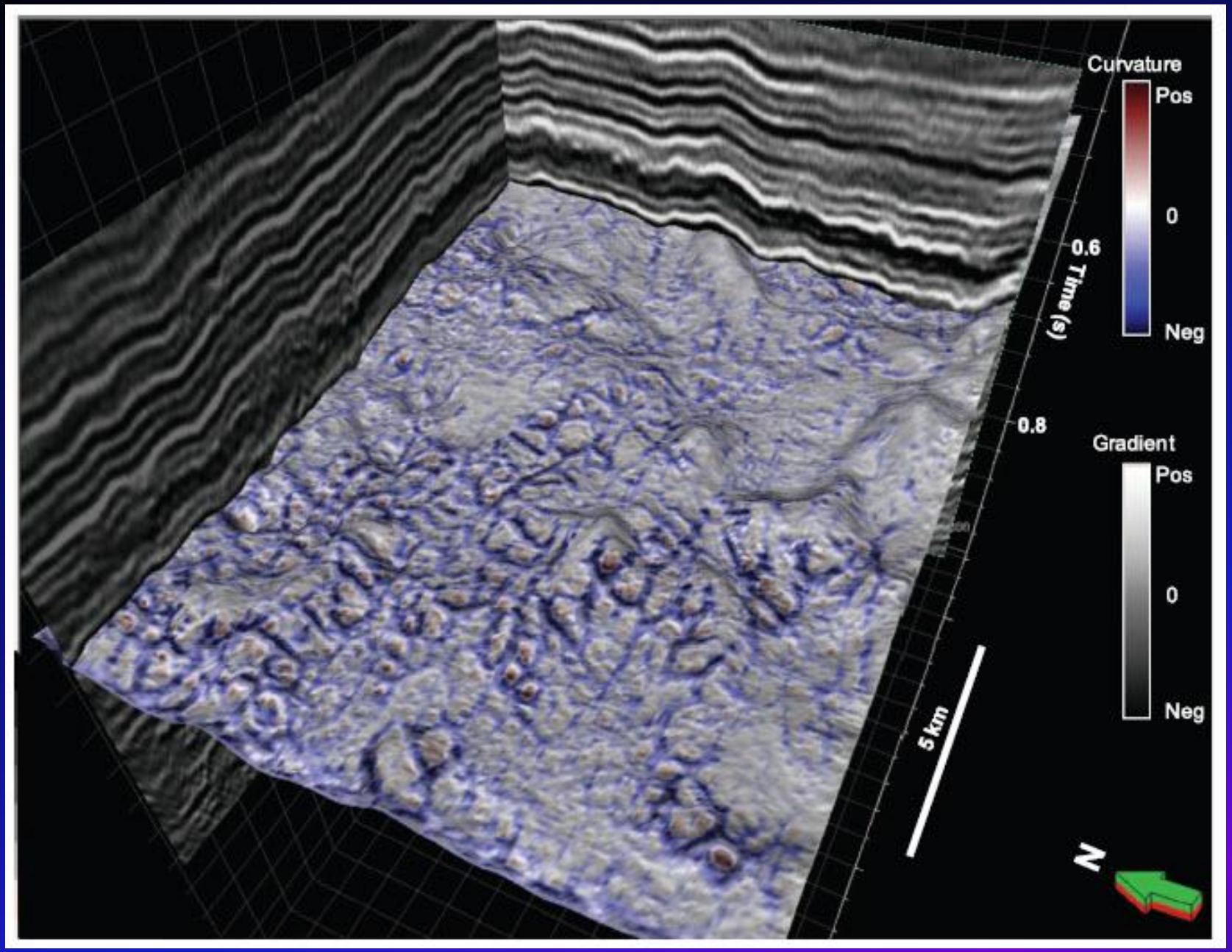


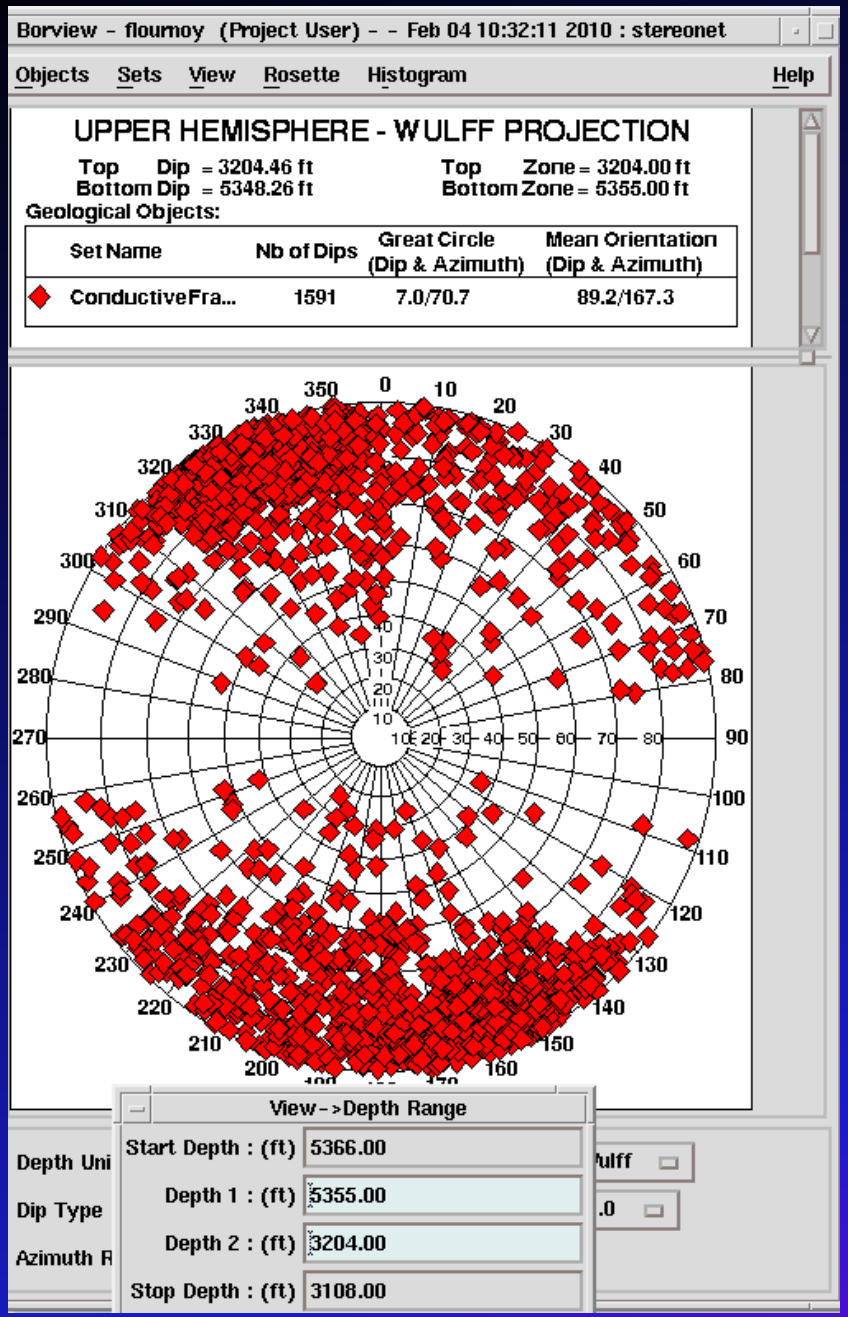
Presenter's notes: 3D seismic shows evidence of extensive wrenched terrane. Diagenetic overprint too great and spatial density of wells too sparse to recognize strike-slip fault systems.

Mississippian Seismic Horizon Slice – Most Negative Curvature

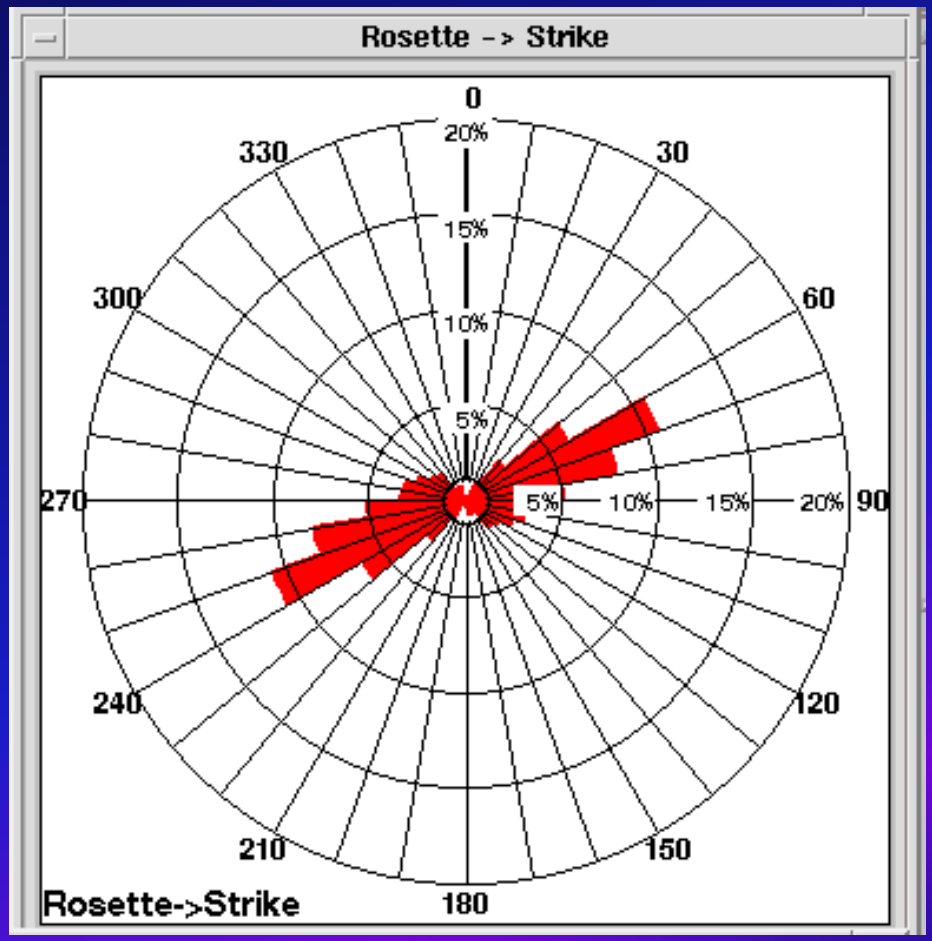


Bunmi Et Al., 2011

Image Log Fracture Quantification – Shattered Rock



- 2350’ of lateral interpreted
- 1591 open natural fractures
- Fracture Density – 10 / ft
- Strike N 70 E



Conclusions

- A confluence of events at play
- Structural trends inform reservoir character
- This play is about water
- Thoughtful stimulation
- Standing on the shoulders of giants
- Much of the acreage is emerging
  - Hundreds of new wells will be coming on line in 2013

An opportunity must be provided for those men with the capacity and with the ability for doing creative geology to actually do geology, and in addition, to be able to spend a part of their time with their feet on a desk looking out of the window where they can generate ideas and where they can reconstruct in their mind the conditions and the environments of past geologic ages.

A. I. Levorsen

Discovery Thinking

The Bulletin of the American Association of Petroleum Geologists

Vol 27, No. 7, July, 1943