# Anadarko Woodford Shale: Improving Production by Understanding Lithologies/Mechanical Stratigraphy and Optimizing Completion Design*

**Craig D. Caldwell[1] and Philip G. Johnson[1]**

Search and Discovery Article #80288 (2013)**
Posted May 20, 2013

*Adapted from oral presentation given at AAPG Education Directorate Woodford Shale Forum, Oklahoma City, Oklahoma, April 11, 2013..
Editor's note: Please refer to two earlier, related articles by the above first author on the subject, "Lithostratigraphy of the Woodford Shale, Anadarko Basin, West-Central Oklahoma," Search and Discovery Article #50518 (2011) and "Rock Types of the Devonian Woodford Shale, Anadarko Basin, West-central Oklahoma," Search and Discovery Article #10425 (2012).


[1]Cimarex Energy Co., Tulsa, OK (ccaldwell@cimarex.com)

## Abstract

Since late 2007 over five hundred horizontal Woodford wells have been completed in the Anadarko Woodford play, west-central Oklahoma, along a northwest-southeast trend approximately 100 miles (161 km) in length and 25 miles (40 km) wide. Shallowest production to date occurs at approximately 8500 ft. (2590 m) along the east side of play, and deepest production occurs at 16100 ft. (4900 m) along the southwest margin of the play.

Seven mudrock lithologies, defined on the basis of percent quartz, clay, dolomite, and TOC, make up the 15 lithostratigraphic units that compose the Basal, Lower, Middle, and Upper Woodford in the central part of the Anadarko Woodford play (Canadian County). The Lower, Middle, and Upper Woodford in this area are of approximately equal thickness (70 to 100 ft/21 to 30 m). This area of thick total Woodford (175 to 330 ft/53 to 100 m) overlies an erosional Hunton thin. By contrast, the Basal Woodford, 10 to 50 ft (3 to 15 m) thick in the central part of the play, thickens to over 100 ft (30 m) to the southwest.

The Basal Woodford in the central part of the Anadarko Woodford play is composed of organic-poor, clayey mudrock (OPCM) characterized by 41 to 52% clay, core-analysis, gas-filled porosities of 1 to 4.5%, and TOC values of generally 0.5 to 4.0%. The Lower and Middle Woodford units in the central part of the play are made up of 10 to 30 ft (3 to 9 m) intervals dominated by one of three lithologies: clayey mudrock (CM) (38% clay and 41% quartz), clayey siliceous mudrock (CSM) (27% clay and 55% quartz), and less common dolomitic clayey mudrock (DCM) (33% clay, 32% quartz, and 15% dolomite). These mudrock lithologies generally have core-analysis, gas-filled porosities averaging 5.6 to 6.8% and TOC values averaging 5 to 6.5%. The Upper Woodford is predominantly CSM and siliceous mudrock.

Siliceous mudrocks (SM) average 14.5% clay and 75% quartz. Quartz in these mudrock lithologies is predominantly biogenic but includes silt-size detrital grains. Clay is predominantly illite, and dolomite is generally ferroan. Sedimentary structures, while dominated by parallel lamination, include burrows, millimeter-scale scour surfaces, and rare soft-sediment-deformation features. SM and CSM display bed-limited dolomite-healed fractures.

In the central part of the play the density/neutron log response has a strong relationship with clay and silica content as determined by XRD. Silica-rich mudrock intervals (SM and CSM) display density/neutron cross-over and are readily distinguishable from clay-rich intervals (CM, DCM and OPCM). Thus, mudrock lithologies and lithostratigraphic units can be mapped using density/neutron logs.

Marked stratigraphic changes occur southwest of the central part of the play. In this area the Woodford is 175 to 250 ft (53 to 76 m) thick and composed largely of OPCM of the Basal Woodford and CSM and SM of the Upper Woodford. The intervening Lower and Middle Woodford in this area have thinned to a combined thickness of approximately 20 ft (6 m). North and east of the central part of the play, where the Woodford thins to between 50 and 125 ft (15 and 38 m), the Basal Woodford is absent. The Lower and Middle Woodford have markedly thinned in these areas, and the Upper Woodford makes up 50 to over 75% of the total Woodford thickness.

“Brittle” silica-rich mudrocks (SM and CSM) display mechanical properties significantly different than those of the more ductile clay-rich mudrocks (CM, DCM, and OPCM). Frac’ stages in the clay-rich lithologies frequently treat at higher pressures and are less likely to place the designed amount of proppant than those stages in the more silica-rich lithologies. Thus, mudrock lithologies and the mechanical/lithostratigraphy model developed here assist in completion design and provide information valuable to the understanding and prediction of regional variations in Woodford production.

## References Cited

Johnson, K.S., R.A. Northcutt, and G.C. Hinshaw, 2000, Petroleum production from marine clastics in Oklahoma, *in* K.S. Johnson (ed.), Marine clastics in the southern Midcontinent, 1997 symposium: Oklahoma Geological Survey Circular 103, p. 1-17.

Passey, Q.R., K.M. Bohacs, W.L. Esch, R.E. Klimentidis, and S. Sinha, 2010, From oil-prone source rock to gas-producing shale reservoir – geologic and petrophysical characterization of unconventional shale-gas reservoirs: SPE 131350, 29 p. Web accessed 27 April 2013. http://www.onepetro.org/mslib/servlet/onepetropreview?id=SPE-131350-MS

Sondergeld, C.H., R.J. Ambrose, C.S. Rai, and J. Moncrieff, 2010, Micro-Structural Studies of Gas Shales: SPE Paper 131771, SPE Unconventional Gas Conference, Pittsburg, Pennsylvania, 17 p. Web accessed 10 November 2011. Web accessed 27 April 2013. http://www.onepetro.org/mslib/servlet/onepetropreview?id=SPE-131771-MS&soc=SPE

# Anadarko Woodford Shale: Improving Production by Understanding Lithologies/Mechanical Stratigraphy and Optimizing Completion Design

**Craig D. Caldwell and Philip G. Johnson**
**Cimarex Energy Co., Tulsa, OK**


AAPG Woodford Shale Forum
April 11, 2013 Oklahoma City, OK

CIMAREX

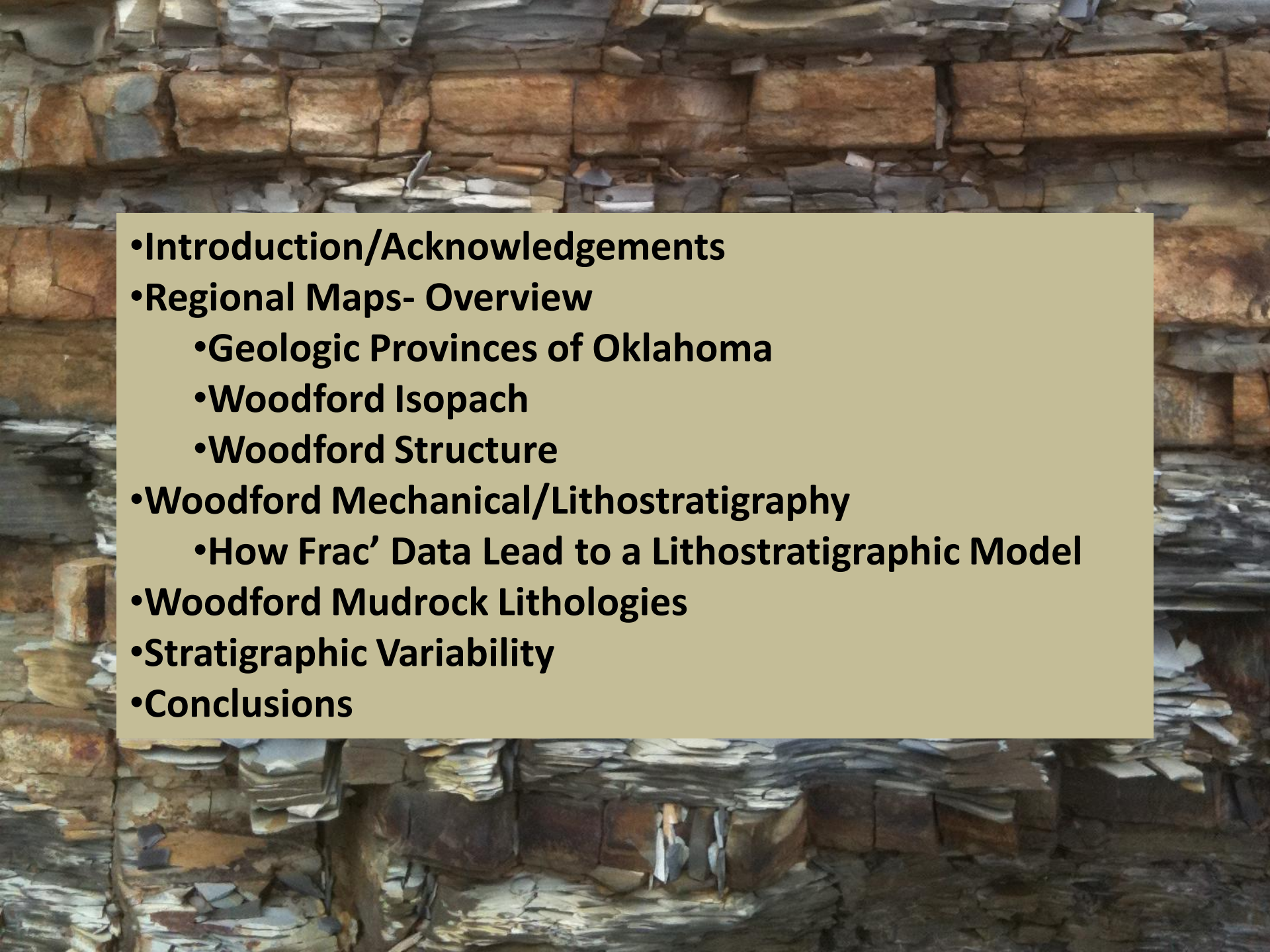

**ACKNOWLEDGEMENTS**

**Cimarex Energy Co.**

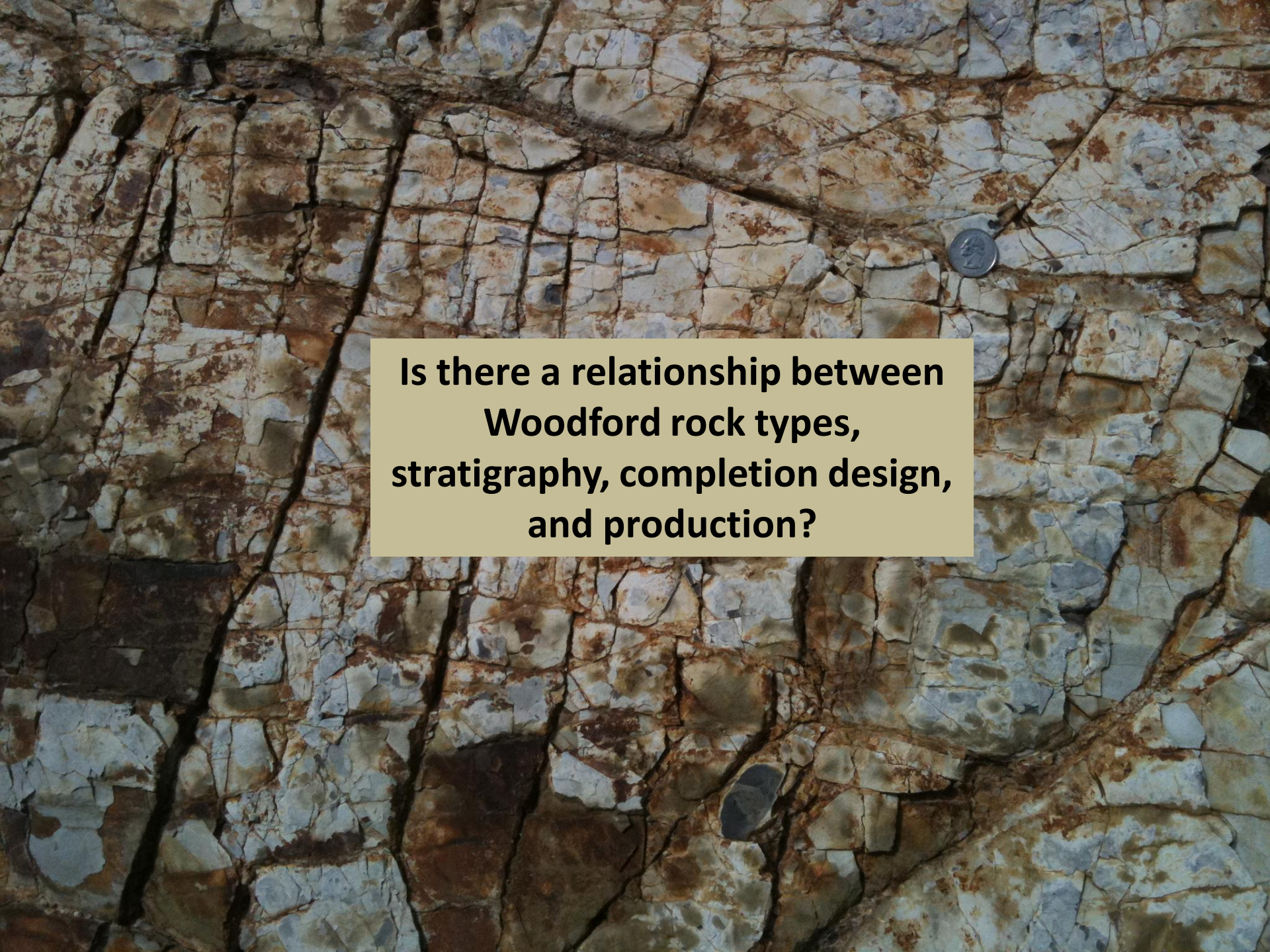
**Devon Energy Corp.**

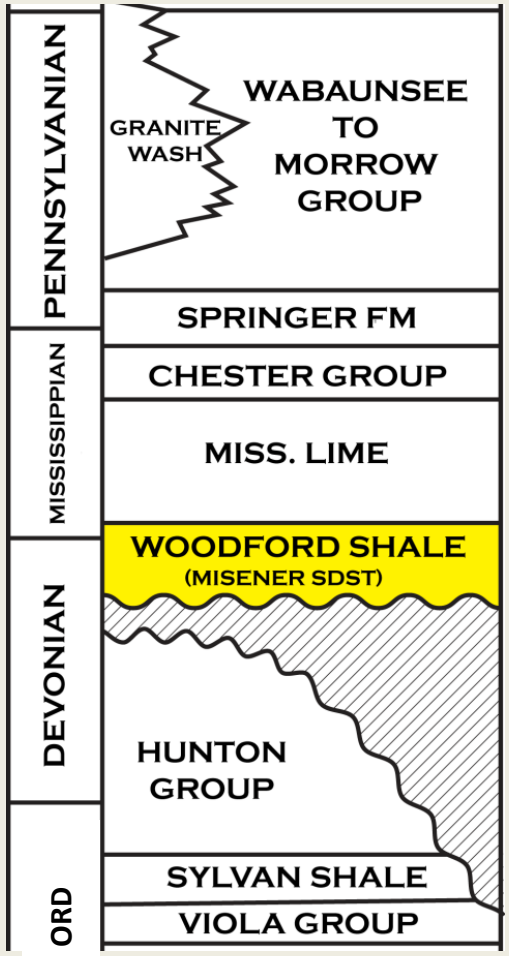
**Weatherford**

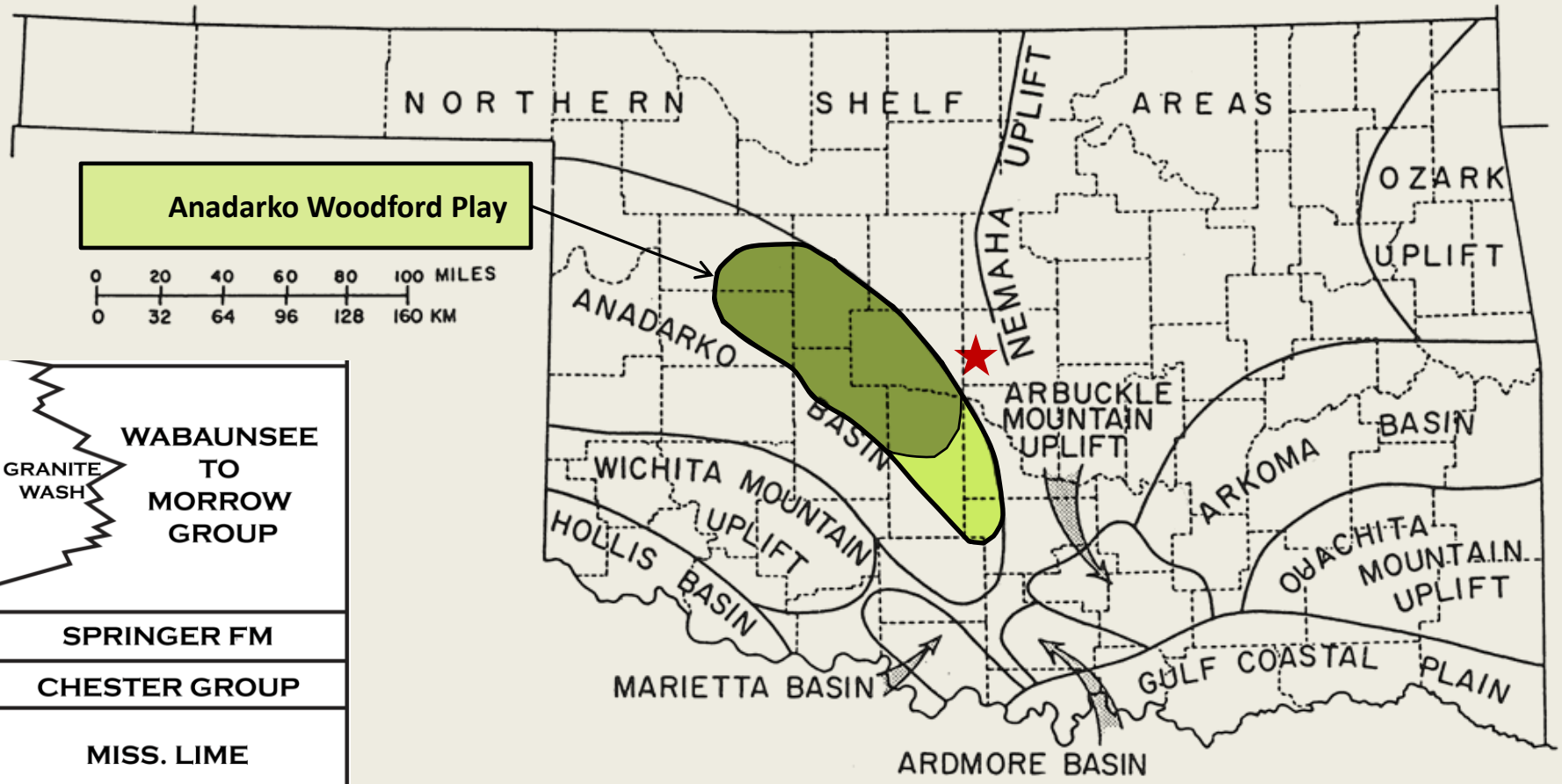
**Terra Tek Inc.**



- Introduction/Acknowledgements
- Regional Maps- Overview
  - Geologic Provinces of Oklahoma
  - Woodford Isopach
  - Woodford Structure
- Woodford Mechanical/Lithostratigraphy
  - How Frac' Data Lead to a Lithostratigraphic Model
- Woodford Mudrock Lithologies
- Stratigraphic Variability
- Conclusions


Is there a relationship between Woodford rock types, stratigraphy, completion design, and production?



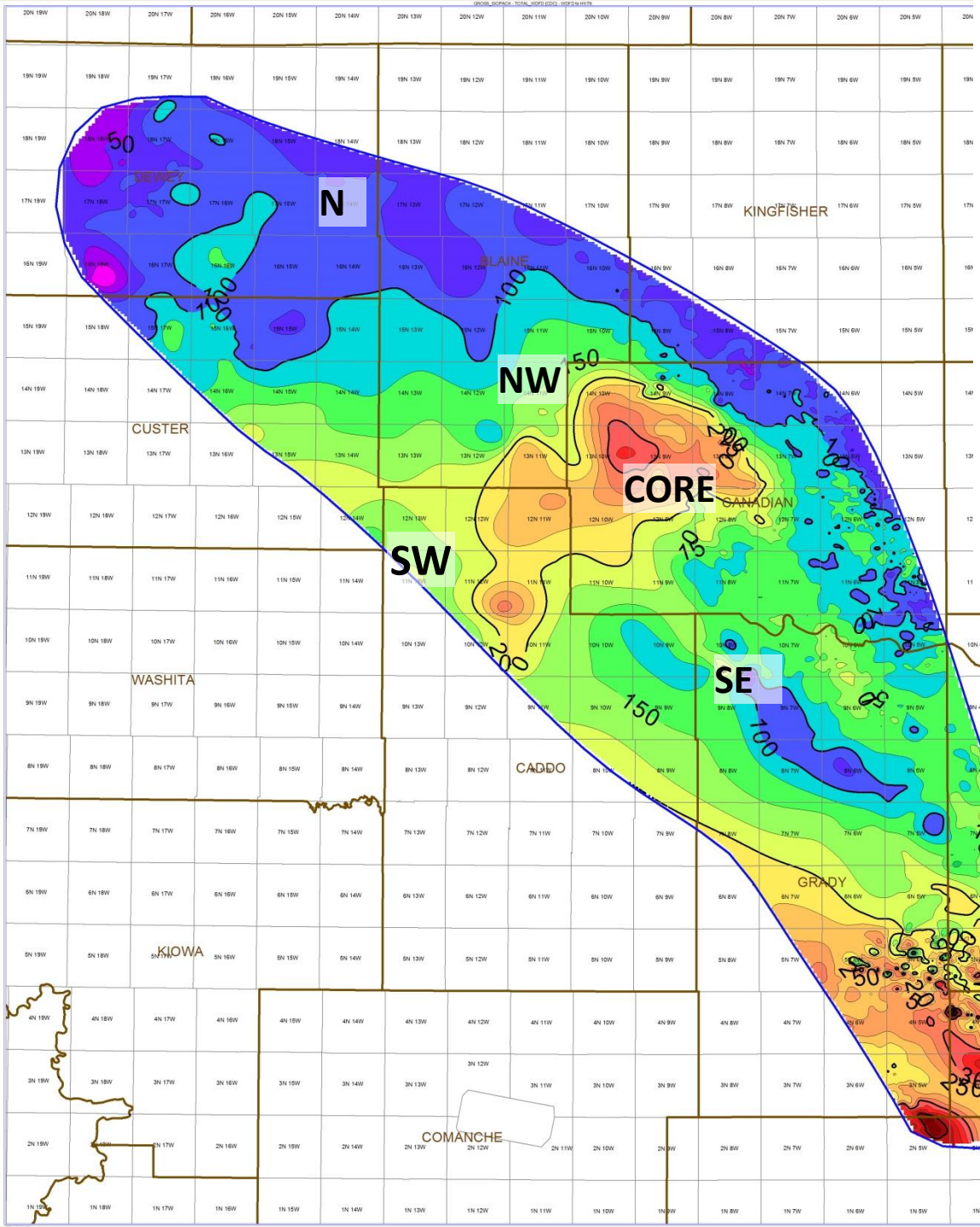




# STRAT COLUMN AND MAJOR GEOLOGIC PROVINCES OF OKLAHOMA

*After Johnson et al. (2000)

# Woodford Isopach

## Anadarko Basin Woodford Play



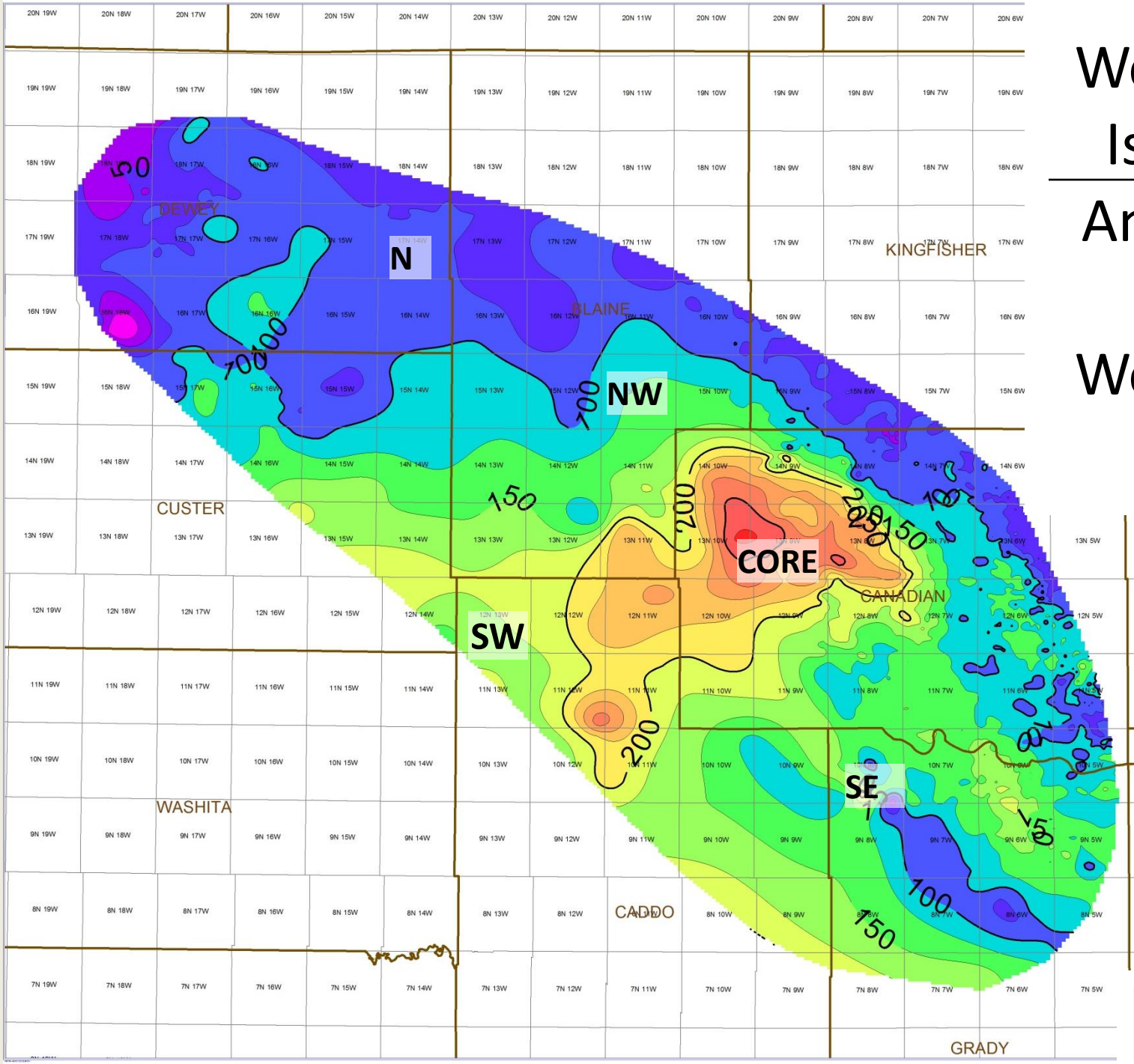

0 5 10

miles

CIMAREX

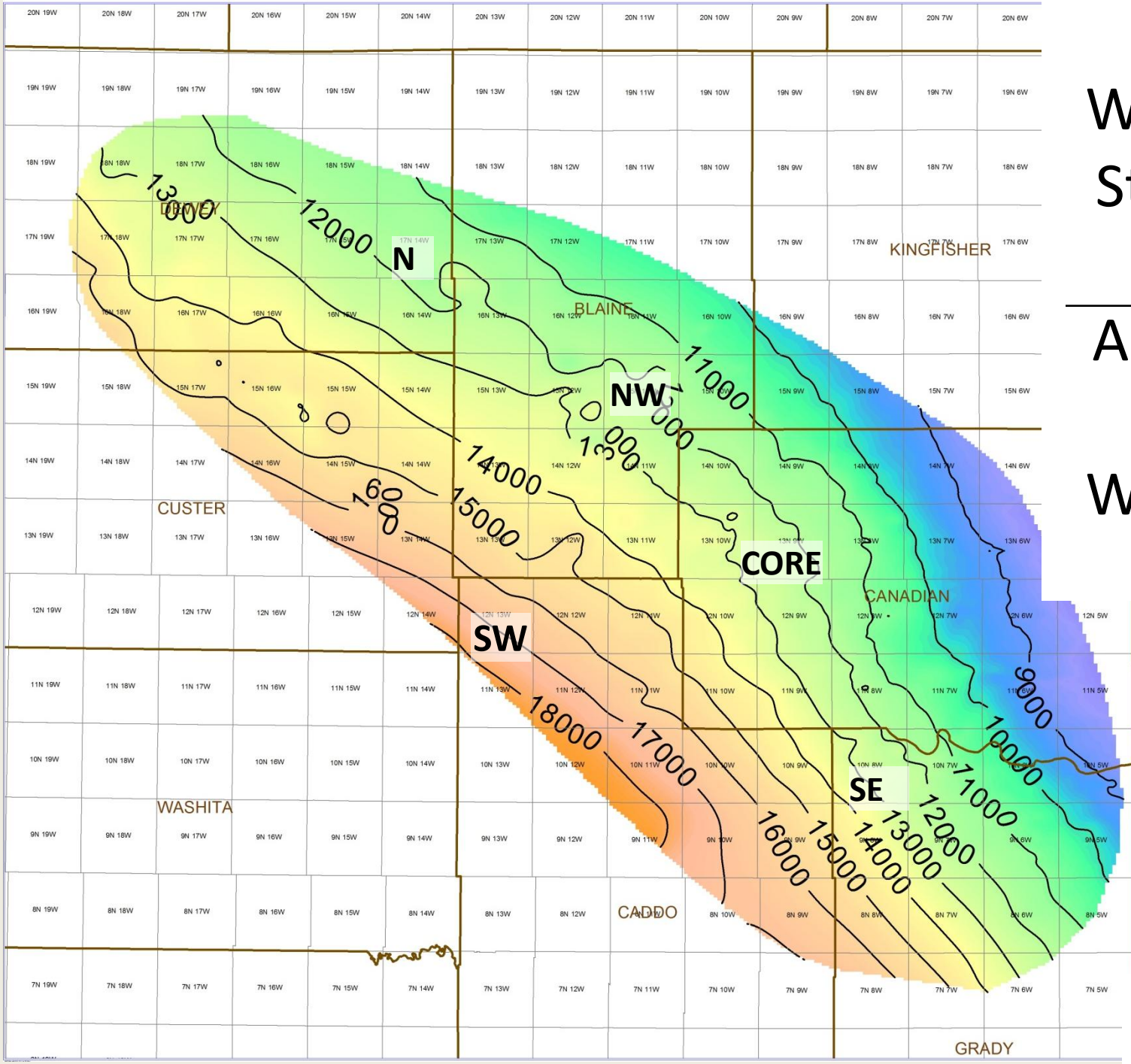
# Woodford Isopach

## Anadarko Basin Woodford Play



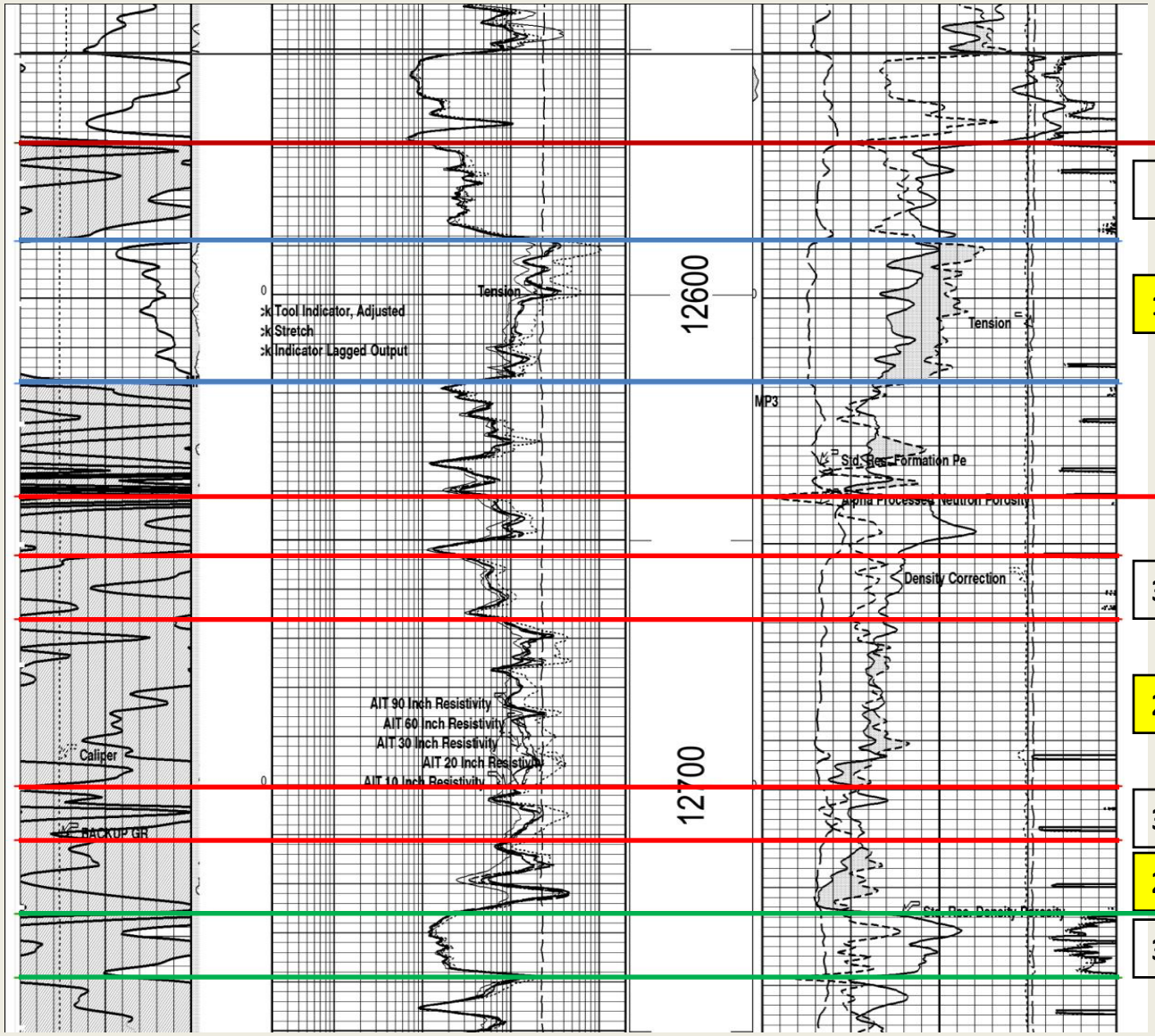
# Top Woodford Structure (MD)

## Anadarko Basin Woodford Play

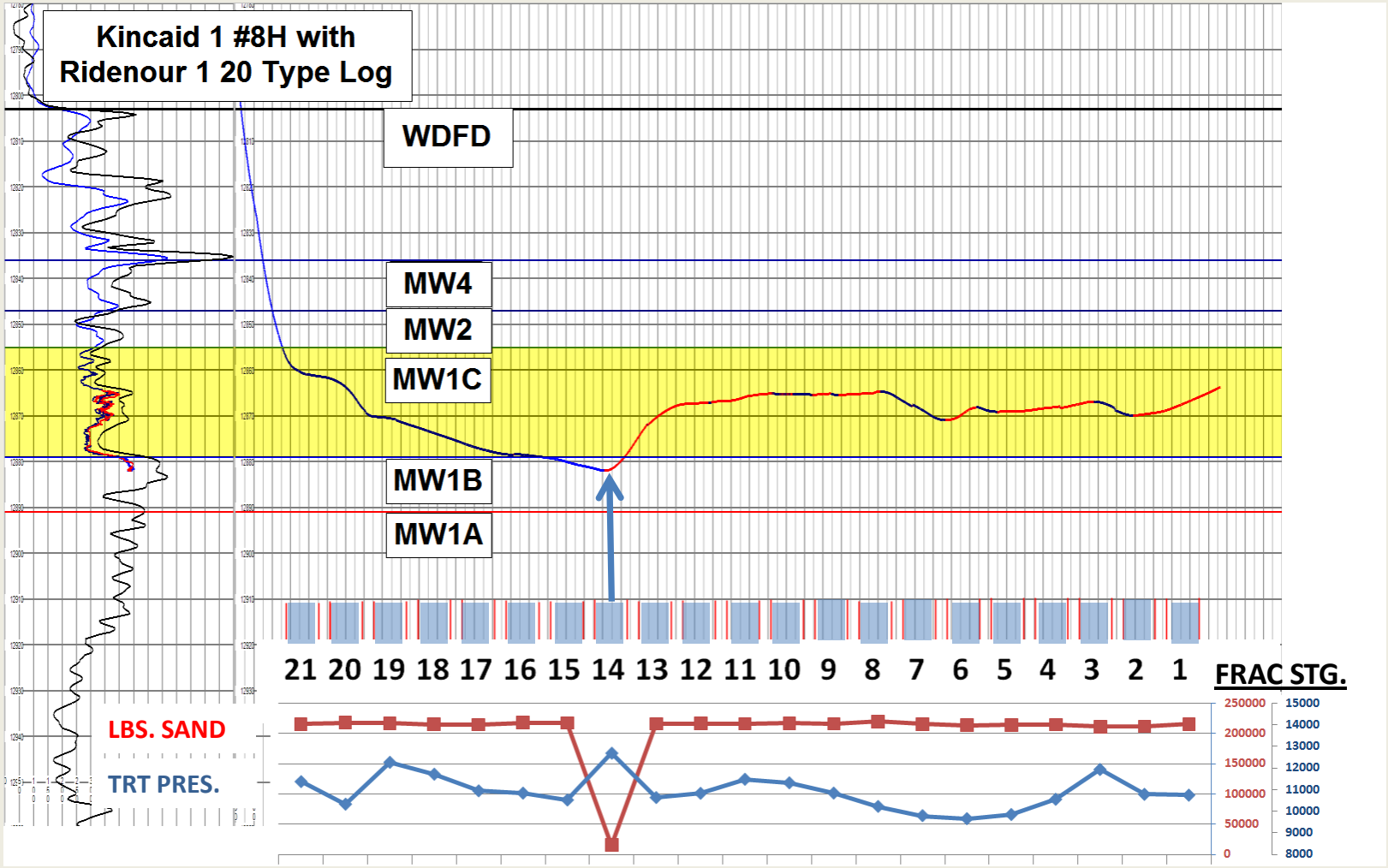



CIMAREX

# Type Log from Core Area Showing Lithostratigraphy and % Clay for Middle & Upper Woodford



# Well Path Showing Woodford Lithostratigraphy and Lateral Placement



# Woodford Rock Types
# Anadarko Basin Woodford Play

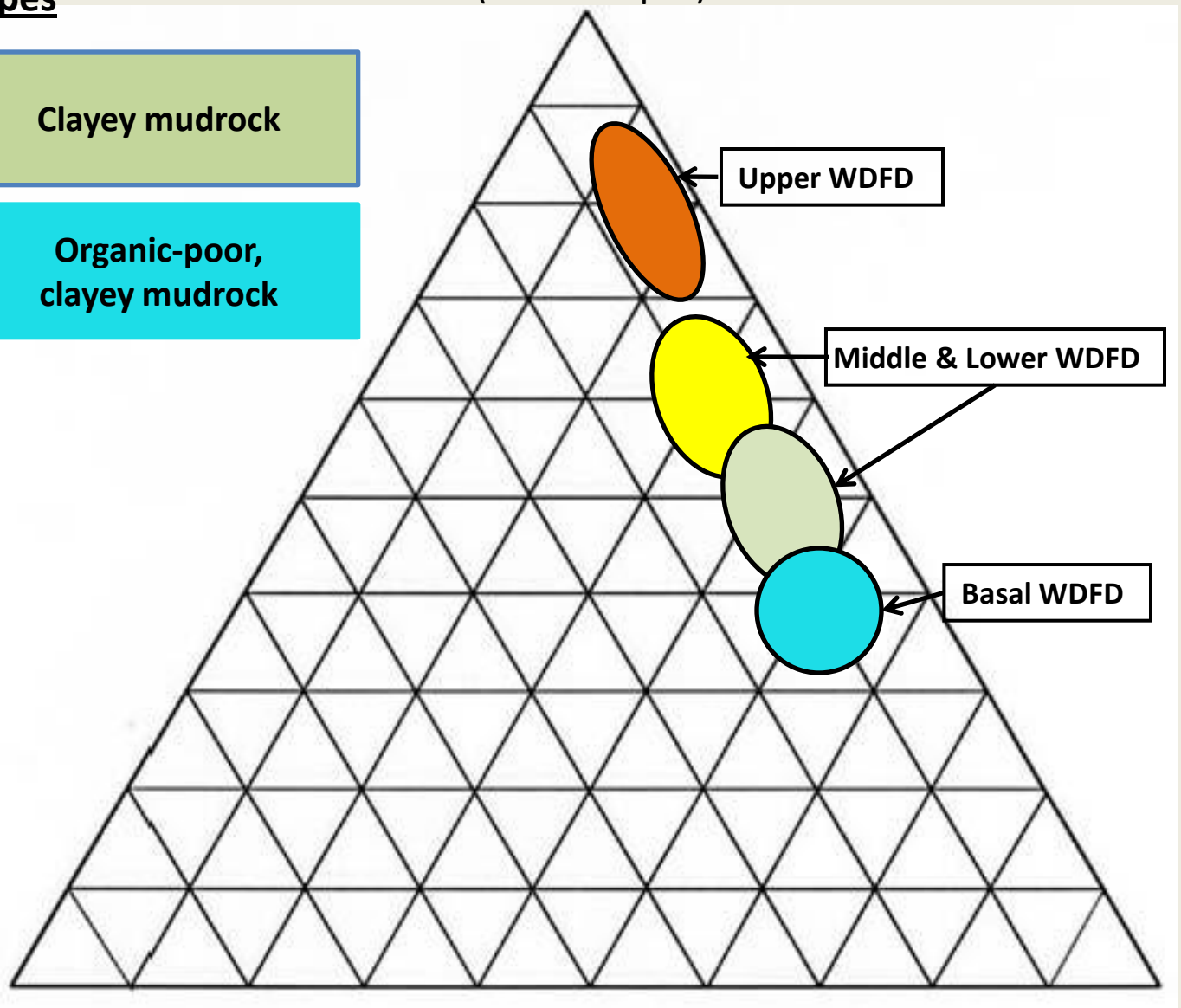
| ROCK TYPE | % QUARTZ | % CLAY | % TOC | % GAS-FILLED POROSITY | PRv | Brittleness Index* |
|---|---|---|---|---|---|---|
| Siliceous mudrock | 75.2 | 14.5 | 4.86 | 5.4 | 0.155 | 0.75 |
| Clayey, siliceous mudrock | 54.8 | 27.4 | 6.43 | 6.8 | 0.164 | 0.55 |
| Clayey mudrock | 40.6 | 38 | 5.97 | 5.6 | 0.192 | 0.41 |
| Organic-poor, clayey mudrock | 27.3 | 52.4 | 0.6 | 1.8 | 0.25 | 0.27 |

*B.I.=Quartz/Qtz+Carbonates+Clay

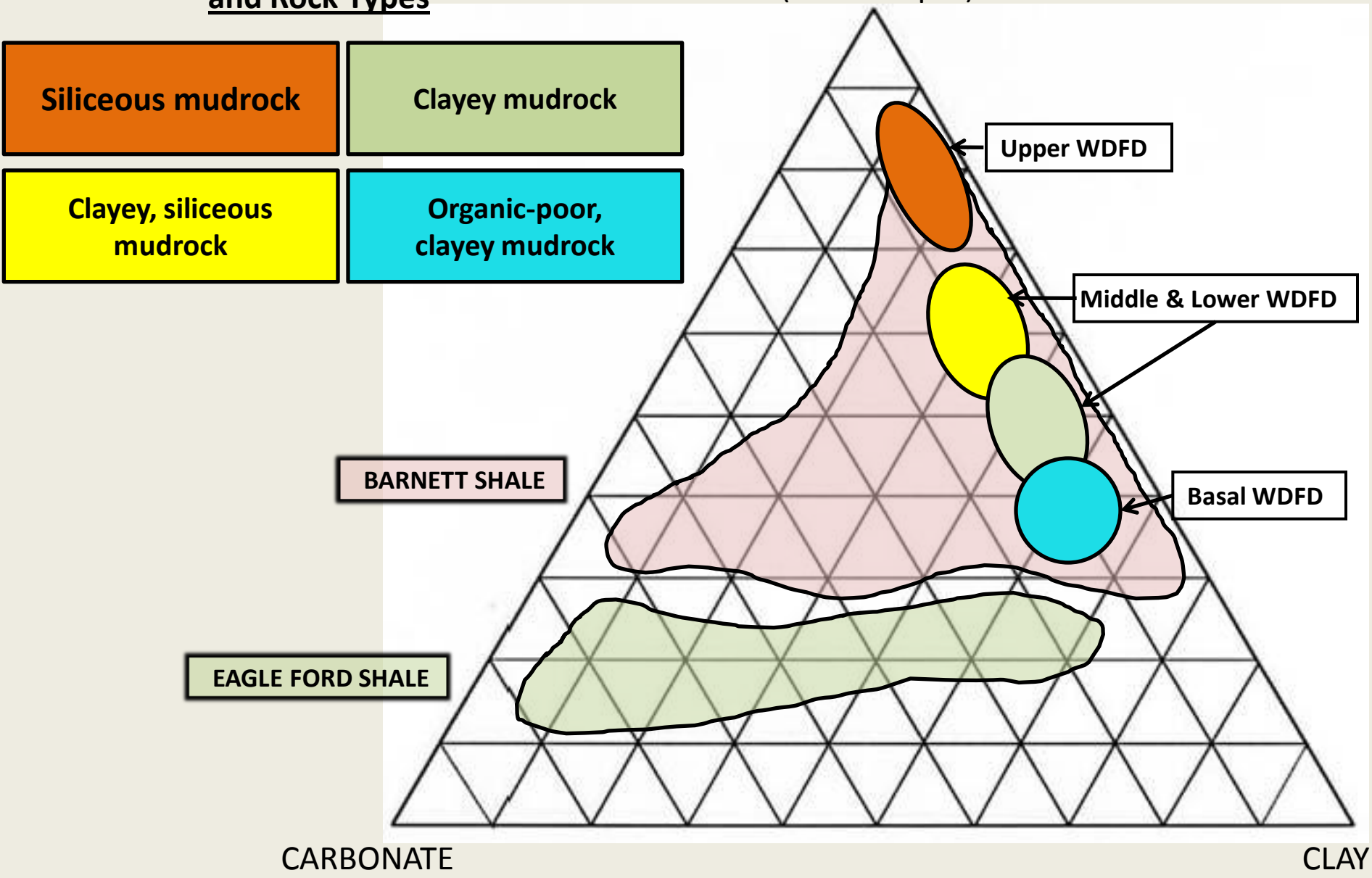
(Sondergeld et al., 2010)

## Anadarko Woodford Mineralogy (XRD) and Rock Types

| | |
|---|---|
| **Siliceous mudrock** | **Clayey mudrock** |
| **Clayey, siliceous mudrock** | **Organic-poor, clayey mudrock** |



## Anadarko Woodford Mineralogy (XRD) and Rock Types



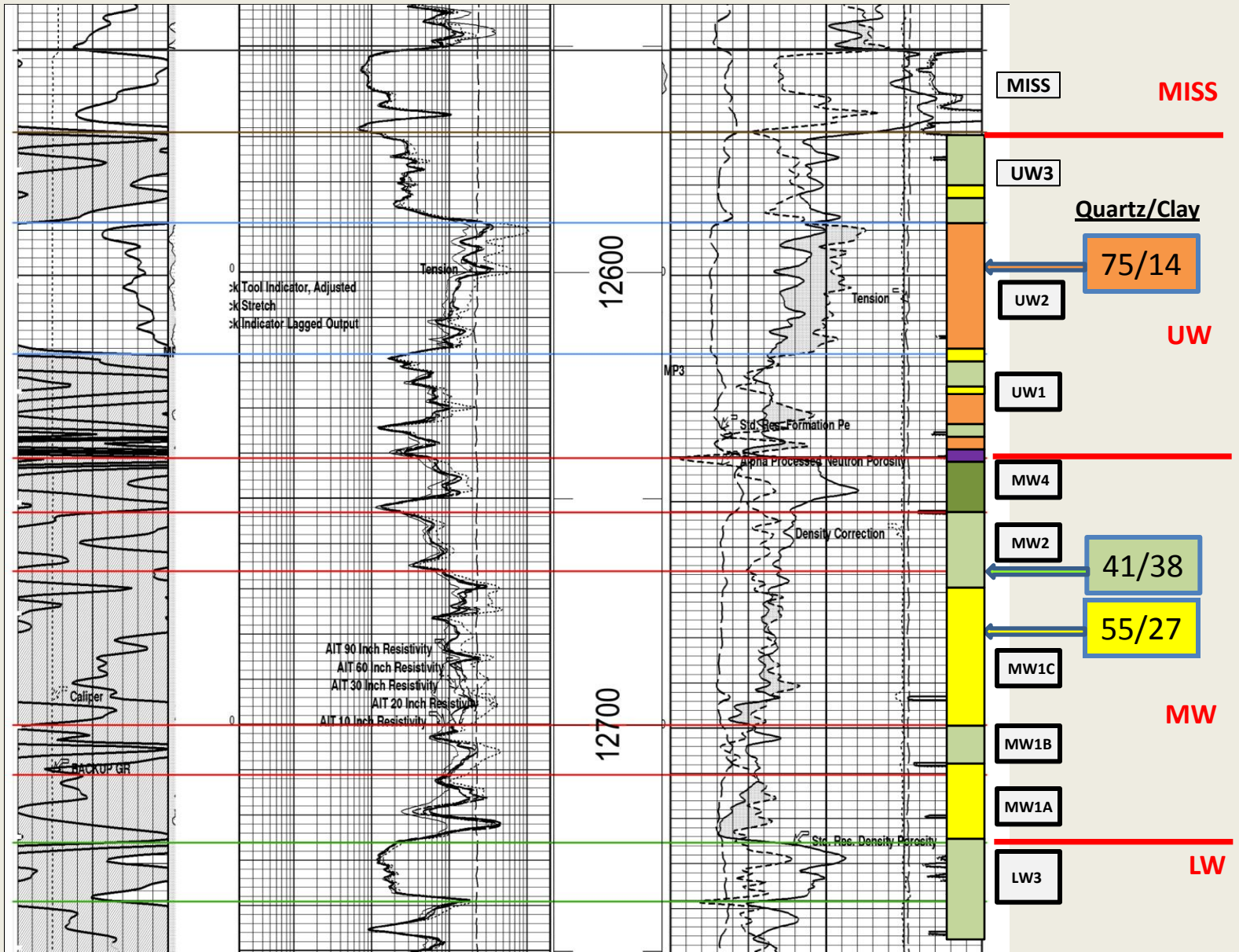

Barnett and Eagle Ford Mineralogy from Q. R. Passey et al. (2010)

# Middle and Upper Woodford Lithostratigraphy, Anadarko Woodford Play – Core Area

**Siliceous mudrock**

**Clayey, siliceous mudrock**

**Clayey mudrock**

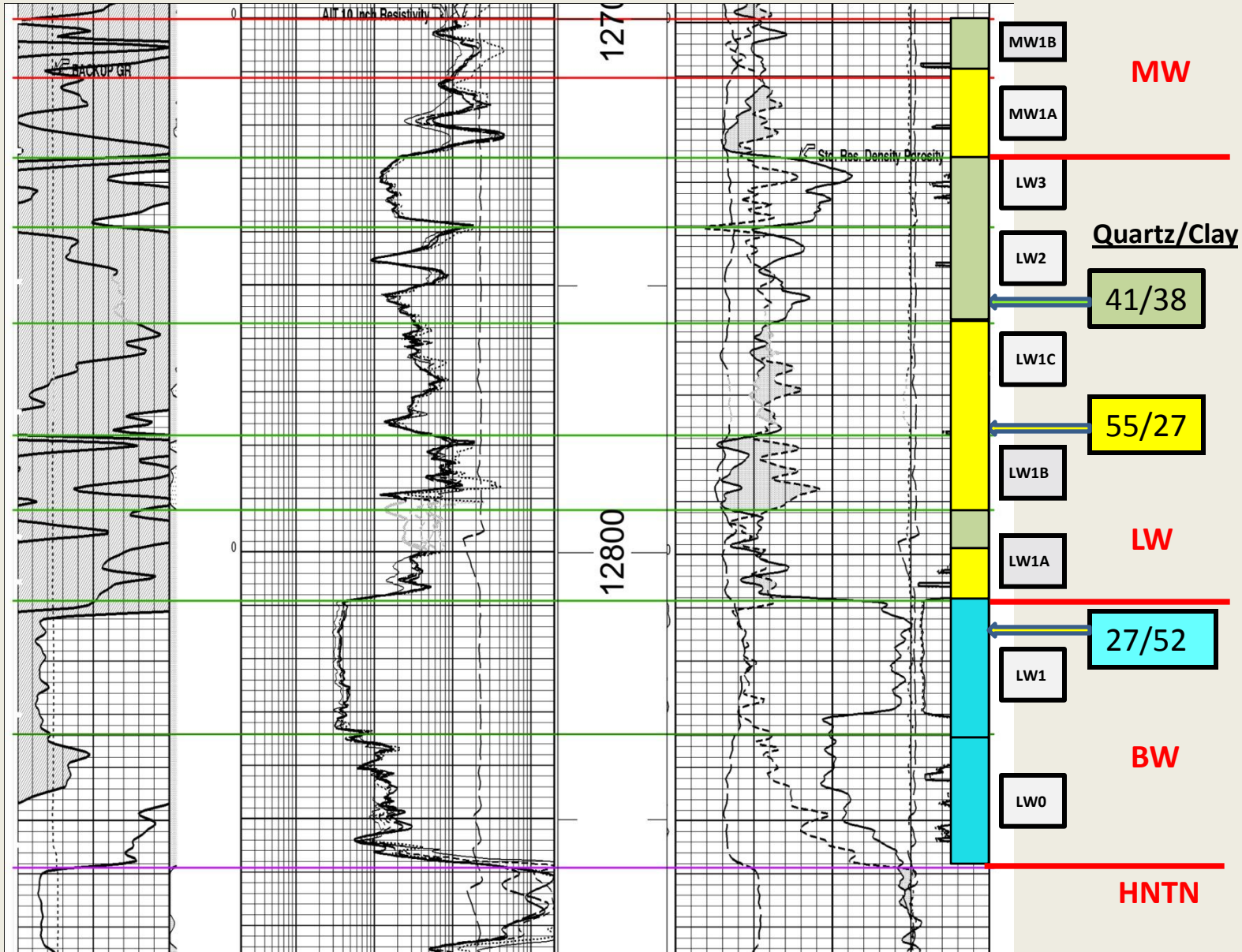


# Basal, Lower, & Middle Woodford Lithostratigraphy, Anadarko Woodford Play – Core Area

**Clayey, siliceous mudrock**

**Clayey mudrock**

**Organic-poor clayey mudrock**



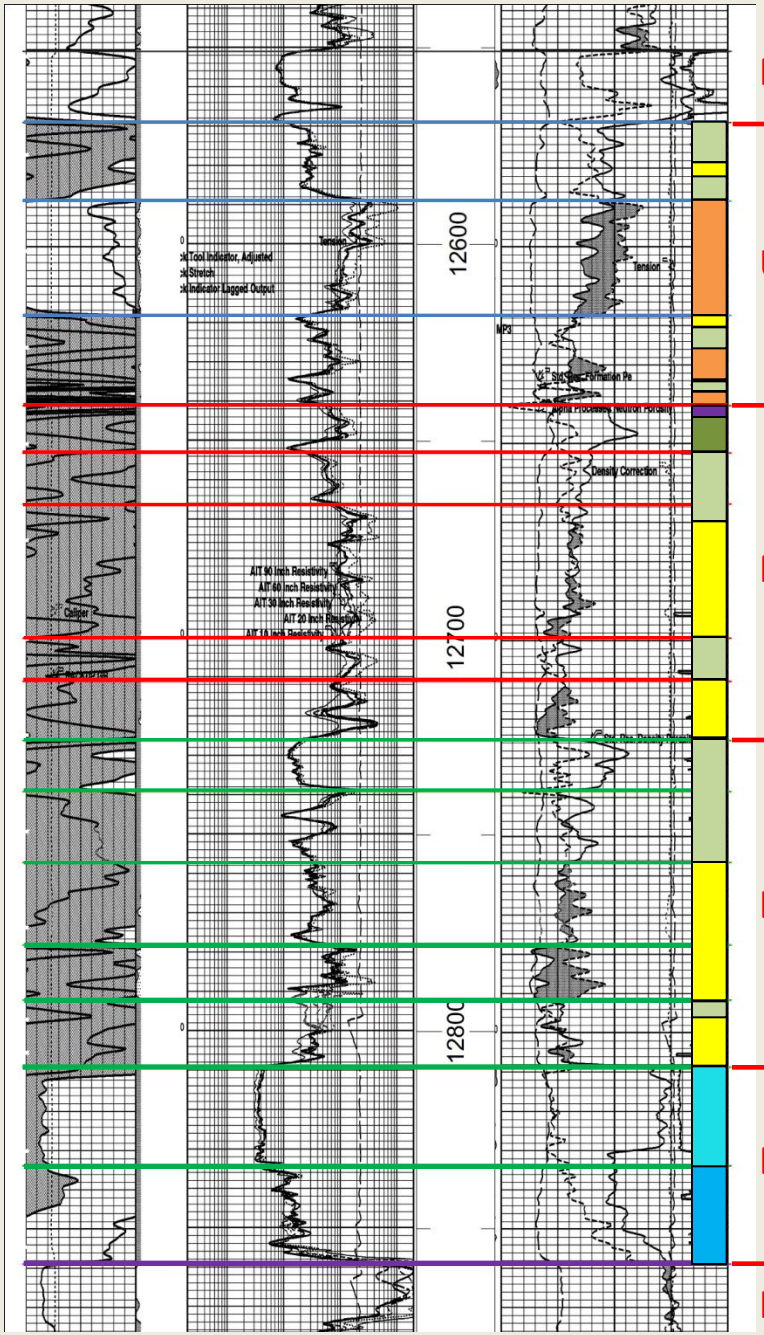
# Woodford Lithostratigraphy Anadarko Basin Woodford Play Core Area

Siliceous mudrock

Clayey, siliceous mudrock

Clayey mudrock

Organic-poor clayey mudrock




WDFD Thk. 290’

CIMAREX

| Frac' Success and Woodford Rock Types | | | |
|---|---|---|---|
| ROCK TYPE | % QUARTZ | % CLAY | % SUCCESS |
| Siliceous mudrock | 75.2 | 14.5 | 100 |
| Clayey, siliceous mudrock | 54.8 | 27.4 | 86 |
| Clayey mudrock | 40.6 | 38 | 53 |

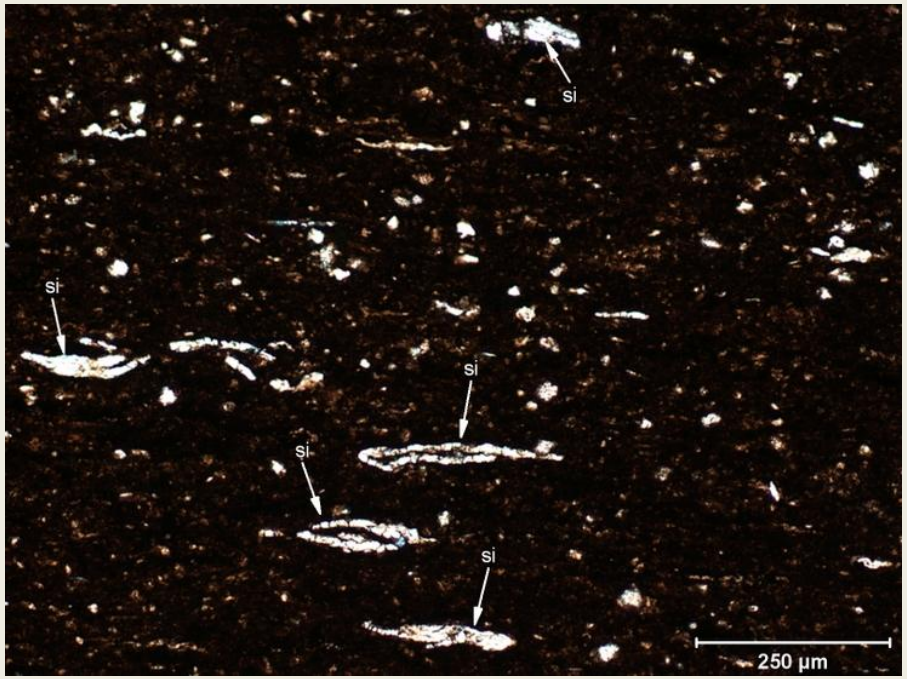
Successful frac' defined as one in which >75% of planned proppant amount was placed.

## Frac' Success and Woodford Rock Types

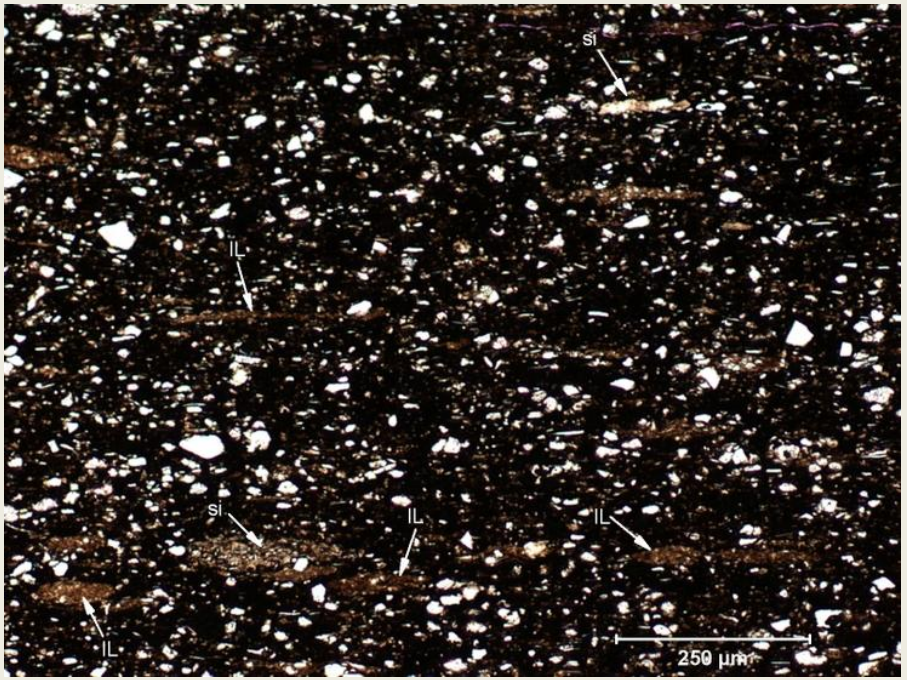
| ROCK TYPE | % QUARTZ | % CLAY | % DOLOMITE | % Success, Pre-HF | % Success, w/ HF |
|---|---|---|---|---|---|
| Siliceous mudrock | 75.2 | 14.5 | 2.8 | 100 | 100 |
| Clayey, siliceous mudrock | 54.8 | 27.4 | 3.6 | 86 | 94 |
| Clayey mudrock | 40.6 | 38 | 5.0 | 53 | 80 |
| Organic-poor, clayey mudrock | 27.3 | 52.4 | 5.1 | | 83 |

Successful frac' defined as one in which >75% of planned proppant amount was placed.
Table drawn from 906 frac stages.

# Thin Section Photomicrographs of Woodford Rock Types



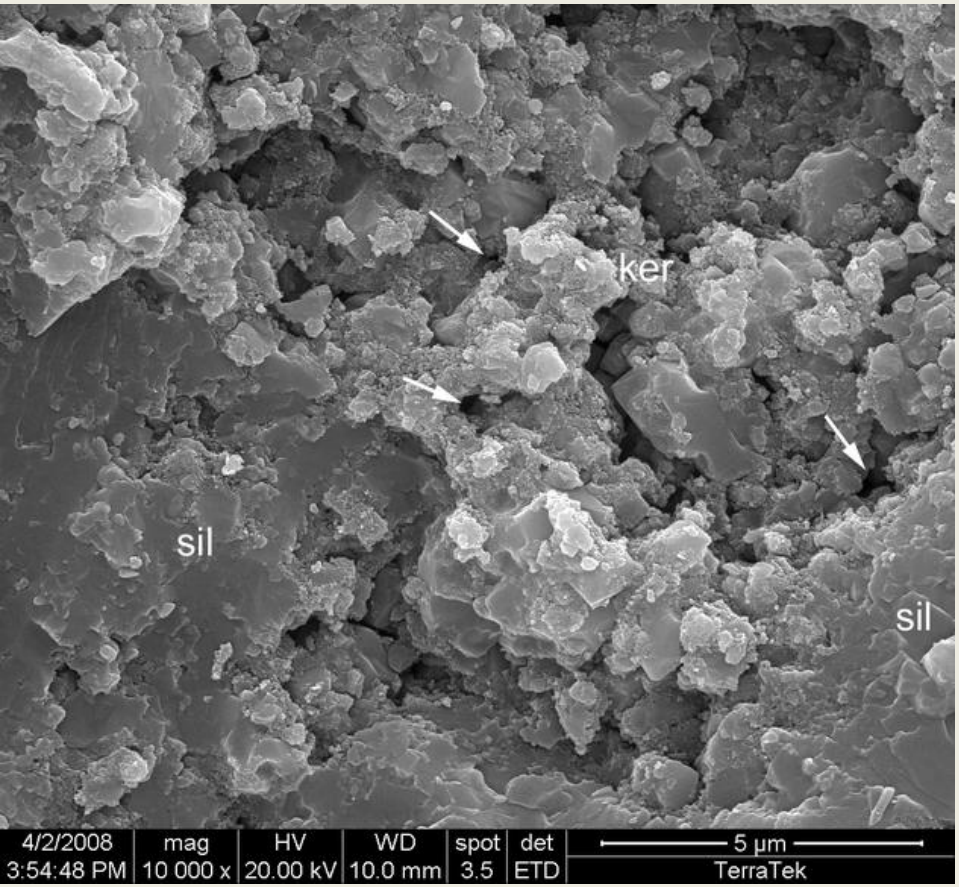

**UW1 sample showing silicified Tasmanites; sample is 64% quartz and 21% clay. Siliceous mudrock lithology.**



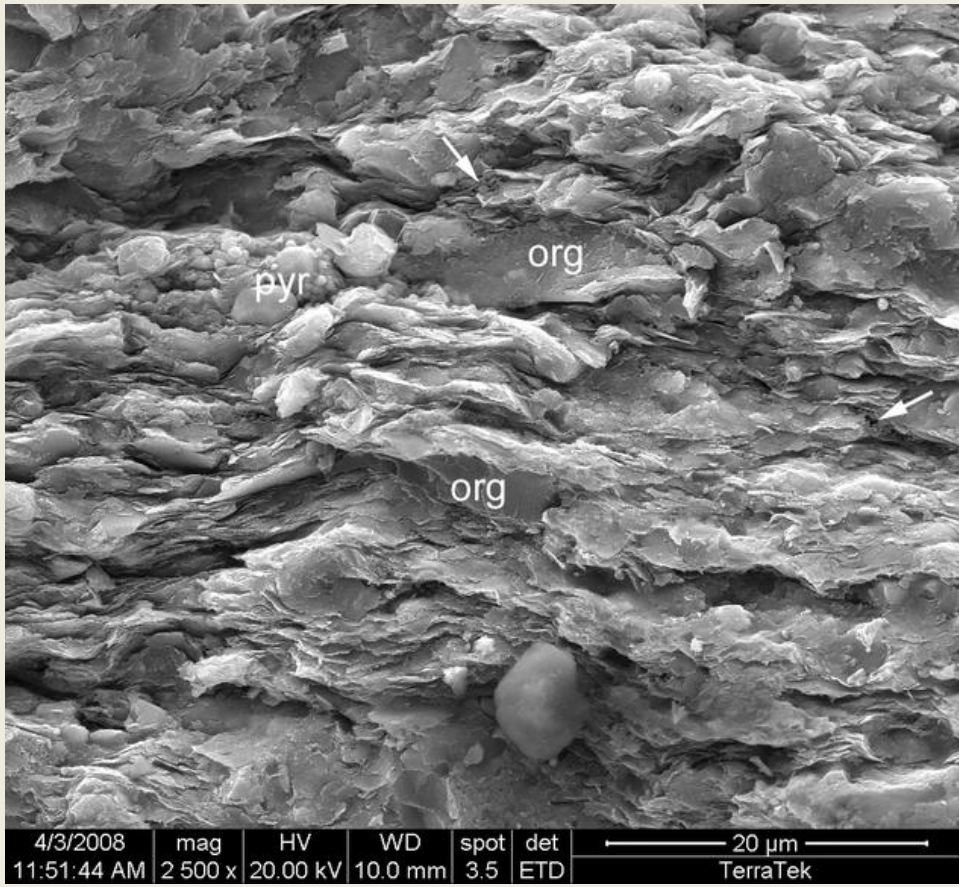

**MW1B sample showing detrital silt; sample is 34% quartz and 38% clay. Clayey mudrock lithology.**

CIMAREX

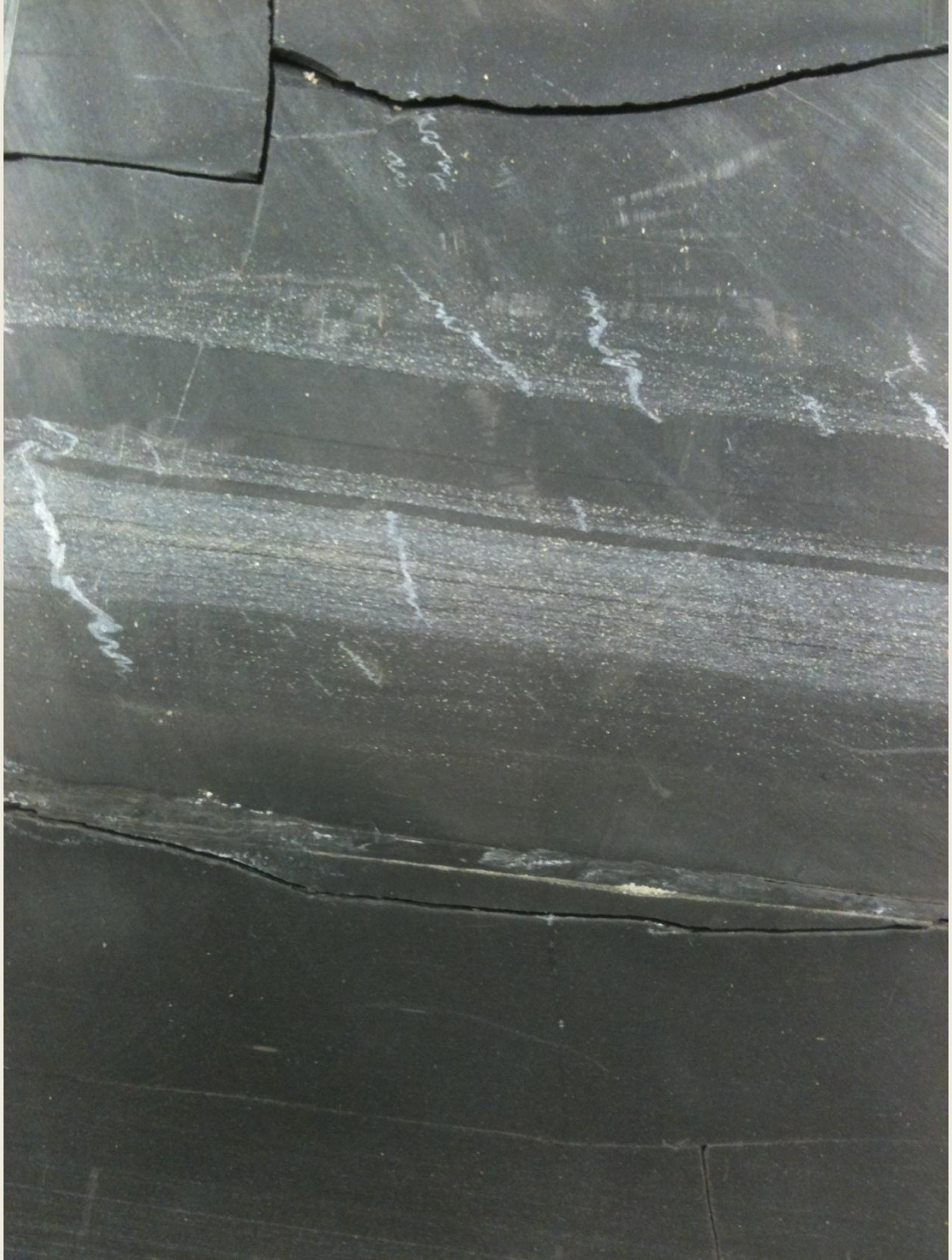
# SEM Photomicrographs of Woodford Microfabrics




**UW2 sample showing microcrystalline silica with intercrystalline porosity; sample is 76% quartz and 18% clay. Siliceous mudrock lithology.**




**MW4 sample showing parallel alignment of illite clay; sample is 26% quartz and 44% clay. Clayey mudrock lithology.**

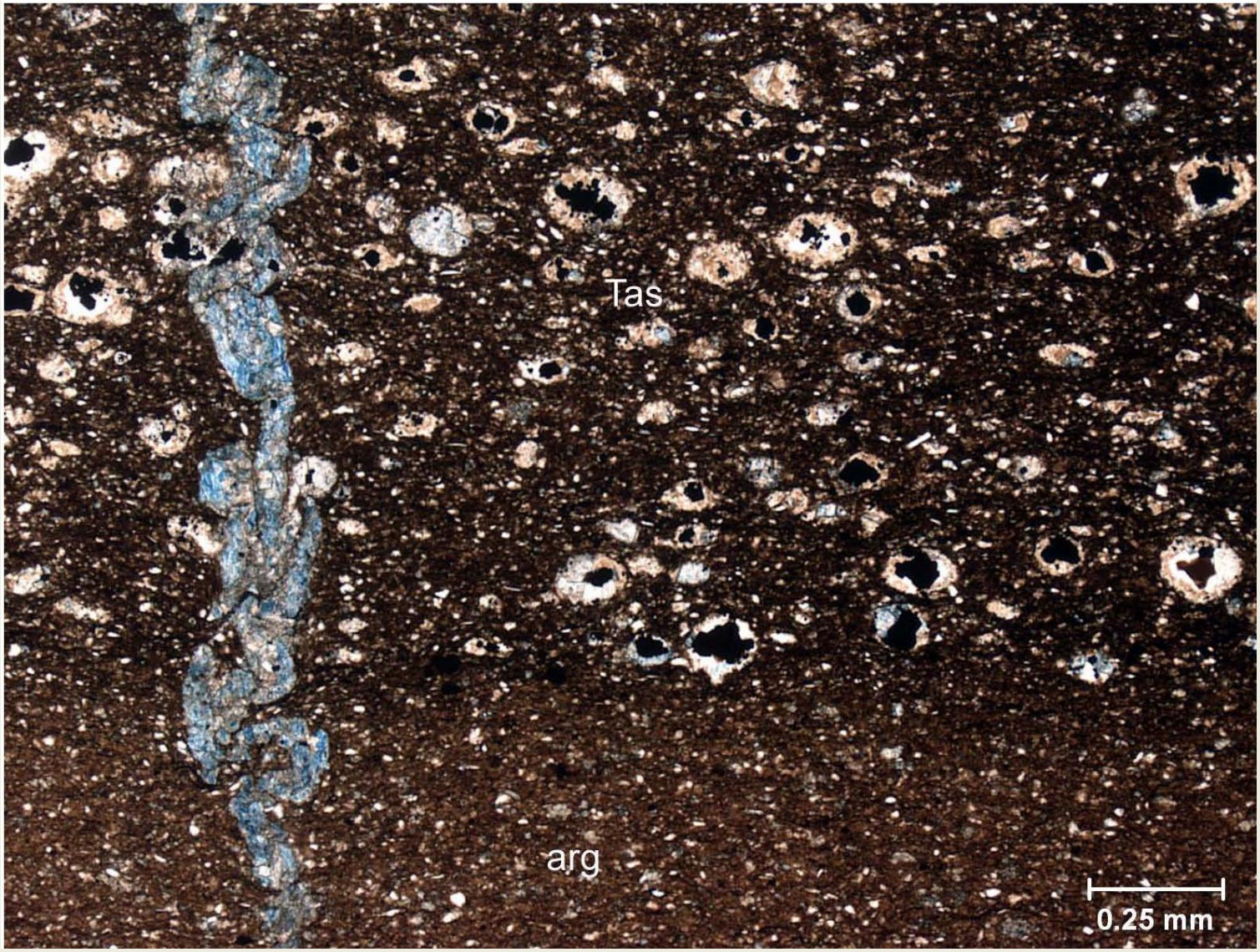


**Bed-limited dolomite-cemented fractures in thin silicic layers**

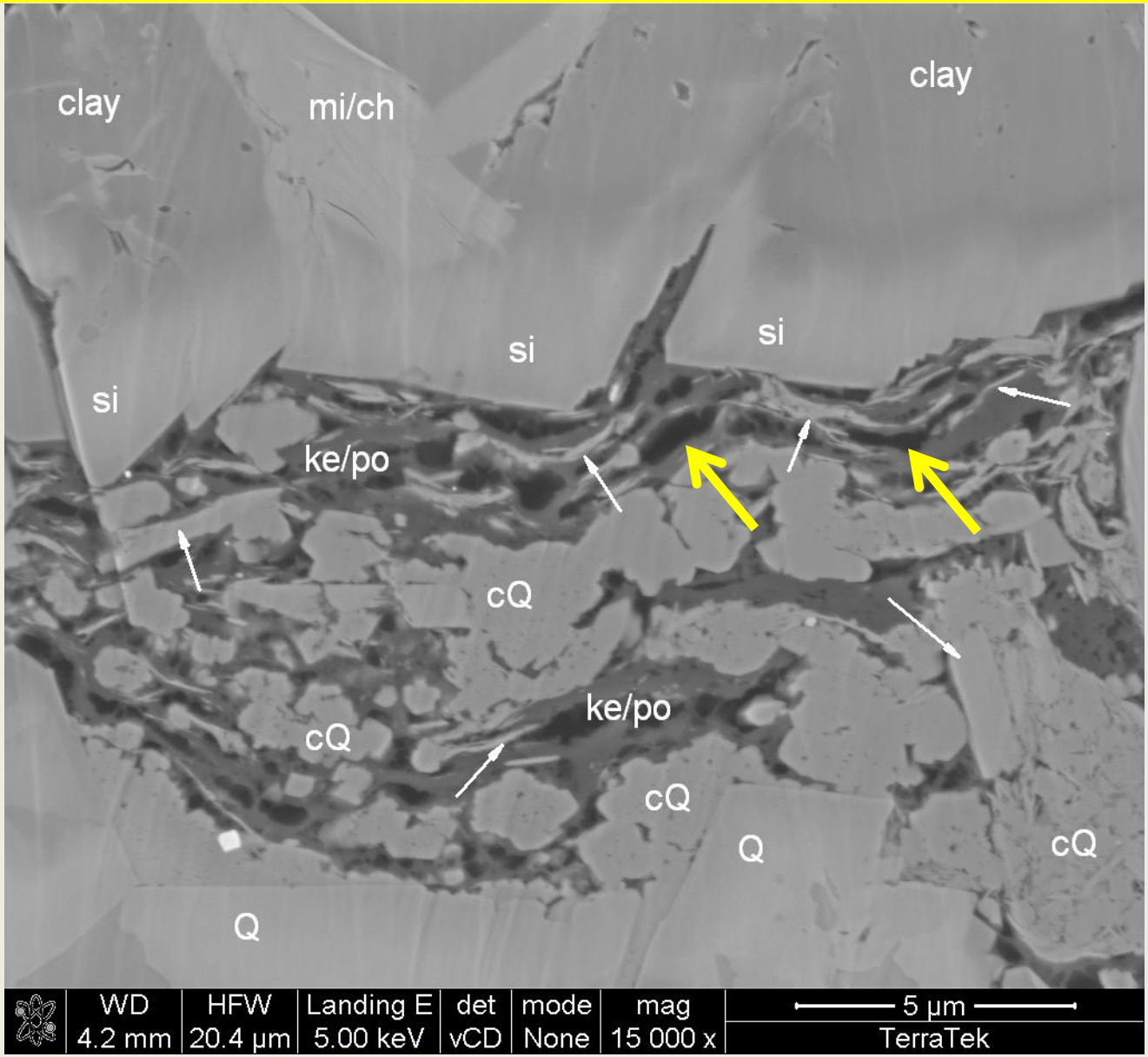
**Siliceous mudrock lithology**

CIMAREX

# Silicic laminae with dolomite-cemented fracture
# Siliceous mudrock lithology

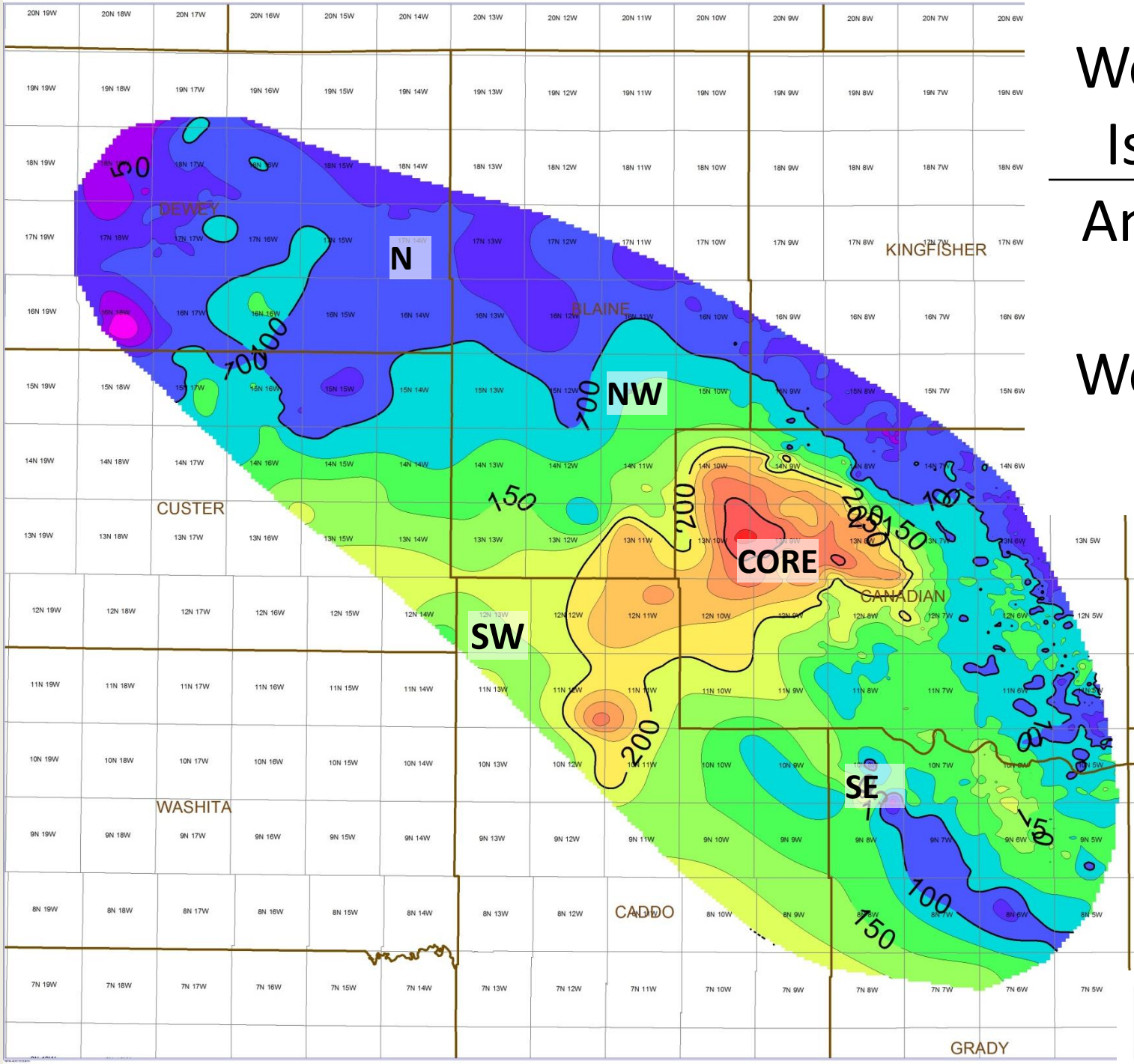


# Porosity in organic laminae
# Clayey siliceous mudrock

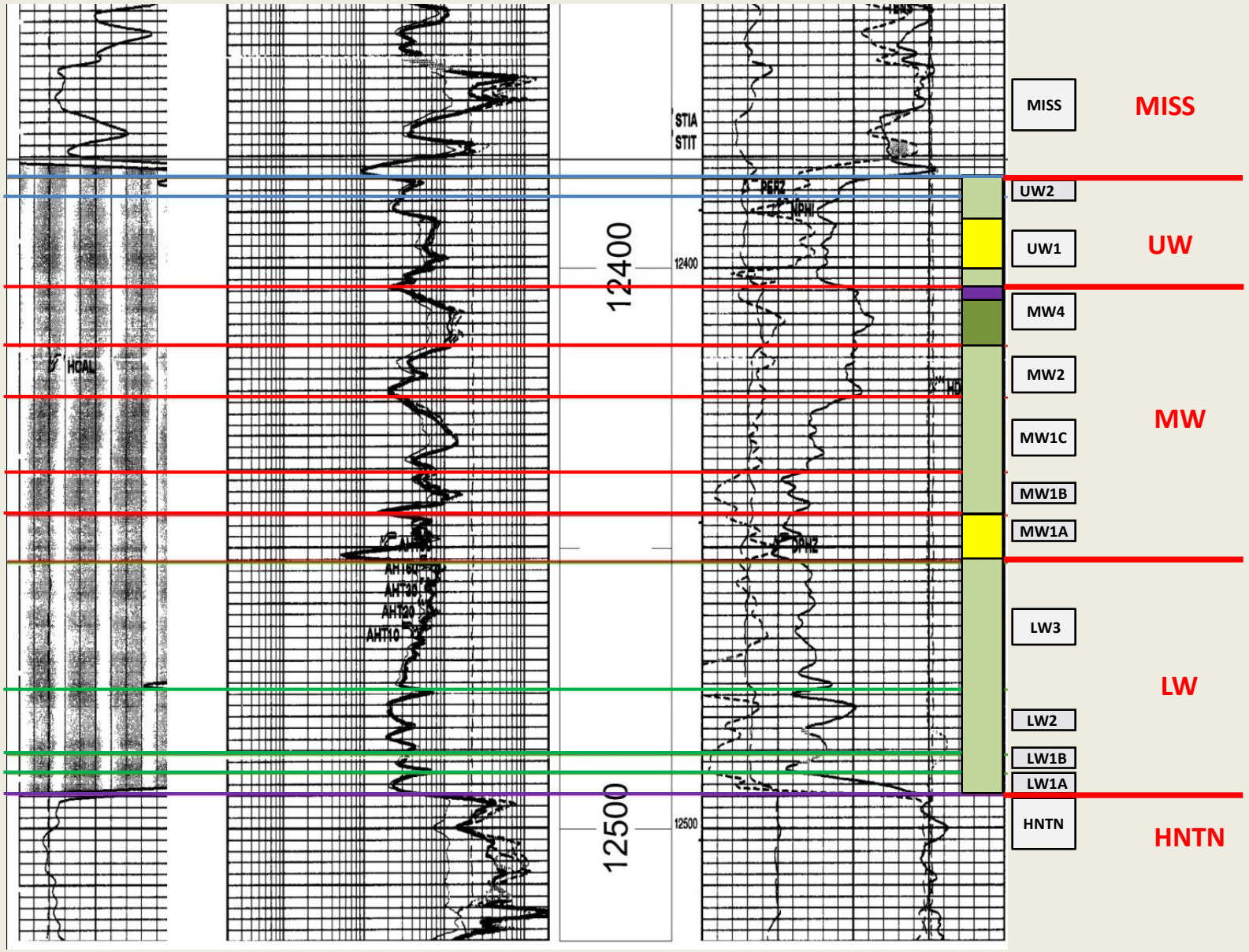


# Woodford Isopach

## Anadarko Basin Woodford Play

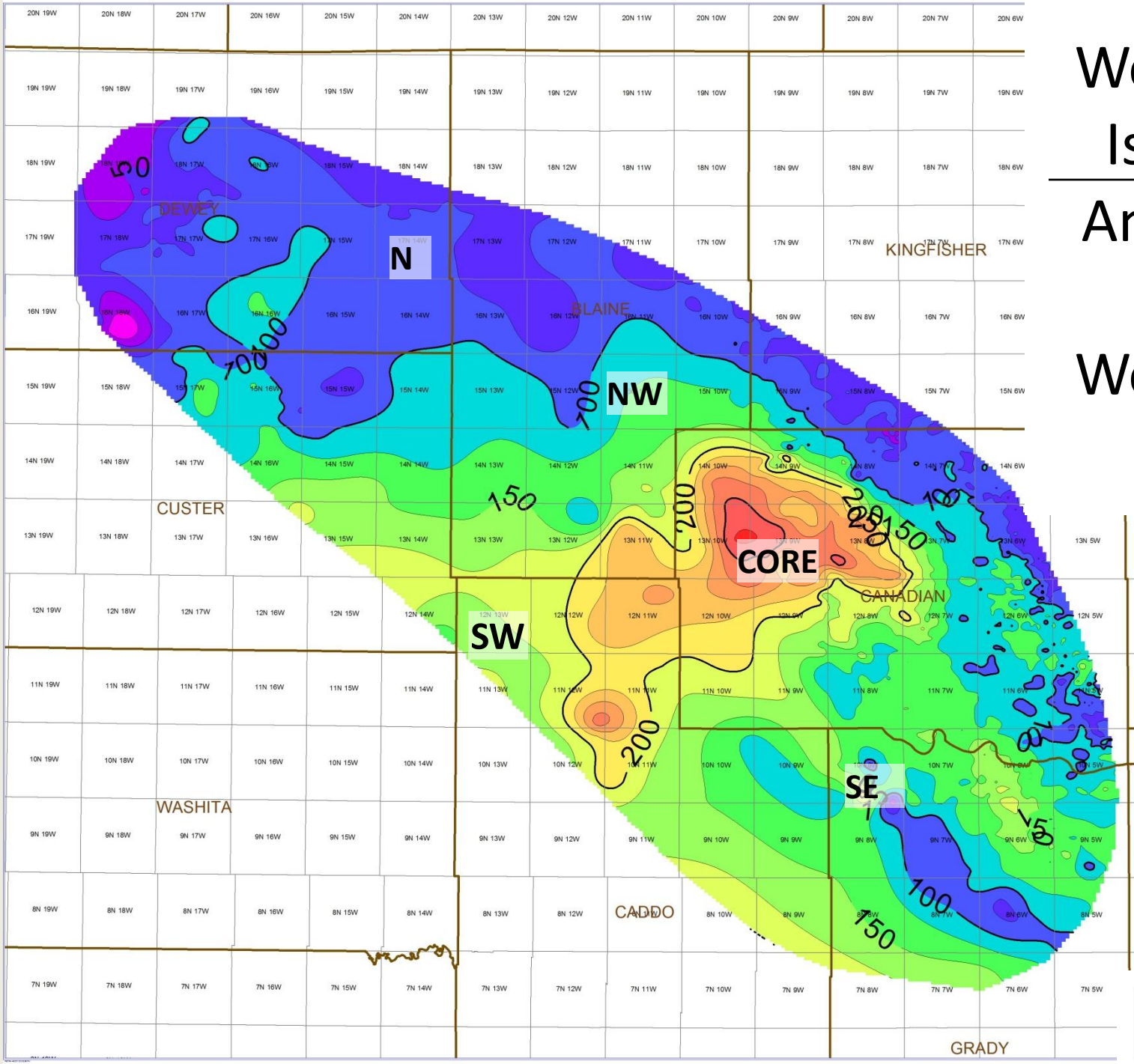


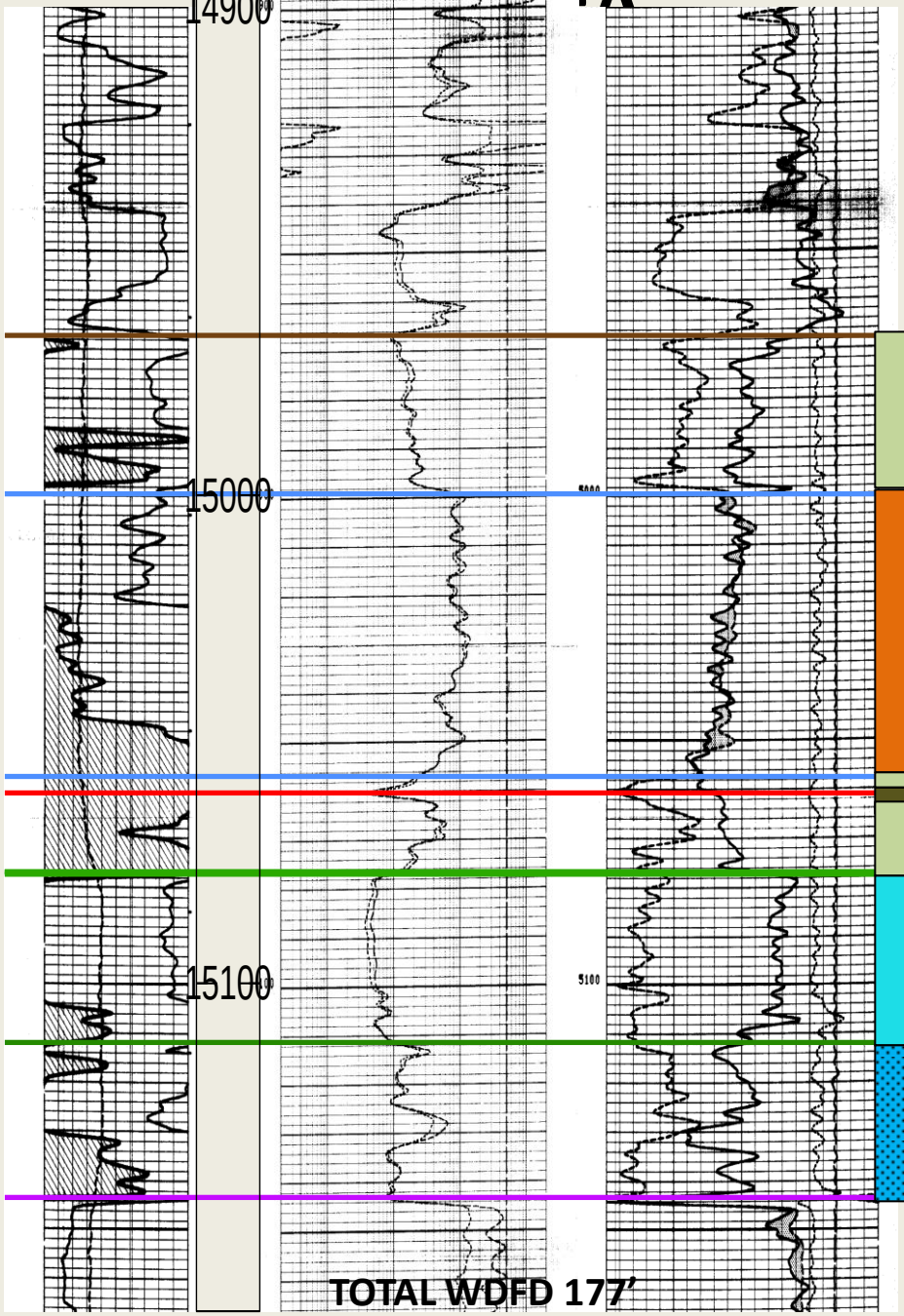
# Woodford Lithostratigraphy Anadarko Basin
# Woodford Play - SE Area



# Woodford Isopach

## Anadarko Basin Woodford Play






Siliceous mudrock

Organic-poor, clayey mudrock

Clayey mudrock

11/1981

Siliceous mudrock

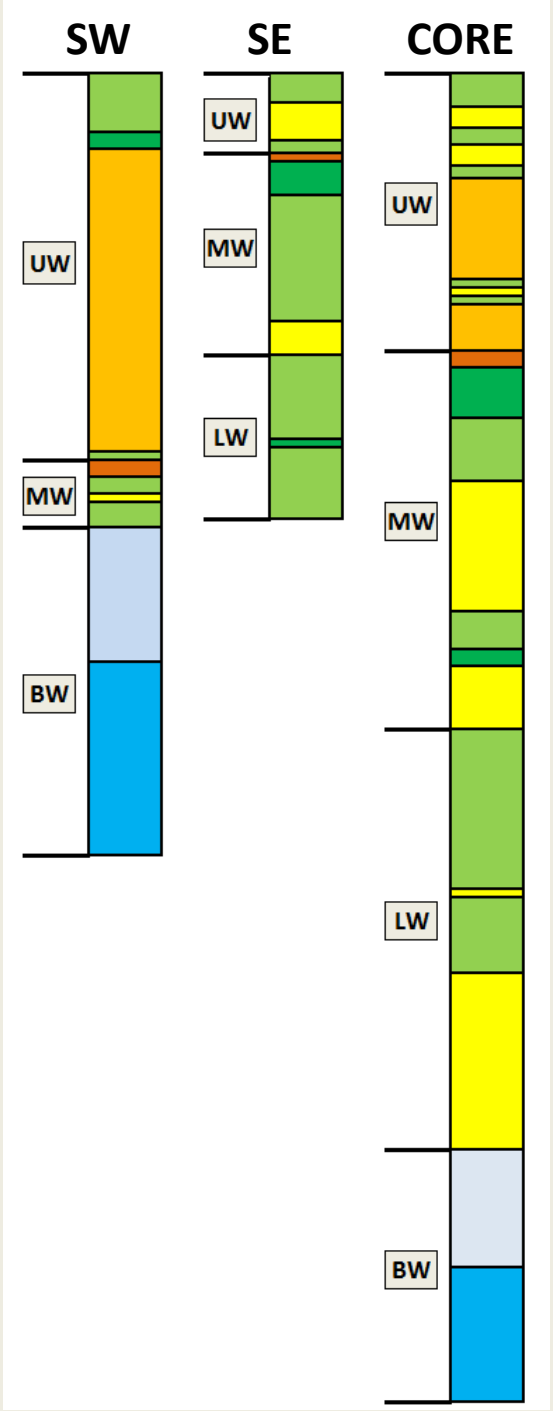
Clayey, siliceous mudrock

Clayey mudrock

Dolomitic, Clayey mudrock

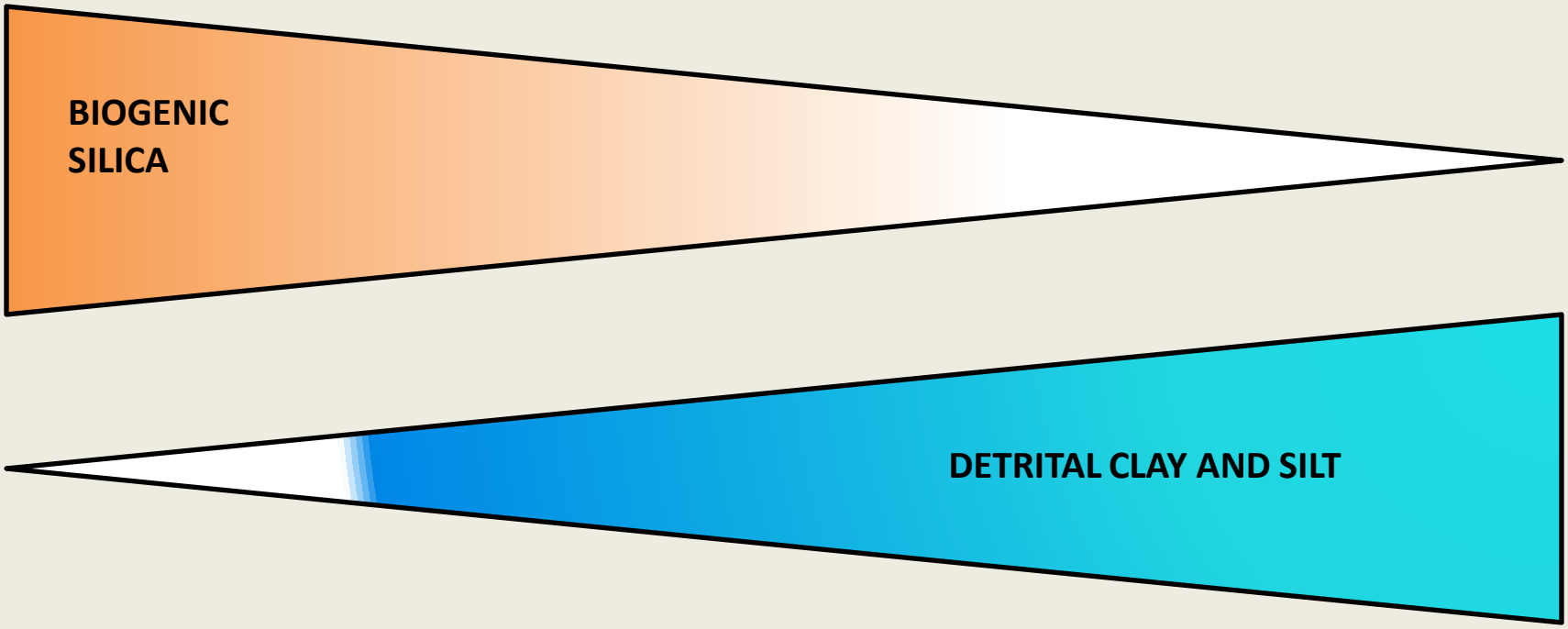
Organic-poor clayey mudrock

Organic-poor clayey mudrock II




Regional Stratigraphic Variability Anadarko Woodford Play

# Woodford Lithofacies





**Distal (?)**

**Proximal (?)**

**“GOOD” MECHANICAL PROPERTIES**

**“POOR” MECHANICAL PROPERTIES**

## CONCLUSIONS:

Seven mudrock lithologies defined on the basis of mineral content and percent TOC make up the 15 mechanical/lithostratigraphic units that composed the Woodford in the central part of the Anadarko Woodford Play.

Early frac' data indicate that the quartz-rich mudrocks and clay-rich mudrocks have distinctively different mechanical properties which can affect treating pressure and proppant placement. Quartz-rich mudstones contain bed-limited, dolomite-healed fractures.

Density/Neutron log signature correlates well with quartz/clay content (x-over=high quartz content) and can be used to establish Woodford lithostratigraphy……in lower thermal maturity areas this relationship gets complicated.

Thinning and marked changes in lithostratigraphy occur away from the central part of the Cana play and impact production.