

WOODFORD SHALE ENCLOSED MINI-BASIN FILL ON THE HUNTON PALEO SHELF. A DEPOSITIONAL MODEL FOR UNCONVENTIONAL RESOURCE SHALES

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1941-2020

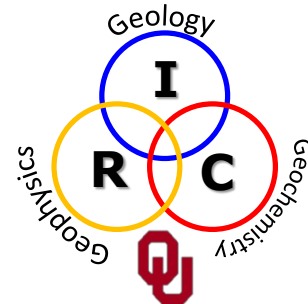
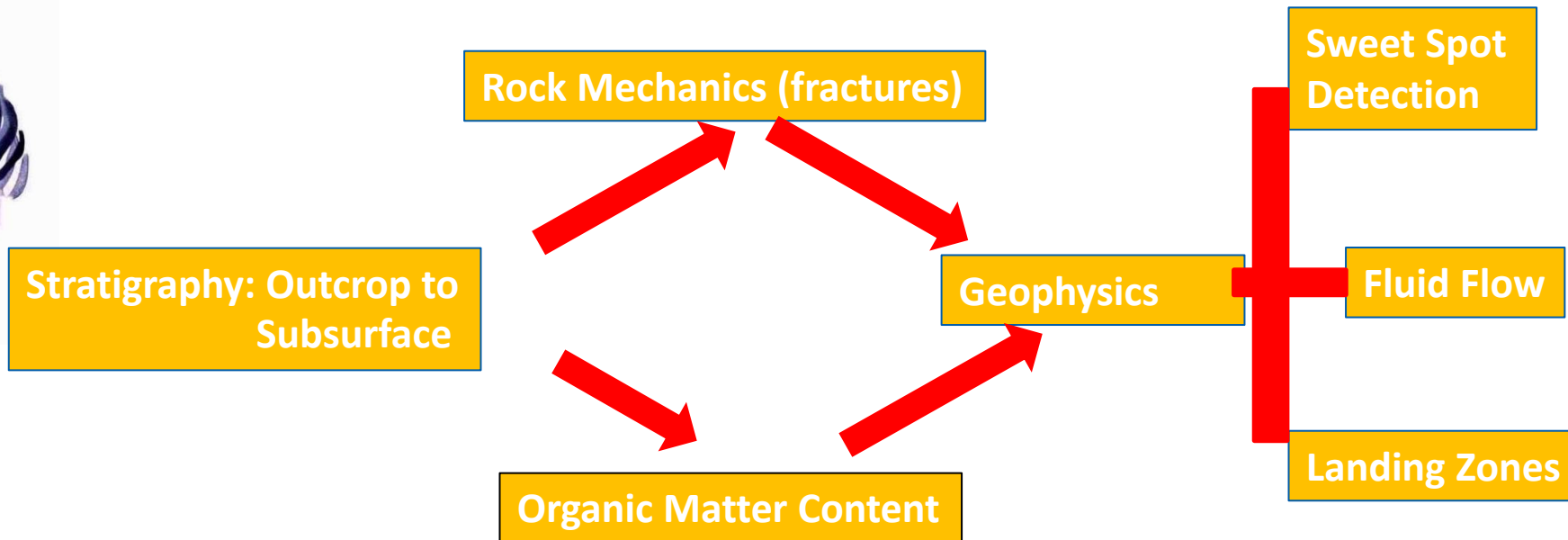
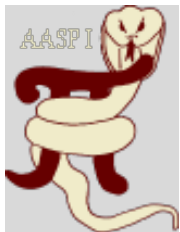
PRESENTATION OUTLINE

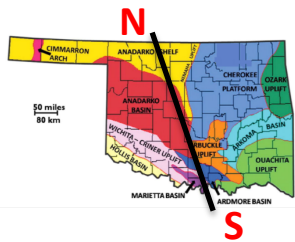
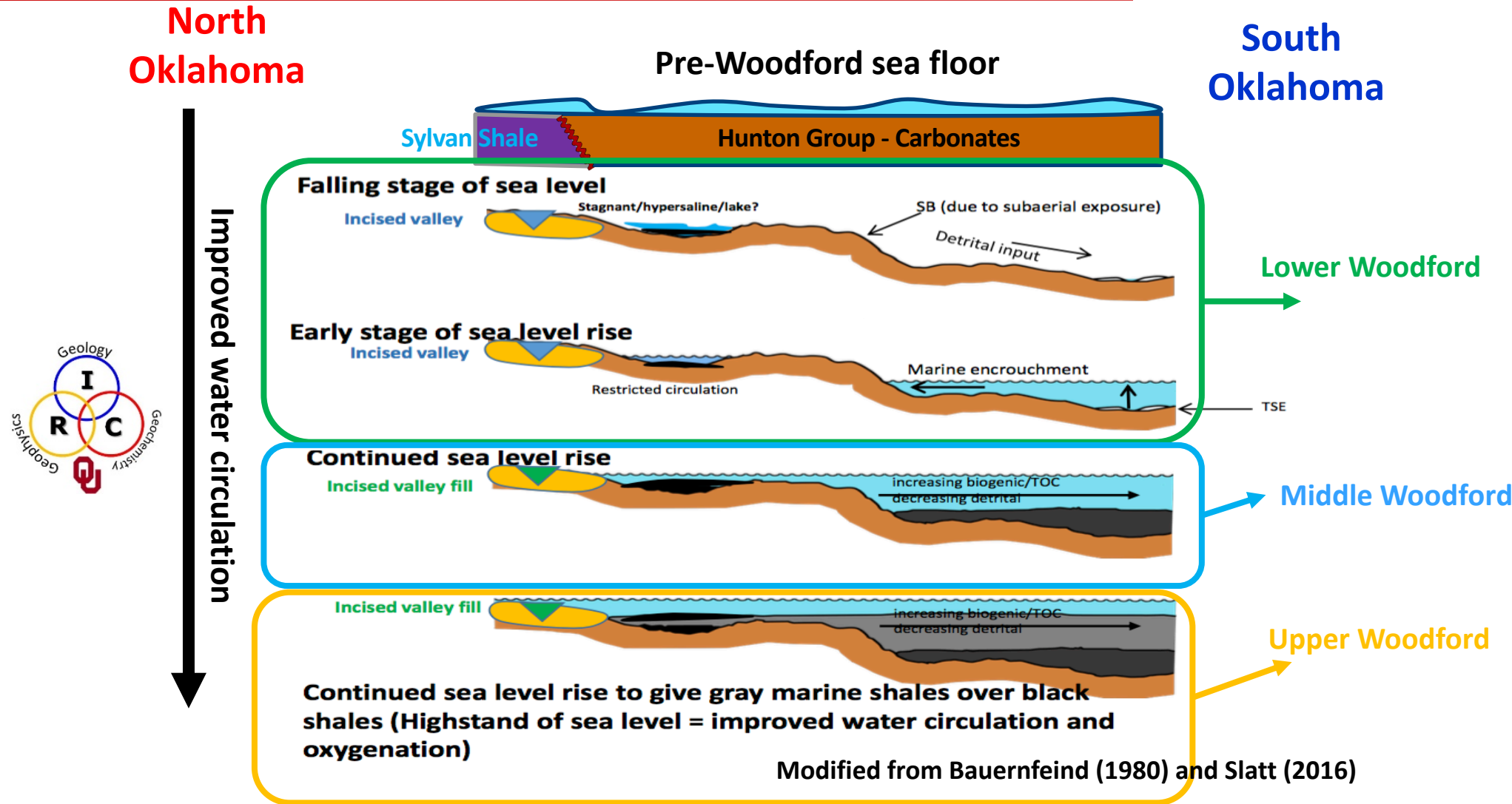
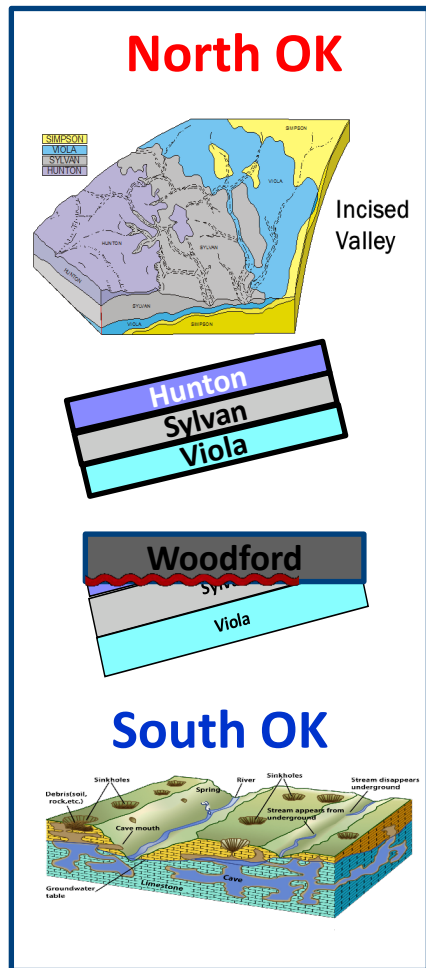
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Mmm that's a large title...
"..at any rate"

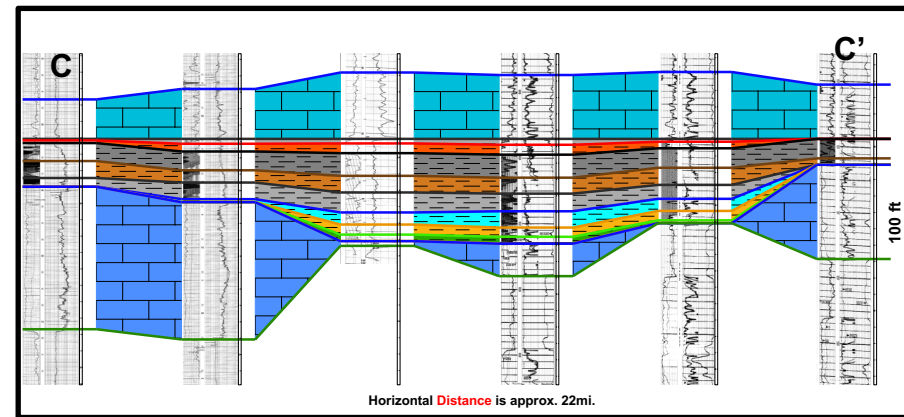
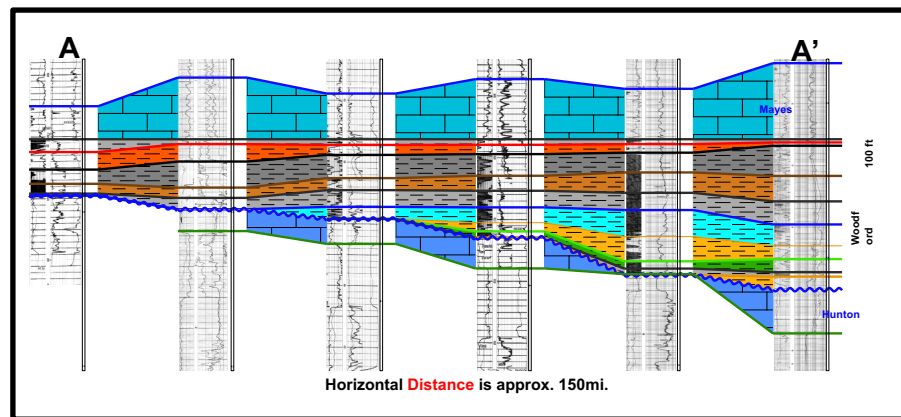
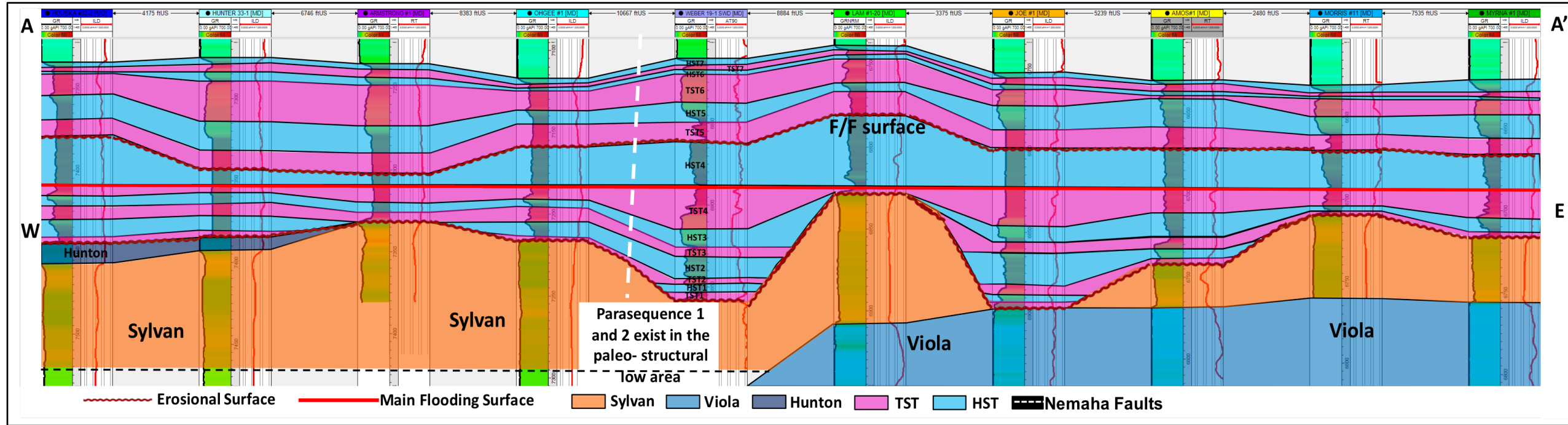
The value of integration





- The early stage of falling sea level may result in water mass isolation and restricted water circulation over topographic depressions left by karst/incised valley development on the underlying carbonate platform.

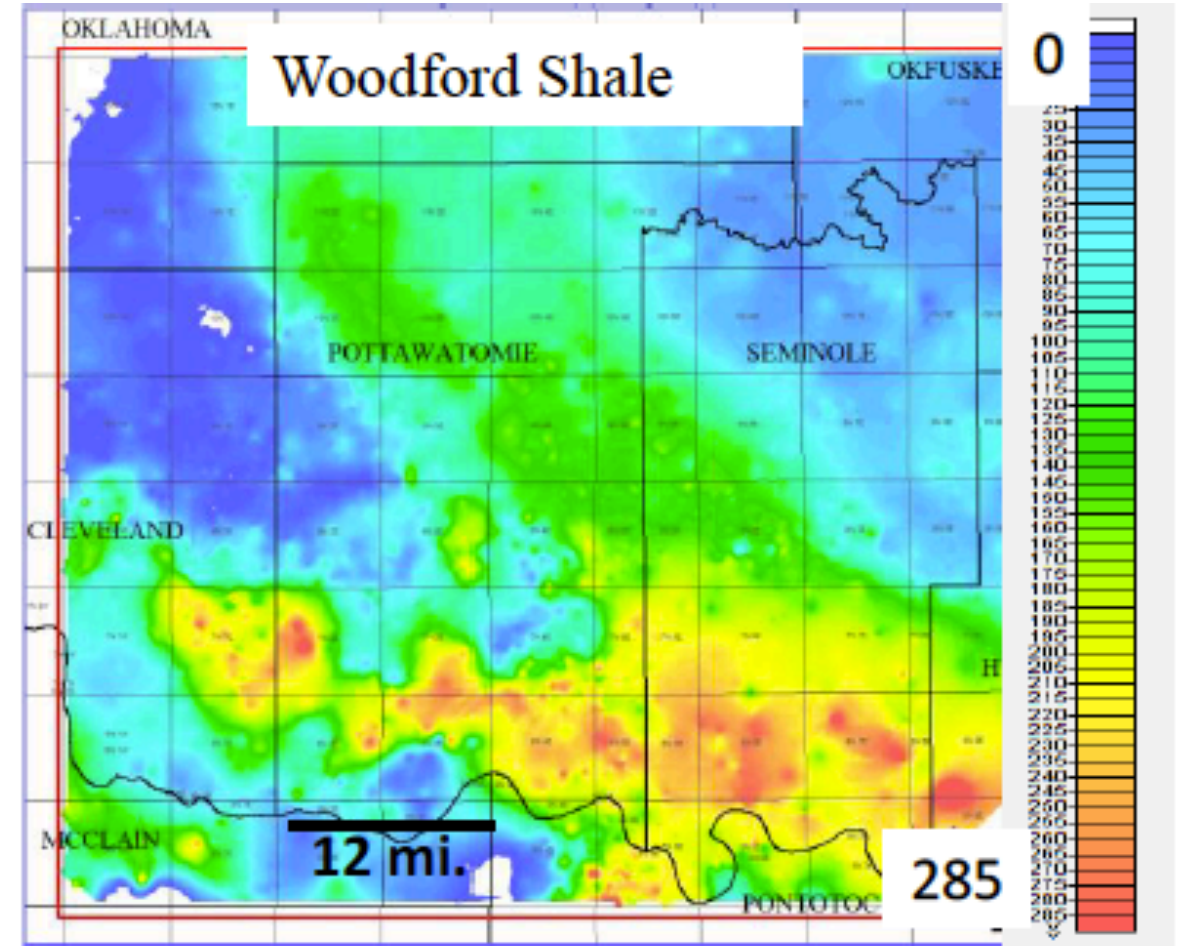
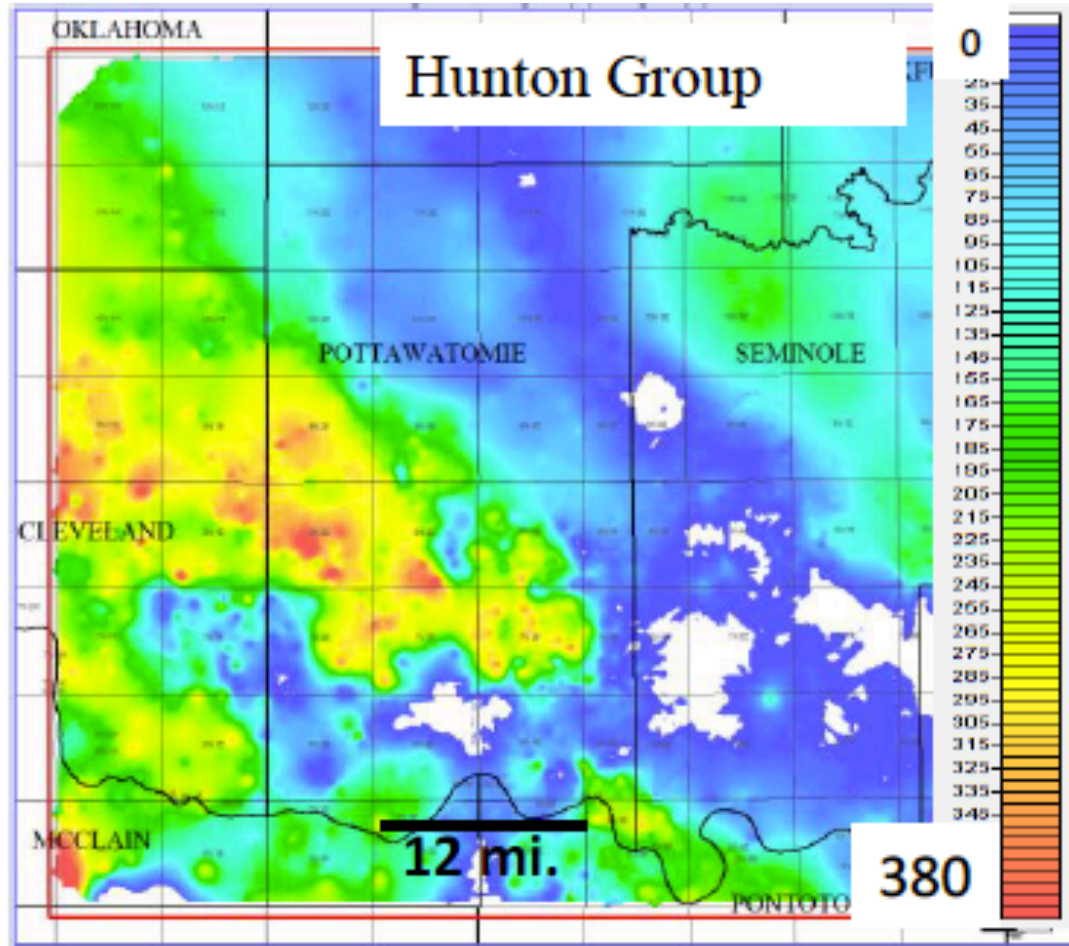
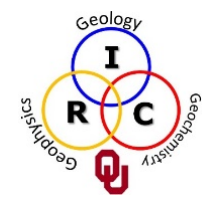
Woodford Shale stratigraphic correlations



(Zhang and Slatt, 2019)

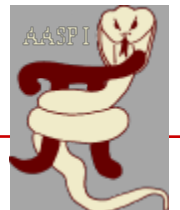
(McCullough and Slatt, 2014)

Woodford Shale regional depositional fairway



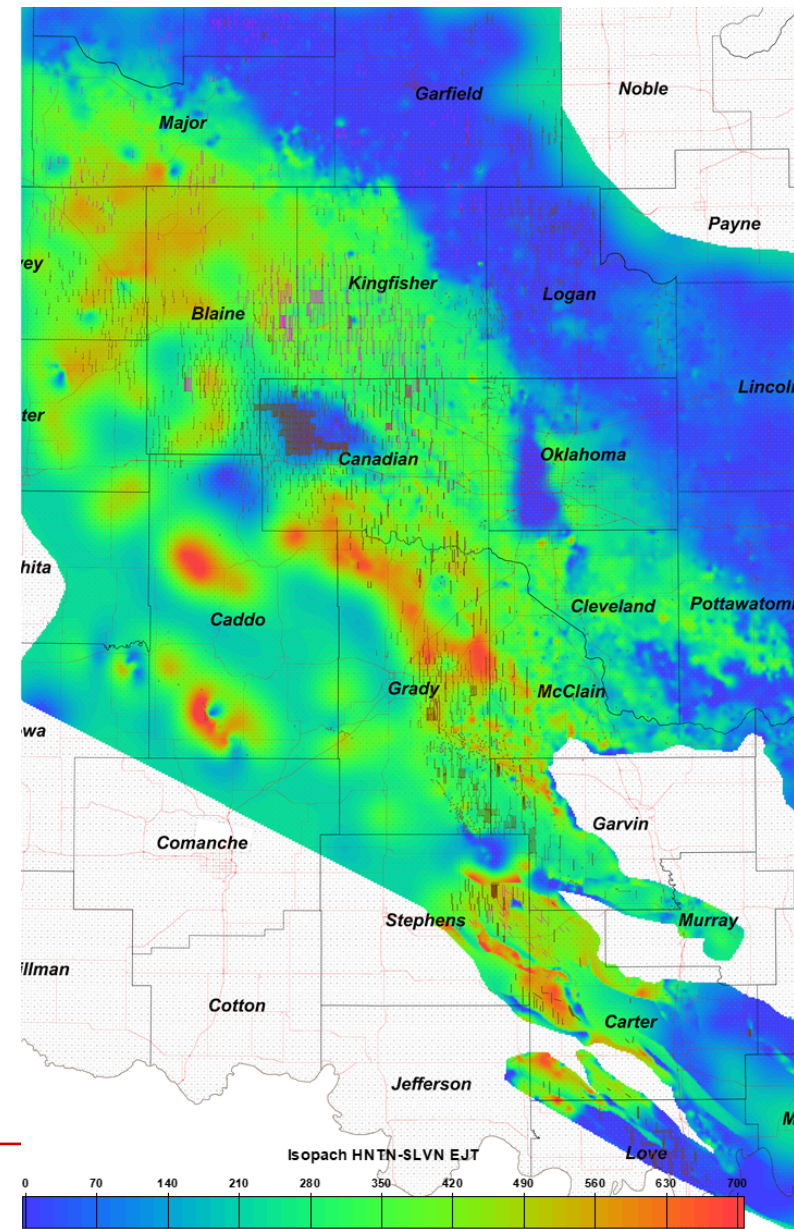
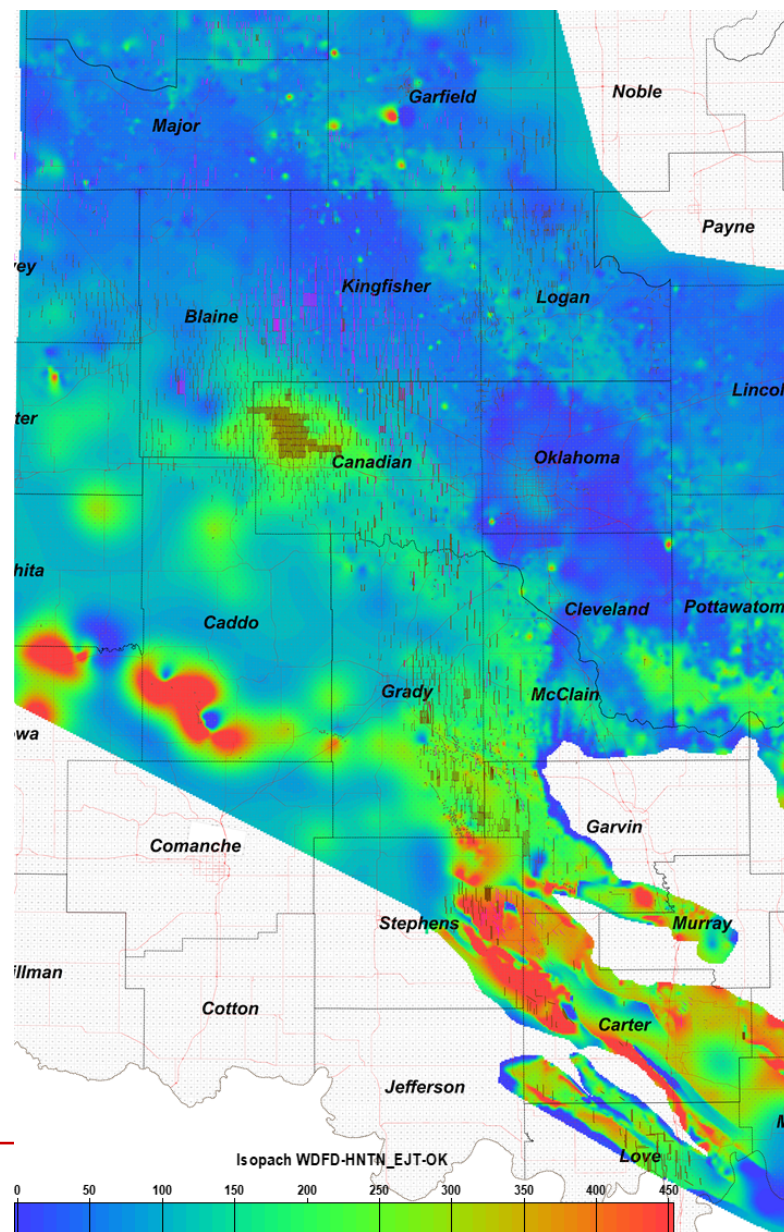
McCullough and Slatt (2014)

- The areas where the Woodford thickens correspond to the areas where the Hunton thins.
- There is an inverse relation between thickness of the Hunton unconformity and the overlying Woodford Shale.

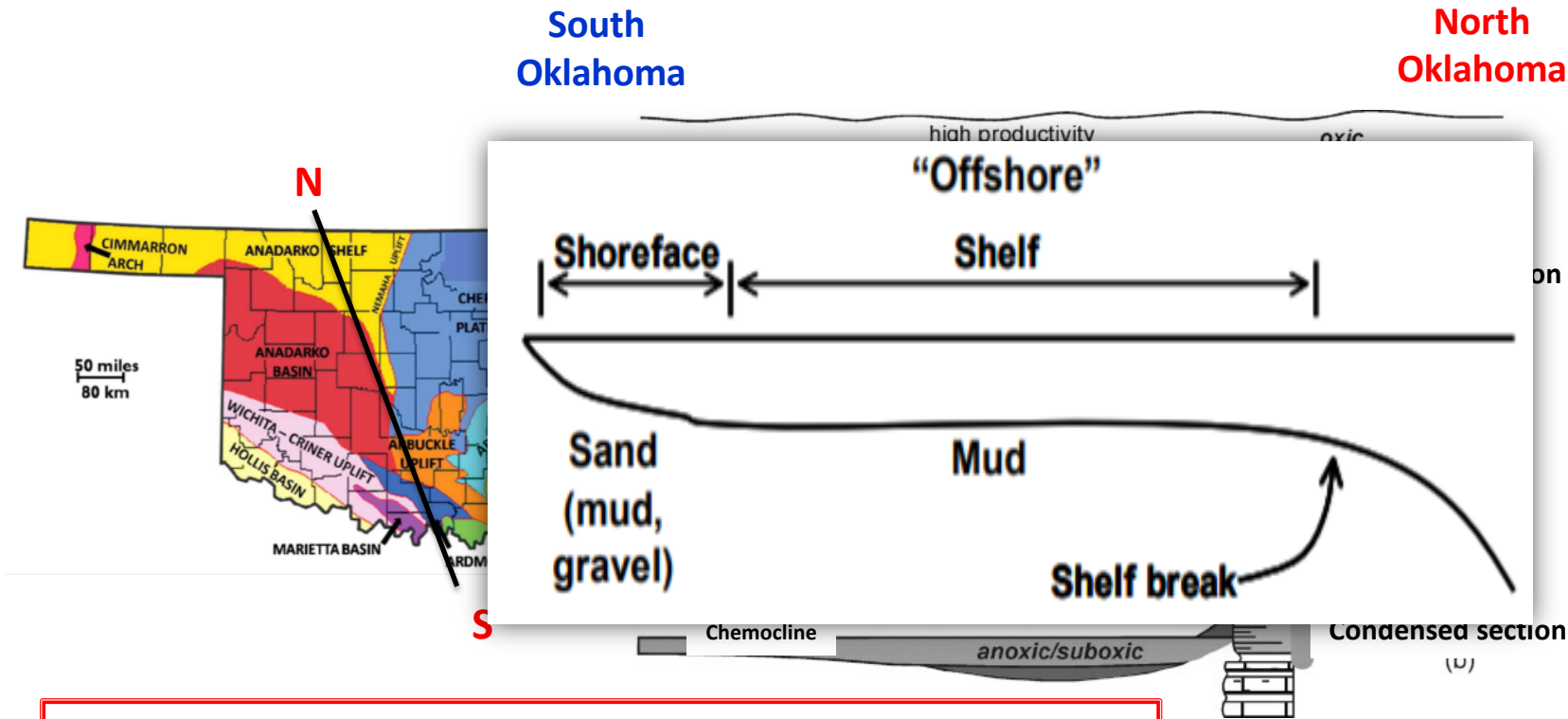


What did Emilio do?

- The macro picture!
- (For Emilio size matters)



1. What do I mean by enclosed mini-basin fill?



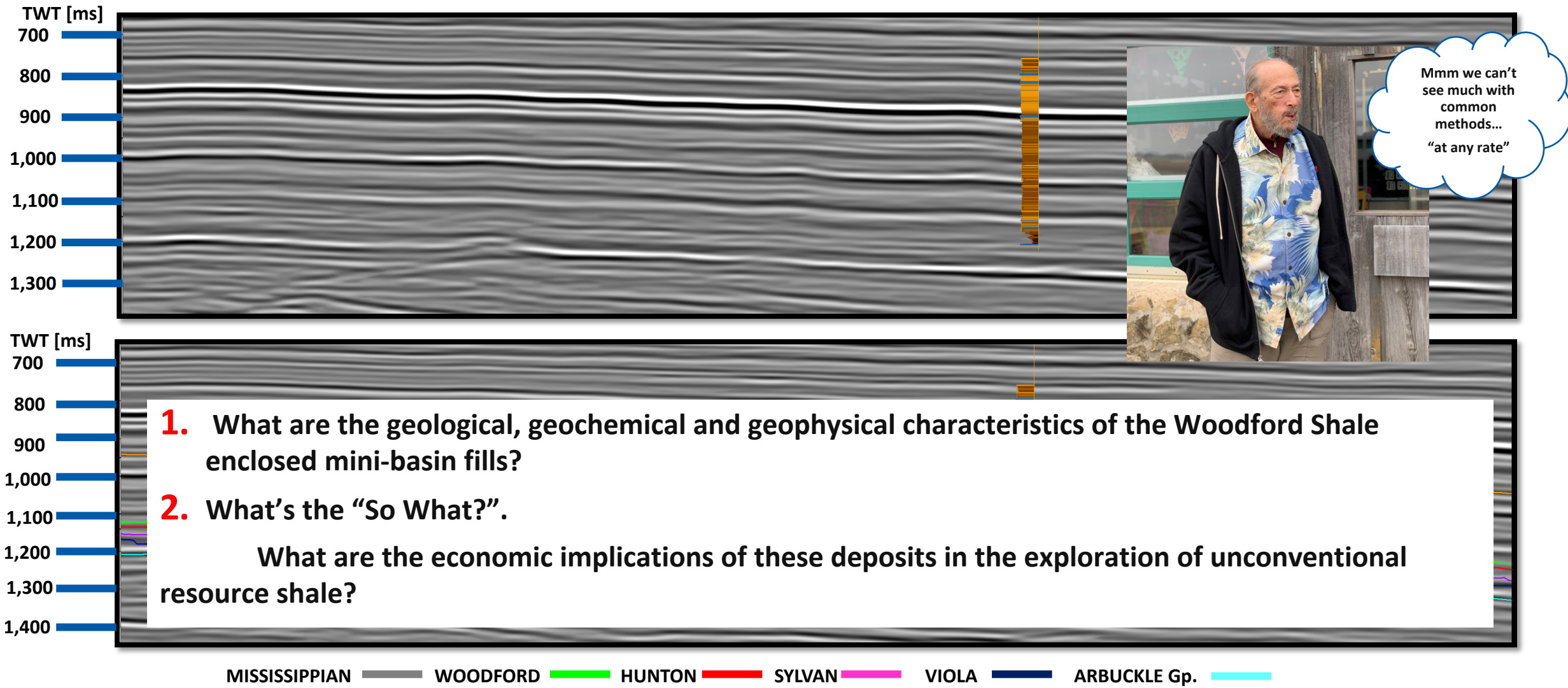
SWEET SPOTS:

- Good organic matter content
- Enough maturity (Temp. and Pressure) to generate HCs
- Can you "break it"? or not?

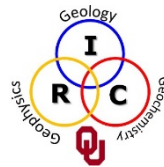
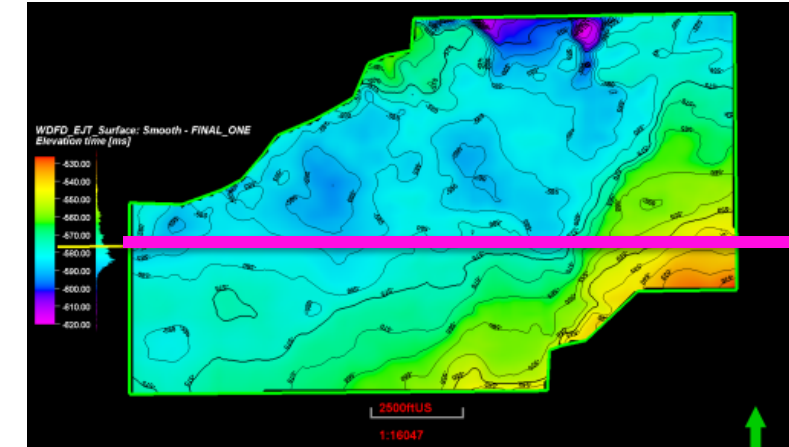
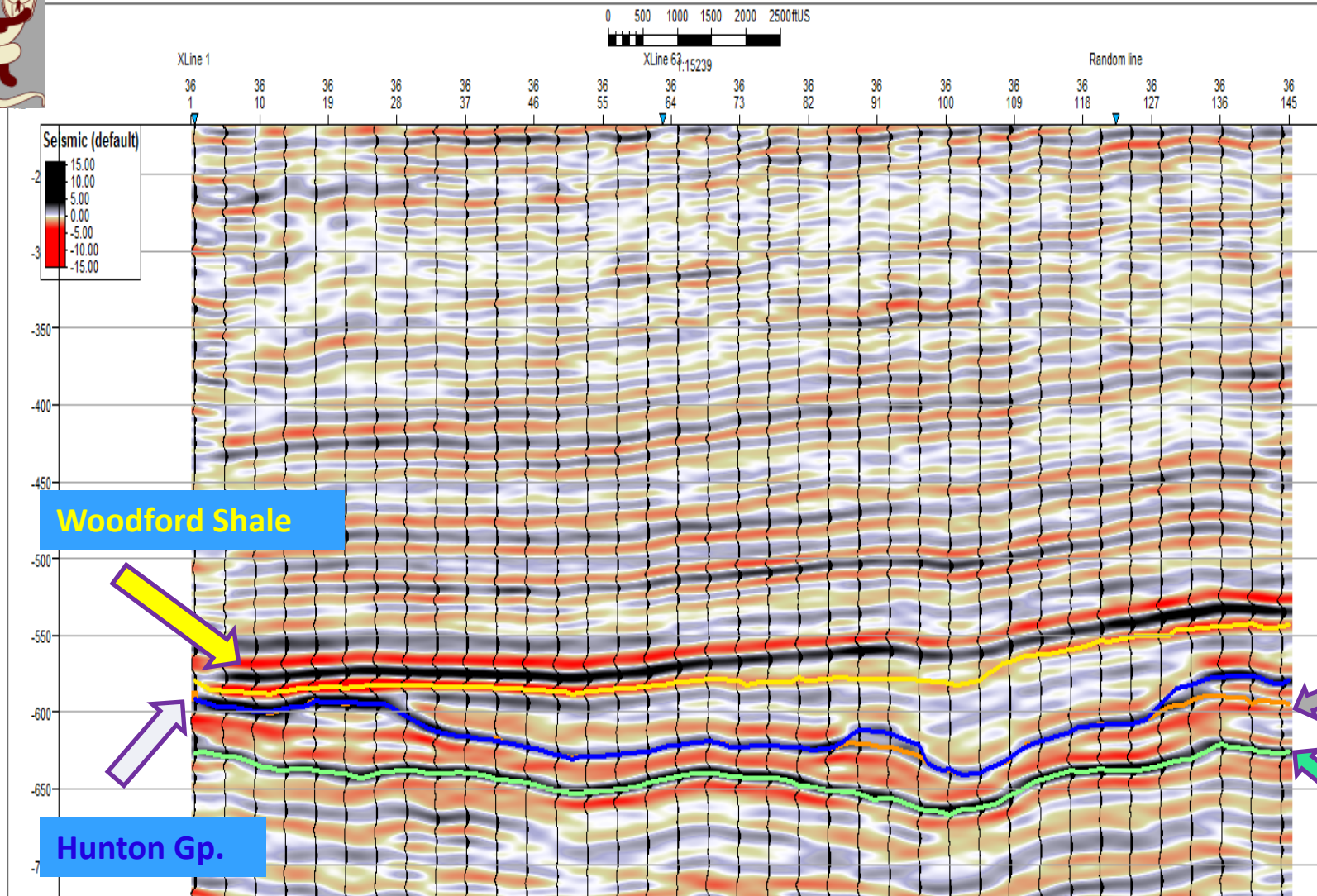
Age, Ma	System	AU Names	Hugoton Embayment Kansas	Northern Anadarko basin	Southern Anadarko Basin
-318.1	Mississippian	Mississippian		Chester Group	Cunningham sands Markham sand Britt sand Aldridge sand Spiers sand Humphreys sand Boatwright sands Sims sands Goddard Shale Goodwin sand
-333			Chester Group	Chester Group	Springer Formation
-340			Meramec line	Meramec line	Mayes Group
-348			Osage Chert	Osage line	Delaware Creek Shale (Caney Shale)
-359.2			Gilmore City Limestone	Osage line	Sycamore Limestone
-365	Devonian	Woodford Shale	Hannibal Shale	Woodford Shale	Woodford Shale
-374				Misener sand	Misener sand
-379	Silurian	Hunton Group		Frisco Formation	Frisco Formation
-416				Bois d' Arc Formation	Bois d' Arc Formation
-421				Haragan Formation	Haragan Formation
-432				Henryhouse Formation	Henryhouse Formation
-443.7	Silurian	Hunton Group	Chimneyhill Limestone	Chimneyhill Limestone	Chimneyhill subgroup
					Clarita Fm. Fitzhugh Mbr. Prices Fall Mb Cochrane Fm. Keel Fm.

1. How these rocks look in the subsurface?

Main scientific questions



2. Woodford Shale Seismic interpretation

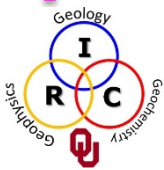
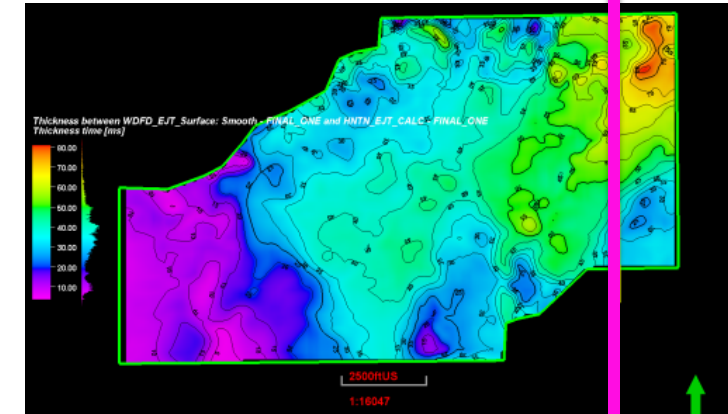
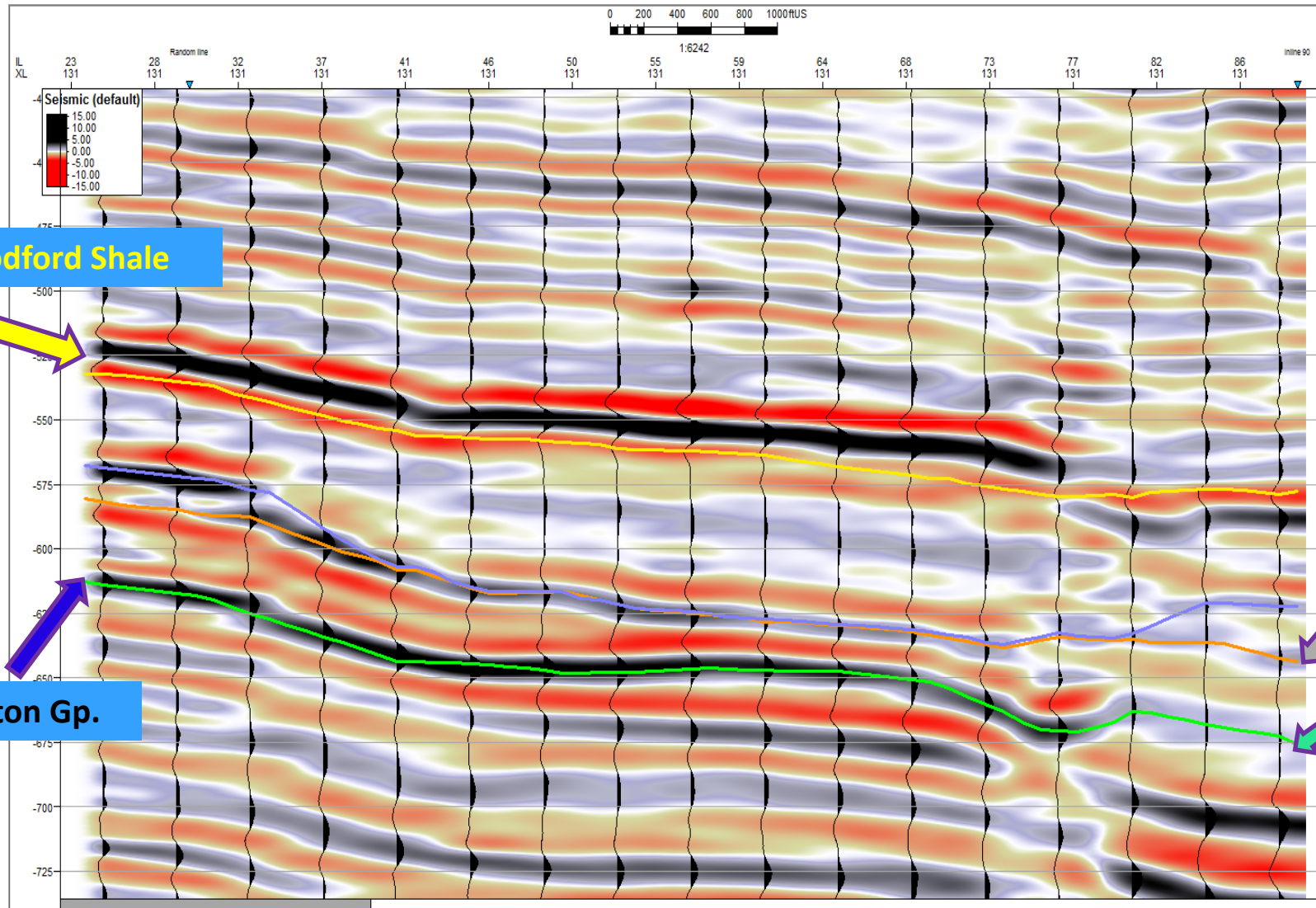


Sylvan Shale

Viola



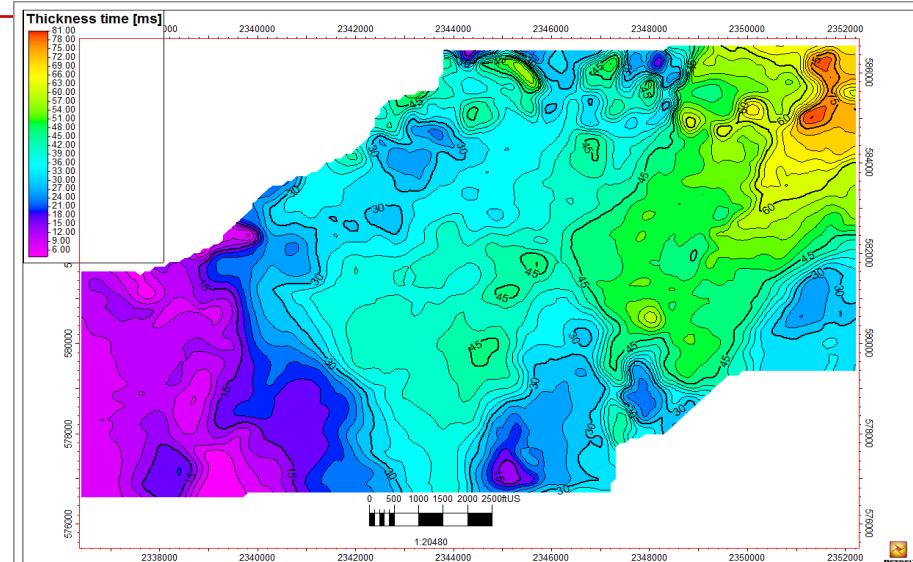
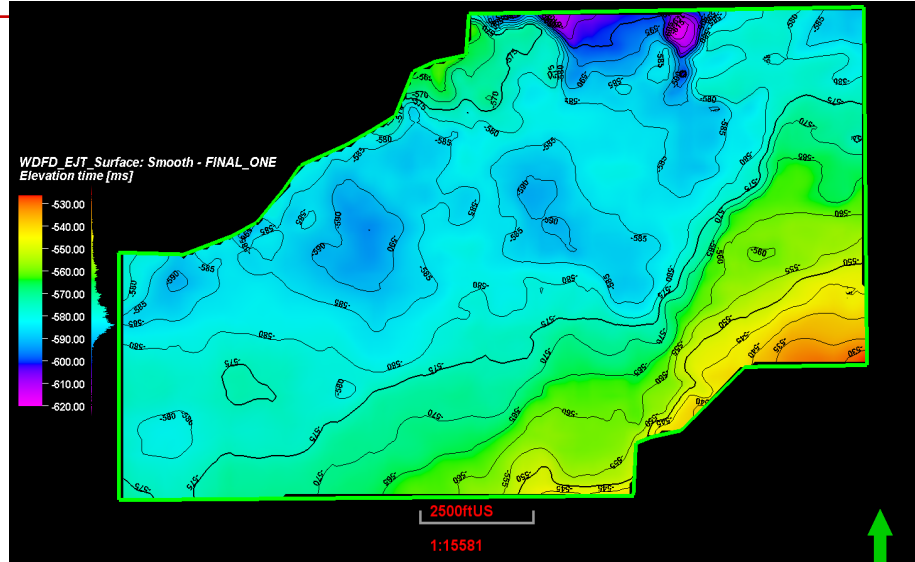
2. Woodford Shale Seismic interpretation



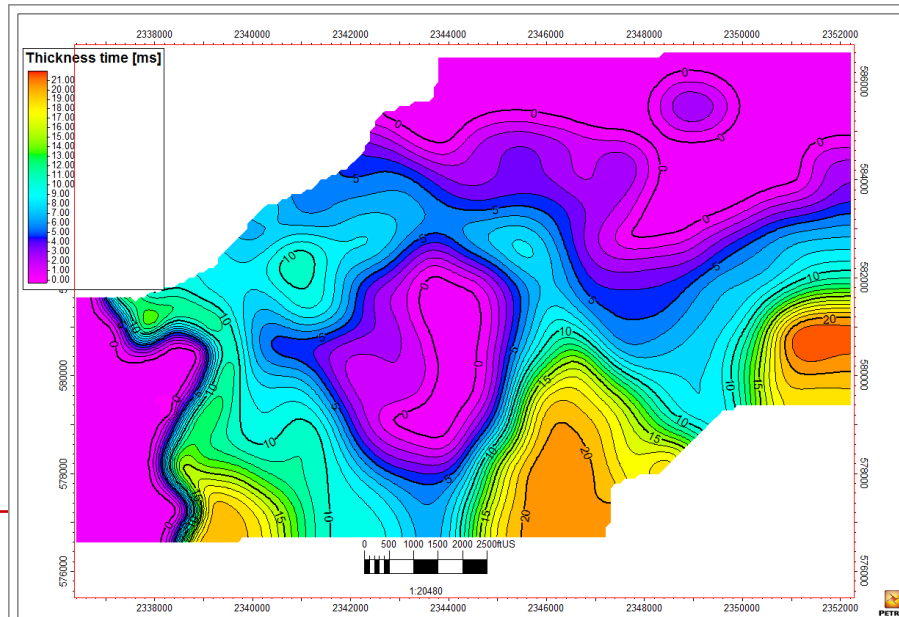
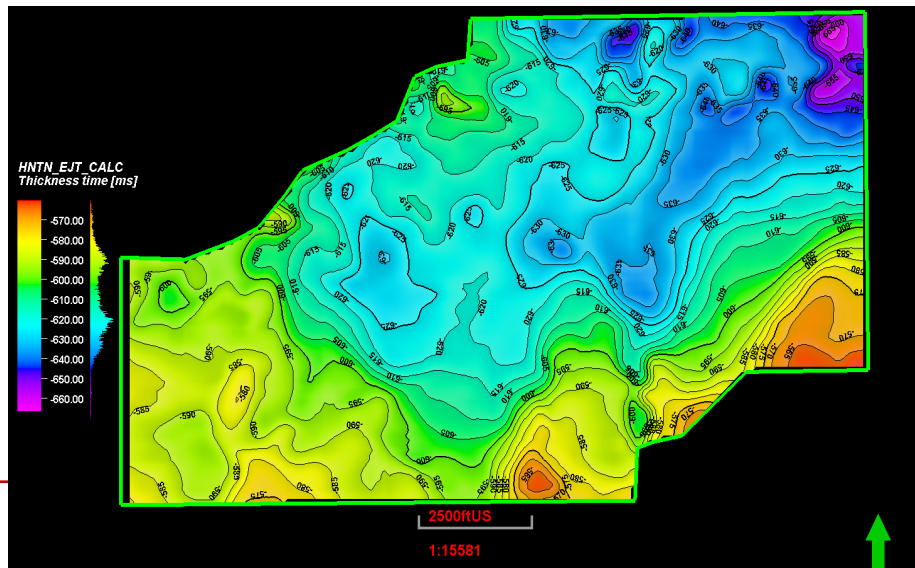
Sylvan Shale

Viola

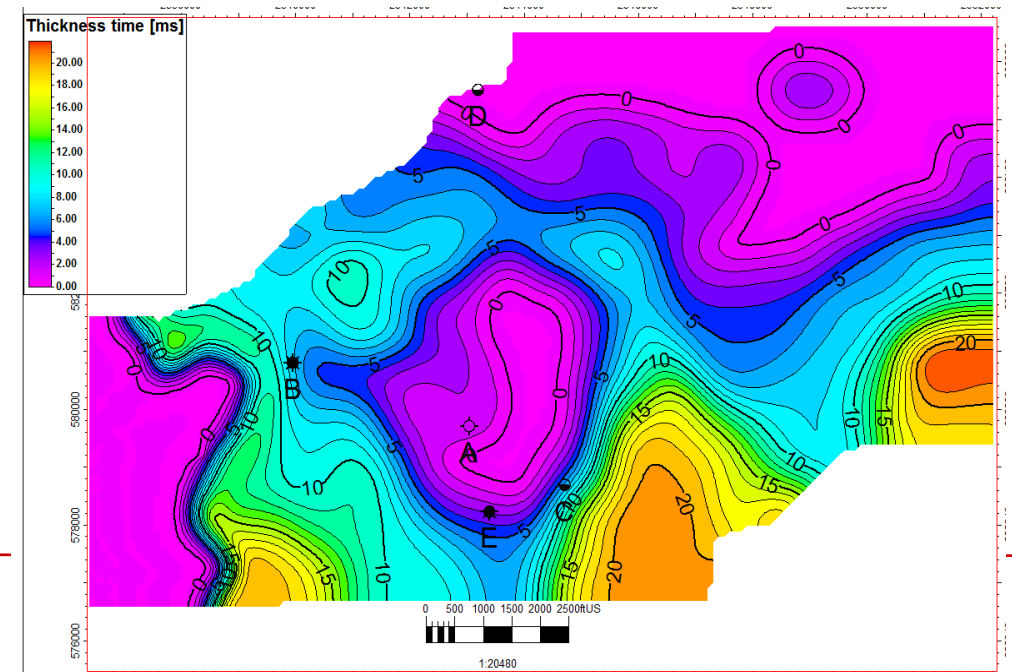
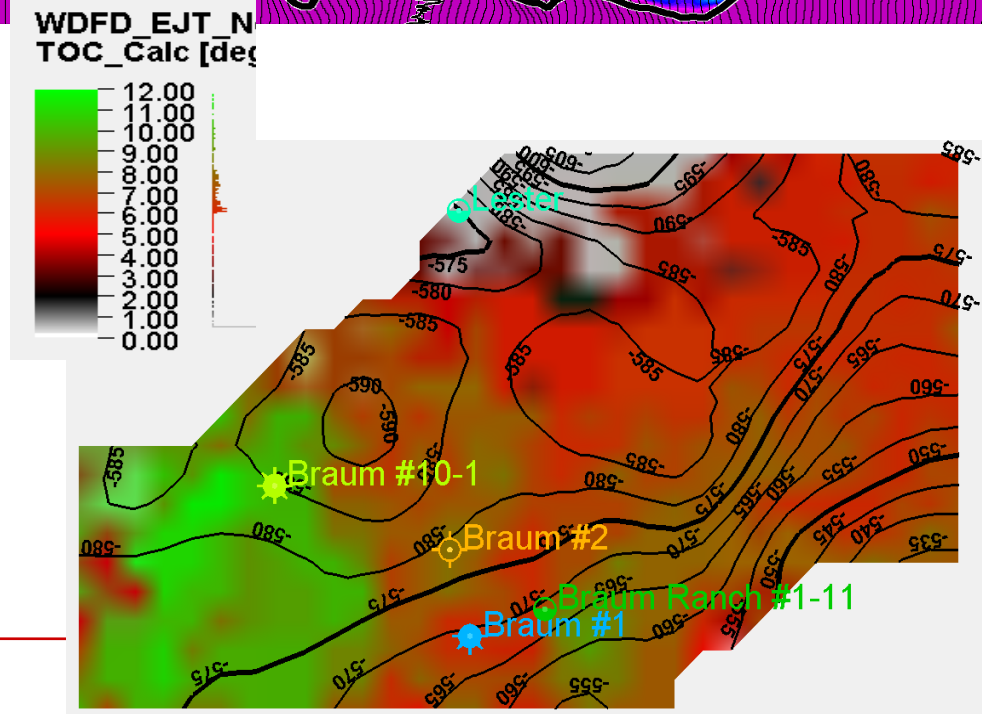
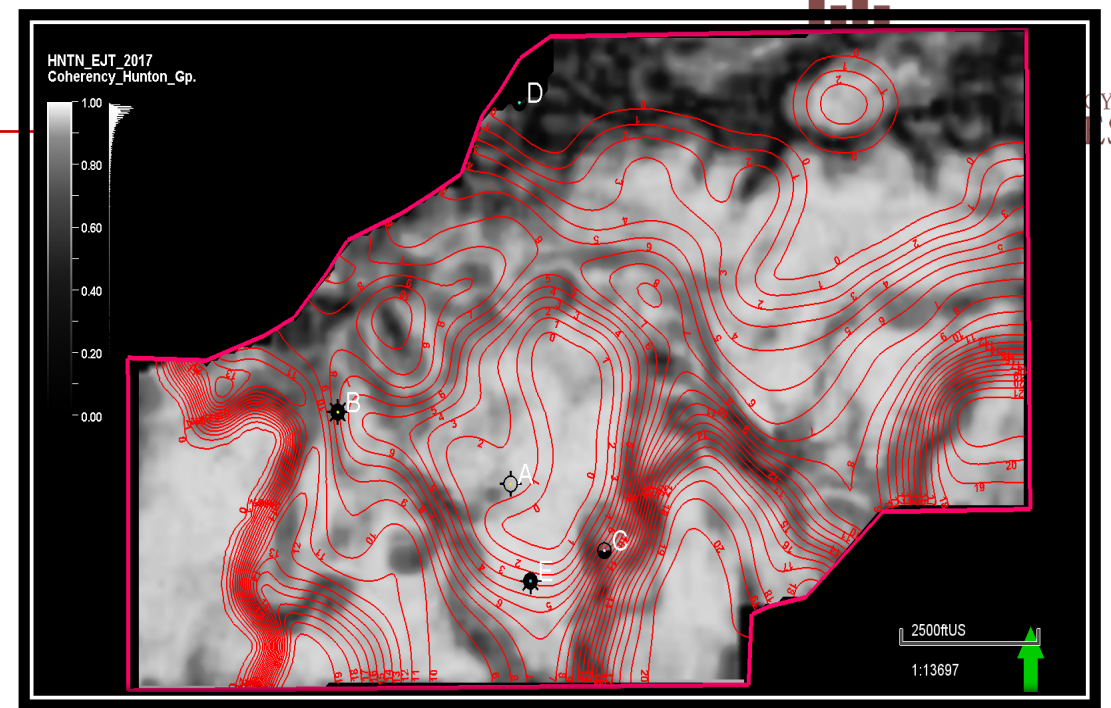
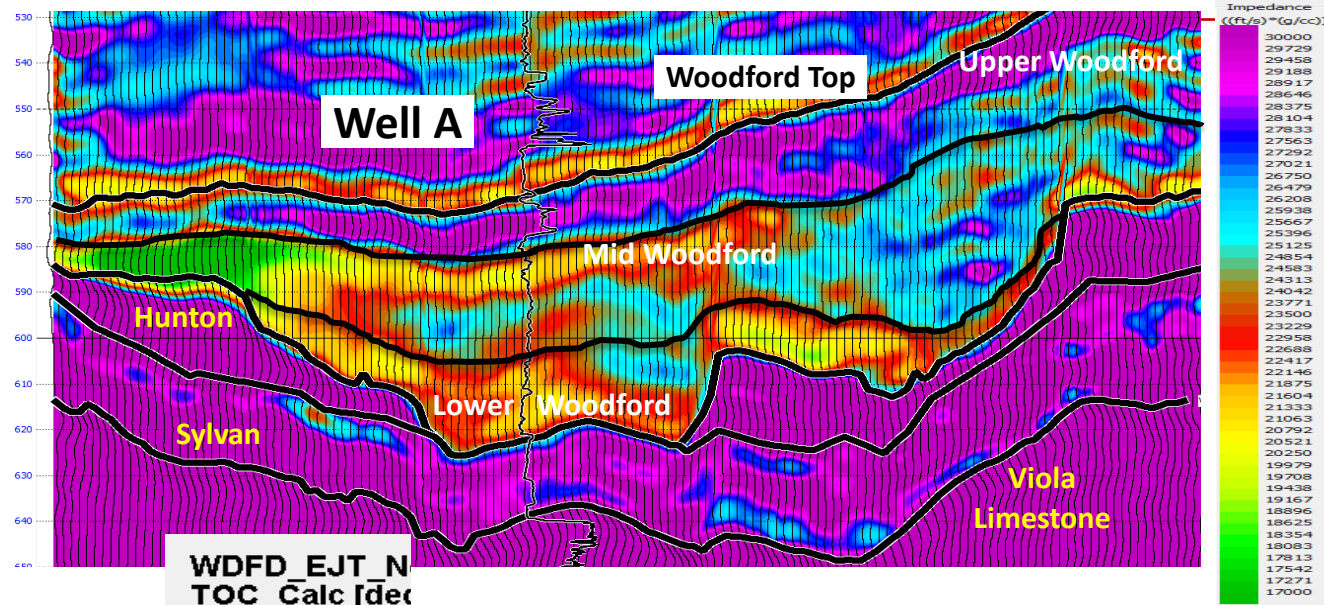
2. Woodford Shale structure and thickness maps



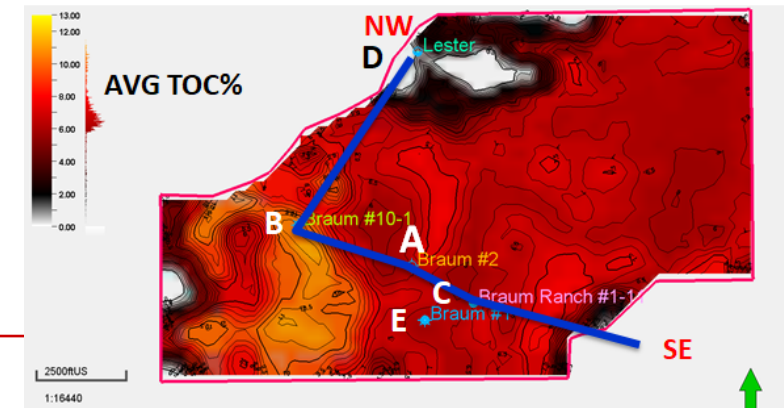
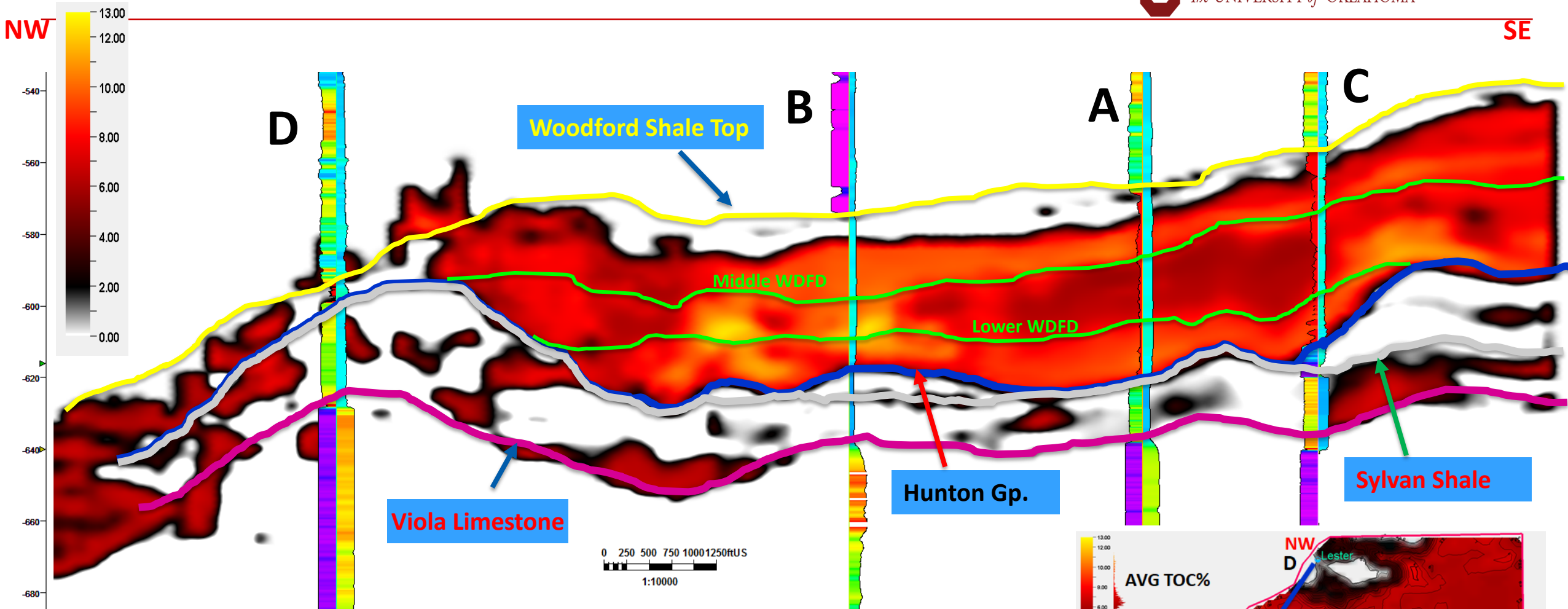
Hunton Group maps



2. %TOC Calculation from Woodford to Hunton gp.



2. Modeled %TOC variation inside the Woodford Shale

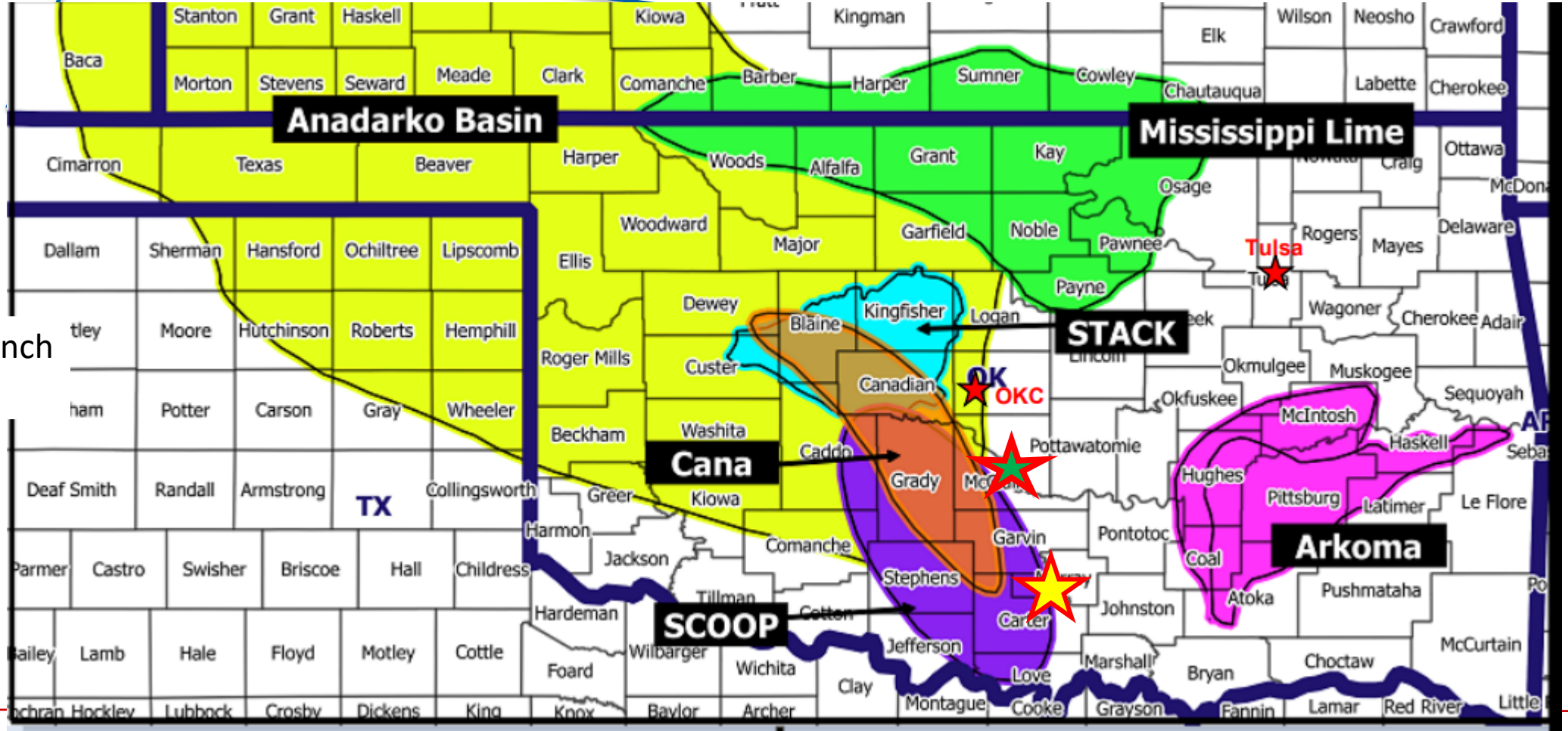


2. Summary of 3D Seismic Characteristics

Seismic characteristics of enclosed mini-basin fill.

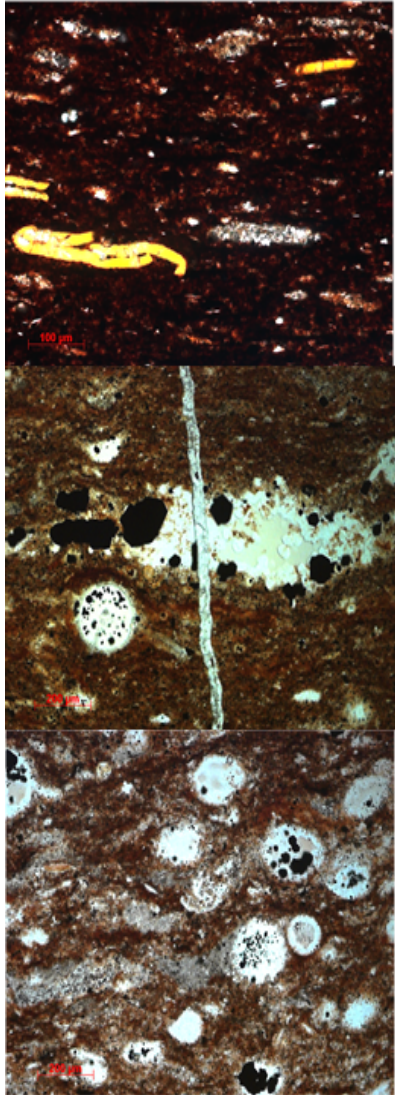
- Thicker basal sections that trend to pinch out towards paleo structural highs of the pre-existing strata. In this case, the seismic resolution was enough to image internal reflectors of the Woodford Shale.
- Incoherent seismic data at the base of the Woodford Shale, caused by erosion or karstification of pre-existing strata
- Most negative curvature values in the areas of these deposits that indicate accommodation space and sedimentation filling the enclosed mini-basin fill pockets.
- Low (or the lowest) acoustic impedance that correlates with higher accumulations of organic matter (%TOC) in the lowermost parts of the Woodford Shale seismic window. This is due to a deeper water column in these areas and more restricted water circulation, therefore, a restricted interaction with upwelling currents that preserve the %TOC.

3. The Speake Ranch outcrop



★ Speake Ranch outcrop

3. Geochemical characteristics of enclosed mini-basin fills Speake Ranch outcrop.



Siliceous shale lithofacies description from Galvis (2017)

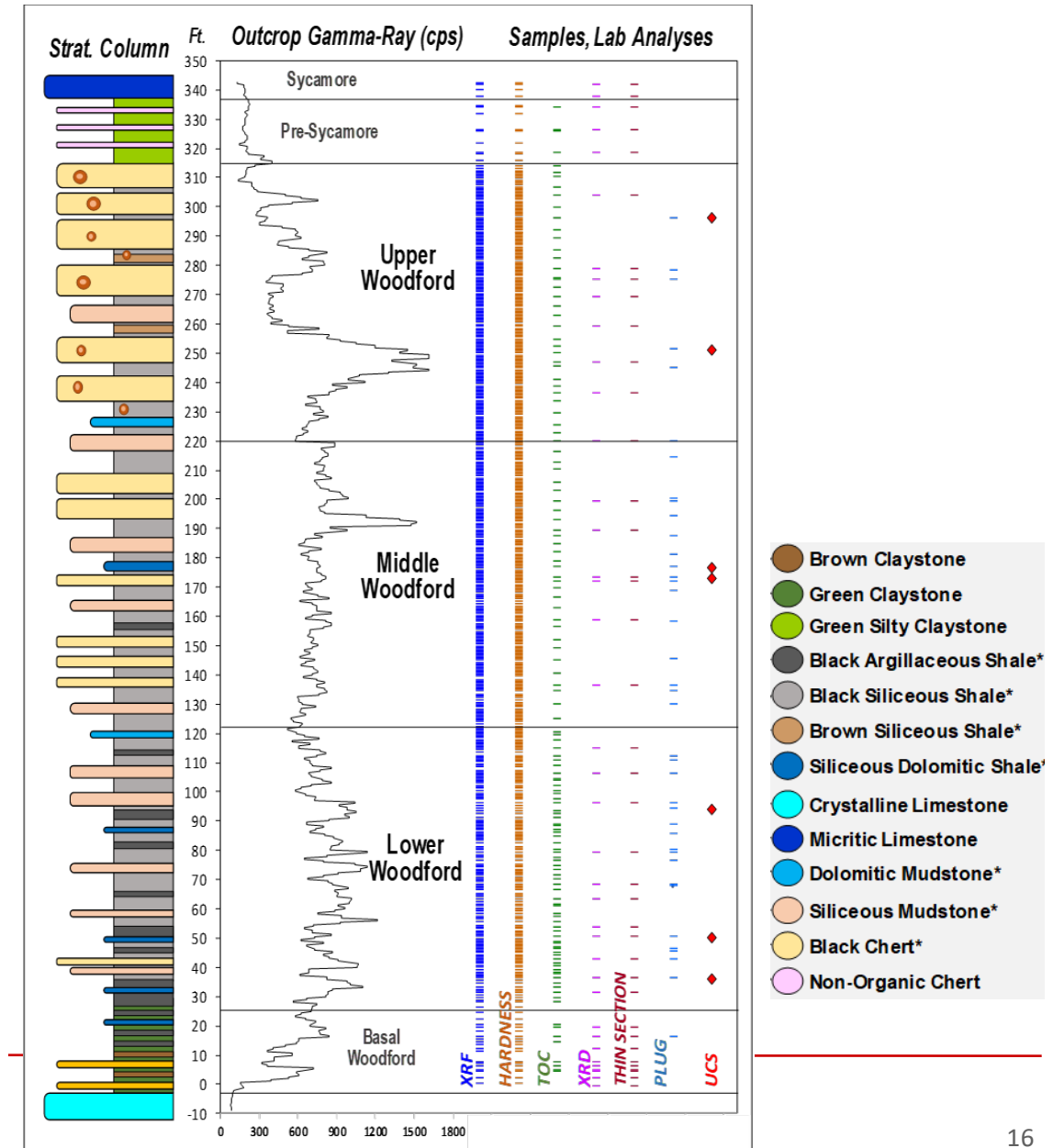
The shale matrix is largely made of microcrystalline authigenic quartz and clays; embedded coarser particles include silt-sized detrital quartz in laminae and flattened *Tasmanites*.

Siliceous mudstone lithofacies description

The shale matrix is made of aggregates of micro-crystalline quartz (no visible discrete grains contacts). Scattered through the matrix there are abundant well-preserved radiolarian and *Tasmanites* filled with chalcedony and pyrite.

Chert lithofacies description

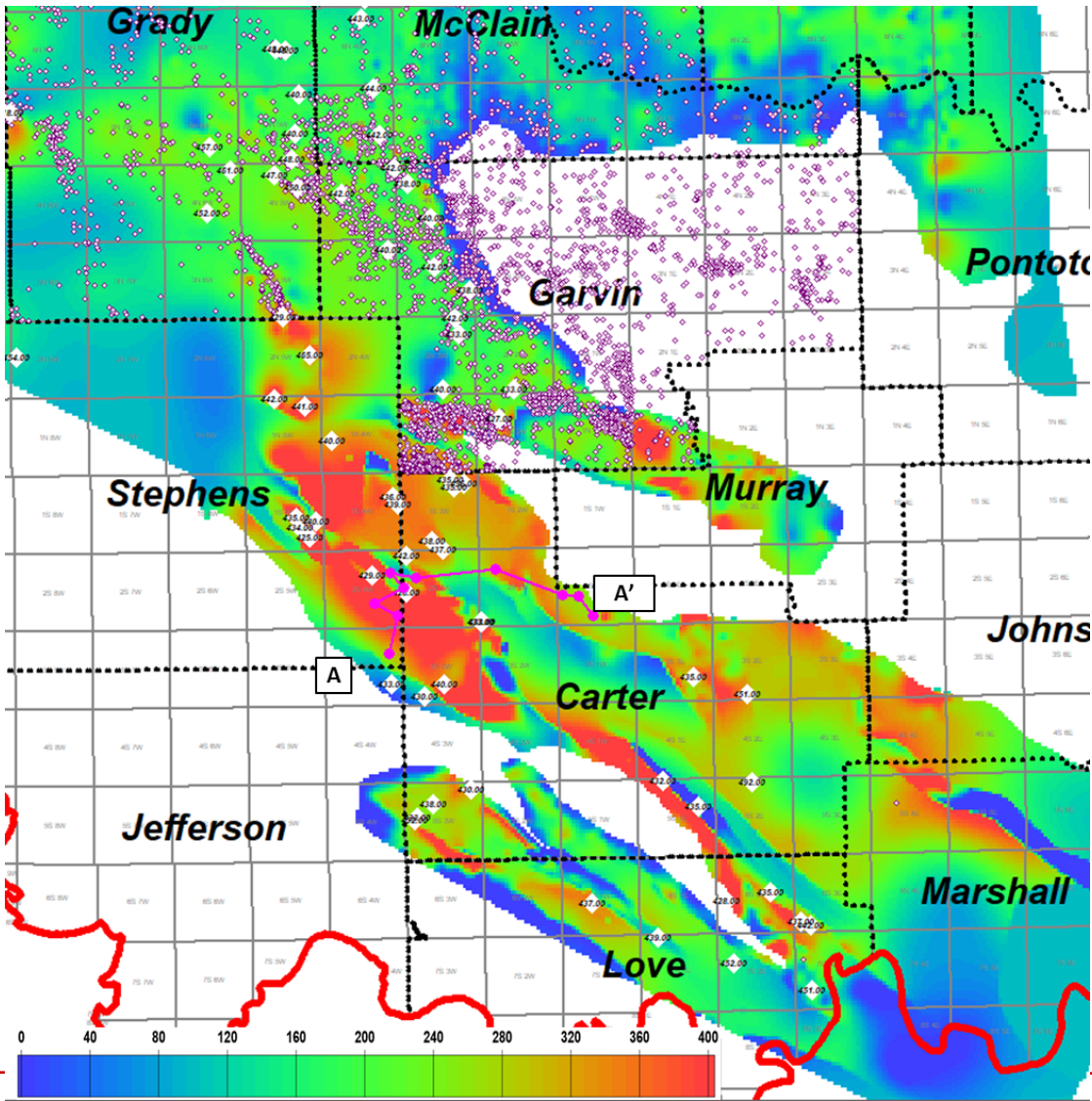
The matrix is made of micro-crystalline quartz aggregates. Well-preserved radiolarian tests and *Tasmanites* are replaced by chalcedony quartz.



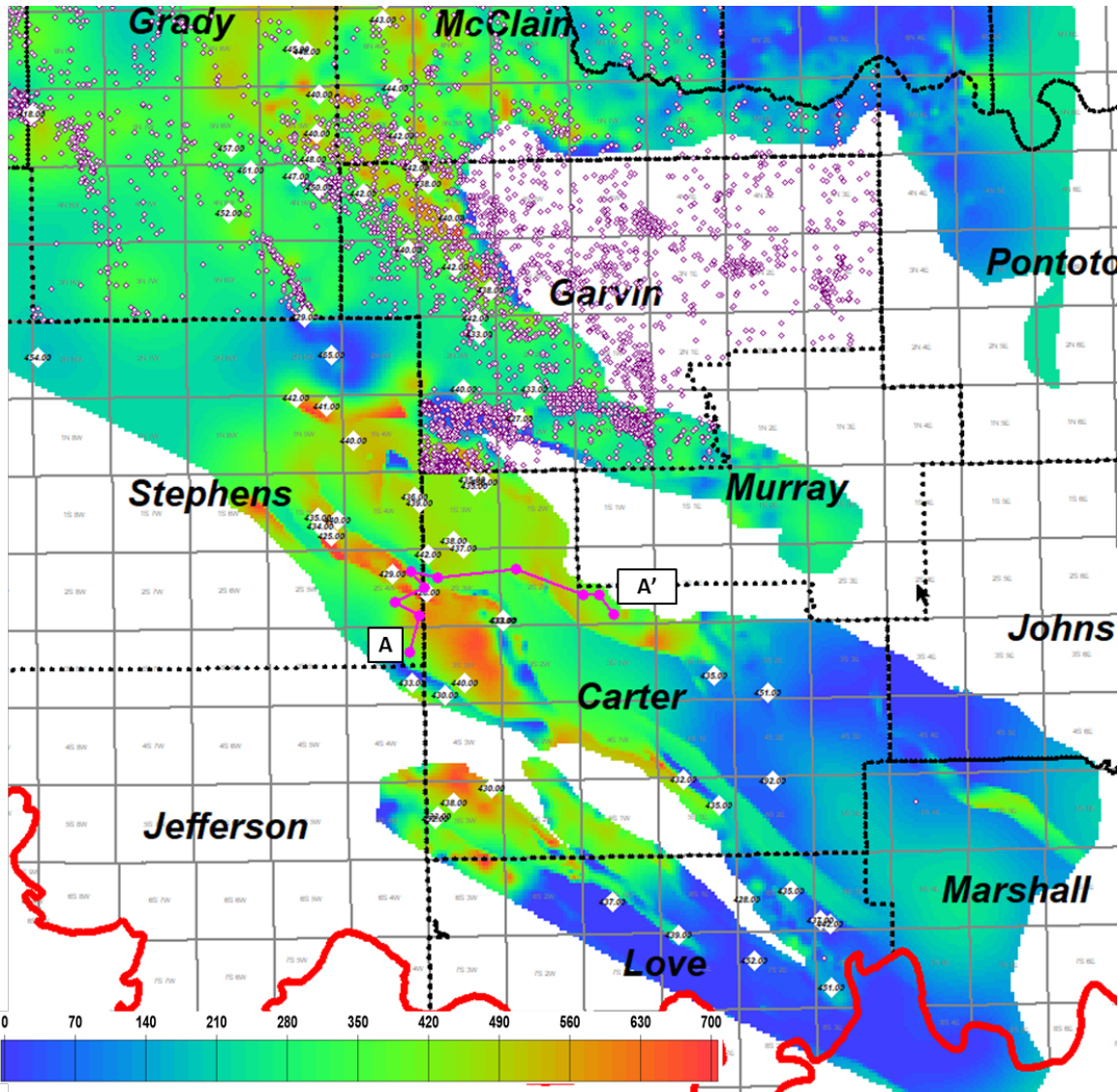
Galvis, 2017; Galvis et al., 2017

3. Why is the SR suspicions of a enclosed mini-basin fill settings?

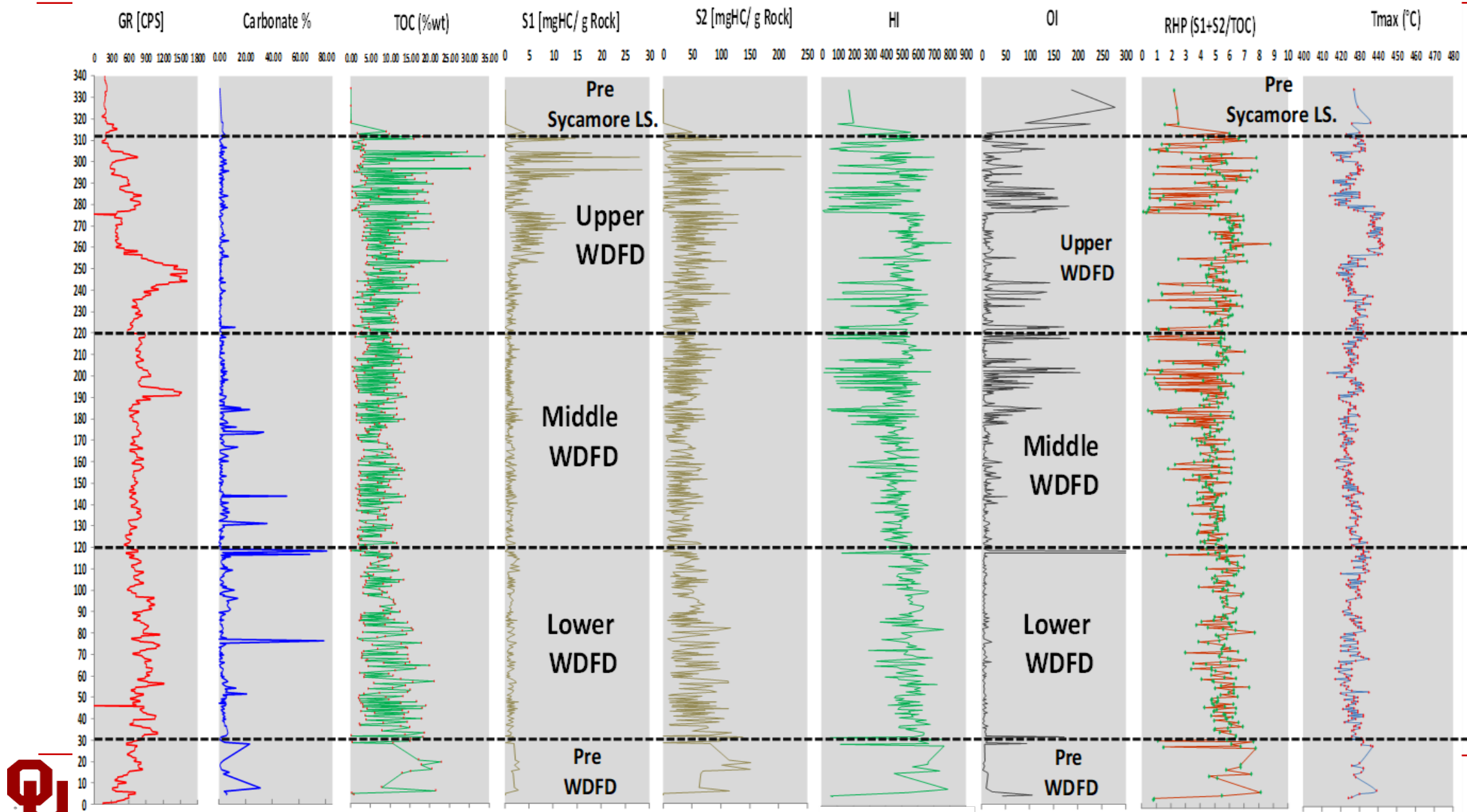
Woodford Shale thickness [ft]



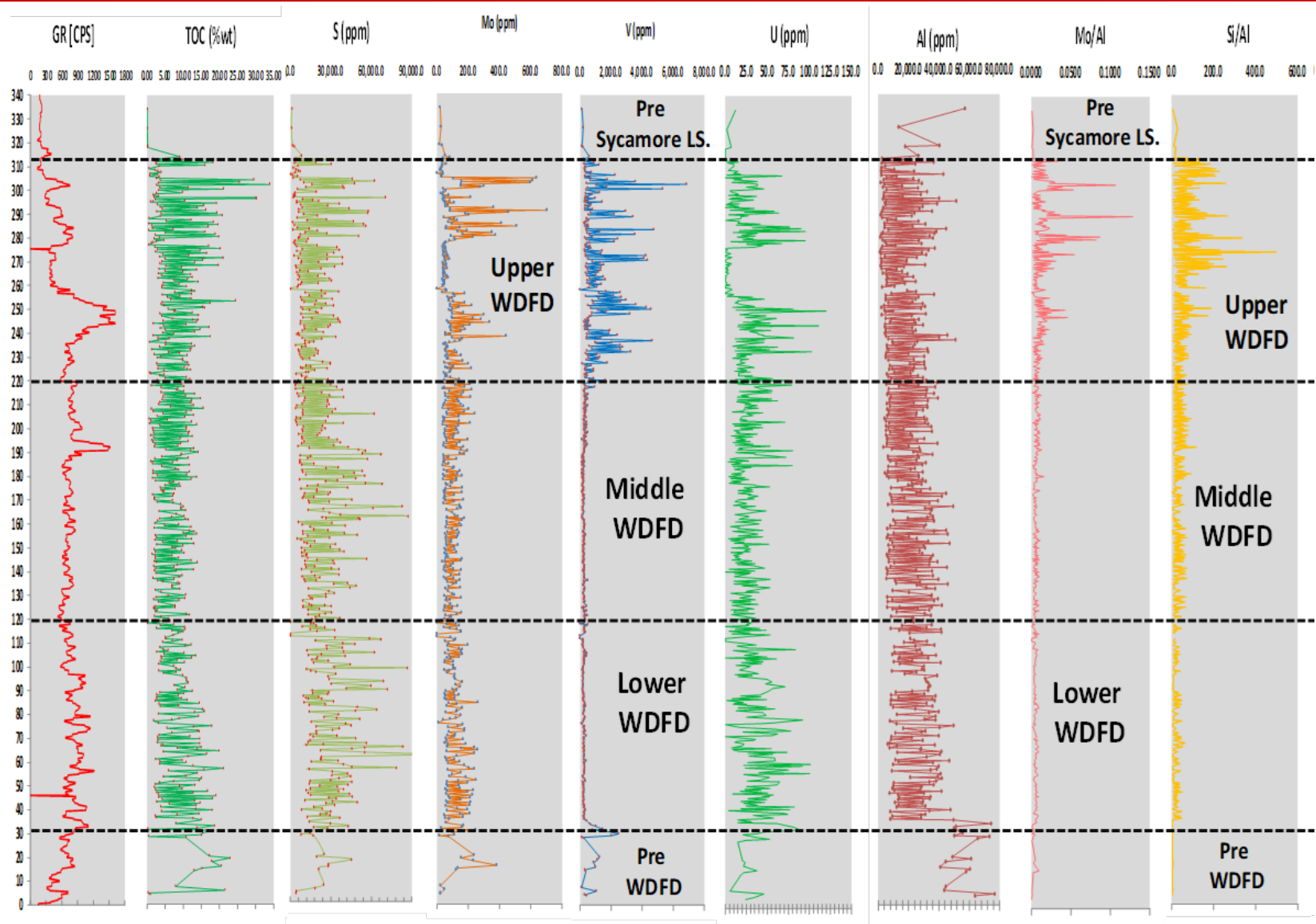
Hunton group thickness [ft]



3. Organic matter content in the Speake Ranch (SR)



3. Inorganic geochemistry characteristics from X-ray fluorescence (XRF) proxies



3. Tetracyclic polyprenoids (Holba et al., 2000 and 2003)

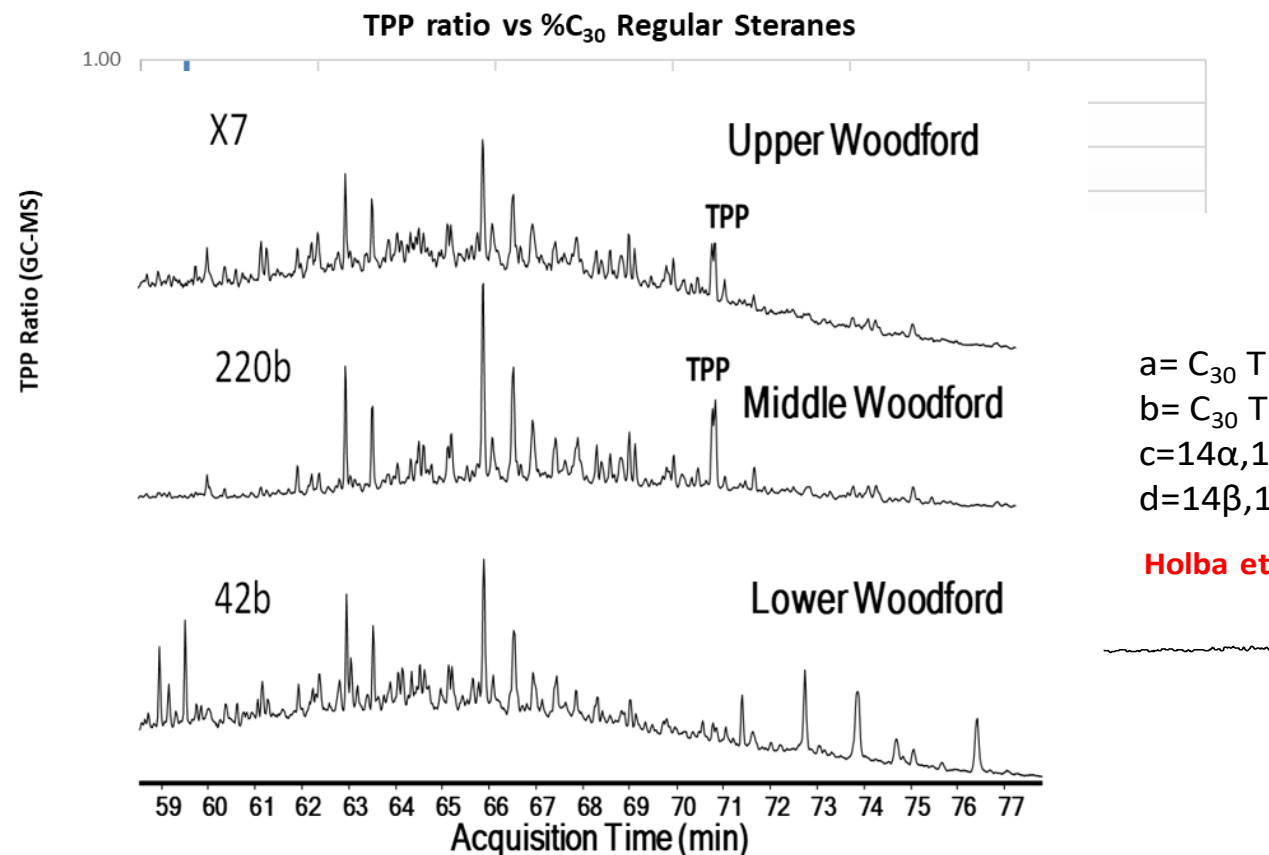


Figure 3.34. GC-MS saturate fraction of one sample in the Upper, one in the Middle, and one in the Lower Woodford members for screening in the m/z 259.3 the possible presence of TPP,

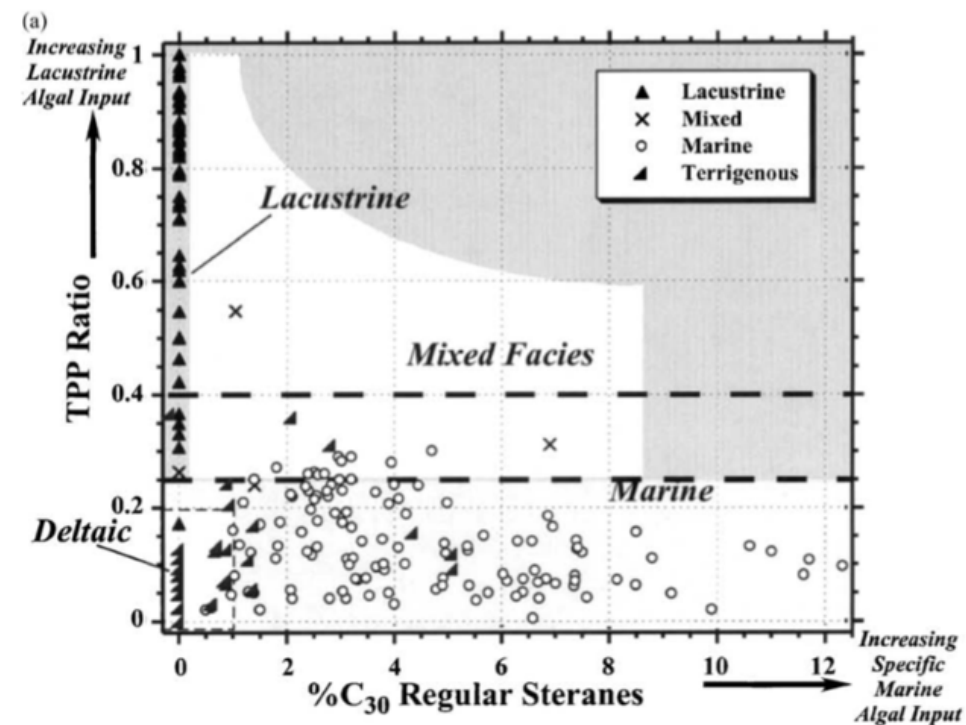
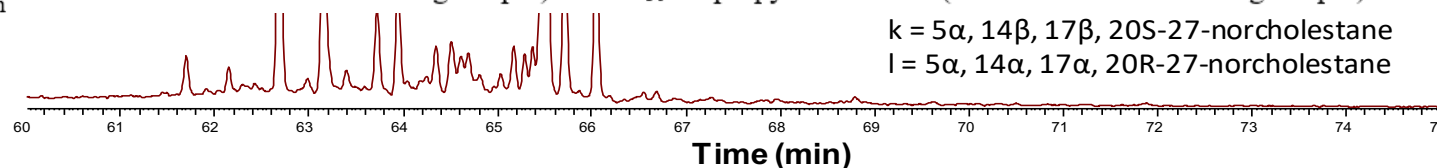


Figure 3.35. Plots of biomarker indicators of depositional environment and biological input (Holba et al., 2003). Holba et al. (2000 and 2003) proposed the TPP ratio (an indicator of fresh/brackish water algal input) vs. %C₃₀ 24-propylcholestanes (an indicator of marine algal input).

k = 5α, 14β, 17β, 20S-27-norcholestane
l = 5α, 14α, 17α, 20R-27-norcholestane



3. Tetracyclic polyprenoids TPPs (Holba et al., 2000 and 2003)

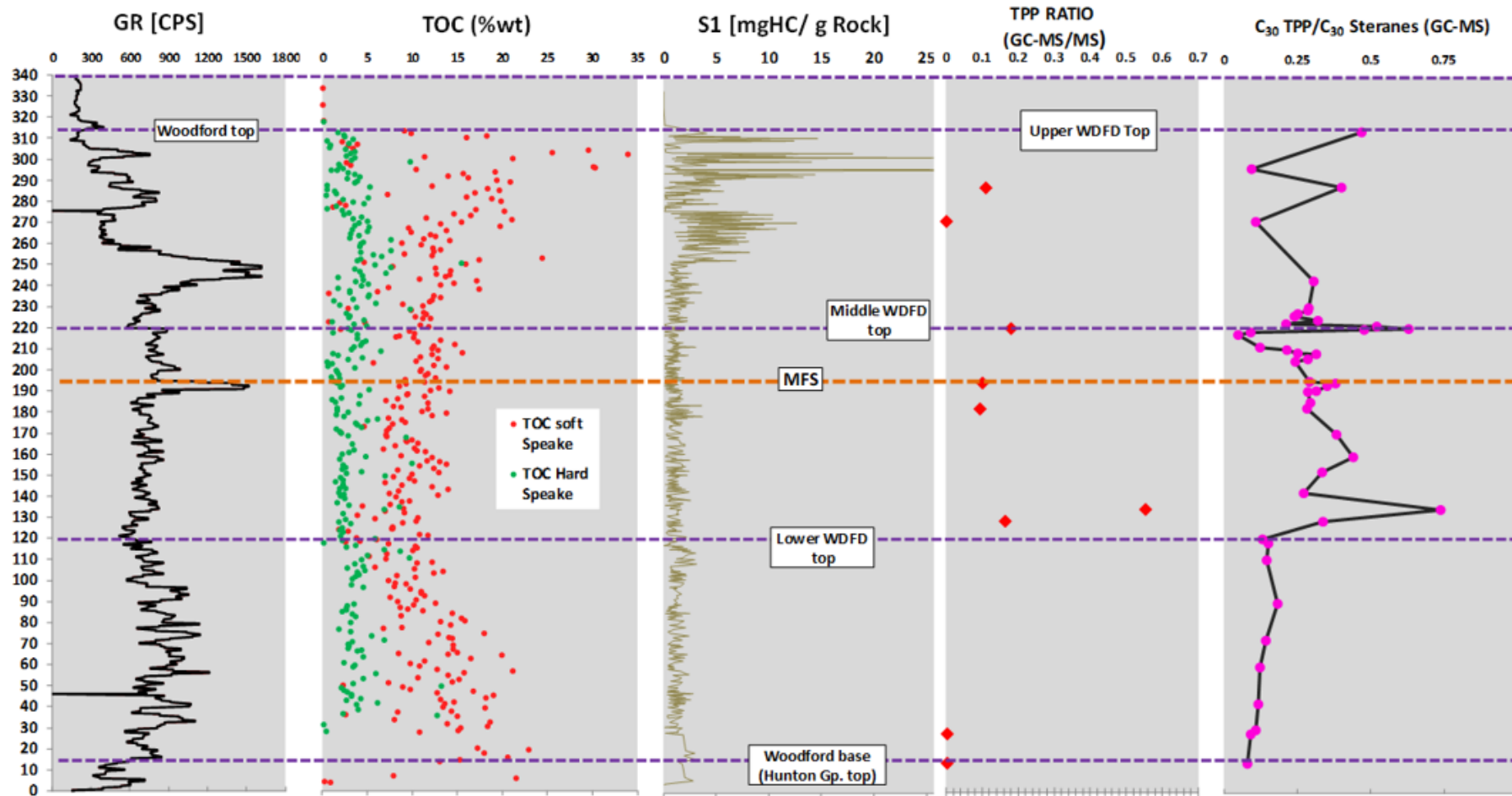
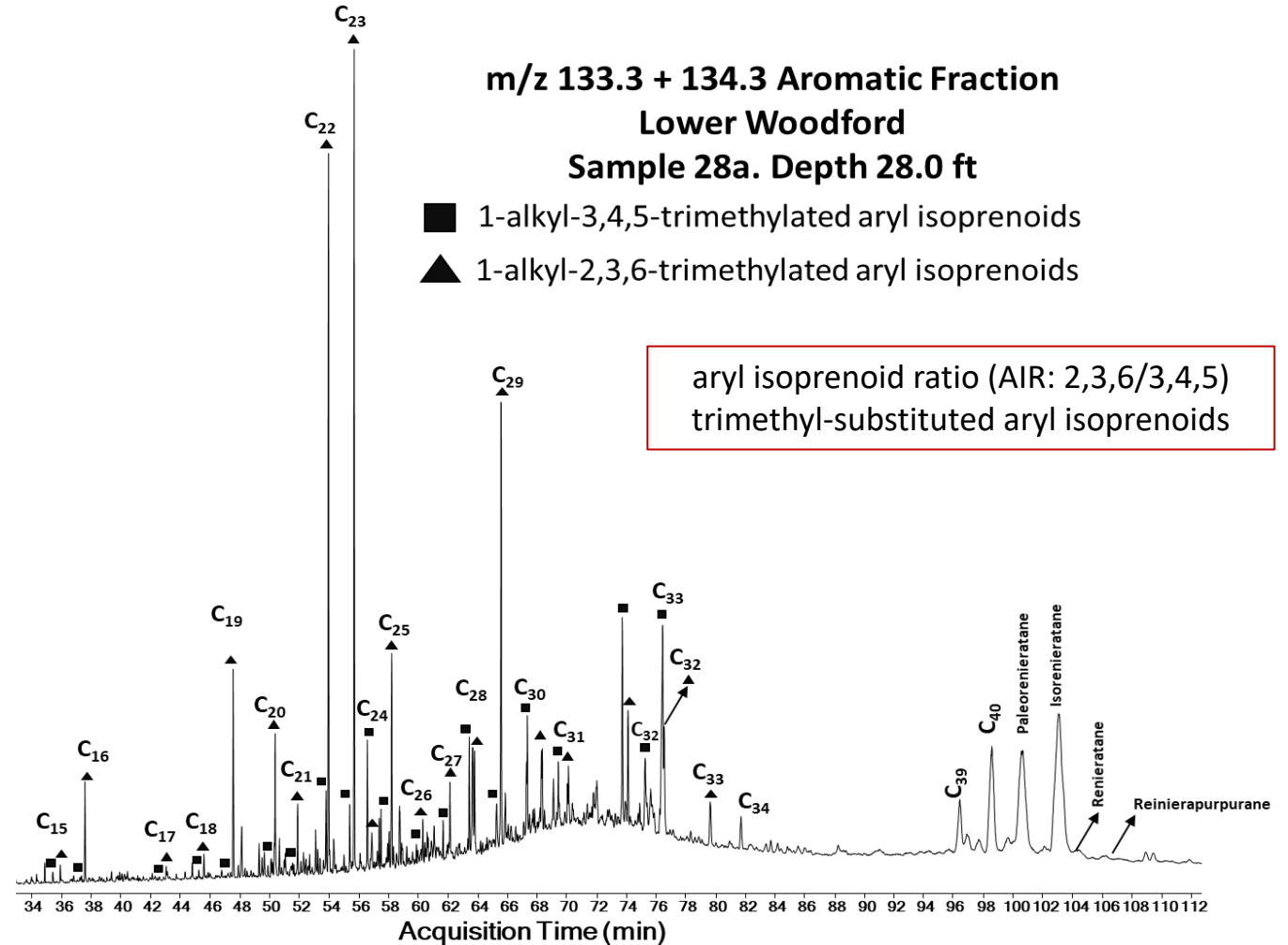
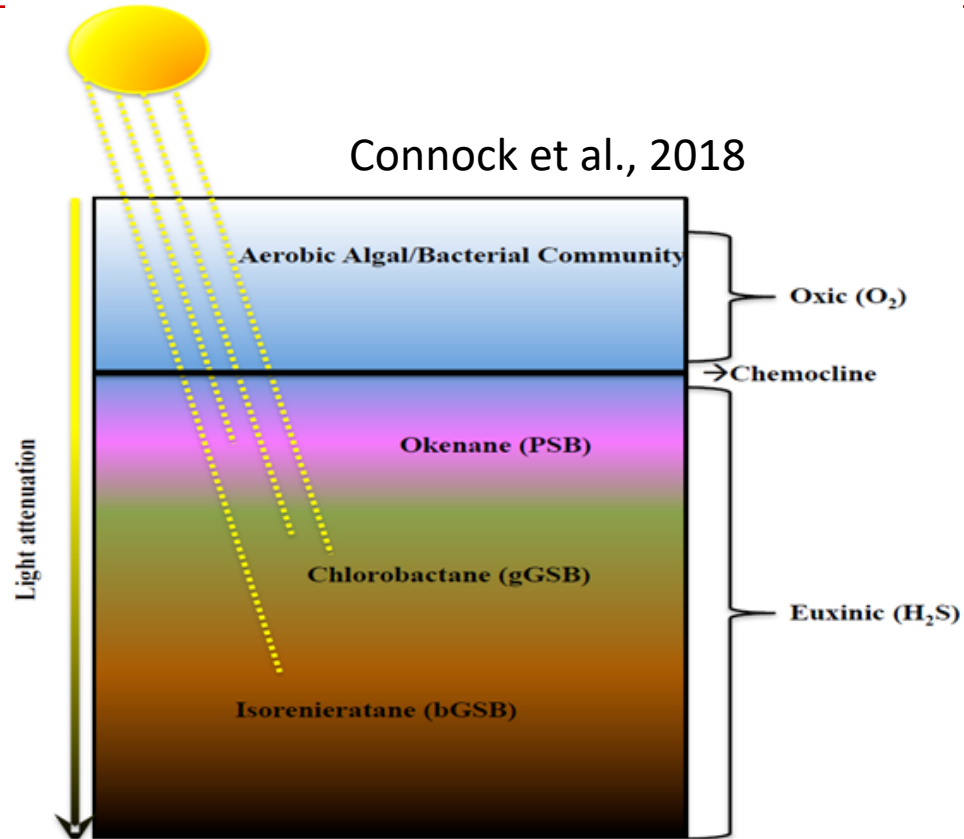


Figure 3.42. Comparison of tricyclic polyprenoid (TPP) abundance (calculated as TPP ratio, with the methodology of Holba et al., 2000 and 2003) from the GC-MS/MS m/z 414→259 and m/z 358→217 ions. TPP ratio as compared to Gamma-Ray log, %TOC (classified by the mechanical stratigraphy of the rock layers, soft vs. hard; Galvis et al., 2017a), Rock-Eval pyrolysis S1 peak, and TPP ratio to C_{30} steranes from the GC-MS m/z 191 and m/z 217 ions. Note the low TPP ratio in the Lower Woodford Shale for both TPP ratio points and TPP/ C_{30} steranes curve, then both TPP ratio and TPP/ C_{30} steranes are increasing from the start of the Middle Woodford member, and the values of the TPP ratio are higher in the uppermost portion of the Upper Woodford member.

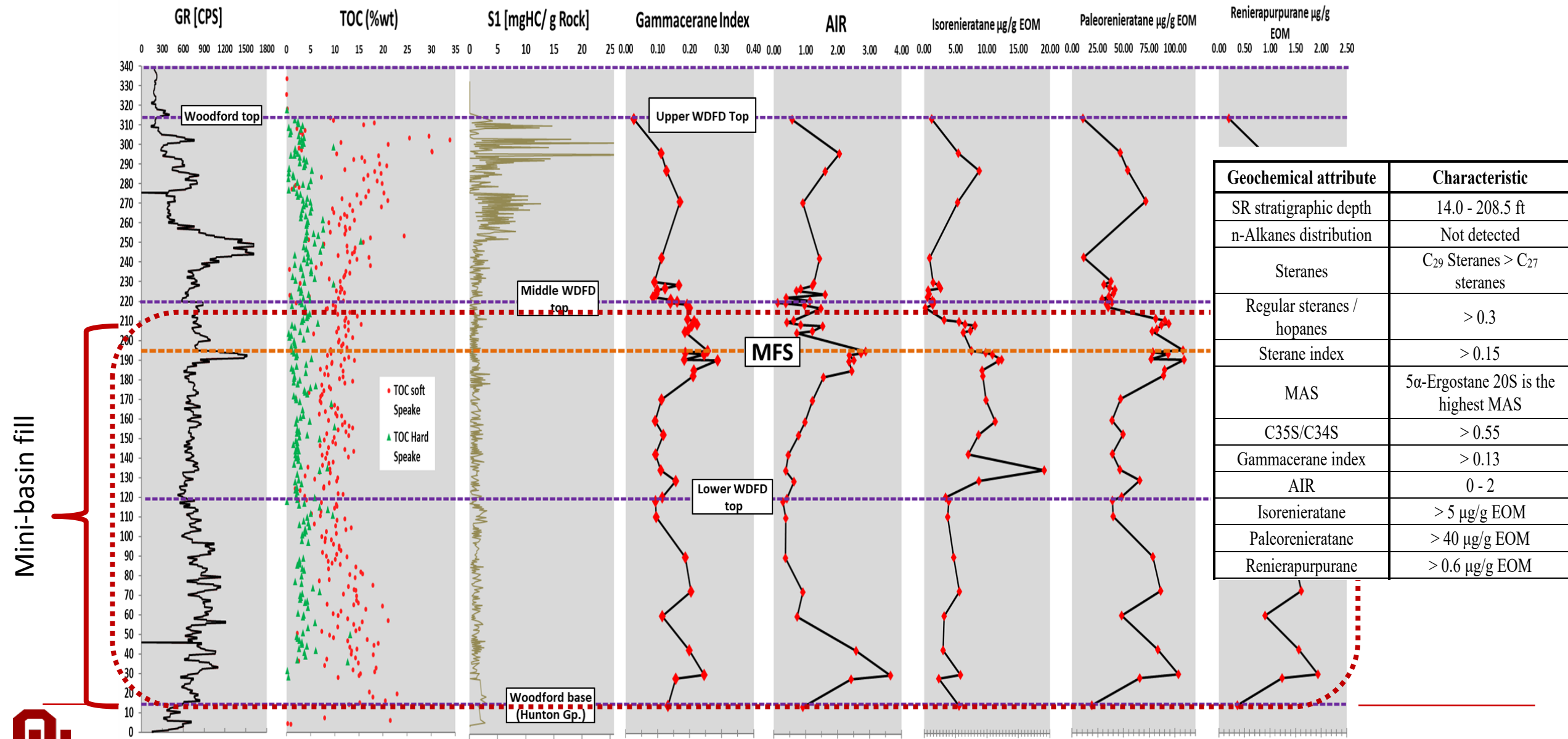
3. Aryl-isoprenoids and C₄₀ carotenoids identified in the m/z 133+134 fraction



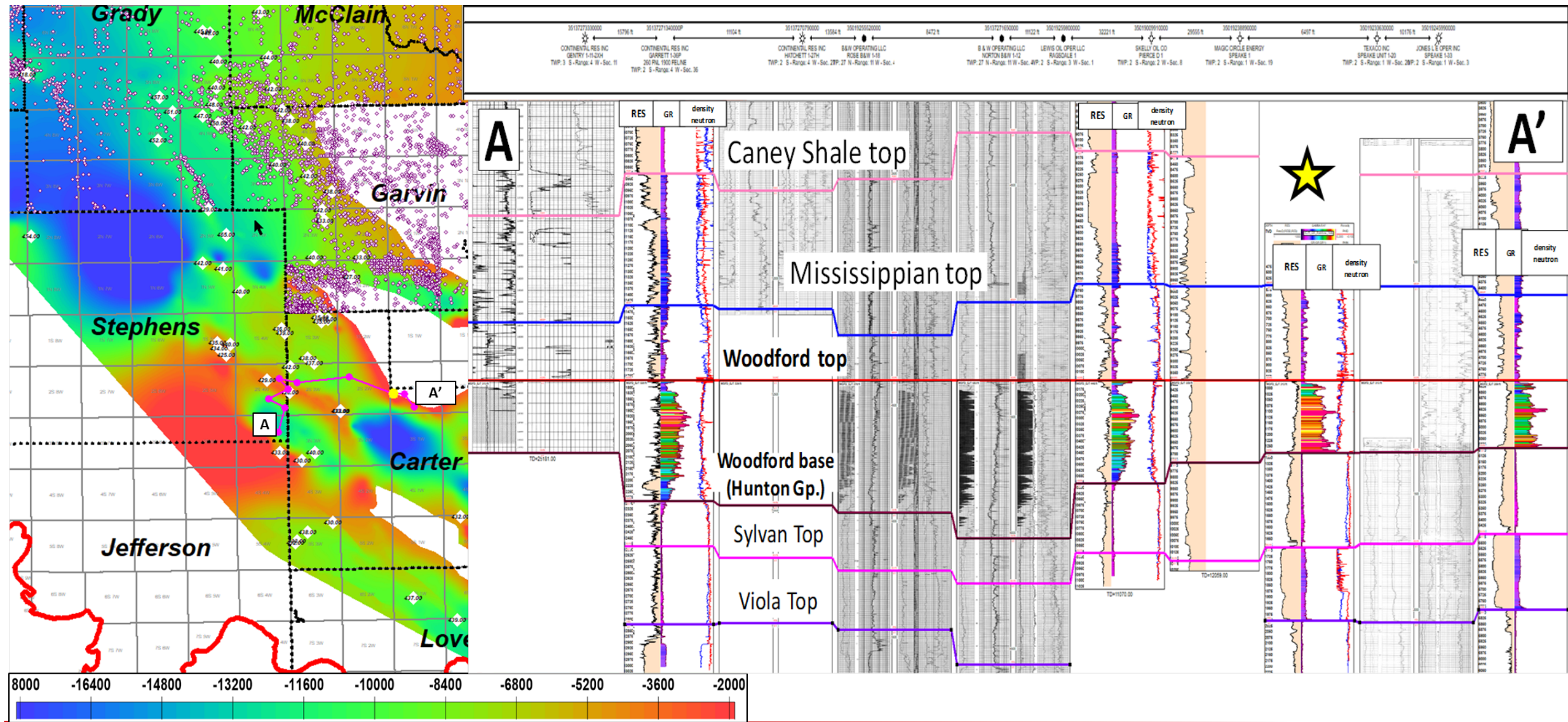
- Isorenieratane and other diagenetic products of isorenieratane are excellent proxies for the assessment of past photic zone euxinia (PZE) present in the water column (Summons and Powell, 1986; Sinninghe Damsté et al., 1987, 1995; Requejo et al., 1992; Koopmans et al., 1996a and 1996b; Schwark and Frimmel, 2004; Sinninghe Damsté and Schouten, 2006).

- High AIR (3.0) are associated with episodic PZA, which leads to alteration of the long- and intermediate-chain aryl isoprenoids. On the contrary, low AIR (0.5) indicates persistent PZA, which contributes to preservation of the long-chain aryl isoprenoids (Schwark and Frimmel, 2004; Miceli-Romero and Philp, 2012).

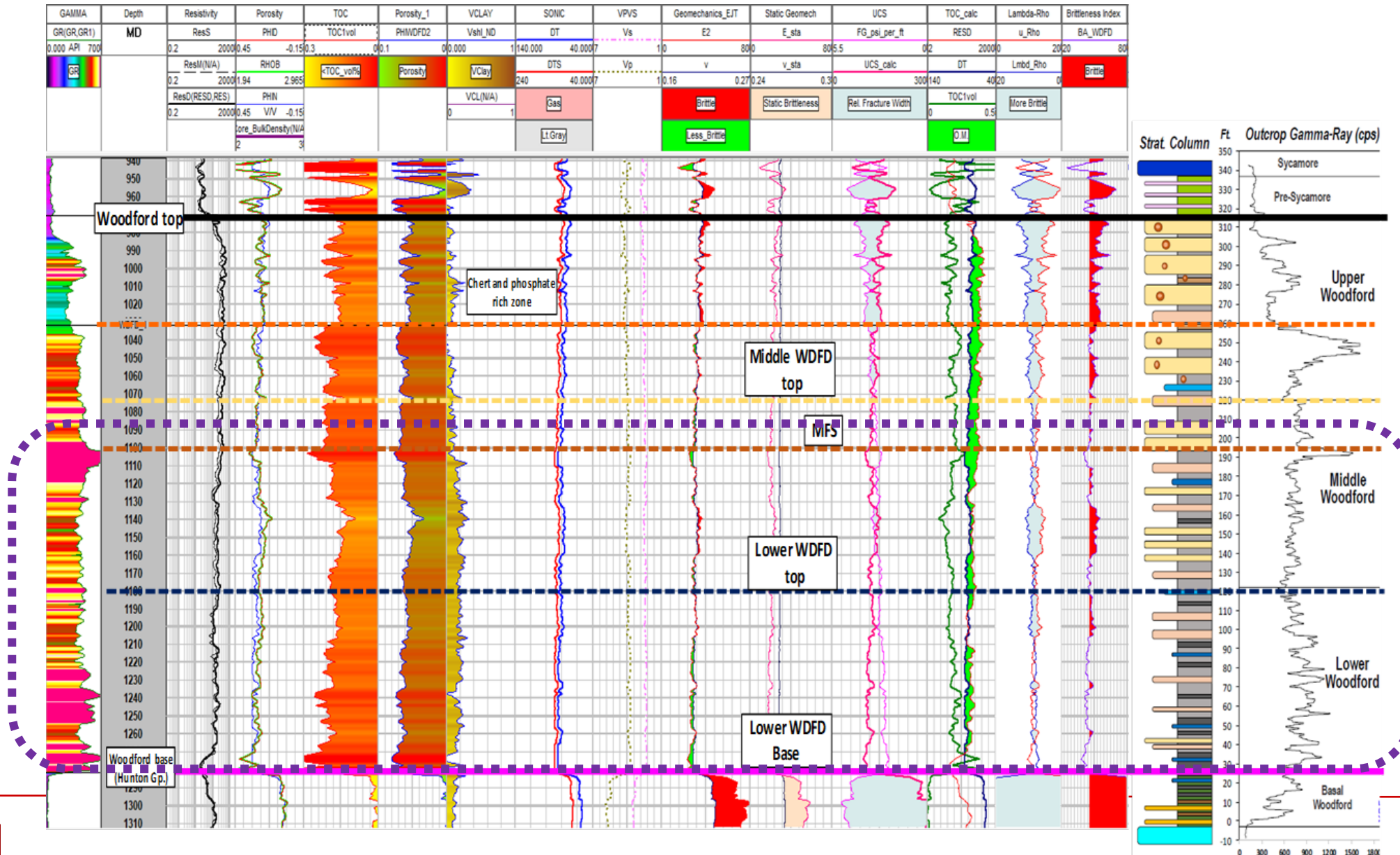
3. Aryl-isoprenoids and C₄₀ carotenoids identified in the m/z 133+134 fraction of different Woodford member samples.



3. SR correlation to the subsurface



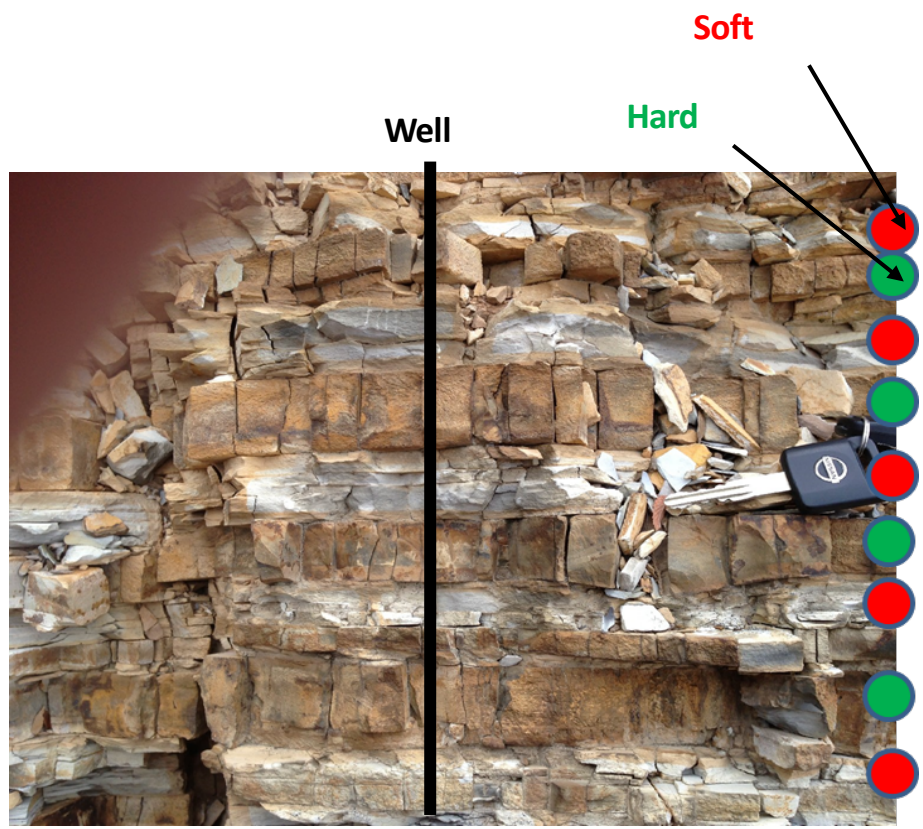
3. Can you break the SR rocks?



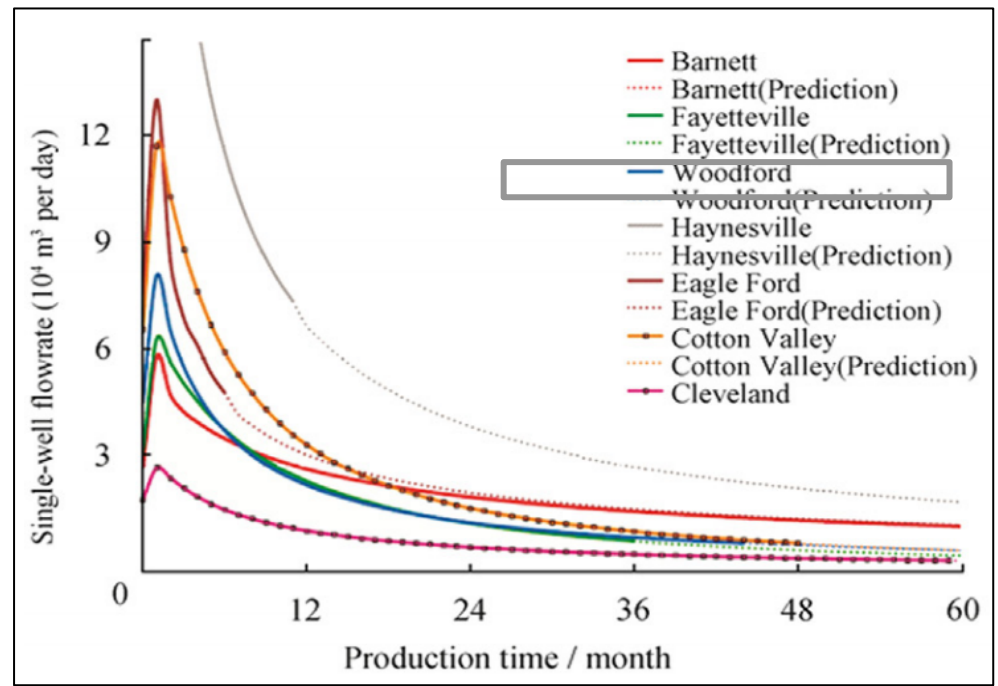
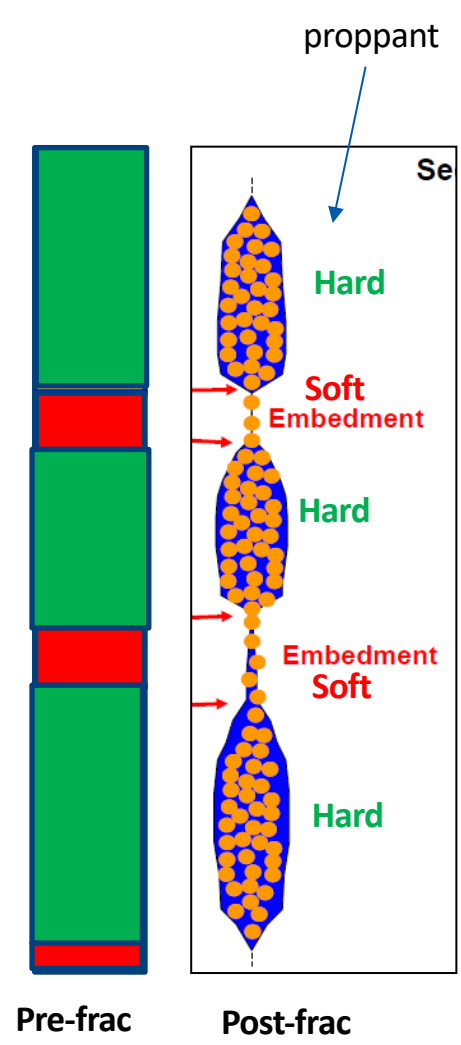
3. Summary of the Speake Ranch WDFD outcrop

- **Principal geological and geochemical indicators for a highly restricted enclosed mini-basin fill settings in the Woodford Shale.**
- The Lower Woodford member gross thickness is, on average, greater than 90 ft
- Locations surrounded by a lot of faulted provinces that can be the reactivation of pre-existing fault grabens could have acted as paleo structural lows. These graben depocenters allowed more accommodation space, higher sedimentation rates if proximal to the sediment supply of a specific petroleum province.
- From the saturate and aromatic biomarker analysis, the indicators of a rise in the gammacerane index, a decrease in sterane/hopane ratios, high content of aryl isoprenoids and C₄₀ carotenoids indicate that the Lower Woodford and upper portion of the Middle Woodford member are characterized by isolated and persistent episodes of photic-zone euxinia (PZE).
- The enrichment in the Upper Woodford member of organically related proxies U, Mo, V, are likely to reflect more open water circulation conditions.

5. Unconventional resources production performance: Geology rules!



-Hydraulic fractures propagate through brittle chert and ductile clay?
-Proppant goes into bed boundaries
-After fracturing, the fractures in chert remain propped open
-But with time, the ductile beds encase proppant and close??



Slatt, 2016

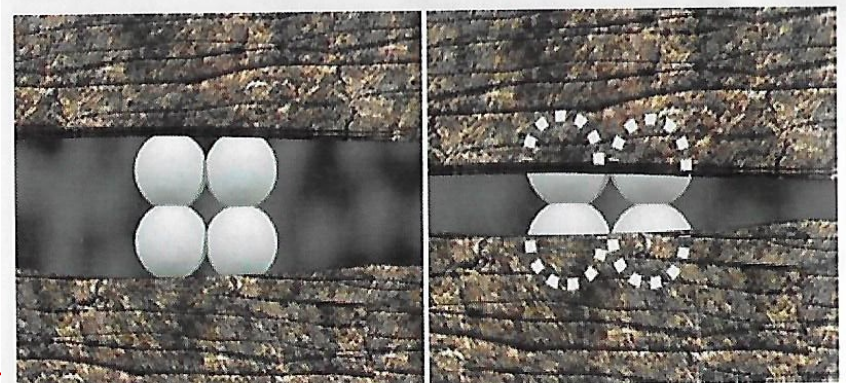
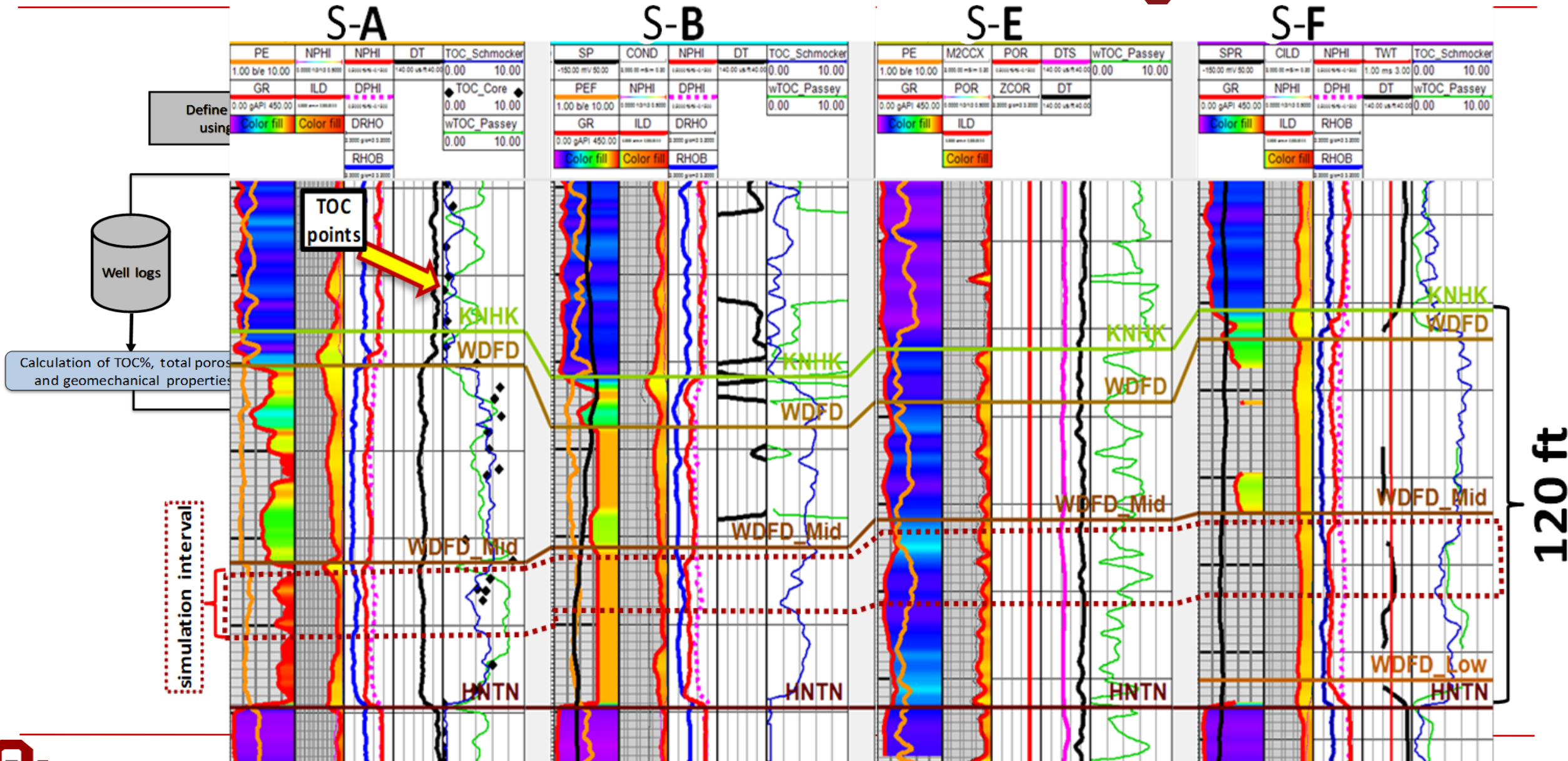


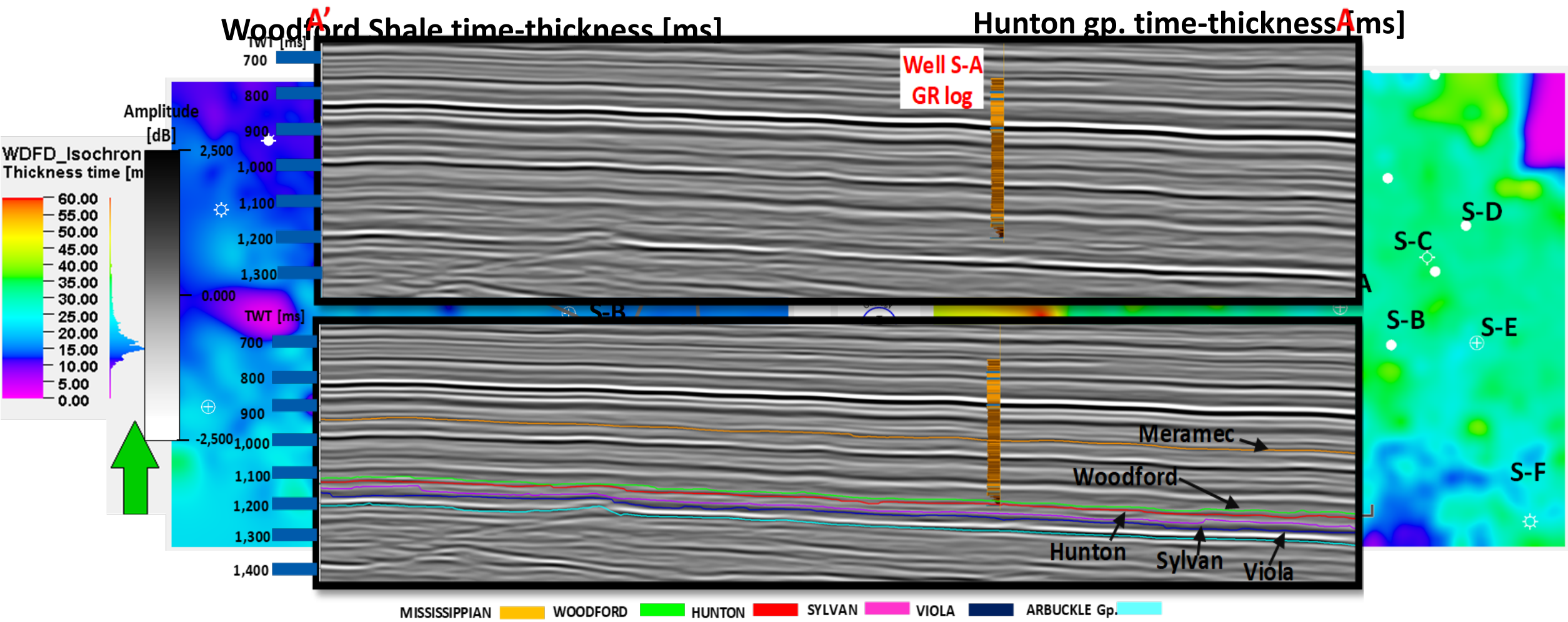
Fig. 8—Proppant embedment into the fracture face reduces fracture width and conductivity.



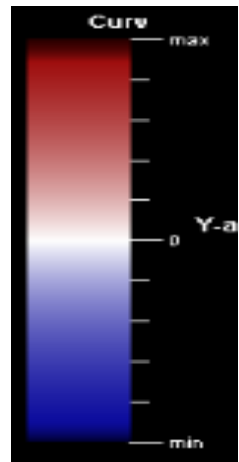
4. 3D seismic again! But this time I perform reservoir simulation




4. Seismic thickness maps again



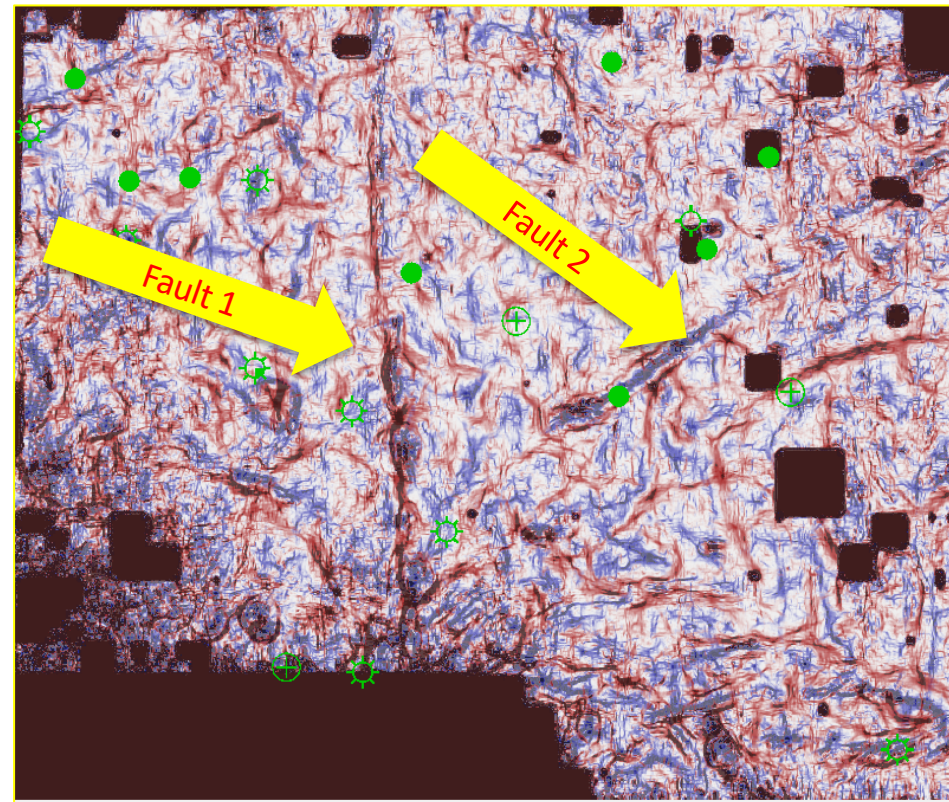
Attributes and Structural framework



High

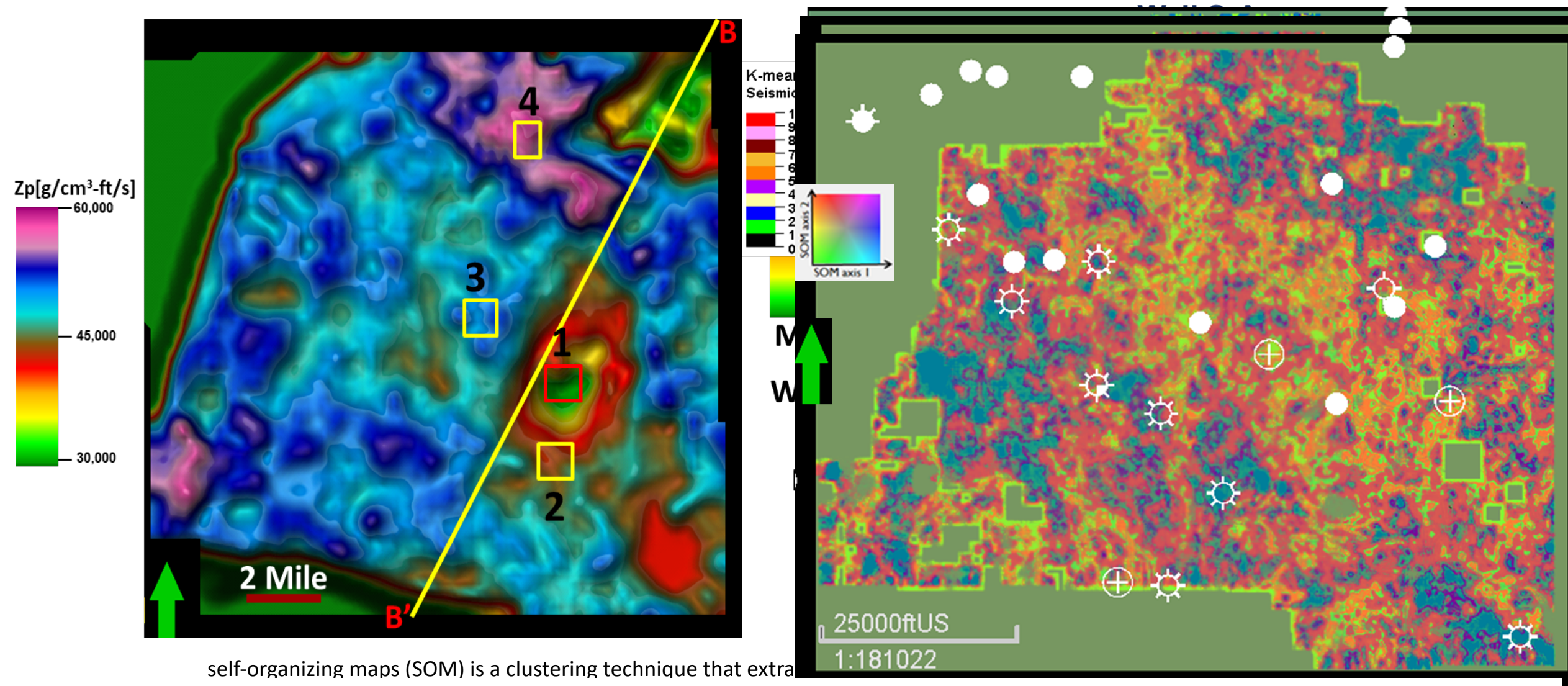


Low



Most positive curvature and most negative curvature co-rendered. Extracted along WDFD

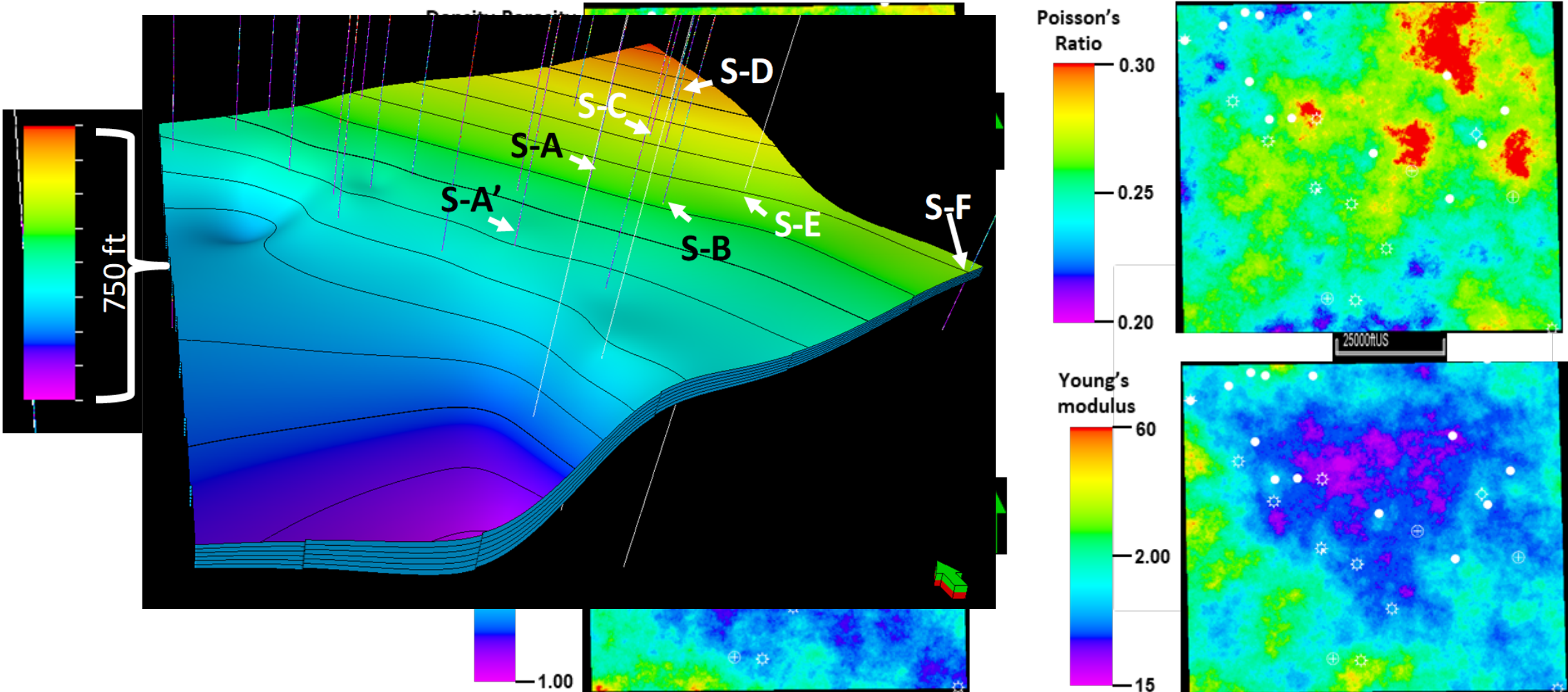
4. Seismic inversion, average acoustic Impedance (Z_p), and machine learning results of multi-attribute analysis



self-organizing maps (SOM) is a clustering technique that extra

Although SOM assigns each voxel to the cluster (and hence a color) that best represents it, it does not provide a measure of how well that cluster (or any other cluster) represents the voxel. While we know which is the most likely cluster (facies) we do not know how confident the prediction is. GTM is and represents a nonlinear dimension reduction method based on Bayesian principles, providing a probabilistic representation of the data vectors in latent space (Bishop et al., 1998; Roy et al., 2014; Chopra and Marfurt, 2014).

4. Static unconventional reservoir model



4. So What??? : reservoir coupled Simulation

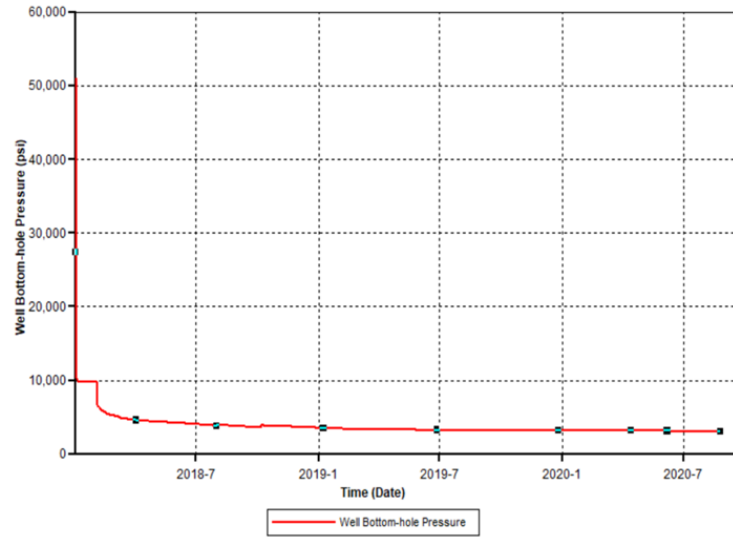
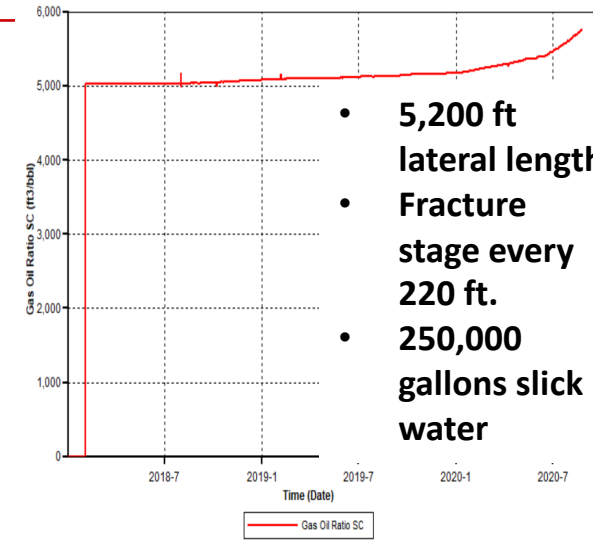
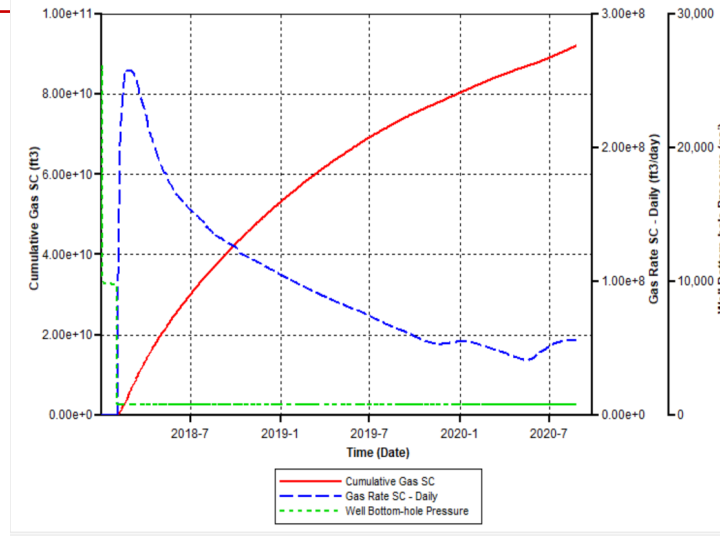
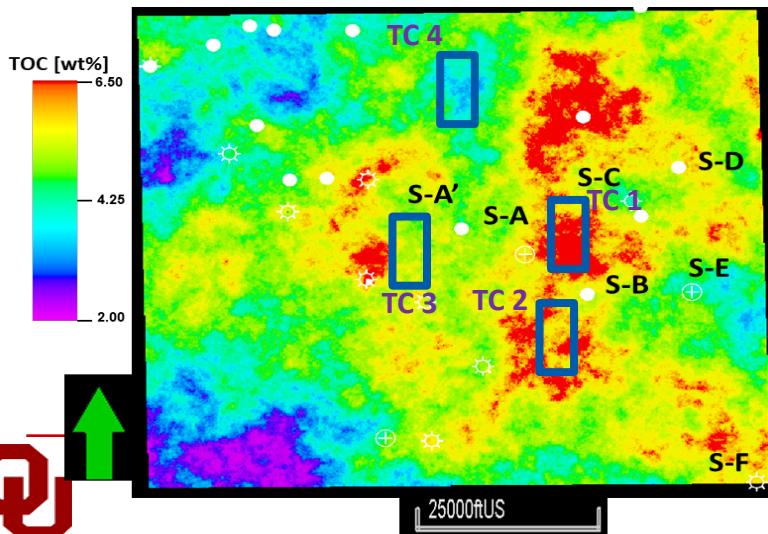


Figure 4.19. Well bottom-hole pressure for the injection. Notice that when a crack occurs at 0 months in time, the stimulated pressure falls rapidly.



- 5,200 ft lateral length
- Fracture stage every 220 ft.
- 250,000 gallons slick water
- Dew point 4,200 PSI
- 0.65 specific gravity
- 55 API Gravity

I told you that organics matter!



Gas rate, BHP and cumulative gas for type curve area 1

Gas oil ratio for type curve area 1

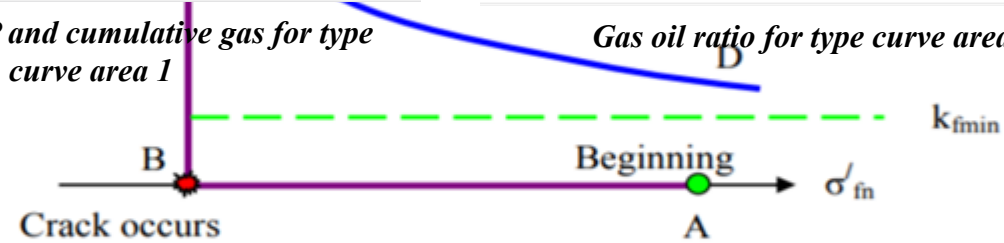
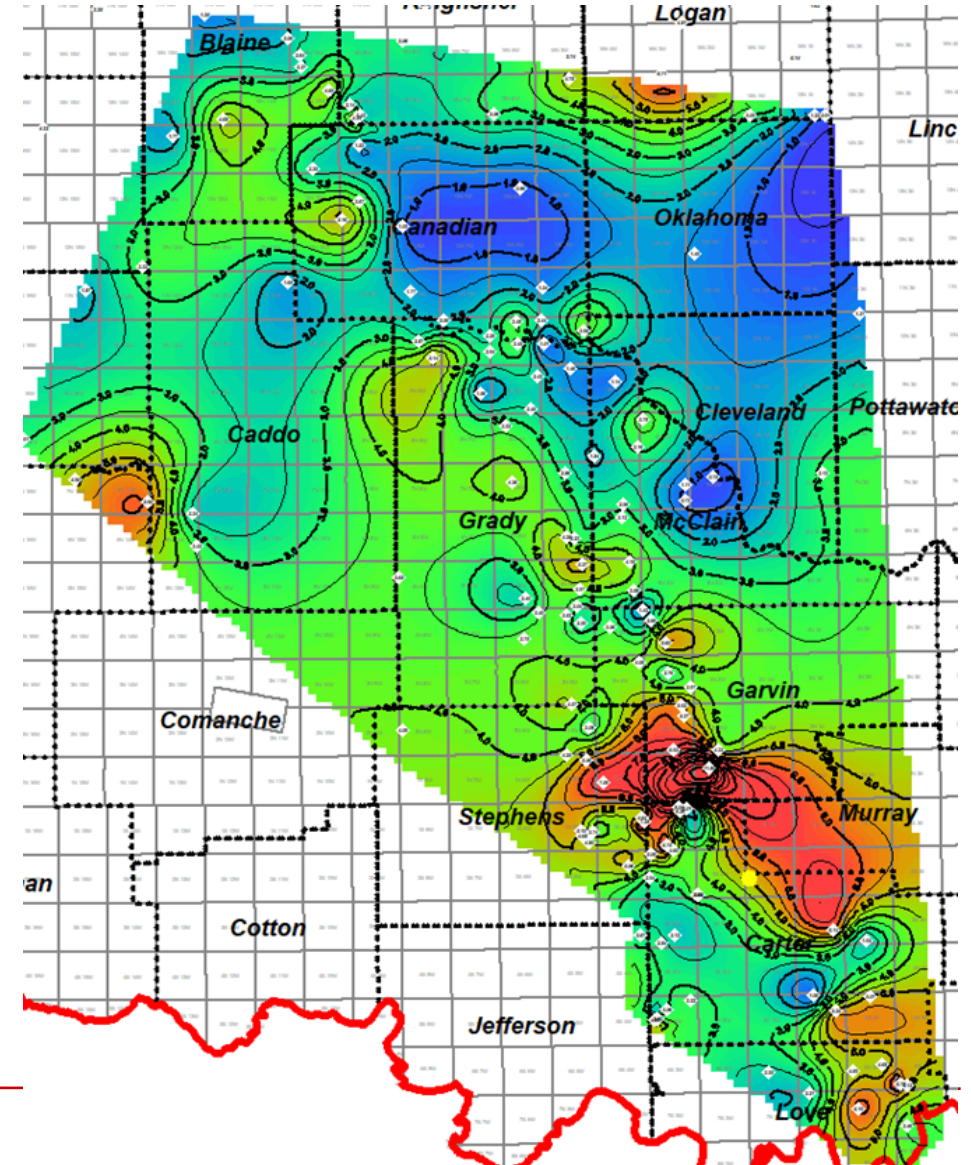


Figure 4.18. Conceptual implementation of Barton – Bandis model (after Tran et al., 2009). Initially, the bottom hole conditions are at the beginning point. As injection continues, the effective stress decreases, and at a certain point, when it reaches the minimum stress, the natural fracture opens, and the permeability increases. As injection stops and well is put on production, due to fluid withdrawal, the permeability decreases again due to a rise in stress. The well ultimately reaches a permeability of K_{fmin} and continues to produce at that permeability. In our case, we keep the $K_{fmin} = 25$ mD for the fractures.

In conclusion

- The enclosed mini-basin fill is critical for allowing the higher accumulation, restriction and preservation of organic matter, which is observed by a higher total organic carbon (%TOC), high hydrogen index (HI), low oxygen index (OI) and higher concentrations and ratios of biomarker analyses that indicate anoxia (C_{40} carotenoids, gammacerane index, DBT, $C_{35}S/C_{34}S$).
- The bulk %TOC regional and local maps indicate that the enclosed mini-basin fill present thicker and higher average %TOC intervals for the Woodford Shale when compared to areas with open circulation conditions.
- The reservoir modeling and simulation shows that the uppermost middle Woodford Shale member is the interval with best reservoir porosity, permeability, and thickness. The thicker and the higher %TOC intervals correspond to the mini-basin fill interval, close to the change to open marine conditions
- The enclosed min-basin fill intervals have relative high brittleness and are likely to produce more volumes of hydrocarbons than the completely open marine Woodford Shale deposits.

Woodford Shale total organic carbon. Average %TOC



Thank you! Questions?

The Woodford shale then



The Woodford shale Now!



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More public data about these studies: <https://shareok.org/handle/11244/323811>