Integrated Geological & Geochemical Characterization of the Mississippian Caney Shale, Oklahoma – Subsurface & Outcrops Delineation

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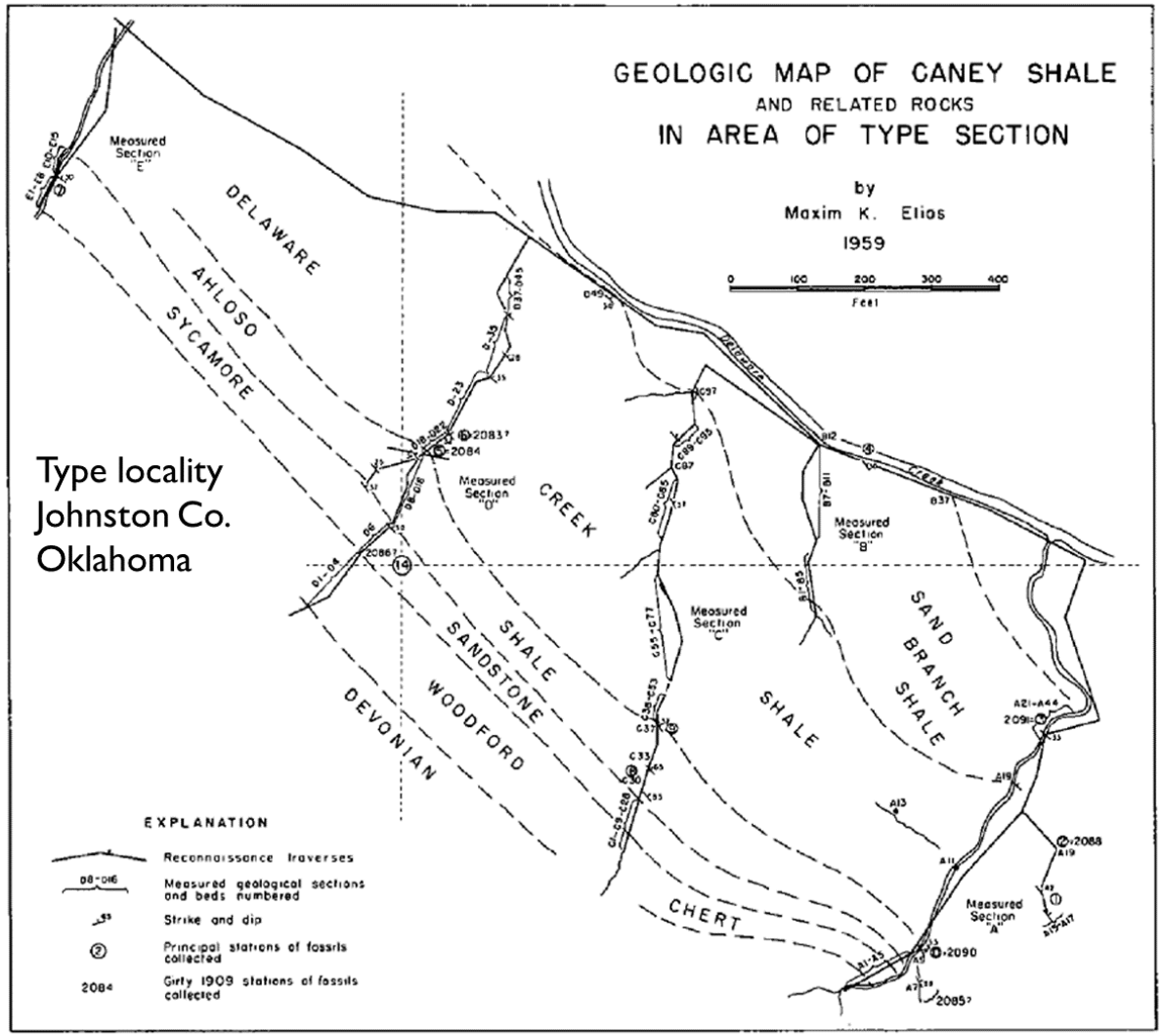
Study Objectives

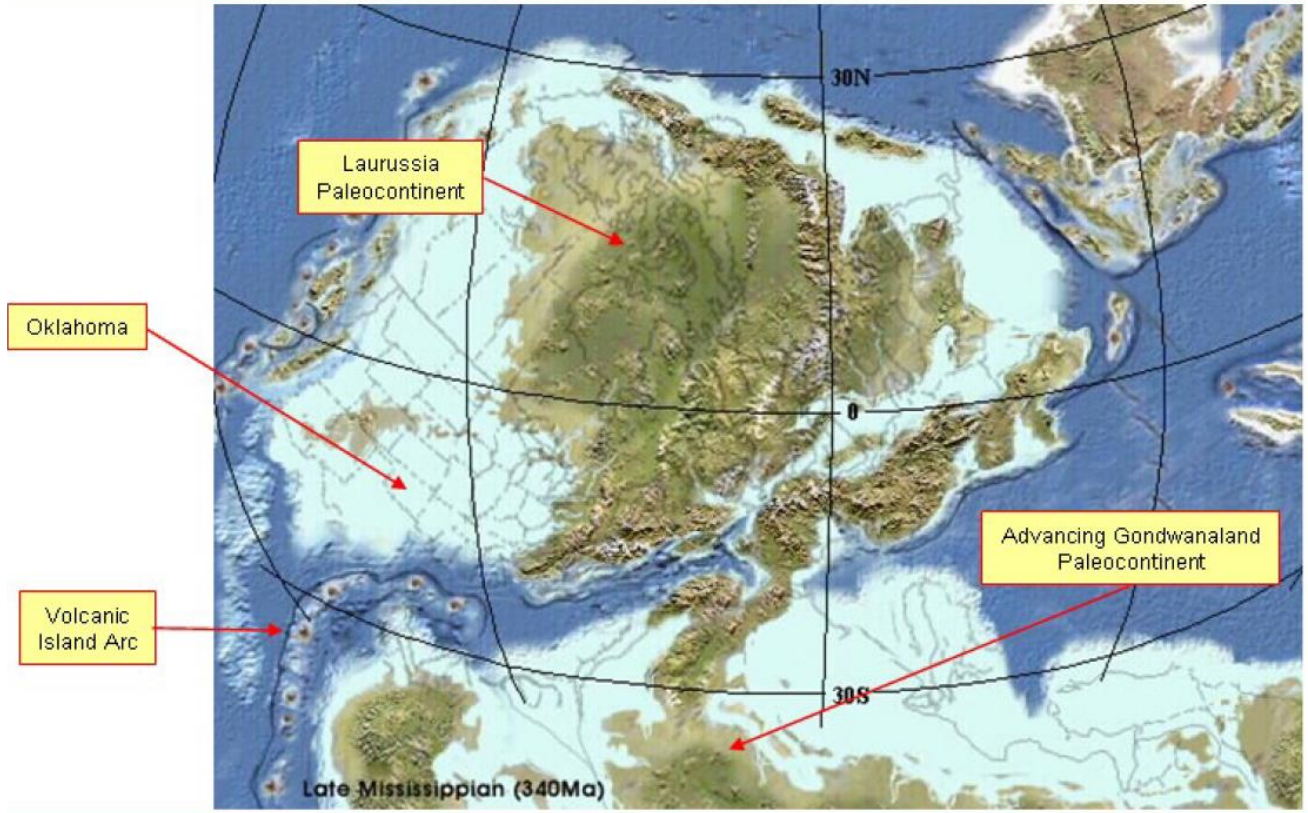
- Establish a regional organic matter content and thermal maturity regime for the Caney Shale in Anadarko, Ardmore, Marietta and Arkoma basins
- Characterize the lithofacies in the Arbuckle Wilderness outcrops (AWO) and Northeast Ardmore Basin
- Develop detailed parasequence sets inside the Caney Shale as quantitative rock properties subdivisions to be correlated across the Oklahoma petroleum provinces
- Describe sedimentological attributes such as provenance, diagenesis, and reservoir quality
- Conduct palynological analyses for age determination and sequence stratigraphy
- Describe OPIC Caney Shale cores and others to generate a DRC (digital rock classification)
- Generate basin modeling for the key wells to predict independently the VRo by depth for the Ardmore and other basins

Stratigraphy, Paleogeography & Type Locality



Type locality
Johnston Co.
Oklahoma

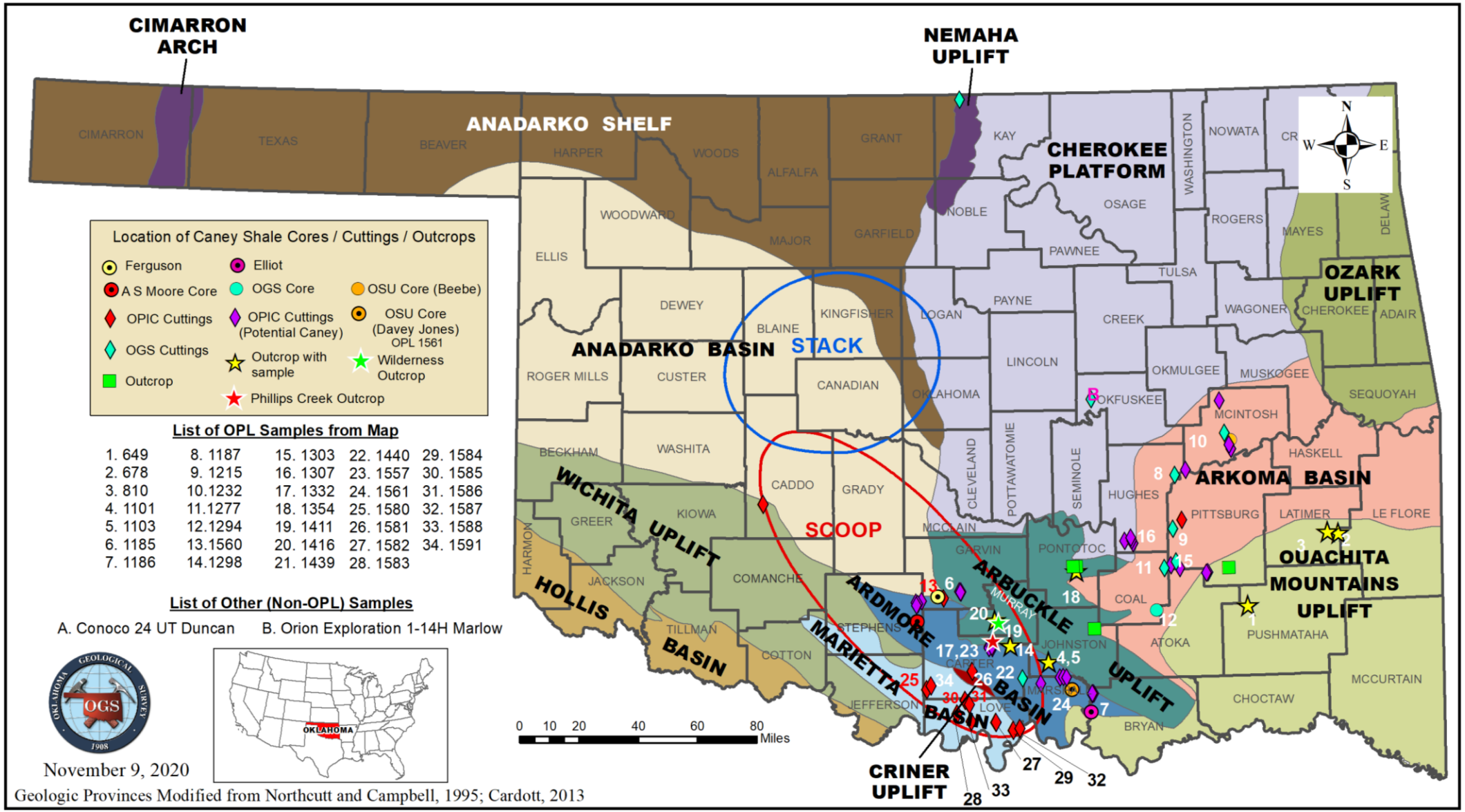
CANEY SHALE (type section)



Late Mississippian paleogeography from Blakey (2004). Web source: http://jan.ucc.nau.edu/~rcb7/340Nat.jpg. Annotated by Schad, 2004

The Caney Shale is mainly composed of very fine-grained material with interbedded siltstone/fine-grained sandstone, and carbonates (common in outcrops and cores). It is typically gray to black, thinly bedded, calcareous and generally brittle.

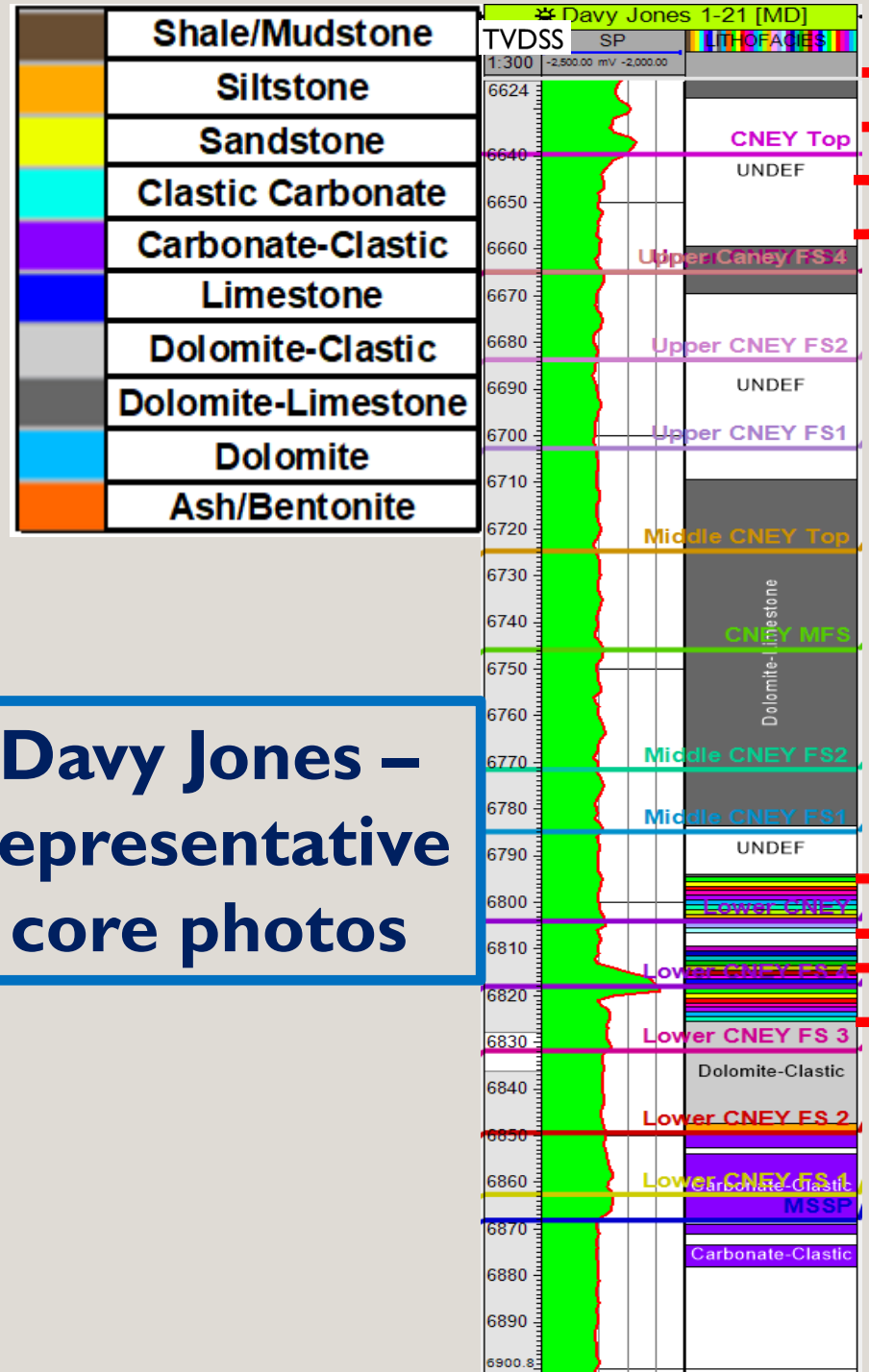
Oklahoma Province Map with Location of Studied Caney Shale Cores/Cuttings & Outcrops



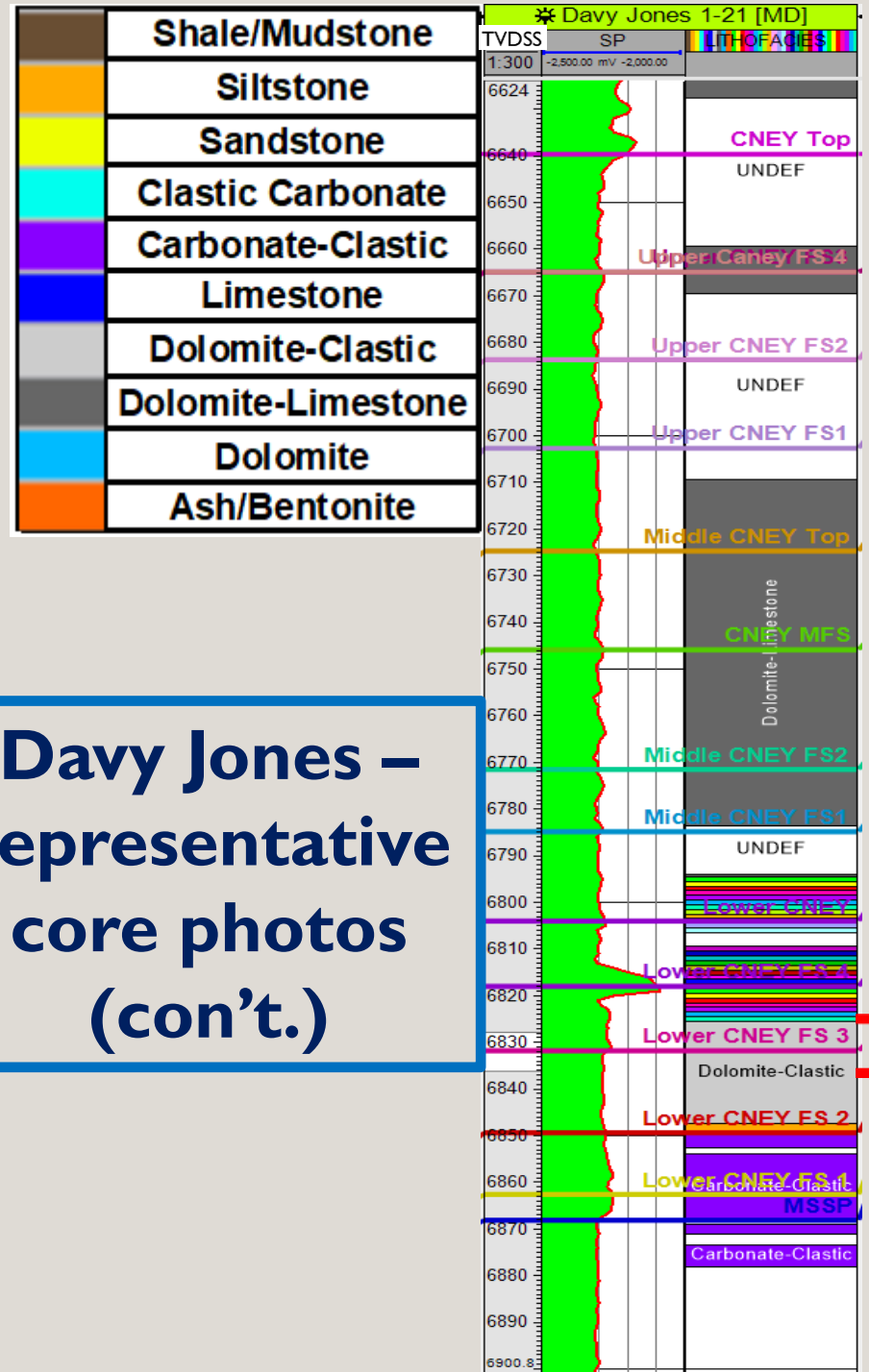
Caney Shale Core Study

Davy Jones – representative core photos

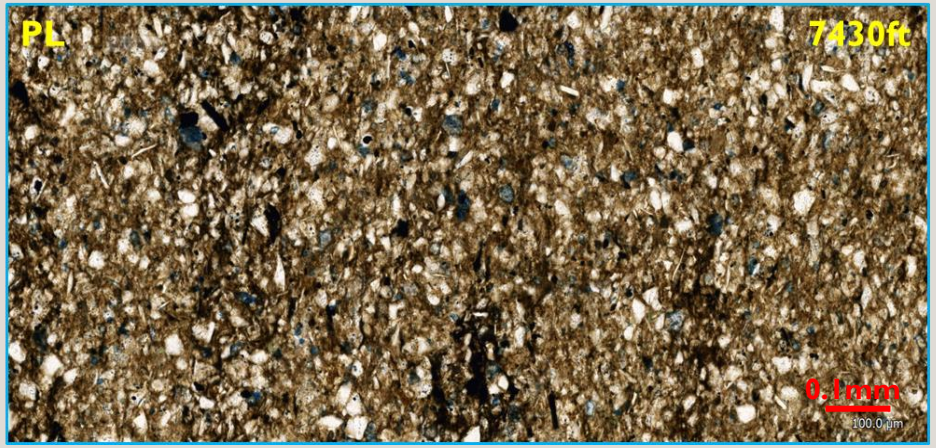
All Images Taken in Plane Light

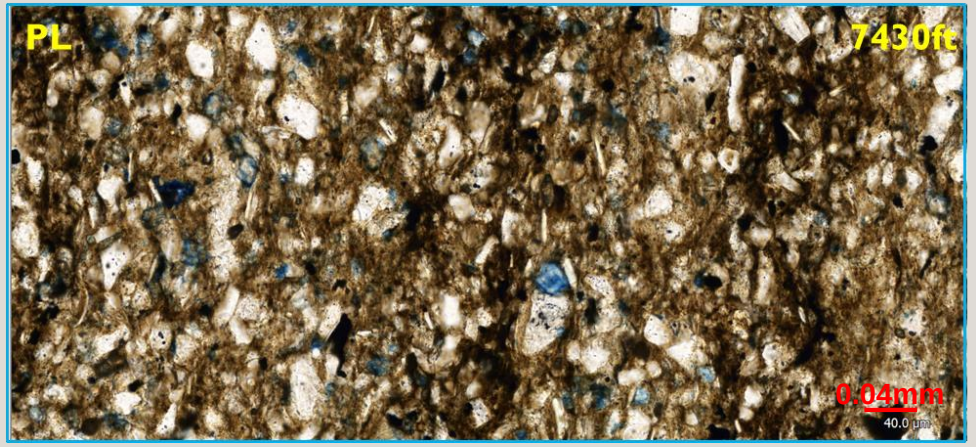


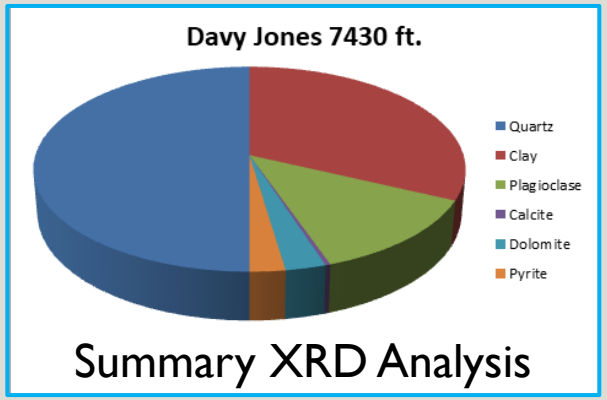
Davy Jones – representative core photos (con't.)



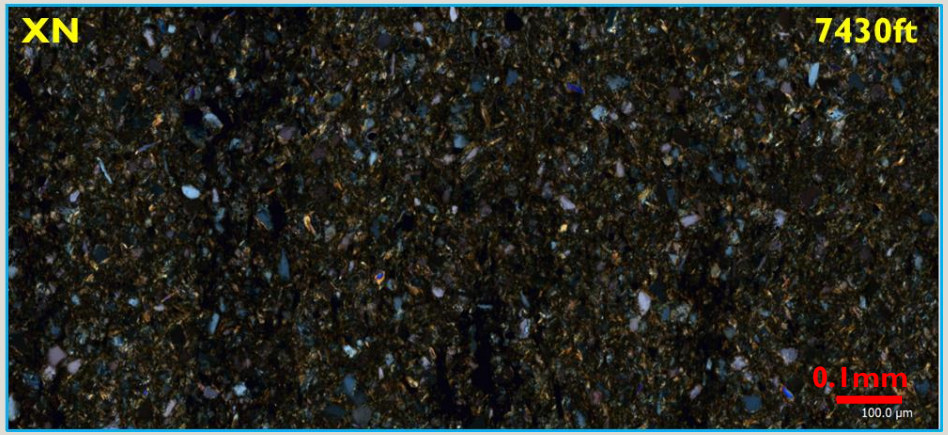
Davy Jones Images

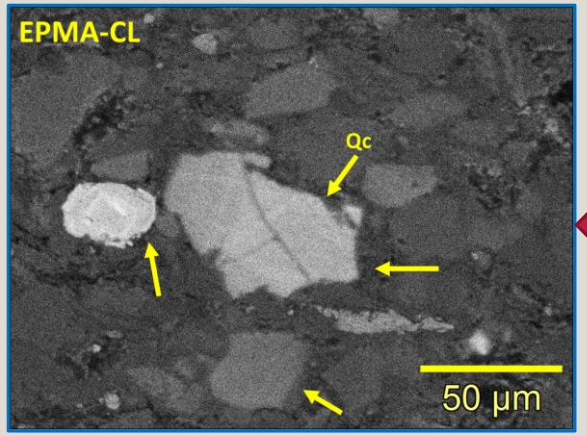






Summary XRD Analysis

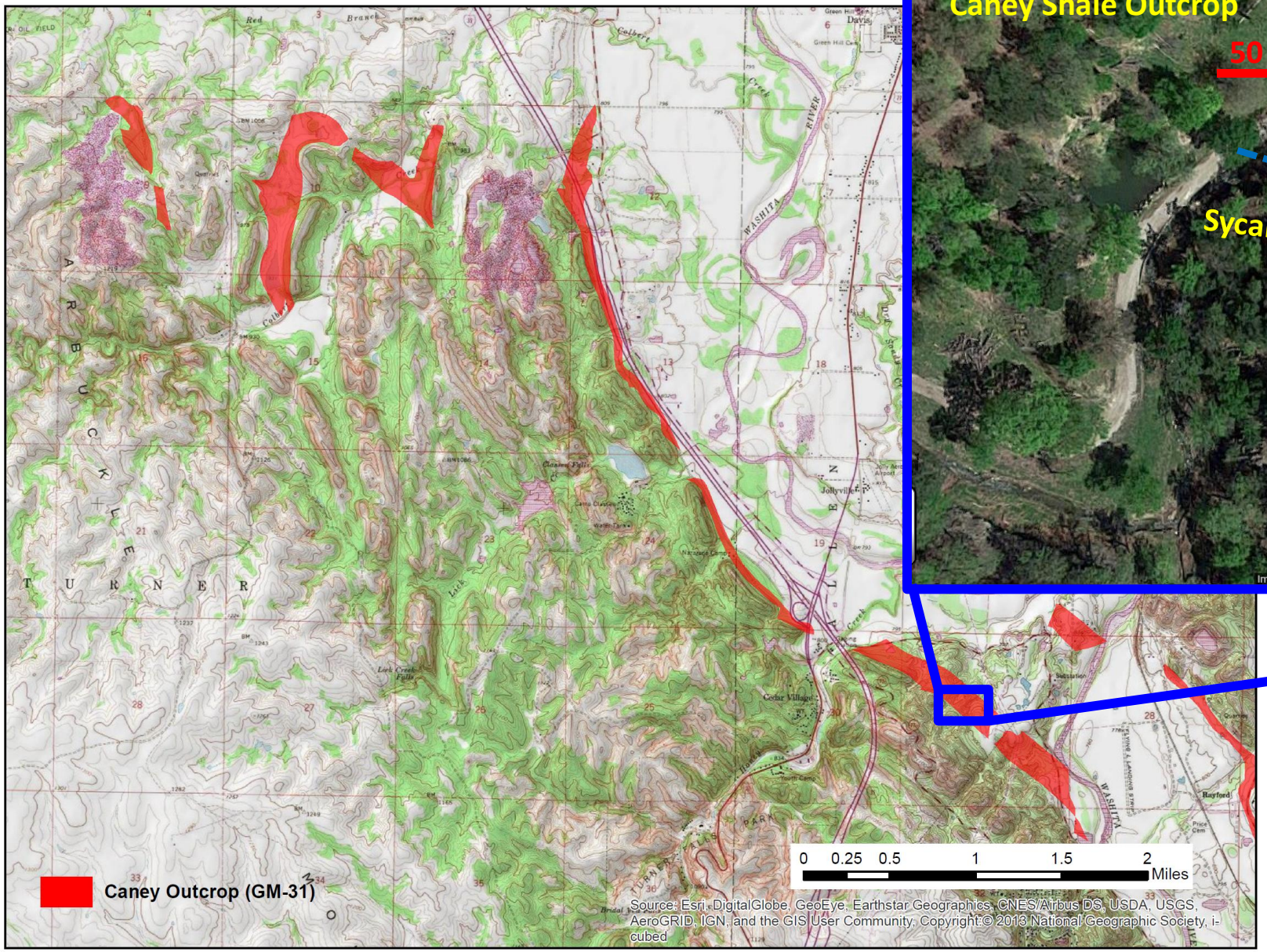


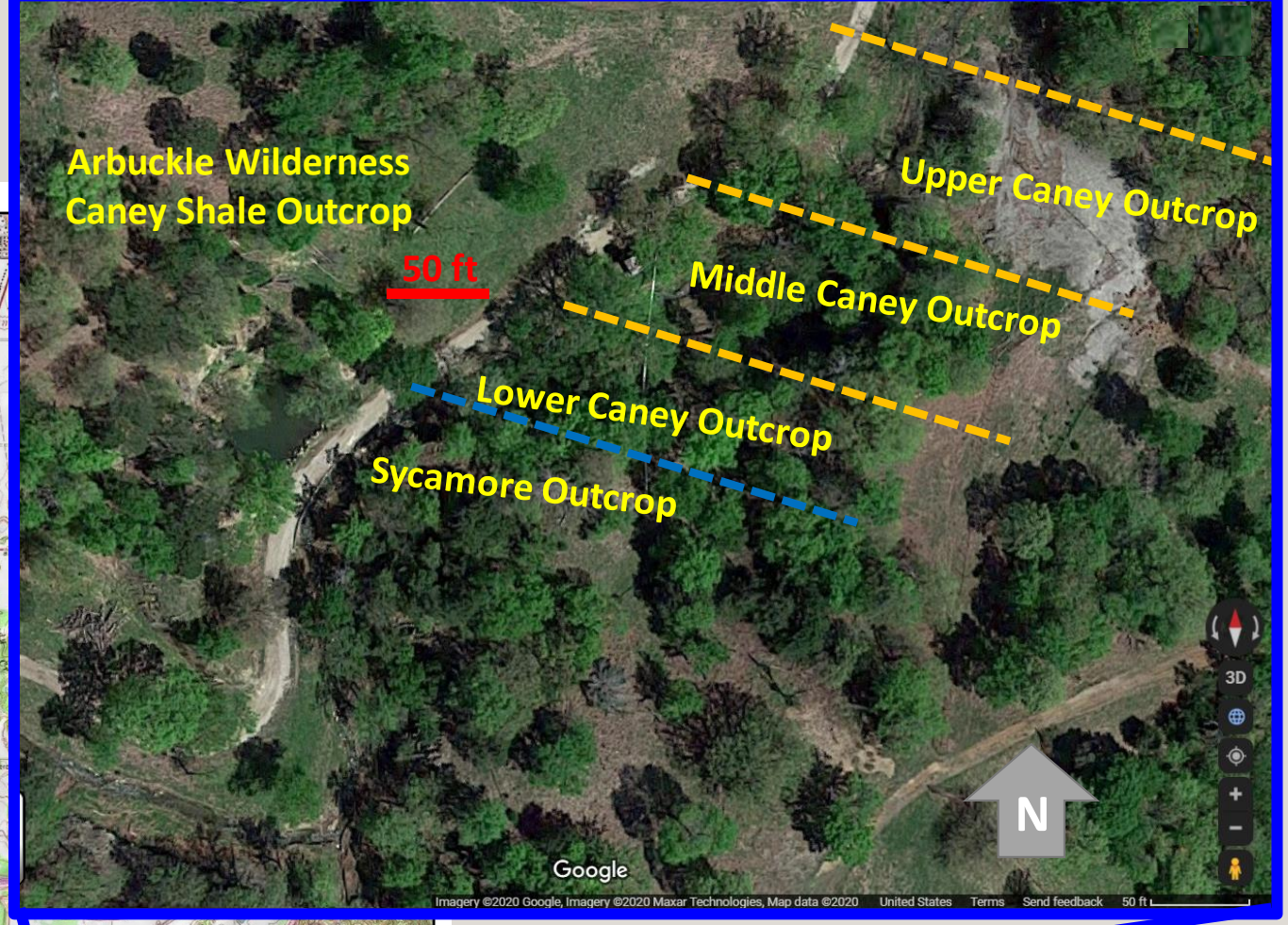


The CL imaging of that sample showed evidence of cement surrounding quartz grains, as well as annealed fractures in some of the individual quartz grains, both which support the presence of quartz cement.
Compositionally, it is similar to the other DJ samples, only it contained the most quartz, with significant pyrite and Fe-dolomite and less silt-sized clay grains, and siderite

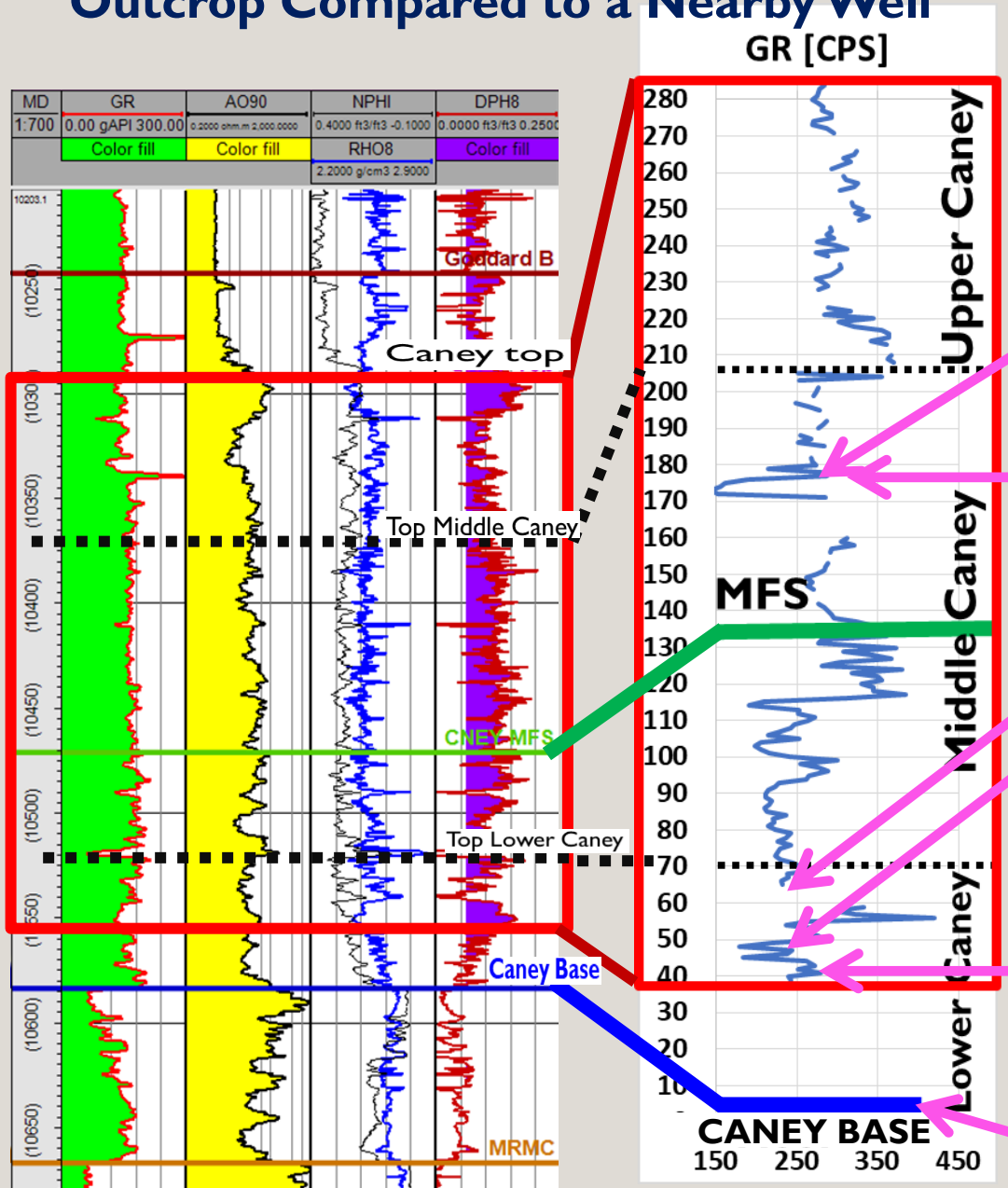
Low magnification (Plane Light; PL and Cross Nichols; XN) view where common compacted grains are displayed. This is a silty, clay-rich, calcareous mudstone. Some of the compacted features are probably burrows. Especially the low magnification image where maybe a darker mineral lining is seen. Significant bioturbation is noted. Also, note the close-up with better details of potential burrows. Detailed view shows grains of average 30 microns ranging from 10 to 40 microns. The cross polar view displays grains that are both silicate and carbonate. A little Fe-dolomite (blue) is observed. Close-up view of detrital mineral grains (silicate or carbonate?) brown wisps around the grains may be clay or crypto-crystalline carbonate of silicates. Alternatively, these brown detrital wisps could be hydrocarbon or organic matter stained.

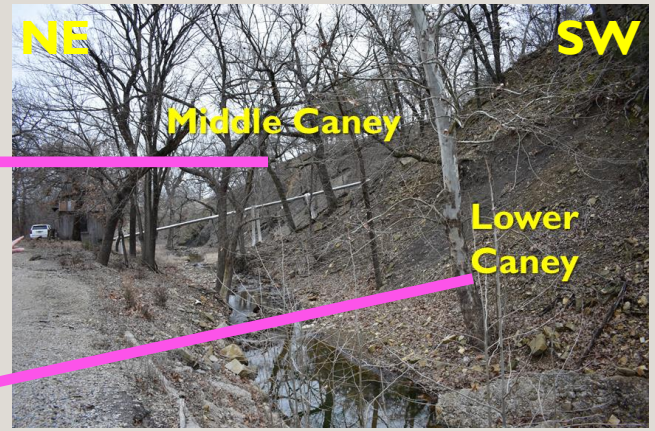
Arbuckle Wilderness: Caney Shale Outcrops

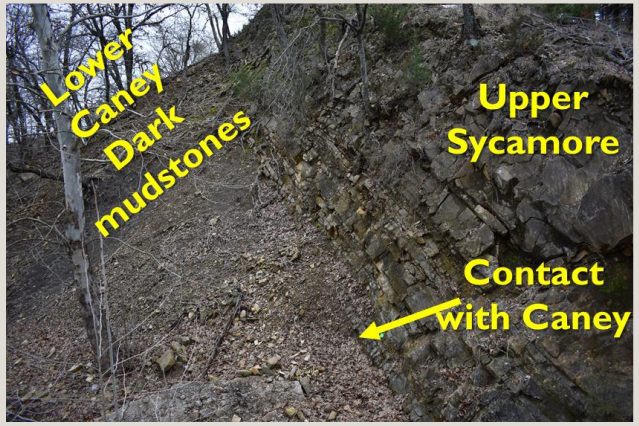




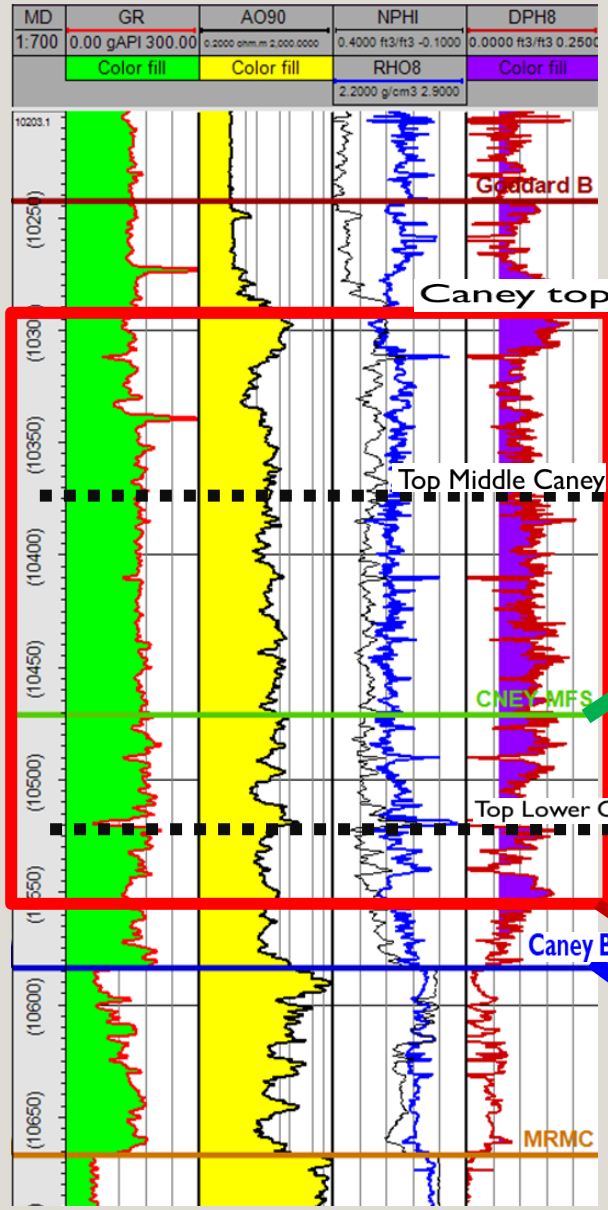
Arbuckle Wilderness: Caney Shale Outcrop Compared to a Nearby Well

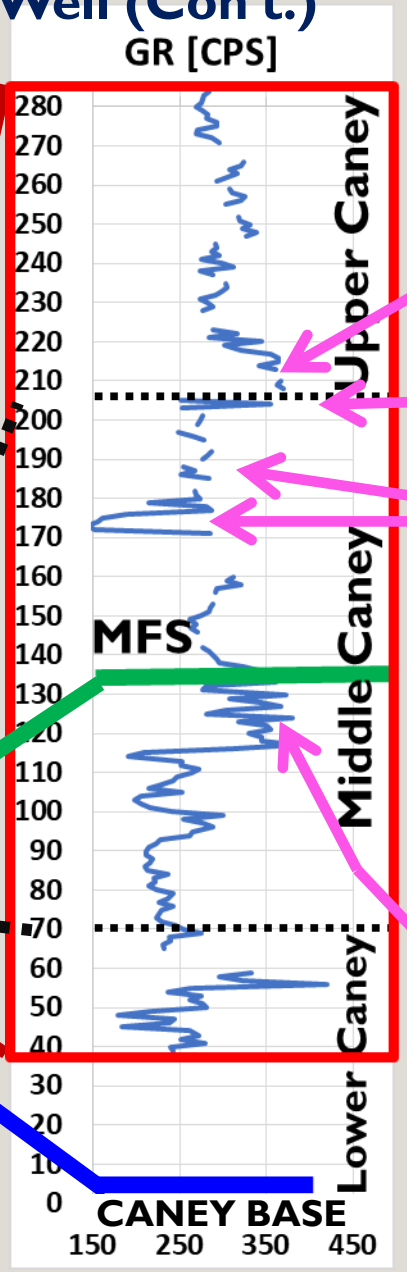


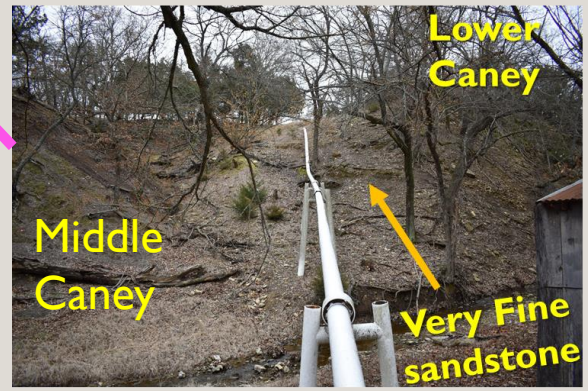


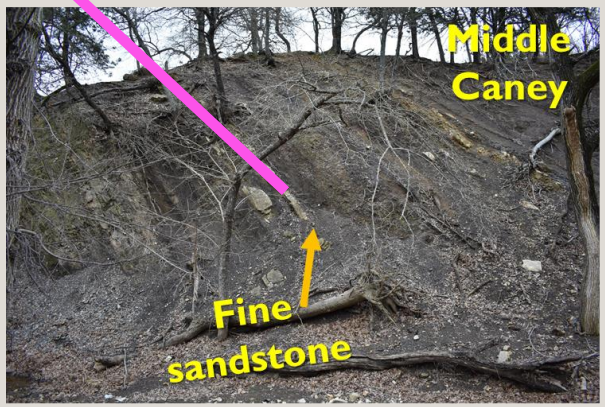


Arbuckle Wilderness: Caney Shale Outcrop Compared to a Nearby Well (Con't.)

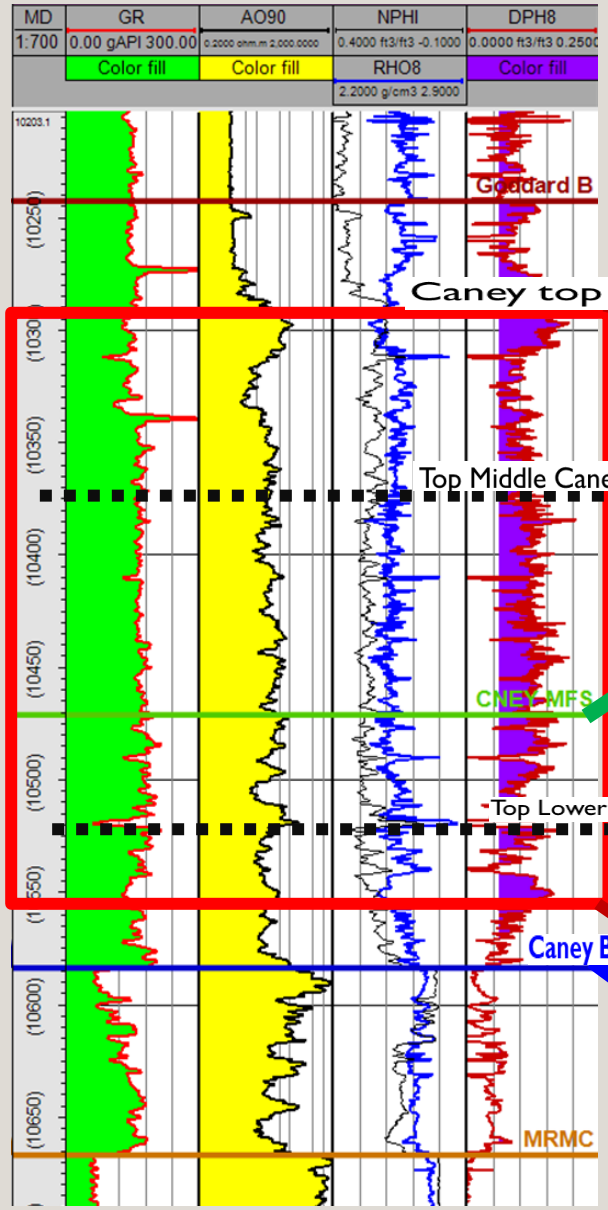


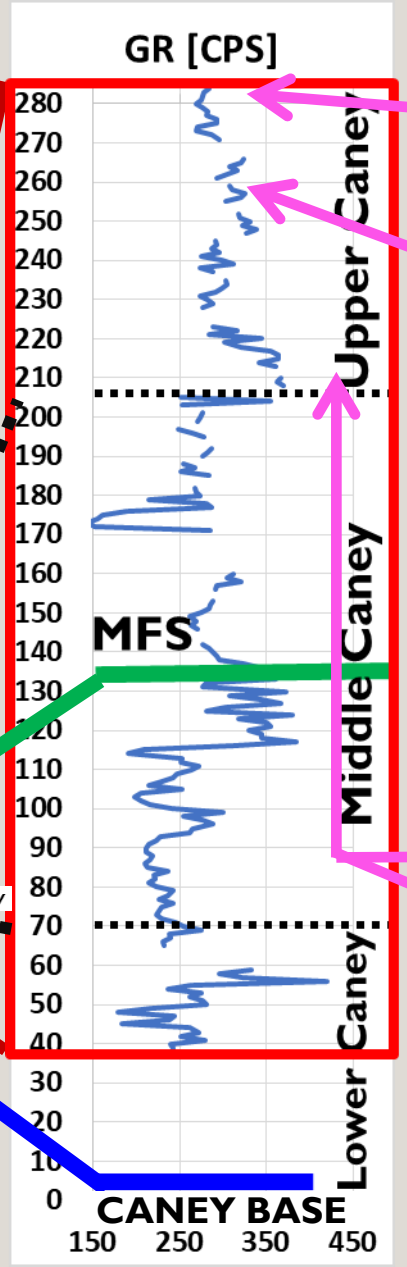


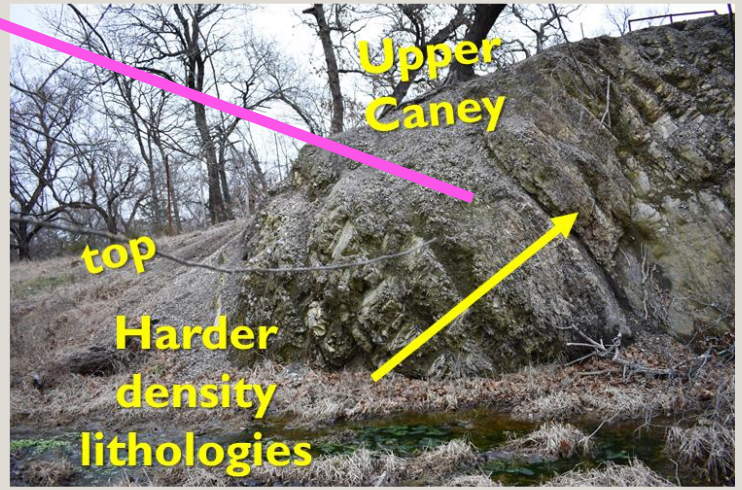


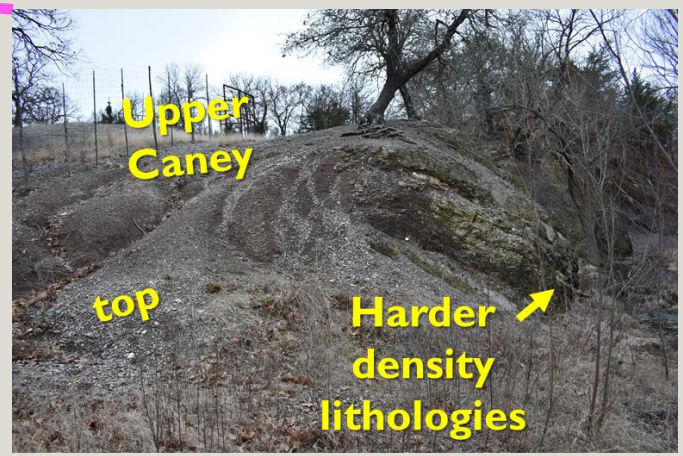


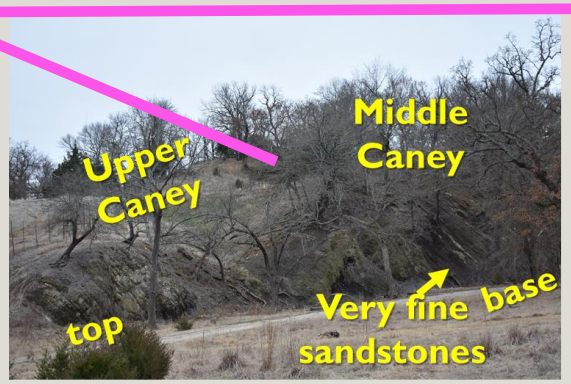
Arbuckle Wilderness: Caney Shale Outcrop Compared to a Nearby Well (Con't.)



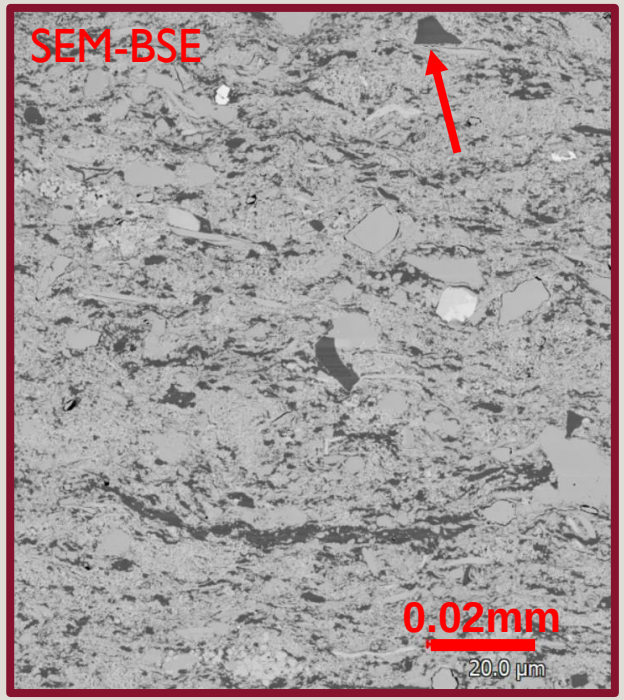


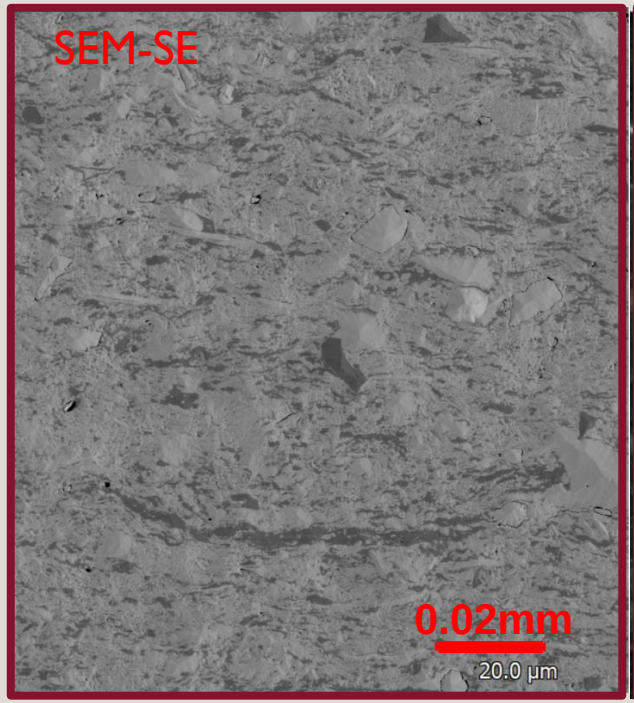


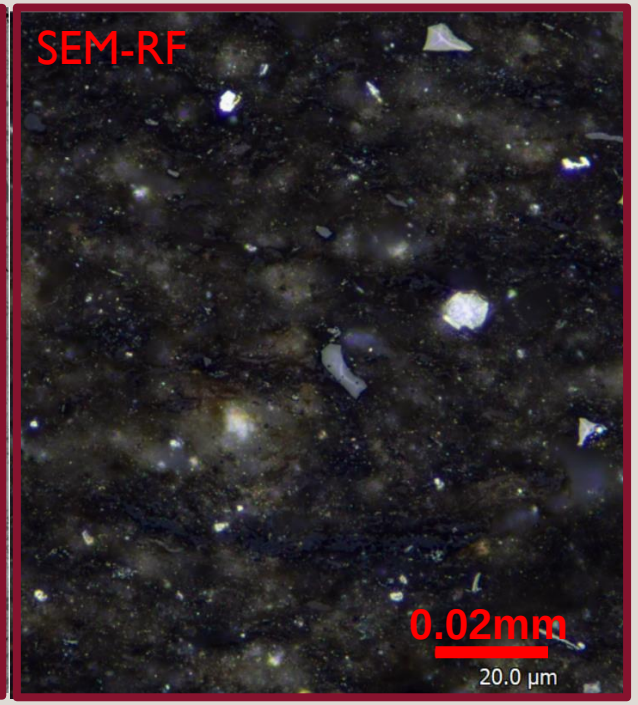


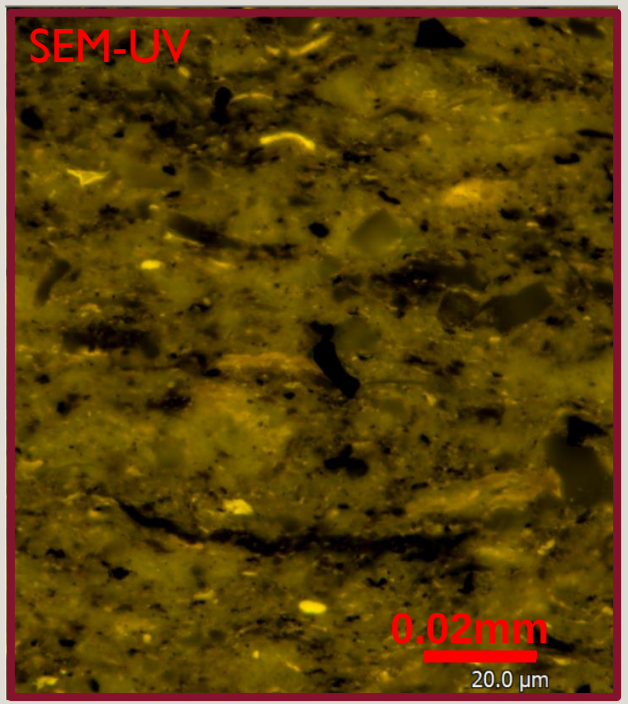


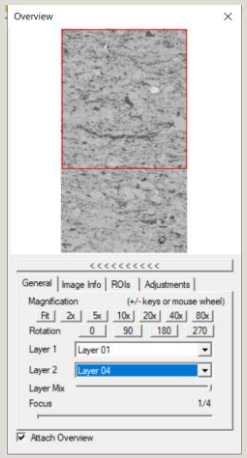
Caney Shale - Philips Creek Outcrop, Carter County







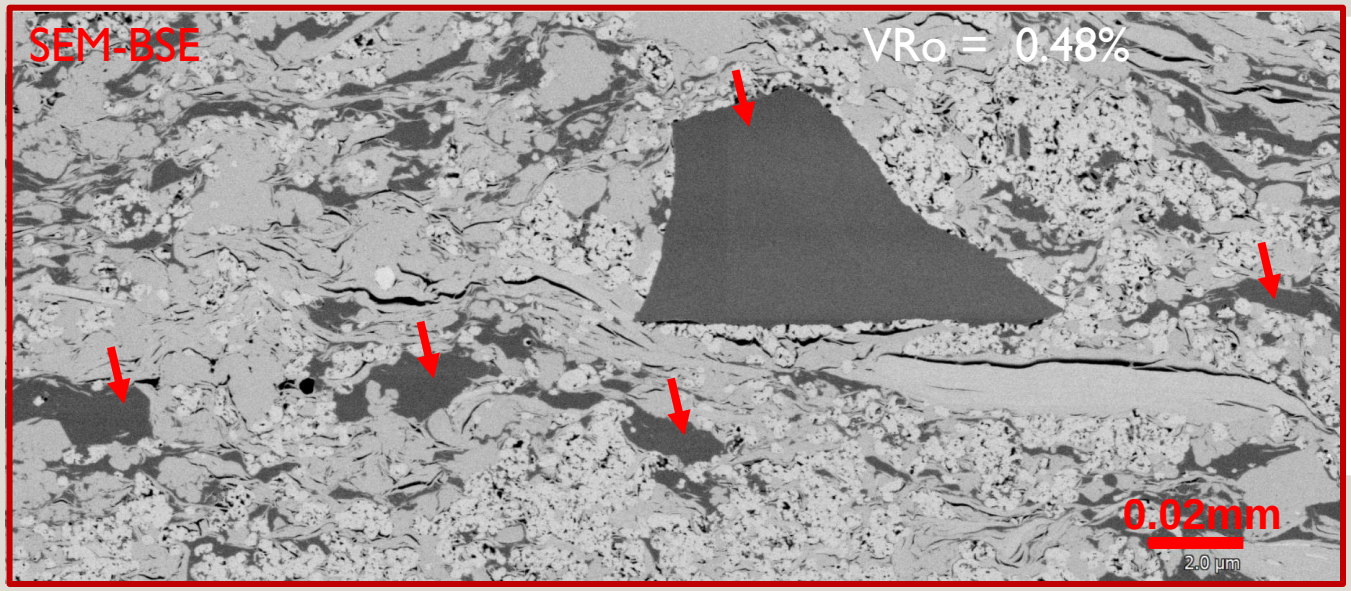


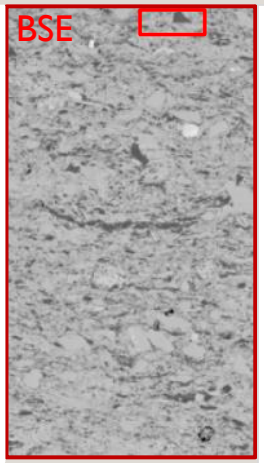


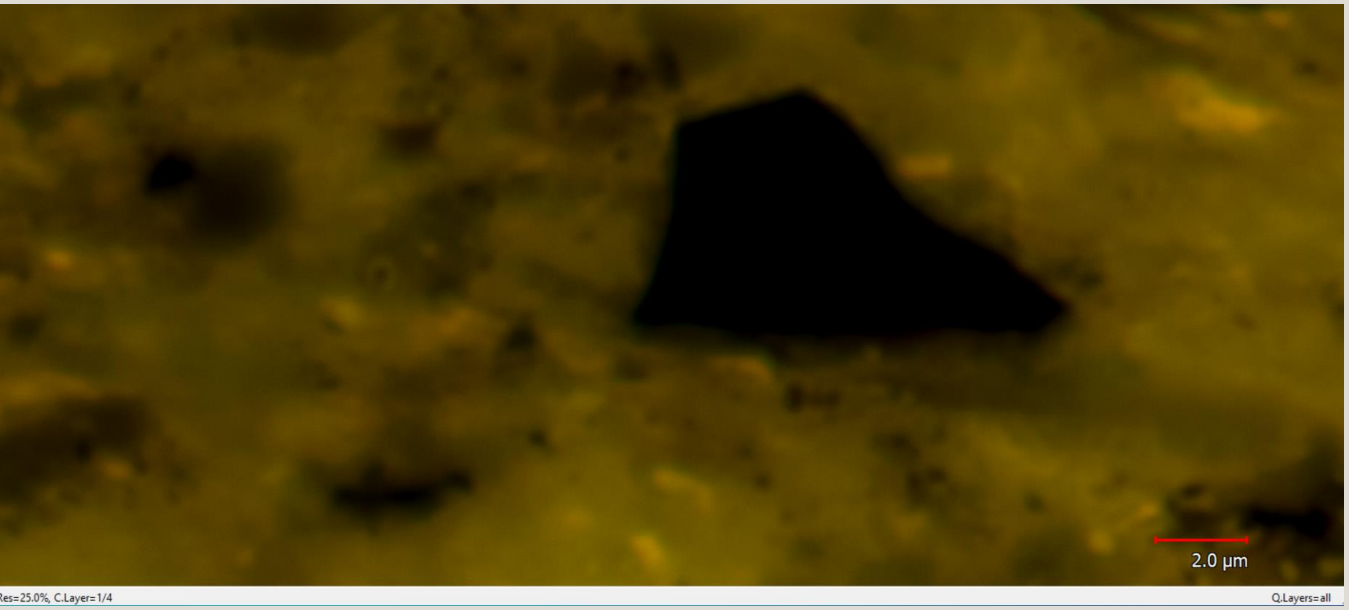
The BSE image shows the difference between organic matter and minerals. The SE image is used to see the pores. The RF image shows inertinite macerals. Comparing the BSE and RF images shows what looks like solid bitumen as the east-west line near the bottom (non-fluorescing). The carbonate minerals are what is fluorescing. The kerogen assemblage recovered is dominated by Amorphous Organic Matter (AOM) with frequent/common structured black and brown woods (inertinite/vitrinite).

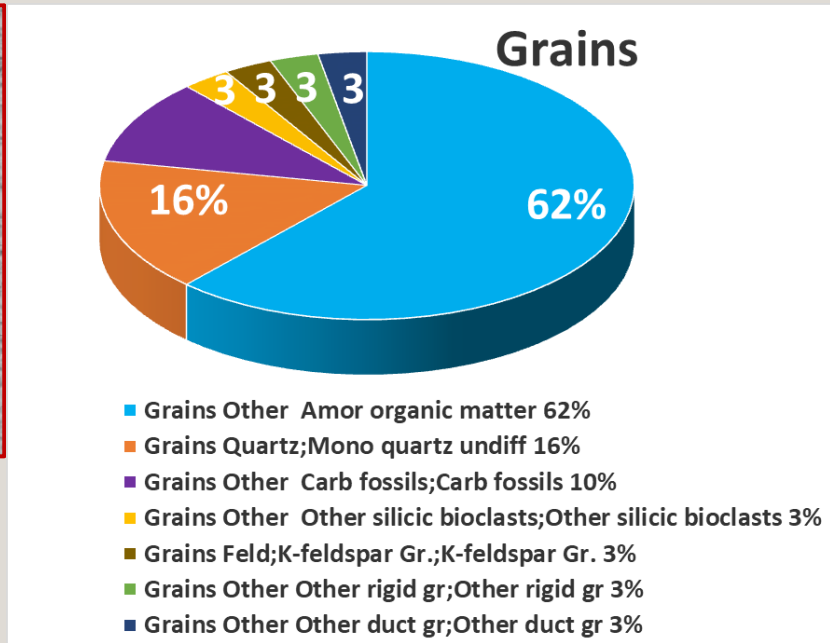
The occurrence of brackish water Veryhachium (acritarch genus) spp. (2 specimens) may suggest marine influence.

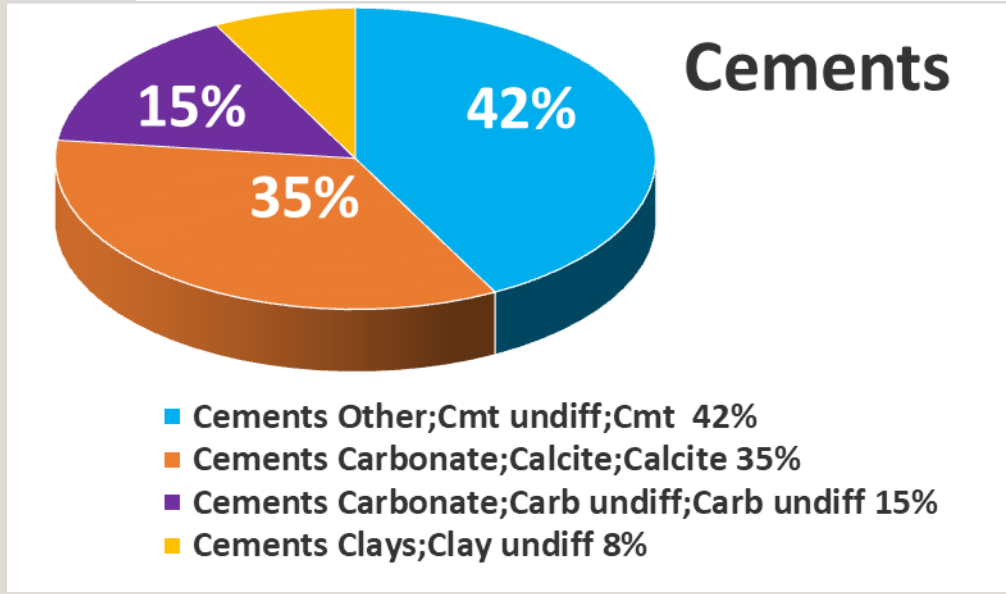
Caney Shale - Philips Creek Outcrop, Carter County (Cont.)



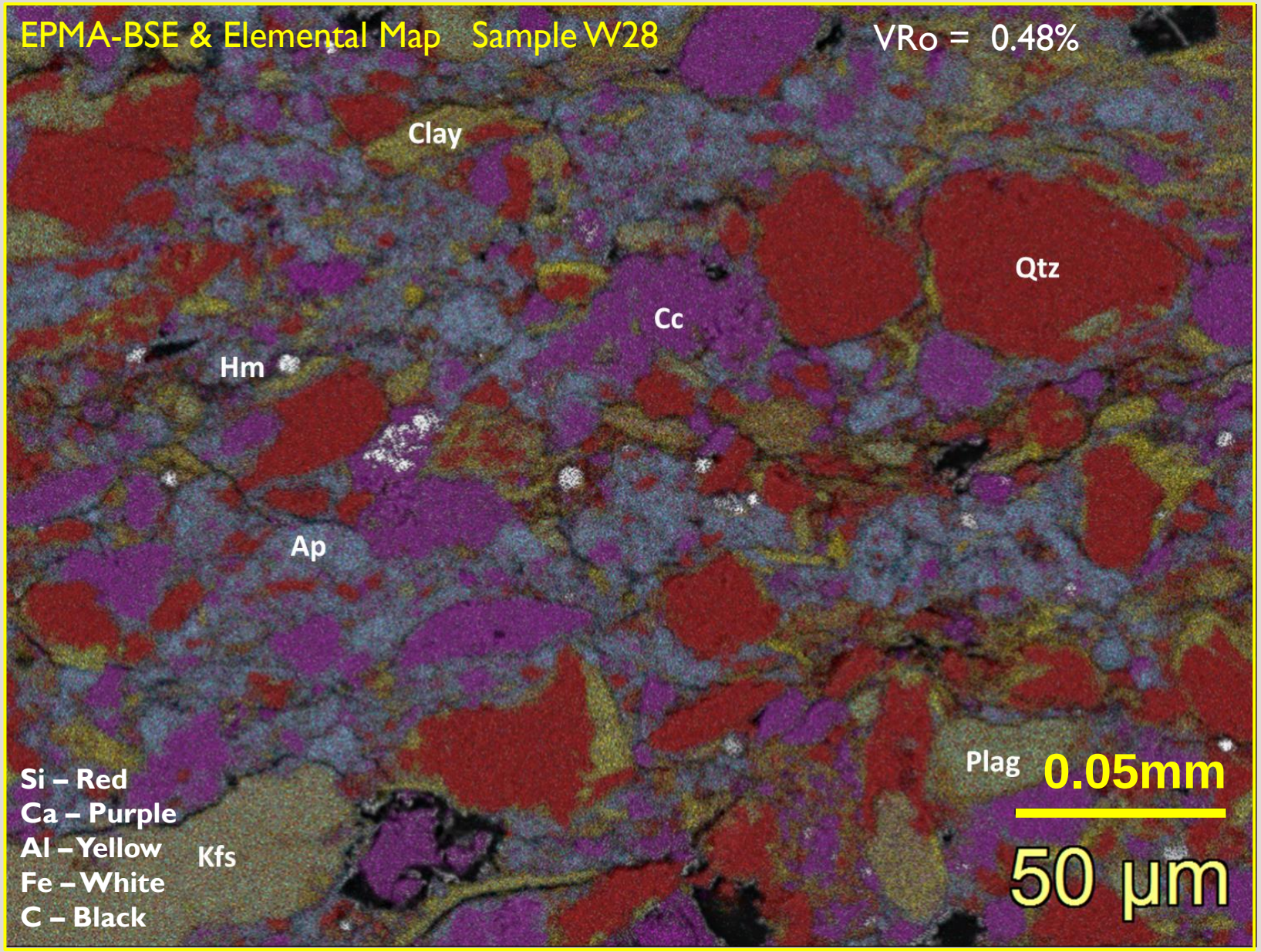


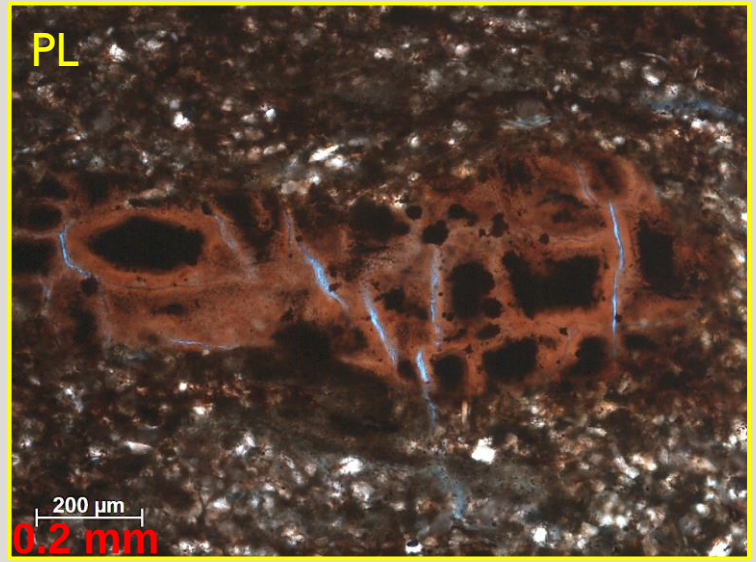






Caney Shale – Wilderness Outcrops, Murray County



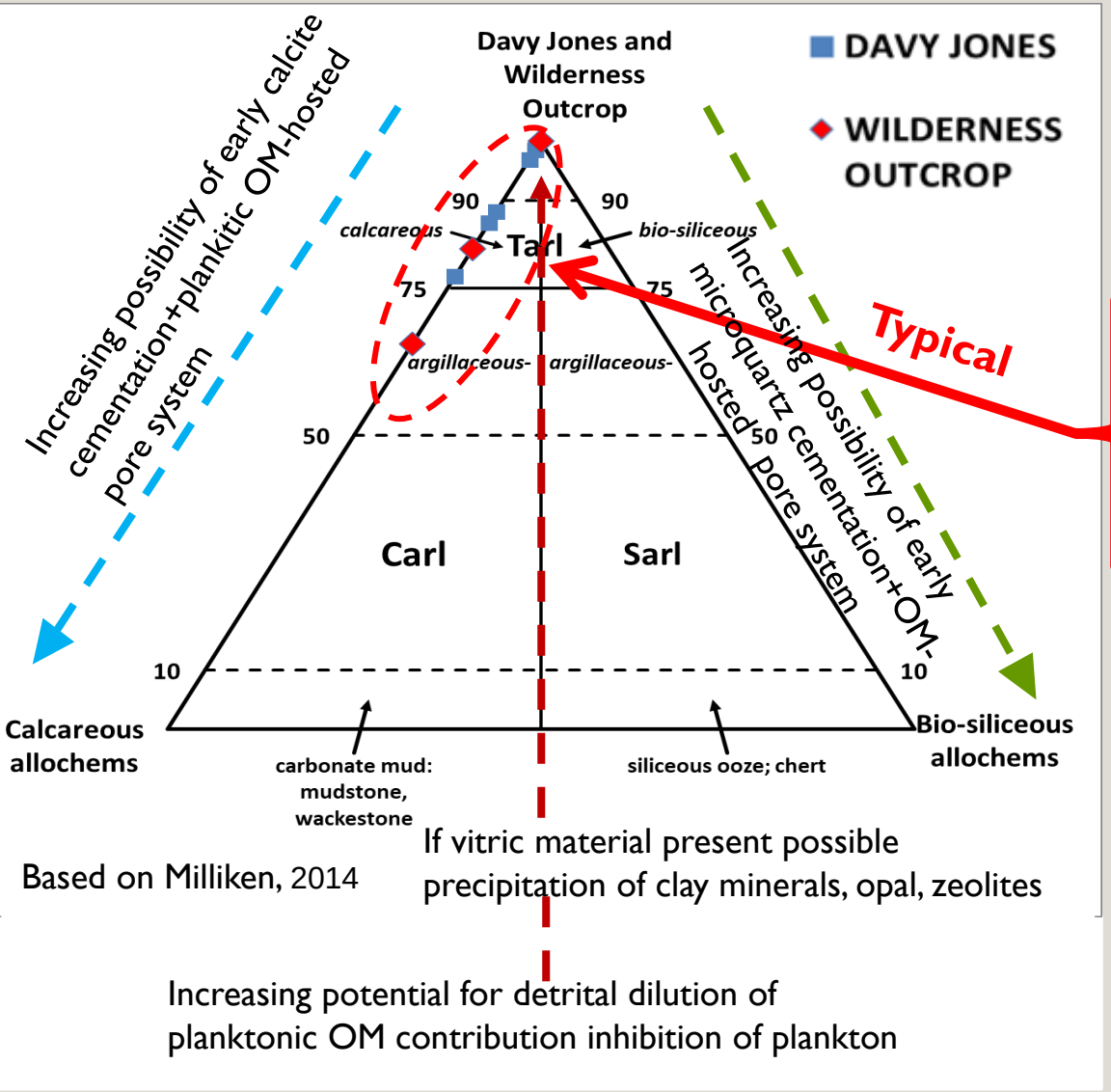


Key Similarities & Differences: Outcrops & Subsurface Samples

EDS, BSE & CL image analysis	Davy Jones	Arbuckle Wilderness Outcrop
★ Grain size	Much finer grained. Grain boundaries were almost impossible to see	Grain boundaries are much more defined
Carbonate Content	Dominated by all three carbonates, dolomite, siderite and calcite	Dominated by calcite, with only minor amounts of dolomite and/or siderite
	Davy Jones (DJ samples have less carbonates and more clay and quartz	Wilderness samples have much more carbonates than DJ
	Both sample sets contain rimmed carbonates, but they are much more common in the DJ samples	
Radiolarian content	The presence of radiolarians in either sample set is not common. Radiolarians are observed in Wilderness samples, but not in Davy Jones	
Hematite vs pyrite	The DJ samples all have a considerable amount of pyrite.	Samples all contain pyrite, but they contain much more hematite in comparison (often rimming pyrite) (e.g., W28 Lower Caney)
Feldspars	All samples contain plagioclase (albite).	Samples also contain K-Feldspars and Albite
Apatite	Minor	Some
★ Organics	Minor	Possible organics in almost all the BSE images
Quartz Cement	Samples have much more quartz cement than the Wilderness samples	For all the samples (at least in the samples that the grain size was sufficient) do not appear to show a quartz cement even around the larger quartz grains
	Quartz cement, as quartz overgrowths were observed along many grain boundaries	Only one of the Wilderness samples showing a considerable amount of quartz cement in the matrix in the Middle Caney
Clay Content	All the samples are matrix-supported (clay) and are dominated by clay and silt-sized grains.	
	Clay is illite in composition (K, Mg, Fe) and occurs as both individual grains and as the matrix	
★ In summary	Both sets of samples are very similar compositionally and texturally, containing intermixed layers of clay, quartz, quartz cement, kaolinite, feldspar (plagioclase and k-feldspar), carbonates (e.g. dolomite, siderite, and calcite), pyrite, and/or hematite.	

Caney Mudstone Compositional Diagram: Davy Jones & Wilderness Outcrop

Compositional Classification for Fine-Grained Sediments and Sedimentary Rocks

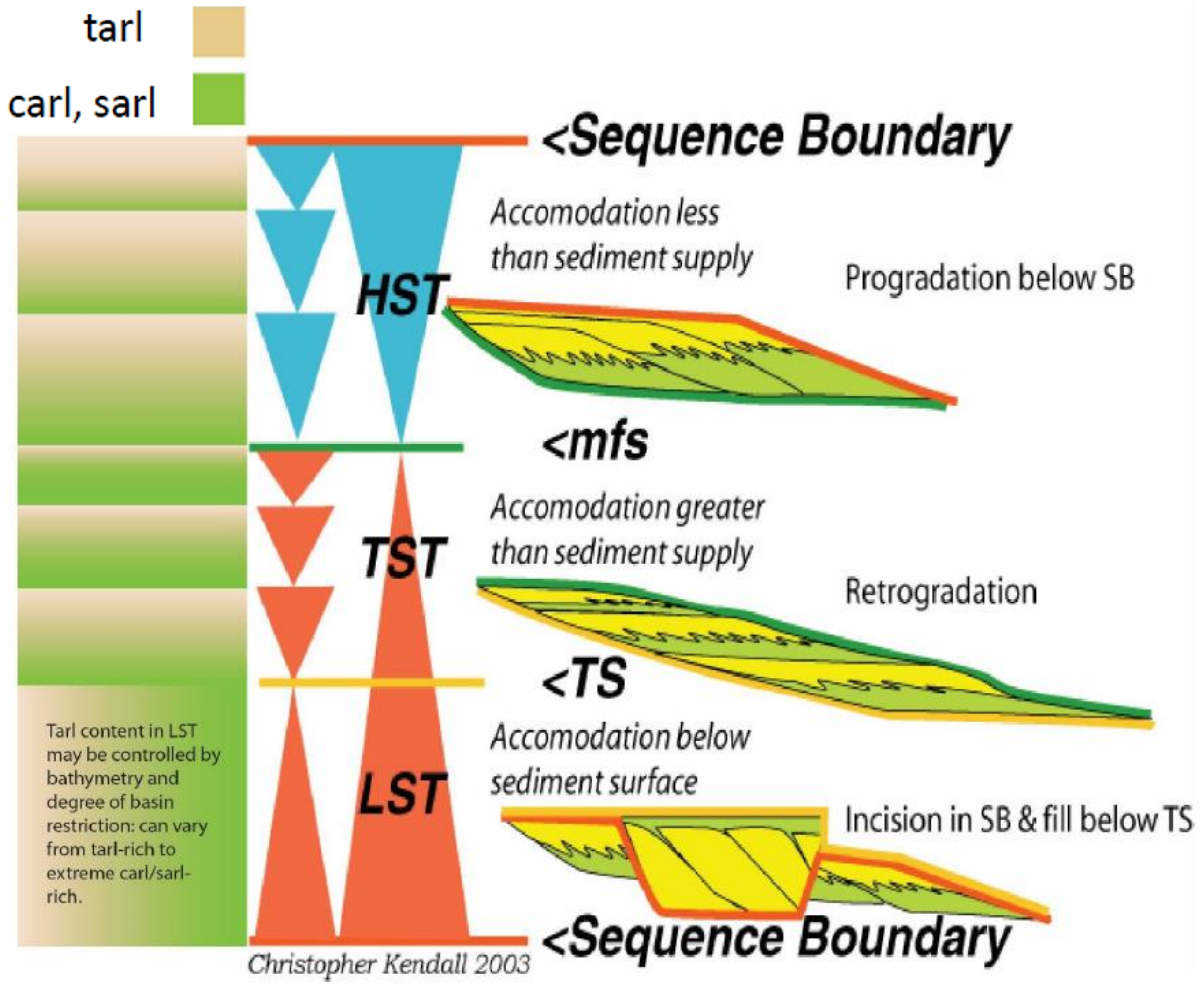


Based on Milliken, 2014

If vitric material present possible precipitation of clay minerals, opal, zeolites

Increasing potential for detrital dilution of planktonic OM contribution inhibition of plankton

Future Exploration Model?

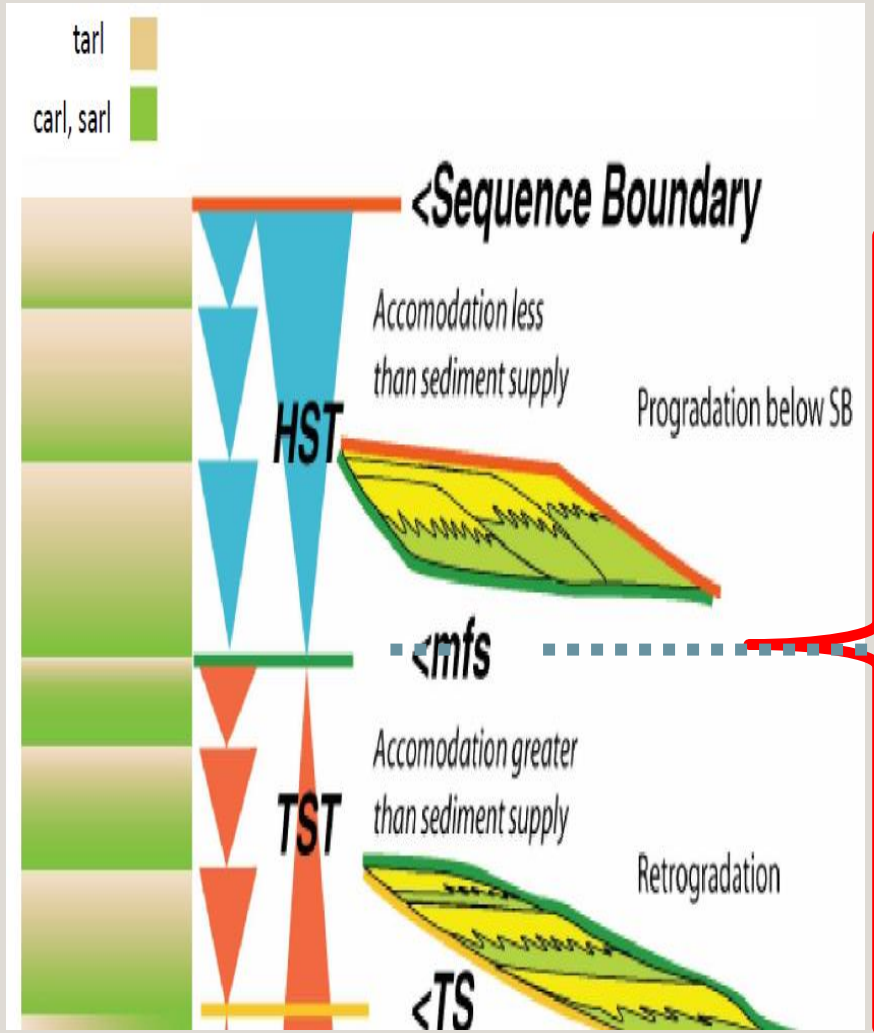


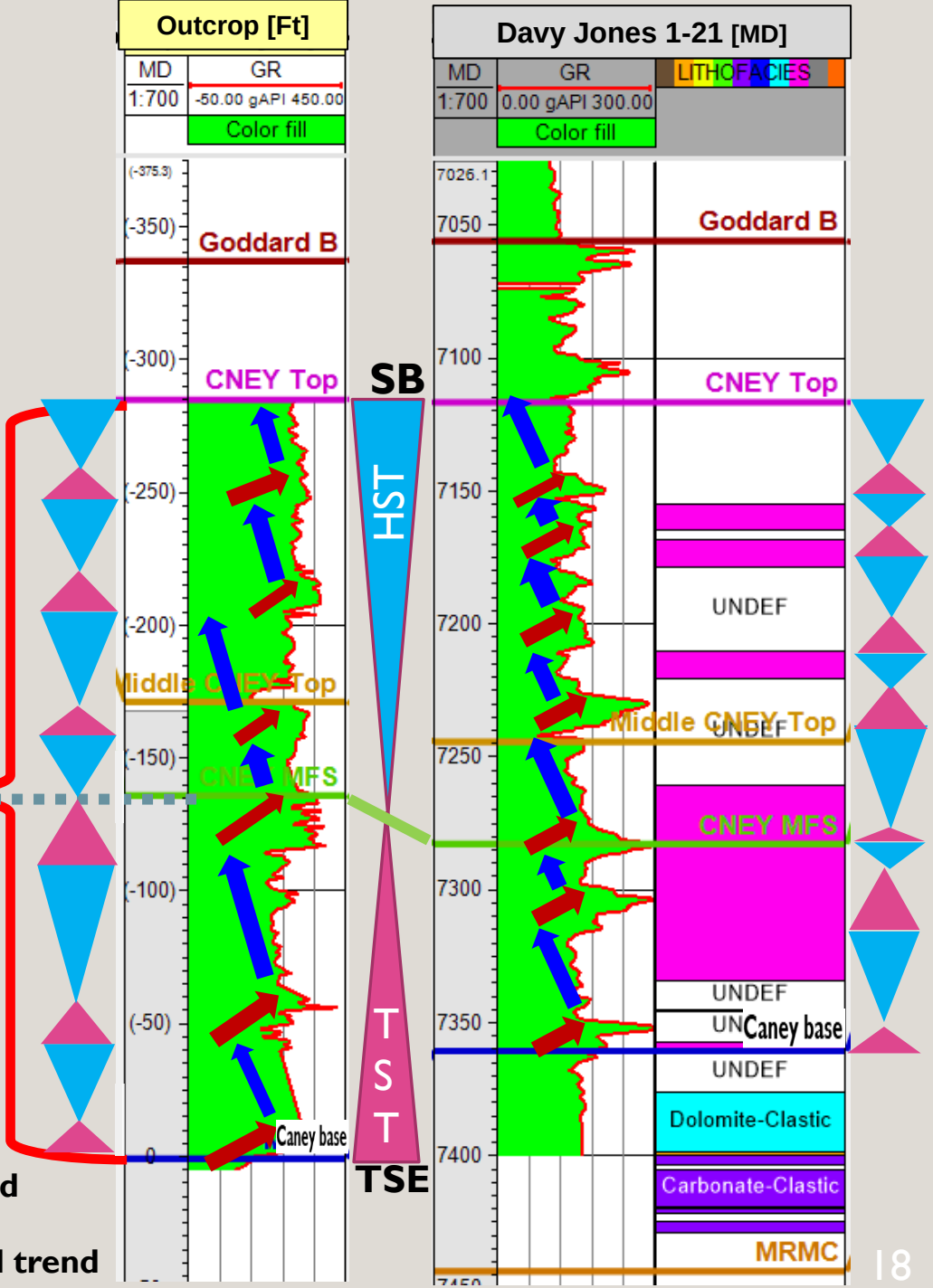
Note the composition of the Caney Shale samples that is plotted in the Tarl and Carl fields.

Sequence Stratigraphy Trends at the Arbuckle Wilderness Outcrop & Davy Jones Well

- **Before the MFS, the depositional system consists of more major flooding cycles, a retrogradation regime where there is more basinal accommodation space and less ratio of sediment supply with lower energy levels. These strata correspond to the Lower and Middle Caney members.**

- **Right after the MFS (which is part of the Middle Caney member), the depositional regime is more HST conditions and there are more progradational detrital deposits towards the basin. These correspond mostly to the Upper Caney Member where there is higher sediment supply than accommodation space.**

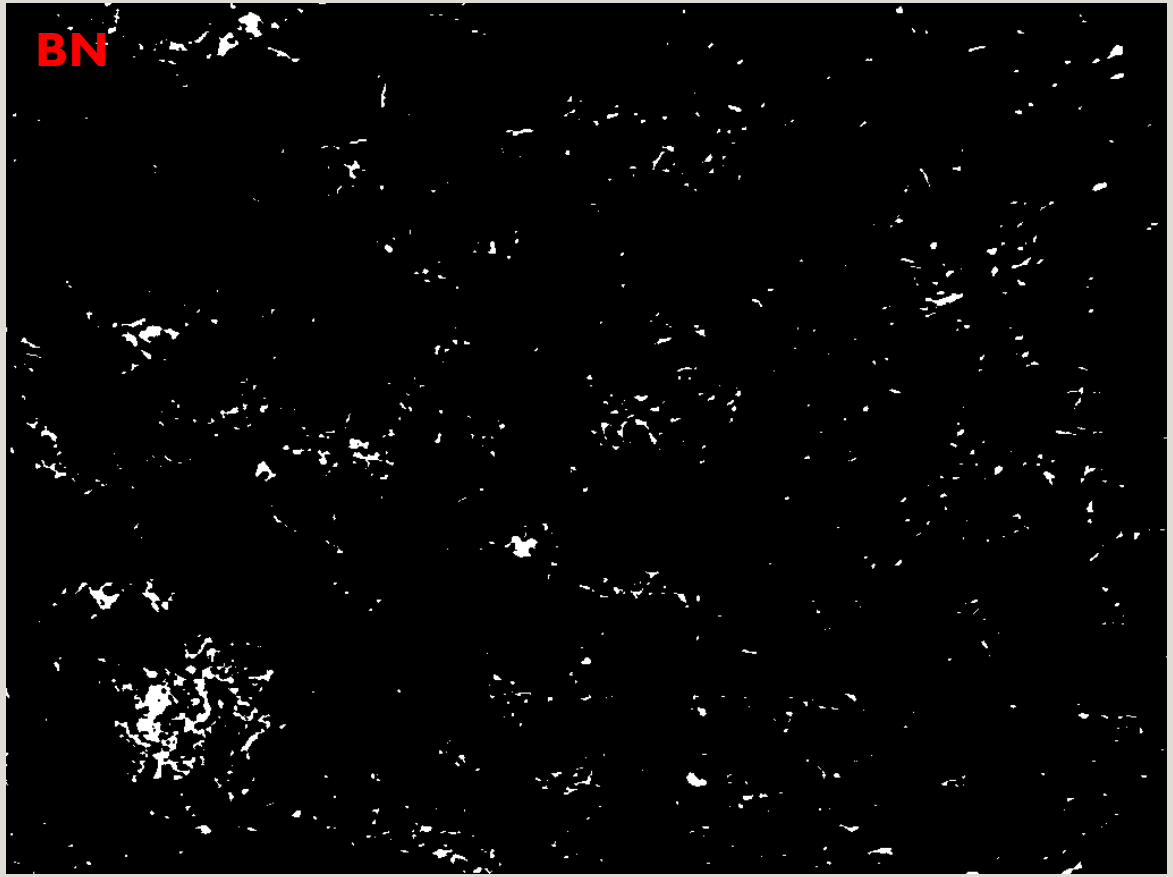


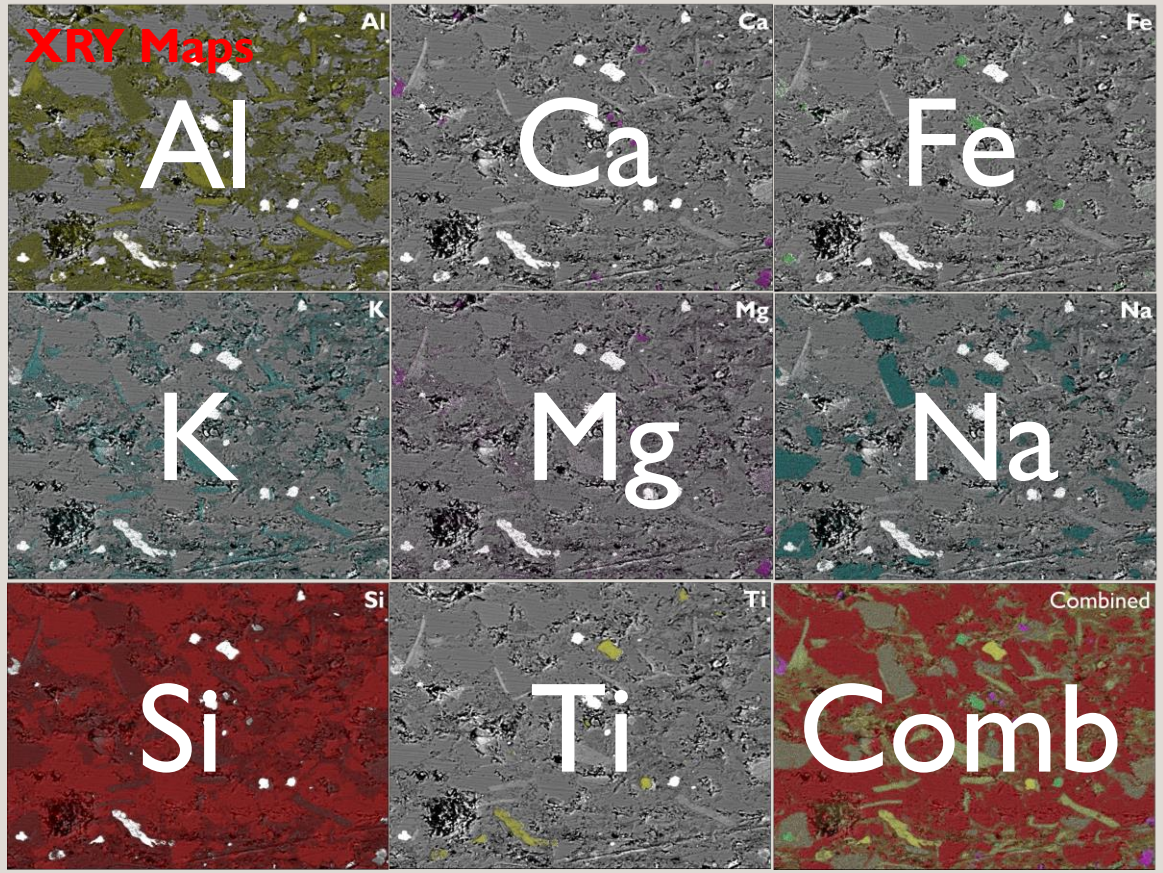


Fining upward trend

Coarsening upward trend

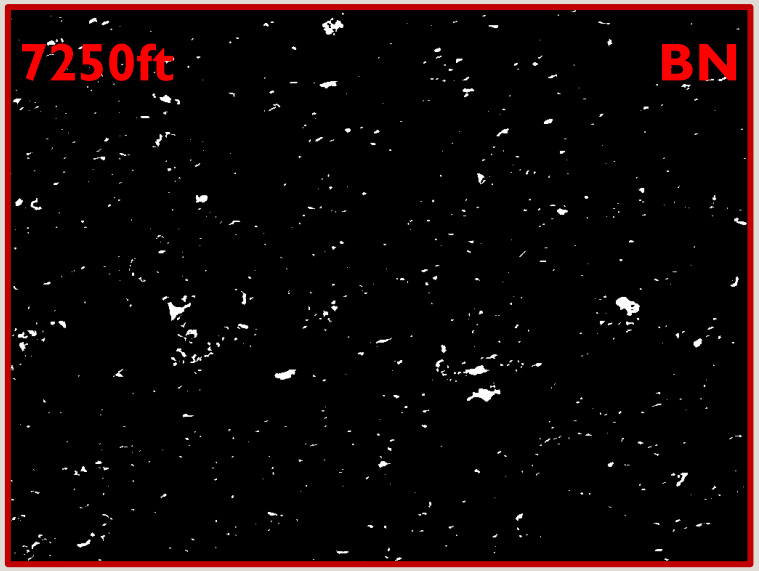
Feature Extraction Using BSE & X-Ray Mapping - Sample from Davy Jones: 7430.1 ft



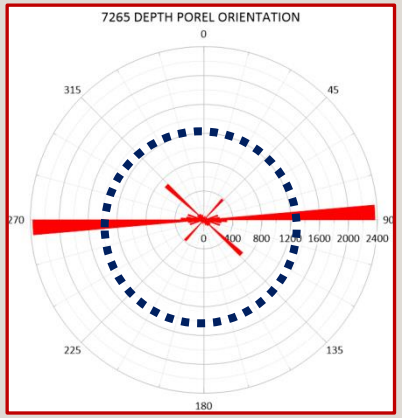


BSE imaging and X-Ray mapping (right mosaic of images) were used to help define individual grains, minerals, organic material (C mapping used for this) and pores (left image where the white pixels were identified as pores). The binary pore images (left image) where then used to extract pore geometry and similar quantitative information while the elemental maps (right mosaic of images) were used for mineral identification and particle size and shape analysis. Comb = Combined X-Ray image.

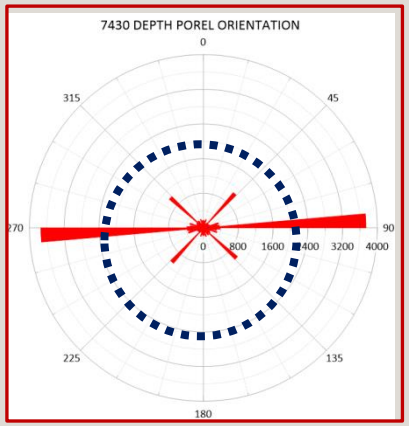
Image Analysis – The use of image techniques were applied to the digital images of thin sections taken from the Davy Jones core from five rock types. The goal was to gain further insights in the nature and properties of the pores found in the rock. The images were composites taken from BSE and X-Ray images using a micro-probe instrument.



Binary image from depth 7250ft: white represents pores (porels) and black represents rock. Image size ~ 3,519 microns wide by 2,634 microns long. Total Optical Porosity (TOP) = 1.35%

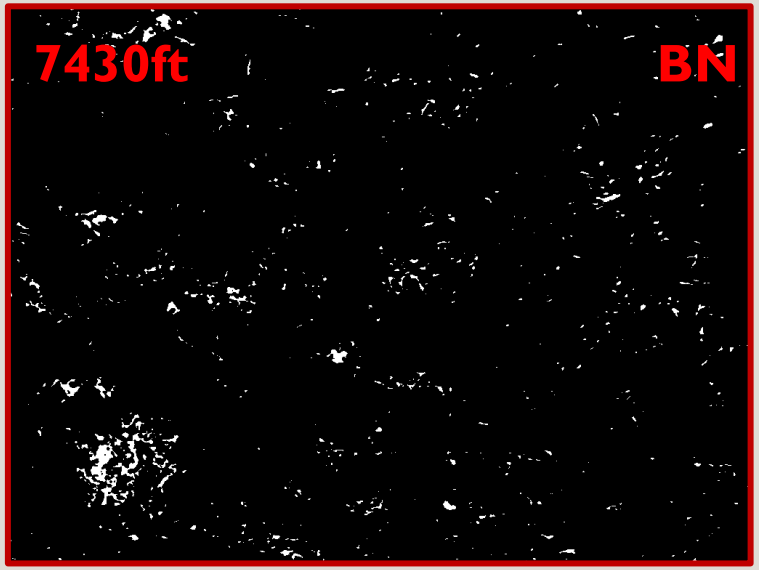


Orientation of 7,796 porels at 7250ft



Orientation of 11688 porels at 7430ft

Porel orientation is a function of local stresses, rock fabric and diagenetic history. It directly influences engineering related to fracking, petrophysical response and flow efficiency. These two samples show similar properties except with some variability near the center of the Rose diagrams outlined in blue dashes.



Binary image from depth 7430ft: white represents pores (porels) and black represents rock. Image size ~ 3,519 microns wide by 2,634 microns long. TOP = 1.59%

Porel Geometry: Average Results for the Davy Jones Core

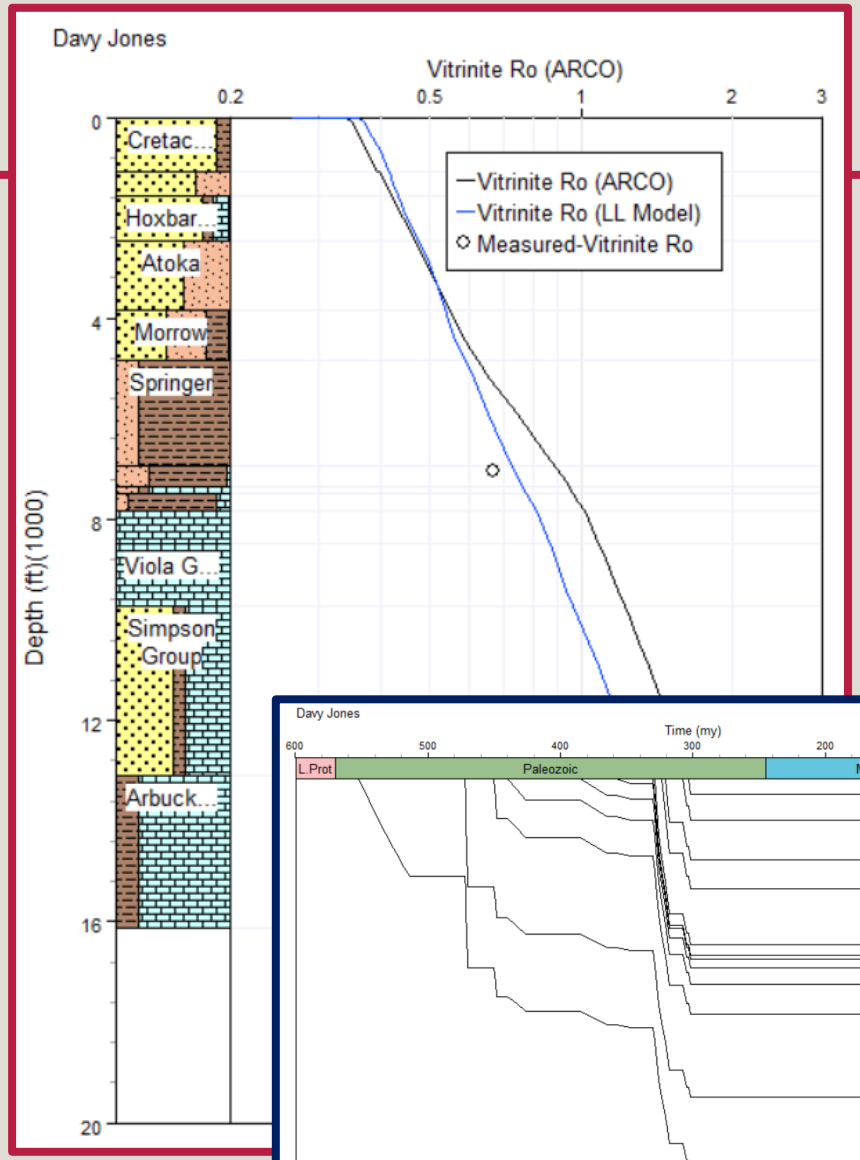
IMAGE DEPTH	NUMBER OF PORELS	TOTAL POREL AREA (MICRONS^2)	SMOOTH POREL AREA (MICRONS*2)	ROUGH POREL AREA (MICRONS^2)	TOTAL POREL PERIMTER (MICRONS)	TOTAL BENDING ENERGY (N/m)	AVERAGE POREL BENDING ENERGY (N/m)	TOTAL OPTICAL POROSITY (%) ★	PROPORTION OF PORELS SMOOTH	PROPORTION OF PORELS ROUGH	SMOOTH/ROUGH RATIO	TOTAL PERIMETER/TOTAL AREA RATIO	POREL AREA/TOTAL PERIMETER RATIO	TOTAL PERIMETER/POREL AREA RATIO	TOTAL POREL COMPLEXITY (UNITLESS)	AVERAGE POREL ORIENTATION	LONGEST POREL DIMENSION AVERAGE (MICRONS)	RIGHT ANGLE TO LONGEST POREL DIMENSION AVERAGE (MICRONS)	AVERAGE LONGEST/RIGHT ANGLE RATIO ★
7265	779.67	118791.44	82568.69	36222.81	27000.60	6422.93	8.29	1.28	0.69	0.31	2.28	0.00	4.40	0.23	6147.30	96.27	39.89	18.41	1.92
7350	1601.70	295603.60	198204.60	97399.31	65342.69	11914.06	7.53	3.19	0.68	0.32	2.13	0.01	4.46	0.22	14473.22	84.94	42.99	22.67	1.81
7406	1142.30	457225.20	236776.90	220456.60	71320.16	8252.98	7.22	4.94	0.52	0.48	1.10	0.01	6.46	0.16	11198.18	89.22	79.61	47.11	1.75
7419	756.73	159996.19	102499.99	57496.20	33092.73	5735.31	7.72	1.73	0.67	0.33	2.15	0.00	4.69	0.21	6874.77	90.25	41.57	23.47	1.79
7430	1168.85	237926.15	151588.66	86338.41	49485.78	8713.83	7.52	2.57	0.66	0.34	2.02	0.01	4.70	0.22	10483.47	88.93	45.11	25.09	1.79

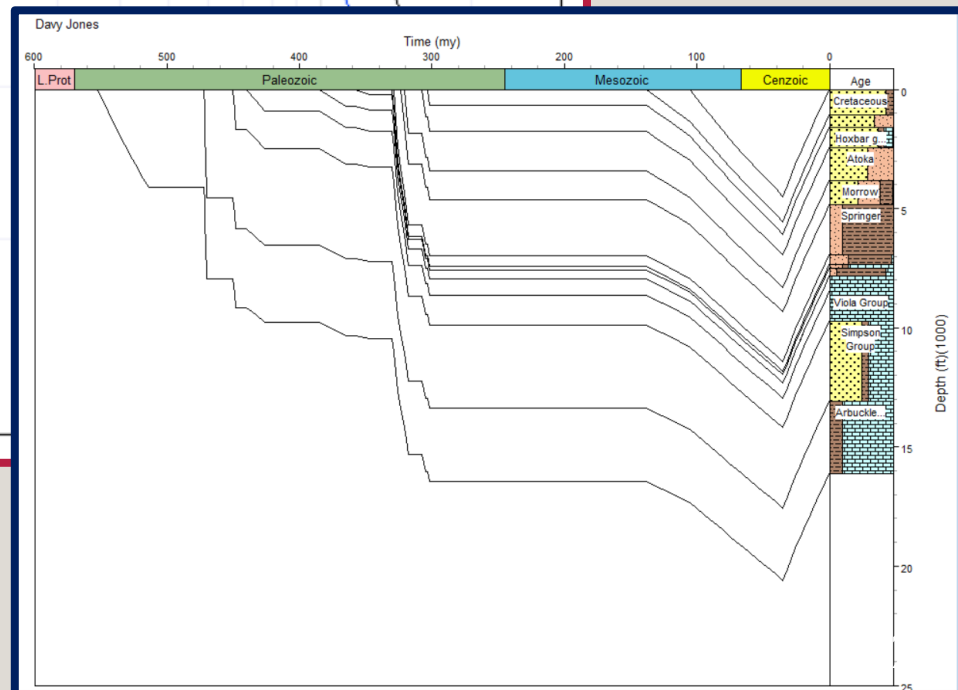
Porel size and geometry directly related to Petrophysical and Engineering parameters. Each porel's geometry is decomposed into smooth (largest capillary that would fit inside the porel) and rough (what remains) components, the outline ascertained and various standard variables calculated. In this core, it can be observed there is quite a bit of variability in each of these observations such as show by the Total Optical Porosity (TOP – red starred column) data (ranges from 1.28% to 4.94%) and other parameters. Note also that the sample 7406' has the highest TOP yet the lowest proportions of smooth porel area% suggesting the pores contain mostly elongated, rough edge porels. This is supported by the fact that this sample has the smallest long dimension divided by the short dimension ratio (right most column marked by orange star). All of these measurements can be related to rock properties and ultimately to recoverability.

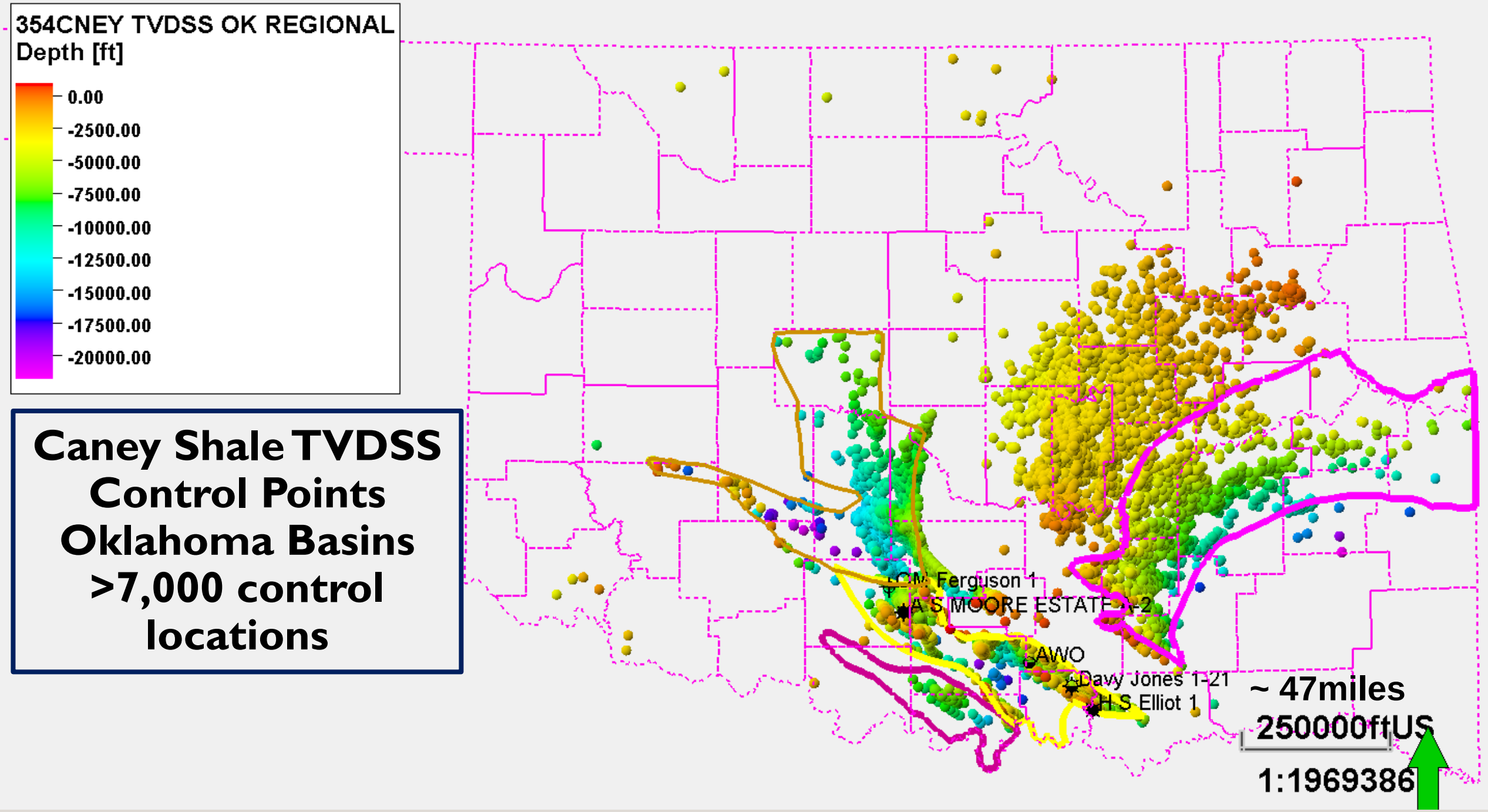
Caney Shale Basin
Scale Study

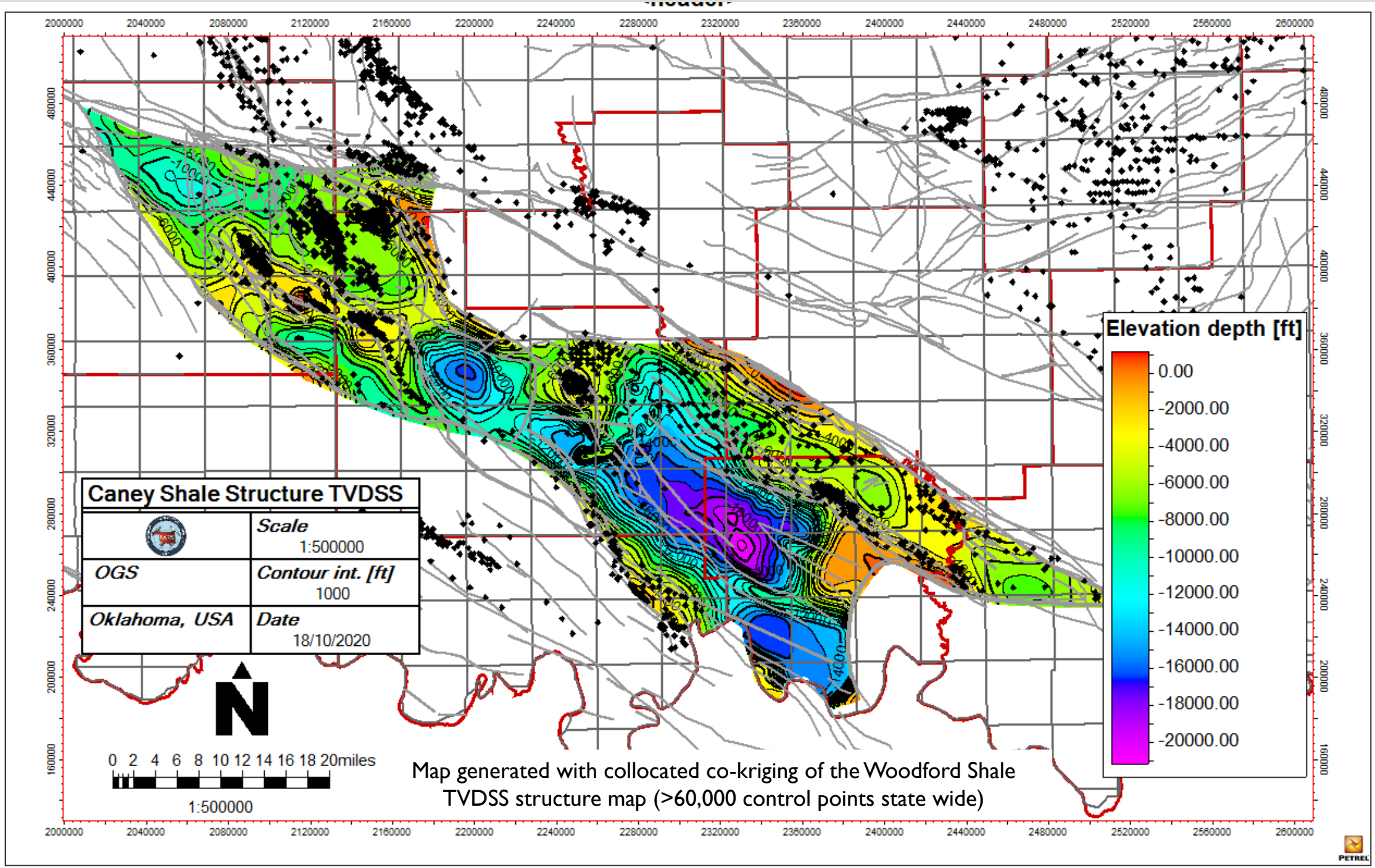
Thermal Maturity Estimates

- One dimensional basin modeling is in progress. This is a methodology utilized for burial history modeling, thermal evolution and thermal stress analysis across the Oklahoman basins
- The models are calibrated at the core locations and serve to calculate estimated maturity values in other basin locations and to other stratigraphic levels where there are no hard data available
- Certain assumptions have been made such as lithospheric and mantle thickness, heat flow variations and thickness of eroded strata
- The Davy Jones core basin modeling is complete
- Work is in progress for other wells in the Ardmore Basin






354CNEY TVDSS OK REGIONAL
Depth [ft]
0.00
-2500.00
-5000.00
-7500.00
-10000.00
-12500.00
-15000.00
-17500.00
-20000.00
Caney Shale TVDSS
Control Points
Oklahoma Basins
>7,000 control
locations
Ferguson 1
A S MOORE ESTATE A-2
AWO
Davy Jones 1-21
H S Elliot 1
~ 47miles
250000ftUS
1:1969386



Map generated with collocated co-kriging of the Woodford Shale TVDSS structure map (>60,000 control points state wide)

Work In Progress

- Massive digitalization of well logs for quantitative petrophysical properties analysis and modeling in the Oklahoma basins. These data will be calibrated with core and cutting data sets
- Regional burial, subsidence and thermal evolution analysis in the Marietta, Anadarko, Ardmore and Arkoma Basins
- Building depositional models, paleogeographic reconstruction, and facies model
- Integration of products for proposing the regional depositional model from local interpretations tied to key core analyses (%TOC, maturity, palynology, SEM, XRD, XRF, sequence stratigraphic models, and geomechanical properties)
- Extent and Volume of the Caney Shale in Oklahoma
- Additional wells undergoing image and reservoir analyses

Any Questions?

Contribute & Help to Provide Knowledge & Promote the Vast Oklahoma Resources!!!