Estimating Total Organic Carbon (TOC wt.%) using Rock, Well-Logs, and Impedance Inversion Volumes: A Woodford Shale Example – How Geophysics Helps to Clarify Geology

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1. SUMMARY

The Woodford shale in Oklahoma is a prolific conventional and unconventional hydrocarbon source and reservoir rock. Detailed characterization of the Woodford continues to unlock unique information related to its depositional history/environments, nature of the source material, and hydrocarbon potential. The Total Organic Carbon (TOC wt.%) stratification mimics the fine-scale stratification within the Woodford Shale lithologies providing information about prolific areas. In order to highlight possible TOC sweet spots, time thickness interpretation, coherent energy, most-positive and most-negative curvature volumes were computed and interpreted. As a proposed strategy for determining the geological and internal organic facies variations, the TOC was calculated in six wells of the study area applying the Passey et al. (1990) methodology, additionally the seismic attributes were extracted and combined with the impedance inversion volumes to predict and distribute TOC along the study area in a confident manner. A supervised probabilistic neural network (PNN) workflow was applied to incorporate the post-stack 3D seismic data, and to generate statistical relationship with the calculated TOC in the wells. The input attributes in the PNN were: Zp, Coherent Energy and Spectral Components.

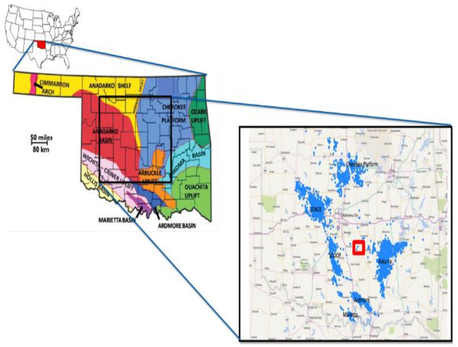


Figure 1. Location of the 3D seismic survey in South Central Oklahoma.

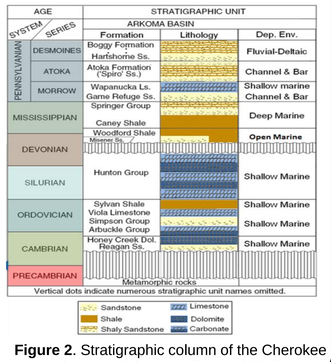


Figure 2. Stratigraphic column of the Cherokee platform, Oklahoma. Portas (2009).

2. WOODFORD SHALE REGIONAL DEPOSITIONAL MODEL IN OKLAHOMA

The depositional model of the Woodford Shale through one eustatic sea level cycle (Slatt et al., 2016) proposes that during the early stage of falling sea level, can be recognized isolated water masses with restricted water circulation over topographic depressions left by karst/incised valley development on the underlying carbonate surface (Hunton Limestone in the case of the Woodford).

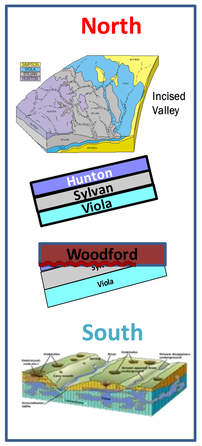


Figure 3. Schematic illustration showing the erosion mechanisms of the pre-Woodford strata [Slatt (2016) after Grotzinger and Jordan (2010)].

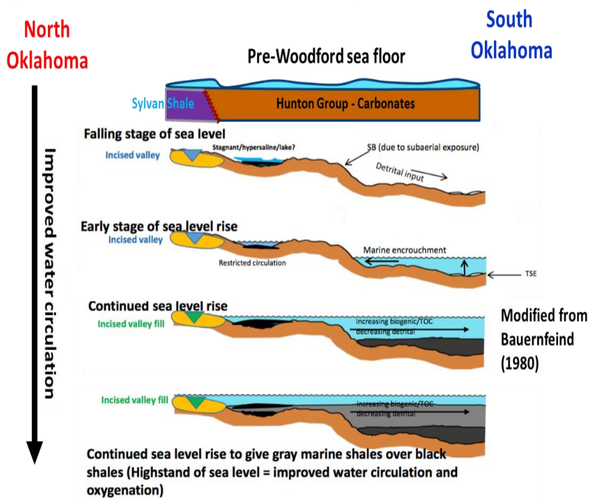


Figure 4. Depositional model from North to South of Oklahoma through a sea level cycle of the Woodford Shale. Note towards the North the occurrence of incised valley fill erosion

3. WOODFORD SHALE DEPOSITIONAL FAIRWAY IN STUDY AREA

Regional isopach maps along the study area interpreted by McCullough (2014) for the Woodford Shale and Hunton Group in the Cherokee platform, and the 3D seismic survey of this study located in South East Cherokee Platform Oklahoma, reveal an unconformity surface on top of Woodford Shale underlying carbonate rocks (Hunton Group), with considerable karst topography and around >100m of vertical relief. From this, a geological model claims that during lowstand of sea level, karst topography forms an irregular surface, which can provide discontinuous catchment areas for ponding of highly restricted anoxic water masses, forming restricted water circulation and establishing conditions for higher deposition and preservation of organic matter. The 3D seismic survey is inverted to predict TOC variability that shows discontinuous TOC zones that can define an unconventional sweet spot.

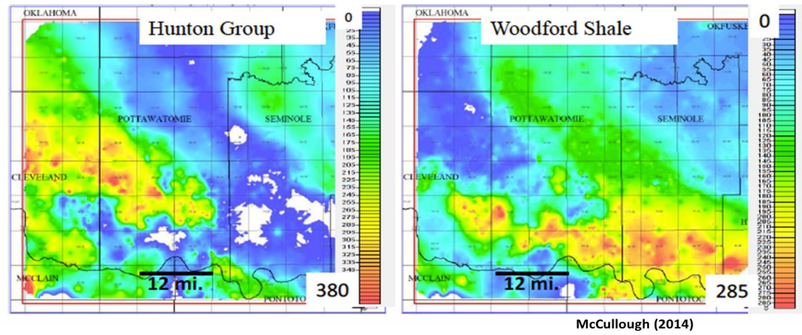


Figure 5. Regional Isopach maps created from well tops (McCullough, 2014) for the Woodford Shale and Hunton group. Note the inverse correlation of the formation thickness, where the Hunton is eroded the Woodford Shale is thicker, this is attributed to the depositional model of the Woodford shale where karstifications occur to the Hunton exposure leading into more accumulation space for the Woodford depositional fairway and catchment areas for TOC.

4. APPLIED AASPI WORKFLOW

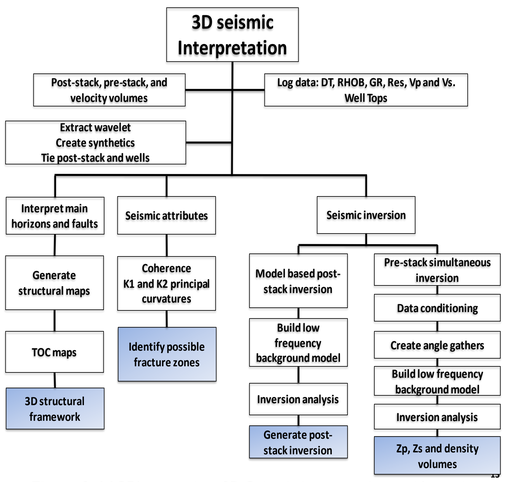
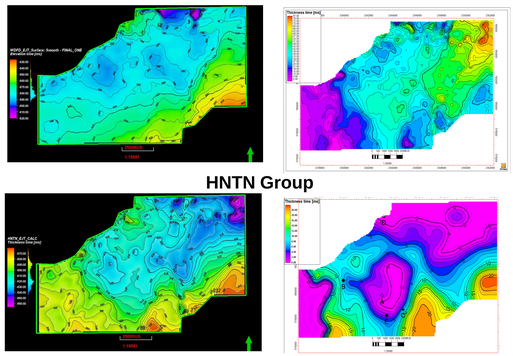


Figure 6. AASPI consortium 3D Seismic interpretation and Inversion workflow. Only post-stack data was available for inversion.

WDFD Shale



HNTN Group

Figure 7. Time structure maps and isochrone maps of the Woodford Shale and the Hunton group.

5. SEISMIC MULTI-ATTRIBUTES, INVERSION AND SUPERVISED PROBABILISTIC NEURAL NETWORK ANALYSIS

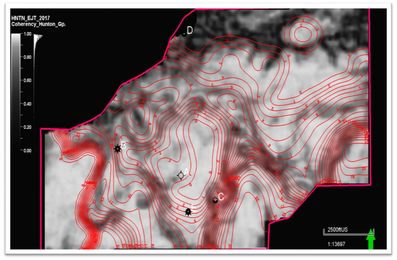


Figure 8. Coherency extracted along the Hunton Group. Contours correspond to Hunton time thickness in milliseconds. Dark colors to karstifications.

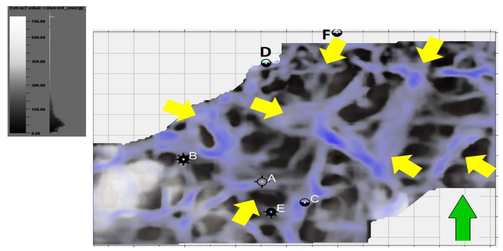


Figure 9. Hunton time-structure co-rendered with coherent energy and most negative curvature (Yellow arrows indicates karst features and possible lake pods, the Hunton Group is eroded -almost gone- in the study area).

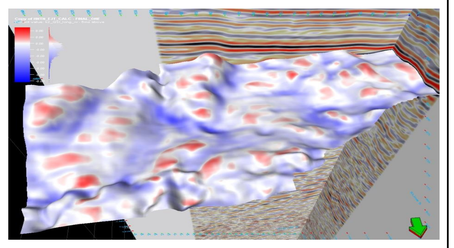


Figure 10. Horizon slice along the top Hunton through the most positive curvature and most negative curvature volume. Most negative curvature (blue areas) associated with major karstifications

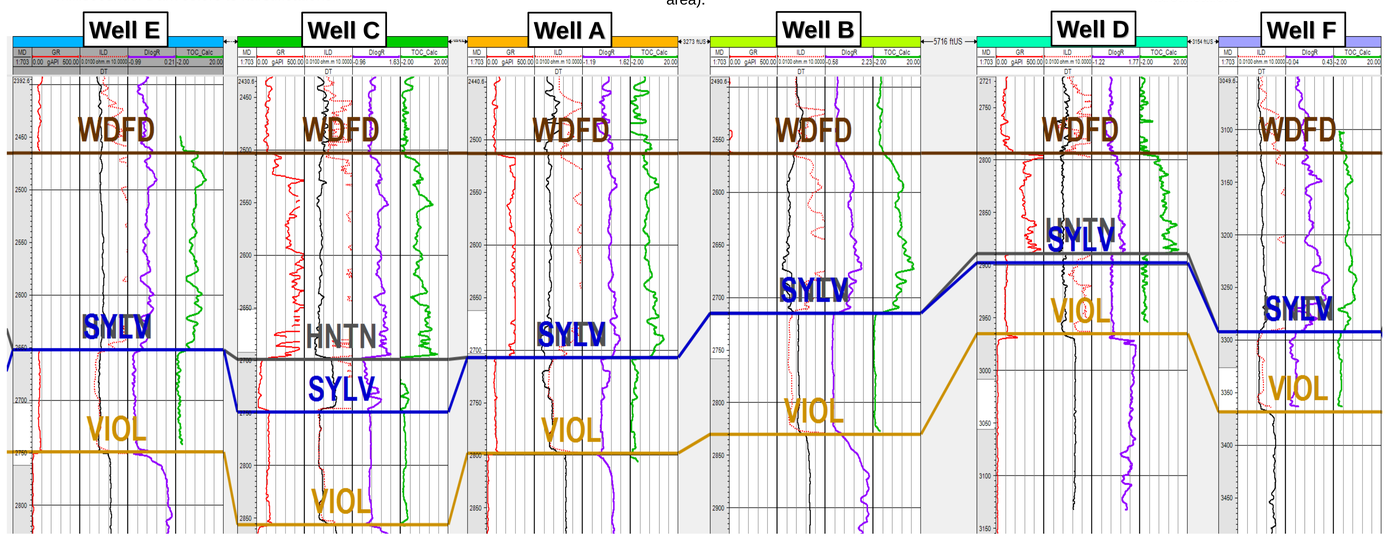
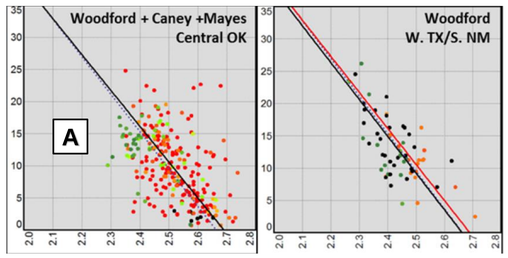
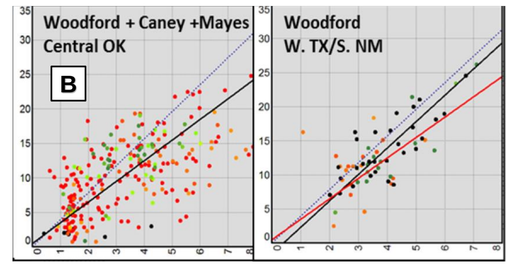


Figure 11. Stratigraphic correlation of the wells in the Study area, flattened at the Woodford shale top. Note the thickness variations of the Hunton Group and where is absent the Woodford shale has the highest thickness. These restricted intervals served as TOC catchment areas.

6. TOC vs Well Logs GR and RHOB





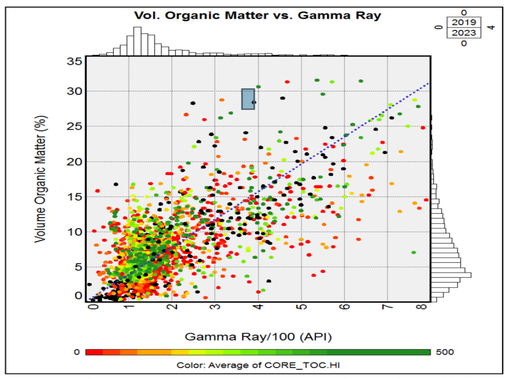


Figure 12. A)TOC vs RHOB; **B)** TOC vs GR from other Oklahoma areas. Haeckner et al. (2016).

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7. LOW FREQUENCY BACKGROUND MODEL - SEISMIC INVERSION OF THE WOODFORD SHALE

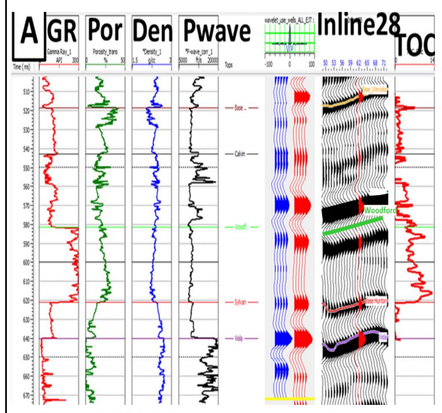


Figure 13. TOC Calculation and seismic tie for Well A using the Passey et al., (1990) method;

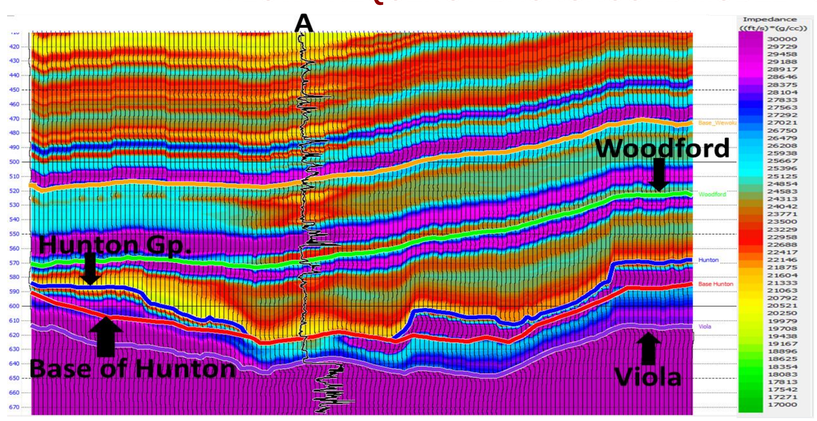


Figure 14. Initial low frequency background model on a crossline passing through well A

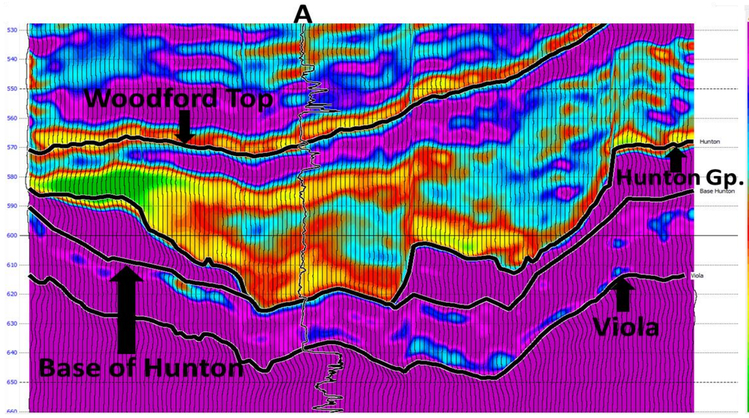


Figure 15. Inversion Zp results in arbitrary impedance line showing well A

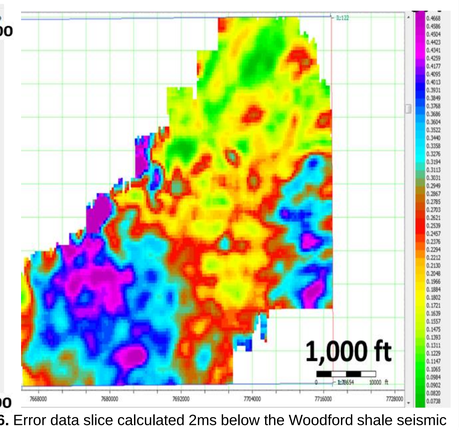
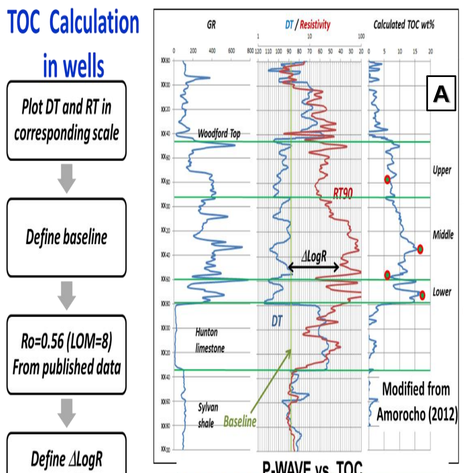
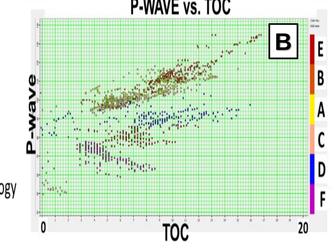
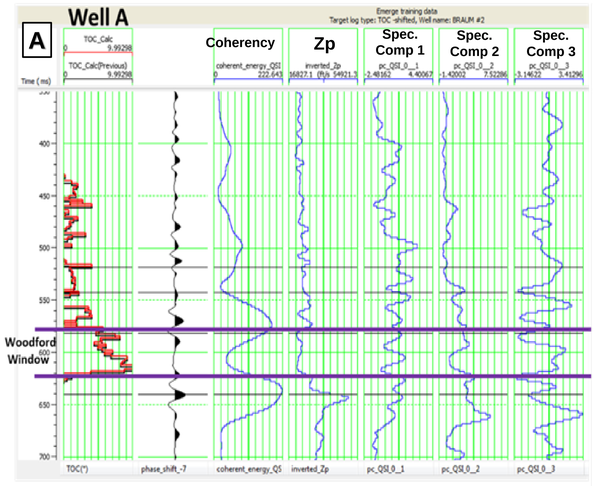


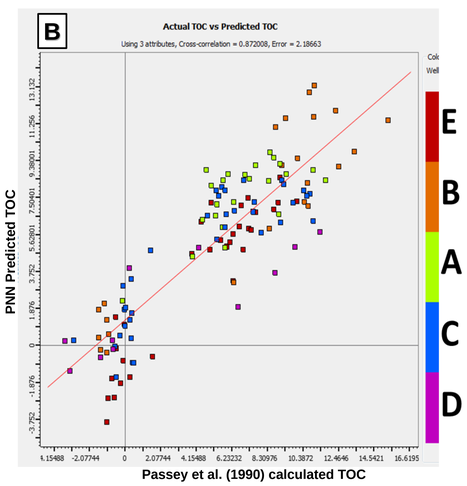
Figure 16. Error data slice calculated 2ms below the Woodford shale seismic horizon.

8. TOC [wt.%] CALCULATION AND PROBABILISTIC NEURAL NETWORK INTERPOLATION









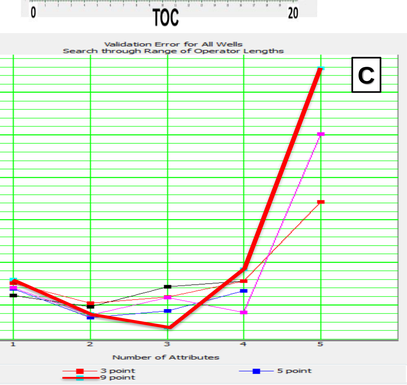
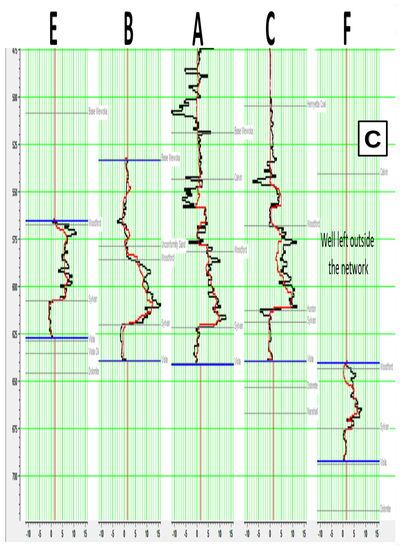


Figure 14. (A) TOC calculation process using Passey et al. (1990) methodology; **(B)** Cross-plot of well calculated TOC and P-Impedance (calculated in all wells); **(C)** Neural network training operator length and attribute selection



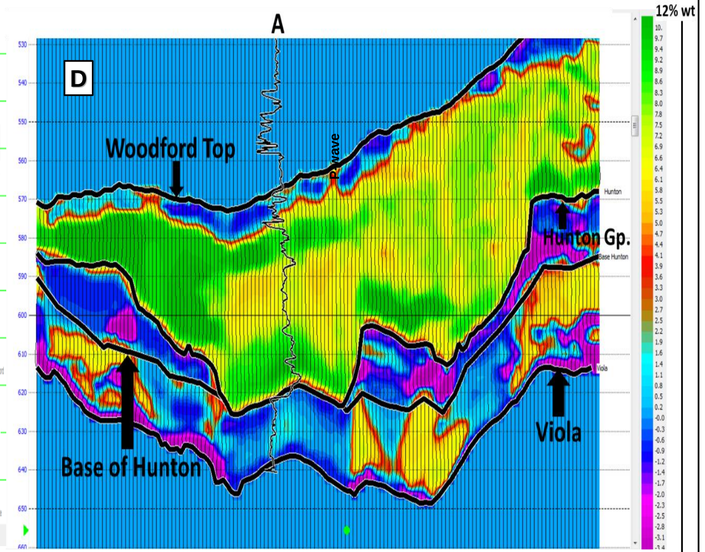


Figure 15. Hampson et al. (2001) methodology**. (A)** Neural Network Training data. TOC (red) with extracted seismic data, Coherent Energy and Zp from Seismic Inversion, Spectral Decompositions Principal Components 1, 2 and 3; **(B)** Multi-attribute regression of actual TOC vs. predicted TOC. Three attributes were used in the regression: Zp, Coherent Energy and Spectral Components. Negative TOC values correspond to the Hunton Group; **(C)** Probabilistic neural network results and QC; **(D)** TOC section along the Woodford Shale Seismic Window.

9. CONCLUSIONS

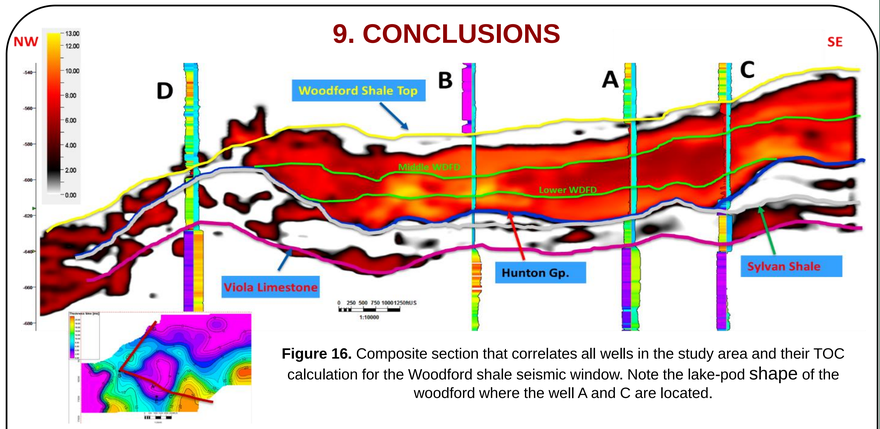


Figure 16. Composite section that correlates all wells in the study area and their TOC calculation for the Woodford shale seismic window. Note the lake-pod shape of the woodford where the well A and C are located.

- The applied methodology that integrates seismic and well log data products as main inputs to the Probabilistic Neural Networks, confirm that the amplitude anomalies and discontinuous reflectors within the Woodford Shale seismic-stratigraphic window correspond to internal lateral and vertical TOC-bearing facies variations.
- The Woodford shale is both thicker and more TOC-rich where the underlying Hunton Group (carbonates) is completely eroded and the topographic relief is high. Seismic analysis at and above the unconformity surface produced by the erosion of the Hunton Group, reveals pod-shaped intervals of high TOC that may have been deposited as a very restricted intervals, thereby providing opportunities for more innovative unconventionals exploration targeting and strategies.

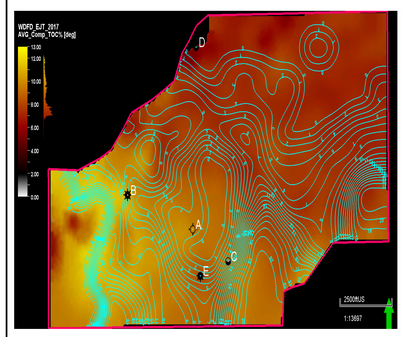


Figure 17. Average TOC map, extracted along the Woodford Shale interpreted section. Contours represent time thickness intervals of the Hunton Gp.

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11. ACKNOWLEDGMENTS

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