PS Analysis and Integration of Well Logs and Ultrasonic Velocities of Productive Facies in the Upper Viola Formation in Southwestern Kansas*

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Abstract

The Ordovician-aged Viola Limestone of southwestern Kansas is a developing carbonate resource play with significant accumulations of hydrocarbons. The Viola surface is an unconformity, and production comes from regions of preserved dolomite on paleo-topographic highs. Evaluation of a cored interval of the upper Viola recognized several distinct facies, which were examined in conjunction with detailed well log analysis and major and trace element concentrations to recognize facies control on Viola production. Cross plots of well log and geochemical data were used to discriminate facies and sequences. Ultrasonic P-wave laboratory measurements and comparison with seismic frequency P-wave velocities were conducted on the same core to understand the potential of seismic attenuation effects and velocity variation in reservoir facies identification.

Seismic amplitude and attenuation characteristics of each Viola facies were determined, with implications for seismic facies interpretation and hydrocarbon prospect evaluation. Because of the high frequency nature of the ultrasonic measurements, differences in elastic properties were compared with sonic logs of borehole with the well-log facies, where core samples were not available. Correlating facies of the core sample to ultrasonic measurements, elemental composition, and well-log characteristics provides a work-flow to explore potential Viola targets using 3D seismic datasets. Due to the thin-bed nature of the Viola reservoir facies, seismic resolution is a problem when generating prospect models. Coupling core analysis, attenuation results, and well log facies, enabled a well-established interpretation of 3D seismic facies. This study illustrates the advantages of correlating depositional facies with reservoir quality and linking specific reservoir petrofacies with well log signatures and seismic attenuation effects, ultimately to create a greater understanding of the controls on reservoir quality to aid in predicting new areas of exploration.

ANALYSIS AND INTEGRATION OF WELL LOGS AND ULTRASONIC VELOCITIES OF PRODUCTIVE FACIES IN THE UPPER VIOLA FORMATION IN SOUTHWESTERN KANSAS

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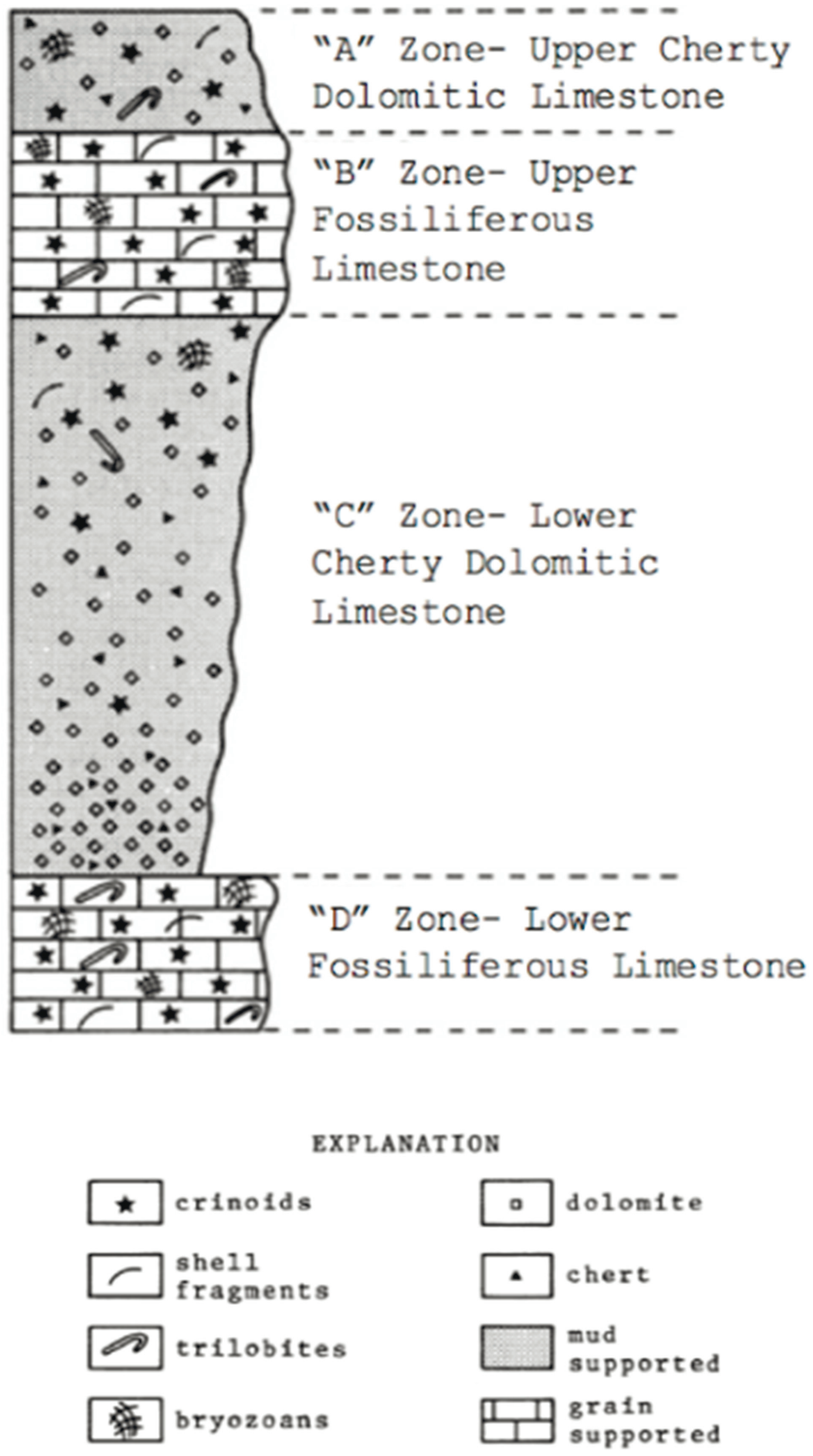
Introduction

This study evaluates a producing well in the Herd field of Comanche County, KS (Rich C-7). Three distinct dolomitic facies, named the A, B, and C zones (Richardson, 2013). Each zone can be recognized by their characteristic well log signatures, and distinct petrology. Laboratory measurements of ultrasonic velocities of well cores show an agreement with each of the well log facies. The control of rock properties on reservoir quality could ultimately result in the identification of these productive facies using seismic attributes. This study illustrates the advantages of correlating rock properties measured by well log signatures, and petrographic study with the corresponding elastic properties of core.

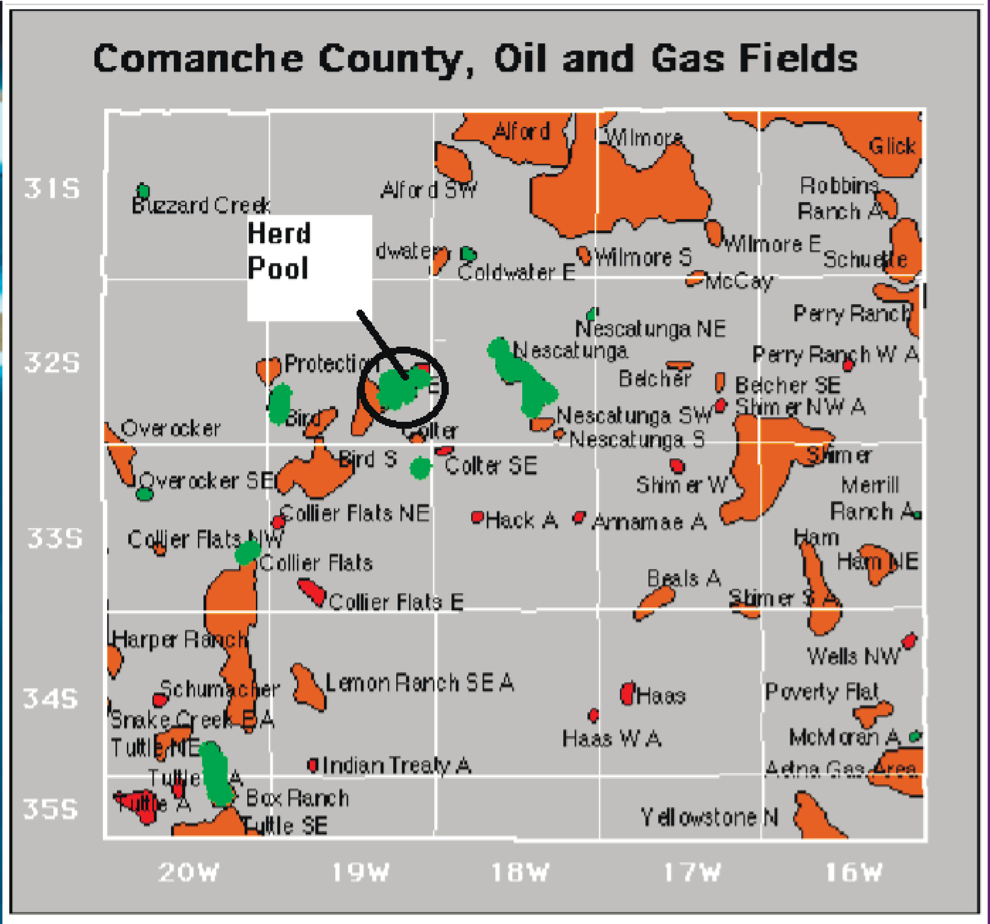
Viola Limestone

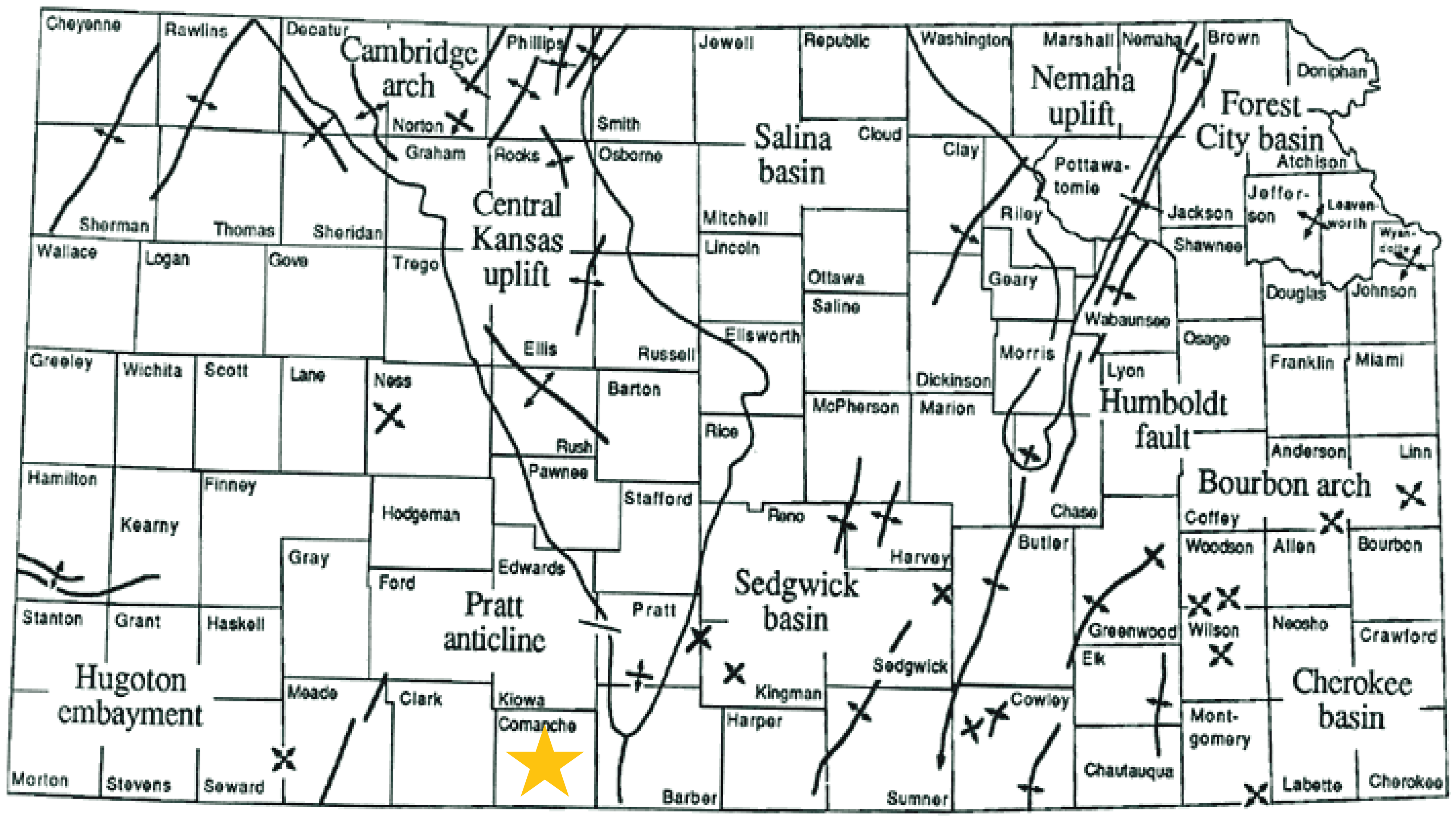
Shallow epicontinental seas covered most of Kansas during the Ordovician period. This resulted in a sequence of shallow-marine limestones, dolomites, and cherty dolomites that comprise the Viola formation. The dolomite zones in the upper Viola are ideal reservoir rocks, unlike most of the limestone in the Viola, which does not typically produce. Paleo-topographic high areas of the Viola can trap significant amounts of hydrocarbons in southwestern Kansas (Richardson, 2013).

Time Stratigraphic Units: SYS-TEM	Series	Rock-Stratigraphic Units: Based on correlation with surface sections (Kansas Geol. Survey Bull. 189)	Lithology	Based on common usage by Kansas petroleum geologists and used in this report
ORDOVICIAN	Upper	Maquoketa Shale		Maquoketa Shale
	Middle	Viola Limestone		Viola Limestone
		Simpson Group		Simpson Group
	Lower	Arbuckle Group		"Arbuckle" Group
CAMBRIAN	Upper	Bonneterre Dolomite		
		Lamotte Sandstone		
Precambrian		Precambrian		Precambrian



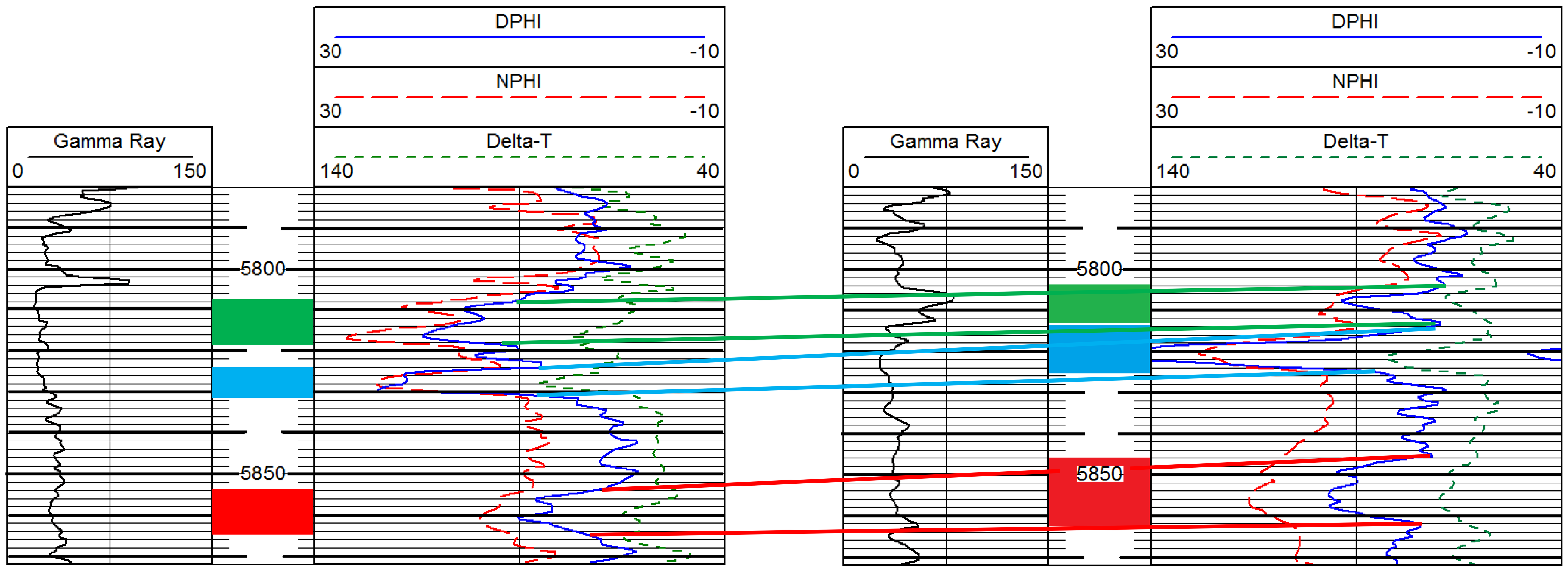
Study Area

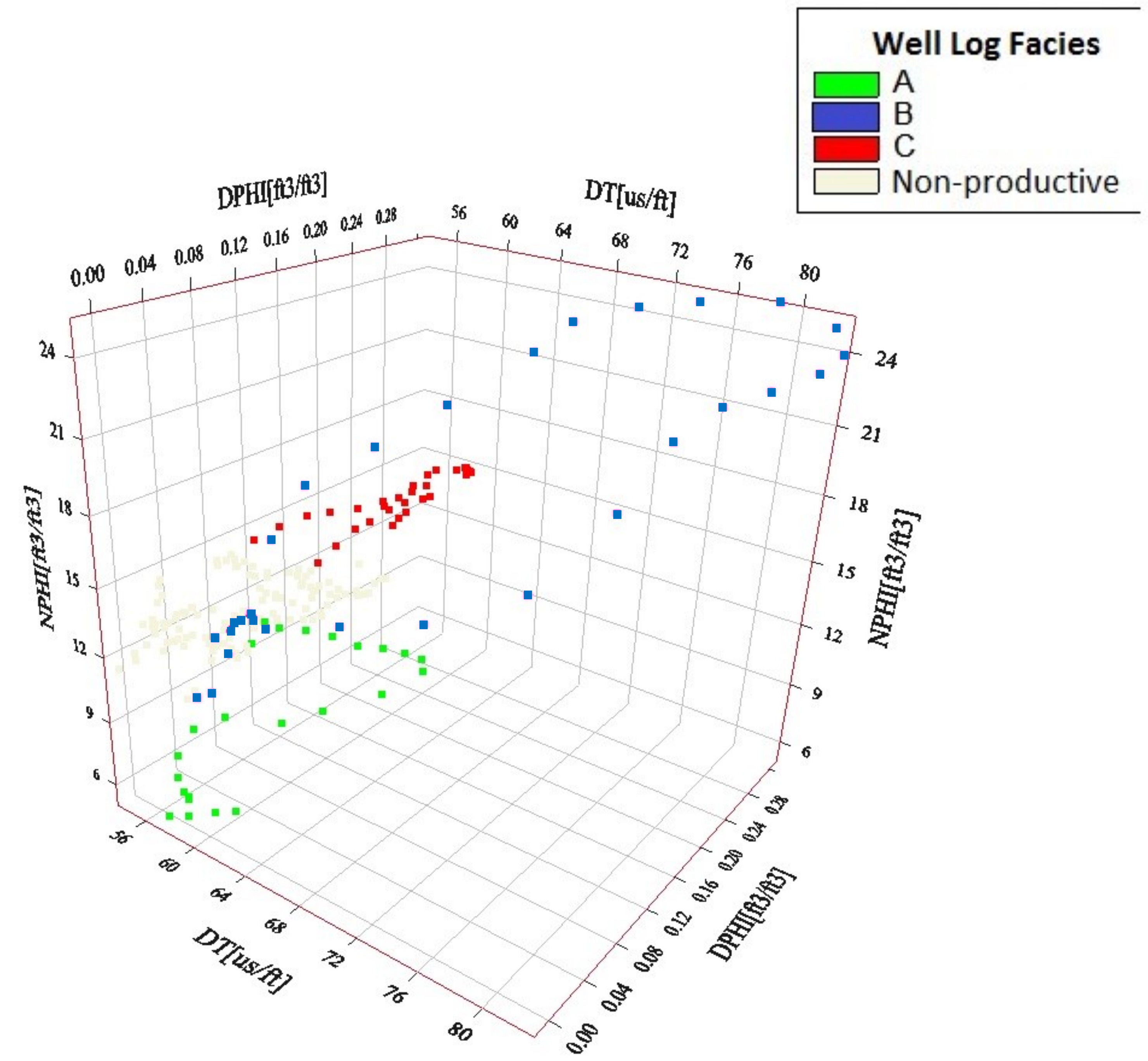




To the left is an idealized cross section of a paleotopographic trap, orientated North-South across the Herd Field, which includes the study well, Rich C-7, (Vohs, 2017). The paleotopgraphic highs preserved the dolomitic reservoir facies

Well Log Signatures of Productive Zones





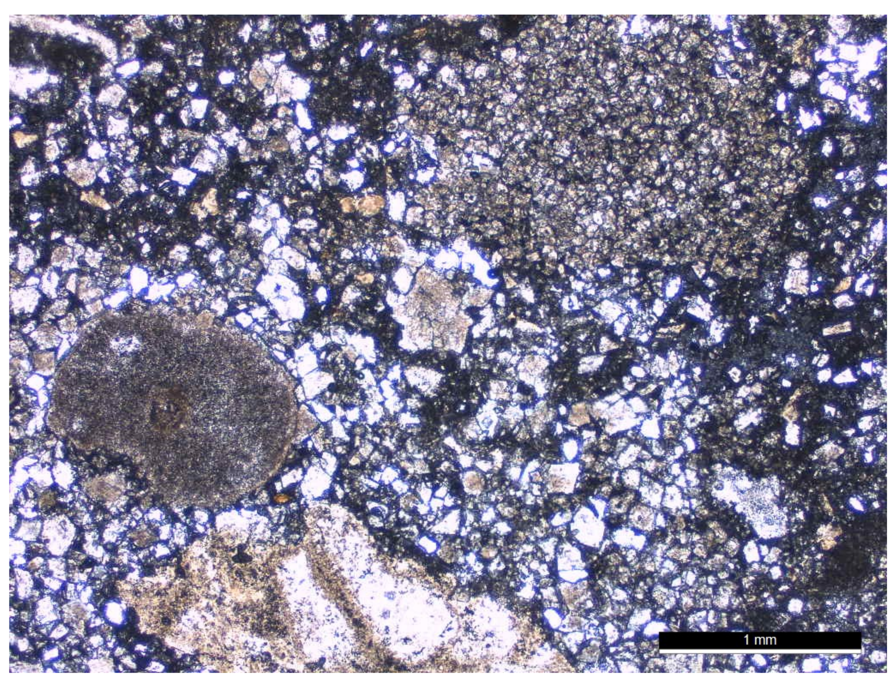
Compensated Density Neutron PE logs of the Herd 1 (left) and Rich C-7 (right) wells. The A, B, and C zones have DPHI and NPHI well log signatures that discriminate them into separate zones. The correlation between the A, B, and C zones between the two wells can be seen here. The A and B zones typically produce in this area (Richardson 2013).

3-D cross plot of Density porosity (DPHI), Neutron porosity (NPHI), and Delta Time (DT). The A (green), B (blue), and C (red) zones are discriminated from this cross plot.

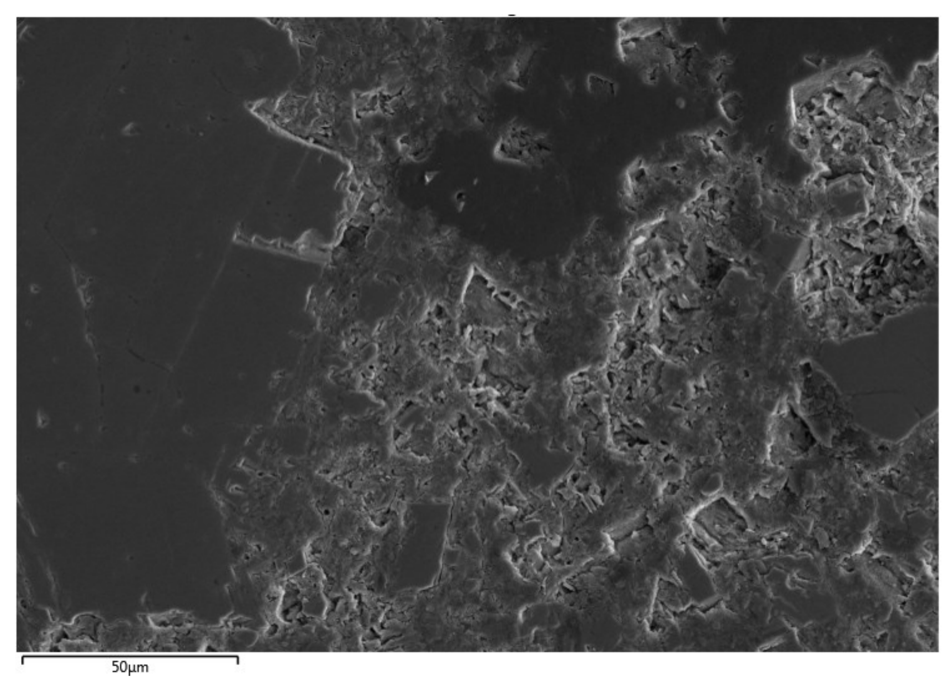
Petrographic Analysis

A Zone

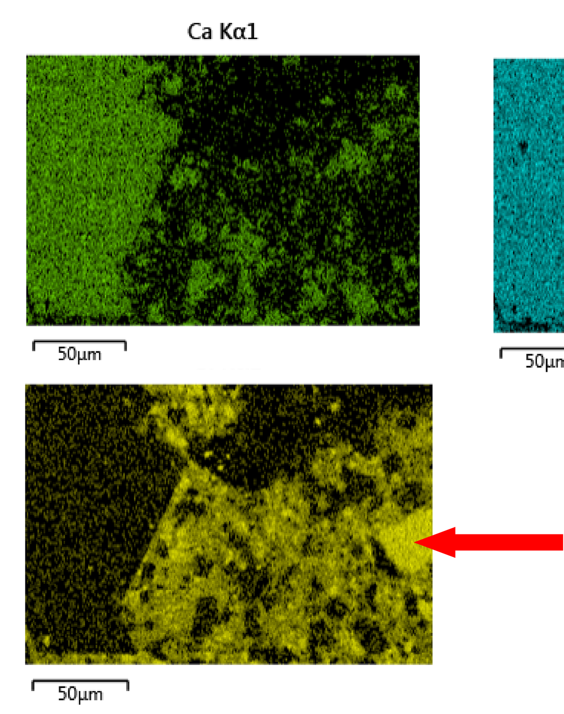
Core piece located near the bottom of the A Zone.



Photomicrograph of Rudstone taken from pictured core piece that is located near the bottom of the A Zone. 7-10% visible porosity seen throughout the entire slide.

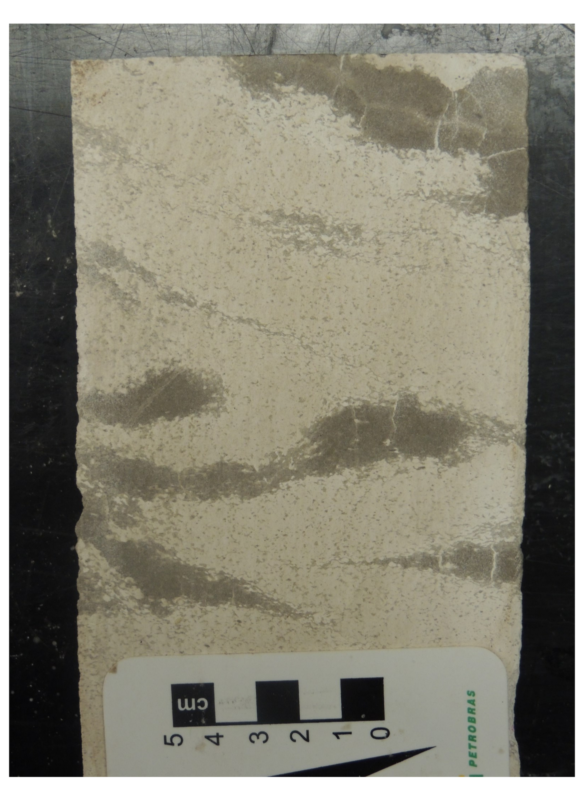


SEM (Everhart-Thornley detector [ETD]) image taken from microscope slide located near the bottom of the A Zone .

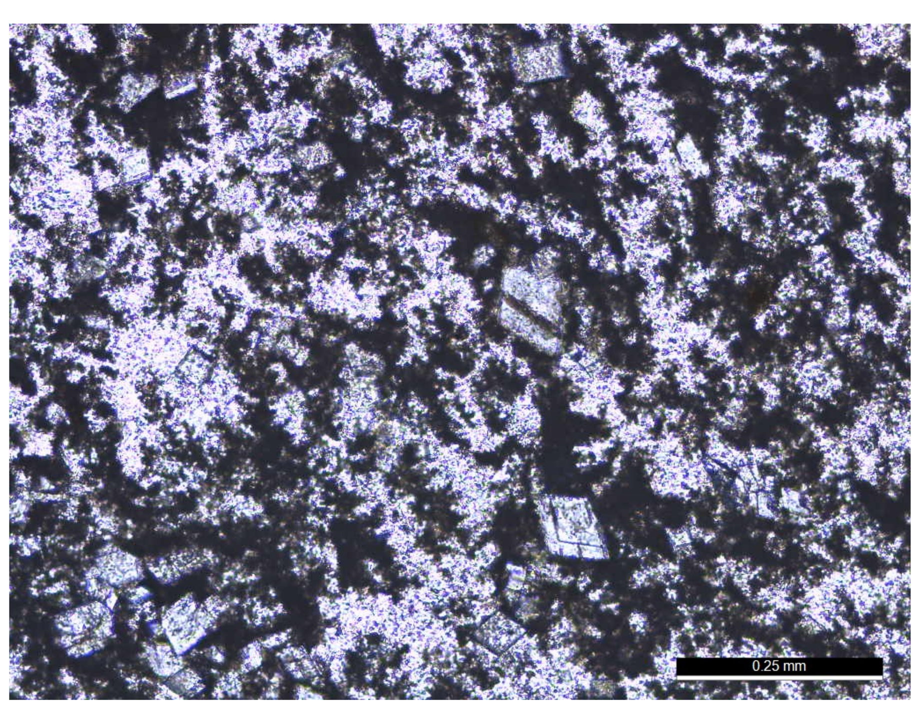


The Si EDS map approximates the distribution of chert, the combination of the Ca and Mg EDS maps approximates the distribution of dolomite, and the Ca EDS map by itself approximates the distribution of calcite. A chert clast is shown above by the red arrow.

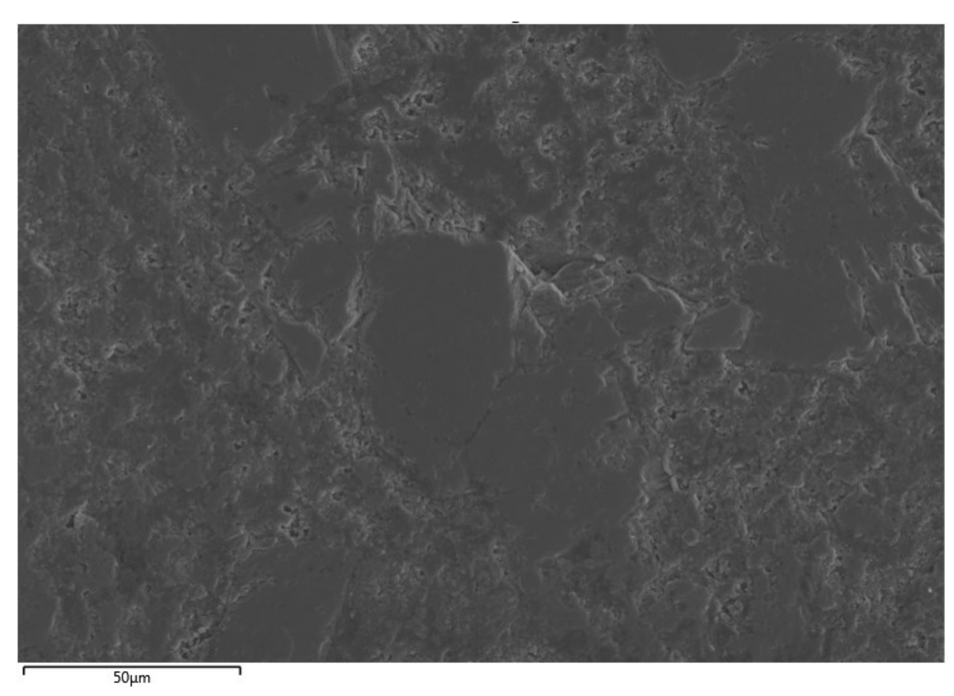
B Zone



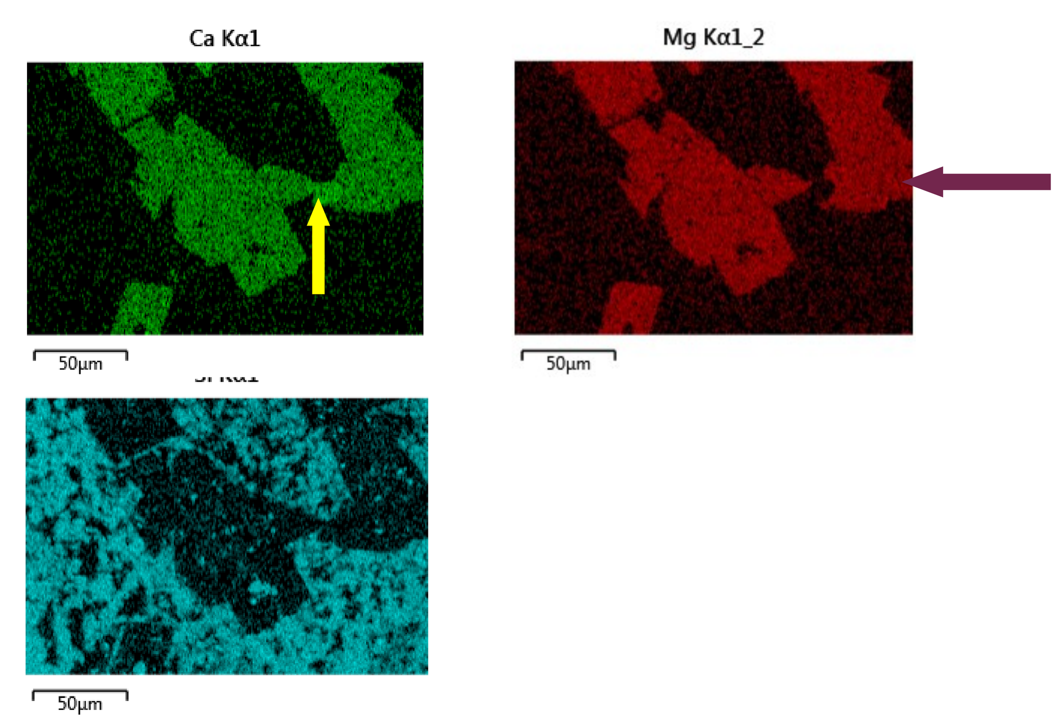
Core piece located near peak log porosity in the B Zone.



Photomicrograph of Cherty dolomite taken from pictured core piece that is located near peak log porosity in the B Zone. 25-30% visible porosity seen throughout the entire slide.



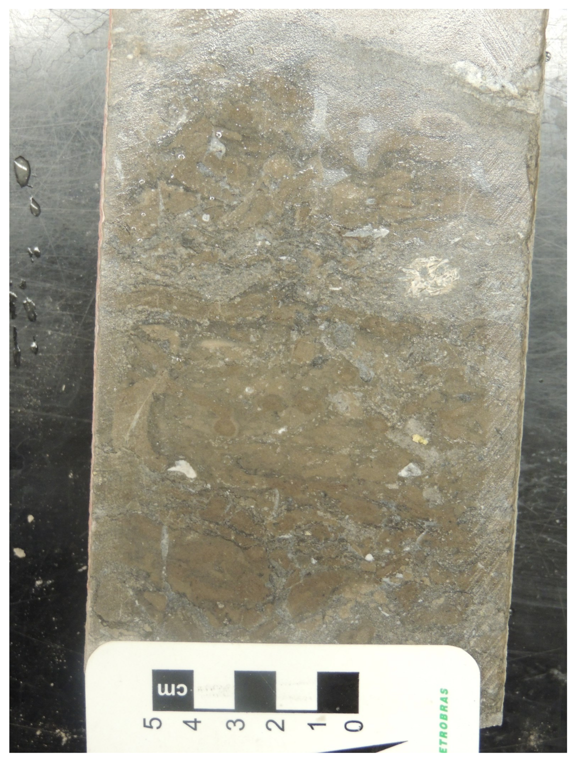
SEM (ETD) image taken from microscope slide located near peak log porosity in the B Zone.



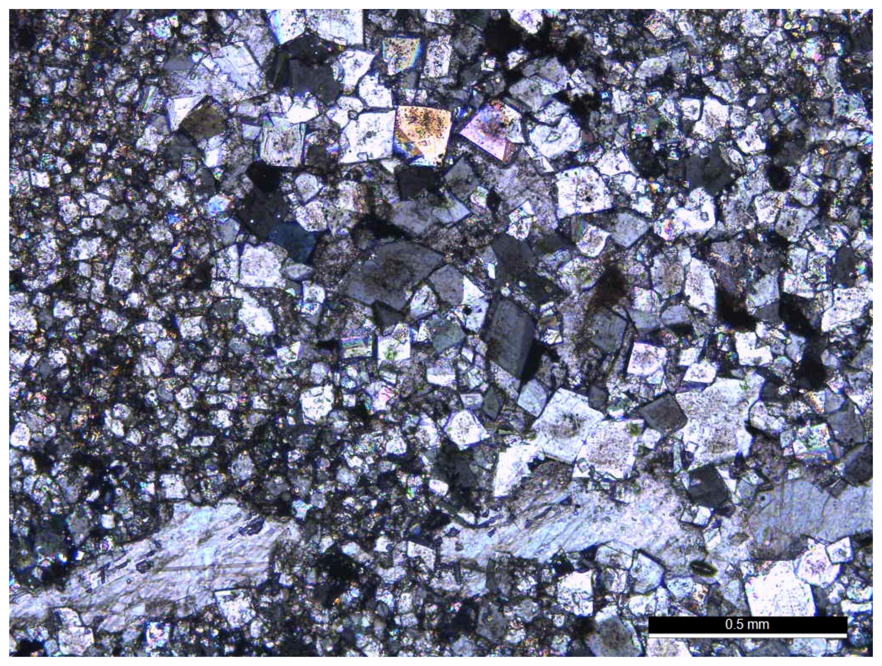
The Si EDS map approximates the distribution of chert, the combination of the Ca and Mg EDS maps approximates the distribution of dolomite, and the Ca EDS map by itself approximates the distribution of calcite. A calcite crystal is shown above by the yellow arrow, and a dolomite crystal is shown by the purple arrow.

Petrographic Analysis

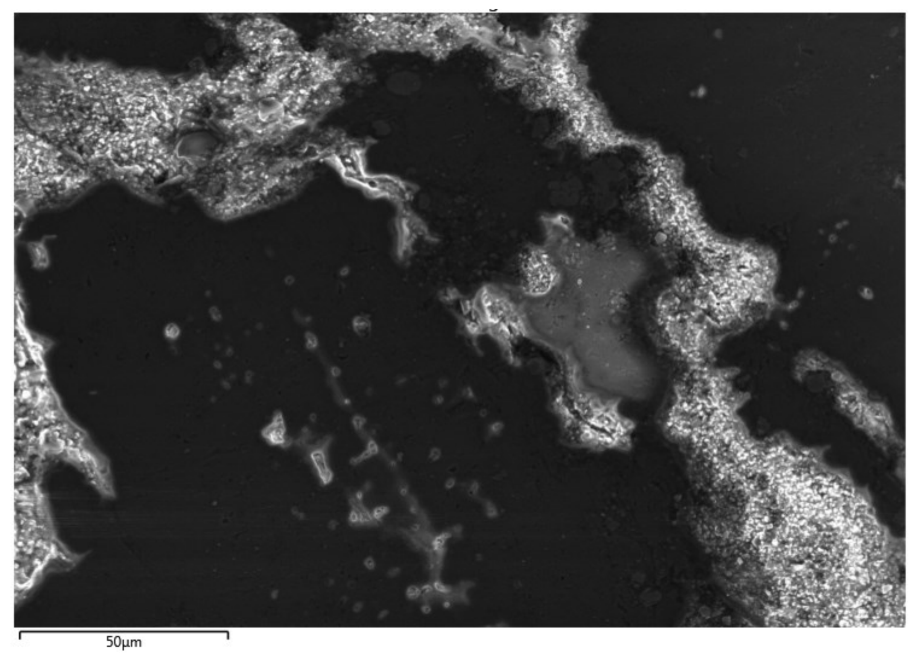
Between B and C Zone



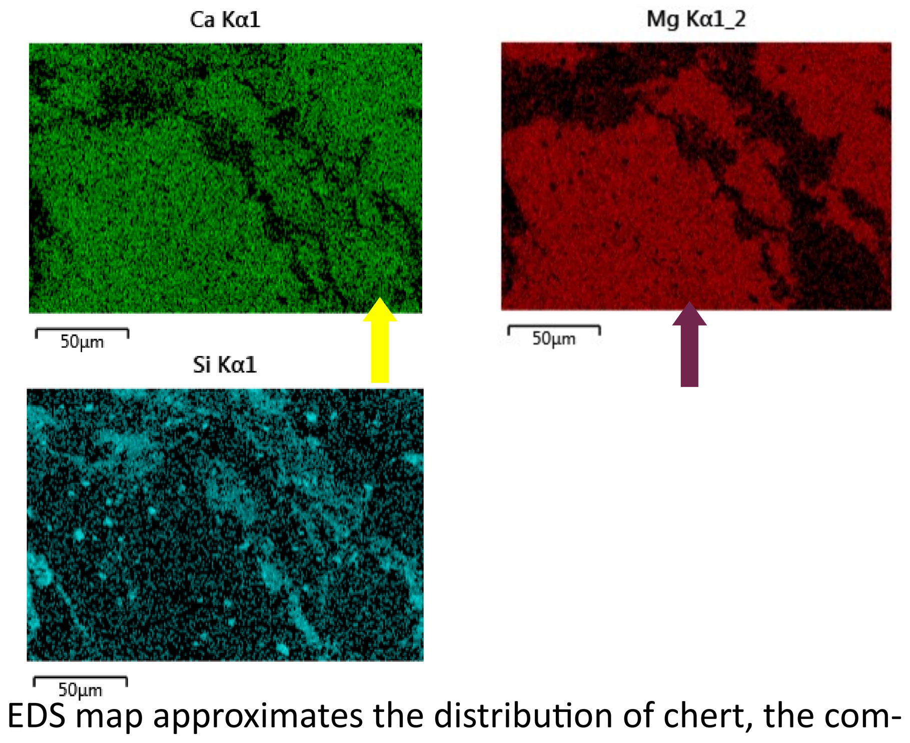
Core piece located between the B and C Zone.



Photomicrograph of Rudstone taken from pictured core piece that is located between the B and C Zone. 5-10% visible porosity seen throughout the entire slide.

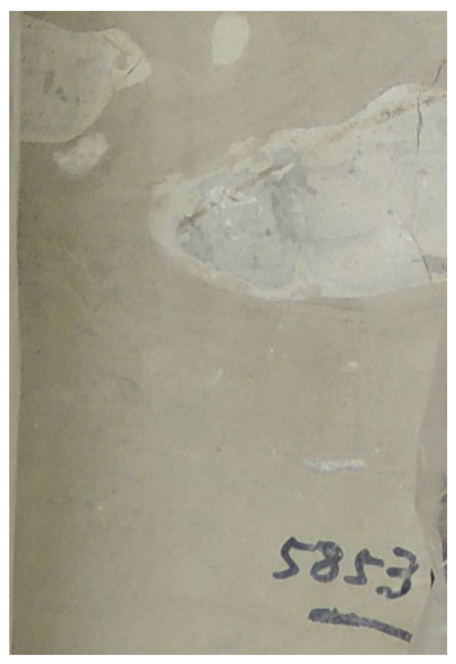


SEM (ETD) image taken from microscope slide located between the B and C zone .

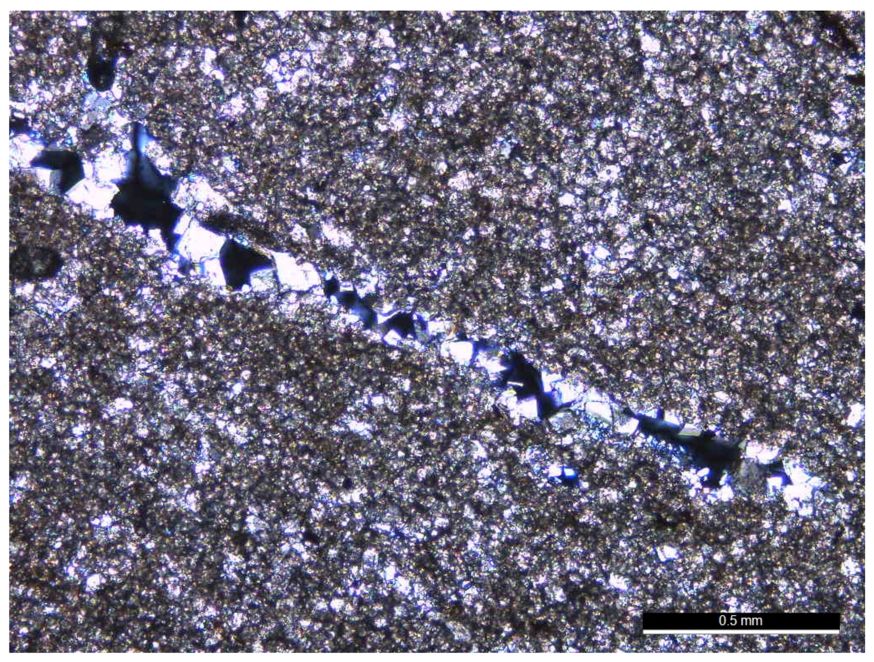


The Si EDS map approximates the distribution of chert, the combination of the Ca and Mg EDS maps approximates the distribution of dolomite, and the Ca EDS map by itself approximates the distribution of calcite. A vein of calcite is show by the yellow arrow, and the surrounding dolomite is show by the purple arrow.

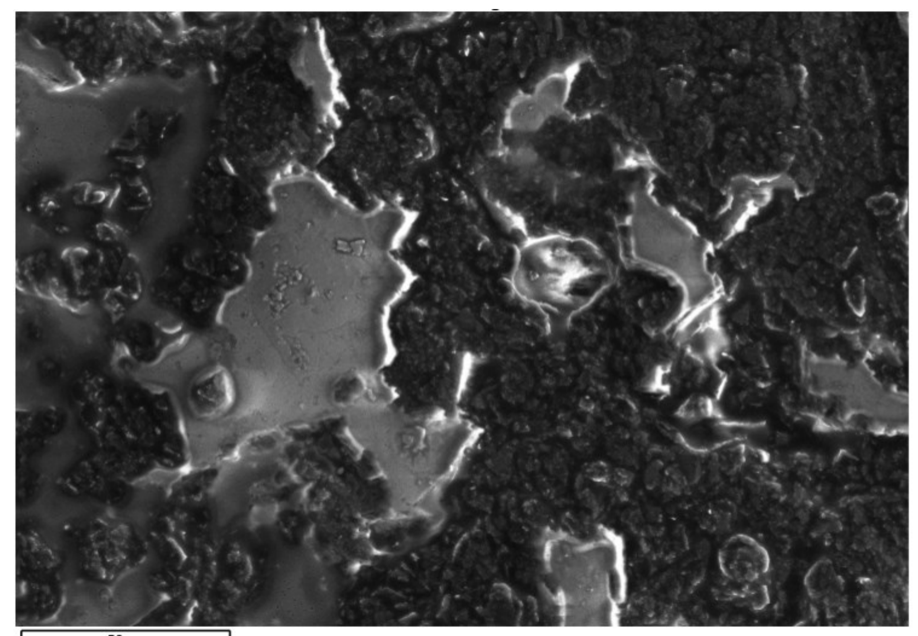
C Zone



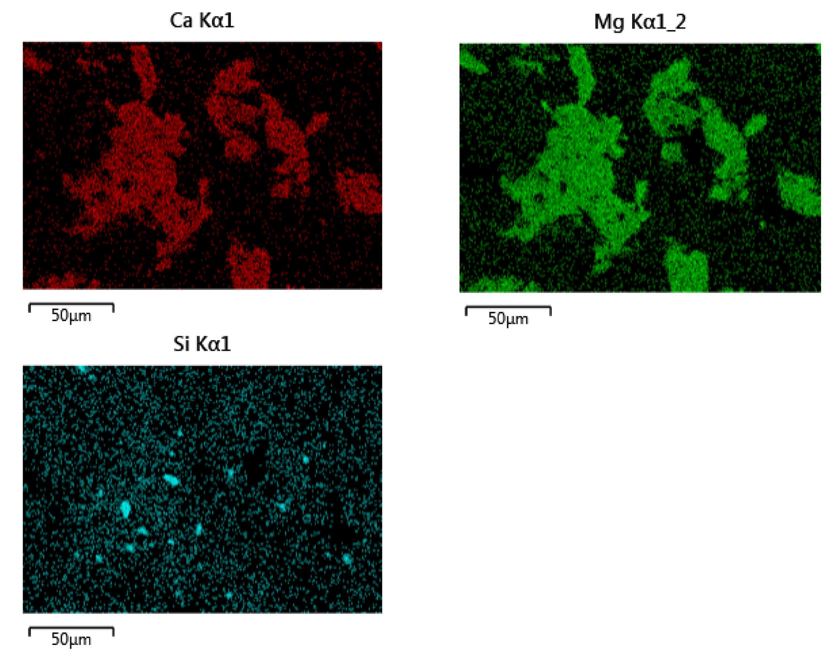
Core piece located near peak log porosity in the C Zone.



Photomicrograph of Muddy dolostone taken from pictured core piece that is located near peak log porosity in the C Zone. 7-10% visible porosity seen throughout the entire slide.

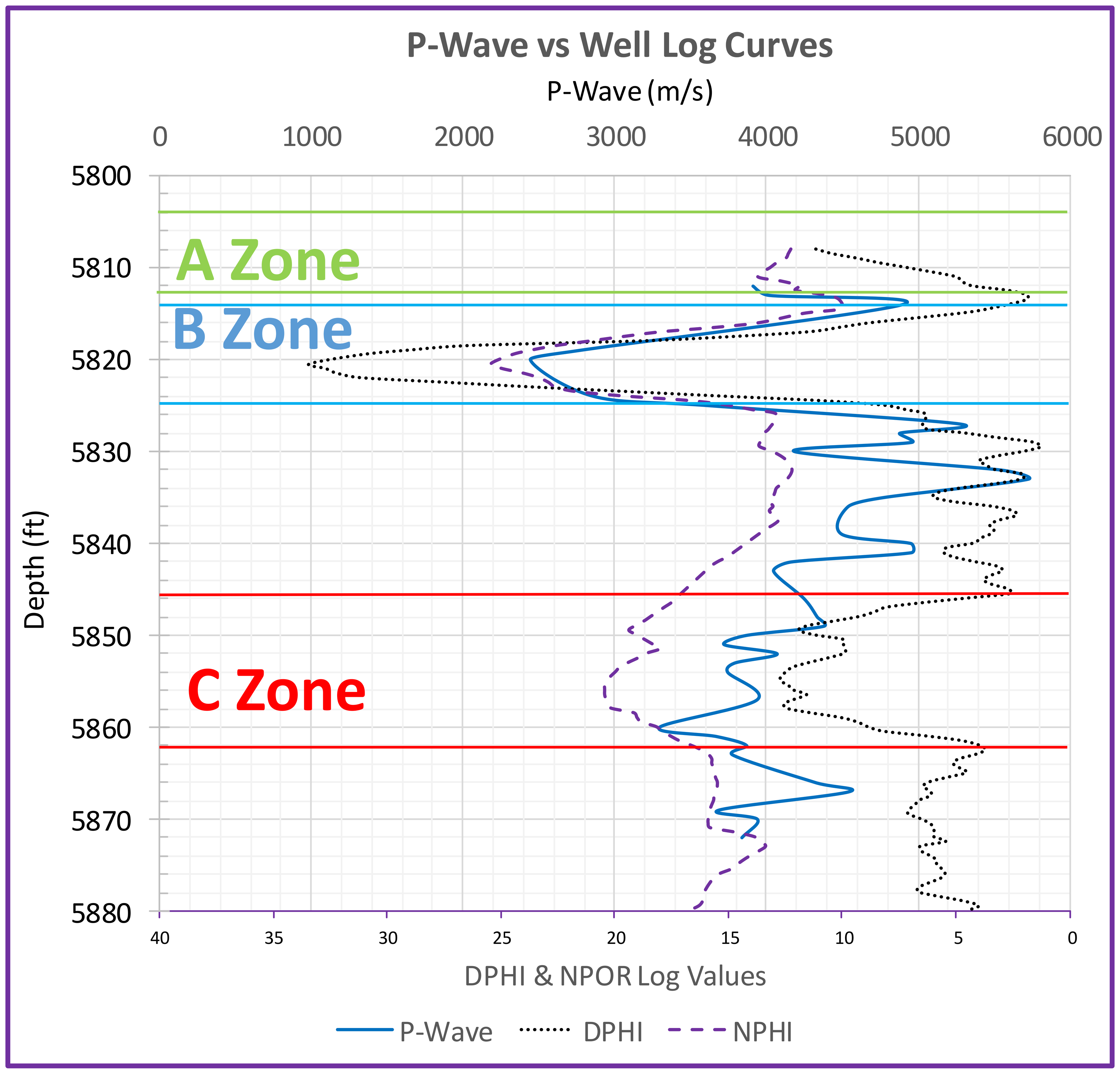


SEM (ETD) image taken from microscope slide located near peak log porosity in the C Zone.

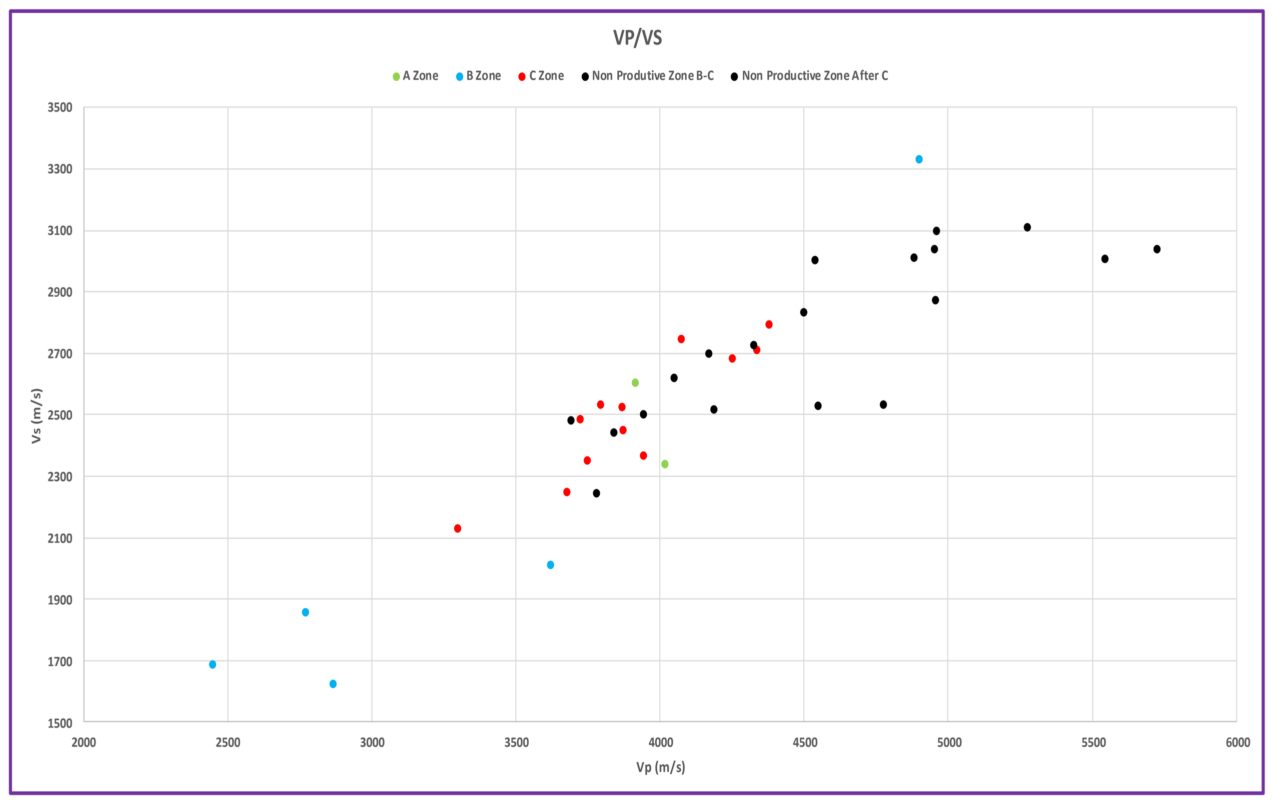


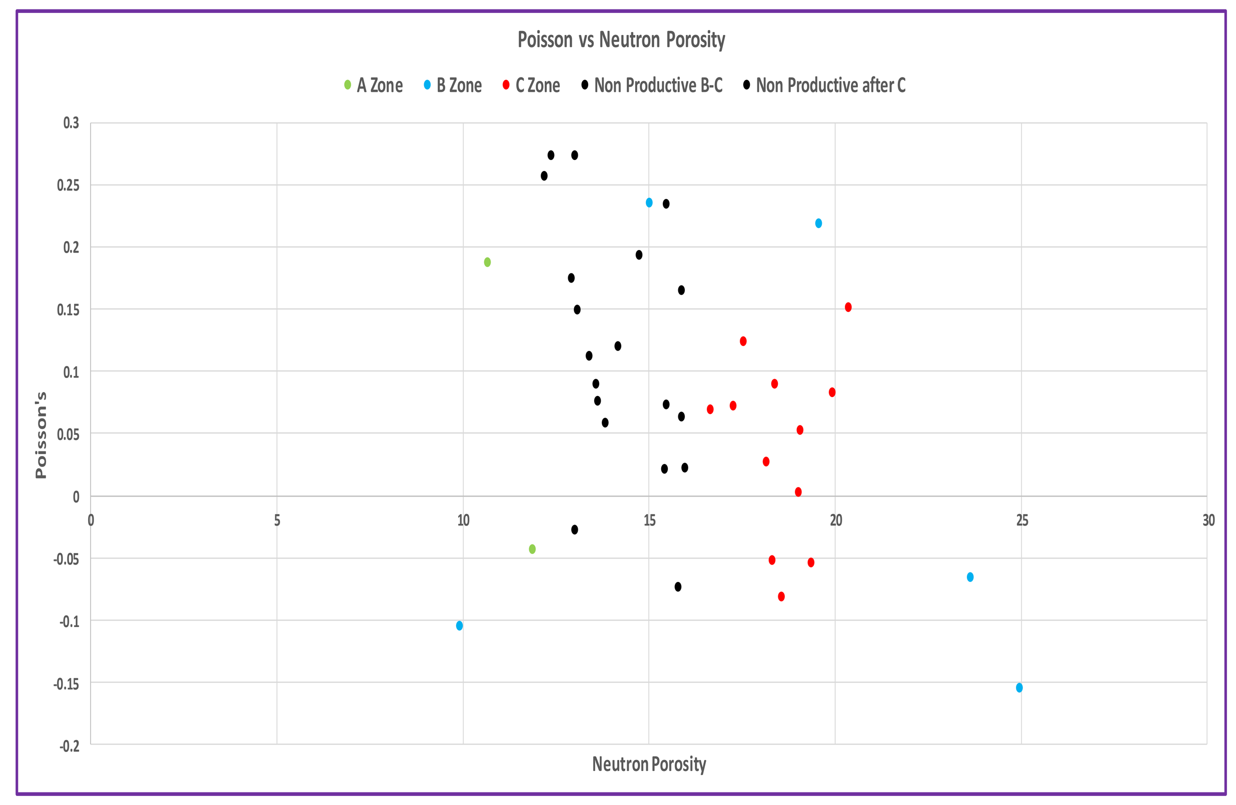
The Si EDS map approximates the distribution of chert, the combination of the Ca and Mg EDS maps approximates the distribution of dolomite, and the Ca EDS map by itself approximates the distribution of calcite.

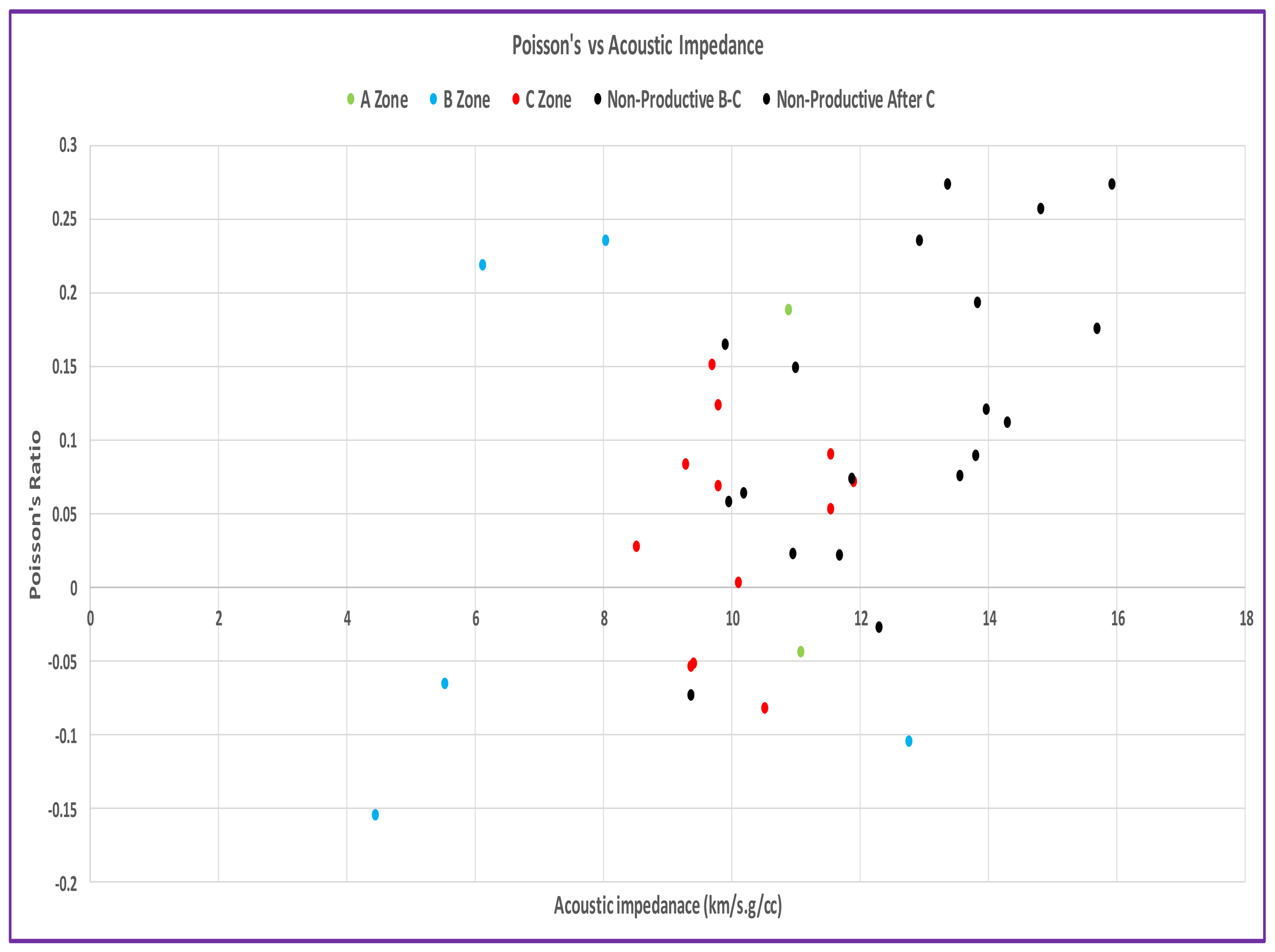
Productive Zone to Elastic Properties Correlation

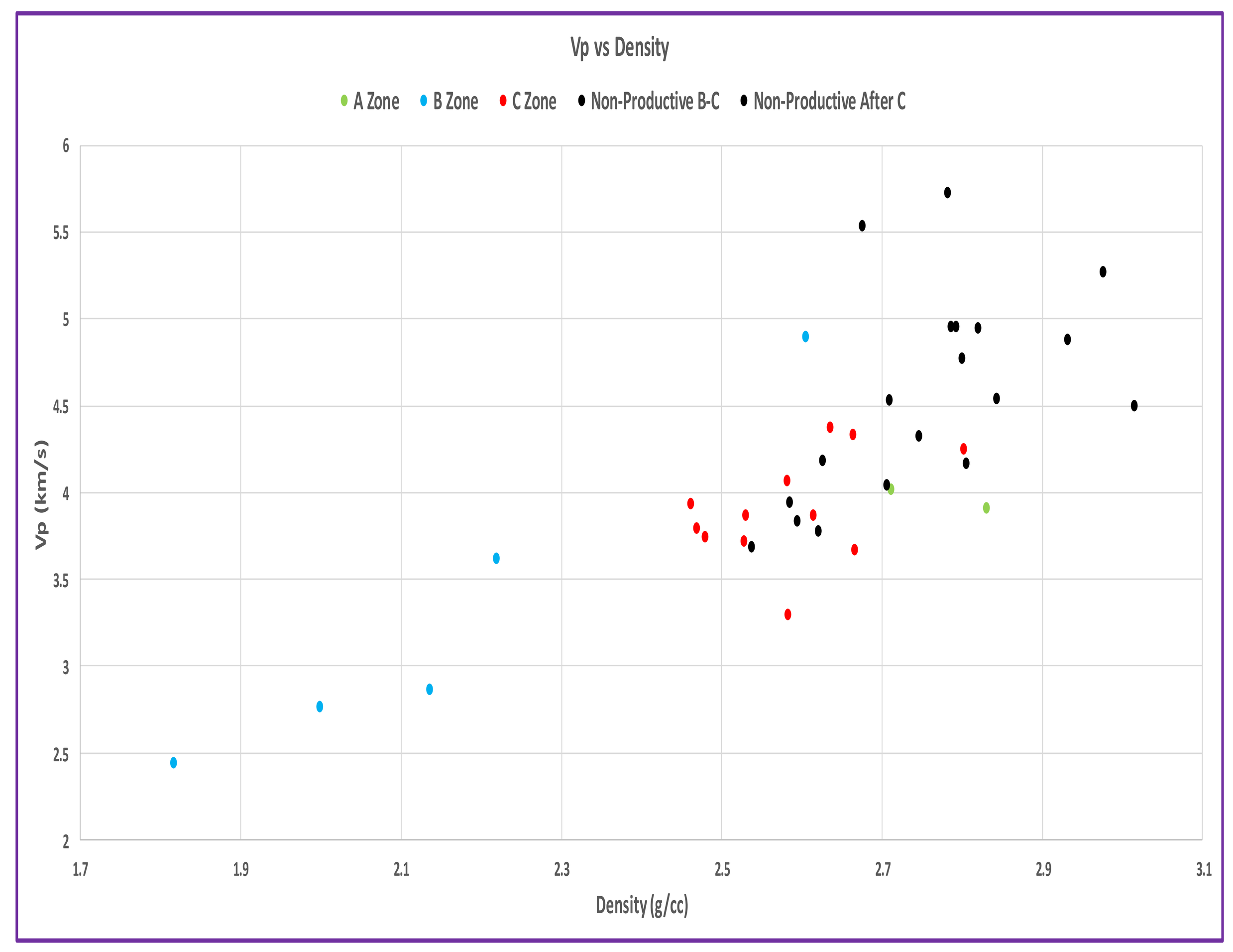


The figure above is a stacked graph including Neutron Porosity, Density Porosity, and lab measured P-Wave velocity of a core from the Rich C-7 well. Lab measurements of the Rich C-7 core were done to identify P & S-wave velocities at specific depth intervals from the base of the Viola A zone to the base of the Viola B zone. The stacked curves show that P-Wave velocity directly correlates with production zones such as the A, B, and C zones.



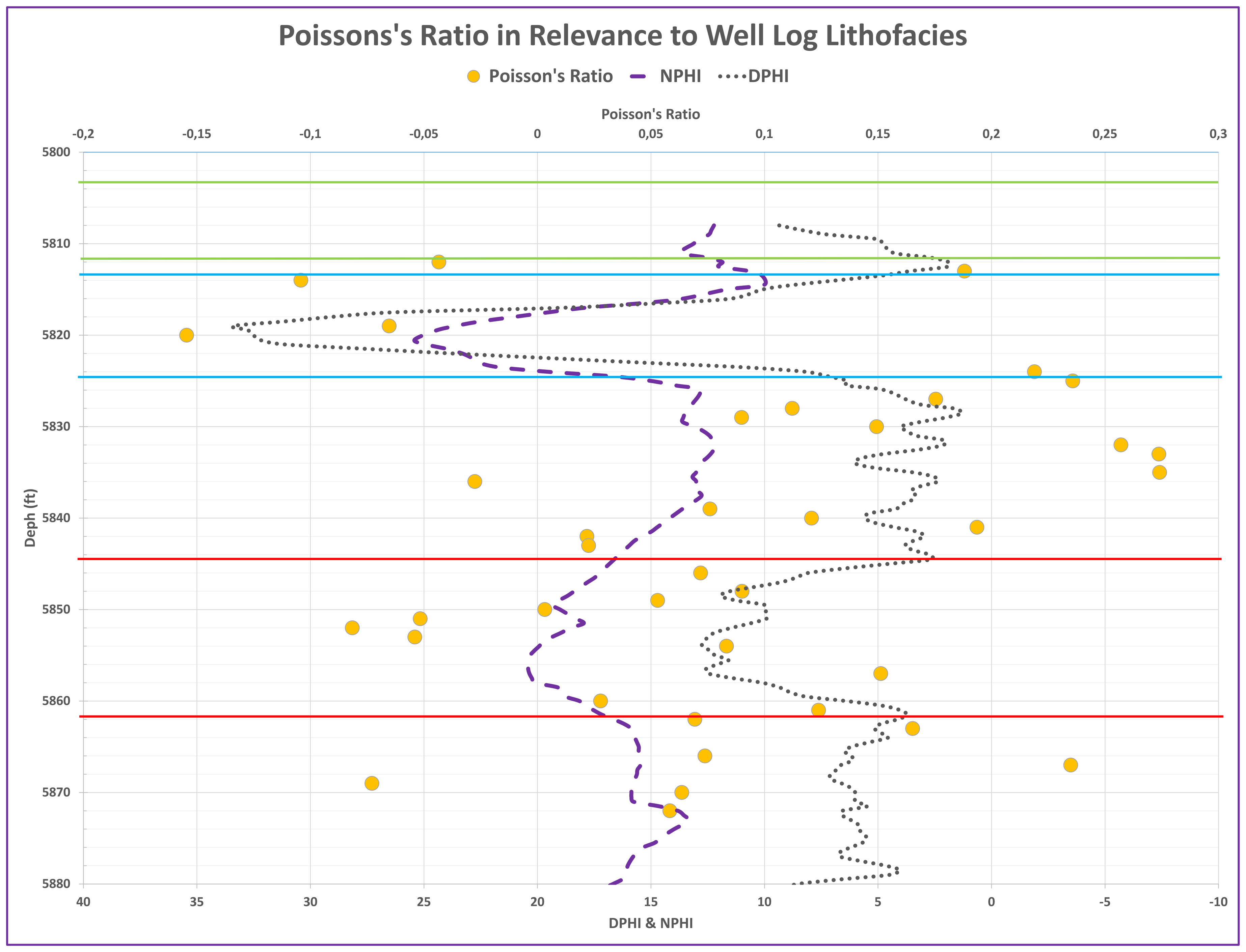






The follow figures above were made using well log properties and lab based measurements. Each zone was color coded to distinguish the different well log facies. Figure 1 in the top left is a Vp/Vs relationship identifying lithology. Figure 2 in the upper right is a cross plot of Poisson's ratio and the Neutron Porosity well log. The negative values seen in Poisson's ratio correlate with the onset of productivity in the B zone, high porosity in the C zone, and the conclusion of the A zone. All three well log facies can be determined. Figure 3 on bottom left indicates Poisson's ratio to acoustic impedance. The A and C zone can be distinguished while the B zone has a bell curve nature similar to Figure 2. Figure 4 is in the bottom right and clearly identifies the three well log facies when using P-wave velocity and density.

Productive Zone to Elastic Properties Correlation



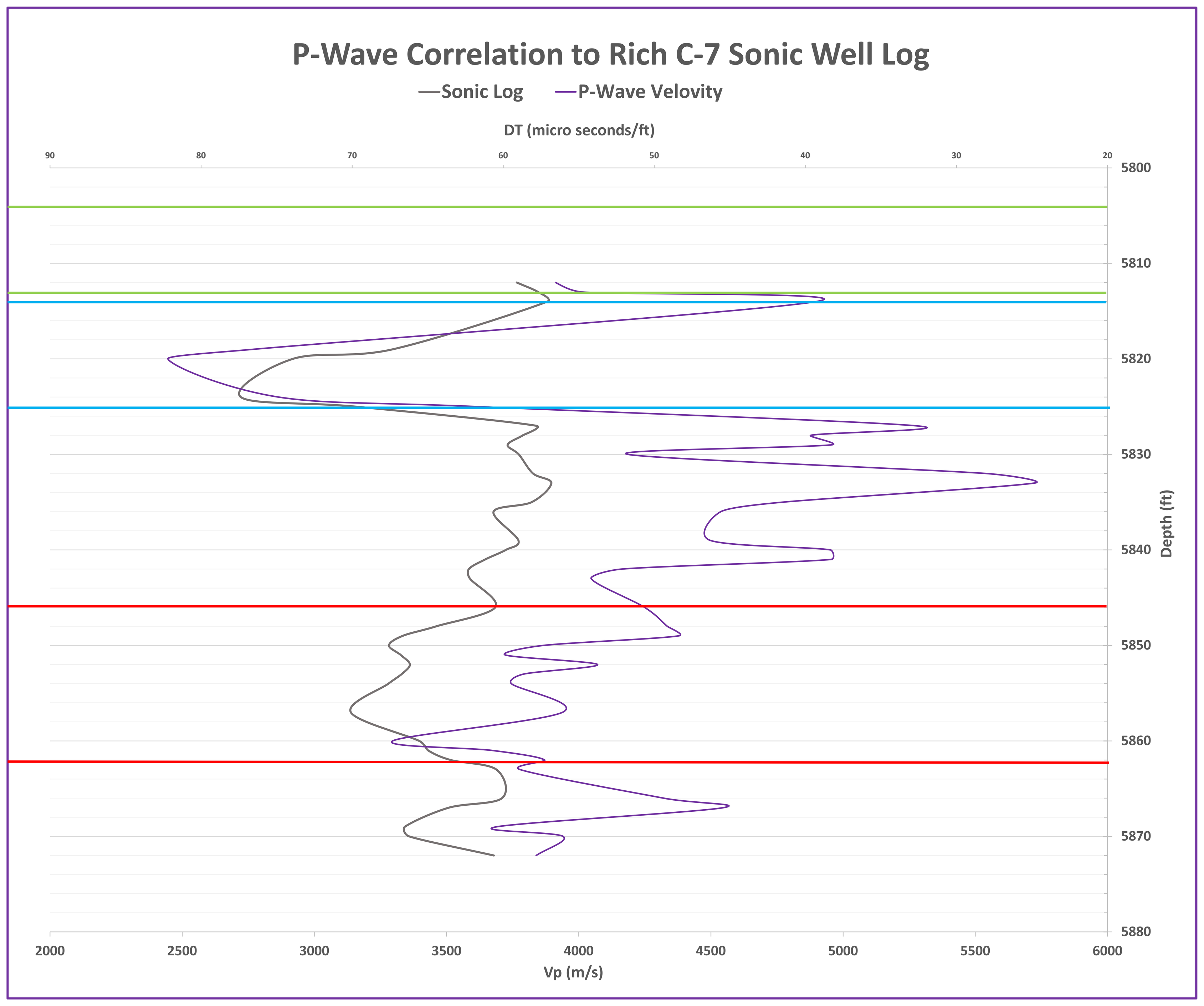
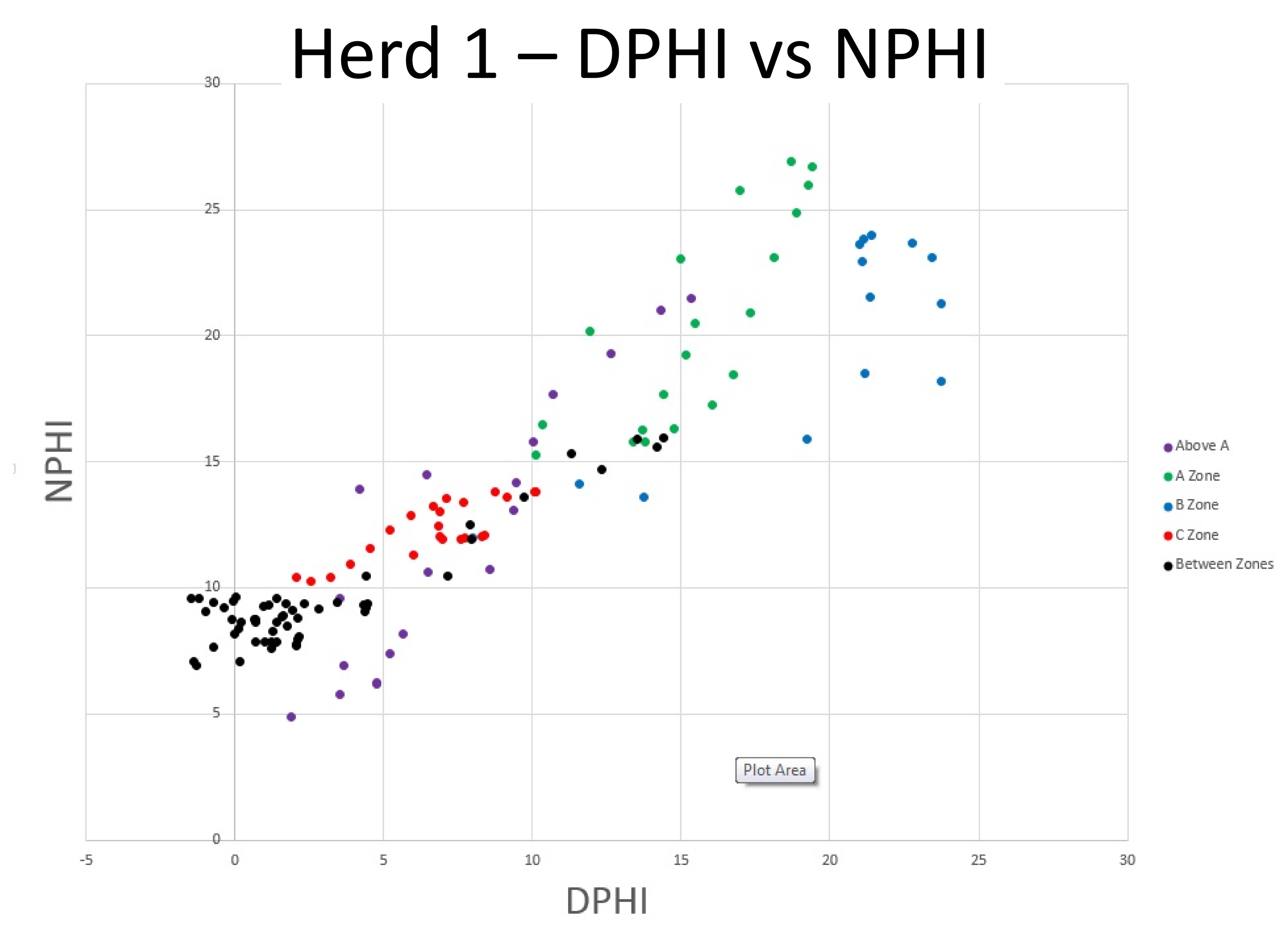


Figure 2 (left) shows the relationship between P-wave velocities and the Sonic log of Rich C-7. Within the zones of interest, a relationship can be seen between the two curves. Where velocity slows within the sonic log so does P-wave velocity from core measurement. Thus, providing an analogue during exploration when identifying the Viola A, B, and C zone respectfully within a seismic survey. Presence and thickness of each zone can be successfully tracked and mapped within a seismic survey due to this relationship. As seen in the previous crossplot of acoustic impedance and density, different seismic properties may be used to identify homogeneity of each zone throughout the formation.

Figure 1 (above) depicts both Neutron Porosity and Density Porosity well log curves compared to Poisson's ratio. There are instances where Poisson's ratio appears to be negative based upon lab measurements of Vp and Vs. These negative values appear during the offset of the A Zone, onset of the B zone, and within the C zone. These characteristics could establish areas where production potential is very high within each zone respectfully. Further research should be conducted on available drill cores in the surrounding area of the Viola formation. If this trend is homogenous within other cores, then Poisson's ratio could be an effective parameter when establishing production zones within the Viola A, B, and C zones. Such properties may also provide insight during seismic exploration in identifying zones of production within the formation.

The ULT 100 Ultrasonic Velocity Measurement System was used in this study to measure the P and S wave velocities of the Rich C-7 core at 44 specific depths. Each samples was measured for density and height before undergoing velocity testing. Pressure was applied from 1000 lbs to 10,000 lbs to identify first arrival times as pressure increased. First arrival times taken at 10,000 lbs of force were used in this study to determine P and S wave velocities. The samples were measured dry and there is no presence of dispersion. Values used were taken at 1.25 MHz.

Productive Zone to Elastic Properties Correlation



A crossplot of DPHI vs NPHI from the Herd 1 well. The A, B, and C zone points have close groupings that discriminate the zones. Wells in the Herd field with similar well log signatures could have correlations to the ultrasonic velocities and elastic properties. A similar study may be replicated within the Herd field with objectives of identifying production potential within the Viola formation for hydrocarbon exploration. Through seismic exploration, the Viola A, B, and C zones can be discriminated and mapped across the formation for production potential along with which hydrocarbon presence can be identified using elastic properties and further analysis with Gassmann's fluid replacement modeling.

Conclusions

- **Well log signatures can discriminate the productive zones of the Viola formation in the region around the Herd field in Comanche county, KS**
- **P-Wave velocities are seen to correlate with well log values within the productive zones of the Viola A, B, and C zones.**
- **Elastic properties discriminate each zone respectfully, indicating changes in lithology and porosity.**
- **Results may identify distinct Viola zones along with production potential during seismic exploration.**
- **Lithofacies and hydrocarbon presence may be identified within seismic surveys.**
- **Further research may propose prediction workflows to be used during seismic exploration.**

Acknowledgements

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