PS Characterizing a Mississippian Carbonate Reservoir for CO_2-EOR and Carbon Sequestration: Applicability of Existing Rock Physics Models and Implications to Feasibility of Time Lapse Monitoring Programs in the Wellington Oil Field, Sumner County, Kansas*

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Abstract

This study will characterize subsurface rock units of the Wellington Field in Sumner County, Kansas for both geosequestration of CO_2 in the saline Arbuckle Group and enhanced oil recovery of a Mississippian oil reservoir. Multiscale data including lithofacies core samples, digital rock physics scans, well log data and 3D seismic techniques will be integrated to establish or validate a new or existing rock physics model that best represents our reservoir rock characteristics. We will acquire P-wave and S-wave velocity data from core samples by running ultrasonic tests and compare them to sonic and dipole sonic log data from the Wellington 1-32 well. The elastic constants Young's Modulus, Bulk Modulus, Shear Modulus and Poisson's Ratio will also be extracted. These data will be integrated to validate a lithofacies classification statistical model which will be applied to the largely unknown Arbuckle Group with hopes for a connection, perhaps through Poisson's Ratio, allowing a time-lapse seismic feasibility assessment and potentially developing a transformation of P-wave sonic velocities to S-wave dipole sonic for all wells. We will also be testing our rock physics model by predicting effects of changing effective fluid composition on seismic properties and the implications on feasibility of seismic monitoring. Lessons learned from characterizing the Mississippian are essential to understanding the potential of utilizing similar workflows for the Arbuckle aquifer.

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CHARACTERIZING A MISSISSIPPIAN CARBONATE RESERVOIR FOR CO2-EOR AND CARBON GEOSEQUESTRATION: APPLICABILITY OF EXISTING ROCK PHYSICS MODELS AND IMPLICATIONS FOR FEASIBILITY OF A TIME LAPSE MONITORING PROGRAM IN THE WELLINGTON OIL FIELD, SUMNER COUNTY, KANSAS.

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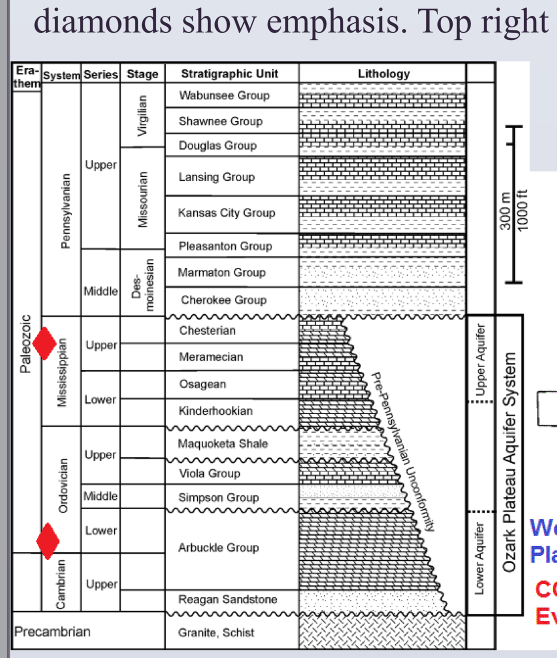
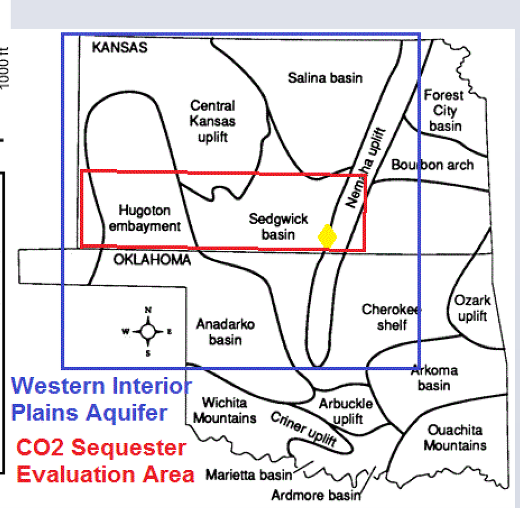
ABSTRACT

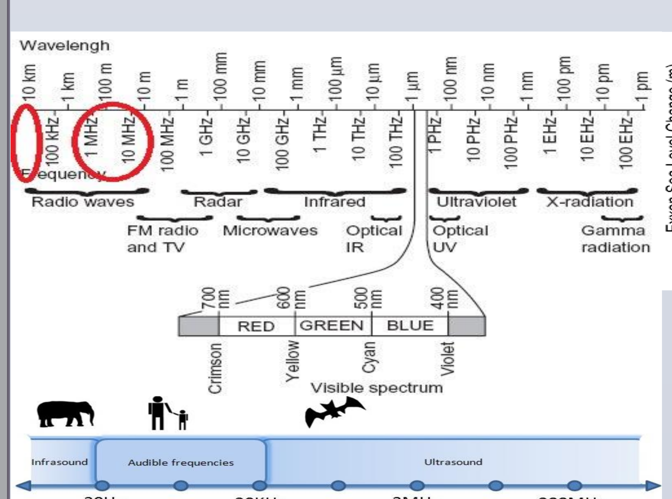
This study focuses on characterizing subsurface rock formations of the Wellington Field, in Sumner County, Kansas, for both geosequestration of carbon dioxide (CO_2) in the saline Arbuckle formation and enhanced oil recovery of a depleting Mississippian oil reservoir. Multi-scale data including lithofacies core samples, X-ray diffraction, well log data including sonic and dipole sonic, and surface 3D seismic reflection data will be integrated in an effort to establish and/or validate a new or existing rock physics model that best represents our reservoir rock types and characteristics. We acquired compressional wave velocity and shear wave velocity data from Mississippian and Arbuckle cores by ultrasonic measurements of arrival times using an Ult 100 Ultrasonic System and a 12 ton hydraulic jack located in the geophysics lab in Thompson Hall at Kansas State University. The elastic constants Young's Modulus, Bulk Modulus, Shear (Rigidity) Modulus and Poisson's Ratio have been calculated based on these velocity data. Ultrasonic velocities have been also compared to sonic and dipole sonic log data from the Wellington 1-32 well. We aim to create a transformation of compressional wave sonic velocities to shear wave sonic for all wells where compressional wave sonic is available. Furthermore, saturated elastic moduli and velocities based on sonic and dipole sonic well logs, in addition to dry rock moduli acquired from core samples will allow for the testing of various rock physics models. These will predict effects of changing effective (brine + CO2 +hydrocarbon) fluid composition on seismic properties, and will be compared to known values to ensure accuracy, thus revealing implications for feasibility of seismic monitoring. Lessons learned from characterizing the Mississippian are essential to understanding the potential of utilizing similar workflows for the much less known saline aquifer of the Arbuckle in south central Kansas.

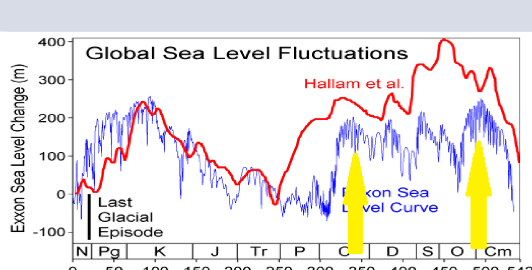
BACKGROUND

Our study focuses on carbonates in the Mississippian and Arbuckle groups in southern Kansas. Top left is a stratigraphic column of our study area; red diamonds show emphasis. Top right is a geographic map of the study area, with the yellow diamond showing our exact study site location, well KGS 1-32.



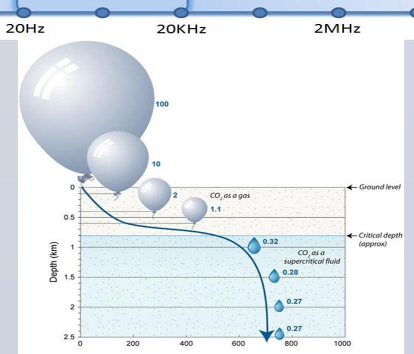




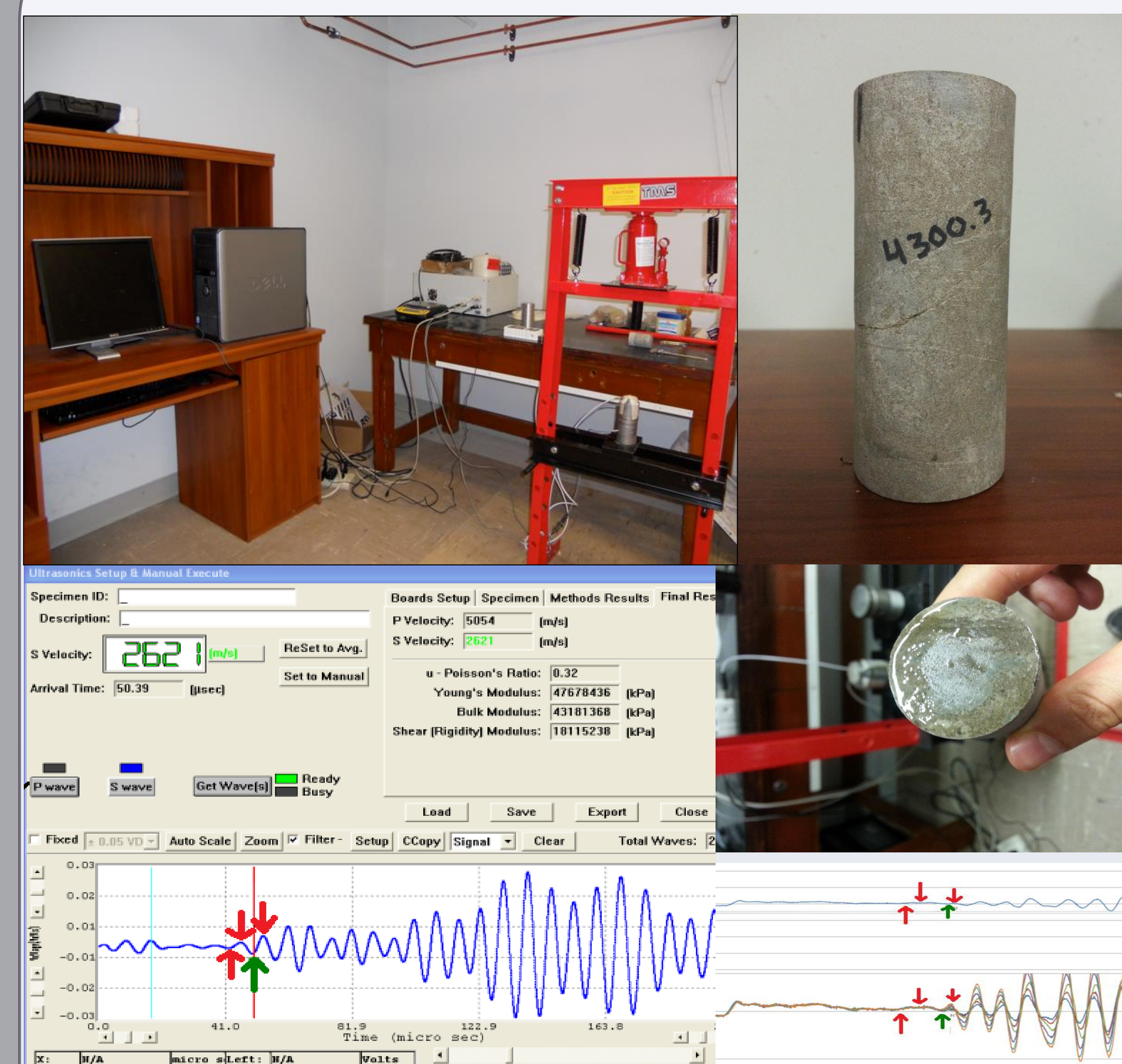


Top left: orientation and context about the frequency ranges used in this study, ultrasonic vs sonic.

Top right: sea level fluctuations through geologic time; yellow arrows emphasize sea level during the Mississippian and Arbuckle, indicating warm tropical epicontinental seas. Bottom left: a diagram showing how the volume taken up by CO2 changes with changing pressure, eventually becoming a more dense supercritical liquid, taking up less space.

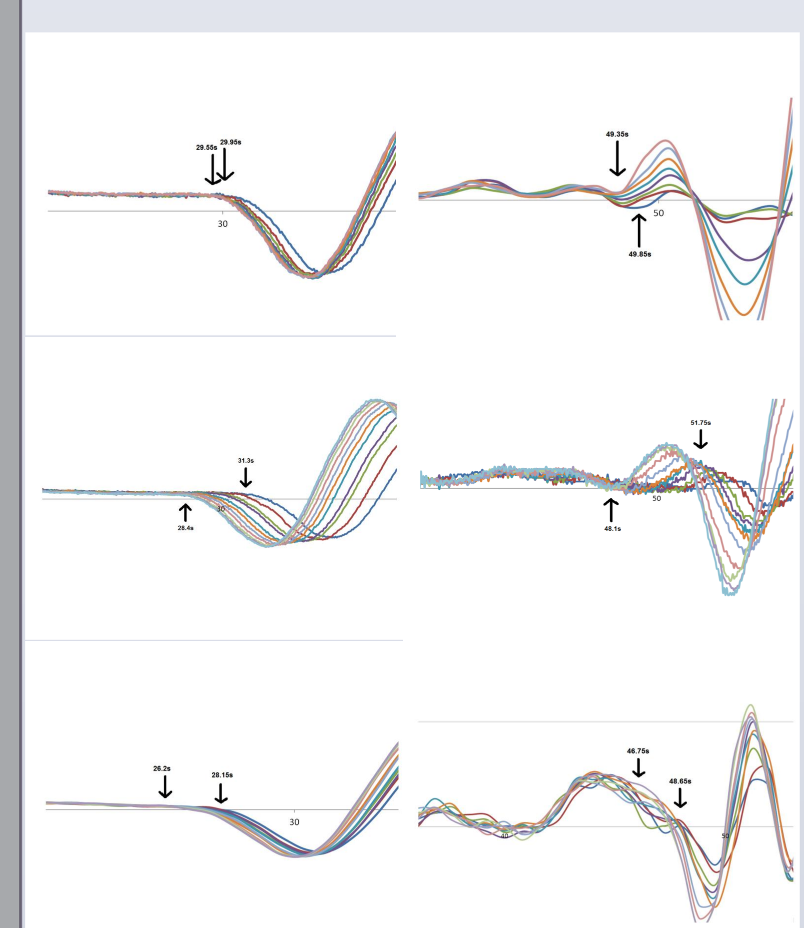


METHODS



We obtained core plugs from the Kansas Core Library from the Kansas Geological Survey; the cores are from the KGS 1-32 well in Sumner County, Kansas. Ultrasonic frequency velocity tests were run using an Ult-100 Ultrasonic Velocity Testing System and a 12-ton hydraulic jack. P-waves, S-waves and elastic moduli were obtained and recorded for further analysis.

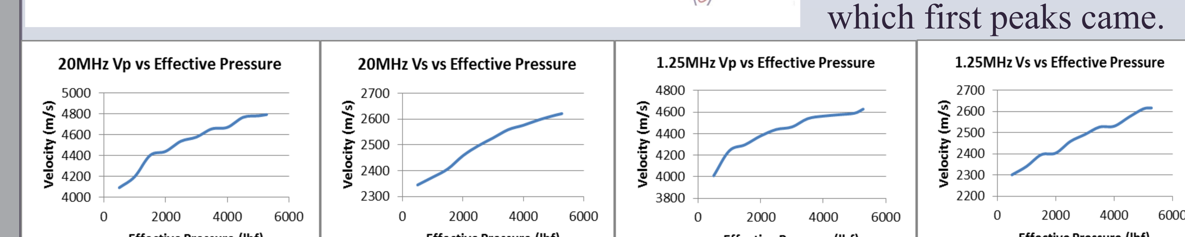
RESULTS



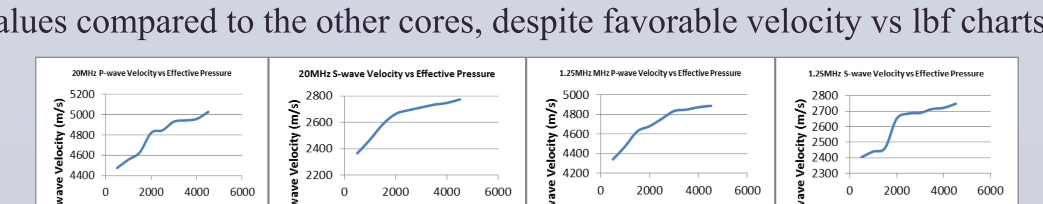
Core DM3829.5 Waveform: this core was hard to pick because the initial arrival signal of the waves was weak and did not vary much with increasing pressure

Core DA4300.4 Waveform: this core was easy to pick initial arrival times of waves, because of strong arrival signals and clear changes in arrival times with changing pressure.

Core DA4472.6 Waveform: this was an odd example because of the unusual location in which first peaks came.



Core DA4300.4 (above), core DA4300.3 (below). Velocity vs Pressure charts are used to show an asymptote of velocities with the highest applied pressures indicating near in-situ pressures, and thus most accurate velocities. However, core DA4300.4 and associated well log velocities show a large difference in values compared to the other cores, despite favorable velocity vs lbf charts.

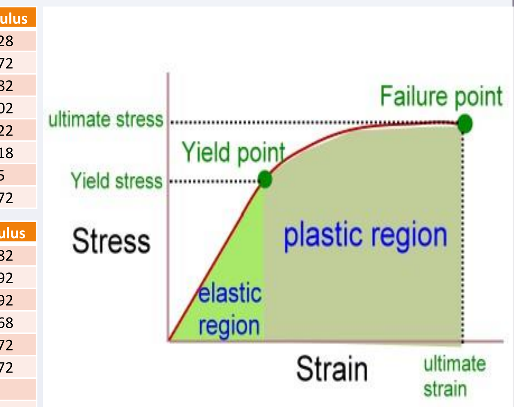


ADDITIONAL RESULTS

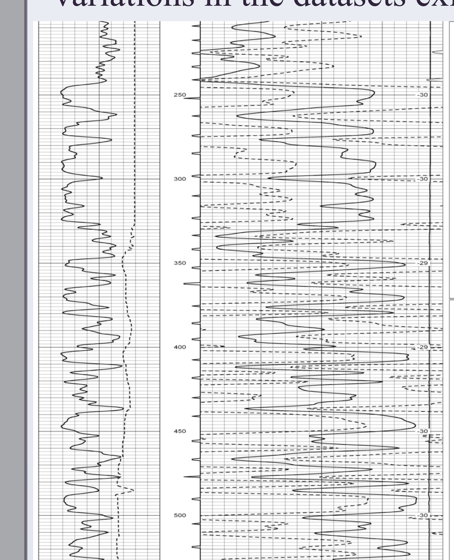
Core DM3829.5 20MHz and 1.25MHz Elastic Moduli. This and other data will later be integrated as inputs to rock physics fluid replacement models.

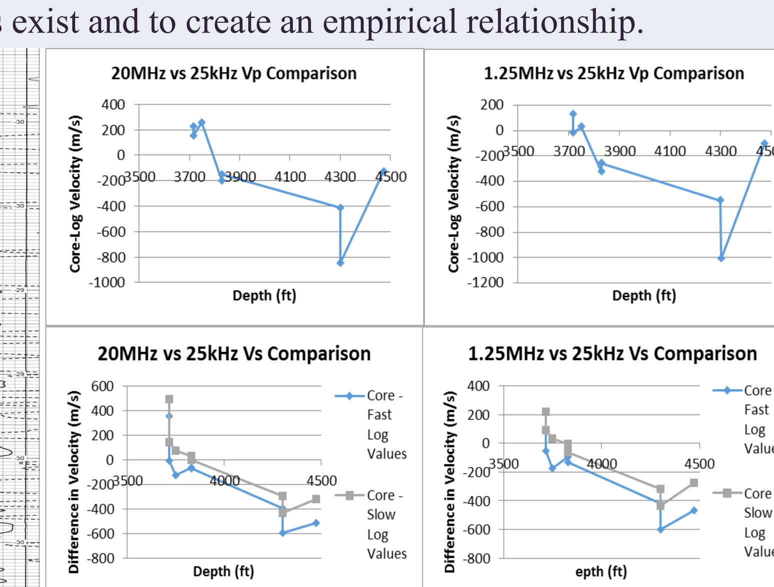
Lbf	Poisson's Ratio	Young's Modulus	Bulk Modulus	Shear Modulus
500	0.256589823	41549336.73	28449465.63	16532577.28
1000	0.257412158	41709042.08	28655628.19	16585270.72
1500	0.257046546	42195577.63	28946270.03	16783617.82
2000	0.256722627	42451801.33	29083264.59	16889885.02
2500	0.250958386	42925436.65	28727084.32	17157020.22
3000	0.250811796	43189183.4	28886589.05	17264461.18
3500	0.252496267	43517325.25	29304154.17	17372237.5
4200	0.25206044	43806806.99	29447234.99	17493886.72

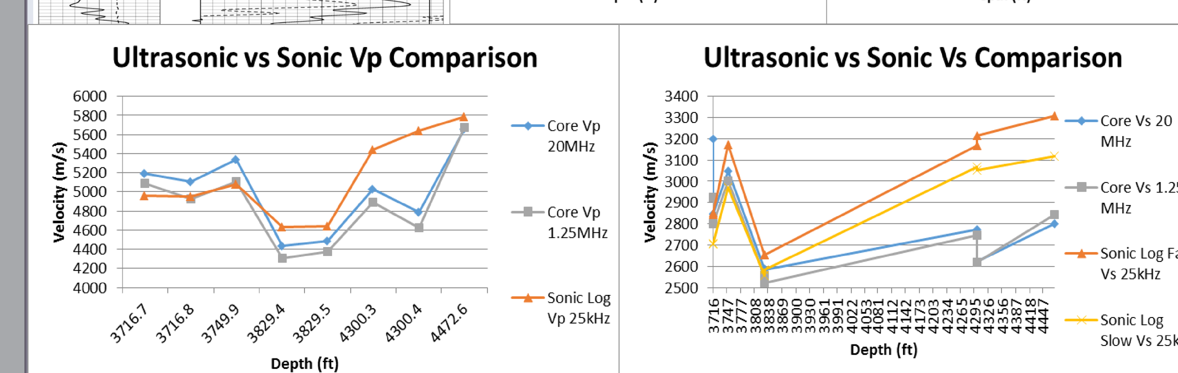
Lbf	Poisson's Ratio	young's modulus	bulk modulus	shear modulus
500	0.243906668	40121079.65	26110975.02	16127045.82
1000	0.24290976	40835655.8	26472971.69	16427441.92
1500	0.249123254	41039799.41	27264250.99	16427441.92
2000	0.249830113	41194319.73	27444230.14	16479967.68
2500	0.249510457	41446938.4	27577291.21	16585270.72
3000	0.249510457	41446938.4	27577291.21	16585270.72
3500	0.25038303	41607865.74	27781141.18	16638048
4200	0.252256547	41670209.08	28033172.08	16638048



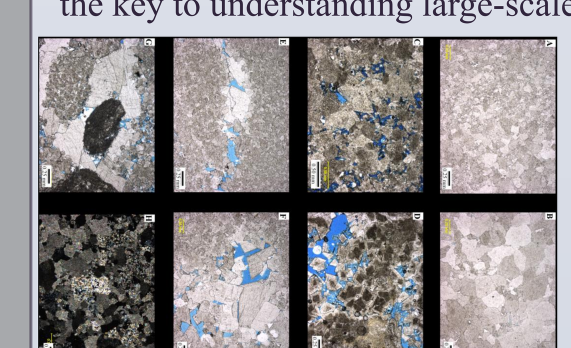
We want to find a connection between ultrasonic laboratory and in-situ sonic and dipole sonic well log velocities, in order to provide cost-effectiveness for future industrial and academic benefit. We are trying to understand why variations in the datasets exist and to create an empirical relationship.

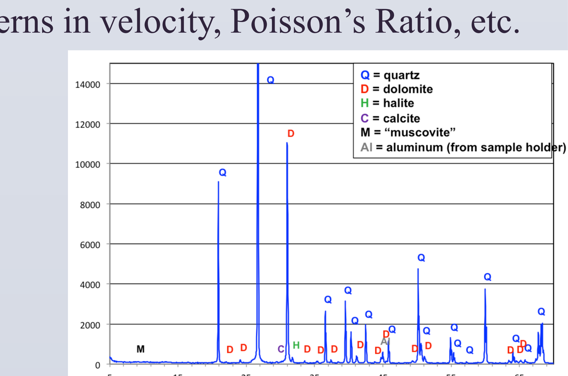




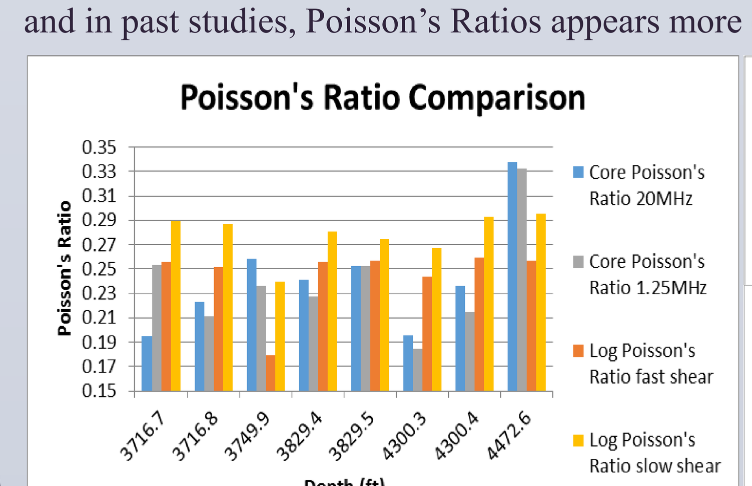


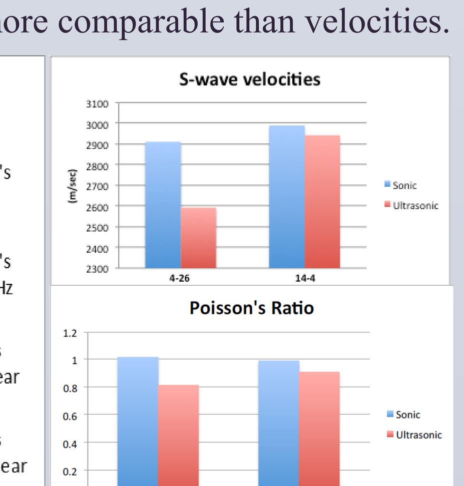
According to mineralogical analyses done in the past, strong quartz and dolomite peaks with some minor clay minerals have been seen on XRF, and thin sections often show mineralogy dominated by fragmented porous dolomite, some anhydrite and also silicified sponge spicules. Pore and grain structure is important to understand too. These small-scale features may hold the key to understanding large-scale patterns in velocity, Poisson's Ratio, etc.





Poisson's Ratio may be an important factor in being able to accurately and robustly link ultrasonic and sonic frequency datasets together, because it is not as prone to be affected by velocity dispersion since it is a ratio. In this study and in past studies, Poisson's Ratios appears more comparable than velocities.



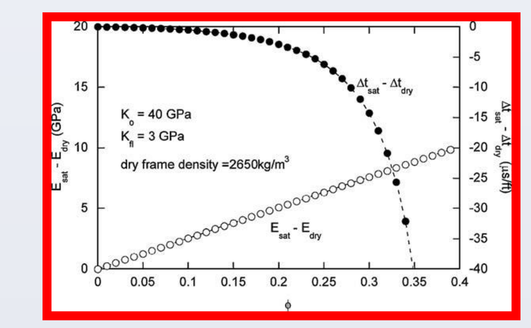


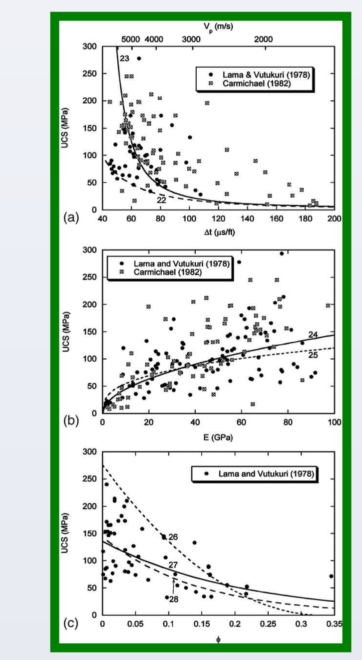
NEXT STEPS: FLUID REPLACEMENT MODELING

We will next look into testing as many applicable fluid replacement models as available, though inputting data obtained from our dry core samples. These will predict saturated values from dry cores; to validate which model is best, we will compare the predictions to known data provided by well logs and other sources. Equations for Gassmann, one model we'll test, are displayed.

$$K_{sat} = K^* + \frac{\left(1-\left(\frac{K^*}{K_o}\right)\right)^2}{\frac{\Phi}{K_{fl}} + \frac{1-\Phi}{K_o} - \frac{K^*}{(K_o)^2}}$$

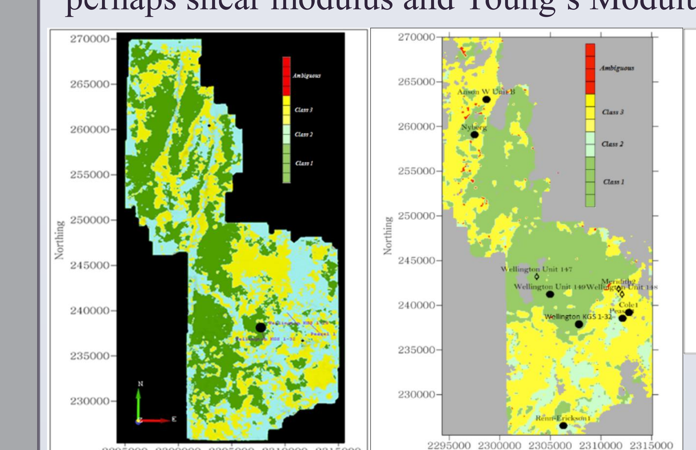
$$\frac{K_{Sat}}{K_s - K_{Sat}} = \frac{K_{Dry}}{K_s - K_{Dry}} + \frac{K_f}{\Phi(K_s - K_f)}$$

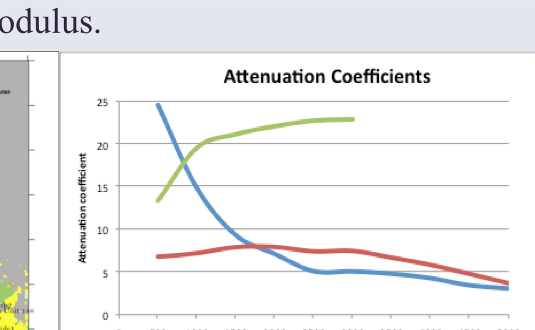




NEXT STEPS: 3D SEISMIC ATTRIBUTE ANALYSIS

We have a 3D seismic dataset available, too, allowing for the area to be analyzed on the micro, core, log and seismic scales. An artificial neural network (ANN) was previously created to determine porosity classes for tops of the Arbuckle (left) and Mississippian (right) near well KGS 1-32; we may transform these porosity classes to various elastic moduli maps, including perhaps shear modulus and Young's Modulus.





Attenuation coefficients will also be analyzed more in depth; a recent study by Isham (2013) showed anomalous attenuation coefficients. Normally, attenuation coefficients decrease with increasing effective pressure- in the hypothetical case of sequestering CO2 (increase in pore pressure present). Anomalies may be useful in fracture monitoring applications.

CONCLUSION

This study is well underway, now entering a data analysis phase. In all, we hope to 1) find a transformation between ultrasonic and sonic frequency datasets to provide cost-effectiveness to industry and academia, 2) validate a rock physics fluid substitution model as accurate when applied to our lithofacies by comparing predicted values to actual known values, 3) better understand how 3D seismic attributes react to changing saturations of effective fluids including CO2, for applications in future time lapse 4D CO2 plume tracking, 4) to transform 3D seismic-generated porosity maps to various effective moduli maps in order to extend data away from well control.

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