Combining Pore Architecture and Sonic Velocity Response to Predict Reservoir Quality: An Example from a Mid-Continent Mississippian Carbonate*

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Abstract

Laboratory measured sonic velocities in carbonates are related to porosity, pore architecture, and diagenetic alterations, which are in turn related to the depositional environment and basin history. Understanding how these properties are related allows quantitative correlation of sonic velocity response to permeability. Predictable relationships between sonic velocity response and porosity are recognized in carbonate rocks, but the data have significant scatter. For example, a porosity of 40% can produce an acoustic velocity response varying from 2400-5000 m/s. The reason for this scatter is variations in pore architecture, depositional fabric, and diagenetic history. Classification by primary pore type (intergranular, moldic, etc.) decreases the scatter but not enough to establish a quantitative relationship. Additional controls include the percentage of micro- and macro-porosity, dolomitization, non-carbonate mineralogy, and pore geometry. Because of this variability, laboratory measured sonic velocity response must be compared to petrophysical properties unique to each reservoir.

The Mississippi Lime play, a Mid-Continent Mississippian carbonate, is primarily located in Oklahoma and Kansas. Depositional environments vary from a deep basin to carbonate slope and ramp. Regional depositional settings and diagenetic alterations are mostly agreed upon; however details controlling reservoir quality are poorly understood. Petrophysical analyses of a Mississippi Lime outcrop will be integrated with laboratory sonic velocity response to quantify the porosity-pore architecture-permeability relationship. Laboratory analysis and field observations will be correlated with high resolution sequence stratigraphic studies to correlate results with specific facies and depositional environments. Quantification of sonic velocity relationships will provide valuable insight into the reservoir characterization and how to target key intervals within the Mississippian play.

Selected References

Anselmetti, F.S. and G.P. Eberli, 1999, The velocity-deviation log; a tool to predict pore type and permeability trends in carbonate drill holes from sonic and porosity or density logs: AAPG Bulletin, v. 83/3, p. 450-466.

Eberli, G.P., L.B. Smith, E. Morettini, and L. Al-Kharusi, 2003, Porosity partitioning in sedimentary cycles; implications for reservoir modeling: AAPG Annual Meeting Expanded Abstracts, v. 12, p. 48.

Loucks, R.G., R.M. Reed, S.C. Ruppel, and U. Hammes, 2012, Spectrum of pore types and networks in mudrocks and a descriptive classification for matrix-related mudrock pores: AAPG Bulletin, v. 96/6, p. 1071-1098.

Weger, R.J., G.T. Baechle, J.L. Massaferro, and G.P. Eberli, 2004, Effects of pore structure on sonic velocity in carbonates: SEG Technical Program Expanded Abstracts, v. 23, p. 1774-1777.

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Research Goal

Utilize sonic velocity (laboratory measured and wireline logs) coupled with characterization of pore architecture at the macro-, meso-, micro- and nanoscale predict producing reservoir facies and producing intervals in an unconventional carbonate reservoir.

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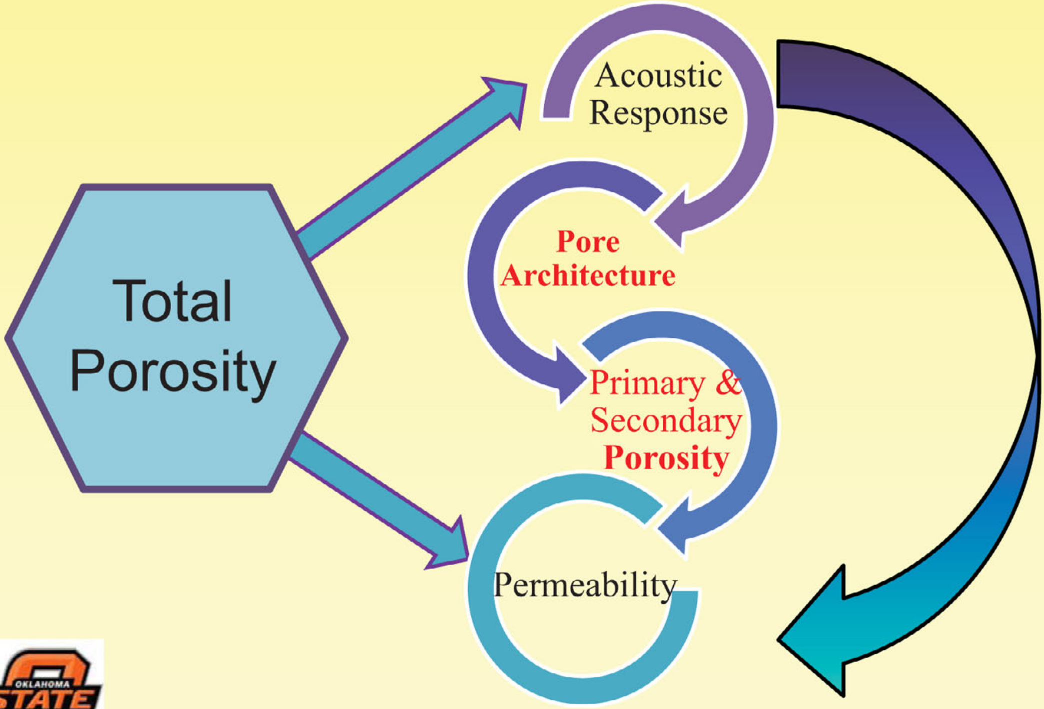
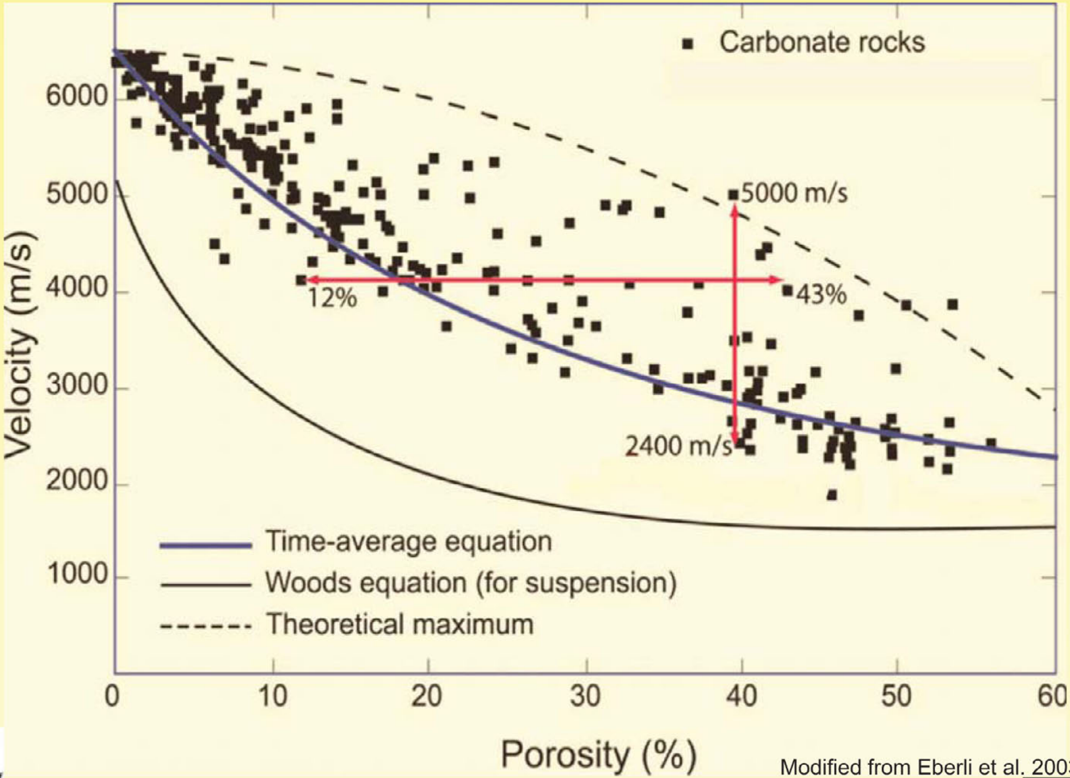
Pathway to Reservoir Prediction



Carbonate Rock Acoustic Response



Modified from Eberli et al. 2003

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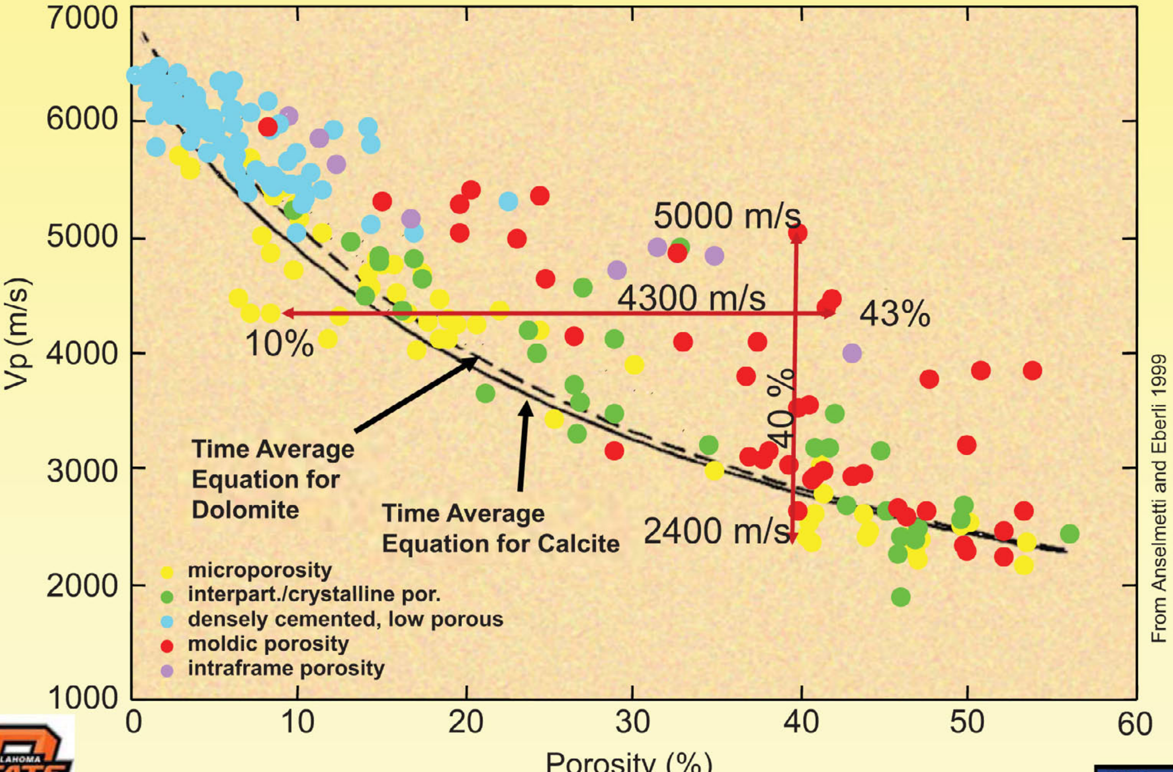
Velocity Correlation to Pore Type



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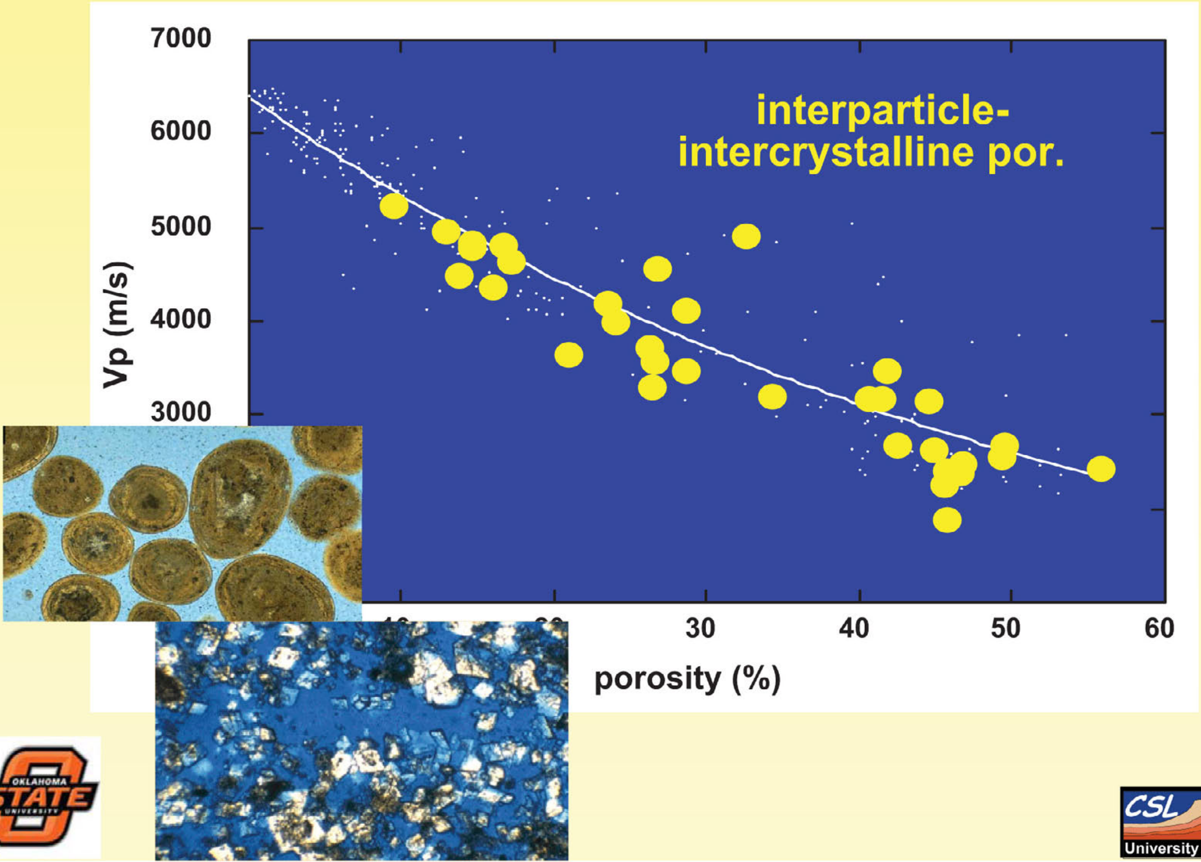
Velocity-Porosity Relationship



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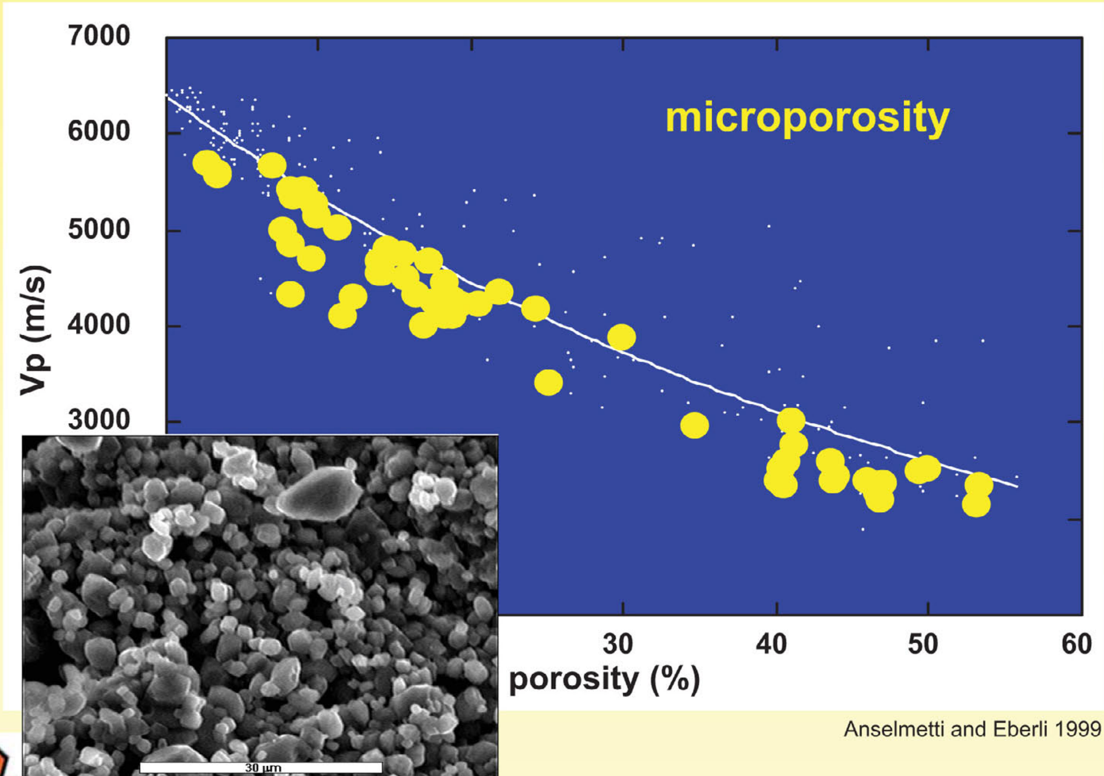
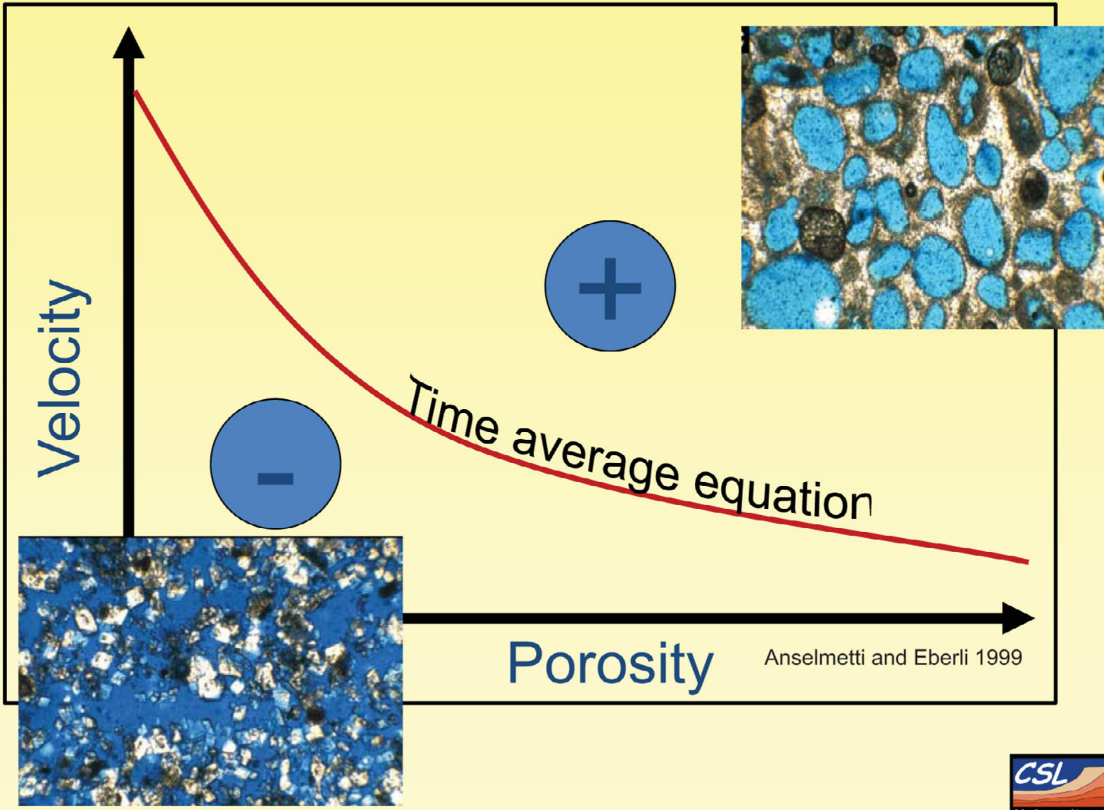
Velocity-Porosity Relationship

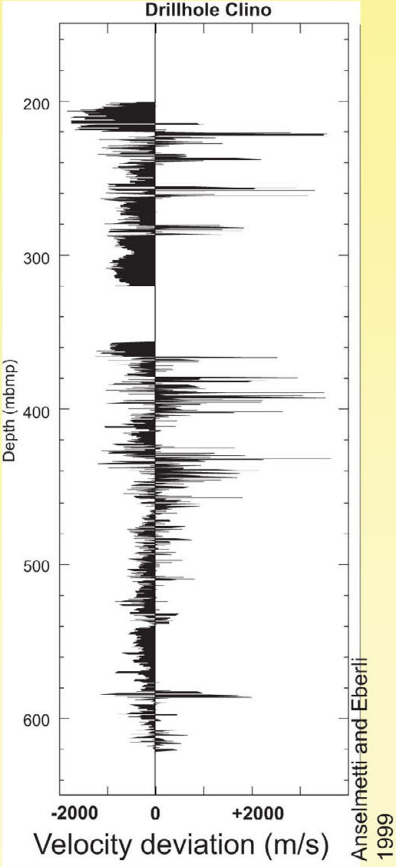


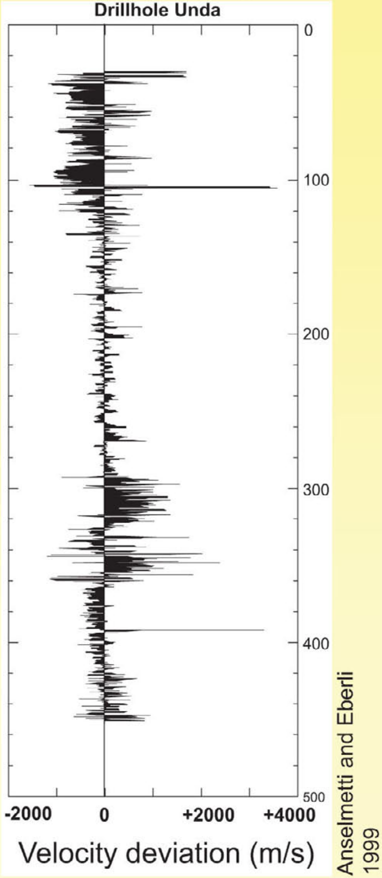
Anselmetti and Eberli 1999

Predictable Velocity from Pore Type

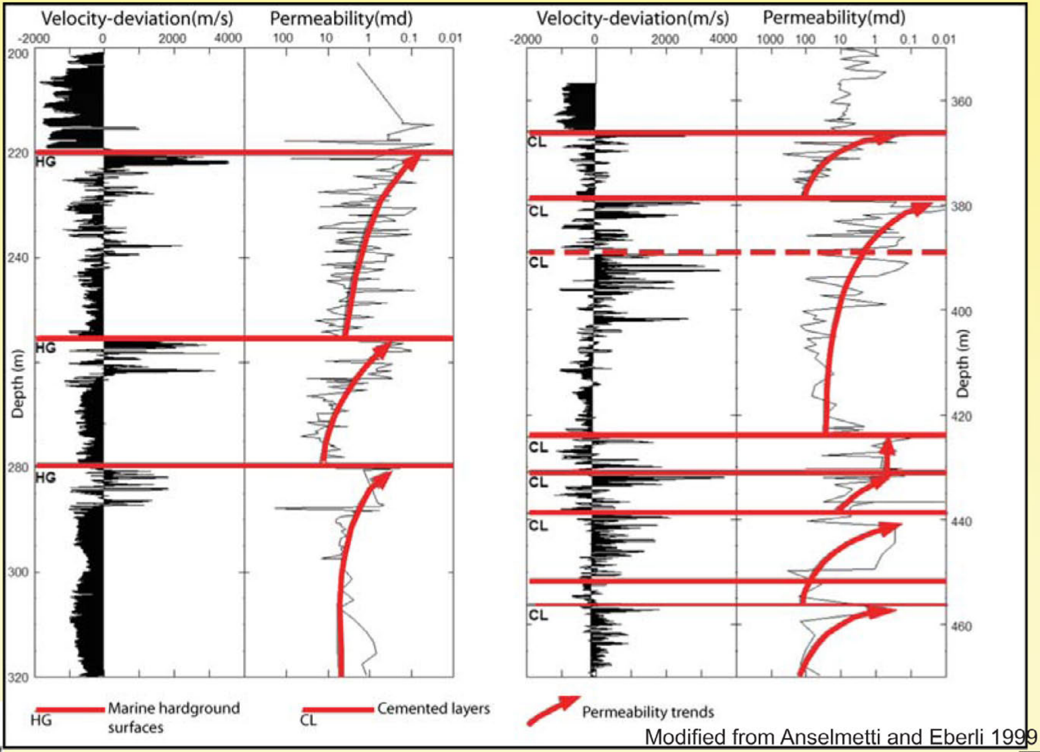


Velocity Deviation Log



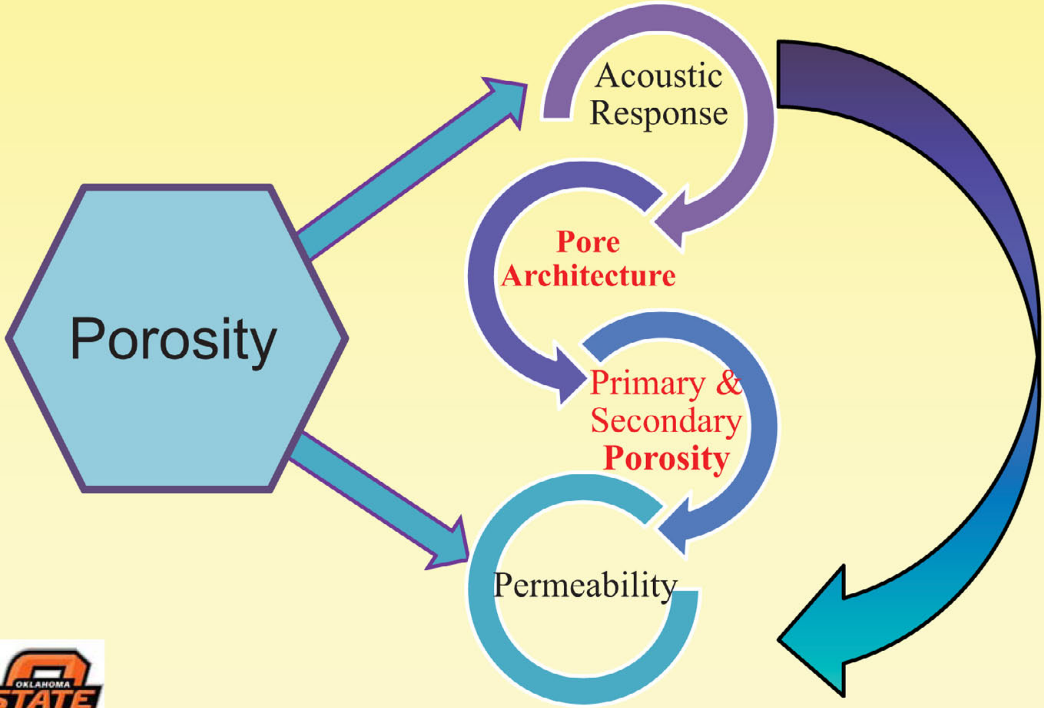


Velocity Correlation to Permeability

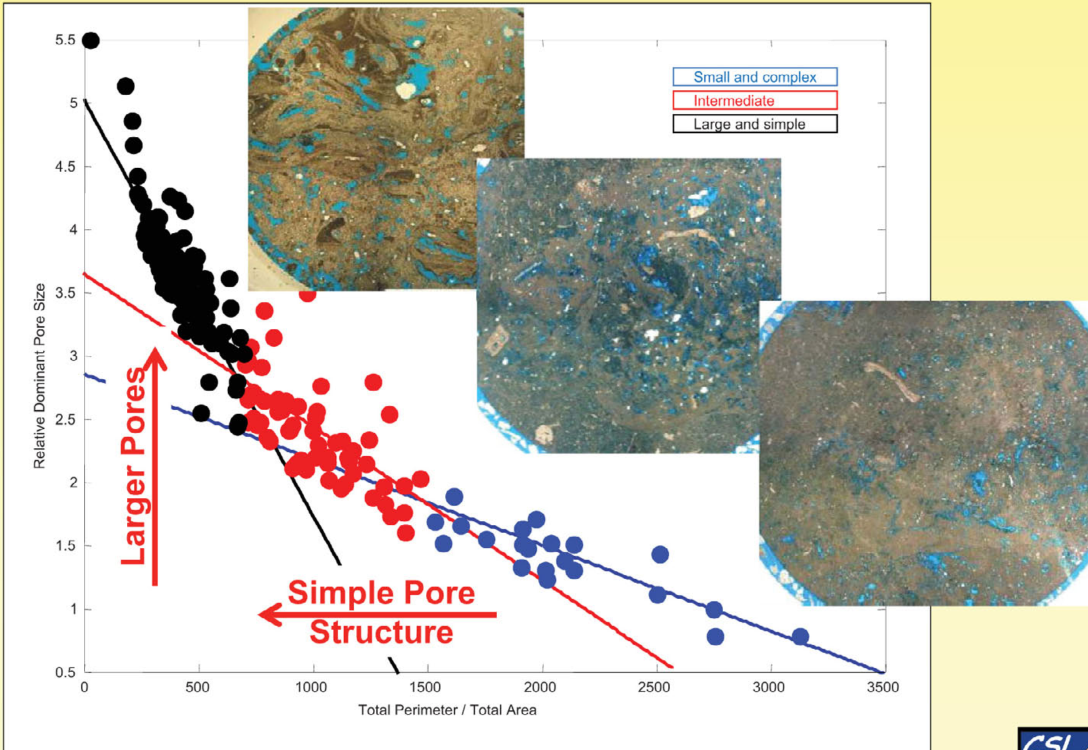


Modified from Anselmetti and Eberli 1999

Pathway to Permeability Prediction



Pore Architecture (Digital Image Analysis)



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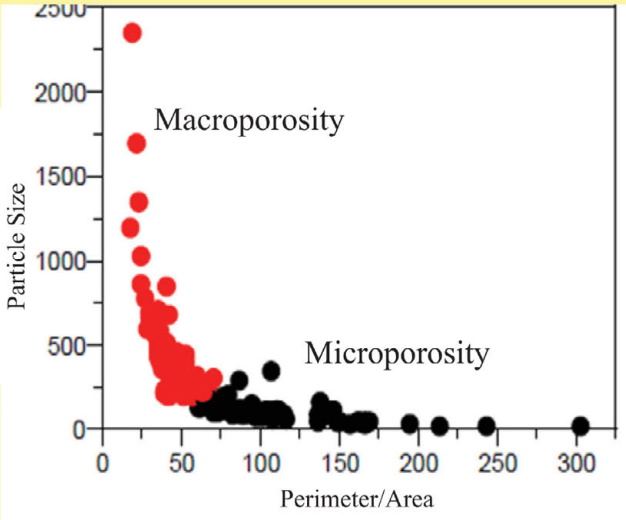
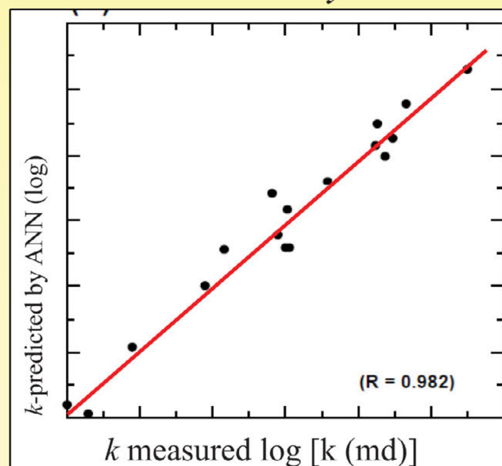
Permeability Prediction from Pore Architecture and Primary Porosity



Weger et al. 2004

Quantified acoustic response
Quantified pore architecture
Quantified macro- and microporosity

Predictable Permeability



Weger et al. 2004

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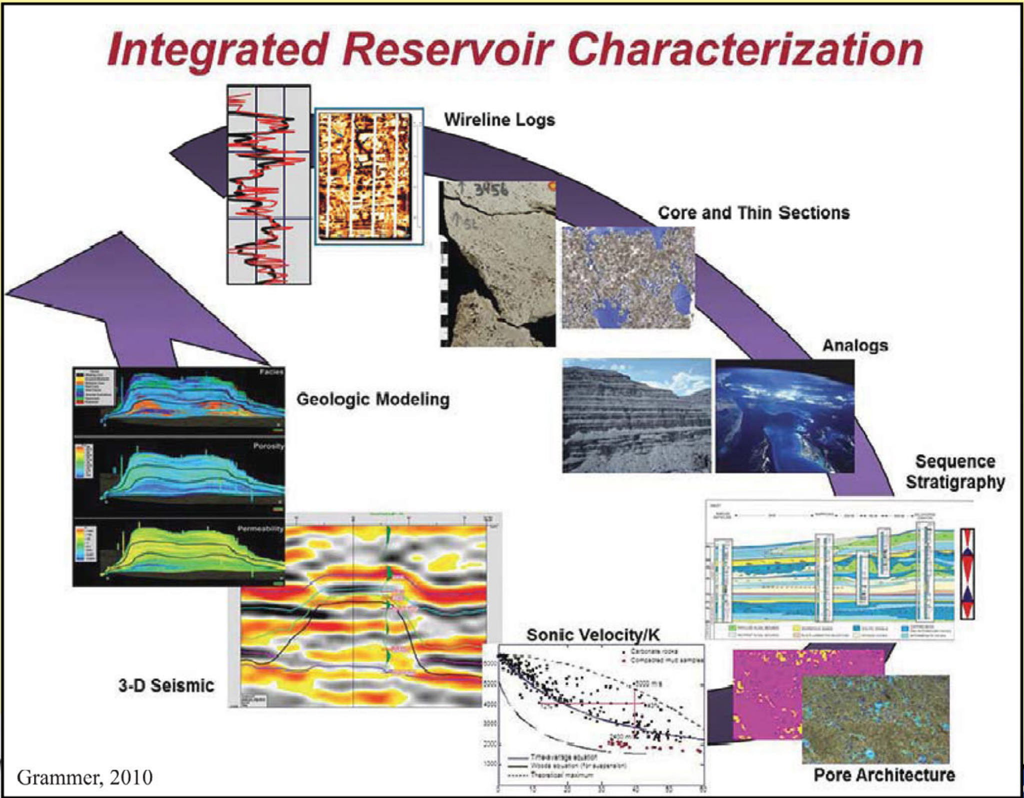
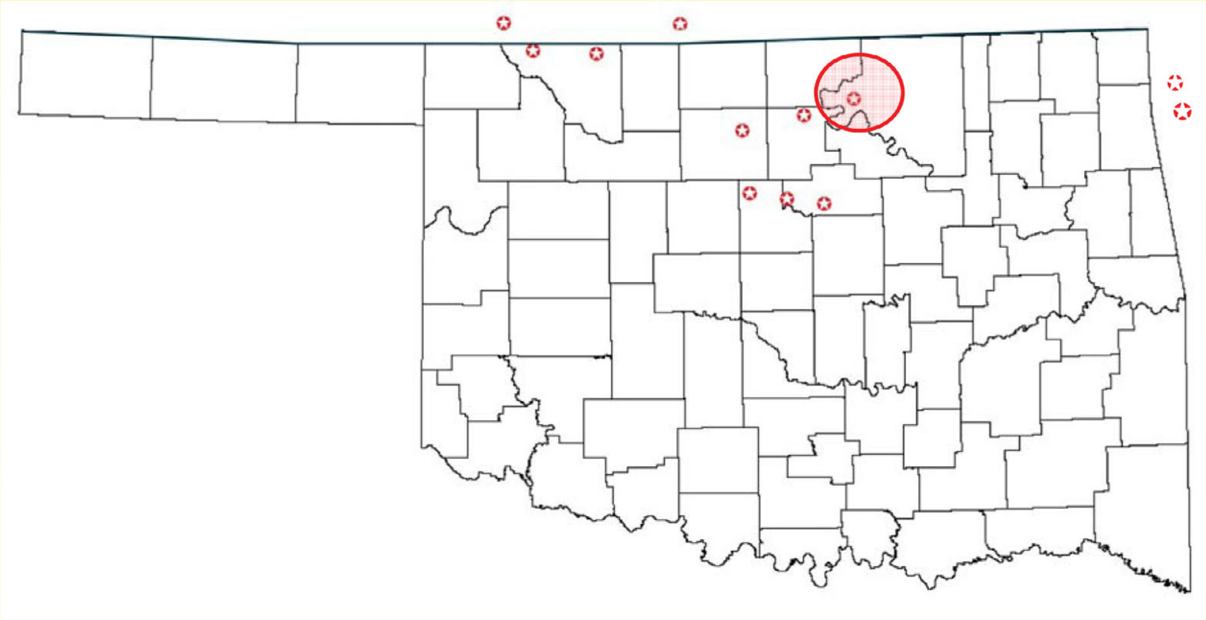
Methodology

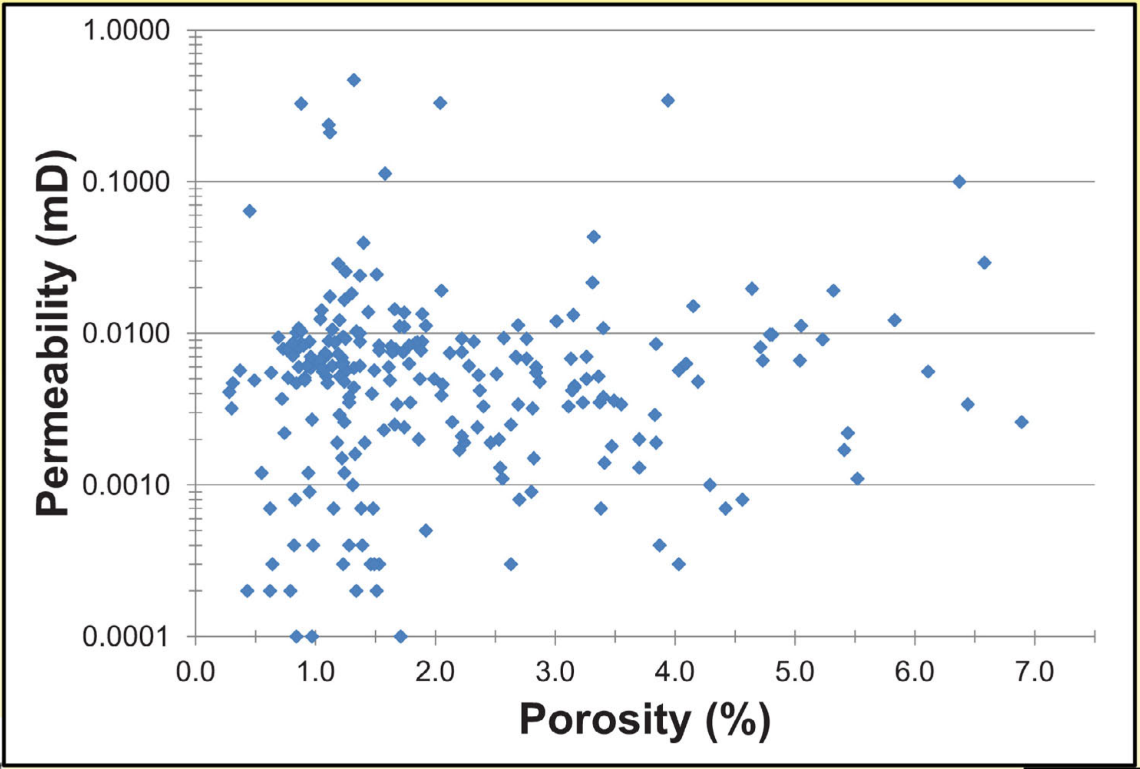


Grammer, 2010

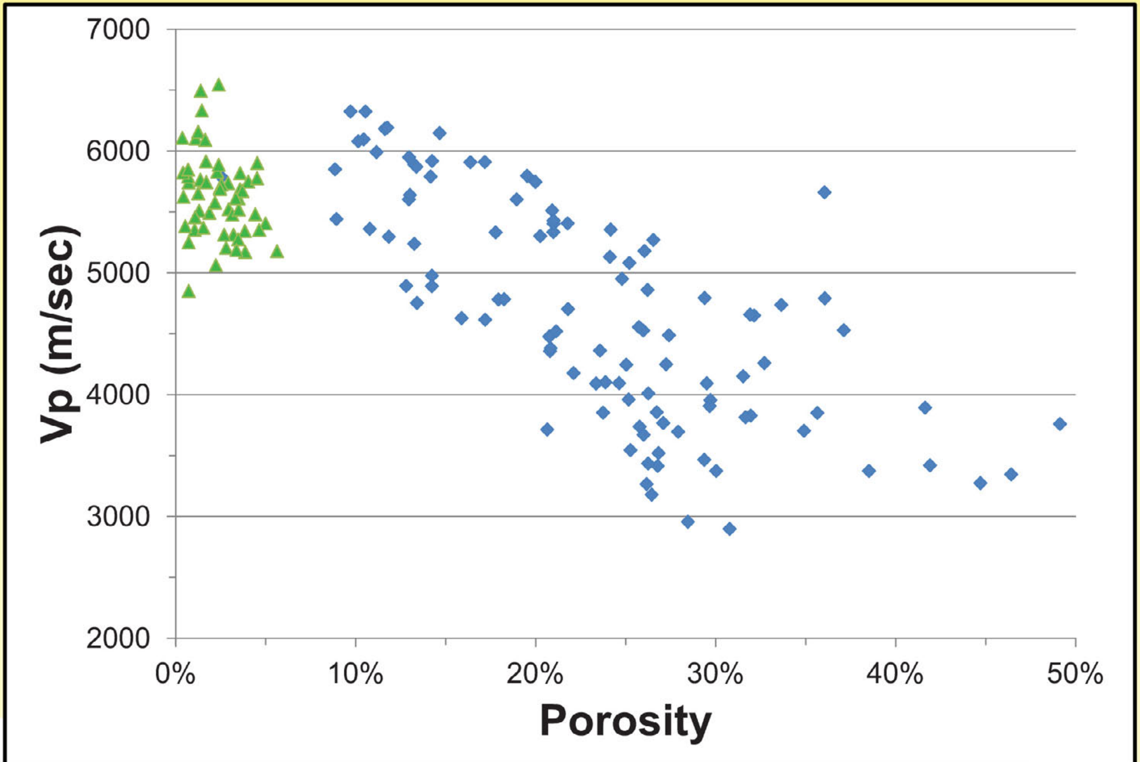
Mississippian Data Location Map



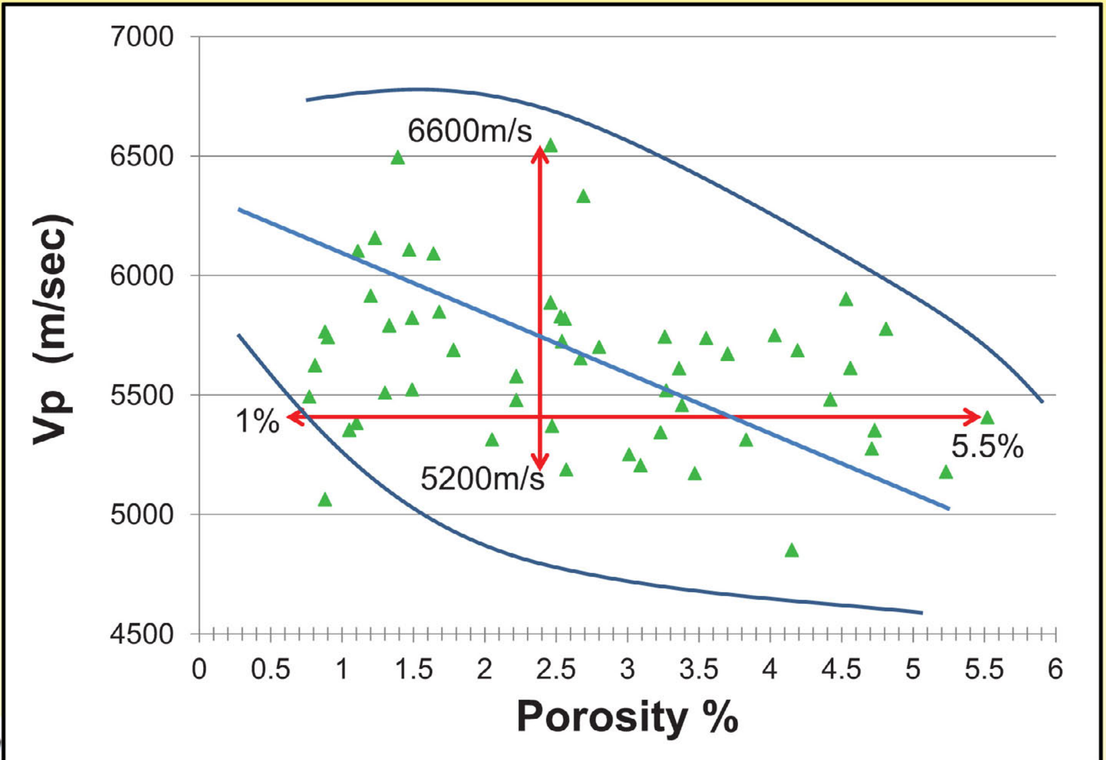
Porosity vs. Permeability



Macropore vs. Nanopore Systems



Velocity vs. Porosity



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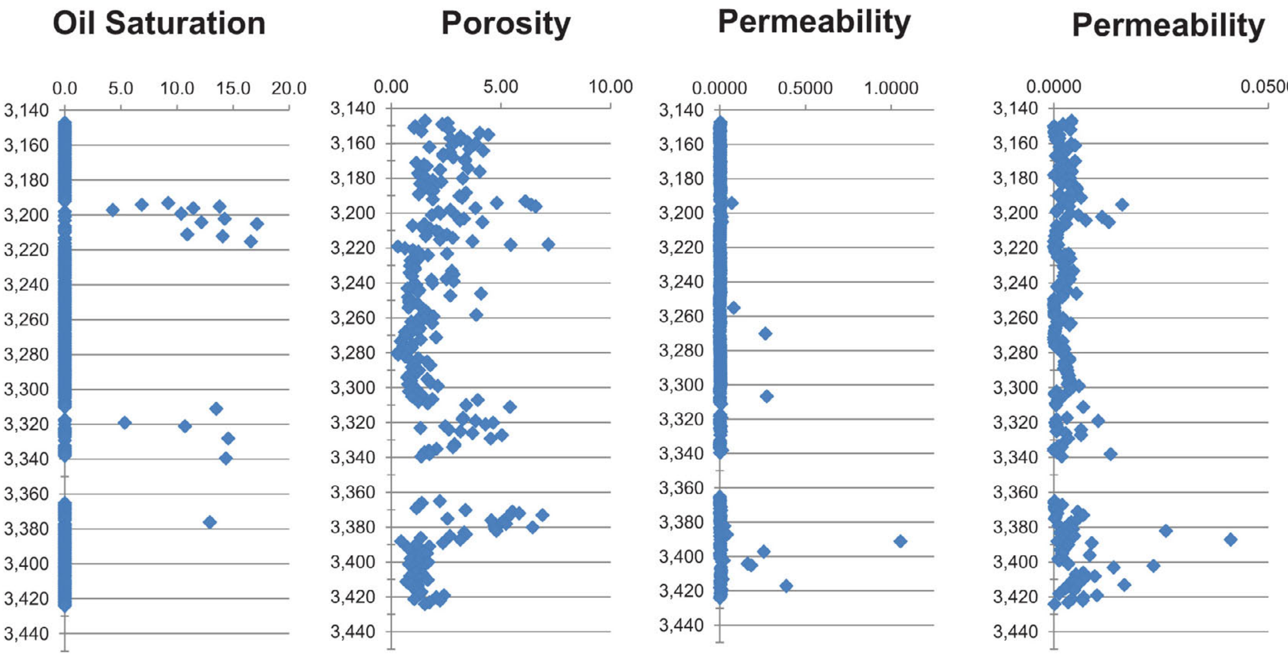
Oil Saturation, Porosity, and Permeability



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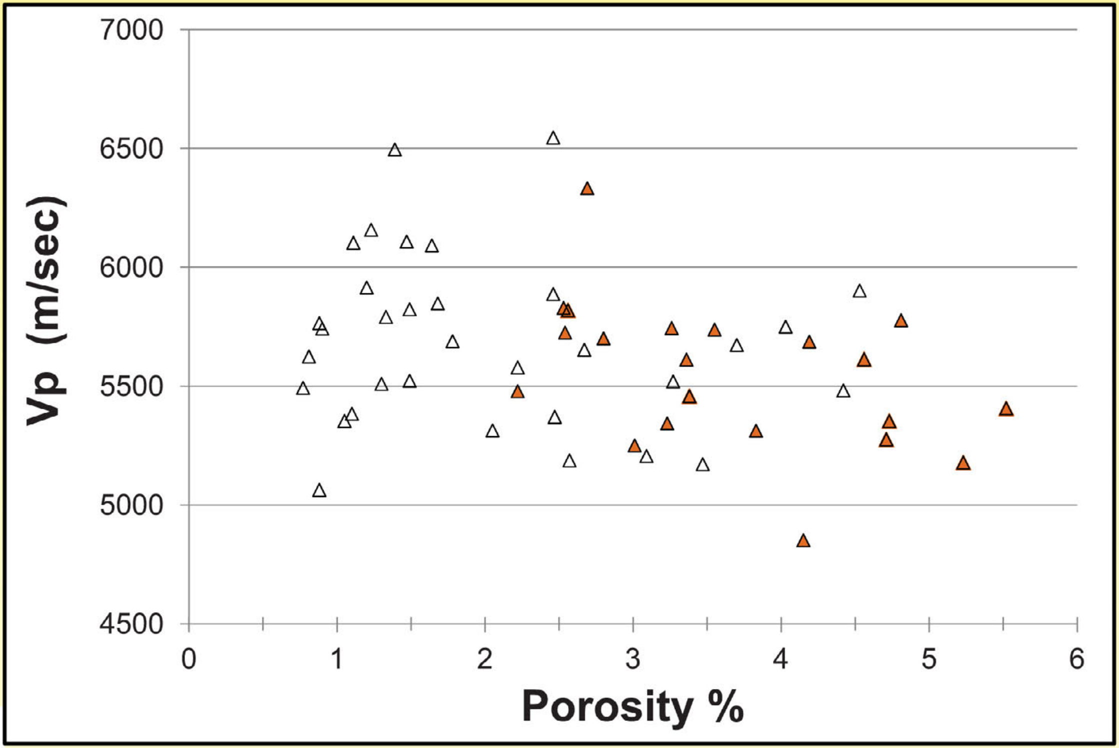
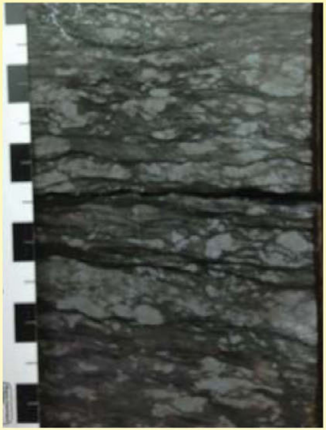
Velocity vs. Oil Saturated Zones



Core Examination

Large shoaling upward sequence with smaller shoaling upward packages in an overall regressive sequence.

- Very fine grain, black laminated, carbonate mudstone with mm-scale bioturbation,
- Bioturbated mudstone to crinoid-brachiopod wackestone.
- Fine grain, massively bedded, wackestone with large scale bioturbation.



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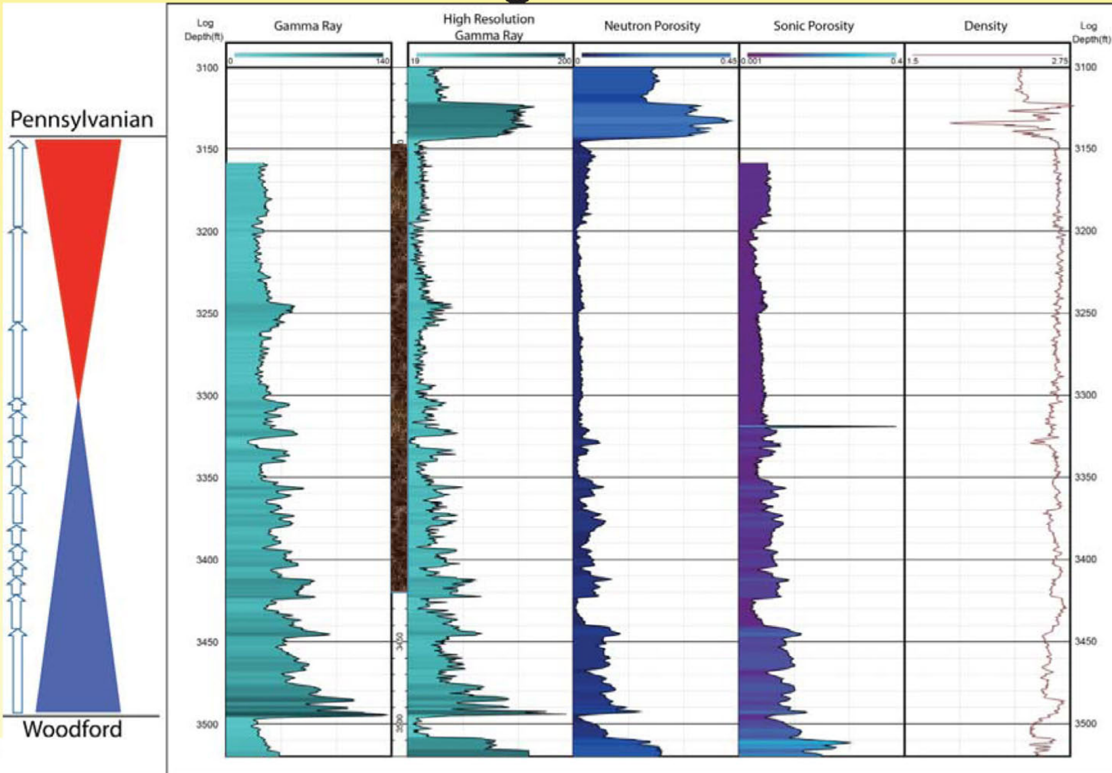
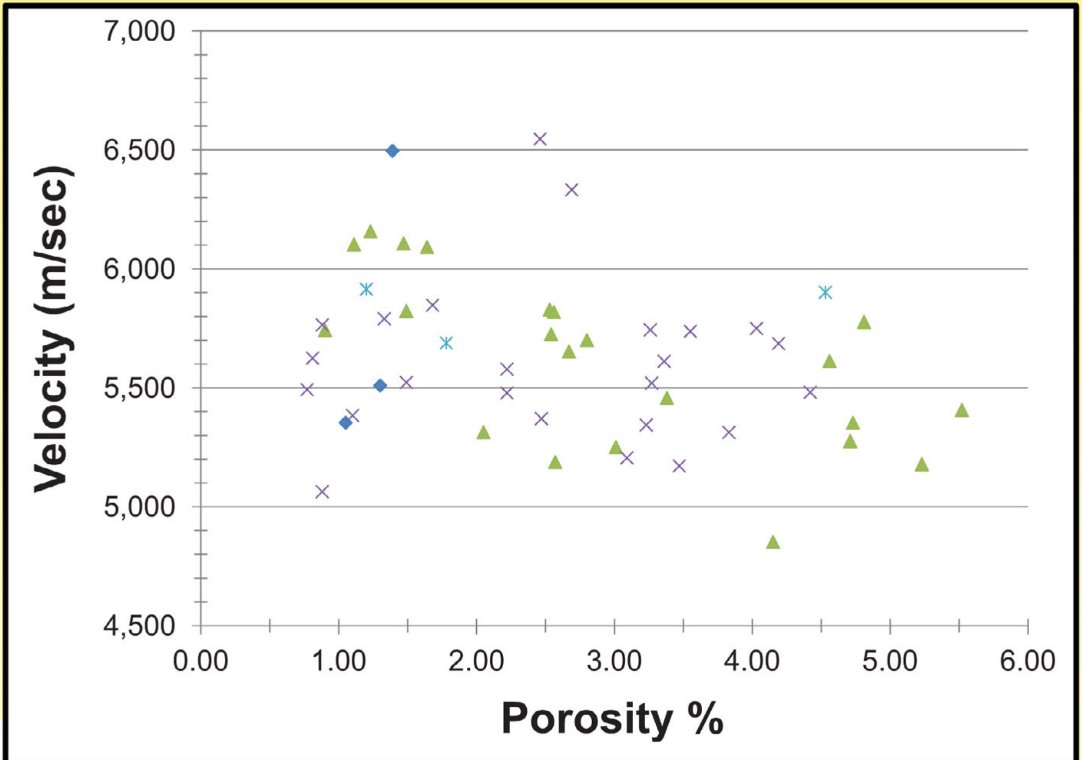
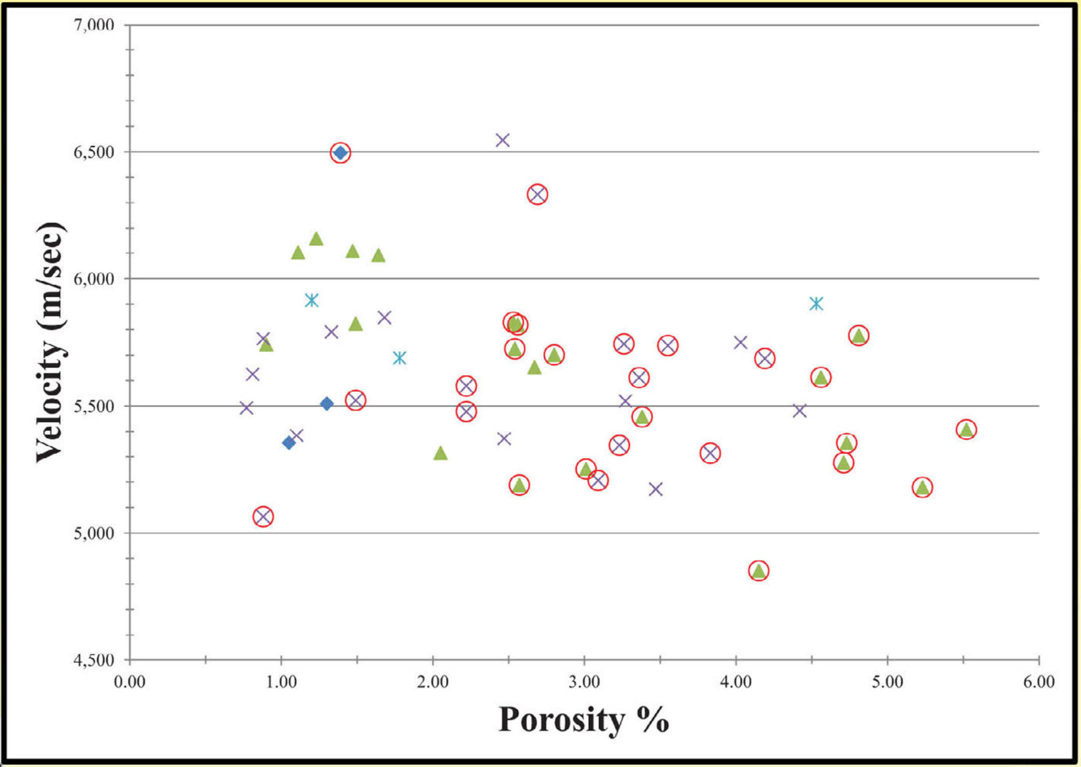
Wireline Log Correlation



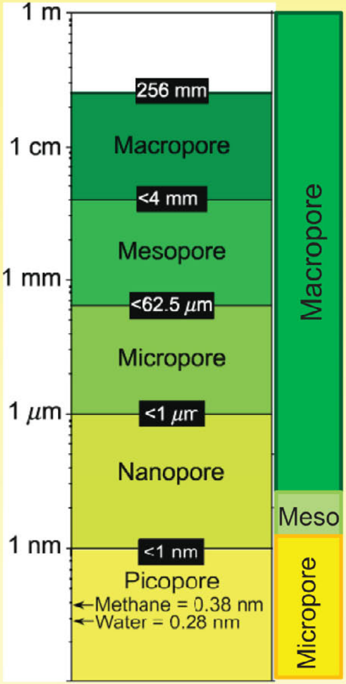
Velocity Correlation to Facies



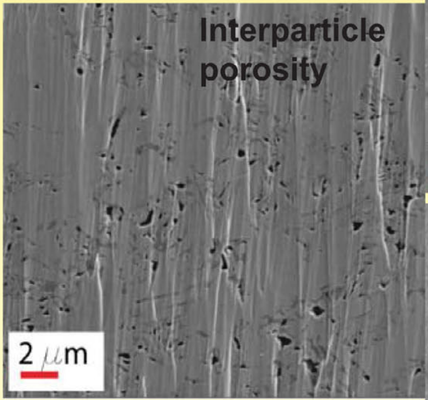
Velocity, Facies & Oil Saturation

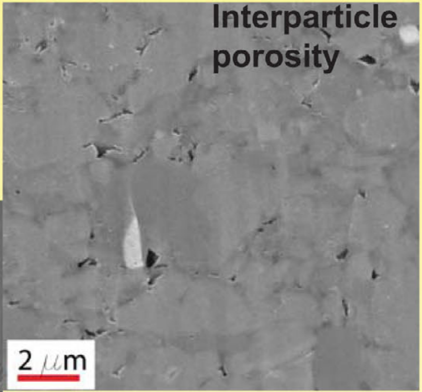


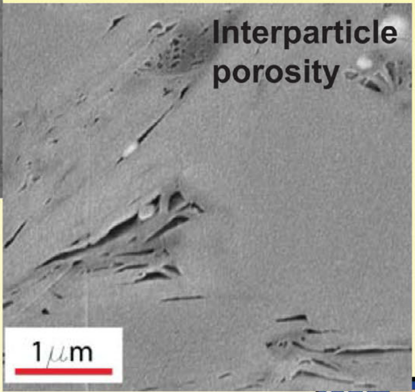
Pore Classification for Mudrocks



Loucks et al., 2012







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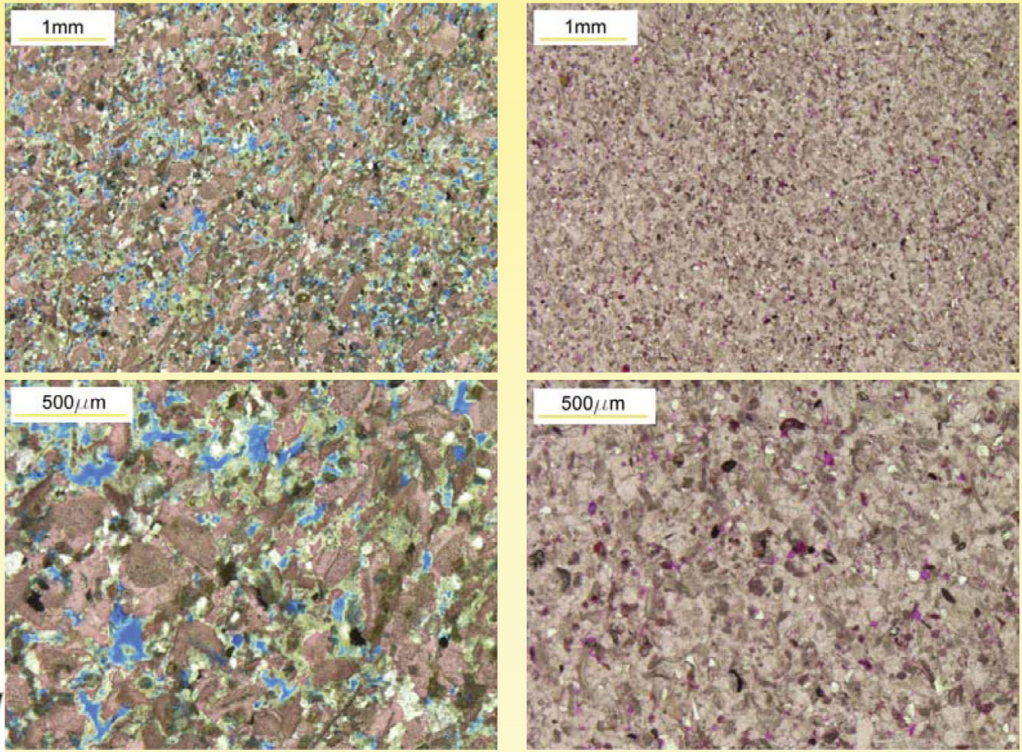
Pore Architecture

Thin Section Photomicrographs



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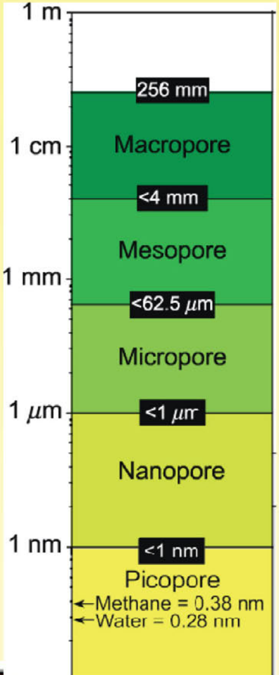
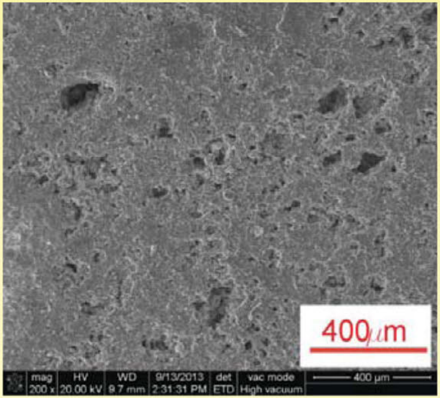
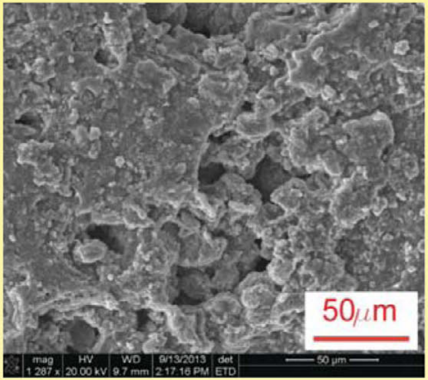
Pore Architecture

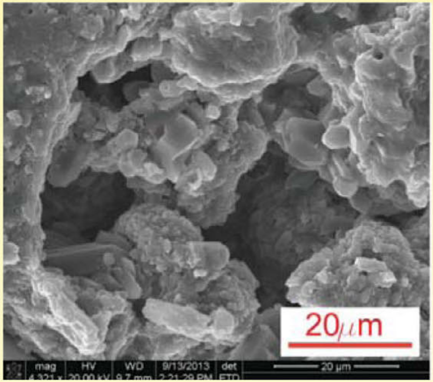
SEM Photomicrographs



Loucks et al., 2012

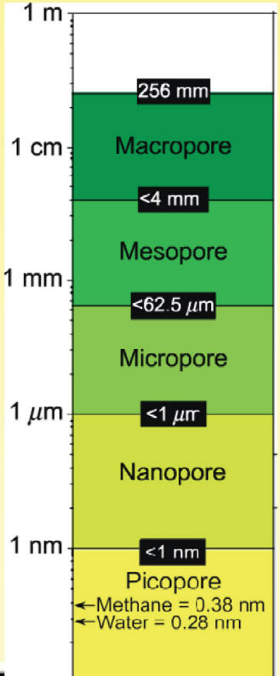




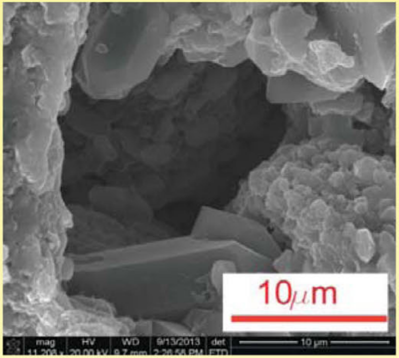


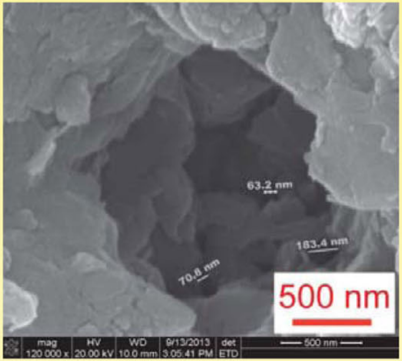
Pore Architecture

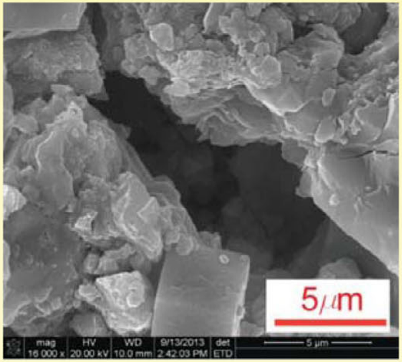
SEM Photomicrographs

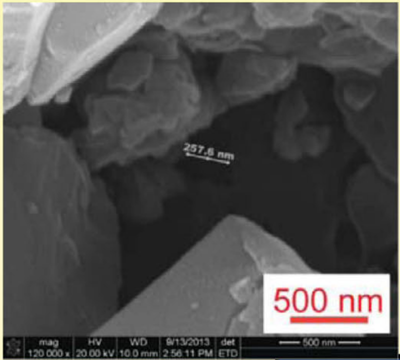


Loucks et al., 2012









Preliminary Conclusions

- Acoustic response of an unconventional carbonate is consistent with previous work.
- Acoustic response can be correlated to facies.
- Oil Saturated zones correlate with facies and acoustic response.
- Pore types range from the macro-, meso-, micro- and nanoscale.
- The entire core shoals upward and has several shoaling upward cycles observed in core.
- Shoaling upward cycles correlate to wireline logs (gamma ray).

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Continued (Future) Work

- Argon milling at 0.5 to 1.0 micron increments with SEM and digital image analyses.
- Integration of core and outcrop analyses from Northern Oklahoma, Arkansas and Missouri.
- Correlation to a sequence stratigraphic framework.
- Data extrapolation using 3-D modeling software to test predictability of permeability from sonic velocity and characterization of pore architecture

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