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


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

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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.
Pathway to Reservoir Prediction

- Total Porosity
- Acoustic Response
  - Pore Architecture
  - Primary & Secondary Porosity
- Permeability

[Diagram showing the relationships between the components]
Carbonate Rock Acoustic Response

Modified from Eberli et al. 2003
Velocity Correlation to Pore Type

- Time Average Equation for Dolomite
- Time Average Equation for Calcite

Microporosity
- Interpart./crystalline por.
- Densely cemented, low porous
- Moldic porosity
- Intraframe porosity

Porosity (%)

From Anselmetti and Eberli, 1999
Velocity-Porosity Relationship

interparticle-intercrystalline por.
Velocity-Porosity Relationship

Anselmetti and Eberli 1999
Predictable Velocity from Pore Type

Anselmetti and Eberli 1999

Time average equation
Velocity Correlation to Permeability

Modified from Anselmetti and Eberli 1999
Pathway to Permeability Prediction

Porosity

Acoustic Response

Pore Architecture

Primary & Secondary Porosity

Permeability
Pore Architecture (Digital Image Analysis)

- Small and complex
- Intermediate
- Large and simple

Graph showing relationship between Relative Dominant Pore Size and Total Perimeter / Total Area.
Permeability Prediction from Pore Architecture and Primary Porosity

- Quantified acoustic response
- Quantified pore architecture
- Quantified macro- and microporosity

*Predictable Permeability*

Weger et al. 2004
Methodology

Integrated Reservoir Characterization

Wireline Logs
Core and Thin Sections
Analogs
Sequence Stratigraphy
Geologic Modeling
3-D Seismic
Pore Architecture

Grammer, 2010
Porosity vs. Permeability
Macropore vs. Nanopore Systems

The graph shows the relationship between porosity and Vp (m/sec). The data points are color-coded to differentiate between macropore and nanopore systems. The y-axis represents Vp values ranging from 0 to 7000 m/sec, while the x-axis shows porosity percentages from 0% to 50%.

- Green triangles represent macropore systems.
- Blue diamonds represent nanopore systems.

The graph indicates a generally positive correlation between porosity and Vp for both macropore and nanopore systems, with a slight trend of increasing Vp values with decreasing porosity.
Velocity vs. Porosity

- Velocity (Vp) vs. Porosity %
- Data points and trend lines
- Key values: 6600 m/s at 1% porosity, 5200 m/s at 5.5% porosity
Oil Saturation, Porosity, and Permeability

Oil Saturation

Porosity

Permeability

Permeability
Velocity vs. Oil Saturated Zones

![Graph showing velocity vs. porosity](chart.png)
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.
Velocity Correlation to Facies

Porosity %

Velocity (m/sec)
Velocity, Facies & Oil Saturation

Porosity %

Velocity (m/sec)
Pore Classification for Mudrocks

Loucks et al., 2012
Pore Architecture
Thin Section Photomicrographs
Pore Architecture

SEM Photomicrographs

- **Macropore**
- **Mesopore**
- **Micropore**
- **Nanopore**
- **Picopore**

- Methane = 0.38 nm
- Water = 0.28 nm

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).
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.