Core Analysis to Characterize Caprock and Injection Intervals, Kevin Dome Phase III Project

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Introduction

The Big Sky Carbon Sequestration Partnership's Kevin Dome Large Scale Injection Project in Toole County, Montana offers a unique opportunity to analyze core with and without long-term exposure to CO_2 in a heterogeneous carbonate reservoir. Research on core from two wells, one in the CO_2 gas cap of the dome and one down-dip in the water leg, is greatly improving our understanding of the local geology. Core recovered from injection and caprock intervals, along with derived thin sections, have allowed for detailed characterization. Recent analysis explores heterogeneity in rock porosity and permeability as related to formation diagenesis and impact on fluid flow. Results form the basis for ongoing CO_2-brine flow-through experiments. Measurements of the Potlatch anhydrite are revealing a very strong and stiff material that also yields plastically prior to failure, excellent properties for a caprock. Lastly, seismic properties derived from core are helping to interpret seismic inversion results and develop models to simulate dissolution effects. Results of this work are presented in the panels below.

Assessment of Heterogeneity and Porosity Characteristics of the Middle Duperow Formation

The Middle Duperow is a heterogeneous carbonate reservoir. Core analysis shows changes in porosity and permeability at the < 1ft scale that are interpreted to reflect a combination of processes, high-order cyclicity and diagenesis based on core observations. These small-scale changes may greatly impact fluid flow.

Moldic, intergranular/intercrystalline, and fracture porosity are the most common types of porosity present in Middle Duperow core samples, with intergranular/intercrystalline and fracture porosity being most conducive to higher permeabilities. Images below show core properties of the CO_2 production area (Danielson 33-17) and injection area (Wallewein 22-1) of the formation at Kevin Dome. Sampling points for core plug porosity and permeability measurements and supercritical CO_2-brine batch reactions, are indicated by sample labels (D68-70 and W44 & 46).

Figure a: Danielson 33-17

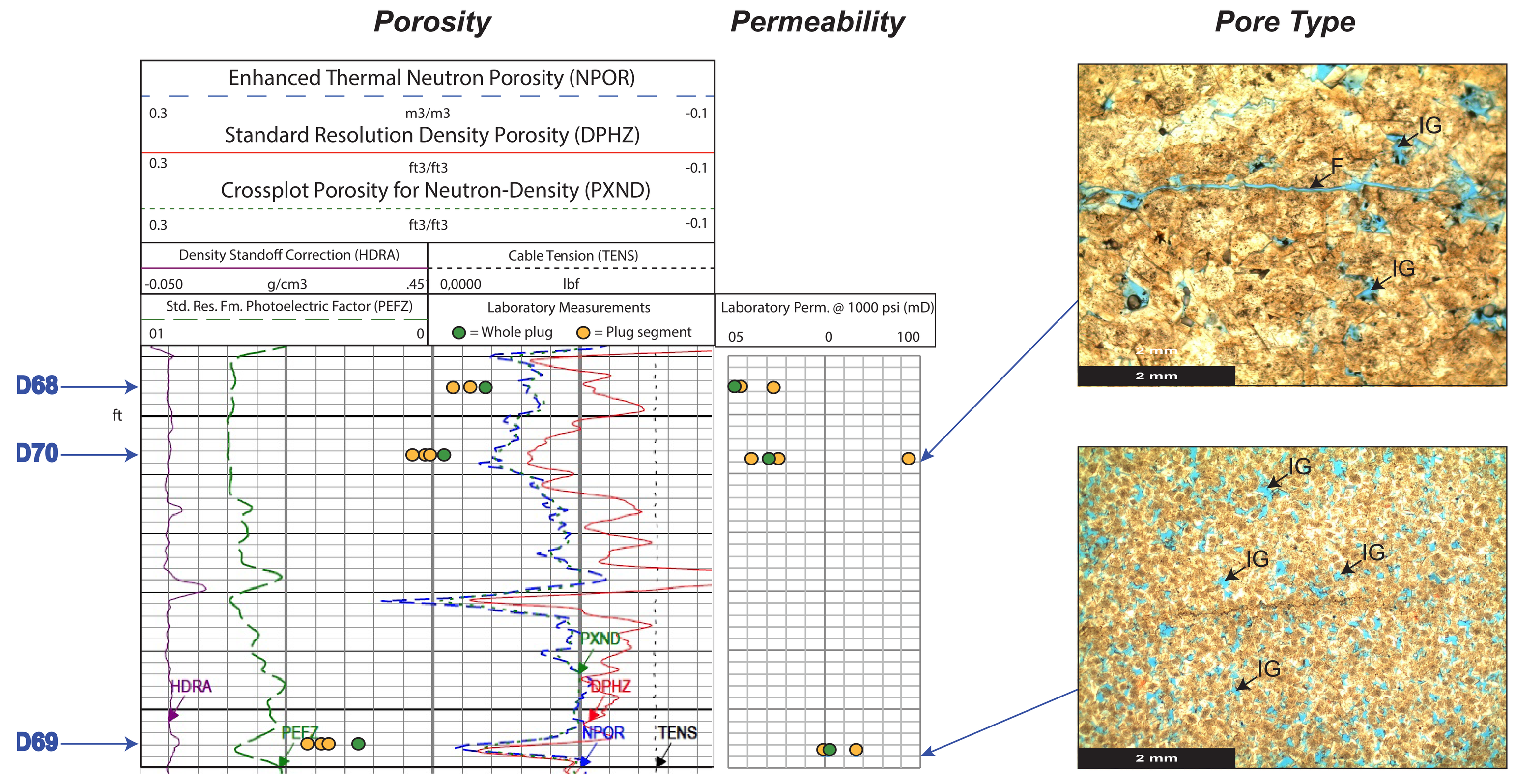
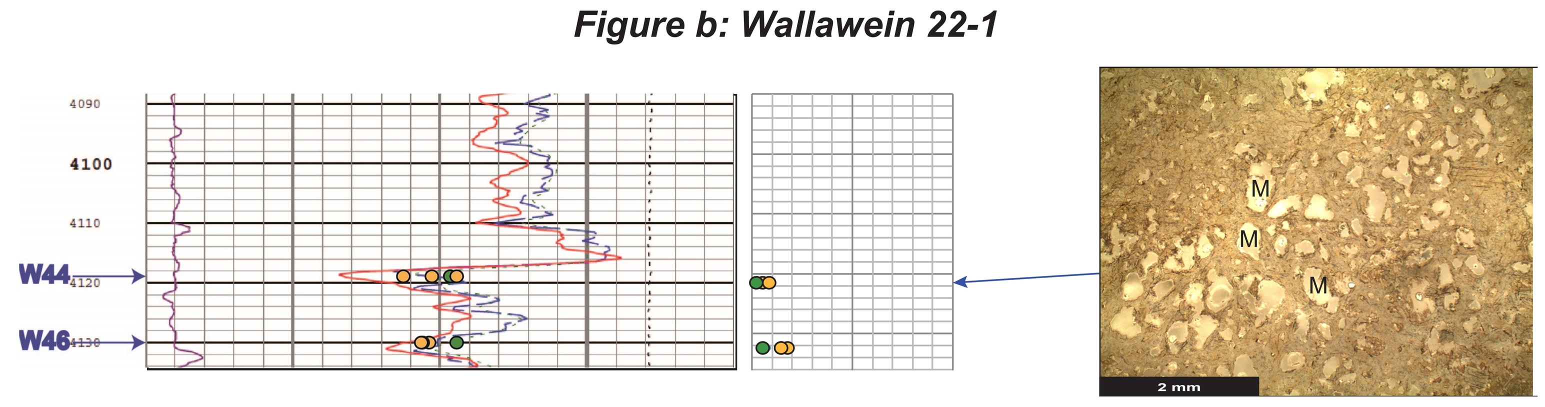


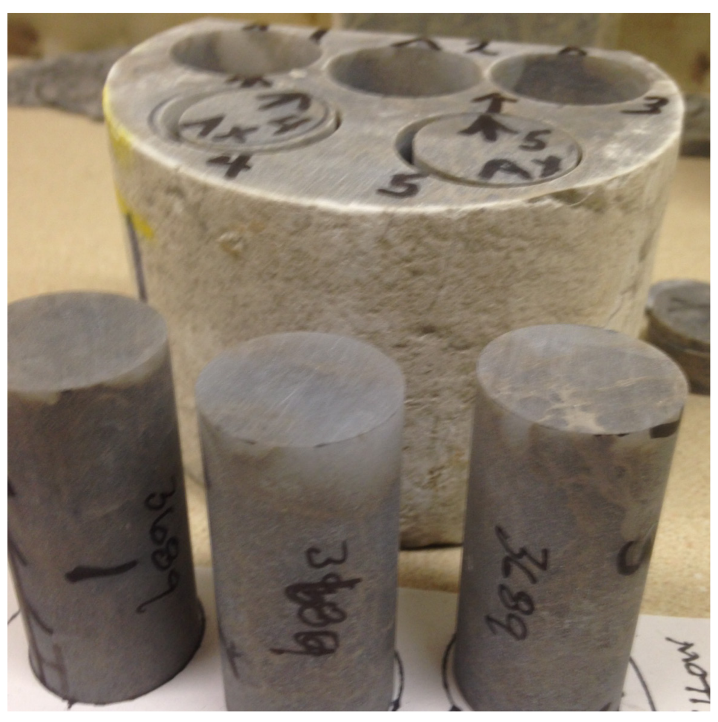
Figure b: Wallawein 22-1



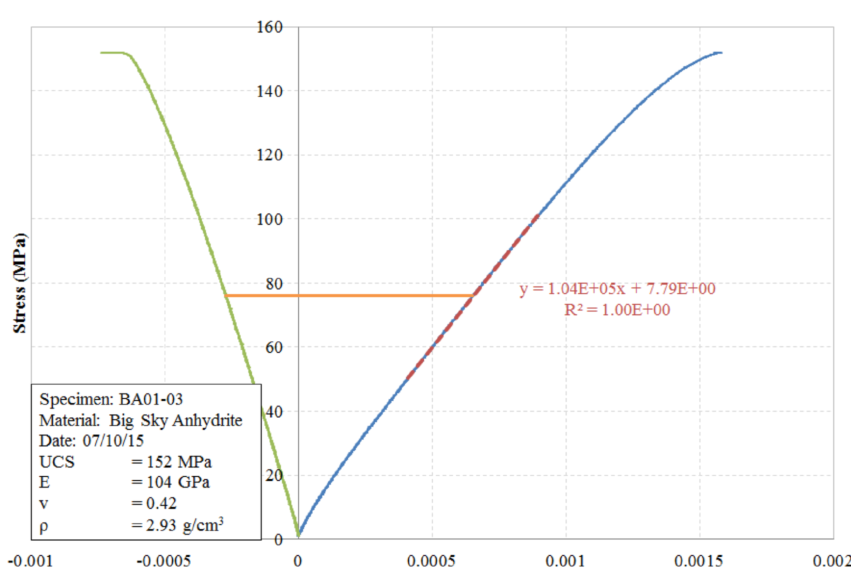
Left column: Laboratory porosity measurements (green and orange circles) overlain on a portion of the porosity logs for Danielson 33-17 and Wallawein 22-1 and displayed at the same scale. Core plugs are 1 inch in diameter with whole plugs measuring 1.9-2.4 inches and plug segments 0.54-0.62 inches in length. Center column: Klinkenberg-corrected laboratory permeability measurements for each sample (green and orange circles) at a confining pressure of 1000 psi, same nomenclature as for the porosity measurements. Right column: 2.5X photomicrographs illustrating common pore types seen in this sample set (M=moldic, IG= intergranular, F= fracture).

Geomechanical Properties of the Caprock: Potlatch Anhydrite

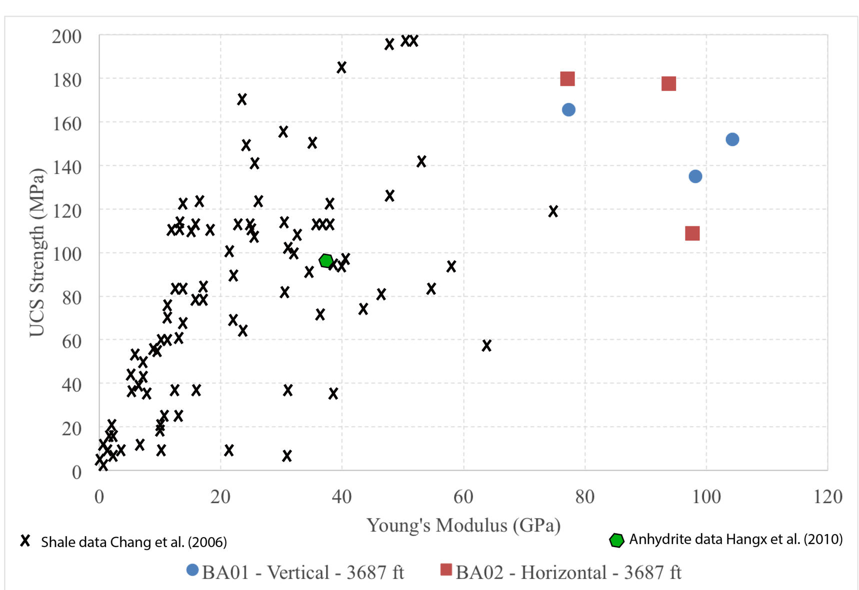
The Potlatch is a dolomite-bearing anhydrite caprock that overlies the Middle Duperow dolomite reservoir at Kevin Dome. The Wallawein 22-1 (monitoring) well provided 1x2" cores for geomechanical tests of strength and elastic parameters. Geomechanical testing was done at unconfined conditions and room temperature. Results indicate that the Potlatch is unusually strong and stiff but still displays plasticity in unconfined tests to failure under compression.



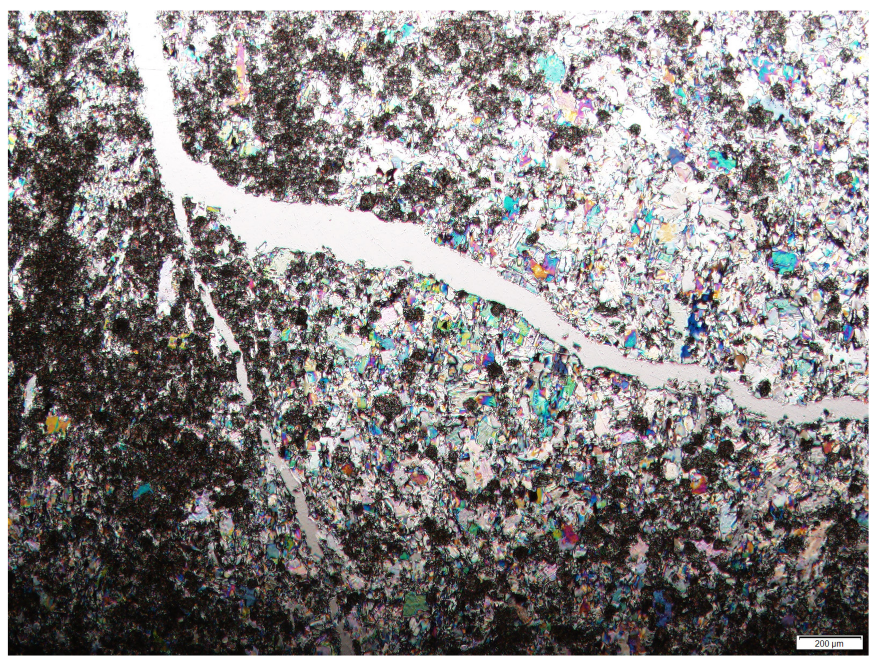
"Vertical" core taken parallel to the Wallawein borehole



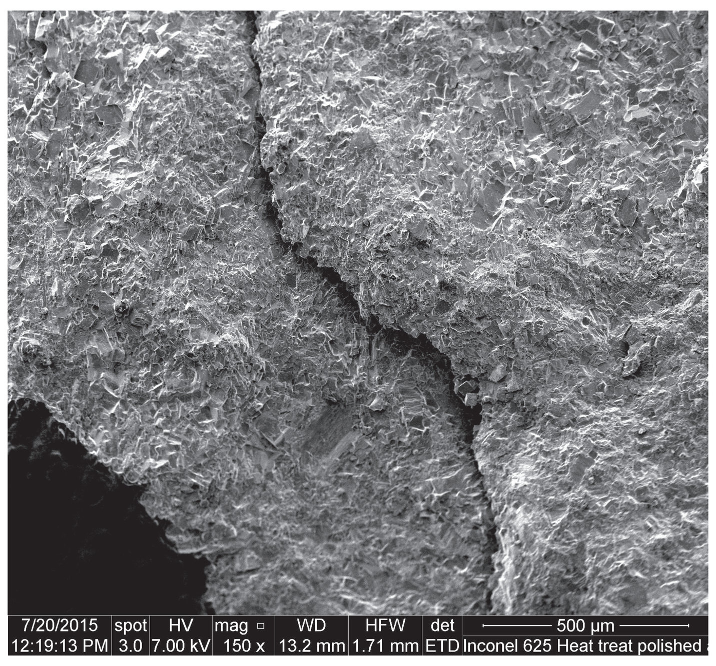
Data collected for a vertical anhydrite core shows the very stiff stress-strain response and the plastic yield at the failure point of 152 MPa.



Summary of unconfined strength (150±24 MPa) and Young's modulus (90±10 Gpa) compared with shale and anhydrite. The Poisson's ratio is 0.32±0.05.



Photomicrograph of fracture textures in the Potlatch following mechanical failure.

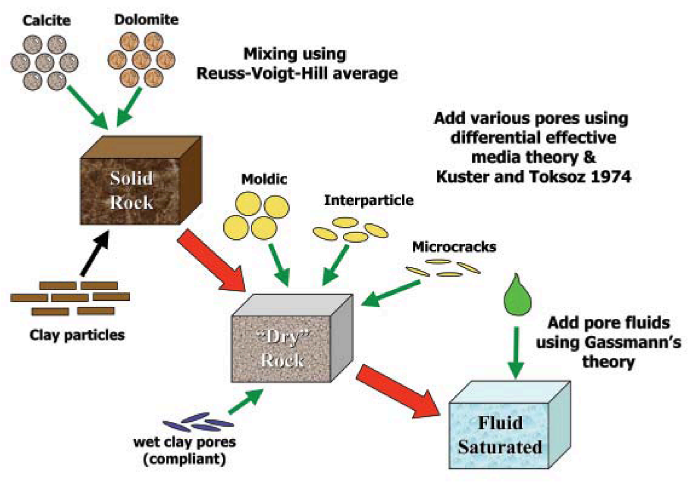


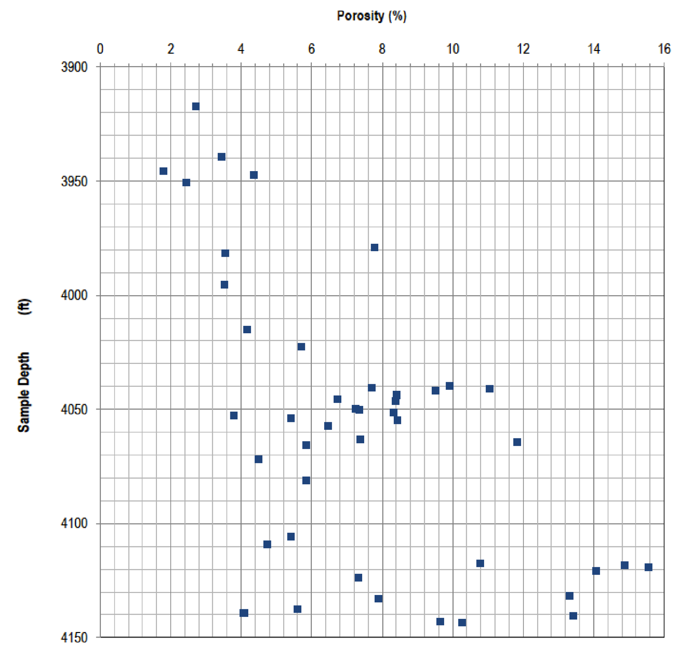
Scanning electron microscopy of fractured Potlatch anhydrite.

Porosity Dependence of the Duperow Formation: Ambient Vp & Vs

The Duperow Formation is the primary production and injection target for the BSCSP Kevin Dome pilot. Minimal prior laboratory measurements of seismic properties (Vp & Vs) have been conducted to assist interpretation of seismic inversion results and develop models to predict dissolution effects. We present the results from 10 dry ultrasonic measurements on cores from the Wallewein 22-1 well, a comparison to sonic log and porosity data, and best fit using a modified Kuster-Toksoz (KT) effective medium model.

Procedure: Vp & Vs measurements were obtained for 1 inch plugs taken from whole core from the Wallewein 22-1 well. Seismic measurements were conducted with 500 kHz NER transducers & a Panametrics pulser recorded on a digitizing oscilloscope (Tektronix TDS 210) after Helium porosity/gas permeability at BSCSP. Samples were dried with a small (100 g) axial load. Data was fit using the Kuster-Toksoz effective medium model as modified by Xu & Payne (2008), a crack aspect ratio of 0.2, and a calcite/dolomite ratio obtained from XRD measurements. Sonic and neutron logs were extracted for the same depth horizons for comparison.

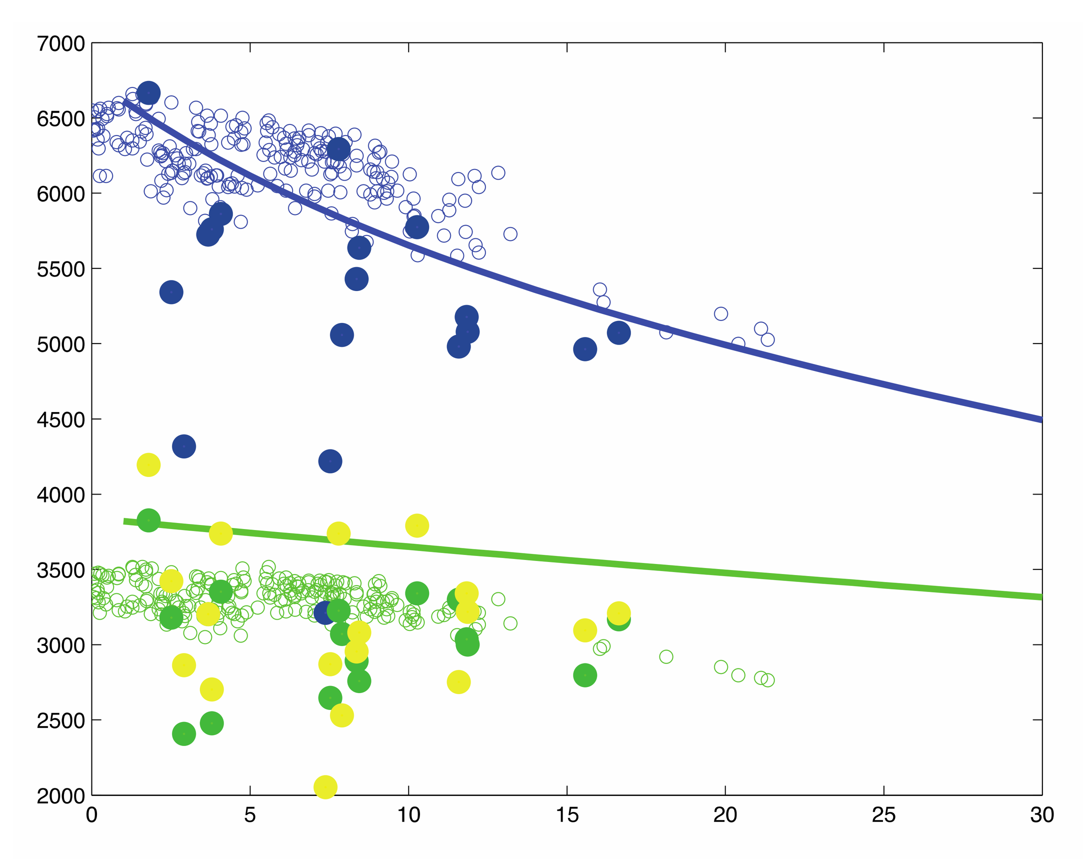




Wallewein Porosity/Permeability measurements, obtained by BSCSP.

Results: Ambient pressure Vp (solid blue) as well as Vs (solid yellow/green) compared to sonic log/neutron porosity crossplot (open symbols) and a carbonate effective medium theory based on a modified Kuster-Toksoz relation

Wallewein Samples Measured:
- 3 = 1.79% porosity
- 6 = 7.79%
- 17 = 8.37%
- 21 = 3.8%
- 23 = 8.44%
- 26 = 11.84%
- 34B = 15.57%
- 38B = 7.89%
- 40B = 4.08%
- 43B = 10.28%



Conclusions: Laboratory Vp & Vs measurements were comparable to log values despite obvious differences in conditions (saturation state, effective stress, frequency). Ambient lab measurements showed a larger spread, likely due to small fractures which were not closed at ambient conditions. The fit KT model effectively captured Vp vs. porosity trends but tended to over-estimate Vs, suggesting opportunity for refinement.

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