Impact of Fluid Injection on Permeability and Pore Structure of Shales

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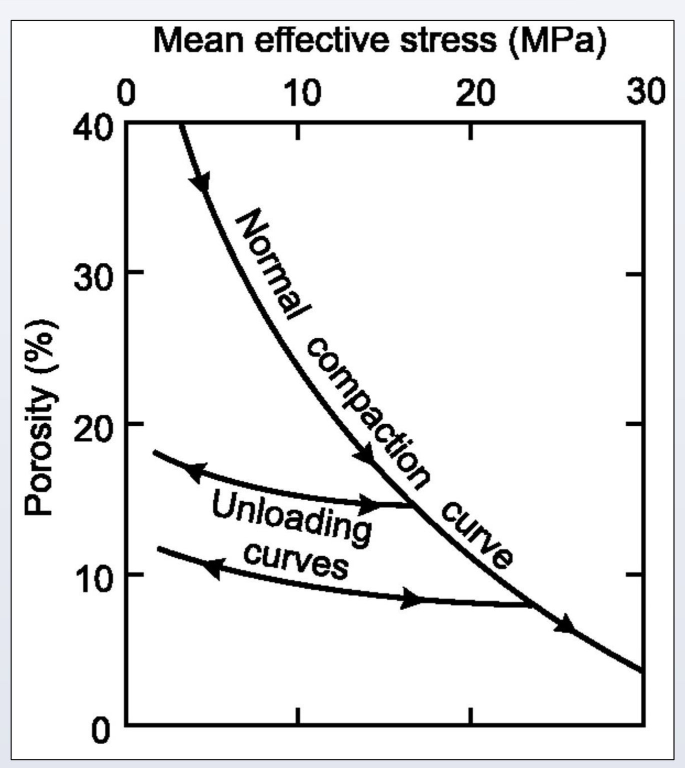
Abstract

Subsurface fluid injection has been used for hydraulic fracturing, wastewater management, and carbon capture. Such anthropogenic processes decrease the effective stress by increasing pore pressure, a process known as unloading. Flow back volumes during hydraulic fracturing range from 25-75% of injected fluid. The fate of injected fluid, evolution of pore structure, and fluid migration pathways upon injection remain largely unknown. We have developed analogs for three pore structure evolution pathways in shale upon unloading: dilation, micro-fracture network growth, and fracture propagation. We predict the permeability associated with different pore expansion models using Lattice Boltzmann simulations. The next step is to measure the permeability, the pore-size distribution, and the P-wave/S-wave velocity of shale during unloading due to fluid injection. To define the absolute changes in these properties we will measure permeability and velocity on individual samples in a pressurized core holder and the nuclear magnetic resonance (NMR) T2 relaxation time in a pressurized NMR system, which can be related to the pore size distribution. Linkage of the laboratory data and numerical models will help us identify the ways in which pore structure changes during unloading, how they are influenced by type and rate of unloading, and the implications they have for fluid transport.

Fluid Injection is an unloading process

$$\sigma_{eff} = \sigma_V - \alpha P_p$$

σ_{eff} : Effective Stress
σ_V : Vertical Stress
α : Pressure constant
P_p : Pore Pressure

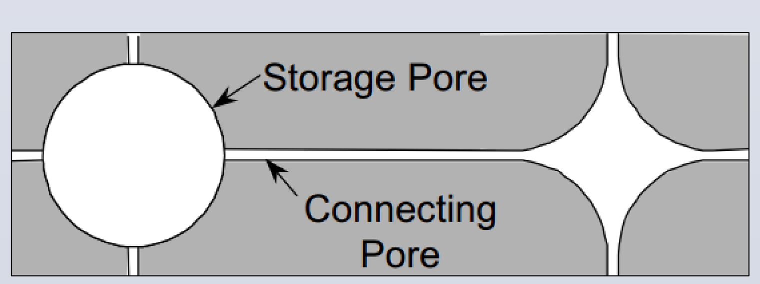


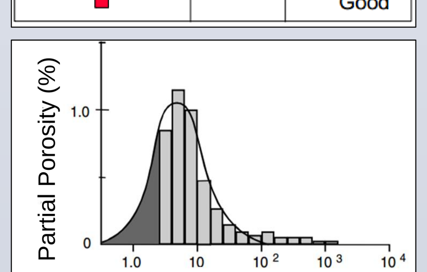
Pores within shale rocks are of two types:

Storage Pores
- High aspect ratios
- Stiff

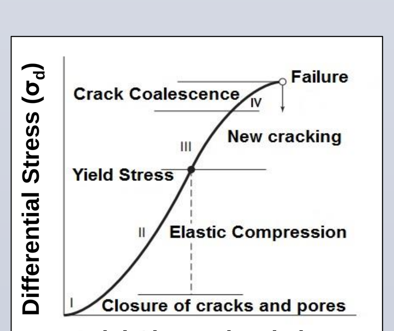
Connecting Pores
- Low aspect ratios
- Flexible

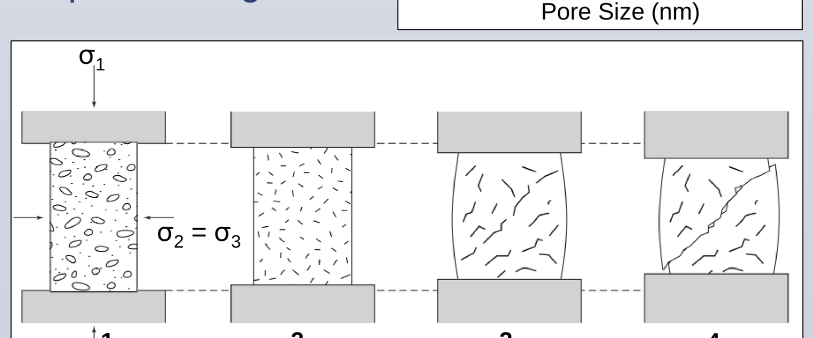
Pore Shape	Aspect Ratio	Sensitivity to Fluid Expansion
	> 0.1	Poor
	0.001 - 0.1	Good
S_{min}, P	< 0.001	If P < S_{min} Poor; If P = S_{min} Good





Pore structure evolution upon loading

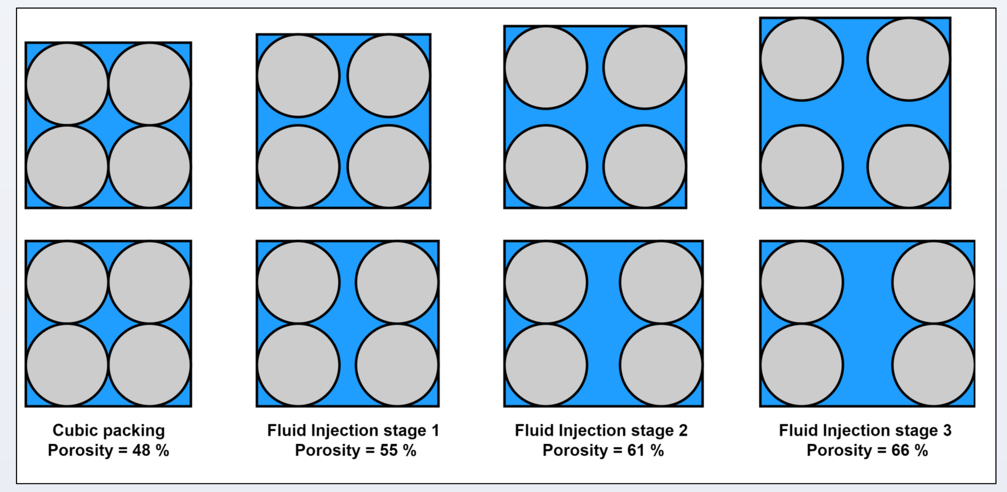


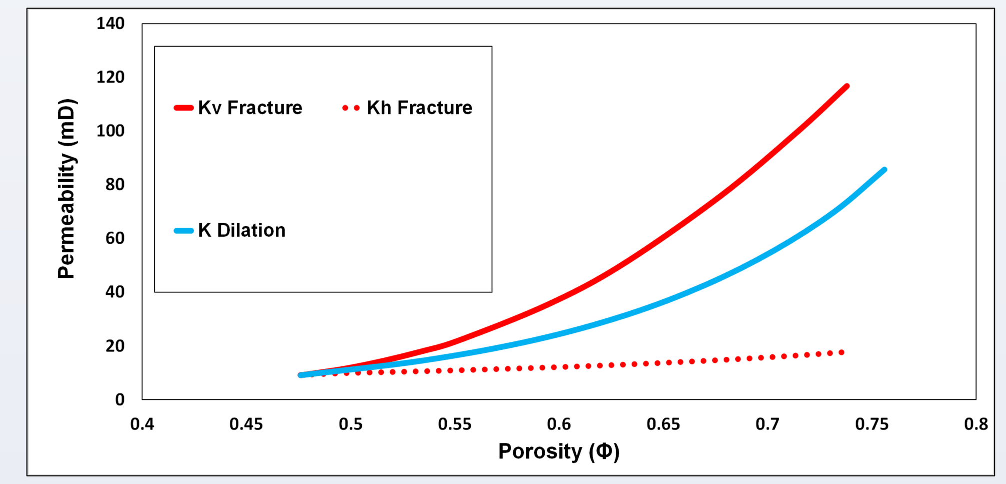


Permeability analogs for fluid injection using Lattice Boltzmann Method

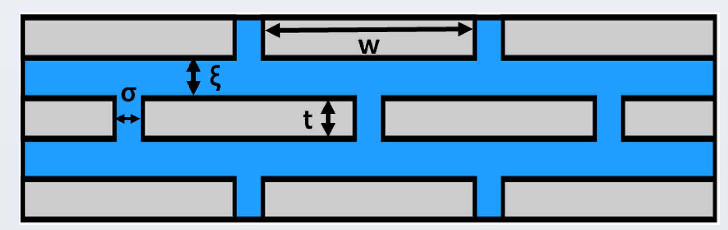
Lattice Boltzmann Simulations allow us to predict permeability through a defined pore geometry and develop porosity-permeability analogs for varying fluid transport and storage mechanisms.

Sandstone model





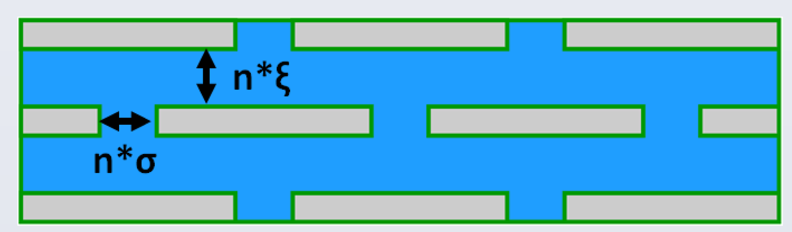
Shale Model

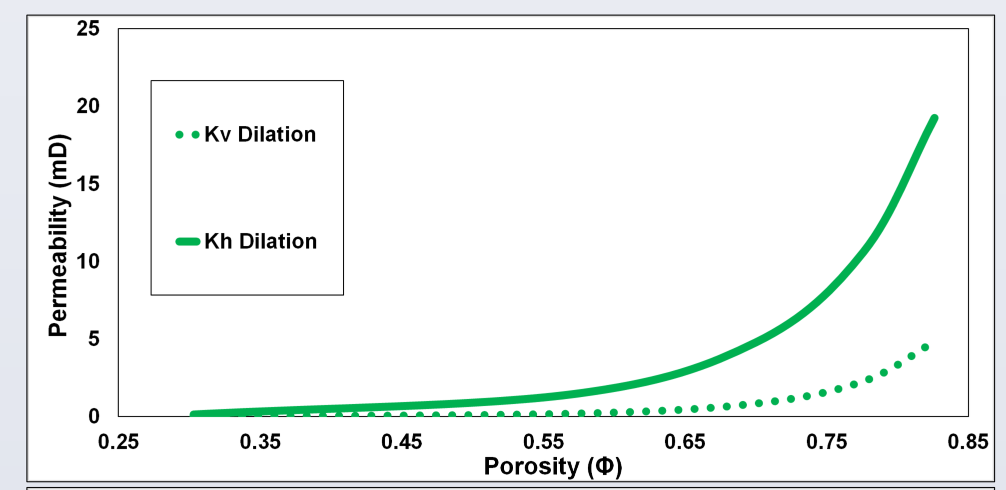


w = 1 µm
t = (1/40) w
Φ_i = 0.303
Kh = 0.15 mD
Kv = 0.014 mD

Dilation

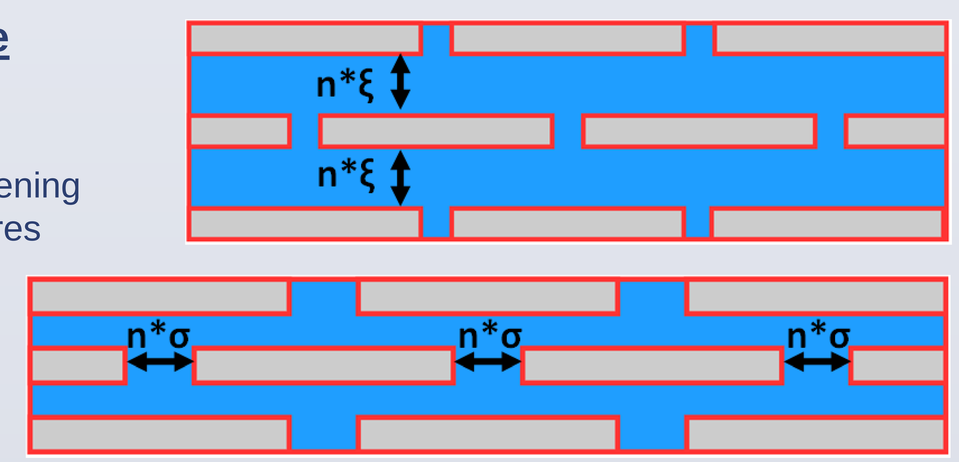
Expansion of connecting and storage pores

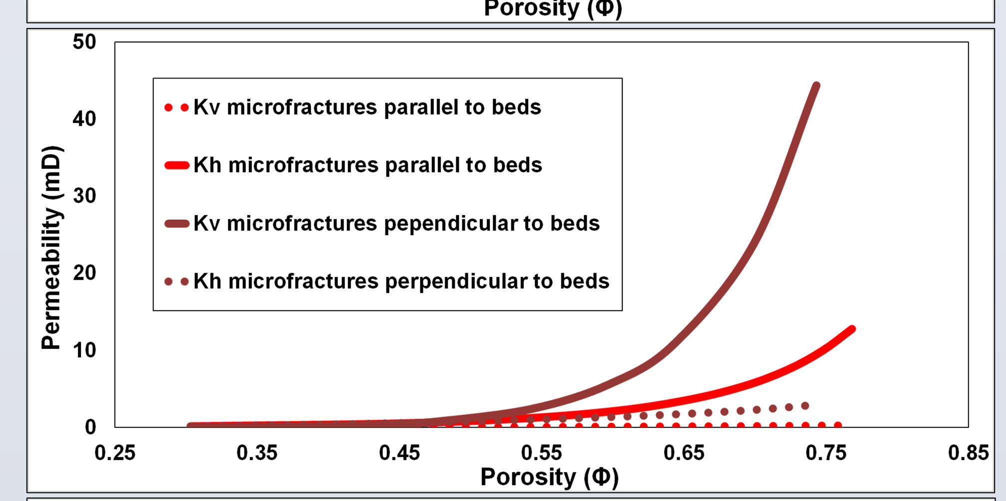




Micro-fracture growth

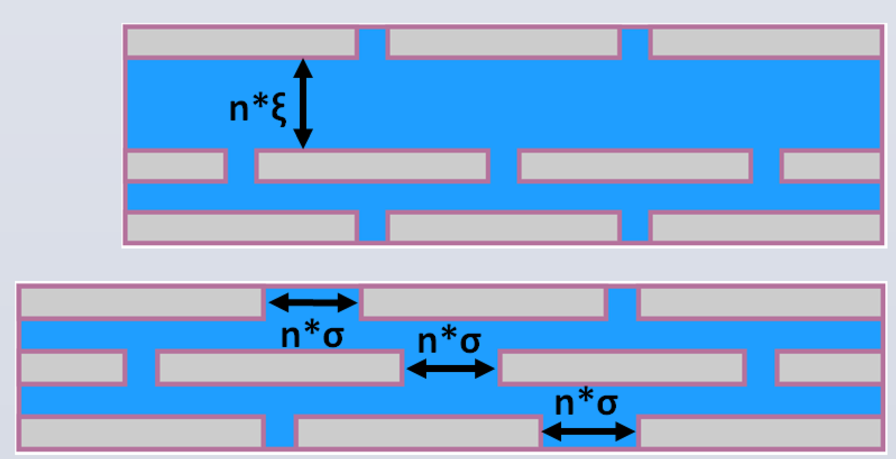
Preferential reopening of connecting pores

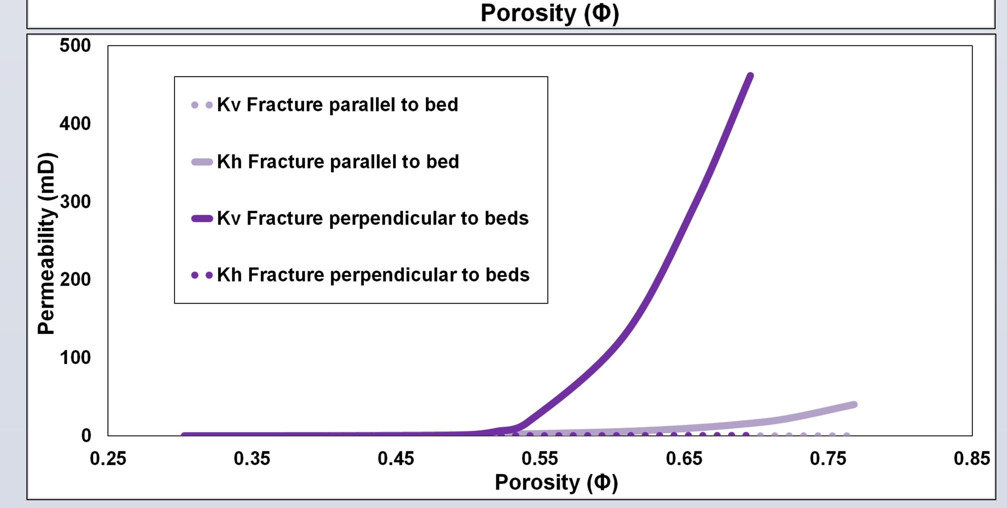




Fracture Propagation

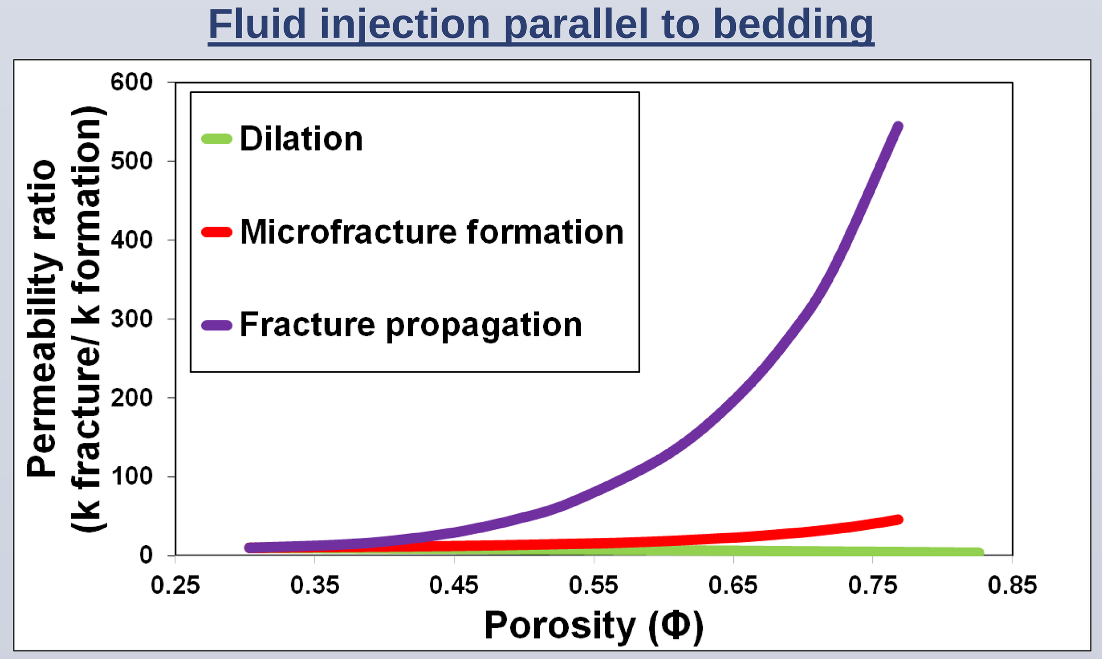
Formation of high conductivity pathway



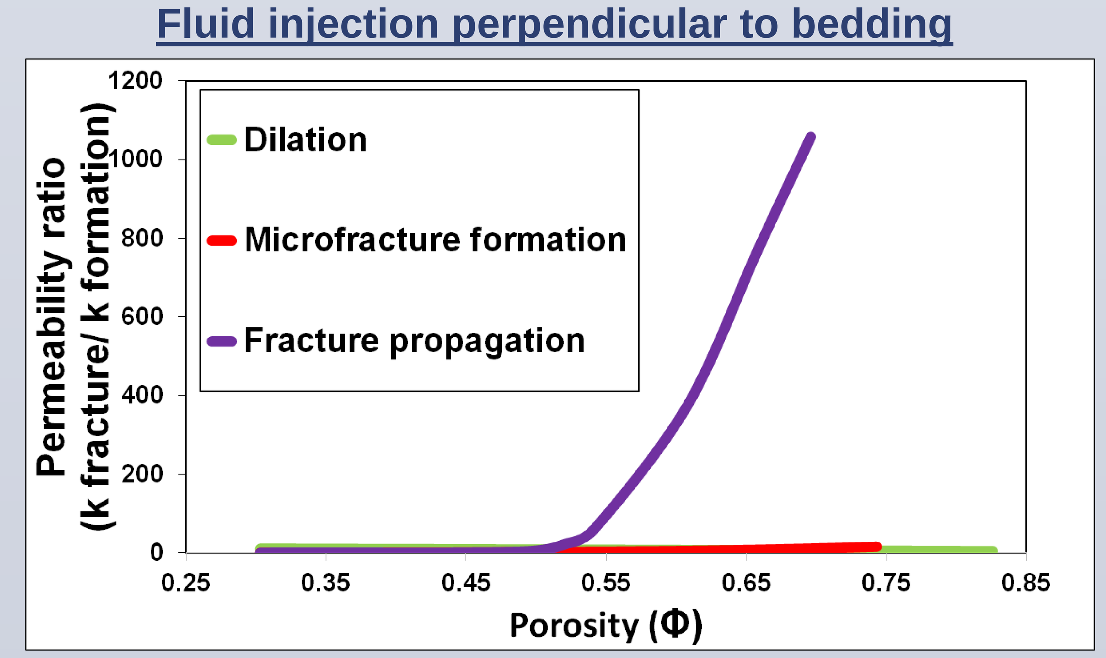


Permeability anisotropy signatures to identify Pore Structure Evolution mechanism

Fluid injection parallel to bedding



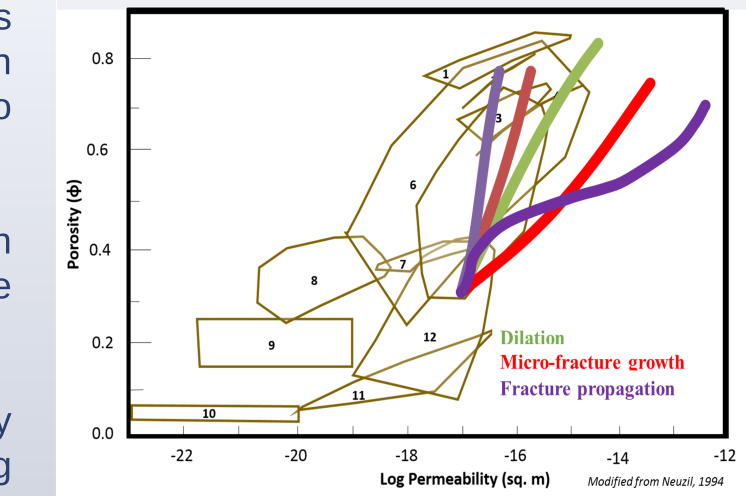
Fluid injection perpendicular to bedding



Future modeling approach: Modify initial pore geometry to match porosity of selected shale samples for experimental analysis. Permeability growth and anisotropy trends from Lattice-Boltzmann simulations can be developed to infer dominating pore structure evolution mechanisms upon unloading.

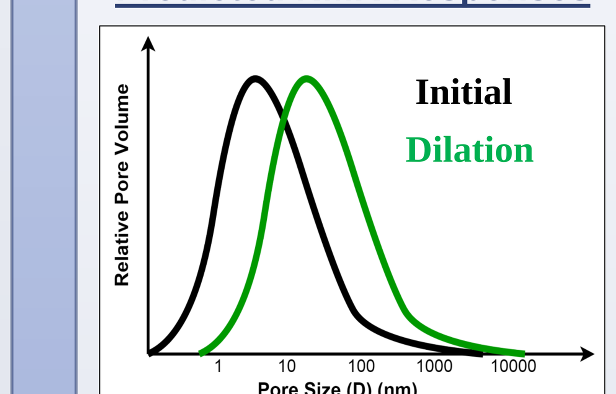
Key Results

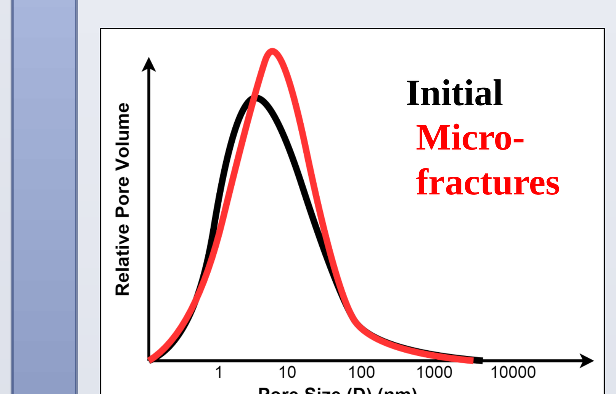
1. Porosity – Permeability trends developed from Lattice Boltzmann simulations are comparable to experimental datasets
2. Permeability analogs have been developed for dilation, micro-fracture growth and fracture propagation
3. Permeability anisotropy trends vary significantly based on unloading response

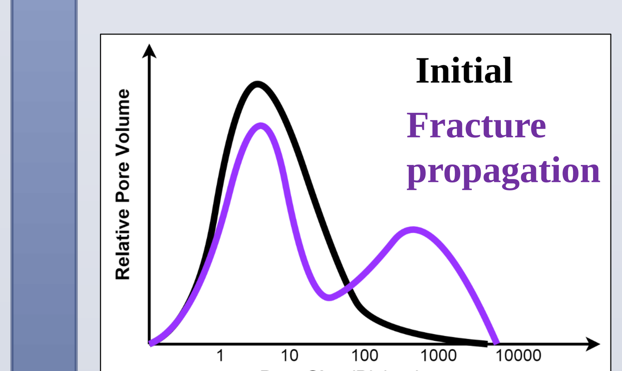


Future Work: Experimental Results

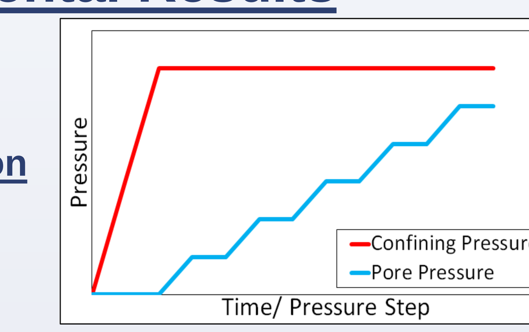
Predicted NMR Responses



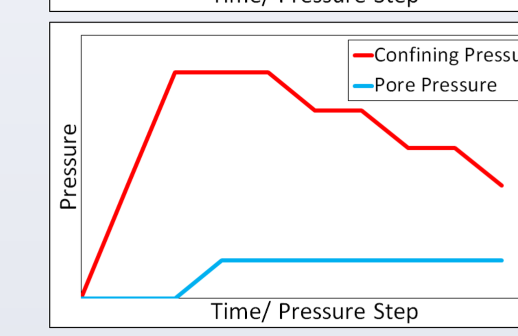




Fluid Injection

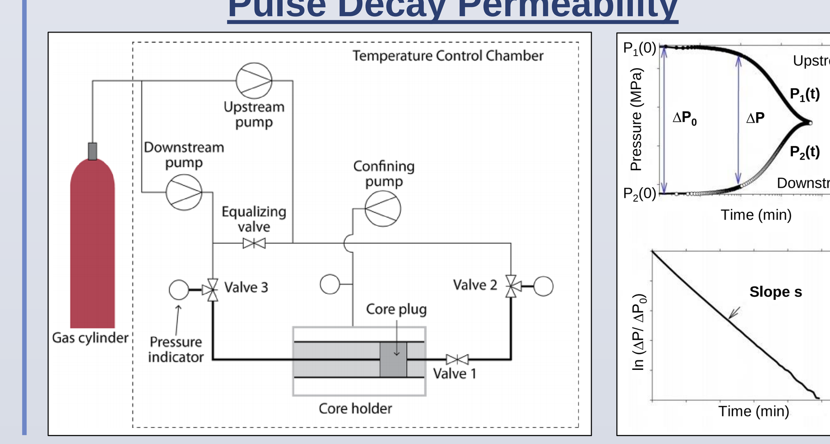


Erosion and Unroofing



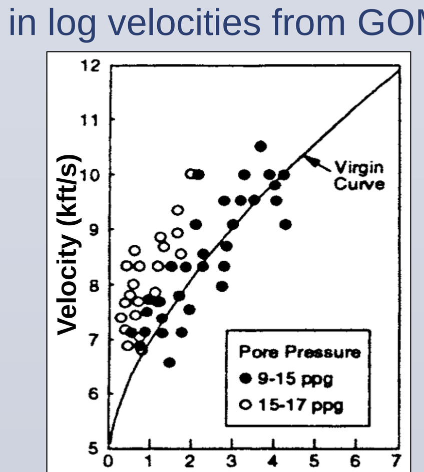
Petrophysical responses will be recorded at each effective stress state:
- Relaxation time (T2)
- Permeability (k)
- Compressional wave velocity (Vp)
- Shear wave velocity (Vs)

Pulse Decay Permeability



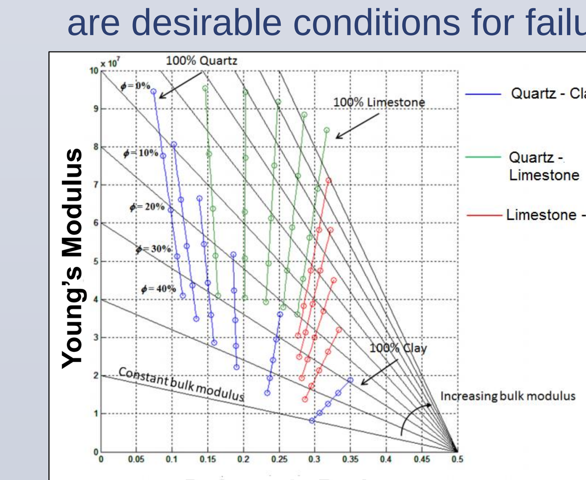
Wave Velocities – Vp and Vs

Unloading signatures observed in log velocities from GOM



Frackability of shales

A low Bulk Modulus and Poisson's Ratio are desirable conditions for failure



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