



SHALE PETROPHYSICAL CHARACTERISTICS

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INFUSE

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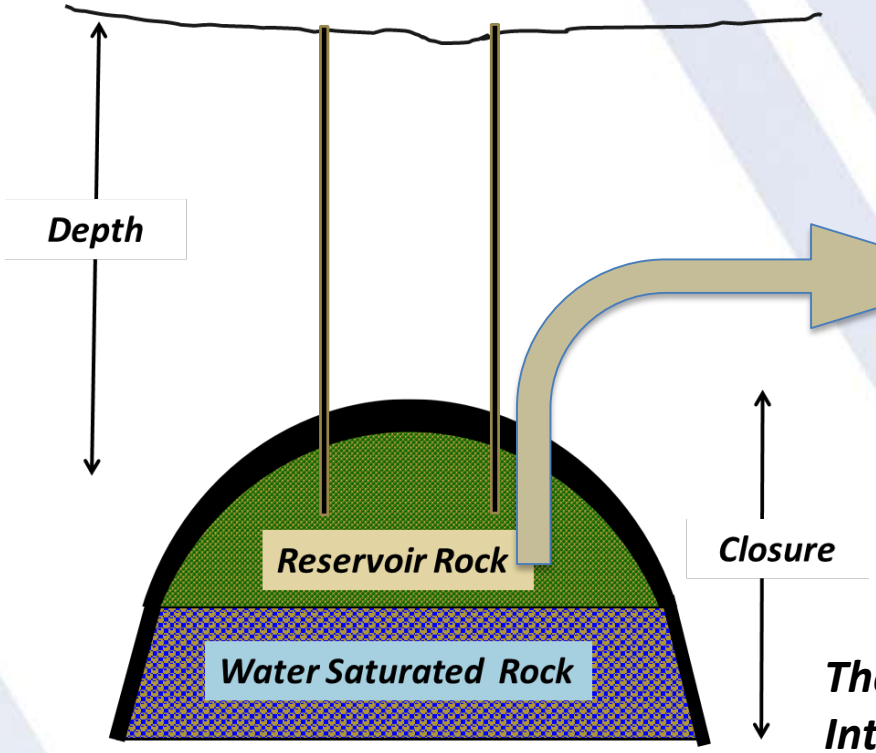
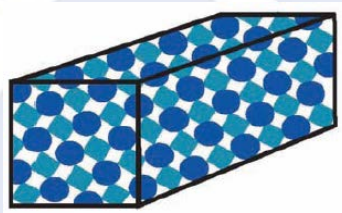
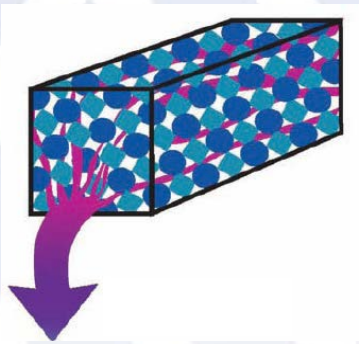
KEY RESERVOIR CHARACTERISTICS





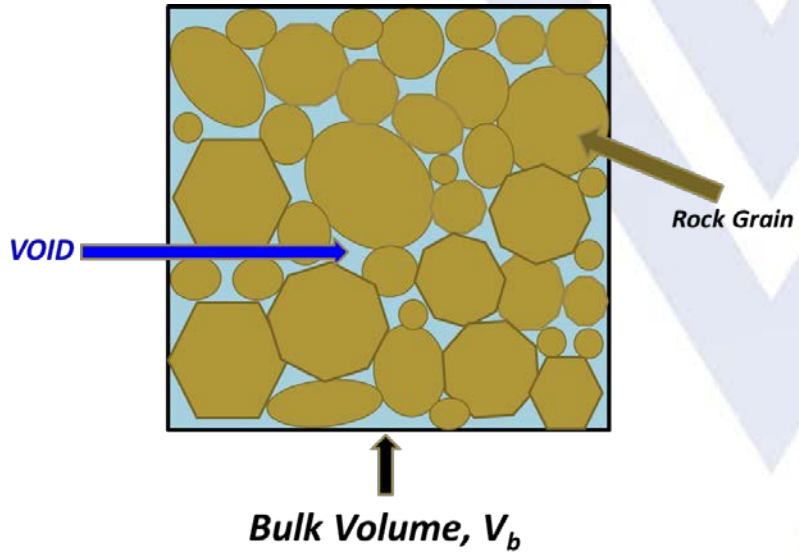
Porosity



Permeability

The Reservoir Rock Contains a 3-D Network of Interconnected Pores which allows for to Storage and Transmission of Fluids.

KEY RESERVOIR CHARACTERISTICS



$$\phi = \frac{V_p}{V_b}$$

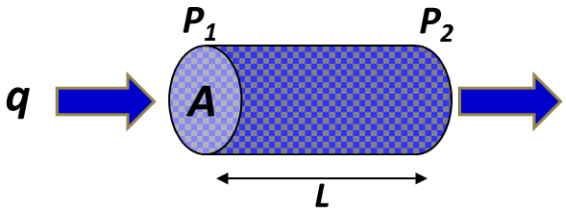
$$V_b = Bulk\ Volume$$

$$V_p = Pore\left(Void\right)\ Volume$$

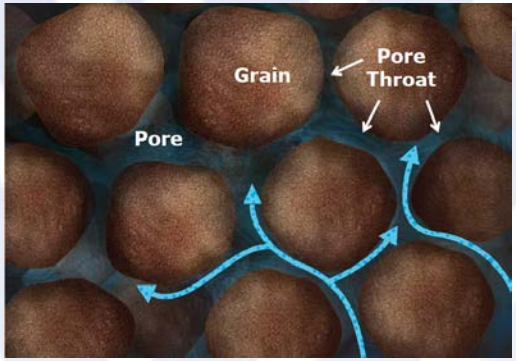
THE OPEN SPACE CREATED BETWEEN GRAINS DURING DEPOSITION IS REFERRED TO AS THE VOID, OR PORE, SPACE.

KEY RESERVOIR CHARACTERISTICS

PERMEABILITY IS DEFINED BASED ON AN EQUATION, DEVELOPED BY HENRY DARCY:



$$k = \frac{q\,\mu\,L}{A\left(p_1 - p_2\right)}$$



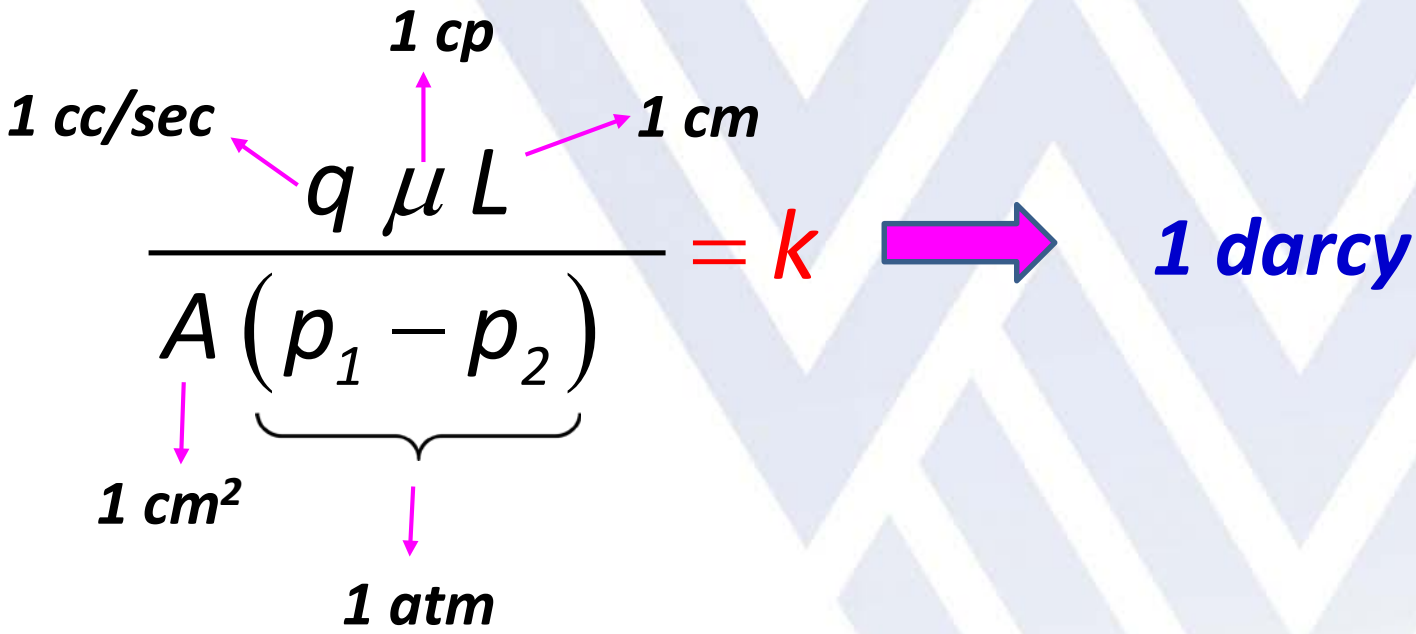
q = *Flow Rate through the Porous Medium*

A = *The Area across which the flow occurs*

μ = *Fluid Viscosity*

L = *Length of the Medium.*

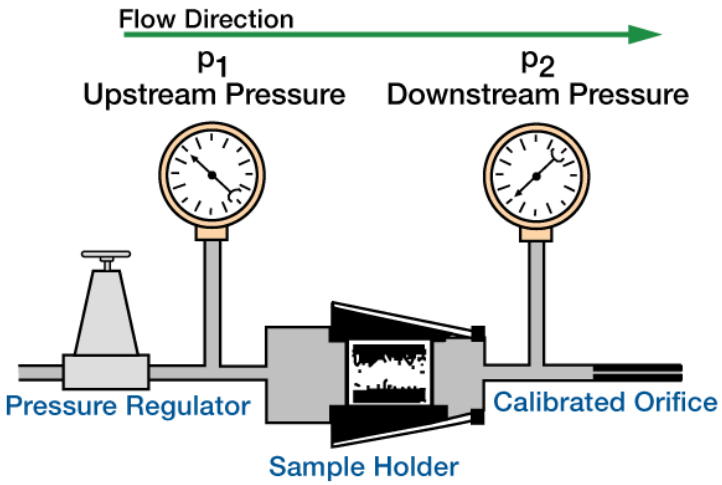
KEY RESERVOIR CHARACTERISTICS



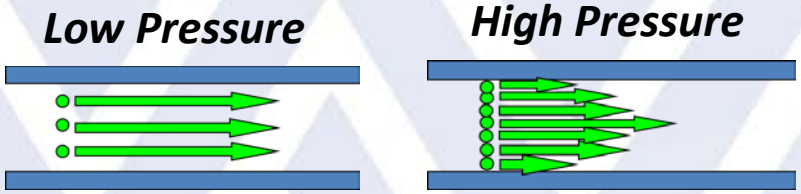
One darcy is a relatively high permeability and millidarcy (md) is commonly used as the permeability unit.

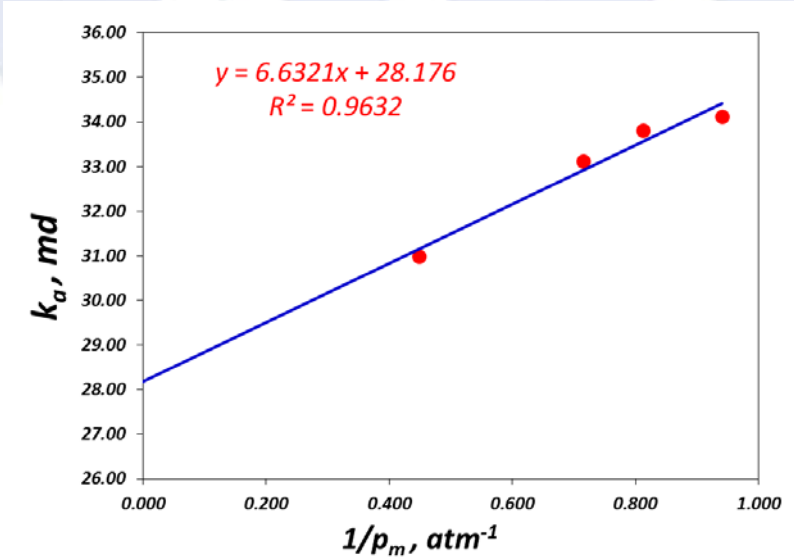
1 darcy = 1000 md

PERMEABILITY MEASUREMENT

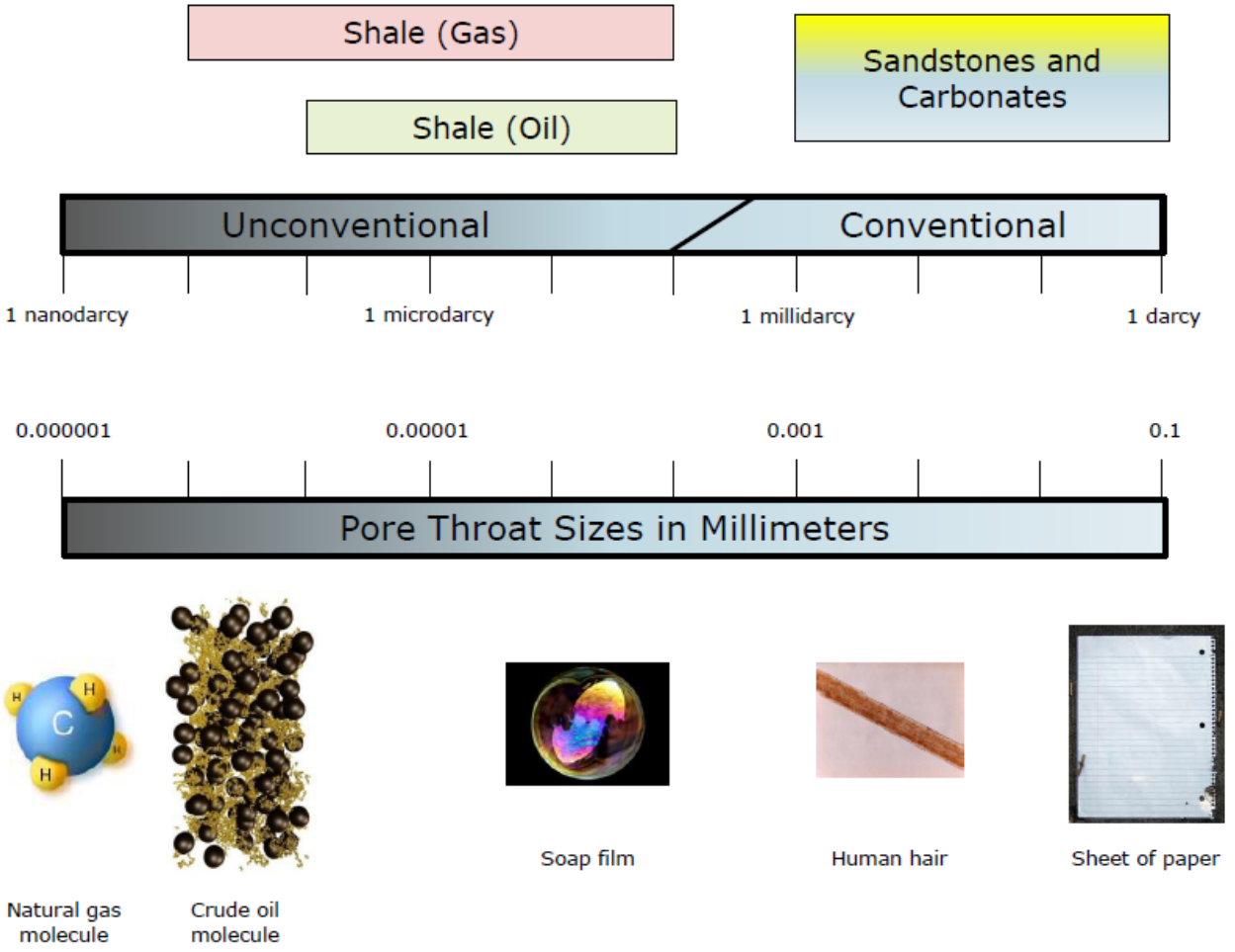


GAS SLIPPAGE

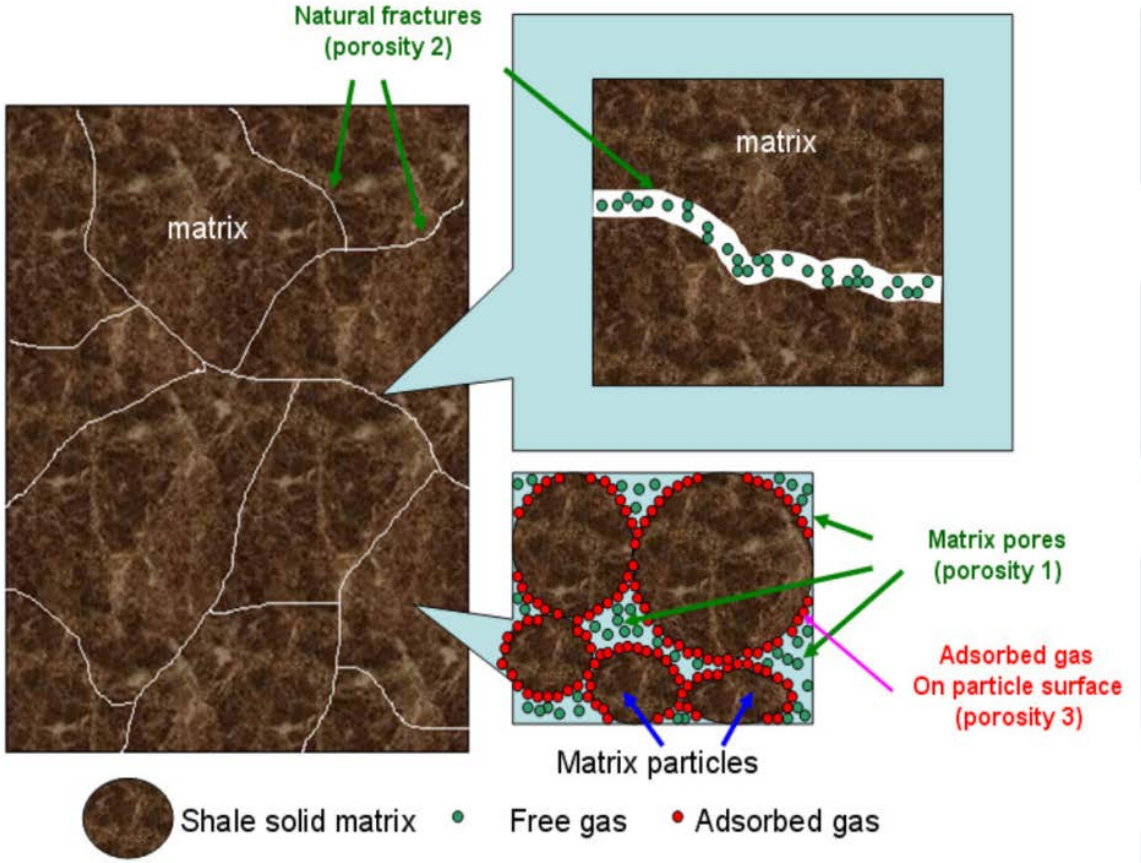




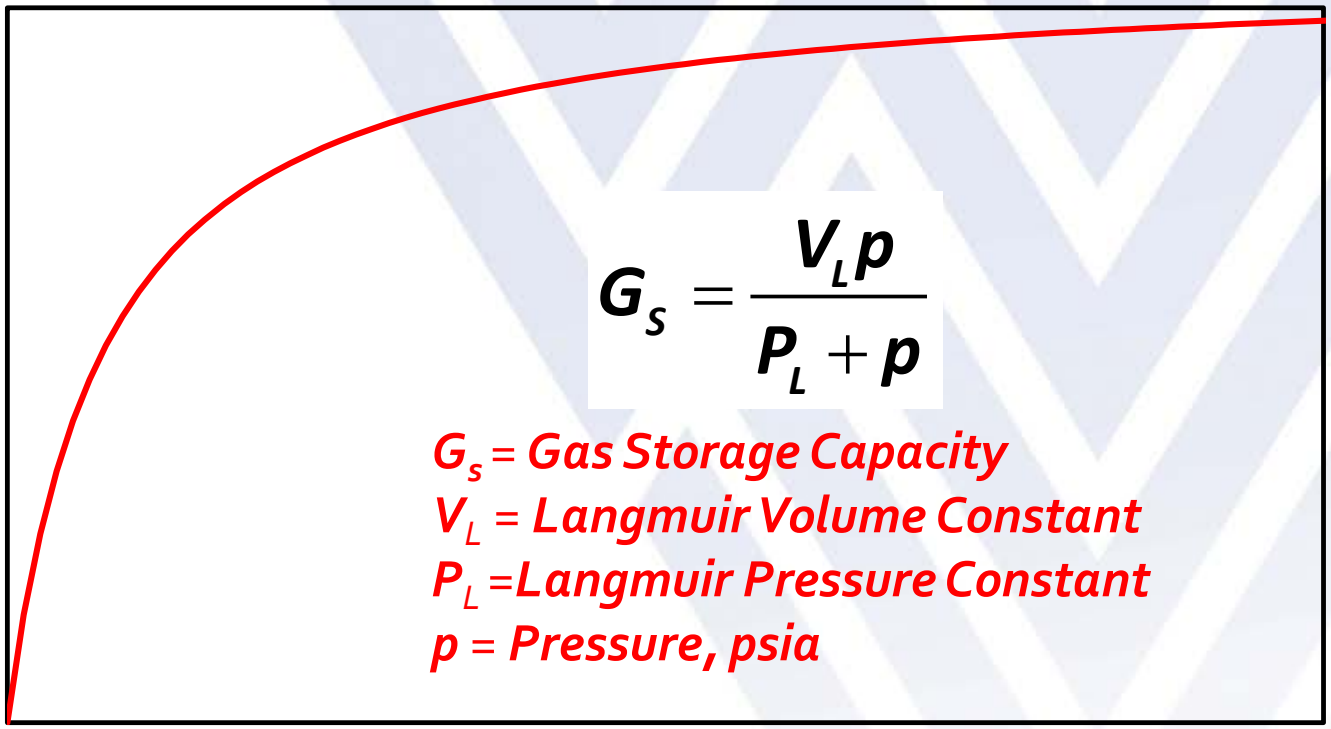
UNCONVENTIONAL RESERVOIRS



SHALE GAS RESERVOIRS



Langmuir Isotherm



$$G_s = \frac{V_L p}{P_L + p}$$

G_s = Gas Storage Capacity
V_L = Langmuir Volume Constant
P_L = Langmuir Pressure Constant
p = Pressure, psia

Measurement of Shale Petrophysical Properties

Pore Volume

- Low-pressure gas pycnometry
- High-pressure mercury injection
- Low-temperature adsorption

Permeability

- GRI Method
- Pressure Pulse Decay

Pore Size Distribution

- MICP
- NMR
- SEM/STEM
- Low-temperature Adsorption

Adsorption

- Gravimetric
- Volumetric

Shale Permeability Measurement

- It is not practical to measure the permeability of shale by conventional (steady-state) techniques because of low permeability.

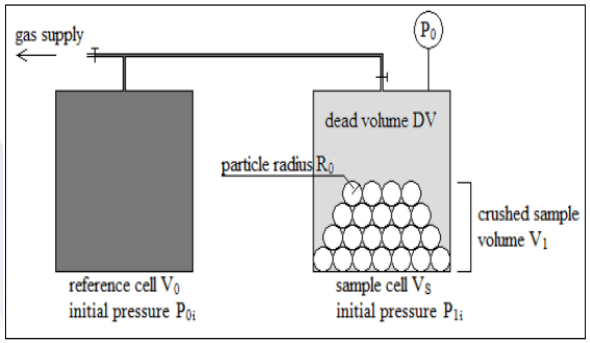
- Unsteady-State Methods
  - GRI Method (Crushed Sample)
  - Pressure Pulse Decay

Crushed Sample Permeability

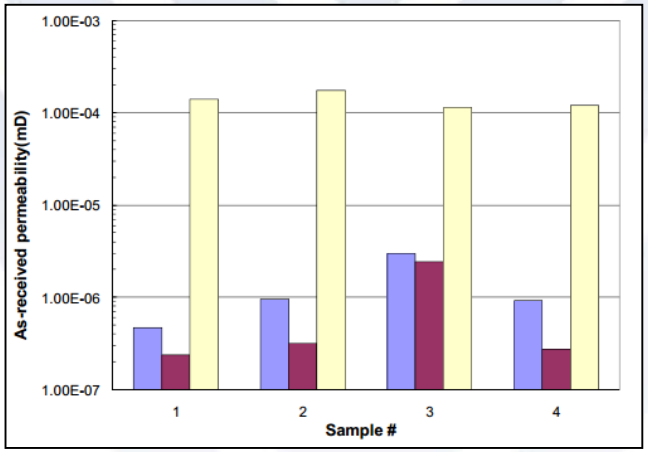
Developed by Gas Research Institute and is referred to as "GRI" Method.

Roosevelt Dime = 17.9 mm

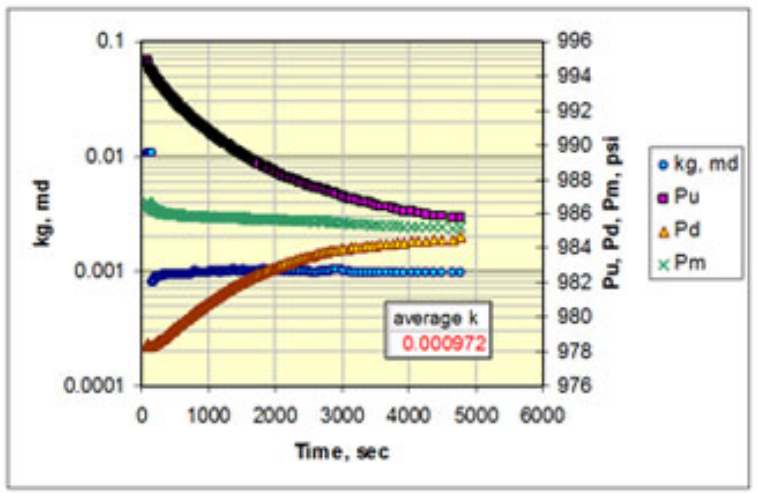
Particles in the 20-35 US mesh size range (0.85 to 0.5mm)

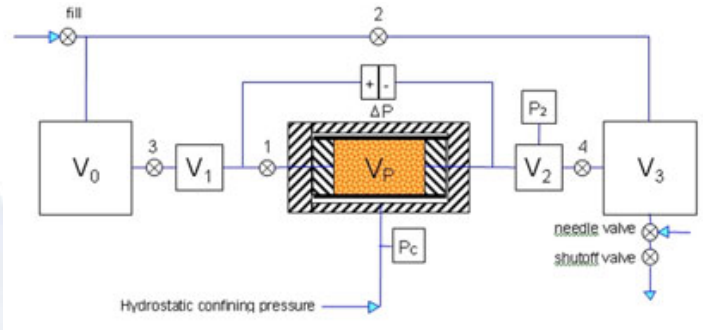


- ✓ *No Standard Protocol*
- ✓ *Inconsistent Results*



PRESSURE PLUS DECAY



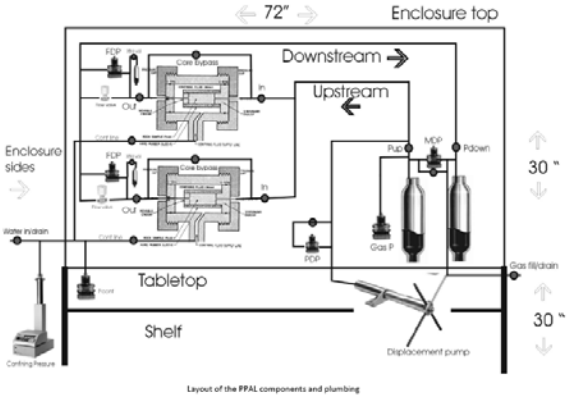


- ✓ DIFFERENT INTERPRETATIONS
- ✓ COMPLEX AND TEDIOUS CALCULATIONS

Challenges

- Gas Slippage Correction
- Impact of Gas Adsorption
- Impact of Stress

Precision Petrophysical Analysis Laboratory (PPAL) at WVU



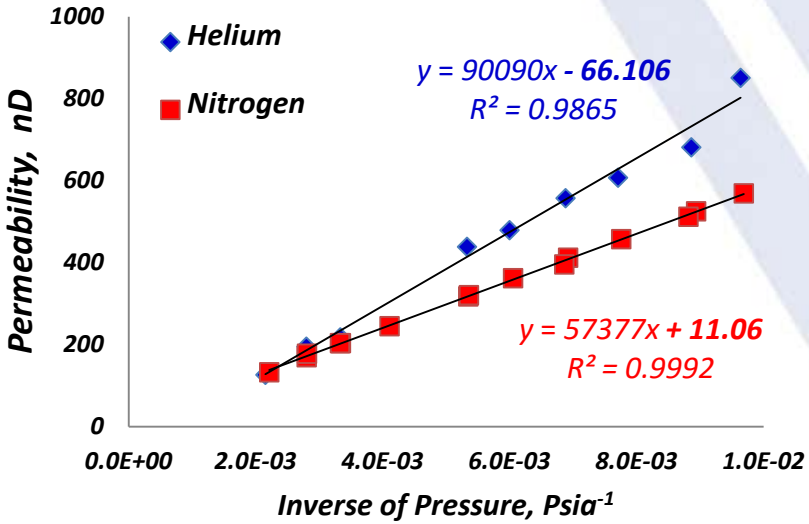
Layout of the PPAL components and plumbing

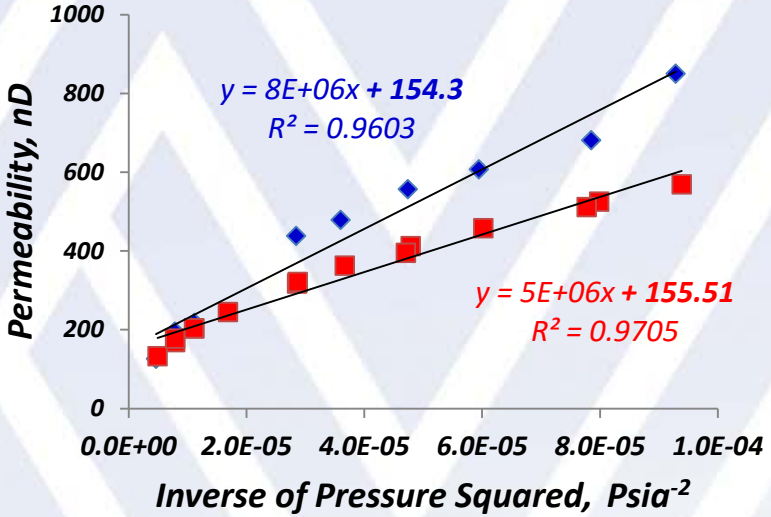
Measurement Capabilities

- *Permeability (nano-darcy range).*
- *Pore volume (0.1% accuracy).*
- *Absolute Permeability (Gas Pressure Correction)*
- *Impact of Stress (Reservoir Conditions).*
- *Impact of Adsorption*
- *Pore structure characterization*

Accurate, Consistent, and Repeatable Results

ABSOLUTE PERMEABILITY

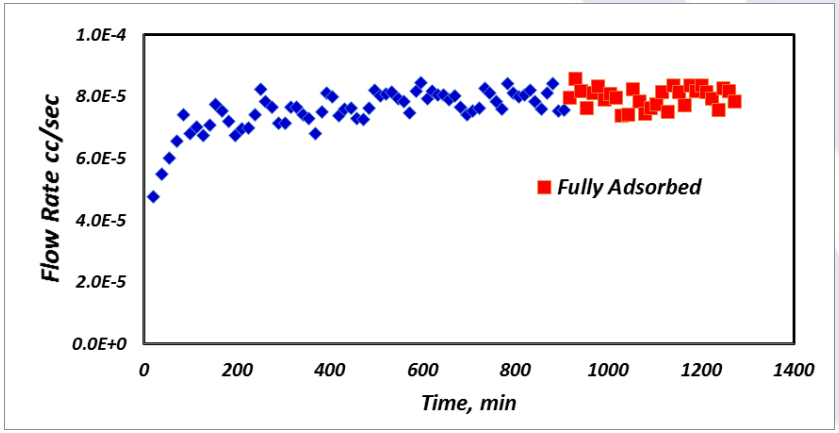


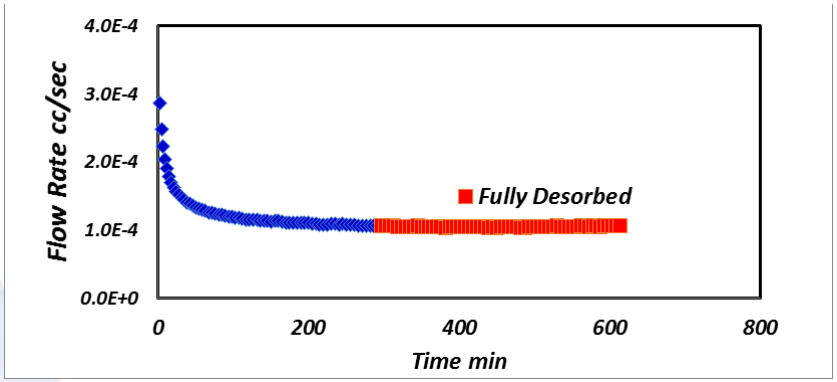


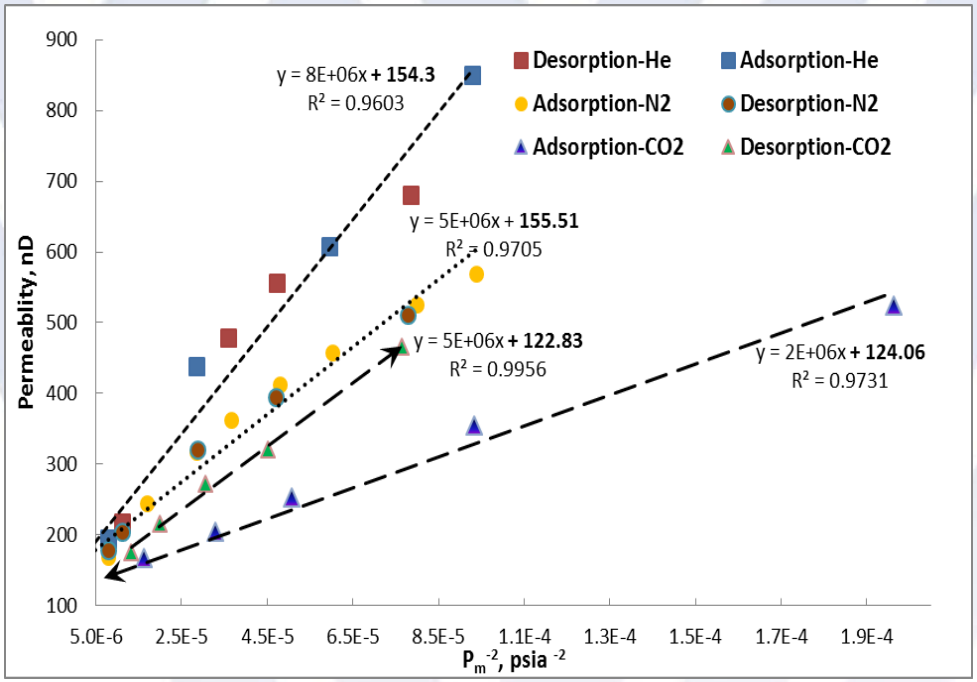
Traditional Klinkenberg Analysis
Gas Slippage

Modified Klinkenberg Analysis
Gas Double Slippage

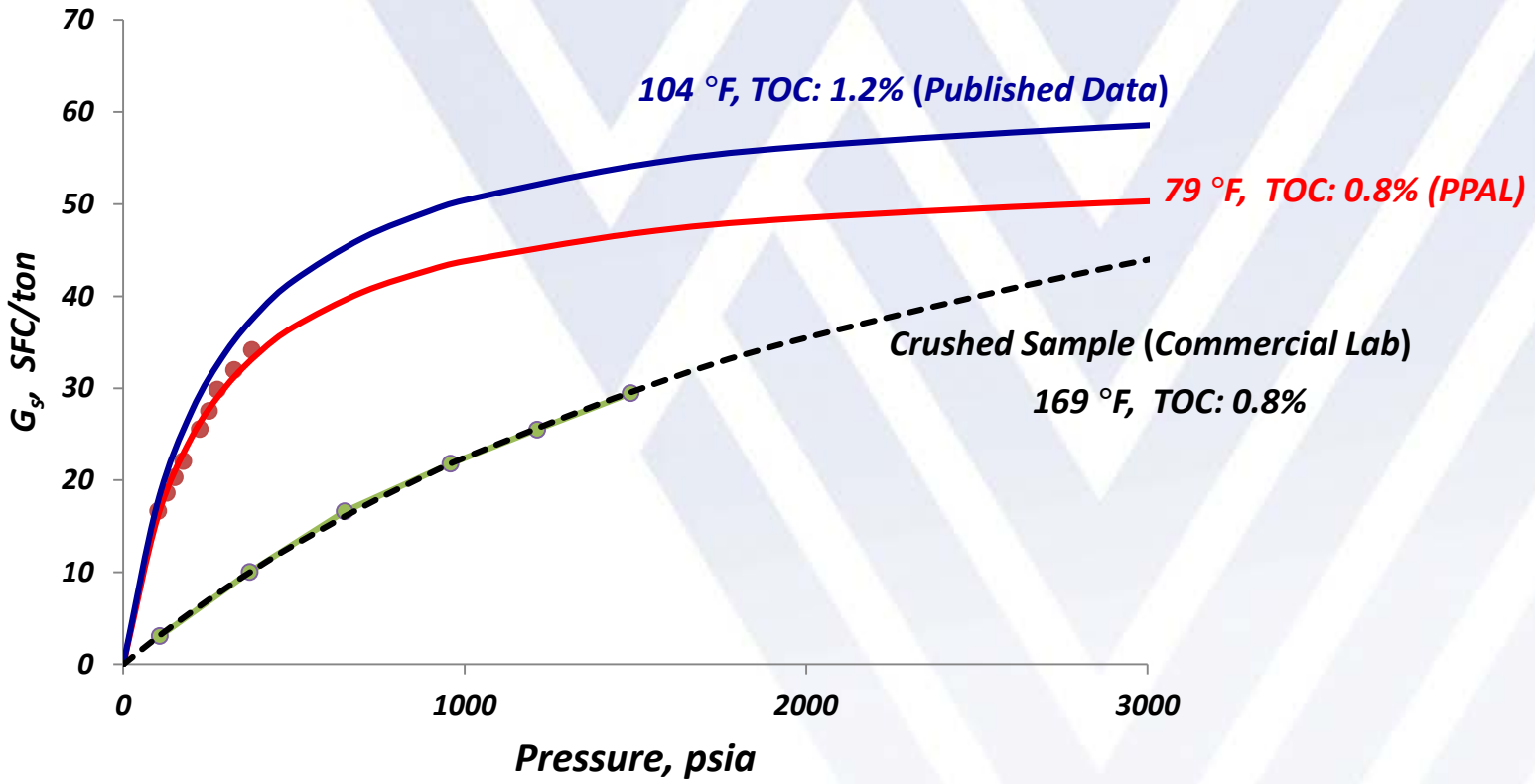
ADSORPTION


Flow Rate cc/sec
1.0E-4
8.0E-5
6.0E-5
4.0E-5
2.0E-5
0.0E+0
0
200
400
600
800
1000
1200
1400
Time, min
Fully Adsorbed

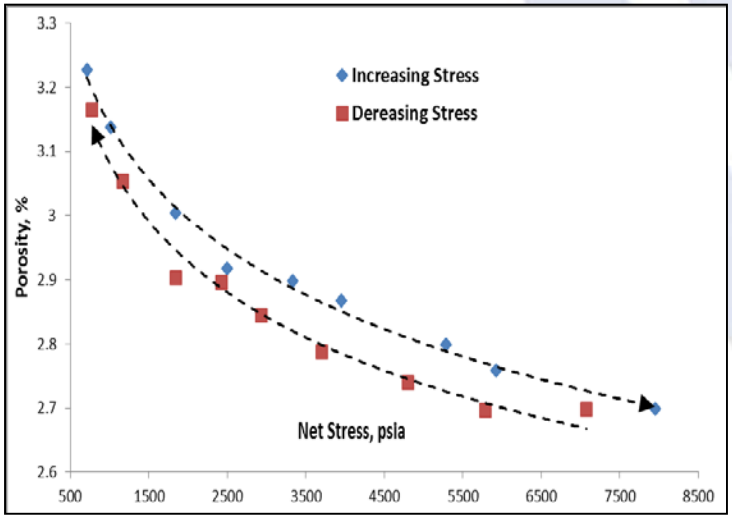

Flow Rate cc/sec
4.0E-4
3.0E-4
2.0E-4
1.0E-4
0.0E+0
0
200
400
600
800
Time min
Fully Desorbed

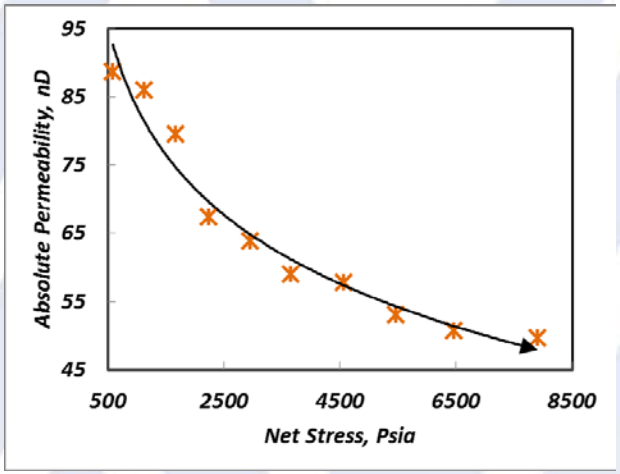

Permeablity, nD
900
800
700
600
500
400
300
200
100
5.0E-6
2.5E-5
4.5E-5
6.5E-5
8.5E-5
1.1E-4
1.3E-4
1.5E-4
1.7E-4
1.9E-4
Pm-2, psia -2
y = 8E+06x + 154.3
R² = 0.9603
y = 5E+06x + 155.51
R² = 0.9705
y = 5E+06x + 122.83
R² = 0.9956
y = 2E+06x + 124.06
R² = 0.9731
Desorption-He
Adsorption-He
Adsorption-N2
Desorption-N2
Adsorption-CO2
Desorption-CO2

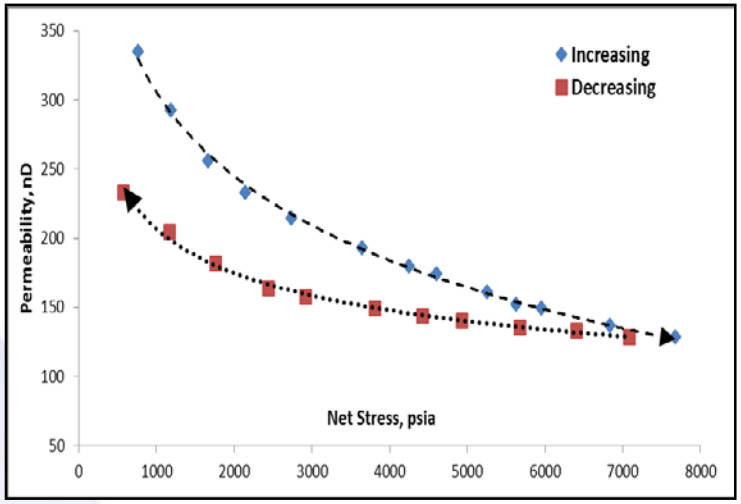
Adsorption Isotherm

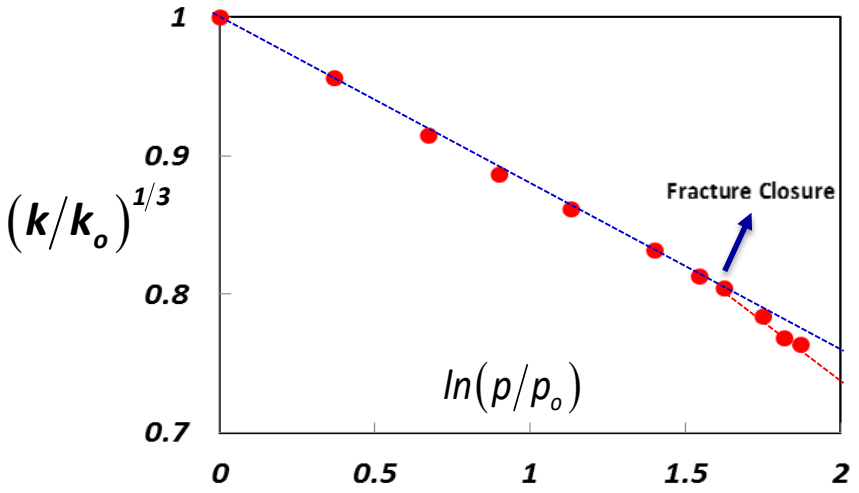


IMPACT OF STRESS

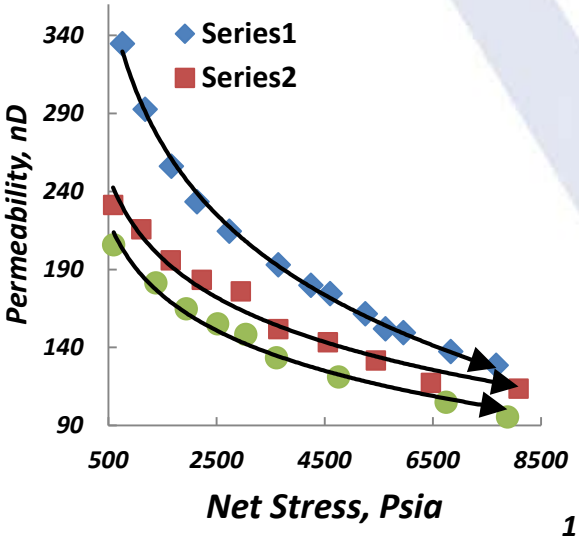


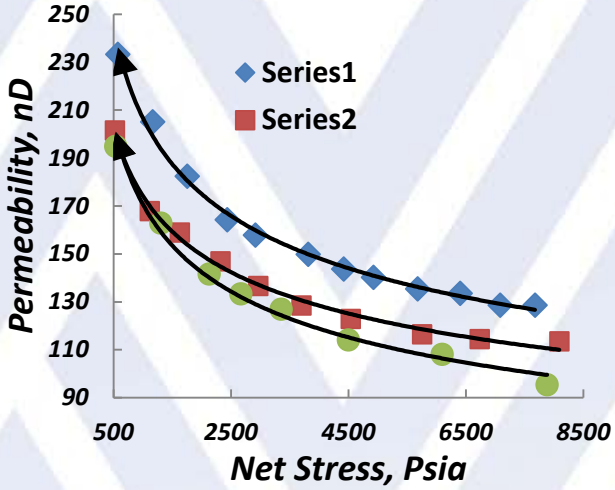


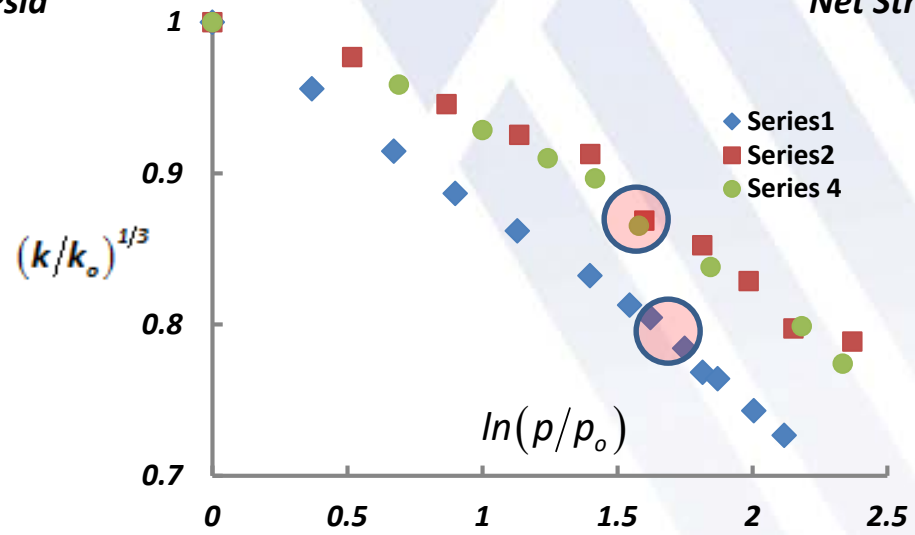




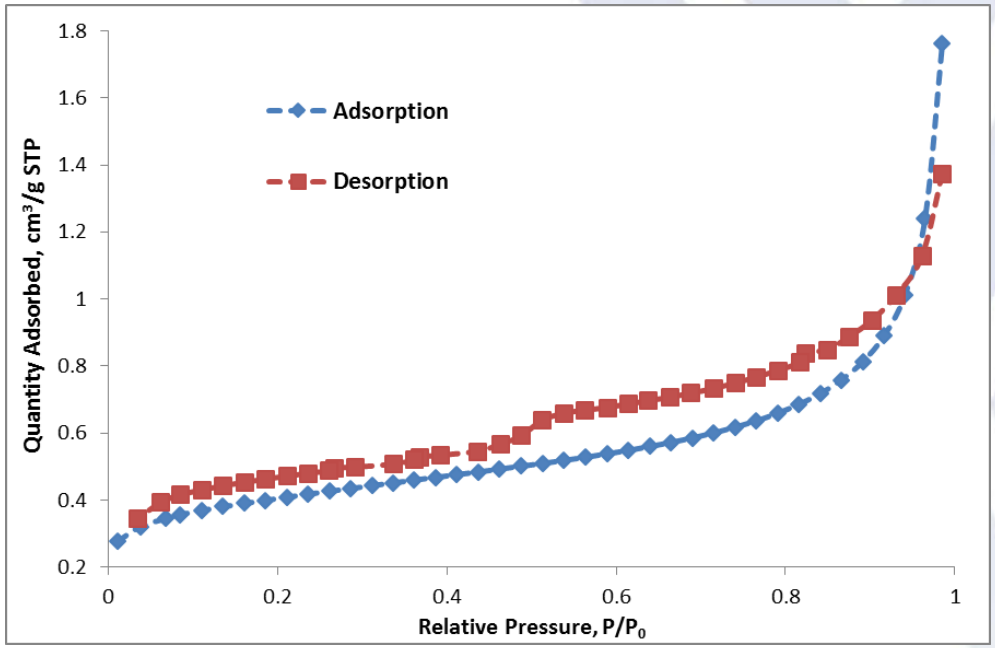
SEQUENTIAL STRESS







Adsorption Isotherms



- ✓ *Multilayer Adsorption*
- ✓ *Slit-like pores*

Micromeritics ASAP 2020

Nitrogen Adsorption at Low Temperature