Capillary Pressure Properties of Mesaverde Group Low-Permeability Sandstones in Six Basins, Western U.S.

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US DOE # DE-FC26-05NT42660

US DOE Project Summary

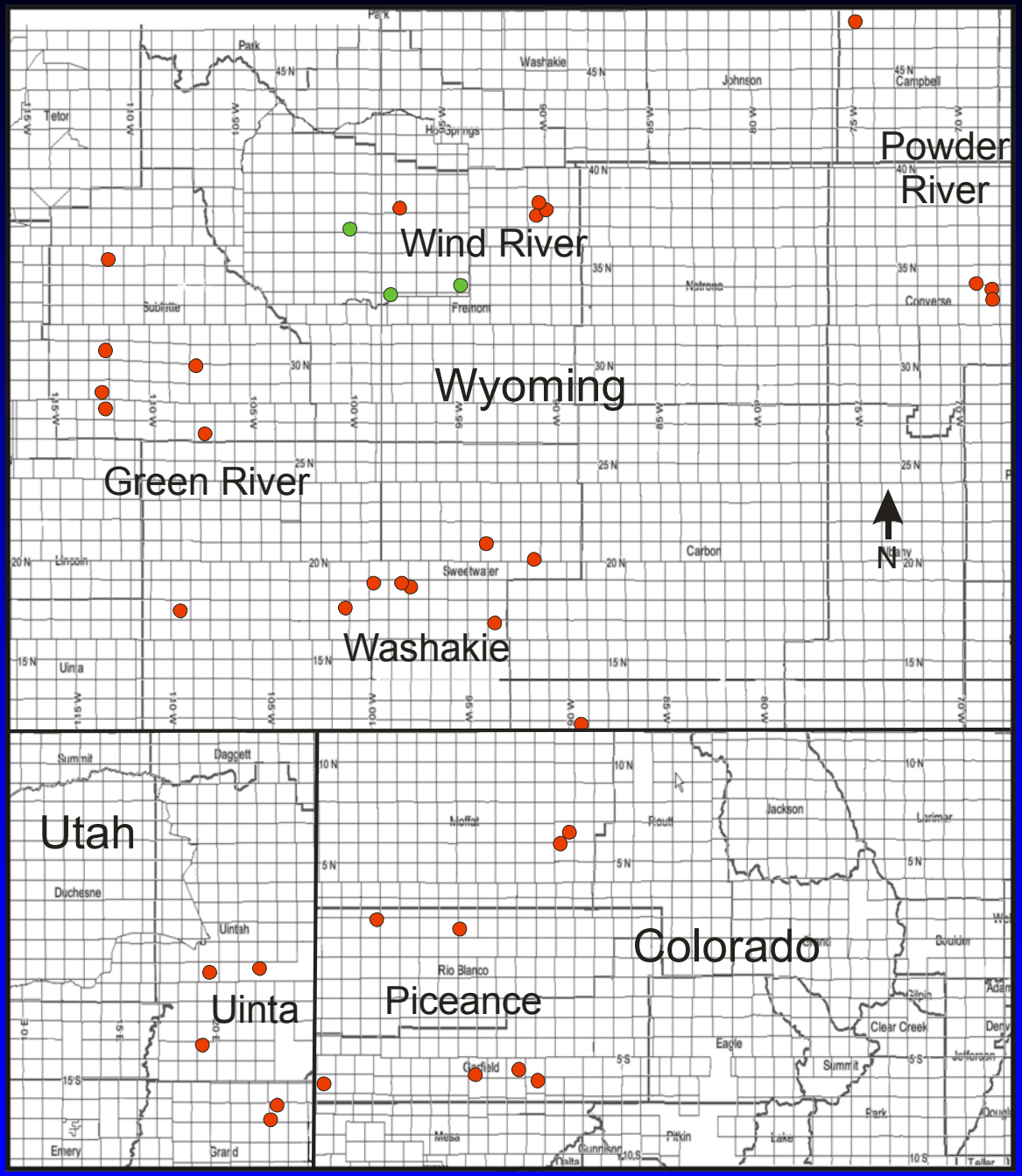
- Solicitation DE-PS26-04NT42072-0
  - subtopic area 1: Understanding Tight Gas Resources
  - Award Date: October 1, 2005
  - Completion Date: June 30, 2008
  - Contract # DE-FC26-05NT42660
- Organization: University of Kansas, Kansas Geological Survey
- Principal Investigator: Alan P. Byrnes, KGS
- KGS-Discovery Group, Inc. co-participants
- DOE share $411,030 (80%)
- Industry share $102,804 (20%)

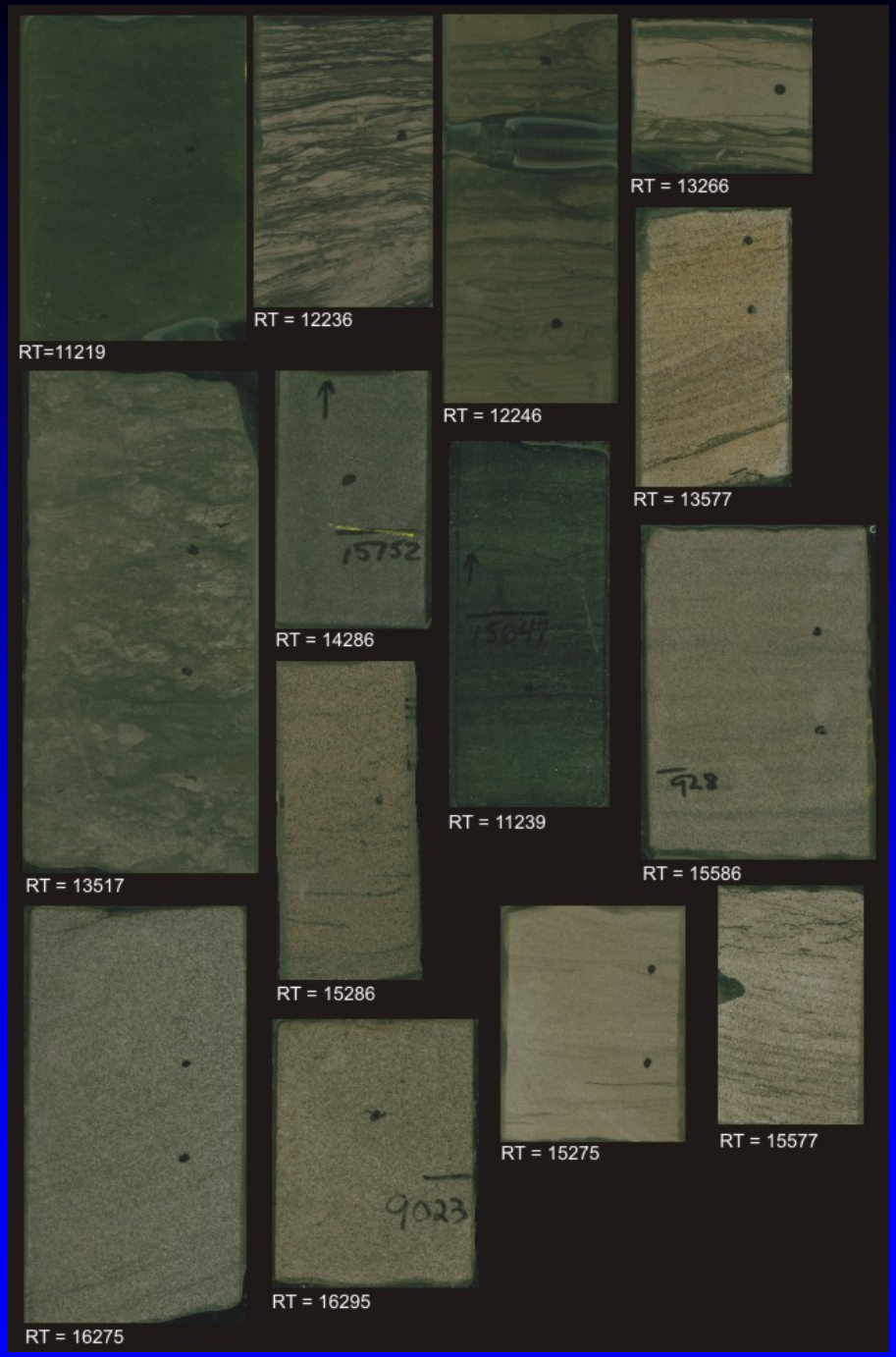
Objectives

- The project will provide petrophysical tools that address:
  - 1) minimum gas flow, critical and residual gas saturation, Sgc=f(lithofacies, Pc, architecture)
  - 2) capillary pressure, Pc=f(P), Pc=f(lithofacies, k, ϕ, architecture)
  - 3) electrical properties, m*
  - 4) facies and upscaling issues
  - 5) wireline log interpretation algorithms
  - 6) providing a web-accessible database of advanced rock properties.

Sampling

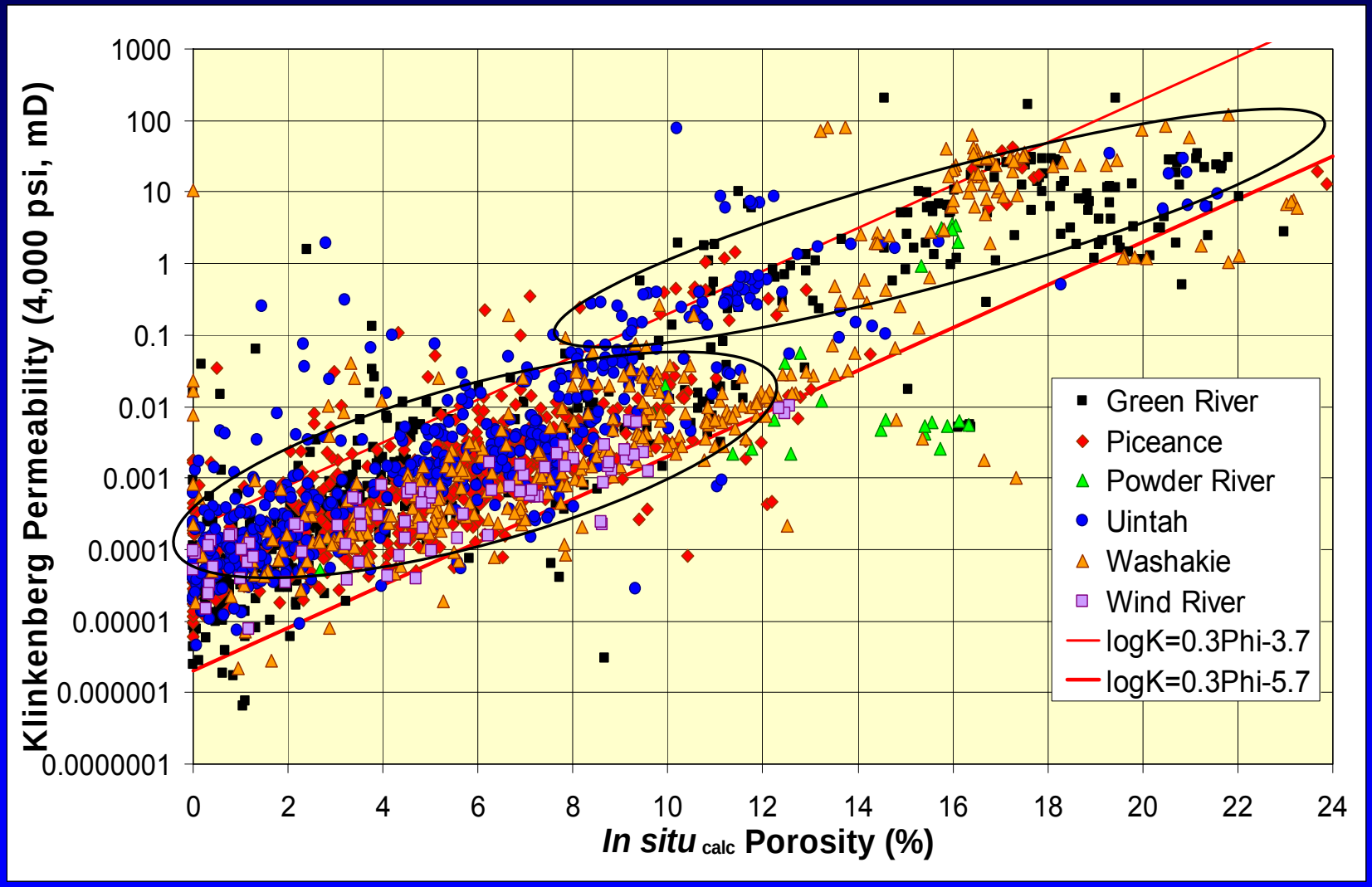
- 44 wells/6 basins
- Describe ~7000 ft core
- 2200 core samples
- 120-400 advanced properties samples



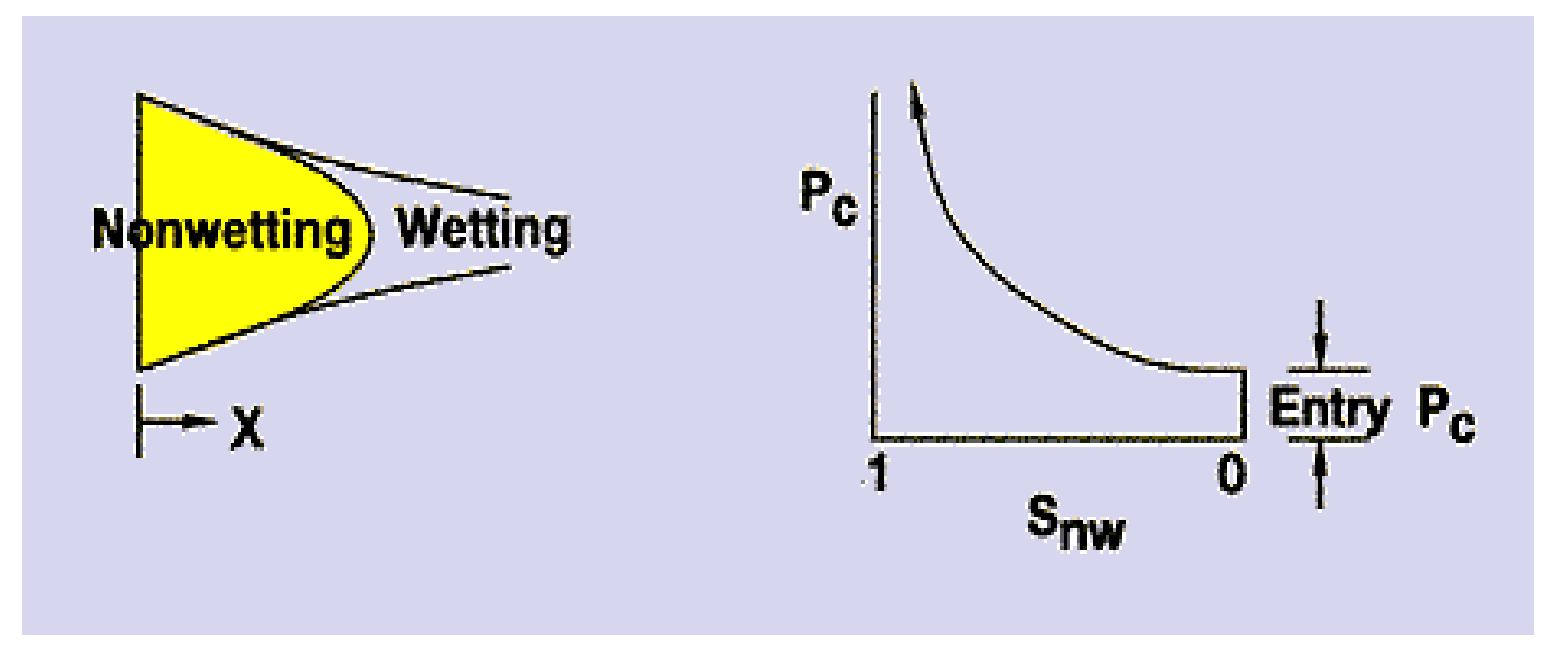


Sampled across wide range of lithofacies

Sampled over wide range of porosity and permeability



Capillary Pressure in Uniformly Variable Capillary



(after Lake, 2005)

- $Pc = 2\tau \cos\theta / r$

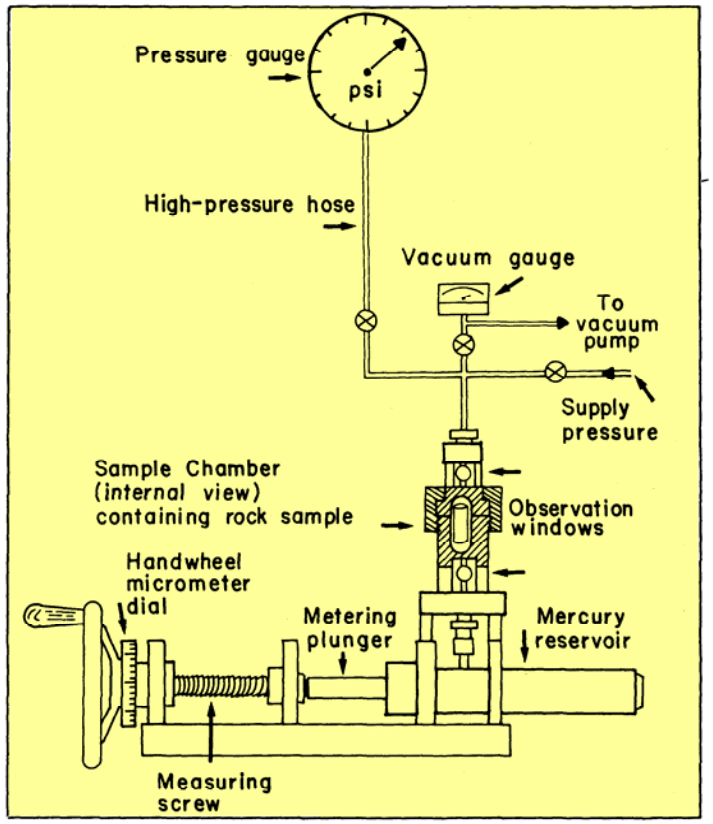
Pc = capillary pressure

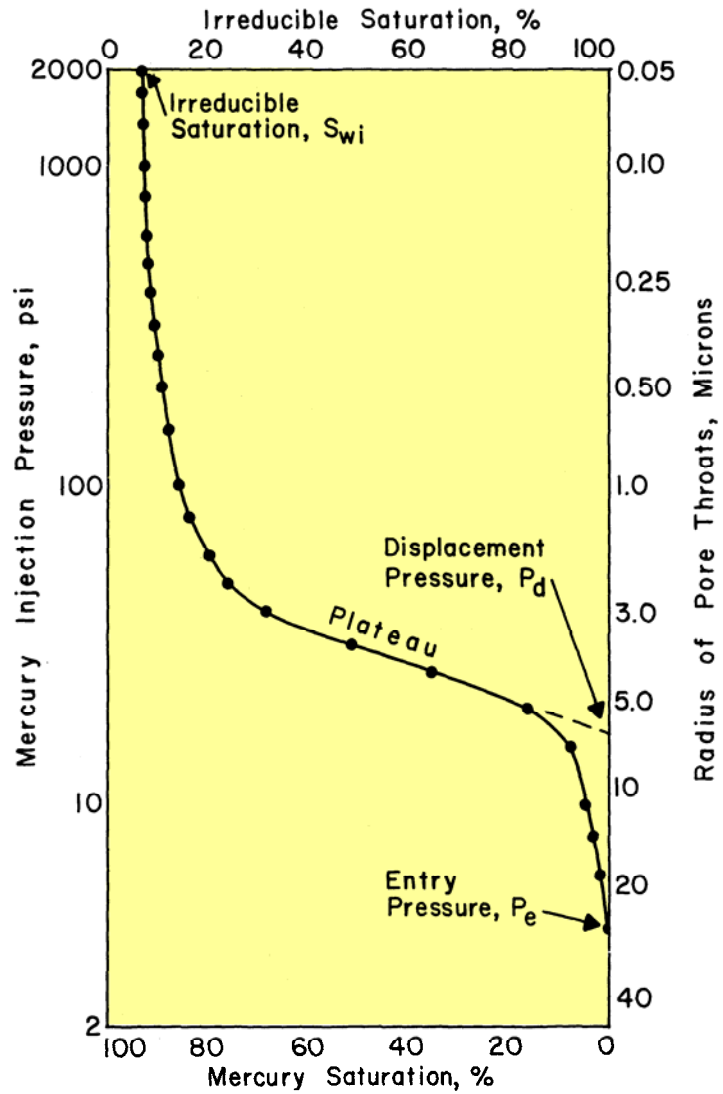
τ = interfacial tension

θ = contact angle

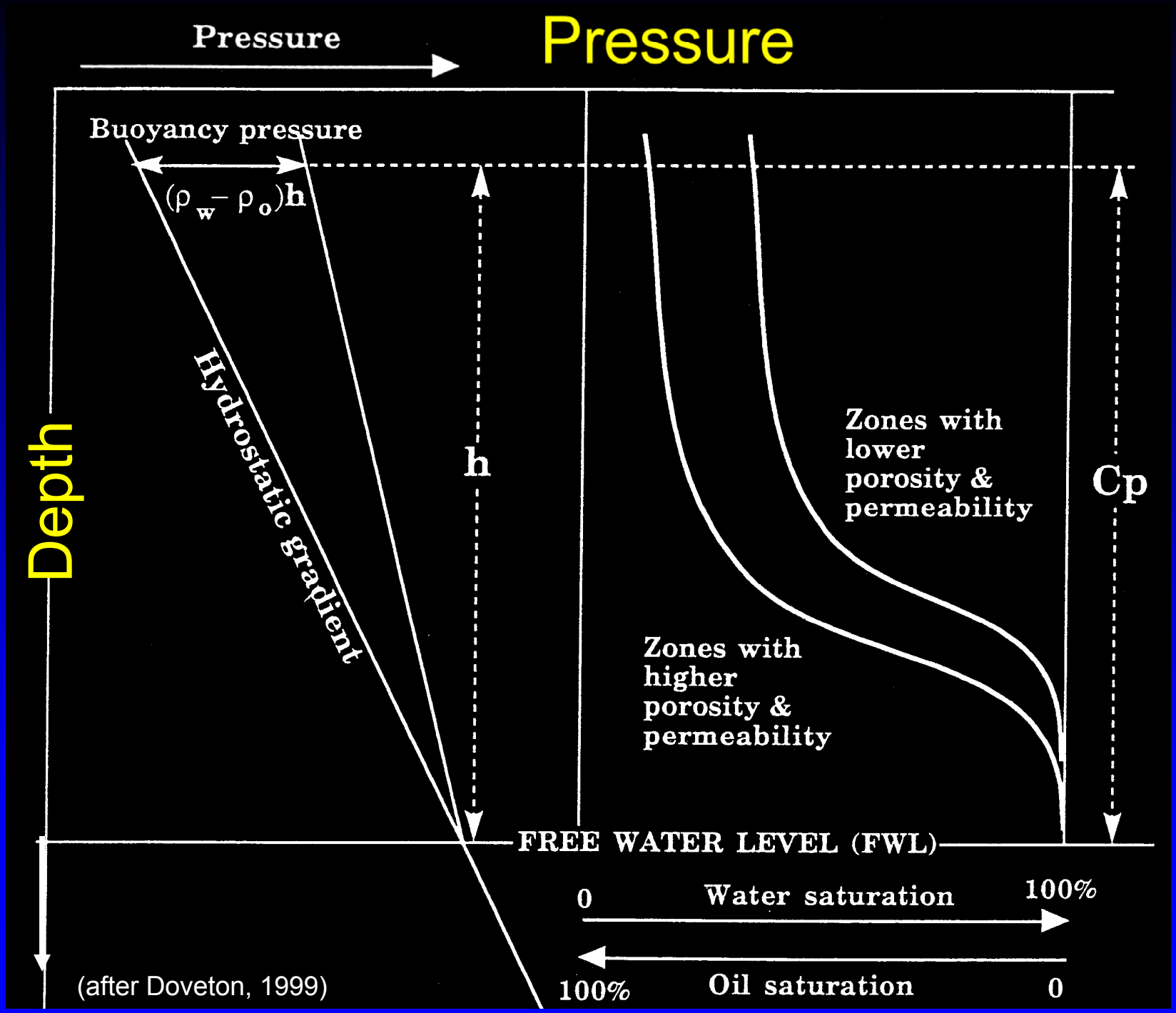
r = pore radius

Mercury Capillary Pressure





(after Jennings, 1981)


Pressure
Pressure
Buoyancy pressure
$(\rho_w - \rho_o)h$
Hydrostatic gradient
h
Depth
Zones with lower porosity & permeability
Zones with higher porosity & permeability
Cp
FREE WATER LEVEL (FWL)
0
Water saturation
100%
100%
Oil saturation
0
(after Doveton, 1999)

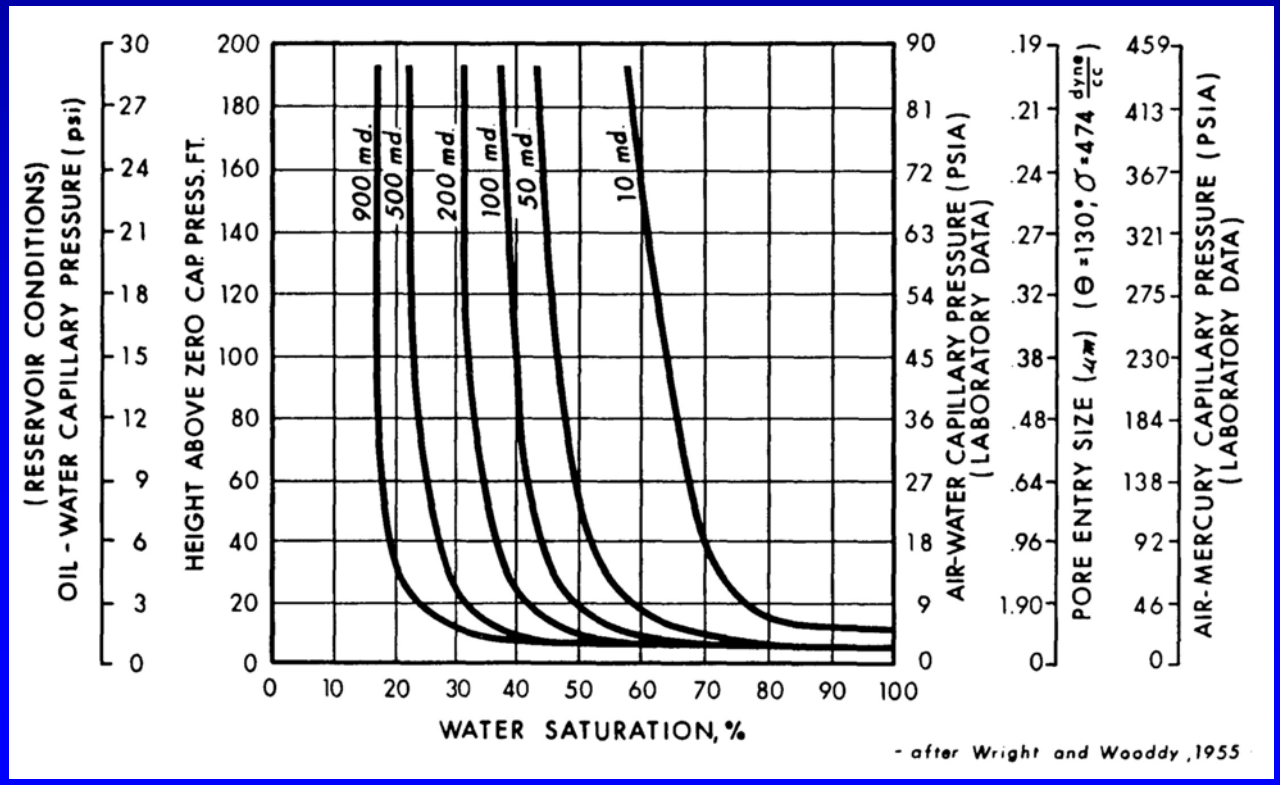
Capillary Pressure Equations

- $Pc = 2\tau \cos\theta / r$
- $r = 2\tau \cos\theta / Pc$

where:

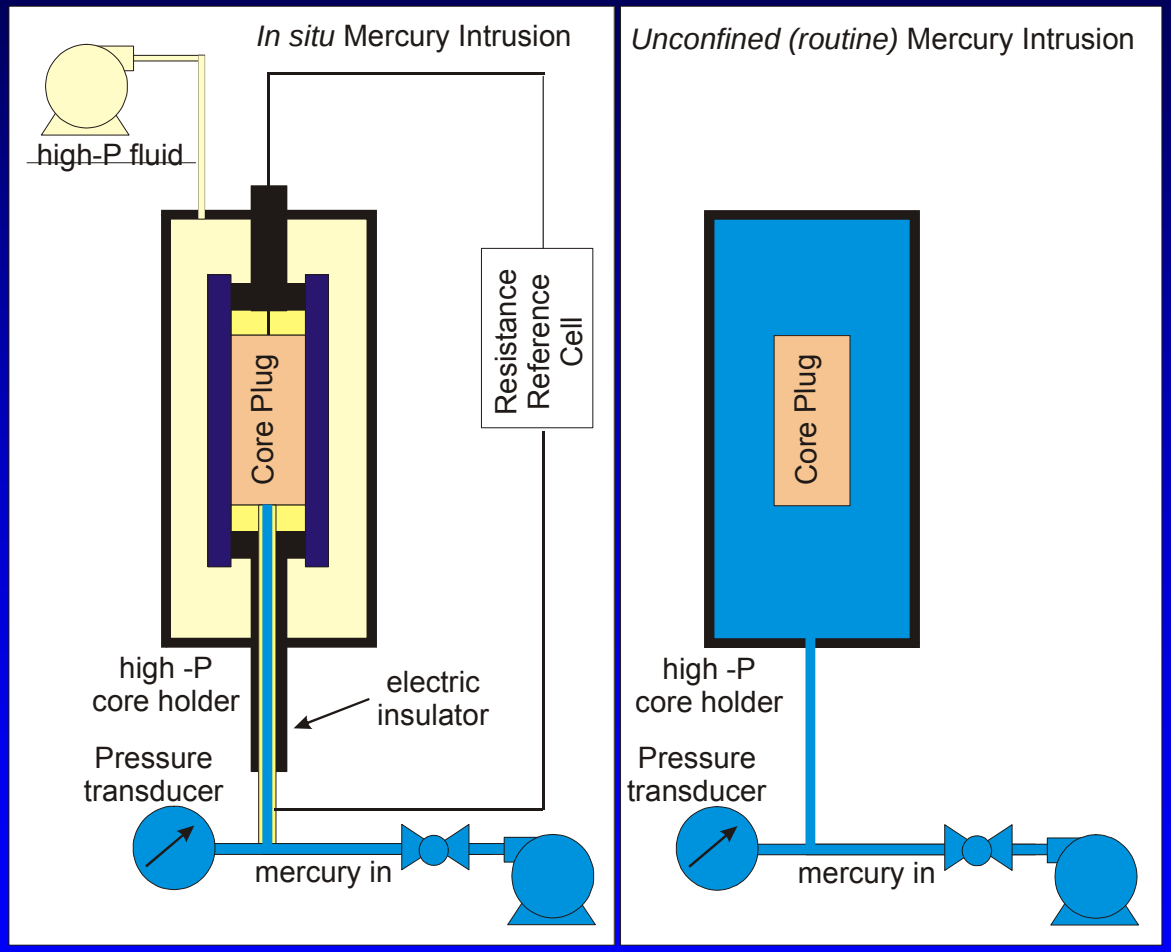
Pc = capillary pressure
τ = interfacial tension
θ = contact angle
r = pore radius

- $H = \dfrac{Pc_{res}}{(\sigma_{brine} - \sigma_{oil,gas}) \times 0.433}$
- $Pc_{res} = Pc_{air\text{-}Hg} \dfrac{\tau \cos\theta_{res}}{\tau \cos\theta_{air\text{-}hg}}$



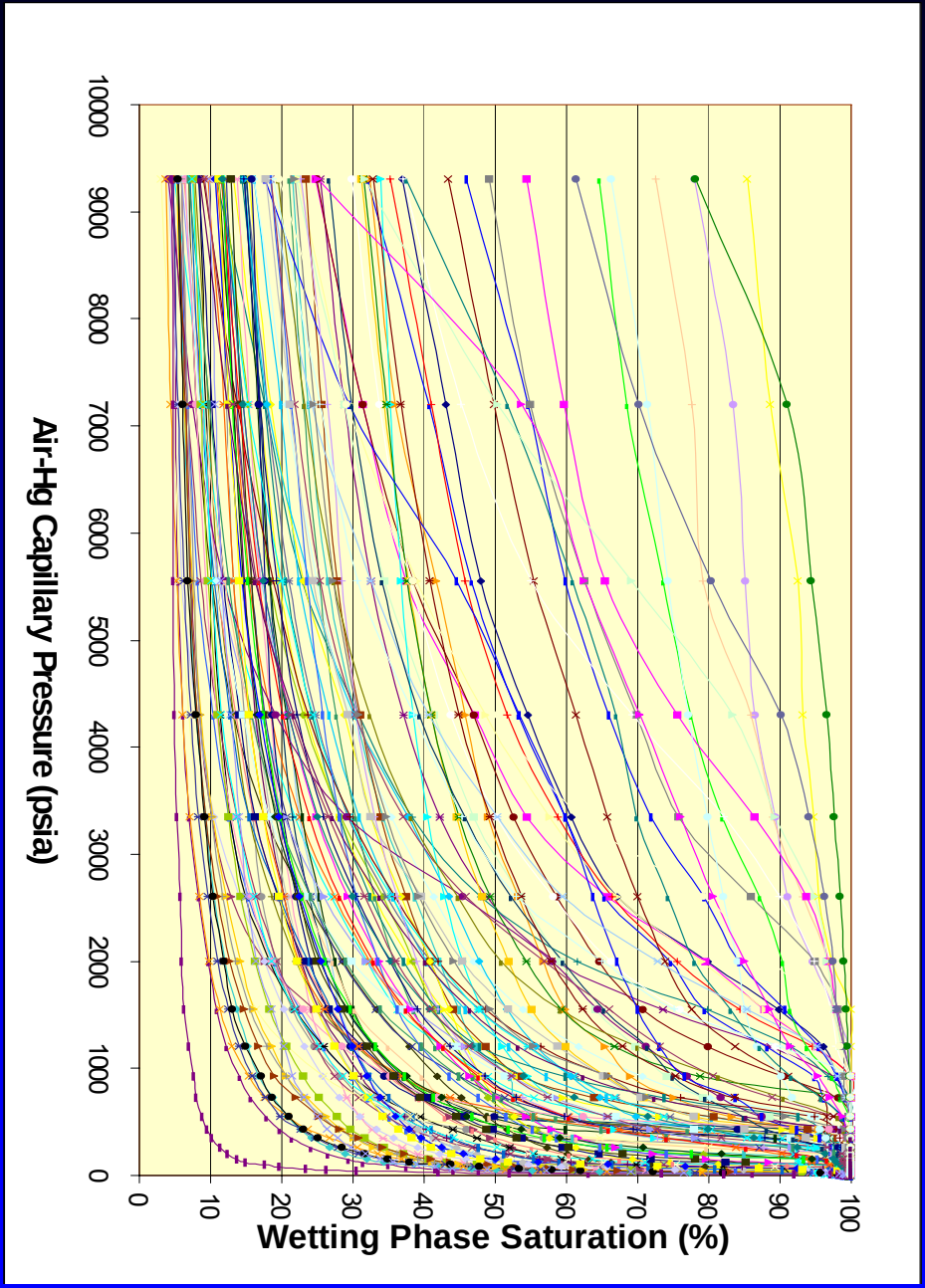
Capilary Pressure Measurement

- Three different air-Hg measurements
  - Unconfined (n=150)
  - In situ
    - Drainage-imbibition (n=37)
    - Drainage only (n=90)
    - NES = 4000 psi



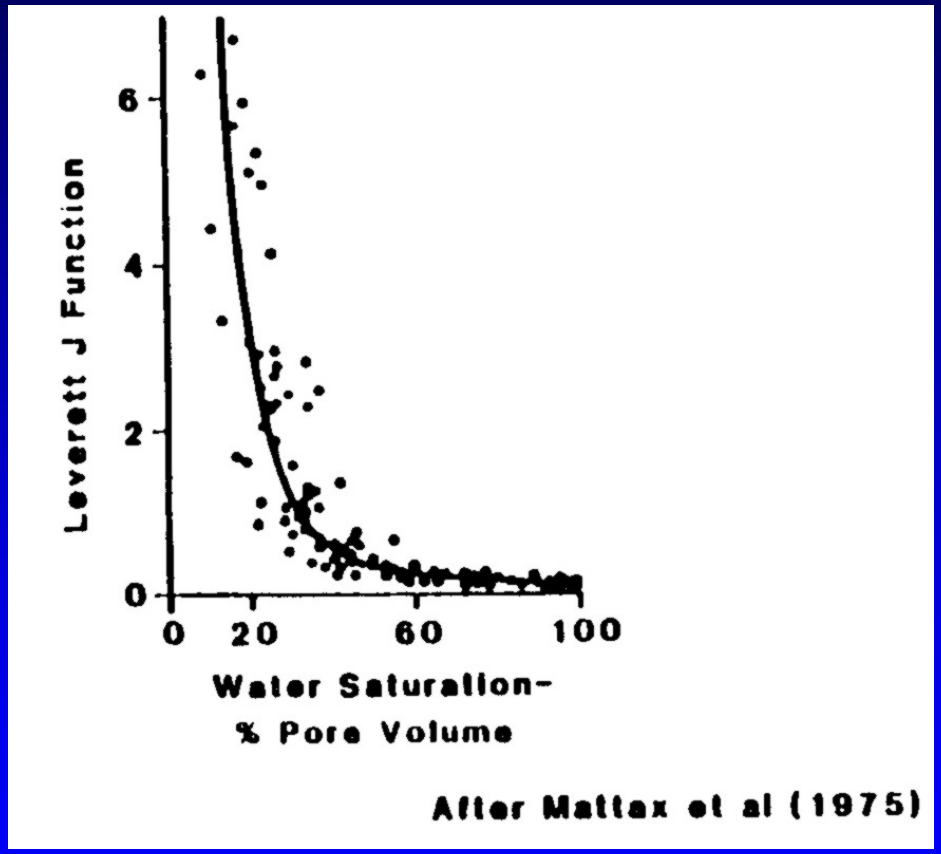
Unconfined Capillary Pressure

- Capillary Pressure Varies with Lithofacies and associated pore size distribution and permeability



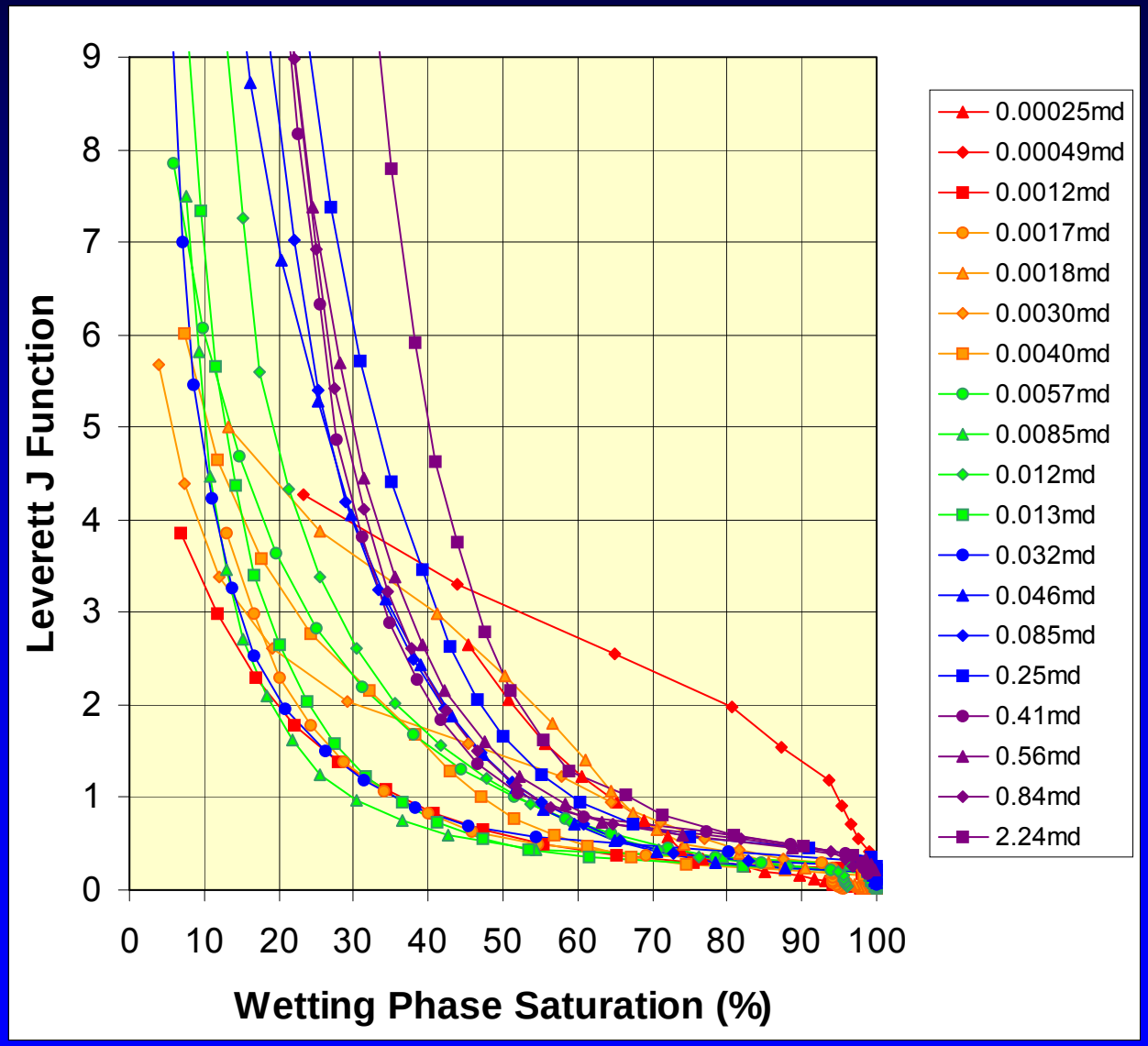
Pc Normalization - Leverett J function

- $J(S_w) = C\ Pc\ (k/\phi)^{0.5}/\tau\cos\theta$
  - J = dimensionless Pc function, function of Sw
  - C = conversion constant = 0.2166
  - Pc = capillary pressure (psi)
  - $\tau\cos\theta$ = interfacial tension (dyne/cm) X cosine of the contact angle (degrees)
  - k = permeability (md)
  - ϕ = porosity (fraction)



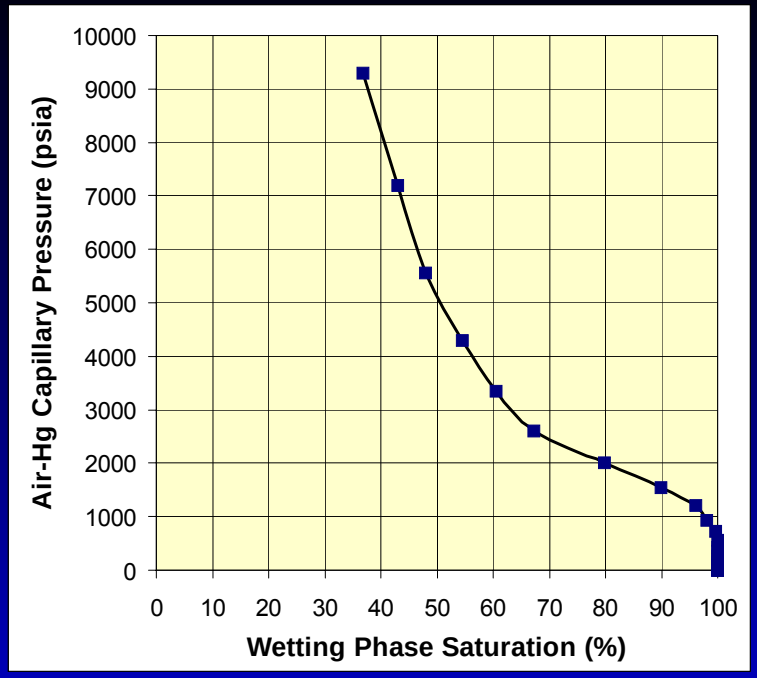
Normalization: Leverett J Function

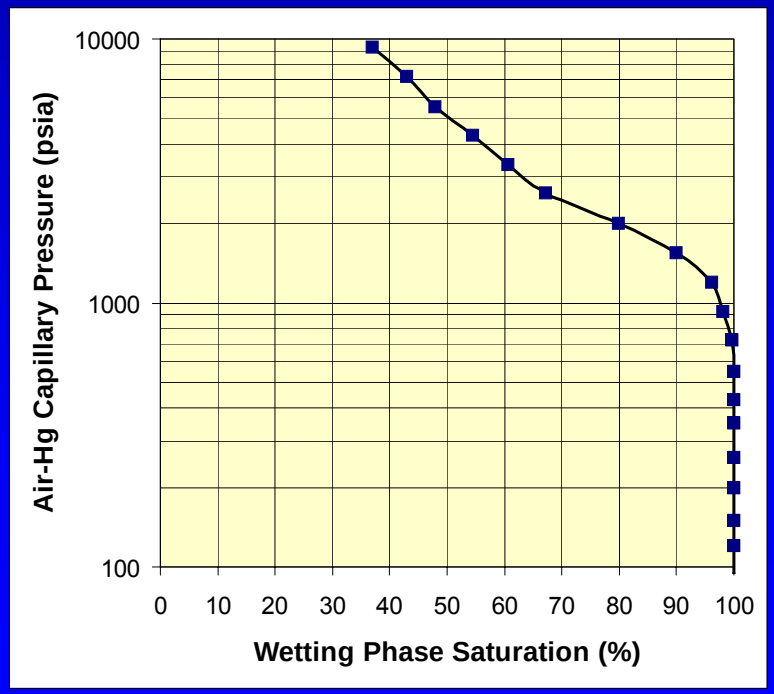
- J function works poorly for mixed lithofacies and between basins
- Does work OK for single lithofacies in a small area

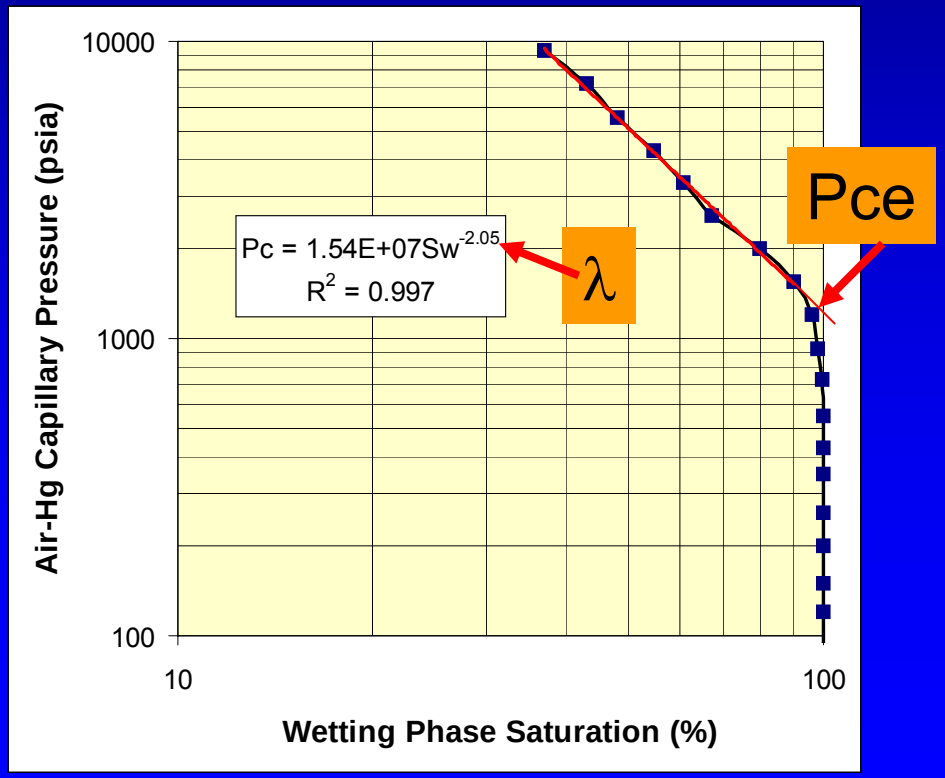


Normalization: Brooks-Corey Capillary Pressure

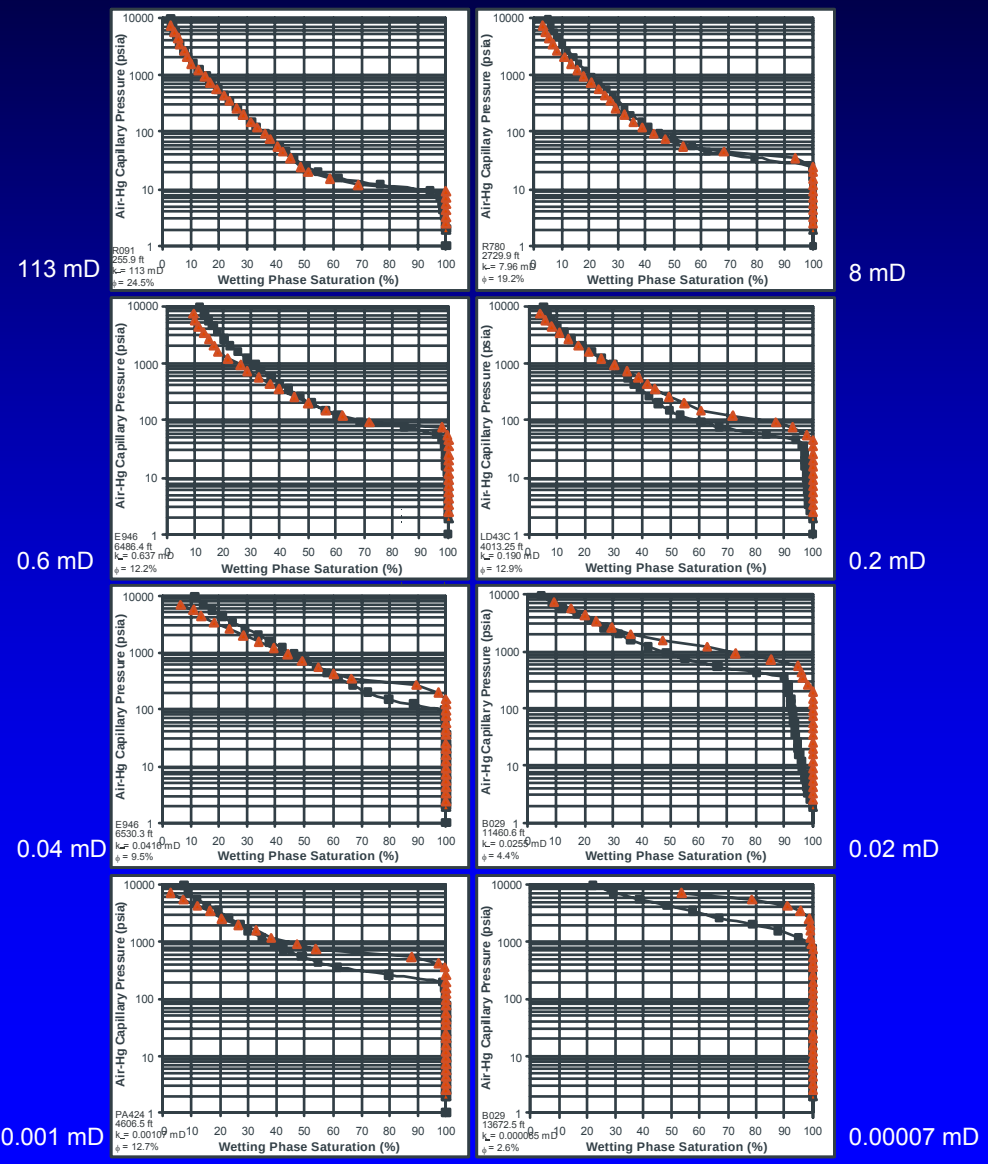
- Transform taking logarithm of Pc and Sw
- λ represents pore throat size distribution
- Standard unimodal curves can be reduced to intercept (Pce = extrapolated threshold entry) and slope (λ)



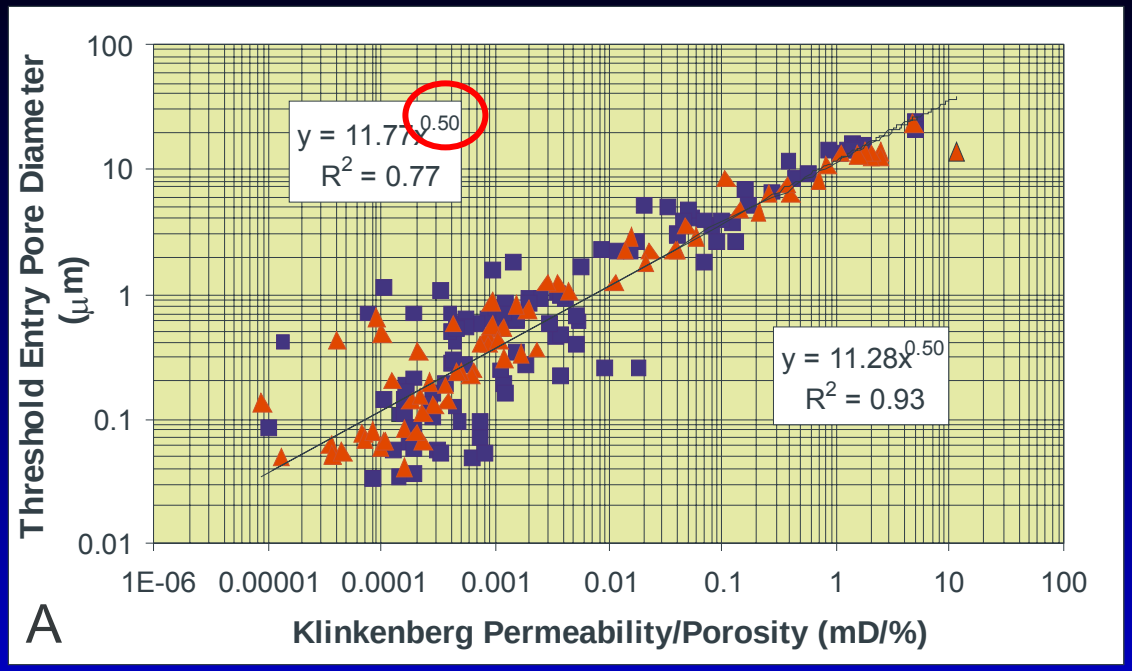


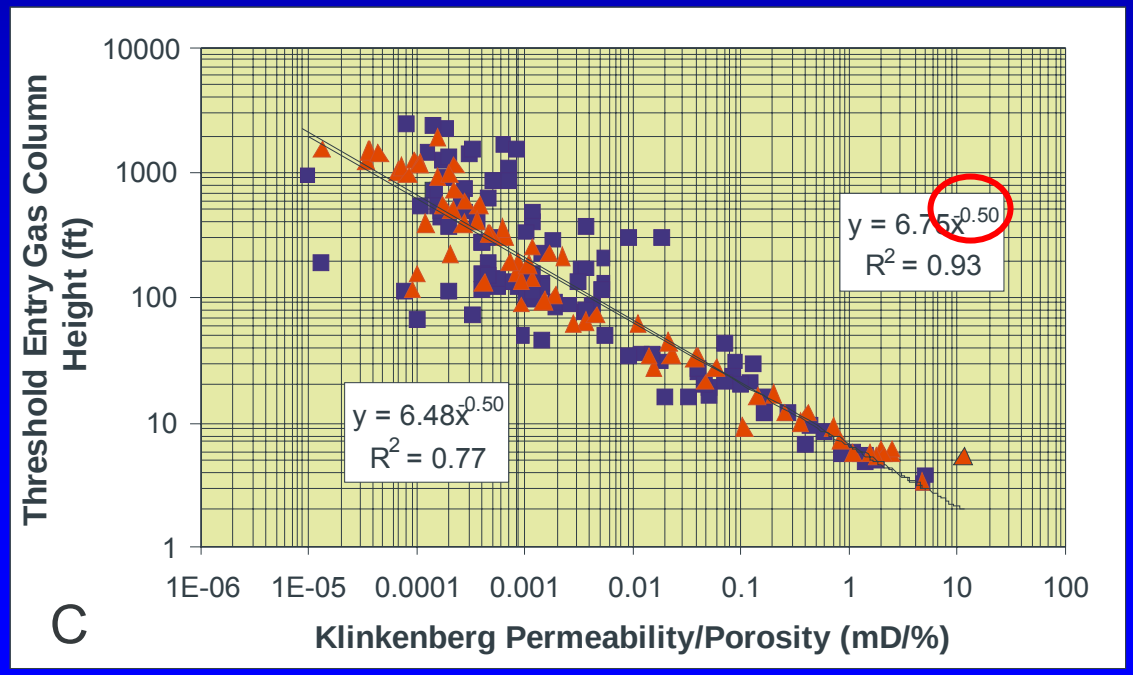


Stress effect on Pc



- no significant difference in high-low pairs at high K
- increasing Pce separation with decreasing K
- merging of curves at 35-50% Sw
  - smaller pores are in protected pore space
- users of Winland R35 need to adjust for confining stress





- threshold entry pressure is predictable from $\sqrt{K/\phi}$ at any confining pressure
- correct unconfined Pce to insitu Pce based on perm change with stress

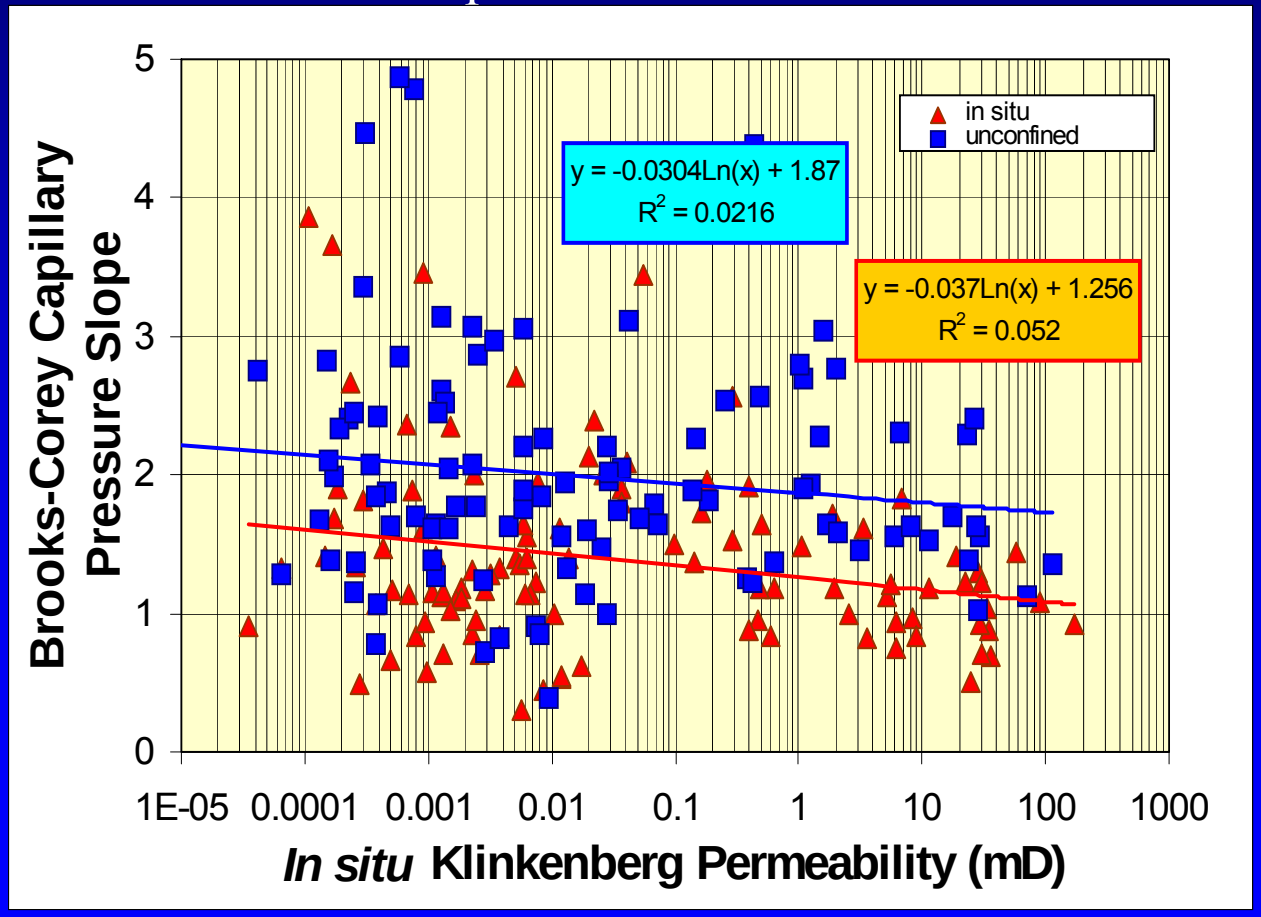
Brooks-Corey Slope

Leverett J(Sw) =
Pc $(k/\phi)^{0.5}/\tau\cos\theta$

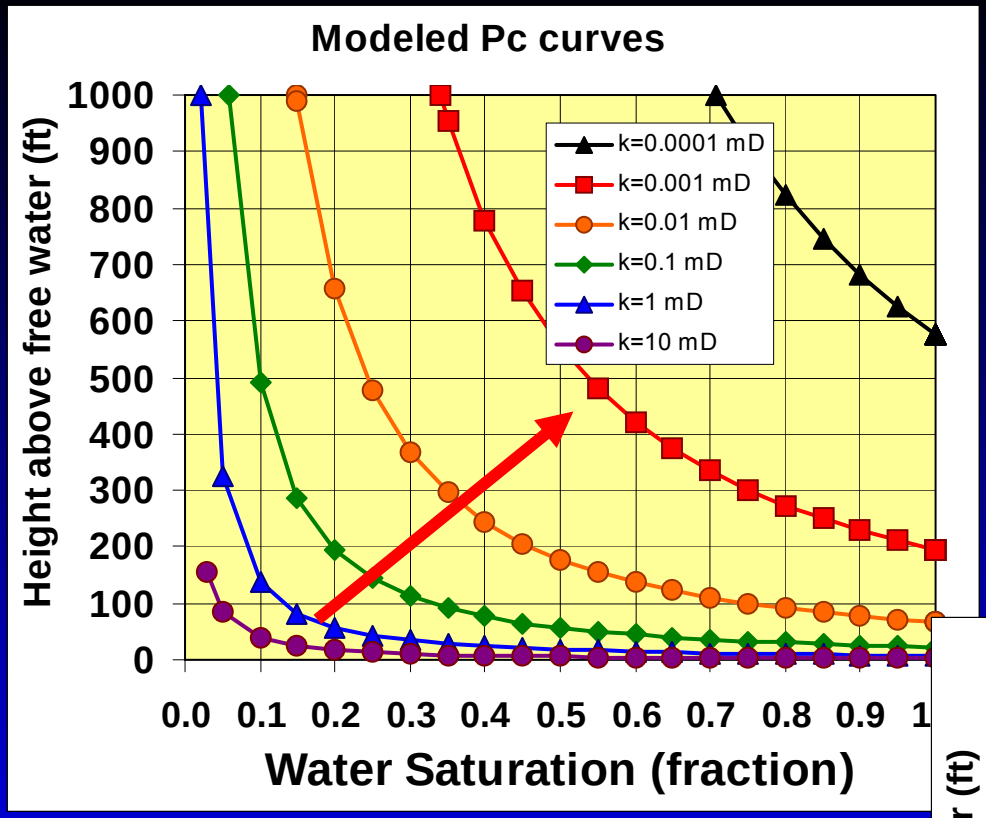
Implicitly assumes
Pc_{slope} = Constant

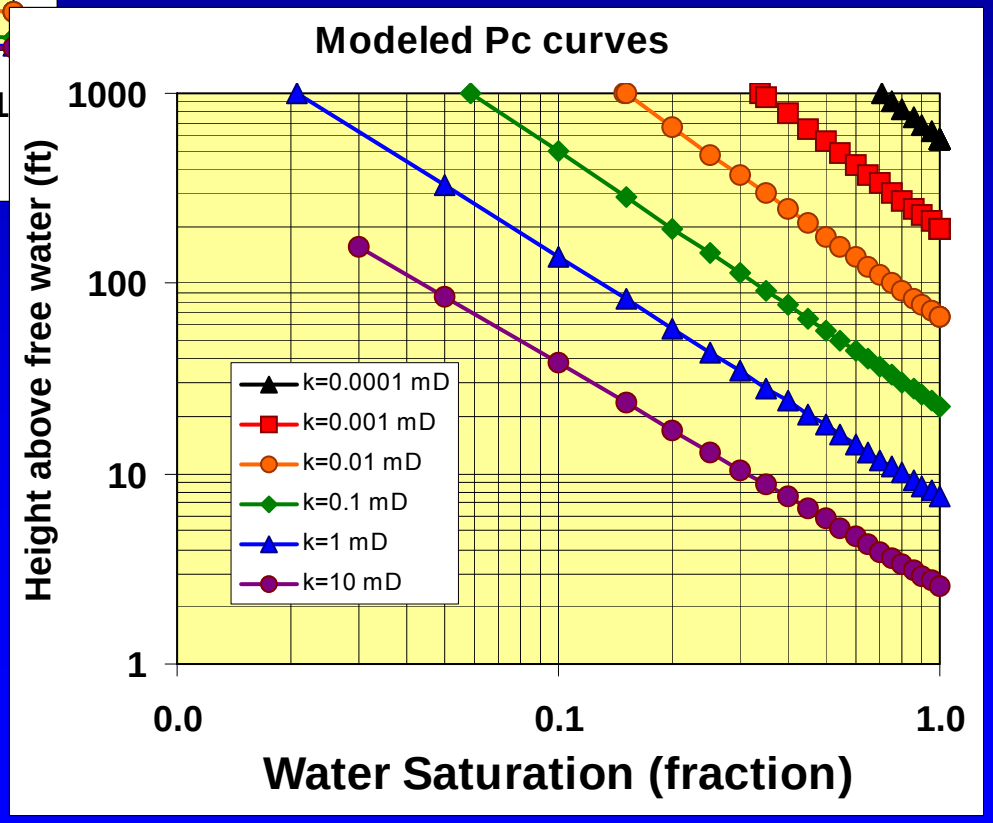
Poor fit because
$Pc_{slope} \neq C = f(k, lith)$

- PSD expressed by Pc_{slope}
- $Pc_{slope} = f(k)$
- $Pc_{slope} \downarrow$ with $P \uparrow$



Modeled Pc Curves

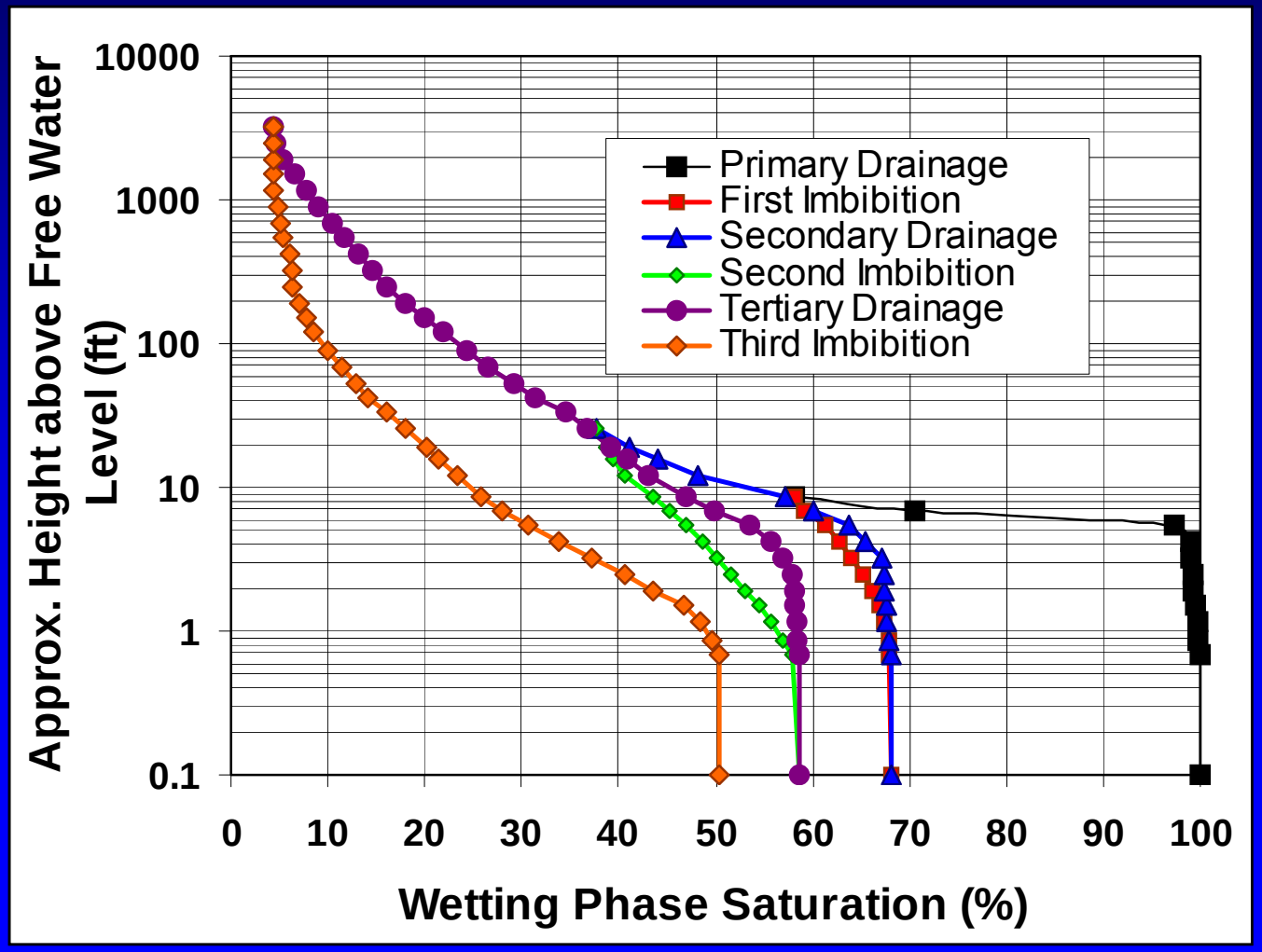




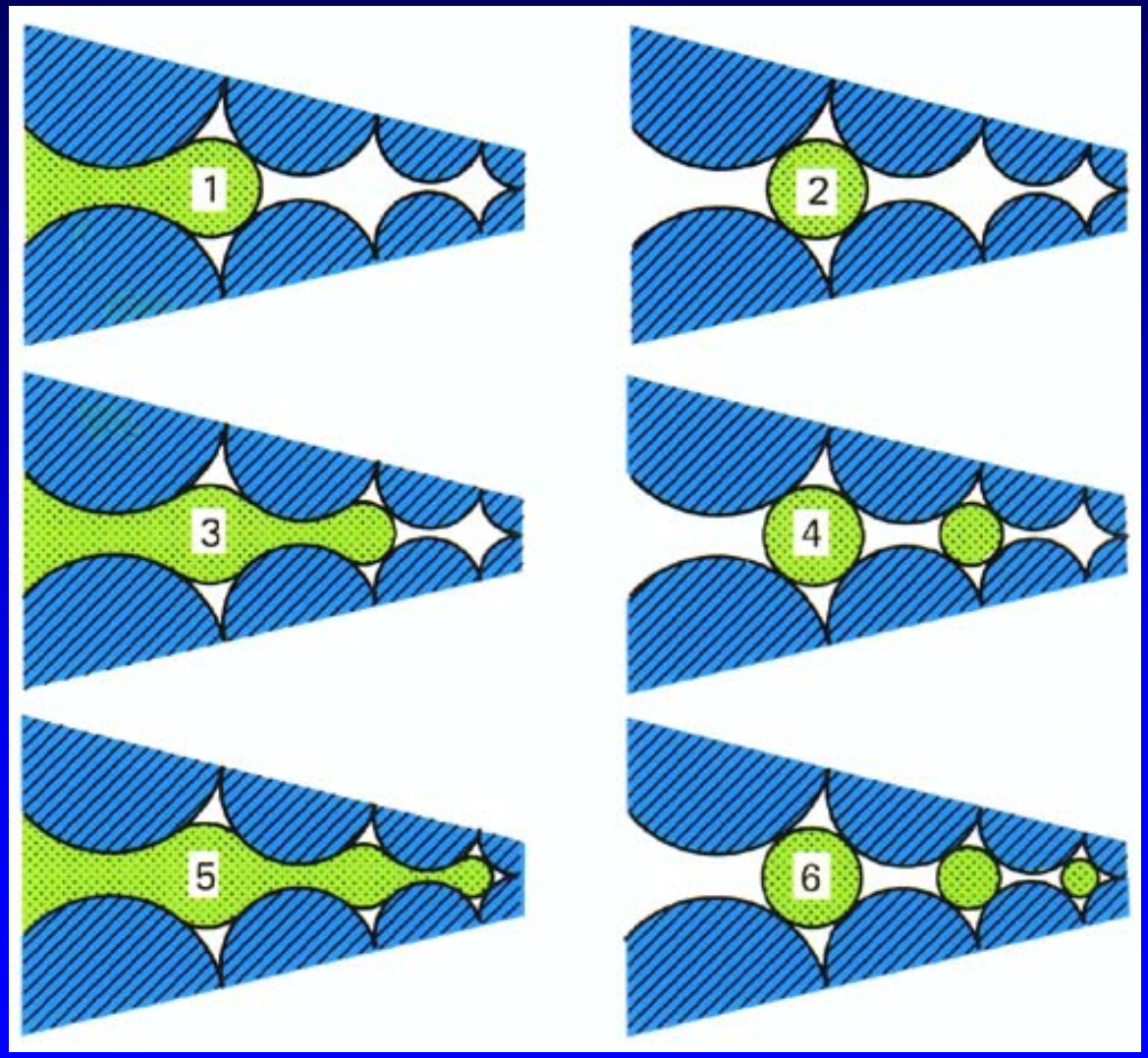
Pc properties evolve over time as diagenesis changes porosity and pore architecture

Drainge-Imbibition

- what is the residual trapped gas when a reservoir leaks or along a gas migration path?

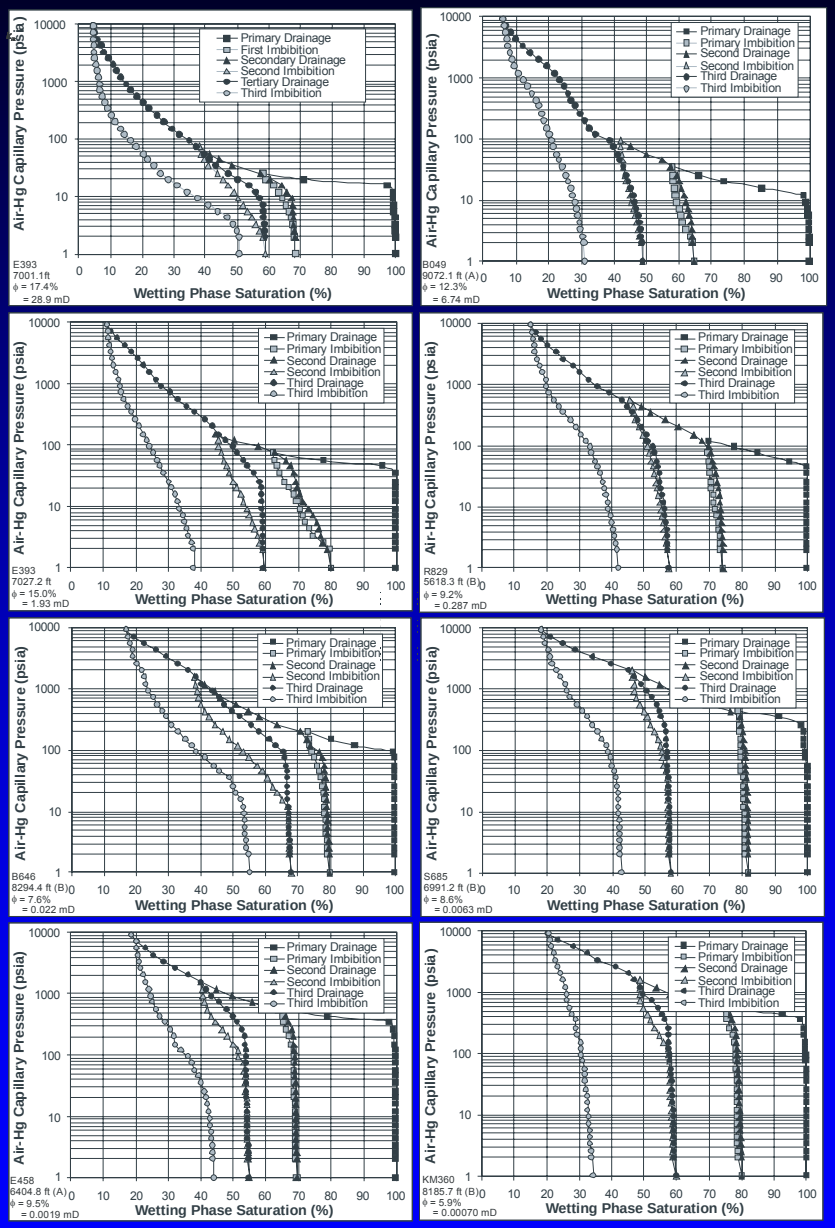


Trapping increases with increasing initial saturation



(after Lake 2005)

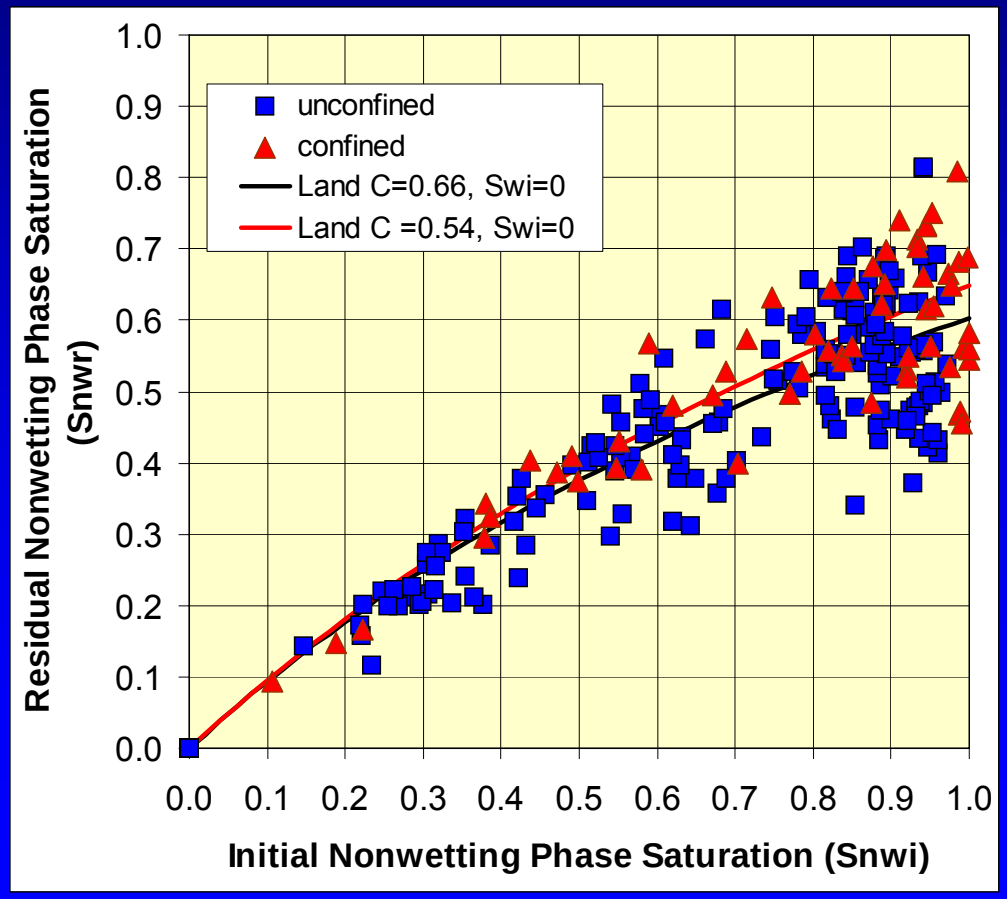
Residual Gas Saturation



$$C = 1/[(Snwr-Swi)-1/(Snwi-Swi)]$$

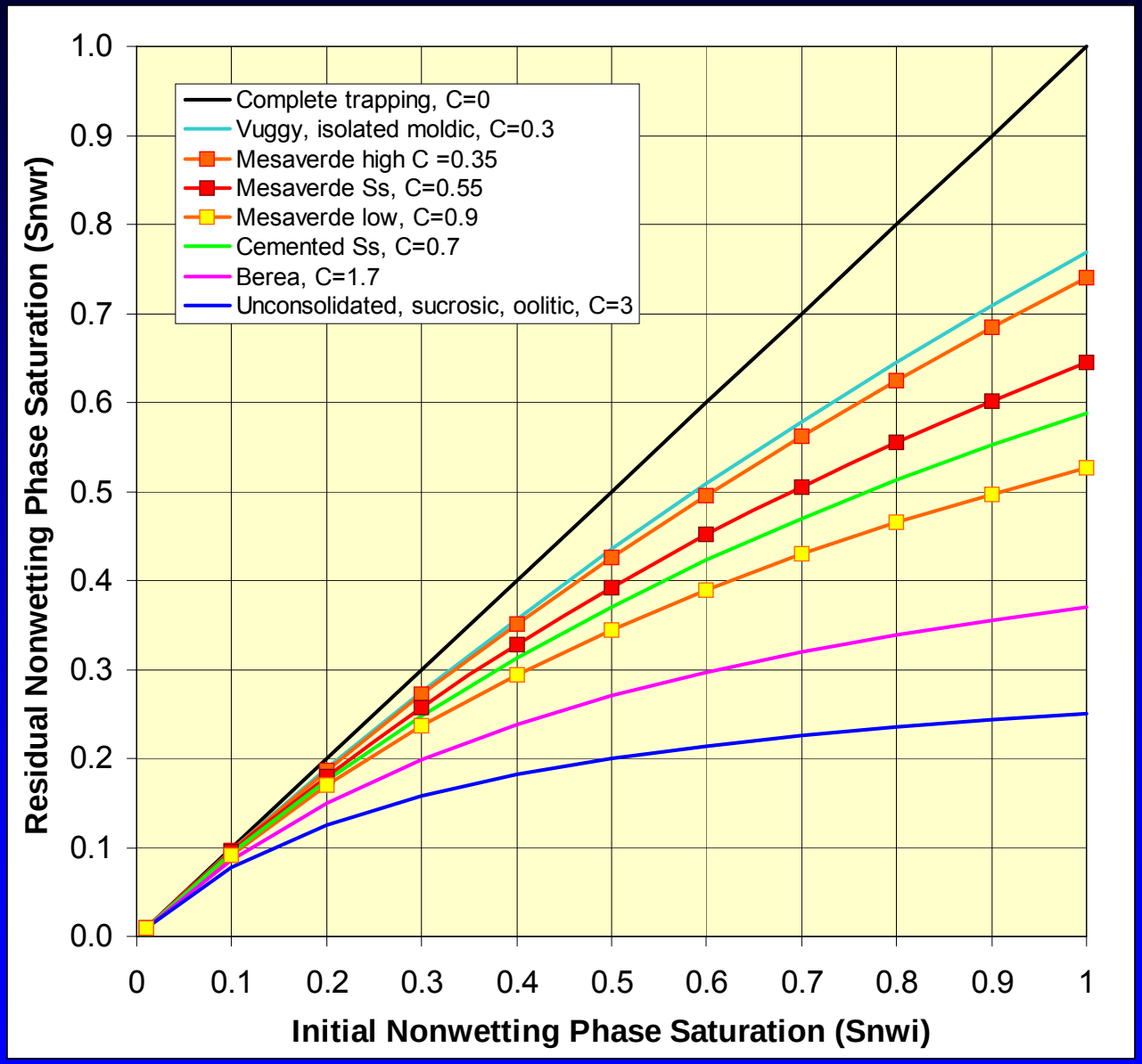
$$Snwr = 1/[C + 1/Snwi]$$

$$C = 0.55\ (\min \varepsilon);\ Swi = 0$$



Residual gas saturation

- Trapping constant, C consistent with cemented sandstone



Conclusions

- Drainage capillary pressure (Pc) can be modeled using equations for threshold entry pressure (Pte) and Brooks-Corey λ slopes.
- Confining pressure decreases largest pores consistent with permeability decrease but has little influence on smaller pores (pores largely protected by matrix)
- Snwr ↑ with Snwi ↑ Land-type relation: Snwr = 1/[0.55 + 1/Snwi]
- Mesaverde Project website is http://www.kgs.ku.edu/mesaverde

The Discovery Group, Inc.