



Core Analysis Uncertainty and Rock Typing

SPWLA Carbonate Workshop

Abu Dhabi

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Houston

Is Rock Typing the Same as Facies?



- **Facies are a body of rock with specified characteristics** (from Wikipedia)

Is Rock Typing the Same as Facies?



- **Facies are a body of rock with specified characteristics** (from Wikipedia)
- **Types of facies**
 - **Lithofacies - based on lithology (sandstones, siltstones etc)**
 - **Microfacies - based on micro fabric**
 - **Ichnofacies - based on burrow forms**
 - **Electrofacies - based on electric log responses**
 - **Seismicfacies - based on velocity response**

Rock Type

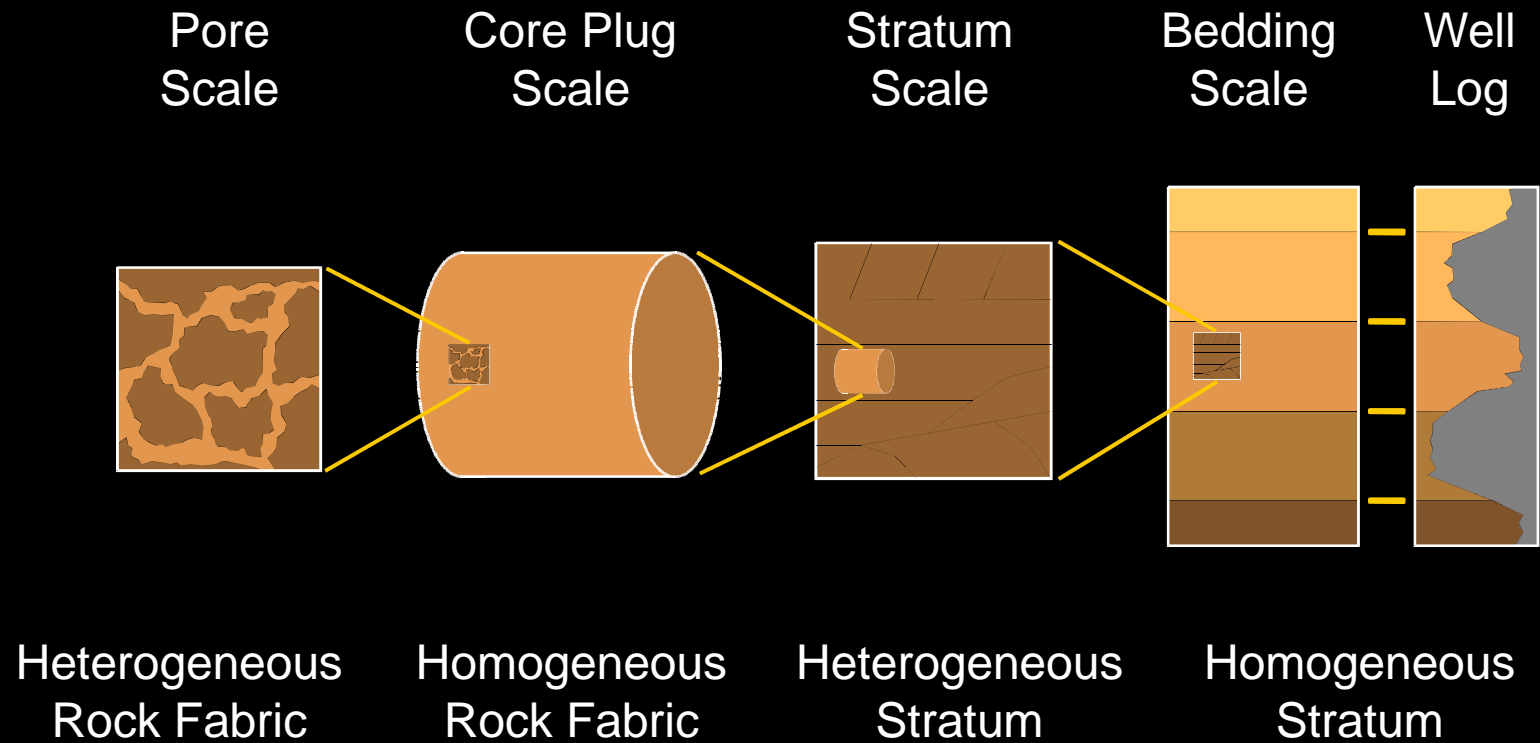


- **Rock types that have been classified according to their petrophysical properties, especially properties that pertain to fluid behavior within the rock, such as porosity, capillary pressure, permeabilities, irreducible saturations or saturations.** (from Schlumberger Oilfield Glossary)

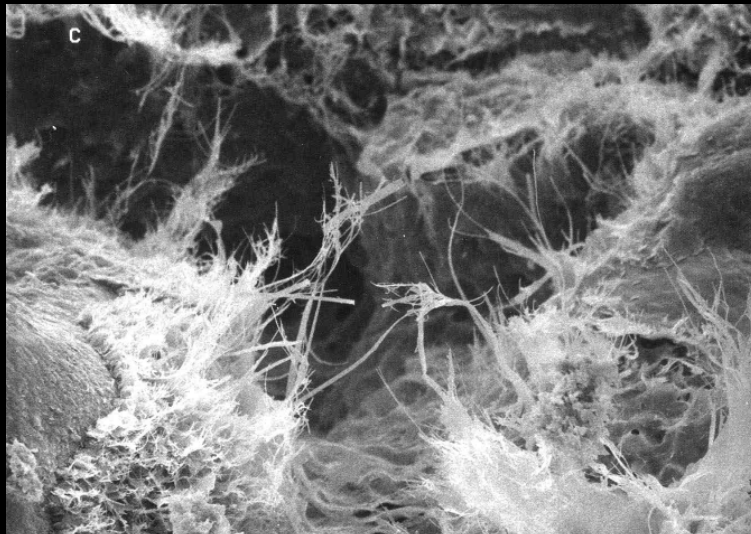
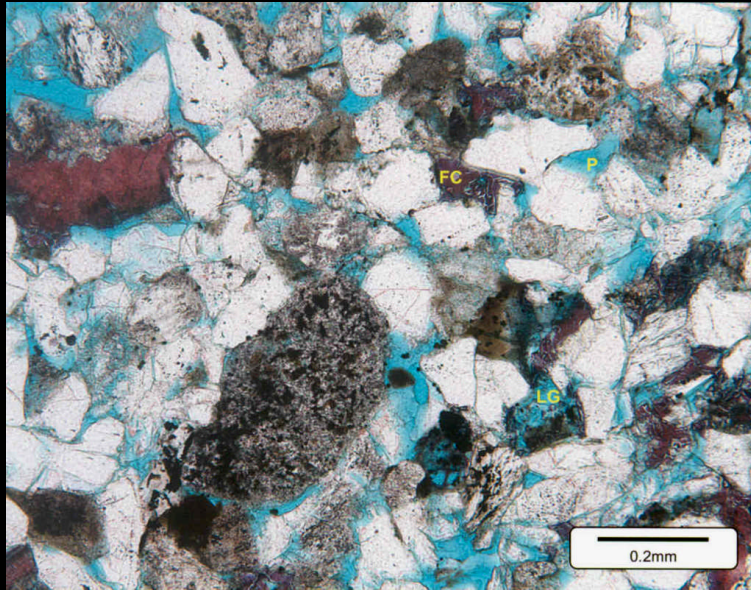
Rock Type



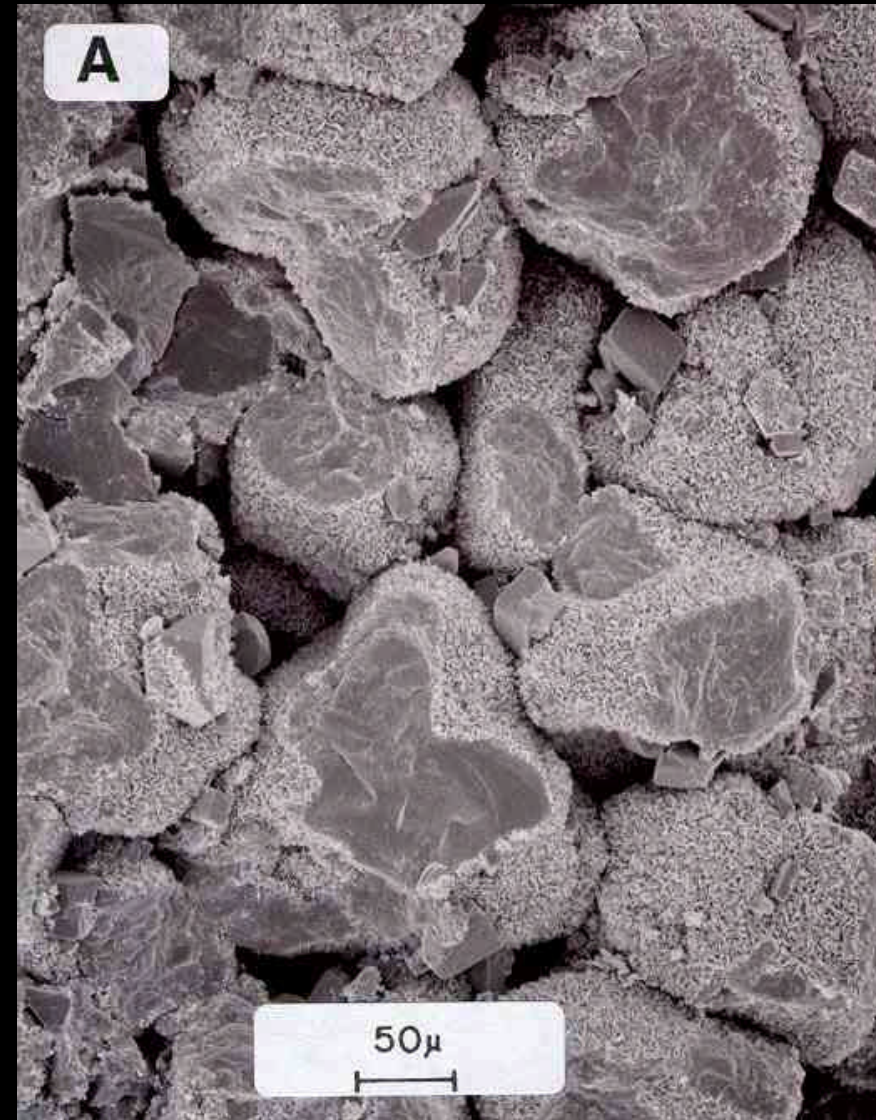
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- **Rock Types are categorized by properties important to HC storage and flow.**



Pore Scale Controls



Fibrous illite growing over grain-coating illite-smectite



How are Rock Types Determined



- **Porosity and Permeability**
 - **Considers pore throat size**

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- **Capillary Pressure**
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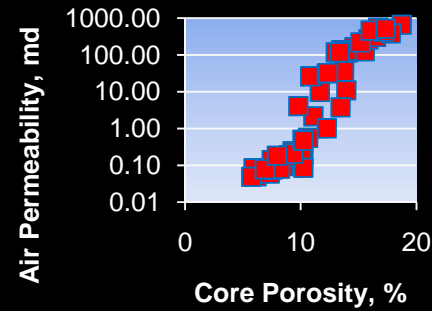


- **Porosity and Permeability**
 - Considers pore throat size
- **Capillary Pressure**
 - Considers interconnection and distribution of pore throats with storage
- **Relative Permeability**
 - Includes wettability

Rock Types by Porosity and Permeability



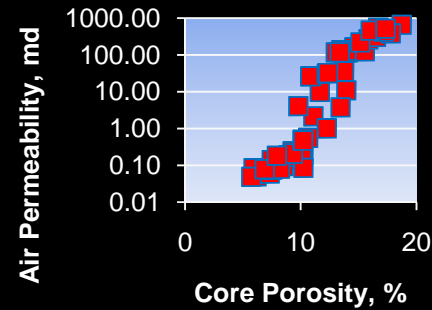
- K-Phi Cross Plot



Rock Types by Porosity and Permeability



- K-Phi Cross Plot



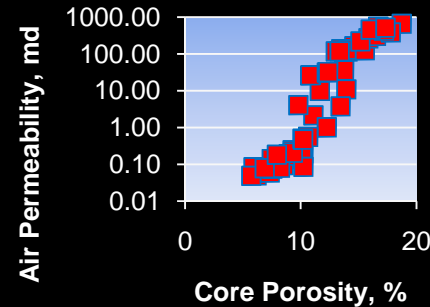
- Winland

$$- \text{Log} (R_{35}) = .732 + .588 \text{Log}(K) - .864 \text{Log}(\Phi)$$

Rock Types by Porosity and Permeability



- **K-Phi Cross Plot**



- **Winland**

- $\text{Log}(R_{35}) = .732 + .588\text{Log}(K) - .864\text{Log}(\phi)$

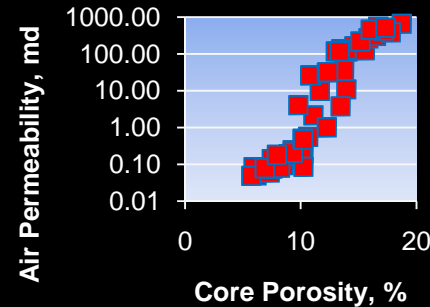
- **Pittman**

- $\text{Pittman Log}(R_{10}) = .459 + .500\text{Log}(K) - .385\text{Log}(\phi)$
 - $\text{Pittman Log}(R_{20}) = .218 + .519\text{Log}(K) - .303\text{Log}(\phi)$
 - $\text{Pittman Log}(R_{30}) = .215 + .547\text{Log}(K) - .420\text{Log}(\phi)$
 - $\text{Pittman Log}(R_{35}) = .255 + .565\text{Log}(K) - .523\text{Log}(\phi)$
 - $\text{Pittman Log}(R_{40}) = .360 + .582\text{Log}(K) - .680\text{Log}(\phi)$
 - $\text{Pittman Log}(R_{50}) = .778 + .626\text{Log}(K) - 1.205\text{Log}(\phi)$

Rock Types by Porosity and Permeability



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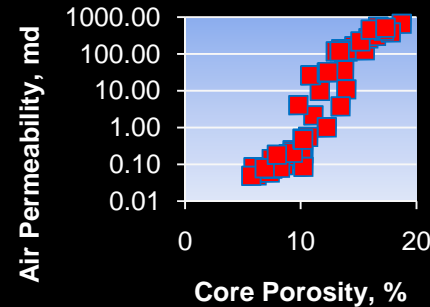
- **Rock Quality Index**

$$RQI = 0.0314 \sqrt{\frac{k}{\phi_e}}$$

Rock Types by Porosity and Permeability



- **K-Phi Cross Plot**



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- **Rock Quality Index**

$$RQI = 0.0314 \sqrt{\frac{k}{\phi_e}}$$

All from equating Poiseuille's and Darcy's equation

Poiseuille`s/Darcy`s equation relates Pore Throat to K & Phi



- Poiseuille`s Equation for a tube

$$q = \left(\frac{r^2}{8\mu} \right) (A) \frac{\Delta P}{L}$$

Poiseuille`s/Darcy`s equation relates Pore Throat to K & Phi



- Poiseuille`s Equation for a fracture

$$q = \left(\frac{d^2}{12\mu} \right) (A) \frac{\Delta P}{L}$$

Poiseuille`s/Darcy`s equation relates Pore Throat to K & Phi



- Poiseuille`s Equation for a tube

$$q = \left(\frac{r^2}{8\mu} \right) (A) \frac{\Delta P}{L}$$

- Darcy`s Equation

$$q = \frac{k}{\mu} \frac{A \cdot \Delta P}{L}$$

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- Combined

$$k = \frac{r^2}{8}$$

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$$q = \left(\frac{r^2}{8\mu} \right) (A) \frac{\Delta P}{L}$$

- Darcy`s Equation

$$q = \frac{k}{\mu} \frac{A \cdot \Delta P}{L}$$

- Combined with porosity

$$k = \frac{r^2}{8}$$

$$k = \frac{r^2}{8} \phi$$

Poiseuille's/Darcy's Equation Relates Pore Throat to K & Phi



Solve for radius

$$r = \sqrt{\frac{8k}{\phi}}$$

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Similar to RQI

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$$r = \sqrt{\frac{8k}{\phi}}$$

Similar to RQI

$$RQI = 0.0314 \sqrt{\frac{k}{\phi_e}}$$

Logrithm

$$\log r = 0.452 + 0.5 \log k - 0.5 \log \phi$$

Poiseuille's/Darcy's Equation Relates Pore Throat to K & Phi



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$$r = \sqrt{\frac{8k}{\phi}}$$

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$$RQI = 0.0314 \sqrt{\frac{k}{\phi_e}}$$

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$$\log r = 0.452 + 0.5 \log k - 0.5 \log \phi$$

Compare to Winland and Pittman equations

$$\text{Winland Log } (R_{35}) = .732 + .588 \text{Log}(K) - .864 \text{Log}(\Phi)$$

$$\text{Pittman Log } (R_{10}) = .459 + .500 \text{Log}(K) - .385 \text{Log}(\phi)$$

Lab Performance in Measuring K and Phi



Internal Core Lab Quality Assurance Program

- **Twenty- three (23) locations**
- **Some 3200 total points of data for evaluation**
- **Over 2 year(s) involved in each data series**
- **Updated program as existed for 8 years**

RCAL QA/QC Plugs - *materials & plan*



Twenty-four (24) total samples

Twelve (12) 1.0" diameter

Twelve (12) 1.5" diameter



Porosity Ranges: 2.0 – 23.0%

K_{inf} Ranges: 0.0001 – 1050 mD

Grain Den. Ranges: 2.599 – 2.858 g/cc



QA/QC Results - *assessment criteria*



Table 1: Maximum acceptable deviation in standard core plug analysis

| Measurement | Experience-based | Statistically-derived ¹ | Mean coefficient of variance, % |
|-------------------|---------------------------|------------------------------------|---------------------------------|
| Porosity | +/-0.5 Por% | +/-0.23% | 0.67 |
| Grain density | +/-0.01 g/cm ³ | +/-0.0093 g/cm ³ | 0.13 |
| Air permeability: | | | |
| 0.01 - 0.1 md | +/-30% | +/-21% | 8.0 |
| 0.1 - 1.0 md | +/-25% | +/-21% | 8.0 |
| 1.0 - 50 md | +/-15% | +/-13% | 5.0 |
| 50 md - 1 darcy | +/-15% | +/-8% | 3.0 |

¹ A single measurement made on the same sample that falls outside the specified limit is 99% likely to be in error, assuming that both tests are performed with the same standard deviation

Taken from:

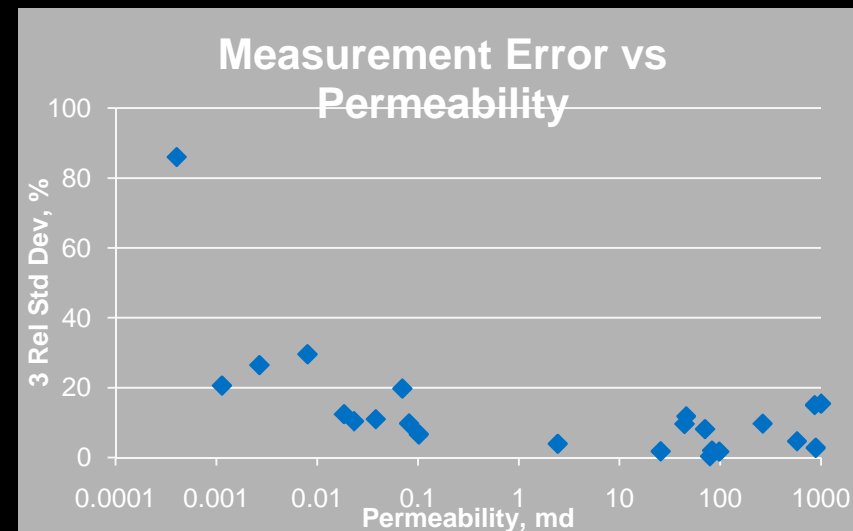
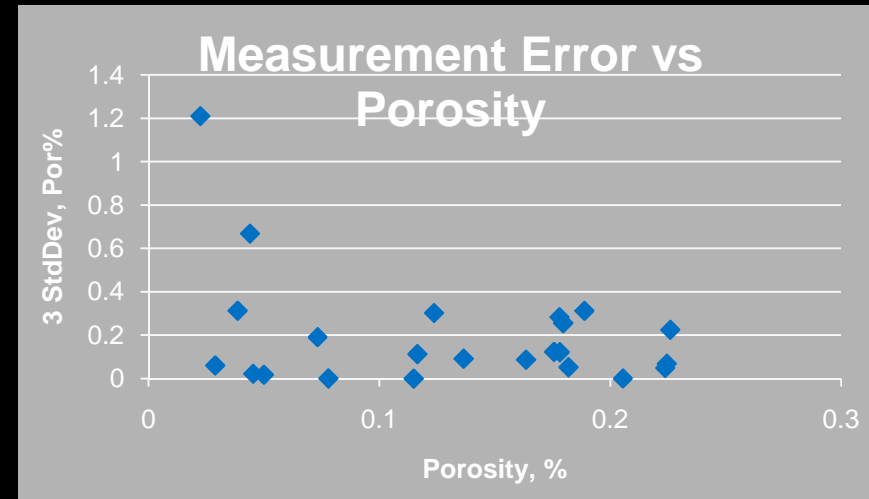
Thomas, D.C. and Pugh, V.J.: "A Statistical Analysis of the Accuracy and Reproducibility of Standard Core Analysis", The Log Analyst, March-April, 1989, 71-77. (*journal version of SCA 8701*)

- **“Experienced-based acceptable deviations” of Thomas & Pugh used for performance assessments**
- **Prelim results compared to mean of limited “standard” measurements**

Core Labs` QA Experience



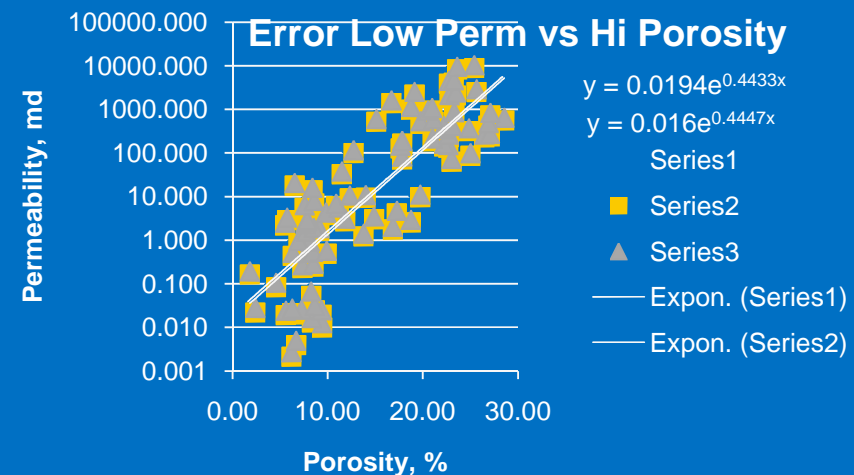
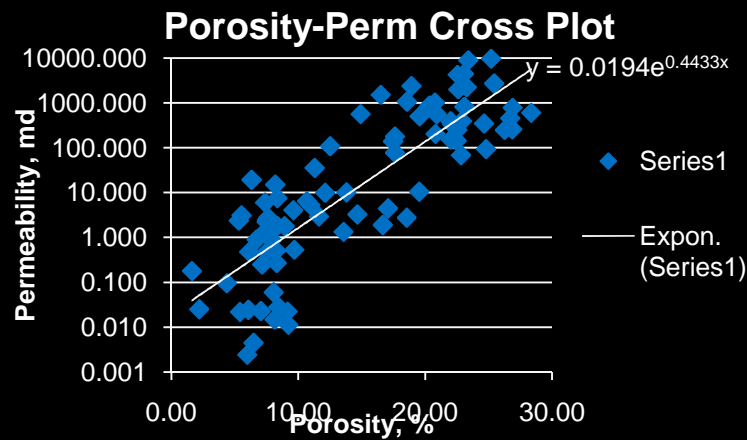
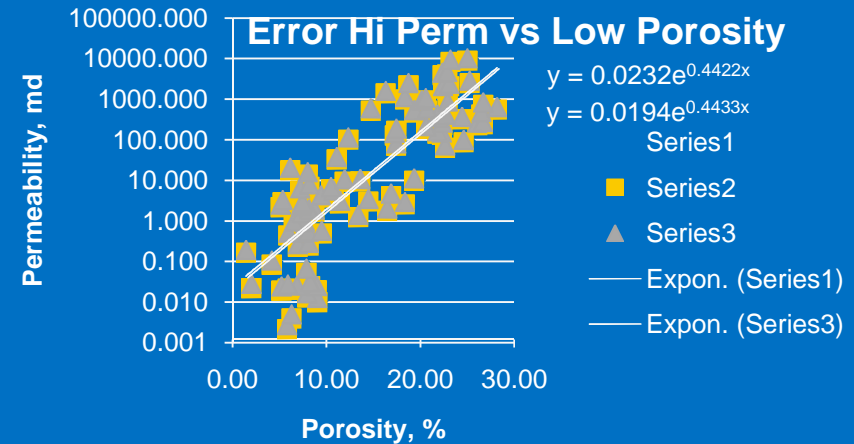
| Measurement | Thomas & Pugh Experience Error | Internal Core Lab QA |
|----------------|--------------------------------|----------------------|
| Porosity | 0.50 Por% | 0.20 Por% |
| Permeability | | |
| <0.001 md | -- | 26% |
| 0.01 - 0.1 md | 30% | 12% |
| 0.1-1.0 md | 25% | 8 |
| 1.0-50 md | 15% | 7 |
| 50 md- 1 darcy | 15% | 7 |



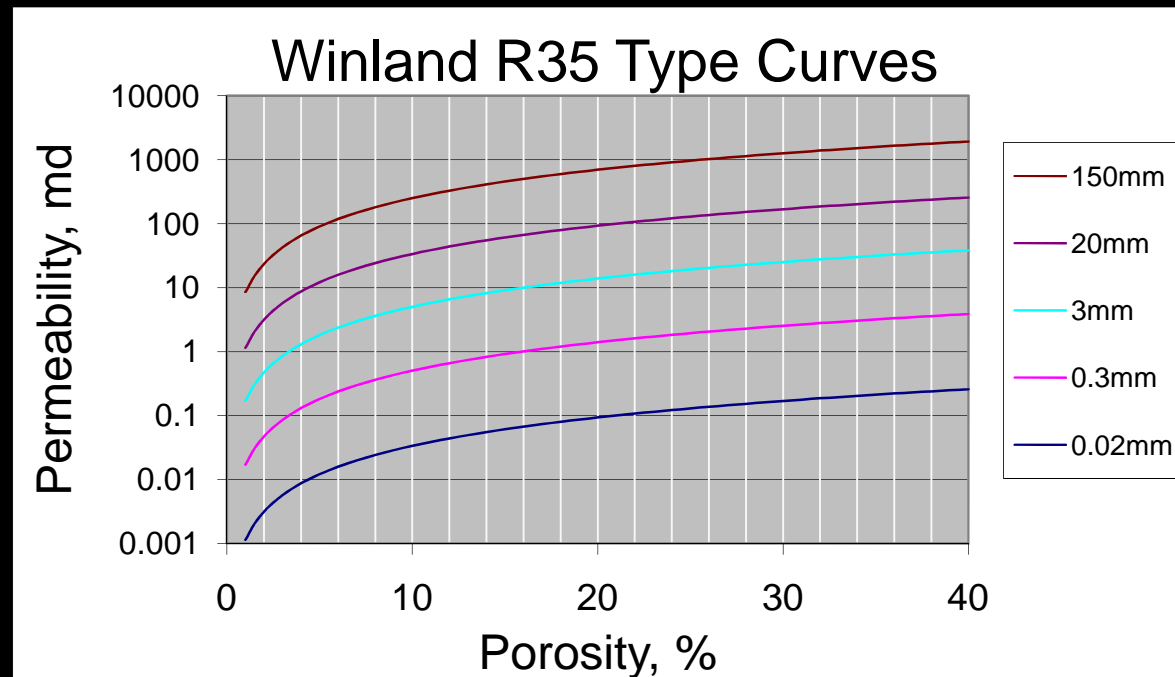
Impact on K&Phi Crossplot



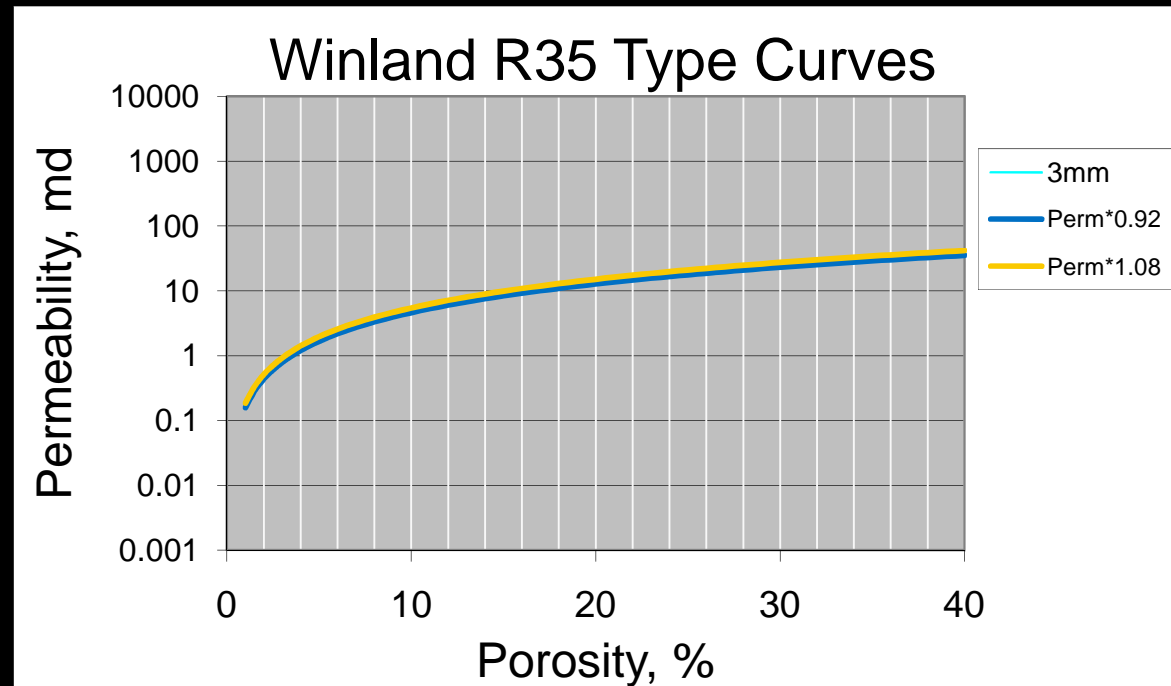
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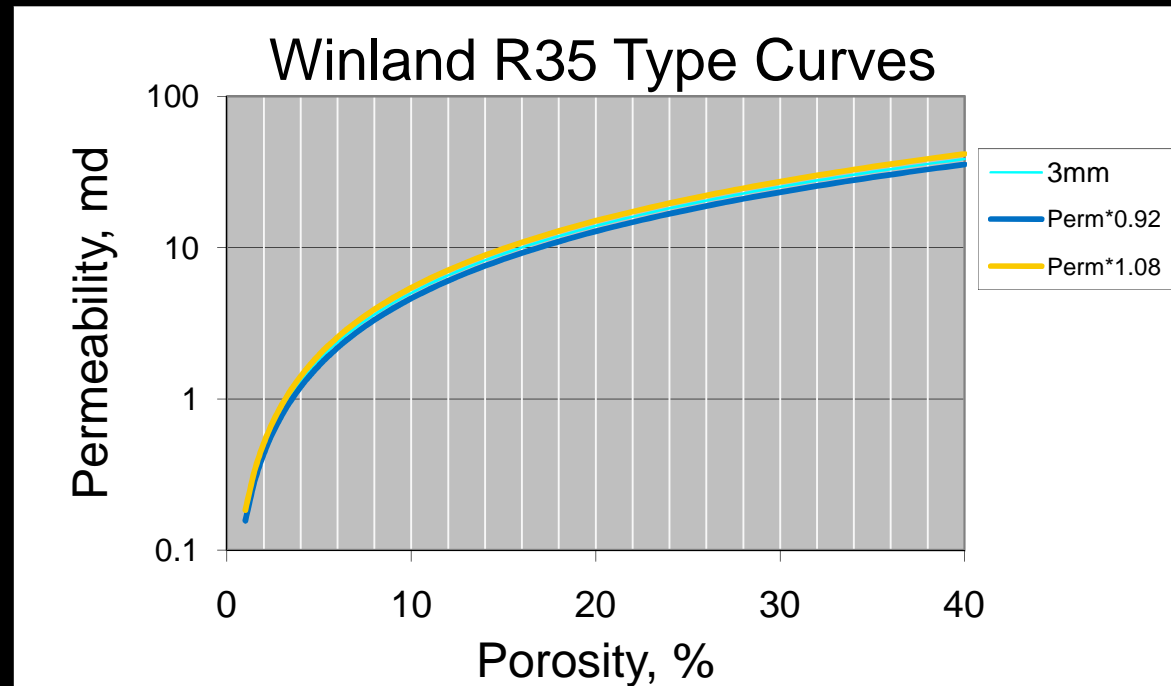
Impact in Pitman/Winland curves



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Using Leverett J-Function



- J-Function used to normalize capillary pressure for different K and ϕ within a rock type
- J-Function data that does not group indicates different rock type
- J-Function

$$P_c = \frac{2\gamma \cos \theta}{r} = \frac{J\gamma \cos \theta}{\sqrt{\frac{k}{\phi}}}$$

Leverett J-Function

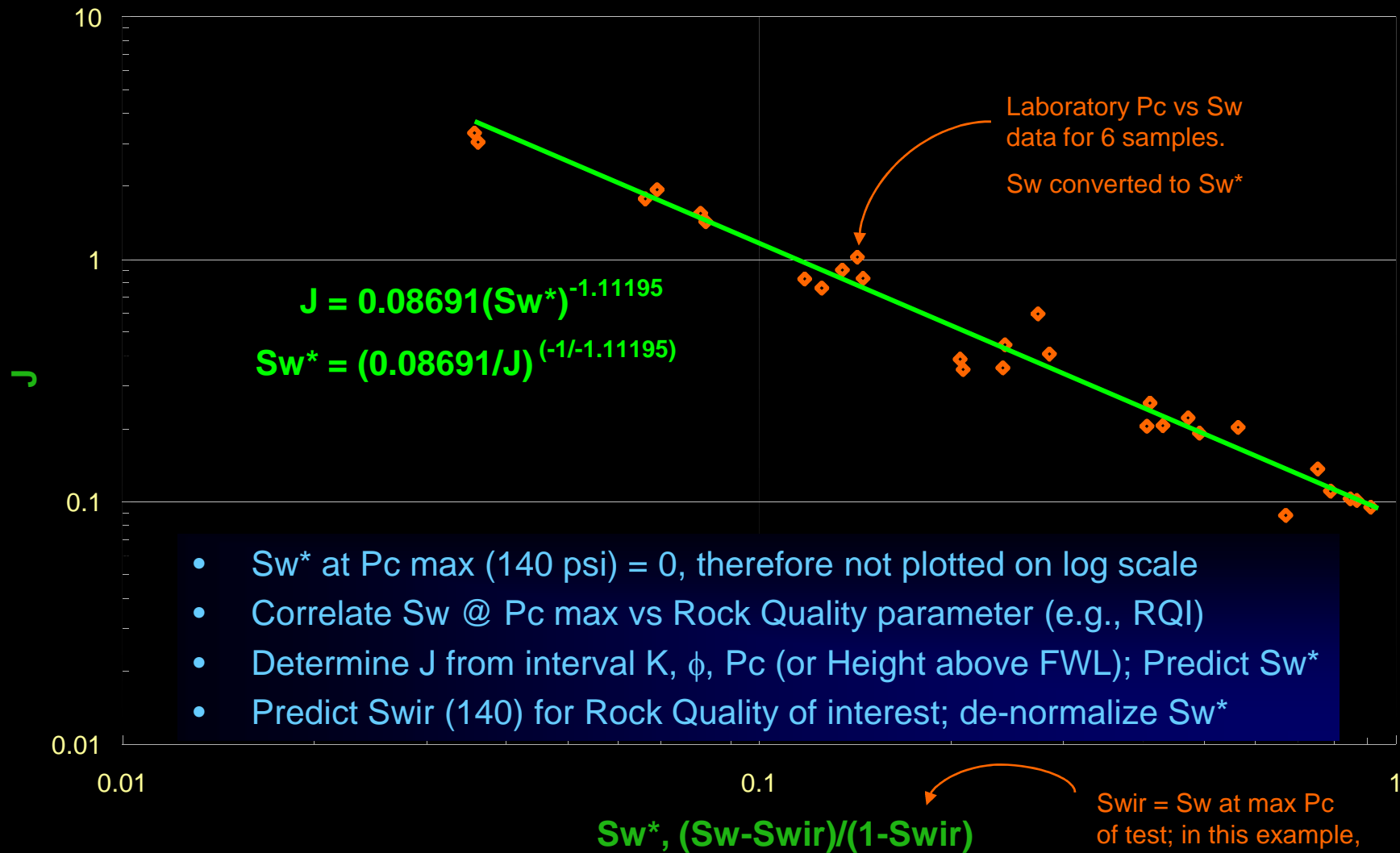


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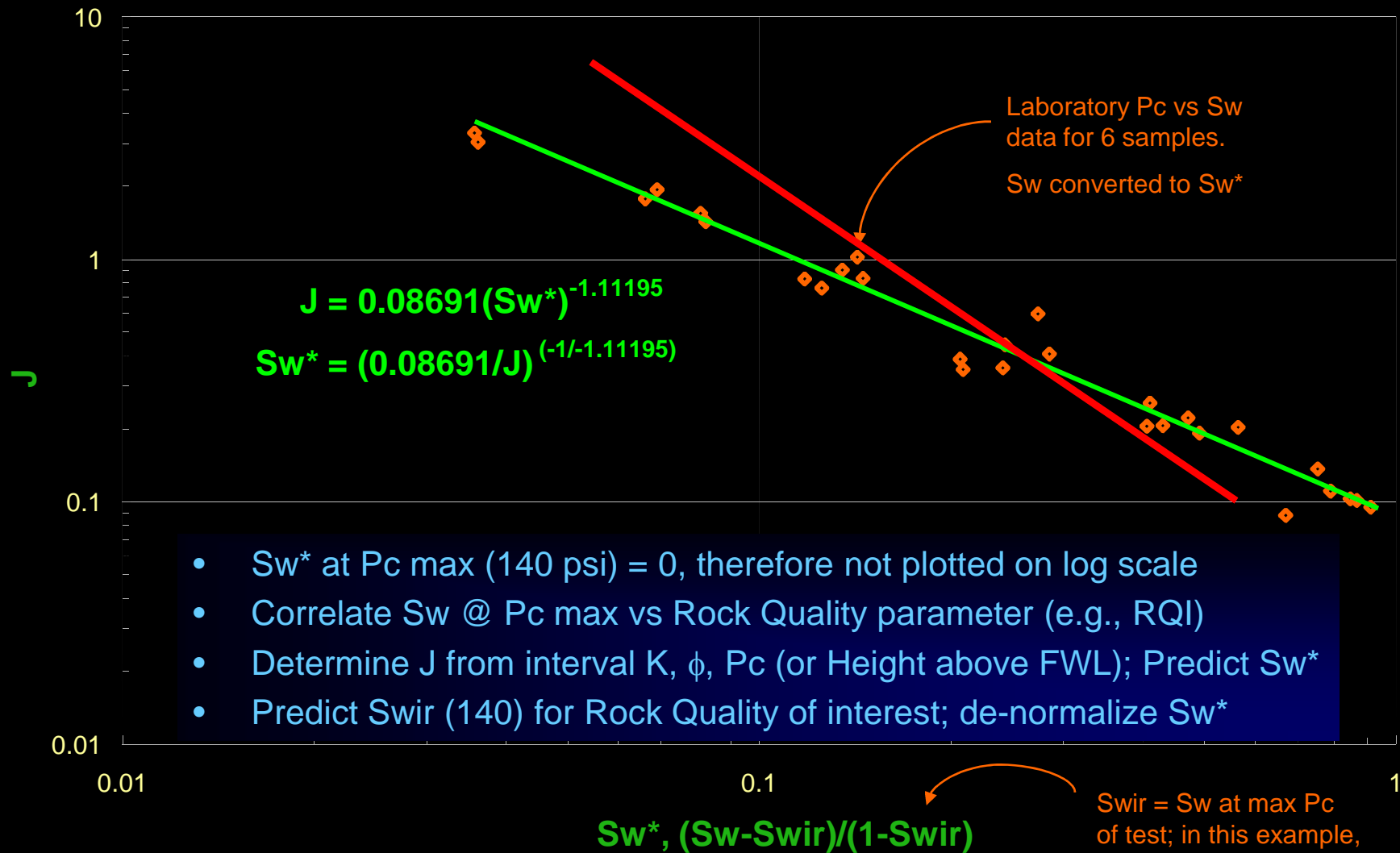
$$J = \frac{0.2166 P_c \sqrt{\frac{k}{\phi}}}{\gamma \cos \theta}$$

Leverett J Function vs Sw*



- Sw* at Pc max (140 psi) = 0, therefore not plotted on log scale
- Correlate Sw @ Pc max vs Rock Quality parameter (e.g., RQI)
- Determine J from interval K, ϕ , Pc (or Height above FWL); Predict Sw*
- Predict Swir (140) for Rock Quality of interest; de-normalize Sw*

Leverett J Function vs Sw*

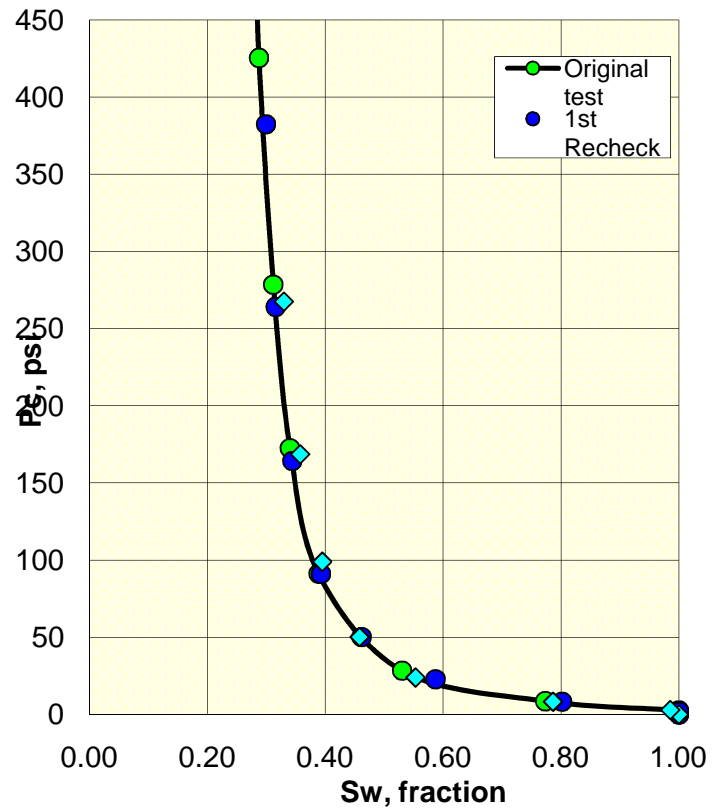


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Lab Measurement error in Capillary pressure



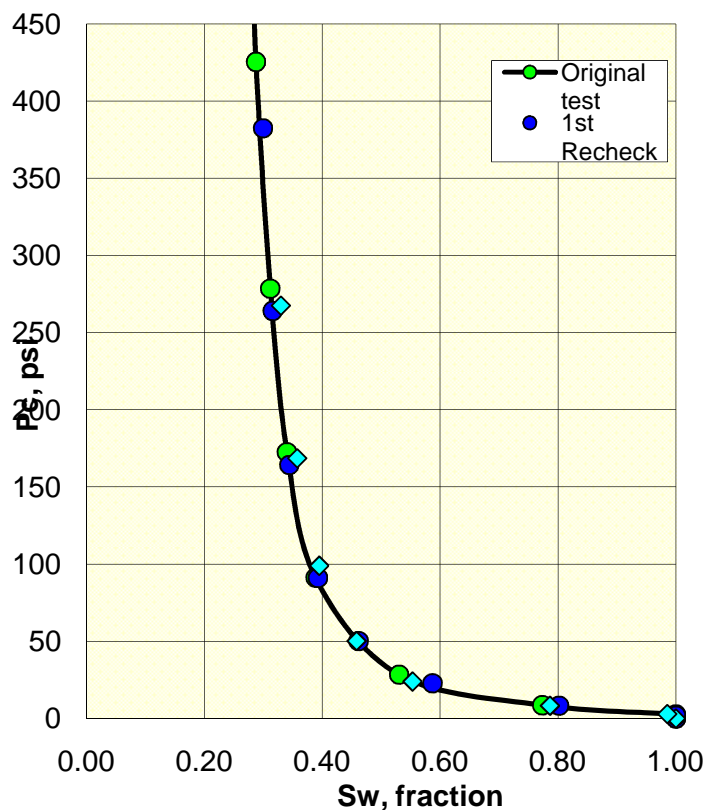
CENTRIFUGE GAS/WATER P_c
Repeatability Testing



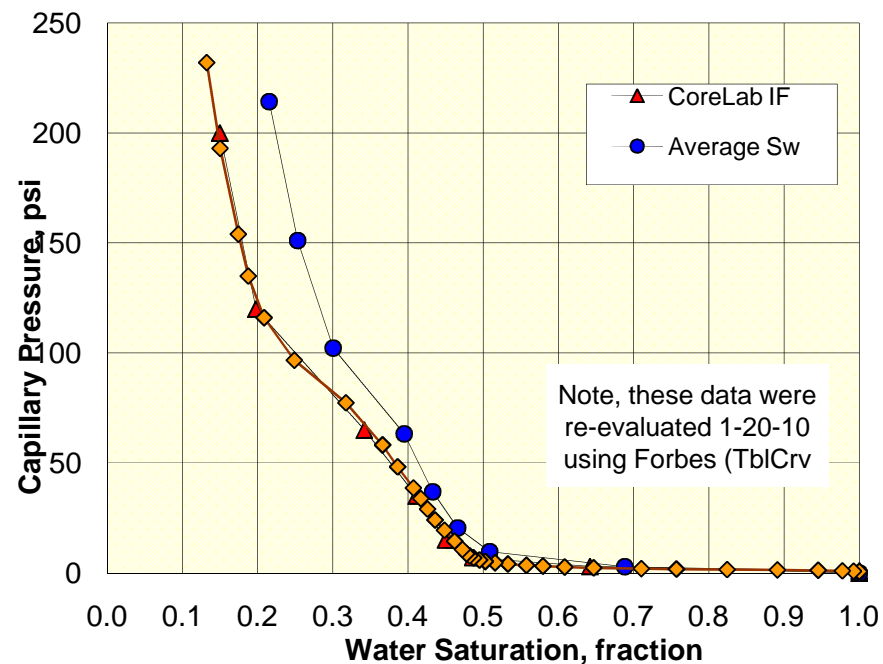
Lab Measurement error in Capillary pressure



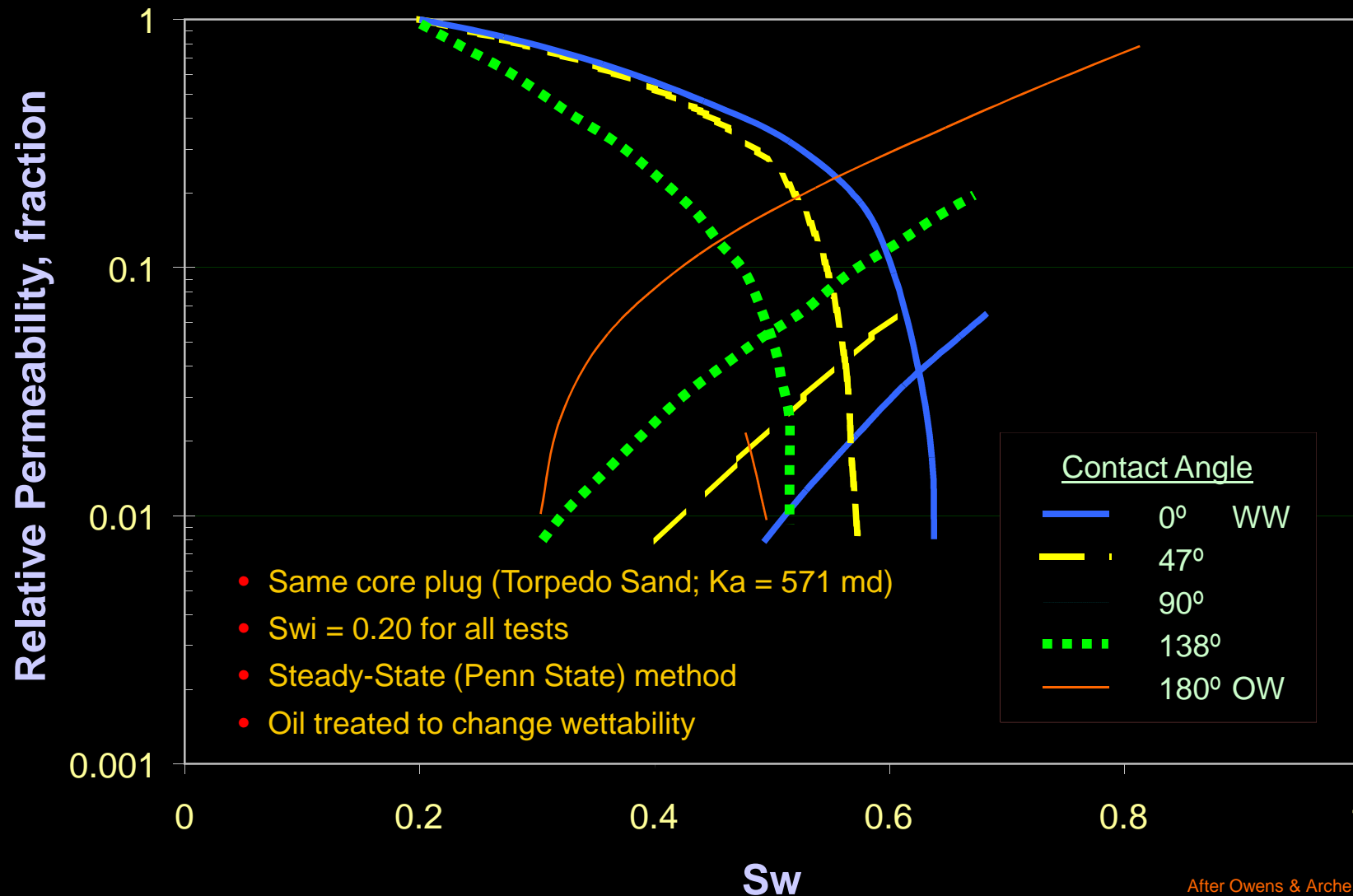
CENTRIFUGE GAS/WATER P_c Repeatability Testing



P_c COMPARISON
Unconfined Centrifuge gas/water



Relative Permeability includes Wettability



Unsteady-State Relative Permeability Error



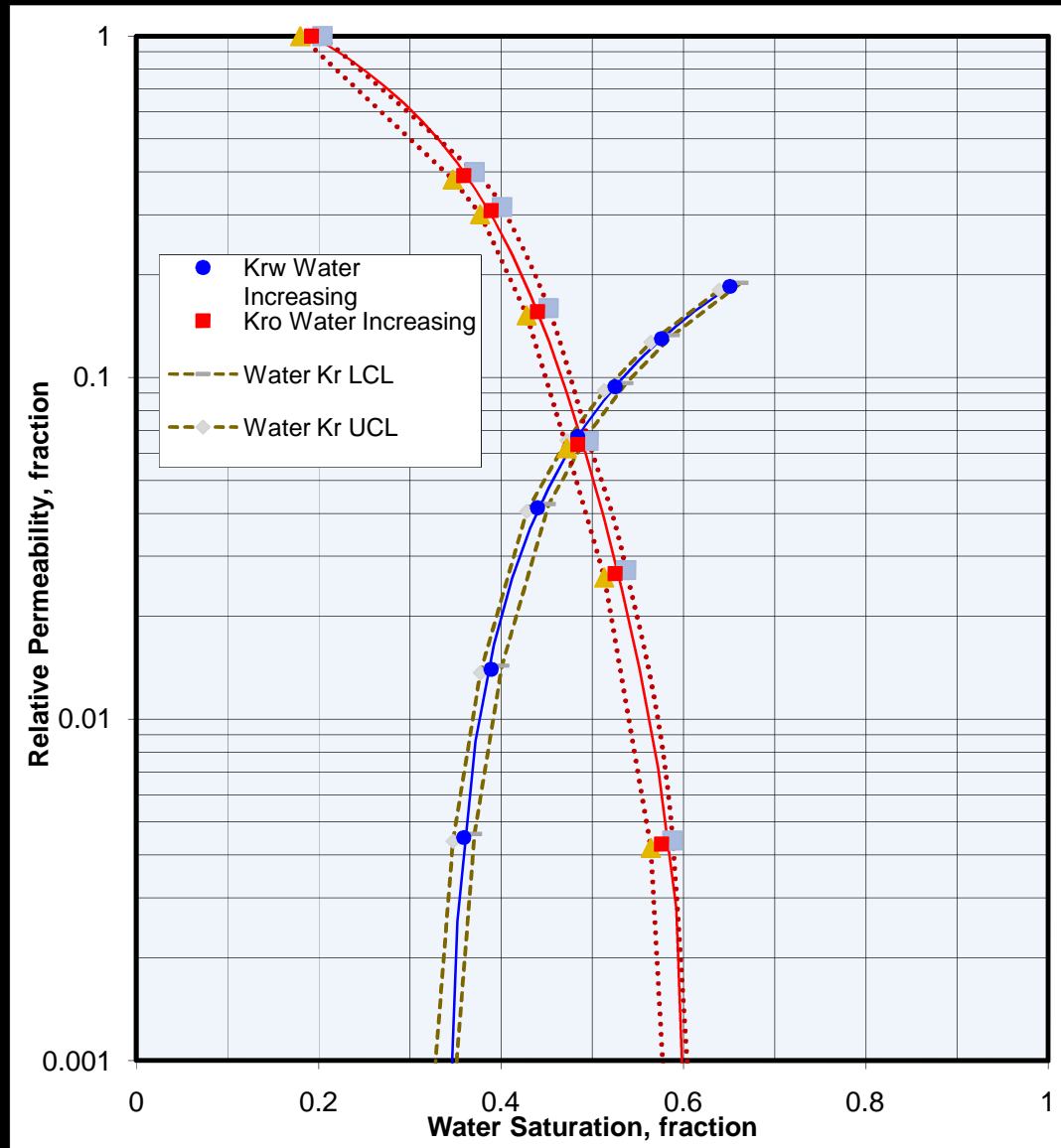
- Pore volume major factor
- In JBN analysis
 - Smoothness of data critical
 - Knowing dead volumes and detecting breakthrough very important
 - Experience indicates
 - Effective Perm +/- 5% of value
 - Saturation +/- 10% saturation unit
 - Variability decreases as floodout is approached

Steady-State Relative Permeability Error



- **X-ray saturation data**
 - +/- 1.2% saturation % units
 - At least 1 million photons used (Poisson's statistics)
- **Effective permeability data**
 - Typically +/- 2% of value
 - Low flow rate, +/-10 – 50% of value

Error bounds on Relative Permeability



Conclusion



- **Rock type is used to group rocks that have common storage and flow properties**
- **Rock typing is mostly based on pore size**
- **Rock properties measurement variabilities have no impact on rock typing**
- **Rock typing uses porosity, permeability, capillary pressure, and relative permeability**