Understanding Porosity and Permeability using High-Pressure MICP Data: Insights into Hydrocarbon Recovery*

John S. Sneider[1] and George W. Bolger[2]

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Abstract

A study using over 400 samples with porosity, permeability and mercury injection capillary pressure (MICP) data identified several key parameters calculated from MICP data that characterize reservoir quality and quantify the likelihood of hydrocarbon recovery. The sum of pore-throat diameter x the porosity accessed by a pore-throat of a given diameter (SumDB) accurately predicts permeability using the equation kair = 10(C1*LOG(SumDB) - C2) over a range of permeability from <0.001 md to over 1000 md , where C1 = 1.6337 and C2 = 2.2081. The "Pseudo Pore Throat Aperture" (PPTA) is equal to SumDB/(Total Porosity) and is the effective hydraulic radius of the rock.

The PPTA can be used to divide the reservoir into flow units. A cross plot of porosity versus permeability contoured by PPTA indicates that the size of the connecting pore-throats controls the effectiveness of porosity toward permeability. At higher porosity values, pore-throat size is the dominant control on permeability. Porosity has a greater impact on permeability as the hydraulic radius and the porosity of the rock decrease. Although the research is preliminary, the ability of hydrocarbons to be produced seems to be linked to a combination of pore-throat size and fluid properties. When comparing rocks with the same air permeability but different porosities, rocks with lower porosity are better reservoirs because the pore-throats are larger, and therefore will have higher relative permeability to hydrocarbons. The more viscous the fluid, the larger the pore-throats must be to recover the hydrocarbons.

Using this logic, effective porosity values are determined by fluid type using different pore-throat size cut-offs. Pay in a field can be ranked based on pore-throat size cutoffs and fluid properties.

Understanding
Porosity and Permeability
using
High-Pressure MICP Data

"Insights into Hydrocarbon Recovery"

John S. Sneider
George W. Bolger

What is the lower limit of pay?

Outline

- Introduction
- Review
  - Rock Relationships
    - Porosity vs. Permeability
- Studying the Rocks Via Pc
  - Rock Properties vs. MICP
  - Capillary Tube Model
  - Simplifying Pore Structure
- Defining Pay using Pc
- Summary & Conclusions

Main Goal of Research

Find simple relationships to help determine if hydrocarbons can be recovered from potential reservoir rocks.

Project

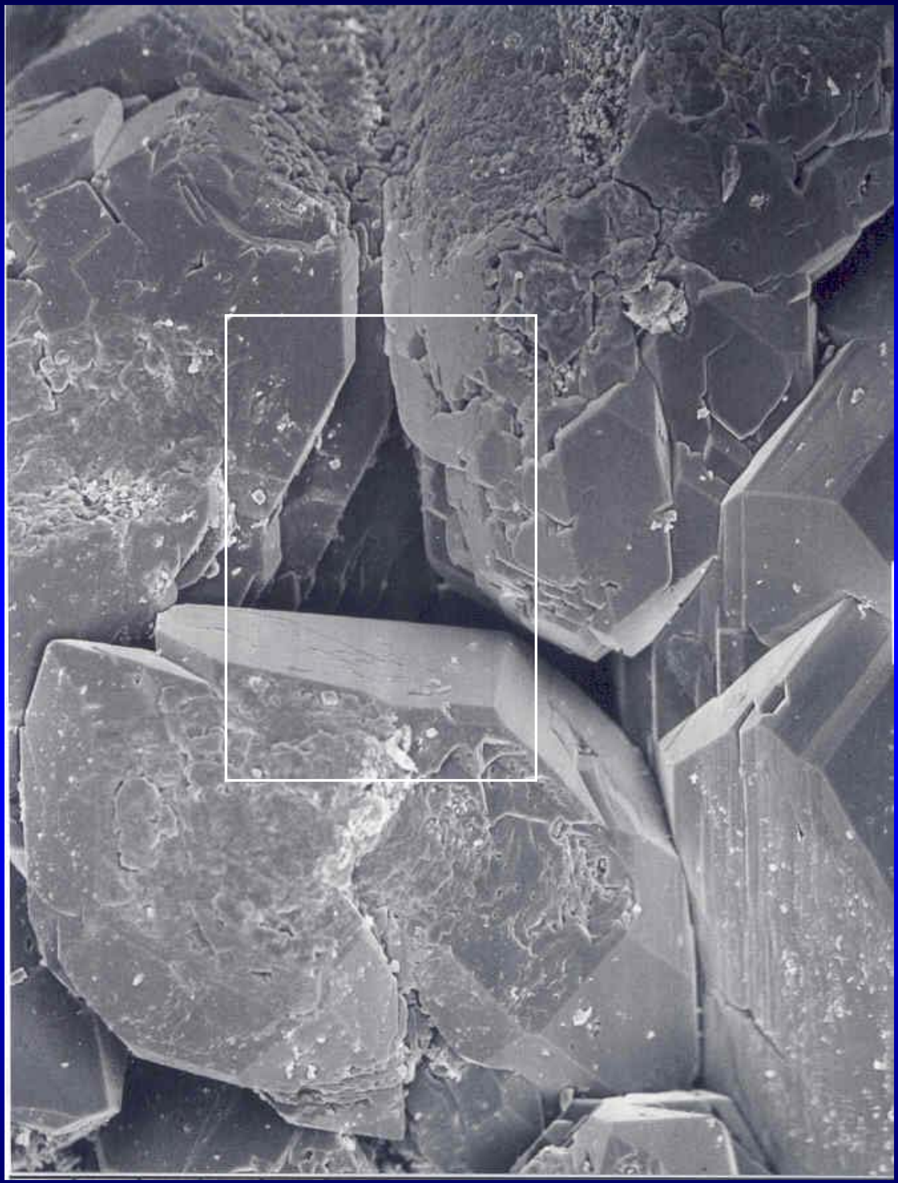
- Studied >400 samples with
  - Porosity, permeability and mercury injection capillary pressure (MICP) data
- Characterized reservoir quality
  - Simple calculations using MICP data
- Compared to production
  - Difficult to do in practice
  - Quantify the likelihood of hydrocarbon recovery

In a nutshell!

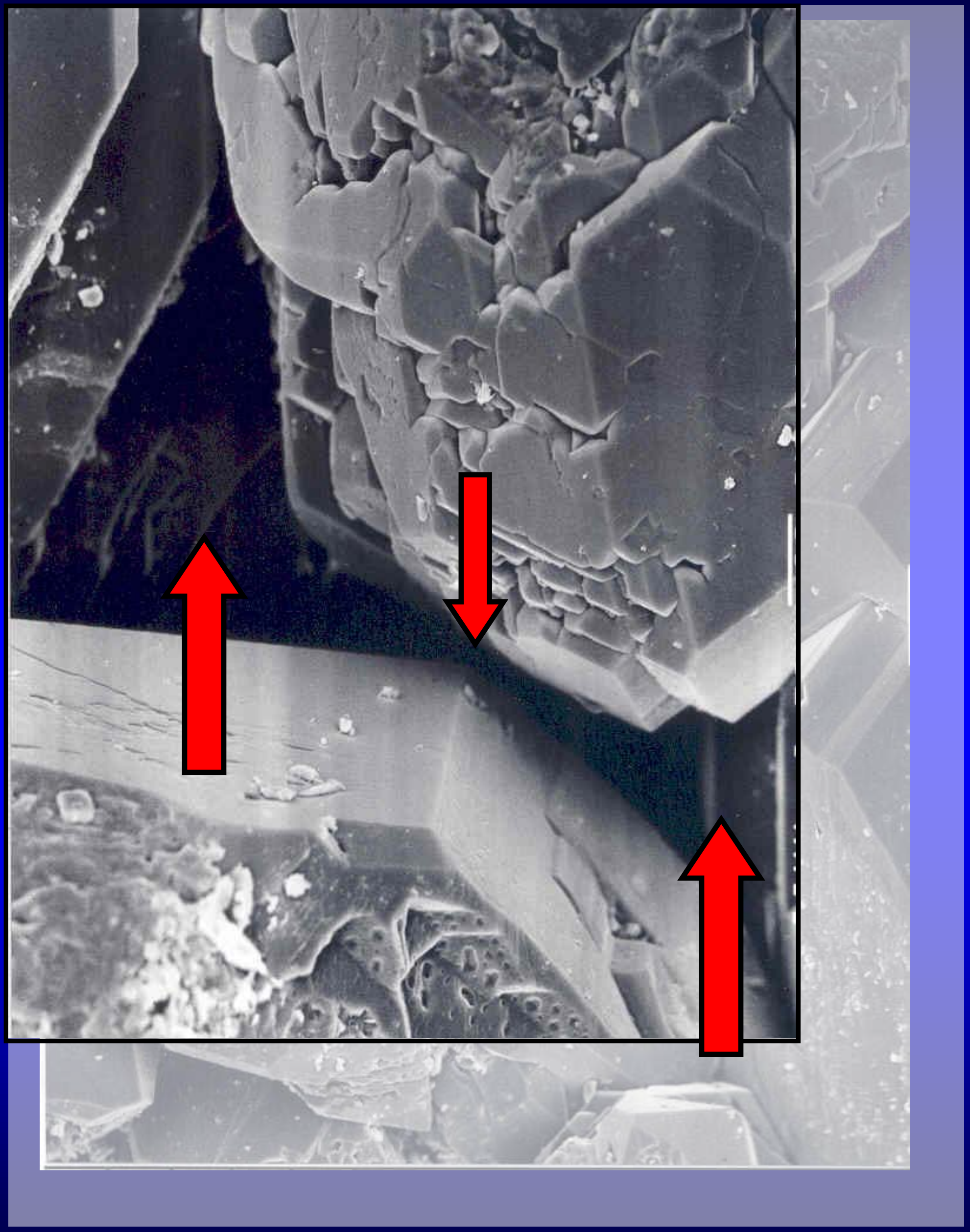
The SIZE of…

…PORE THROATS…

…determines if a rock
PRODUCES hydrocarbons



IT'S THE PORE THROAT SIZE THAT MATTERS!



IT'S THE PORE THROAT SIZE THAT MATTERS!

The pore-throat connects larger pores together

Other Important Factors

- Fluid properties*****
  - Heavy Oil
  - Light Oil
  - Gas
- Other Factors
  - Wettability
  - Well spacing
  - Completion
  - Drive mechanism

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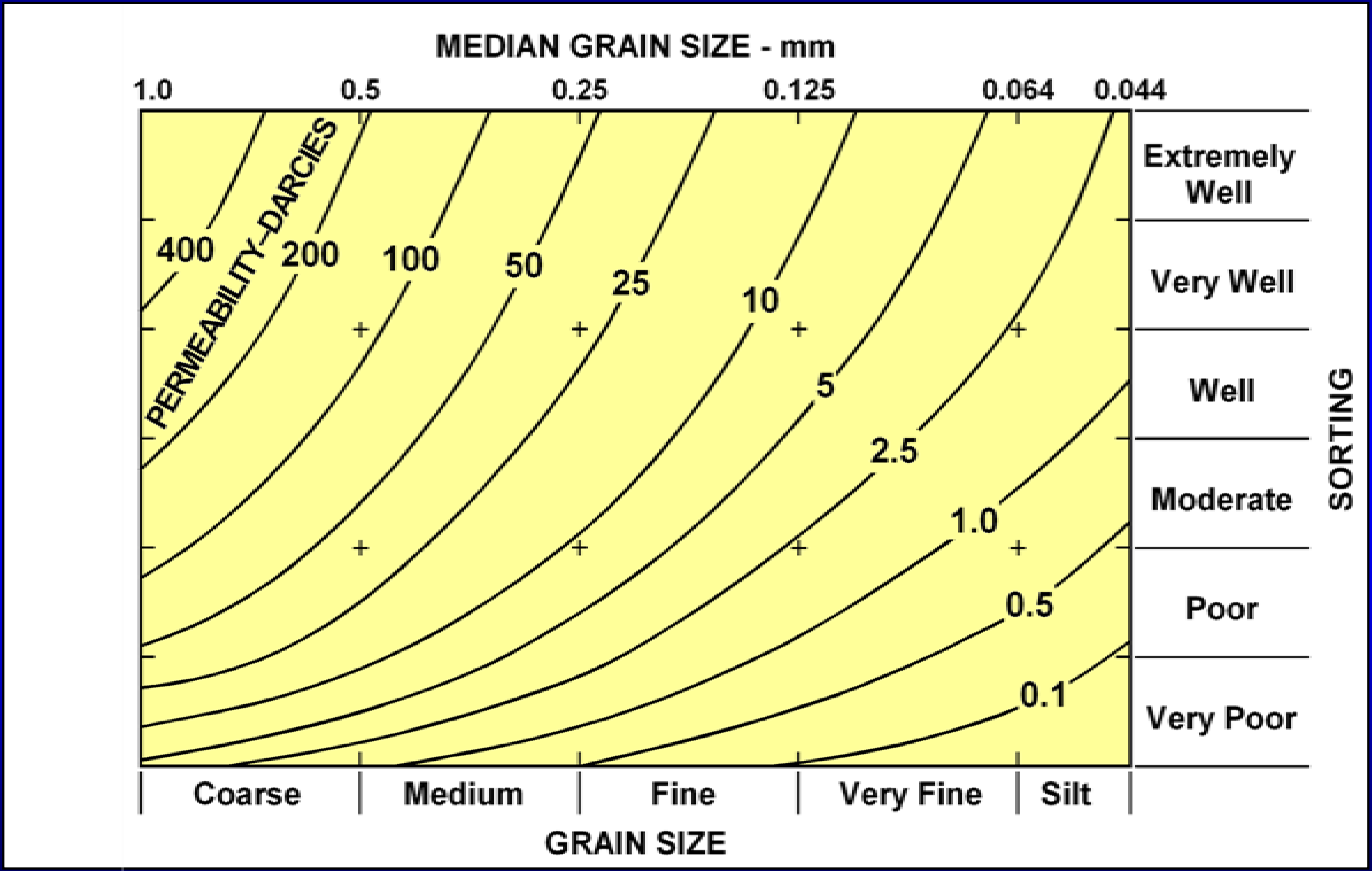
Clastics

The Effect of Texture

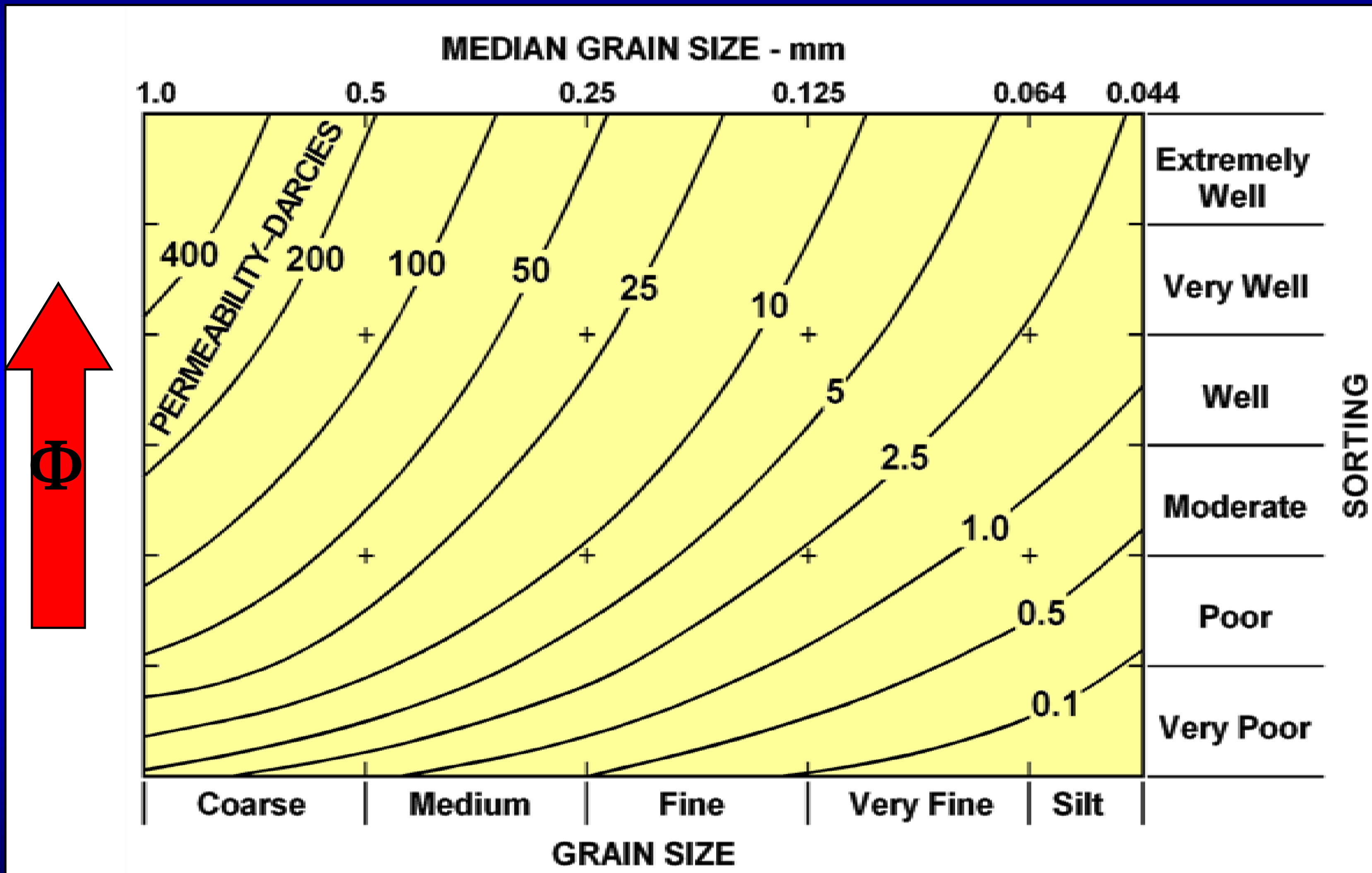
(grain size & sorting)

Effect of Grain-Size & Sorting



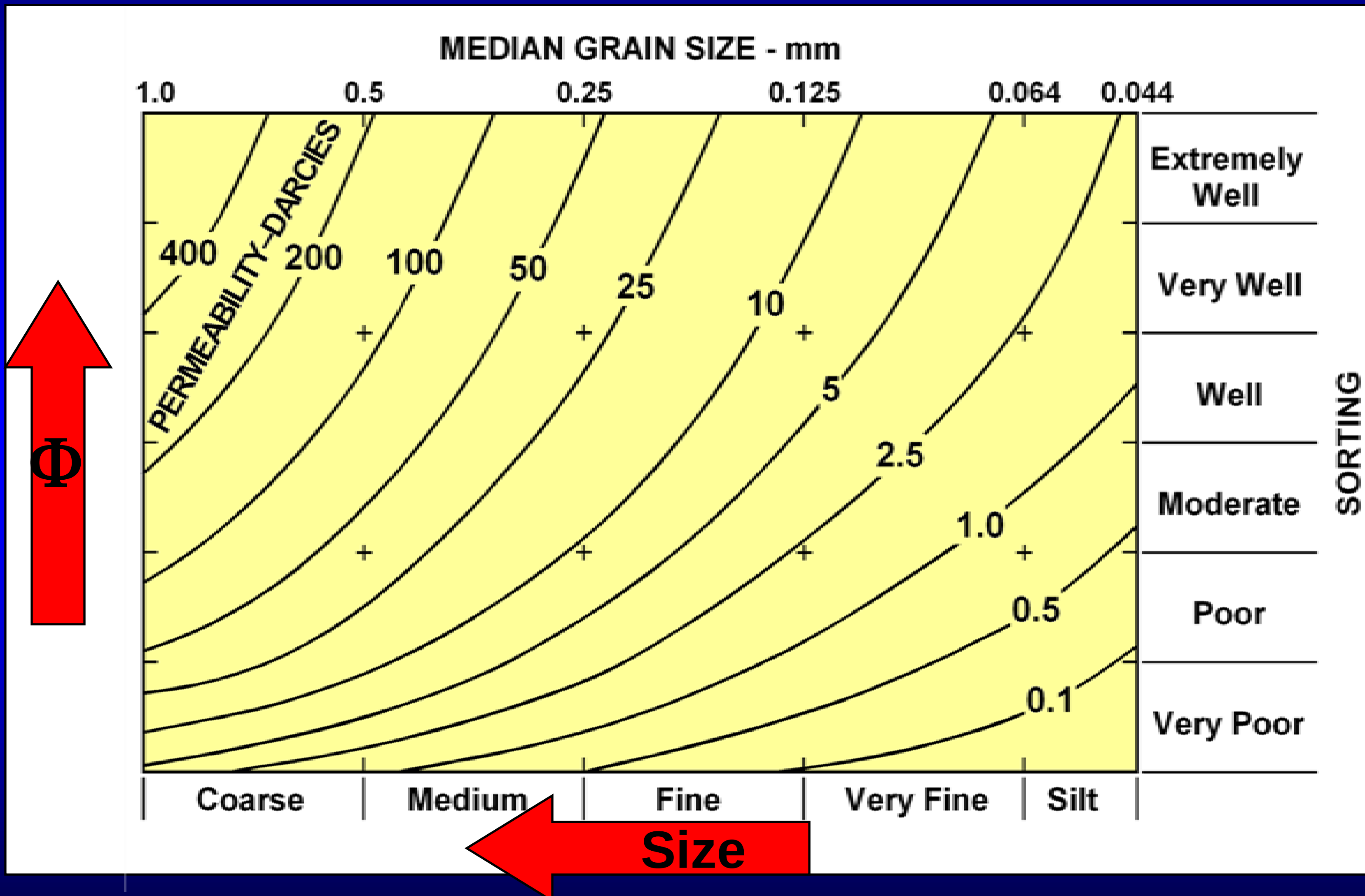
After Beard & Weyl (1973)

Increased Sorting = Increased Porosity



After Beard & Weyl

Increased Grain Size = ↑ Pore-Throat Size



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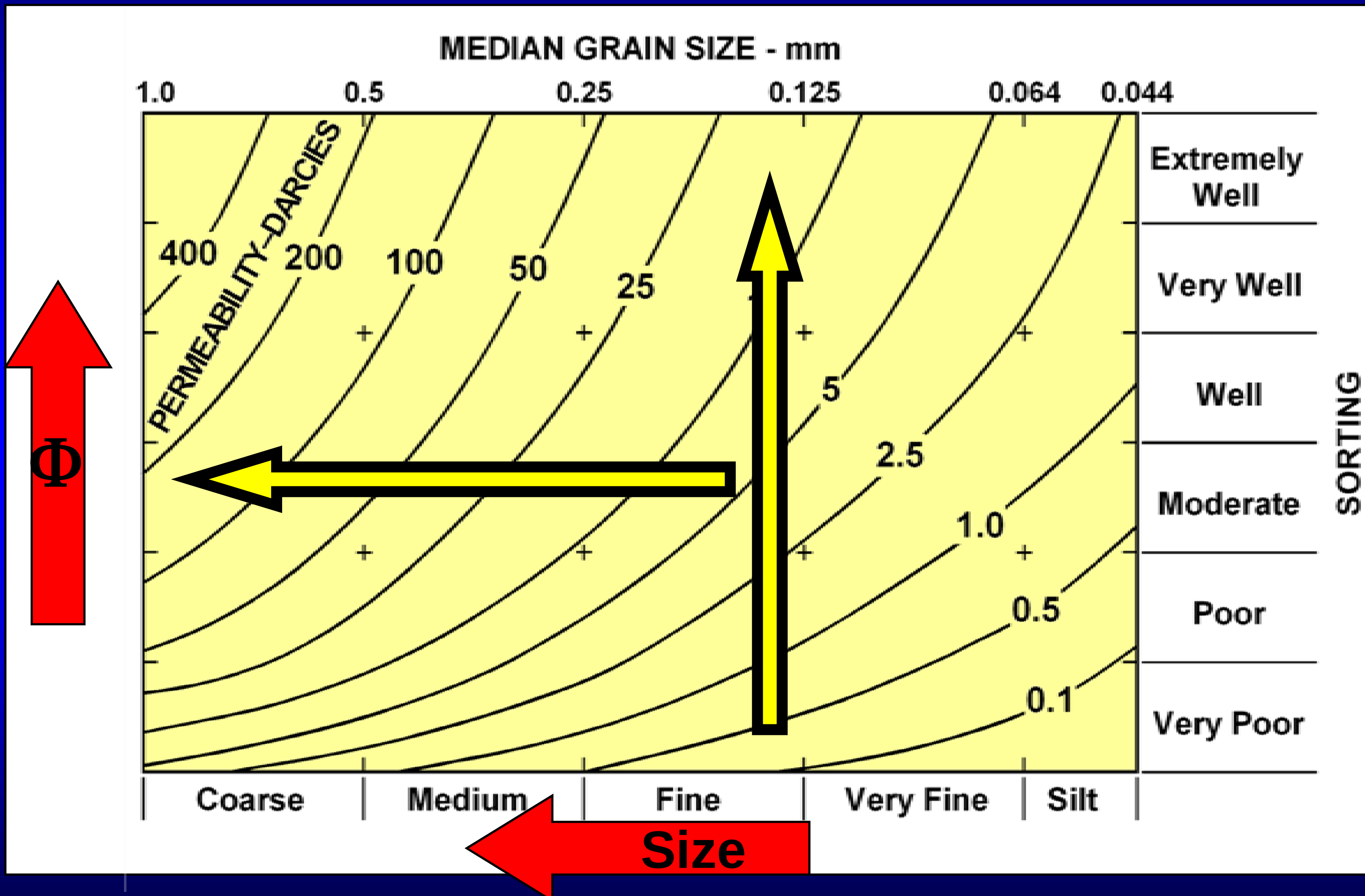
After Beard & Weyl

Permeability Increases



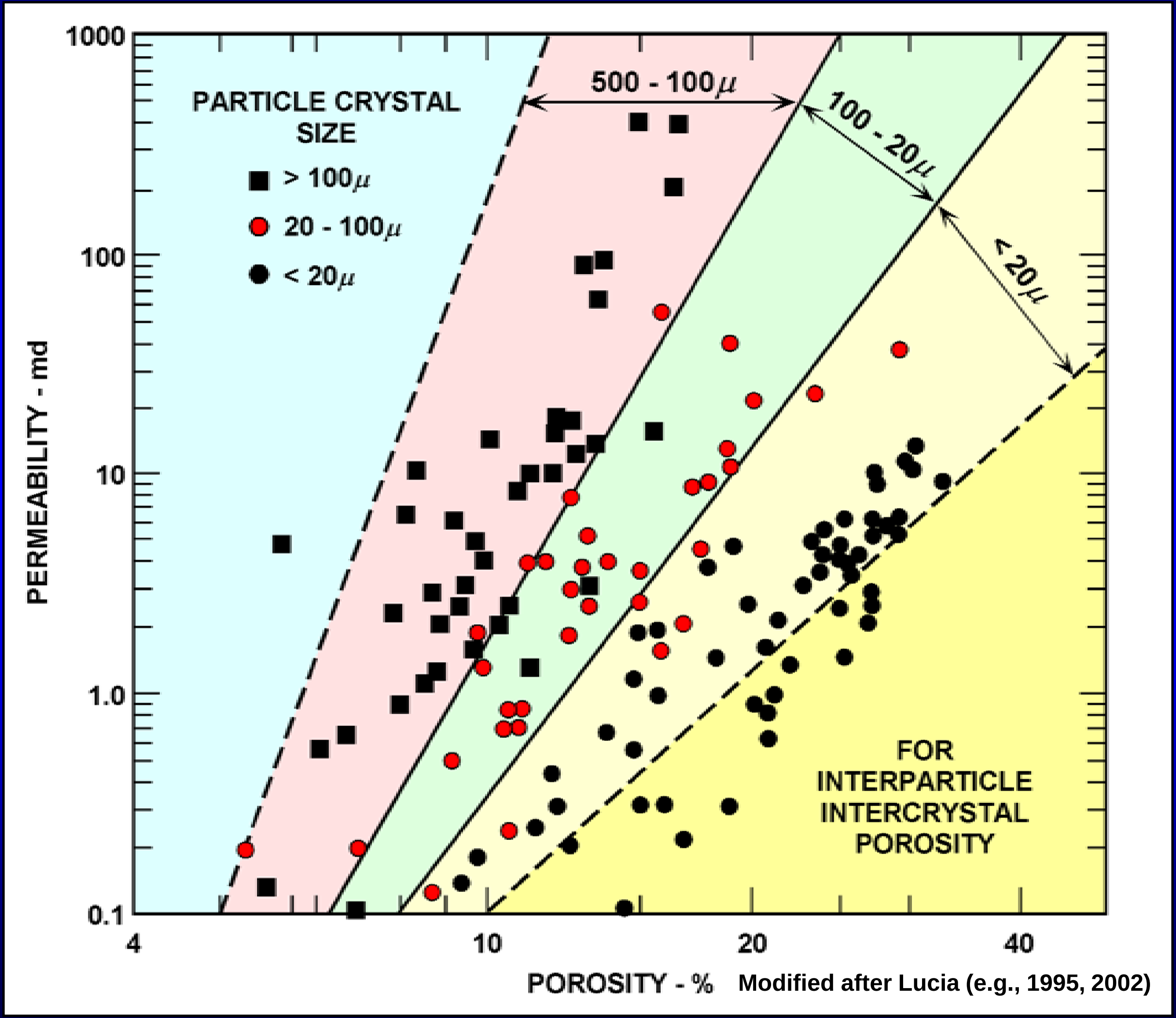
After Beard & Weyl

Carbonates

The Effect of Crystal Size

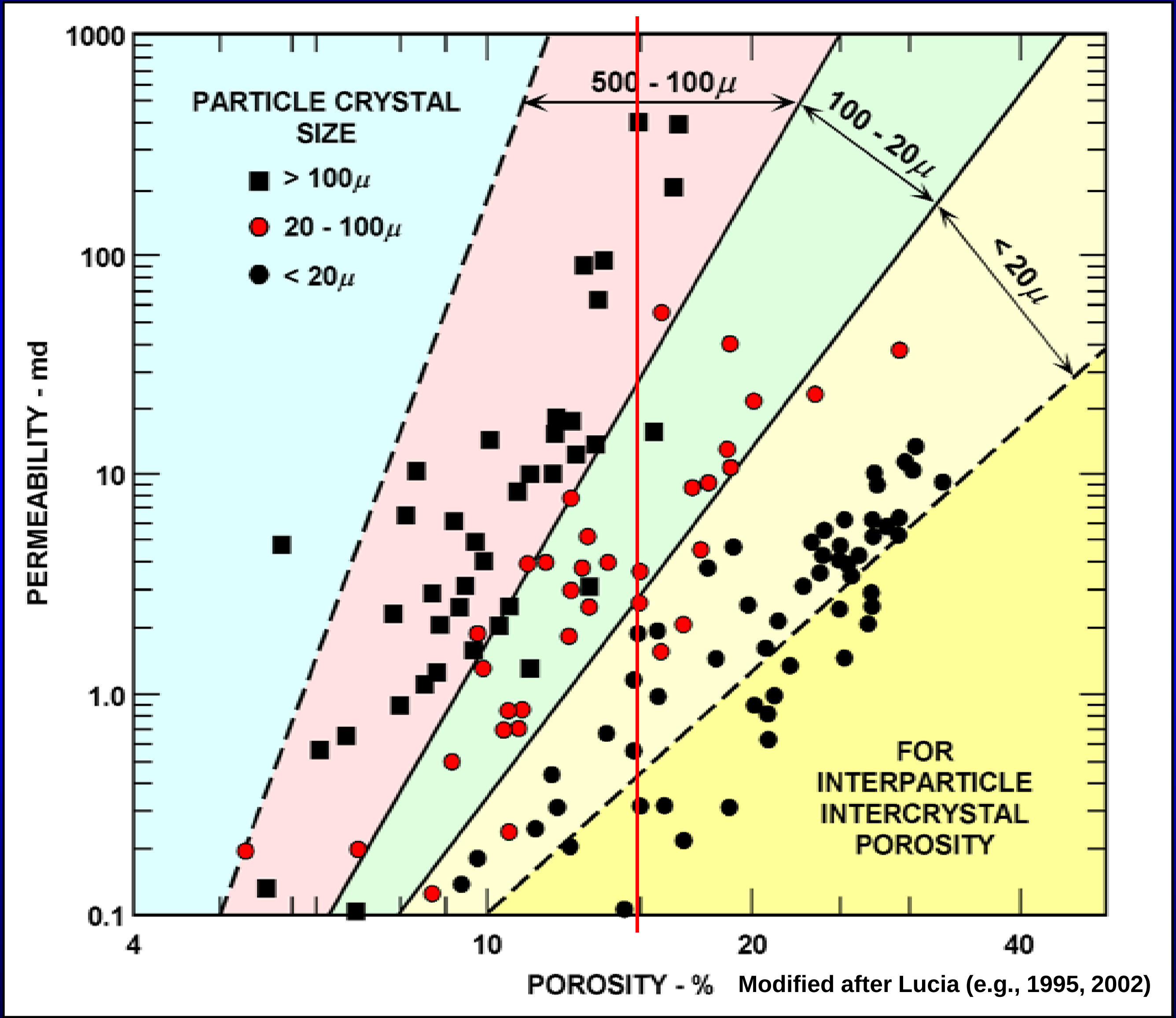
Porosity vs. Permeability

Particle - Crystals Size



RMS840896

At a constant Φ



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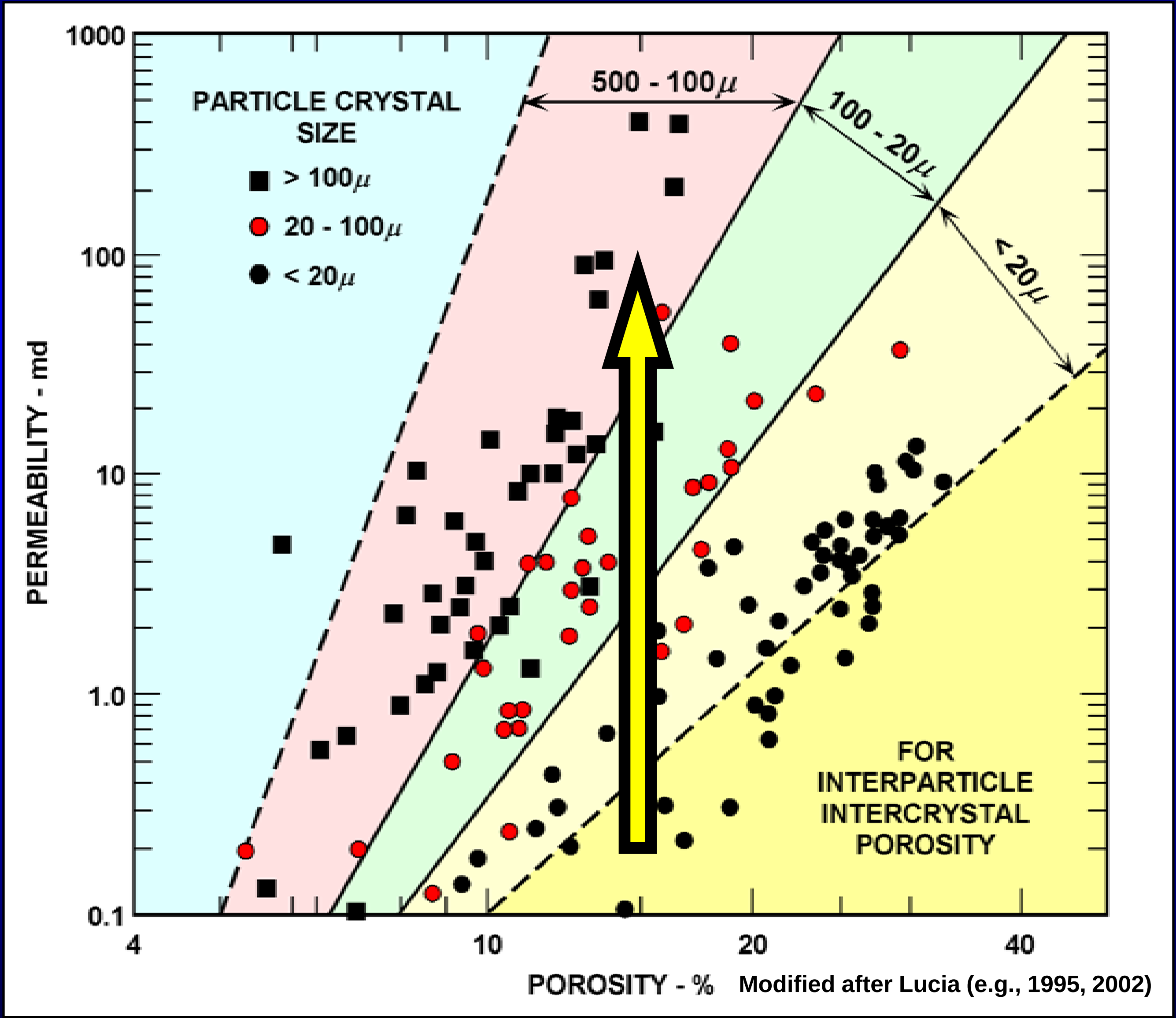
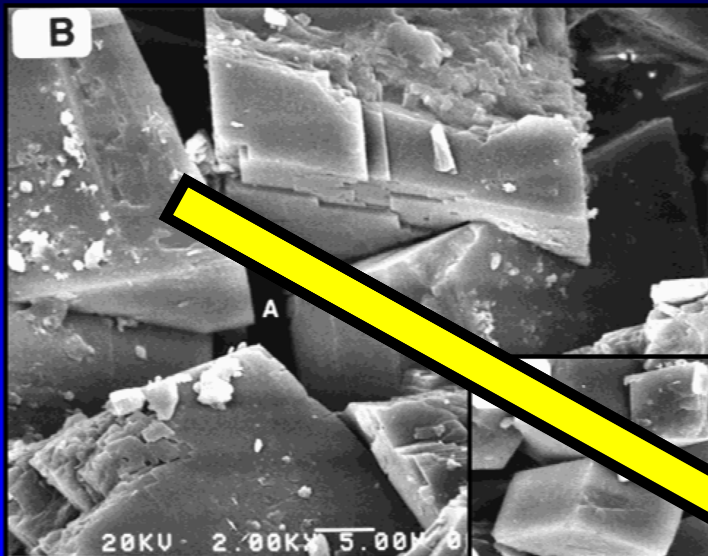
Modified after Lucia, 1982

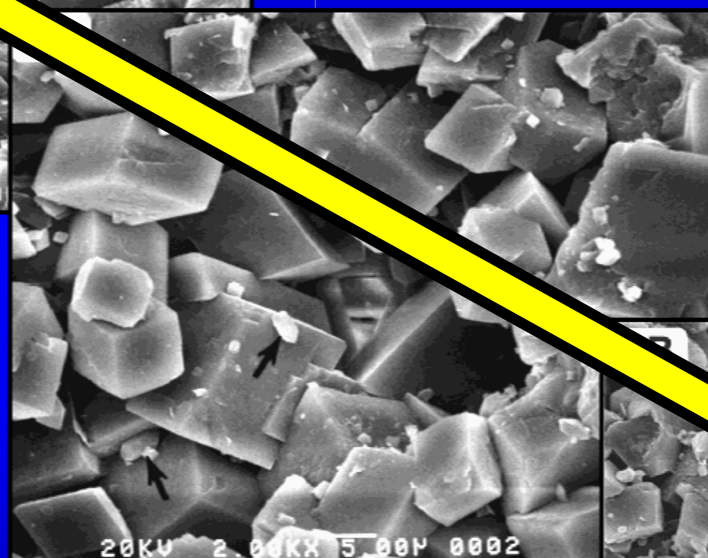
Bigger Crystals = Higher k

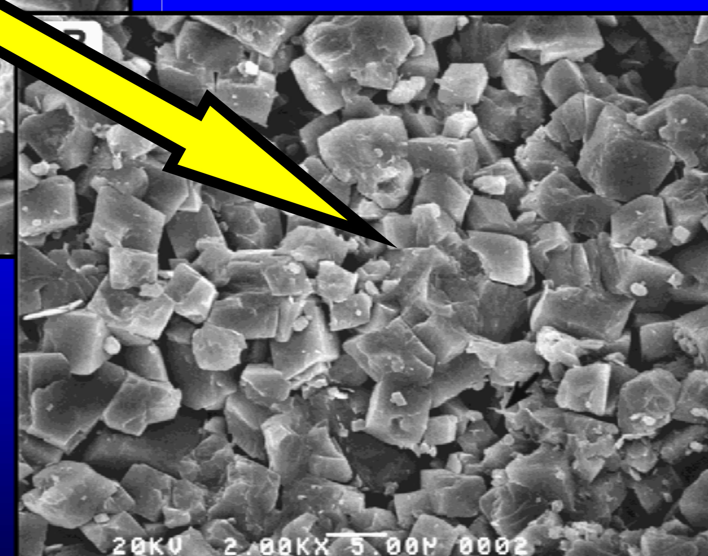


Modified after Lucia, 1982

DOLOMITE RESERVOIR ROCKS

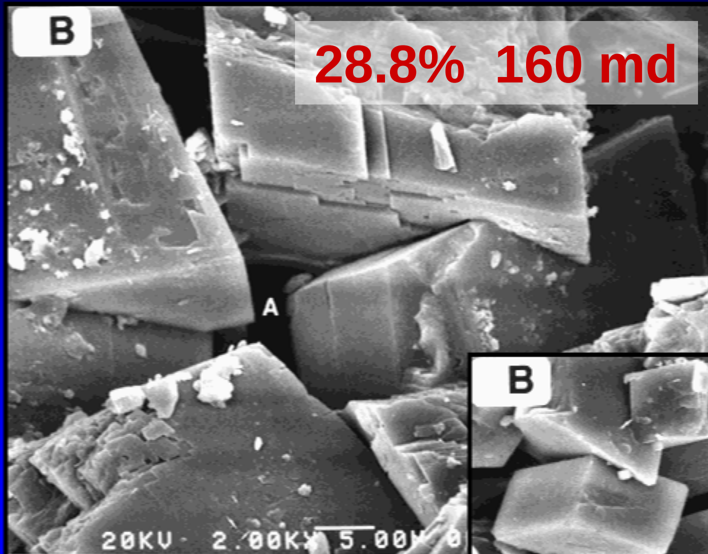


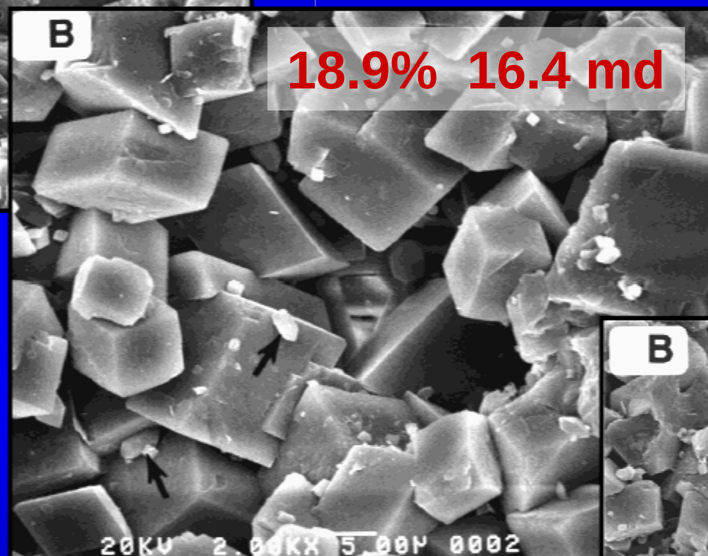


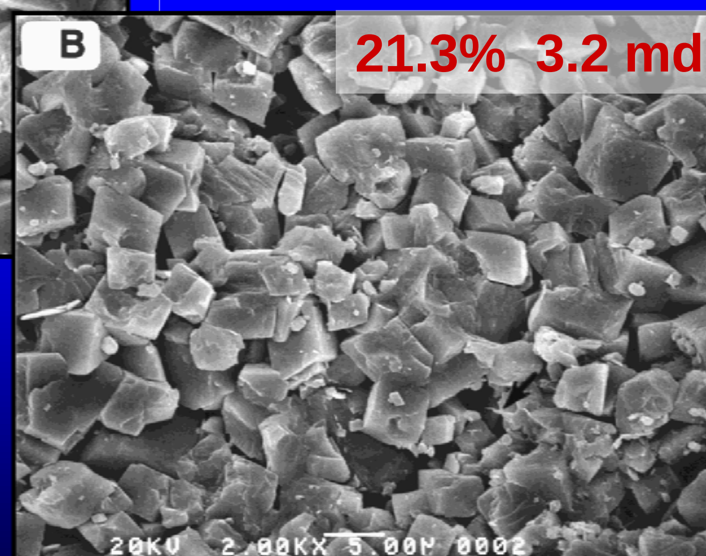


DECREASING CRYSTAL SIZE

DOLOMITE RESERVOIR ROCKS







DECREASING PERMEABILITY

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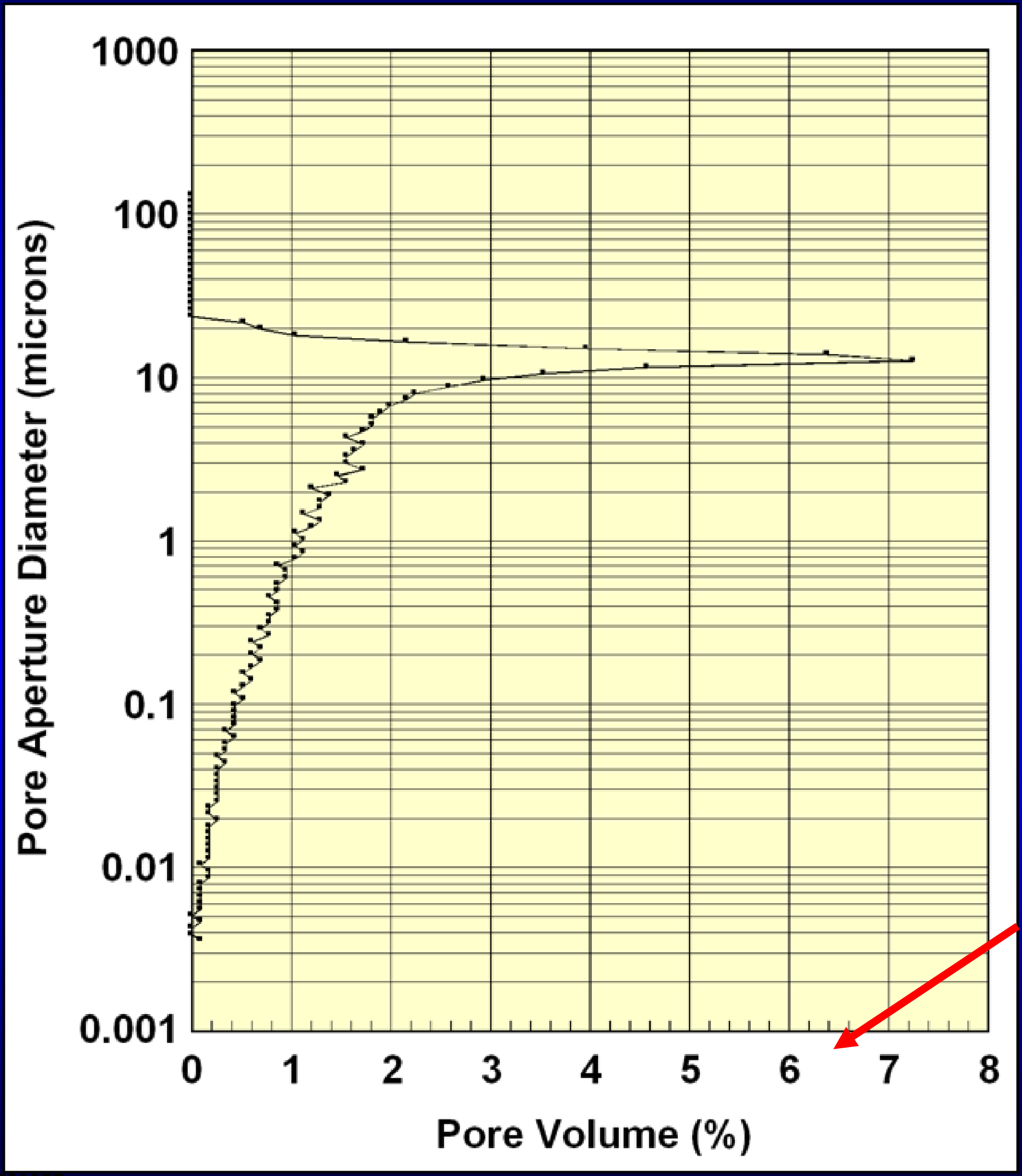
Pore Aperture Size Distribution



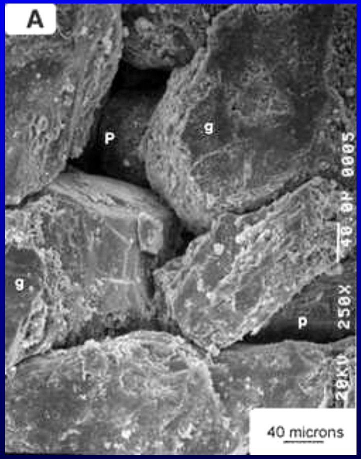
- Create from Pc data

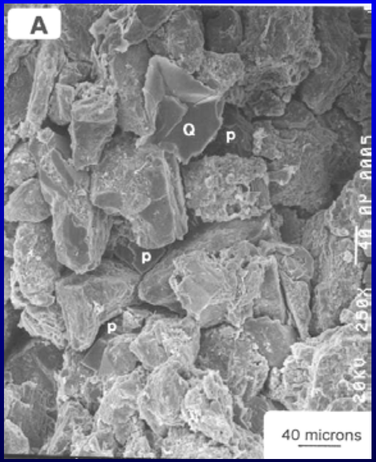
The amount of porosity accessed

2 Rocks with Similar Porosity

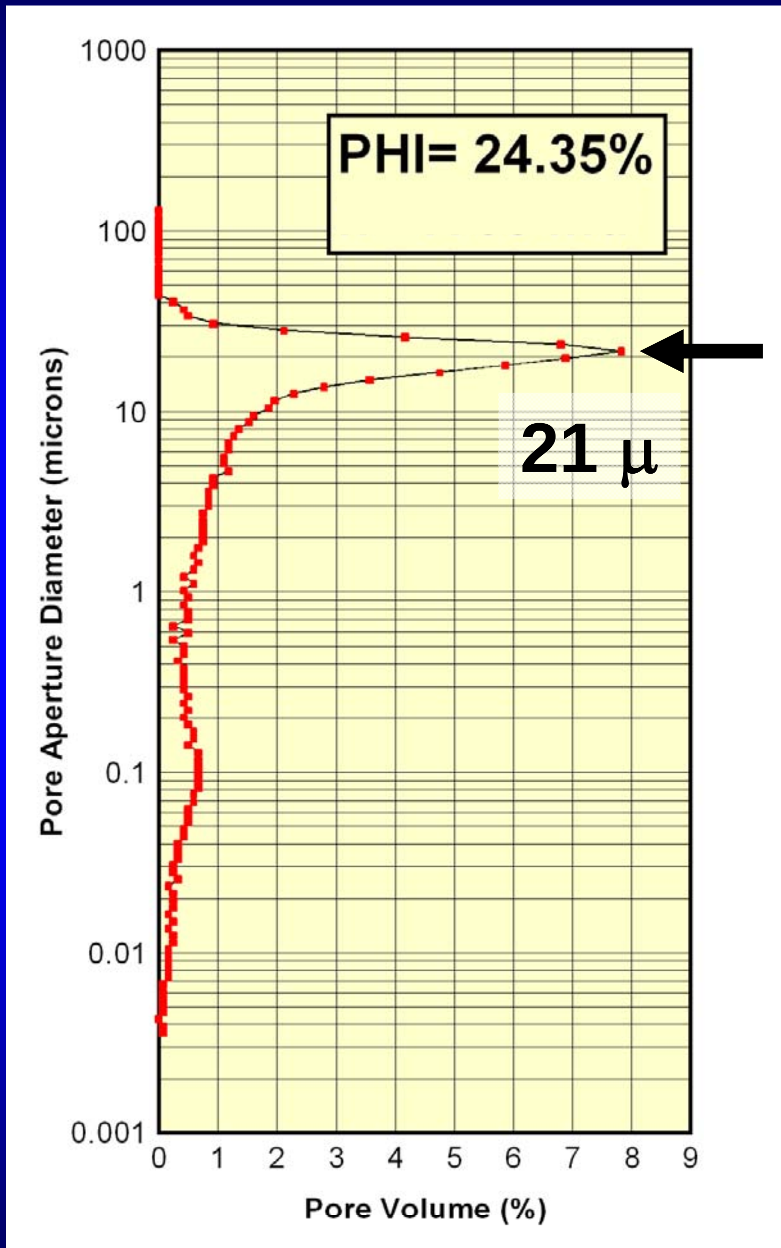
Ø=24.35%,

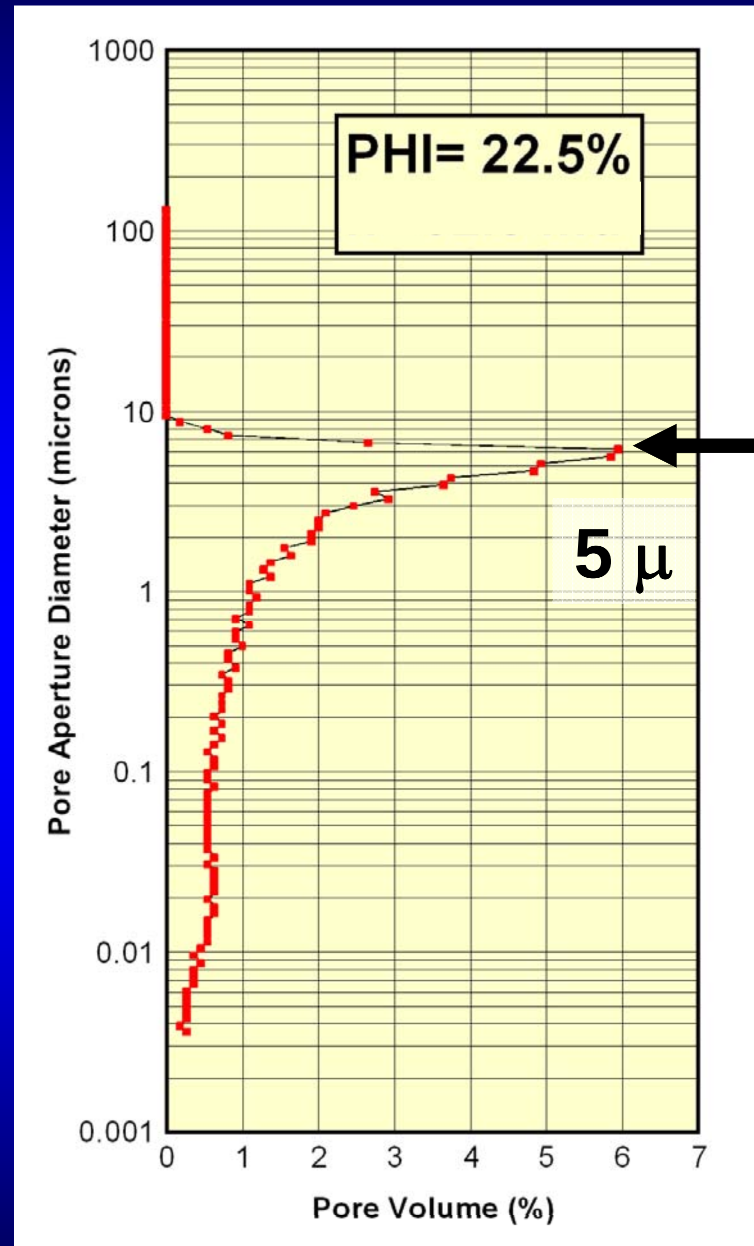
Ø=22.5%,



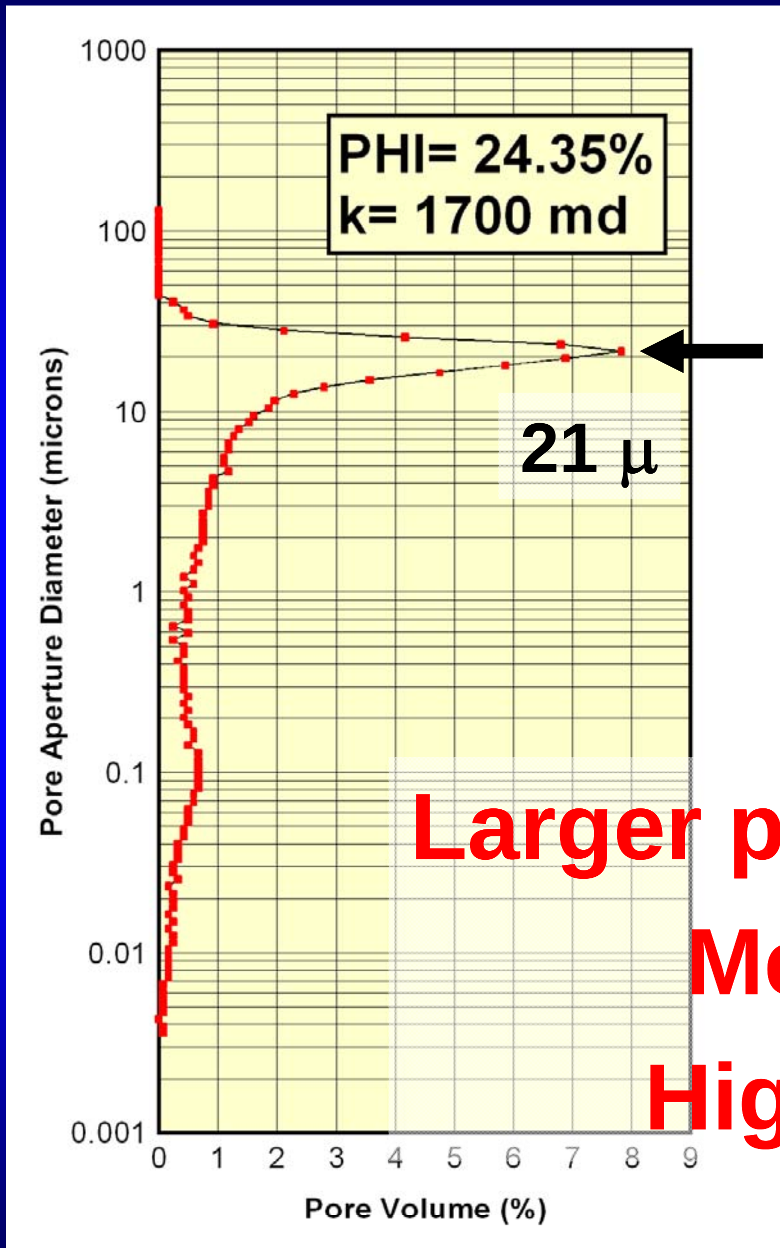


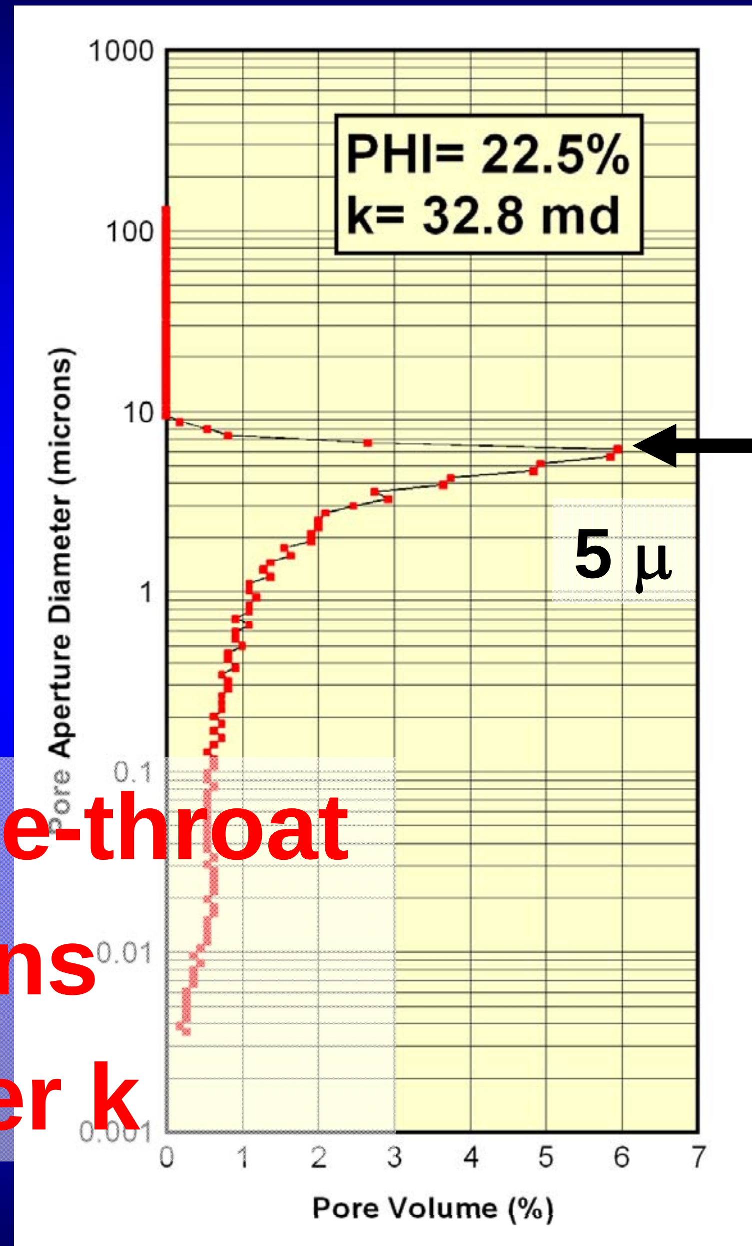
At ~constant Φ





At ~constant Φ





Larger pore-throat
Means
Higher k

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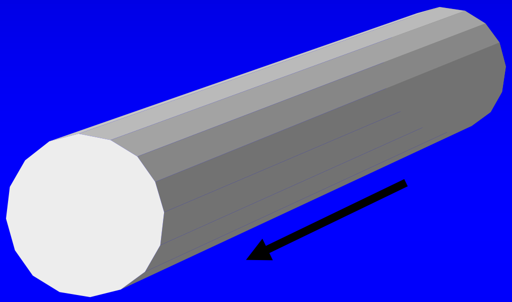
Capillary Tube

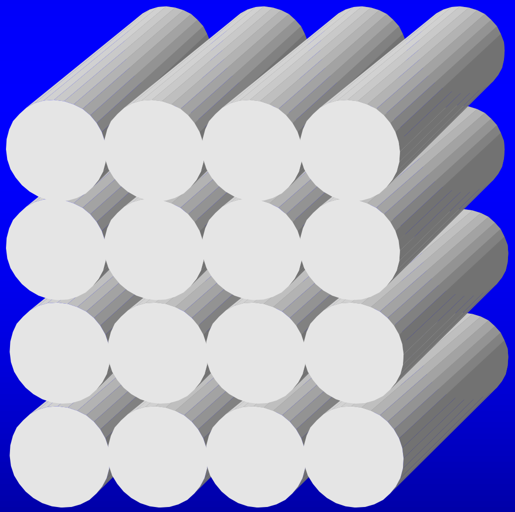
Flow Velocity



Velocity = $1/\mu \cdot R^2 \cdot \Delta P/8L'$

Hagen-Poiseuille law

Bundle of Capillary Tubes



- ↑ # Capillaries (↑Φ)
  - ↑ fluid flow
- ↑ Size Capillaries
  - ↑ fluid flow

Characterization of Flow Potential

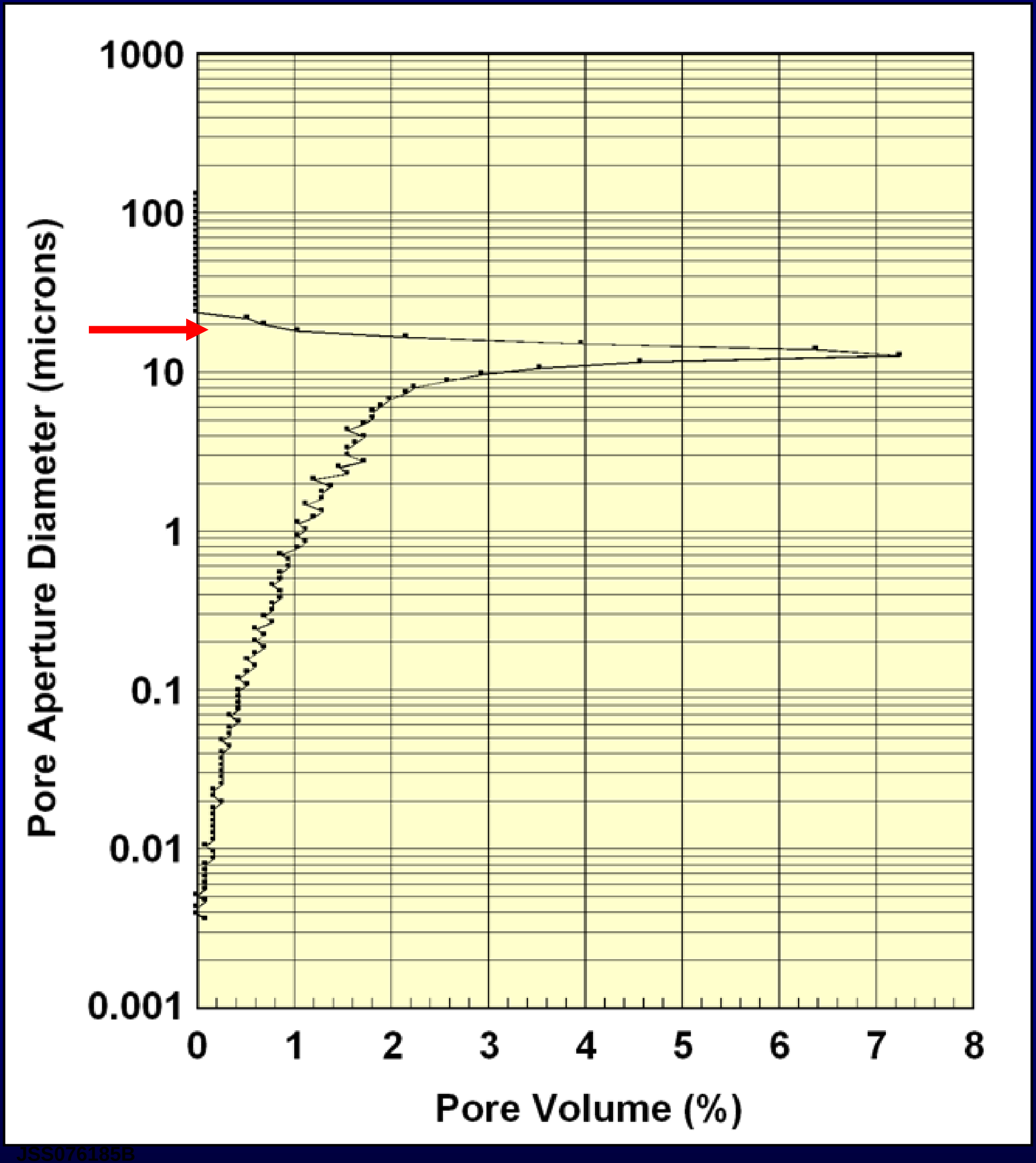
Characterization
Flow Potential

$$SumDia = \Sigma(\Delta\Phi \bullet D)$$

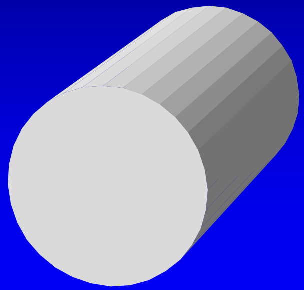
$\Delta\Phi$ = Porosity accessed through pore-throat

D = Threshold Diameter
i.e. size of pore-throat

Pore Aperture Size Distribution

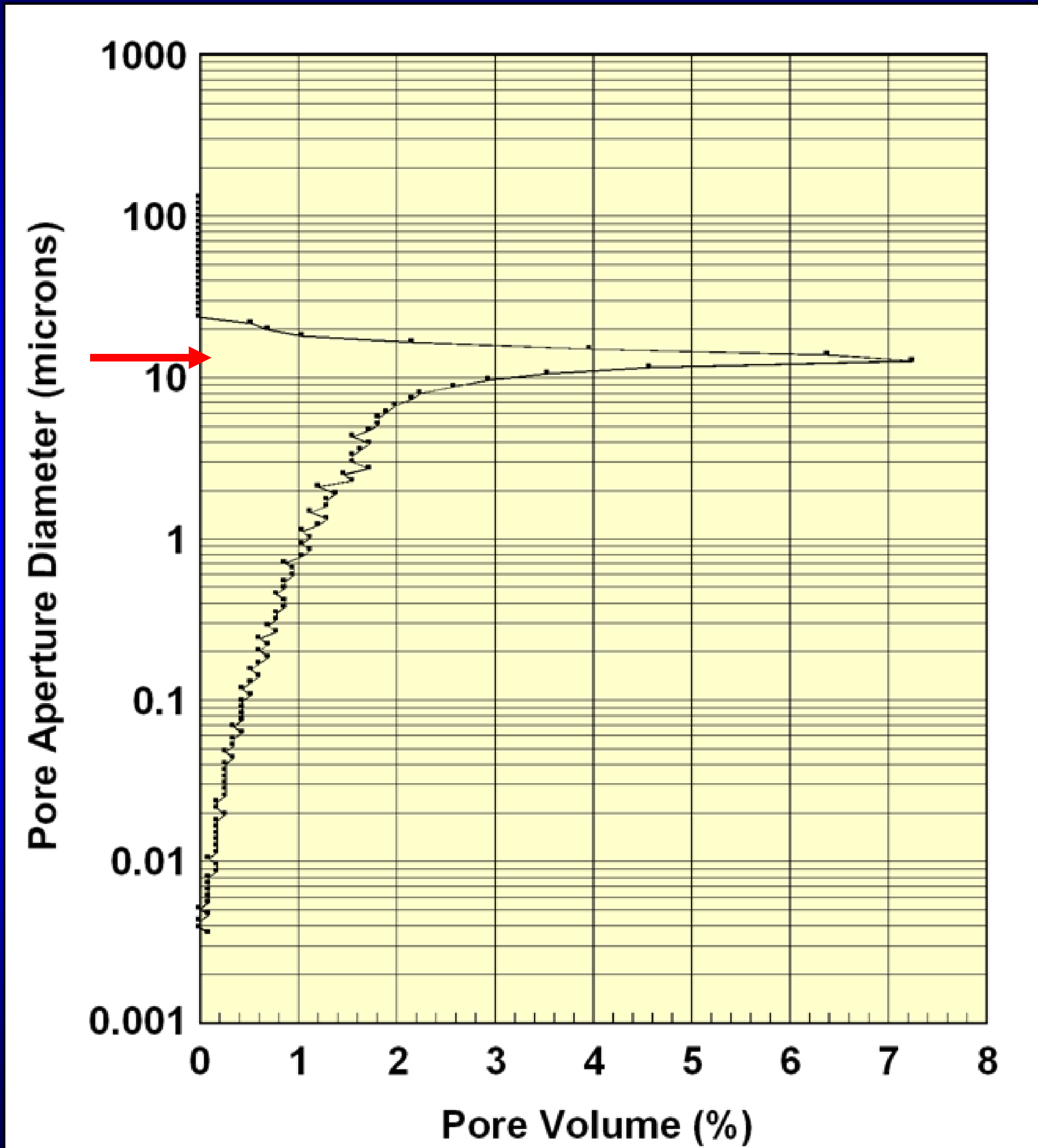


SumDia =

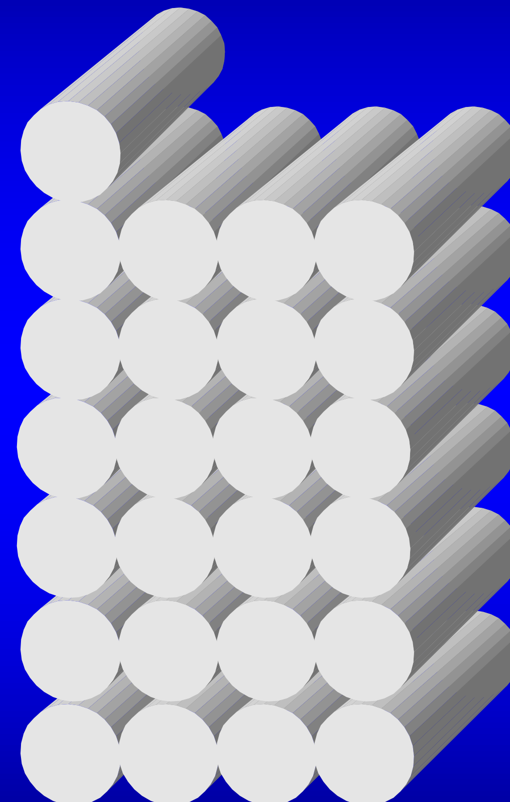


+ (1% •19μ) +

Pore Aperture Size Distribution

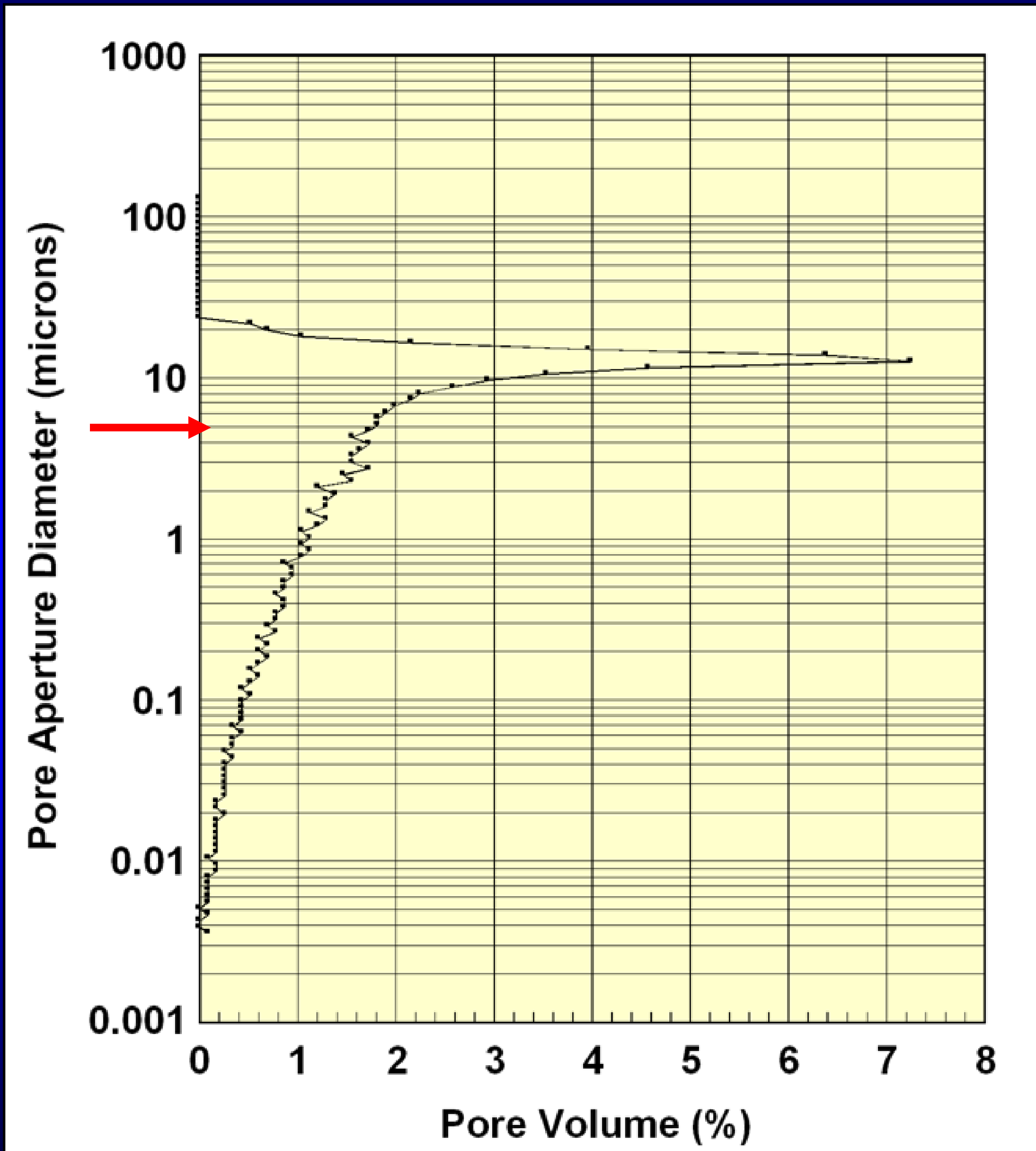


SumDia =

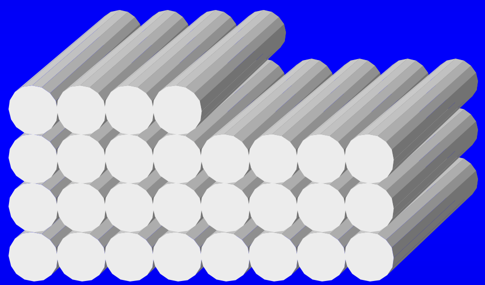


= + (7.3% •12 μ) +

Pore Aperture Size Distribution

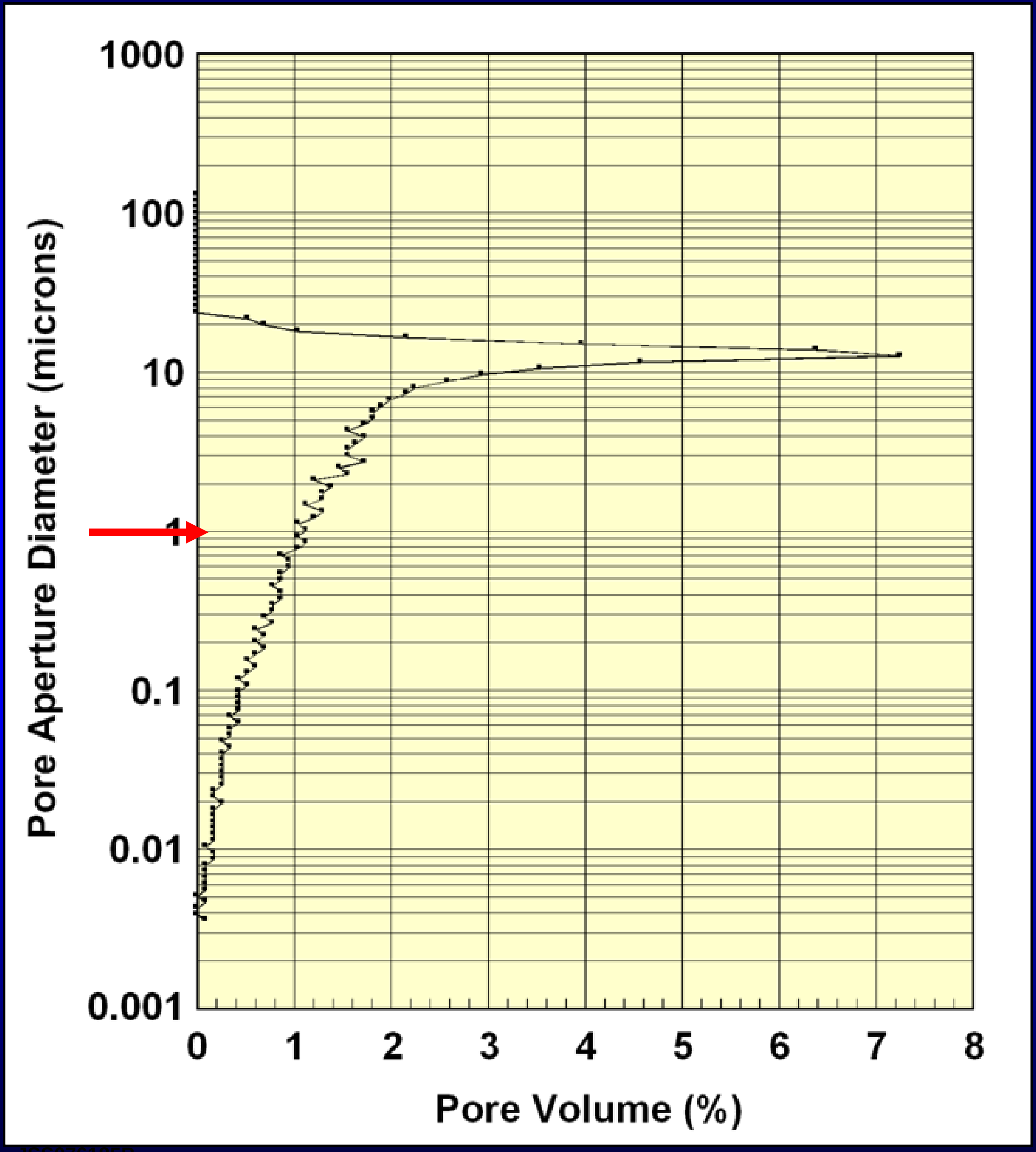


SumDia =

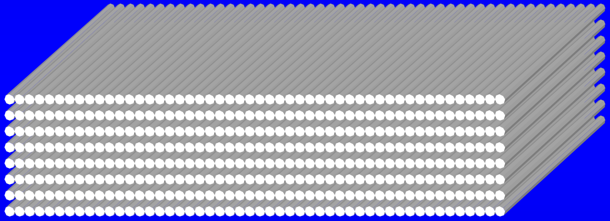


= +(1.8% • 5 μ) +

Pore Aperture Size Distribution

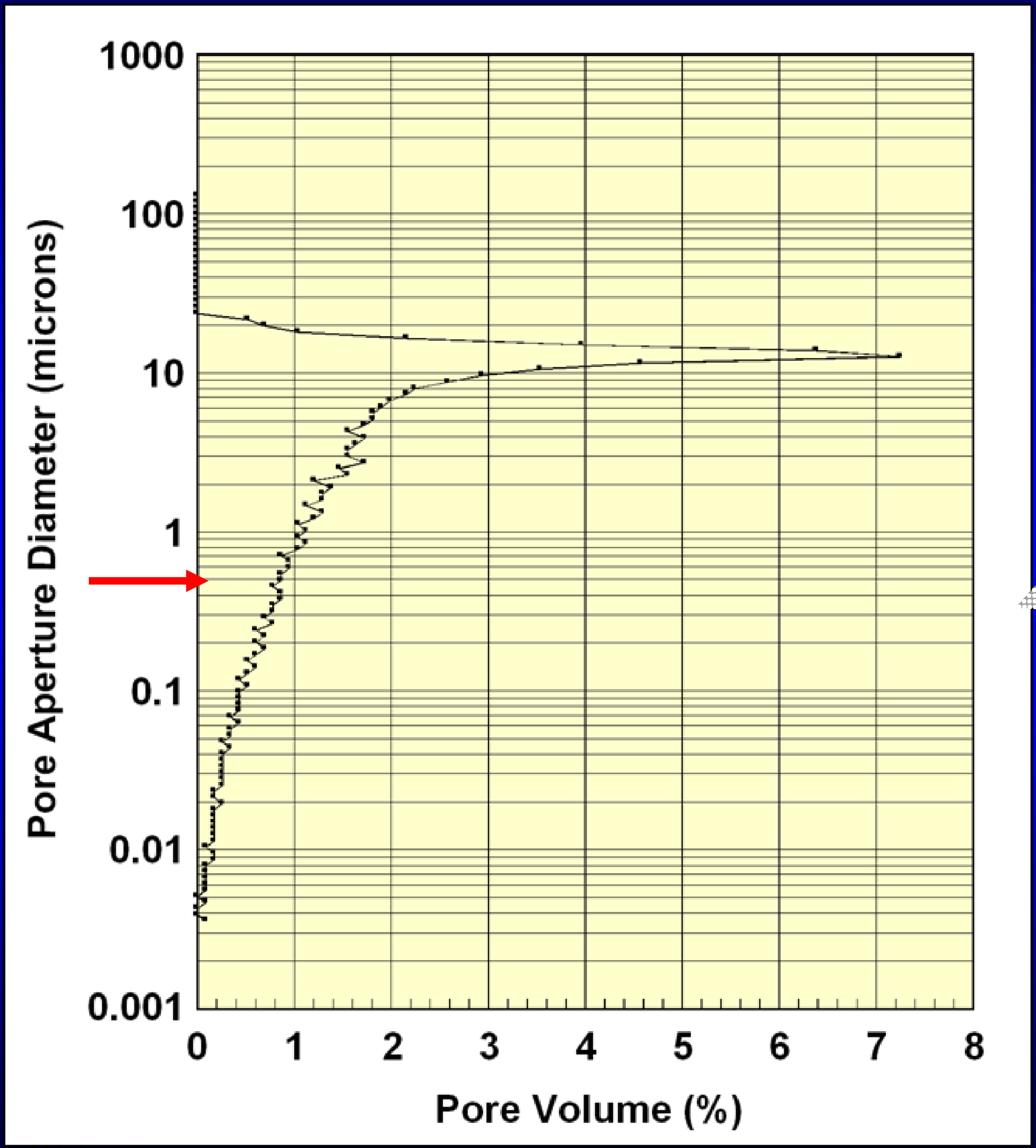


SumDia =

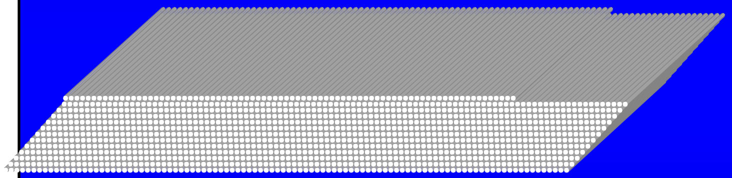


= + (1% • 1 μ) +

Pore Aperture Size Distribution

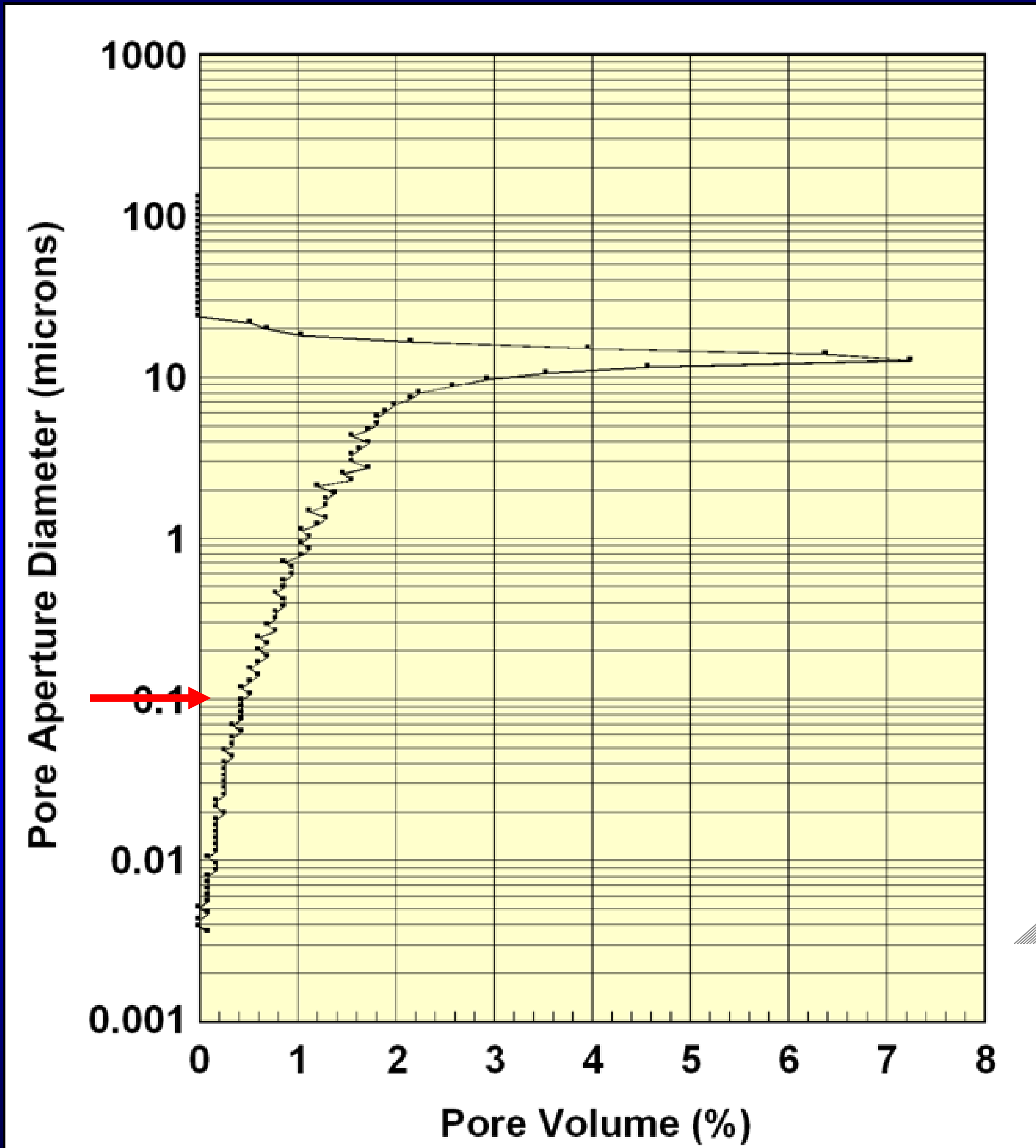


SumDia =



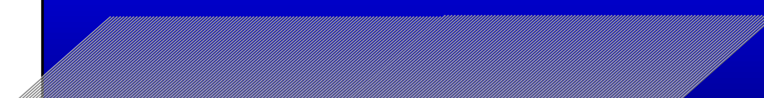
= + (0.8% • 0.5μ) +

Pore Aperture Size Distribution



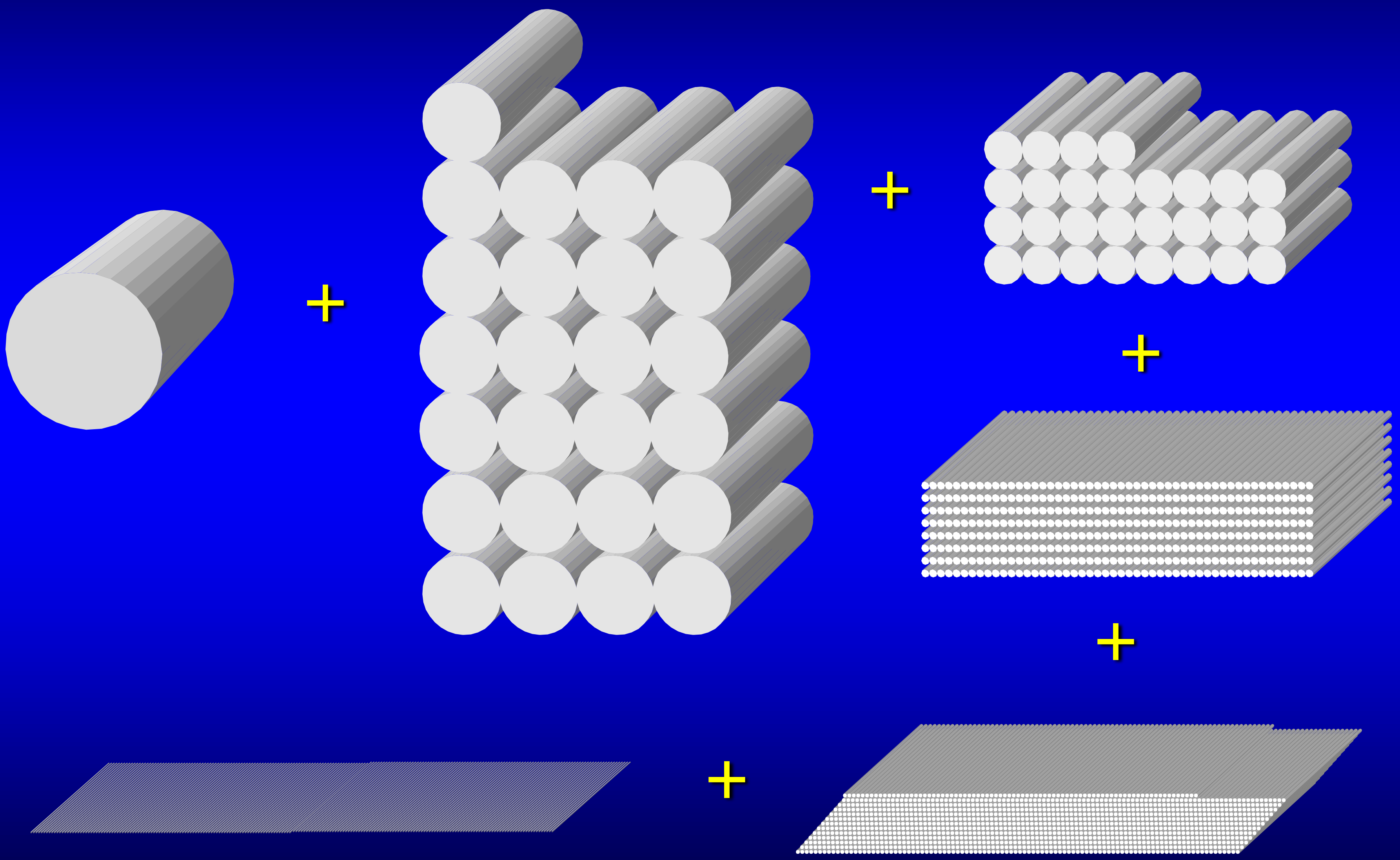
SumDia =

200 Tubes Across Stacked 100 High



= + (0.4% • 0.1μ)+

$$\text{SumDia} = \Sigma(\Delta\Phi \cdot D)$$



Characterization

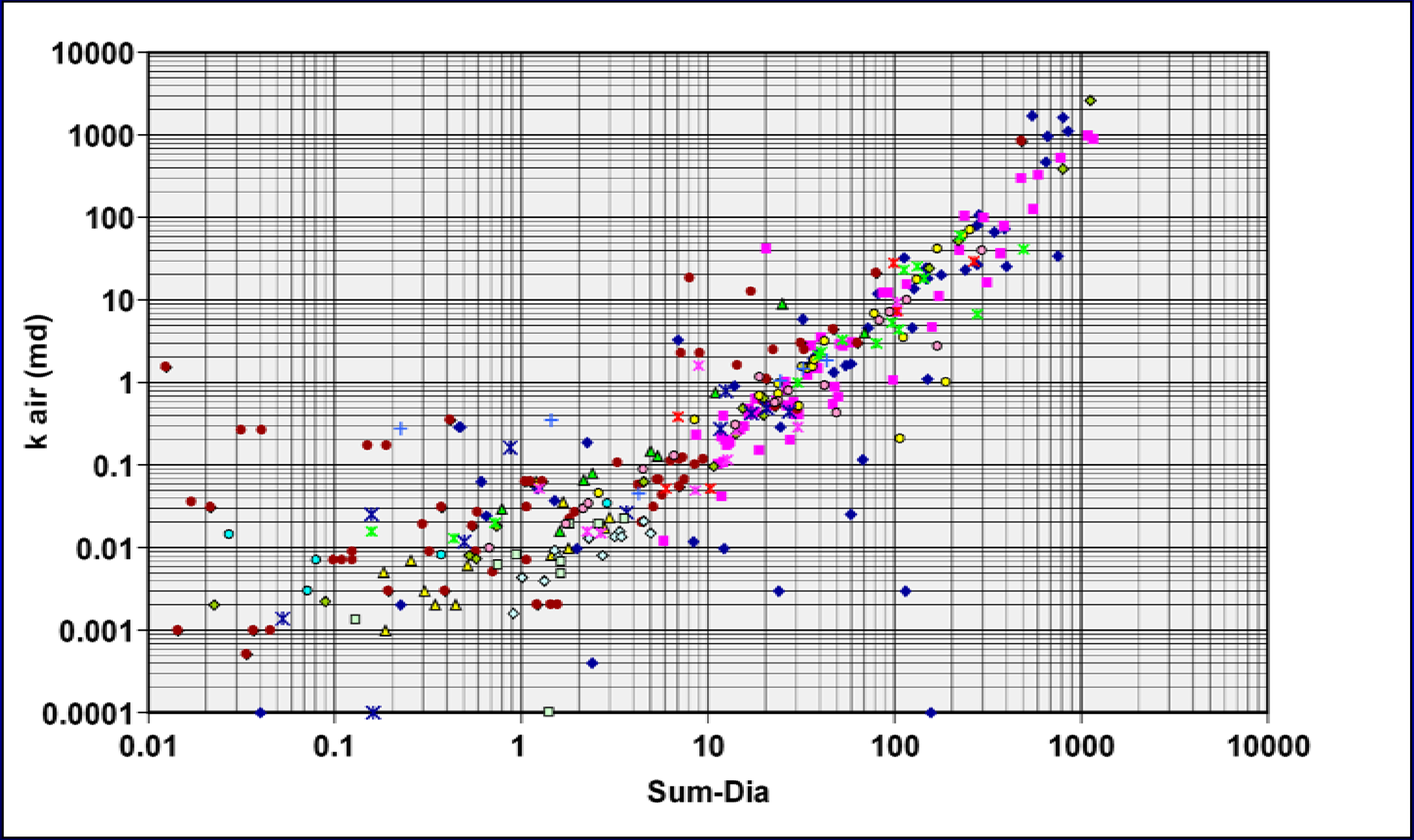
Flow Potential

$$\text{SumDia} = \Sigma(\Delta\Phi \bullet D)$$

Proxy for

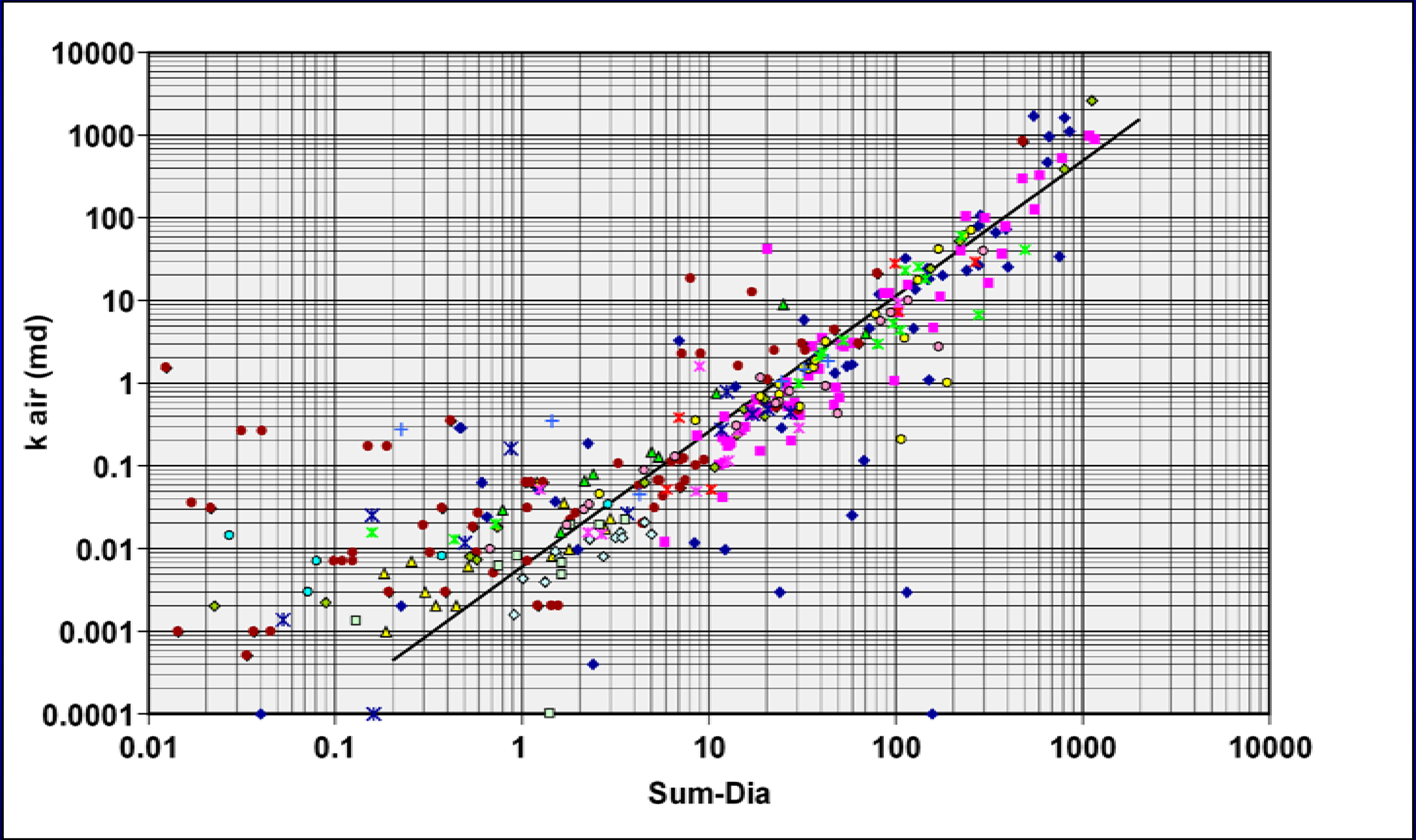
Permeability

K_{air} vs SumDia

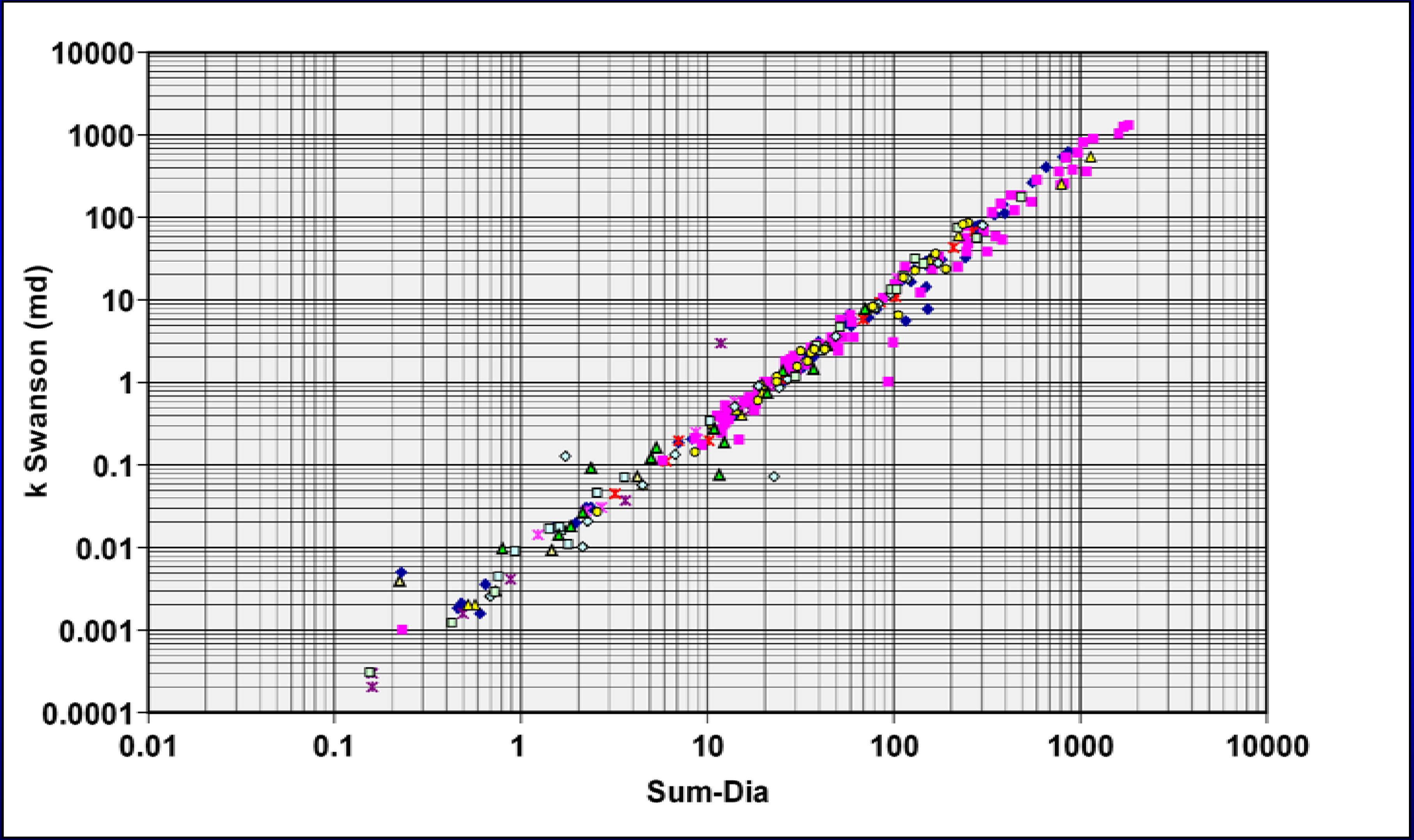


$$k_{air} = 10^{(C1*LOG(SumDia) - C2)}$$

C1 = 1.6337 C2 = 2.2081



$K_{swanson}$ vs SumDia



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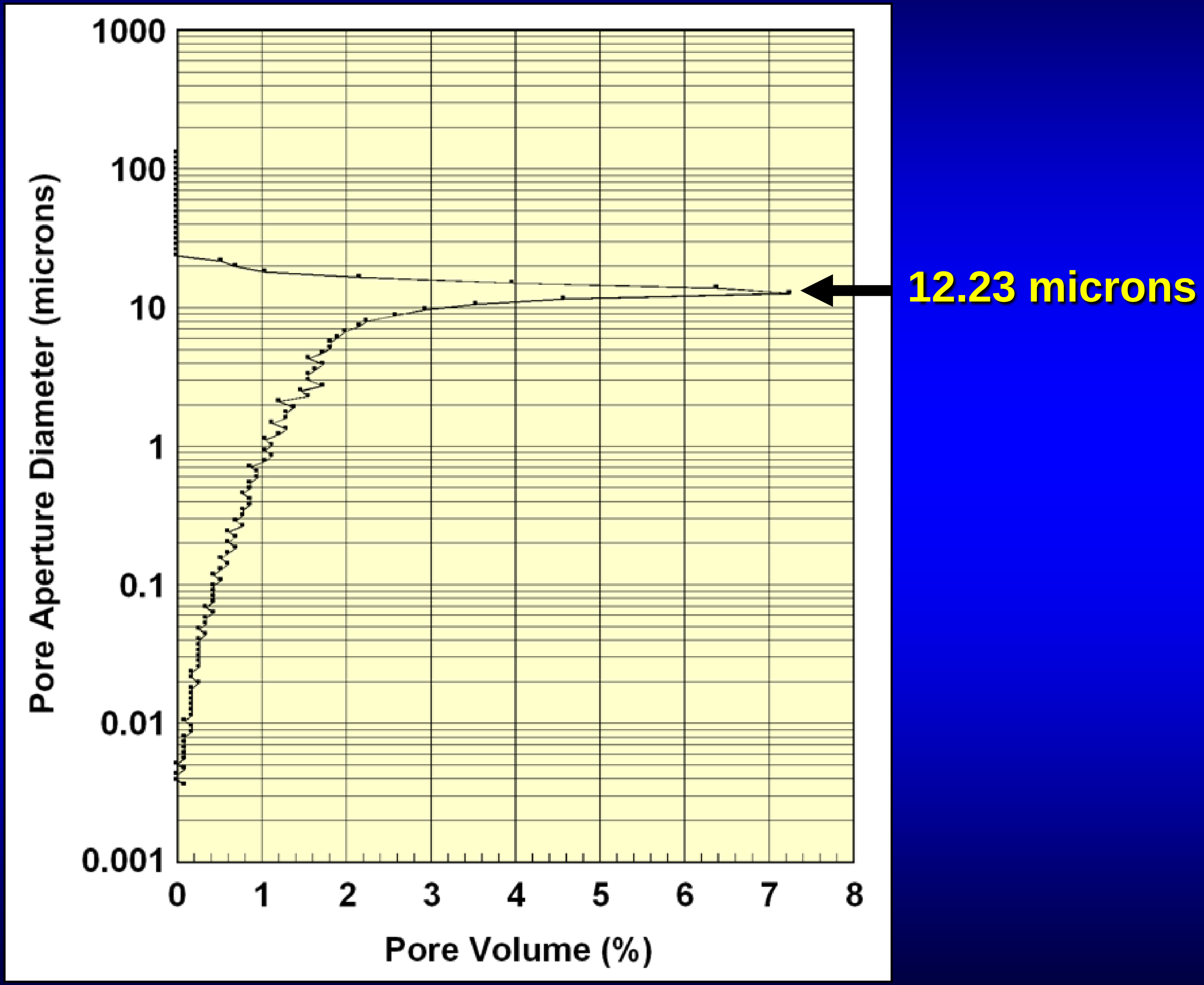
Characterization
Flow Potential

Pseudo Pore-Throat Size =

$$= \frac{\text{SumDia}}{\Phi_{\text{Total}}}$$

- Equivalent capillary tube size
  - Characterize pore-throats with single value
  - ~*"Dominant"* pore-throat size
- Larger Pseudo Pore-Throat Size
  - Higher permeability – same Φ

Pseudo Pore Throat



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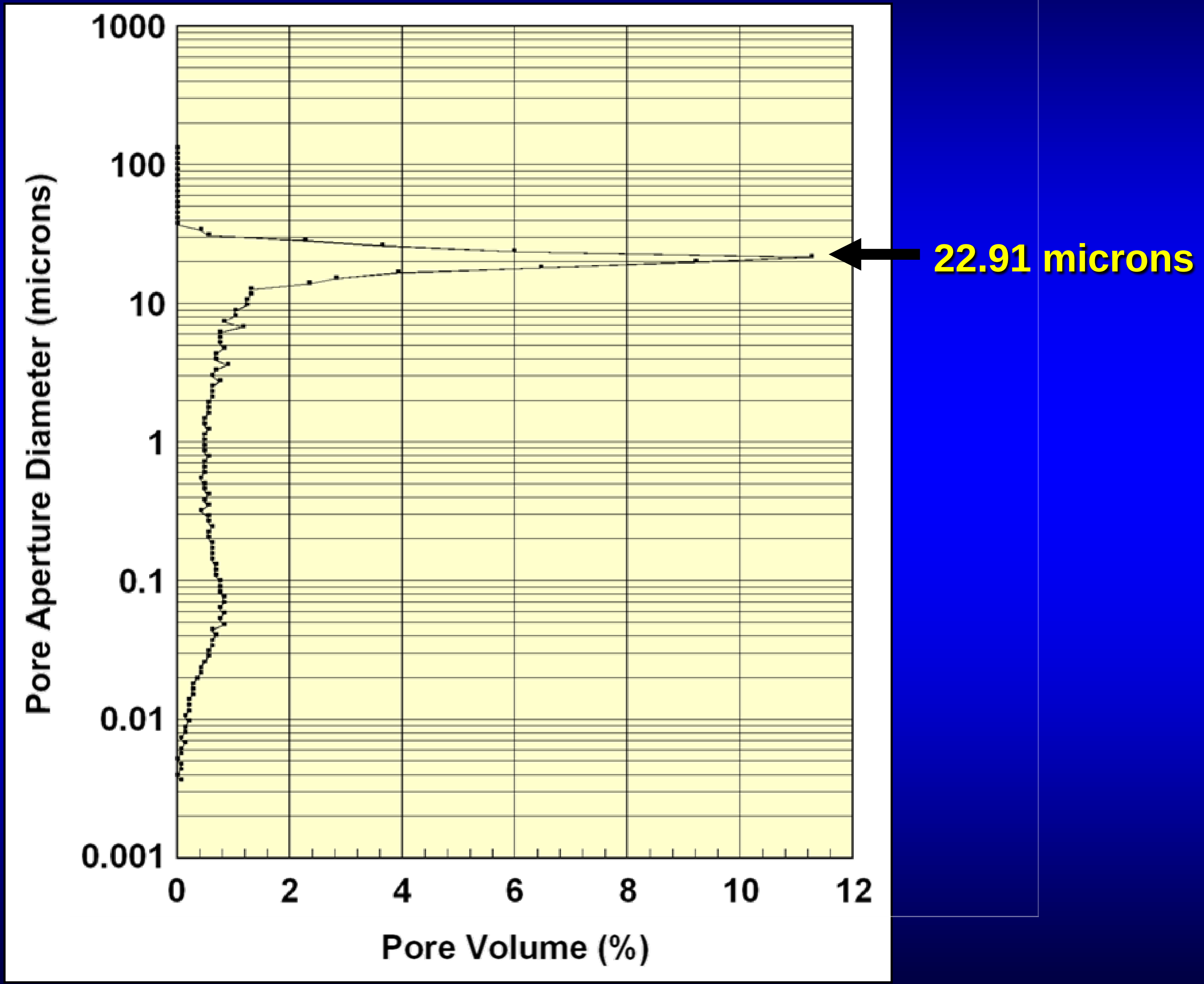
Pseudo Pore Throat



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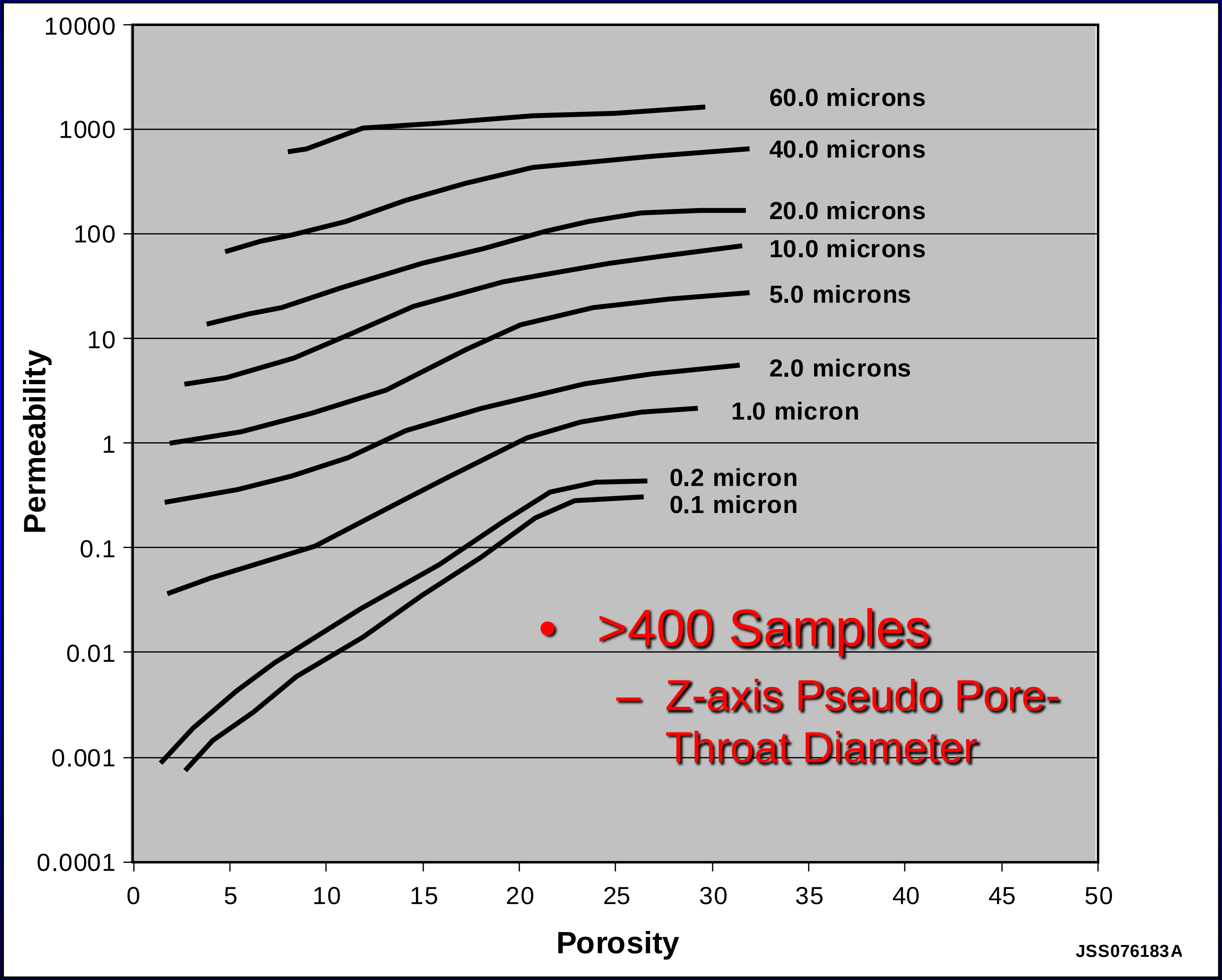
POROSITY VS. PERMEABILITY (Pseudo Pore Throat)



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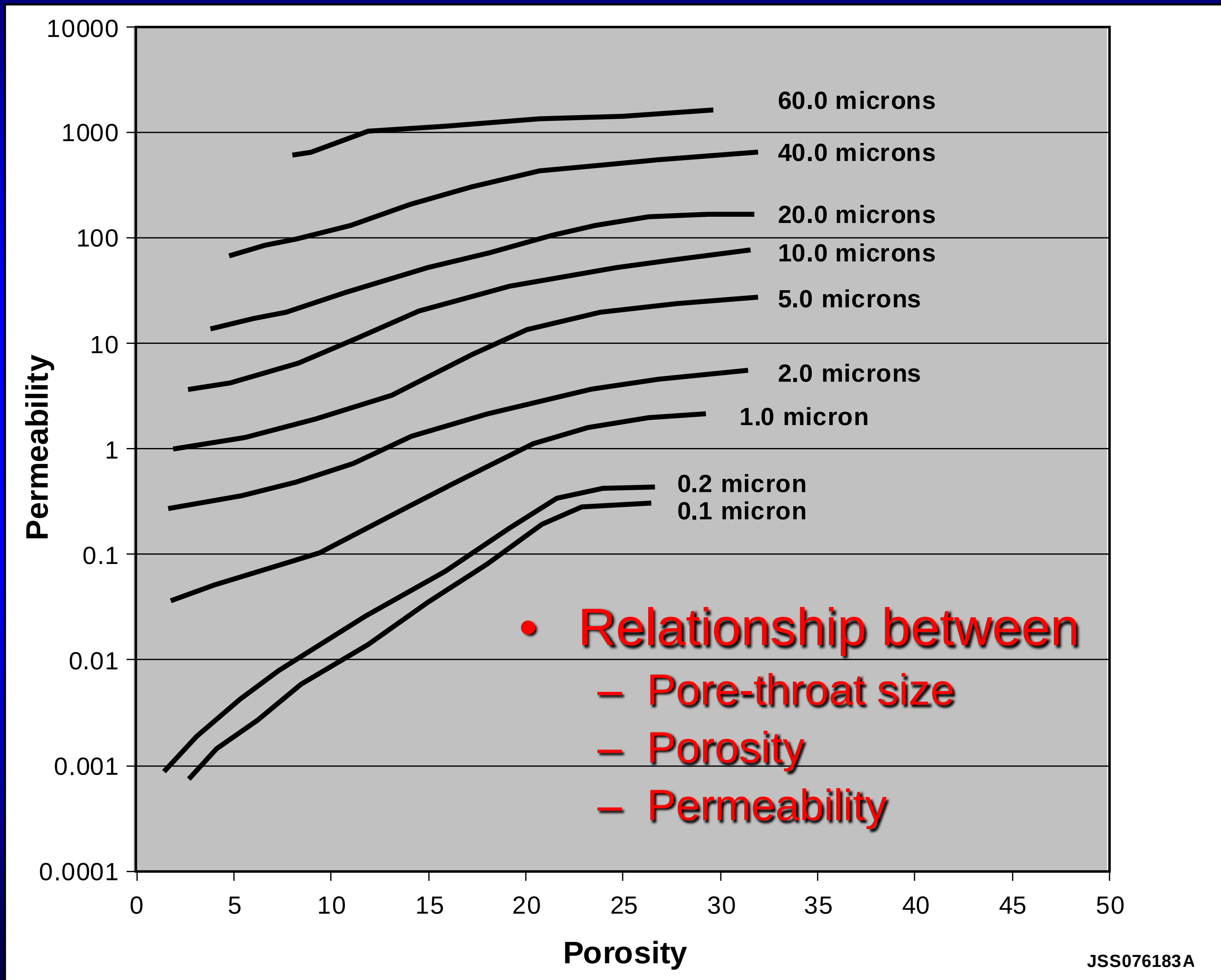
POROSITY VS. PERMEABILITY (Pseudo Pore Throat)



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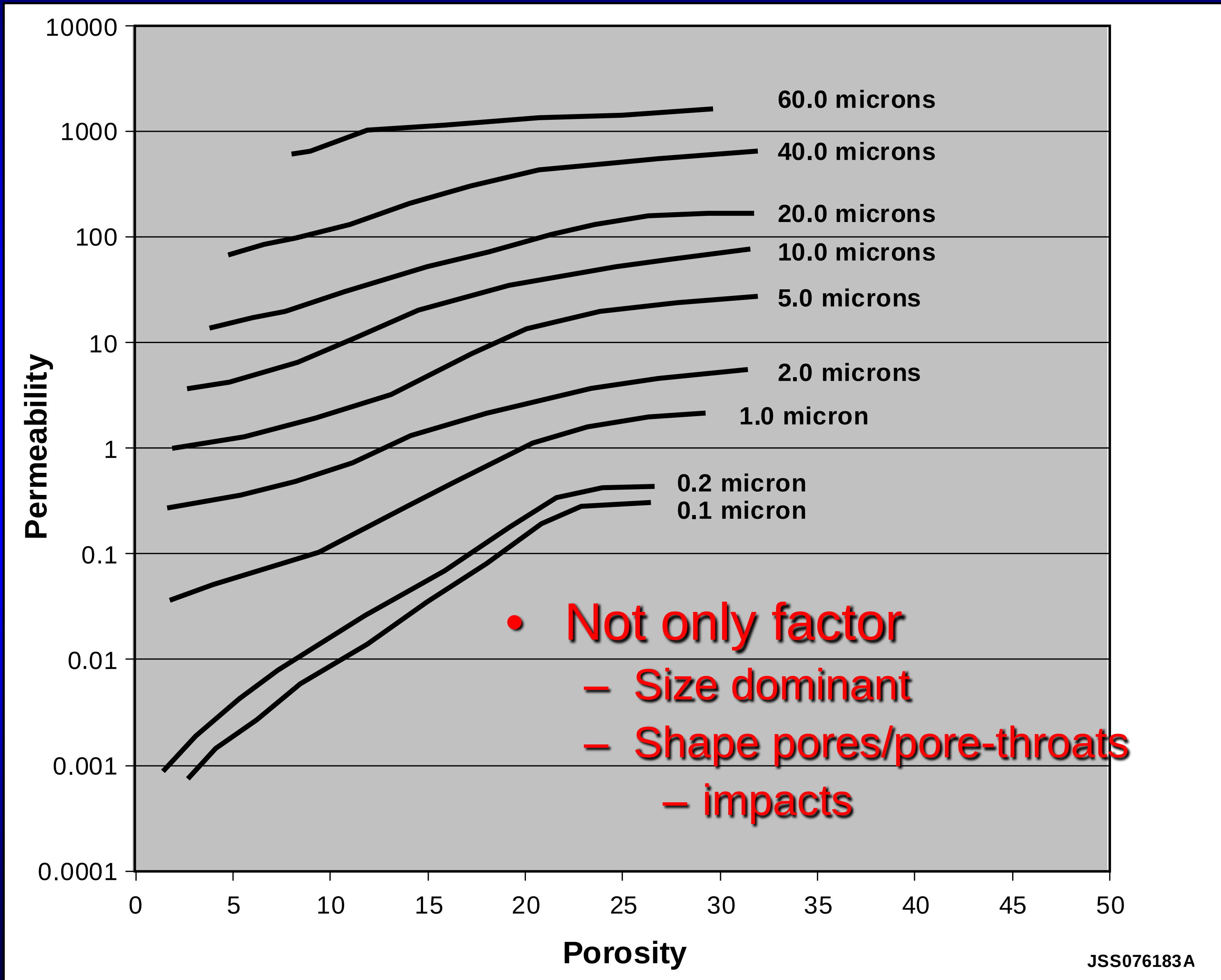
POROSITY VS. PERMEABILITY (Pseudo Pore Throat)



- Not only factor
  - Size dominant
  - Shape pores/pore-throats
    - impacts

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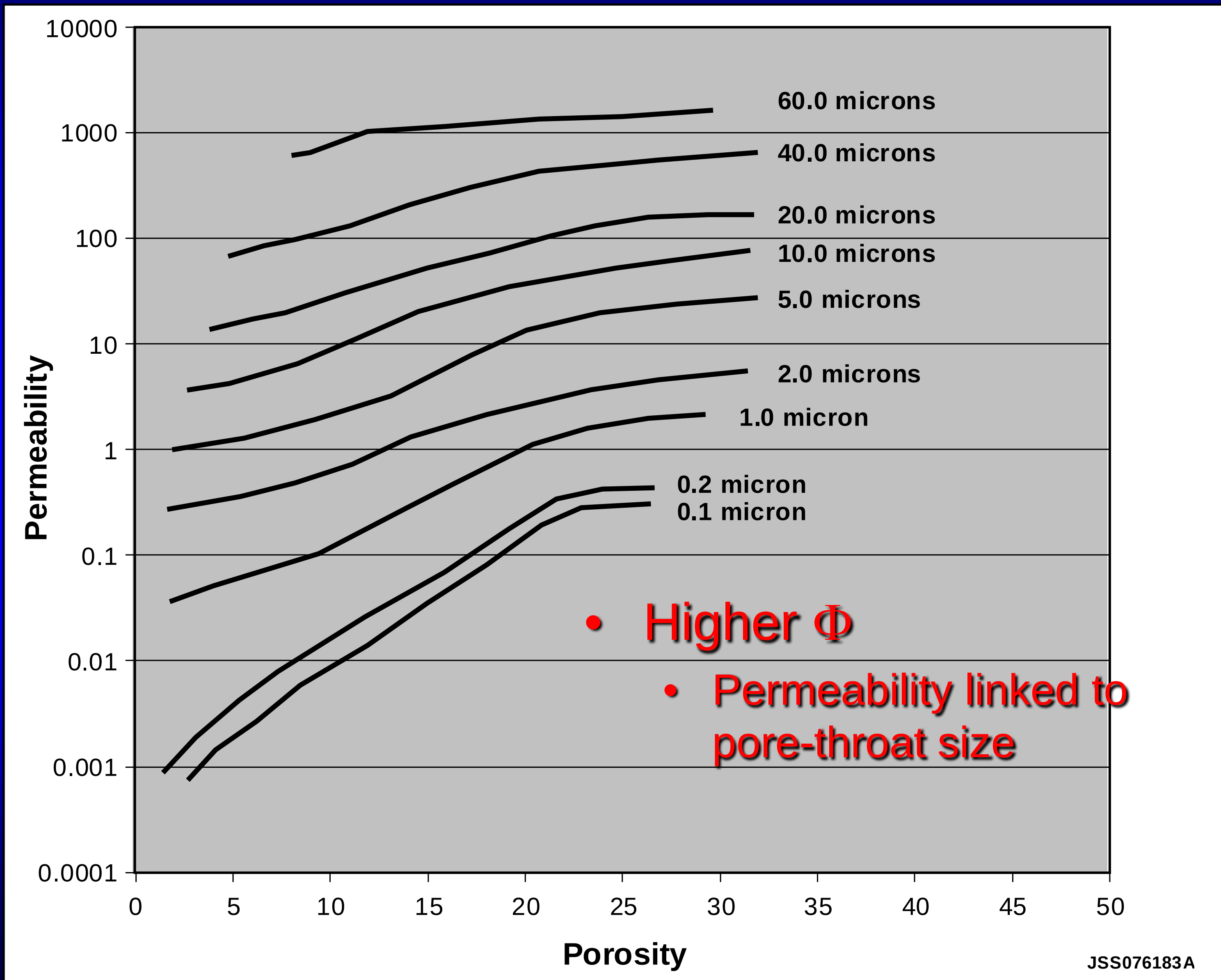
POROSITY VS. PERMEABILITY (Pseudo Pore Throat)



- Higher Φ
  - Permeability linked to pore-throat size

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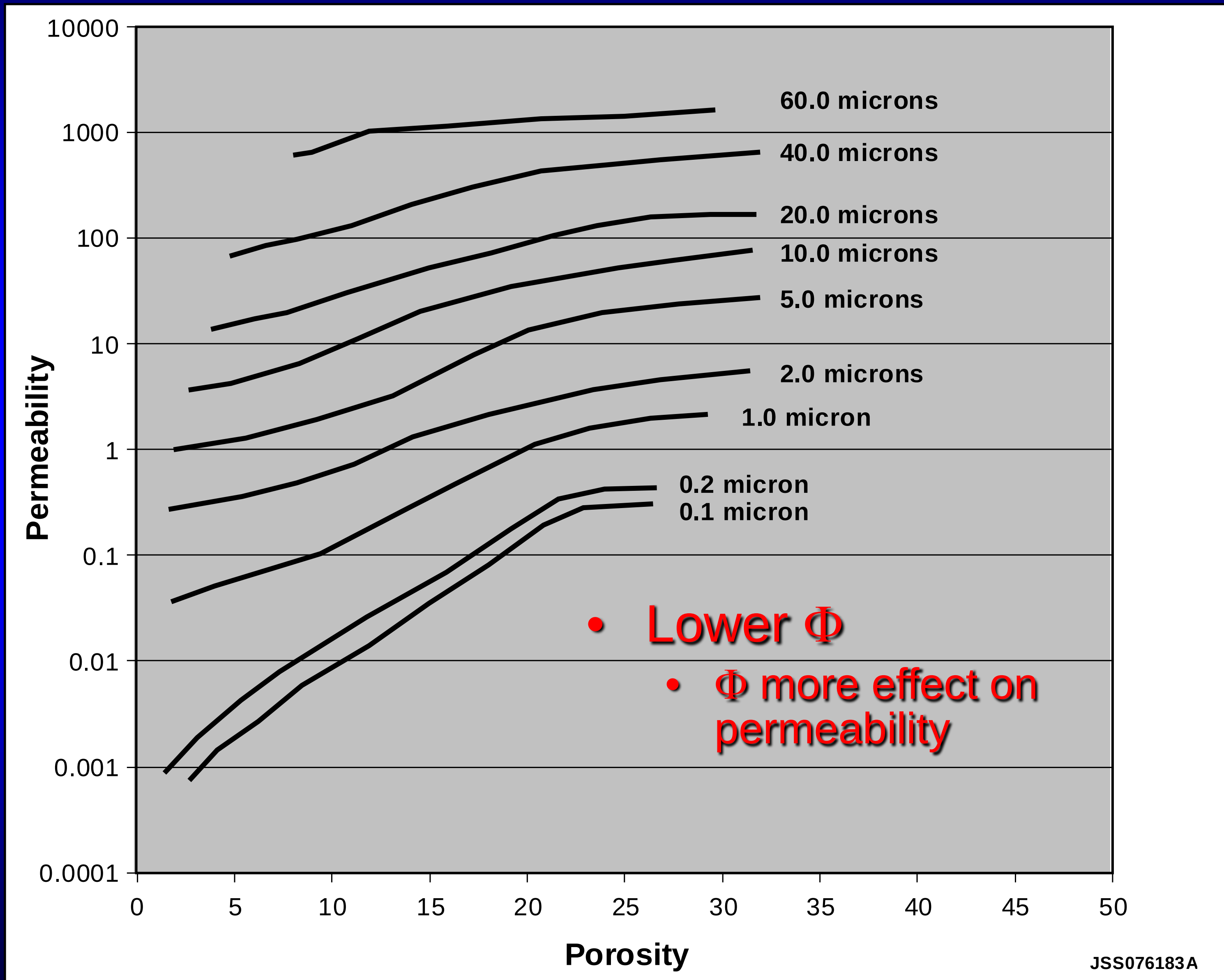
POROSITY VS. PERMEABILITY (Pseudo Pore Throat)



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Pay

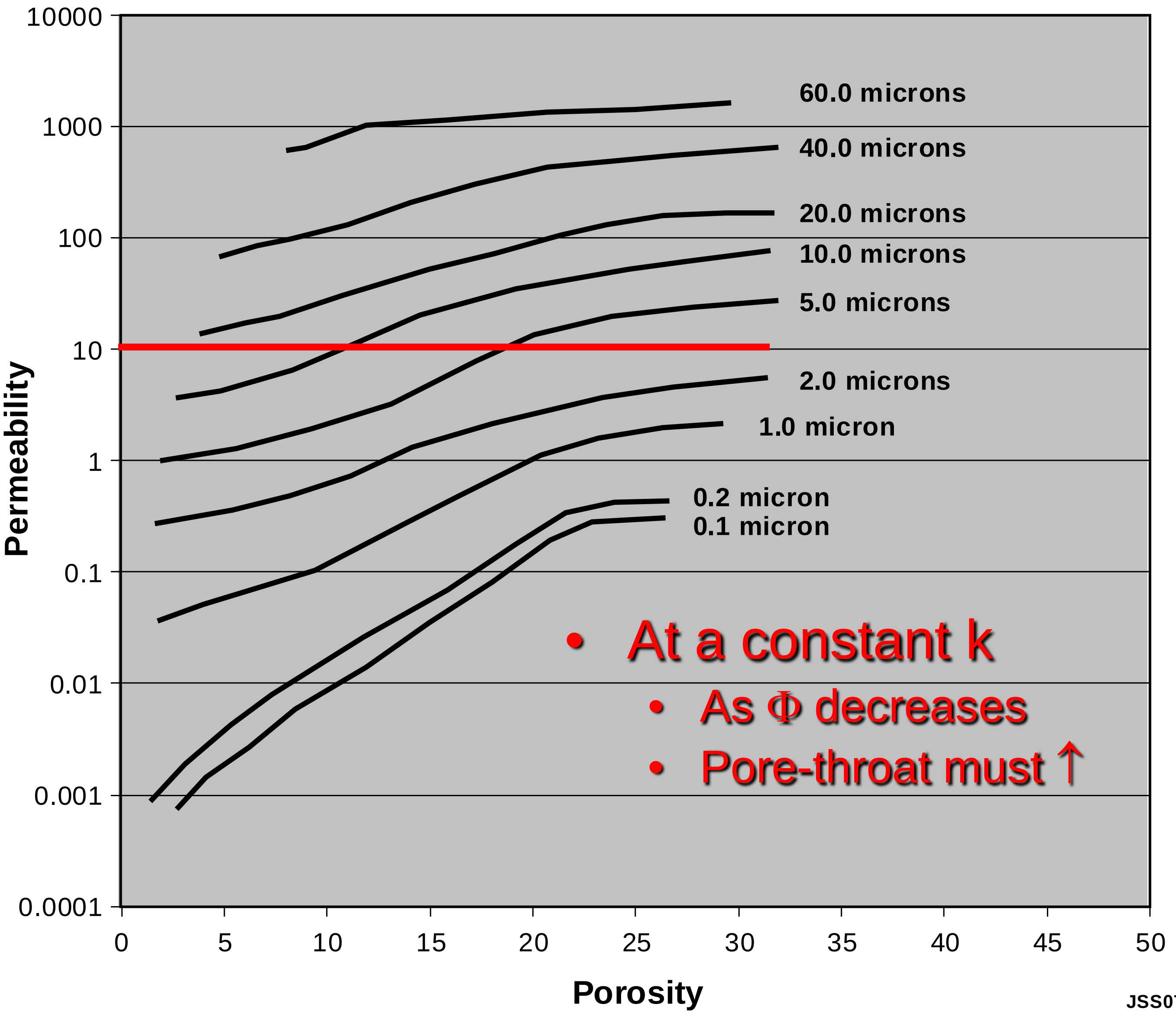
- Rock capable of flowing hydrocarbons economically
- Two parts
  - Does rock contain hydrocarbons?
  - Can they be produced?

Pore-throat size can be used to identify pay potential

Criteria for Pay

- Why not just use permeability as the criteria for pay?

POROSITY VS. PERMEABILITY (Pseudo Pore Throat)



- At a constant k
  - As Φ decreases
  - Pore-throat must ↑

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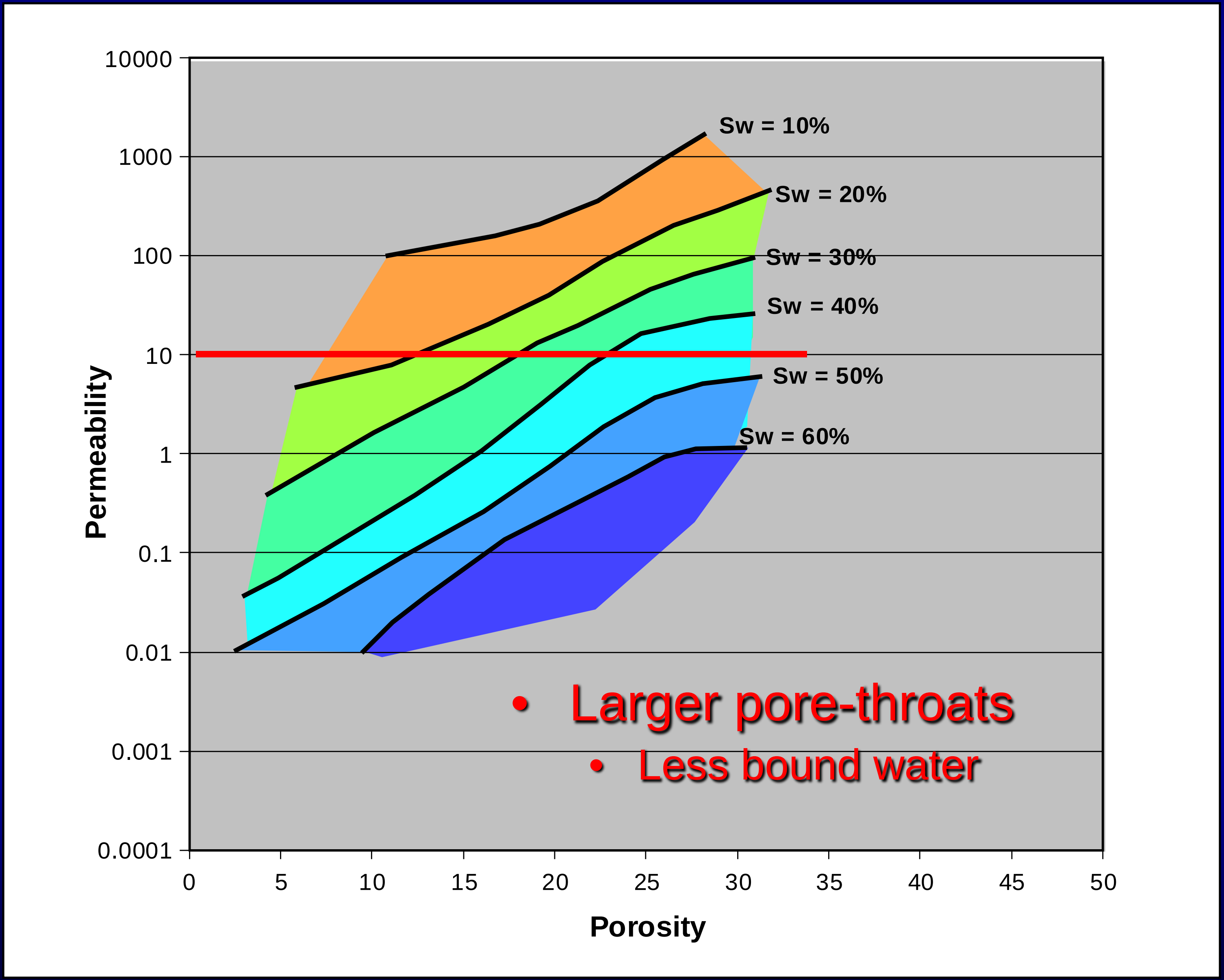
POROSITY VS. PERMEABILITY (Sw_{irr})



Criteria for Pay

- Why not just use permeability as the criteria for pay?
  - Larger pore-throats $\rightarrow$ higher $k_{o \text{ or } g}$
    - For rocks with the same k_{air}
      - Lower Φ $\rightarrow$ Larger Diameter
      - Larger Diameter $\rightarrow$ Lower Sw_{irr}
      - Lower Sw_{irr} $\rightarrow$ Higher $k_{o \text{ or } g}$

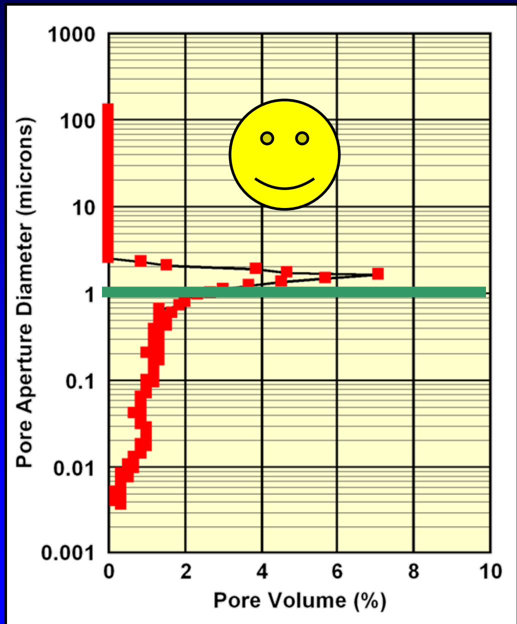
Rocks with same K_{air} & lower Φ
BETTER RESERVOIRS!

Empirical Data

Likelihood of Production

- Oil
  - Φ accessed >1 micron dia.
- Gas
  - Φ accessed >0.1 micron dia.

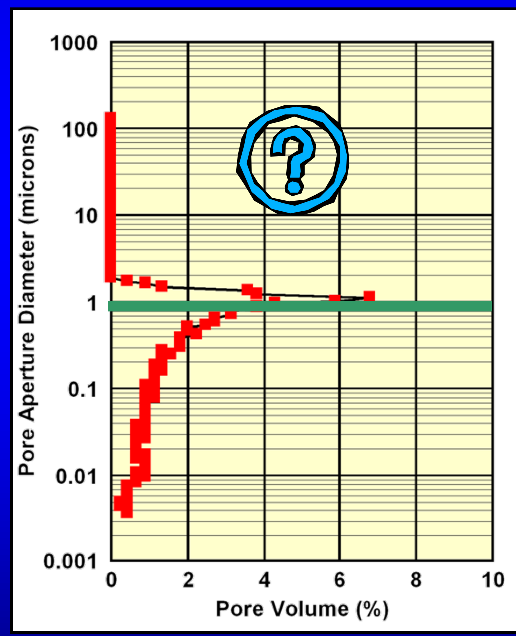
Detailed Review



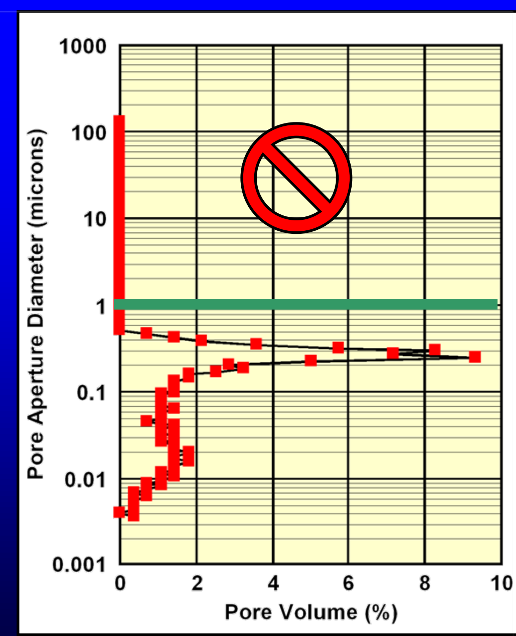
14.4% 1.57 md

Oil

$$\Phi_{e_{1.0}} = \Phi > 1.0\mu$$

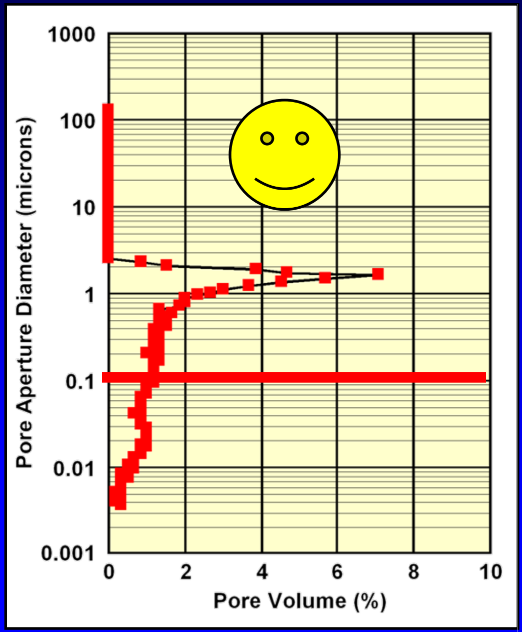


10.96% 0.061 md



9.37% 0.028 md

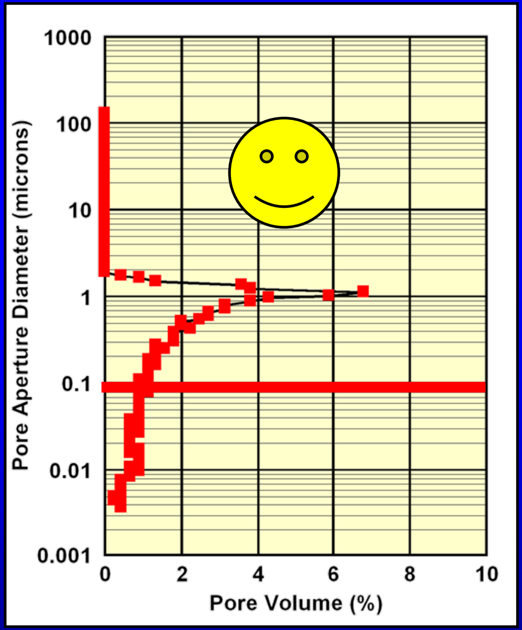
Detailed Review



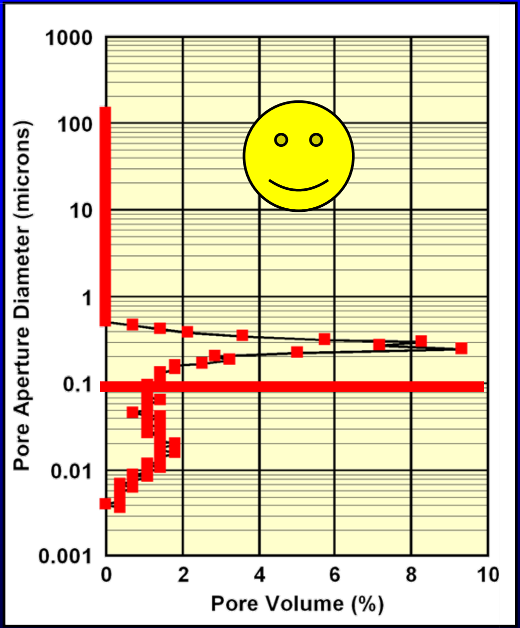
14.4% 1.57 md

Gas

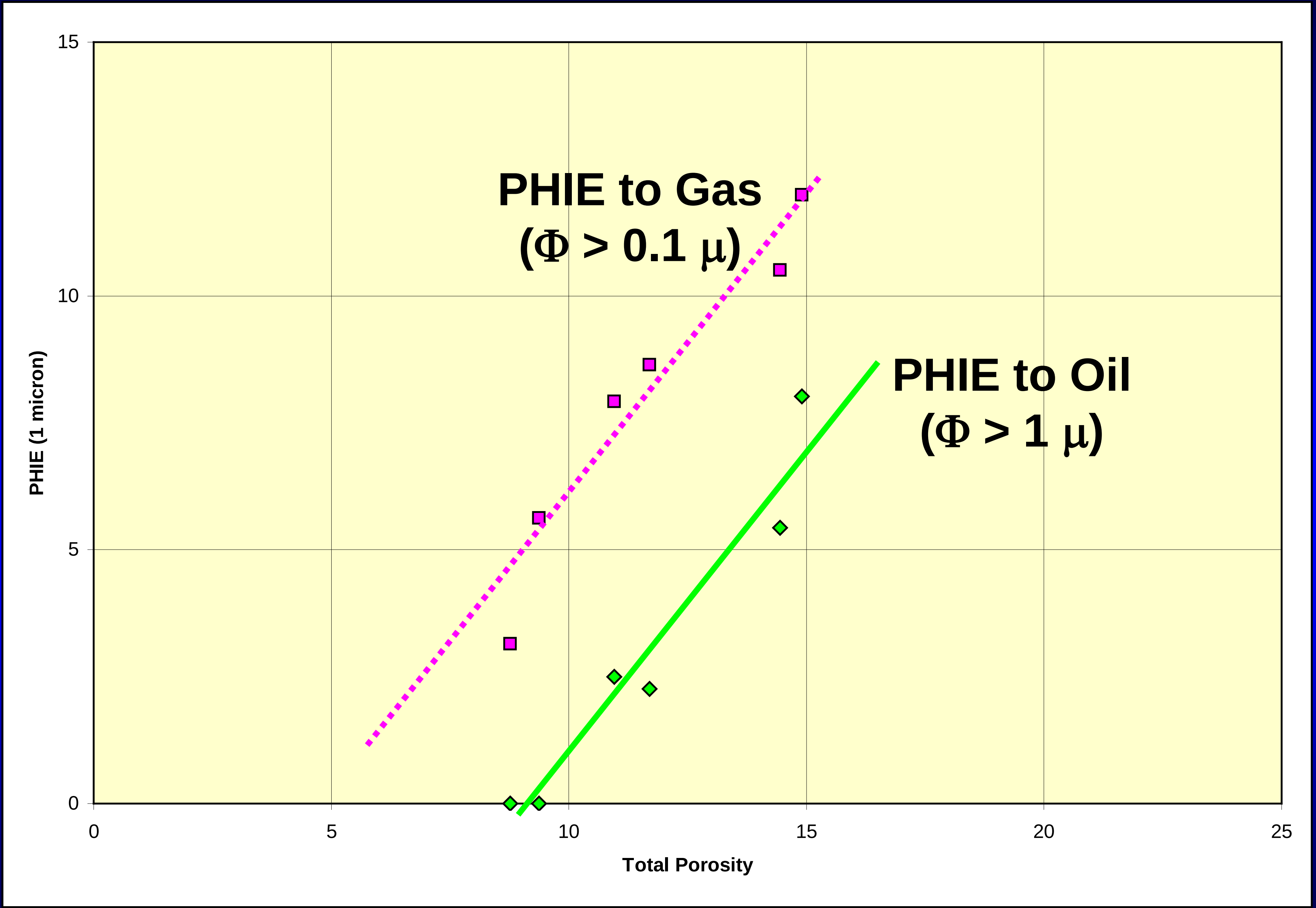
$$\Phi_{e_{0.1}} = \Phi > 0.1\mu$$



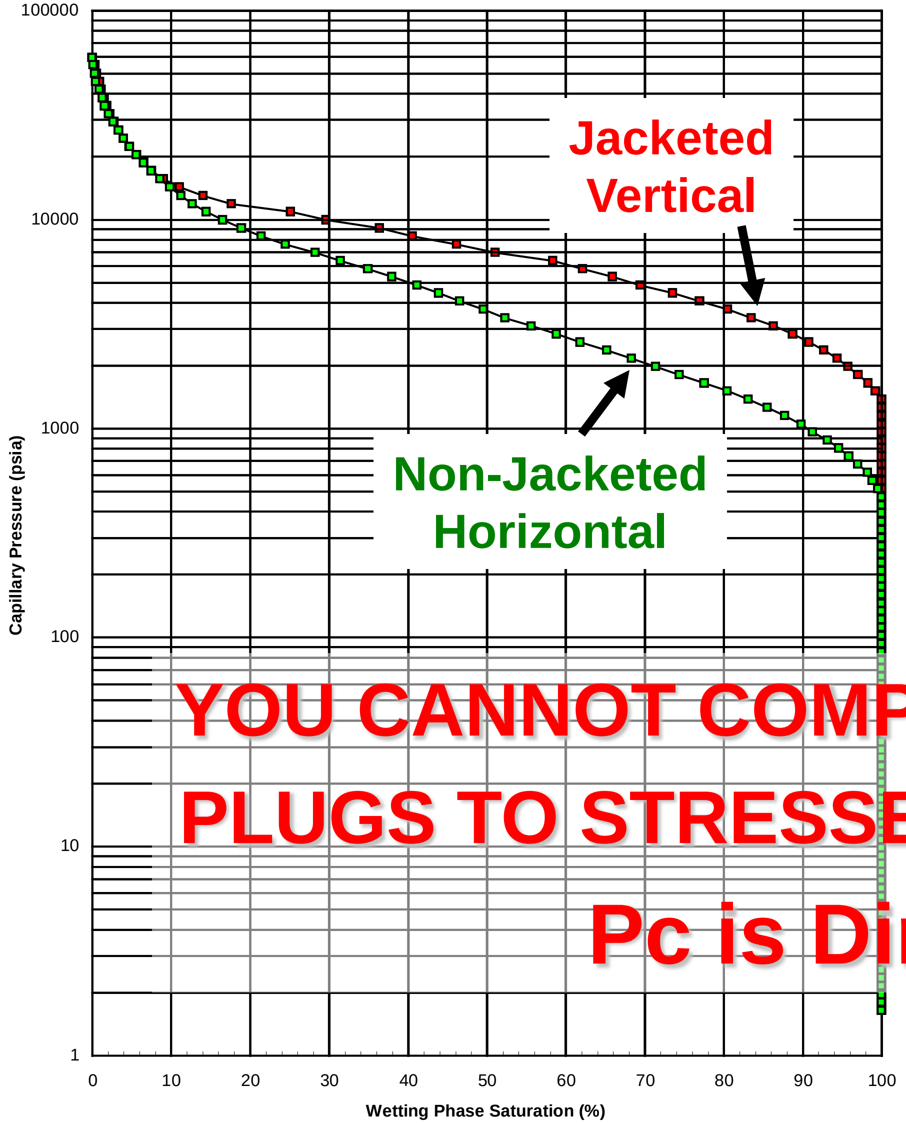
10.96% 0.061 md

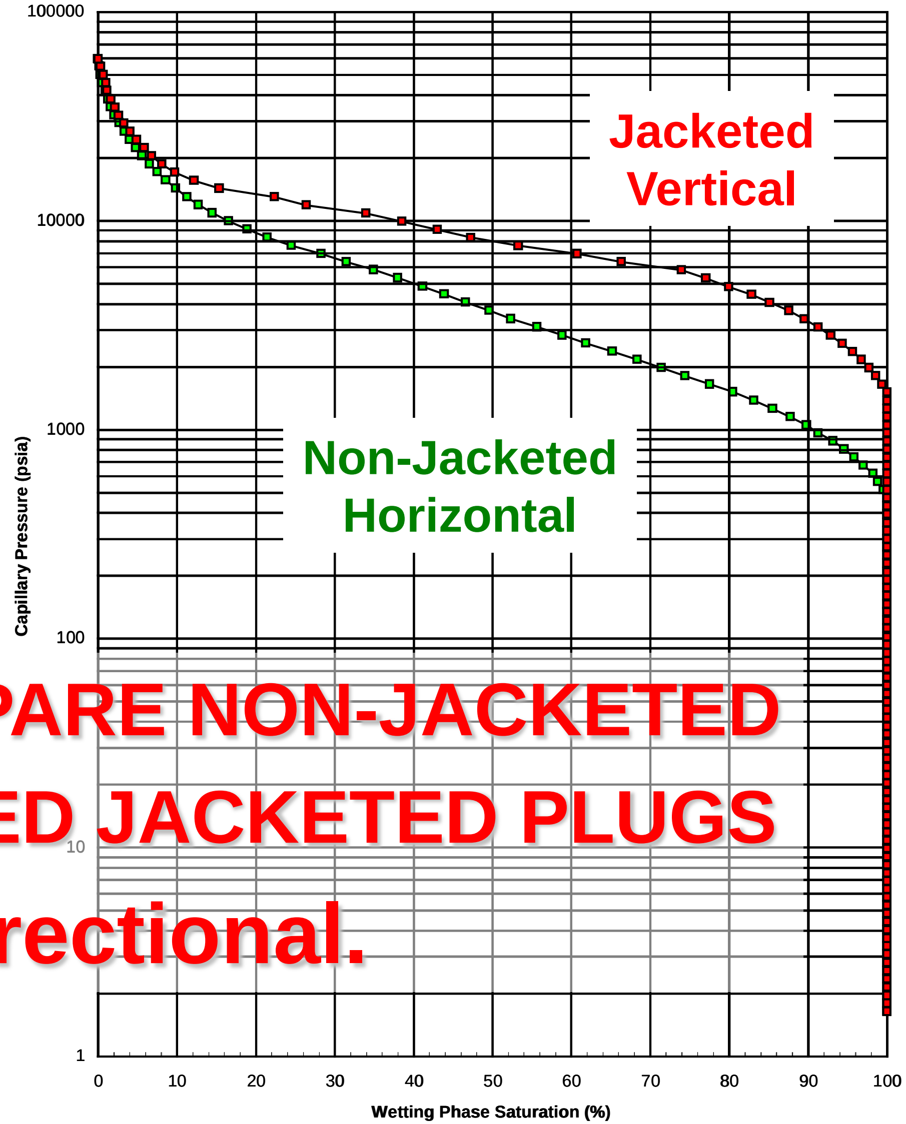


9.37% 0.028 md


PHIE to Gas
(Φ > 0.1 μ)
PHIE to Oil
(Φ > 1 μ)
PHIE (1 micron)
Total Porosity
0
5
10
15
0
5
10
15
20
25

Jacketed (vert.) vs. non-Jacketed (horz.) Plug

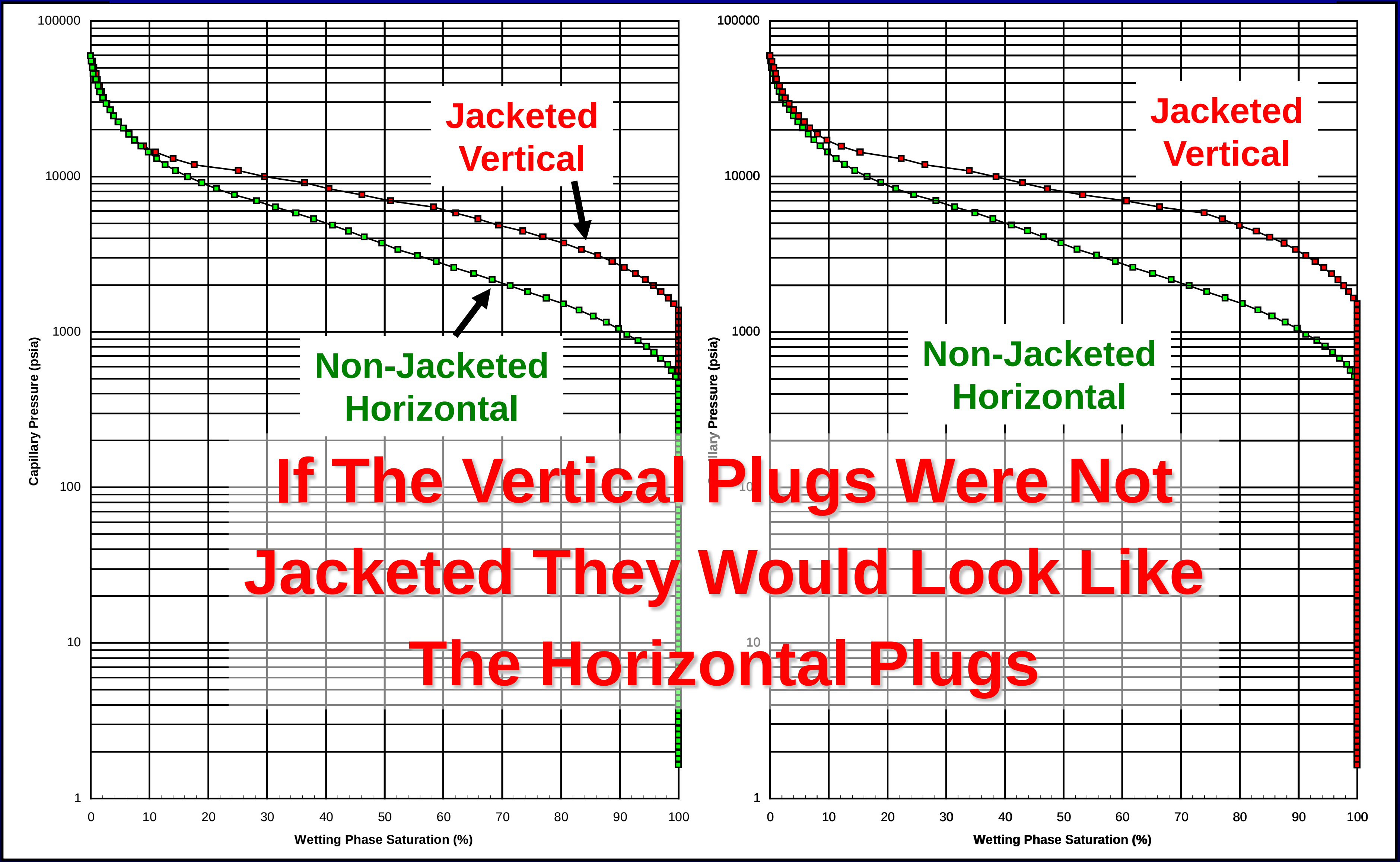




YOU CANNOT COMPARE NON-JACKETED PLUGS TO STRESSED JACKETED PLUGS

Pc is Directional.

Jacketed (vert.) vs. non-Jacketed (horz.) Plug



Summary & Conclusions

- Reservoir Quality
  - Larger grain size & crystal size
    - Bigger pore-throats
  - Bigger pore-throats
    - Higher k
    - Lower Sw_{irr}
    - Lower $Sw_{irr} \rightarrow$ higher $kr_{o\ or\ g}$
- Determining Pay
  - Throat-size better than k
    - 2 phase flow
  - Smaller pore-throats need more mobile fluid
    - >1 micron dia. oil
    - >0.1 micron dia. for gas

References

Beard, D.C., and P.K. Weyl, 1973, Influence of texture on porosity and permeability of unconsolidated sand: AAPG Bulletin, v. 57, p.. 349-369.

Lucia, F.J., 1995, Rock-fabric/petrophysical classification of carbonate pore space for reservoir characterization: AAPG Bulletin, v. 79, p. 1275-1300.

Lucia, F.J. 2002, Estimating permeability from porosity in Alabama Ferry Field: the rock-fabric approach: GCAGS Transactions, v. 52, 673-680.