A Simplified Shaly-Sand Model
To Provide Qualitative If Not Quantitative Insight into Observations*

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Abstract

Clay minerals affect essentially every measured petrophysical property. They destroy effective porosity and permeability, as well as contaminate essentially all wireline measurements.

A simplified mixing model consisting of coarse and fine grains of about two orders of magnitude difference offers qualitative, if not quantitative insight on these effects. The qualitative results predicted from this simplified model are remarkably similar to those observed from a Canadian Arctic shaly-sand well and published by Alan Heslop, in the mid-1970s.

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A Simplified Shaly-Sand Model

To Provide ***Qualitative***
If not ***Quantitative*** Insight
into Observations

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Clay Minerals

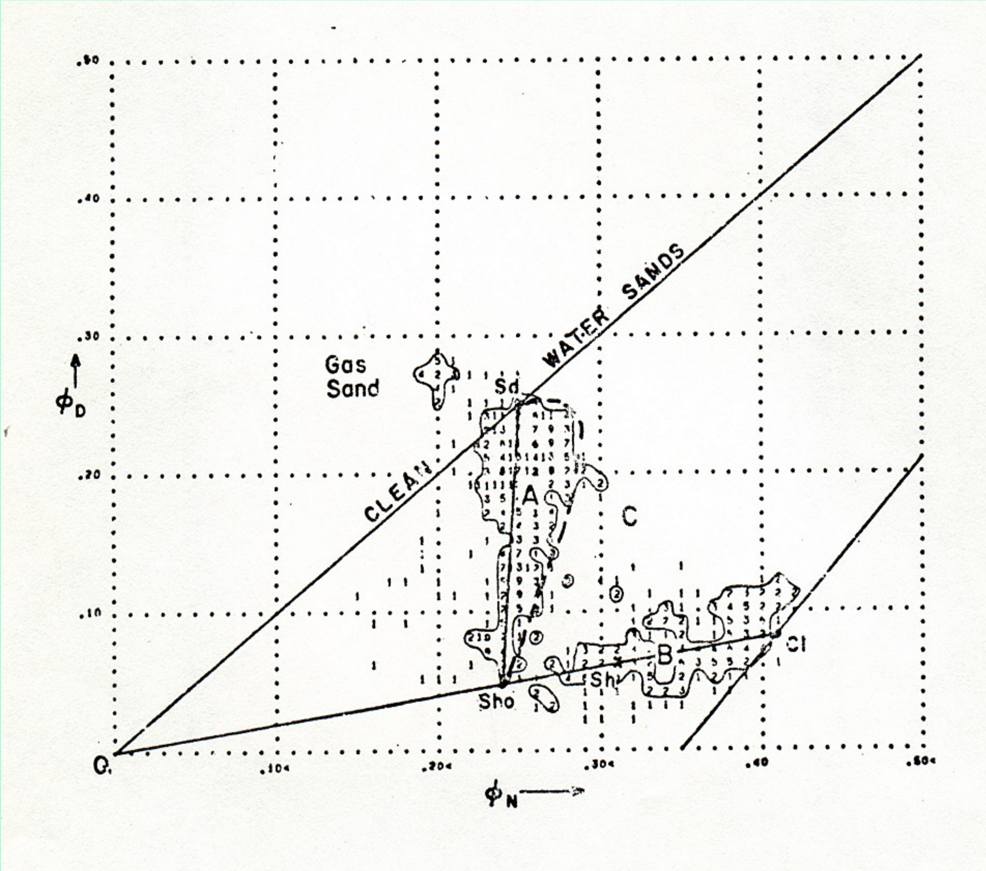
Bane of Petrophysicists Since 1950's

- Destroy Effective Porosity & Permeability.
- Increase *Apparent* Neutron Porosity.
- Decrease/Increase *Apparent* Density Porosity.
- Increase *Apparent* Water Salinity.
- Increase apparent S_w.
- Increase *Apparent* Sonic Δt.
- Decrease *Apparent* NMR T_2. (Surface Relaxation).

Shaly-Sand Petrophysics

- Not Needed in 1940's:
  - Only Clean Pays competed.
- Then Some Crazy Idiot Completed a Shaly-Sand:
  - There was a ***lot*** of oil in those rocks.
- The Birth of Shaly-Sand FE:
  - V_{sh} Algorithms.
  - Electro-Chemical Algorithms.
- Now Hundreds of Shaly-Sand Algorithms Abound:
  - Each one seemingly more complex than the last.

Need a Simple Model to Explain:



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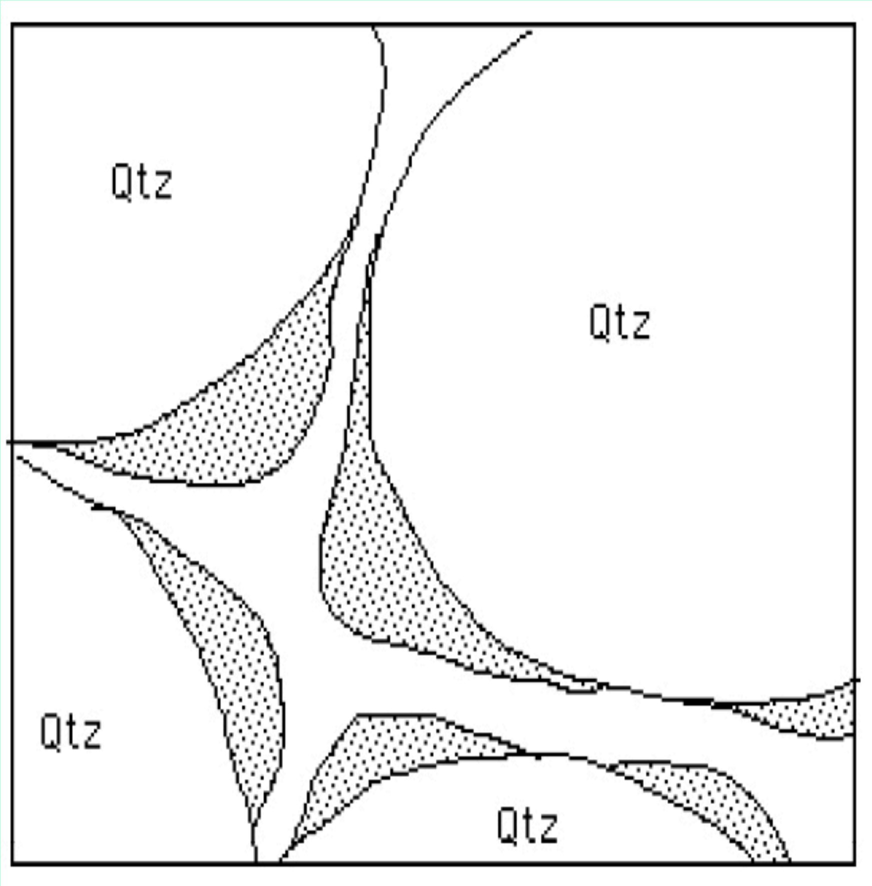
Consider A Rock Consisting of

- A *Coarse-Grained Framework:*
  - *Porosity,* φ_c.
  - *Matrix volume,* V_{mac}.
- With Coarse-Grained Framework Pores Filled with *Fine-Grained Material:*
  - *Porosity,* φ_f.
  - *Matrix volume,* V_{maf}.

Conceptual Model



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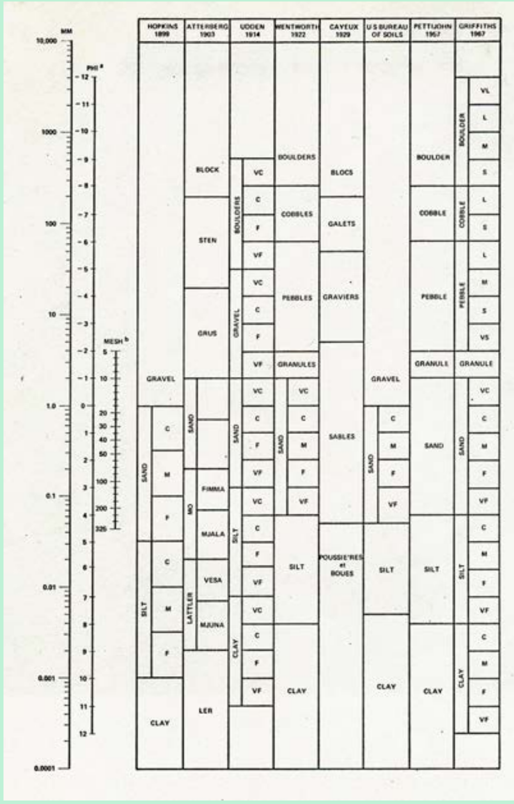
Bi-Modal Grain Size Model

Two Orders of Magnitude

Sedimentary Particle Size



Two Orders of Magnitude

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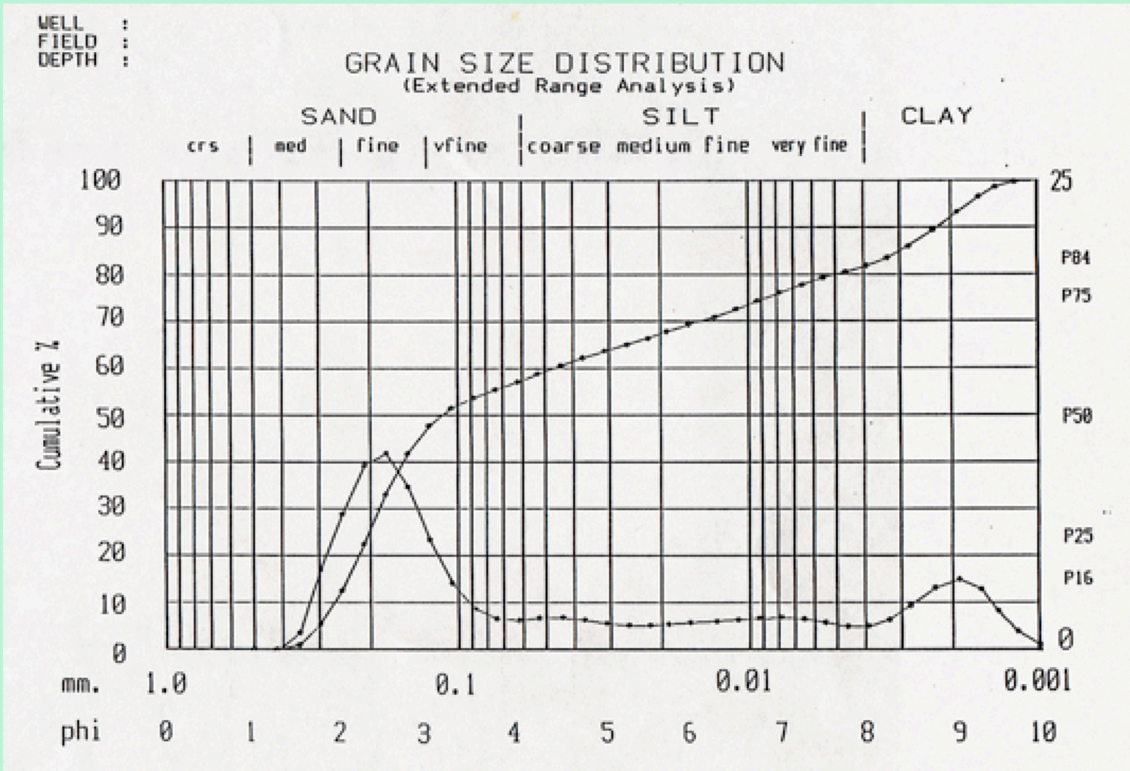
Recent Gulf Coast Sediment Sieve Analysis



Two orders of Magnitude Difference

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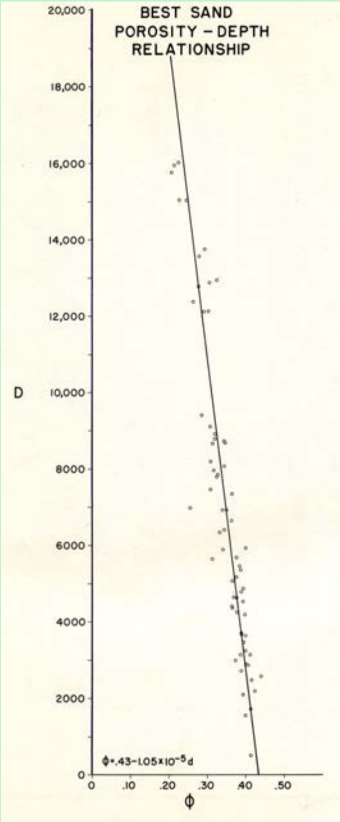
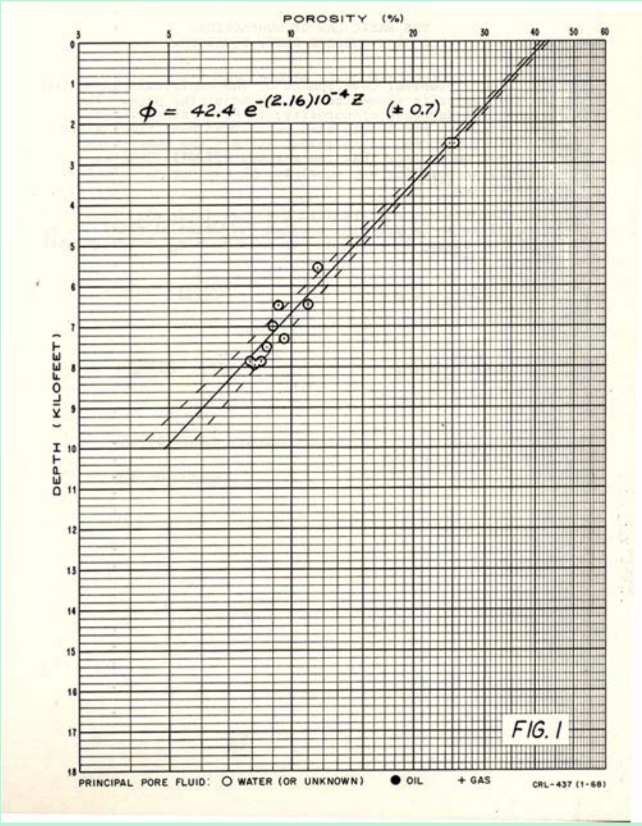
Gulf Coast Compaction Models

(*Both Indicate Deposition Porosities of ~ 42.5%*)

Sand Compaction Model



Shale Compaction Model



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Coarse & Fine-Grained Porosities

Coarse-Grained Framework “Porosity’

$$X_c = \frac{V_{mac}}{\left(V_{mac} + V_{maf}\right)}$$

$$and:$$

$$V_{pc} = V_R - V_{mac}$$

$$and;$$

$$j_c = \frac{V_{pc}}{V_R} = \frac{V_{pc}}{\left(V_{pc} + V_{mac}\right)}$$

Fine- Grained Intergranular “Porosity”

$$X_f = \frac{V_{maf}}{\left(V_{mac} + V_{maf}\right)}$$

$$and:$$

$$V_{fn} = V_{pf} + V_{maf}$$

$$and:$$

$$j_{fn} = \frac{V_{pf}}{V_{fn}} = \frac{V_{pf}}{\left(V_{pf} + V_{maf}\right)}.$$

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X_c & X_{fn} Mixing Relationships

For 1.00 > X_c > X'_c

$$\varphi_T = \frac{V_p}{V_R} = \frac{(V_{pc} - V_{maf})}{(V_{pc} + V_{mac})} = \frac{(V_{pc} + V_{pf} - V_{mf})}{(V_{pc} + V_{mac})}$$

or:

$$\varphi_T = 1 - \frac{(1 - \varphi_c)}{X_c} = \frac{(\varphi_c - X_{fn})}{(1 - X_{fn})}$$

For X'_c > X_c > 0.00

$$j_T = \frac{\left(1 - X_c\right) j_{fn}}{\left(1 - X_c j_{fn}\right)}$$

or :

$$j_T = \frac{X_{fn} j_{fn}}{\left(1 - j_{fn} + X_{fn} j_{fn}\right)}$$

at :

$$X_c = X'_c = \frac{\left(1 - j_c\right)}{\left(1 - f_c j_{fn}\right)}$$

and :

$$j_T = j_{Tmn} = \frac{V_p}{V_R} = j_c j_{fn}$$

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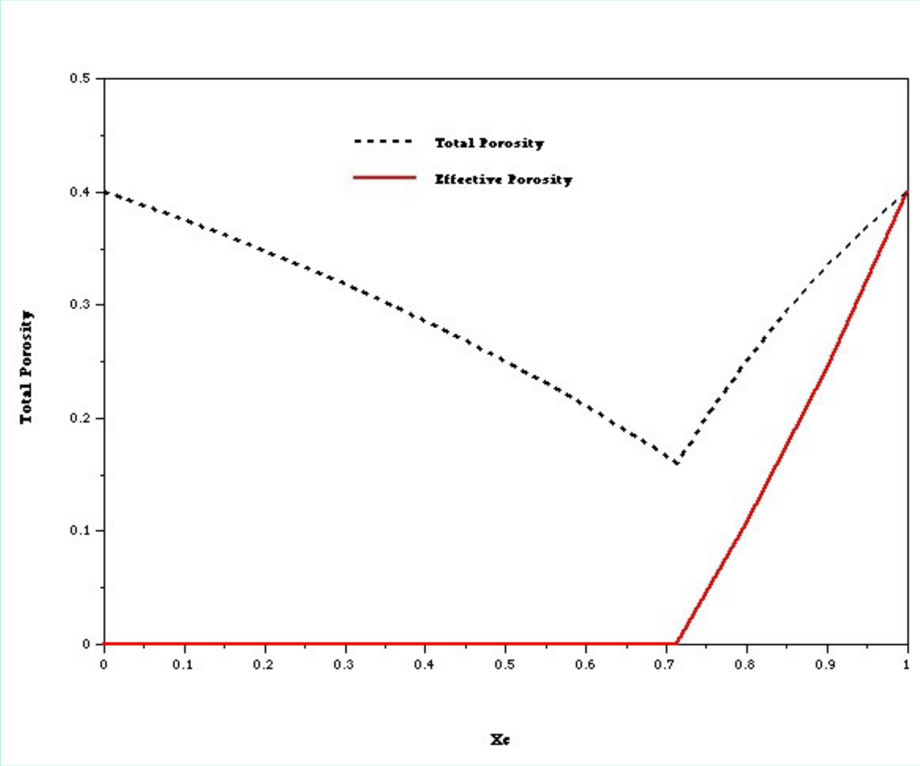
Through the Magic of Algebra



φ_t & φ_e for 100:1 grain size and $\varphi_c = \varphi_{fn} = 40\%$

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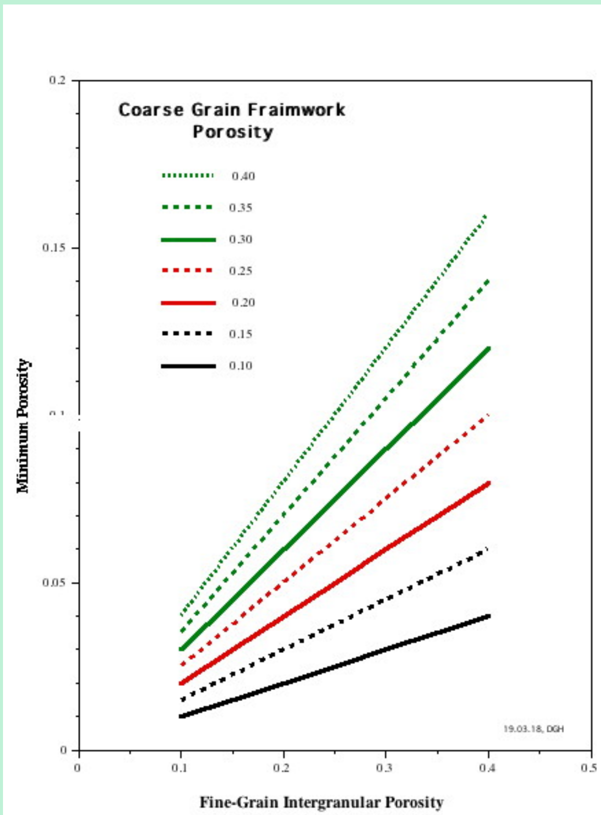
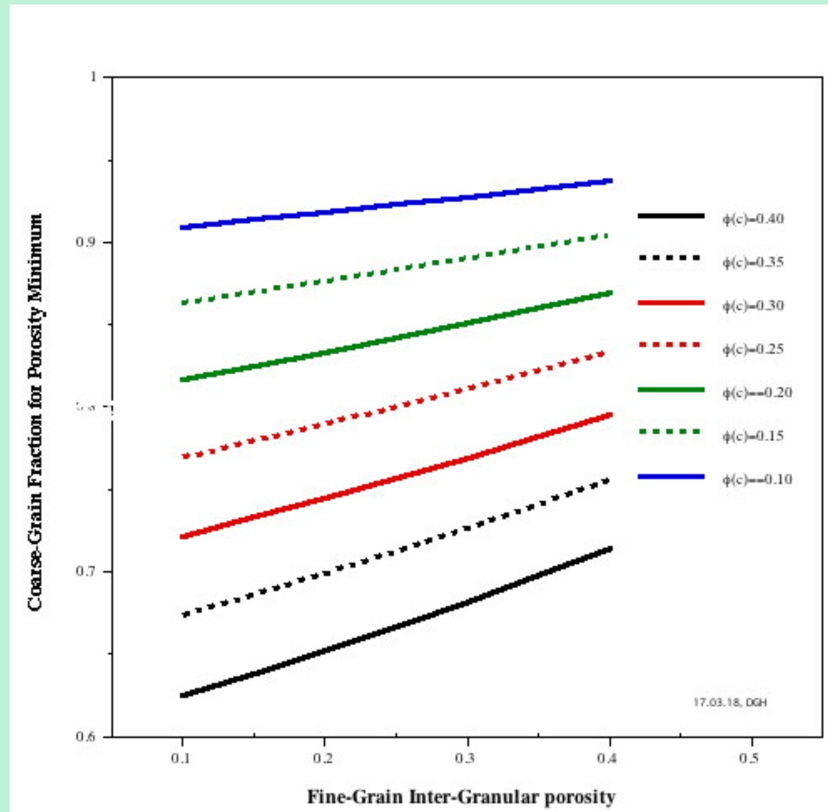
Variation of X_c' *and* φ_m

with Changes in φ_c *and* φ_f

φ_m Variations



X'$_c$ Variations



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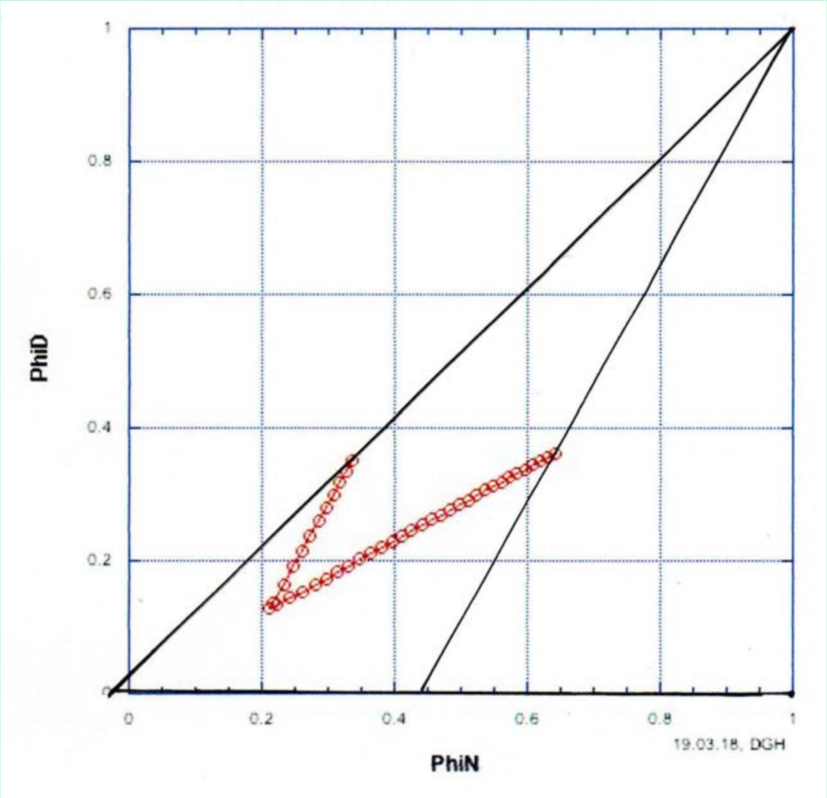
Bi-Modal Model $\varphi_N - \varphi_D$ X-Plot



$\varphi_c = \varphi_{fn} = 35\%$

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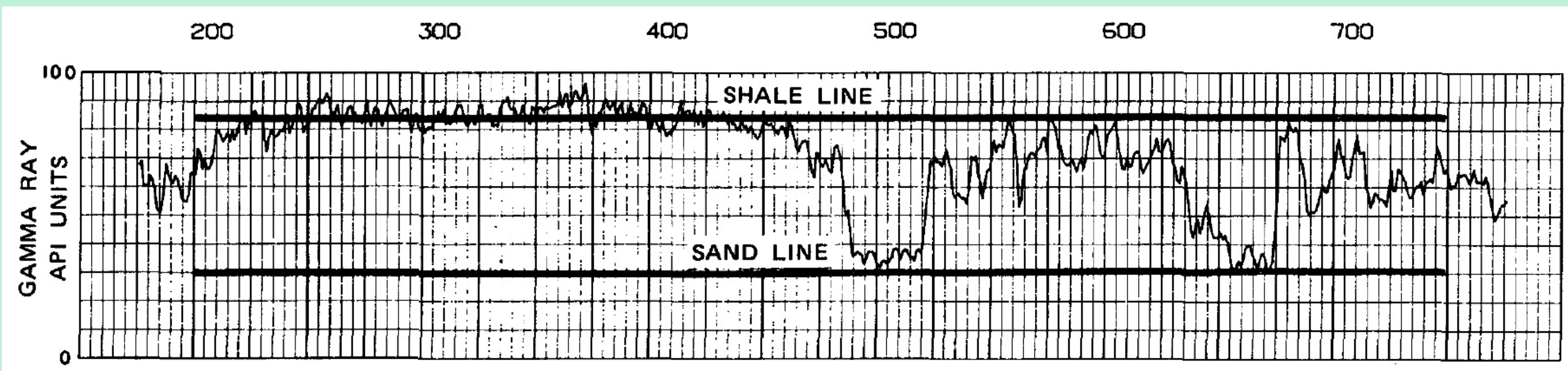
Heslop Canadian Arctic Well



GR log with Sand,& Shale Lines

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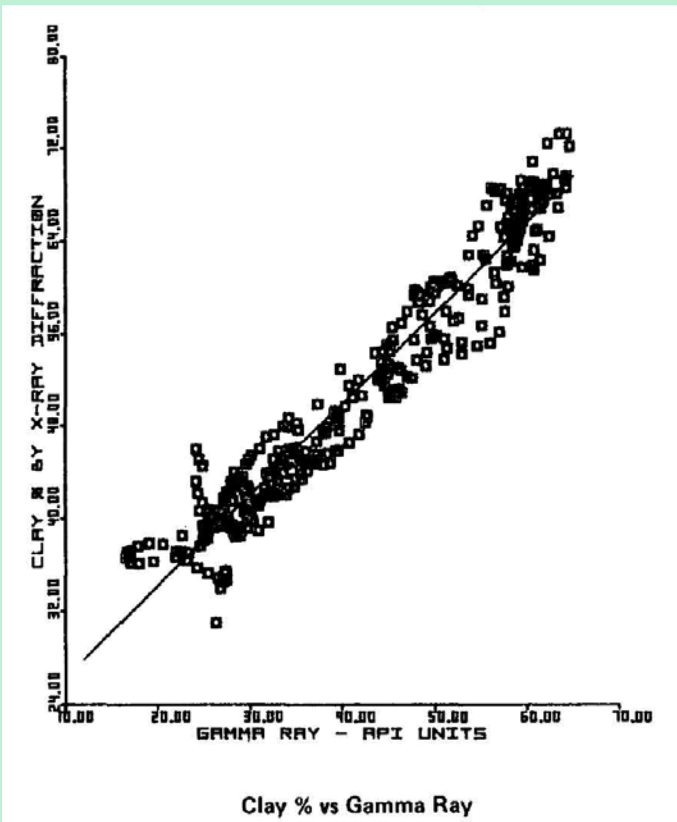
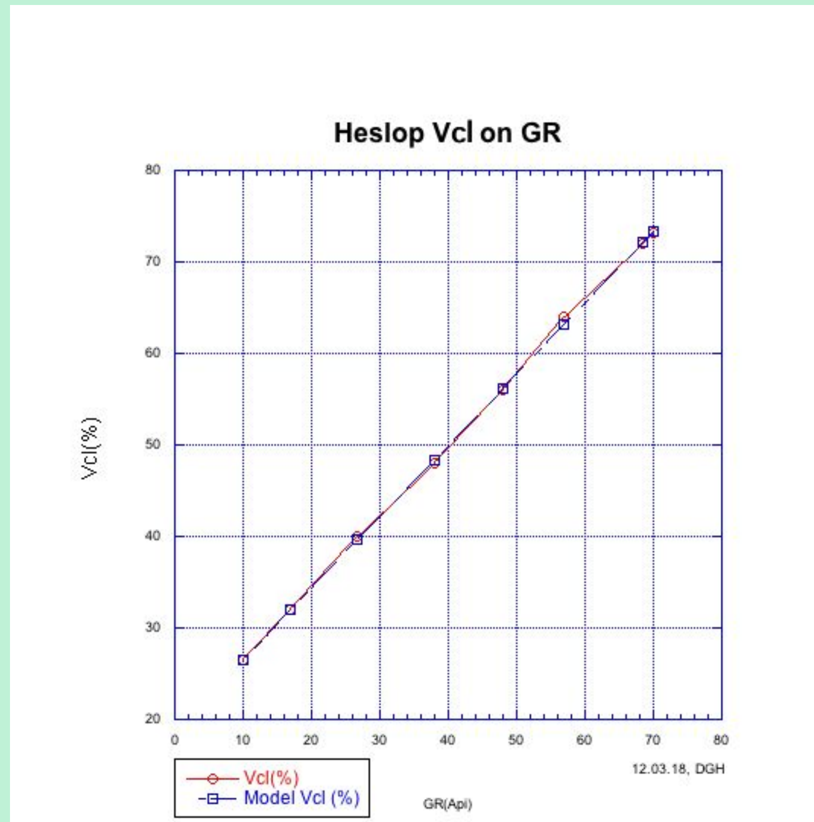
Heslop Canadian Arctic Well

W/L GR vs. Core Clay Content



Clay % vs Gamma Ray

V_{cl} vs. GR Trend



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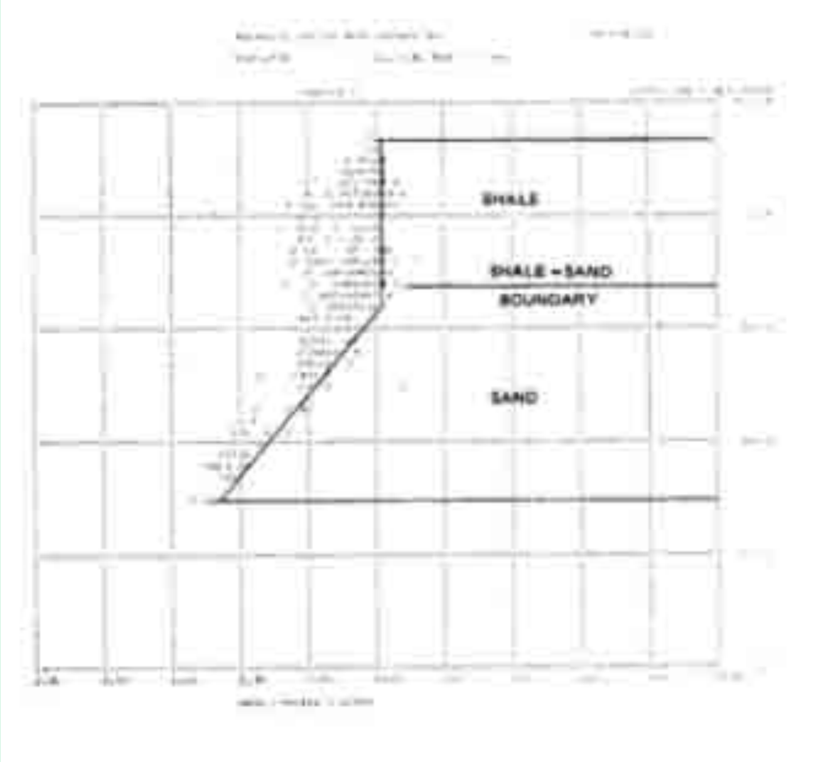
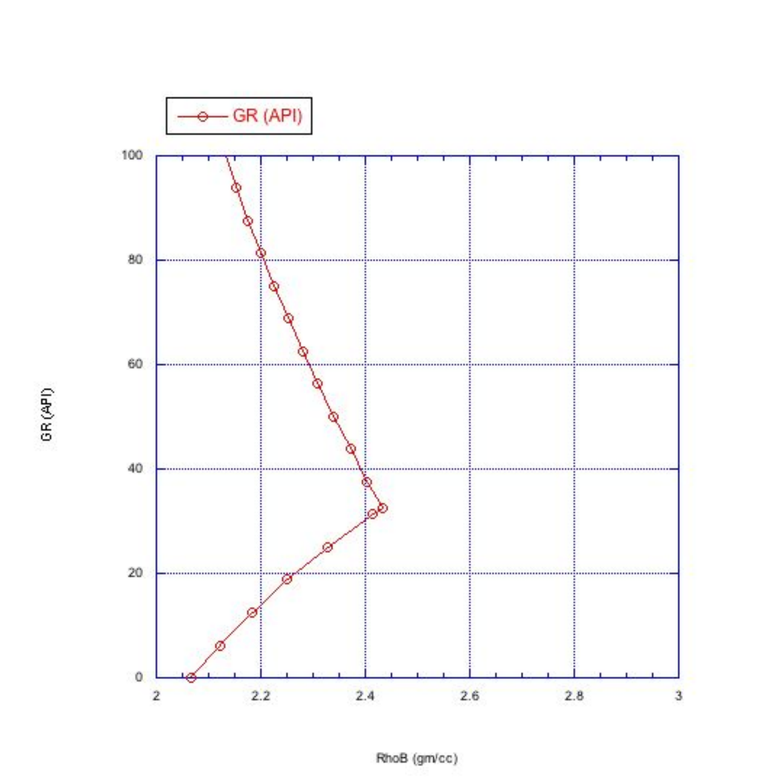
Density vs. GR

Heslop Canadian Arctic Well



Bi-Modal Model



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PhiN vs. GR

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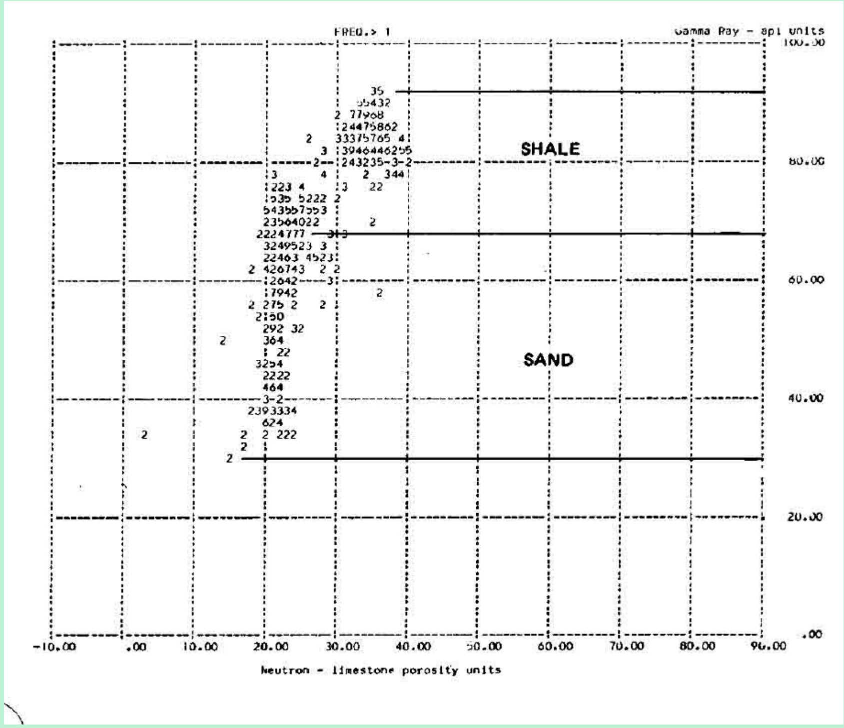
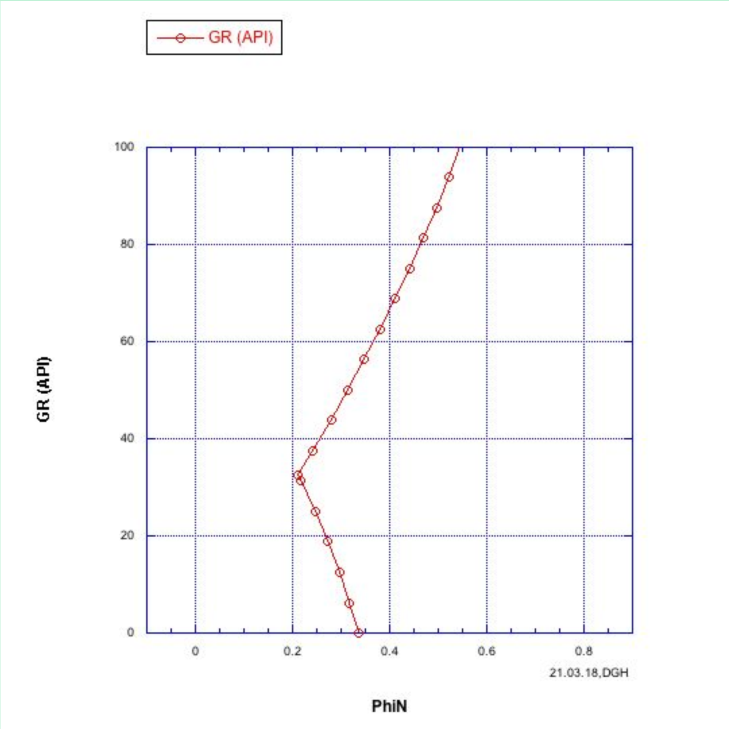


Bimodal Model



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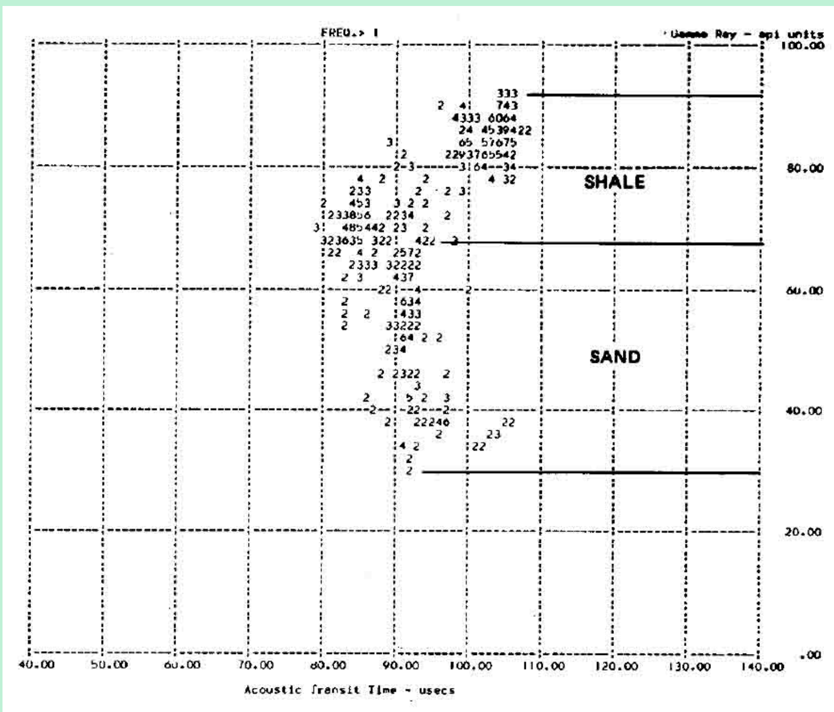
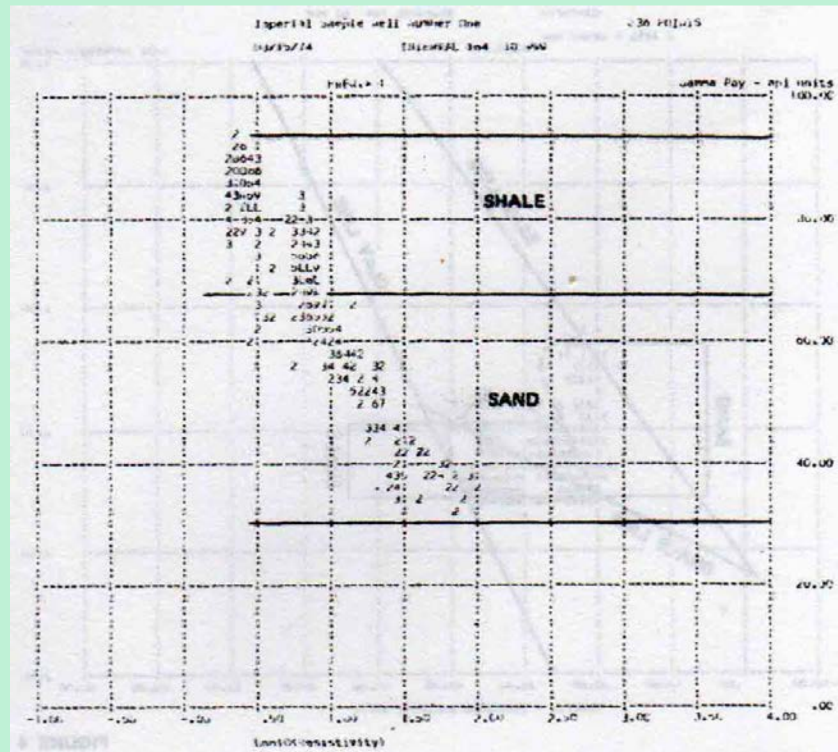
Heslop Canadian Arctic Well

ΔT vs GR



Rt vs GR



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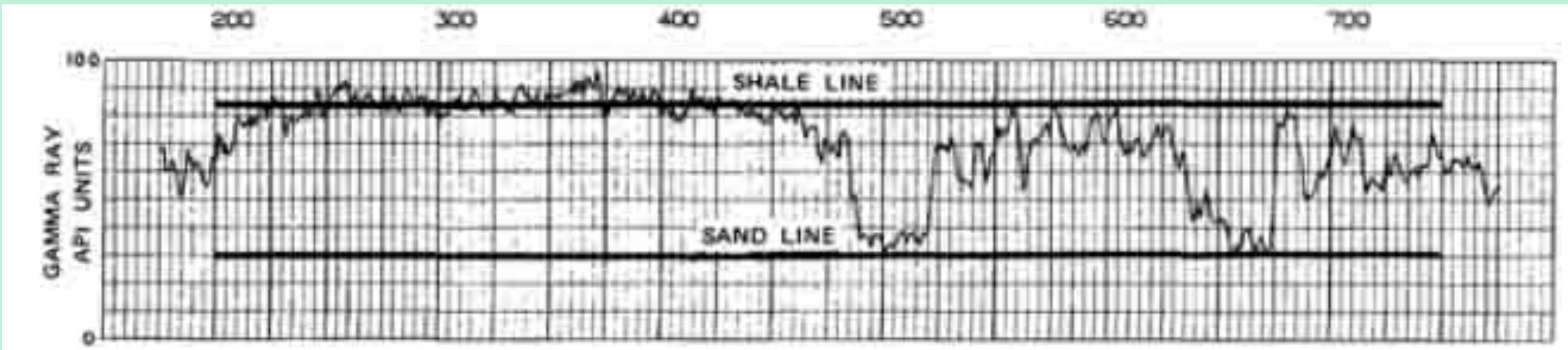
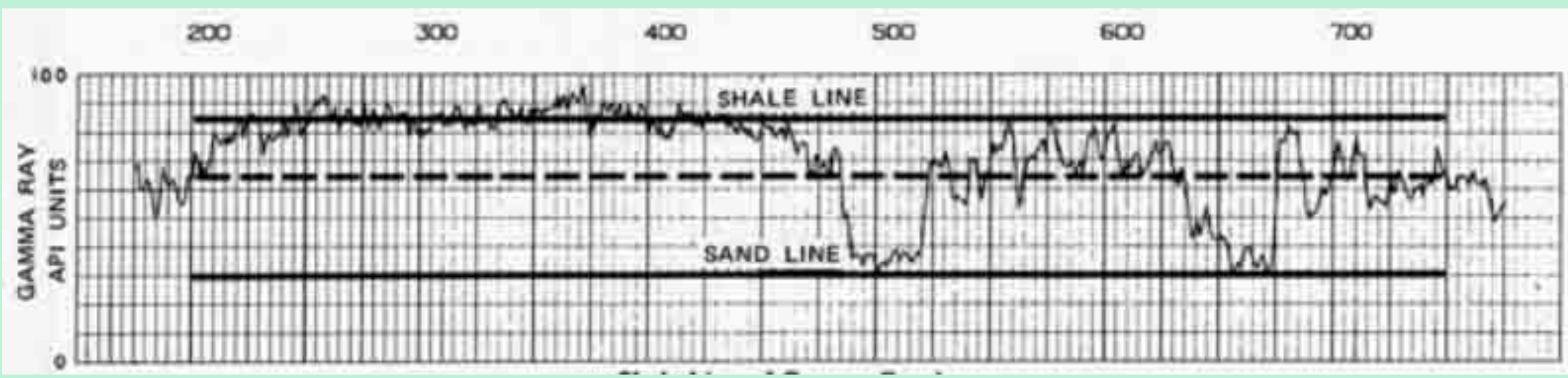
Heslop’s Canadian Arctic Well
GR Log Picks





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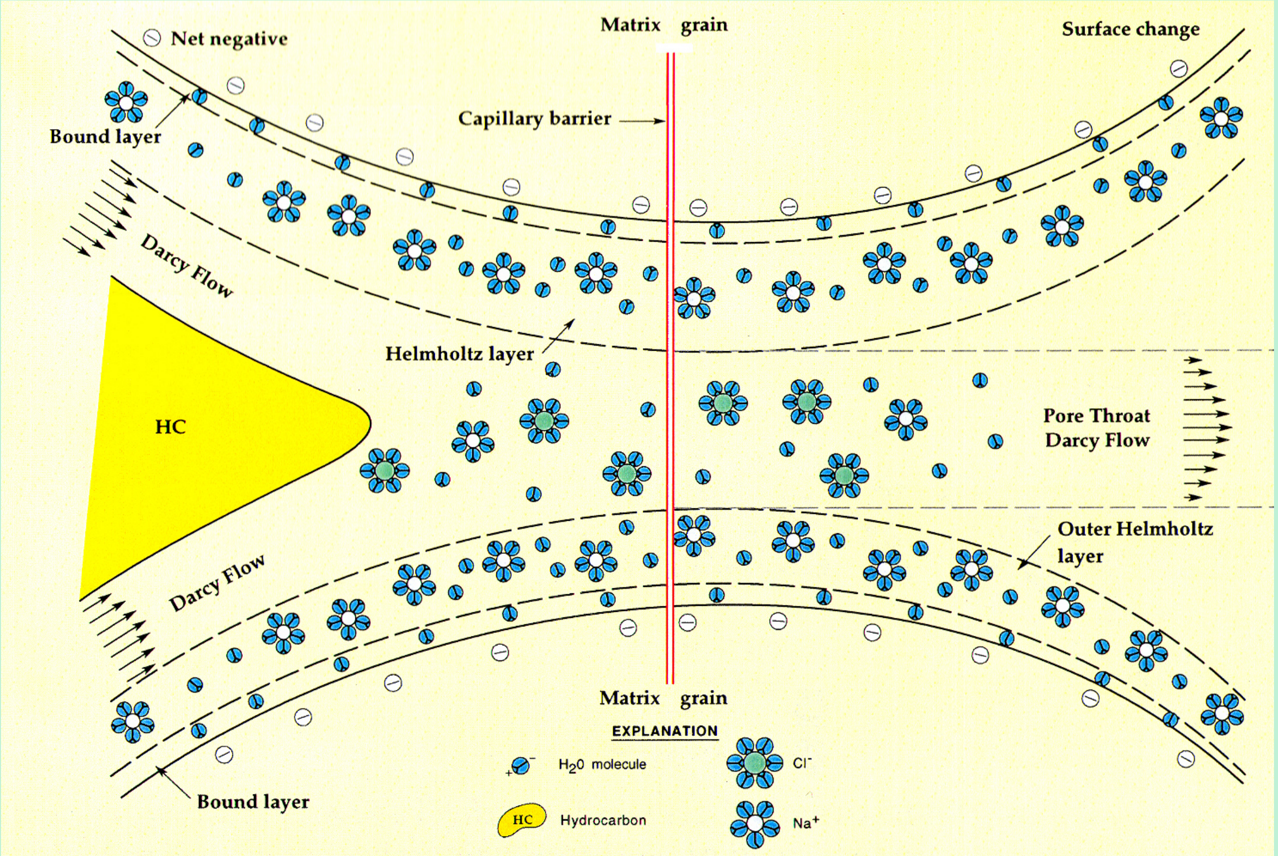
Why this is Important



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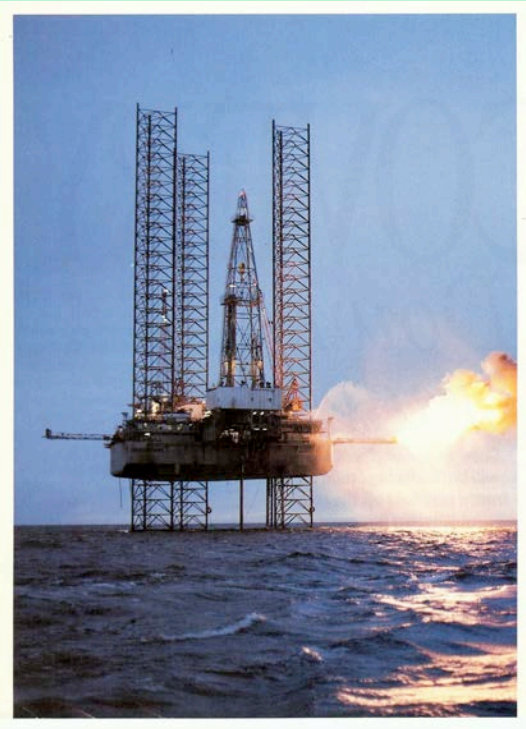

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