10/20/23

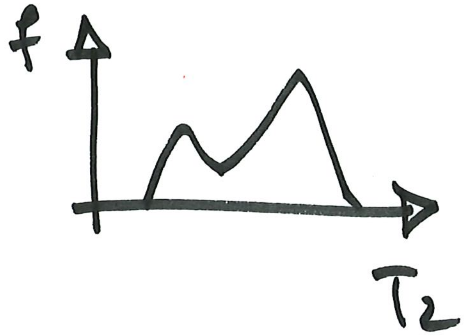
* Introduction to pet.
  - Rock prop.
  - Meas. tools/methods
  - Data
  - Impact of env. on data

* Porosity
  - What affect porosity?
  - ϕ def.
  - Quantification → Lab
    - ↳ Imaging
    - ↳ In-situ
      - ↳ Well logs

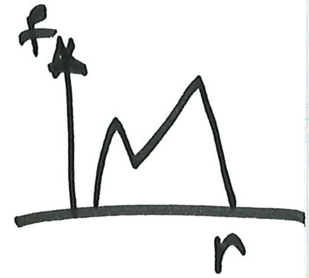
$\rightsquigarrow \rho_b$ $\qquad \phi = \dfrac{\rho_b - \rho_m}{\rho_f - \rho_m}$

$\rightsquigarrow \rho_b$ & ϕ_N

$\rightsquigarrow$ NMR



$\rightarrow$



(I) clay-free rocks

(II) shady sandstones

- Laminated
- Dispersed
- structural

Laminated

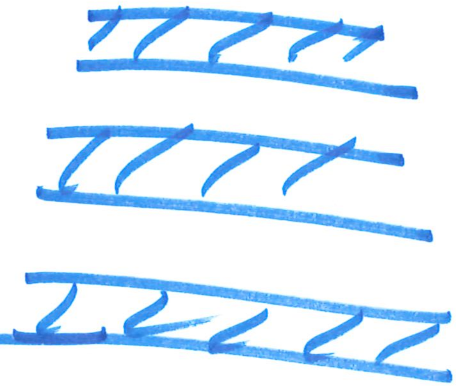
1 $\rightarrow$ C_{sh} $\rightarrow$ GR $\rightarrow$ $C_{sh} \simeq \dfrac{GR - GR_s}{GR_{sh} - GR_s}$

$\rightarrow \phi_N, \phi_D$

$\rightarrow$ Integration of above

$$2 \rightarrow \phi_N^{(sh)} = \frac{\phi_N - C_{sh}(\phi_N)_{sh}}{1 - C_{sh}}$$

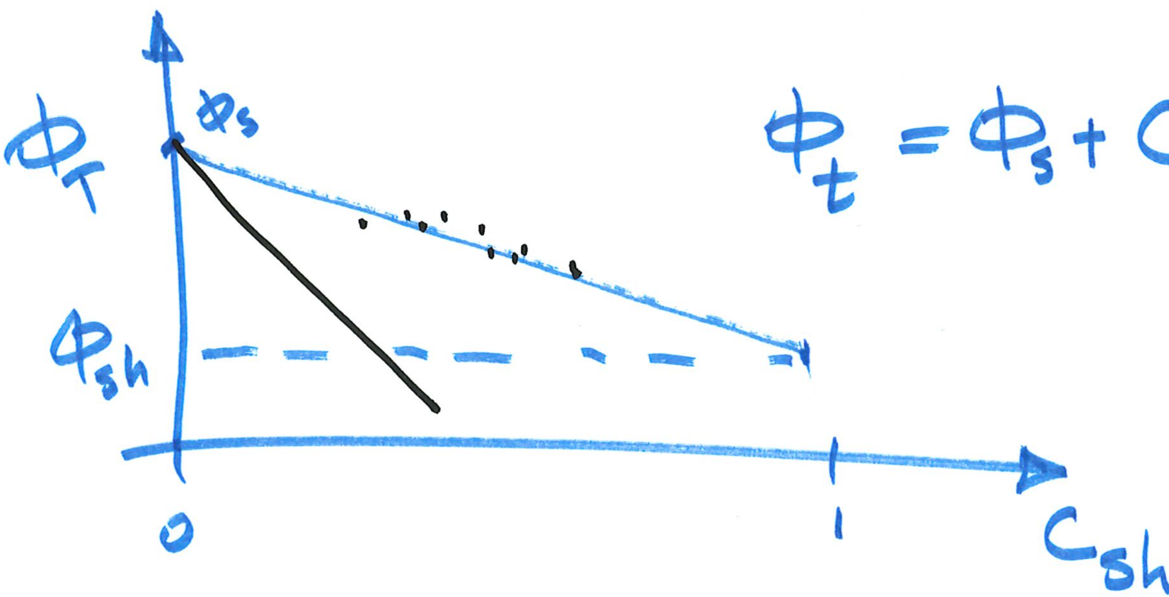
$$\phi_D^{(sh)} = \dots$$



$$\phi_N^{(sh)} = \phi_D^{(sh)} \rightarrow \text{Water}$$

$$\phi_N^{(sh)} < \phi_D^{(sh)} \rightarrow \phi_s = \sqrt{\frac{\phi_N^{(sh)^2} + \phi_D^{(sh)^2}}{2}}$$

$$\phi_t = \phi_s + C_{sh}\,\phi_{sh}$$



* Fluid Saturation

- Def.
- Quantification → Lab
  - ↳ In_situ → Res.
    - ↳ NMR

⟹ clay-free

⟹ Shaly sandstones

---

clay-free

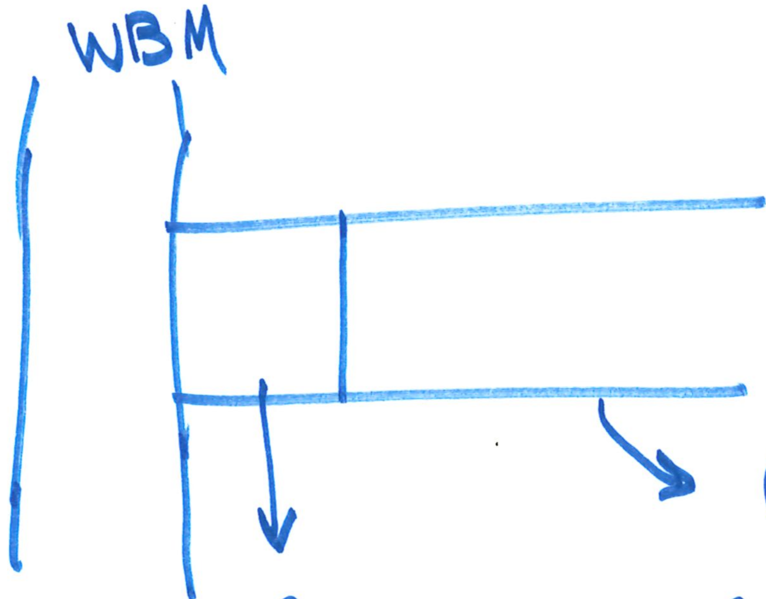
$$F = \frac{a}{\phi^m} = \frac{R_o}{R_w}$$

$$I_R = \frac{R_t}{R_o} = \frac{1}{S_w^n}$$

Archie's Eq.

$$R_t = R_w \frac{a}{\phi^m S_w^n}$$

$$\Rightarrow S_w, \; S_{xo}, \; S_{res,HC}$$
$$S_{mov,HC}$$

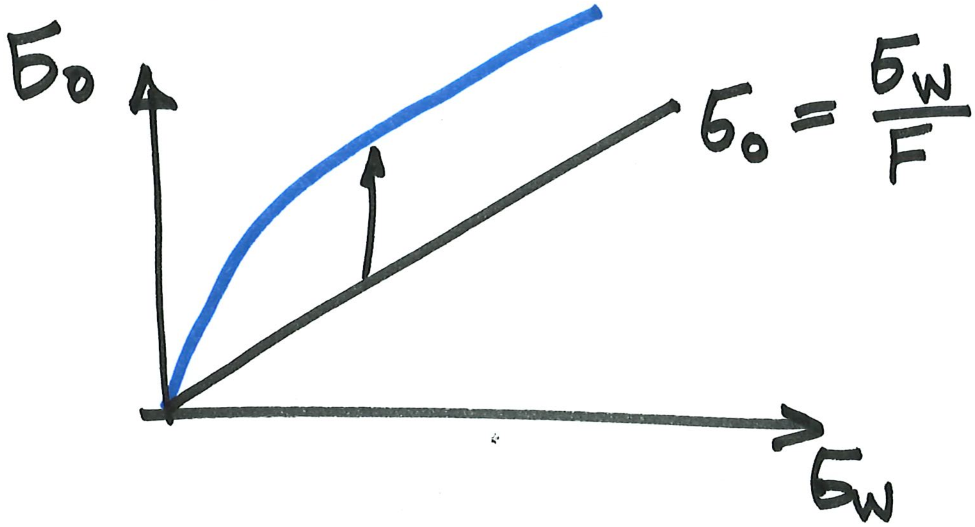


$$R_{Deep} = R_w \frac{a}{\phi^m S_w^n}$$

$$R_{shallow} = R_{mf} \frac{a}{\phi^m}$$

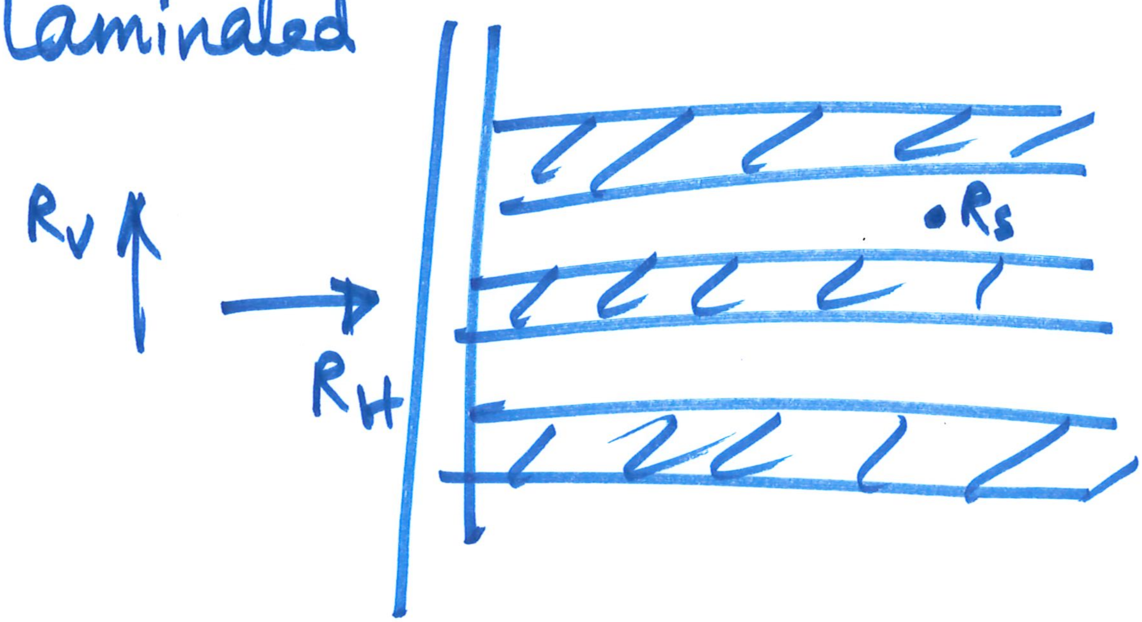
Shaly - Sands

$$\sigma_o = \frac{\sigma_w}{F} + X$$



$\rightsquigarrow$ Shaly-sand models

$\Rightarrow$ Laminated



$$\begin{cases} R_V = (1-C_{sh})\,R_s + C_{sh}\,R_{sh} \\ \dfrac{1}{R_H} = \dfrac{1-C_{sh}}{R_s} + \dfrac{C_{sh}}{R_{sh}} \end{cases}$$

$$\Longrightarrow \boxed{R_s.}$$

---

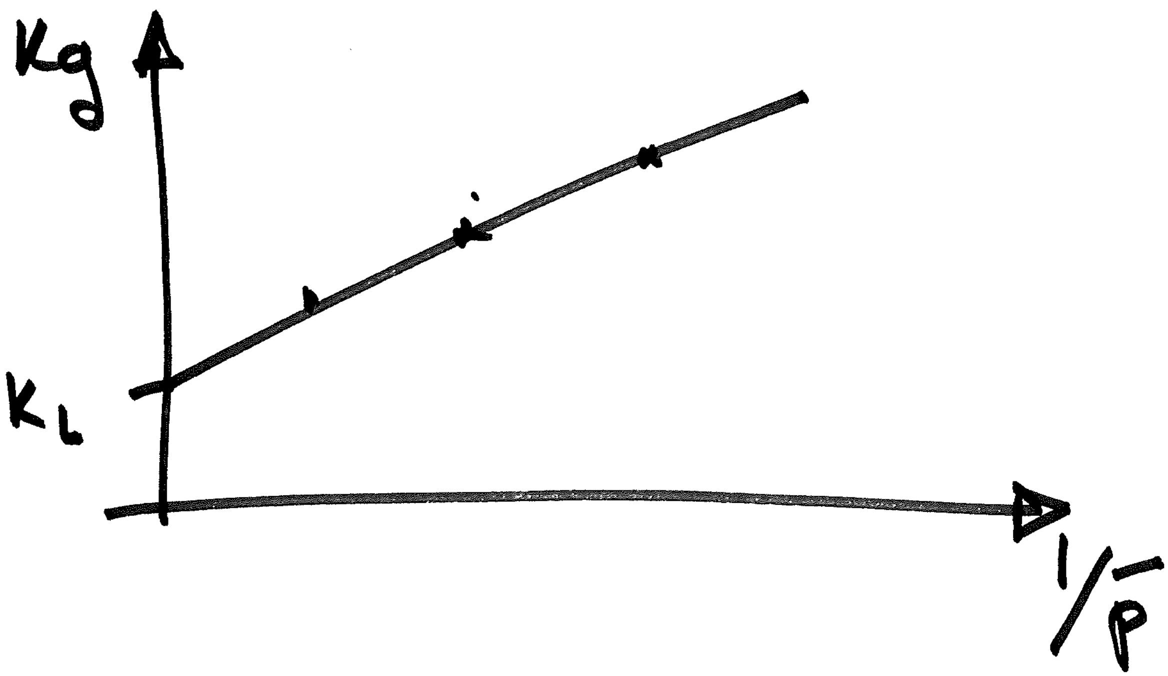
* Permeability

- Def.
- Darcy's Law
- Carman–Kozeny Eq.

$$K = \frac{\phi}{2\tau S_p^2} = \frac{\phi^3}{K_0 \tau S^2} = \frac{\phi^3}{K_0 \tau S_s^2 (1-\phi)^2}$$

- Lab → Steady-state
↓
Gas

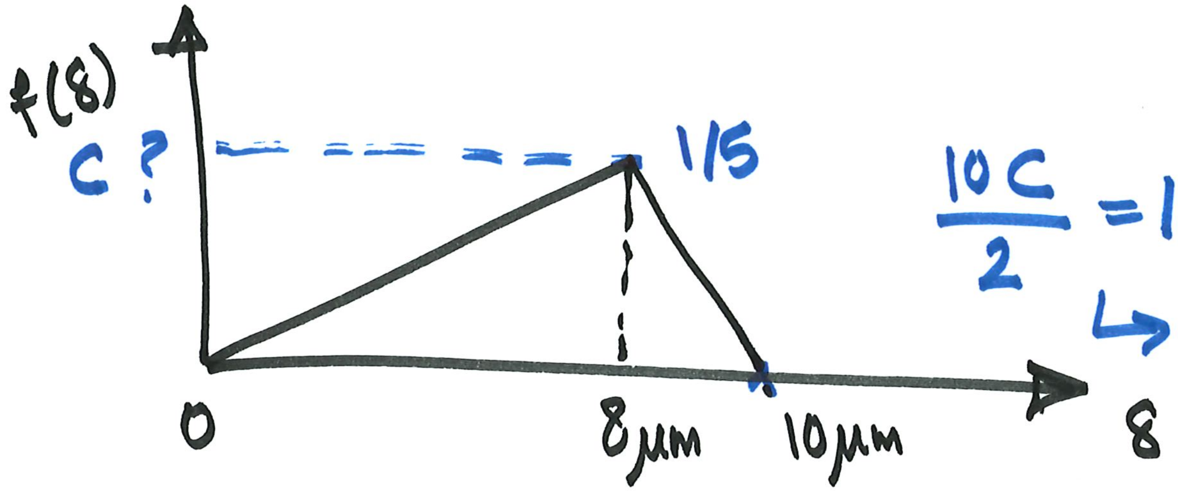
$$k_g = \frac{2 q_{sc} \mu L P_{sc}}{A(P_1^2 - P_2^2)}$$



- Pressure transient test

- In-situ well-log-based

Example:



$$\frac{10C}{2} = 1$$

$$\hookrightarrow C = \frac{1}{5}$$

$\phi = 15\%$

$K = ?$

$$f(\delta) = \begin{cases} \delta/40 & 0 < \delta < 8\,\mu m \\ 1 - \delta/10 & 8 < \delta < 10\,\mu m \end{cases}$$

$y = ax + b$

$x = 0 \rightarrow y = 0 \quad \rightarrow b = 0$

$x = 8 \rightarrow y = 1/5 \quad \rightarrow \frac{1}{5} = a(8) \rightarrow a = \frac{1}{40}$

$$\Rightarrow y = \frac{x}{40}$$

$$y = ax + b$$

$$\left.\begin{aligned} x = 10 \rightarrow y = 0 \quad &\Rightarrow \quad 0 = 10a + b \\ x = 8 \rightarrow y = \tfrac{1}{5} \quad &\Rightarrow \quad \tfrac{1}{5} = 8a + b \end{aligned}\right\}$$

$$\Rightarrow y = 1 - \frac{x}{10}$$

$$Q = \frac{\pi}{128\mu} \frac{\Delta P}{L} \int_{\delta_a}^{\delta_b} f(\delta)\, \delta^4 \, d\delta$$

$$Q = \frac{K A_T}{\mu} \frac{\Delta P}{L}$$

$$\hookrightarrow A_T = \frac{\Sigma A_i}{\phi} = \frac{\pi}{4} \left(\frac{1}{\phi}\right) \Sigma \delta_i^2$$

$$= \frac{\pi}{4\phi} \int_{\delta_a}^{\delta_b} f(\delta)\, \delta^2 \, d\delta$$

$$\Rightarrow \boxed{K = 261.7 \text{ mD}}$$

$$\overline{\overline{k}}_{xy} = \begin{bmatrix} 100 & 50 \\ 50 & 100 \end{bmatrix} \text{ md} \qquad \mu = 1 \text{ cp}$$

$$\nabla\Phi = -0.15\,\hat{i} + 0.05\,\hat{j} \quad (\text{atm/cm})$$

$$\vec{v}_d = -\frac{k}{\mu}\nabla\Phi$$

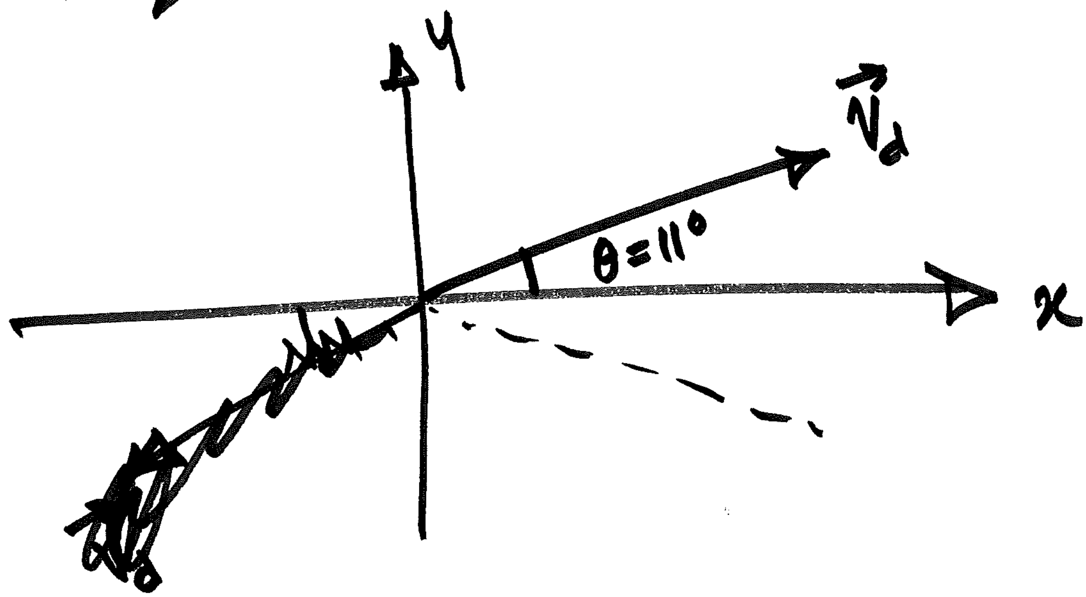
$$= -\begin{bmatrix} 0.1 & 0.05 \\ 0.05 & 0.1 \end{bmatrix} \begin{bmatrix} -0.15 \\ 0.05 \end{bmatrix}$$

$$= \begin{bmatrix} +0.0125 \\ +0.0025 \end{bmatrix} \quad \text{cm/s}$$

$$|\vec{v}_d| = \sqrt{0.0125^2 + 0.0025^2} = 0.0127 \text{ cm/s}$$

$$\cos\theta = \frac{\vec{v}_d \cdot \hat{i}}{|\vec{v}_d|\,|\hat{i}|} = \frac{+0.0125}{0.0127}$$

$$\Rightarrow \theta = 11.3^\circ$$



---

principal values & direction:

$$\bar{\bar{K}}_{xy} = \begin{bmatrix} 100 & 50 \\ 50 & 100 \end{bmatrix} \longrightarrow \bar{\bar{K}}_{uv} = \begin{bmatrix} K_{uu} & 0 \\ 0 & K_{vv} \end{bmatrix}$$

$$\begin{vmatrix} 100-\lambda & 50 \\ 50 & 100-\lambda \end{vmatrix} = 0$$

$$\rightarrow \lambda^2 + 7500 - 200\lambda = 0$$

$$\rightarrow \lambda_1 = 150 \text{ md}$$

$$\lambda_2 = 50 \text{ md}$$

$$\begin{bmatrix} 100-150 & 50 \\ 50 & 100-150 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

$$\rightarrow \begin{bmatrix} -50 & 50 \\ 50 & -50 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

$$\Rightarrow x = y,$$