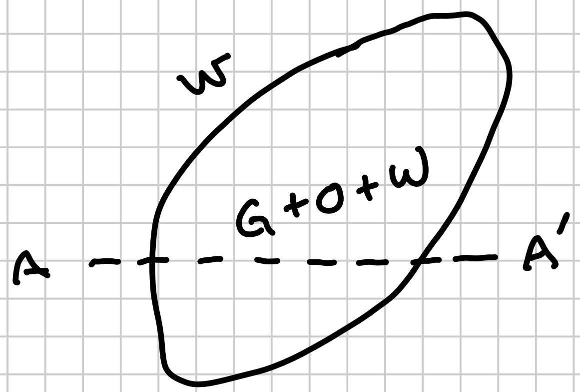
TPG 4105 Sept. 25, 2006

Introductory Lecture in Petroleum Engineering (Reservoir)

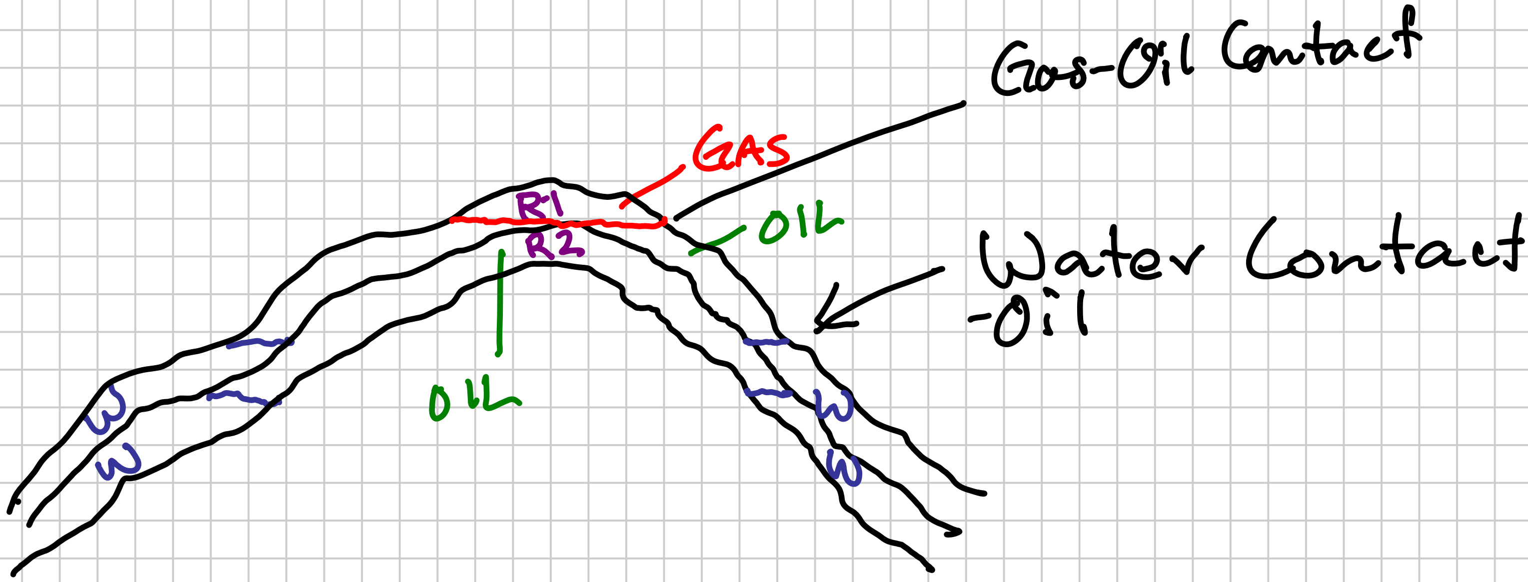
Curtis H. Whitson

Topic: "Initial Fluids In Place"

?SURFACE



Top View



Variation of everything (x, y, z)

- V_b (x, y, z)
- ϕ (x, y, z)
- (*) Contacts (z)
- S_w (x, y, z)
- Molecular Composition (Methane, H_2S, ...)

$(z_j ;\ x, y)$; Gas-Oil Ratio, $R = \frac{V_{SG}}{V_{SO}}$; R_s solution GOR

- Conversion factors from Reservoir Volumes (RG, RO) to Surface Volumes (SG, SO). "Formation Volume Factors" (FVF)

$$B = \frac{V_R}{V_S}$$

$$b = \frac{V_S}{V_R}$$

$$B(z_j ; x, y)$$

RESERVOIR GAS → (surface) → PRODUCTS

SURFACE "STOCK-TANK"
- GAS
- OIL*
- WATER

RESERVOIR OIL → (surface) → PRODUCTS

SURFACE
- GAS
- OIL*
- WATER

* CONDENSATE

* CRUDE OIL

DEFINITIONS:

$$\phi \equiv \frac{V_p}{V_b} \qquad \begin{matrix}\text{pore} \\ \text{bulk}\end{matrix}$$

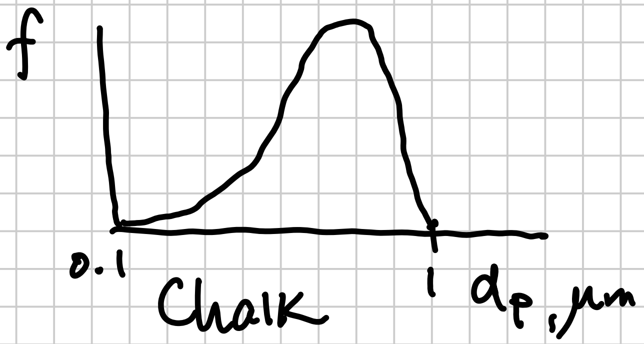
2-45%

5-30% Common

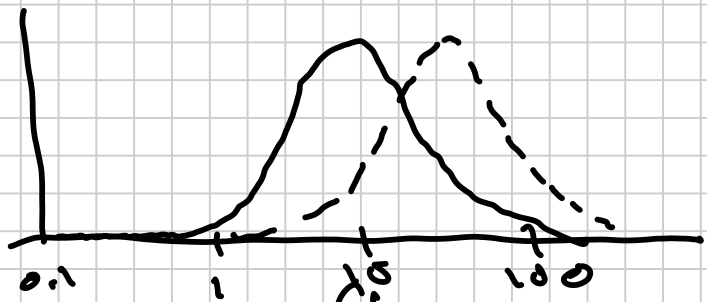
- Primary (main pore volume, interconnected)
  95-99.95% of total porosity

- Secondary (may or may not be interconnected)
  - Vugs
  - Fractures
  - other

Pore sizes: 0.1 – 100 μm diameters



Narrow distribution



Clean, Unconsolidated Sandstone

Wider dist, larger average $\bar{d}_p$

Measurement / Estimation:

(1) Log (neutron, density)
(2) Core data
(3) Correlation, mapping

$\pm$ 0.5-3 por-%

WATER SAT. S_w

S_{wc} = "connate" wat. sat. ("initial")

S_{wi} = "irreducible" wat. sat.

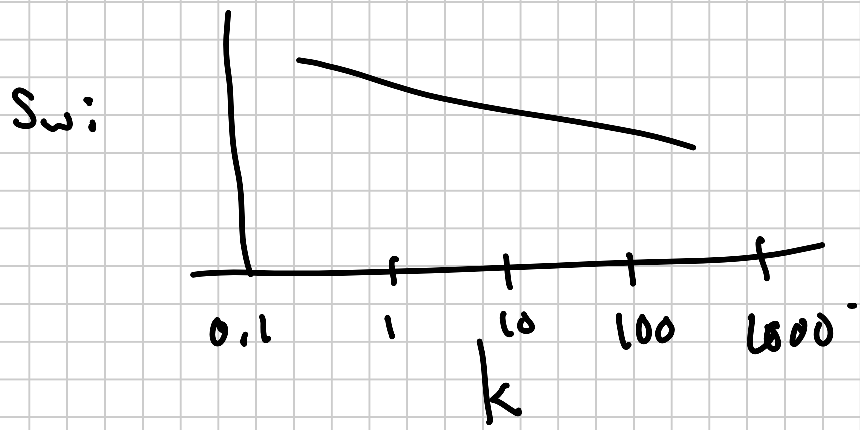
$$S_w \equiv \frac{V_w}{V_p}$$

$$S_o \equiv \frac{V_o}{V_p} \qquad \sum_p S_p = 1$$

$$S_g \equiv \frac{V_g}{V_p} \qquad \text{phases, } p \in (g, o, w)$$

S_{wi} ~ 5-50%

10-30% common



Rule of Thumb (SS)

Measurement / Correlation:

- Logs (Resistivity; +++)
- Core (difficult for S_{wc})
  - Centrifuge
  - Porous Plate

  } S_{wi} ± 3 sat-%

CONTACTS:

Contact : Equal phase pressures

- e.g. OWC $\quad P_o = P_w$

GOC $\quad P_g = P_o$

Introduce definition "Capillary Pressure"

$$P_c \equiv P_{lp} - P_{hp}$$

light phase — heavy phase

e.g.

$$P_g - P_o \equiv P_{cgo}$$

$$P_o - P_w \equiv P_{cow}$$

$$P_g - P_w \equiv P_{cgw}$$

Contact: $P_c = 0$

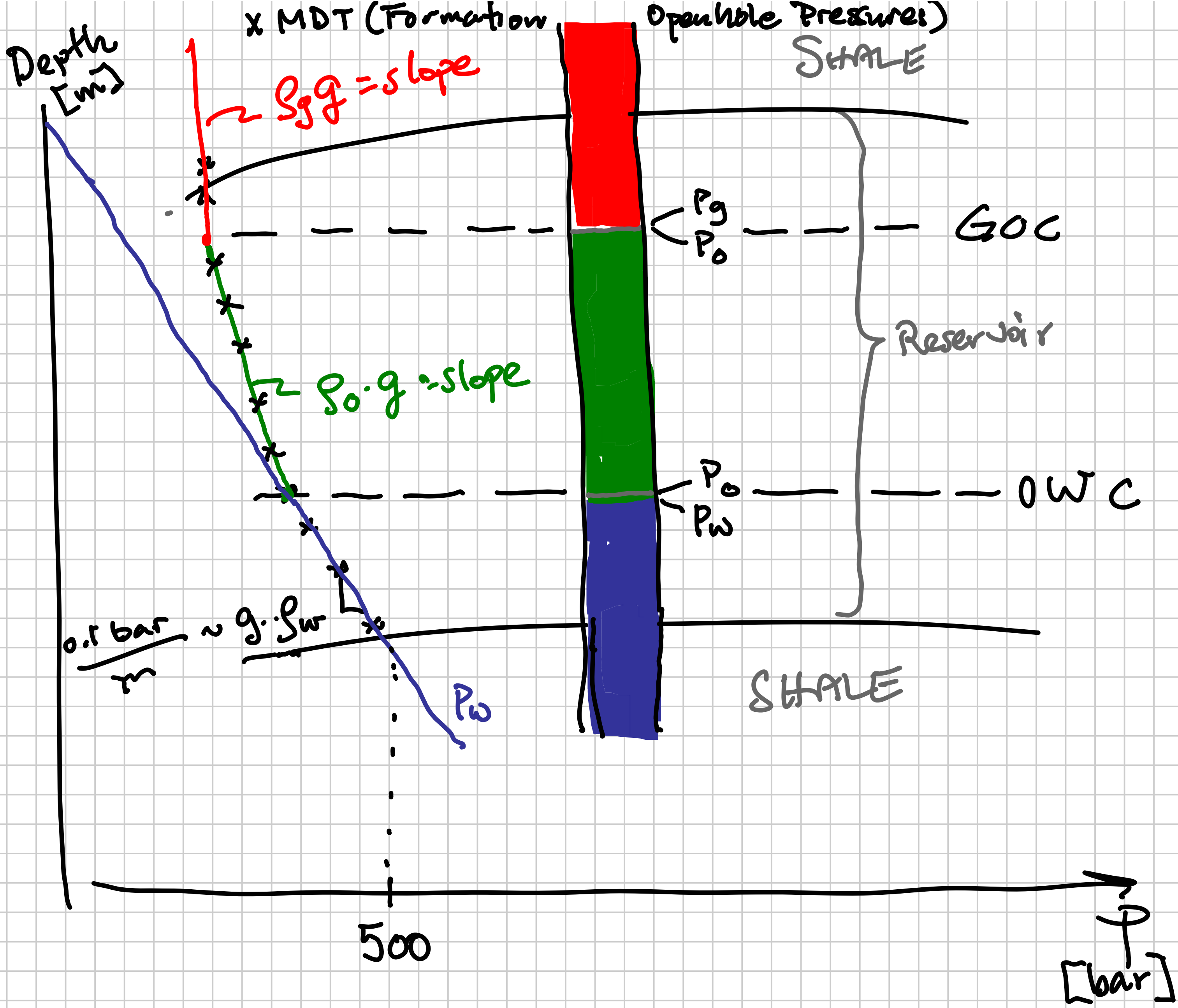
Contacts Measurement:

(1) Openhole p(depth)

(2) Electric logs (Resistivity < HC < G: $(\phi_N - \phi_D)$, O ; W)

$$P_{MDT} \simeq \lambda_g P_g + \lambda_o P_o + \lambda_w P_w$$

λ_p = mobility = k_p/μ_p



x MDT (Formation Openhole Pressures)
Depth [m]
$\rho_g g$ = slope
SHALE
p_g
p_o
GOC
Reservoir
$\rho_o \cdot g$ = slope
p_o
p_w
OWC
0.1 bar/m ~ $g \cdot \rho_w$
SHALE
p_w
500
p [bar]

2006.09.29

FLUID INITIALIZATION

Summary

$$IFIP = \begin{cases} \text{"Surface" Oil } IOIP = \dfrac{\overbrace{\underbrace{\bar{h}\cdot\bar{\phi}\cdot\bar{A}}_{\text{Reservoir PV}}\cdot\underbrace{(1-\bar{S}_{wc})}_{\bar{S}_o}}^{HCPV(R_O)}}{\bar{B}_{oi}} \\ \text{"Surface" Gas } IGIP = \underbrace{\dfrac{\left[\bar{h}\ \bar{\phi}\ \bar{A}\ \overbrace{(1-\bar{S}_{wc})}^{\bar{S}_g}\right]^{HCPV_{RG}}}{\bar{B}_{gi}}}_{\text{"Free Gas in Place"}} + \left.IOIP \times R_s\right\} IGIP_{RO} \end{cases}$$

R_s = solution gas-oil ratio (GOR, R)

$$= \frac{V_{gs}}{V_{os}}$$

B_o = Oil Formation Volume Factor

$$= \frac{V_{oR}}{V_{os}} \qquad \frac{\text{reservoir oil volume}}{\text{surface oil volume}} \qquad \sim 1.1 - 3.0$$

$$B_{gi} = \frac{V_{gR}}{V_{gs}} \qquad \sim \frac{1}{50} - \frac{1}{400}$$

($\frac{1}{50}$ ↑ low-p; $\frac{1}{400}$ ↑ high-p)

Ekofisk: oil only $HCPV_{RG} = 0$; $S_{gi} = 0$; $S_{oi} = 0.8$

$HCPV \sim 12 \cdot 10^9 \cdot bbl$ (RB)

(surface)
STB = Stock-tank barrel

$B_{oi} \sim 2$ RB/STB

$$IOIP \sim \frac{12 \cdot 10^9}{2} = 6 \cdot 10^9 \text{ STB}$$

Small Problem:

$IGIP \sim 6 \cdot 10^{12}$ scf } ? from where
(Solution Gas)

$S_{gi} \sim 0.8$, $S_{oi} = 0$

standard (surface) ft^3

Frigg: $IGIP \sim 6 \cdot 10^{12}$ scf

$$B_{gi} \sim \frac{1}{200}$$

$$HCPV_{RG} = IGIP \cdot B_{gi} = 6 \cdot 10^{12} \cdot \frac{1}{200}$$

$$= 3 \cdot 10^{10} \, ft^3$$

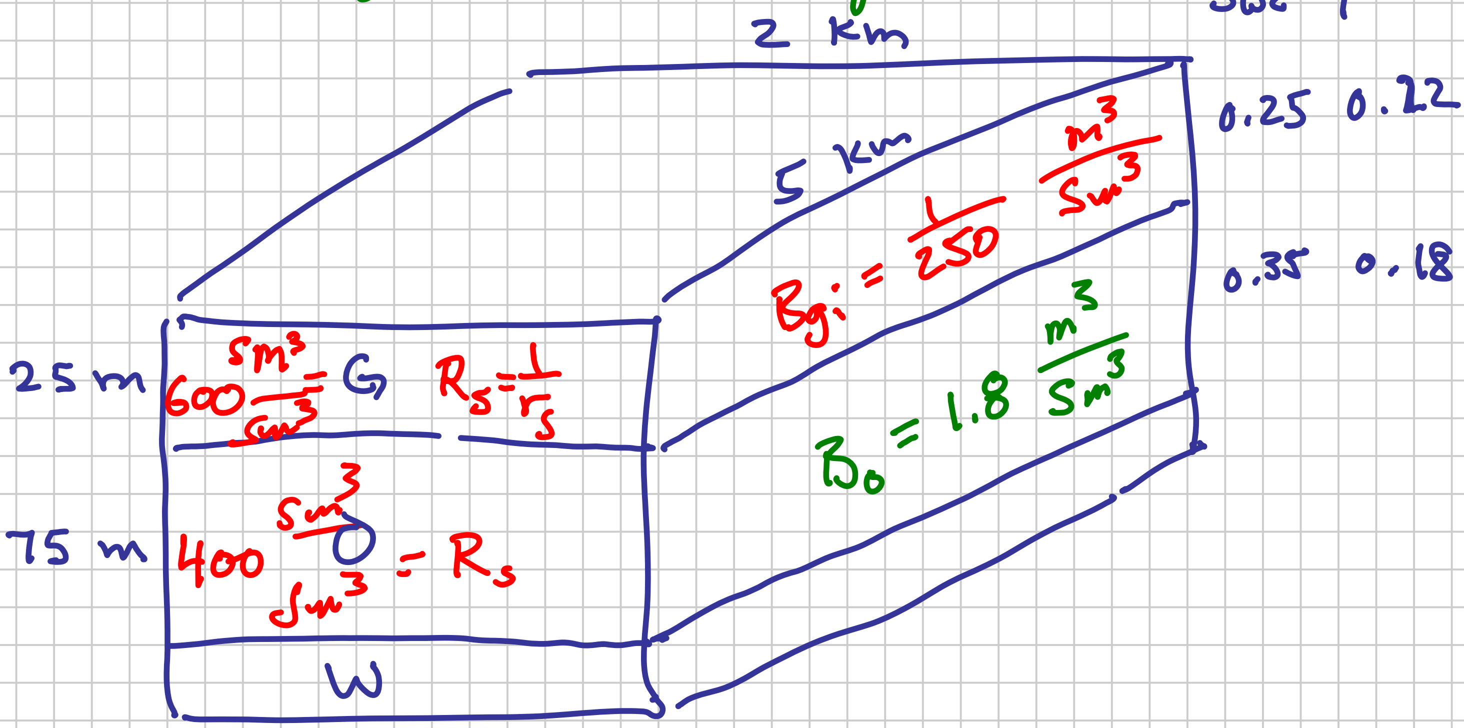
FREE PHASE | SOLUTION PHASE

$$\text{Total OIIP} = OIIP_{RO} + OIIP_{RG} \quad ; r_s$$

$$\text{Total IGIP} = IGIP_{RG} + IGIP_{RO} \quad ; R_s$$

$$\underbrace{IGIP_{RG}}_{\frac{HCPV}{B}} \qquad \underbrace{IGIP_{RO}}_{\frac{HCPV}{B} \times \begin{Bmatrix} r_s \\ R_s \end{Bmatrix}}$$

r_s = solution oil-gas ratio

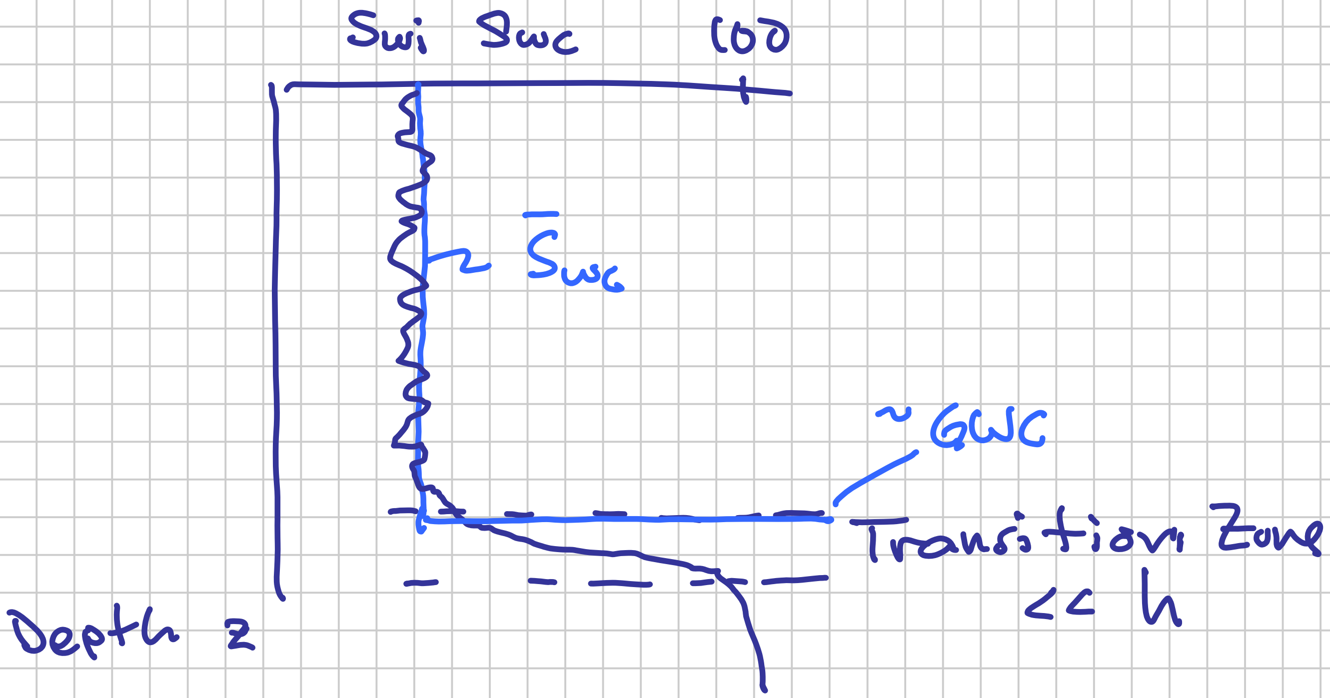


35.31 scf / Sm^3 gas

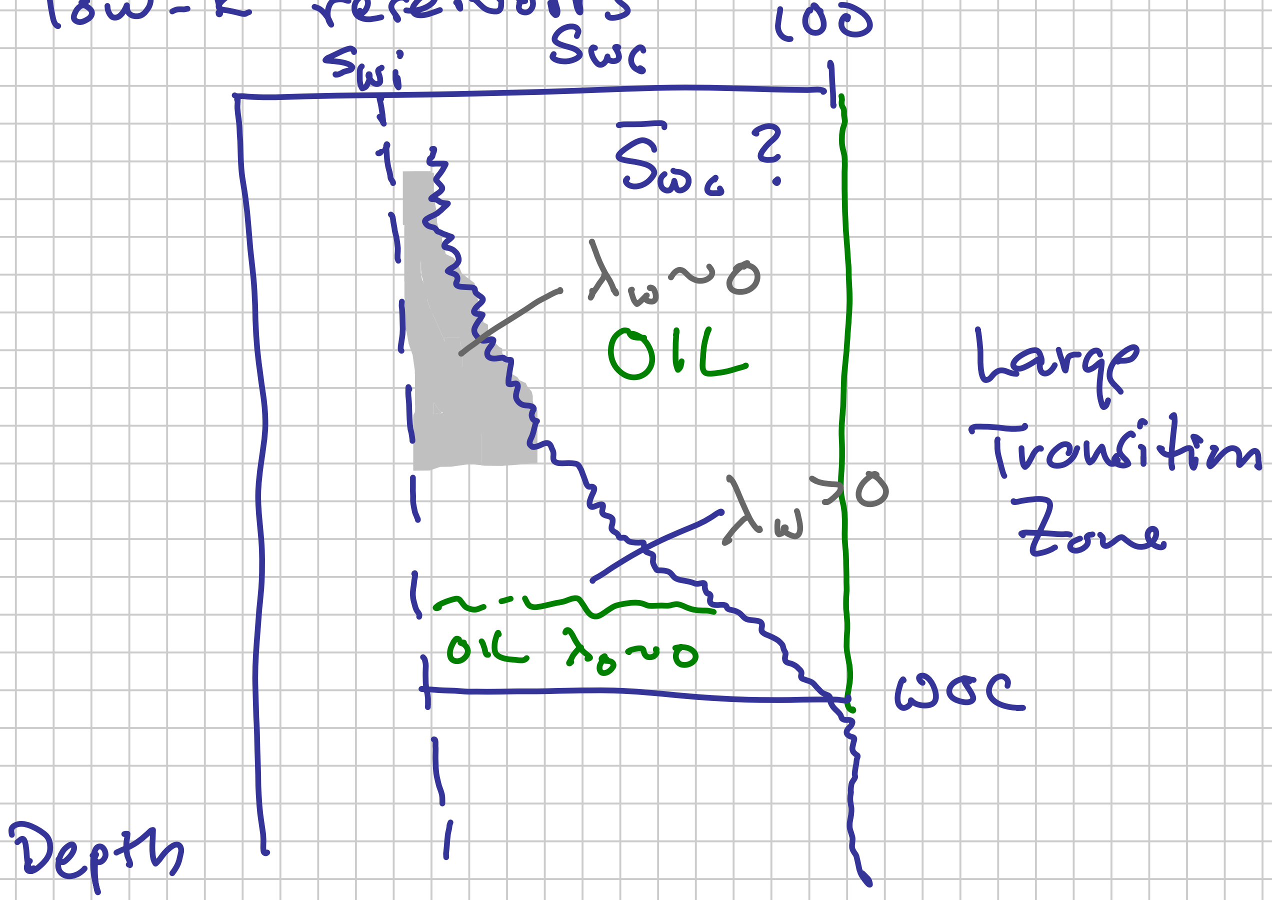
6.28 STB / Sm^3 oil

$S_{wc}(z)$

(1) medium-to-high k reservoirs ($>$ 10–100 md)

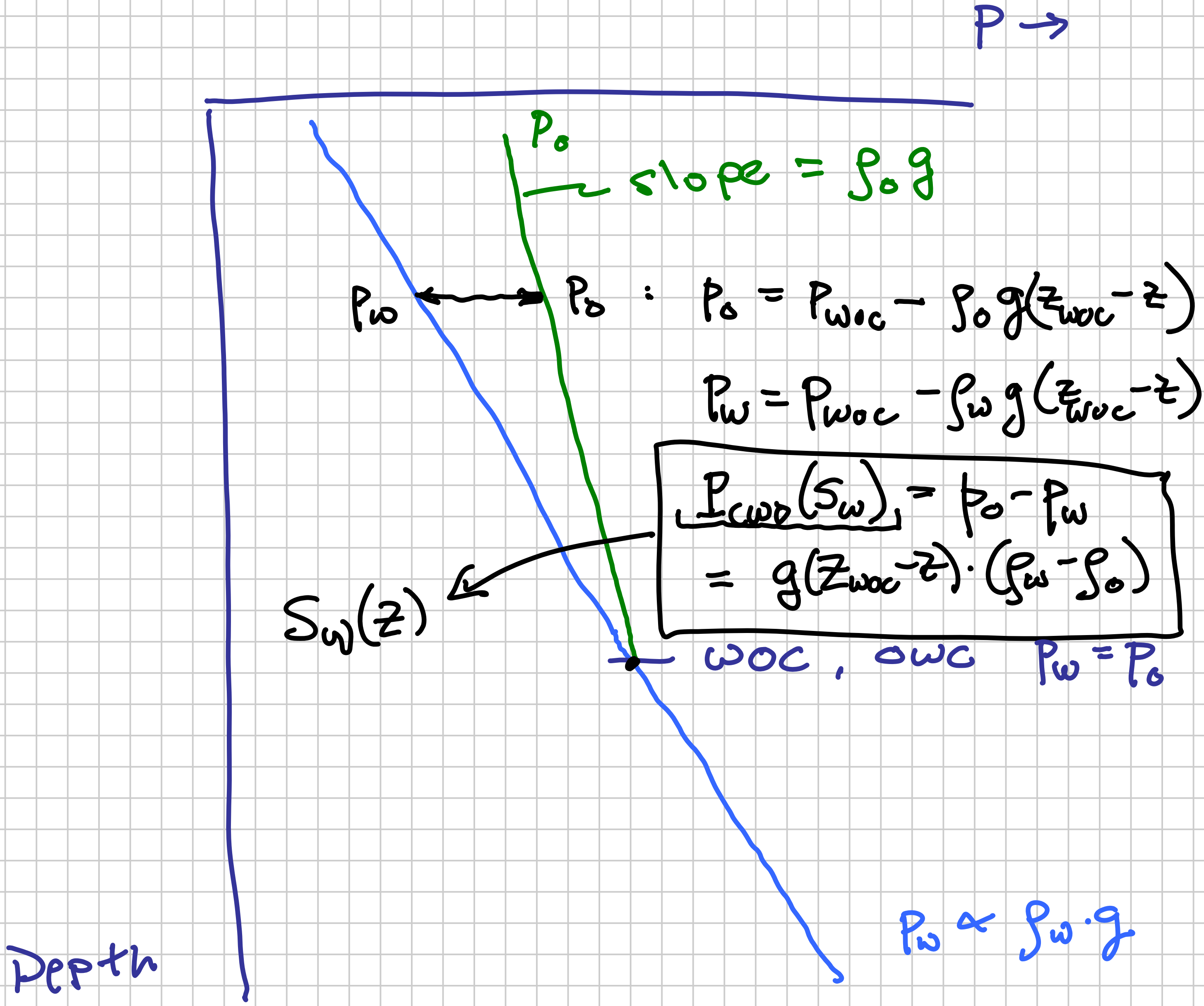


(2) low-k oil reservoirs



How & Why $S_{wc}(z)$

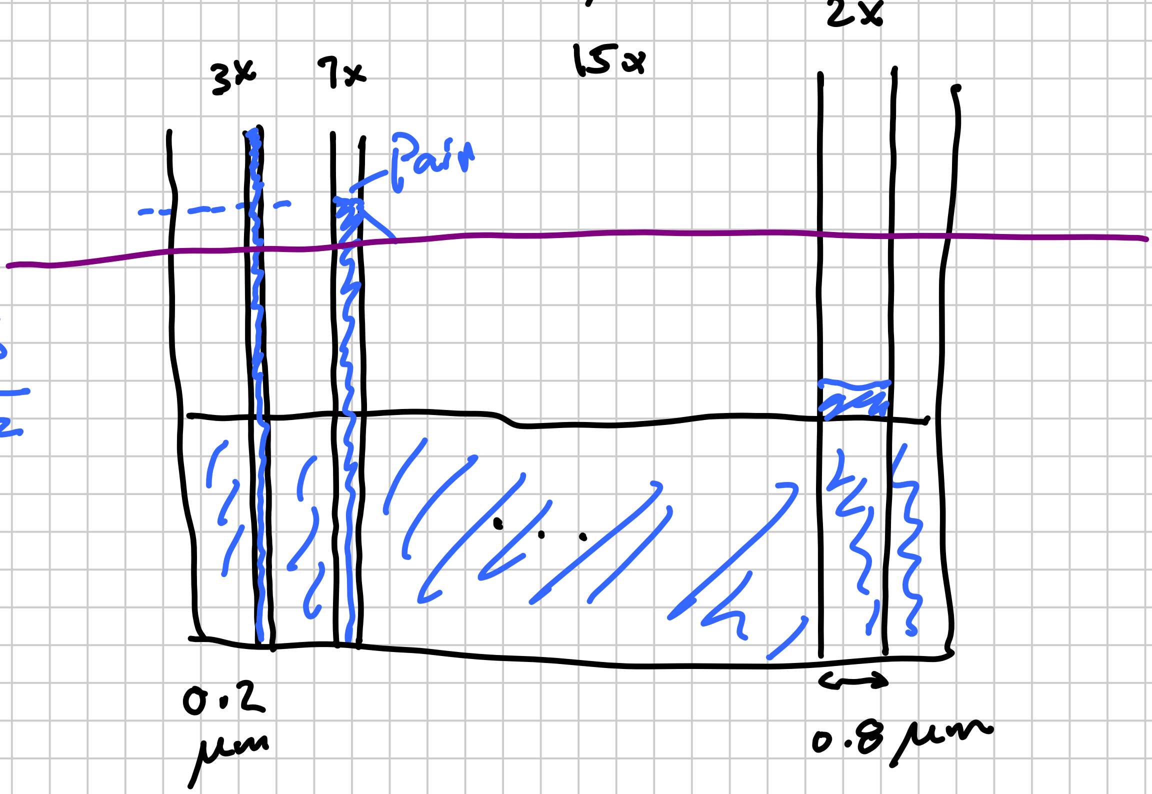
(Oil Reservoirs – most important)



$$p_o = p_{woc} - \rho_o g (z_{woc} - z)$$

$$p_w = p_{woc} - \rho_w g (z_{woc} - z)$$

$$\underline{P_{cwo}(S_w)} = p_o - p_w = g(z_{woc} - z) \cdot (\rho_w - \rho_o)$$



$$\bar{S}_w(z) = \frac{\sum \pi d_w^2}{\sum \pi d^2}$$

Capillary Pressure Curve

$$P_c = \frac{2\sigma}{r}$$

σ ← interfacial tension air-water

$$P_c(S_w) = P_{air} - P_w$$

Measured in the laboratory

$$P_{cow} = P_{caw} \cdot \left(\frac{\sigma_{ow}}{\sigma_{aw}}\right)$$

P_{cow} ↑ field

P_{caw} ↑ lab

$\left(\frac{\sigma_{ow}}{\sigma_{aw}}\right)$ Fluid Property

$\sigma_{aw} \sim 70$ mN/m

$\sigma_{ow} \sim 20$-50 mN/m

$$P_{cow}(S_w) = p_o - p_w$$

$P_{cow}(S_w)$: Know

Transition Zone:

- Level P_{cow}
- $\Delta\rho_{wo} = \rho_w - \rho_o$

Large

High P_{cow} (low k)

Small $\Delta\rho_{wo}$ (heavy oils)