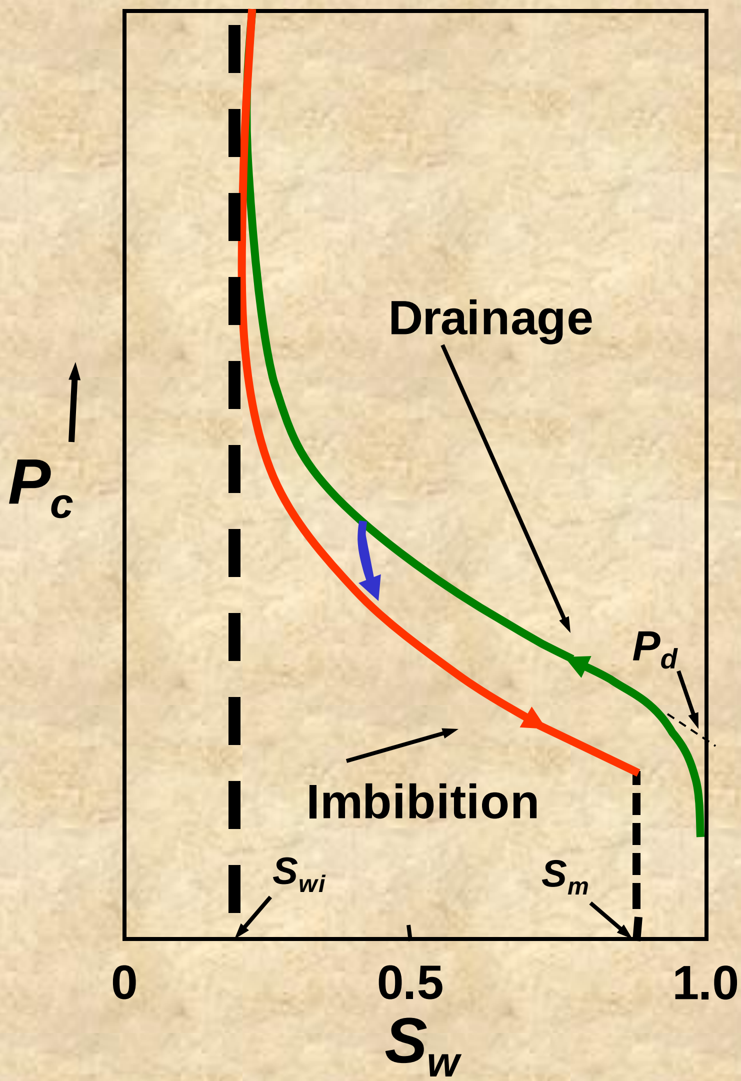
Capillary Pressure and Saturation History

Capillary Pressure in Reservoir Rock

DRAINAGE AND IMBIBITION CAPILLARY PRESSURE CURVES



DRAINAGE

- **Fluid flow process in which the saturation of the nonwetting phase increases**

IMBIBITION

- **Fluid flow process in which the saturation of the wetting phase increases**

Saturation History - Hysteresis

- Capillary pressure depends on both direction of change, and previous saturation history

- Blue arrow indicates probable path from drainage curve to imbibition curve at S_{wt}=0.4

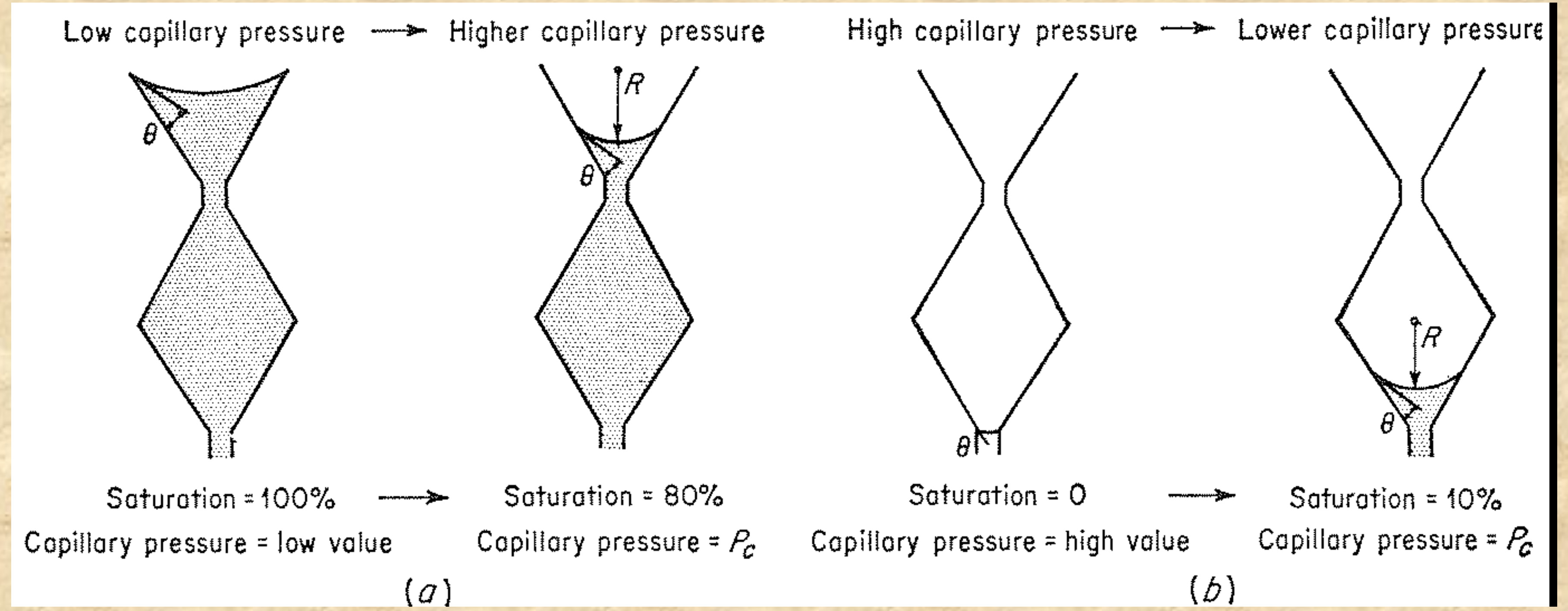
- At S_m, nonwetting phase cannot flow, resulting in residual nonwetting phase saturation (imbibition)

- At S_{wi}, wetting phase cannot flow, resulting in irreducible wetting phase saturation (drainage)

Modified from NExT, 1999, after …

Saturation History

- The same P_c value can occur at more than one wetting phase saturation



Rock Type

- Rock Type (Archie's Definition - Jorden and Campbell)
  - Formations that "... have been deposited under similar conditions and ... undergone similar processes of later weathering, cementing, or re-solution...."
- Pore Systems of a Rock Type (Jorden and Campbell)
  - "A given rock type has particular lithologic (especially pore space) properties and similar and/or related petrophysical and reservoir characteristics"

Thomeer’s Parameters for Capillary Pressure Curves

- Thomeer’s Data
  - Mercury Injection - drainage
    - Very high capillary pressures
- $(V_b)_{P\infty}$ The (assymptotically approached) fraction of bulk volume occupied by mercury at infinite capillary pressure (similar to previous parameter, irreducible wetting phase saturation)
- P_d Displacement Pressure, capillary pressure required to force nonwetting phase into largest pores (same as previously discussed)
- G Parameter describing pore-size distribution (similar to previous parameter, $1/\lambda$. Increasing G (or decreasing λ), suggests poor sorting, and/or tortuous flow paths)

Figures 2.4 and 2.5

- *(V_b)* $p = \infty$ is the fractional volume occupied by Hg at infinite pressure, or total interconnected pore volume.
- ***pd*** is the extrapolated Hg displacement pressure (psi); pressure required to enter largest pore throat.
- ***G*** is pore geometrical factor; range in size and tortuosity of pore throats.

- Large ***pd*** = small pore thorats
- Large ***G*** = tortuous, poorly sorted pore thorats

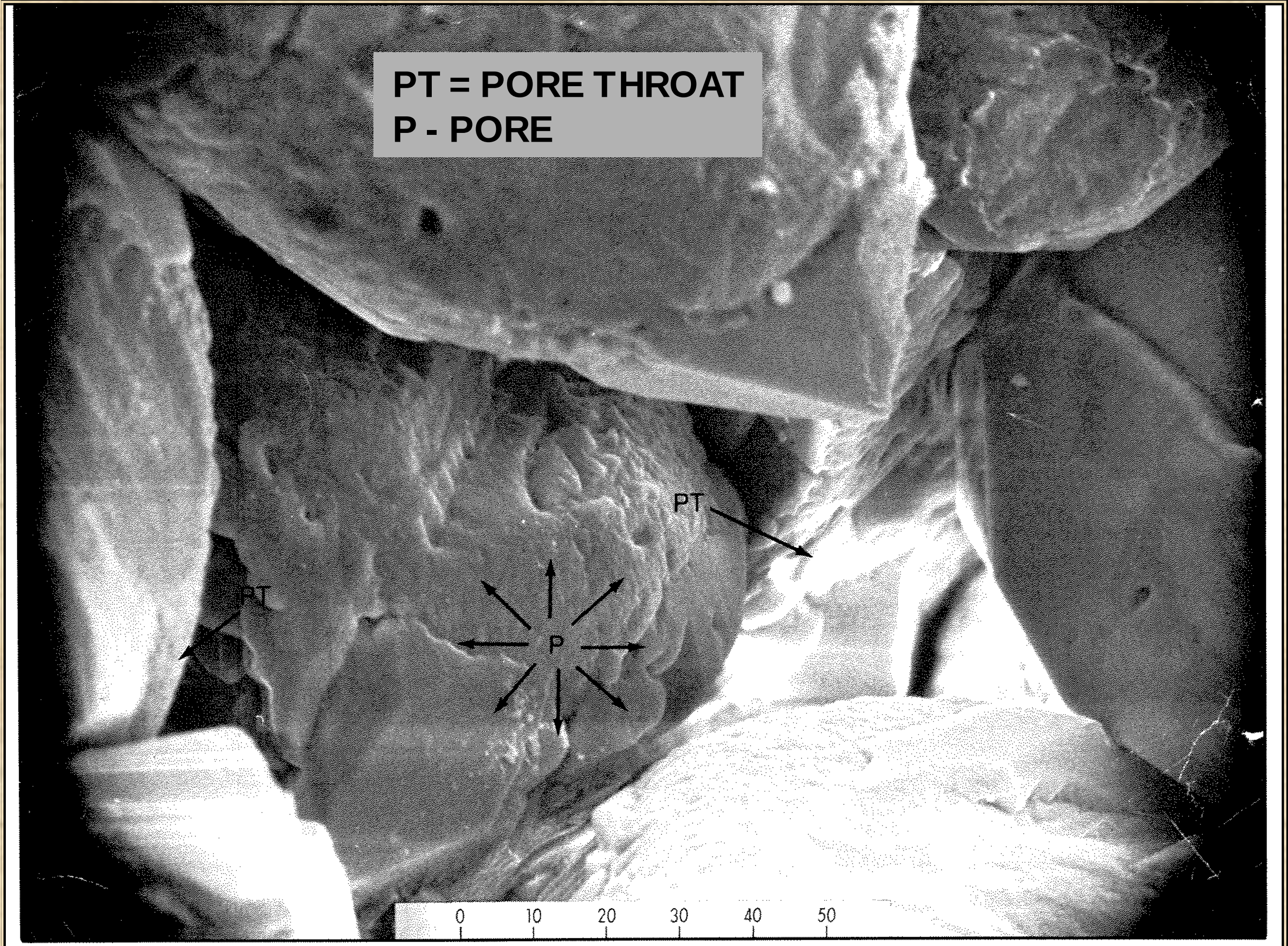


Fig. 2.4—Pores and pore throats in a pore-space system.

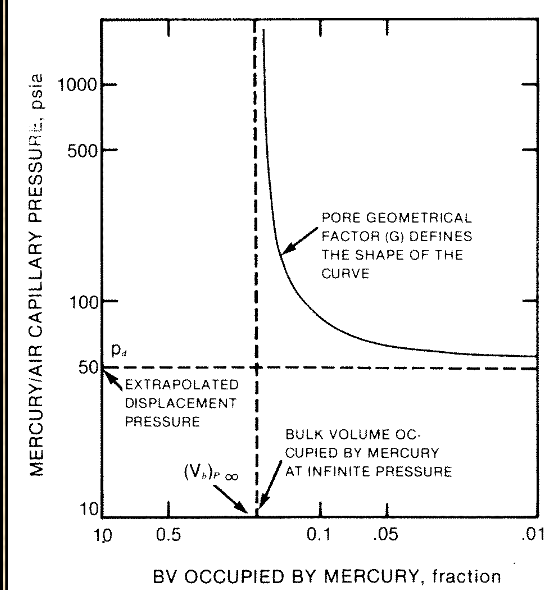
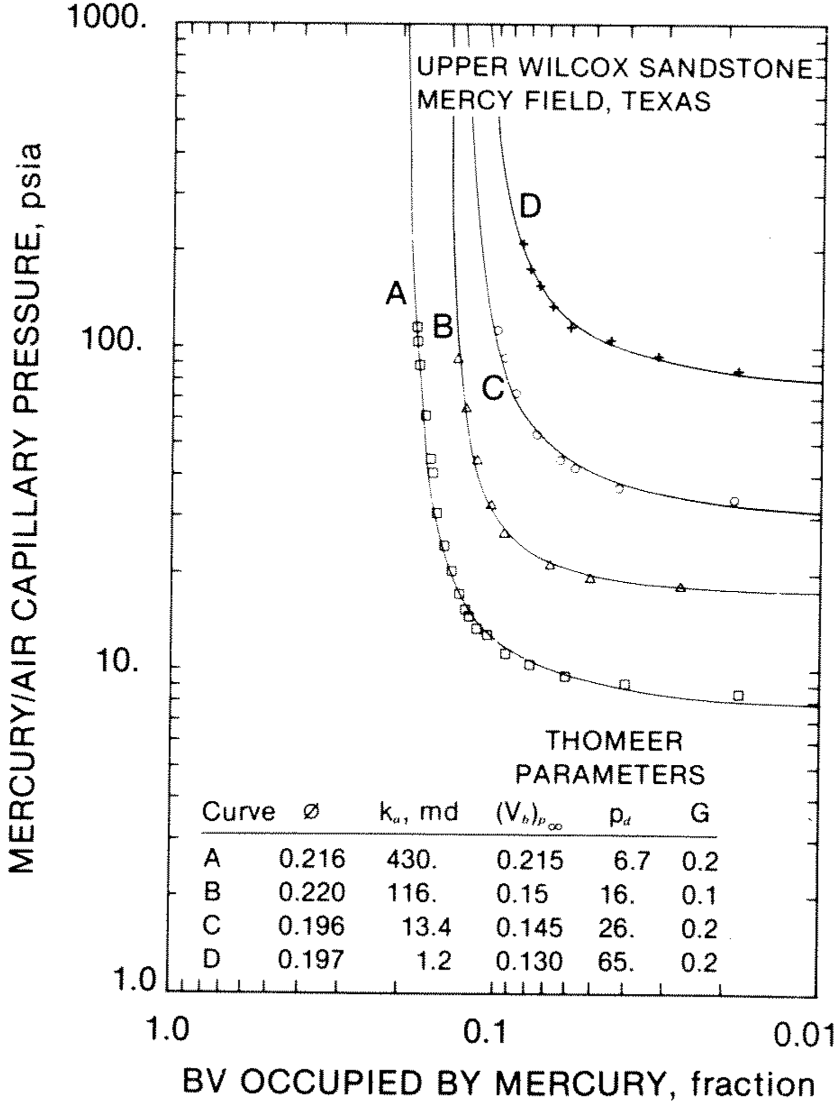


Fig. 2.5—Characterization of capillary-pressure curve with Thomeer parameters (after Thomeer[10]).

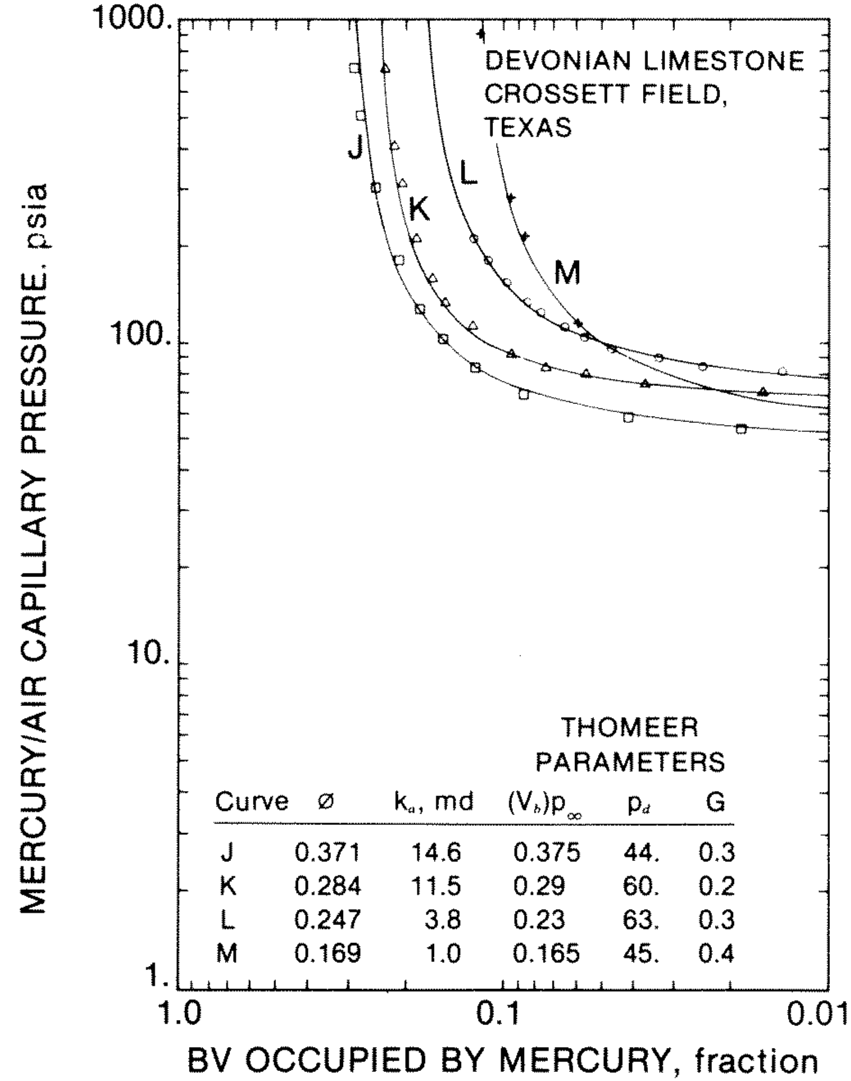
Modfied from Jordan and Campbell, 1984, vol. 1

• Note variation in pore properties and permeability within a formation



Curve	Ø	k_a, md	$(V_b)_{p_\infty}$	p_d	G
A	0.216	430.	0.215	6.7	0.2
B	0.220	116.	0.15	16.	0.1
C	0.196	13.4	0.145	26.	0.2
D	0.197	1.2	0.130	65.	0.2

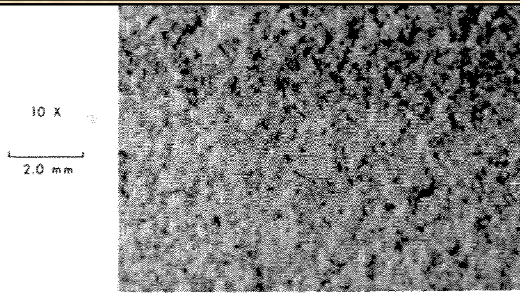
Fig. 2.6—Family of capillary-pressure curves in a sandstone formation (modified after Archie[1]).

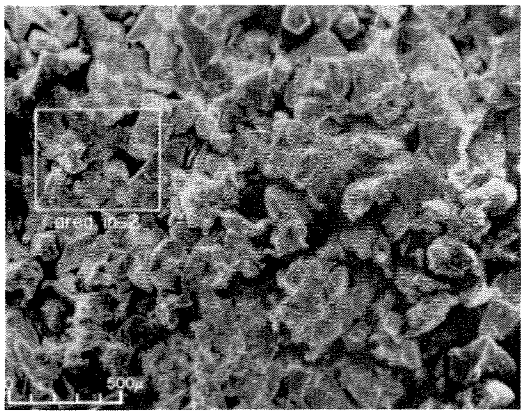


Curve	Ø	k_a, md	$(V_b)p_\infty$	p_d	G
J	0.371	14.6	0.375	44.	0.3
K	0.284	11.5	0.29	60.	0.2
L	0.247	3.8	0.23	63.	0.3
M	0.169	1.0	0.165	45.	0.4

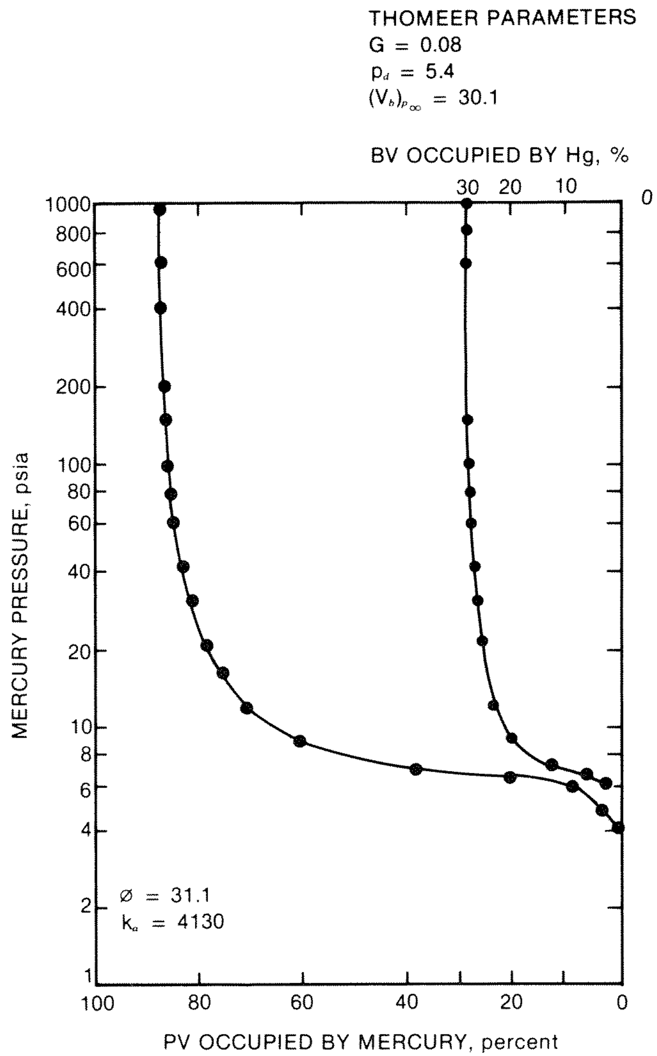
Fig. 2.7—Family of capillary-pressure curves in a limestone formation (modified after Archie[1]).

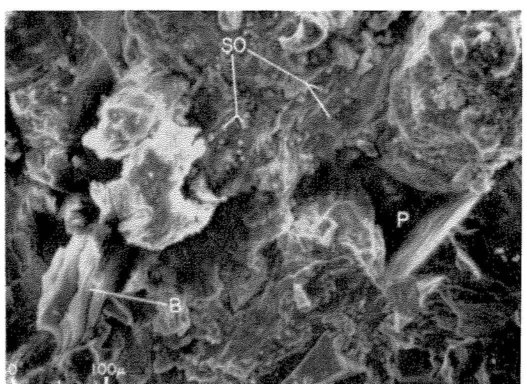
Modfied from Jordan and Campbell, 1984, vol. 1





1. Rock texture and pore space characteristics. 48X





2. Grain-to-grain relationships; pore space (P); biotite (mica) grain (B); small crystals on grain surface are silica overgrowths (SO). 200X

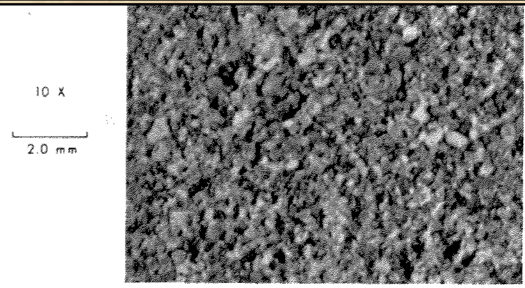
SANDSTONE, quartz,
lower fine, very well sorted, subrounded, slightlv argillaceous, quartz (0.8% BV) and chert (0.4% BV) cement, pore-filling clay (0.7% BV), unconsolidated.

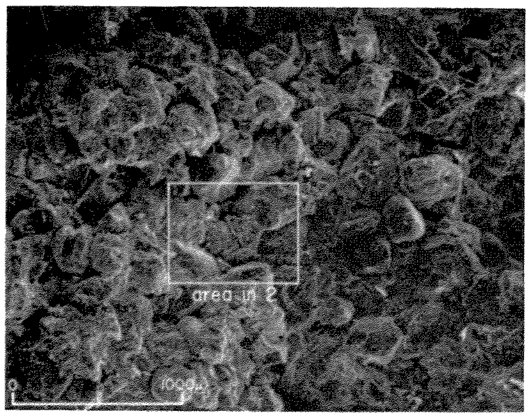
Figure 2.8

<u>size:</u> lower fine

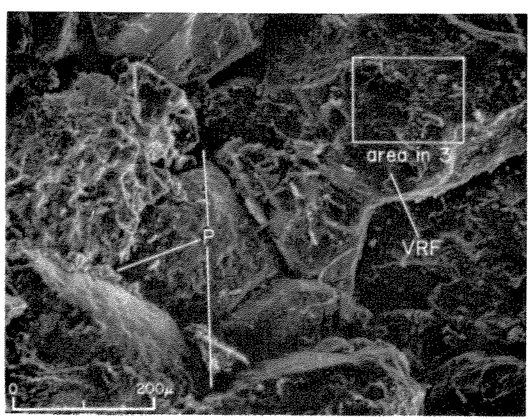
<u>sorting</u>: very well sorted

Modfied from Jordan and Campbell, 1984, vol. 1



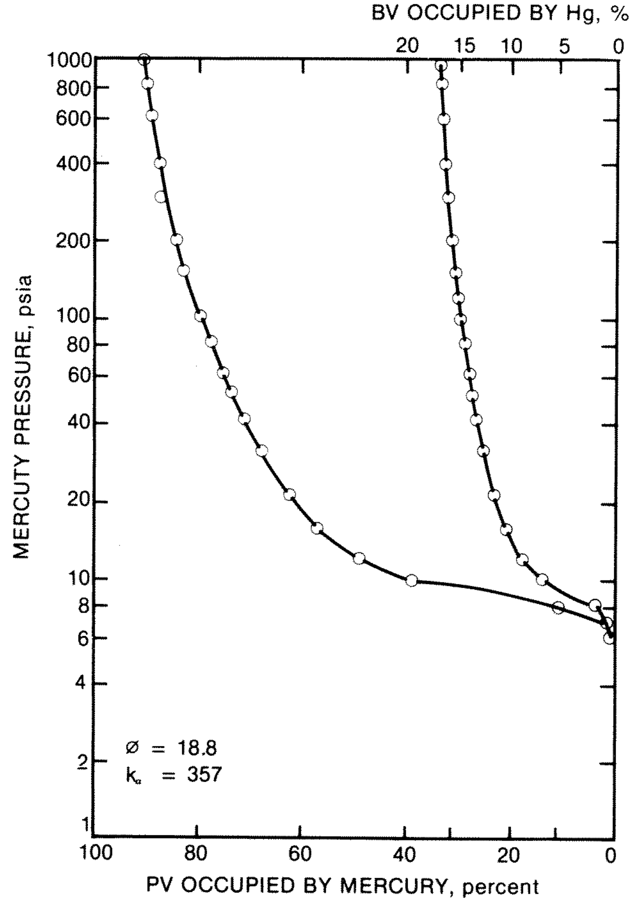


1. Rock texture and pore space characteristics. 36X



2. Rock fabric showing volcanic rock fragments (VRF) and intergranular pore space (P). Note altered texture of grain surfaces. 150X

THOMEER PARAMETERS
G = 0.1
p_d = 7.0
$(V_b)_{p_\infty}$ = 14.8

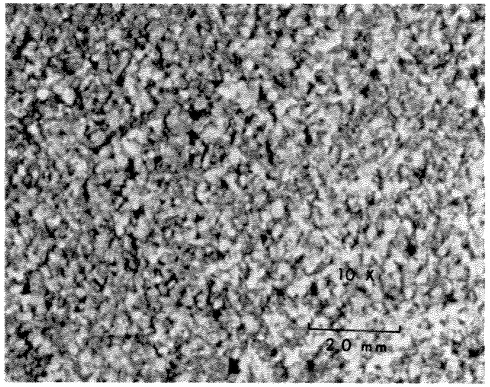


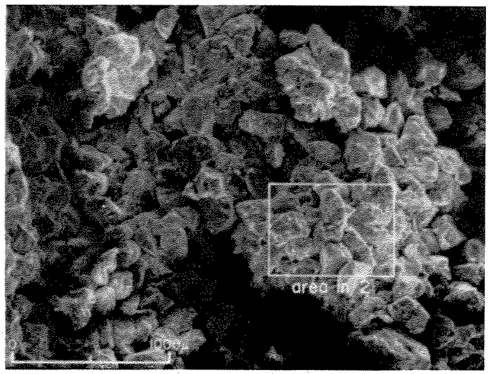
SANDSTONE, lithic,
lower fine, moderately sorted, moderately argillaceous, calcite (0.8% BV) and opal (0.2% BV) cement, moderately consolidated.

Figure 2.9

<u>size:</u> lower fine
<u>sorting</u>: moderately sorted

Modfied from Jordan and Campbell, 1984, vol. 1





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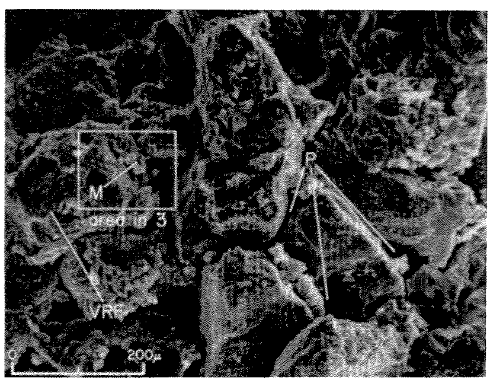
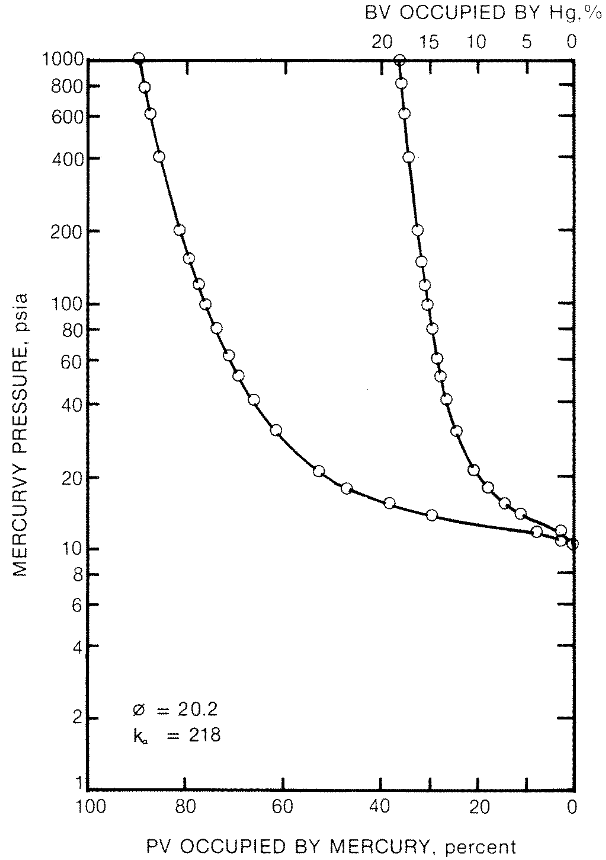


2. Rock fabric showing volcanic rock fragments (VRF), intergranular pore space (P), and pore-filling montmorillonite (M). Note altered grain surfaces. 150X.

THOMEER PARAMETERS

G = 0.15
P_d = 10.1
$(V_b)p_\infty$ = 17.5



SANDSTONE, lithic
upper very fine, moderately sorted, moderately argillaceous, chlorite (2.3% BV) calcite (0.6% BV) and opal (0.4% BV) cement, pore-filling clay (1.1% BV), moderately consolidated.

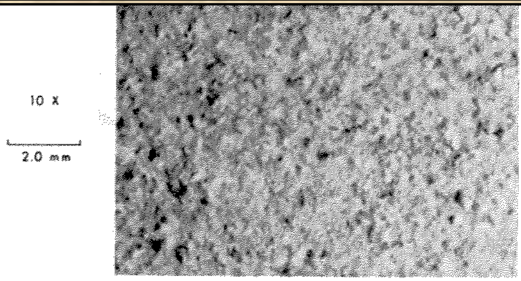
Figure 2.10

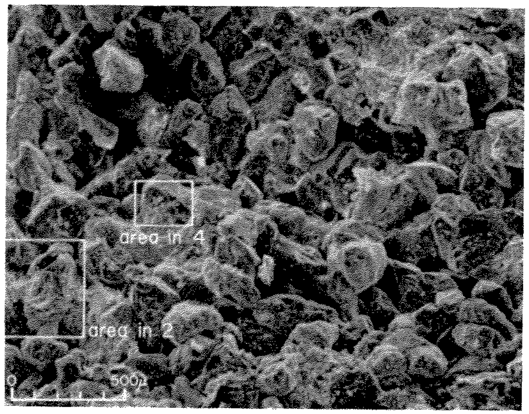
<u>size:</u> upper very fine

<u>sorting</u>: moderately sorted

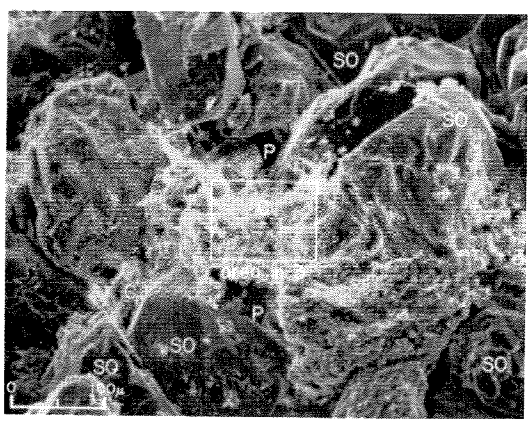
Modfied from Jordan and Campbell, 1984, vol. 1

Figure 2.11
-effect of significant cementing and clay

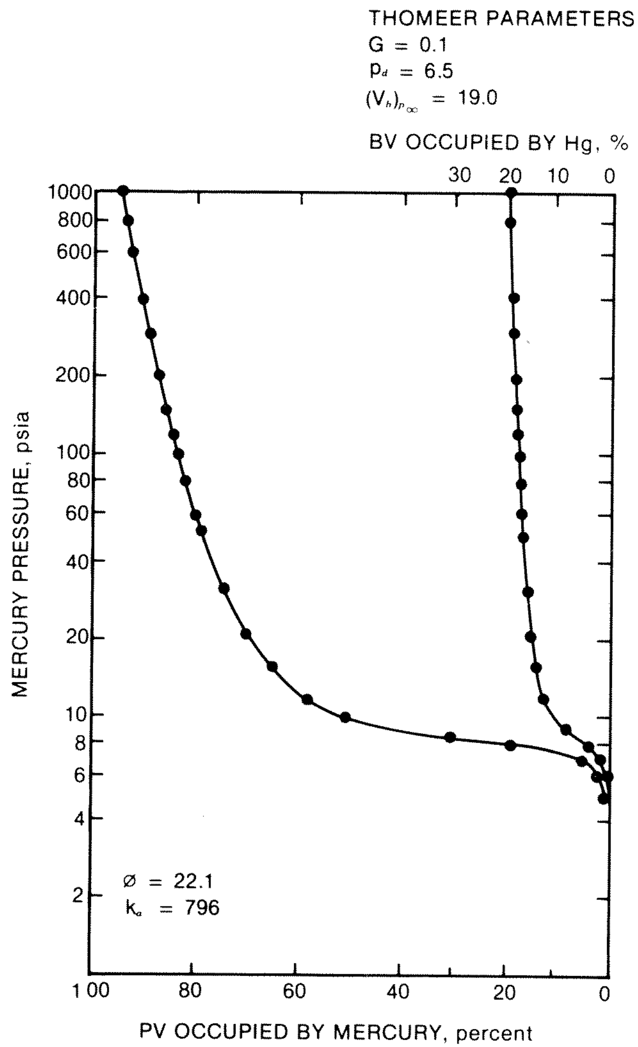




1. Rock texture and pore space characteristics. 48X



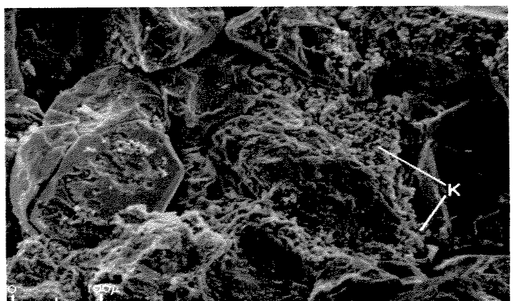
2. Grain-to-grain relationships; intergranular pore space (P); and pore-filling clays (C). Note quartz grain silica overgrowths (SO) 200X



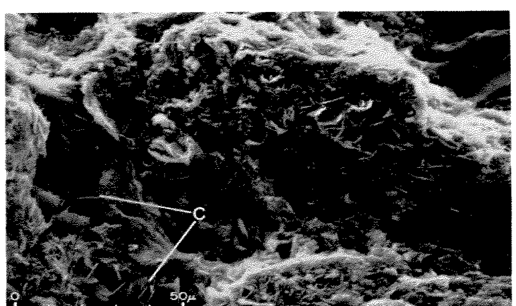
SANDSTONE, quartz,
lower fine, very well sorted, subrounded, slightly argillaceous, quartz (0.3% BV) chert (0.8% BV) and carbonate (4.5% BV) cement, pore-filling clay (2.5% BV), and iron minerals (1.2% BV), moderately consolidated.

Modfied from Jordan and Campbell, 1984, vol. 1

MIOCENE "S" SAND CONTAINING
"DISCRETE PARTICLE" KAOLINITE
$\phi = 22.9\%$
$k_a = 1173$ md.



TUSCALOOSA SAND CONTAINING
"PORE-LINING" CHLORITE (C)
$\phi = 25.7\%$
$k_a = 41$ md.



VICKSBURG SAND CONTAINING
"PORE-BRIDGING" CHLORITE (C)
$\phi = 19.1\%$
$k_a = 0.09$ md.

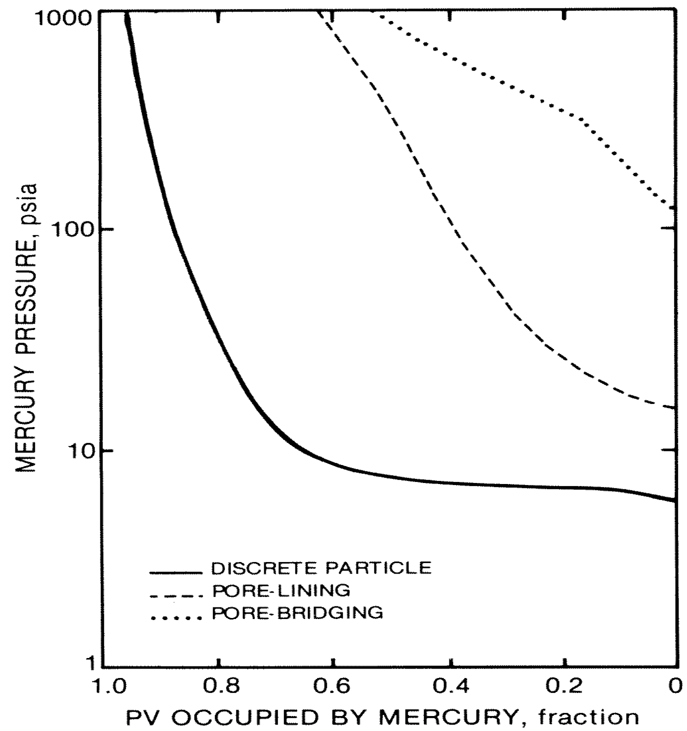
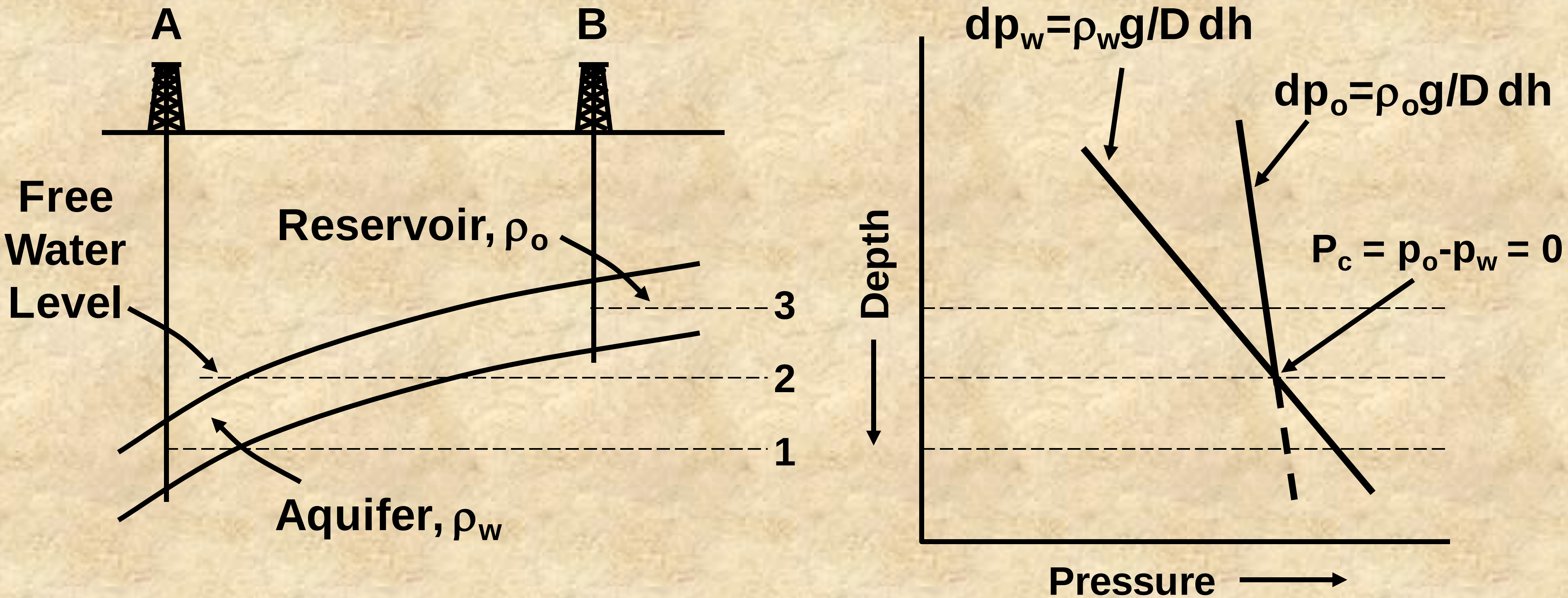


Figure 2.12

Effect of Dispersed Clays

Modfied from Jordan and Campbell, 1984, vol. 1; after Neasham, 1977

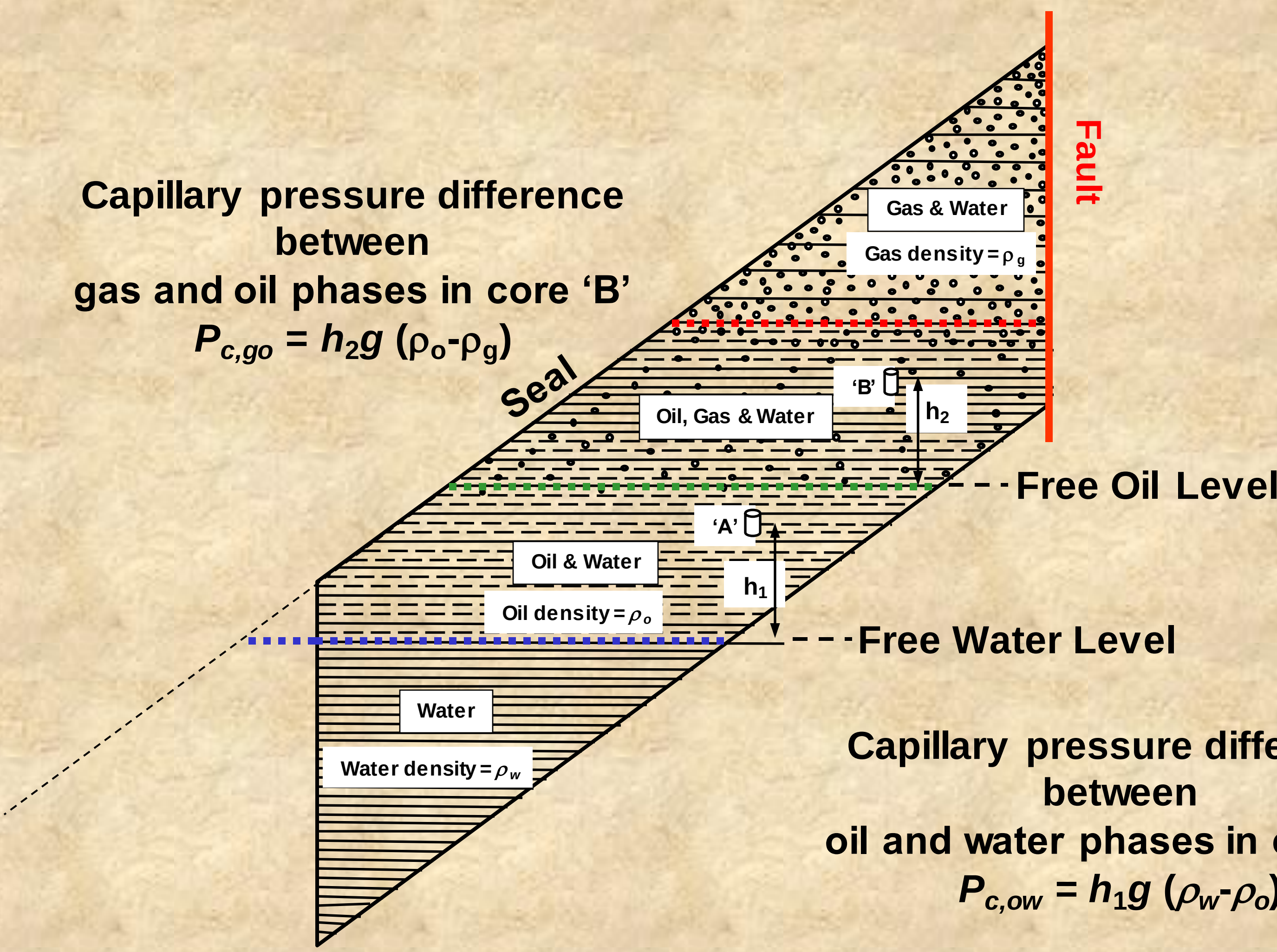
Capillary Pressure in Reservoirs



Fluid Distribution in Reservoirs

Capillary pressure difference between gas and oil phases in core 'B'

$$P_{c,go} = h_2 g\,(\rho_o - \rho_g)$$

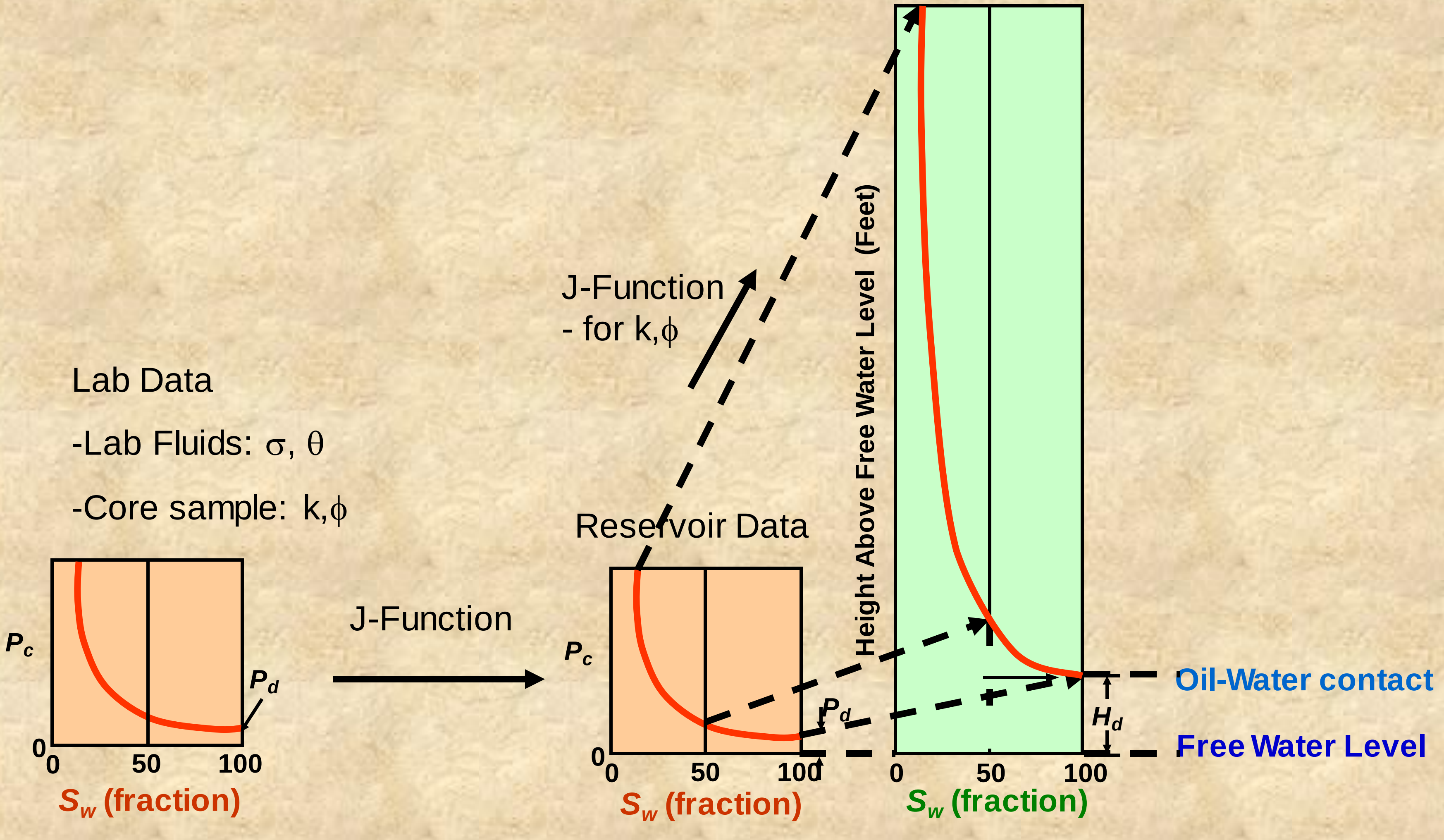


Capillary pressure difference between oil and water phases in core 'A'

$$P_{c,ow} = h_1 g\,(\rho_w - \rho_o)$$

Modified from NExT, 1999, modified after Welge and Bruce, 1947

RELATION BETWEEN CAPILLARY PRESSURE AND FLUID SATURATION



Modified from NExT, 1999, after …

Saturation in Reservoir vs. Depth

- Results from two analysis methods (after ABW)
  - Laboratory capillary pressure curve
    - Converted to reservoir conditions
  - Analysis of well logs
    - Water saturation has strong effect on resistivity curves (future topic)