Lecture Presentation

Advanced Multi-Well Formation Evaluation

Shaly Sandstone Interpretation

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Objectives:

1. To understand the influence of shale on the electrical resistivity of sands,
2. To introduce petrophysical models used to assess the various types of "shale emplacement" in sands,
3. To introduce the concepts of clay-bound water and cation-ion exchange capacity of clays,
4. To introduce the various petrophysical models used to describe the electrical resistivity of shaly sands, and
5. To introduce the governing factors and measurements thereof necessary to properly correct the influence of shale in the assessment of hydrocarbon saturation.

Examples of Turbidites: Bouma Sequences

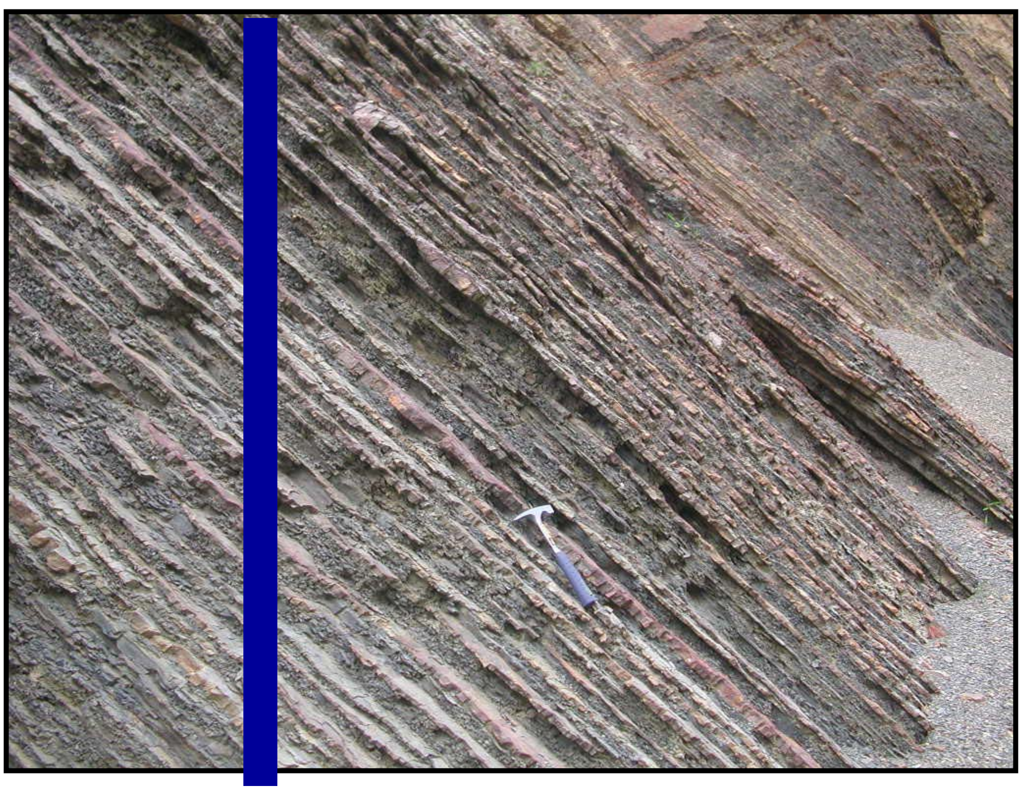
Thick-bedded turbidite sands

Thick-bedded turbidite sand with discontinuous shale-clast horizons

Example of Laminated Sands in Distal Turbidite Systems

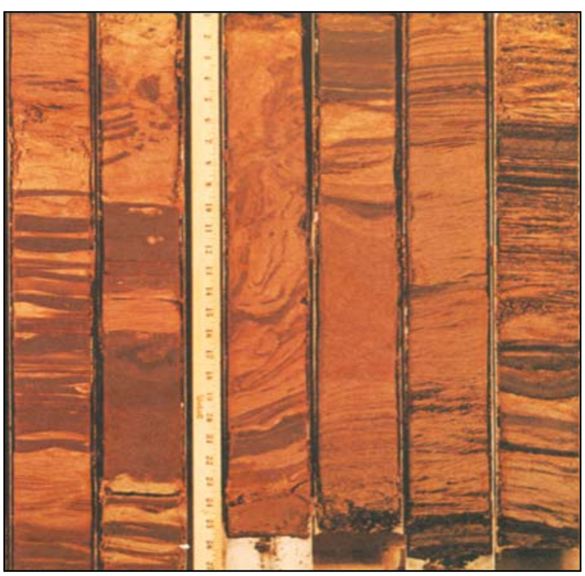
Delta Front

Bedding Orientation vs. Measurement Orientation



Deltaic Sequences: Thinly-Bedded Rock Formations

Origin of Electrical Anisotropy



- Laminated sand-shale sequences

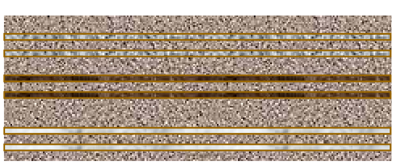
- Different grain sizes
- Poor sorting

Example of Fine Layering

Origin of Electrical Anisotropy

Laminated sand-shale sequences

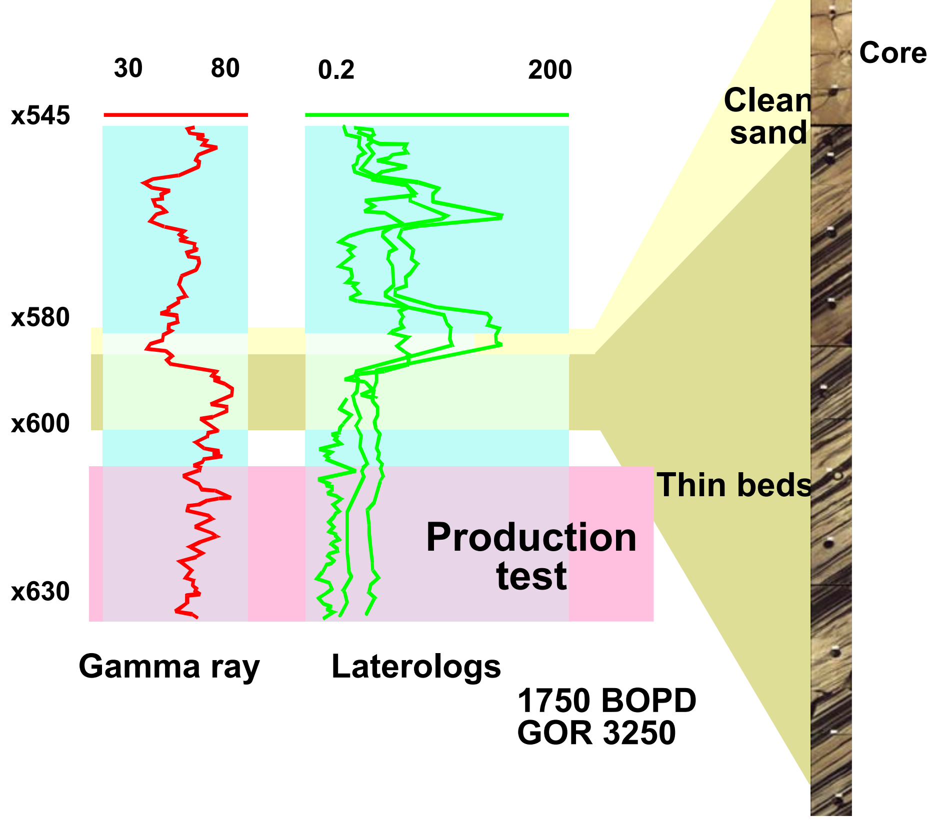
Sands With Different Grain Size



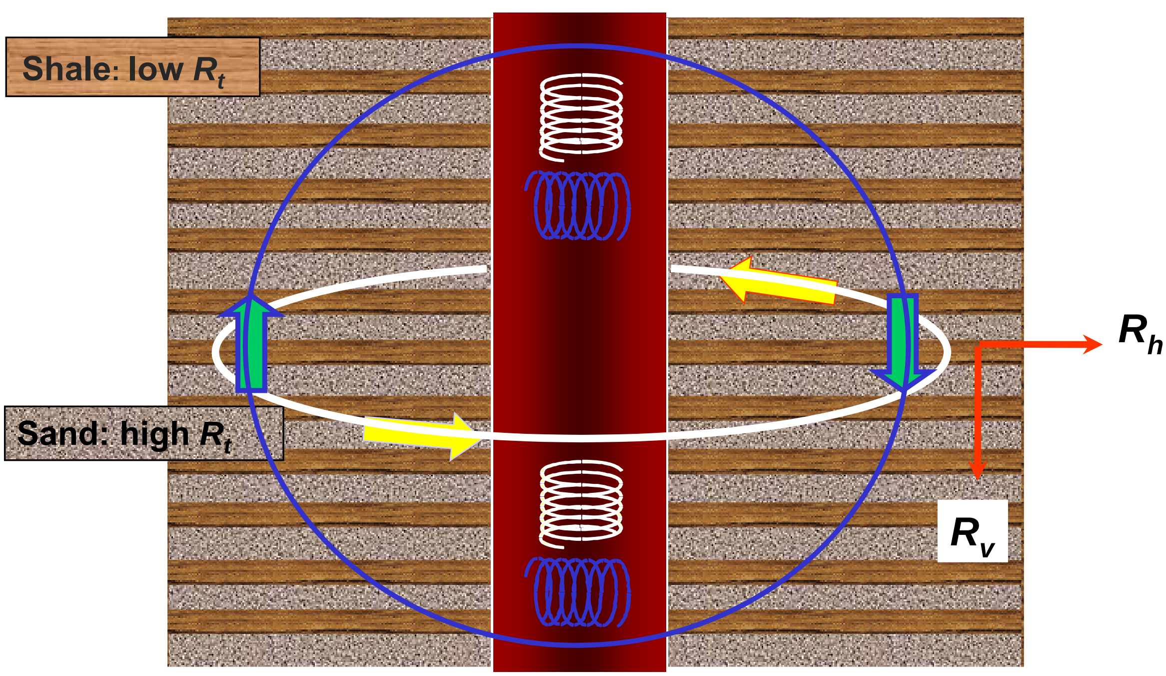
Thin resistive or conductive streaks

20-30% of global reserves in anisotropic reservoirs

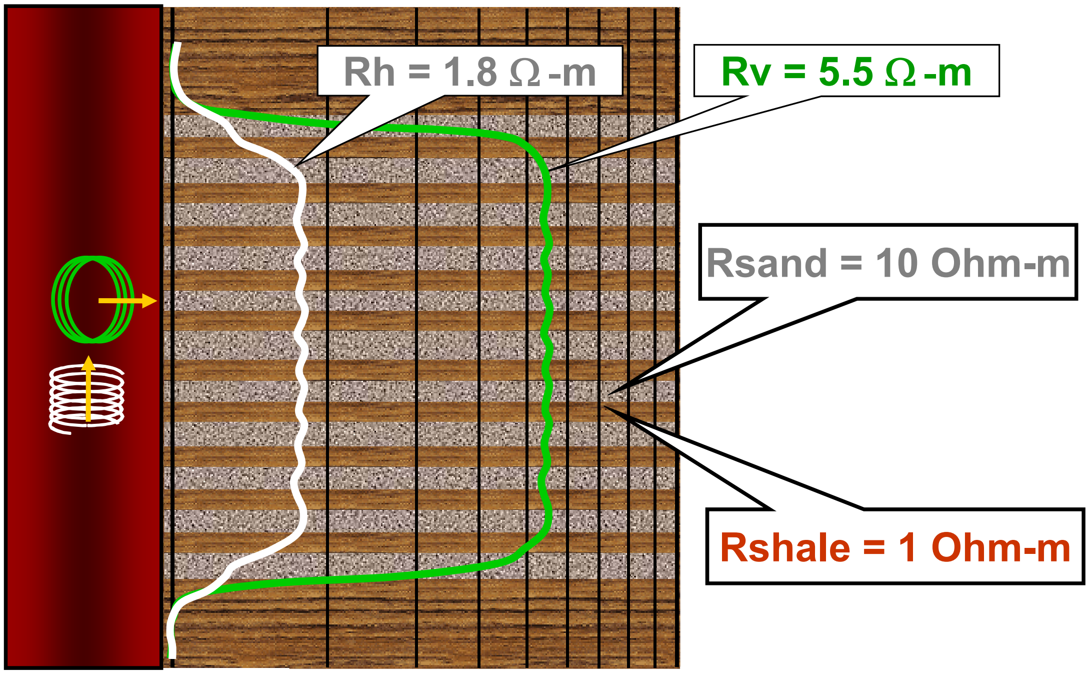
Resistivity: example



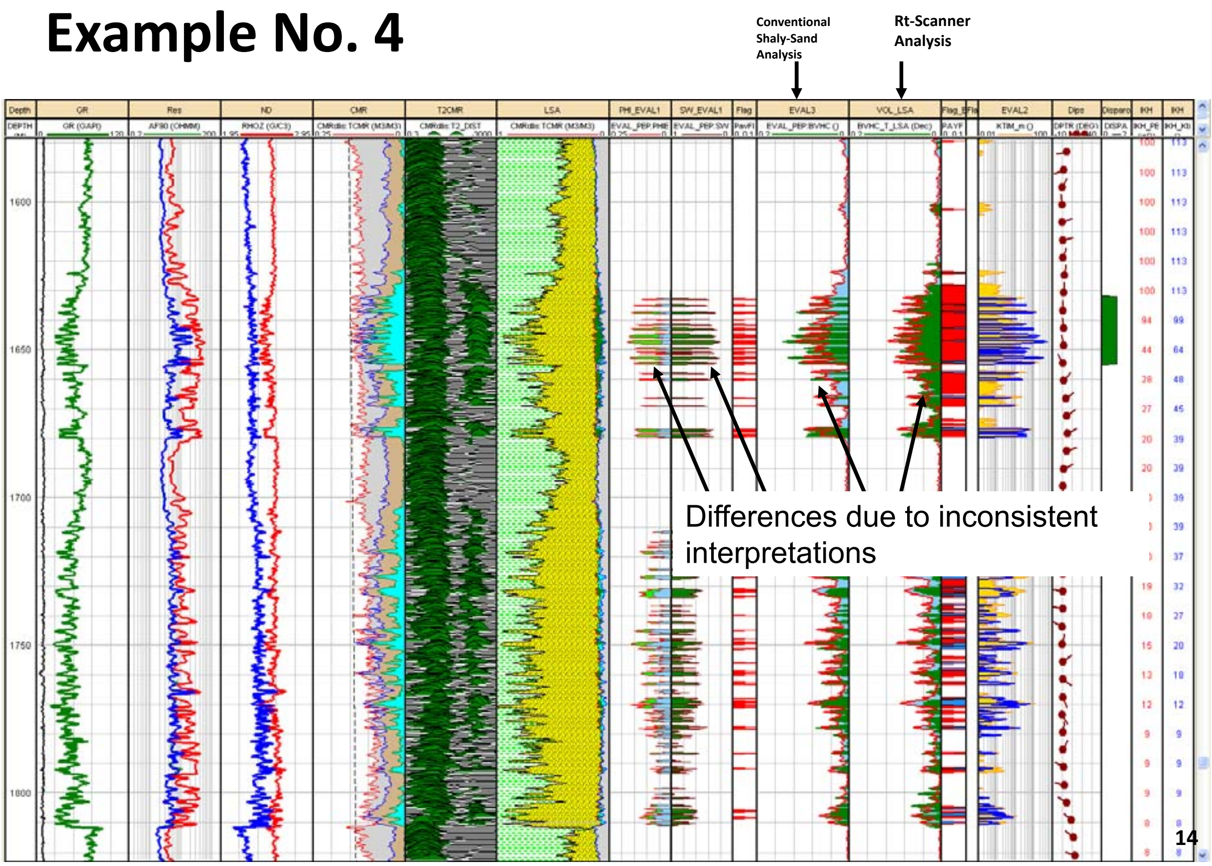
Measurement Principle



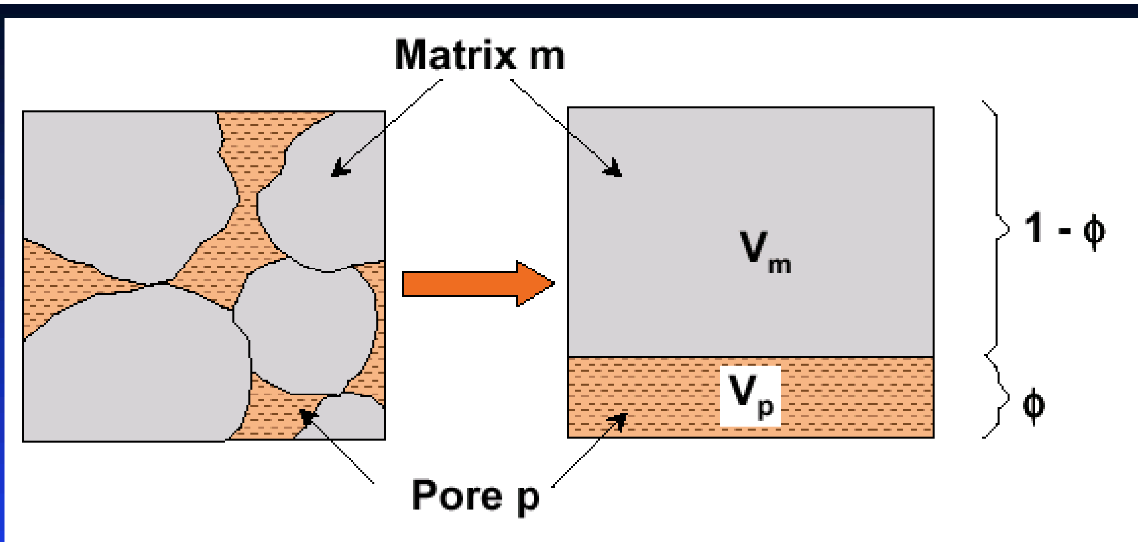
Sand-Shale Resistivity Model



Example No. 4



Review: Definition of Porosity



$$porosity = \frac{volume\ of\ pores}{total\ volume\ of\ sample} \qquad \phi = \frac{V_{pores}}{V_{sample}}$$

POROSITY

- TOTAL POROSITY?
- NON-SHALE POROSITY?
- EFFECTIVE POROSITY

WATER SATURATION

- TOTAL WATER SATURATION?
- FREE (MOVABLE) WATER?
- IRREDUCIBLE WATER SATURATION (i.e. clay-bound water and capillary-bound water)?

Review: Fluids in the Pore Space

$$\text{saturation}_i = \frac{\text{volume fluid i}}{\text{pore volume}}$$

Bulk Volume Water — BVW

- fraction of pore volume occupied by water

Bulk Volume Irreducible — BVI

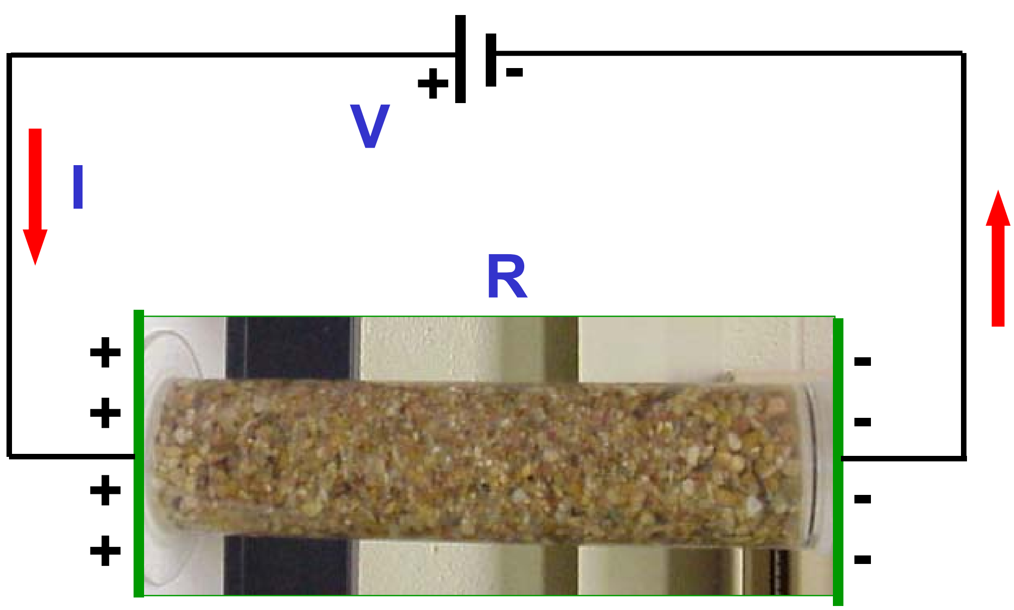
- fraction of pore volume occupied by immobile capillary-bound water

Clay Bound Water — CBW

- water bound to negatively charged clay mineral surface

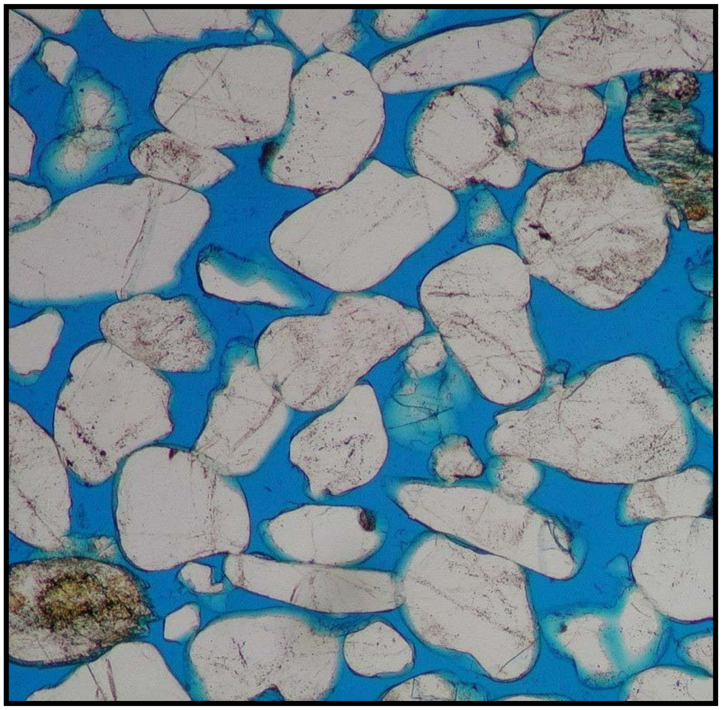
LABORATORY SAMPLE

Brine-Water Saturation

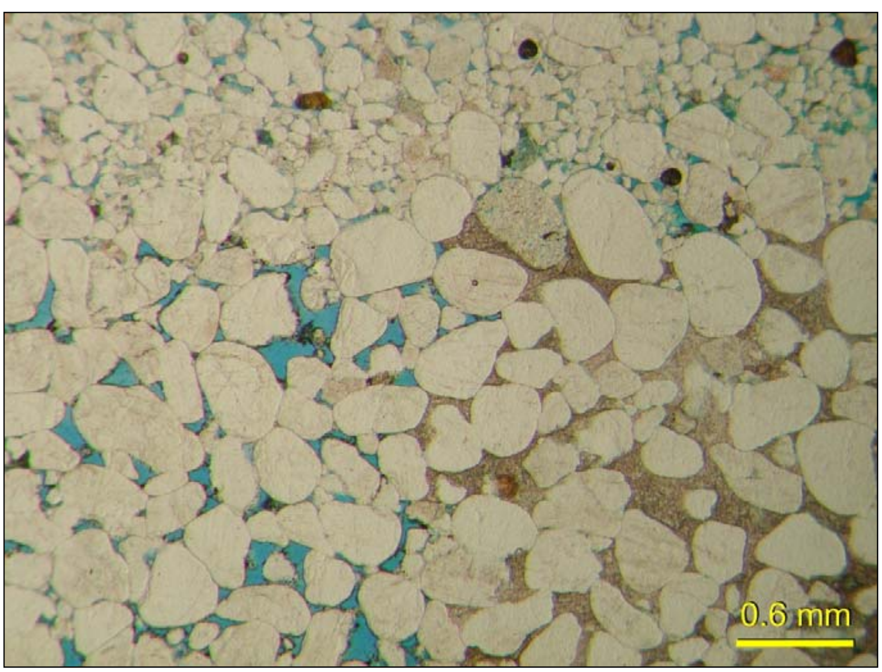


$$R = \frac{V}{I}$$

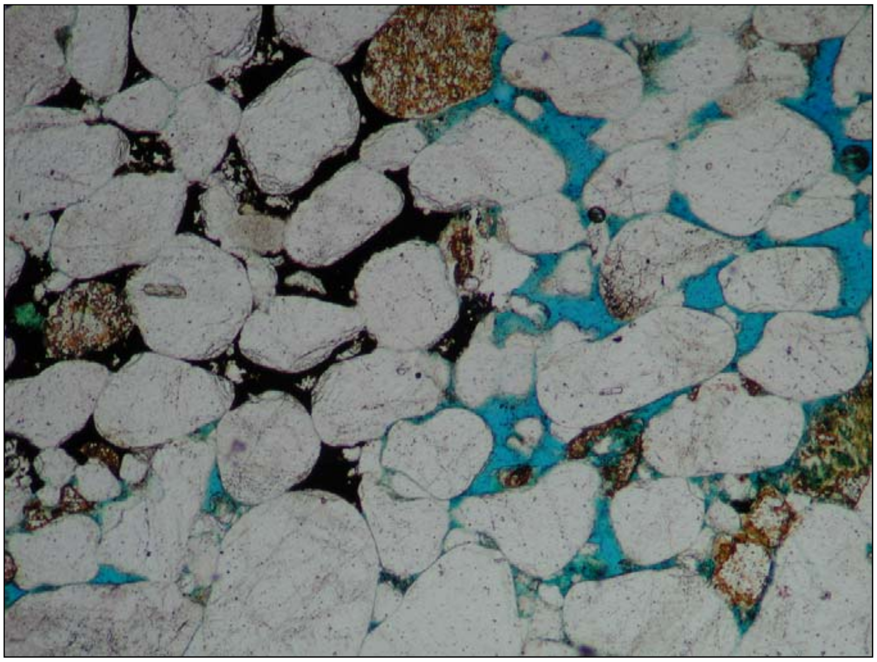
DC ELECTRICAL CONDUCTION PHENOMENA IN POROUS MEDIA: Resistivity of Connate Water and Effective Porosity



DC ELECTRICAL CONDUCTION PHENOMENA IN POROUS MEDIA: Path of Electrical Conduction and Cementation



DC ELECTRICAL CONDUCTION PHENOMENA IN POROUS MEDIA: Blockage of Conduction Paths by Hydrocarbons



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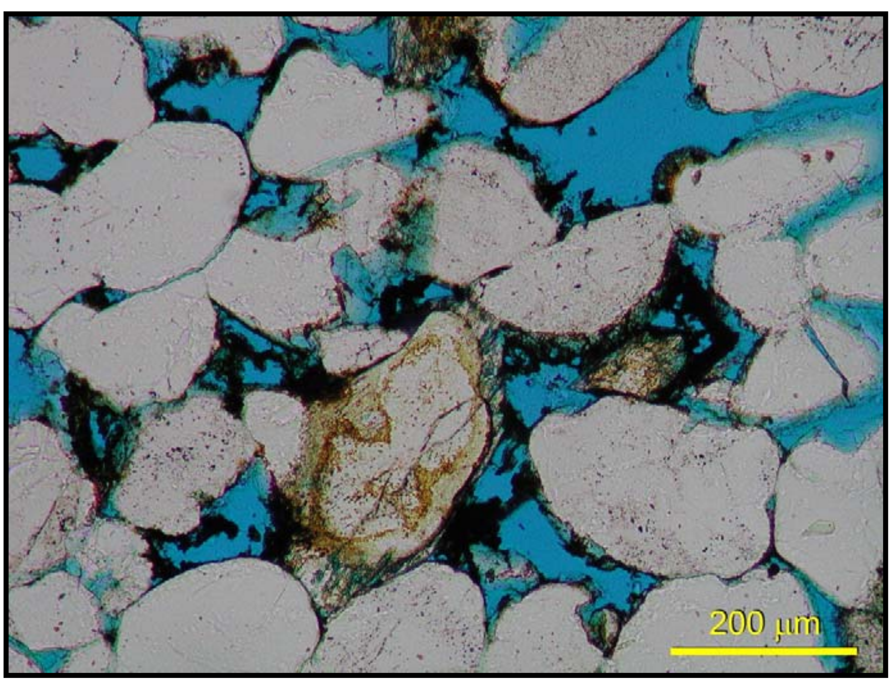
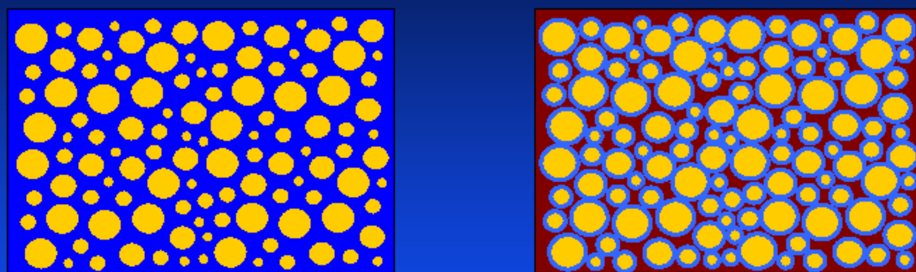


ARCHIE'S "Clean Sand" Equation
Effective DC Resistivity Response

$$Ro = \frac{a \cdot Rw}{\Phi^{m}}$$

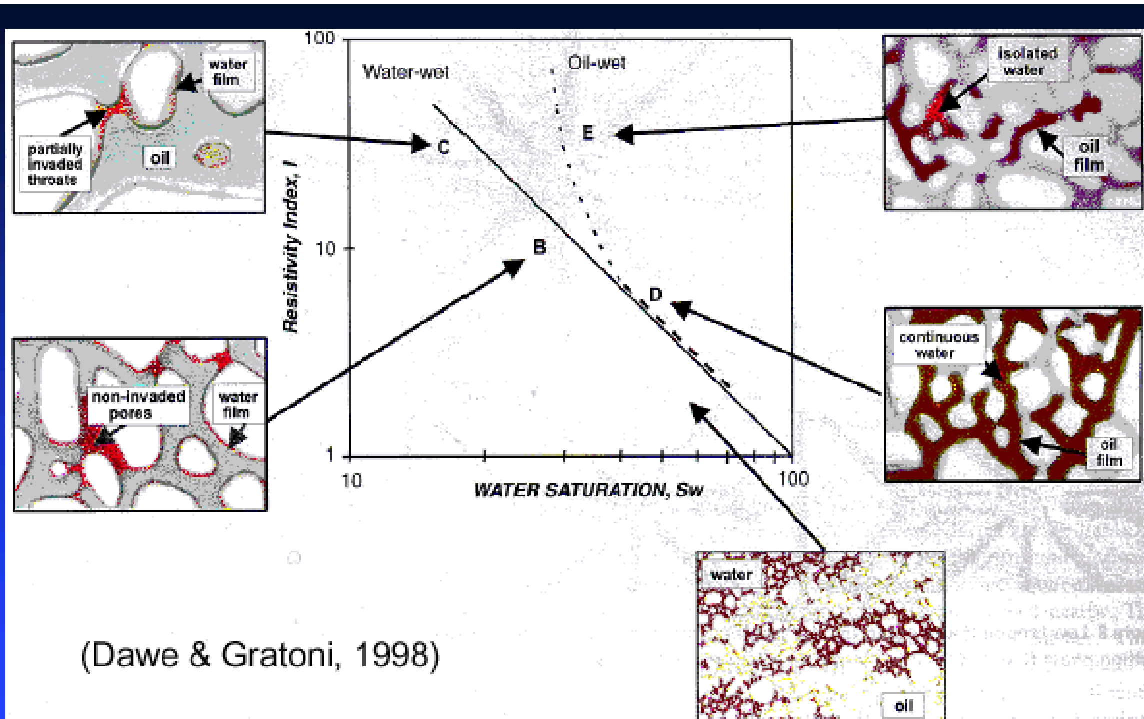
$$Sw^{n} = \frac{Ro}{Rt}$$



Φ = Porosity
m = Cementation Exponent
n = Saturation Exponent
Rw = Fm Water Resistivity
Sw = Water Saturation

Water Sand, Ro
Hydrocarbon Sand, Rt
Connate Water, Sw

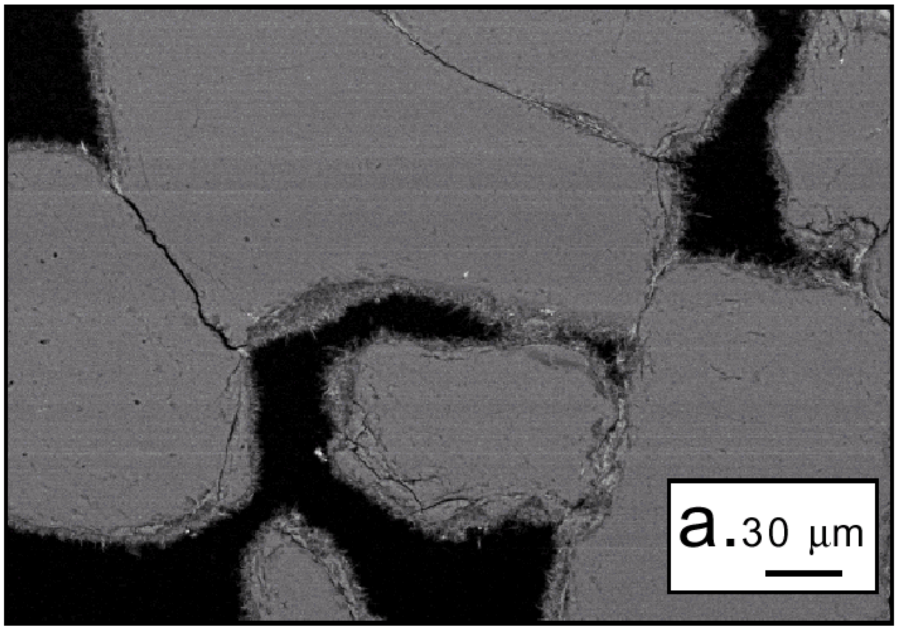
Saturation Exponent: Water-Wet vs. Oil Wet

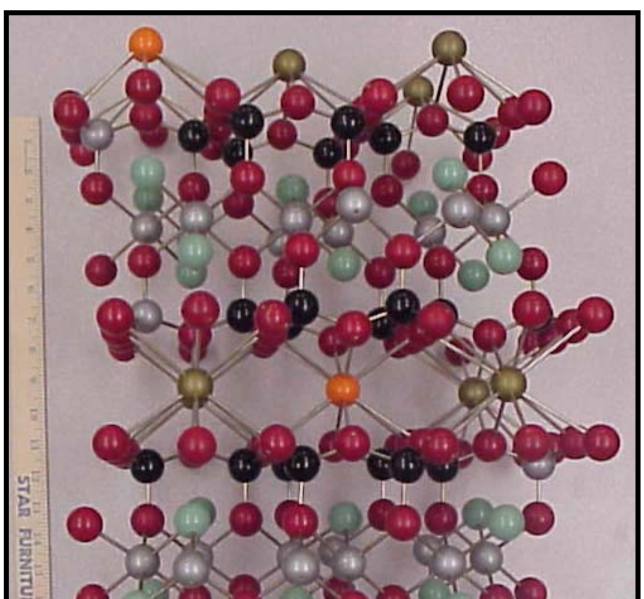


(Dawe & Gratoni, 1998)

What is a clay?

Example of Clay-Coated Sand Grains

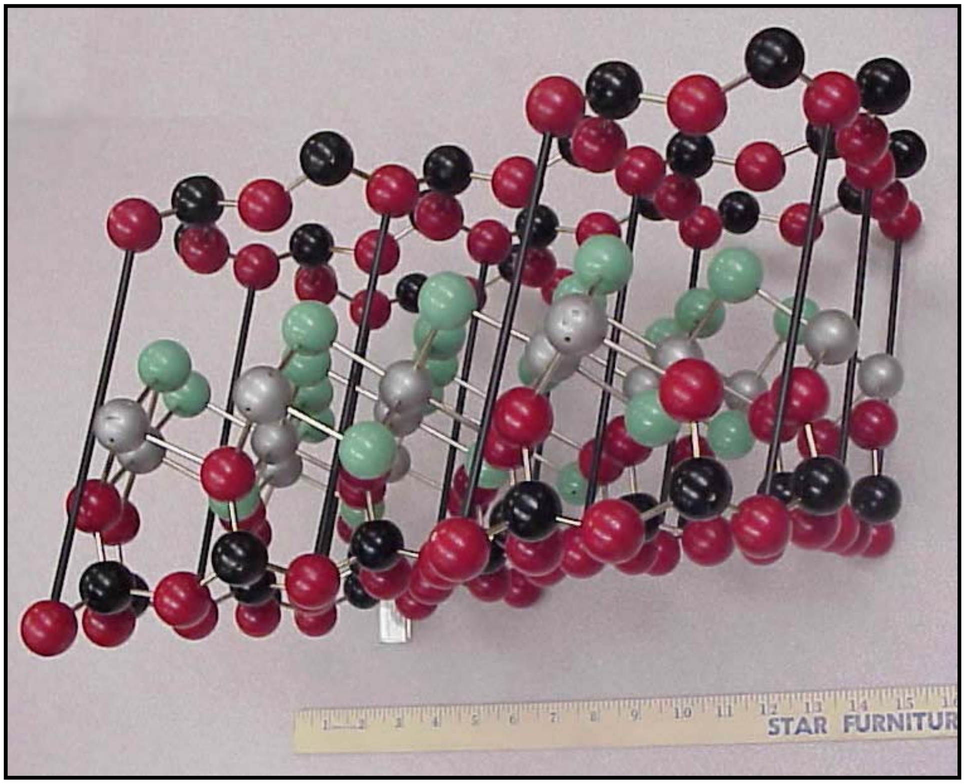


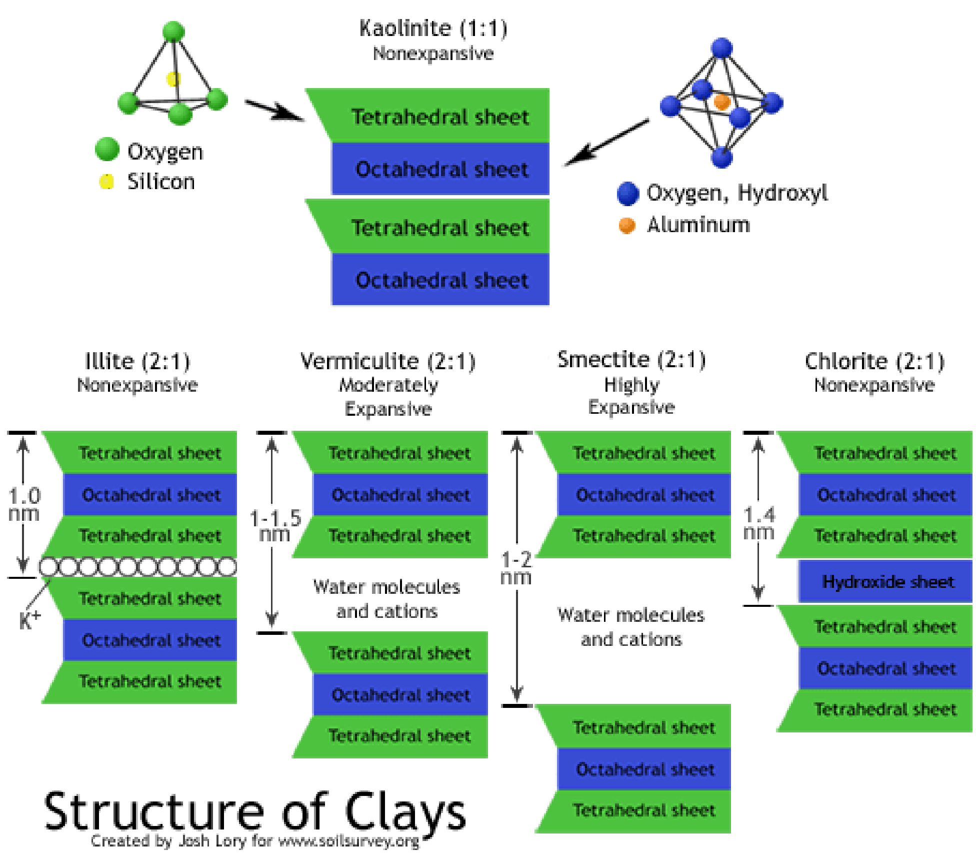


ILLITE:

CRYSTALINE STRUCTURE

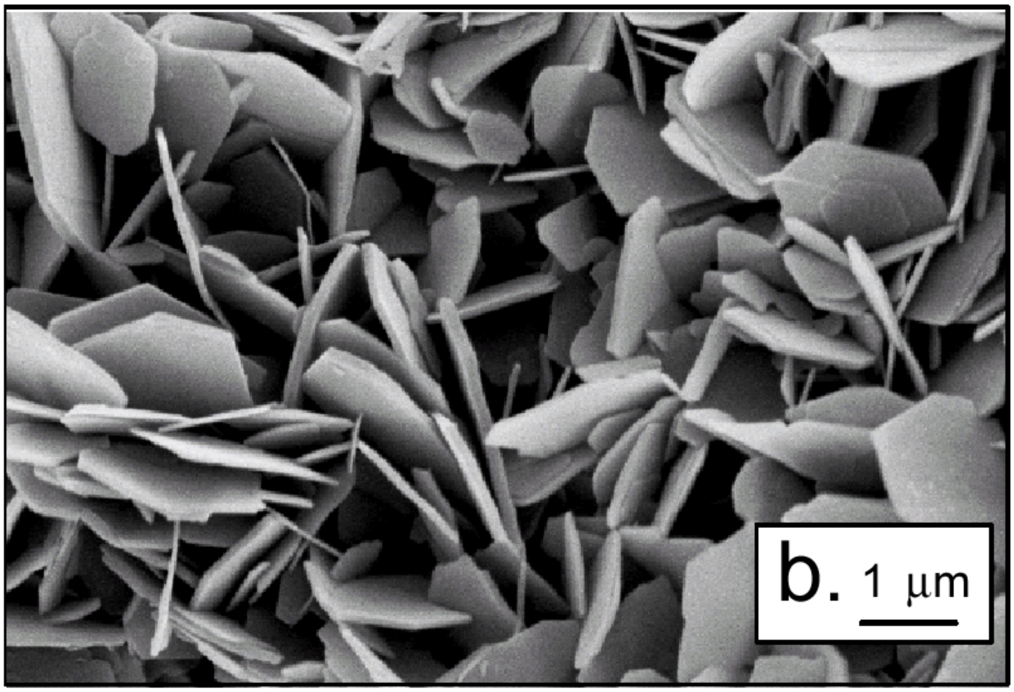
KAOLINITE: CRYSTALINE STRUCTURE

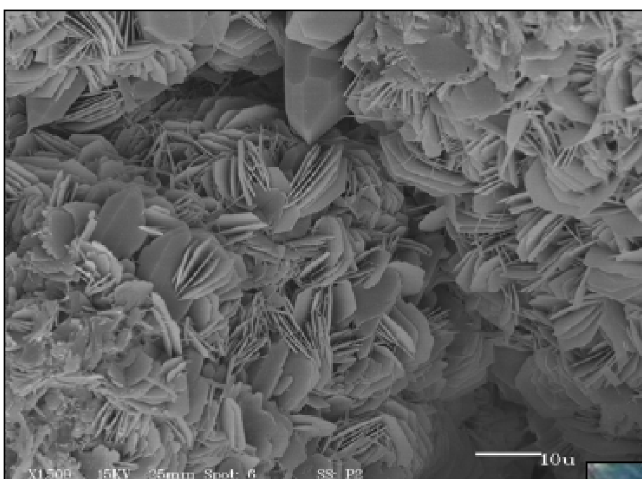




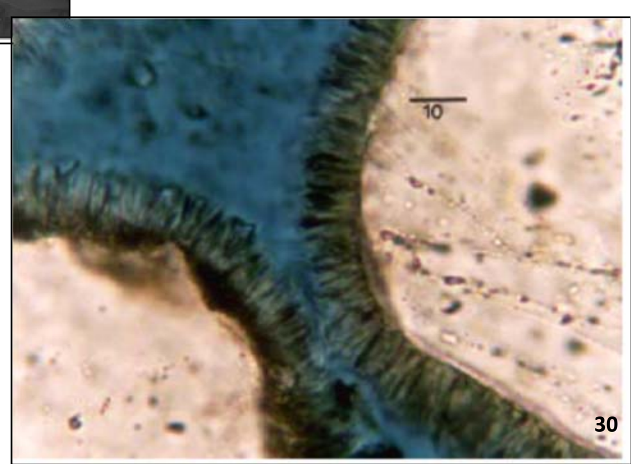
What is a clay?

Example: Chlorite

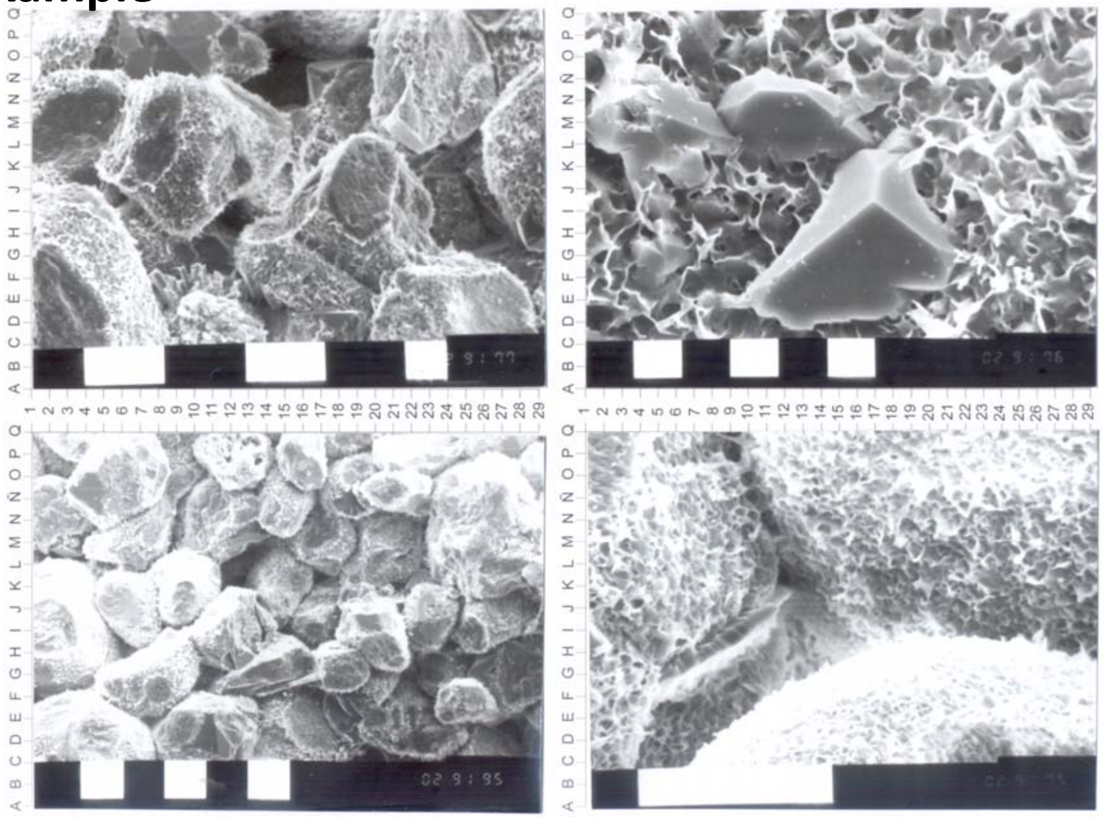




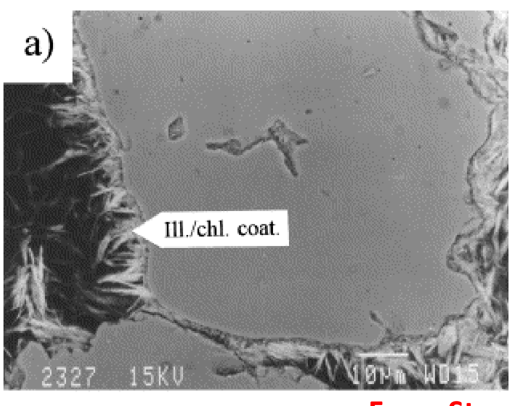
Examples of Grain-Coating Chlorite

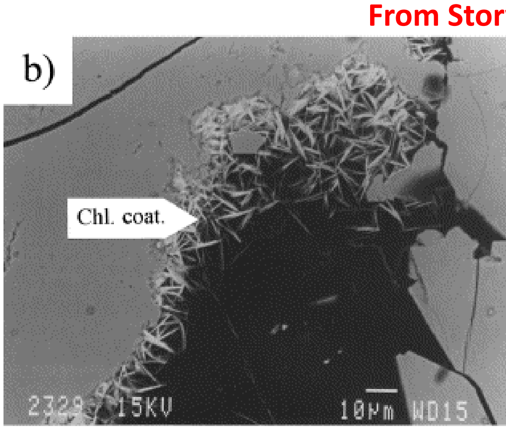


Example

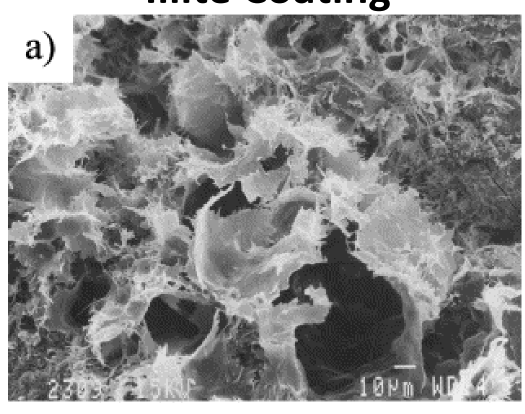


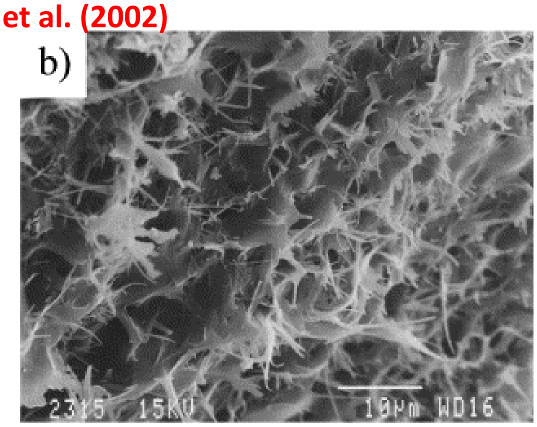
Illite and Chlorite Coating





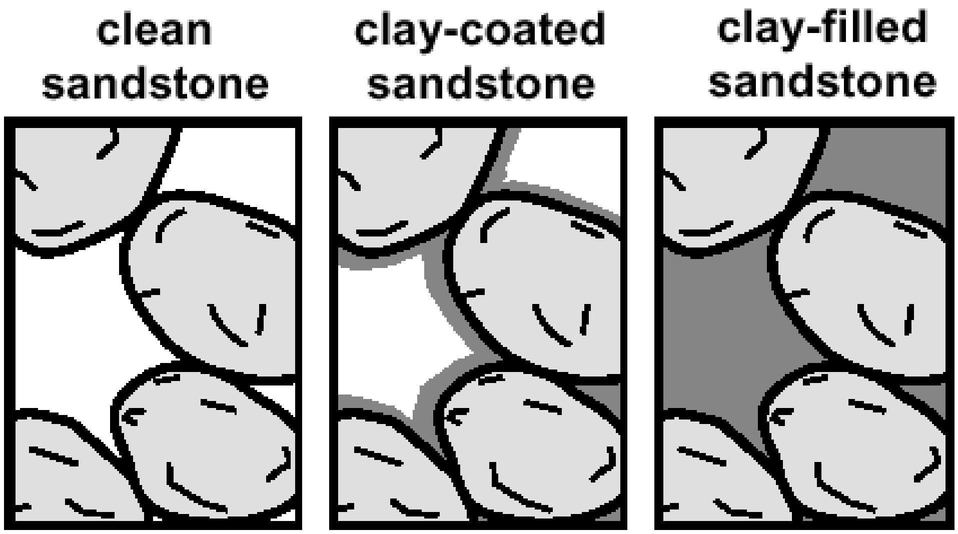
Illite Coating





From Storvoll et al. (2002)

Clay and Sandstone

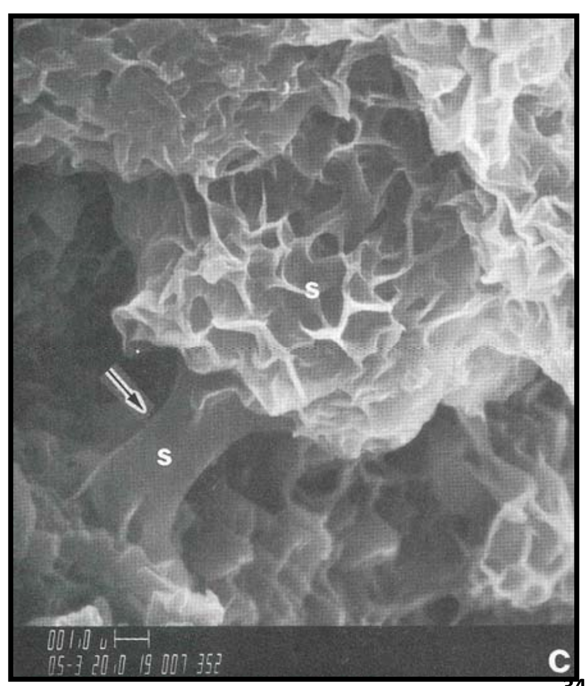


After Rabaute et al. (2003)

SEM Images

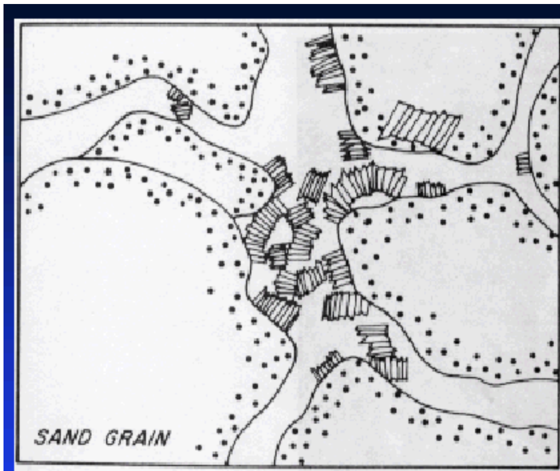
Kaolinite

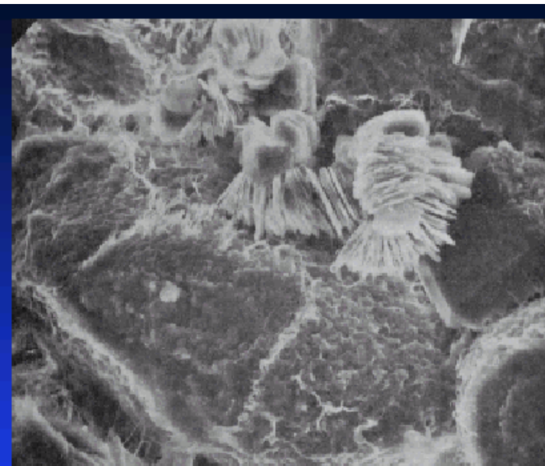
Smectite



What is a clay?

Example: Pore-Filling Kaolinite



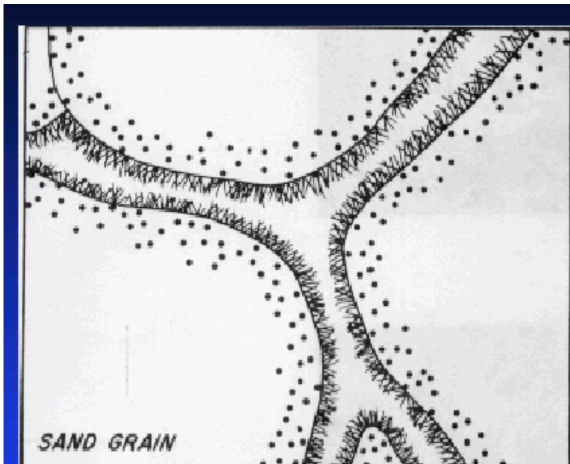


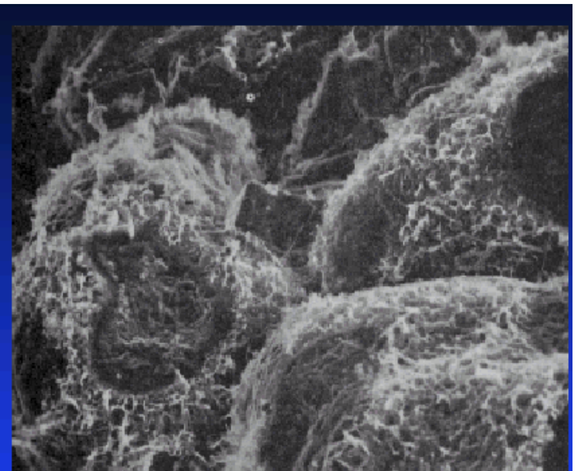
Classical Kaolinite “booklets” - potential for formation damage

From Neasham 1977, SPE 6858

What is a clay?

Example: Pore-Lining Chlorite



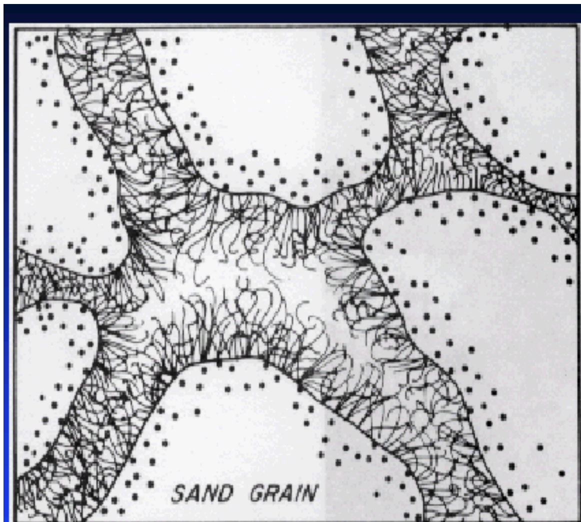


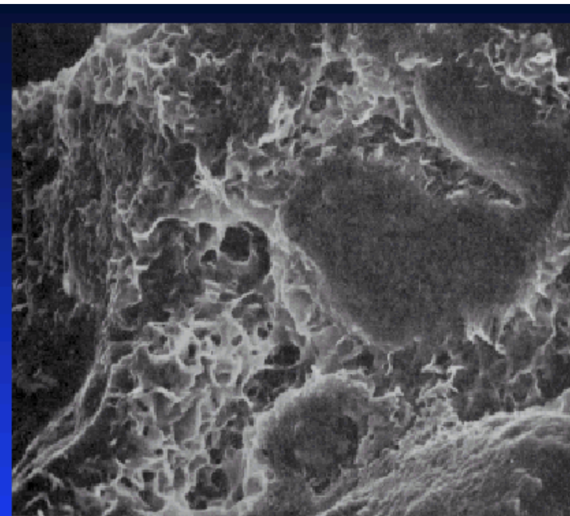
Cause of significant “Clay Bound Water” - detectable with ϕ_n

From Neasham 1977, SPE 6858

What is a clay?

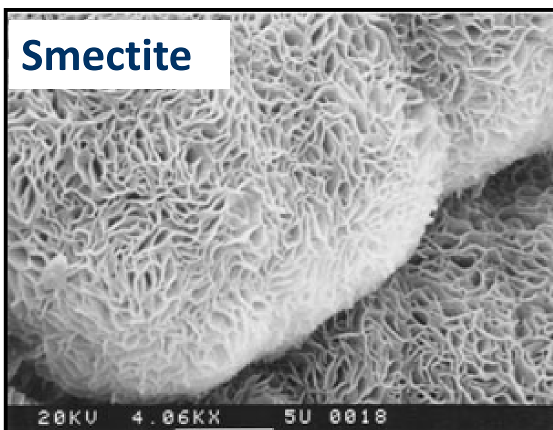
Example: Pore-Bridging Illite

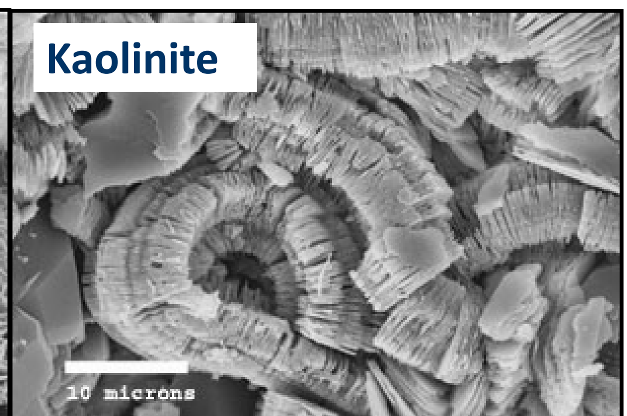


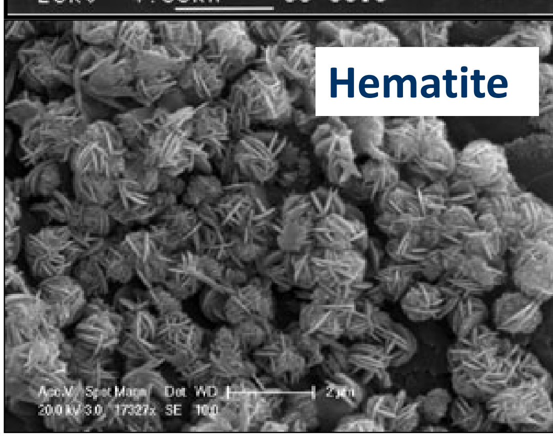


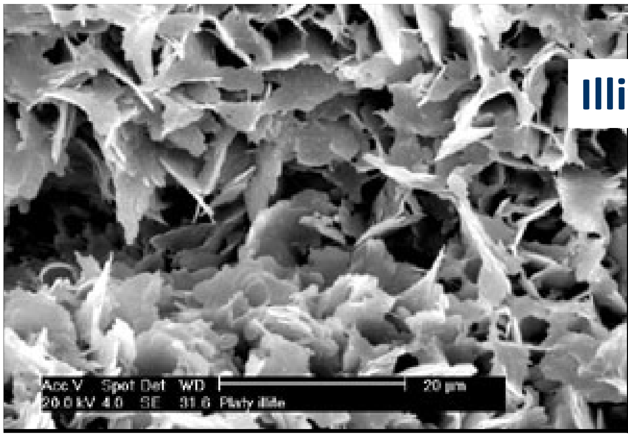
High surface area - high bound water - swelling clay

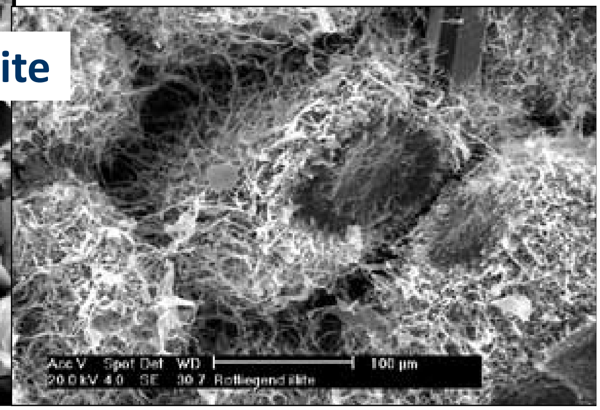
From Neasham, 1977, SPE 6858



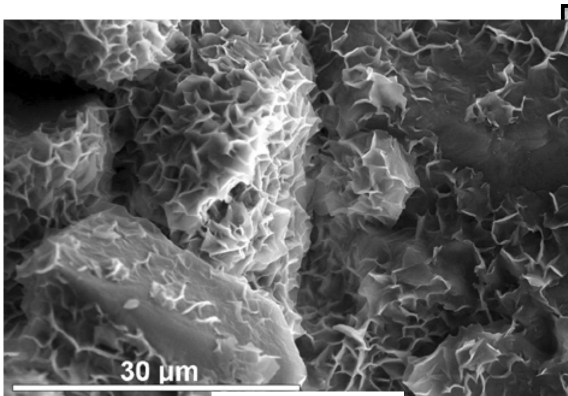




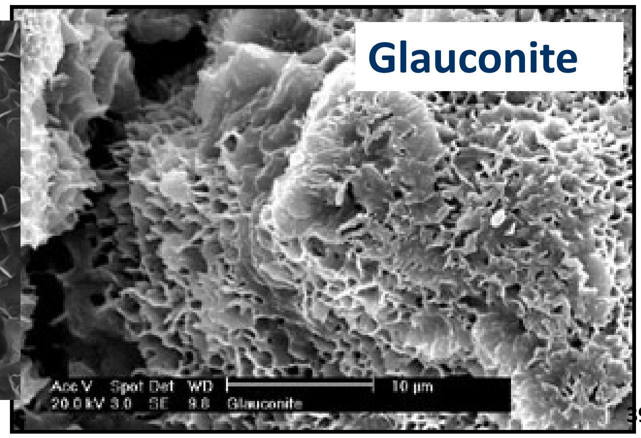




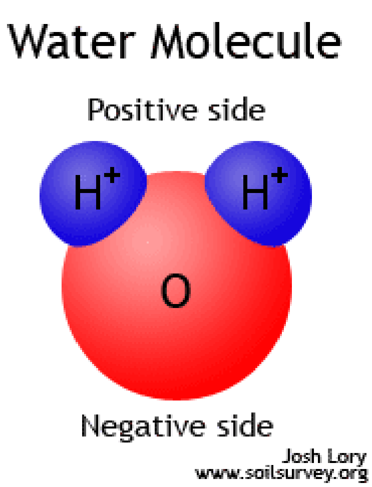
Illite

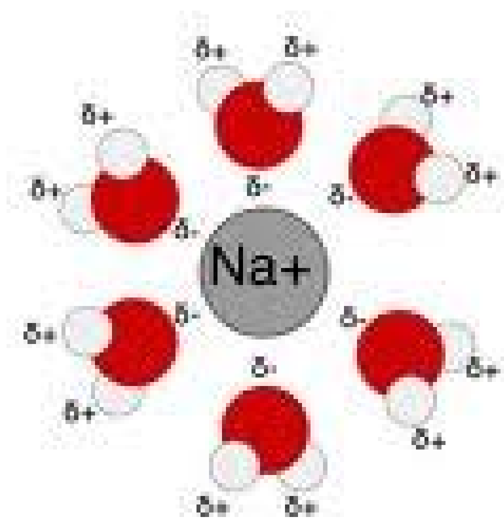


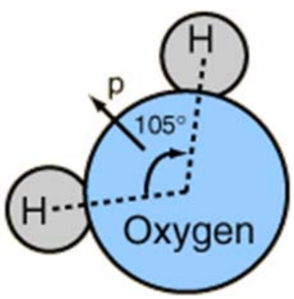
Smectite

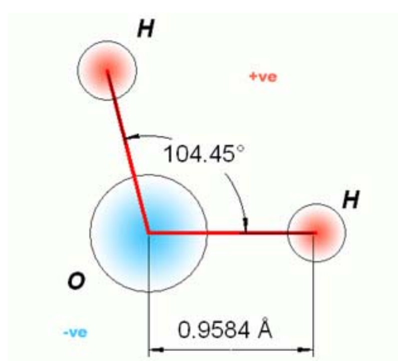


Glauconite

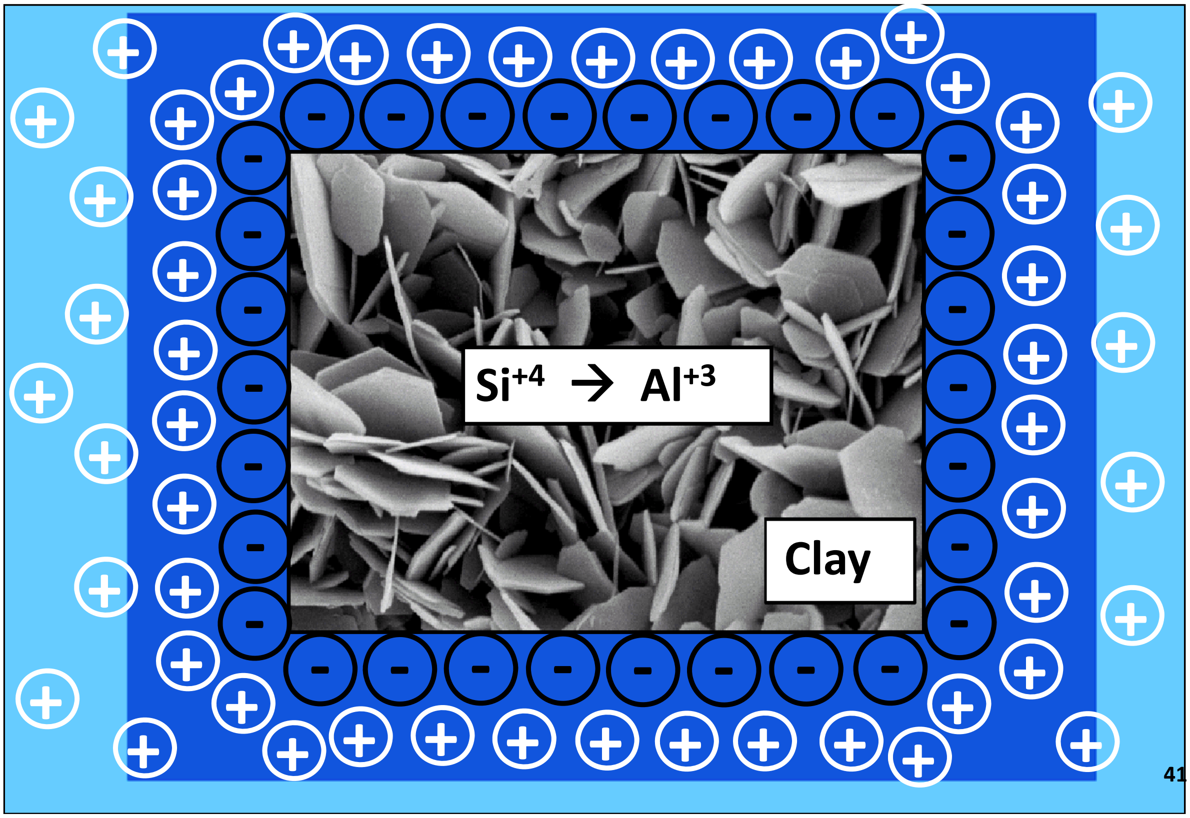




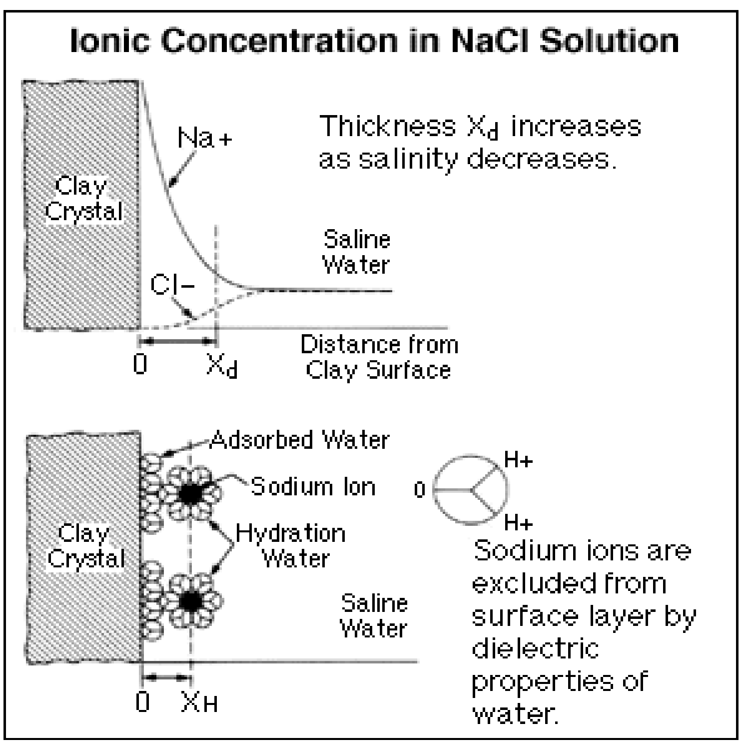


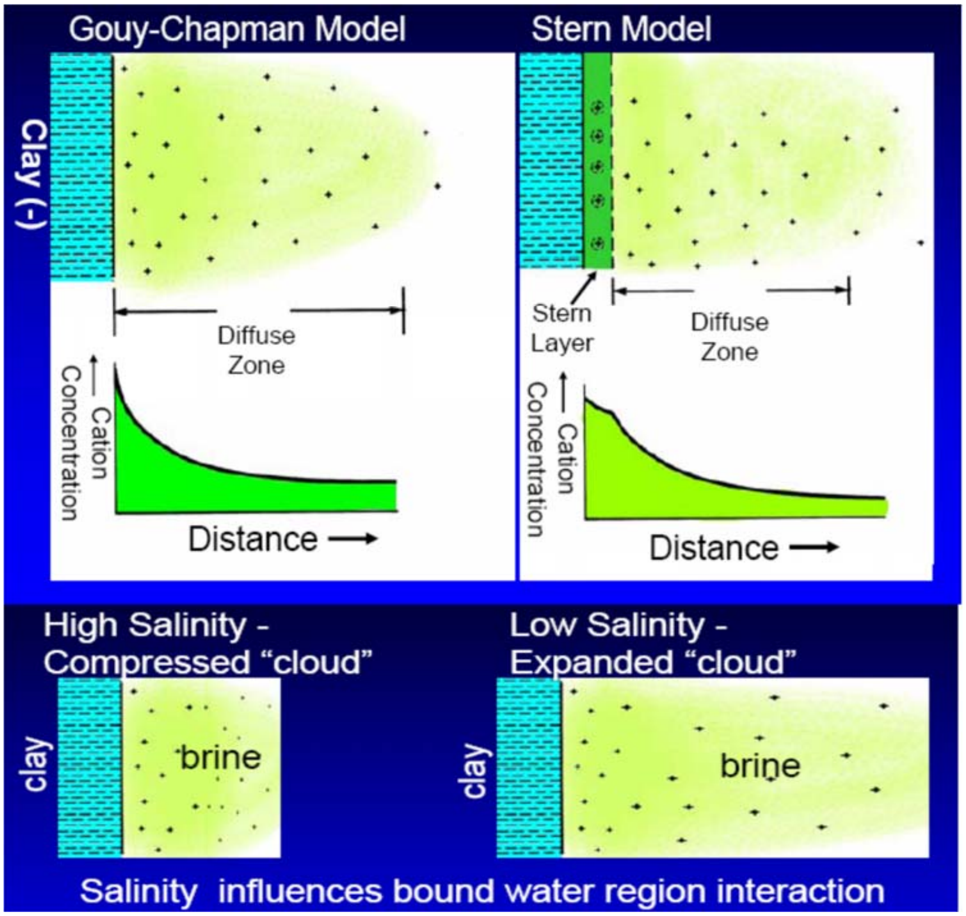


ELECTRICAL DOUBLE LAYER OF CLAYS



Water Adsorption by Clays
[Cation-Exchange-Capacity (CEC) Mechanism]

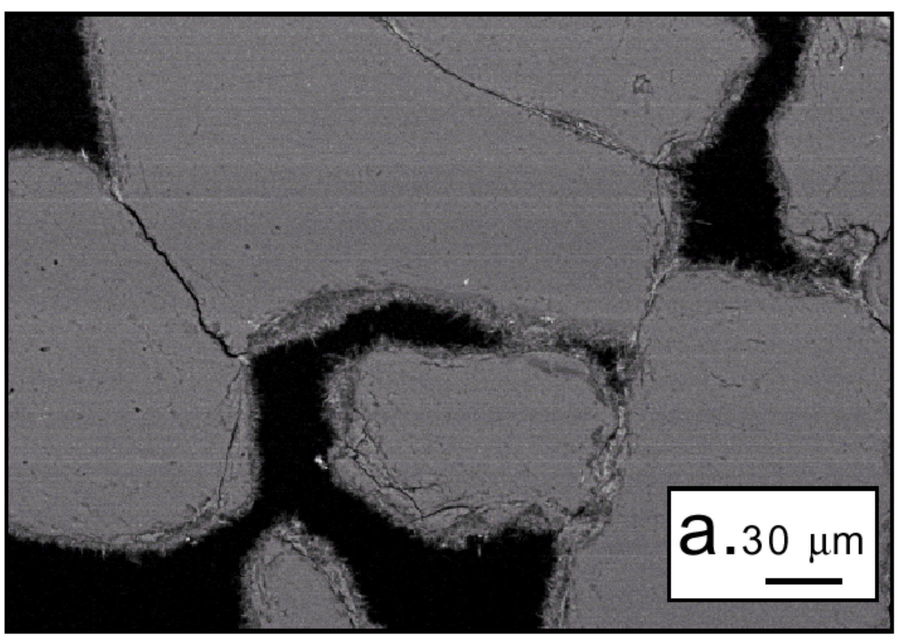




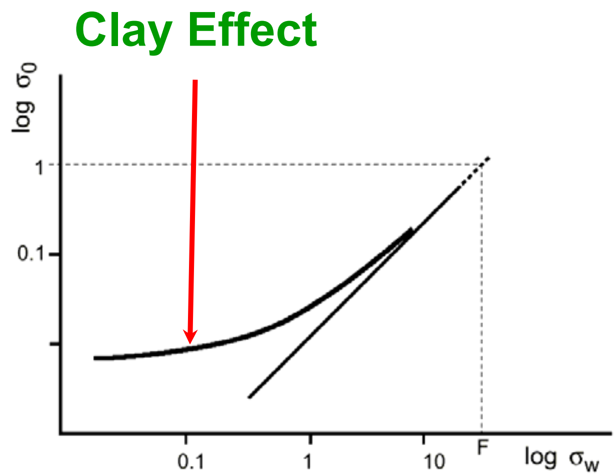
MODELS

What is a clay?

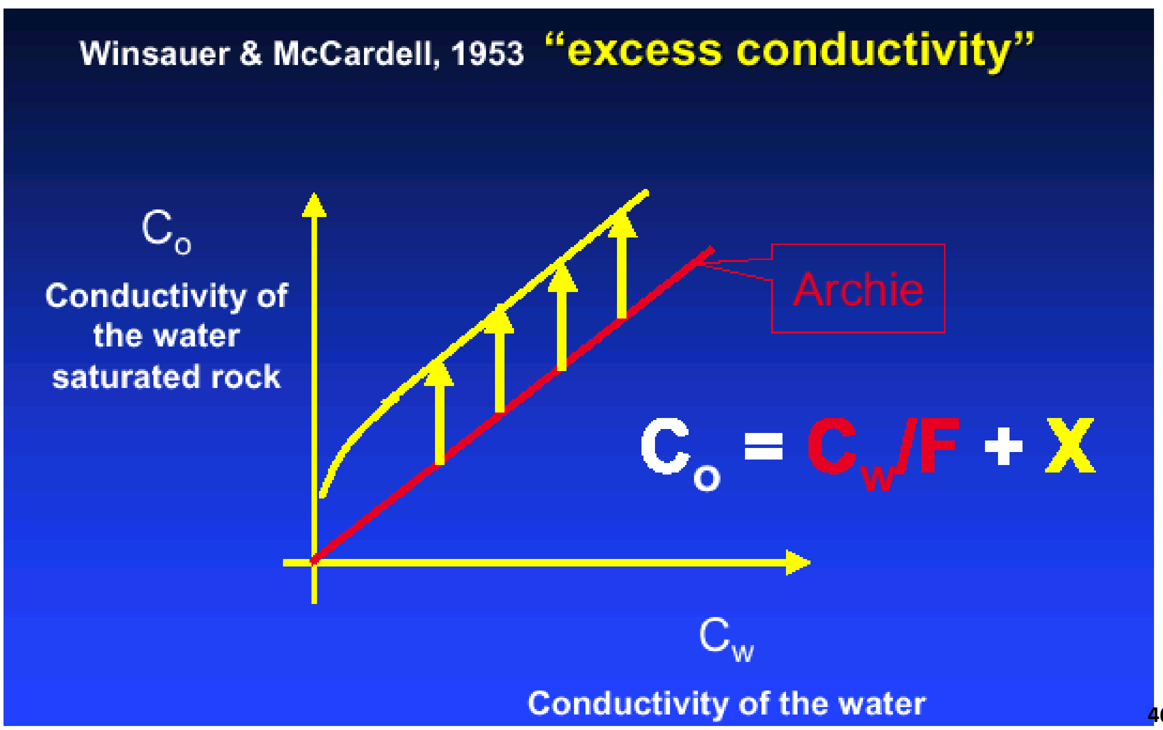
Example of Clay-Coated Sand Grains



- Archie valid at high salinities > 100ppk at 200°F
- Archie also valid if there are no conductive materials (clays).
- In very fresh water surface conductance of ordinary grains can also be a problem



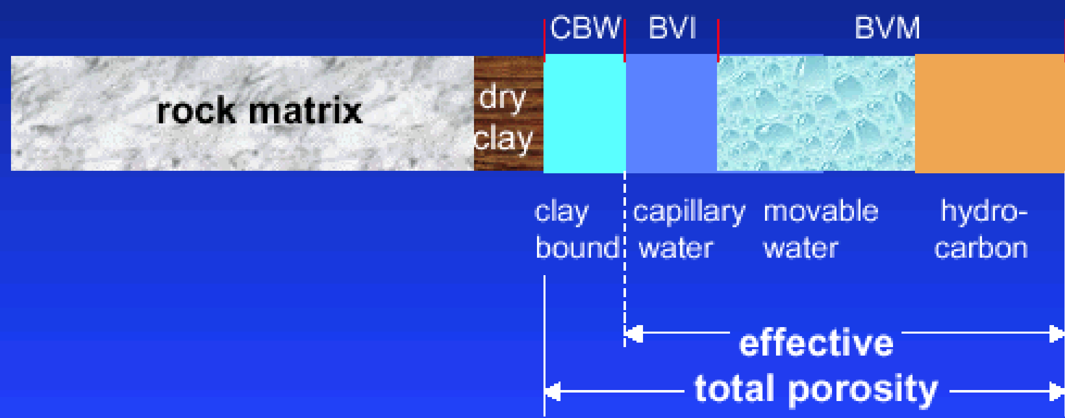
ELECTRICAL PROPERTIES OF SHALY SANDS



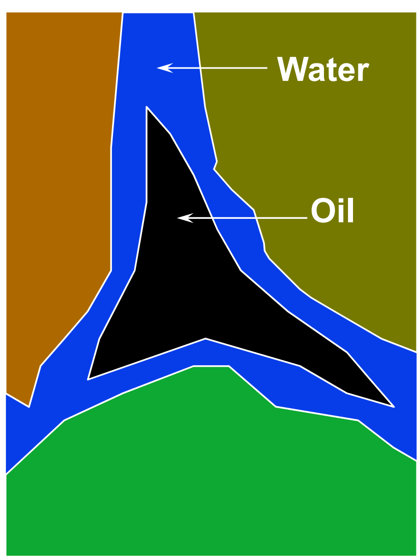
Fluids in the Pore Space

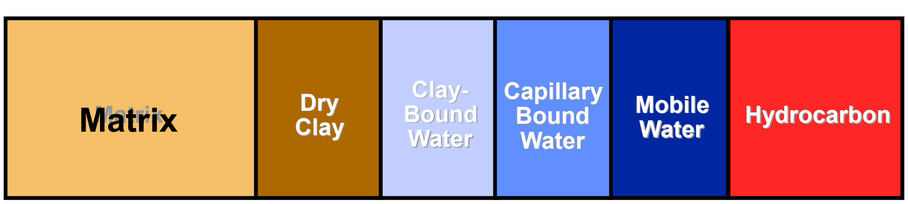
$$\text{saturation}_i = \frac{\text{volume fluid i}}{\text{pore volume}}$$

volumetric model

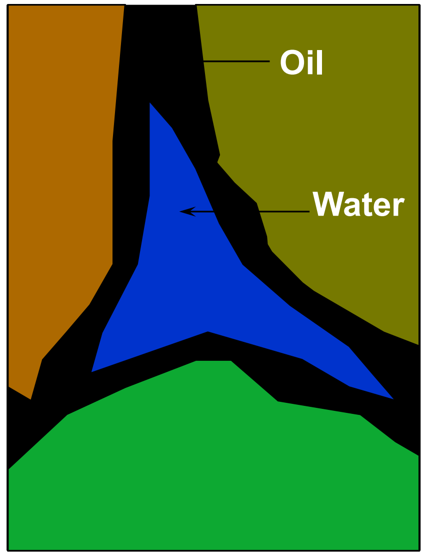


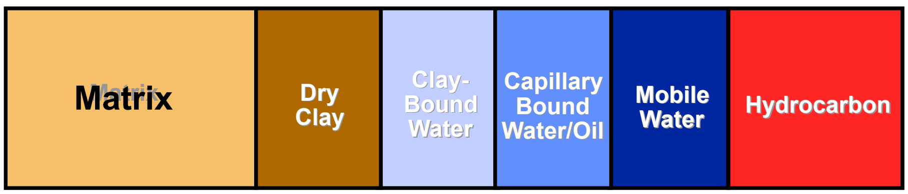
Water-Wet Hydrocarbon-Bearing Rock Formation





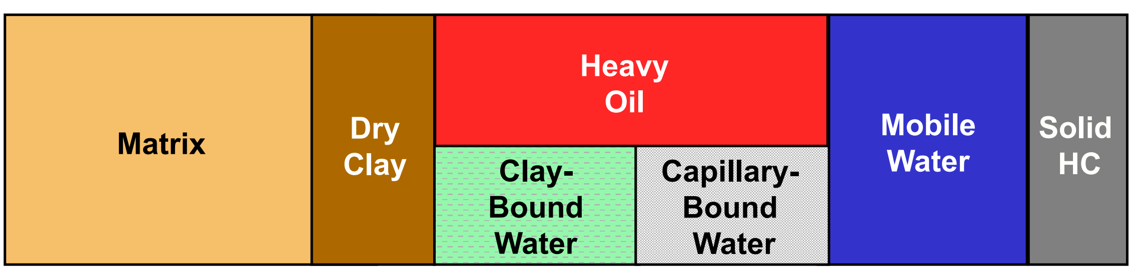
Oil-Wet Hydrocarbon-Bearing Rock Formation





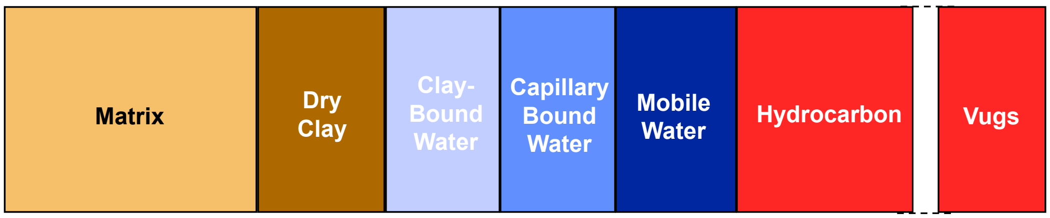
The Case of Heavy Oil

Matrix and Fluid Distributions



Water-Wet Hydrocarbon-Bearing Carbonates

Matrix and Fluid Distributions



Several Water Saturation Models

Shale-Free Electrical Model

- Archie (1942)

Laminated Shale Electrical Model

- Poupon-Leveaux (Indonesian)

“Double-Layer” Dispersed Clay Electrical Models

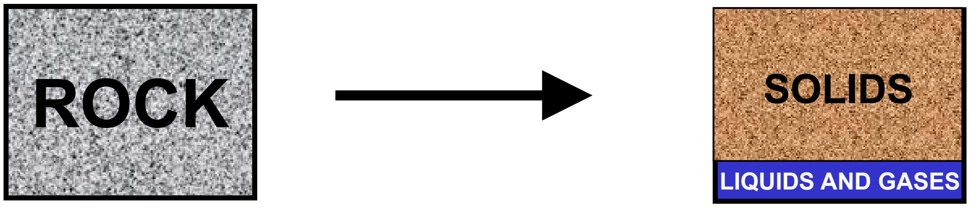
- Waxman-Smits
- Dual-Water

Mixed Dispersed-Clay / Laminar-Shale Electrical Model

- Patchett-Herrick

DEFINITION OF VOLUME OF SHALE

Rock = Fluids + Solids (Matrix)



Shale

Solid + Fluid Components

$$\text{Volumetric Concentration of Shale} = \frac{\text{Volume of Shale}}{\text{Total Rock Volume}}$$

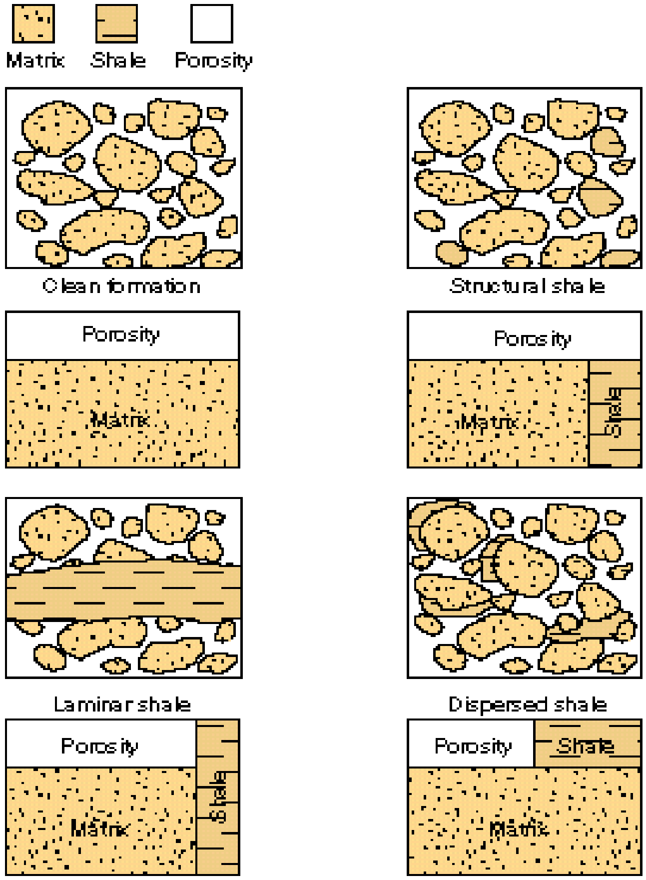
SHALE AND ELECTRICAL RESISTIVITY

Conductivity contribution of clay depends on

- clay type (clay mineral)
- clay content (volume fraction)
- distribution of clay in the formation

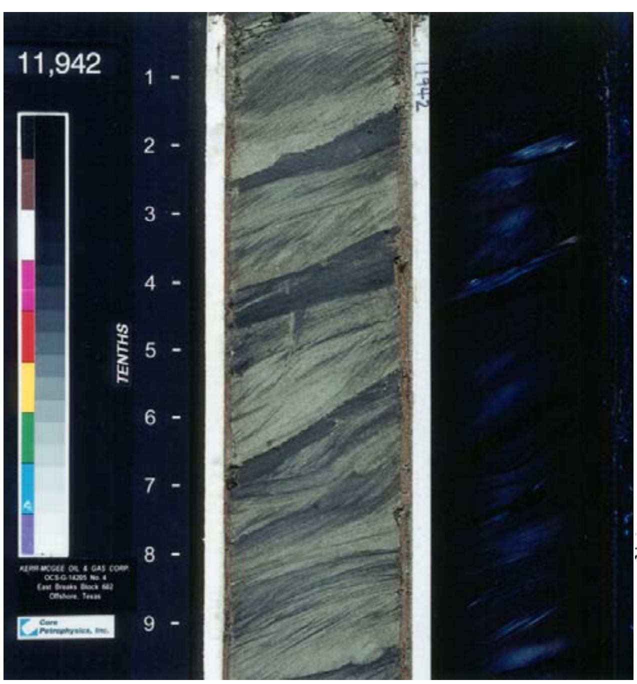
Clay distribution is described by 3 types of shale (Boyd et al. 1995, Doveton 1997) :

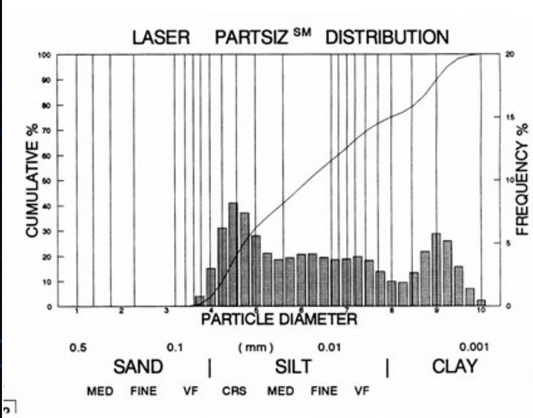
- Laminar shale
- Dispersed shale
- Structural shale



Shale Distribution

Core Vshale: Example

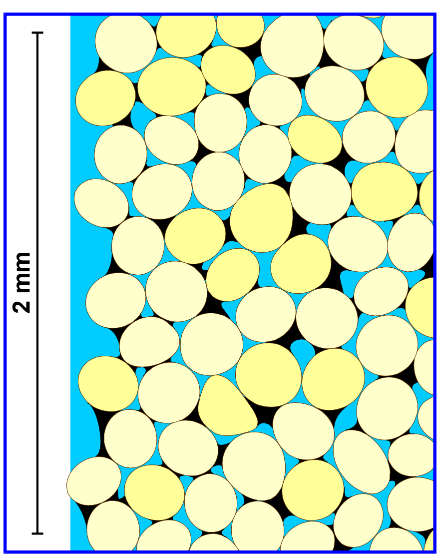




Definitions

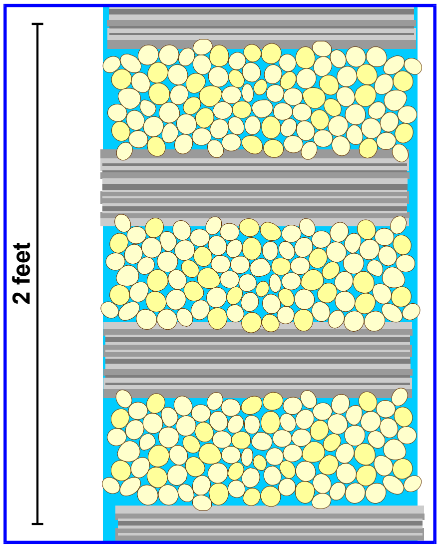
- Shale can be dispersed, laminated or structural
- Shale structure is not critical in computing hydrocarbons-in-place. It is important in determining producibility.
- Shale structure can only be determined from core or with image logs, like the FMI.

Dispersed Shale



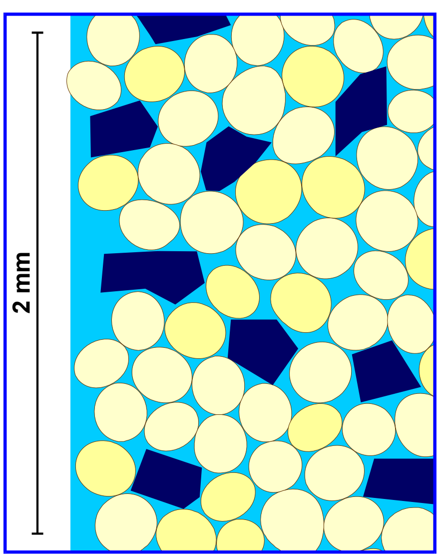
- **Dispersed shale occupies only pore space**
- **$\phi_e = \phi_{ss} - Vsh_D$**
- **ϕ_{ss} or PHIMAX is the maximum clean sandstone ϕ**

Laminated Shale



- **Shale laminae occupy both pore space and grain space**
- $\phi_e = \phi_{ss} - Vsh_L\, \phi_{ss}$
- **These laminae are at the density resolution limit. (sand grains not to scale)**

Structural Shale



- Structural shale occupies grain space
- $\phi_e = \phi_{ss}$

ESTIMATION OF SHALE CONTENT

- Basis: correlation between shale content and gamma activity
- Assumption: only shale and clay are radioactive components in rock, no other radioactive minerals

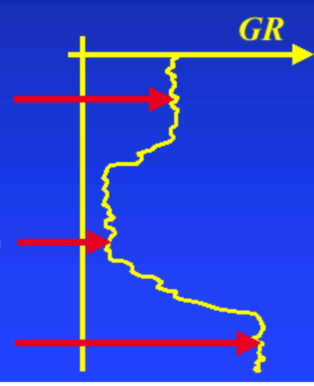
First step: Calculation of "gamma ray shale index"

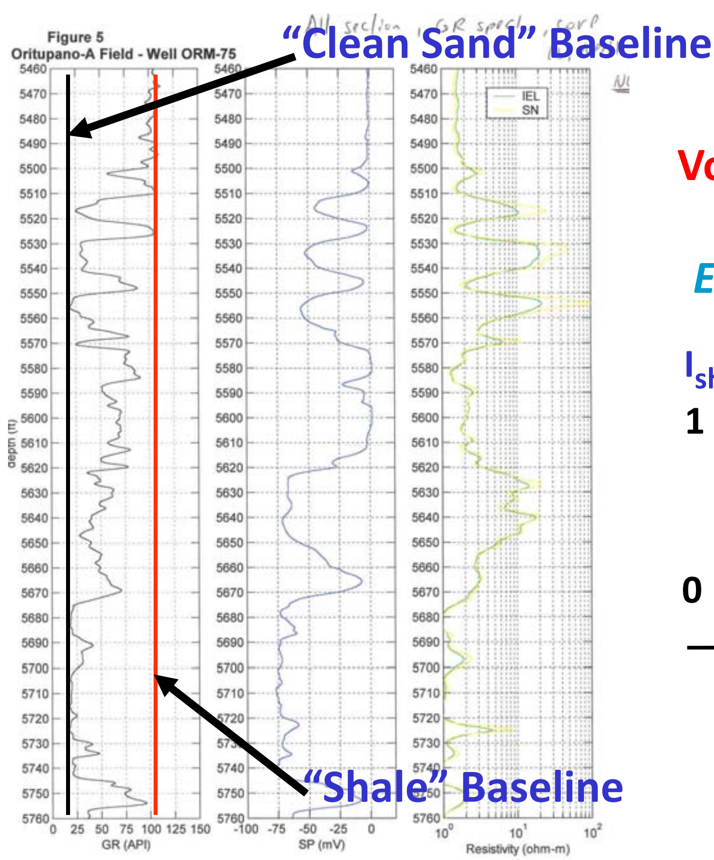
$$I_{GR} = \frac{GR - GR_{cn}}{GR_{sh} - GR_{cn}}$$

GR log response in zone of interest

GR_{cn} log response in a zone considered clean (shale free)

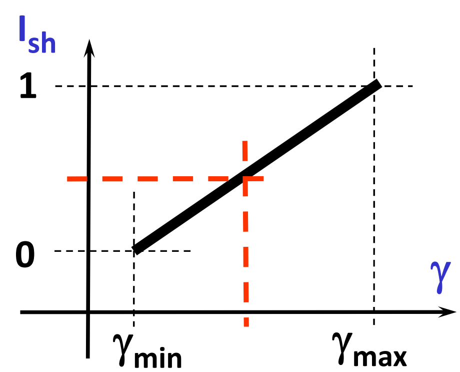
GR_{sh} log response in a shale zone





Volume of Shale (V_{sh}) Computation:

Empirical Technique



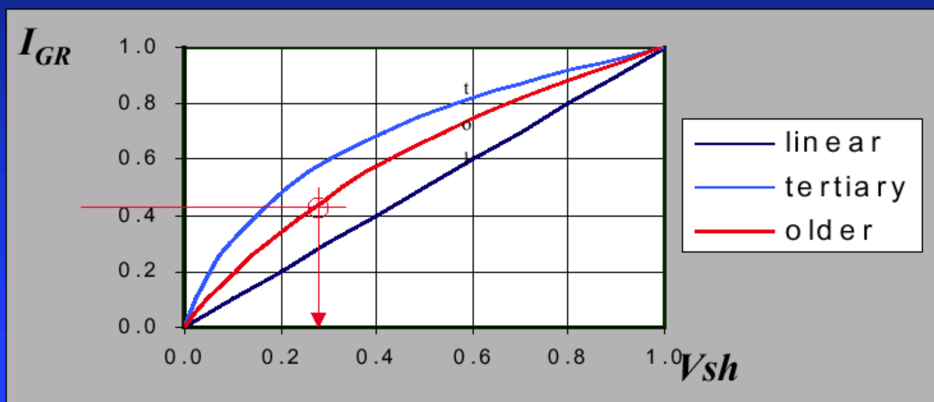
ESTIMATION OF SHALE CONTENT (I)

Second step: Select & apply a relationship I_{GR} vs. shaliness Vsh

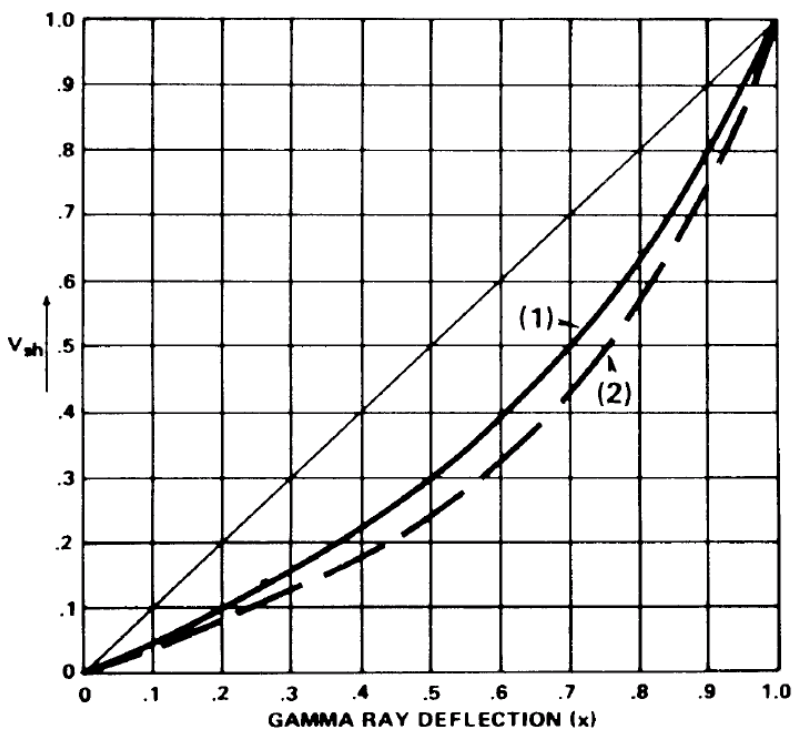
$$Vsh = I_{GR}$$ Linear relationship (upper limit)

$$Vsh = 0.083 \cdot (2^{3.7 \cdot I_{GR}} - 1)$$ Tertiary clastics (Larionov 1969)

$$Vsh = 0.33 \cdot (2^{2 \cdot I_{GR}} - 1)$$ Mesozoic & older rocks (Larionov 1969)



ESTIMATION OF SHALE CONTENT (II)



GAMMA RAY DEFLECTION:

$$\frac{GR - GR_{clean}}{GR_{shale} - GR_{clean}} = x$$

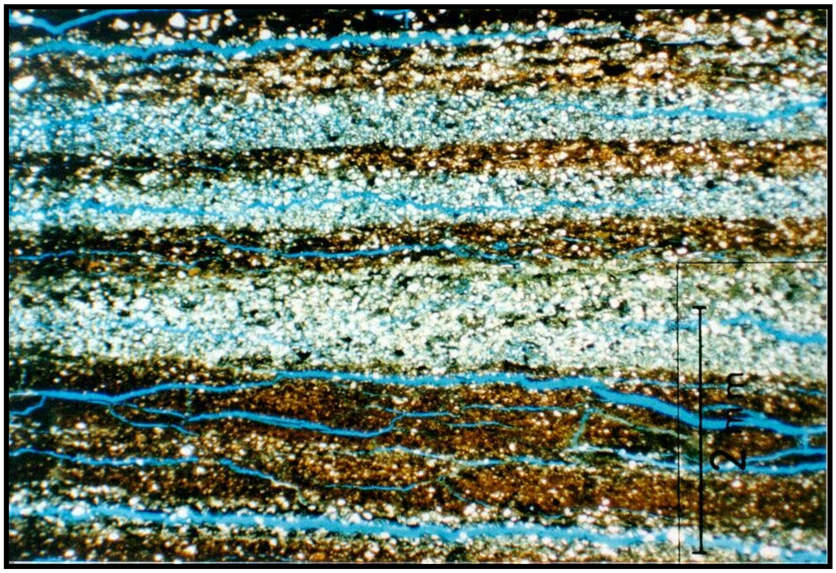
(1) $V_{sh} = 1.7 - \sqrt{3.38 - (x + .7)^2}$

after Clavier et al, JPT-June 1971

(2) $V_{sh} = \frac{.5\,(x)}{1.5 - (x)}$

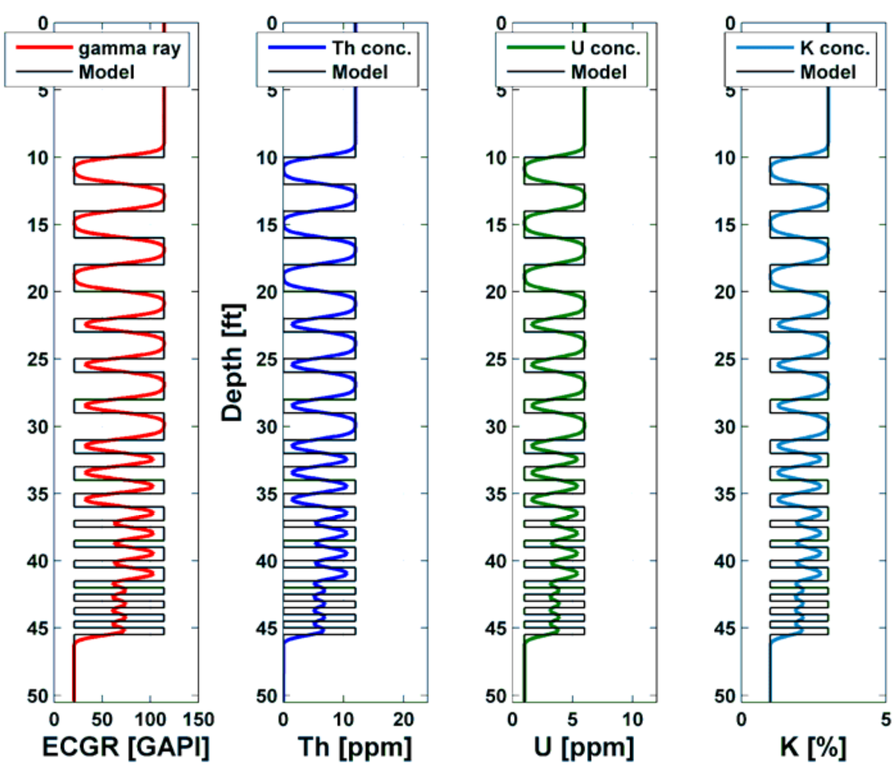
after Steiber, SPE 2961

Issue: Laminated Sandstones



- Laminae can be very thin as in this thin section
- The laminae are about 1 mm thick.

EXAMPLE: Synthetic gamma-ray logs

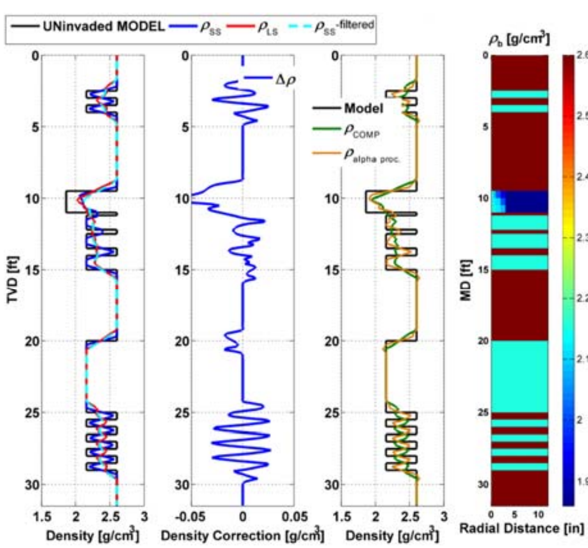


Tide Influenced Delta
Frewins Castle Sandstone
Belle Frourche Member
Frontier Formation
Cretaceous (Cenomanian)
Tisdale Mountain Anticline, Wyoming

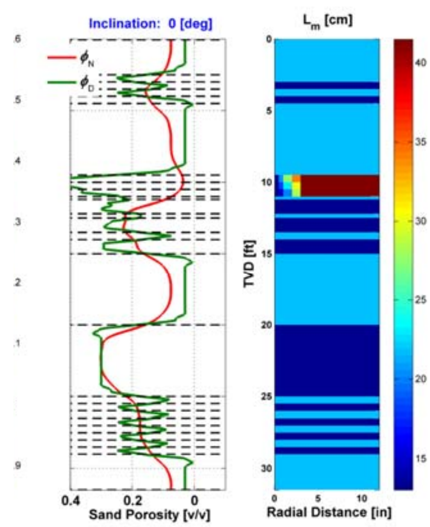
Photo by Rob Wellner

EXAMPLE: Synthetic density and neutron logs

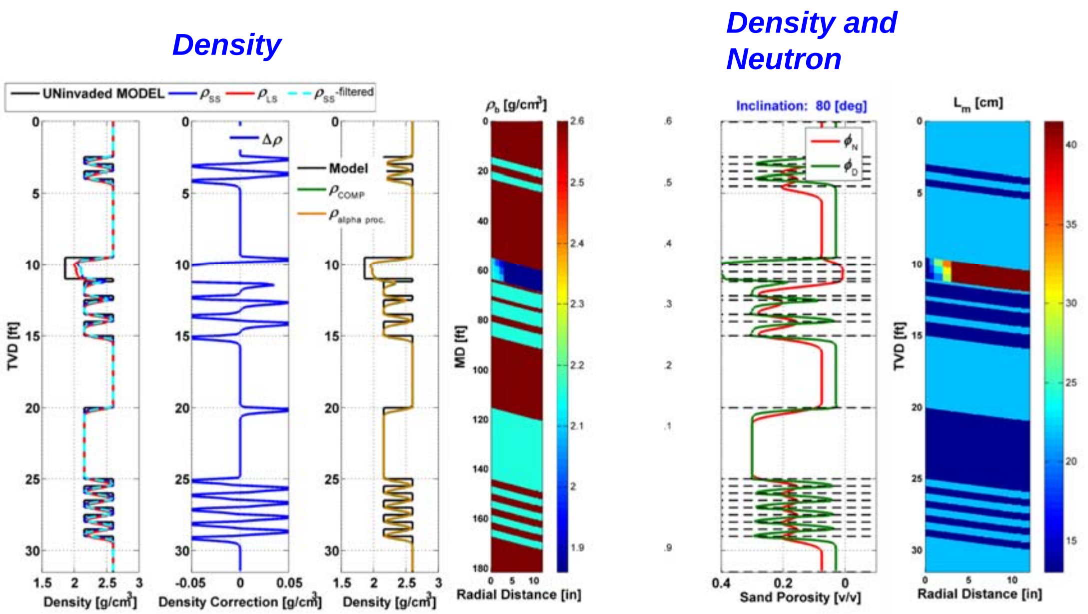
Density



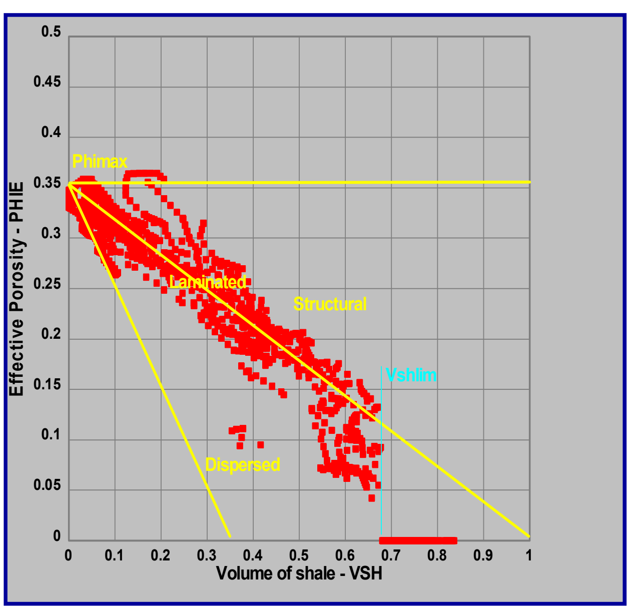
Density and Neutron



EXAMPLE: Synthetic density and neutron logs in dipping beds

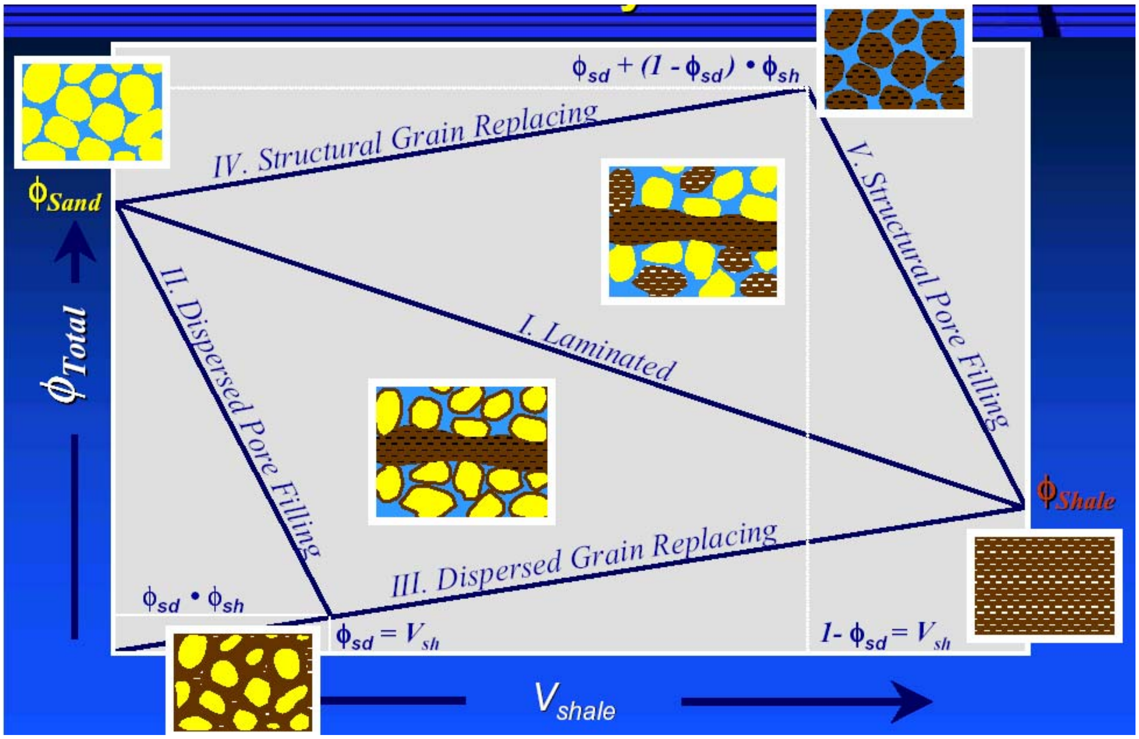


Determining Shale Structure: Thomas-Steiber Plot

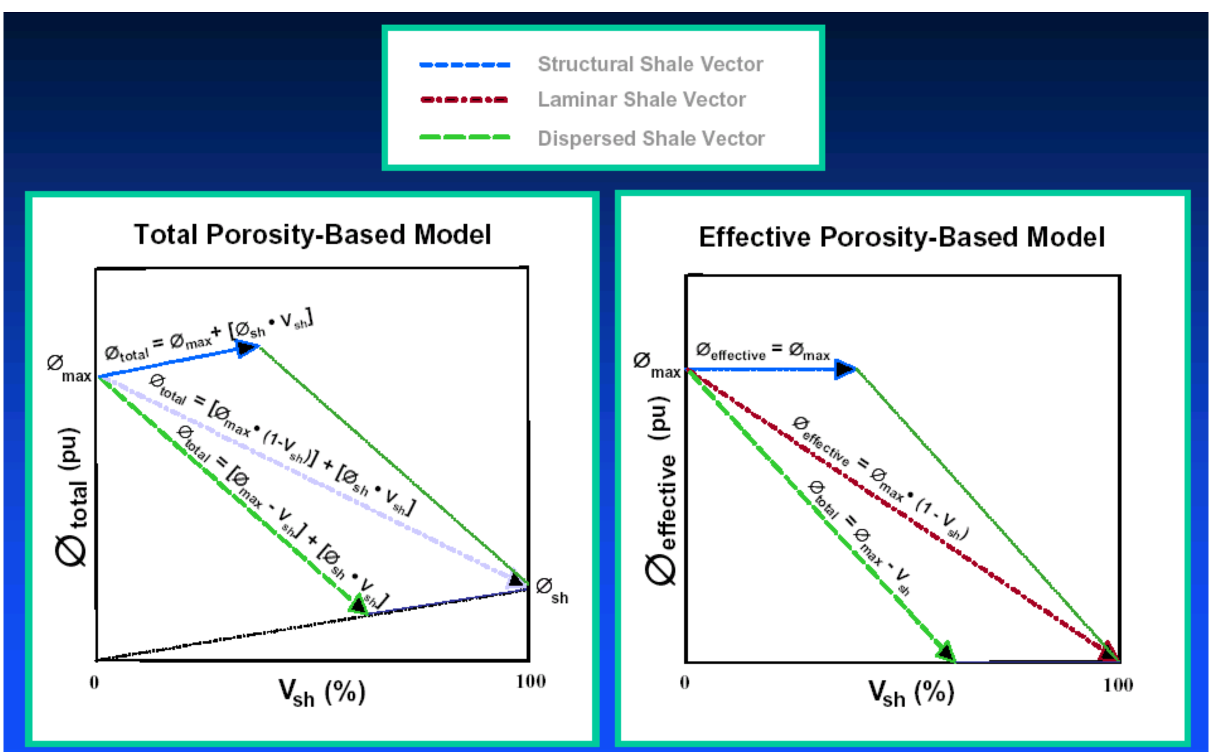


- Points on the Phimax to PHISH (PHIE=0) line are 100% laminated SS
- Points above the line have laminated shale and structural shale
- Points below have dispersed shale and laminated shale

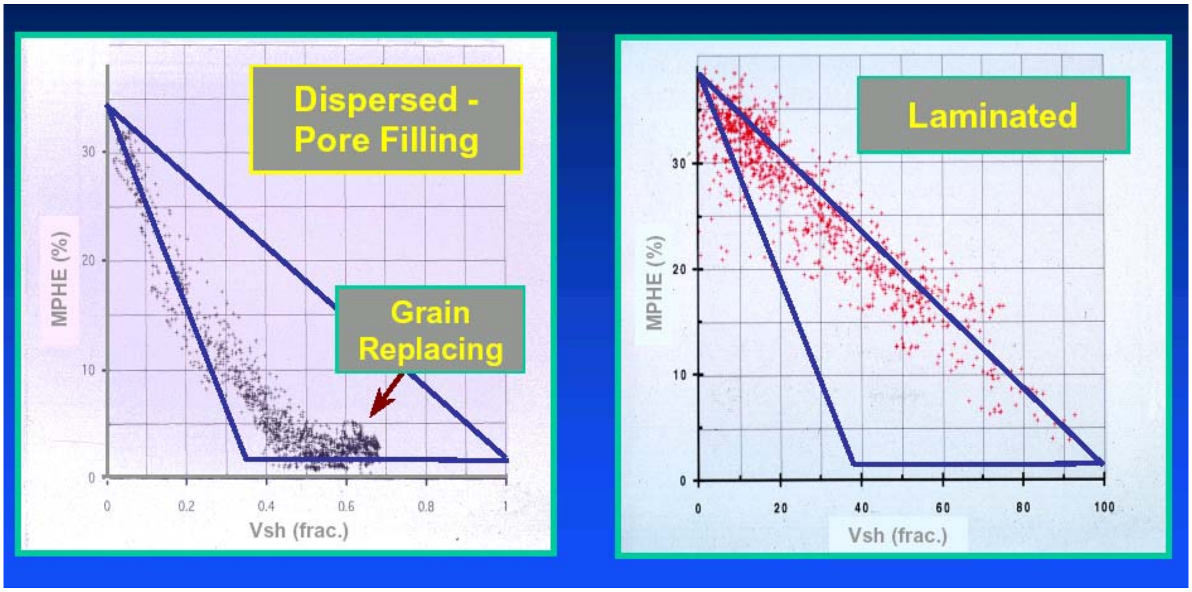
THOMAS-STEIBER PLOT



POROSITY vs. SHALE MODEL



POROSITY vs. SHALE MODEL: Examples



THOMAS-STEIBER POROSITY MODEL

I. Laminated

$\phi_T = \phi_{Sd} - V_{Sh} \bullet (\phi_{Sd} - \phi_{Sh})$

II. Dispersed Pore Filling

$\phi_T = \phi_{Sd} - V_{Sh} \bullet (1 - \phi_{Sh})$ $\quad V_{Sh} \leq \phi_{Sd}$

III. Dispersed Grain Filling

$\phi_T = V_{Sh} \bullet \phi_{Sh}$ $\quad V_{Sh} > \phi_{Sd}$

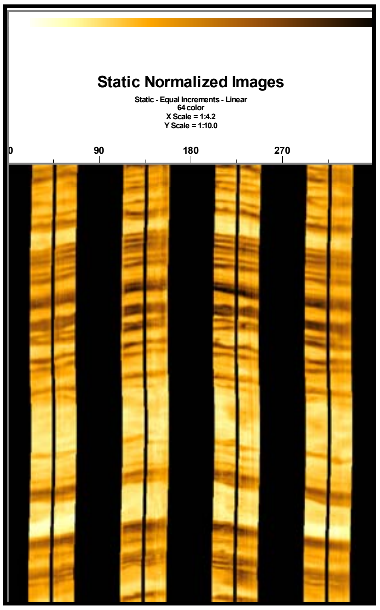
IV. Structural Grain Replacing

$\phi_T = \phi_{Sd} + V_{Sh} \bullet \phi_{Sh}$ $\quad V_{Sh} \leq 1 - \phi_{Sd}$

V. Structural Pore Filling

$\phi_T = 1 - V_{Sh} \bullet (1 - \phi_{Sh})$ $\quad V_{Sh} > 1 - \phi_{Sd}$

Example: Thin Bedded Pay



- **Deep water facies thin bedded pays appear as organized bands and have moderate dips.**
- **This facies makes good reservoirs, even with a very high Vsh and low interval average PHIE.**
- **They are hard to detect due to low resistivity and high GR**

Net Pay Cut-Offs

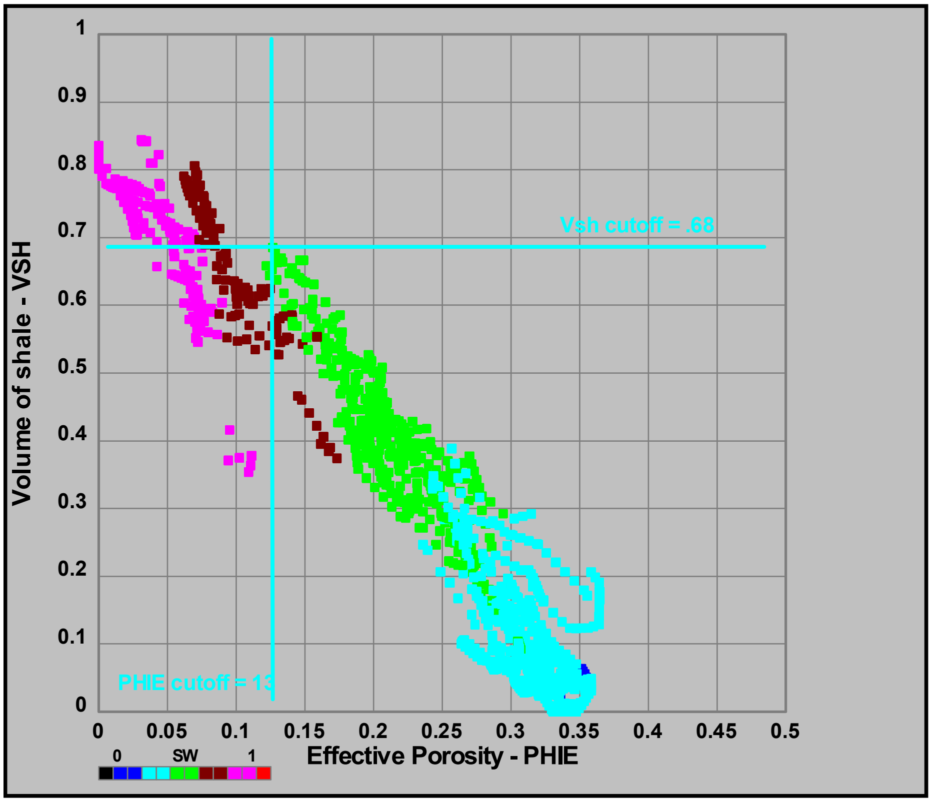
•How are they picked?

•“Typical Values” or “Rules of Thumb”

•Regional knowledge (what about rank wildcat?)

•How to verify?

Determine Cutoffs



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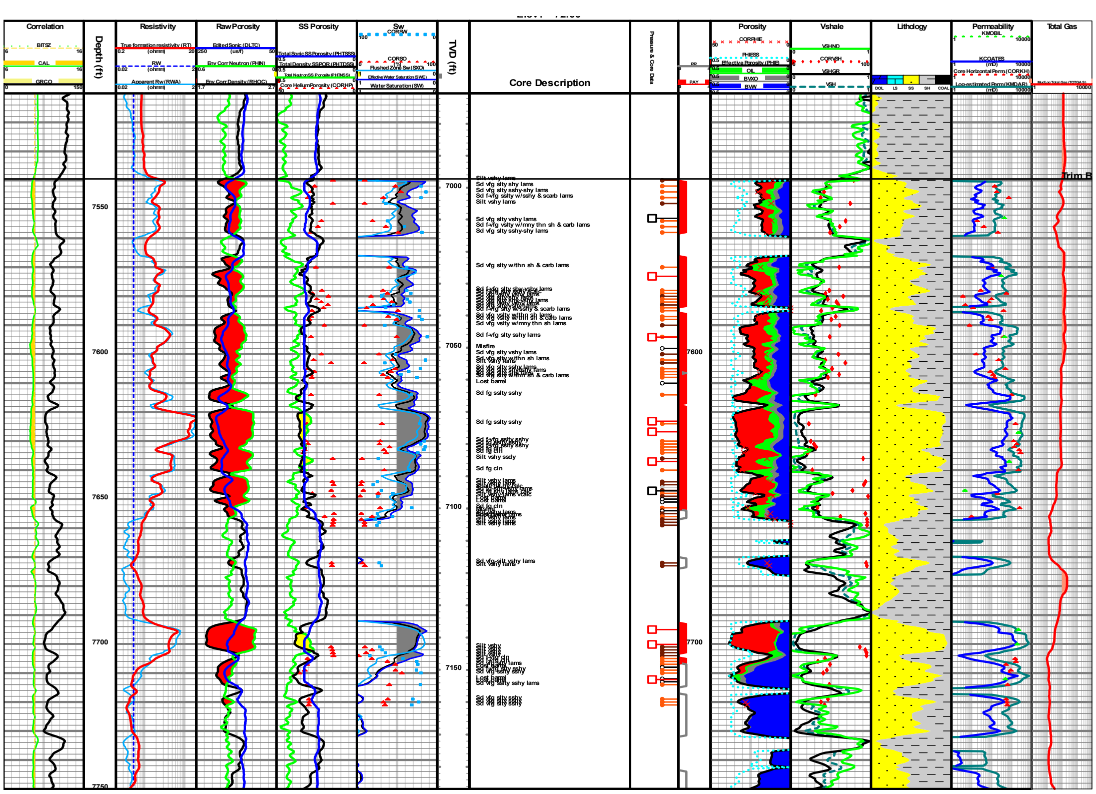
EXAMPLE

VSH LIM = 0.63



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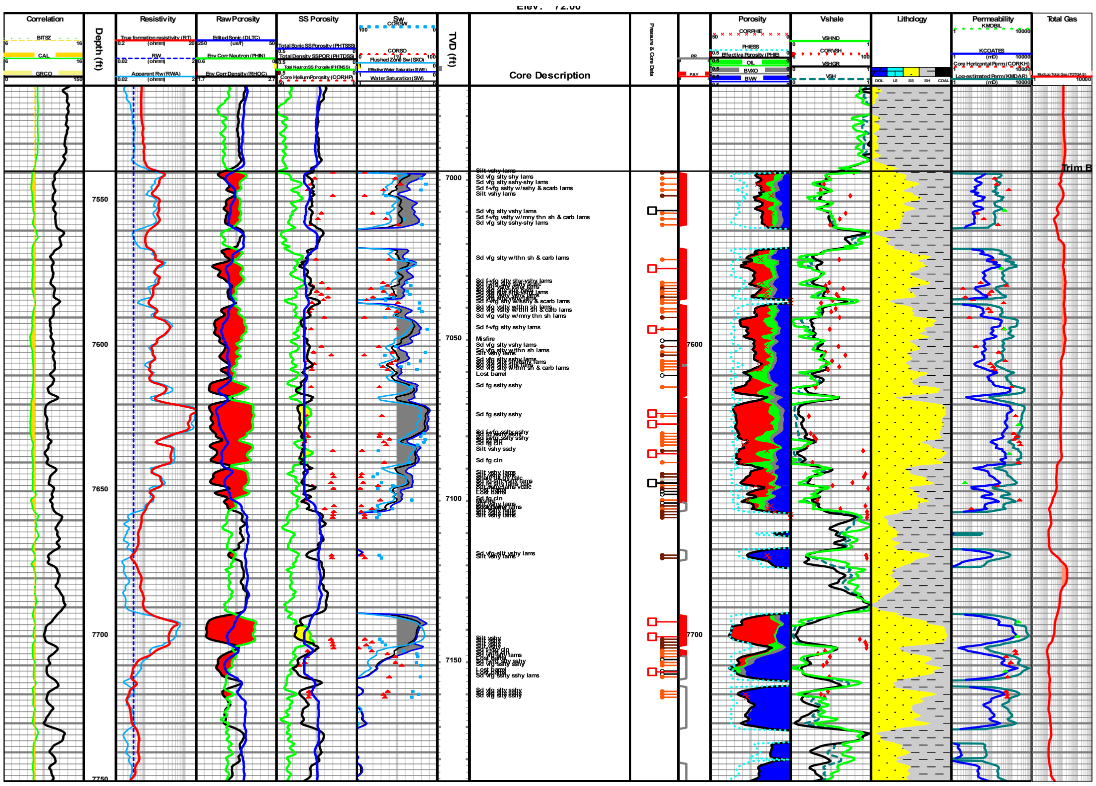
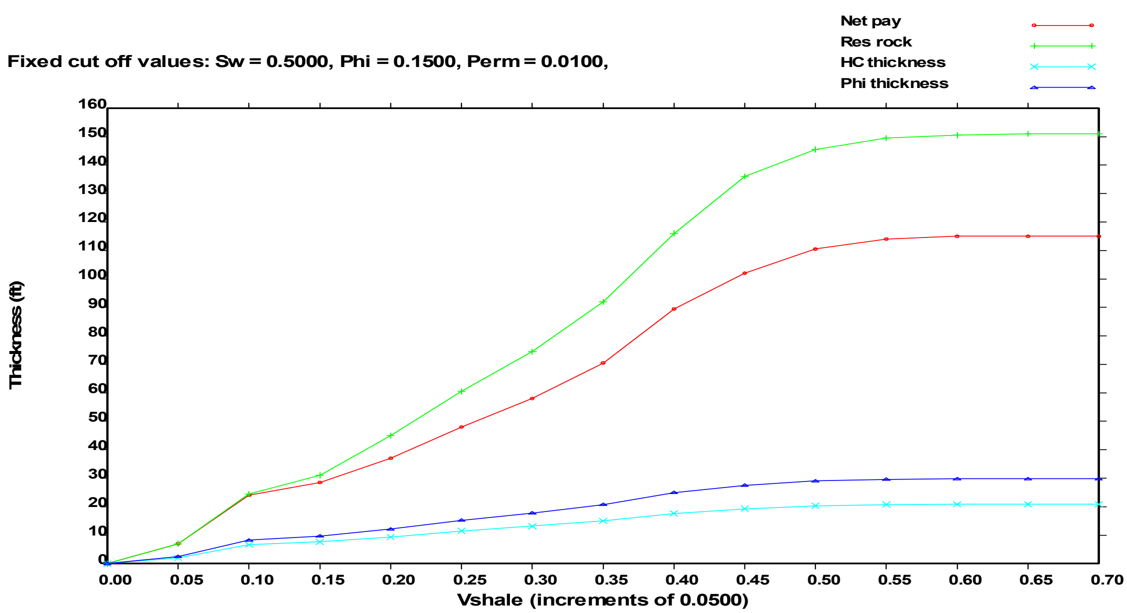
EXAMPLE

VSH LIM = 0.63



EXAMPLE

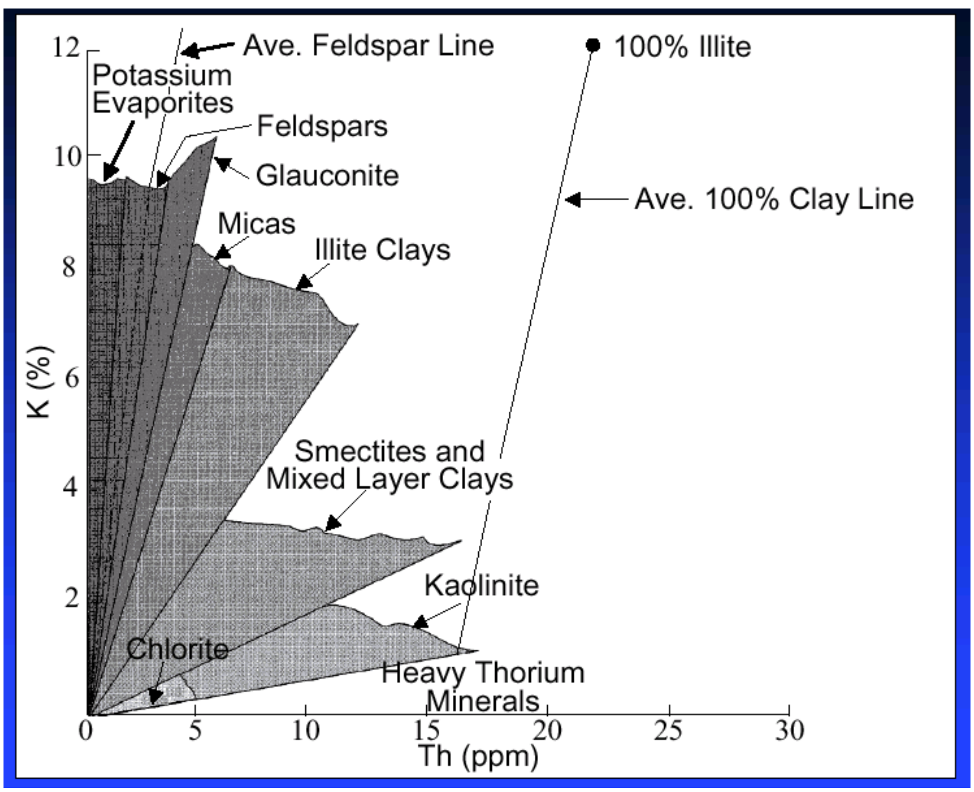


Vshale	0.00	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70
Net pay	0.0	7.0	24.0	28.5	37.0	48.0	58.0	70.5	89.5	102.0	110.5	114.0	115.0	115.0	115.0
Res rock	0.0	7.0	24.5	31.0	45.0	60.5	74.5	92.0	116.0	136.0	145.5	149.5	150.5	151.0	151.0
HC thickness	0.0	2.0	6.6	7.7	9.4	11.5	13.2	15.0	17.6	19.3	20.4	20.8	20.9	20.9	20.9
Phi thickness	0.0	2.5	8.2	9.7	12.1	15.2	17.7	20.8	25.0	27.5	29.0	29.6	29.8	29.8	29.8

CLAY MINERAL IDENTIFICATION

- Clay minerals show different **Th/K** ratios for different mineral composition
- Used for clay mineral identification
- Combination with other properties (**Pe**, neutron) recommended

MINERAL IDENTIFICATION



Several Water Saturation Models

Shale-Free Electrical Model

- **Archie (1942)**

Laminated Shale Electrical Model

- **Poupon-Leveaux (Indonesian)**

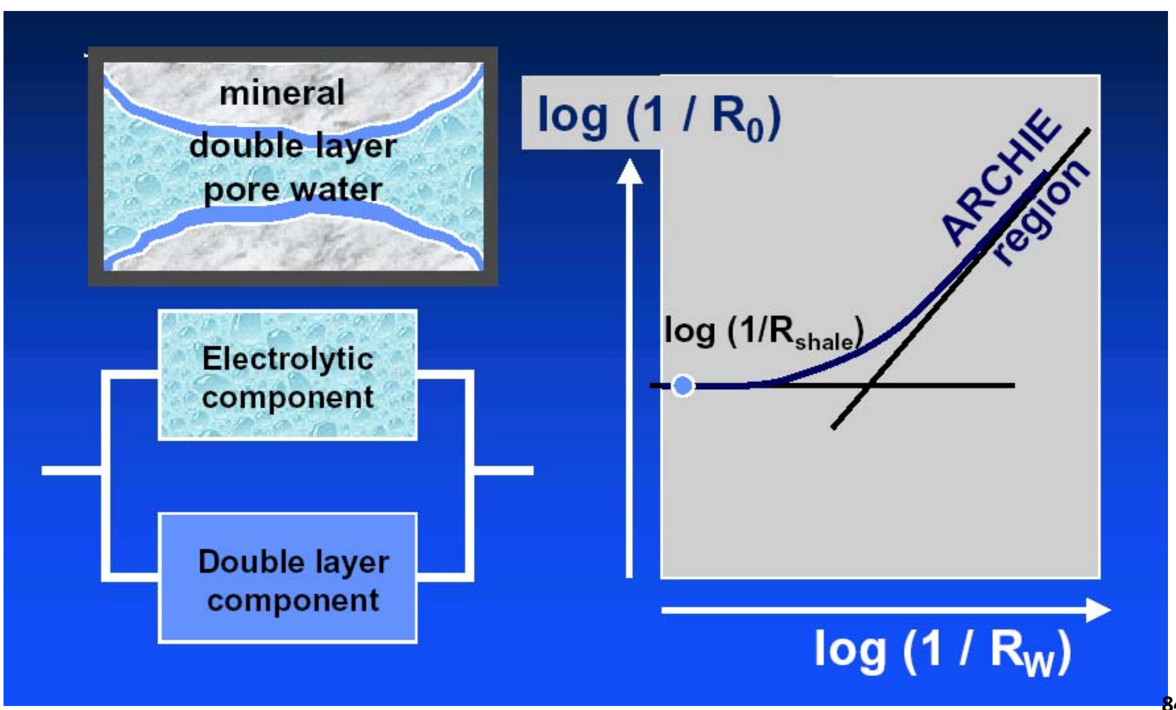
"Double-Layer" Dispersed Clay Electrical Models

- **Waxman-Smits**
- **Dual-Water**

Mixed Dispersed-Clay / Laminar-Shale Electrical Model

- **Patchett-Herrick**

PARALLEL CIRCUIT MODEL



CATION EXCHANGE CAPACITY (CEC)

Physical origin of clay conductance can be described by cation exchange capacity (CEC) phenomenon;

Unit: milliequivalent per 100 grams of dry clay;
CEC & specific surface for minerals (Olhoeft 1981, Keller & Frischknecht 1966, Boyd et al. 1995, Schön 1996)

Mineral	CEC (mequiv/100 g)	Surface area (m^2/g)
montmorillonite	80 … 150	82 … 767
chlorite	4 … 40	42
illite	10 … 40	97 … 113
glauconite	11 … 20	
kaolinite	3 … 15	15 … 23

Conceptual Models for Shaly Sand

Shaly sand

Second conductivity component is described as:

- shale conductivity
- shale volume
- shale distribution (laminar, dispersed, structural shale)

Second conductivity component is described as a double layer:

- cation exchange models (Waxman-Smits 1967)
- Dual-water model (Clavier et al. 1977)

Laminar Shaly Sand Model

(Poupon et al. 1954)

current direction

laminated shale
(clean) sand:

$V_{sh\text{-}lam}$

$1 - V_{sh\text{-}lam}$

Parallel conductor model:

$$\frac{1}{R_t} = \frac{V_{sh-lam}}{R_{sh}} + \frac{1 - V_{sh-lam}}{R_{sd}}$$

R_{sh} shale resistivity

R_{sd} sand resistivity

$$R_{sd} = R_W \cdot F \cdot S_W^{-n}$$

Calculation of Water Saturation

$S_W = ?$

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

$$S_w = \left(\frac{R_w}{R_t} \cdot \frac{a}{\phi^m} \right)^{\frac{1}{n}}$$

perfect world Archie is valid

$$\frac{1}{R_t} = \frac{V_{sh-lam}}{R_{sh}} + \frac{1 - V_{sh-lam}}{R_{sd}}$$

$$R_{sd} = (1 - V_{sh-lam}) \cdot \left(\frac{1}{R_t} - \frac{V_{sh-lam}}{R_{sh}} \right)^{-1}$$

$$R_{sd} = R_w \cdot F \cdot S_w^{-n} = R_w \cdot \frac{a}{\phi^m} \cdot S_w^{-n}$$

$$S_w = \left[R_w \cdot \left(\frac{1}{R_t} - \frac{V_{sh-lam}}{R_{sh}} \right) \cdot \frac{a}{\phi^m} \cdot \frac{1}{1 - V_{sh-lam}} \right]^{\frac{1}{n}}$$

shaly sand simplest model

Waxman-Smits Model

Terminology:

C_t conductivity of the shaly-sand

C_W conductivity of the formation-water

Φ porosity

S_W water-saturation

F^* formation factor for shaly sand

a, m, n Archie parameters

Q_v shaliness factor, cation exchange capacity per unit volume (meq cm^{-3})

B equivalent conductivity of sodium clay-exchange cations

Water-saturated shaly sand

$$\frac{1}{R_0} = C_0 = \frac{1}{F^*} \cdot (C_W + B \cdot Q_v)$$

Waxman-Smits Model

$S_w = 1$

$$\frac{1}{R_0} = C_0 = \frac{1}{F^*} \cdot (C_W + B \cdot Q_v)$$

$$R_0 = F^* \cdot \left(R_w^{-1} + B \cdot Q_v\right)^{-1}$$

mobility of the ions

$$B = \frac{-5.41 + 0.133 \cdot T - 1.253 \cdot 10^{-4} \cdot T^{-2}}{1 + R_w^{1.23} \cdot (0.025 \cdot T - 1.07)}$$

Juhasz (1981)

T in Fahrenheit

$$B = \frac{-1.28 + 0.255 \cdot T - 4.059 \cdot 10^{-4} \cdot T^{-2}}{1 + R_w^{1.23} \cdot (0.045 \cdot T - 0.27)}$$

T in Celsius

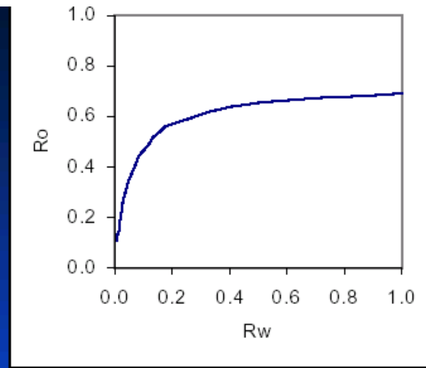
charge per unit pore volume

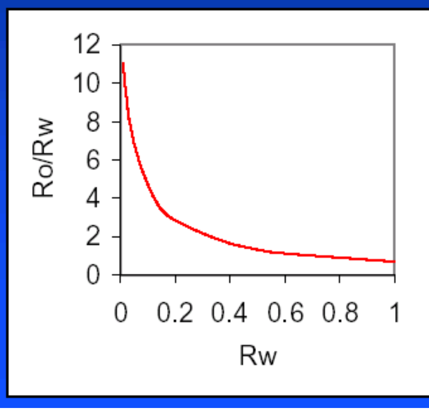
$$Q_v = CEC \cdot \frac{1-\phi}{\phi} \cdot \rho_{\text{mineral}}$$

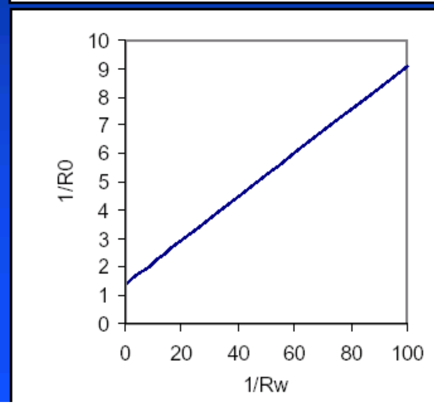
Example: Waxman-Smits Model, Sw =1

$$R_0 = F^* \cdot \left(R_w^{-1} + B \cdot Q_v\right)^{-1}$$

				Rw	R0	R0/Rw
ϕ =	0.25					
F =	12.96			0.01	0.11	11.00
a =	0.81			0.02	0.19	9.56
m =	2			0.05	0.34	6.86
B =	14			0.1	0.47	4.67
Qv =	1.27			0.2	0.57	2.84
				0.5	0.66	1.31
				1	0.69	0.69







Example: Waxman-Smits Model, Sw =?

Sw = ?

$$\frac{1}{R_t} = \frac{S_w^n}{F^*} \cdot \left(\frac{1}{R_w} + \frac{B \cdot Q_v}{S_w}\right)$$

assume n = 2:

$$\frac{1}{R_t} = \frac{S_w^2}{F^*} \cdot \left(\frac{1}{R_w} + \frac{B \cdot Q_v}{S_w}\right) = \frac{1}{F^*} \cdot \left(\frac{S_w^2}{R_w} + B \cdot Q_v \cdot S_w\right)$$

explicit solution

$$S_w = \left(\frac{F^* \cdot R_w}{R_t} + \left(\frac{B \cdot Q_v \cdot R_w}{2}\right)^2\right)^{\frac{1}{2}} - \left(\frac{B \cdot Q_v \cdot R_w}{2}\right)$$

Example: Waxman-Smits Model, Sw =?

Sw = ?

$$\frac{1}{R_t} = \frac{S_w^n}{F^*} \cdot \left(\frac{1}{R_w} + \frac{B \cdot Q_v}{S_w} \right)$$

n ≠ 2: no explicit solution --> iteration

$$S_w = \left(\frac{F^* \cdot R_w}{R_t \cdot \left(1 + \frac{B \cdot Q_v \cdot R_w}{S_w} \right)} \right)^{\frac{1}{n}}$$

start with assumption for Sw and calculate iteratively

Example: Waxman-Smits Model, Sw =?

Example 1 (Introduction to Wireline Log Analysis/Baker Atlas, p. 260)

Given:
a = 0.81 m = 2.0 n = 2.0
Rw = 0.05 ohm-m B Q_v = 17 ϕ = 25 % Rt = 10 ohm-m

1. Calculation based on ARCHIE equation:

$$S_w = \left(\frac{R_w}{R_t} \cdot \frac{a}{\phi^m} \right)^{\frac{1}{n}} = \sqrt{\frac{0.05}{10} \cdot \frac{0.81}{0.25^2}} = 0.254$$

Sw = 25 %

2. Calculation based on Waxman-Smits equation:

$$S_w = \left(\frac{F^* \cdot R_w}{R_t} + \left(\frac{B \cdot Q_v \cdot R_w}{2} \right)^2 \right)^{\frac{1}{2}} - \left(\frac{B \cdot Q_v \cdot R_w}{2} \right)$$

$$= \left(\frac{0.81}{0.25^2} \frac{0.05}{10} + \left(\frac{14 \cdot 1.27 \cdot 0.05}{2} \right)^2 \right)^{\frac{1}{2}} - \left(\frac{14 \cdot 1.27 \cdot 0.05}{2} \right)$$

$$= \left(0.0648 + (0.4445)^2 \right)^{\frac{1}{2}} - 0.4445 = 0.067$$

Sw = 7 %

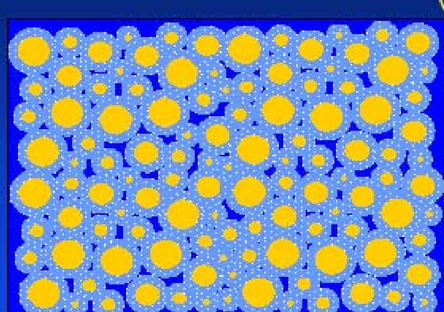
TABLE 6-1 – A Few of the Many Shaly Sand Saturation Equations

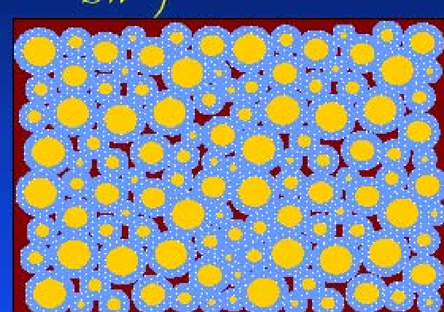
Simandoux	$C_t = \frac{C_w}{F} S_w^2 + \varepsilon V_{sh} C_{sh}$	1	ε = 1 for high S_w; ε < 1 for low S_w.
Schlumberger	$C_t = \frac{C_w}{F(1 - V_{sh})} S_w^2 + V_{sh} C_{sh} S_w$	2	F relates to the free fluid porosity of the total rock volume, inclusive of intra-formational (laminated) shales.
Clavier *et al.*	$C_t = \frac{C_w}{F_o} S_w^2 + \frac{(C_{bw} - C_w v_Q Q_v)}{F_o} S_w$	2	Dual-water model. F_o relates to total interconnected porosity. S_w relates to the total interconnected pore space.
Waxman and Smits	$C_t = \frac{C_w}{F*} S_w^2 + \frac{BQ_v}{F*} S_w$	2	$F*$ relates to total interconnected porosity. S_w relates to total interconnected pore space.
Juhasz	$C_t = \frac{C_w}{F} S_w^2 + \left(\frac{C_{sh}}{F_{sh}} - C_w\right)\frac{V_{sh}\phi_{sh}S_w}{\phi}$	2	Normalized Waxman-Smits equation. $F = 1/\phi^m$ where ϕ is the porosity derived from the density log and corrected for hydrocarbon effects. $F_{sh} = \frac{1}{\phi_{sh}^m}$ where ϕ_{sh} is the shale porosity derived from the density log. S_w relates to total interconnected pore space.
Poupon and Leveaux	$C_t = \frac{C_w}{F} S_w^2 + 2\sqrt{\frac{C_w V_{sh}^{2-V_{sh}} C_{sh}}{F}} S_w^2 + V_{sh}^{2-V_{sh}} C_{sh} S_w^2$	3	"Indonesia" formula
Poupon and Leveaux	$C_t = \frac{C_w}{F} S_w^2 + 2\sqrt{\frac{C_w V_{sh} C_{sh}}{F}} S_w^2 + V_{sh}^2 C_{sh} S_w^2$	3	Simplified Indonesia formula for $V_{sh} \leq 0.5$

WAXMAN-SMITS "Dispersed Clay" Equation

Effective DC Resistivity Response

$$Sw^{n*} = \frac{a \cdot Rw}{\Phi^{m*} \cdot \left(1 + Rw \cdot B \cdot \frac{Qv}{Sw}\right)} \cdot \frac{1}{Rt}$$





Dispersed Clay

m* = Clay Corrected m

n* = Clay Corrected n

B = Temp & Salinity Factor

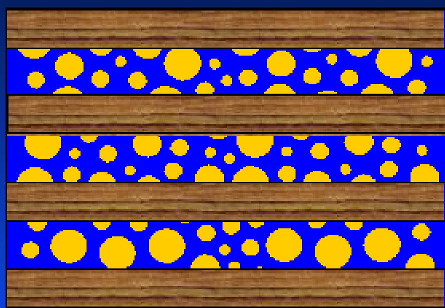
Qv = Clay Conductivity Factor

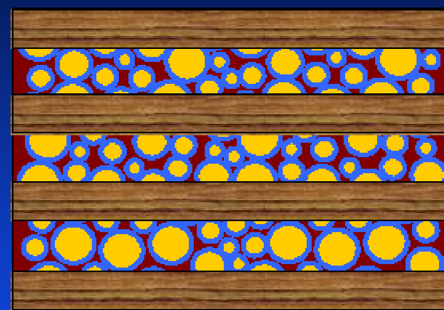
POUPON “Laminar Sand-Shale” Equation

Effective DC Resistivity Response

$$\frac{1}{Rt} = \frac{1}{Rsd}\cdot(1-Vlam) + \frac{1}{Rsh}\cdot Vlam$$

$$Sw^{n} = \left[\frac{1}{(1-Vlam)}\cdot\frac{a\cdot Rw}{\Phi^{m}}\right]\cdot\left[\frac{1}{Rt}-\frac{Vlam}{Rsh}\right]$$





Rt = Total Resistivity
Rsd = Sand Resistivity
Rsh = Laminar Shale Resistivity
Vlam = Laminar Shale Volume

Laminar Shale
Water Sand
Hydrocarbon Sand
Connate Water

PATCHETT-HERRICK (Poupon + Waxman-Smits) Equation

Effective DC Resistivity Response

$$Sw^{n^*} = \left[\frac{1}{(1-Vlam)}\cdot\frac{a\cdot Rw}{\Phi^{m^*}\cdot\left(1+Rw\cdot B\cdot\frac{Qv}{Sw}\right)}\right]\cdot\left[\frac{1}{Rt}-\frac{Vlam}{Rsh}\right]$$

Dispersed Clay
Laminar Shale

m* = Clay Corrected m
n* = Clay Corrected n
B = Temp & Salinity Factor
Qv = Clay Conductivity Factor

Laminar Shaly Sand Model

(Poupon et al. 1954)

current direction

laminated shale
(clean) sand:

$V_{sh\text{-}lam}$

$1 - V_{sh\text{-}lam}$

Parallel conductor model:

$$\frac{1}{R_t} = \frac{V_{sh-lam}}{R_{sh}} + \frac{1 - V_{sh-lam}}{R_{sd}}$$

R_{sh} shale resistivity

R_{sd} sand resistivity

$$R_{sd} = R_W \cdot F \cdot S_W^{-n}$$

Anisotropic Sand-Shale Resistivity Model

Case of Electrically Isotropic Shale

Horizontal Resistivity

$$\frac{1}{R_H} = \frac{V_{sh\text{-}lam}}{R_{sh}} + \frac{1 - V_{sh\text{-}lam}}{R_{sand}}$$

Vertical Resistivity

$$R_V = V_{sh\text{-}lam} \cdot R_{sh} + \left(1 - V_{sh\text{-}lam}\right) \cdot R_{sand}$$

Solve for R_{sand}

Anisotropic Sand-Shale Resistivity Model
Case of Transversely-Isotropic (TI) Shale

Horizontal Resistivity

$$\frac{1}{R_H} = \frac{V_{sh\text{-}lam}}{R_{H-sh}} + \frac{1 - V_{sh\text{-}lam}}{R_{sand}}$$

Vertical Resistivity

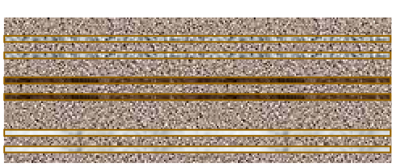
$$R_V = V_{sh\text{-}lam} \cdot R_{V-sh} + \left(1 - V_{sh\text{-}lam}\right) \cdot R_{sand}$$

Solve for R_{sand}

Origin of Electrical Anisotropy

Laminated sand-shale sequences

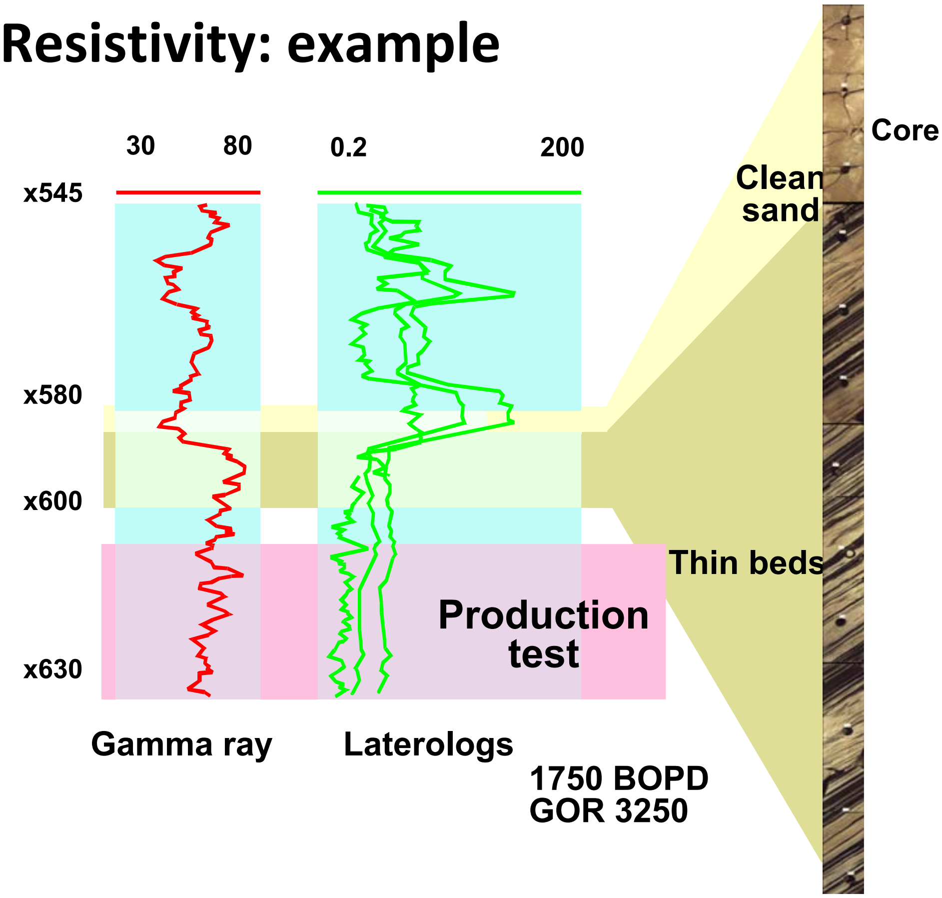
Sands With Different Grain Size



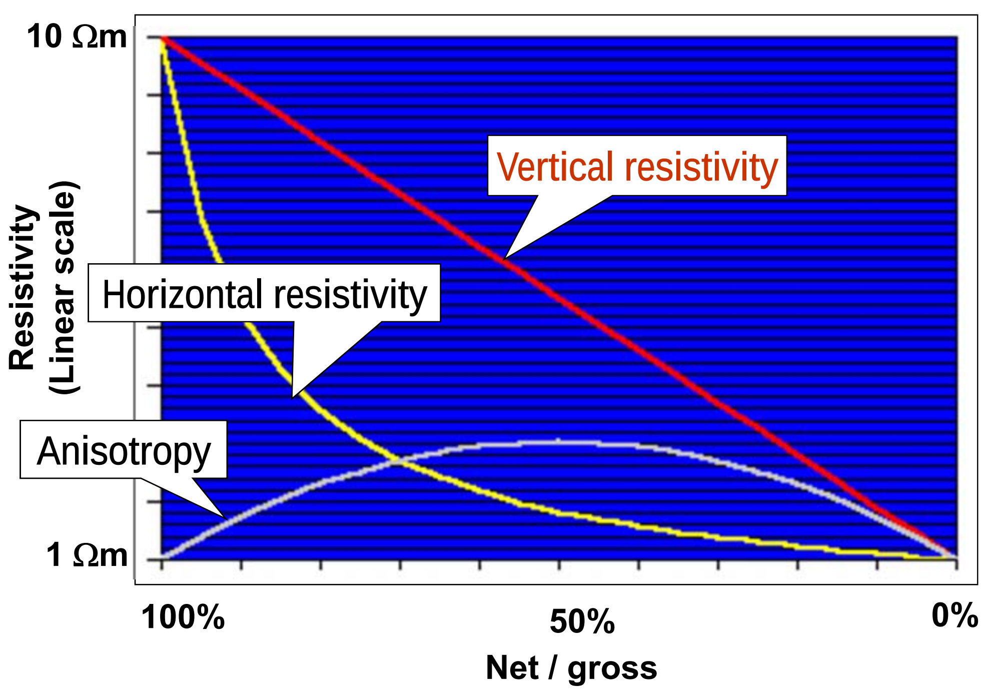
Thin resistive or conductive streaks

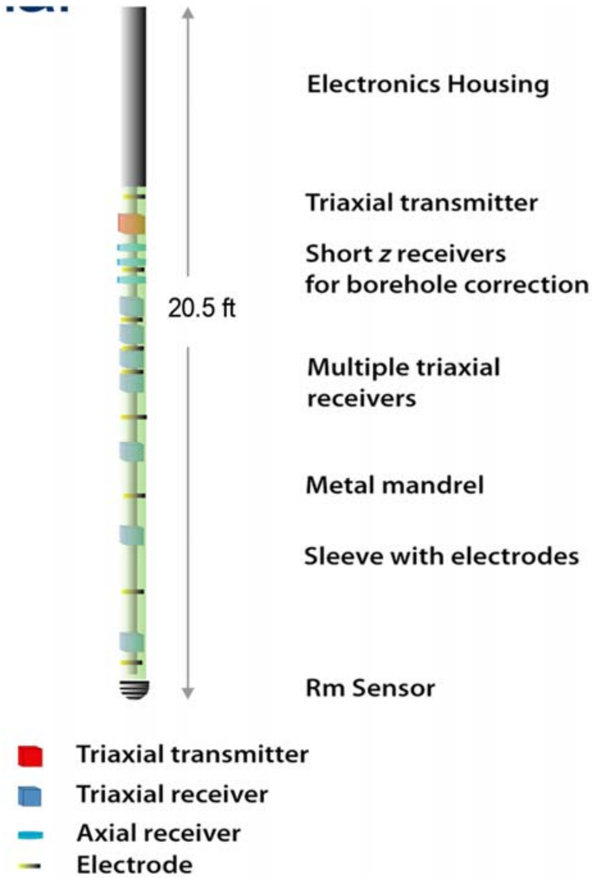
20-30% of global reserves in anisotropic reservoirs

Resistivity: example



Resistivity Response in Laminar Sand/Shale Sequences

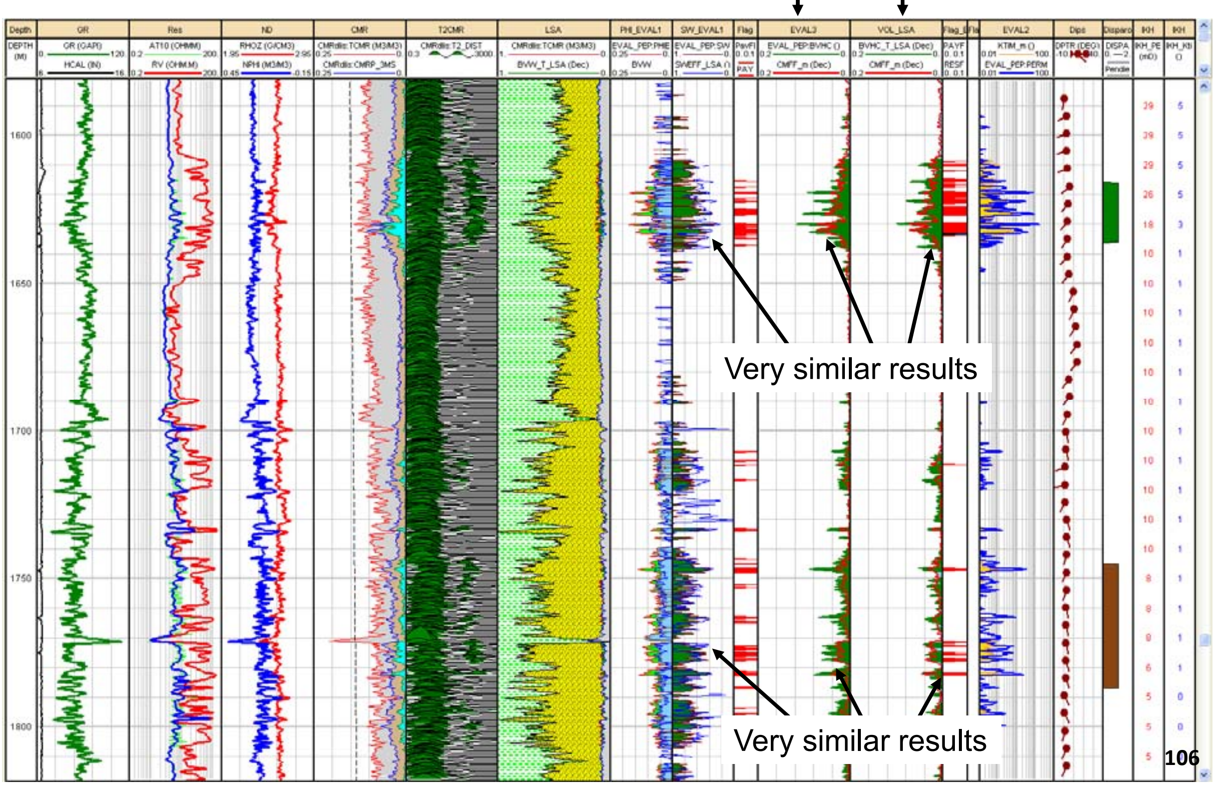




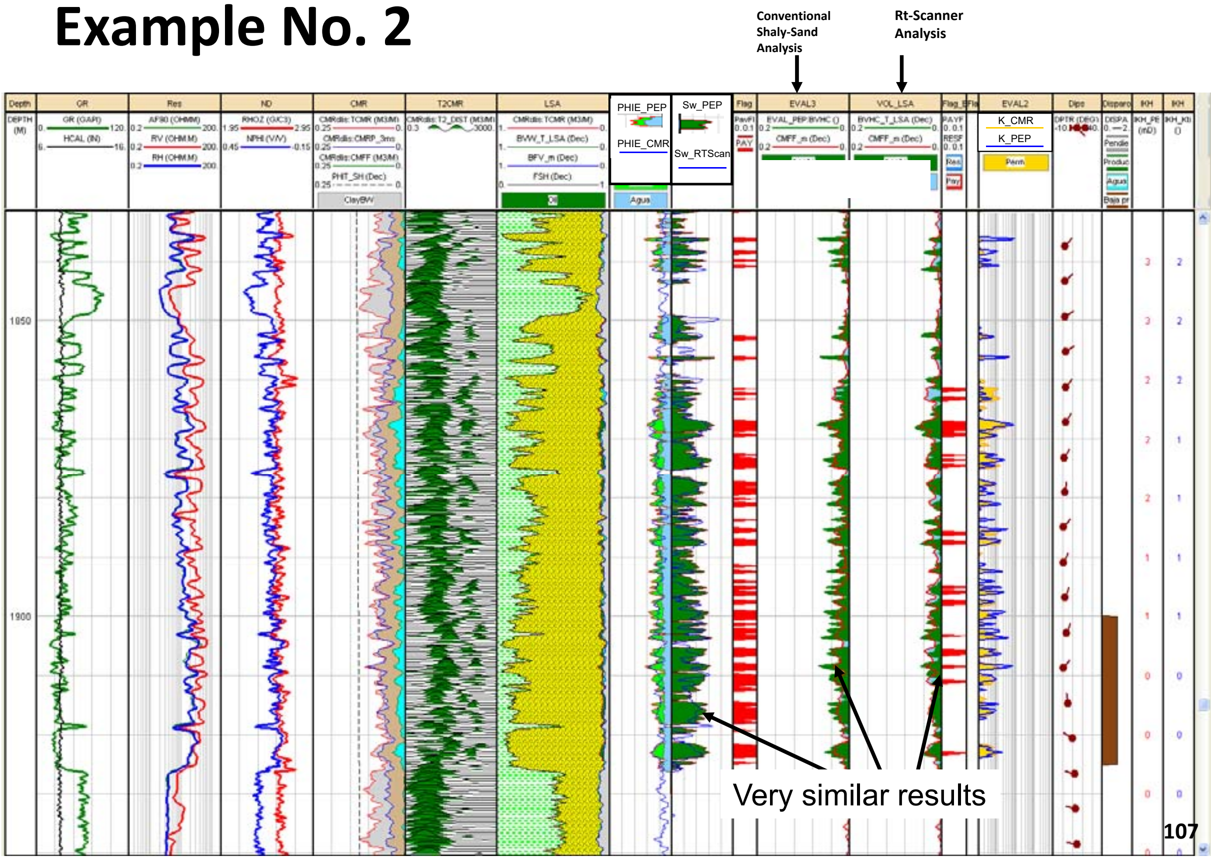
Schlumberger's Rt-Scanner Tool

Schlumberger

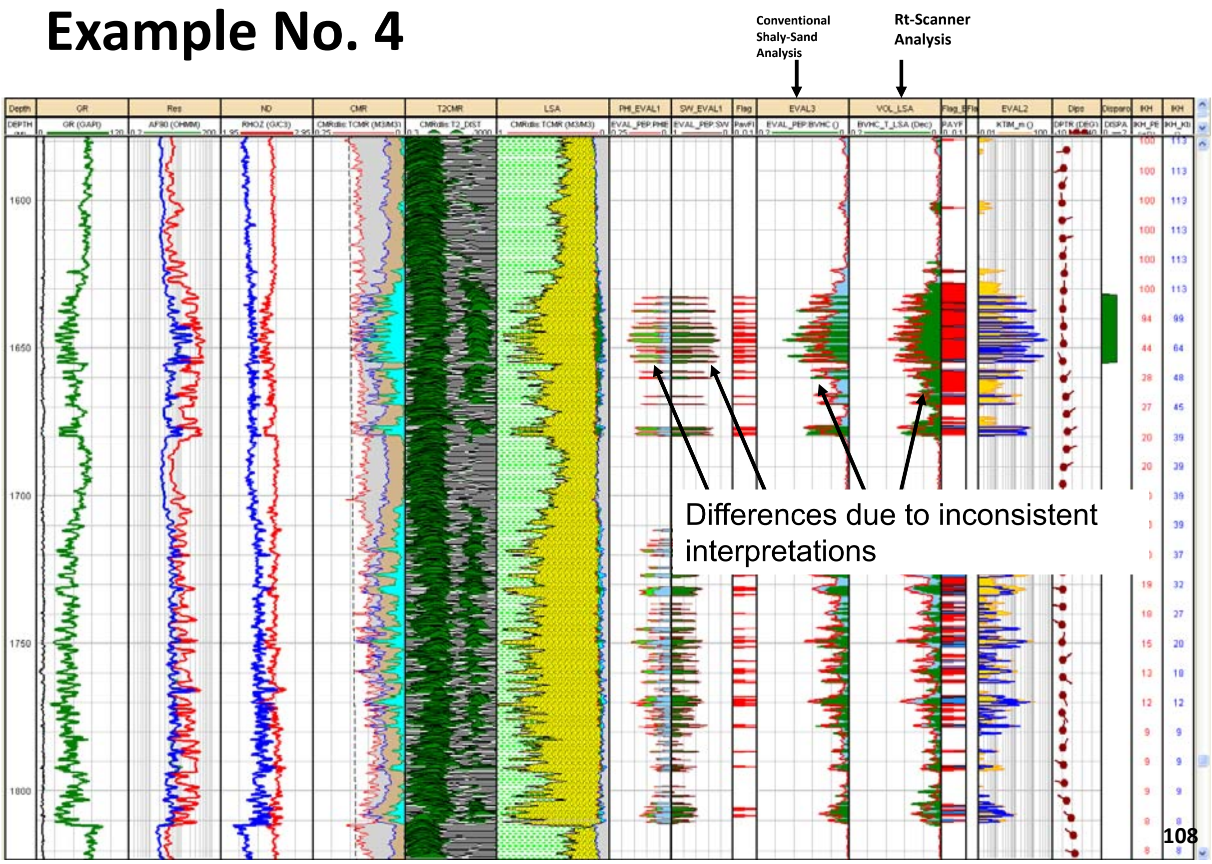
Example No. 1



Example No. 2

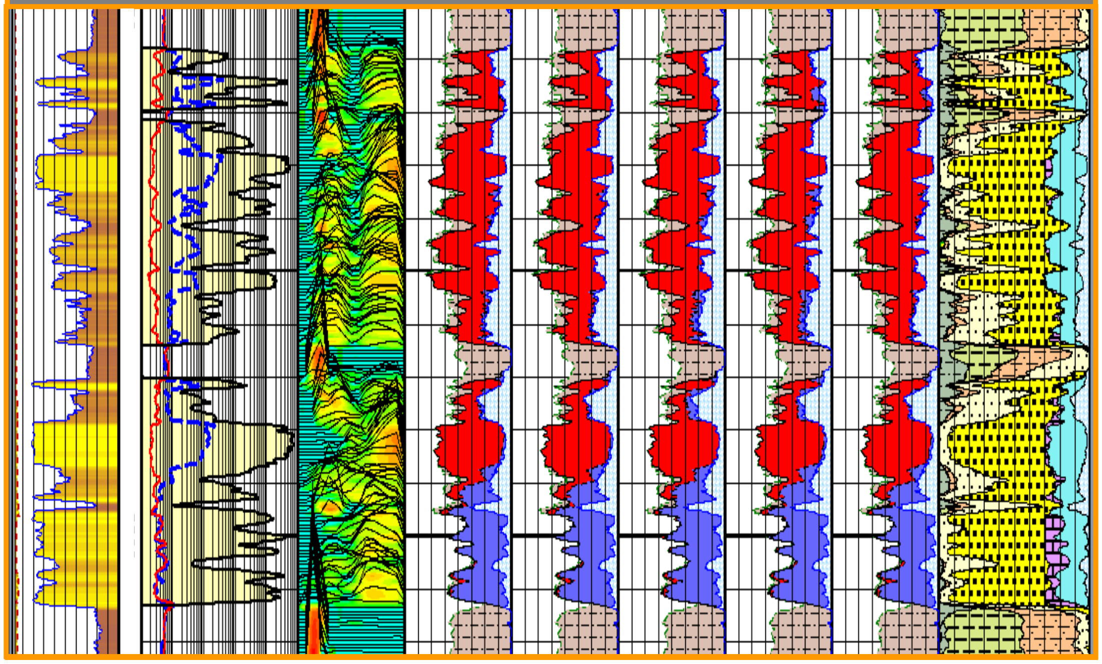


Example No. 4



MULTIPLE WATER SATURATION INTERPRETATIONS

GR & Caliper	Permeability & Resistivity	T_2 Spectra	Archie	Waxman Smits	Dual Water	Poupon - Leveaux	Patchett - Herrick	Formation Volumetrics



Acknowledgements:

- Baker Atlas
- Schlumberger