Resistivity Log

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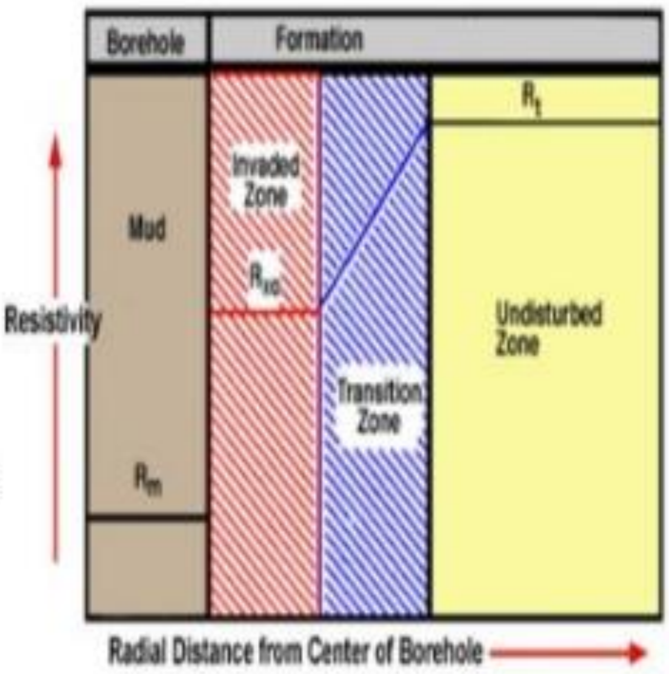
Resistivity: The Degree to which the subsurface resist flow of current to pass through.

Basics about the Resistivity :

- **Resistivity is the inverse of conductivity.**
- **Measures resistance of flow of electric current**
- **Is function of porosity & pore fluid in rock**
- **Resistivity measures the electric properties of the formation,**
- **Resistivity is measured as, R in ohm per m,**
- **The ability to conduct electric current depends upon:**
  - The **Volume** of water,
  - The **Temperature** of the formation,
  - The **Salinity** of the formation



Resistivity Principles

Common Terminology

Borehole

R_m: Borehole mud resistivity

R_{mc}: Mud cake resistivity

Invaded zone

R_{mf}: Mud filtrate resistivity

R_{xo}: Invaded zone resistivity

S_{xo}: Invaded zone water saturation

Uninvaded zone

R_w: Interstitial water resistivity

R_t: Uninvaded zone resistivity

S_w: Uninvaded zone water saturation

$$\text{Resistivity} = \frac{1}{\text{Conductivity}}$$

Increasing Resistivity ↑

(1) Rock
(2) Gas
(3) Oil
(4) Fresh Water
(5) Salt Water

↓ Increasing Conductivity

Electricity And Earth Materials

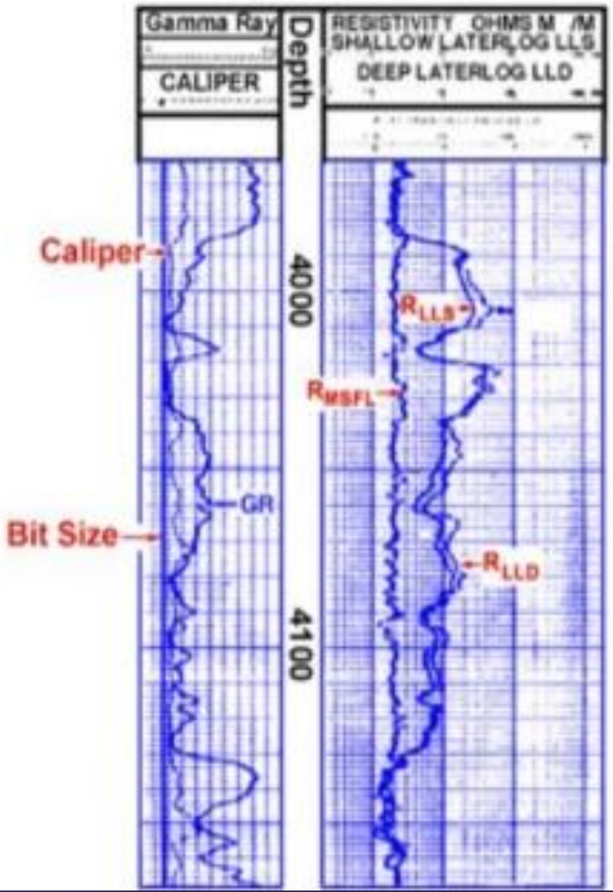
- Electrical conduction is by ions in water
- Na^+ and Cl^- are very common
- Other monovalent ions: K^+ and OH^-
- Common bivalent ions: Ca^{++}, Mg^{++}

Factors Affecting Resistivity

- Resistivity of water
- Porosity of the formation,
- Pore geometry - tortuosity
- Lithology of the formation
- Degree of cementation, and
- Type and amount of clay in the rock

The Usage:

- Resistivity logs are electric logs which are used to:
- **Determine Hydrocarbon versus Water-bearing zones,**
- **Indicate Permeable zones.**



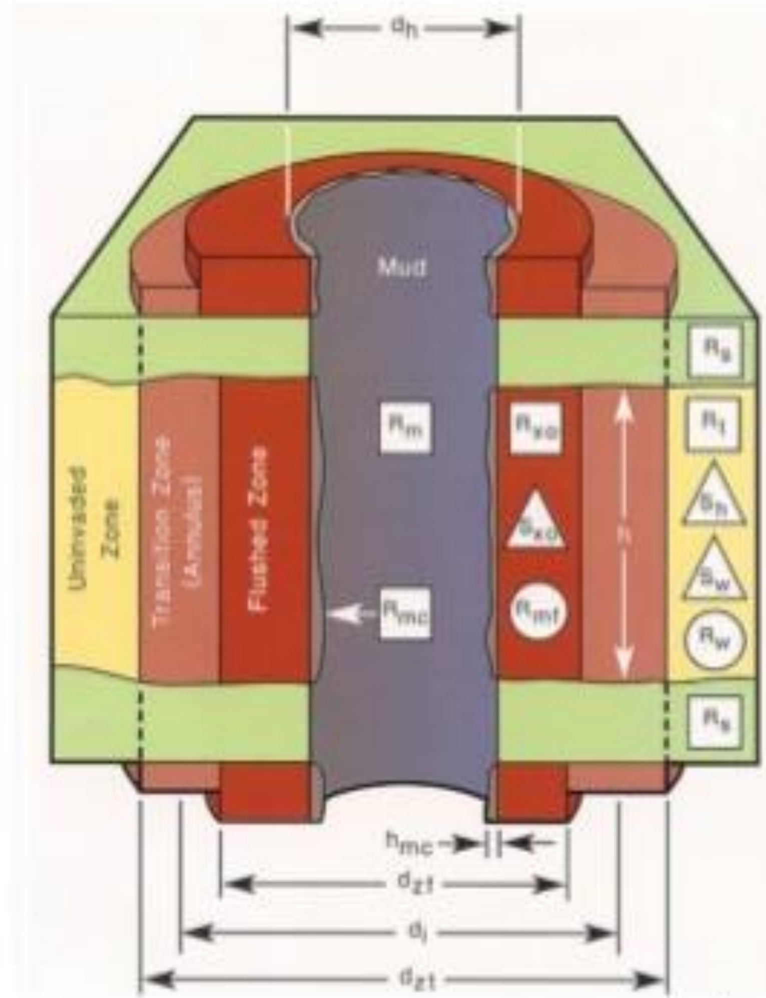
Uses

The resistivity of a formation depends on:

- Resistivity of the formation water.
- Amount of water present.
- Pore structure geometry.

Resistivity profiles around Borehole

- Formation water is typically saline and normally has a **low Rw.**
- Water used in drilling mud may be saline or fresh **Fresh water** has a **high Rmf.**
- The resistivity profile around a borehole depends on whether the mud uses **fresh or saline water or is oil based.**

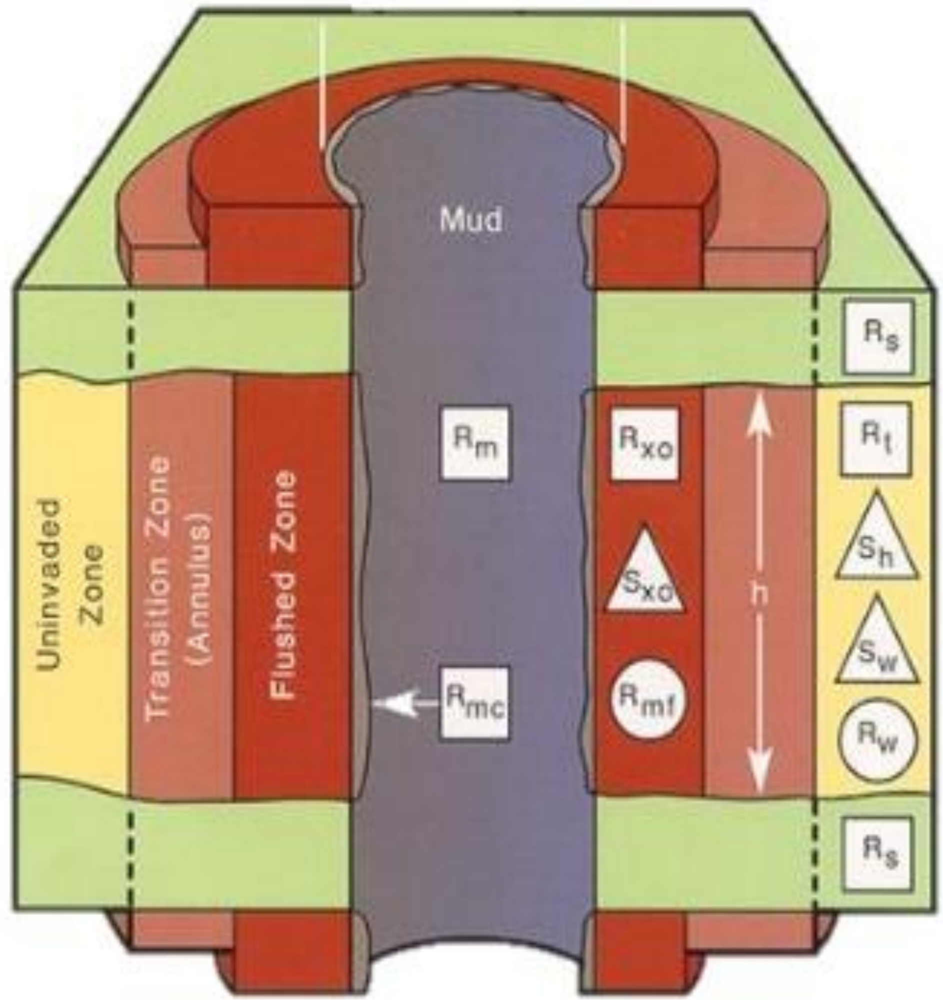


Borehole Environment

h : Bed Thickness
h_{mc} : Mudcake Thickness
d_h : Borehole Diameter
d_i : Diameter of flushed zone.
d_j : Diameter of Transition zone

S_{hy}: Hydrocarbon saturation
S_w : Water Saturation
S_{xo} : Flushed zone water saturation
S_{ro} : Residual HC. saturation

R_m : Mud resistivity
R_{mc} : Mudcake resistivity
R_{mf} : Mudfiltrate resistivity
R_s : Adjacent bed resistivity
R_t : True formation resistivity
R_{xo} : Flushed zone resistivity
R_w : Formation water resistivity



There are two general types of resistivity tools:

- **Electrode:** forces a current through the rock and measures resistivity.
- **Induction:** Uses a fluctuating electro-magnetic field to induce electrical currents in the rock; it measures conductivity which is converted to resistivity.

Various electrode logs and depth of measurement:

Flushed Zone	Invaded Zone	Un-invaded Zone
Microlog (ML)	Short Normal (SN)	Long Normal (LN)
Microlaterolog (MLL)	Laterolog8 (LL8)	Lateral Log
Proximity Log (PL)	Spherically Focused Log (SFL)	Deep Laterolog (LLD)
Microspherically Focused Log (MSFL)	Shallow Laterolog (LLs)	Laterolog 3 (LL3)
		Laterolog 7 (LL7)

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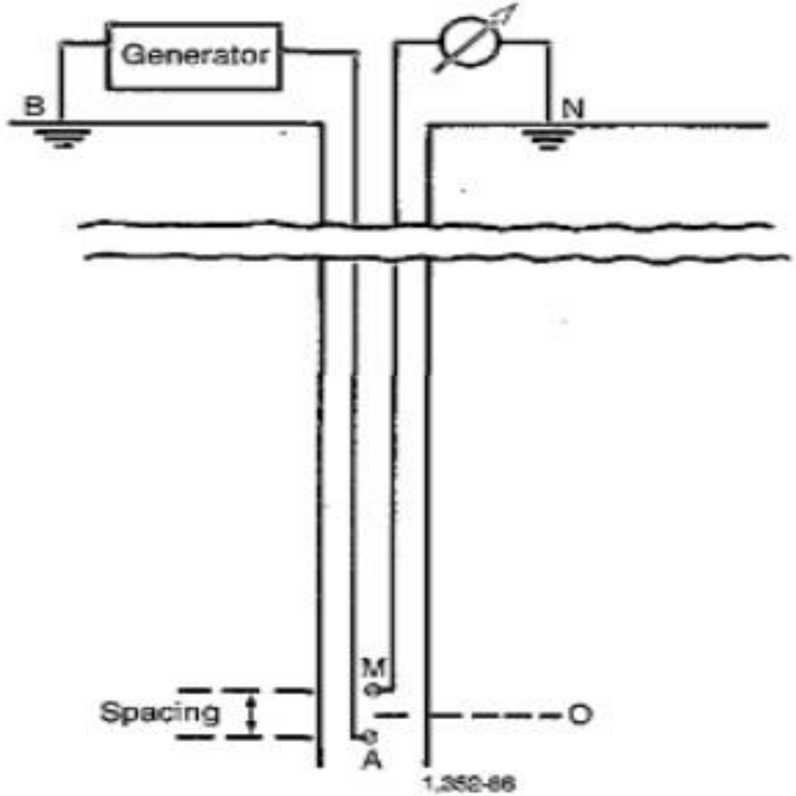
Resistivity Tools

- In the normal device a current of constant intensity is passed between **two electrodes, A and B.**
- **The resultant potential difference** is measured between two other electrodes, **M and N.**
- Electrodes **A and M** are on the sonde. B and N are, theoretically, located an infinite distance away.
- **The distance AM is called the spacing.**



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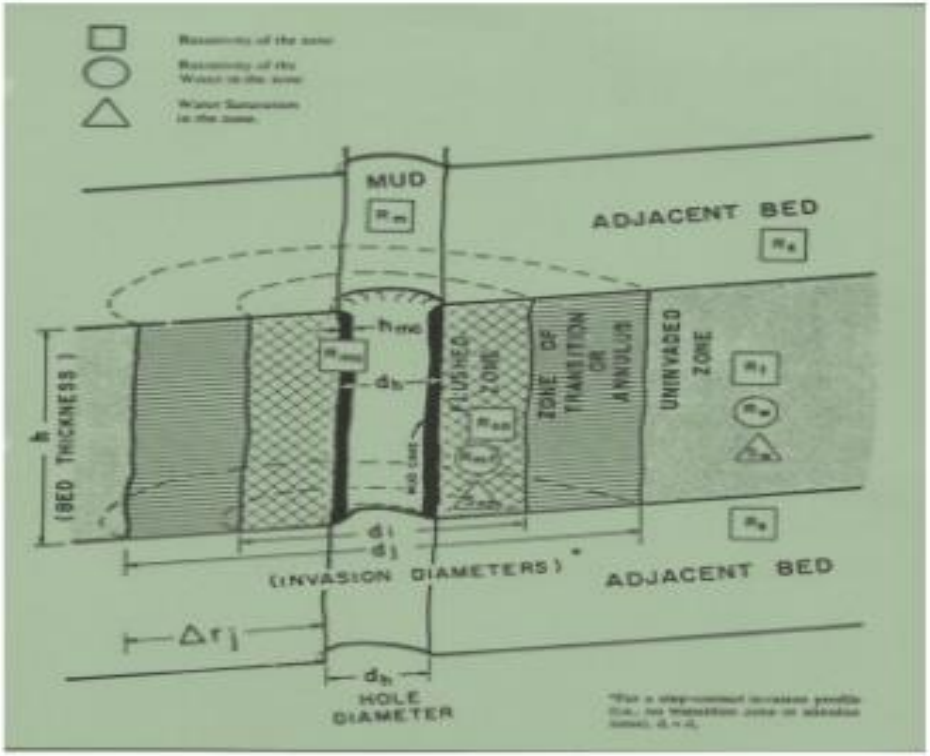
Resistivity log

Resistivity Logs are used to determine Water saturation, S_w and hydrocarbon zones, porosity and permeability.



Borehole Environment

- D_h = Hole Diameter
- R = Resistivity
- R_m = mud
- R_{mc} = mud cake
- R_{mf} = mud fluids (filtrate)
- R_{xo} = rock and filtrate
- R_t = rock and formation fluids

Borehole Environment

- **S_w,** water saturation can be estimated from a resistivity measurement using the *Archie Equation,* an empirical relationship derived from experiments done by G.E. Archie in 1942.

$$Sw = \left({R_0}/{R_t} \right)^{1/n}$$

- **R_0** is the resistivity of rock 100% saturated by water, and **R_t** is resistivity of same rock with formation fluids.

If,

- **R_w** = Resistivity of water in the rock pores (measured)
- **R_0** = Resistivity of rock 100% saturated by water of **R_w**.

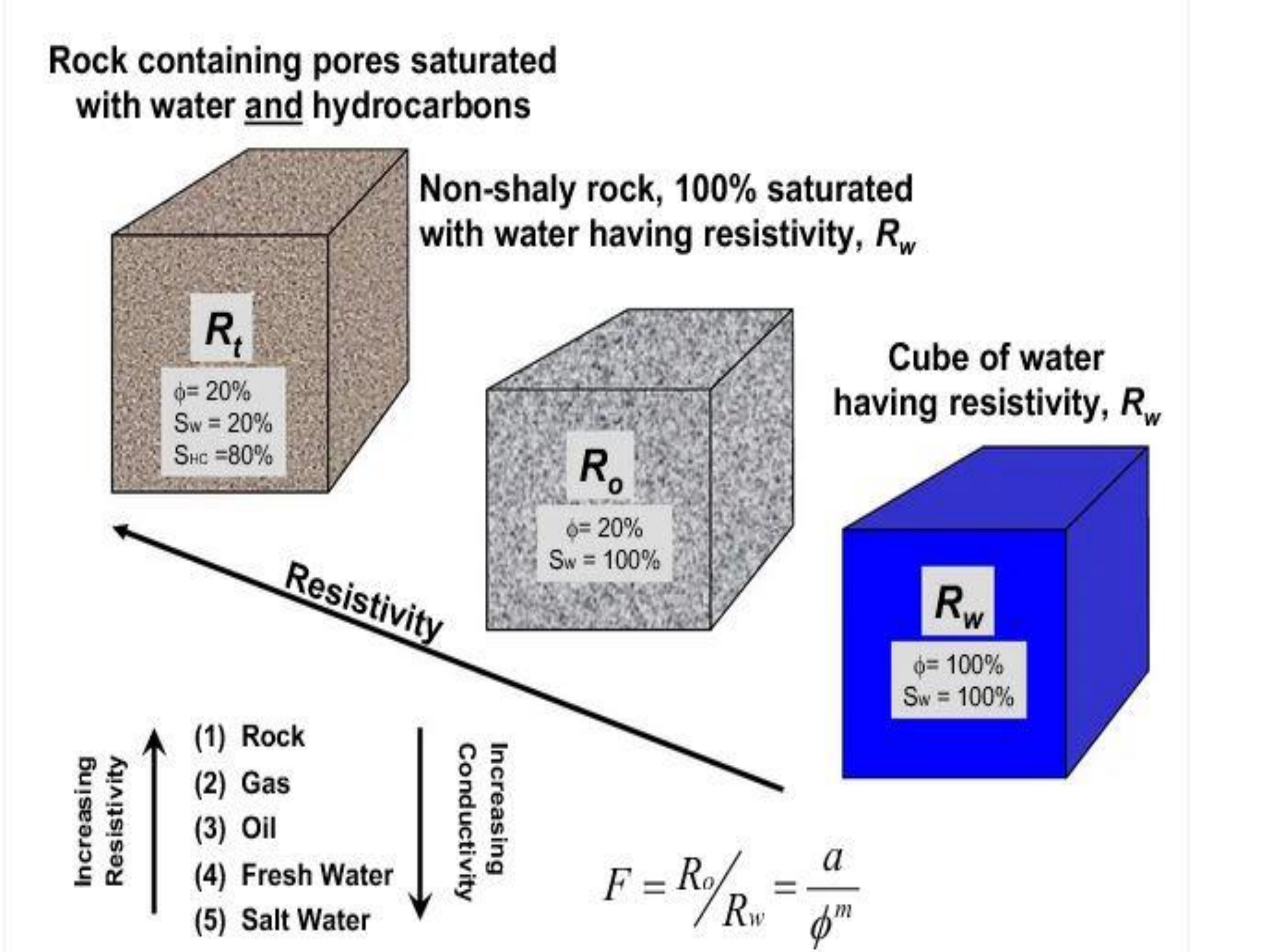
Then, a Formation Resistivity Factor (F) can be defined:

$$F = R_0/R_w,$$

and

$$R_0 = F\,R_w$$

Log review



Rock containing pores saturated with water and hydrocarbons
Non-shaly rock, 100% saturated with water having resistivity, R_w
Cube of water having resistivity, R_w
R_t
ϕ= 20%
S_w = 20%
S_{HC} =80%
R_o
ϕ= 20%
S_w = 100%
R_w
ϕ= 100%
S_w = 100%
Resistivity
Increasing Resistivity
(1) Rock
(2) Gas
(3) Oil
(4) Fresh Water
(5) Salt Water
Increasing Conductivity
$F = R_o / R_w = \frac{a}{\phi^m}$

- As the salt water content increases, the formation resistivity will decrease.
- A rock containing oil or gas will have a higher resistivity than the same rock completely saturated with salt water.
- As the shale content increases, the rock matrix will become more conductive.

Formation Factor

The formation factor (*F*) depends on:

- Porosity of the formation.
- Pore geometry.
- Lithology of the formation.
- Degree of cementation.
- Type and amount of clay in the rock.

- Based on experiments, Archie found that **F** could also be related to a tortuosity factor **(a)** the porosity **(ϕ)** and a "cementation exponent" **(m)** by

$$F = a/\Phi^m$$

- Combining these relationships produces the Archie Equation:

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

- **For clean sands, *n* = 2 is common.**
- **Like *a* and *m*, *n* is measured in the lab.**

N, F, a and m are experimentally determined, and there are tables for typical rock types.

R_w = resistivity of fluids in the rock and must be estimated at the well site.

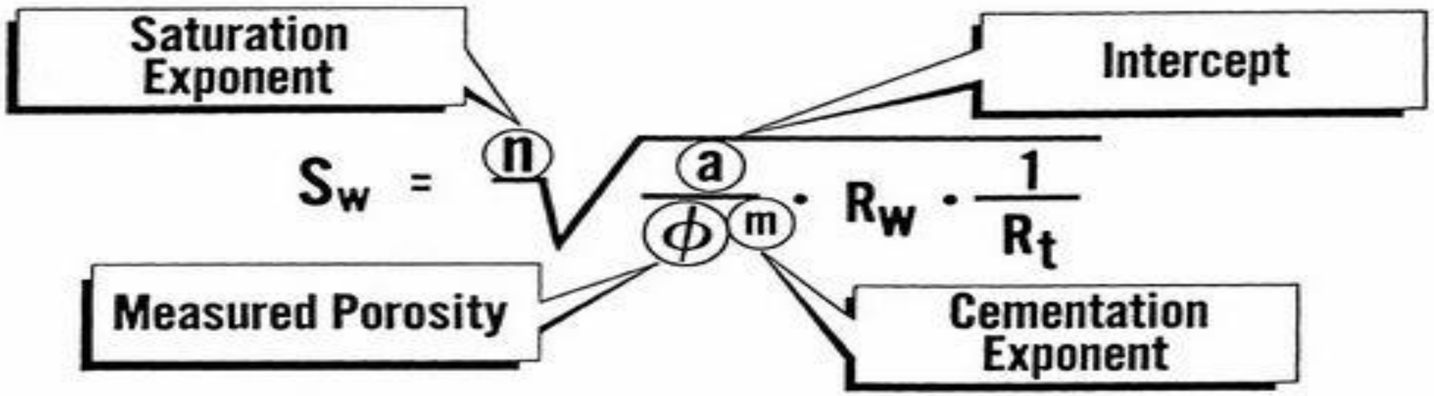
R_t is the resistivity of the combined rock and fluid measured by the logging tool.

Log review

- Experimentally determined formation factors for various lithologies.

$F = a/\phi^m$	general relationship Where: a = tortuosity factor† m = cementation exponent ϕ = porosity
††$F = 1/\phi^2$	for carbonates
††$F = 0.81/\phi^2$	for consolidated sandstones
††$F = 0.62/\phi^{2.15}$	Humble formula for unconsolidated sands
$F = 1.45/\phi^{1.54}$	for average sands (after Carothers, 1958)
$F = 1.65/\phi^{1.33}$	for shaly sands (after Carothers, 1958)
$F = 1.45/\phi^{1.70}$	for calcareous sands (after Carothers, 1958)
$F = 0.85/\phi^{2.14}$	for carbonates (after Carothers, 1958)
$F = 2.45/\phi^{1.08}$	for Pliocene sands, Southern California (after Carothers and Porter, 1970)
$F = 1.97/\phi^{1.29}$	for Miocene sands, Texas-Louisiana Gulf Coast (after Carothers and Porter, 1970)
$F = 1.0/\phi^{(2.05-\phi)}$	for clean granular formations (after Sethi, 1979)

Archie Relation for S_w



Rock Properties Influencing Calculated Water Saturations

From: Keelan, D.: "Special Core Analysis," Core Laboratories Report (1982).

Resistivity Porosity

Dual laterolog (DLL)	Induction Log
• **Measure the resistivity between two electrodes.**	• **Measure the Conductivity between two electrode.**
1. SFL : Shallow depth zone R_{xo}	1. MSFL: Shallow Depth R_{xo}, R_m, R_{mc} and R_{mf}.
2. LLS : Shallow to Medium zone R_{xo}, R_t.	2. ILM: Shallow to Medium R_{xo}, R_t.
3. LLD : Deep zone R_t.	3. ILD: Deep R_t.

Tools

- **Qualitative and Quantitative analysis:**

1. **Qualitative:**

- **High Resistivity deflection:**

1. Porous Rock (Fresh water OR Hydrocarbon).
2. Dry Rock (Anhydrite, Dolomite Or Limestone)

- **Low Resistivity:**

1. Shale
2. Porous rock bearing Saline water.

2. Quantitative:

Resistivity of

Shale 0.1 : 1 — Sand from 2.5

Resistivity Analysis

Helwan University

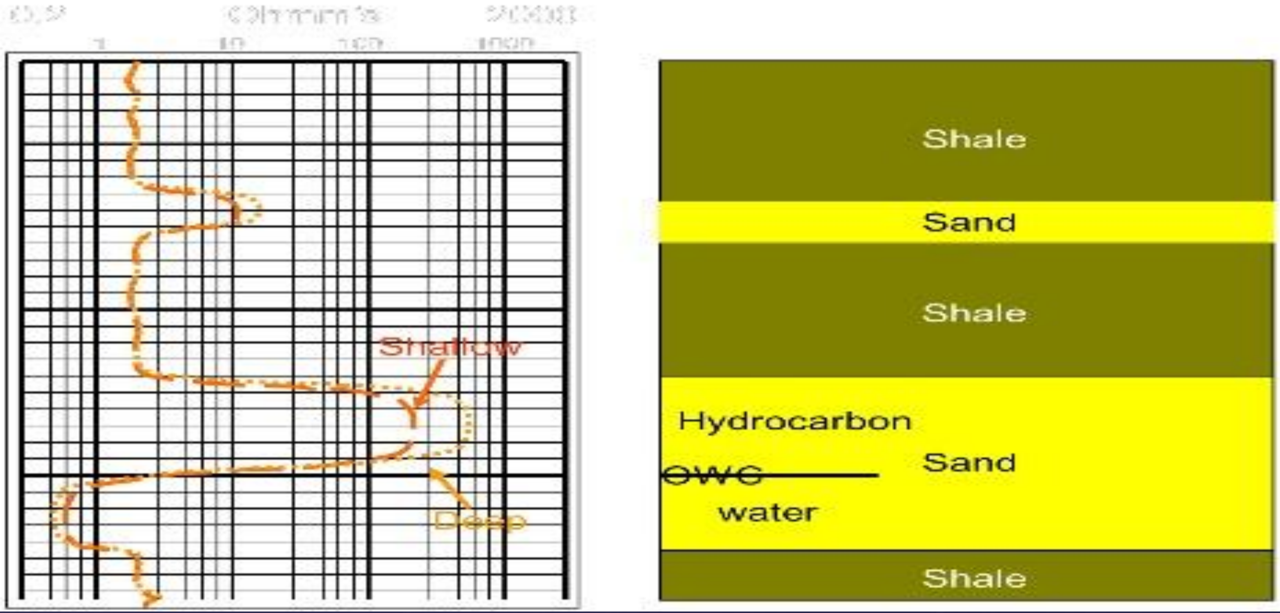
Res. Analysis

Fluid type:

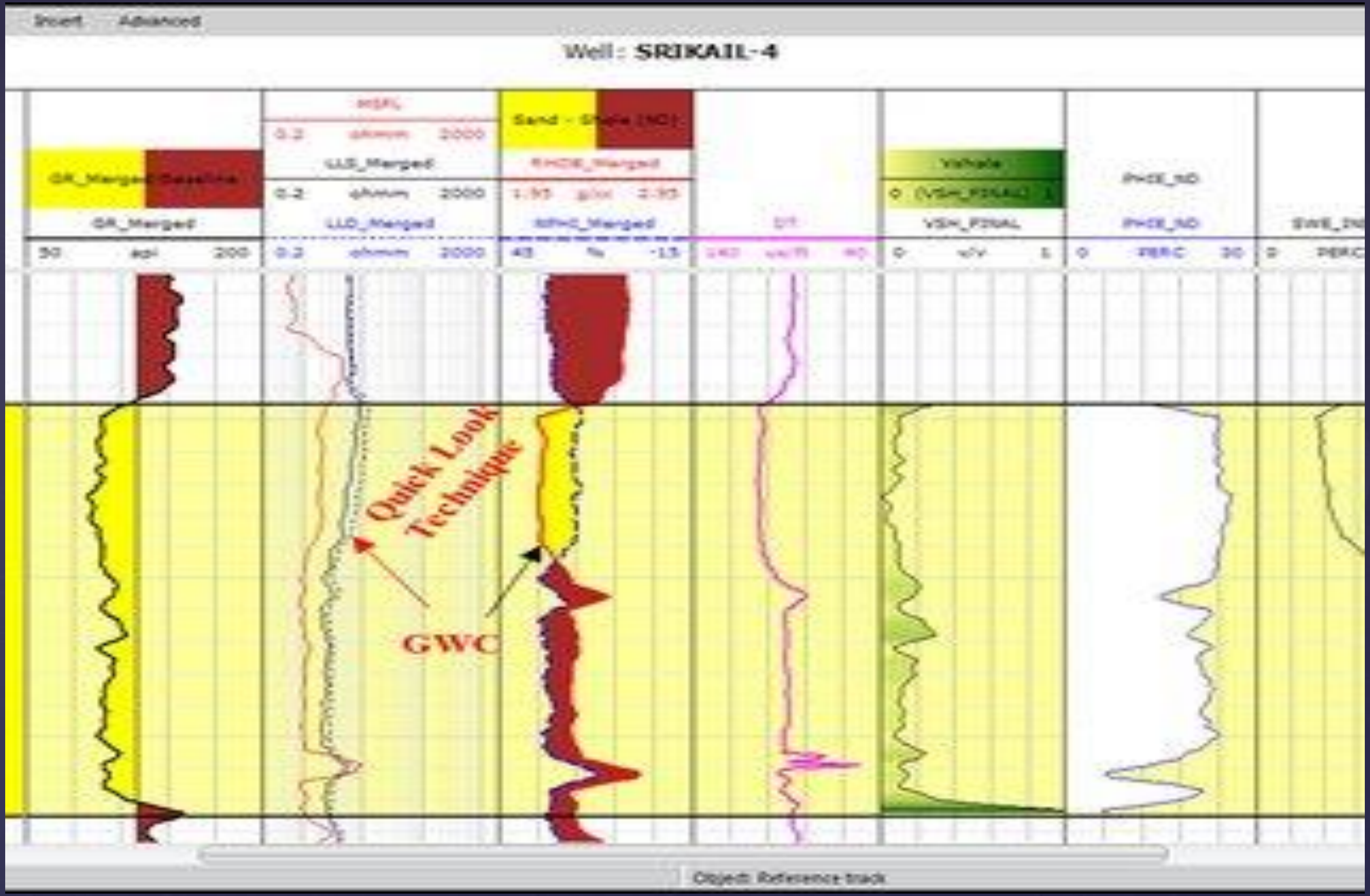
1. LLD > LLS and SFL : (OIL ZONE)

   WITH GOOD SEPARATION

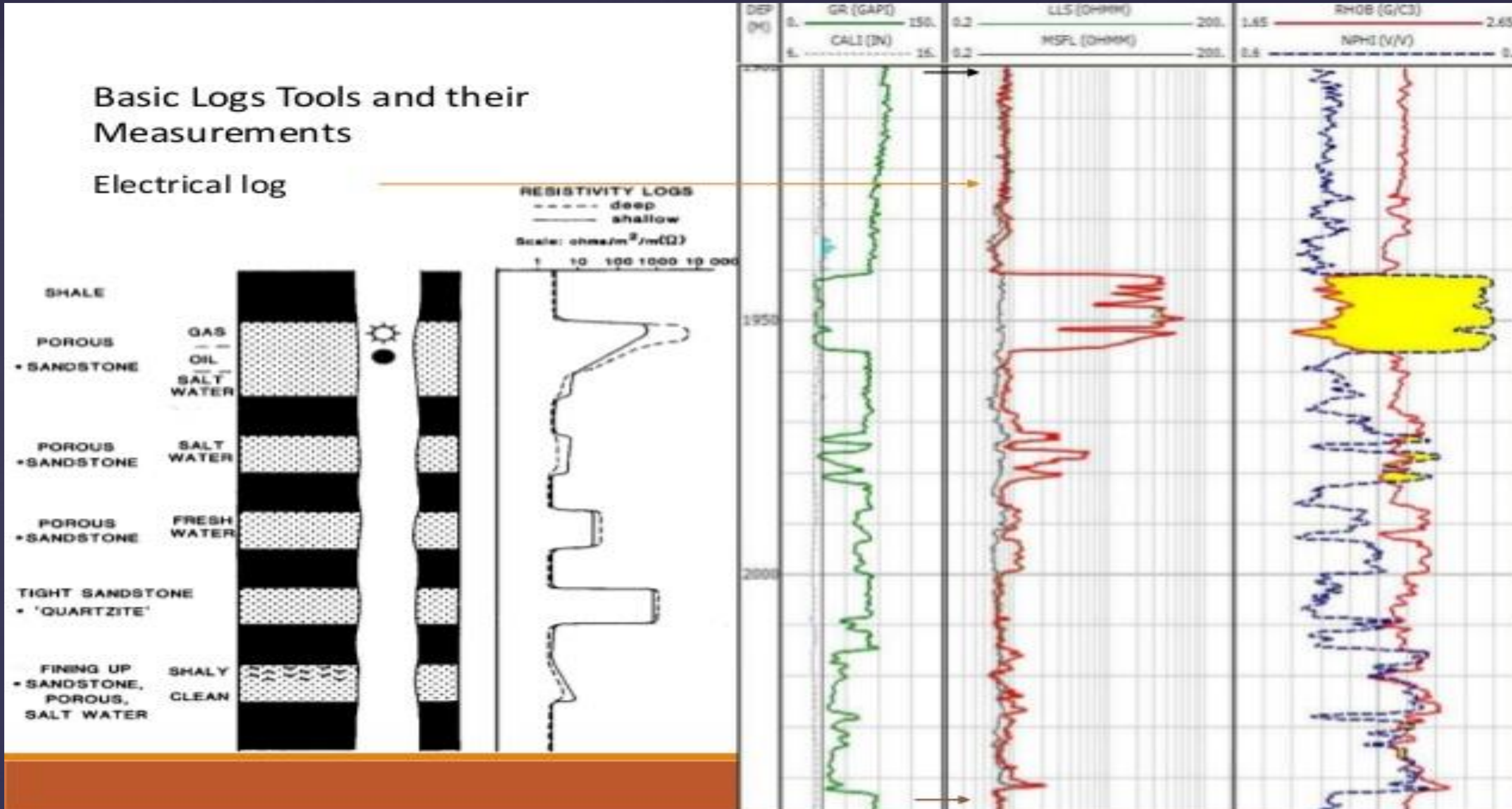
2. LLD < LLS and SFL : (WATER ZONE)



Resistivity Analysis



Quick Look or HC separation

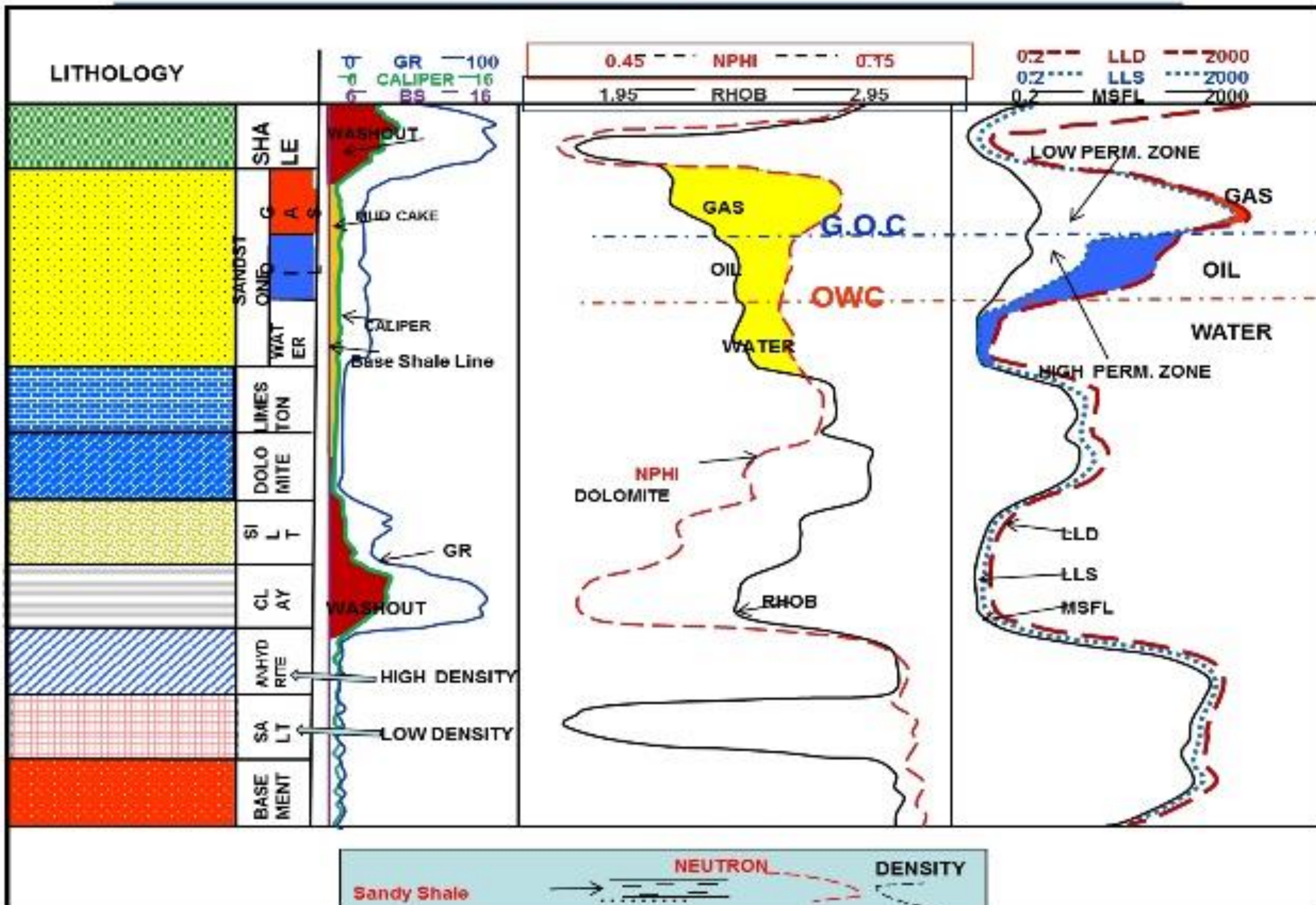


Quick Look or HC separation

Lithology		GR	Density	Neutron	Acoustic	Resistivity
Sandstone		Low (Unless RA min)	2.65	-4	55	high
Limestone		low	2.71	0	47.5	high
Shale		high	2.2-2.7 (water content)	High (water content)	50-150 (water content)	low (water content)
Dolomite		Low (higher if U)	2.85	+4	42.5	high
Anhydrite		V.low	2.95	-1	50	V.high
Salt		Low (Unless K salt)	2.1	0	67	V.high
Water		0	1-1.1 (salt and Temp)	100	180-190	0 - infinite (salt and Temp)
Oil		0	0.6-1.0 (api)	70-100 (H_2 index)	210-240 (api)	V.high
Gas		0	0.2-0.5 (pressure)	10-50 (H_2 index)	~1000	V.high

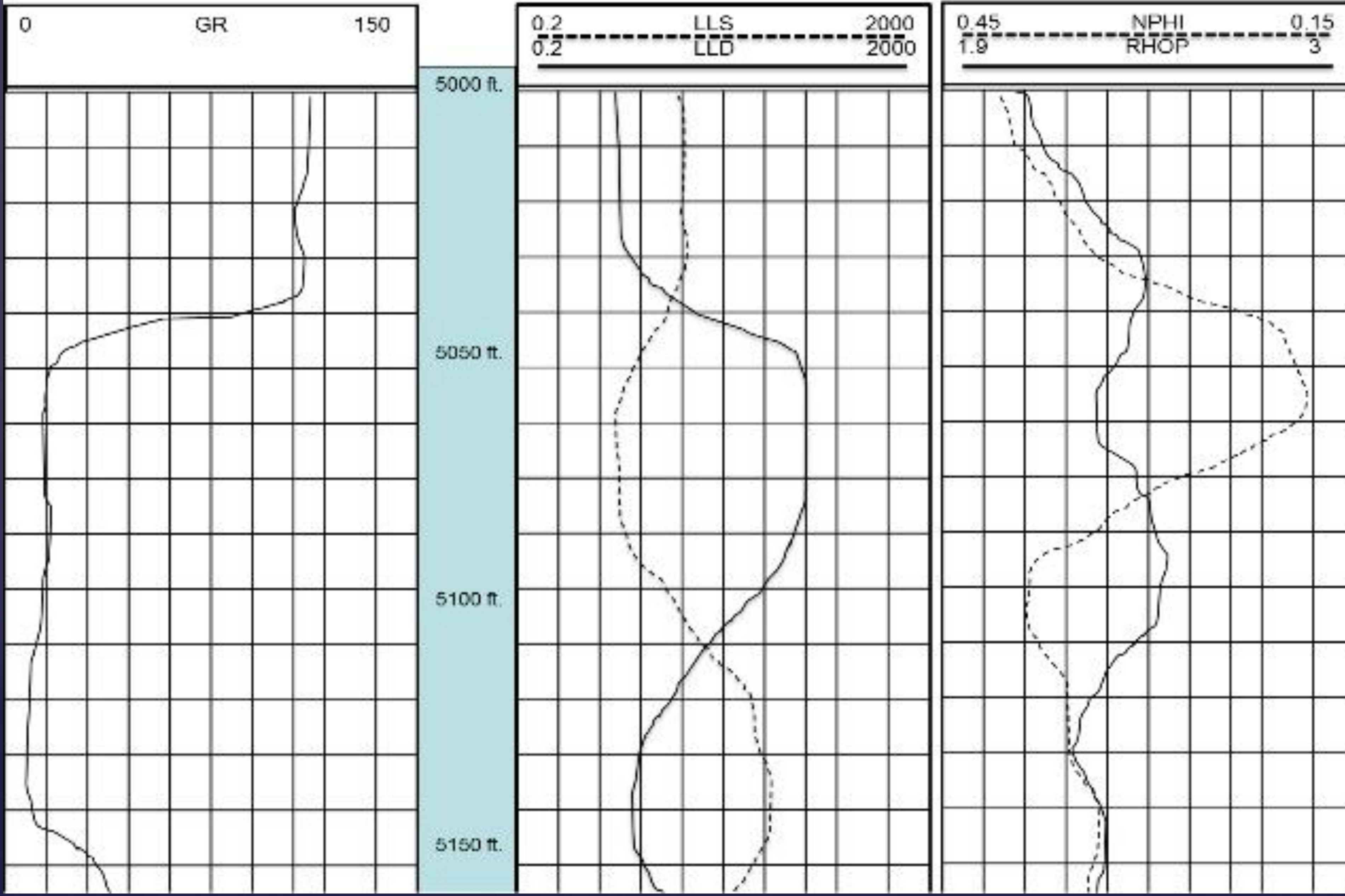
Log Response

Log Responses



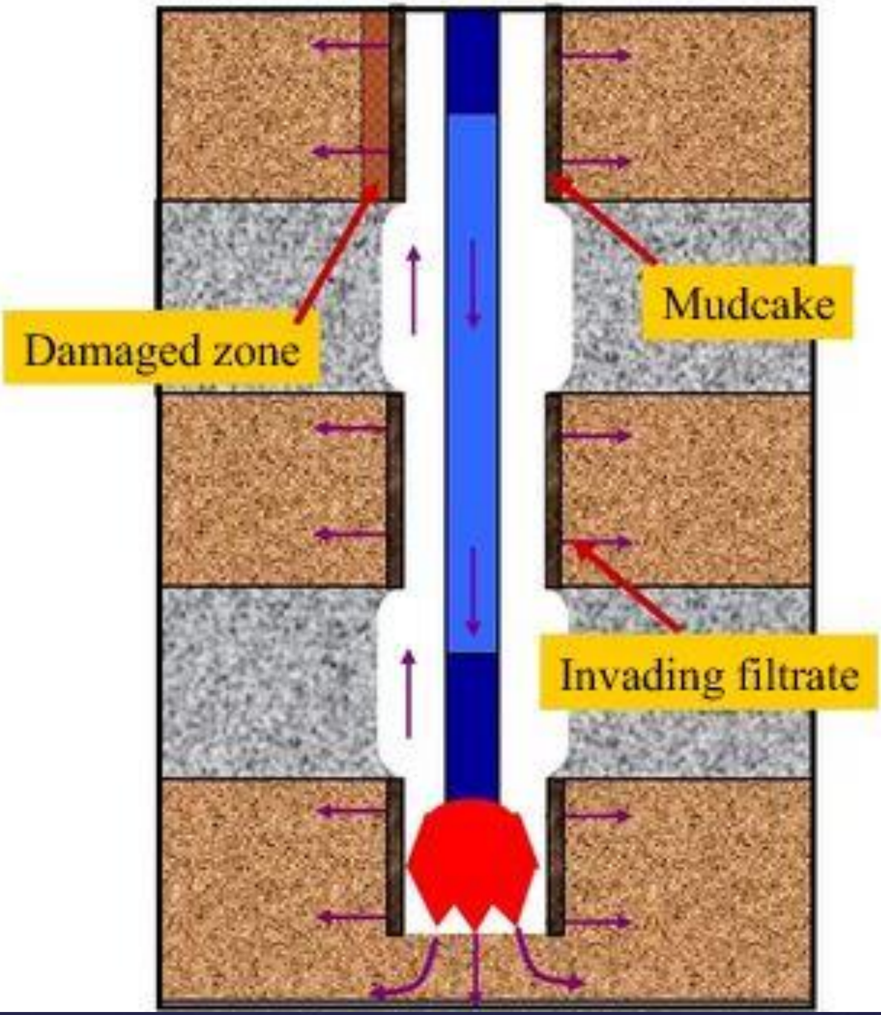
Estimate with coloring

1. **Hydrocarbon, Gas and Water zones.**
2. **O/W & G/O contacts.**

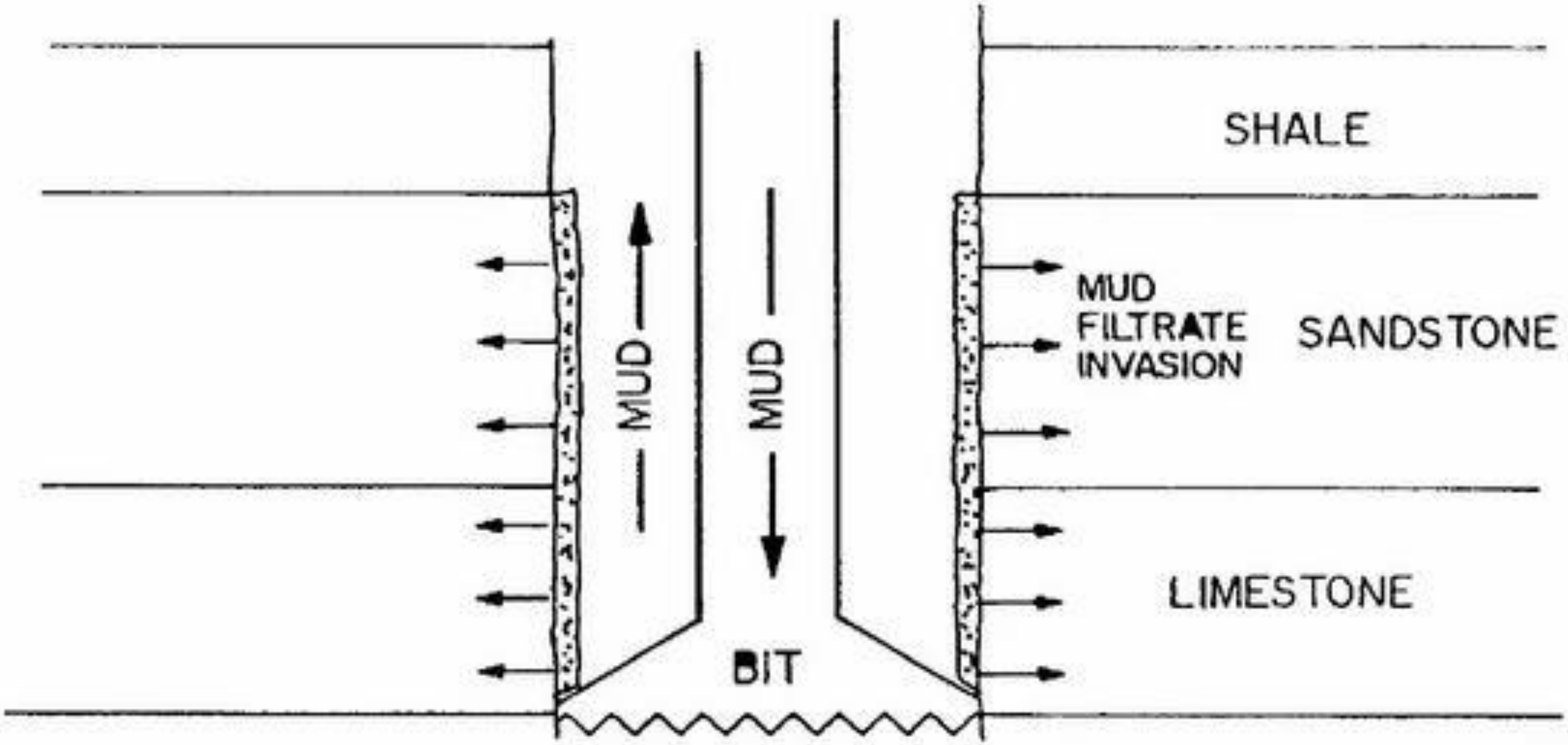


Drilling Disturbs Formation

- Drilling and rock crushing
  - Damage Zone
- Mud systems and invasion
  - Oil-based Mud
    - Small conductivity mud
    - Shallow invasion
    - Thin cake
  - Water-based Mud
    - Moderate to very conductive mud
    - Shallow to deep invasion
    - Thin to thick cake



Effects of Drilling Mud and Mud Filtrate Invasion



Mud Filtrate Invasion