Well Logging

Mining Engineering Department/ 3rd Year

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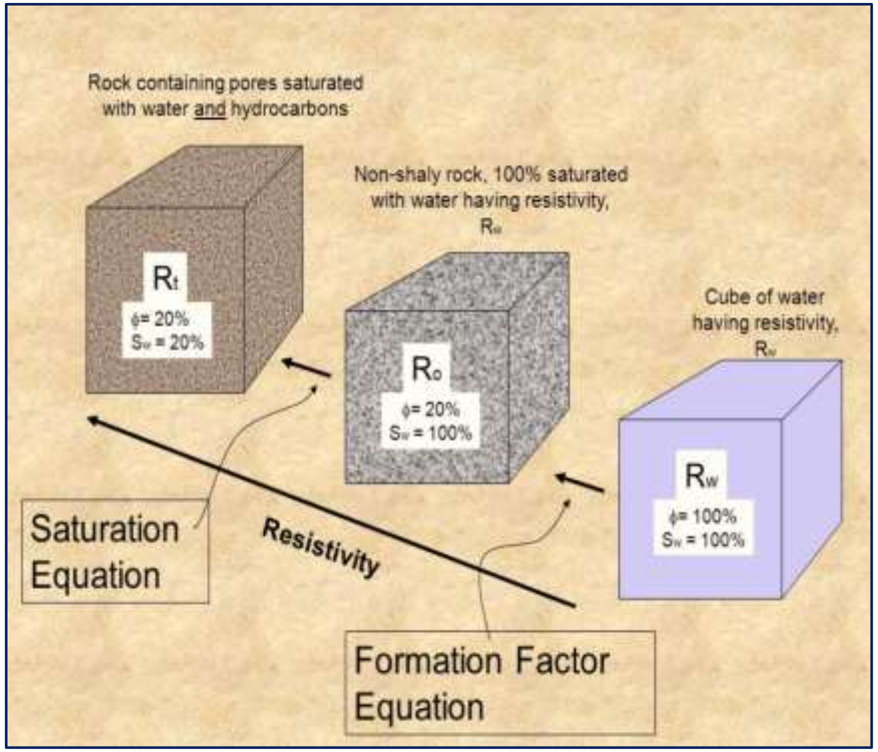
Formation Factor and Porosity:

The ratio of the <u>resistivity</u> of a ***rock filled with water*** **(R_o)** to the ***resistivity of that water*** **(R_w)** called Formation Factor. It depends upon **Archie's experiments:**

$$F = \frac{R_o}{R_w}$$

$$RR_o = F * R_w$$



F = formation resistivity factor
R_w= formation water resistivity
R_o= the resistivity, where porosity is 100% filled with water.

The Formation Factor is depended on ***lithology and pore structure***:

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

a = Constant that is determined empirically, ($0.62 < a < 1.0$).
m = Cementation factor.

Cementation factor is a function of:
the shape and distribution of pores

For **Unconsolidated** sands $$F = \frac{0.62}{\phi^{2.15}}$$

For **Consolidated** sands $$F = \frac{0.81}{\phi^{2}}$$

For **Carbonate** $$F = \frac{1}{\phi^{2}}$$

a: Tortousity factor	*m*: Cementation exponent	Comments
1.0	2.0	Carbonates[1]
0.81	2.0	Consolidated sandstones[1]
0.62	2.15	Unconsolidated sands (Humble formula)[1]
1.45	1.54	Average sands (after Carothers, 1968)
1.65	1.33	Shaly sands (after Carothers, 1968)
1.45	1.70	Calcareous sands (after Carothers, 1968)
0.85	2.14	Carbonates (after Carothers, 1968)
2.45	1.08	Pliocene sands, southern California (after Carothers and Porter, 1970)
1.97	1.29	Miocene sands, Texas–Louisiana Gulf Coast (after Carothers and Porter, 1970)
1.0	$\phi^{(2.05-\phi)}$	Clean granular formations (after Sethi, 1979)

[1]Most commonly used

Note: The less-cemented sands normally have ***higher porosities*** and ***lower resistivity factors***. As the sand becomes more cemented, φ ***decreases*** *and, therefore, F* ***increases***.

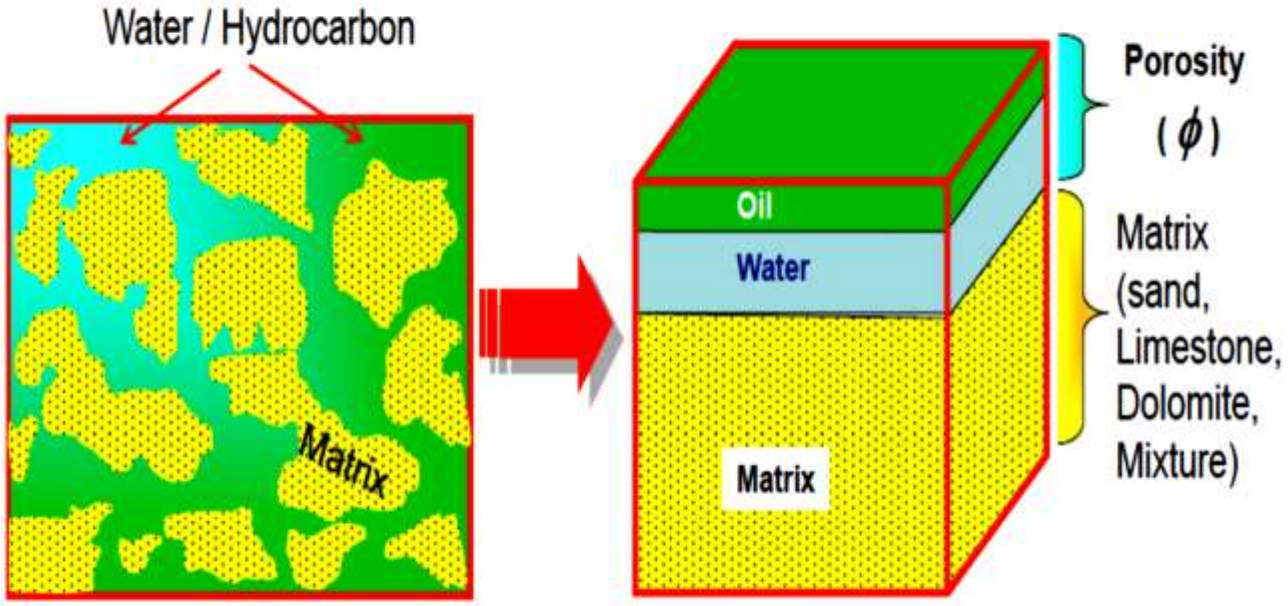
The variables that have an affect on the resistivity of natural porous media

- Temperature
- Water salinity
- Porosity
- Pore geometry
- Rock composition
- Degree of cementation and sorting

Water Saturation Estimation:

$$S_w = \left(\frac{R_o}{R_t}\right)^{1/n}$$

R_o = resistivity of water (matrix+ pore water).
R_t = resistivity of formation
((matrix + pore water + hydrocarbons).
n = saturation exponent,
***n* is usually assumed to be 2**.



$$R_o = F * R_w ,\qquad F = \frac{a}{\emptyset^m}$$

- $$S_w = \left(\frac{a \times R_w}{\emptyset^m \times R_t}\right)^{1/n}$$

$$S_w = 2\sqrt{\frac{a \times R_w}{\emptyset^m \times R_t}}$$

This is formula that is most commonly referred to as the ***Archie equation for water saturation***

Example: Calculate the water saturation if you have the following data
Ø for ***Consolidated Sandstone*** = 18%, the resistivity from log (Rt) is 22 Ωm, the resistivity of formation water (Rw) is 0.025 Ωm.

Solution: for consolidated sandstone : a = 0.81, m = 2

Ø must be in Decimal unit

$$S_w = 2\sqrt{\frac{a \times R_w}{Ø^m \times R_t}}$$

$$S_w = 2\sqrt{\frac{0.81 * 0.025}{0.18^2 * 22}} \longrightarrow$$

Sw= 0.17

17%

Calculate the water resistivity for sandstone formation has porosity 27% and R_o = 0.35 .

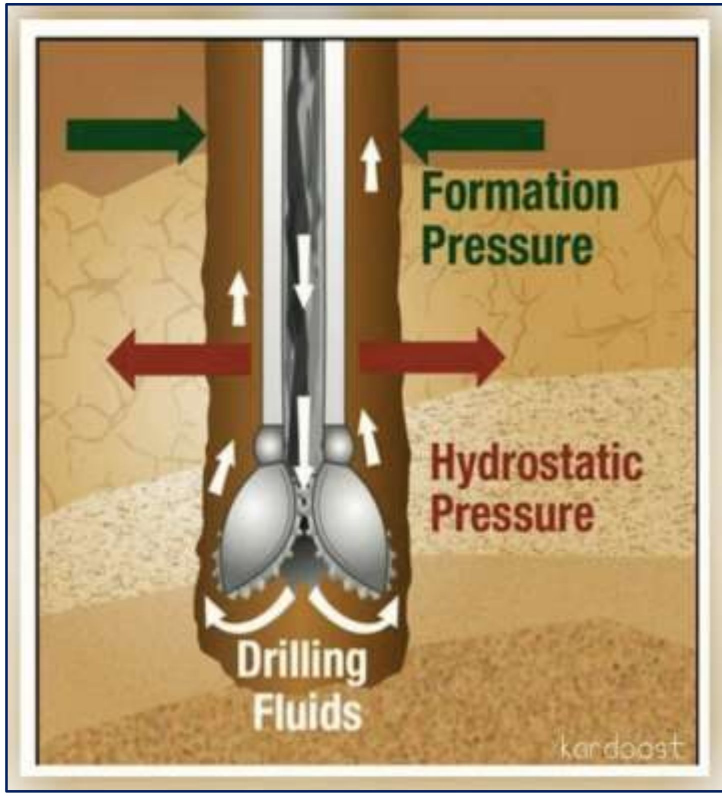
Borehole Environment

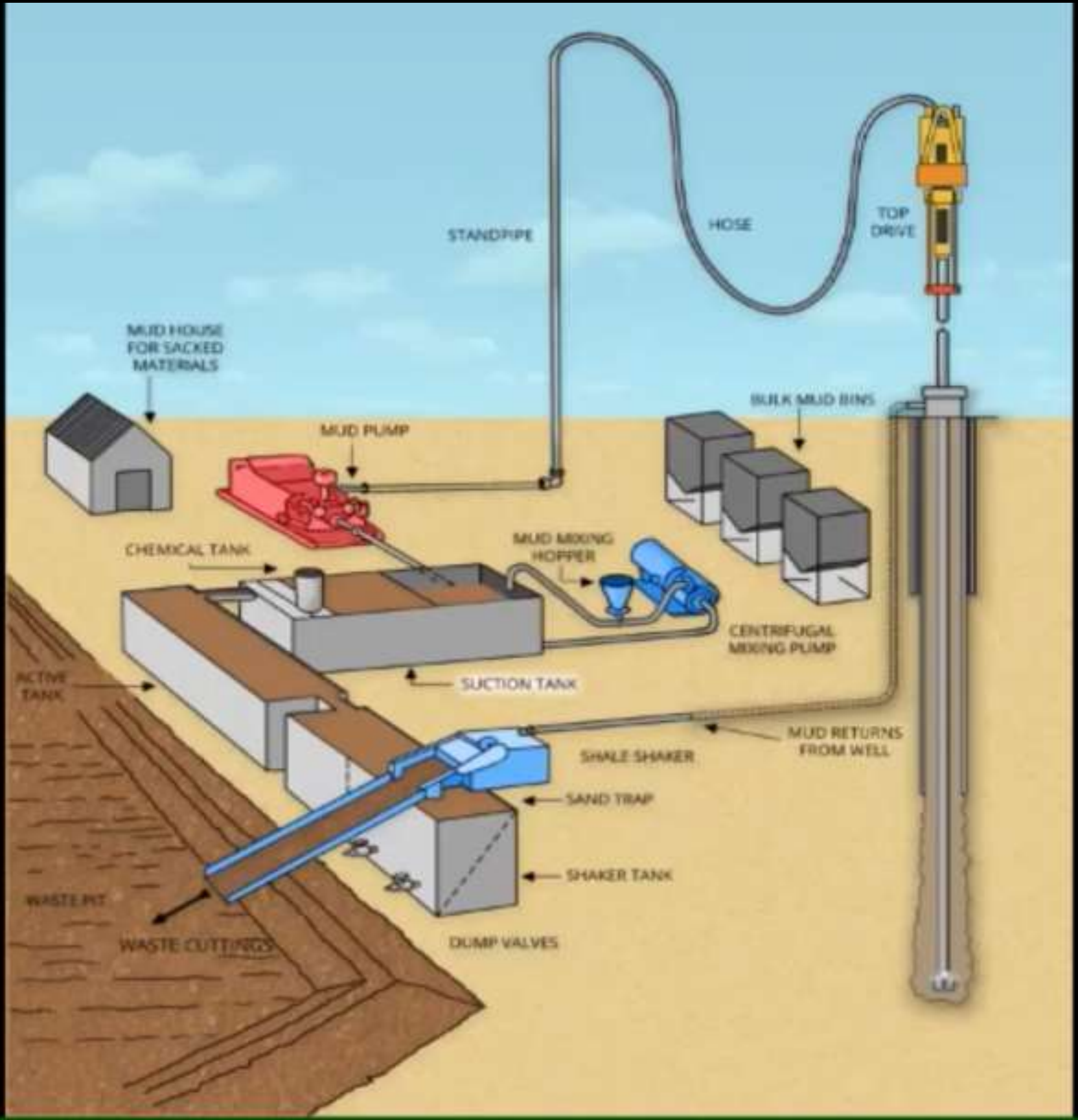
The nature of the fluids in the pore space immediately surrounding the borehole depends upon the ***amount and type of mud filtrate that invades the formation.***

Drilling Process and Drilling Mud Pumping

During the drilling process, drilling mud is pumped down the drill pipe and up the annulus between the drill pipe and the formation.

Because the ***pressure in the drilling mud must exceed the formation pore pressure,*** the mud begins to enter permeable zones in the formation but is normally rapidly stopped by the build-up of a ***mudcake*** that lines the borehole wall.




STANDPIPE
HOSE
TOP DRIVE
MUD HOUSE FOR SACKED MATERIALS
BULK MUD BINS
MUD PUMP
CHEMICAL TANK
MUD MIXING HOPPER
CENTRIFUGAL MIXING PUMP
ACTIVE TANK
SUCTION TANK
MUD RETURNS FROM WELL
SHALE SHAKER
SAND TRAP
SHAKER TANK
WASTE PIT
WASTE CUTTINGS
DUMP VALVES

The Importance of Drilling Mud

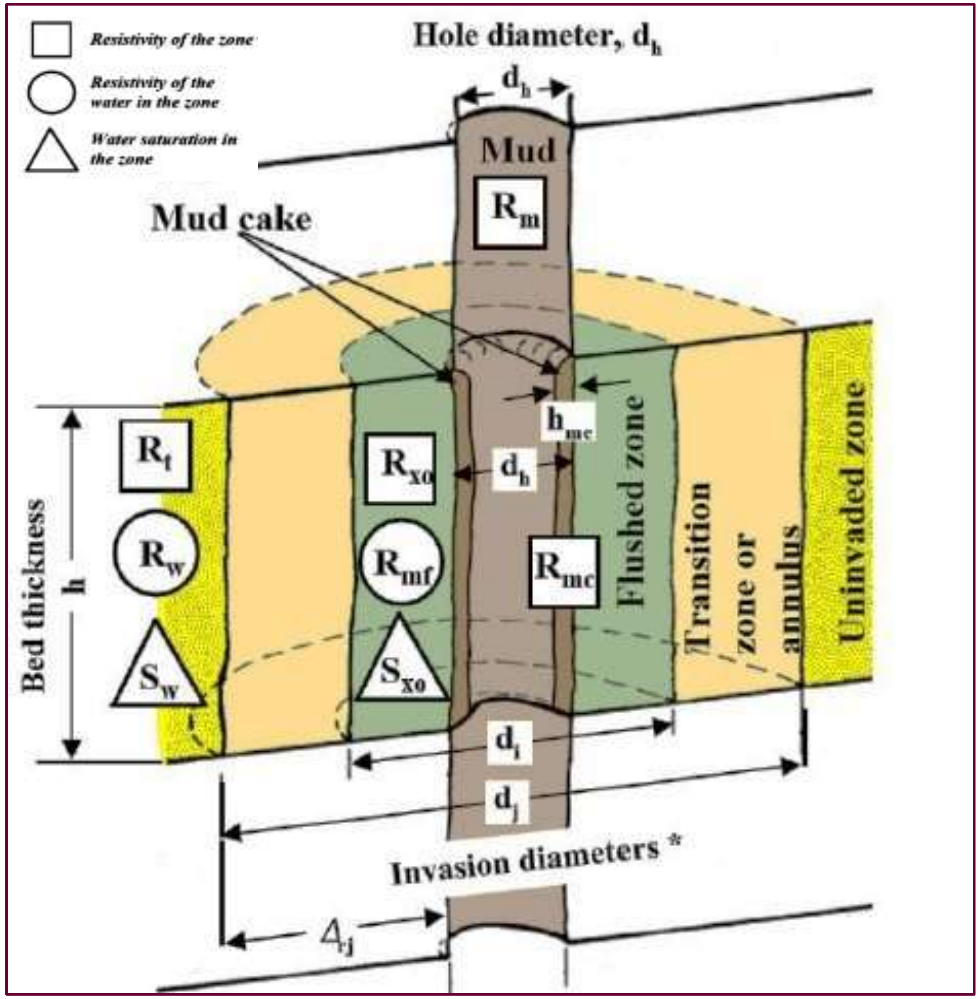
1. Controlling hydrostatic pressure.
2. Avoid formation damage, limit corrosion, and rock stabilization.
3. Keeping the drill bit cool.
4. Reducing friction and heat.
5. Carrying the cuttings to the surface

The drilling mud invades the rock surrounding the borehole, which affects ***logging measurements*** and ***the movement of fluids into and out of the formation***

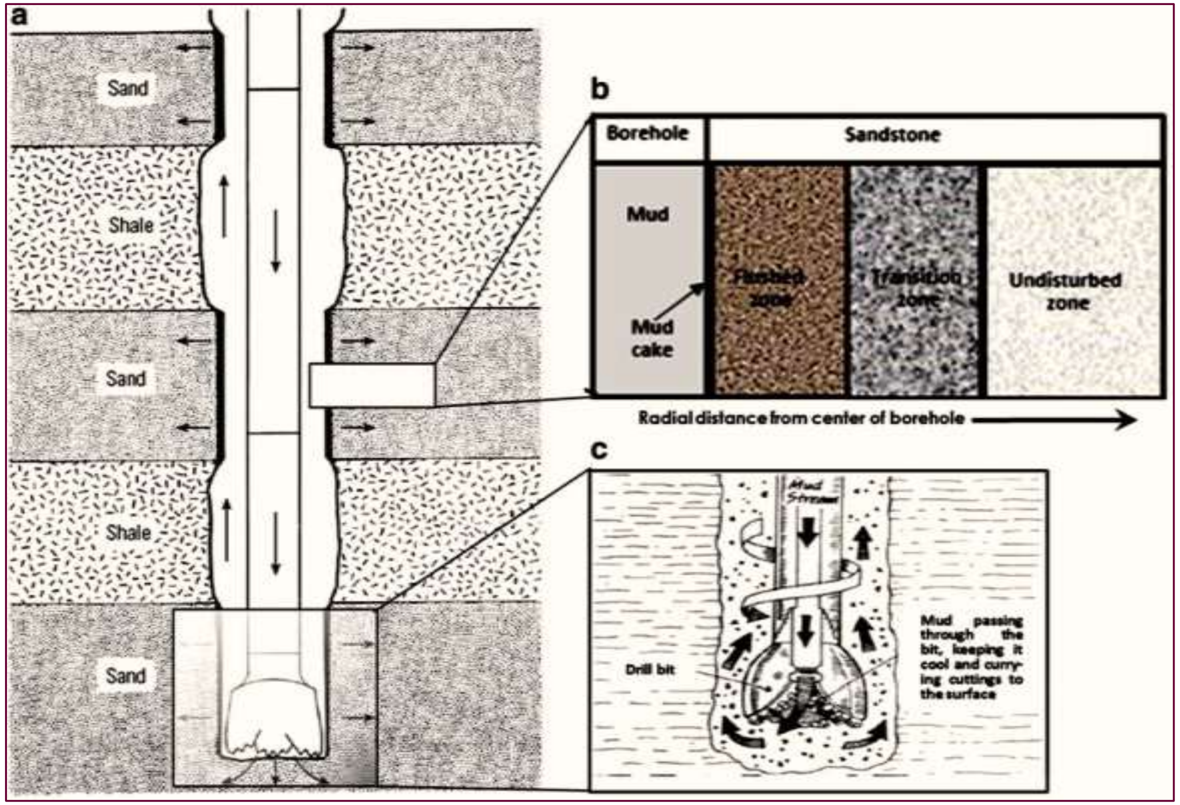
The density of the mud must kept ***high enough so that hydrostatic pressure*** in the mud column is always ***greater than formation pressure***. This pressure difference forces some of the drilling fluid to invade porous and permeable formations

Borehole Environment Definitions

- **Hole diameter (d_h):** The size of the borehole determined by the diameter of the drill bit. It is measured by **Caliper log.**
- **Drilling Mud Resistivity (R_m):** Resistivity of the fluid used to drill a borehole. Drilling mud consists of a variety of clay and other materials (barite, hematite) in a fresh or saline aqueous solution and has a measurable resistivity



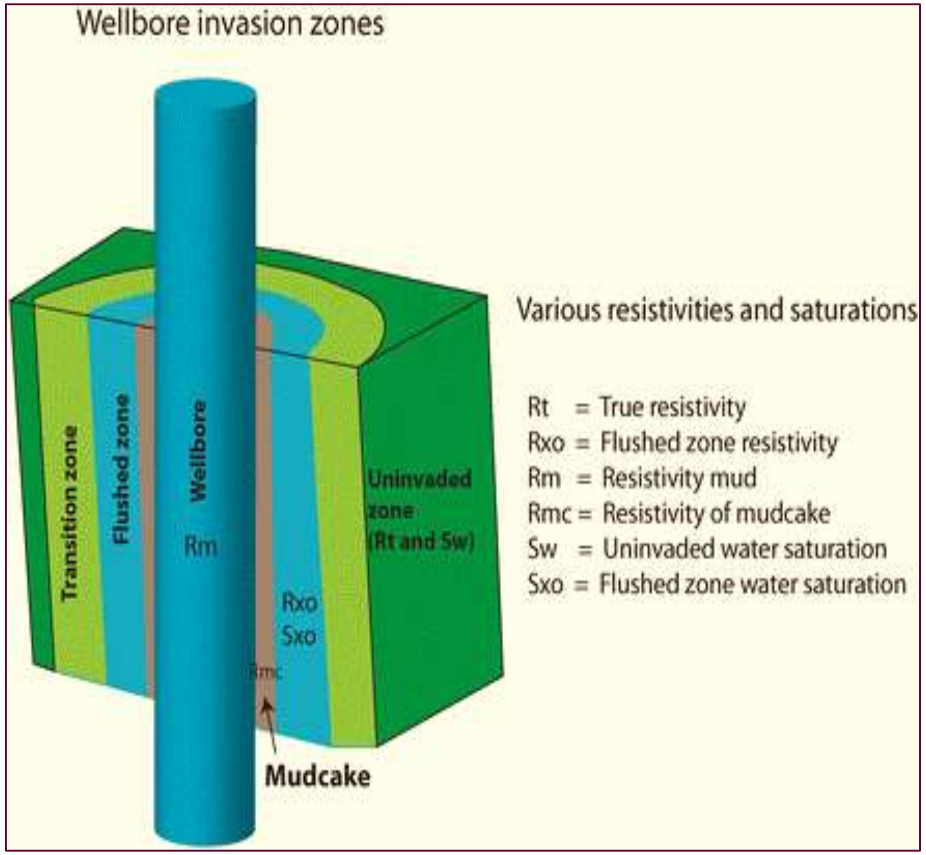
- **Mudcake Resistivity (R_{mc}):** Resistivity of the mineral residue formed by accumulation of solid drilling mud components on the wellbore walls as the mud fluids invade the formations penetrated by the borehole.



- **Mud Filtrate (R_{mf}):** Resistivity of the liquid drilling mud components that infiltrate the formation, leaving the mudcake on the walls of the borehole.

- **Invaded Zone:** The zone that invades by mud filtrate. It consists of a ***flushed zone*** (R_{xo}) and a ***transition or annulus zone*** (R_i).

- **The flushed zone (R_{xo}):** a zone occurs ***close to the borehole*** where the mud filtrate has almost completely flushed out the formation's hydrocarbons and/or water.
- **The transition or annulus zone (R_i):** a zone occurs where a formation's fluids and mud filtrate are mixed, occurs between the flushed zone (R_{xo}) and the univaded zone (R_t).
- **Uninvaded Zone (R_t):** Pores in the univaded zone are **uncontaminated** by mud filtrate; instead, they are saturated with formation fluids (water, oil and/or gas).



Thank You!