



BASIC WELL LOGGING

Munir EL-Mahdy

Geologist at Khafda Petroleum Company



www.facebook.com/munir.elmahdy



www.youtube.com/munirelmahdy

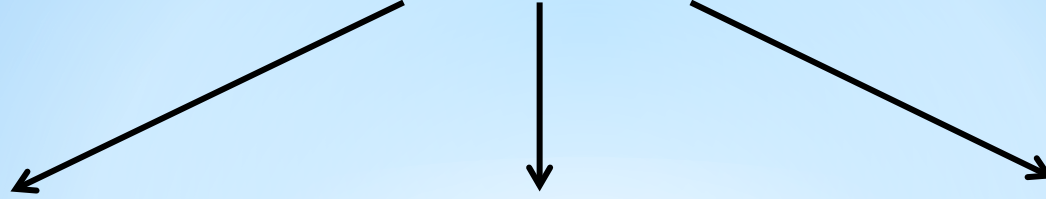


munirelmahdy87@gmail.com



munirelmahdy87@hotmail.com

Oil Gas industry



Upstream

Midstream

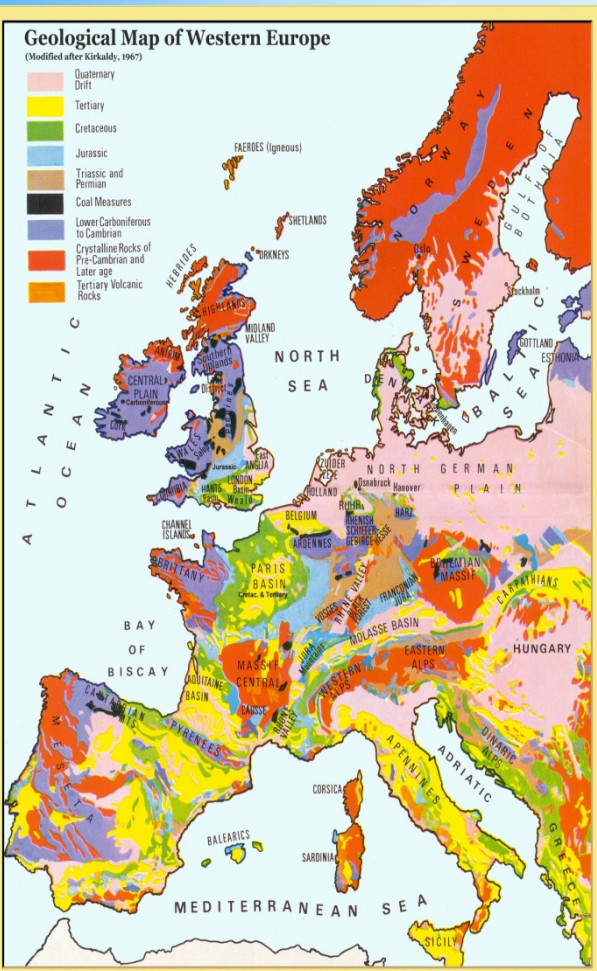
Downstream



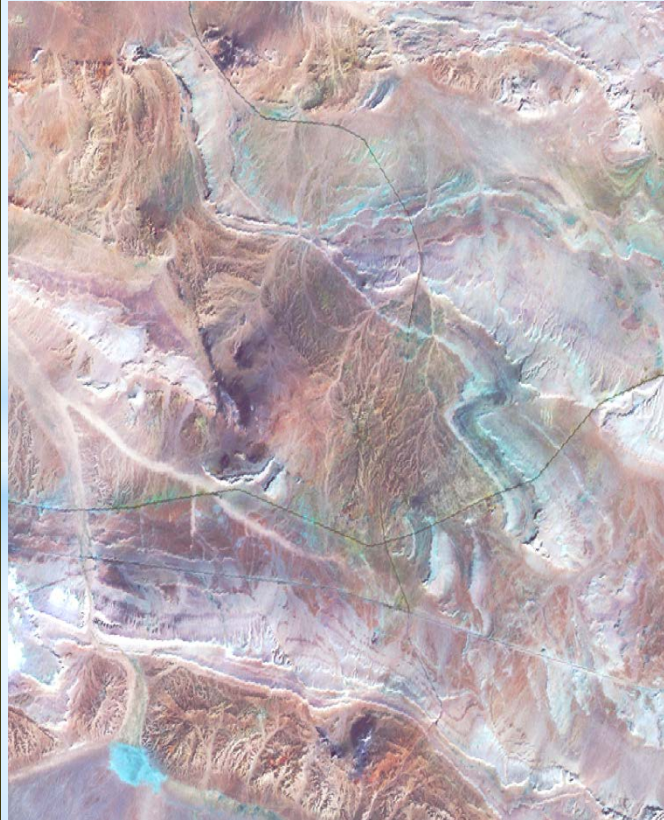
Upstream Petroleum Life Cycle

Exploration surveying

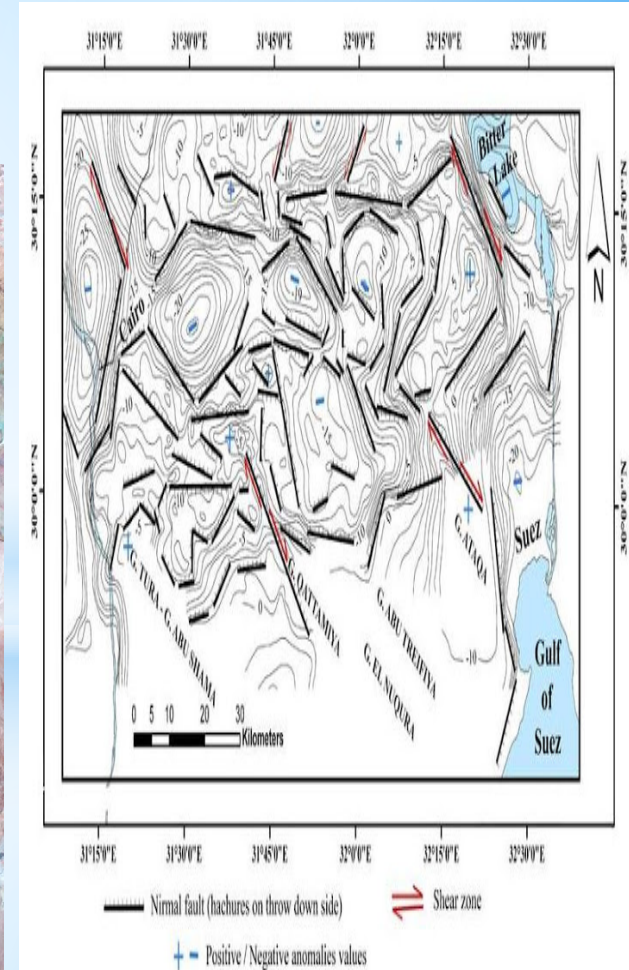
Regional Tectonic
setting



Satellite images &
Field trips
(Geological Maps)



Magnetic, Gravity



Upstream Petroleum Life Cycle

Wild Cat wells

The process of drilling for oil or natural gas in an unproven area, that has no concrete historic production records and has been unexplored as a site for potential oil and gas output.

Upstream Petroleum Life Cycle

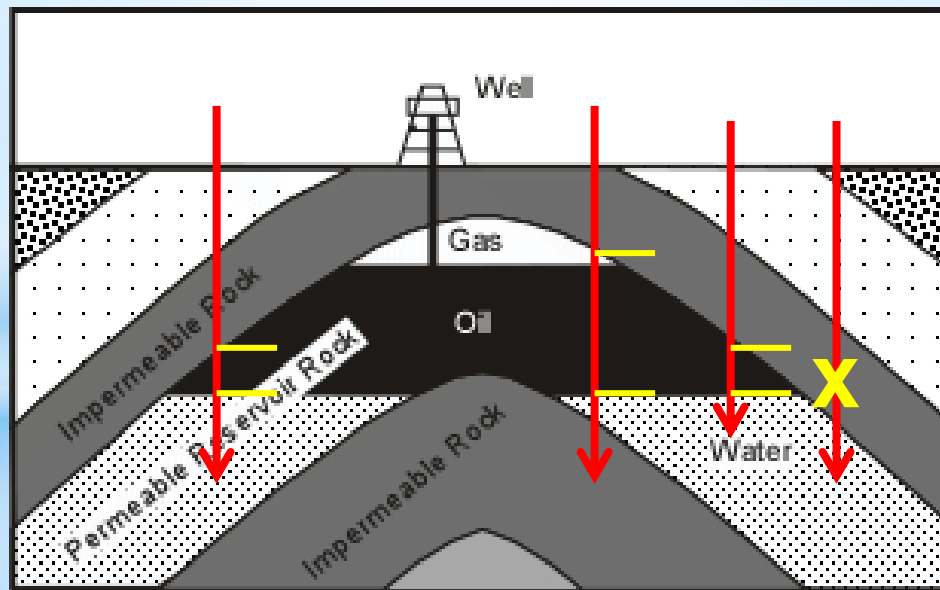
Exploration wells

- a) To find oil or gas in an area previously considered unproductive.
- b) To find a new reservoir in a known field, i.e., one previously producing oil and gas from another reservoir.

Upstream Petroleum Life Cycle

Appraisal wells

Wells drilled after the discovery of oil or gas to establish the limits of the reservoir, the productivity of wells in it and the properties of the oil or gas.



Upstream Petroleum Life Cycle

Production & Development

- The **number of wells** required to exploit the hydrocarbon reservoir varies with the **size of the reservoir** and its **geology**.
- Large** oilfields can require a **hundred** or more wells to be drilled, whereas **smaller** fields may only require **ten** or so.
- Most **commercial** oil and gas **wells** are initially **free flowing**.

The rate of flow depends on:

1. The **properties** of the reservoir rock (**porosity & permeability**).
2. The underground **pressures**.
3. The **viscosity** of the **oil**.
4. & the **oil/gas ratio**.

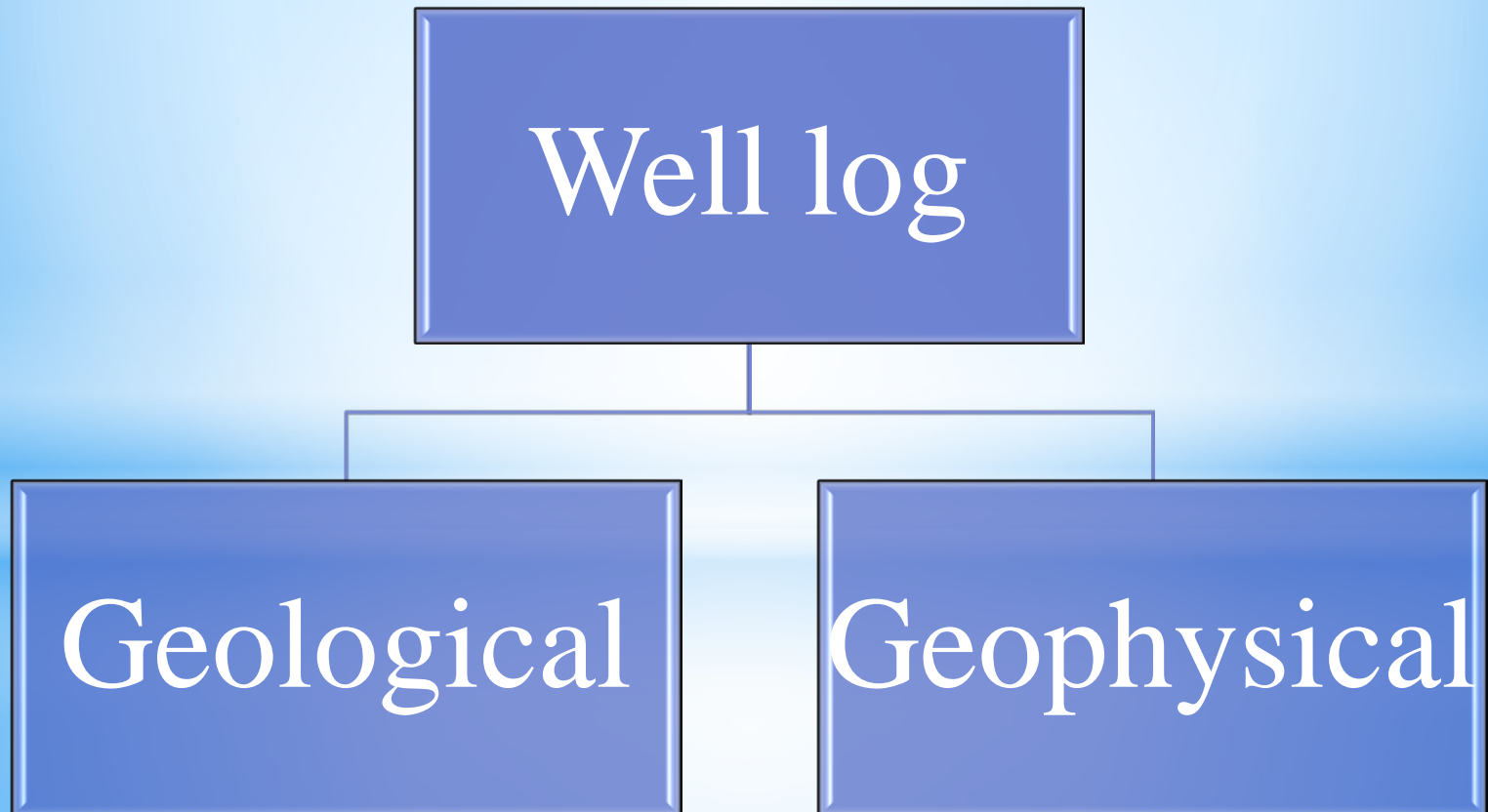
Injection wells:

When the **oil cannot** reach the **surface** unaided, some form of **additional lift** is required, such as **injection** of **gas, water or steam** to maintain reservoir pressures which require the drilling of additional wells called **injection wells**.

Well Logging

Known as **borehole logging**.

Making a detailed record (a *well log*) of the geologic formations penetrated by a borehole.



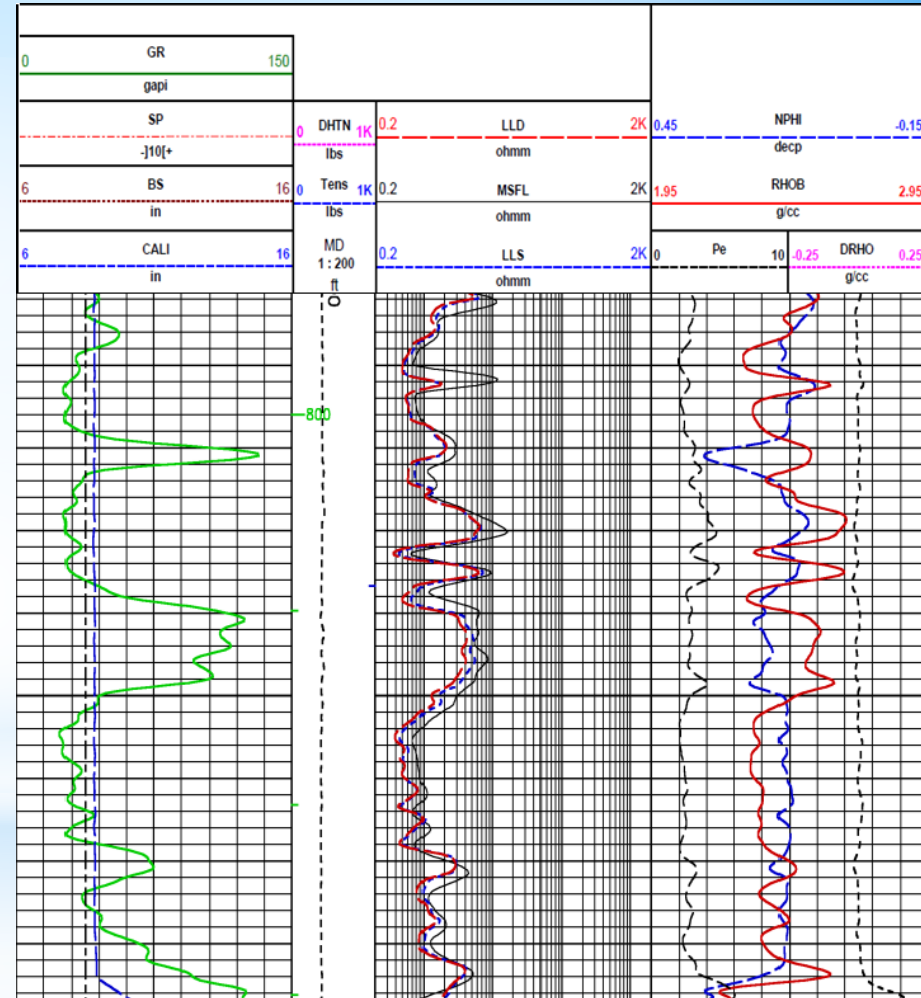
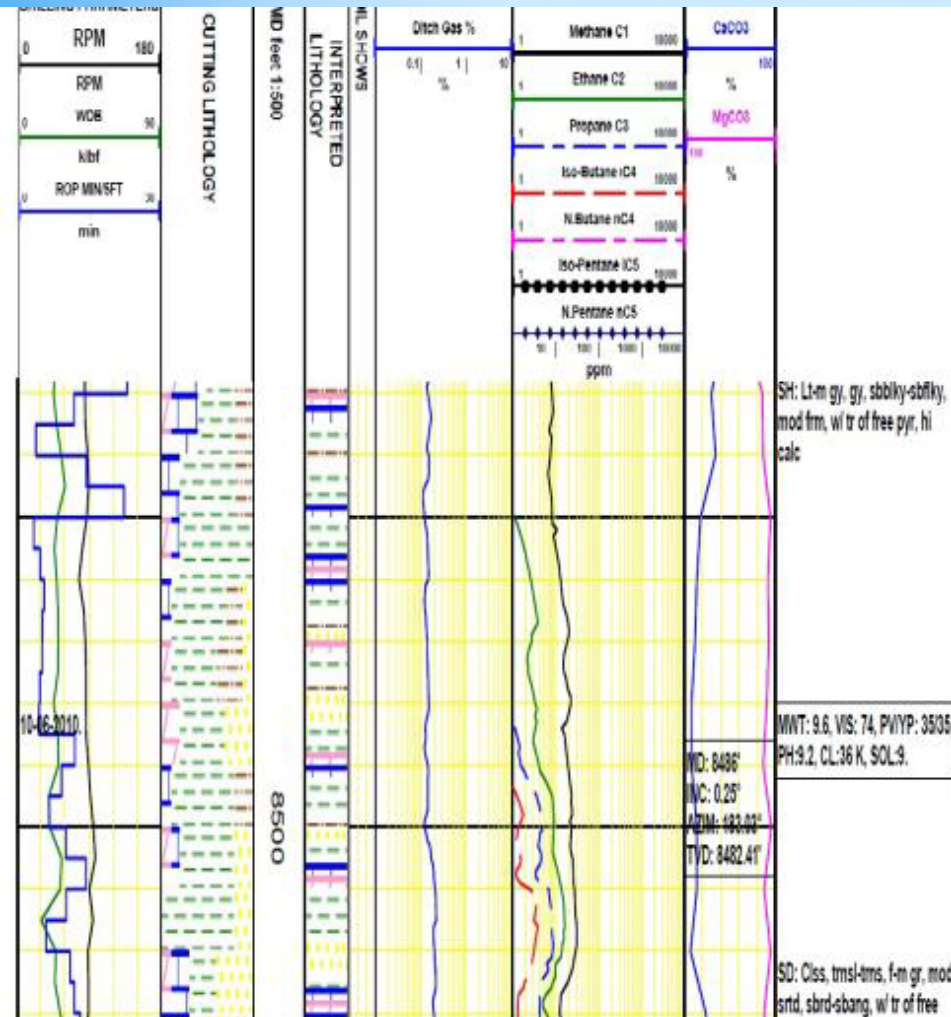
Well Logging

	Geological well logging	Geophysical well logging
Data out put	Mud log	Composite e- log
Logging time	Prepared during drilling	Recorded after drilling
Type of data	<ul style="list-style-type: none">• Lithology percentage• Gas percentage & its analysis• Rock description• Drilling parameters• Mud data	<ul style="list-style-type: none">• It represents the only continuous record of real lithology.• All the runs from the well must be plotted to give one composite plot

Well Logging



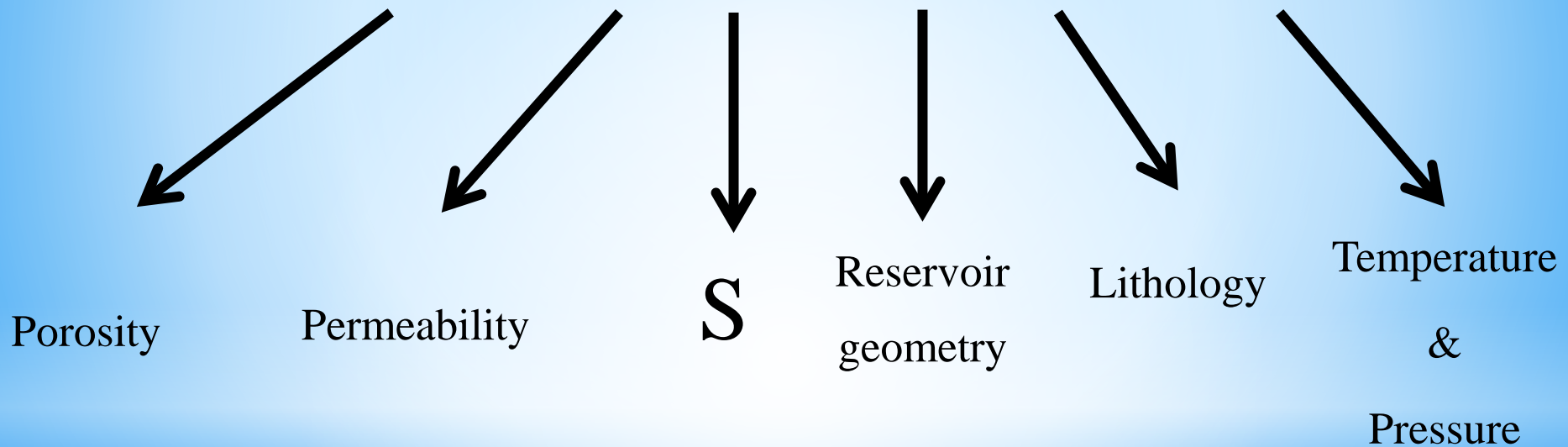
Well Logging



Geophysical Well Logging

- It **fills** the **gap** between **cuttings** (which leaves an imprecise record of the formation encountered) and **core** (which is slow and expensive).
- All the logging **runs** are recorded from **down** (bottom) to **up**.

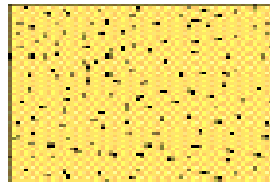
The Main Parameters needed to evaluate reservoir



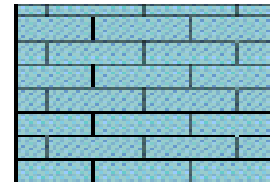
Lithology

Lithology of a formation can be:

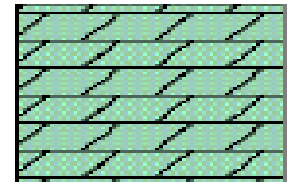
Simple



Sandstone



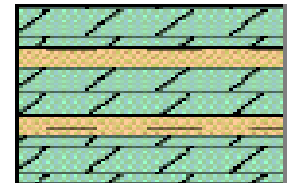
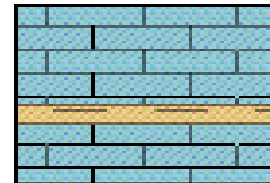
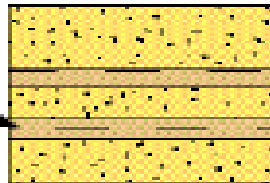
Limestone



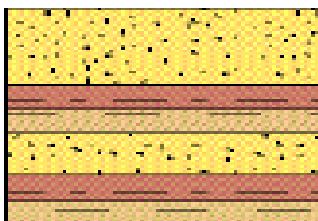
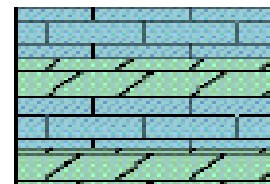
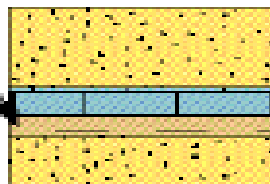
Dolomite

Dirty

Shale



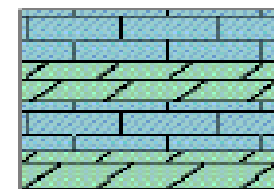
Complex



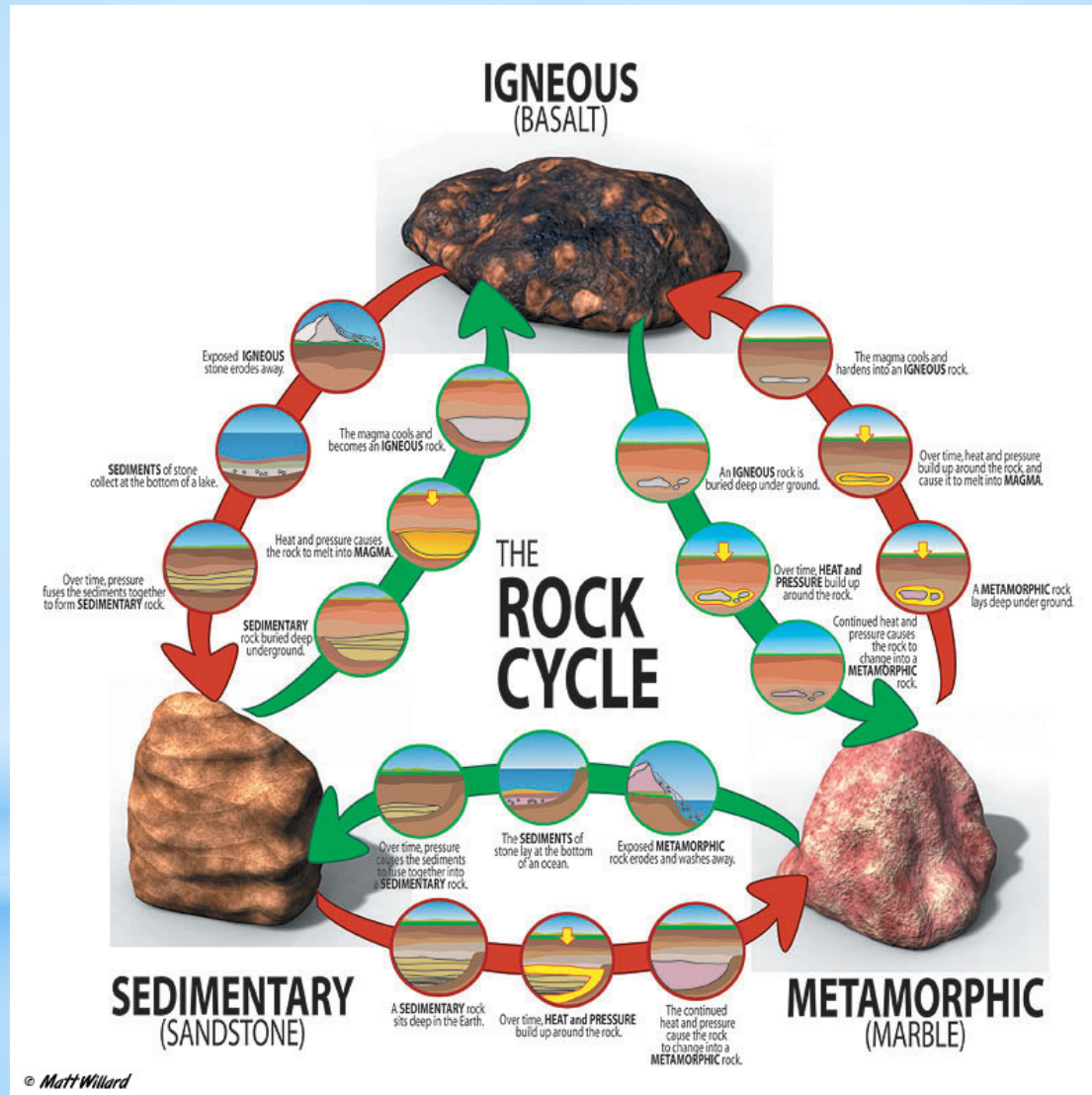
Sand

Silt (+mica)
Shale

Silt (+mica)
Shale



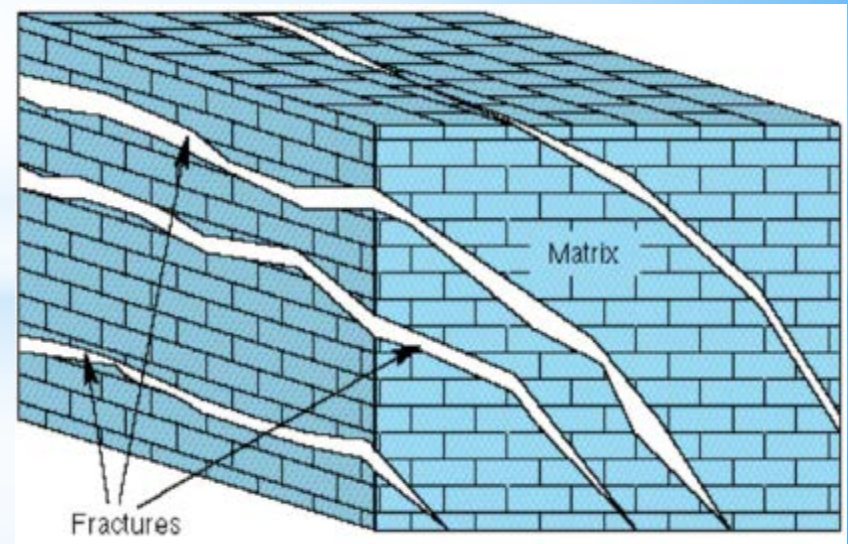
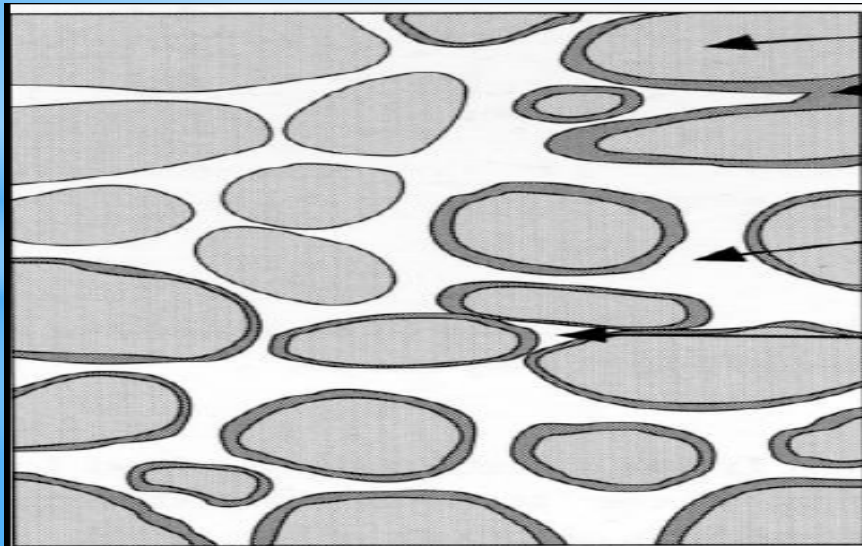
Lithology



Lithology

Porosity

- The ratio of a volume of void spaces within a rock to the total bulk volume of that rock in percentage.
- **Primary:** developed during deposition of the sediment
- **Secondary:** developed by some geologic process subsequent to the deposition of the rock.



Porosity

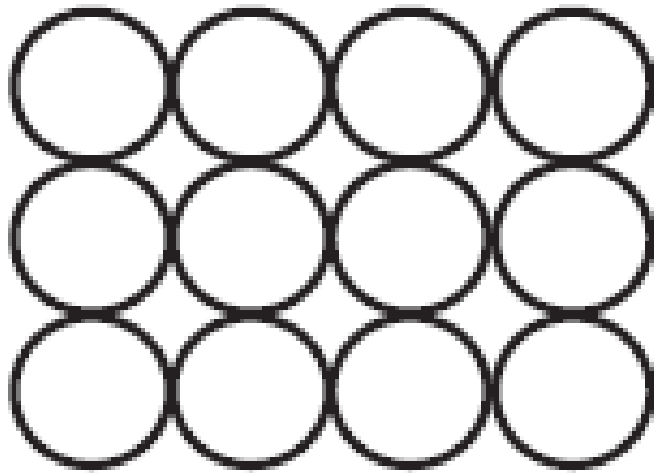
$$\text{Total porosity, } \phi_t = \frac{\text{Total Pore Space}}{\text{Bulk Volume}}$$

$$\text{Effective porosity, } \phi_e = \frac{\text{Interconnected Pore Space}}{\text{Bulk Volume}}$$

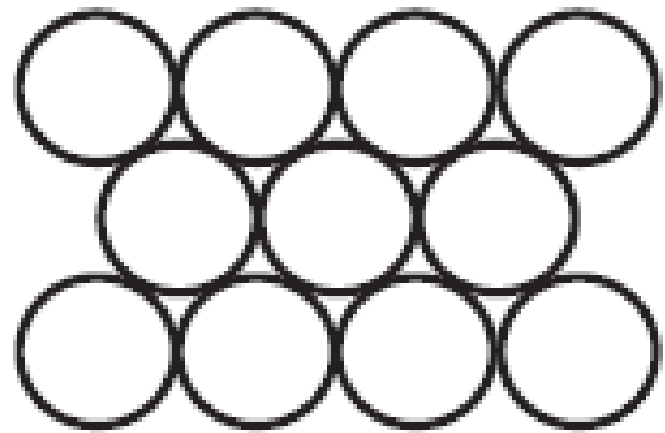
Porosity

Porosity is principally depends on:

- The arrangement and shape of the rock grains.
- The mixing of grains of different sizes and shapes.
- and the amount of cementing material present.



Cubic packing
 $\phi = 47.6\%$

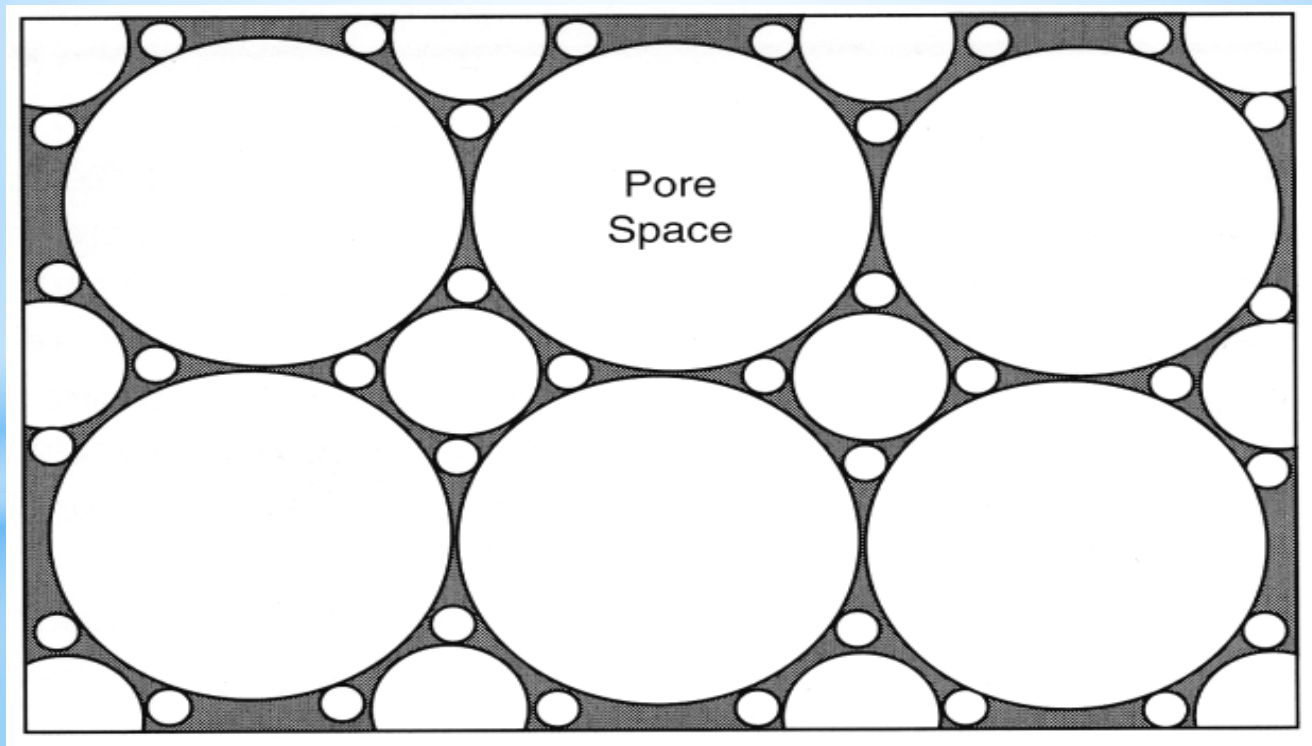


Rhombohedral packing
 $\phi = 26\%$

Porosity

Porosity is principally depends on:

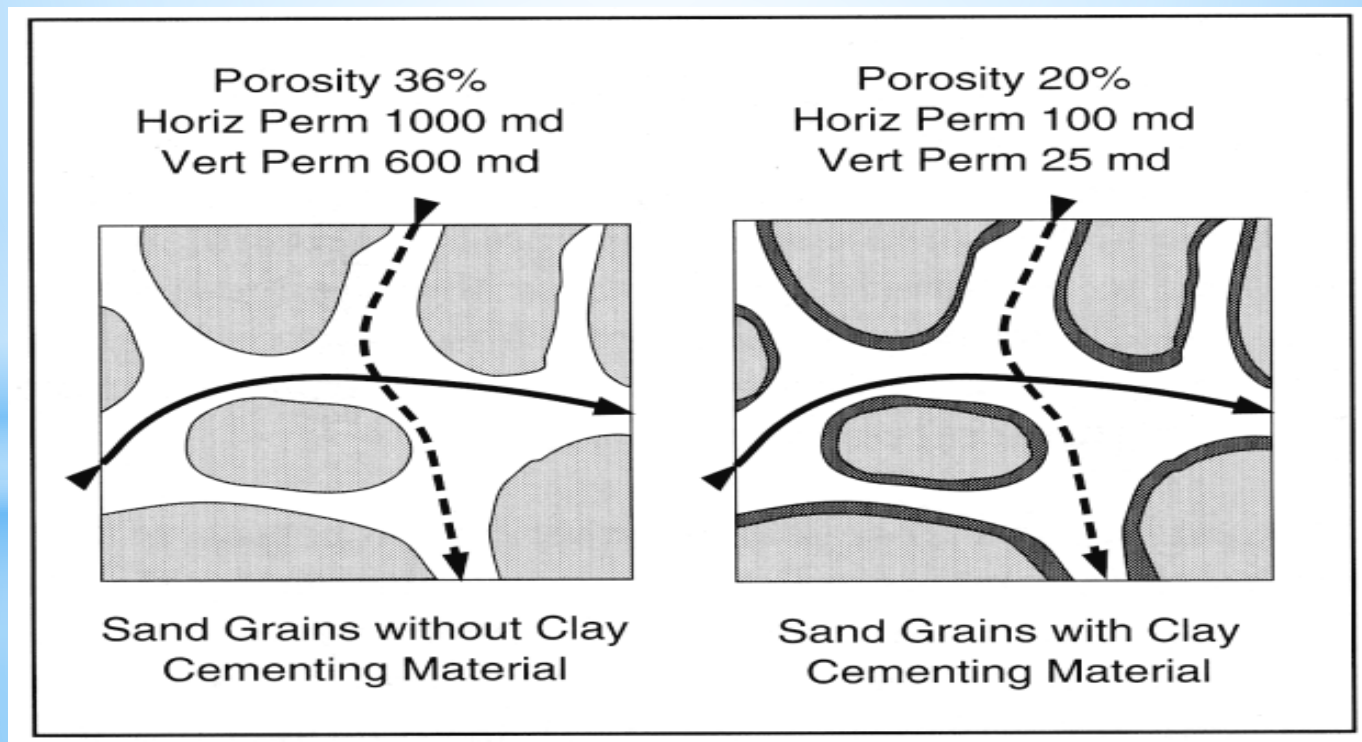
- The arrangement and shape of the rock grains.
- The mixing of grains of different sizes and shapes.
- and the amount of cementing material present.



Porosity

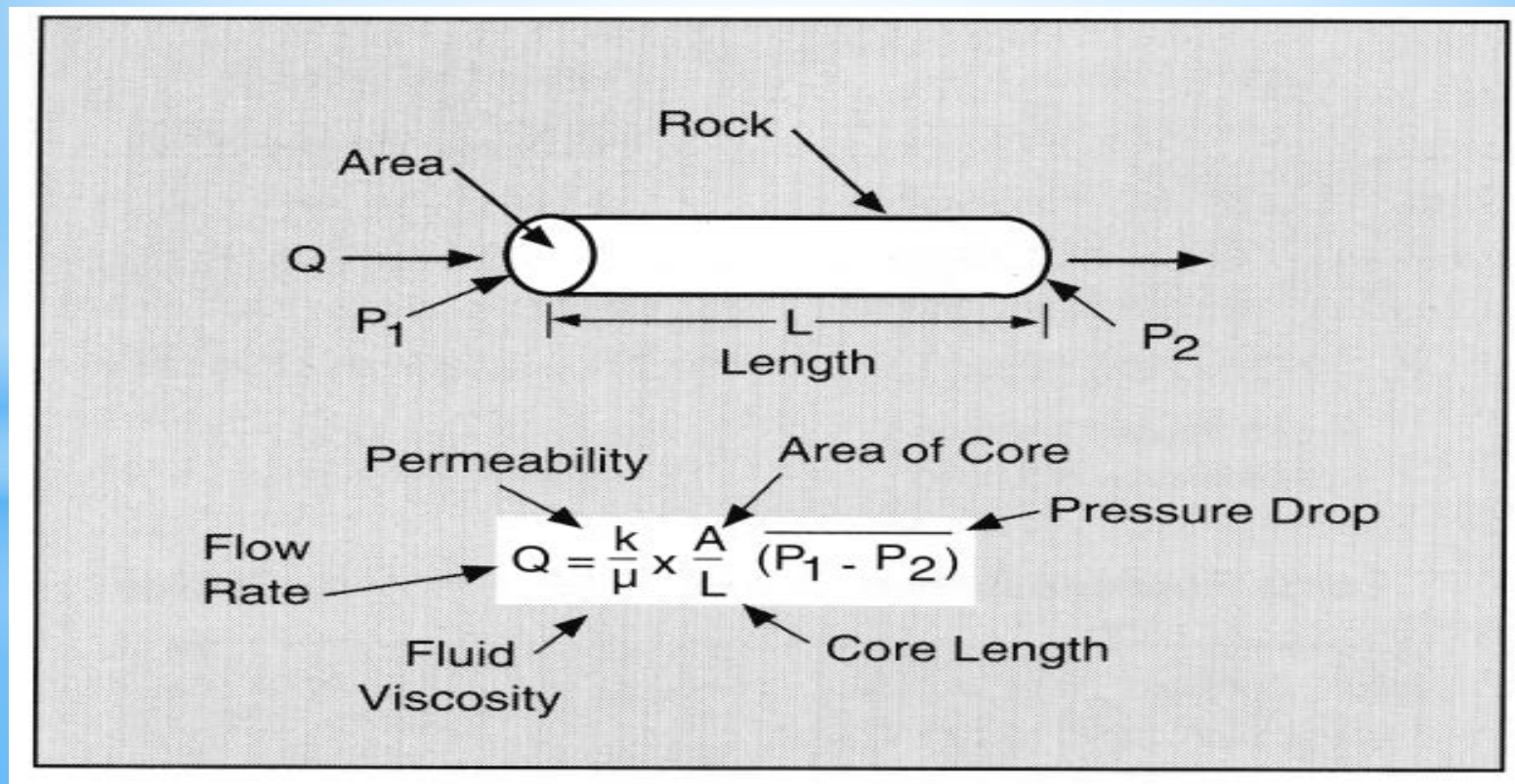
Porosity is principally depends on:

- The arrangement and shape of the rock grains.
- The mixing of grains of different sizes and shapes.
- and the amount of cementing material present.



Permeability

- Is the calculation of the ease with which a fluid flows through connecting pore spaces of reservoir rock.
- It is very important in predicting the rate of production from a reservoir.

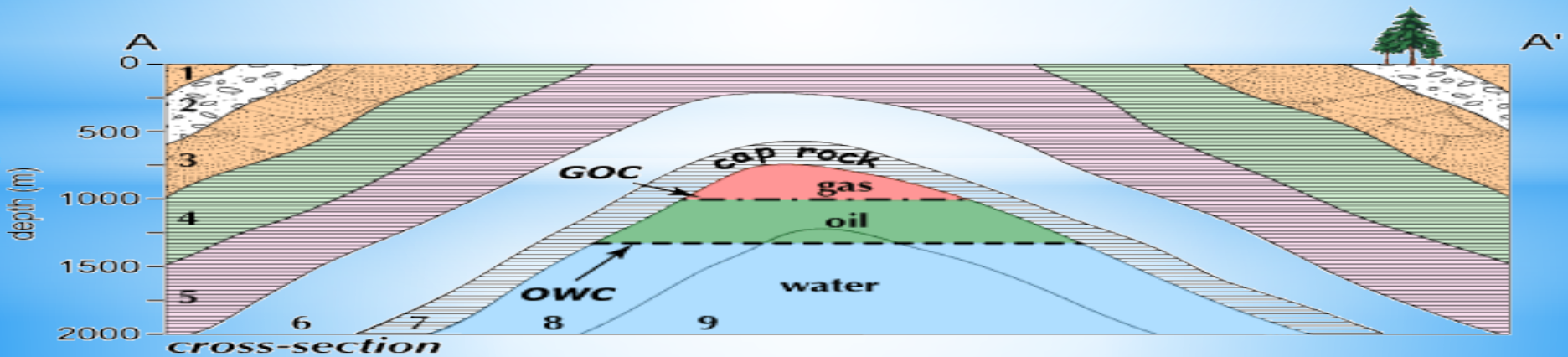
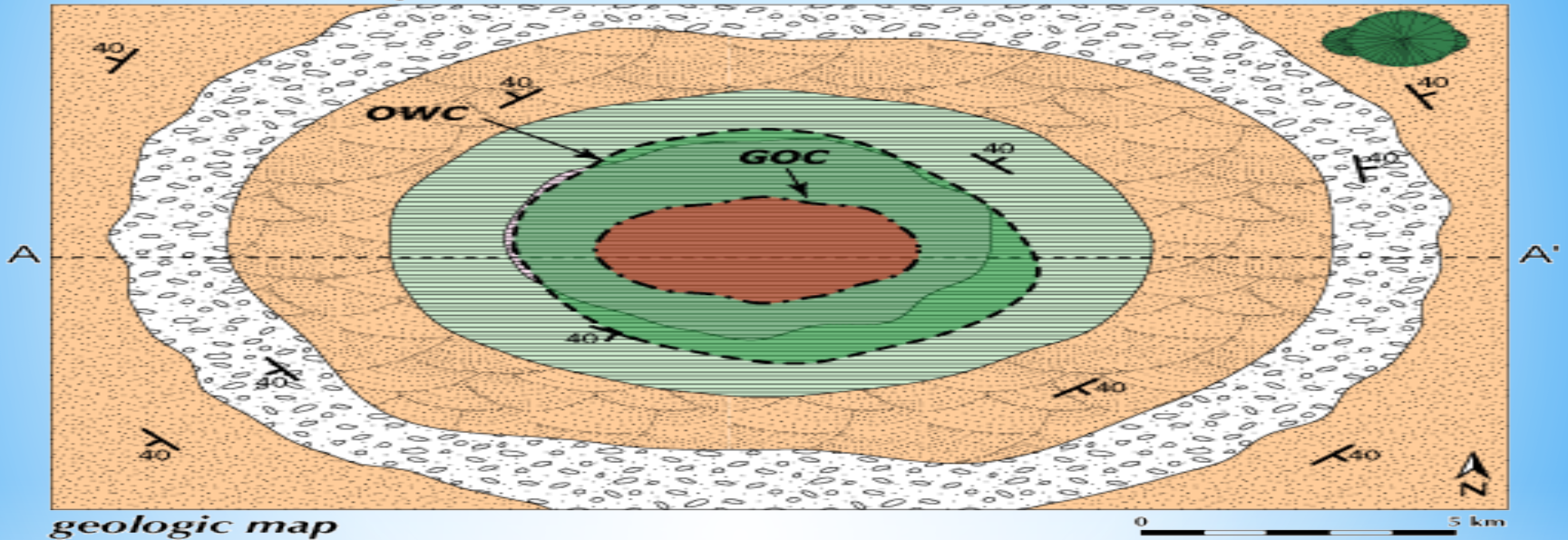


Saturation

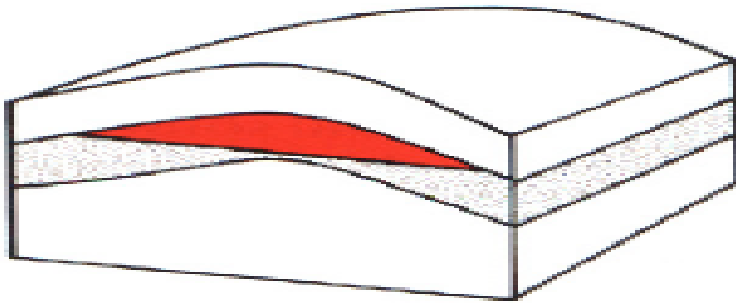
- ✧ The saturation of a formation is the fraction of its pore volume occupied by a fluid under consideration.
- ✧ If the formation have only one fluid (water) so the water saturation in the fluid is 100 %
- ✧ The summation of all saturations in a given formation rock must be equal to 100 %
- ✧ The symbol of the saturation is : (S)
- ✧ The saturation of water is : (S_w)
- ✧ The saturation of oil is : (S_o)
- ✧ The saturation of Gas is: (S_g)
 - ✧ $S_o + S_g + S_w = 100\%$,

OWC & GOC

Sundowner Prospect



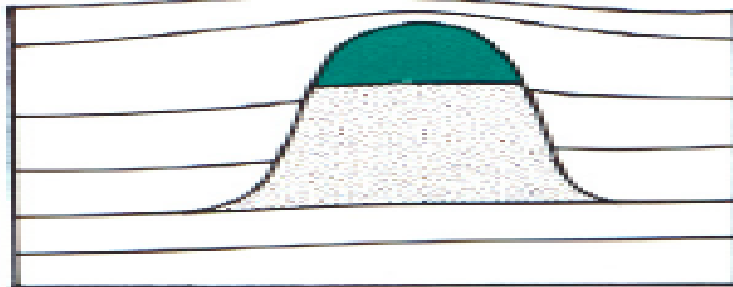
Reservoir geometry



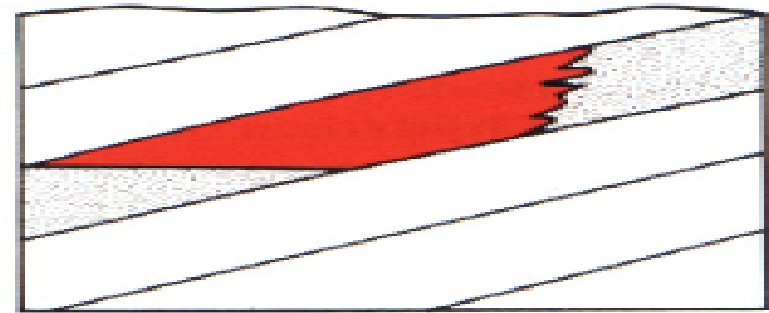
Anticline



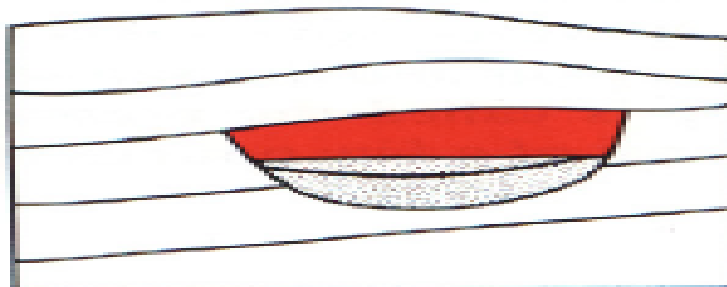
Piercement Salt Dome



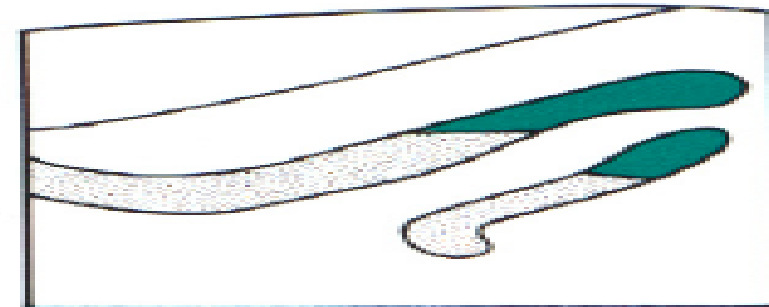
Pinnacle Reef



Low-Permeability Barrier



Channel Fill

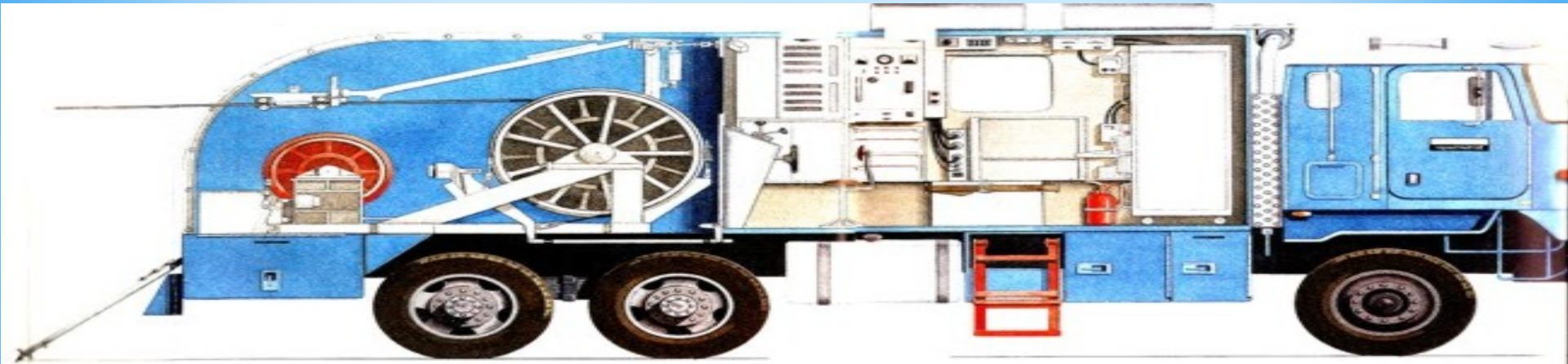


Lenticular Traps

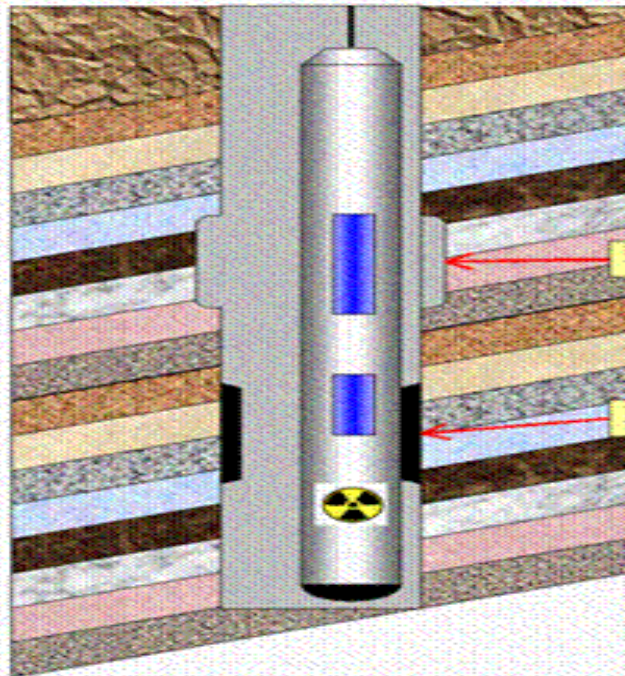
Temperature & Pressure

- ✂ The temperature and pressure control the viscosities and mutual solubility of the three fluids oil, gas & water.

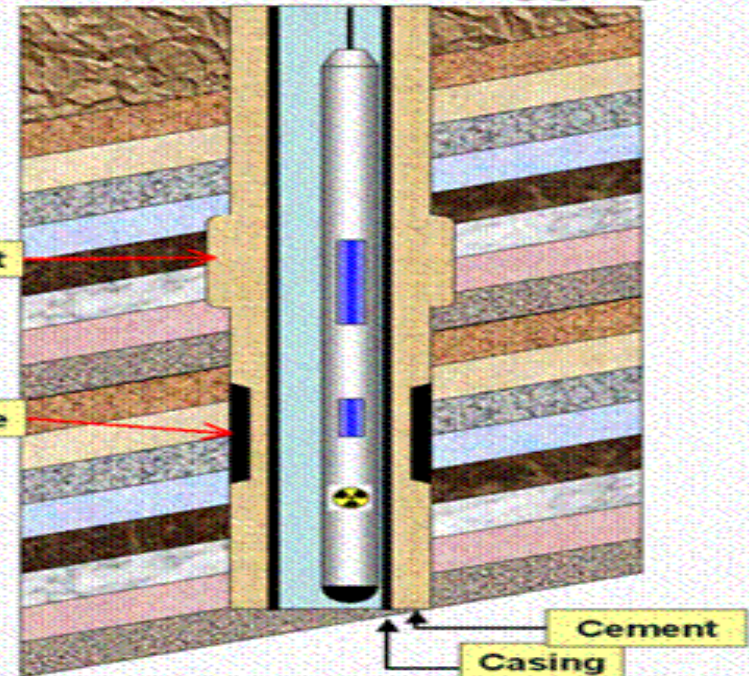
Wire Line Logging



Open Hole Well Logging



Cased Hole Well Logging



Logging While Drilling (LWD)

Logging While Drilling (LWD) is a technique of conveying well logging tools into the well borehole down hole as a part of the bottom hole assembly(BHA).

It consists of main three elements:

1. Down hole logging sensors.
2. Data transmission system.
3. Surface interface.

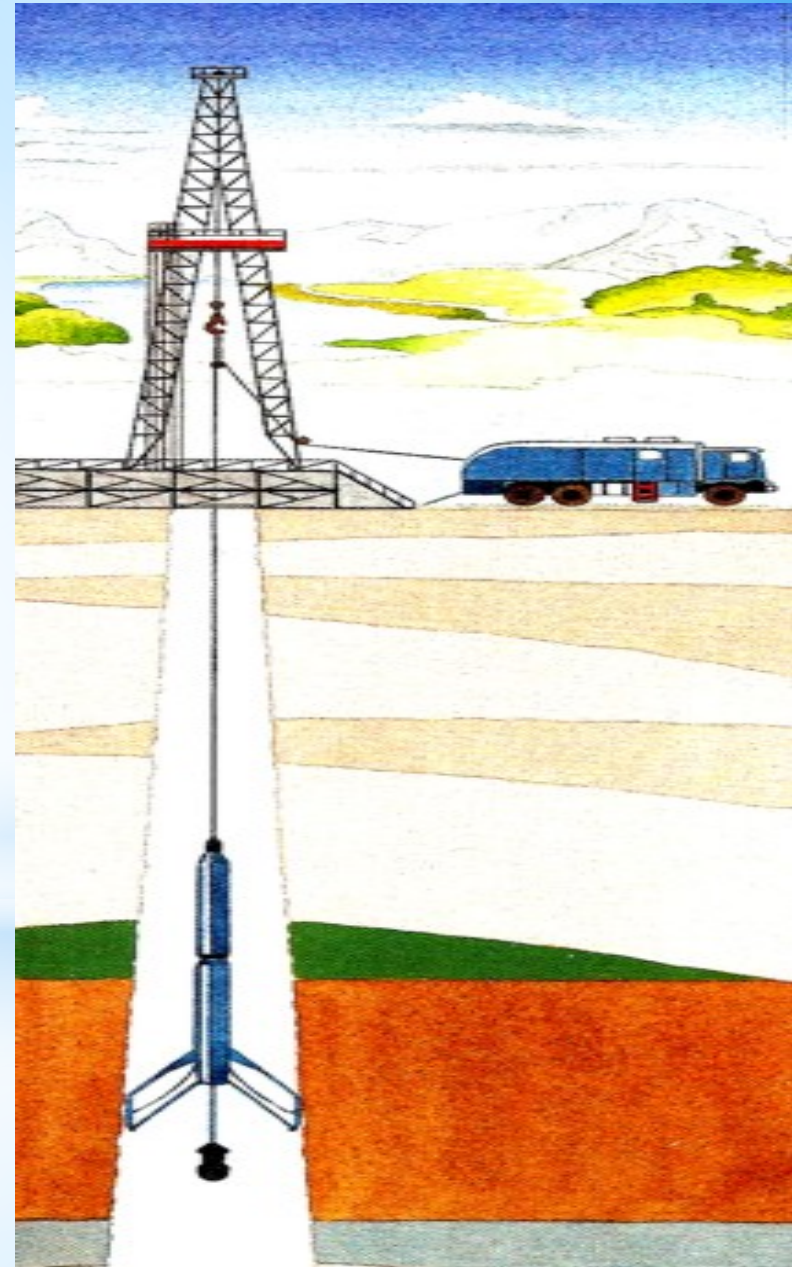
Logging While Drilling (LWD)

- The **sensors** are placed **behind** the drill **bit** in the drill collars and are **active** during **drilling**.
- The **signal** are transmitted to the surface in digital format by **pulse** telemetry through the drilling **mud** & collected by **surface receivers**.
- The **formation** is logged very **soon** after drilling, a matter of **minuets** to several **hours** depending on **drilling rates** and the **distance** between the bit & the down hole **sensors**.



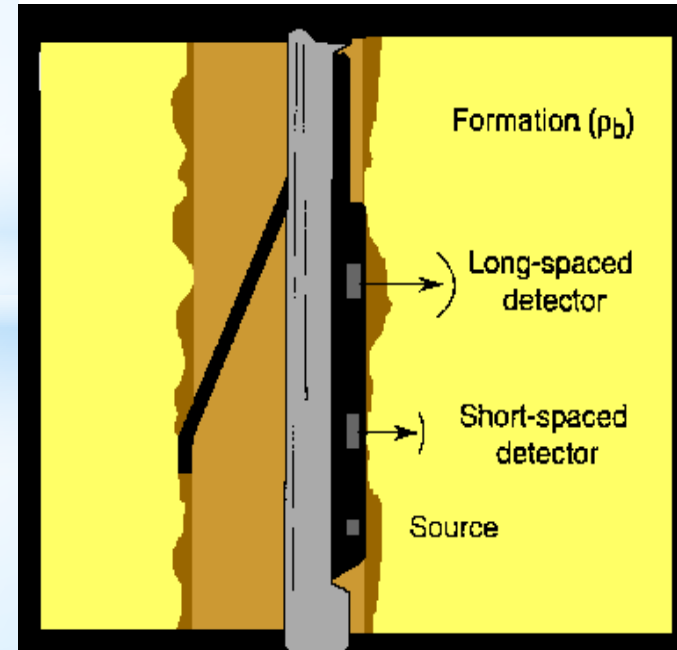
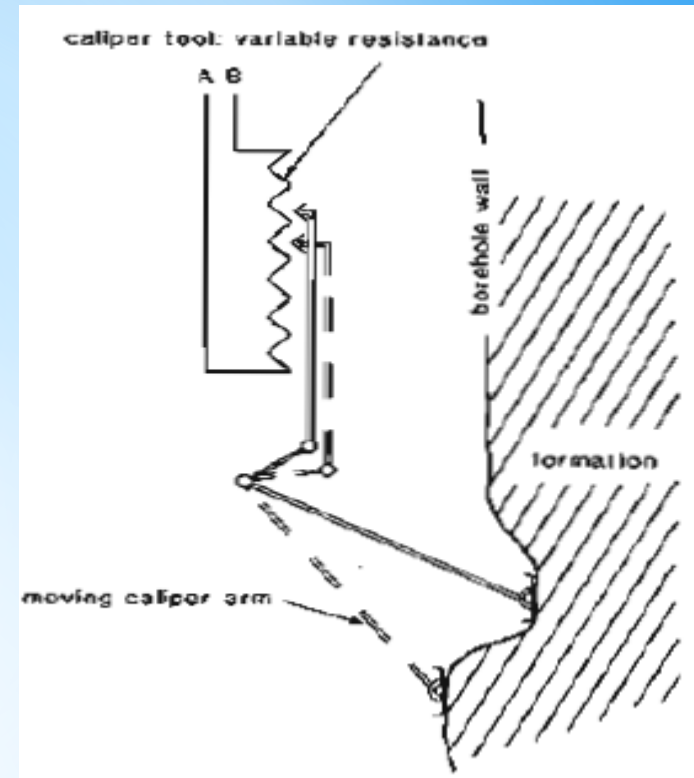
Geophysical well logging

- The logging procedure consists of lowering a 'logging tool' on the end of a wire line into an oil well (or hole) to measure the rock and fluid properties of the formation and make decisions about drilling and production operations.
- **Types:**
 1. Triple compo (composite): (GR, SP, Caliper), (Resistivity) , (Neutron & Density).
 2. Formation fluid sampling & formation pressure measurement.
 3. Dimensional measurements of the wellbore & sonic. (Dipmeter).
 4. Wireline-conveyed sidewall coring tools.



Caliper

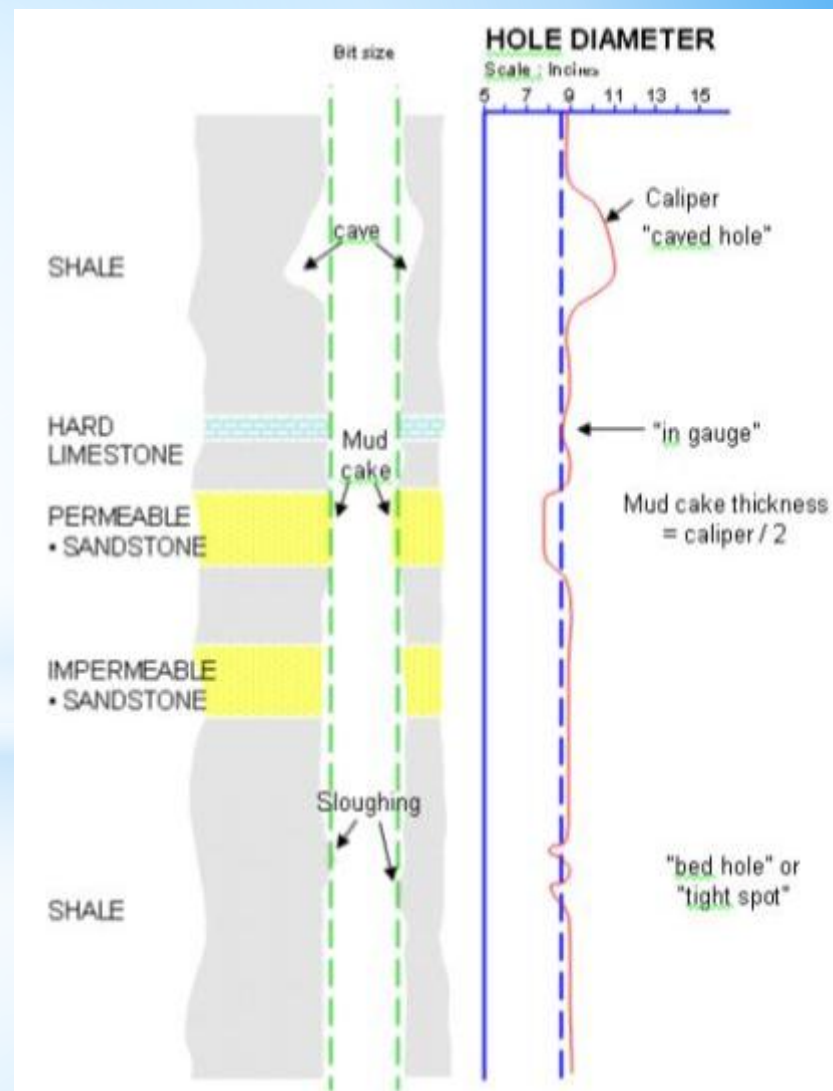
- The **Caliper Log** is a tool for measuring the **diameter and shape of a borehole**.
- It uses a tool which has **1, 2, 4, or more extendable arms**. The **arms can move in and out** as the tool is withdrawn from the borehole, and the **movement is converted** into an **electrical signal** by a potentiometer.
- Some **tools** are automatically **equipped** with a **caliper** such as:
 - Microspherical
 - Density
 - Dipmeter



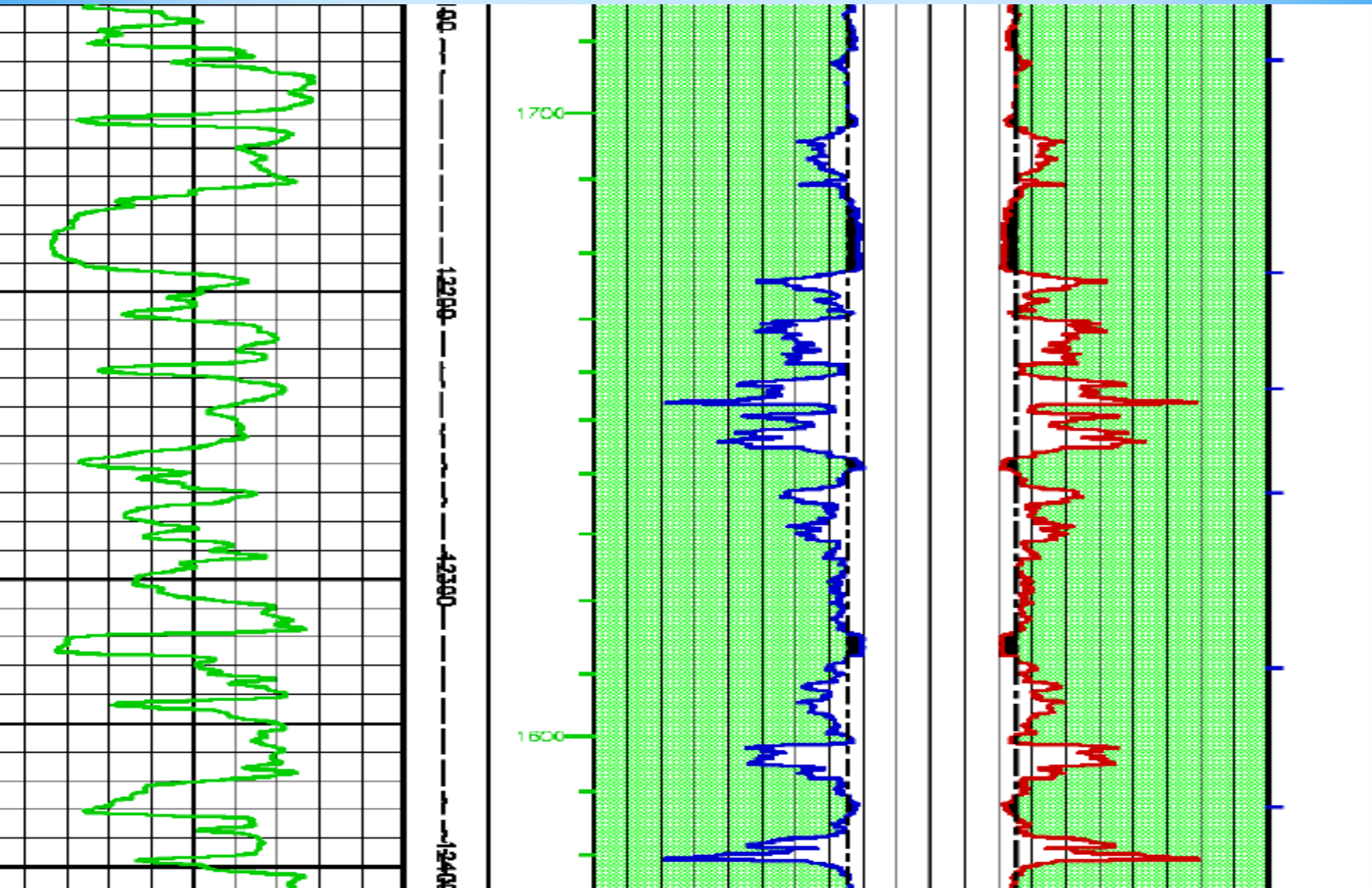
Caliper

The caliper shows where **deviations** occur from the nominal drill bit diameter.

Hole Diameter	Cause	Possible Lithologies
On Gauge	Well consolidated formations Non-permeable formations.	Massive sandstones Calcareous shales Igneous rocks Metamorphic rocks
Larger than Bit Size	<ol style="list-style-type: none"> Formation soluble in drilling mud. Formations weak and cave in. 	<ol style="list-style-type: none"> Salt formations drilled with fresh water. Unconsolidated sands, gravels, brittle shales.
Smaller than Bit Size	<ol style="list-style-type: none"> Formations swell and flow into borehole. Development of mudcake for porous and permeable formations. 	<ol style="list-style-type: none"> Swelling shales. Porous, permeable sandstones.

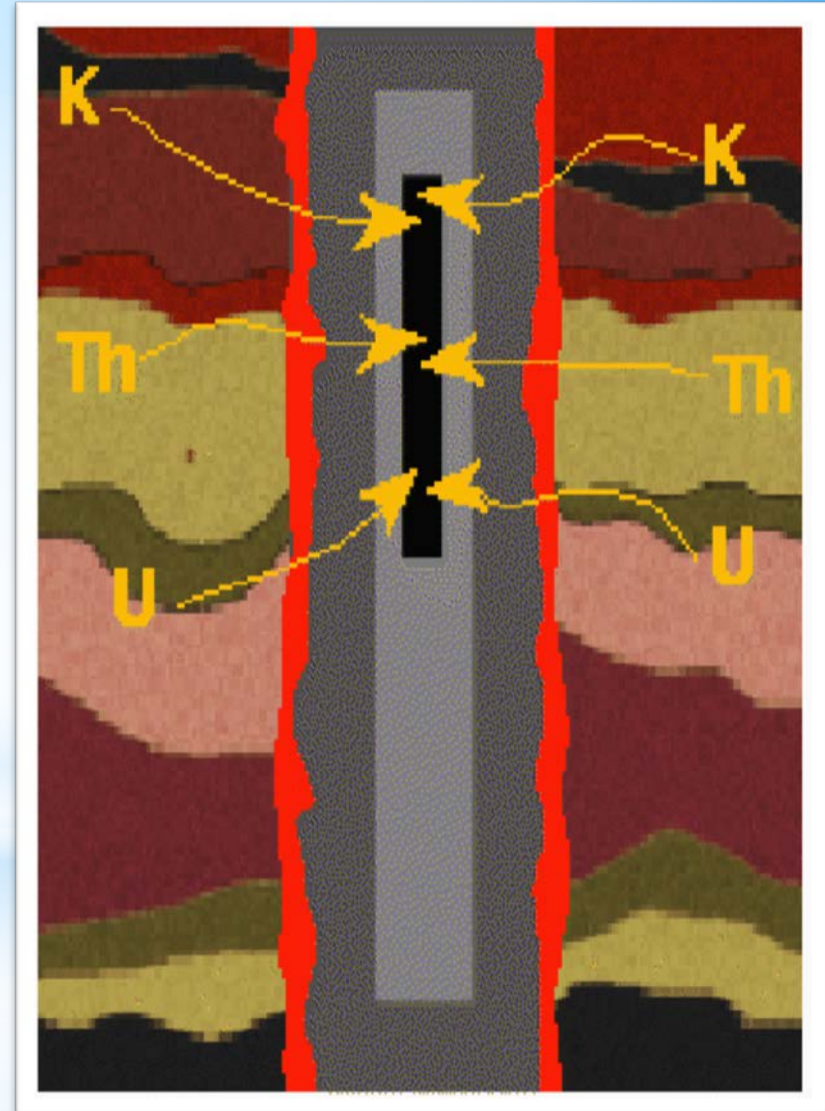


Caliper



Gamma ray

- Records naturally occurring gamma radiation.
- Potassium (K), Thorium (Th), Uranium (Ur)
- Shale & Clay minerals: emit high gamma rays.
- Other sedimentary rocks:
- Volcanic ash (Th), Dissolved radioactive salts in the formation waters (K), Algal origin (K), Glauconite (iron potassium phyllosilicate) (K), Organic matter (Ur).



Gamma ray

- Tools:

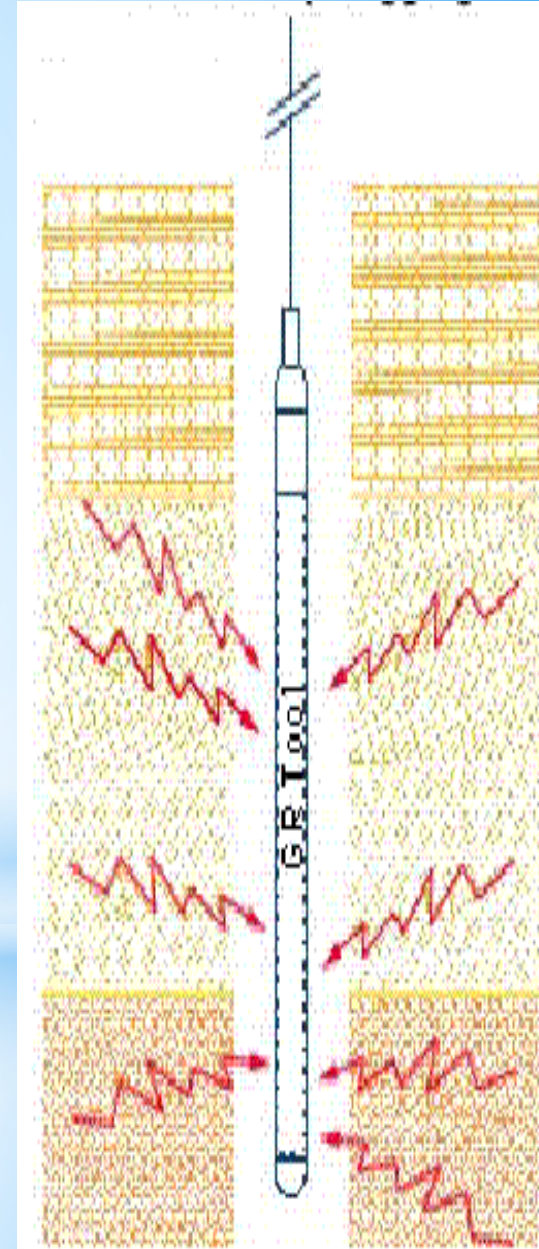
- Single gamma ray detector, records the natural gamma rays against depths.

- Unit: API 0 ————— 150

- Uses:

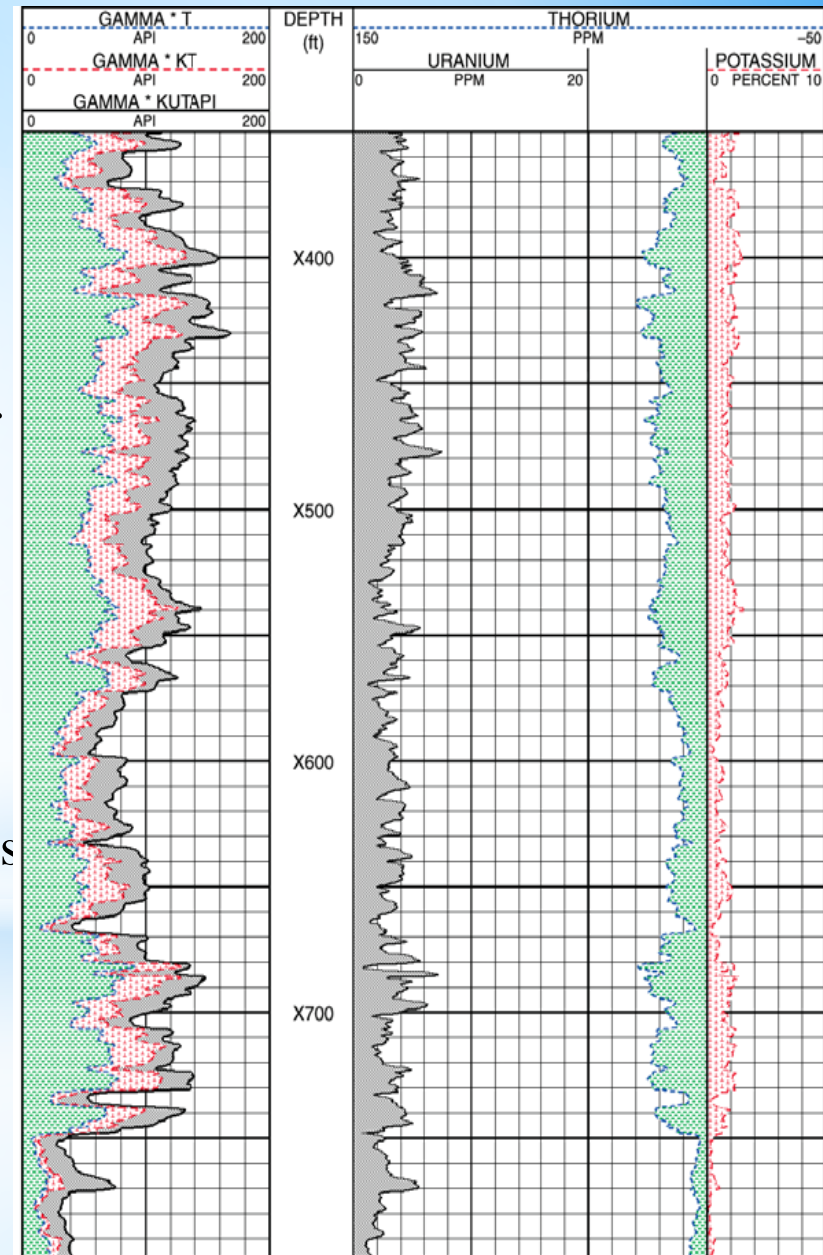
1. 1st indicator for lithology.
2. Identify radioactivity in sandstone, carbonates & evaporites.
3. Discriminate between reservoir & non- reservoir.
4. Determine facies & grain size.
5. Correlation.
6. Estimate shaliness of the reservoir.

$$V_{sh} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}}$$



Spectral Gamma ray

- Identifying Potassium (%), Thorium (ppm) & Uranium (ppm).
- **High uranium :**
 - Organic-rich shale that represent source beds.
 - Acidic igneous rocks.
- **High potassium :**
 - Glauconitic sands, Micaceous sands, concentrations of Illite clays, Algal limestones
- **High Thorium :**
 - Acidic & Intermediate igneous rocks.
 - Bentonite, Kaolinite.



Porosity

```
graph TD; A[Porosity] --> B[Density]; A --> C[Neutron]; A --> D[Sonic];
```

Density

ρ (g/cm³)

Neutron

ϕ (%)

Sonic

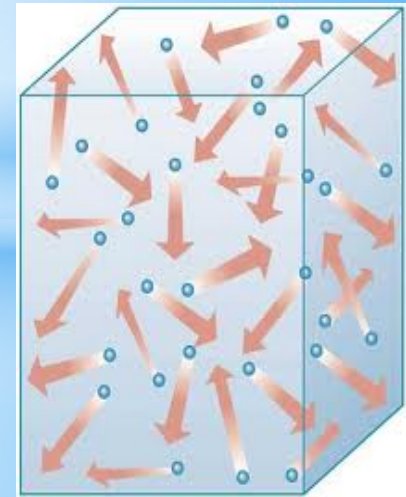
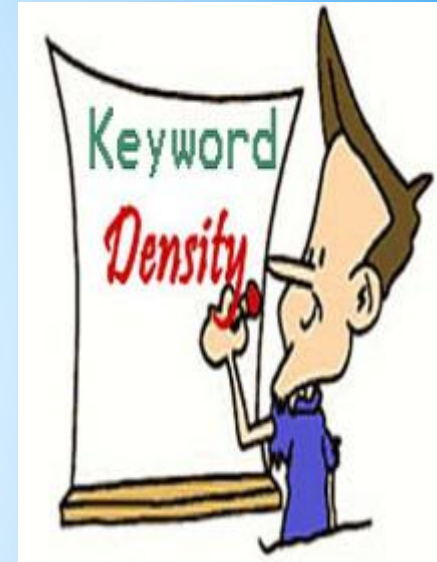
t (μ sec/ft)

***NOTE**

* The depth of investigation of these logging tools is very shallow- only a few inches or less- and therefore generally within the flushed zone.

Density ρ (g/cm³)

- Measures formation **bulk density (ρ_b)** (overall density of a rock including solid matrix and the fluid enclosed in pores) and **photoelectric absorption index (Pe)**.
- **Principle:**
- A radioactive **source** emits medium energy **gamma rays** in the formation. These gamma rays **collides** with the **electrons** of the formation and **lose** some of its **energy** (Compton Scatterings). The **scattered** gamma **ray** reached the **detector** are **counted** as indication of the formation **density**
- The **higher** the formation **density**, the **lower** the intensity of **gamma radiation** at the detectors.



Density ρ (g/cm³)

- **Tools:**

- The source and two detectors are mounted in a pad, which is pressed against the bore hole wall.
- The near detector responds to the borehole effect which when removed from the far detector readings enhance the formation effect

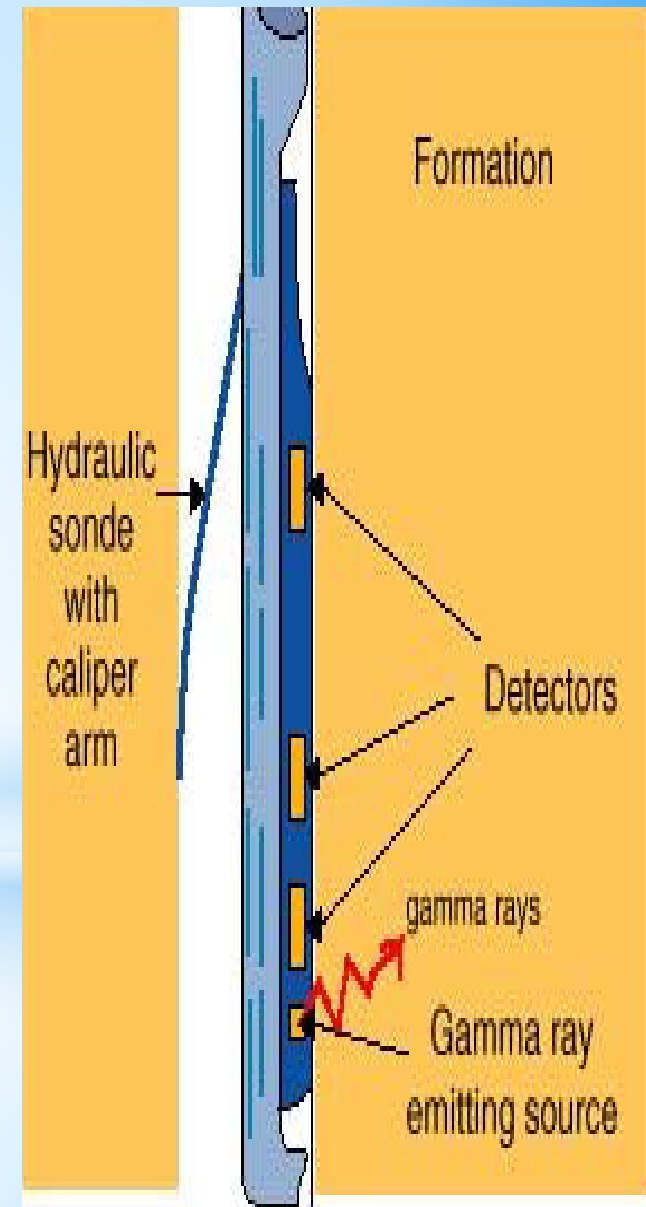
- **Unit:** 1.95 ——— 2.95 g/cm³

- **Uses:**

- Measure bulk density,
- Lithology determination using P_e ,
- Correlation.
- Mineral identification in evaporates .
- Gas detection (w/ other logs).

- **Porosity equation:**

$$\phi = \frac{\rho_{\text{matrix}} - \rho_{\text{bulk}}}{\rho_{\text{matrix}} - \rho_{\text{fluid}}}$$



Density ρ (g/cm³)

Density & Pe values of the most common rocks

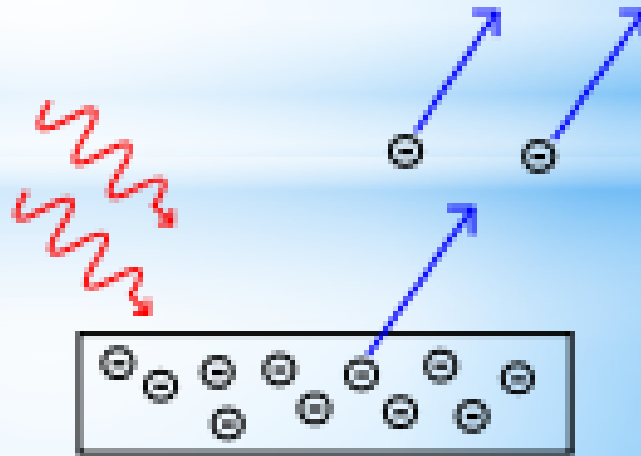
Rock	Matrix Density	Pe
Sandstone	2.65	1.8 - 2.5
Siltstone	2.65	2.5 - 3.5
Shale	2.20 – 2.60	3.5 - 4.5
Limestone	2.71	> 5
Dolomite	2.85	3.5 - 5
Anhydrite	2.96	> 5

Values of filtrate densities

Filtrate (Fluids)	Density (g/cc)
Fresh water	1
Salt water (120,000)	1.1
Oil (med. Gravity)	0.8
Gas (160F,5000psia)	0.2

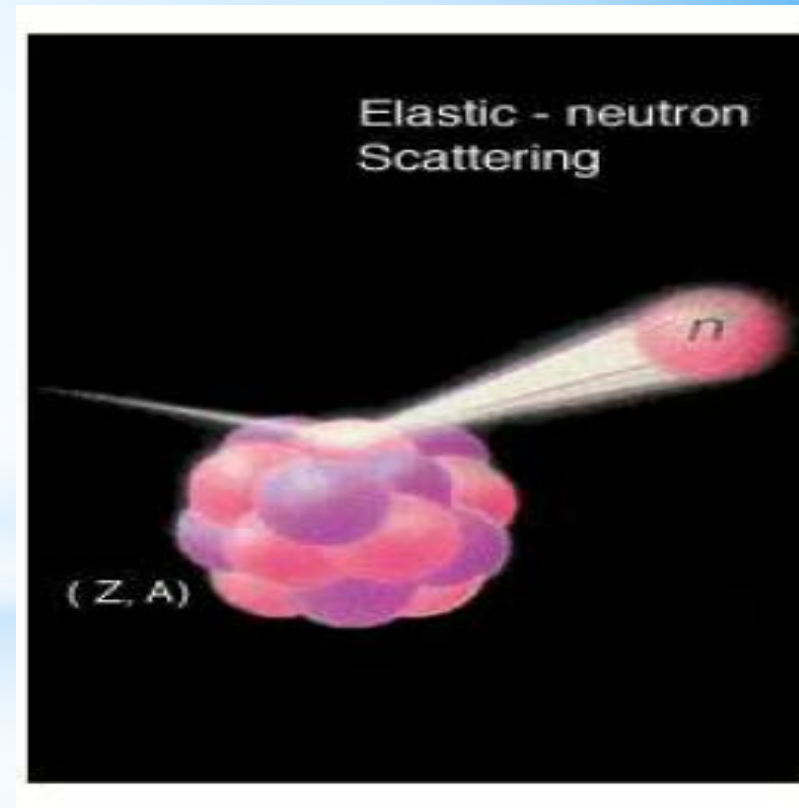
Photoelectric factor effect (pe)

- It is a continuous record of the effective photoelectric absorption cross section index.
- The photoelectric effect occurs when gamma rays have lost sufficient energy to be captured & absorbed by electrons electrically bound to atoms. These electrons will leave its atomic orbit & becomes ionized.
- Pe is related to the atomic no. (the number of electrons per atom) hence fixed for each element.

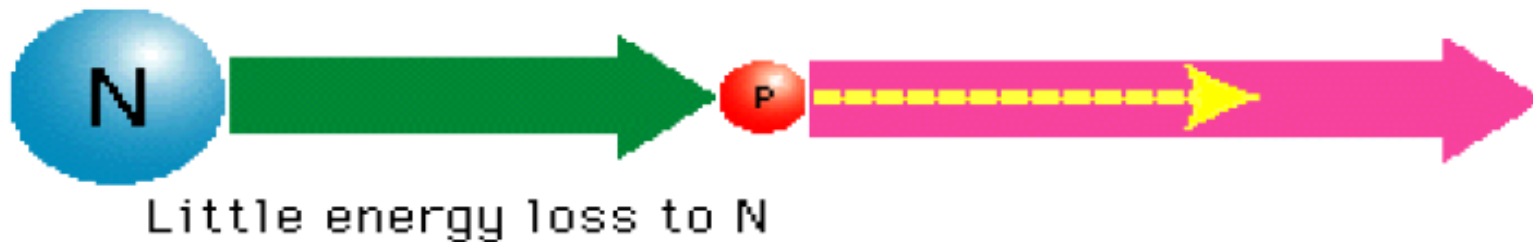


Neutron ϕ (%)




- Measuring formations porosity.
- They respond to the amount of hydrogen in the formation.
- In clean formations whose pores are filled with water or oil, the neutron log reflects the amount of liquid-filled porosity.
- Measuring formations porosity.
- They respond to the amount of hydrogen in the formation.
- In clean formations whose pores are filled with water or oil, the neutron log reflects the amount of liquid-filled porosity.
- Principal:
- Collision between a fast-moving
- neutron and a stationary nucleus in the formation.
- With each interaction, the neutron loses kinetic energy, imparting some to the bombarded nucleus, which remains in its ground state.



Neutron ϕ (%)



**Hydrogen mass =
Neutron mass**

-  Kinetic energy of the neutron prior to collision
-  Kinetic energy passed on to the particle after the collision
-  Kinetic energy of the neutron after the collision

Neutron ϕ (%)

- Hydrogen index (HI)

is the quantity of hydrogen per unit volume.

- High HI

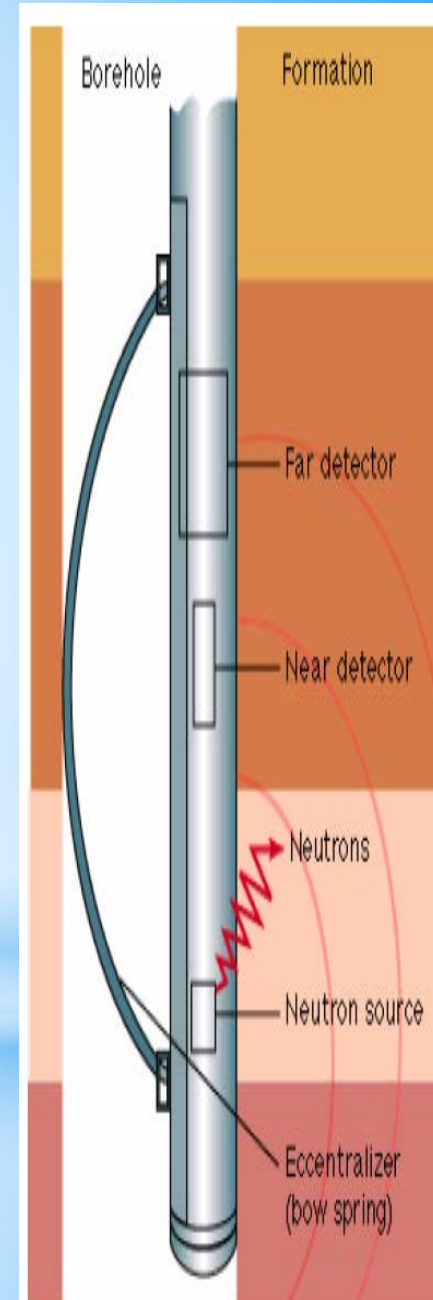
Most of the neutrons are slowed and captured within a short distance from the source.

- Low HI

The neutrons source travel farther from the source before they are captured.

- Tool:

A source and two detectors are mounted in a tool which is pressed against the borehole wall.



Neutron ϕ (%)

Gas Effect:

Gas has a low HI leading to a noticeable drop in the neutron porosity

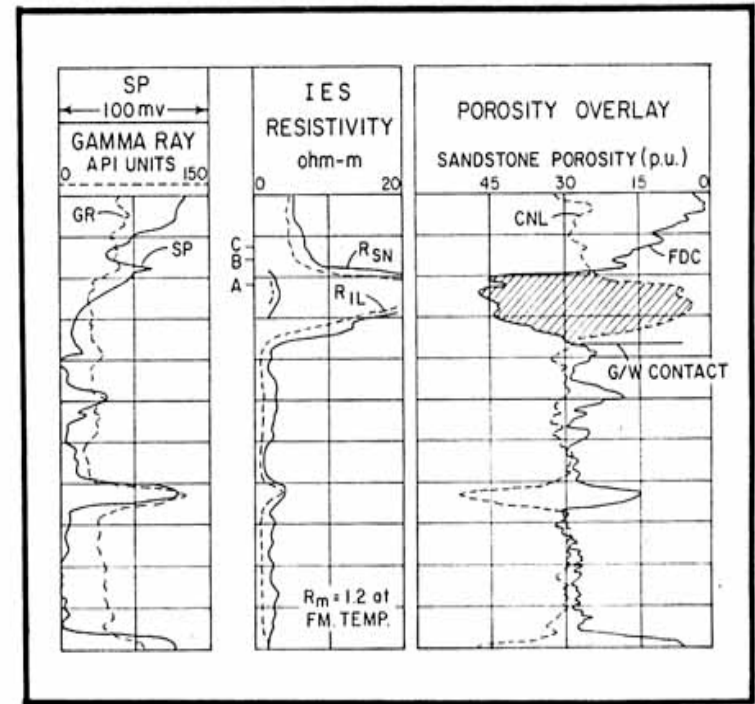
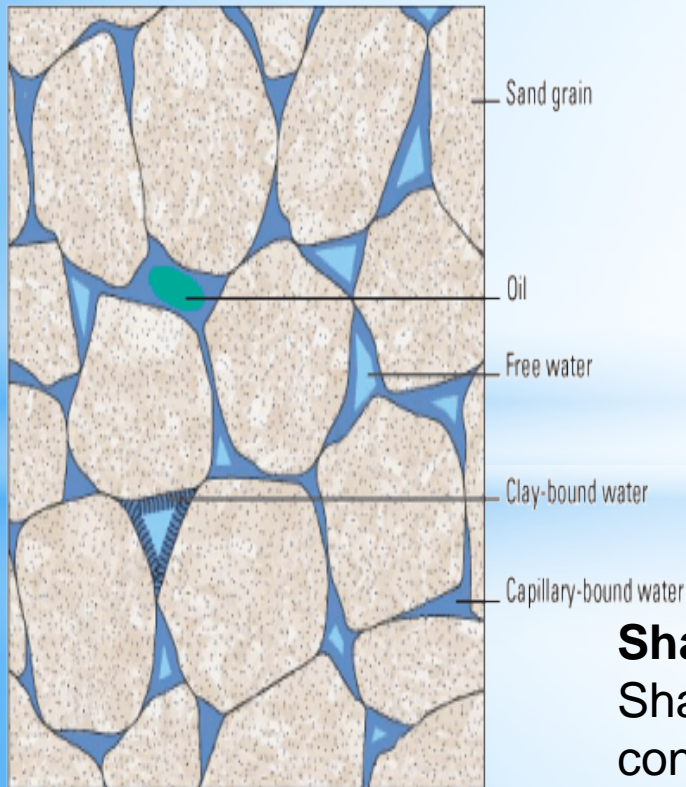


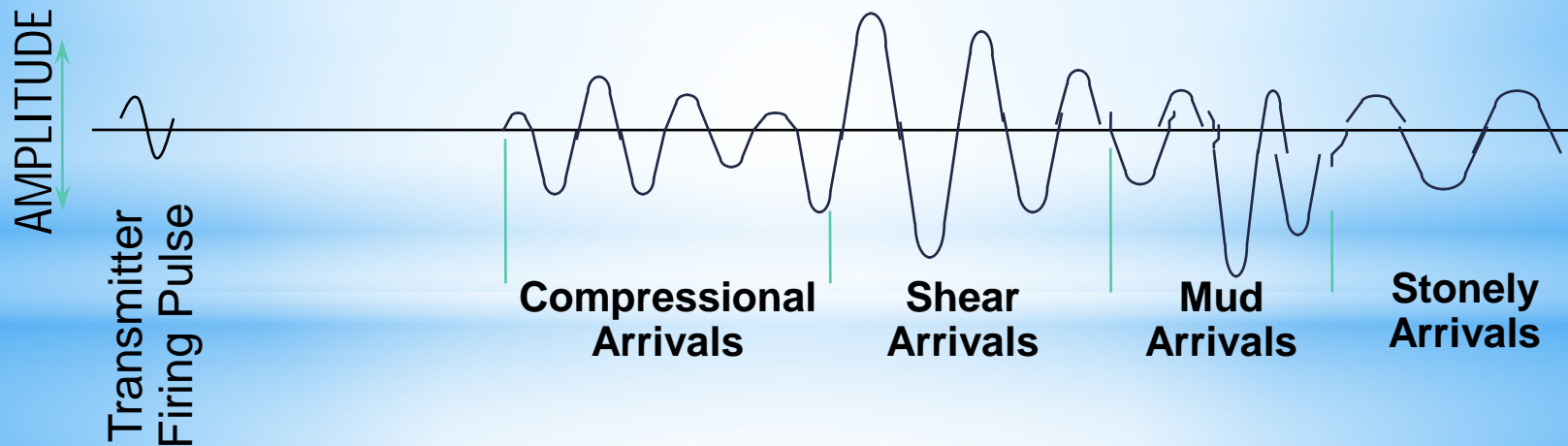
Fig. 3-4 — CNL-FDC overlay showing gas zone in cleaner part of sand. As shown by Gamma Ray the upper part of the interval is shaly. (From Ref. 1, courtesy of SPWLA.)

Shale Effect:

Shale has not true porosity because it contain a lot of bound water.

Sonic Δt ($\mu\text{sec}/\text{ft}$)

- **Principle:**
- Measures the **time** it takes for **sound pulses** to travel between a transmitter & receiver through the formation (Δt).
- The travel time can be used to estimate the **primary porosity only**.
- The waveform contains shear, compressional, stonely, and mud waves



Sonic Δt ($\mu\text{sec}/\text{ft}$)

- **Compressional Waves (P- waves)**

- The direction of **particle** displacement is **parallel** to the direction of **propagation**.
- It is called the **first arrival waves**.

- **Shear Waves (S-waves)**

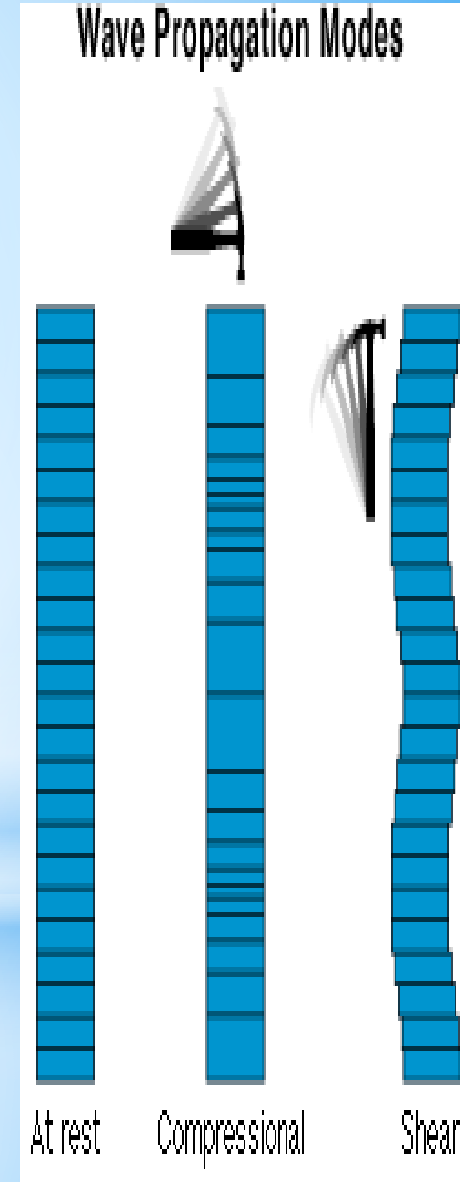
- The direction of particle displacement is **perpendicular** to the direction of **propagation**.

- **Stonely Waves**

- Take place in the **mud** by **interaction** with the **formation surface**.
- Very sensitive to **wall rigidity**.

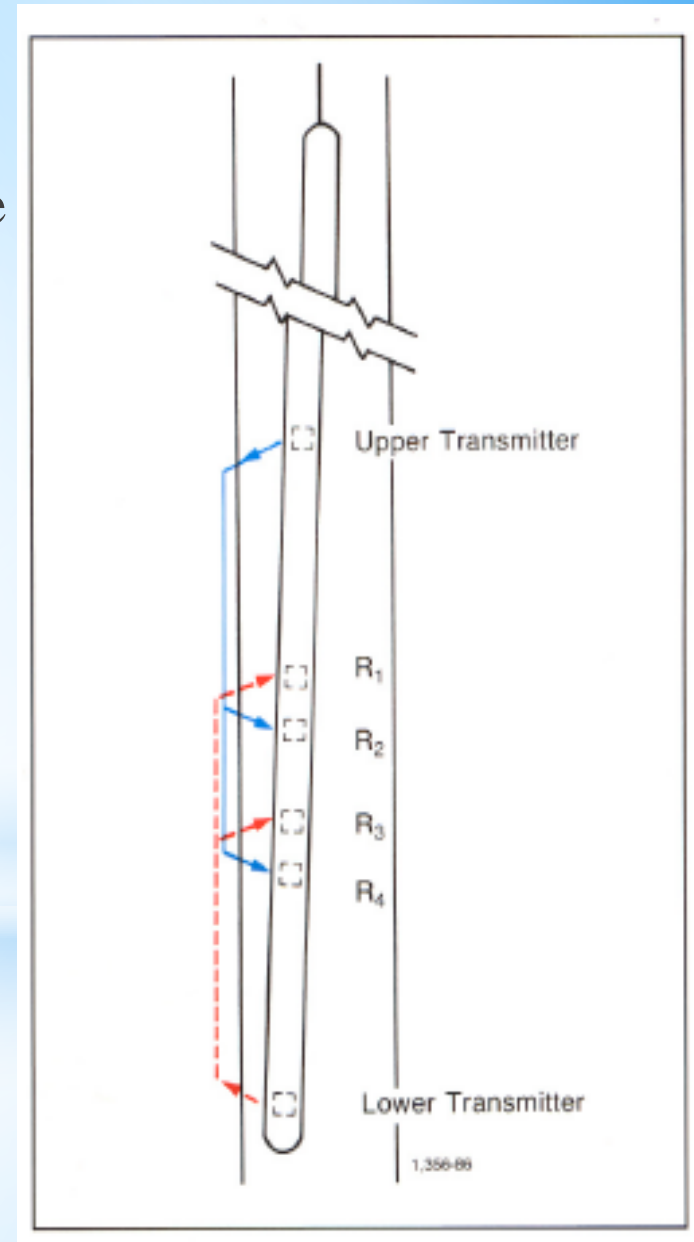
- **Mud Waves**

- Travel **directly** through the **mud column** to the receiver without contact with the borehole wall.



Sonic Δt ($\mu\text{sec}/\text{ft}$)

- **Tools:**
- Because the sonic is run hole- centered, any pulse transmitted by the tool, passes first into the mud, it is then refracted at the borehole wall & refracted back into the mud so to reach the tool again.
- A **transmitter** sends out a **sound pulse**. The **difference** in arrival time of the pulse at **two receivers** ,which are 60 cm apart, is measured.
- A **second transmitter & pair of receivers** measure the same parameter in the **opposite direction**.
- **By averaging** the two measurements, **the borehole effects** on the travel time are **eliminated**.



Sonic Δt ($\mu\text{sec}/\text{ft}$)

- The sonic measurements can be used to calculate the primary porosity of the formation.

$$\phi_s = \frac{\Delta t \log - \Delta t_{\text{ma}}}{\Delta t_f - \Delta t_{\text{ma}}}$$

- ϕ = porosity.
- $\Delta t \log$ = acoustic transit time log reading ($\mu\text{sec}/\text{ft}$).
- Δt_{ma} = acoustic transit time of the rock matrix. ($\mu\text{sec}/\text{ft}$).
- Δt_f = acoustic transit time of interstitial fluids. ($\mu\text{sec}/\text{ft}$).
- The difference between the **total density** porosity & the **sonic porosity** can determine the secondary porosity.

Sonic Δt ($\mu\text{sec}/\text{ft}$)

Unit:

$$Dt = \mu\text{sec}/\text{ft} \quad 40 \text{ ————— } 140$$

Uses:

- Porosity analysis in liquid filled open holes
- Lithology determination

Fluid	Δt_f ($\mu\text{sec}/\text{ft}$)
Water with 20% NaCl	189
Water with 15% NaCl	200
Water with 10% NaCl	208
Water (pure)	218
Oil	238

Fm	ΔT ma (msec/ft)	ΔT ma (used)
Sandstone	58.8 – 56.0	57
Sandstone	55.5 – 51.0	55
Limestone	47.6 – 43.5	47
Dolomite	43.5	43
Anhydrite	50.0	50
Salt	66.7	67
Casing (Iron)	57.0	57

Resistivity ohm-m.

Principle:

- The formation resistivity is the resistance of the formation to the passage of an electric current.
- It is expressed in ohm - m²/m, usually written as ohm-m.

$$R = r A / L,$$

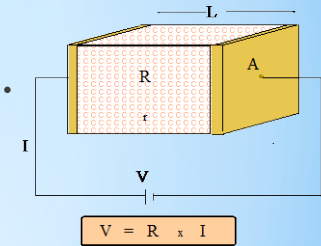
- Where:

R is resistivity of the formation in ohm- meters,

r is resistance in ohms,

A is area in square meters

L is length in meters.



$$R = r L / A$$

$$V = r L / A \times I$$

$$r = V / I \times A / L$$

$$k = A / L$$

$$r = V / I \times k$$

The formation conductivity is the ability of the formation to conduct an electric current.

$$C = 1000 / R$$

Resistivity ohm-m.

- **Resistivity tools** measures the **formations resistance** to an applied electric current.
- **Dry rocks** are good electrical **insulators** but their enclosed **fluids** are **conductors**.
- **Hydrocarbons** is the only fluid that have **high resistivity**.

*Factors affecting on formation resistivity:

1. Resistivity of formation water.
2. Pore structure geometry (Formation Resistivity Factor).
3. Resistivity of clays.

Resistivity ohm-m.

* Factors affecting on formation resistivity:

1. Resistivity of formation water.

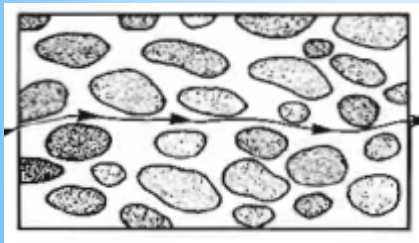
- The formation water vary from **fresh water to very saline** water, but **usually** they are **saline** and the salinity **increase** with depth.
- Salinity of **fresh** water= **<5000 ppm**
Salinity of **sea** water= **35000 ppm**
Salinity of **brine** formation water = **200,000 ppm**
- As the **salinity increase**, the **conductivity** of the fluid **increase**, where the current is carried by the **dissociated ions**, ex. Na^+ , Cl^-

Resistivity ohm-m.

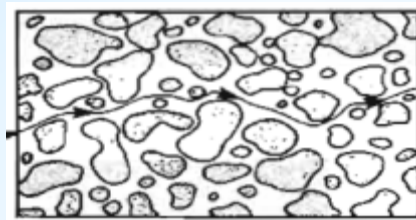
Factors affecting on formation resistivity:

2. Pore structure geometry (Formation Resistivity Factor)

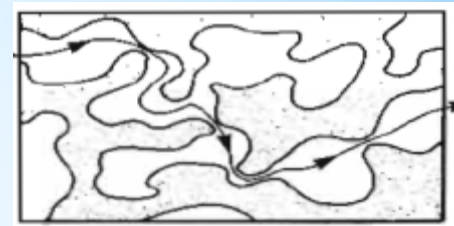
- The Rock **affect** passively on the resistivity by the geometry of its pores (**grain shape**)



F low
(≈ 10)



F moderate
(≈ 50)



F high
(≈ 300)

- This what is know by the **formation resistivity factor (F)** which is strongly **influenced** by the grain shape (change in **pore throat geometry**)

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

Where:

- F** → is the **formation resistivity factor**.
- ϕ** → **Porosity**
- m** → **Cementation factor**.
- a** → **Constant** (0.6 to 1, usually 1).

Resistivity ohm-m.

Factors affecting on formation resistivity:

3. Resistivity of clays.

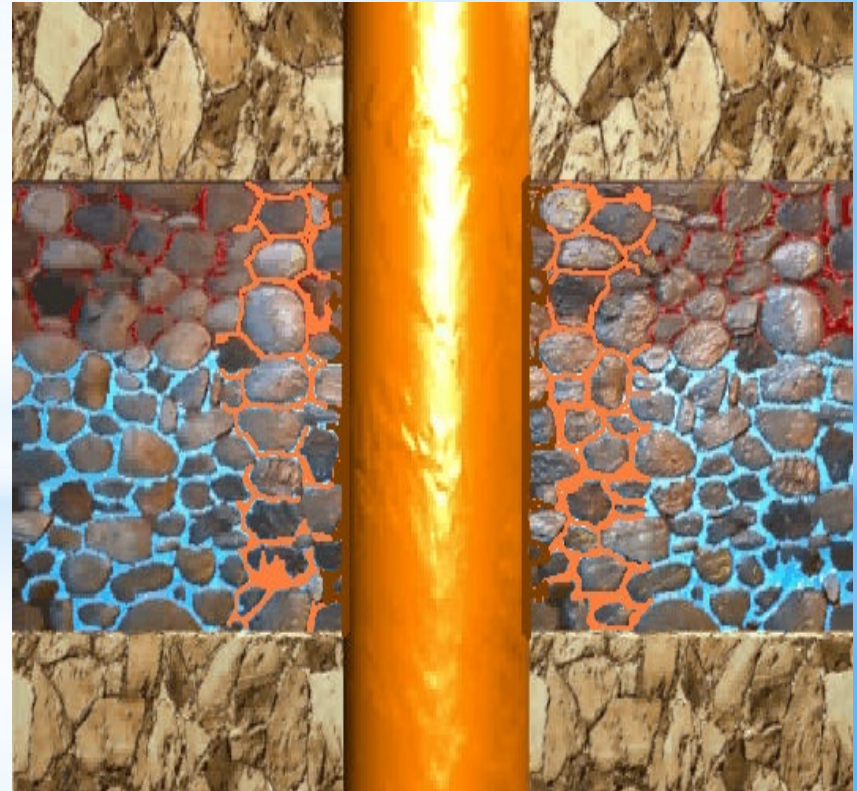
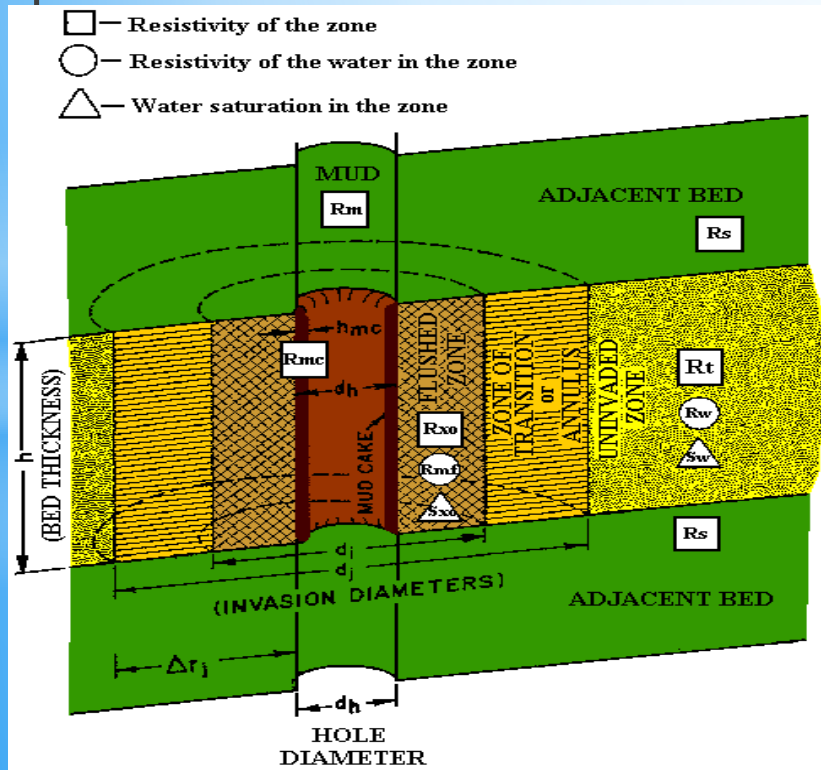
Clays conduct electricity in two ways:

1. Through the **pore water** where the **newly- deposited** clays **encloses** conductive formation **water**. This **diminishes** rapidly through **compaction** (Shale).
2. Through the **clay itself** where it consists of **silicate layers** which, in the presence of **water**, become **negatively charged**, i.e. **clay** is considered as **negatively charged framework** and **positive** current **conducting** ions.

Resistivity ohm-m.

Invasion:

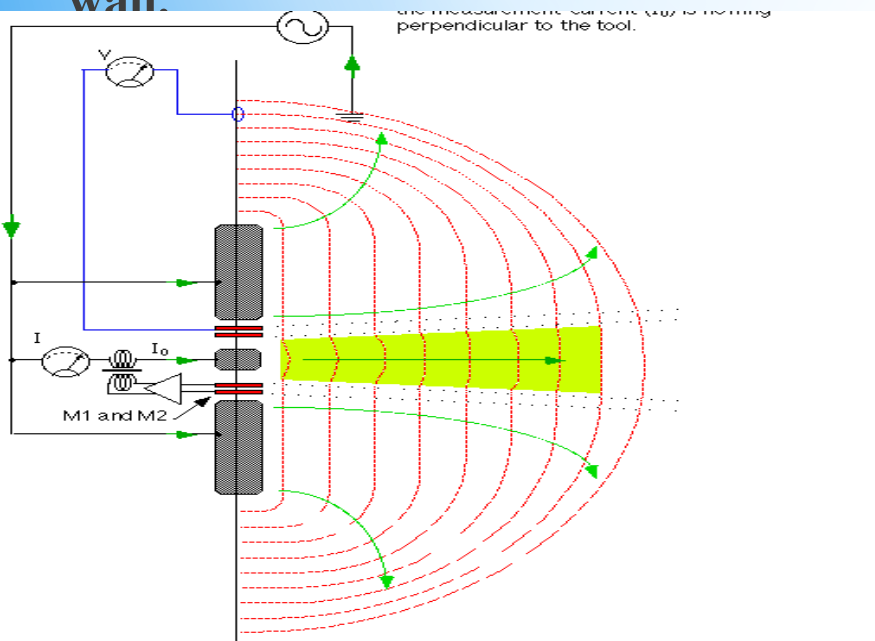
- Process by which mud filtrate is forced into permeable formations, and the solid particles of the mud are deposited on the borehole wall where they form a mud cake.
- Due to pressure difference between mud column and formation pressure.



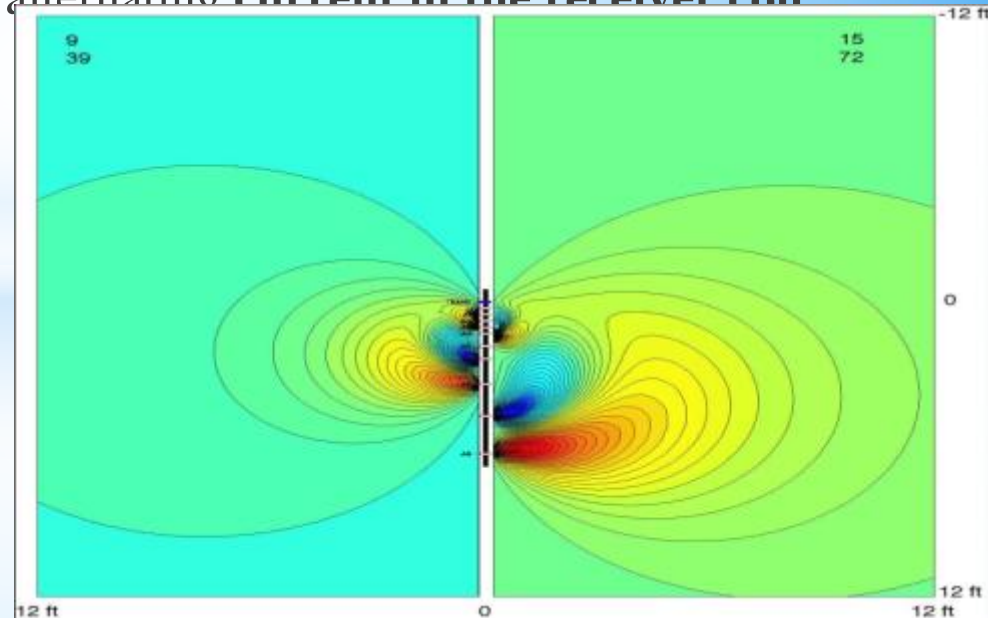
Resistivity ohm-m.

Laterolog Tools Induction Tools

- Respond to **resistivity**
- **Send** an electric **current** from an electrode on the sonde directly into the **formation.**
- Require **conductive mud.**
- The **deeper** looking devices are **hole centered** while the **shallow** devices are **mounted** on a pad against the **borehole wall.**



- Respond to **conductivity**
- **Induce current** in the formation
- Better for **low resistivity formations**
- Can also work in **nonconductive mud.**
- The **transmitter coil** creates a **magnetic field** around the tool which **induced eddy currents** in the **formation.** This **eddy currents** creates their own **magnetic field** and **induced an alternating current in the receiver coil**



Resistivity ohm-m.

* Uses:

- Locate Hydrocarbons (presence & depth).
- Determine mud resistivity to help define the invasion profile.
- Determine the fluid saturation.
- Correlation.

* Unite:

0.2 ————— 2000 ohm-m



Resistivity ohm-m.

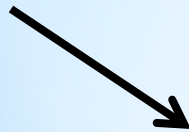
Saturation calculation:

- * The **quantitative** use of the resistivity logs is to determine **the volume of oil** in a reservoir, i.e. to define the **water saturation** S_w

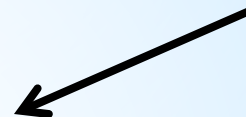
$$1 - S_w = S_{hc} \text{ (} S_{hc} : \text{hydrocarbon saturation)}$$

Archie Equation:

$$S_w^n = \frac{F R_w}{R_t}$$



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



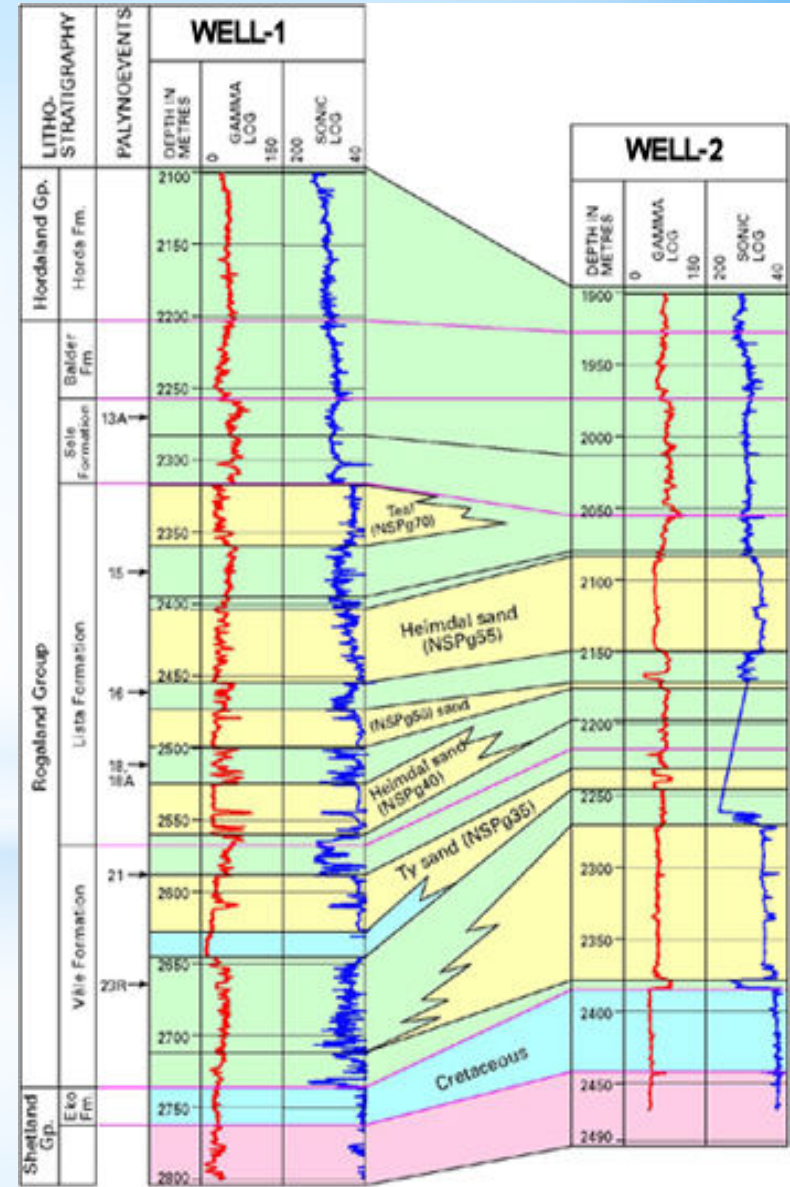
$$F = a / \phi^m$$

- $R_w \rightarrow$ is the **formation water resistivity**,
- $R_t \rightarrow$ is the **true formation resistivity**, and
- $F \rightarrow$ is the **formation resistivity factor**.
- $m \rightarrow$ **Cementation factor**.
- $a \rightarrow$ **Constant** (0.6 to 1, usually 1).
- $n \rightarrow$ **Saturation exponent** (usually 2).

Note: Values for a , m & n are found experimentally for different formations

Correlation

- **Subsurface correlation** forms the **basis** for the geological interpretation.
- Correlations are often made using **composite logs**, which are displays of all well-related **information** such as **paleontological, litho logical and petro physical subdivisions**.
- **Well to well log correlation** methods vary somewhat from one geologist to another, but normally the following logs are used, **Resistivity, Sp, Gamma Ray and Density Neutron**.



شَرَحَ مُحَمَّدٌ بْنُ عَبْدِ اللَّهِ