Chapter 3

Reservoir characterization

3.1. Introduction:

Wireline logging is performed with asonde or probe lowered into the borehole or well, usually after the drill string has been withdrawn.

A log is a continuous recording of a geophysical parameter along a borehole. The wireline logging performed in both open hole and cased hole.

Open hole logging is based on measurements of the formation's electrical, nuclear and acoustical properties. Other open hole wireline services include formation sampling, fluid sampling and pressure measurements.

Cased-hole logging includes measurement of nuclear, acoustical and magnetic properties. Other cased-hole wireline tools include perforator guns and various production logs.

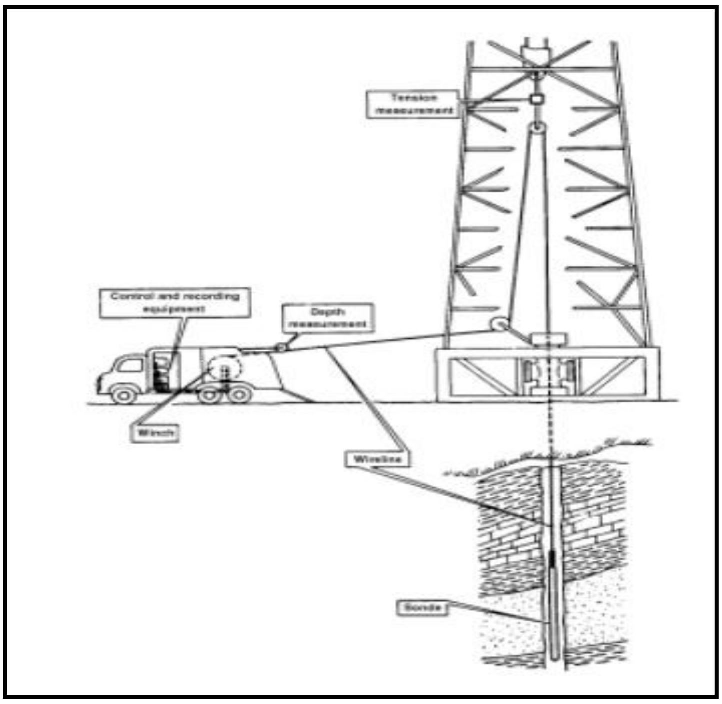


Figure 3.1: Shows logging Technique

Core analysis has come a long way from the days when reservoir productivity was determined by blowing through a piece of cable tool- produced core. Properly engineered core analysis provides a direct measurement of these reservoir-rock properties and is an essential step in formation-evaluation, reservoir, and production engineering. Fundamental core-analysis measurements are unchanged, but advances provide the ability to test at reservoir conditions and to acquire simultaneous measurements of reservoir dependent properties.

Core analyses must integrate with field and production data and eliminate reservoir uncertainties that cannot be addressed with log, well-test, or seismic data.

Coring Fluids is modern drilling fluids are used during most coring operations. However, if determination of endpoint saturations is one of the objectives, a coring fluid is designed to maintain the immobile-phase saturation. If a core is to be used to define fluid saturation- dependent parameters, such as relative permeability، capillary pressure, or electrical properties, the drilling fluid should be formulated to maintain core-wettability characteristics as they were in the reservoir. Core-handling and preservation procedures are designed to maintain the physical integrity and reservoir wettability until planned tests are completed. The ideal coring program considers rock type, degree of consolidation, and fluid type. It minimizes physical and chemical alteration of the rock and can include specialized pressure, sponge, or gel coring systems. (Servet Unalmiser and James J. Funk,1998)

The wireline logging on drilled wells and core analysis on lab both used in determination in petrophysical properties (i.e. Porosity, permeability, resistivity, saturation, etc).

3.2. Porosity:

Porosity is a measure of storage capacity of a reservoir. It is defined as the ratio of the pore volume to bulk volume, and is may be expressed as either a percent or a fraction. In equation form:

$$\phi = \frac{V_{pore}}{V_{bulk}} = \frac{V_{bulk} - V_{matrix}}{V_{bulk}} = \frac{V_{bulk} - (W_{dry} / \rho_{matrix})}{V_{bulk}} \text{.........(3.1)}$$

Where:

V_{pore} = pore volume.

V_{bulk} = bulk rock volume.

V_{matrix} = volume of solid particles composing the rock matrix.

W_{dry} = total dry weight of the rock.

ρ_{matrix} = mean density of the matrix minerals.

Two types of porosity may be measured: total or absolute porosity and effective porosity. Total porosity is the ratio of all the pore spaces in a rock to the bulk volume of the rock. Effective porosity (Øe) is the ratio of interconnected void spaces to the bulk volume. Thus، only the effective porosity contains fluids that can be produced from wells.

Porosity may be classified according to its origin as either primary or secondary. Primary or original porosity is developed during deposition of the sediment. Secondary porosity is caused by some geologic process subsequent to formation of the deposit.

3.2.1. Porosity from wireline logging:

3.2.1.1. Density Log:

Density tool is one of the most important instruments used to evaluate formations which measures formation density and directly ties to formation porosity. The density tool measures the electron density, by emitting gamma ray from radioactive source and returning to two detectors.

Electron density is related to bulk density of mineral or rock. In most cases environmental correction for Density log is not significant, field log density can be readily used for interpretation. (Sigit Sutiyono, 1999).

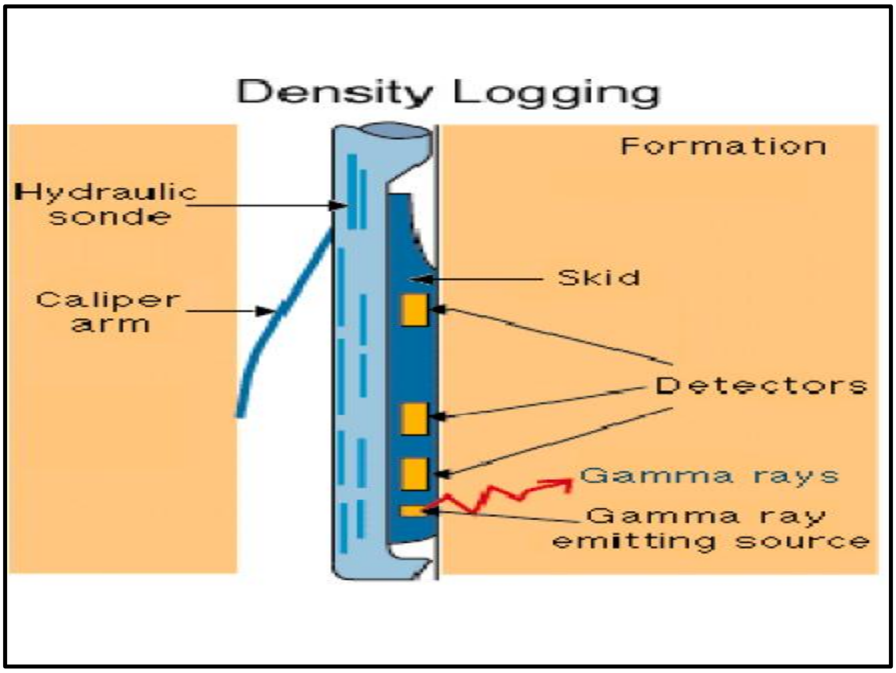


Figure 3.2: Shows density tool.

If the grain density and the density of the mud filtrate are known, density logs give direct estimates of porosity using the following equation:

$$\phi = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} \ldots\ldots\ldots\ldots(3.2)$$

Where:

ρ_{ma} = matrix desity.

ρ_b= log density.

ρ_f= formation fluid density.

Ø= Density derived porosity.

Mud filtrate has a density from 1.0 to 1.1 Mg/m3.

If the formation is gas-saturated (porosity calculated from density logs give anomalously high values since ρf for gas is 0.1 to 0.3 Mg/m3 and 1.0 to 1.1 was assumed.

The density log affected by many environmental factors like:

1. Mudcake effect.
2. Rugosity effect.

The density log is a part of almost every open hole wireline logging suite.

3.2.1.2. Neutron Log:

The neutron is a particle that has approximately the same mass as a proton but no electrical charge. The neutrons are produced by:

1. Chemical source.
2. Pulsed source. (CNLC,2006).

The tool measures the Hydrogen Index which is the quantity of Hydrogen per unit volume. The tools emit high energy neutrons either from radioactive source or minitron. They are slowed down by collisions with formation nuclei, collision will result energy loss.Water has high neutron counts, Oil has a little less counts than Water, Gas will have very low neutron counts.

Neutron log is very sensitive to environment change; bore hole size, mud cake, mud weight, temperature, stand-off, pressure and formation salinity, measurement is compensation of far and near count rates.

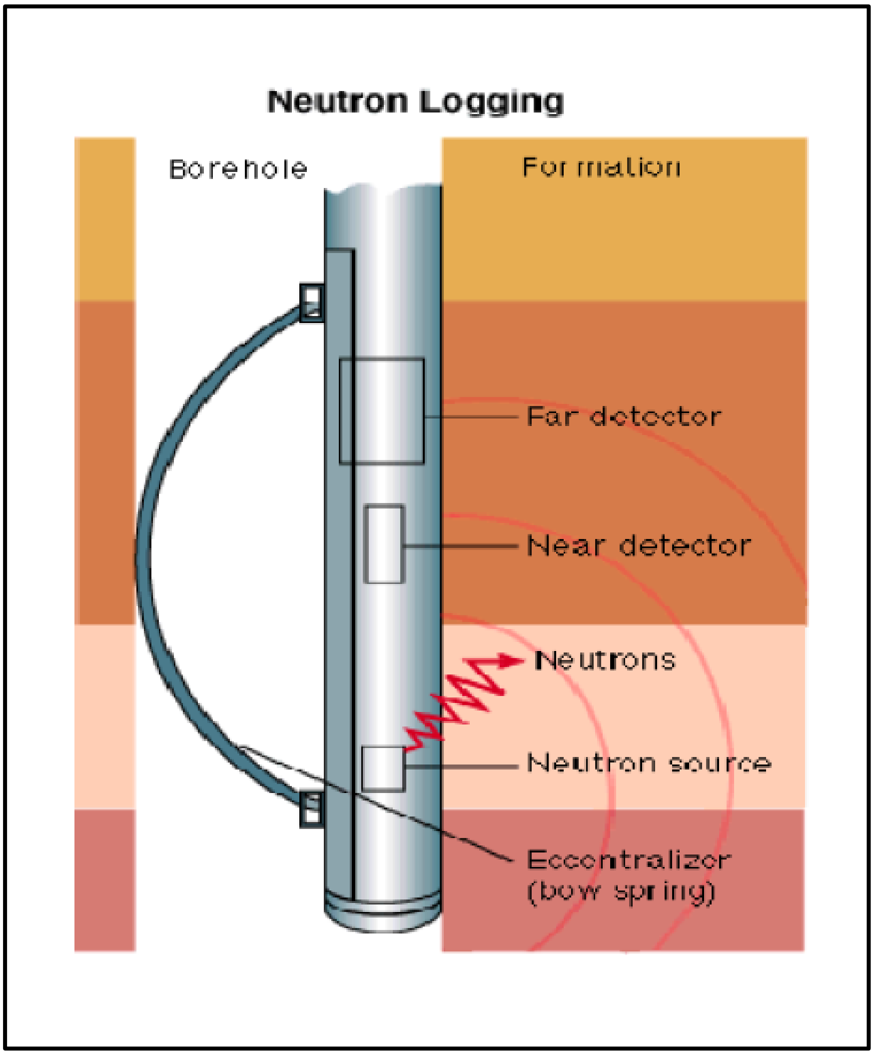


Figure 3.3: Shows neutron tool.

The Compensated Neutron Log (CNL) tool has two detector spacings and is sensitive to slow neutrons.

The Dual Porosity CNL tool has two sets of detectors for both thermal and epithermal neutrons. CNL logs can be run in liquid-filled openholes and cased-holes.

In addition, there are several single-detector, pad-type neutron tools that use epithermal detectors. These include the Sidewall Neutron Porosity (SNP).

There are two principal interactions to consider for neutron in matter:

1. Elastic and inelastic scattering.
2. Capture image.

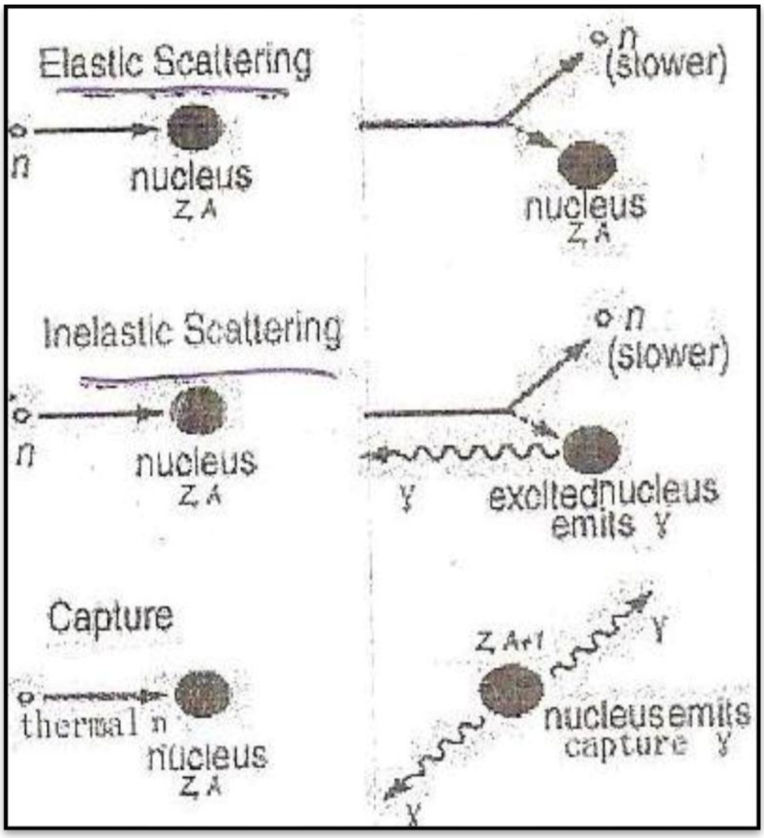


Figure 3.4: Shows the three types of Neutron interactions(CNLC,2006).

Neutron logs can be used in any borehole, open or cased, fluid-filled or air filled. (CNLC, 2006).

The neutron log has others applications include the followings:

1. Gas Detection.
2. Borehole and formation salinity.
3. Reservoir Saturation.
4. Reservoir Monitoring.
5. Borehole Fluid dynamics. (Sigit Sutiyono,1999).

3.2.1.3. Acoustic Log:

Sonic tool generates acoustic signals to measure the time travel to pass through a formation, log measurement in time required to travel in one foot formation (microsec/foot).

Rock properties can be implied from sonic measurements include; Porosity, Lithology, Gas shows, Compaction and Rock strength.

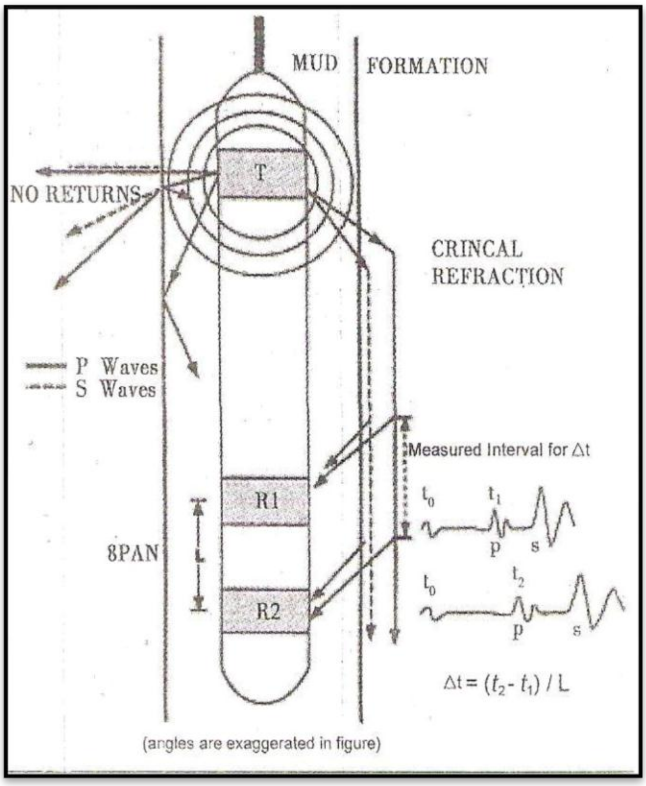


Figure 3.5: Shows Simple sonic tool(CNLC,2006).

The sonic wireline logging has six main branches as follow:

1. Sonic velocity wireline logging.
2. Full waveform sonic wireline logging.
3. Vertical seismic profile(VSP) wireline logging.
4. Sonic amplitude wireline logging.
5. Downhole noise wireline logging.
6. Sonic image wireline logging.

The depth of investigation of a sonic tool is less than 30 in., so it is subject to borehole effects. These include:

1. Gas in the borehole fluid.
2. Large diameter boreholes.
3. Very slow formations.
4. Unconsolidated sands.
5. Fluid corrections. (CNLC, 2006).

The others applications of sonic log include the followings:

1. Seismic Tie.
2. Mechanical properties.

3. Fracture identification. (Sigit Sutiyono, 1999).

In this research we used the density log and neutron log to calculate the porosity.

3.3. Resistivity:

Porous rocks are comprised of solid grains and void space. The solids, with the exception of certain clay minerals, are nonconductors. The electrical properties of a rock depend on the geometry of the voids and the fluid with which those voids are filled. The fluids of interest in petroleum reservoirs are oil, gas, and water. Oil and gas are nonconductors.

Water is a conductor when it contains dissolved salts, such as NaCl, MgCl2, KCl normally found in formation reservoir water. Current is conducted in water by movement of ions and can therefore be termed electrolytic conduction.

The resistivity of a porous material is defined by:

$$R = \frac{rA}{L} \qquad (3.3)$$

Where:

r = resistance, Ω

A = cross-sectional area, m^2.

L = length, m.

And resistivity is expressed in Ohm-meter (Ω.m). However, for a complex material like rock containing water and oil, the resistivity of the rock depends on:

1. Salinity of water.
2. Temperature.
3. Porosity.
4. Pore geometry.
5. Formation stress.
6. Composition of rock.

Due to the conductivity properties of reservoir formation water, the electrical well-log technique is an important tool in the determination of water saturation versus depth and thereby a reliable resource for in situ hydrocarbon evaluation.

The theory of the electrical resistivity log technique generally applied in petroleum engineering was developed by Archie in 1942, the so called Archie’s equation. This empirical equation was derived for clean water-wet sandstones over a reasonable range of water saturation and porosities. In practice, Archie’s equation should be modified according to the rock properties: clay contents, wettability, pore distribution, etc. The following is a brief presentation of the main electrical properties of reservoir rocks and related parameters.

Formation Factor: The most fundamental concept considering electrical properties of rocks is the formation factor F, as defined by Archie:

$$F = \frac{R_o}{R_w} = \frac{a}{\phi^m} \text{....................(3.4)}$$

Resistivity Index: The second fundamental notion of electrical properties of porous rocks containing both water and hydrocarbons is the resistivity index I.

$$I = \frac{R_t}{R_o} = \frac{b}{S_w^n} \text{...(3.5)}$$

Saturation Exponent: The famous Archie’s equation gives the relationship of resistivity index with water saturation of rocks.

$$I = \frac{R_t}{R_o} = S_w^{-n} \text{....................(3.6)}$$

Where:

R_t: Describes the resistivity of a formation undisturbed by the drilling process.

R_o: Describes a special form of Rt. It is the resistivity of a clean formation when all pore space is filled with connate water (Rw).

R_w: Is the symbol for the resistivity of formation (connate) water.

a= empirical constant.

m = cementation factor.

Φ=Porosity.

S_w = Water Saturation.

n=the saturation exponent from 1.4 to 2.2.

In this equation, Rt and Ro can be obtained from well logging data, saturation exponent n is experimentally determined in laboratory. Therefore, the in situ water saturation can be calculated with Archie’s equation. Based on the material balance equation for the formation, Sw+So+ Sg= 1.0, the hydrocarbon reserve in place may be calculated (O. torsæter, 2003).

3.3.1. Resistivity from wireline logging:

In most runs of a resistivity tool, the major purpose is to obtain measurements of Rt, the true resistivity of the formation. However, there are a variety of complicating factors involved which may require corrections to be made to the recorded values in order to obtain good estimates of the true resistivities. All resistivity tools are to some extent "averaging" devices that record resistivities of zones rather than resistivities of discrete points.

A resistivity tool is selected that will best estimate the true resistivity of the formation by taking into account borehole characteristics, drilling mud properties, formation lithologies, and degrees of invasion.(Doveton,1999)

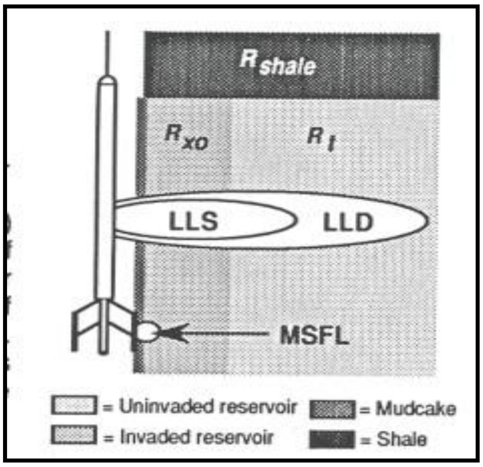
3.3.1.1. Conventional Resistivity Logging:

Conventional resistivity logs were made by means of electrodes in contact with the formation through the drilling mud. There were several sondes capable of measuring to different distances (Short Normal, Long Normal and Lateral).

The Normal and Lateral tools (unfocused): (or guard log) was developed to provide accurate readings of formation resistivity in holes drilled with salt water muds.

The Laterolog, Induction tool (focused by hardware): was developed to measure conductivities deep within the formation with minimal disturbance by the invaded zone. (Doveton,1999).

Both types measure the resistivity in three zones simultaneously. The figure below shows these zones for a DLL.



LLD : looks deep into the reservoir.

LLS : looks shallow into the reservoir.

MSFL : Reads the resistive

Figure 3.6: Shows the three resistivity zones.

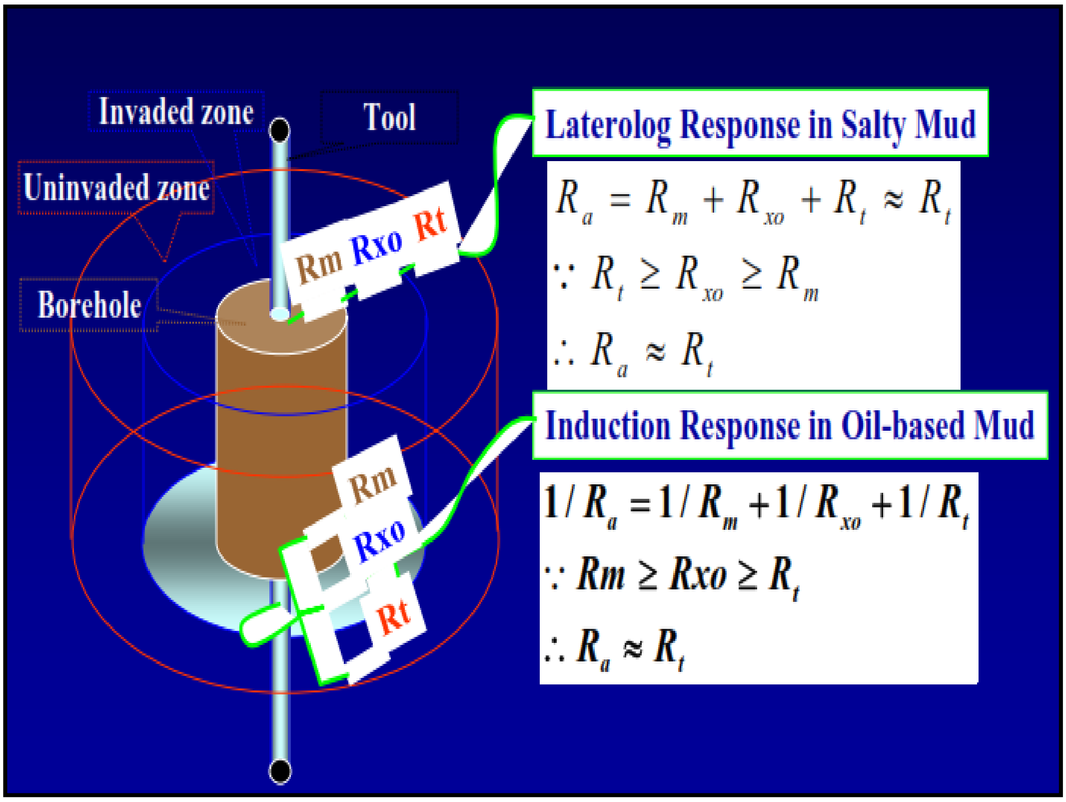


Figure 3.7: Shows the basic physics of laterolog & induction measurements

The Laterologs should be used when the following conditions exist:

1. Seawater or brine mud is in the hole;
2. The R_{mf}/R_w ratio is less than 2.5;
3. Formation resistivities exceed the limits of the induction tool (>200 Ω.m);or
4. Bed thickness is less than 10 ft.

The Induction logs are recommended for use:

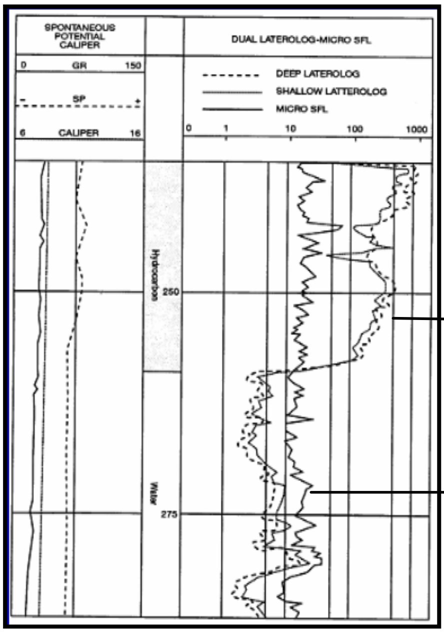
1. Where fresh mud or oil-base mud is used,
2. Where the Rmf/Rw ratio is greater than 2.5,
3. Where Rt is less than 200 Ω.m, and
4. Where bed thickness is greater than 20 ft.

The induction log is the only resistivity device that will work in most oil-base muds or in air-filled holes.

The measuring of formation resistivity affected by many factors including the following:

1. Effects of the borehole itself;
2. Effects of neighboring beds; and
3. Effects of mud filtrate invasion.

The Dual Laterolog (DLL) makes three resistivity measurements: the Laterolog Deep (LLD), the Laterolog Shallow(LIS), and the Micro-Spherically Focused Log (MSFL), a device used to measure Rxo. (CNLC,2006)



The behavior of the DLL-MSFL in zones with movable hydrocarbons permits simple quick-look interpretation.

Hydrocarbon zone:

RLLD >RLLS> RMSFL

Water zone:

RMSFL>RLLS>RLLD

Figure 3.8: Shows DLL-MSFL in hydrocarbon zones.

3.4.Permeability:

Permeability is a property of the porous medium and it is a measure of capacity of the medium to transmit fluids. Permeability is a tensor that in general is a function of pressure.

Darcy's Law:

Darcy (1856) performed a series of experiments on the relationship affecting the downward flow of water through sands. The generalised equation called Darcy's law may be written in the form

$$\frac{q}{A} = v = \frac{K}{\mu}\frac{\Delta P}{L} \text{...}(3.7)$$

Where:

q/A: The ratio of volumetric rate to cross-sectional area perpendicular to flow.

v: flow velocity.

K: permeability tensor.

μ: fluid viscosity.

ΔP: pressure gradient.

L: distance.

3.4.1. Determination of permeable zones using wireline logging:

3.4.1.1. Gamma Ray:

The gamma ray log measures the total natural gamma radiation emanating from a formation. This gamma radiation originates from potassium-40 and the isotopes of the Uranium-Radium and Thorium series. The gamma ray log is commonly given the symbol GR.

Once the gamma rays are emitted from an isotope in the formation, they progressively reduce in energy as the result of collisions with other atoms in the rock (compton scattering). Compton scattering occurs until the gamma ray is of such a low energy that it is completely absorbed by the formation.

Hence, the gamma ray intensity that the log measures is a function of:

1. The initial intensity of gamma ray emission, which is a property of the elemental composition of the rock.
2. The amount of compton scattering that the gamma rays encounter, which is related to the distance between the gamma emission and the detector and the density of the intervening material.

The gamma ray log is combinable with all tools, and is almost always used as part of every logging combination run because of its ability to match the depths of data from each run.

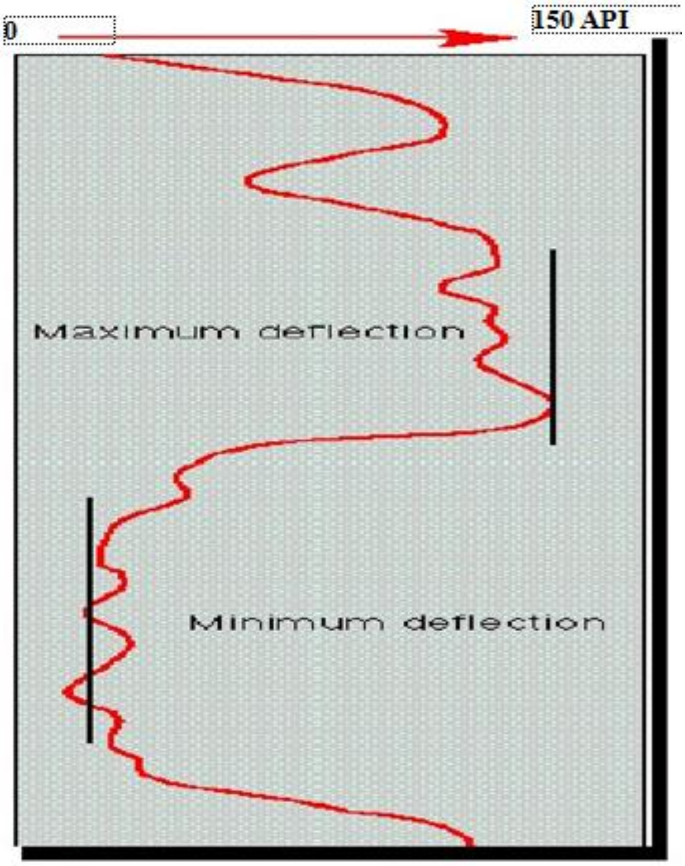
- **Principles:**

The tool consists simply of a highly sensitive gamma ray detector in the form of a scintillation counter. The scintillation counter is composed of a thalium activated single sodium iodide crystal backed by a photomultiplier. When a gamma ray strikes the crystal a small flash of light is produced. This flash is too small to be measured using conventional electronics. Instead, it is amplified by a photomultiplier, which consists of a photocathode and a series of anodes held at progressively higher electrical potentials, all of which are arranged serially in a high vacuum. The flash of light hits the photocathode and causes a number of primary electrons to be produced. These few electrons still represent too small a signal to be measured. The primary electrons are accelerated towards the first anode.

For every electron that hits the anode, a number of secondary electrons are emitted (between 4 and 8 usually). These electrons are accelerated towards the next anode, where each of the secondary electrons produce even more secondary electrons. This process is repeated for each of say 10 anodes. If 6 electrons are emitted at each anode for each incident electron, we can see that a single incident gamma ray ultimately produces 610 = 60,466,176 electrons, which represents a current that can be amplified further by conventional amplifiers. (Glover, 2001)

In the conventional gamma sonde, ascintillation counter indiscriminately detects total disintegrations from all sources in a radial region close to the hole(150-250 mm).

Because K, Th, U tend to be concentrated in shale sand are low or absent in clean sandstones and carbonates, the gamma response is similar to the SP log. Open hole and cased-hole gamma logs can also be correlated and used to precisely locate pay zones for perforation. Gamma-ray logs can yield an approximate quantitative estimate of clay content or shaliness.



Figure(3.9): shows Diagram of GR log (Modified after Russel, 1944).

- **Spectral gamma log:**

Spectral gamma logs record individual responses for K-, Th- and U-bearing minerals. The detectors record radiation in several energy windows as GR-K, GR-U, GR-TH.

The main applications of spectral gamma logs are:

1. Clay content evaluation - spectral logs will distinguish between clays and other radioactive minerals such as phosphate.
2. Clay type identification - ratios such as Th:K are used to distinguish particular clay minerals.
3. Source rock potential - there is an empirical relationship between U:K ratios and organic carbon in shales.
4. Spectral gamma sondes also provide a total GR count that is equivalent to a convention a gamma log.

- **Diffused gamma-ray logs:**

A gamma source is used to bombard the formation and the scattered energy returning to the wellbore is measured. the source is pressed onto the borehole wall by a pad. Two detectors are used at different distances from the source so that a correction for the effect of mud cake can be made.

Gamma rays react with matter in three ways:

1. Photoelectric absorption occurs for low energy gamma rays. The absorption depends on the atomic number of the nucleus and is the basis for the lithology (PE).
2. Compton scattering occurs over the entire energy spectrum and is the basis of the density log (FDC).The intensity at the diffused energy at the borehole wall is proportional to the bulk density.
3. Electron-positron pairs are produced at relatively high energy

The gamma ray log can be used in others applications include the following:

1. Volume of shale determination.
2. Volume of radioactive minerals.
3. Lithology identification.
4. Mineral identifications.
5. Unconformities.
6. Correlation.
7. Facies identification.

8. Depositional environment.
9. Fracture identification.
10. Source rock identification.

3.4.1.2. Caliper Logs:

The caliper log measures the diameter of the borehole. The first caliper logs were developed to determine borehole size in holes shot with nitroglycerin. These early logs showed large variations in hole size, even in the portions of the hole that had not been shot. This illustrated the need for the caliper log over the entire hole.

Methods of Recording Several types of caliper are currently in use. One type consists of three or four spring-driven arms that contact the wall of the borehole. The instrument is lowered to the total depth, and the arms are released either mechanically or electrically. The spring tension against the arms centers the tool in the well. The arms move in and out with the change in wellbore diameter. The arm motion is transmitted to a rheostat so that change in the resistance of an electric circuit is proportional to the hole diameter. The borehole diameter is recorded at the surface by measuring the potential across this resistance.

Another instrument uses three flexible springs that contact the wall of the borehole. These springs are connected to a plunger that moves up or down as the springs expand or contract with changes in borehole diameter. The plunger passes through two coils. When an alternating current is passed through one coil, an electromotive force (emf) is induced in the other coil. The amount of this induced emf is a function of the plunger position and is proportional to borehole diameter.

Both of these instruments may be adjusted to record borehole area rather than hole diameter. If the caliper log is used to determine hole volume, it is desirable to record area on a linear scale. If the caliper log is used to determine hole configuration, the hole diameter is recorded on a linear scale.

A third type of caliper log, the microcaliper, is discussed in connection with the electrical-log microdevices. This instrument uses two pads rather than arms or flexible springs. Hole diameter is determined by the movement of these pads, which are held against the borehole wall by springs.

The primary cause of formation caving is the action of the drilling fluid, bit, and drillpipe. Most drilling muds, composed primarily of water, exert chemical action on shales (hydration of the shales), often causing them to disintegrate and slough into the hole. The amount and rate of this sloughing depend on the nature of the mud and shale. "Heaving" shales swell rather than disintegrate.

If a fresh-water mud is used to drill a salt section, it dissolves salt until the mud becomes salt-saturated. The drilling fluid does not "react" with rock such as limestone, dolomite, and sandstone. If those formations are permeable, however, a mud cake will rapidly form . Mud cake character (density and thickness) varies with the mud used to drill the well, and its thickness is limited by erosion of the circulating drilling fluid. If/when shallow portions of the hole are drilled with water, loosely cemented sands encountered may cave.

The action of the bit is not very important, but if a thin sand is surrounded by shales that have caved, the bit probably knocks off part of the sand ledge with each round trip.

Action of the drillpipe against the side of the hole causes some enlargement even in sandstones and limestone. Though this enlargement may not be great enough to affect hole volume appreciably, it may cause key seating and necessitate a fishing job. Formation "wear" by the drillpipe causes the hole to be no cylindrical, in which case a four-arm caliper will display the long and short axes of the hole.

Interpretation and Application of Caliper Logs :

Caliper logs are usually recorded on vertical scales from 1 in. = 100 ft to 5 in. - 100 ft. The horizontal scale is selected to show a detailed picture of hole diameter and is usually in the order of 1 in. = 4 in. Because of the difference in scales, it is easy to get the impression from caliper logs that tremendous cavities are created. Keep in mind that when a normal borehole is plotted on the same horizontal and vertical scales, it is evident that it is quite "regular."

The primary uses of the caliper log are:

1. To compute hole volume to determine the amount of cement needed to fill up to a certain depth.
2. To determine hole diameter accurately for use in interpreting other logs.
3. To locate permeable zones as evidenced by the presence of a filter cake.

Other applications of the caliper log include proper location of casing centralizers and packer seats for open hole drillstem tests.

Caliper logs are referred to as borehole geometry logs in conjunction with hole deviation and hole azimuth measurement.

3.4.1.3. Spontaneous potential log (sp):

The spontaneous potential log (SP) measures the natural or spontaneous potential difference (sometimes called self-potential) that exists between the borehole and the surface in the absence of any artificially applied current.

It is a very simple log that requires only an electrode in the borehole and a reference electrode at the surface.

These spontaneous potentials arise from the different access that different formations provide for charge carriers in the borehole and formation fluids, which lead to a spontaneous current flow, and hence to a spontaneous potential difference. The spontaneous potential log is given the generic acronym SP.

The log has a low vertical resolution, is rarely useful in offshore environments, and is always recorded in the leftmost track of the log suite, together with the GR log.

It is very important to recognize that this log has no absolute scale – only relative changes in the SP log are important.

This is reflected in the design of the log header, which shows only a bar that represents a change of, say, 10 mV.

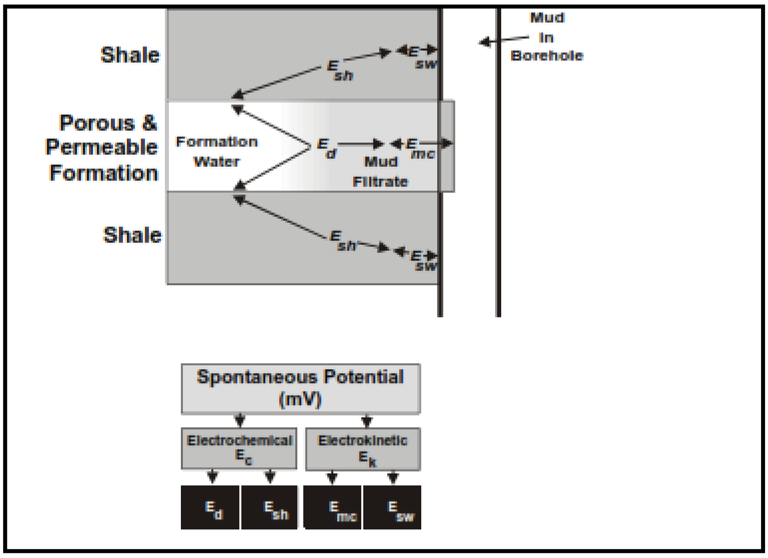
There are three requirements for the existence of an SP current:

1. A conductive borehole fluid (i.e., a water based mud).
2. Asandwich of a porous and permeable bed between low porosity and impermeable formations.
3. A difference in salinity between the borehole fluid and the formation fluid, which are the mud filtrate and the formation fluid in most cases.

Note, however, that in some special cases an SP current can be set-up when there is no difference in salinity, but where a difference in fluid pressures occurs.

The origin of the spontaneous potential has four different components. These are shown in (Fig 3.10).

The spontaneous potential is composed of contributions that are electrochemical (arise from electrical interactions between the various chemical constituents of the rocks and fluids), and electro-kinetic (arise from the movement of electrically charged ions in the fluid relative to the fixed rock).



Figure(3.10): Shows the electromotive components of the spontaneous potential.

Electrochemical Components are arising from the electrochemical interaction of ions in the mud filtrate and formation fluids. The electrochemical contribution, itself, consists of two effects:

1. The diffusion potential (sometimes called the liquid-junction potential).

This potential exists at the junction between the invaded and the non-invaded zone, and is the direct result of the difference in salinity between the mud filtrate and the formation fluid.

2. The membrane potential (sometimes called the shale potential).

This potential exists at the junction between the non-invaded zone and the shale (or other impermeable rock) sandwiching the permeable bed. These beds are usually shale, and the argument that follows applies mainly to shales, but is also valid to a less extent for other low permeability rocks.

Electrokinetic Components are arising from the movement of fluids containing conducting ions. The Electrokinetic contribution, itself, consists of two effects, which are usually very small and act in opposite ways such that they cancel each other out. These contributions depend upon fluid flow, and hence are larger when there is a substantial difference in pressure between the borehole and the formation.

Thus, these contributions may be significant for depleted and under-pressured reservoirs where the differential pressure is high (>500 psi). The contributions also depend upon the development of an electrical double layer at mineral surfaces, which is larger for low salinity fluids. Hence, these contributions are also more important for fresh formation waters or mud filtrates.

The mudcake potential is produced by the movement of charged ions through the mudcake and invaded zone in a permeable formation. Its size depends upon the hydraulic pressure drop, and since most of this is across the low permeability mudcake, the great majority of Electrokinetic potential is also generated across the mudcake, with an insignificant amount in the invaded zone.

The shale wall potential is the same in origin to the mud cake potential, but applies to the flow of fluids from the borehole into shale formations. It is usually very small because the flow into impermeable shales is small. It also acts to set up a current flow into the formation. We will see how this tends to cancel out the mud cake potential. The total Electrokinetic potential is Ek= E mc+ E sw, and because E mc and E have the same polarity, the value of E k is the difference between their absolute values, i.e., E k= |E mc|+ |E sw|.

Static SP versus SP: - Note that Ed is the potential that electrode recorded, the shoulder beds have inevitably affected the value .In fact, SP value should be the Static Spontaneous Potential (SSP) in liquid junction .

$$SSP = Ed - Eda = - K \log \left(\frac{Rmf}{RW} \right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.8)$$

K is a variable changing with Cmf/Cw ,when Temp=18oC,at the junction of pure sand and pure shale formation, K= ‒ 69.6

Pay attention : if the formation is impermeable , there will be no potential generated , SSP does not exist.

- **Others Applications of SP Log:-**

1. Define bed boundaries: Half of abnormal amplitude point will boundaries of shale and sand .The bed thickness is the interval between two boundaries.

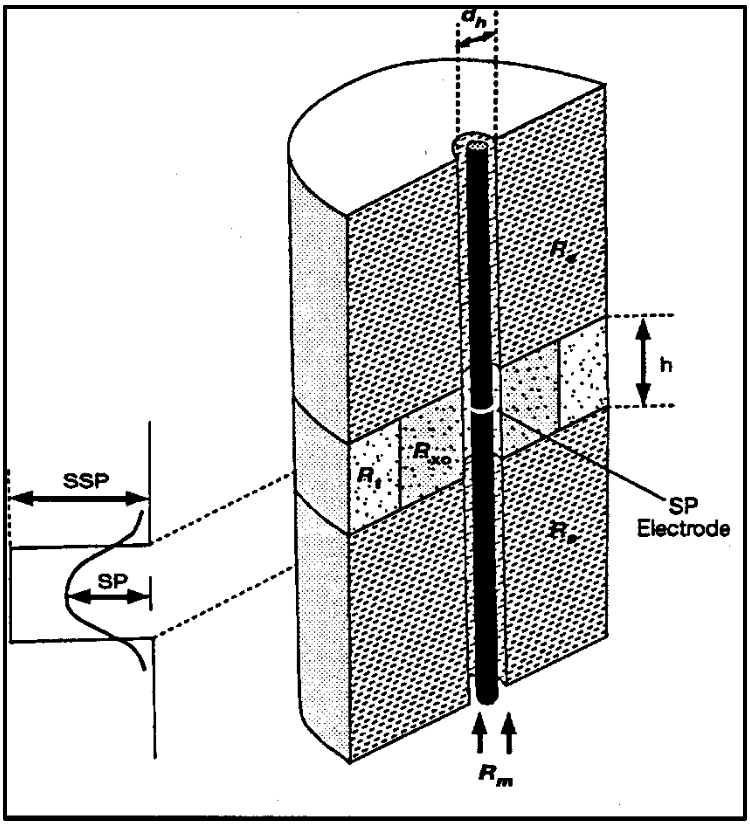


Figure 3.11: Shows bed boundaries from SP log

2. Compute shale content: The presence of shale in an “clean” sand will tend to reduce the SP. This effect can be used to estimate the shale content of a formation.

$$(V_{sh})_{SP} = \frac{(SP - SPclean)}{(SPshale - SPClean)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.9)$$

Here:

- SP_{shale} is the value observed in a shale ;
- SP_{clean} is the value observed in a clean, water-bearing sand; We also call SPshale the base line of shale .

1. Determine values of formation water resistivity:

Formation water resistivity (Rw) is a significant parameter to estimate oil or water saturation . SP curve can be used for estimation of Rw. The equation is

$$SP = - K\,[\log(Rmfe/Rwe)] \ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.10)$$

Where:

R_{mfe} ,R_{we} are “ equivalent ” R_{mf} or R_w which suppose no shoulder bed effect on them . (CNLC,2006)

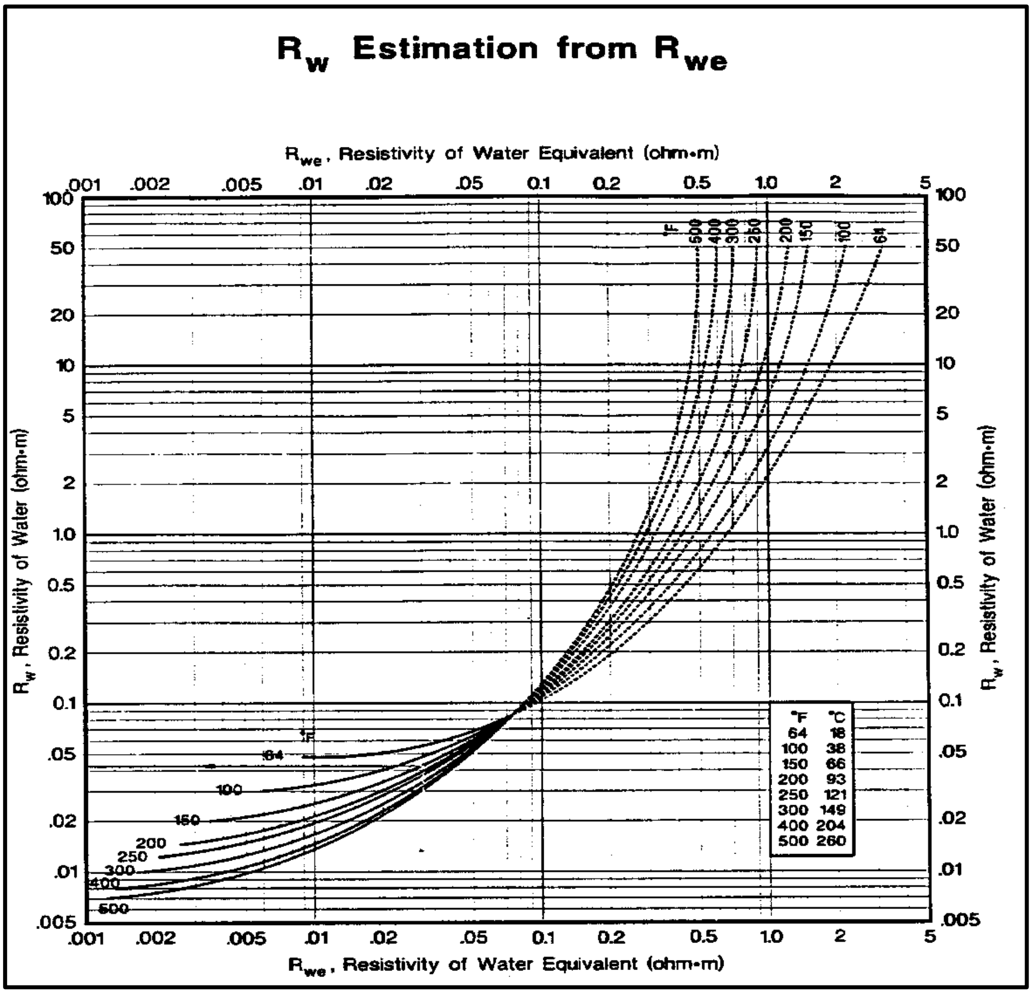
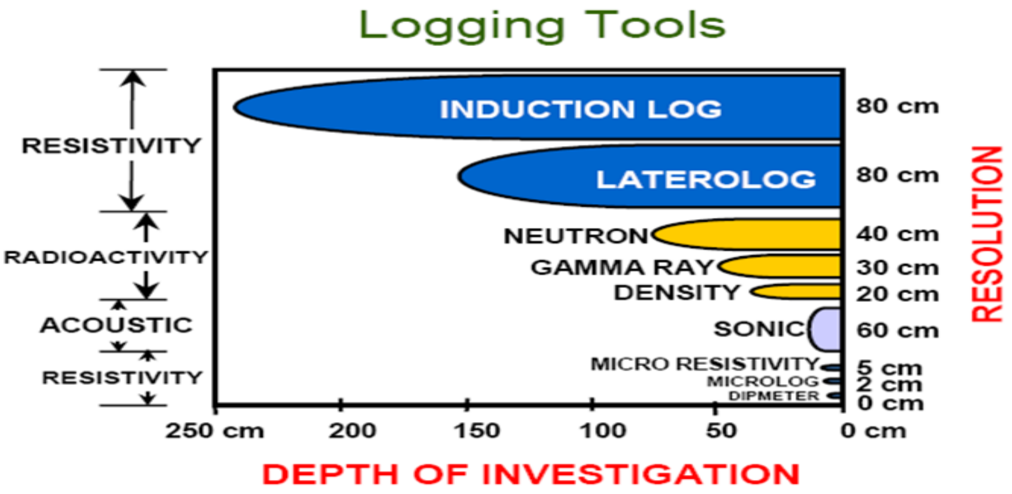


Figure3.12: Shows the relationship between Rwe and Rw or (Rmfe and Rmf) (CNLC,2006).



figure(3.13):shows Depths of Investigation and Resolutions of different logging tools.

3.5. Overview of New Generation Logging Tools:

The new generation of logging tools technology are developed to capture complete map of the borehole wall in terms of diameter, deviation, light and colour. They have higher resolutions.

3.5.1. The Qualitative Devices:

3.5.1.1. Dipmeter:

- Stratigraphical High Resolution Dipmeter Tool (SHDT).
- Oil Base Dipmeter Tool (OBDT).

3.4.1.2. Image Logs:

- Formation Micro-Scanner (FMS) tool.
- Full-bore Formation Micro-image (FMI) tool.
- Borehole Imaging in oil-base mud (OBMI).
- Borehole Televiewer (BHTV).
- Azimuth Resistivity Imager (ARI).
- Array Induction Tool (AIT).

3.5.2.Quantitative Devices:

- Nuclear Magnetic Resonance (NMR).
- Combinable Magnetic Resonance (CMR).
- Pulsed Neutron Capture Log (PNC) .