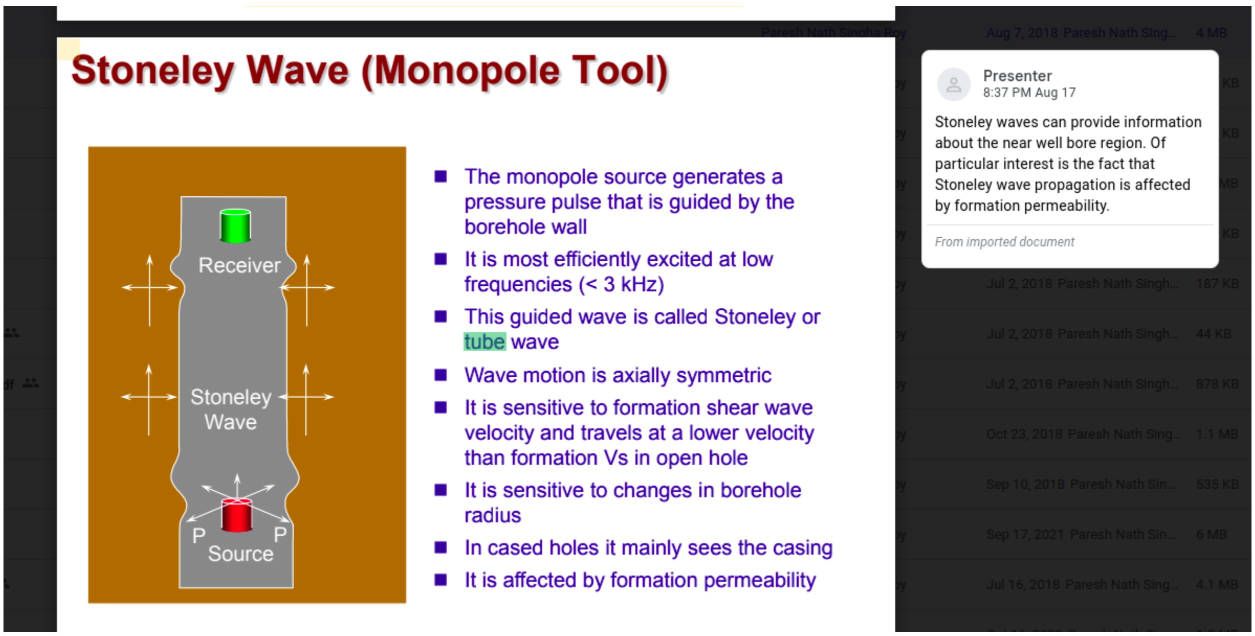
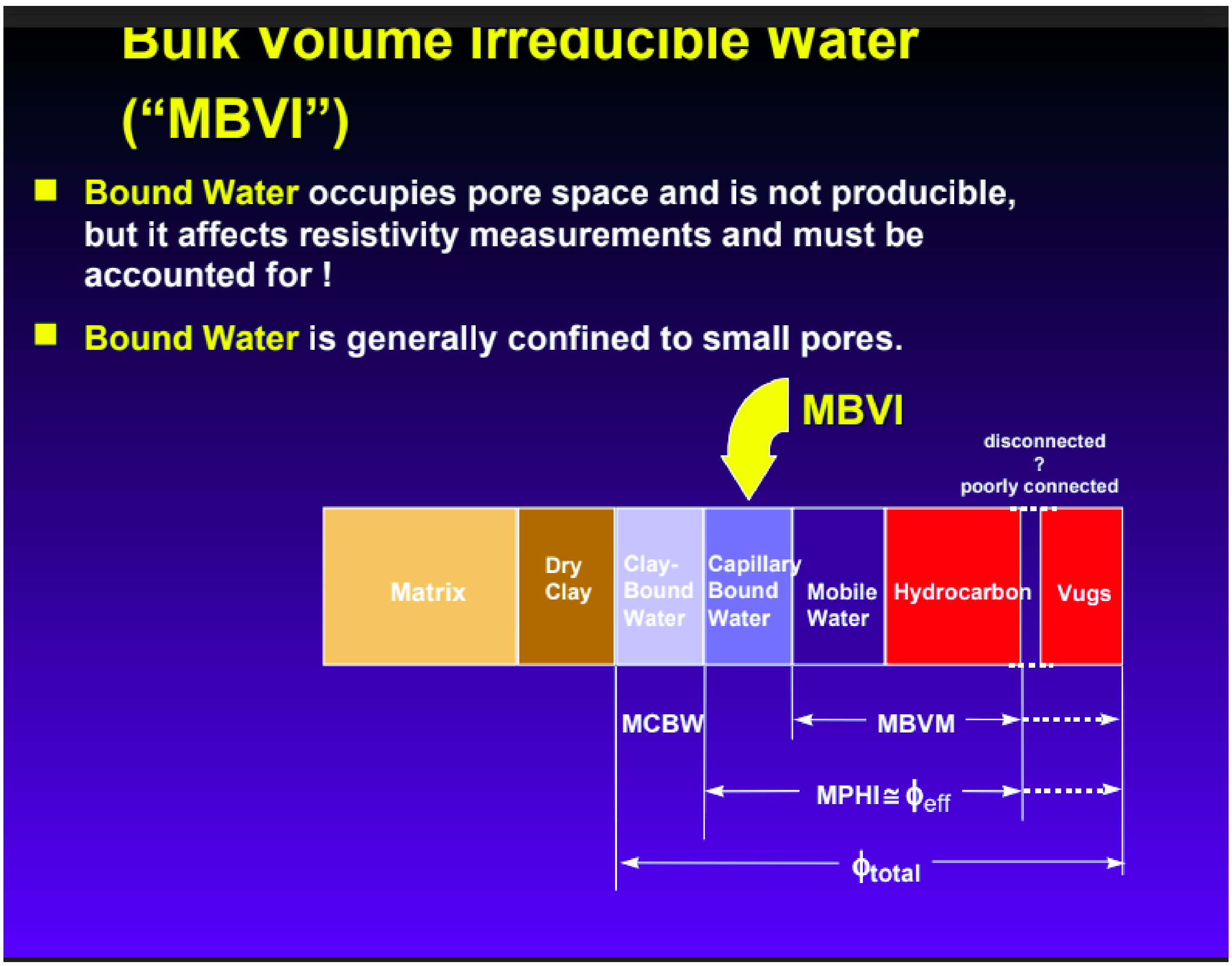
What is stoneley or tube wave?

Acoustic waves initiated in a borehole can travel through the surrounding formation with both P and S components.In addition, there is a third type of propagation along the borehole which is called a tube or Stoneley wave.
The monopole source generates a pressure pulse that is guided by the borehole wall
This guided wave is called Stoneley or tube wave.
Stoneley waves can provide information about the near well bore region.



What is bounded water?

Bound water being the portion of the total water which is adsorbed or bound to, or impermeably held by, the matrix.
Clay bound water and capillary bound water are types of bounded water.
Clay bound water in clay cannot come out as clay is hard and impermeable.
Capillary bound water due to surface tension and smaller pore size cannot come out as more force needed to take it out.



Irreducible water

The lowest water saturation, S_{wi}, that can be achieved in a formation by displacing the water by oil or gas. It represents water that has not been displaced by hydrocarbons because it is trapped by adhering to rock surfaces, trapped in small pore spaces.

Irreducible Water Saturation ($Sw\ i$) can be determined by plotting water saturation versus porosity in a linear scale and drawing hyperbola from minimum water saturation and select the levels that fall on this parabola which represent irreducible water saturation levels

Connate water

Water trapped in the pores of sedimentary rocks (depositional water). Formation water is water found in deeply buried, porous, and permeable sedimentary rocks [59]. Formation water is evidence that oil has formed in closed compartments of rocks.

What is cycle skipping?

The returning signal is a wavetrain and not a sharp pulse, so the detectors are only activated at a certain signal threshold. Sometimes, both detectors won't be activated by the same peak (or trough) and the next peak (or trough) wave will activate one of them instead. This type of error is called cycle skipping and is easily identified because the time difference is equal to the time interval between successive pulse cycles.

C2.1 INTRODUCTION

In its simplest form, a sonic tool consists of a transmitter that emits a sound pulse and a receiver that picks up and records the pulse as it passes the receiver.

The sound emanated from the transmitter impinges on the borehole wall. This establishes compressional and shear waves within the formation, surface waves along the borehole wall and guided waves within the fluid column.

The sonic log is simply a recording versus depth of the time, t_{comp}, required for a compressional sound wave to traverse 1 m of formation. Known as the interval transit time, transit time, Δt or slowness, t_{comp} is the reciprocal of the velocity of the sound wave. (For the remainder of this document, t_{comp} is known as Δt.) The interval transit time for a given formation depends upon its lithology and porosity. This dependence upon porosity, when the lithology is known, makes the sonic log useful as a porosity log. Integrated sonic transit times are also helpful in interpreting seismic records. The sonic log can be run simultaneously with many other services.

The borehole-compensated (BHC) tool transmitters are pulsed alternately, and Δt values are read on alternate pairs of receivers. The Δt values from the two sets of receivers are averaged automatically by a computer at the surface for borehole compensation.

The computer also integrates the transit time readings to obtain total traveltimes (see Figures C1 and C2).

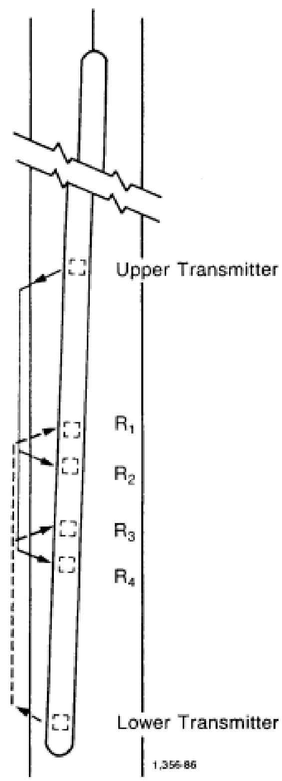


Figure C1: Schematic of BHC sonde, showing ray paths for the two transmitter-receiver sets. Averaging the two Δt measurements cancels errors from the sonde tilt and hole-size charges.

Sometimes the first arrival, although strong enough to trigger the receiver nearer the transmitter, may be too weak by the time it reaches the far receiver to trigger it. Instead, the far receiver may be triggered by a different, later arrival in the sonic wave train, and the travel time measured on this pulse cycle will then be too large. When this occurs, the sonic curve shows an abrupt, large excursion towards a higher Δt value; this is known as cycle skipping. Such skipping is more likely to occur when the signal is strongly attenuated by unconsolidated formations, formation fractures, gas saturation, aerated muds or rugose or enlarged borehole sections.

What is the Chlorine effect for Neutron logging?

Chlorine effect-the neutron emitted are collided and Chlorine that are nearby absorbs the neutron and emits gamma ray this effect is called chlorine effect.

C4.2 PRINCIPLE

Neutrons are electrically neutral particles, each with a mass almost identical to the mass of a hydrogen atom. High-energy (fast) neutrons are continuously emitted from a radioactive source in the sonde. These neutrons collide with the nuclei of the formation materials in what may be thought of as elastic *billiard-ball* collisions. With each collision, the neutron loses some of its energy.

The amount of energy lost per collision depends on the relative mass of the nucleus with which the neutron collides. A greater energy loss occurs when the neutron strikes a nucleus of practically equal mass (i.e., a hydrogen nucleus). Collisions with heavy nuclei do not slow the neutron much. Thus, the slowing of neutrons depends largely on the amount of hydrogen in the formation.

Within a few microseconds, the neutrons have been slowed by successive collisions to thermal velocities, corresponding to energies of about 0.025 eV. They then diffuse randomly, without losing more energy, until they are captured by the nuclei of atoms such as chlorine, hydrogen or silicon.

The capturing nucleus becomes intensely excited and emits a high-energy gamma ray of capture.

When the hydrogen concentration of the material surrounding the neutron source is large, most of the neutrons are slowed and captured within a short distance of the source. On the contrary, if the hydrogen concentration is small, the neutrons travel farther from the source before being captured. Accordingly, the counting rate at the detector increases for decreased hydrogen concentrations and vice versa. Thus, the neutron tool responds to the hydrogen index of the formation. The hydrogen index is a measurement of the amount of hydrogen per unit volume of formation (HI of water = 1).

Neutron logging tools include the GNT (Figure C19) tools series (no longer in use), sidewall neutron porosity (SNP) tools (in limited use) and the CNL tool series, which includes the compensated neutron and DNL* Dual-Energy Neutron Log. The current tools use americium-beryllium (AmBe) sources to provide neutrons with initial energies of several million electron volts.

1) SNP

- detects epithermal neutrons
- utilizes a skid mounted single detector
- can be run in open hole only, either liquid-filled or empty
- most corrections are automatically applied during logging
- limited availability.

What is the gas effect?

Density

- A density log measures the porosity of a formation based on the assumed density of the formation and drill fluid in grams per cubic centimeter (g/cm3).
- The standard porosity calculation (grain density − measured bulk density)/(grain density − drilling fluid density) will overestimate the porosity of a gas-filled formation because the measured bulk density will be lower.
- Hence, when overestimated porosity values (from a density log) are cross-plotted with the underestimated porosity values (from a neutron log), the crossover is an indication of gas in a formation called the *gas effect*.
- Shale, coal, and bentonite beds commonly have low densities and sandstones, and carbonates generally have higher densities.

State the Outlook interpretation approach Rwa to determine producing interval at the wellsite.Also state the condition where the outlook interpretation can be used.

h. In the hydrocarbon zones defined in Step (e), where the neutron porosity decreases and the sonic Δt increases the zone is gas bearing. All other hydrocarbon zones contain oil.
i. On the density porosity log define a cutoff value of porosity based on test and production experience for the area.
j. When the density porosity is above this value, the zone will produce fluid. Below the cutoff value, no production will occur.

D1.3 METHOD TWO: R_{wa} TECHNIQUE

This technique assumes that all zones are 100% wet, estimates a value for R_w, and subsequently studies the anomalies to the first assumption.

Consider Archie's equation:

$$S_w^2 = \frac{aR_w}{\phi^m R_t} = \frac{FR_w}{R_t}$$

Assume: $S_w = 100\%$

then $$\frac{FR_w}{R_t} = 1$$

Rearrange to solve for R_w: $R_w = \dfrac{R_t}{F}$

Because we assume that all zones have S_w = 100%, we state

$$R_{wa} = \frac{R_t}{F}$$

This value will represent R_w for the formation if the assumption that all zones are wet is correct.

If the zones are not all at S_w = 100%, the value of R_{wa} will vary depending upon the actual S_w of the formation.

If we select the minimum value of R_{wa} and call it R_w, then we can make a comparison of all calculated R_{wa} values against this R_{wa} (minimum) value through substitution into Archie's equation as follows:

Given $S_w^2 = \dfrac{FR_w}{R_t}$

If S_w = 100%, then

$$R_{wa} = \frac{R_t}{F}$$

or conversely, $R_t = FR_{wa}$

Substituting R_{wa} (minimum) for R_w, and FR_{wa} for R_t yields

$$S_w^2 = \frac{FR_{wa}(\text{minimum})}{FR_{wa}}$$

$$\text{or } S_w^2 = \frac{R_{wa}(\text{minimum})}{R_{wa}}$$

A note of caution, though, because there are some assumptions that should be considered when using quicklook techniques. The zone should have
1) constant Rw
2) thick, homogenous formation
3) continuous clean lithology
4) clean-water-bearing zone
5) moderate invasion of step profile.

Environmental effects:-
Temperature,conductive mud,washout,invasion

Explain with suitable sketches of all possible way of explaining distribution of shaly formations. Also give the mathematical relation for bulk volume fractions.

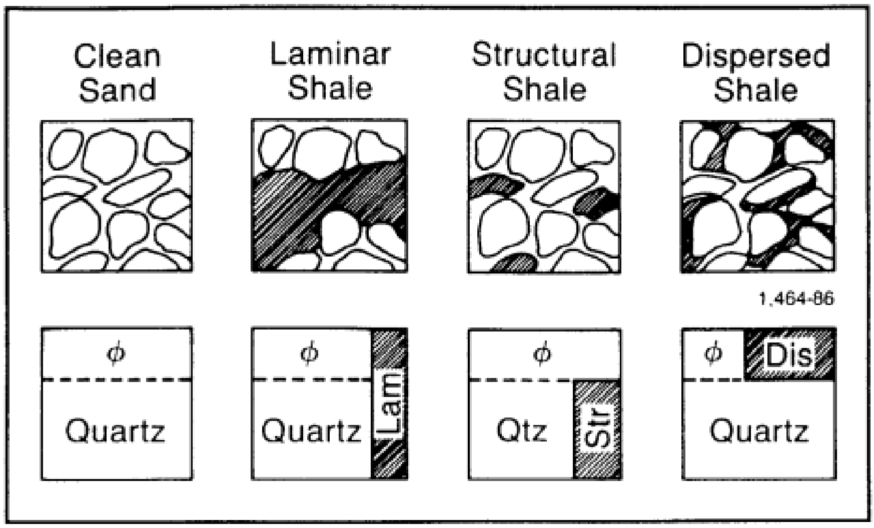


Figure E1: Forms of Shale Classified by Manner of Distribution in the Formation Pictoral Representations Above, Volumetric Representations Below

Laminar Shale: occurs when shale exists in the form of laminae or thin layers between thin layers of sand. The shale streaks do not actually influence the effective porosity of the sand layers in the formation; however, as the bulk volume of shale increases, the overall formation porosity decreases.The presence of the shale may have considerable influence on the logging tool responses.

Structural Shale: is defined as the type of shale that exists as grains or nodules in the formation matrix. It is considered to have properties similar to laminar shale.

Dispersed Shale: occurs where the shaly material is dispersed through the sand to occupy part of the intergranular space. Dispersed shale reduces the pore space available for fluid accumulation and also reduces formation permeability.

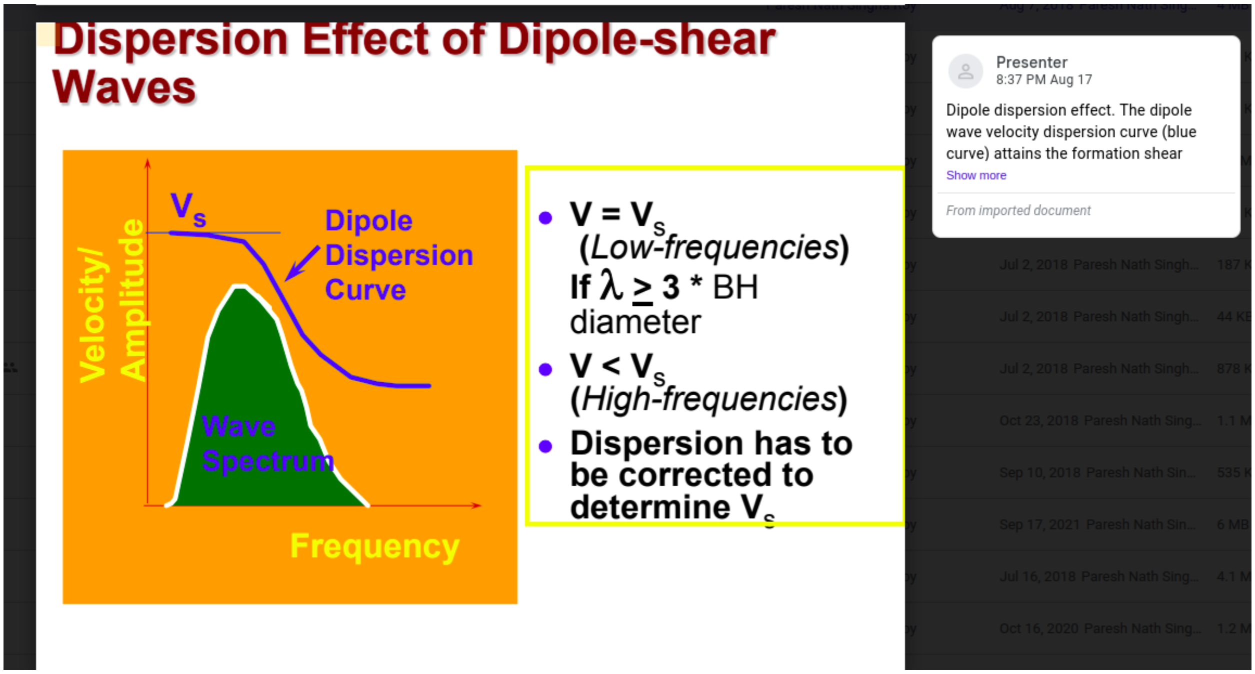
Bulk volume fractions

$$\rho_b = \rho_f \phi_e + \rho_{ma} (1 - \phi_e - V_{sh}) + \rho_{sh} V_{sh}$$

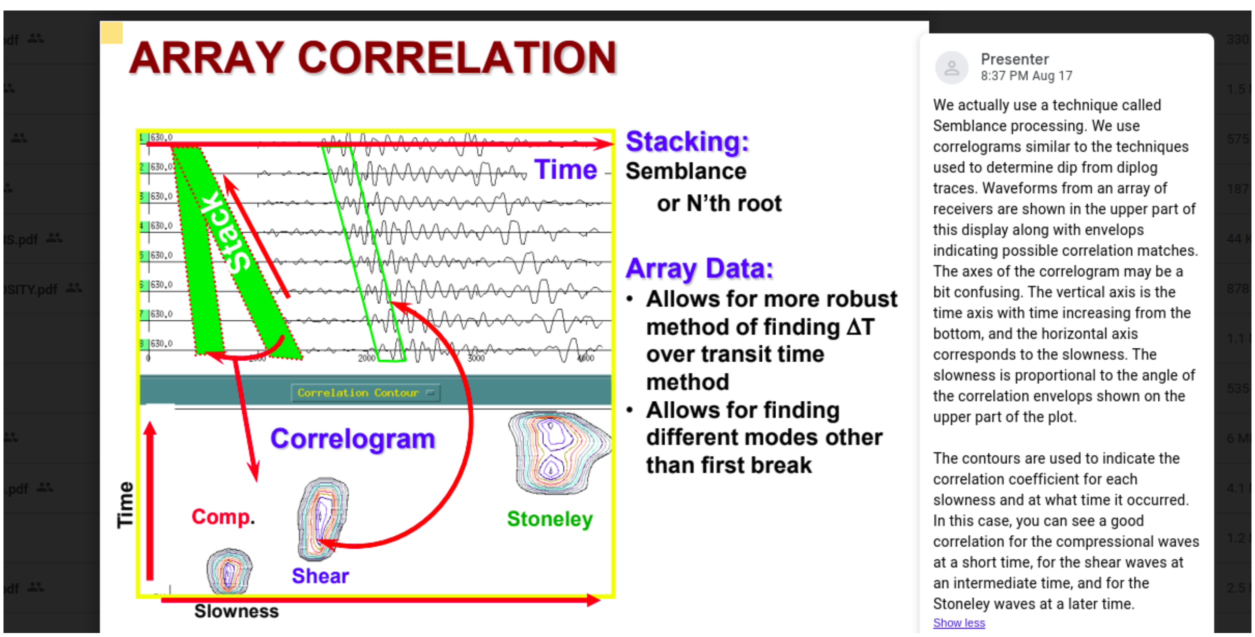
or

$$\rho_b = (1 - \phi_e)\rho_{ma} + \phi_e \rho_f + V_{sh}(\rho_{sh} - \rho_{ma})$$

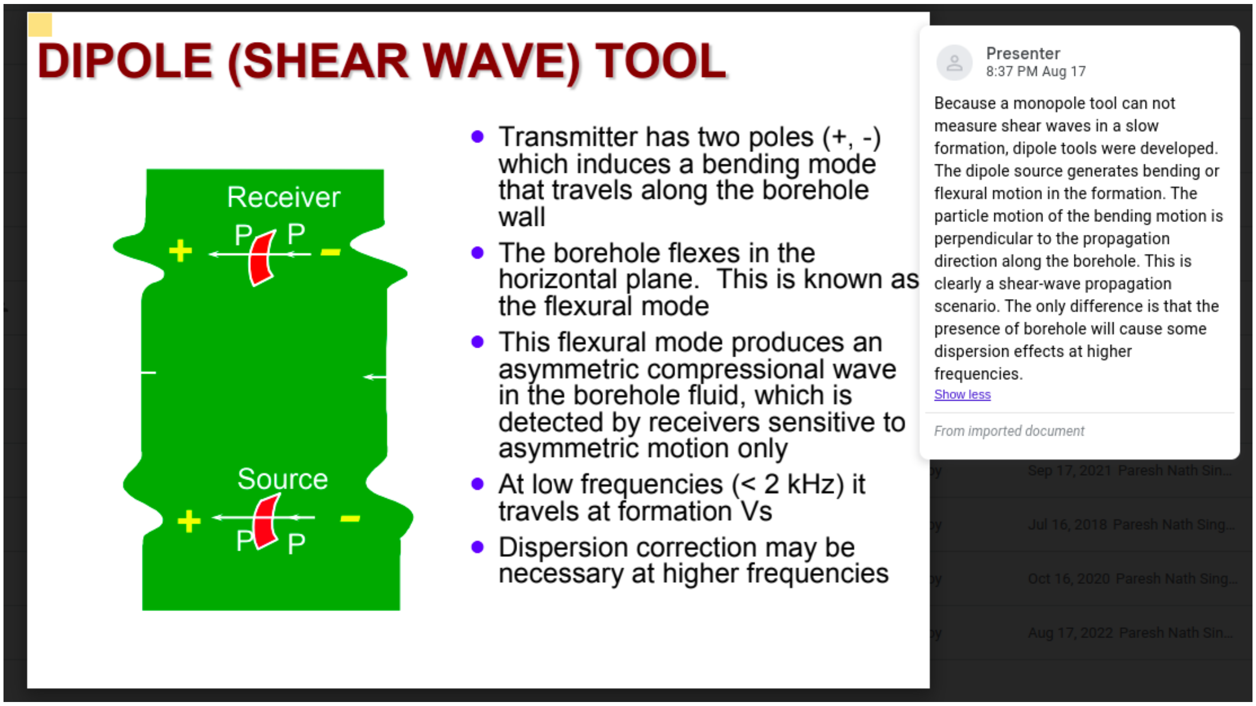
Dispersion Effect of Dipole-shear Waves



Array correlation/Semblance processing



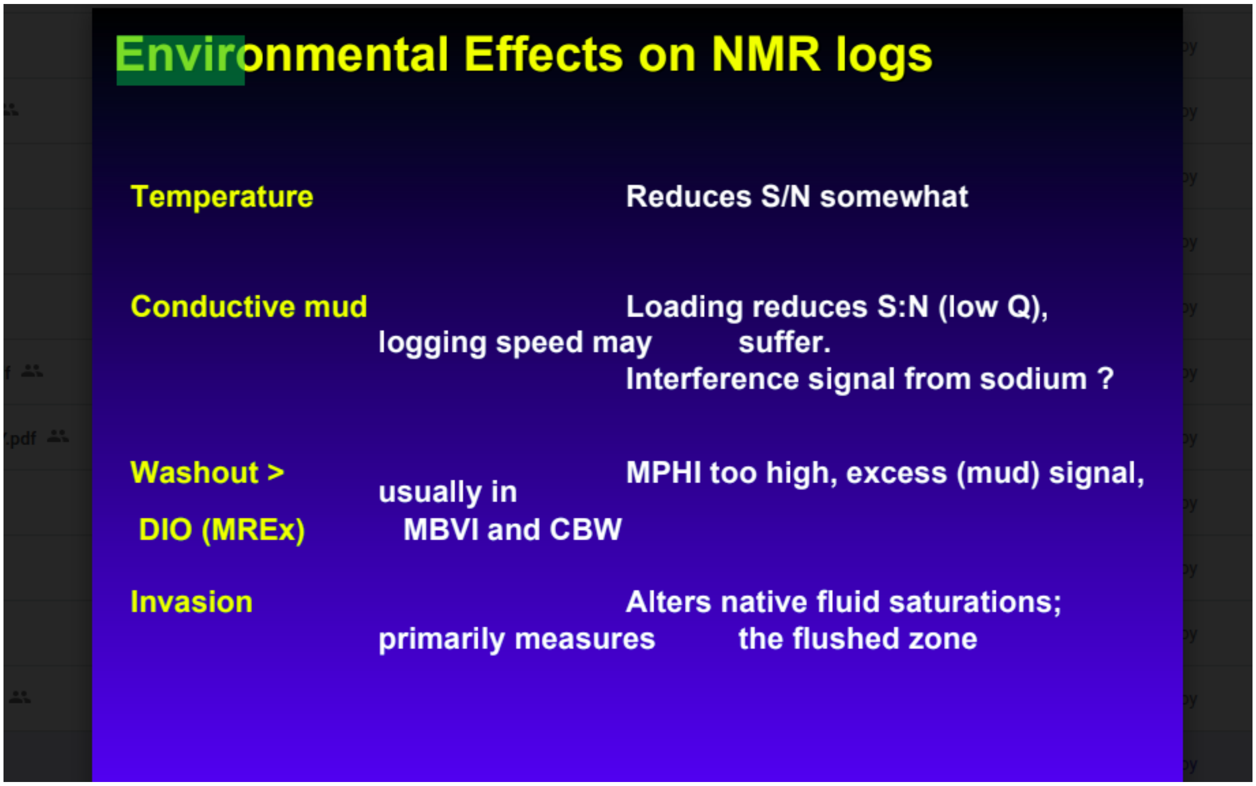
Dipole(Sheer Wave) Tool



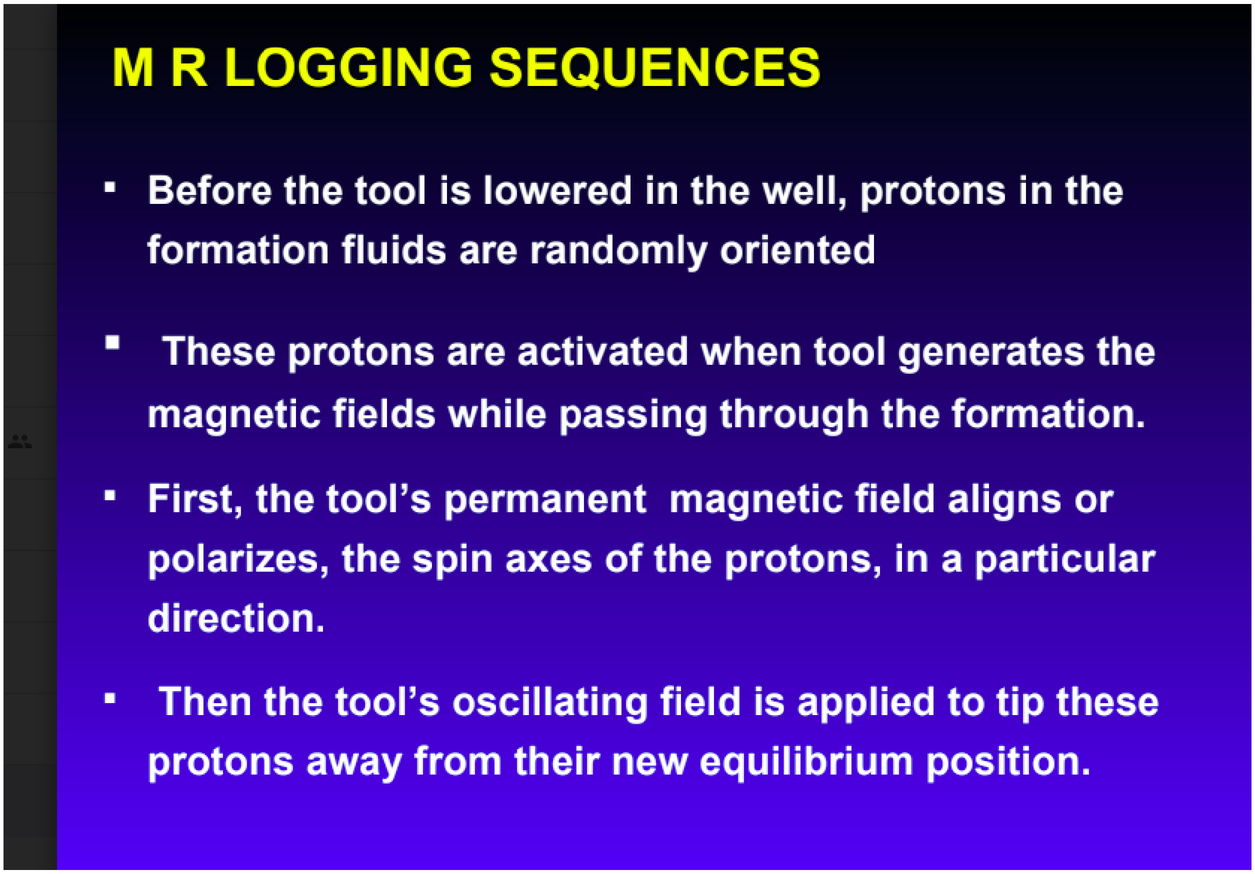
Environmental correction for Induction logging

The measurement of the dual-induction LWD tool is affected by the environment, including borehole size, resistivity of mud, resistivity of the shoulder bed, layer thickness and resistivity and diameter of invasion zone. The apparent resistivity can be expressed as Ra = f(Dh, Rm, Rs, H, Rxo, Di), where Dh is the diameter of the borehole, Rm is the mud resistivity, Rs is the resistivity of the shoulder bed, H is the thickness.

Environmental effects on NMR logs



Details principle of measurement of NMR logging

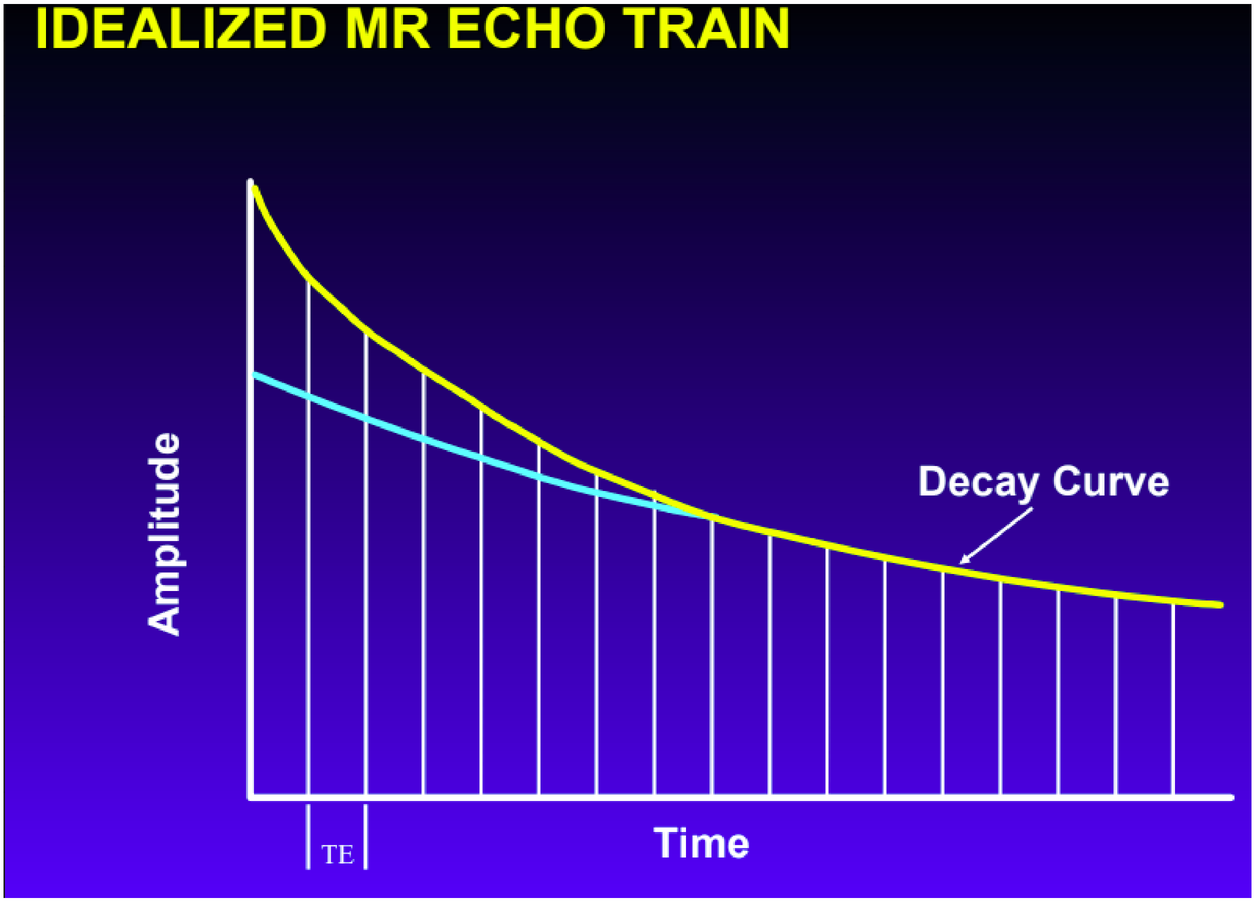


M R LOGGING CONCEPTS

- When the oscillating field is subsequently removed, the protons begin tipping back, or relaxing, towards the original direction in which the static magnetic field aligned them.

- Specified pulse sequences are used to generate a series of spin echos, measured by the tool and are displayed on logs as spin echo trains. These spin echo trains constitute the raw MR data.

- The tool measures the amplitude of the spin echo as a function of time and can be displayed as a function of depth.


IDEALIZED MR ECHO TRAIN
Amplitude
Decay Curve
TE
Time

M R LOGGING CONCEPTS

- The initial amplitude of the spin echo is proportional to the hydrogen nuclei, associated with fluids in the pore and thus amplitude can be calibrated to porosity.

- The observed Echo-train can be linked to:

  1. Data Acquisition Parameter
  2. Properties of the pore fluids located in the measurement area.

Draw a labeled diagram to illustrate resistivity log normal and lateral curves separately for the conditions: a)thick bed more resistive than adjacent…..

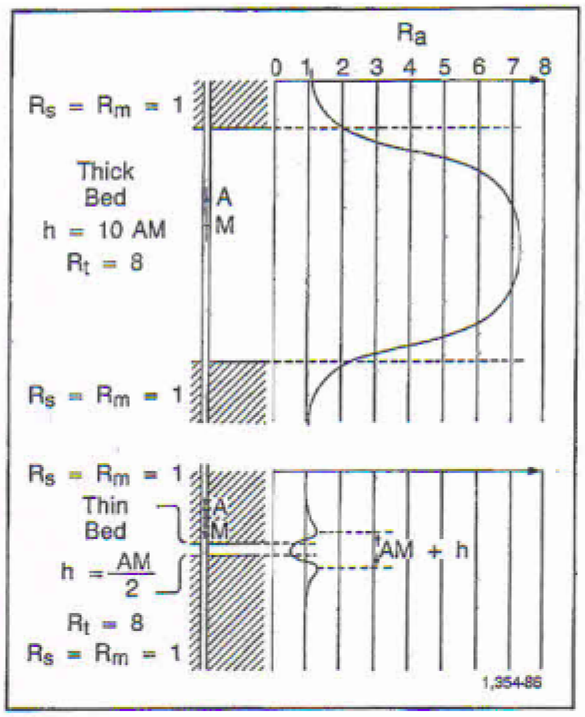


Fig. 7-3—Normal curves—bed more resistive than adjacent formations.

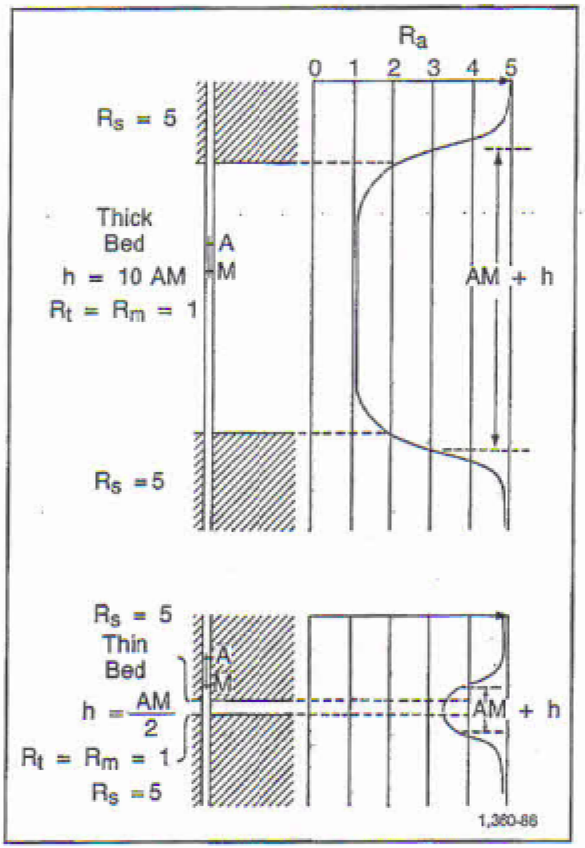


Fig. 7-4—Normal curves—bed less resistive than adjacent formations.

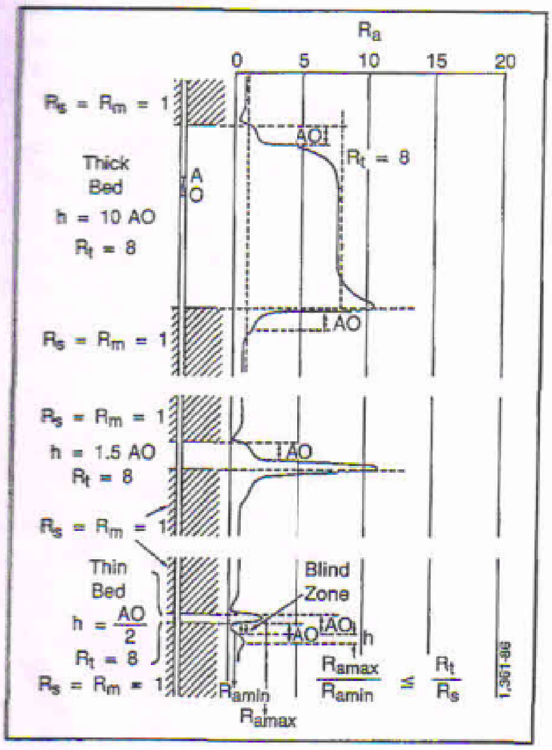


Fig. 7-5—Lateral curves—bed more resistive than adjacent formations.

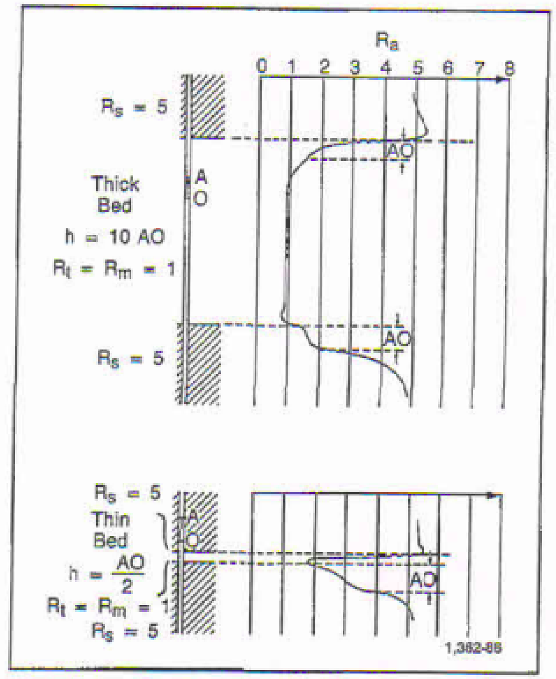


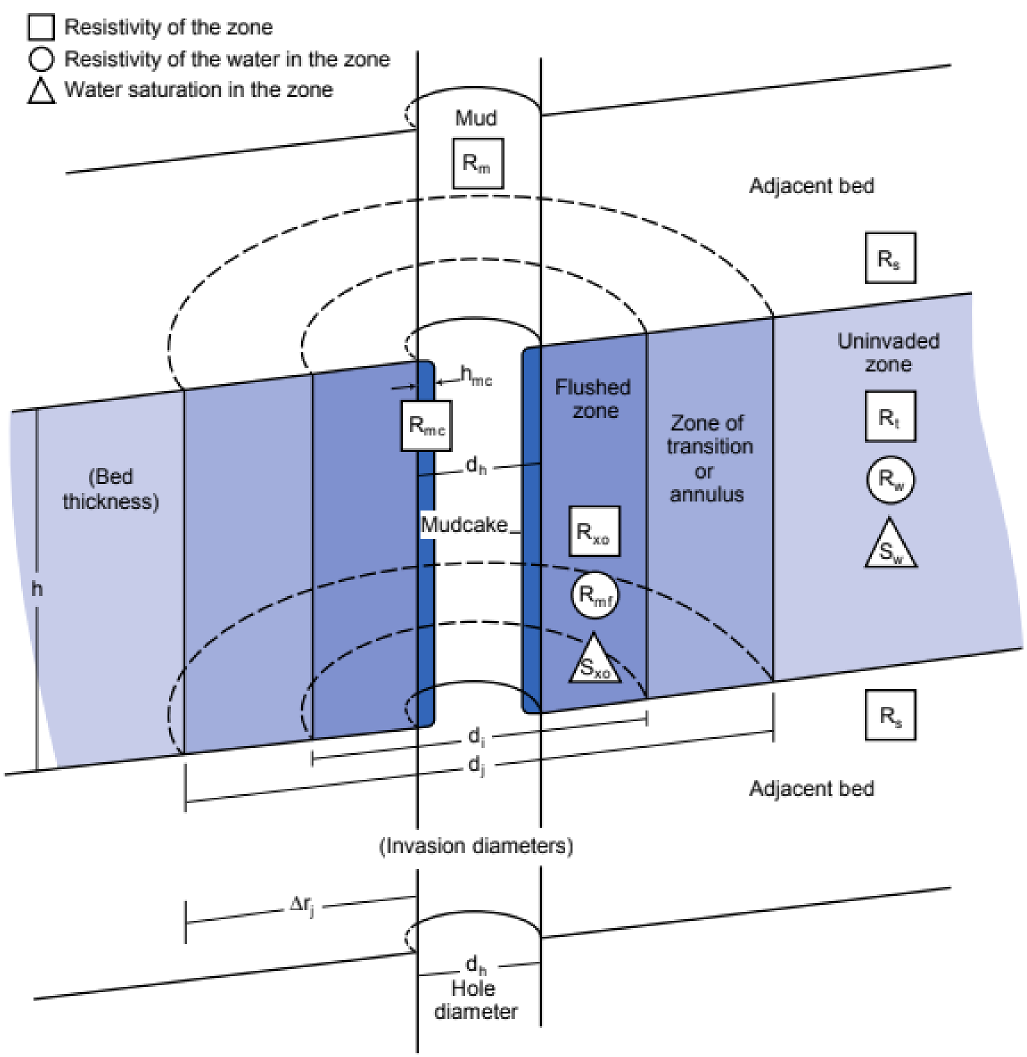
Fig. 7-6—Lateral curves—bed less resistive than adjacent formations.

the resistivities of the mud and surrounding formation. Therefore, formations are subdivided into three classes,

Delaware and Groningen Effect

Delaware and Groningen effects. Both effects give rise to abnormally high readings of DLL measurements under extreme logging conditions. Specifically, a low resistive bed below a highly resistive layer causes electrical currents to concentrate within the borehole, which generates a negative potential at the reference electrode and, consequently, an abnormally high reading in DLL measurements. These effects are exacerbated by the presence of casing and/or at nonzero frequencies. Simulations are performed with a 2D goal-oriented, high-order, self-adaptive hp finite-element method together with an embedded postprocessing method. Results indicate that the presence of electrodes B and N is critical for proper simulation of Delaware effects on DLL measurements. Delaware effects on DLL logs decrease as the current return electrode is moved farther away from either the logging point or the borehole. The frequency of operation also affects deep laterolog measurements, generating the so-called Groningen effect.

Draw a labeled diagram to illustrate idealized invasion profile and variation of resistivity and invasion diameter in permeable zone.



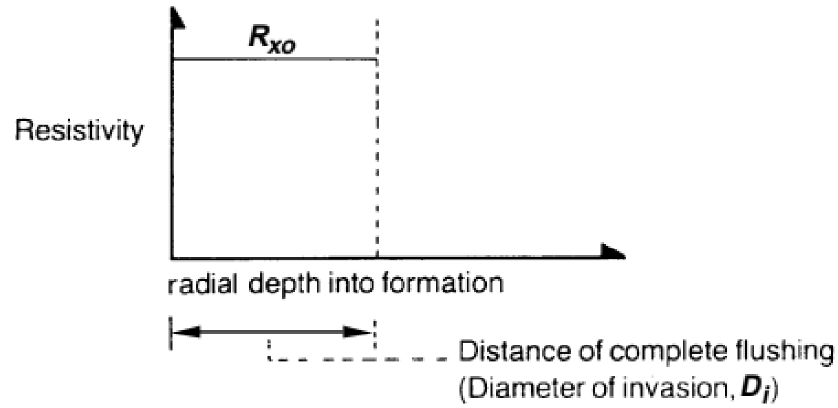


Figure B4: Invasion Process

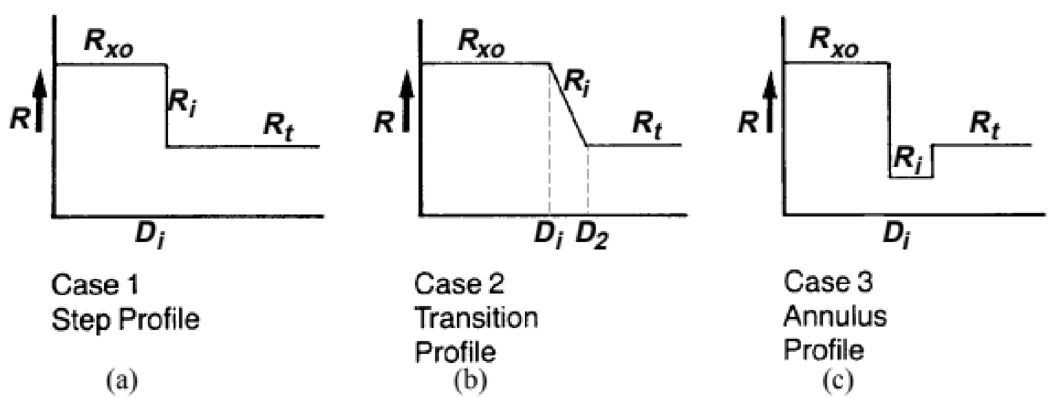


Figure B5

Archie Equation

$S_{hy} = 1 - S_w = 30\%$

Therefore the percentage volume of water saturation

$= \phi \times S_w$

For example: if $\phi = 20\%$ and $S_w = 70\%$, then

14% of the bulk volume is water and 70% of the pore space is water filled.

A.4 RESISTIVITY AS A BASIS FOR INTERPRETATION—THE ARCHIE EQUATION

In the previous section we introduced a number of parameters used to evaluate rock formations. If we could build on the effects of resistivity in conjunction with the other parameters to develop a mathematical relationship, we would have an extremely useful tool for our work with potential hydrocarbon zones.

The remainder of this section is devoted to developing such a formula.

The usefulness of resistivity logging rests on the facts that

- *water is a conductor (low resistivity)*
- *hydrocarbons and rocks are insulators (high resistivity)*

Consider the following unit cubes (Figure A3):

Cube C

The resistivity R_t of the cube will vary with water resistivity R_w (i.e. as R_w increases, R_t increases and vice versa).

Therefore: $R_t \propto R_w$. **(1)**

Cube D

Replace 25% of the cube with rock (hence ϕ = 75%) but maintain a constant R_w. Resistivity R_t increases with decreasing porosity ϕ (i.e. as ϕ decreases, R_t increases).

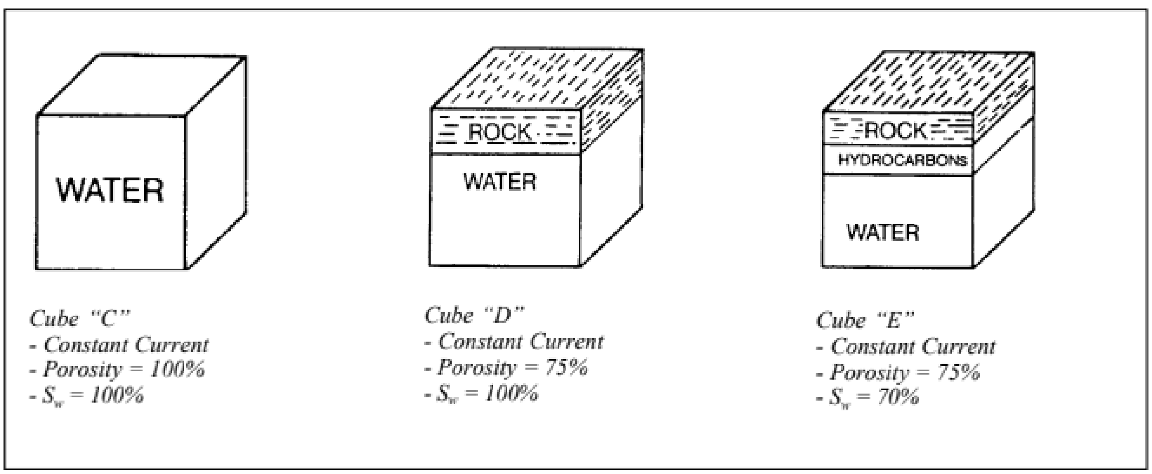


Figure A3

Therefore: $R_t \propto 1/\phi$. **(2)**

Cube E

Replace 30% of remaining porosity ϕ with hydrocarbons. Resistivity R_t increases with decreasing water saturation S_w (i.e. as S_w decreases, R_t increases).

Therefore: $R_t \propto 1/S_w$. **(3)**

By combining the above observations (1, 2 and 3), we can say

$$R_t \propto R_w \times \frac{1}{\phi} \times \frac{1}{S_w}$$

or

$$R_t \propto \frac{R_w}{\phi S_w} \quad \textbf{(4)}$$

To solve for the constants of proportionality let us first limit the equation as follows:

Let S_w = 100% (i.e. there is no hydrocarbon present and the porosity is 100% water filled).

Then, define $R_o = R_t$ (ie: R_o is the wet resistivity of the formation for the condition S_w = 100%):

$$R_o \propto \frac{R_w}{\phi} \quad \textbf{(5)}$$

Now, let $\phi = 1$, then $R_o \propto R_w$.

Now, let F = constant of proportionality defined as the *formation factor*.

Therefore: $R_o = FR_w$

$$\text{or } F = \frac{R_o}{R_w} \quad \textbf{(6)}$$

Returning to Equation 5 and introducing porosity as a variable, it is clear that

$$F \propto \frac{1}{\phi}$$

This is intuitively obvious as the relationship between R_o and R_w is related to that particular unit cube of rock and its porosity characteristics.

Through empirical measurements, it was determined that

$$F = \frac{a}{\phi^m} \quad \textbf{(7)}$$

where

a = constant

m = cementation factor

The cementation factor *m* relates to the porosity type and how it will transmit electrical current to the actual rock (also called tortuosity).

Using the above equations

Recall $R_o = FR_w$ (Equation 6)

$$R_t = R_o = \frac{aR_w}{\phi^m} \text{ when } S_w = 100\%$$

if $S_w \neq 100\%$, then

$$R_t \; \alpha \; \frac{aR_w}{\phi^m} \times \frac{1}{S_w}$$

$$\text{or } R_t \; \alpha \; R_o \times \frac{1}{S_w}$$

$$\text{or } S_w \; \alpha \; \frac{R_o}{R_t} \qquad \textbf{(8)}$$

Through laboratory measurements, it was found that this relationship (8) is dependent on the saturation exponent *n* as

$$S_w^n = \frac{R_o}{R_t}$$

$$\text{or } S_w^n = \frac{FR_w}{R_t}$$

$$\boxed{\text{or } S_w^n = \frac{\boldsymbol{aR_w}}{\boldsymbol{\phi^m R_t}} \qquad \textbf{(9)}}$$

Equation 9 forms the Archie relationship that is the basis for all conventional log interpretation techniques. Enhancements and refinements may be applied for the more complicated rock types.

The remainder of this course is dedicated to measuring, evaluating and using porosity and resistivity to calculate water saturation and hence hydrocarbons reserves using the concepts of this equation.

A.5 DEFINITIONS

a) Formation Porosity (ϕ)

Defined as the fraction of total volume occupied by pores or voids, where

$$\phi = \frac{\text{pore volume}}{\text{total volume}} \times 100\%$$

When the pore space is intergranular it is known as *primary porosity*. When the porosity is due to void space created after deposition, (e.g., vugs or fractures in carbonates), the porosity is known as *secondary porosity*. When shale is present, the pore space occupied by the water in the shale is included with the pore space in the rock to give *total porosity* (ϕ_T). If only the rock pore space is considered in a shaly formation, the pore space is called *effective porosity* (ϕ_e).

SP deflection

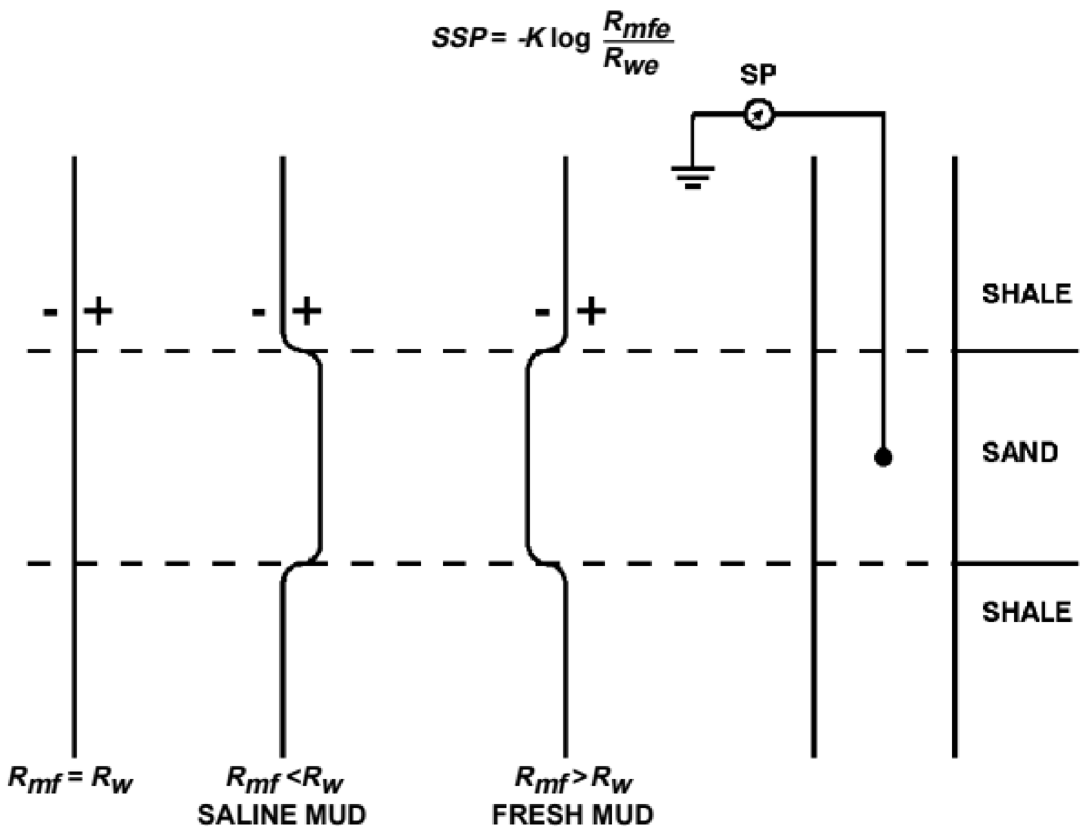


Figure B10: The SP Deflection and its R_{mf}-R_w Dependency

Wyllie Time Average Equation

a) Wyllie Time-Average Equation

After numerous laboratory determinations, M.R.J. Wyllie proposed, for clean and consolidated formations with uniformly distributed small pores, a linear time-average or weighted-average relationship between porosity and transit time (see Figure C4):

$$t_{LOG} = \phi t_f + (1 - \phi) t_{ma} \qquad \textbf{(C1)}$$

$$\text{or} \quad \phi = \frac{t_{LOG} - t_{ma}}{t_f - t_{ma}} \qquad \textbf{(C2)}$$

where

t_{LOG} is the reading on the sonic log in μsec/m

t_{ma} is the transit time of the matrix material

Raymer-Hunt

t_f is the transit time of the saturating fluid (about 620 µsec/m for freshwater mud systems)

ϕ is the porosity or volume occupied by pores

$1 - \phi$ is the volume of the matrix.

Typical Values:

Sand	Δt_{matrix}	= 182 µsec/m
Lime	Δt_{matrix}	= 156 µsec/m
Dolomite	Δt_{matrix}	= 143 µsec/m
Anydrite	Δt_{matrix}	= 164 µsec/m

When the formations are not sufficiently compacted, the observed Δt values are greater than those that correspond to the porosity according to the time-average formula, but the ϕ versus t relationship is still approximately linear. In these cases, an empirical correction factor, C_p, is applied to Equation 2 to give a corrected porosity, ϕ_{SVcor} (Equation 3):

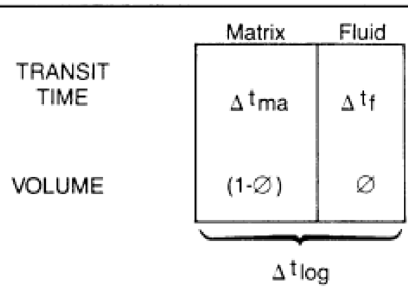


Figure C4: Components of the Wyllie Time-Average Equation

$$\phi_{SVcor} = \frac{t - t_{ma}}{t_f - t_{ma}} \times \frac{1}{C_P} \qquad \textbf{(C3)}$$

The value of C_p is given approximately by dividing the sonic velocity in nearby shale beds by 328. However, the compaction correction factor is best determined by comparing ϕ_{SV}, as obtained from Equations 1 and 2, with the true porosity obtained from another source.

b) Raymer-Hunt

Over the 25 years since acoustic velocity well logging was introduced, deficiencies have been noted in the transform of transit time Δt to porosity ϕ.

Based on extensive field observations of transit times versus porosity, the new empirical Raymer-Hunt transform was derived. The new transform equation is too complicated to be presented in this course. An approximation of the transform is given in Equation C4 and the exact transform is presented in the chart books as the red lines on all sonic charts.

$$\phi_{sv} = C \, \frac{t_{LOG} - t_{ma}}{t_{LOG}} \qquad \textbf{(C4)}$$

The value of the constant C has a range of 0.625 to 0.7 depending upon the investigator. Chart Por-3m (Figure C6) uses 0.7 for C: this was the value originally proposed. However, more recent transit time-to-porosity comparisons indicate that a value of 0.67 is more appropriate.

For the case of a gas-saturated reservoir rock, C becomes 0.6. It should be used when the rock investigated by the sonic tool contains an appreciable amount of hydrocarbon in the gassy (vapor) phase. Because of the shallow depth of investigation, this condition normally exists only in higher porosity sandstones (greater than 30%).

From the example sonic log (Figure C3) at 593 m we read 352 µsec/m. Given Δt_{ma} =182 µsec/m we can solve for ϕ:

Wyllie:

$$\phi = \frac{352 - 182}{620 - 182} \cong 39\%$$

Raymer-Hunt (approximation):

$$\phi = \frac{5(352 - 182)}{8(352)} \cong 30\%$$

Chart Por-3m (Figure C6) solves this equation graphically. Enter t_{log} of 352 µsec/m on abscissa and project upward until the appropriate Δt_{ma} line is reached (V_{ma} = 5500 m/sec). If different values of V_{ma} are used, we get different values of ϕ.

With a Δt_{log} = 250µsec/m we would get

V_{ma}	Wyllie F	Raymer-Hunt F