2. Data Acquisition & Quicklook Log Evaluation

Summary

Part A of this chapter discusses the various data acquisition (or conveyance) methods and a few related aspects (depth measurements, the log header, log resolution and depth of investigation)

Part B of this chapter gives a review of a Quicklook log evaluation. The quicklook evaluation is usually delivered immediately after the acquisition of the key log data. Often operational decisions (e.g. completion or suspension or abandonment) are made on the basis of this evaluation. Often the only sources of information are the logs and mudlog data.

References

Data acquisition

- Books by Bateman, Desbrandes and Serra (mentioned in chapter 1)
- Ph. Theys, Log data acquisition and quality control, Editions Technip, 2nd Edition, 1999

Quicklook evaluation

- Books by Bassiouni, Bateman, Desbrandes, Dewan, Ellis and Ransom Serra (mentioned in chapter 1)
- "Introduction into Petrophysics" E-learning Module, Open University (http://sww-openuniversity.shell.com/)

A. Log Data Acquisition

Tools and methods

The downhole measurements can be performed in the borehole with logging tools. These are physical measuring devices (sondes), which use various physical principles (nuclear, electrical, acoustical). These measured physical properties, which are recorded versus depth (and are called “logs”), can be interpreted in terms of lithology, porosity, hydrocarbon saturation, etc. This process is called “log evaluation” or “log interpretation”.

The data can be acquired by:

- lowering a sonde at the end of an electrical cable after a section of a well has been drilled. Whilst pulling the tools out of the well, various properties of the formations are measured continuously as a function of depth (*Fig. 1*).
- having a sonde as part of the drill string (measuring while drilling: MWD, logging while drilling: LWD, formation evaluation while drilling: FEWD). While drilling the various formation properties are being measured; part of the information is transmitted real time to surface using mud pulses while the remainder on the data is stored in memory. Chapter 6 of this manual discusses this conveyance technique in more detail.
- A recently developed option is wireless logging. See the Figure 31 below. Wireless logging may be a low cost option that requires less rig time and provides a comprehensive petrophysical data suite. For more information search the SWW for “wireless logging” or contact John Runia.

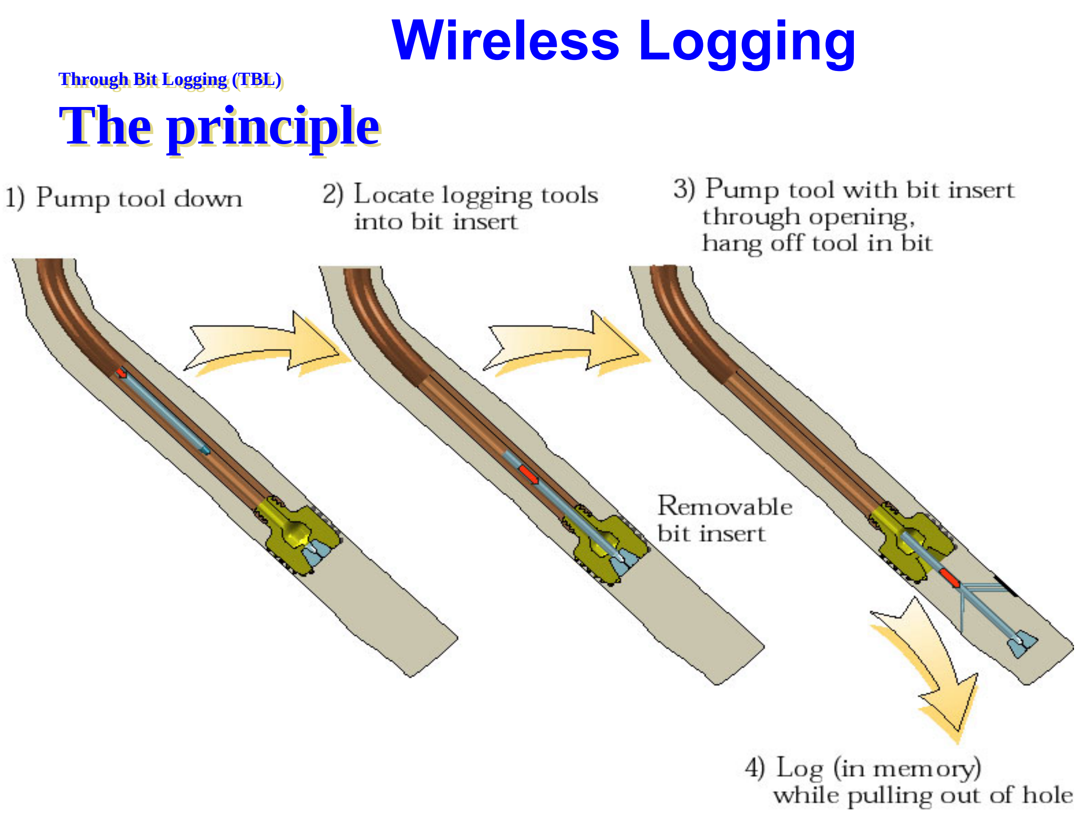

Figure 31 - Wireless Logging

In some cases when wireline logging is difficult, e.g. in strongly deviated holes, the tools can be lowered (after drilling) while connected to drill pipe or coiled tubing. This is sometimes called Tough Logging Conditions (TLC) or Pipe Conveyed Logging (PCL).

Logs, which are used to quantify the hydrocarbon in place, can be classified into three "families":

- Reservoir Thickness (Gamma Ray, Spontaneous Potential).

  These logs discriminate reservoir from non-reservoir.

- Porosity (Density, Neutron, Sonic).

  These logs are used to calculate porosity, identify lithologies and differentiate oil from gas.

- Resistivity (Laterolog, Induction, Microresistivity.)

  These logs, together with porosity logs, are used to calculate hydrocarbon saturations

Other types of wireline tools are:

- Side wall sampler: takes small rock samples, which are used for lithology and fluid type confirmation
- Formation tester: measures formation pressures and can retrieve fluid samples
- Dipmeter and (borehole) Image logs: measure not only dip and azimuth of the layers but also can provide an image of the formation (almost like a core photograph) which can be used for detailed geological interpretations.
- Well shoot & VSP: used to calibrate seismic

All logging is carried out by contractors. The main logging contractors are Schlumberger, Baker Atlas and Halliburton. Important LWD contractors are Anadrill (a Schlumberger company), Sperry Sun (a Halliburton company) and INTEQ (a Baker Atlas company). Most evaluations are carried out in-house by the petrophysicist, using a petrophysical evaluation software called "LOGIC".

The actual tool measurement has to be calibrated by the contractor to ensure that the measured quantity is correct, i.e. not disturbed by temperature fluctuations, tool malfunctioning, etc.. Chapter 13 of this manual elaborates further on this calibration process.

None of the measurements is direct. Hence, the desired results (porosity, hydrocarbon content) have to be evaluated using petrophysical models. The tool may for instance measure the electrical resistivity of the formation. However, the quantity we want to have is water saturation. The measured resistivity must somehow be related to the amount of hydrocarbon in the rock. This is achieved by carrying out calibration experiments on core samples in the laboratory.

Also since the measurements are in-direct account must be taken of the disturbances exerted by the presence of the borehole, mud, mud filtrate invasion, shoulder beds (layers above and below the formation), dip, borehole deviation, pressure, temperature, etc. Therefore, log responses may first have to be environmentally corrected for such effects.

Depth Measurement

The depth is measured along hole (AHD) in meters below derrick floor (mbdf); sometimes this depth is called “measured depth” or “MD”. When the bottom of the tool string touches the drill floor the depth measurement is set at zero (*Fig. 2*). The distance between the various tool detectors and the bottom of the toolstring is automatically compensated by the computer in the surface logging unit. The length of cable in the hole is measured with an accuracy of around 0.1%.

In vertical wells the AHD is equal to the true vertical depth (TVD). In deviated wells, a deviation survey is needed to calculate the TVD from the AHD. The TVD is often expressed in meters below a local datum, e.g. meters subsea (mss). The height of the derrick floor above the common sea level datum is called the Derrick Floor Elevation (DFE).

It is important to know accurately at which depth the logging measurements were recorded, hence depth control is essential. For the first logging survey in the well normally a Gamma-Ray / Resistivity combination is used. The accurate depth determination is done using calibrated “depth wheels” installed at the winch (see *Fig. 2*) and using cable stretch procedures during logging.

Subsequent logging surveys (with other tools) over the same depth intervals have to be depth correlated to the first survey. Errors might be expected if the tool weights are different, or if the travelling block has moved. In subsequent surveys in other (new) intervals, the first log should include a Gamma-Ray. The new run should have an overlap of at least 50 metres with the previous Gamma-ray log (*Fig. 3*). The logs can be confidently correlated if the depth error is less than 0.5 metre.

Note that log data acquired while drilling have the drillers depth as depth reference. Hence depth measurements during LWD are less accurate than during wireline logging as the drillers depth does not take into account stretch!

Log Header

A log consists of a number of different parts (*Fig. 4*). Data, crucial for the evaluation, can be found in the log header (*Fig. 5*):

- Well name and –location (coordinates), date, drill floor elevation (DFE), ground elevation (GE), bit size, mud -type and –properties, Resistivities of the mud (Rm), mud filtrate (Rmf: *Fig. 6* can be used to translate this to NaCl concentration) & mud cake (Rmc)
- Total depth (TD), bottom hole temperature (BHT), Weight-, size-, & depth- of previous casings, Time of last mud circulation
- List of all tools run in this hole section, serial number of tools and logging unit used, name of logging engineer and company representative.

Tool combinations

Logging tools can be combined into one string, such that a basic Gamma-Ray, Density / Neutron, Resistivity combination can be logged in one logging run (Super-Combo). A disadvantage of the longer toolstring is that additional hole has to be drilled to ensure coverage of the Objective by all sensors. A development by Schlumberger is the Platform-Express (“PEX”), which is a Super-Combo but reduced in size and with higher accuracy sensors, thus allowing less “rat-hole” and to log faster and thus save rig time.

Also in LWD the different sensors can be combined.

Depth of investigation versus resolution of logging tools

Different tools have different vertical resolutions (spatial averaging) and different depths of investigation (into the formation, away from the borehole), depending mainly on the spacings between source (transmitter) and detector (receiver).

The nuclear tools (gamma-ray, neutron, density) used for porosity and lithology determination have a rather shallow depth of investigation (typically 1 - 2 ft) because nuclear particles are quickly absorbed (*Fig. 7*). Because of this these tools mainly read the mud filtrate invaded zone (*Fig. 8*). Therefore, for instance, the apparent fluid density to be taken in the calculation of porosity from density is a combination of mud filtrate and gas densities (see section B of this chapter). The fact that the nuclear tools read the invaded zone rather than the virgin zone is not a big problem as the porosity determination is rather insensitive to the invasion process. Most petrophysical tools consist of a shallow and a deep measurement (*Fig. 7*), where the shallow one is used to correct the deep one for mudcake and invasion effects.

However, the main tools for determination of hydrocarbon saturation in open hole are resistivity tools. Of course, the desired saturation is that of the virgin (not invaded) zone (*Figs. 8 & 9*). Therefore, the resistivity tools have been designed such that they can read deep into the formation (deep laterolog / induction), such that they will (hopefully) be influenced mainly by the virgin formation (*Fig. 10*).

In all tools a compromise is made between depth of investigation and resolution, i.e. the deeper a tool "sees" into the formation, the more its response will also be influenced by neighbouring beds above and below its actual position (if a tools sees deep horizontally, it will also read far vertically). Hence, resistivity tools can have a far larger depth of investigation than nuclear tools, but their vertical resolution is correspondingly less (worse).

The **depth of investigation** of a logging tool (in a vertical well) is the horizontal distance away from the borehole that a logging tool can still "see" into the formation (the word "depth" is misleading here: the concept refers more to a horizontal investigation distance). E.g. a density tool only reads about 1 foot into the formation, whereas a deep induction log sees about 2 metres away from the borehole (*Fig. 10*), so that in many cases it reads beyond the invaded zone, whereas a density tool does not. The "depth of investigation" is in general related to the **spacing** between source and detectors in the logging tool: the farther the source is away from the detectors the larger in general is the depth of investigation (*Fig. 7*). However, this spacing is limited by the tool physics, e.g. some nuclear particles are absorbed rapidly by the formation, such that the spacing can not be made too large because in that case no particles would be left to measure. Hence, many nuclear tools do not read beyond the mudfiltrate **invaded zone**, whereas deep resistivity tools often do.

The **resolution** of a logging tool refers to its capability to distinguish and properly measure thin beds. A tool with a good vertical resolution, like the formation image log (chapter 12), is capable of properly measuring rather thin beds, say of a few millimeters thickness. A tool with a bad vertical resolution, like the induction log deep is only capable of properly resolving rather thick beds, say of more than 1 metre thickness.

Obviously, the resolution of a logging tool is again related to the source / detector spacing: the larger the spacing, the worse the resolution (everything between source and detectors is seen as one average value by the tool, *Fig. 7*). Hence, the vertical resolution is also related to the depth of investigation: a tool with a bad vertical resolution generally has a large depth of investigation and vice versa.

Many tools have several detectors, e.g. a short spacing and a long spacing detector (*Fig. 7*). The short spacing detector reads closer to the borehole than the long spacing detector. The short spacing detector reading is then used to correct the log spacing detector reading for borehole and mudcake effects. For instance, large and irregular boreholes can adversely affect the accuracy of the measurements. The log correction needed in these cases can often be quantified using contractor provided environmental correction charts (e.g. Schlumberger or Baker-Atlas chart books).

In some difficult cases, however, such charts are not sufficiently accurate, and tool response modelling and inversion have to be used instead (see chapter 6). Modern tools often have many detectors on a so called "array", such that a profile of the invaded zone can be made, e.g. Schlumberger's "array imaging (induction) tool", the AIT. This requires tool response modelling and inversion in any case.

B. Quicklook Method

Reading log responses

Most petrophysical quicklook evaluations are done using the software “LOGIC”. That means that at every log increment (usually every 0.5 ft) a petrophysical parameters is caluclated.

In the unlikely event that the quicklook evaluation is carried out “by hand” "constant" log values are assigned to the formation beds (despite variations at the incremental scale). These values are then used to calculate the petrophysical parameters of each bed. In such evaluation one can limit the amount of blocks by taking average readings over intervals with a more or less constant log responses. The block boundaries must be at the same depth on all involved logs.

The Hydrocarbon volume in place

The Hydrocarbon volume in place is given by the following equation (*Figs. 11 & 12*):

$$HCIP = A * h * (N/G) * \phi * (1 - S_w)$$[1]

where:

HCIP = volume of hydrocarbon in place

A = area of the reservoir, determined by geophysicists and geologists, mainly on the basis of surface seismic.

h = thickness of the reservoir, determined by geologists and petrophysicists from logs and cores.

N/G = net-to-gross ratio (i.e. fraction of the reservoir that consists of porous rock, e.g. sand or carbonate, hence excluding shale), determined by geologists and petrophysicists from logs and cores. In many cases this boils down to discriminating sand from shale intervals using the gamma-ray log, possibly together with the density/neutron combination (see also *Fig. 12* and chapter 5).

ϕ = porosity of the reservoir, i.e. that fraction of the rock bulk volume that consists of pore space, determined by the petrophysicist from logs and cores. In many cases the porosity is obtained from the density log. Other porosity logs like the neutron and sonic are only used as second bests.

S_w = water saturation, i.e. that fraction of the pore space that contains water, determined by the petrophysicist from logs. In most cases the resistivity logs will be used for this.

Basic steps in Quicklook log evaluation (see also *Fig. 13*)

1. Review The Logs

- Inspect the mud log for intervals with reservoir rock, hydrocarbon shows (primary flourecence, solvent cut color, solvent cut flou) and mud gains
- Review the quality of the wireline logs checking headers, depths, scales calibrations and tool checks as required. Read the remarks section, if present.
- Use logs from surrounding wells, if available, to identify any obvious anomalies in the data (i.e. check log readings in salt, anhydrite, regional shales or other stable markers).

2. Identify Reservoir Rock (Gamma-ray)

- Discriminate potential reservoir rock from non-permeable rock, using the caliper (mudcake present?), Gamma-Ray (GR), Density-Neutron. In clastic environments, intervals with low GR values are probably sand (reservoir), intervals with high GR are probably shale (non-reservoir): *Fig. 14*.

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[1] see also list of symbols at the end of this chapter

- If the sands are radioactive, a spectral Gamma-ray tool (which distinguishes between uranium, thorium and potassium) should be considered. The discrimination can be enhanced by using the neutron-density combination (in shale the neutron lies to the left of the density). Sometimes the SP and/or caliper (mud cake) logs can (also) be used. A total sand count is provided by the software or alternatively prepare a sand count using 1:200 scale logs (preferably the density curve)

3. Discriminate hydrocarbon zones (Resistivity + density/neutron)

- Water-bearing intervals are characterised by low resistivity and tramlining between density and resistivity (porosity is displayed increasing to the left, hence density and neutron scales are chosen accordingly !). Hydrocarbon-bearing intervals are characterised by high resistivity and (often, <u>but not always</u>) by anti-correlation between density and resistivity: *Fig. 15*.
- In case of saline mud the laterolog deep LLD resistivity is used to obtain the uninvaded zone (“true formation”) resistivity, whereas in case of non-saline mud (e.g. OBM) the induction log deep ILD is used (in ideal cases, i.e. if these logs are available). The resistivity should normally be corrected for borehole/invasion effects using shallow and very shallow auxiliary resistivity measurements (laterolog shallow LLS or induction log medium, ILM and/or Micro-Spherically Focused Log, MSFL). In quicklook evaluations such corrections are often ignored though.
- Separation between deep, shallow and micro resistivity tracks indicates movable hydrocarbons.

4. Gas / oil differentiation

- Gas-bearing intervals can often be discriminated from oil-bearing intervals by looking for a large density/neutron separation (in gas bearing zones the neutron lies to the right of the density), combined with anti-correlation between density and neutron (*Fig. 16*). However, this effect is obscured if shale is present, because shale gives rise to the opposite effect. Oil can cause some density/neutron separation, but this will not give anti-correlation. Often the sonic is higher and spikier in the gas bearing intervals as well. Also, WLFT pressure gradients and percussion sidewalls (WBM) may indicate HC type. See the Section on HC Typing.

5. Calculate Porosity & confirm lithology (Density/neutron)

- Calculate porosity preferably using the density log, possibly in combination with the neutron log, depending on lithology (in some cases (e.g. carbonates) the sonic has to be used).

  In ***sandstones*** calculate the porosity ϕ from the density log ρ_{log}, by using a matrix density ρ_{ma} of 2.65 g/cc (unless otherwise known) and a fluid density ρ_{fl} = 1.0 (unless otherwise known: see below):

$$\phi = \frac{\rho_{ma} - \rho_{LOG}}{\rho_{ma} - \rho_{fl}}$$

  In ***carbonates*** use the density/neutron crossplot provided in chart books (or LOGIC) to get porosity directly or establish the matrix density, ρ_{ma}, of the limestone/dolomite mixture before using the above formula.

- The matrix density and apparent fluid density can also be obtained from a calibration of the density log against laboratory measured porosities on core plugs taken over the same interval as the log: see *Fig. 17*.
- Estimate the fluid density, ρ_{fl}, based on the salinity of the mud filtrate e.g. from the mud filtrate resistivity R_{mf} (see log header) and resistivity vs. salinity charts.
- In hydrocarbon bearing zones approximate the invaded zone fluid density using the mud filtrate density and an estimated hydrocarbon density with

$$\rho_{fl} \approx 0.7\rho_{mf} + 0.3\rho_{hc}$$

  If in a hydrocarbon bearing zone a fluid density of 1.0 is taken in stead of the correct (lower) value, the calculated porosity will be too high: see *Fig. 18*.
- Alternatively, in gas-bearing zones, a gas-corrected porosity can be calculated as 2/3 times the density porosity plus 1/3 times the neutron porosity (see *Fig. 19*: the value will be at 1/3 of the distance between density and neutron curves).
- The density / neutron crossplot also gives information on lithology: see *Figs. 20 & 21* (and Chapter 5 of this manual).

Intermezzo: the Archie-equations

- The amount of hydrocarbon can be calculated via the water saturation obtained from the resistivity log, for instance using the Archie equations, outlined below. For that purpose, first the water resistivity R_w is obtained from the resistivity in the water-bearing zone, and then the water saturation S_w in the hydrocarbon-bearing zone is calculated using the Archie-equations and the just obtained R_w value. The water saturation is the fraction of pore volume filled with water. Hence, 1 - S_w is the fraction of pore volume filled with hydrocarbon: the hydrocarbon saturation.
- In many cases substantially more oil can be found by applying more advanced measurements and/or evaluation techniques, especially in the case of thin beds and/or thinly laminated shaly sands. Such techniques will be described in various other chapters of this manual. Moreover, often auxiliary data are required for accurate log evaluations. Such data can for instance be obtained from core analysis (see next chapter), and/or wireline formation (pressure and fluid) tests.

- ***The Archie-equation for water-bearing rock***
  In a clean water bearing reservoir, all the pore space is filled with formation water. The matrix is an electrical insulator. The only conductor present is the formation water (*Fig. 22*). Its resistivity (R_w) depends on the concentration of salts dissolved in the water and the temperature of the reservoir. The total resistivity of a water bearing formation (R_o) depends on the resistivity of the water (R_w), the amount of water present (equal to ϕ) and the shape of the water body (expressed by the cementation factor "m").

$$R_o = R_w \phi^{-m}$$

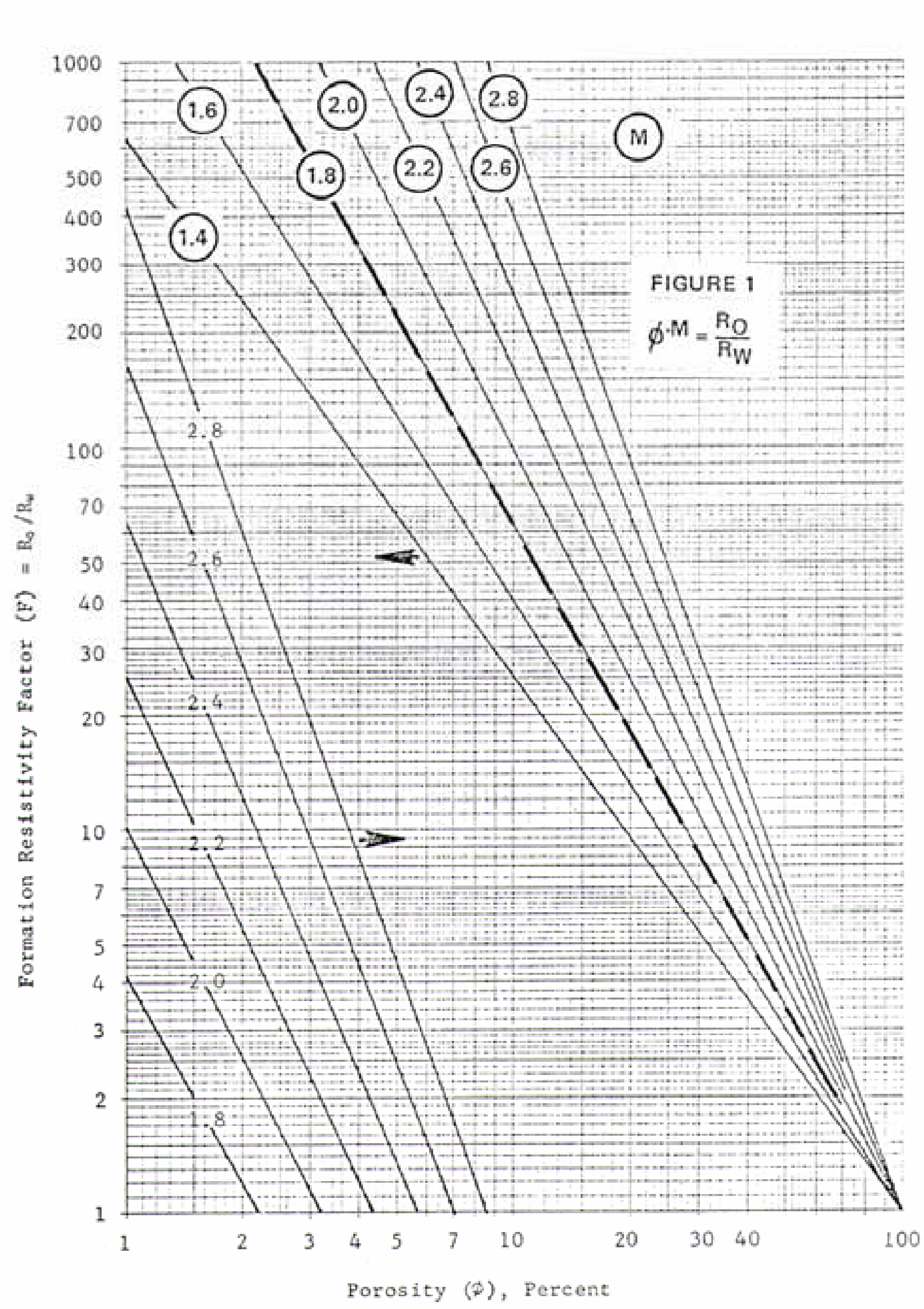


Chart A - the First Archie Relationship, graphically

This is the first Archie equation. It is sometimes written in terms of the ratio between the resistivity of the fully water-bearing rock R_o and the water-resistivity R_w. This ratio is called the formation resistivity factor (FRF, or F) (*Fig. 23*):

$$F = R_o / R_w = \phi^{-m}$$

The cementation factor m depends on the shape of the pore space (*Fig. 24*). m is reasonably constant within granular rocks, independent of porosity ϕ. It 's value can be measured on core plugs, deduced from various combinations of logs or estimated for the described rock type. Please note that each individual fully water saturated core plug yields one value of m, and hence a number of plugs have to be measured to obtain good statistical accuracy. For quick look evaluations use the following m values, if no other accurate estimate is available: Sandstone, m = 1.8, Carbonate, m = 2.0

The Archie equation predicts that a double-logarithmic plot of the deep resistivity log versus porosity log in a fully water bearing rock yields a straight line, with slope m and intercept R_w (*Fig. 25*). This is called the Pickett plot (see also step 6 below).

- ***The Archie-equation for hydrocarbon-bearing rock***

In a hydrocarbon bearing reservoir part of the water is replaced by oil or gas, which are also electrical insulators. If the rock is water-wet (i.e."it is attracted to water"), the hydrocarbon is accumulated in the centre of the pore spaces. The remaining water coats the grain surfaces. Electrical current can still travel through the reservoir, along the water layer around the grains. The total resistivity of the reservoir (R_t) can be orders of magnitude higher than the R_o of a similar water bearing formation, because the volume and the connectivity of the conductor (water) is smaller (hence, in a Pickett plot hydrocarbon bearing points would lie above the line through the points of the water-bearing zone). Therefore, in addition to the parameters of the first Archie equation, the total resistivity also depends on the water saturation (S_w = fraction of the pore volume which is filled with water) and the geometry of the water coating the grains (expressed by the saturation exponent n).

The increase of the resistivity R_t of the partly hydrocarbon-filled rock over the resistivity R_o of the fully water-filled rock is called the resistivity index I (*Fig. 26*). It is a function of the water saturation S_w:

$$I = R_t / R_o = S_w^{-n}$$

Similar to m, n is often constant within a particular rock, independent of S_w. It's value can be measured on core plugs or estimated for the described rock type. For quick look purposes n is often assumed equal to m. Please note that measurement of each core plug in the laboratory would involve desaturation of the plug to yield various values of S_w and the associated R_t, thus yielding one complete I – S_w curve for each individual plug.

- ***The combined Archie equations***
  The combination of the first and second Archie equations gives the following equation which describes how the actually measured resistivity depends on the water resistivity, porosity and water saturation (in case of clean sands or carbonates, for which the Archie equation applies):

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

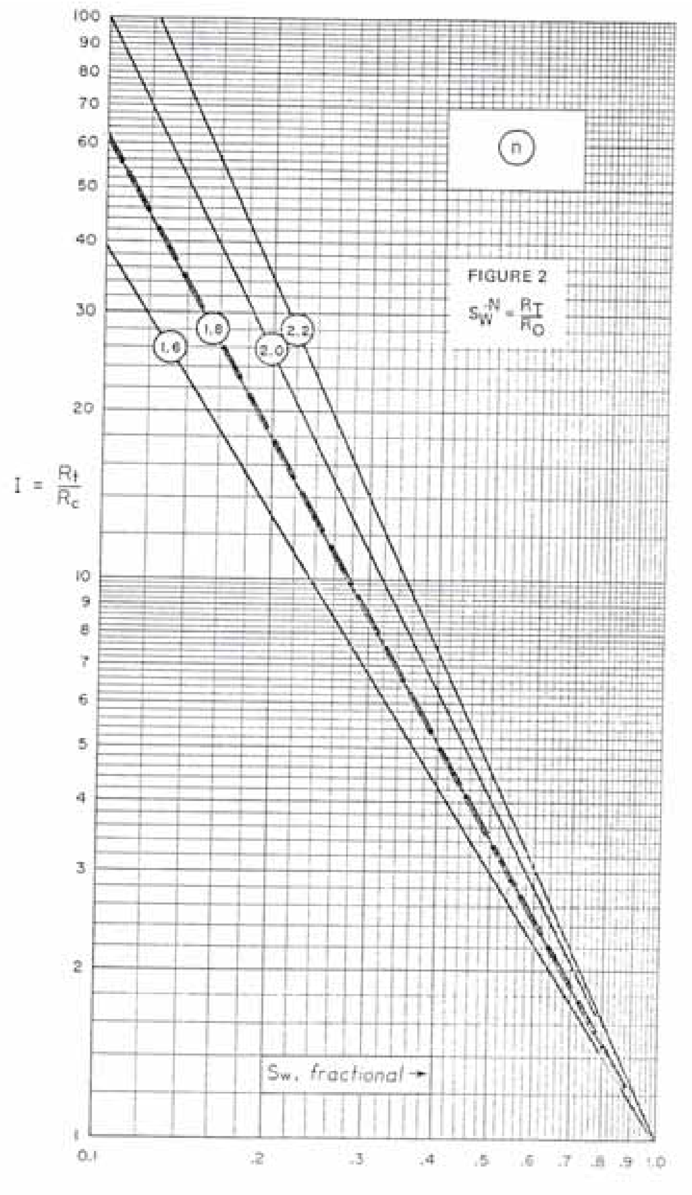


Chart B - the Second Archie Relationship, graphically

6. Establish the water resistivity R_w

To calculate R_w from log readings across a water bearing interval:

- Identify an appropriate fully water bearing section on the logs.
- Calculate porosity ϕ from a porosity log over this section.
- Estimate an m-value (preferably obtain it from laboratory measurements on core plugs), otherwise use the values quoted above for sandstone and carbonate.
- Read the resistivity of the water bearing zone R_o from a deep resistivity tool.
- If the resistivity and porosity show sufficient variation over this interval, plot them on a double logarithmic Pickett plot to obtain R_w by regression (*Fig. 25*).
- Otherwise take average values over the entire water-bearing interval and apply the first Archie equation, re-written as:

$$R_w = R_o \, \phi^m$$

- If there is no obvious water bearing interval available, R_w can be estimated using local well data, regional knowledge / experience, an R_w atlas, the SP log, or from measurement on a water sample taken from the same formation in a nearby well.

7. Calculate the water saturation S_w in the hydrocarbon bearing reservoir (Resistivity / porosity)

To calculate S_w from log readings across a hydrocarbon bearing interval:

- Identify the hydrocarbon bearing section on the logs.
- Calculate porosity ϕ from a porosity log over this section.
- Estimate m and n values (preferably obtain it from laboratory measurements on core plugs), otherwise use the values quoted above for sandstone and carbonate.
- Assume R_w to be equal to the R_w in the water bearing interval.
- Read the resistivity of the hydrocarbon bearing zone from a deep resistivity tool.
- Use as the approximate true resistivity, R_t, the deep laterolog reading, R_{LLD}.
- In the absence of a laterolog, assume the deep induction log approximates R_t.
- Calculate hydrocarbon saturation, S_h, from the combined Archie equation, re-written below in terms of S_w, using (if not known otherwise) *m*=*n*=1.8 in sandstones and 2.0 in carbonates:

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

$$S_h = 1 - S_w$$

- The whole procedure is summarised in *Figs. 27 and 28.*

- A simplified procedure is possible if n is close to 2.0 and the porosity of the hydrocarbon zone is about equal to that of the water zone. In that case above equation for S_w reduces to (*Fig. 29*):

$$S_w = (R_o / R_t)^{1/2}$$

8. Hydrocarbon Distribution(Wireline Formation Tester

- Determine, as far as possible, the presence of the various fluid contacts (GOC, OWC, GDT, OUT, ODT WUT: *Fig. 30)* from the logs. Identify the presence of transition zones.
- Use sidewall samples, wireline pressure data and wireline fluid samples to confirm the presence of oil and gas and identify pressure regimes. Target wireline sampling at areas of uncertainty from the log evaluation, particularly where calculated S_h values are between 50 % and 70 % pore volume.

  When selecting wireline sample depths take note of the following:

  - Specify depths with respect to a named and dated log (e.g. GR of density/neutron/GR of 4/5/94)
  - Use the caliper to identify smooth hole or in-gauge hole sections
  - For the wireline pressures pick high porosity intervals where possible to avoid supercharging: identify these by high porosity and low GR (shale content)
  - In picking wireline pressures, consider the requirement spacing and position required for gradient calculation and establishing communication between reservoir units. In long reservoir units take sufficient pressures to identify changes in fluid properties with depth.

  Chapter 9 provides more detail on the wireline formation tester.

9. Reporting

- Report the results of the quicklook evaluation summarising the following elements for each major reservoir and fluid type:
  - *Total net hydrocarbon sand count*
    (Net/Gross ratio if gross interval known/defined)
    Average porosity
    Average hydrocarbon saturation (transition zone separate)
  - *Observed fluid contacts and source (wireline pressures or logs)*
  - *Petrophysical parameters used (ρ_{ma}, R_w , m, n, etc.)*
  - *Special considerations or peculiarities of the evaluation*

Summary of nomenclature:

ϕ	Porosity (fraction of bulk volume)
ρ_b	Bulk density (measured by the density log) (g / cc)
ρ_{fl}	Fluid density (g / cc)
ρ_g	Grain (= matrix) density (g / cc)
ρ_{hc}	Hydrocarbon (= fluid) density (g/cc)
ρ_{log}	Formation density measureds by the logging tool (g / cc)
ρ_{ma}	Matrix (= grain) density (g / cc)
ρ_{mf}	Mud filtrate (= fluid) density (g / cc)
F	Formation Resistivity Factor = Ro / Rw
I	Resistivity Index = Rt / Ro
m	Cementation exponent in first Archie equation
n	Saturation exponent in second Archie equation
R_o	Resistivity of fully water bearing rock (Ohmm)
R_t	Resistivity of partly water (partly hydrocarbon) bearing rock (Ohmm)
R_w	Resistivity of the water (brine) (Ohmm)
S_h	Hydrocarbon saturation (fraction of pore volume) = 1 - Sw
S_w	Water saturation (fraction of pore volume)

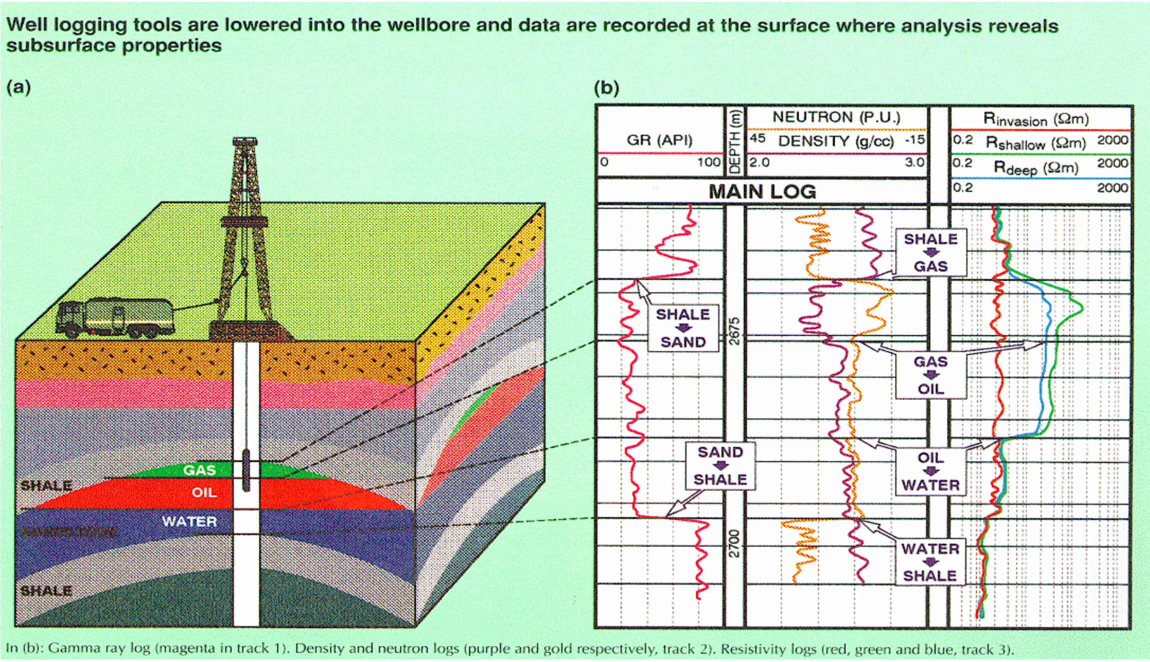


Figure 1 - Well Logging

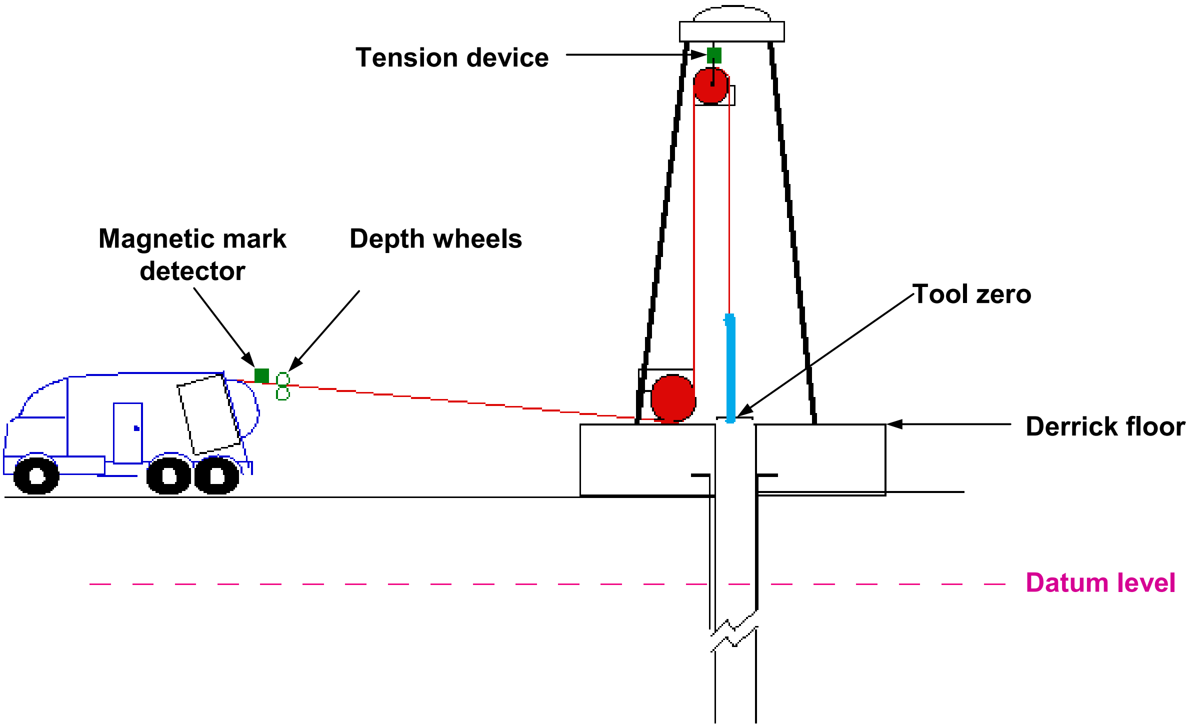
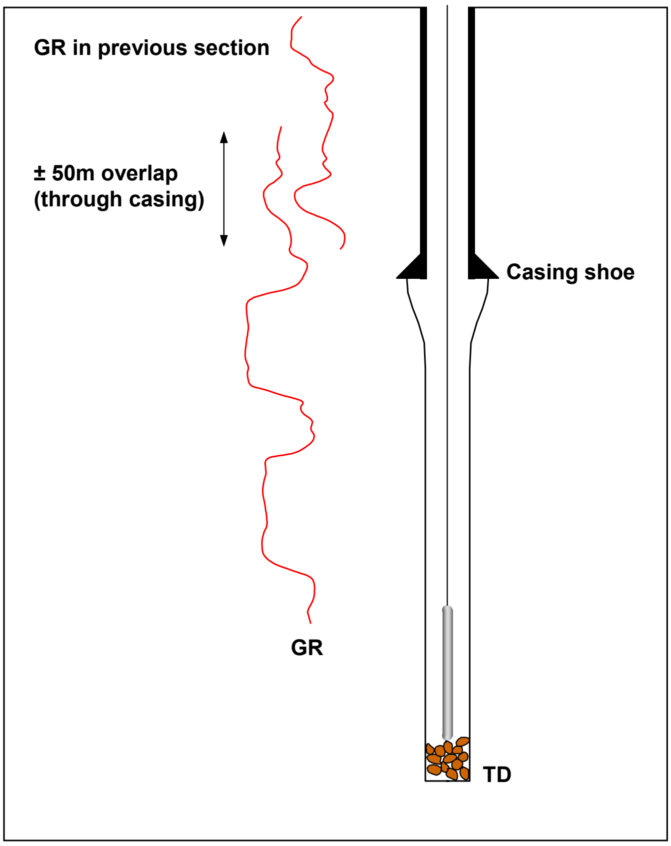


Figure 2 - Depth Measurement



Casing shoe: Depth logger = Depth driller ± 0.1%

TD: Depth logger ≤ Depth driller

Figure 3 - Depth Checks

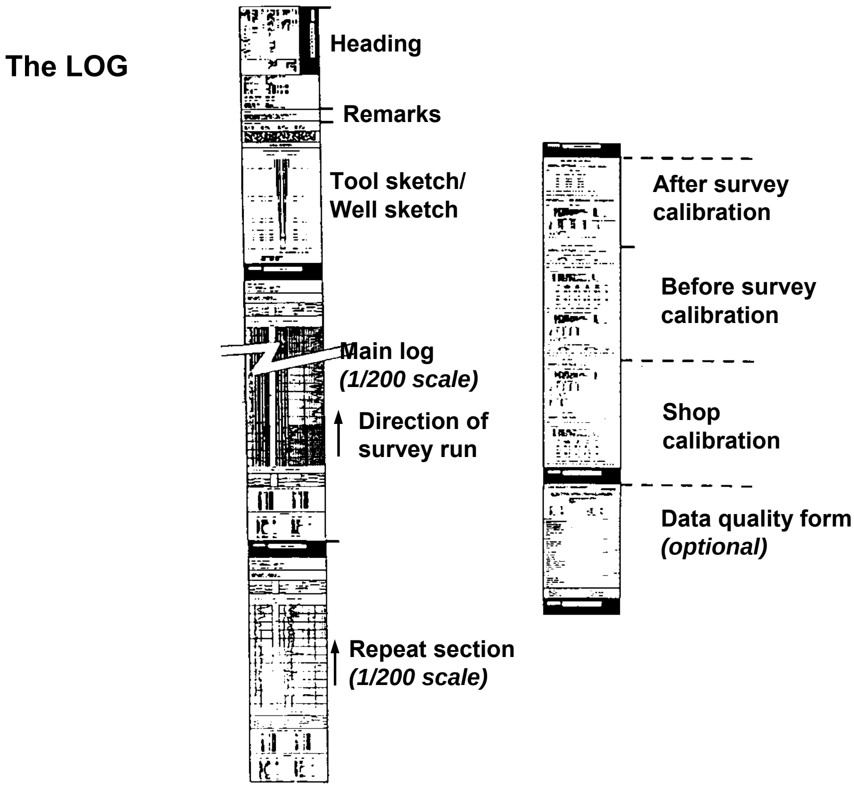


Figure 4 - Standard Log Presentation

COMPANY:	
WELL:	
FIELD:	
RIG:	Sedco - 702 COUNTRY:

Schlumberger

PEx(HALS)-DSI-NGS
SUITE - 1 , RUN - 1
SCALE: 1/200

LOCATION		Elevation	
WA-6-L		Elev.: R.T.	25.9 M
Eastings:		G.L.	-127.6 M
Northings:		D.F.	25.9 M
Permanent Datum:	L.A.T.	Elev.:	0 M
Log Measured From:	D.F.	25.9 M	above Perm. Datum
Drilling Measured From:	D.F.		

RIG: Field: Location: Well: Company:

STATE:	Max. Well Deviation 2.7 DEG	Longitude	Latitude
Logging Date	12-APR-1998		
Run Number	1		
Depth Driller	3495 M		
Schlumberger Depth	3480.5 M (HUD)		
Bottom Log Interval	3477.5 M		
Top Log Interval	153.5 M		
Casing Driller Size @ Depth	9.625 IN @ 1566.84 M	@	
Casing Schlumberger	1568.5 M		
Bit Size	8.500 IN		
Type Fluid In Hole	KCl / PHPA		
MUD Density / Viscosity	1.22 G/C3 / 70 S		
MUD Fluid Loss / PH	3.4 C3 / 9.5		
MUD Source Of Sample	Pits		
RM @ Measured Temperature	0.099 OHMM @ 29 DEGC	@	
RMF @ Measured Temperature	0.078 OHMM @ 29 DEGC	@	
RMC @ Measured Temperature	0.186 OHMM @ 28 DEGC	@	
Source RMF / RMC	Sample Pressed / Sample Pressed		
RM @ MRT / RMF @ MRT	0.038 @ 111 / 0.030 @ 111	@	@
Maximum Recorded Temperatures	111 DEGC / 111 / 109		
Circulation Stopped / Time	12-APR-1998 / 12:00		
Logger On Bottom / Time	13-APR-1998 / 5:20		
Unit Number / Location	242 / MWA		
Recorded By			
Witnessed By			

Figure 5 - Standard Log Presentation

Conversion approximated by: $R_2=R_1[(T_1+6.77)/(T_2+6.77)]$ °F or $R_2=R_1[(T_1+21.5)/(T_2+21.5)]$°C

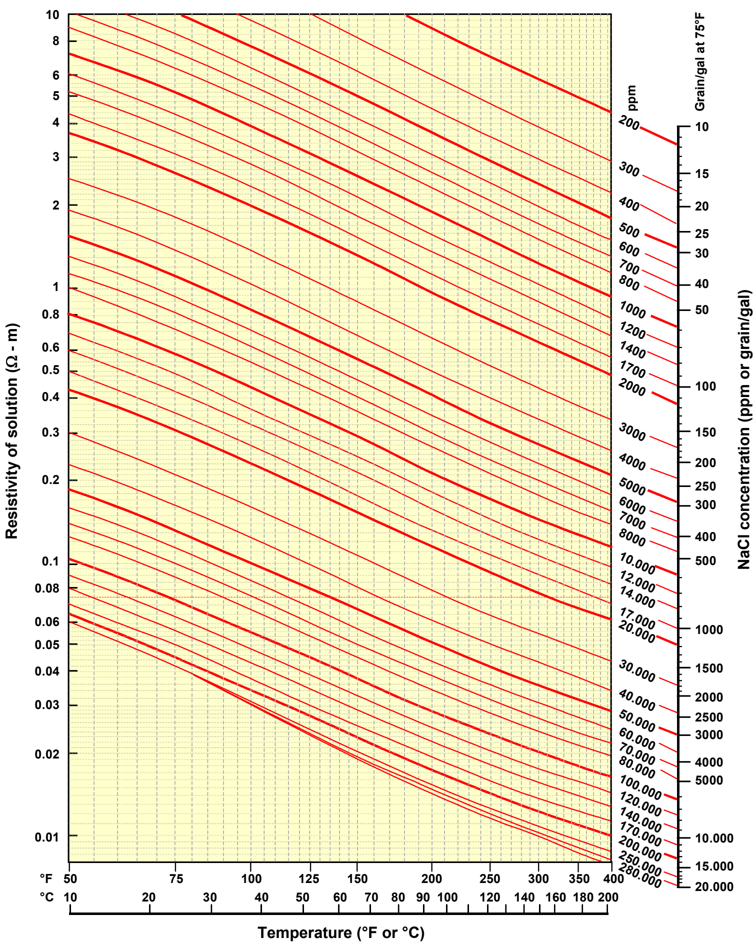


Figure 6 - Resistivity of NaCl Solutions

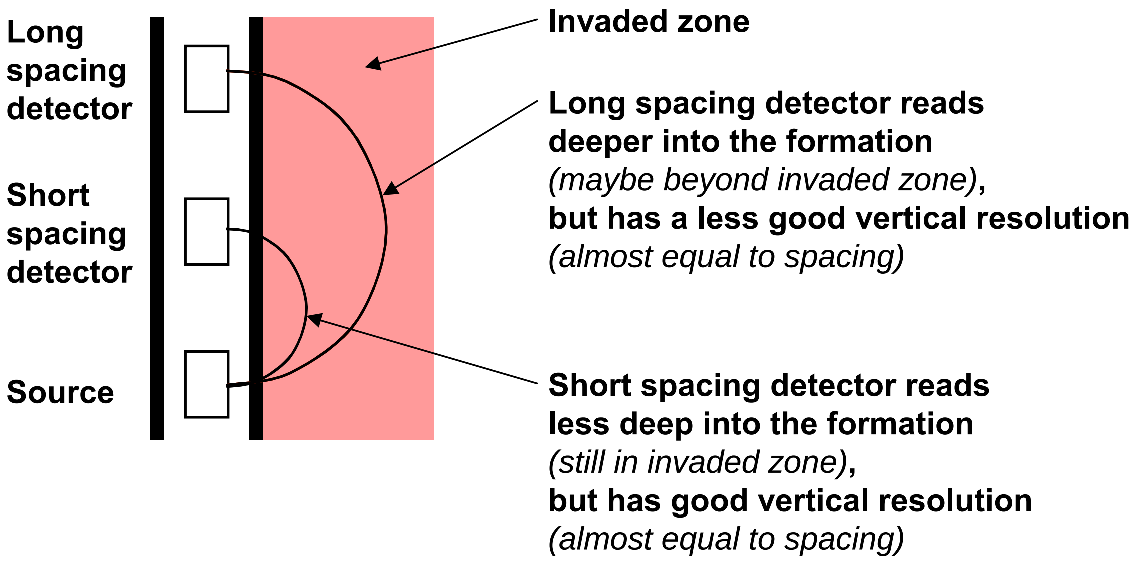


Figure 7- Depth of Investigation and Resolution

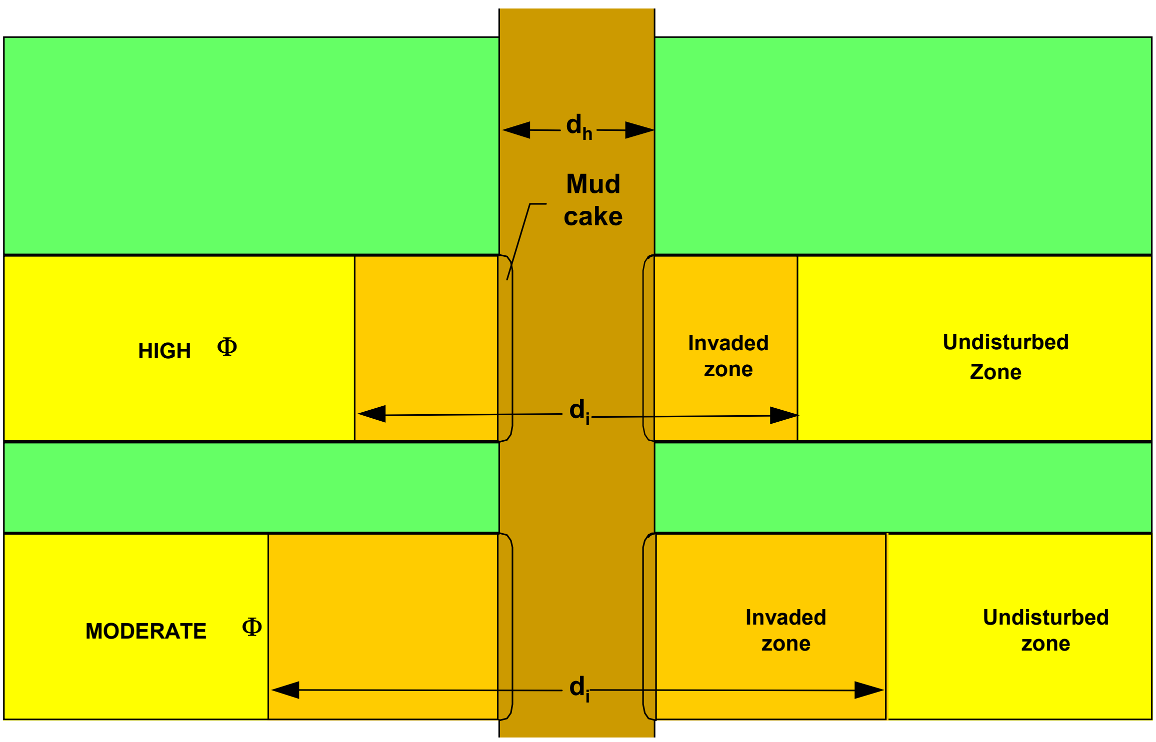


Figure 8 - Mud Filtrate Invsaion

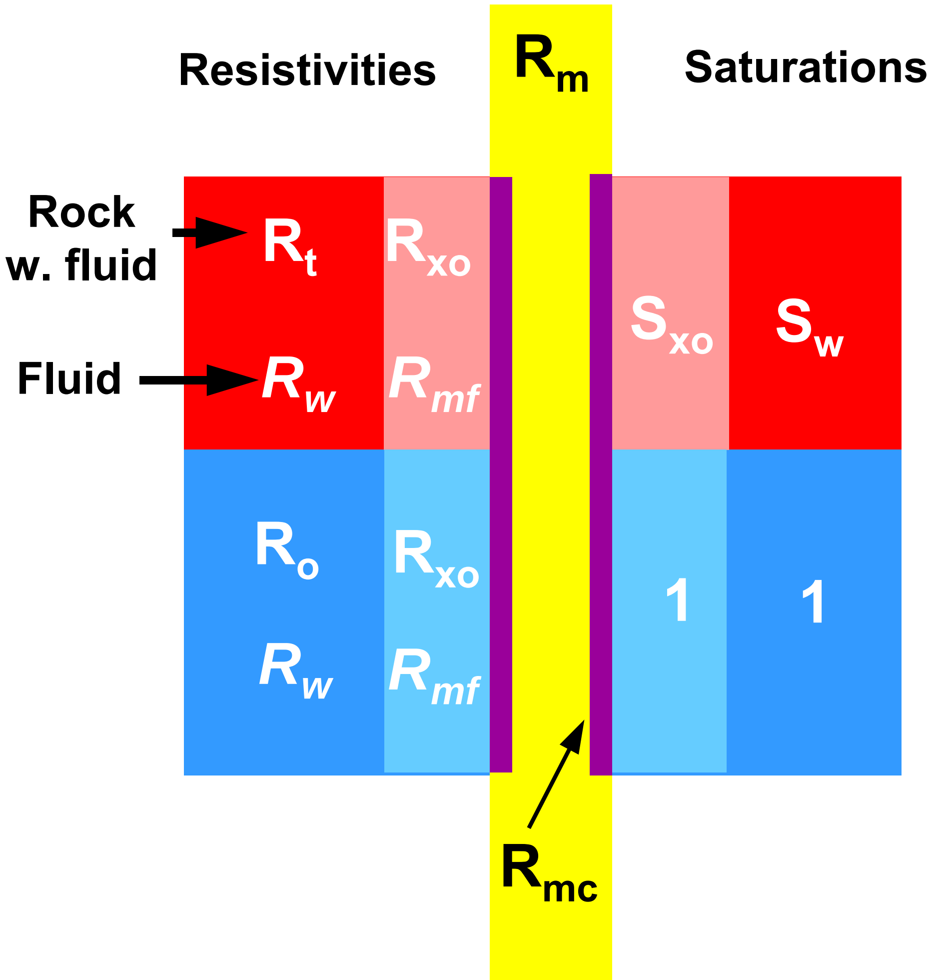


Figure 9 - Invaded Zone and Virgin Zone (nomenclature)

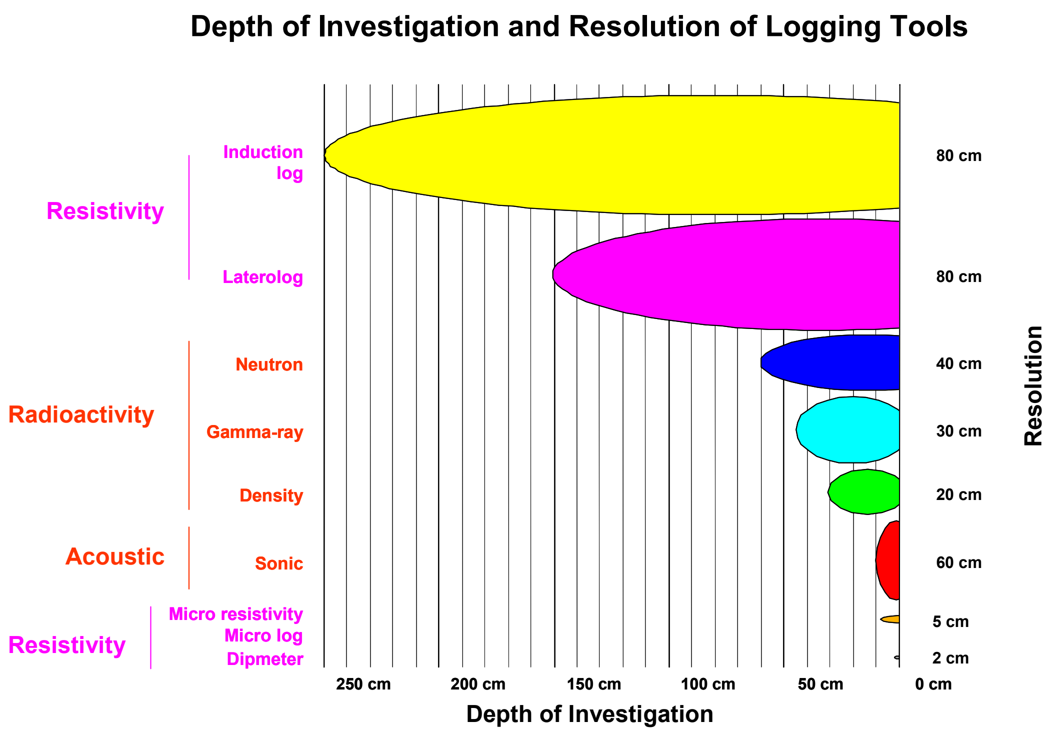


Figure 10 - Logging Tools: Investigation Depths vs. Resolution

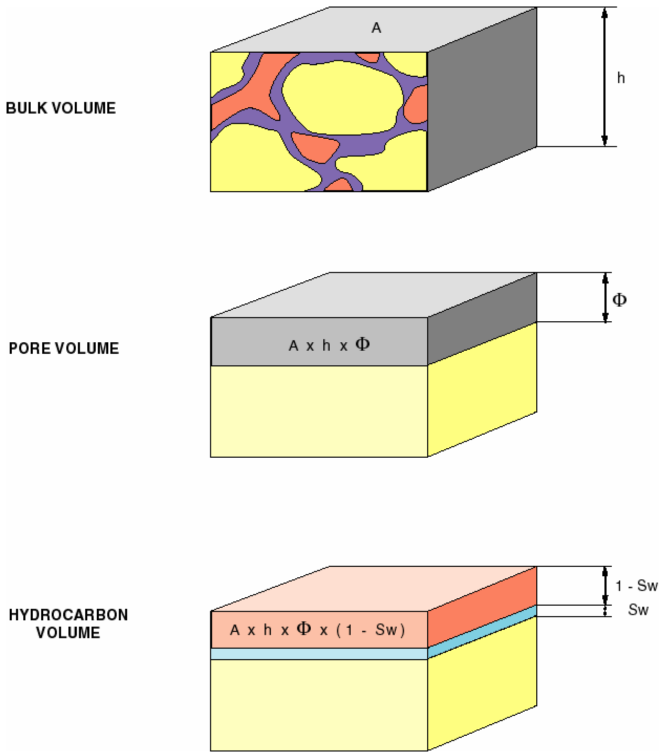


Figure 11 - Volume of Hydrocarbons In Place

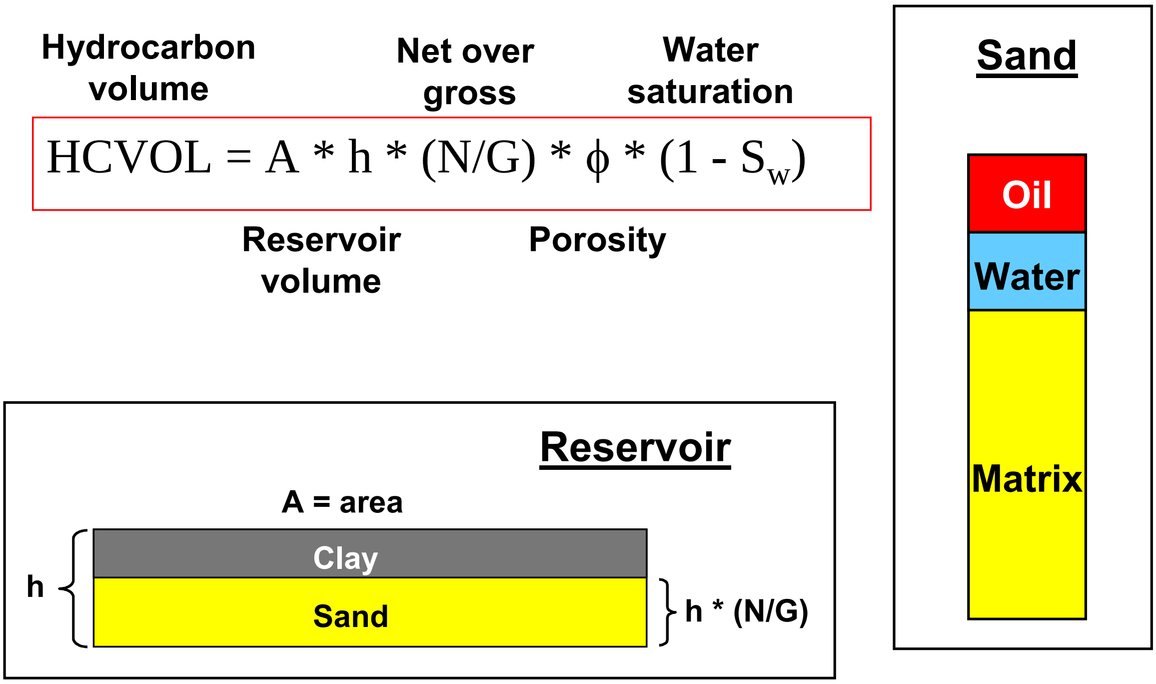


Figure 12 - Hydrocarbon Volume

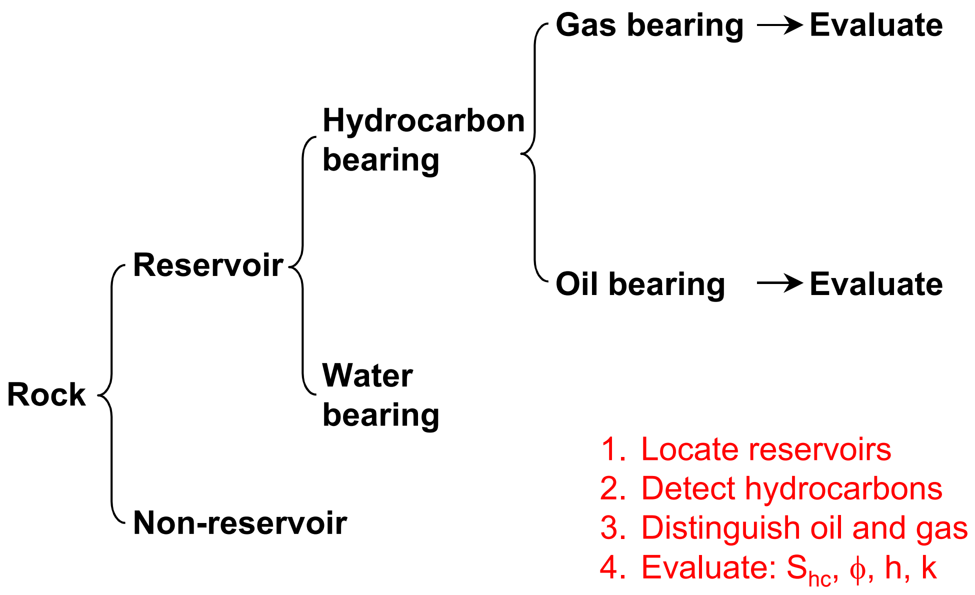


Figure 13 - Basic Petrophysical Evaluation Steps

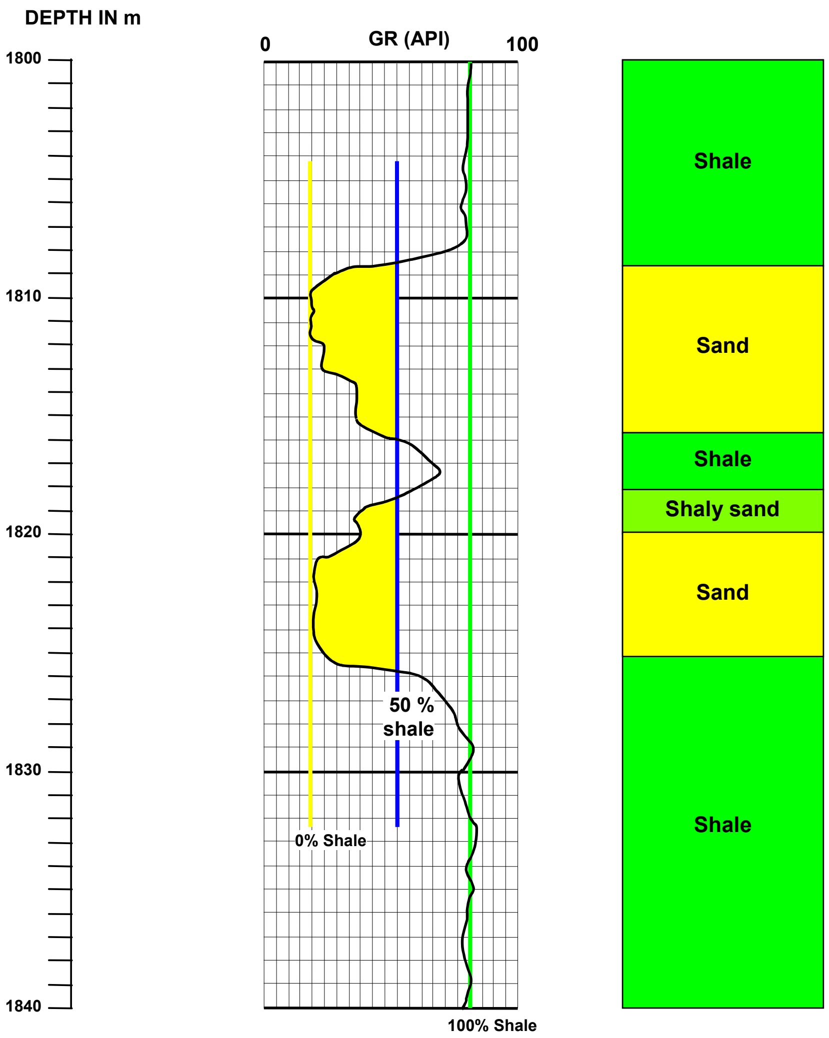


Figure 14 - GR Interpretation in a Sand-Shale Sequence

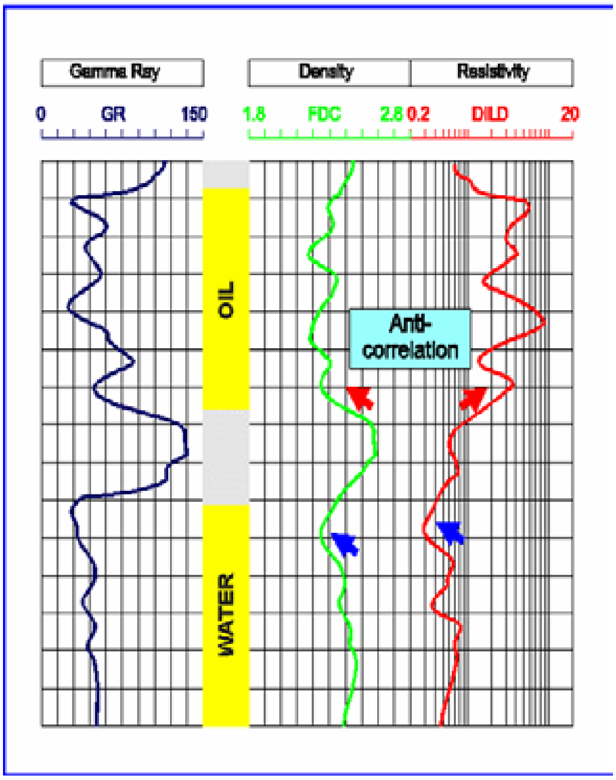


Figure 15 - Hydrocarbon Effect

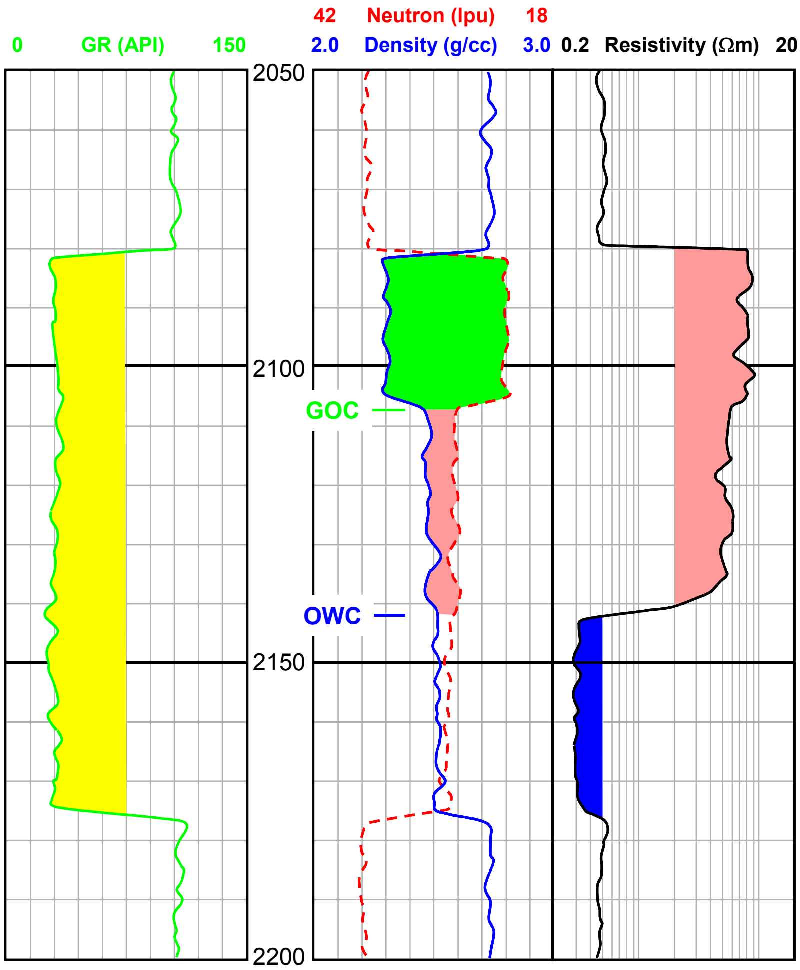


Figure 16 - Quicklook Evaluation

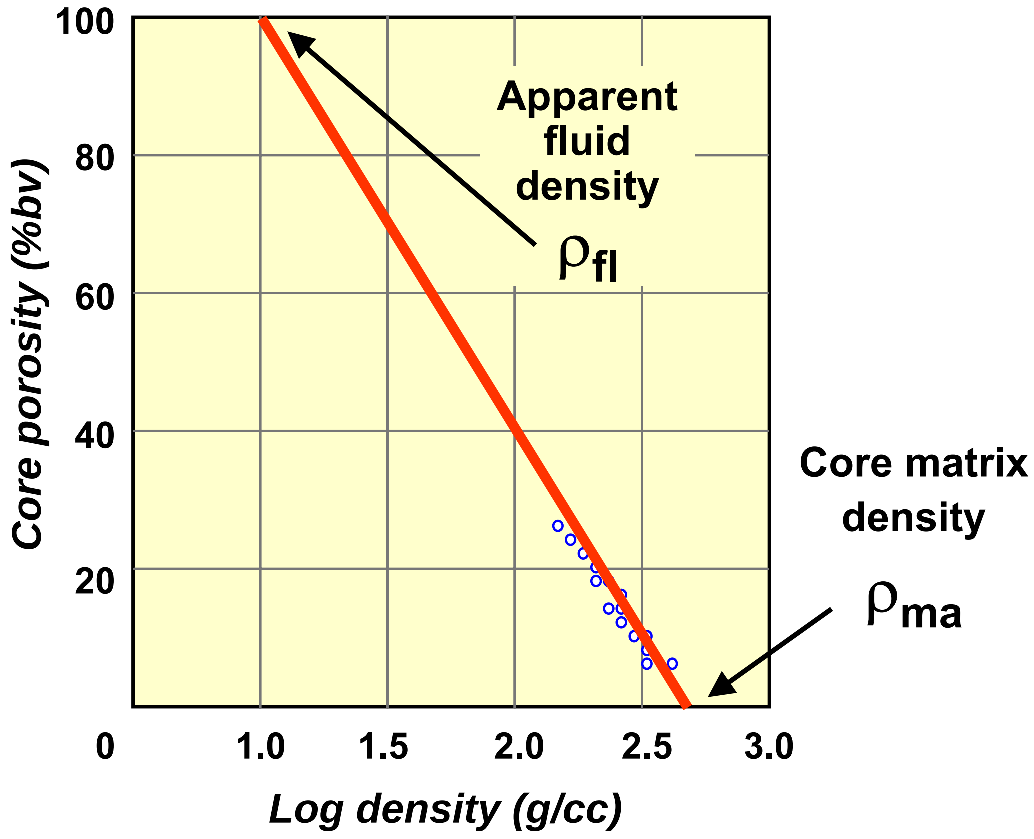


Figure 17 - Core Porosity Calibration

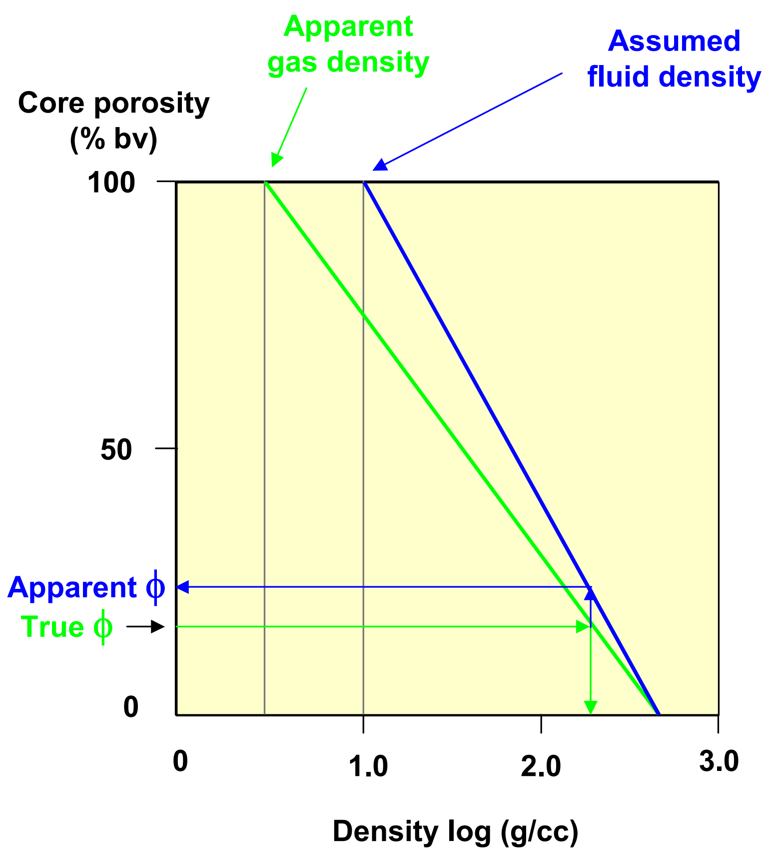


Figure 18 - Gas Effect on Density Porosity

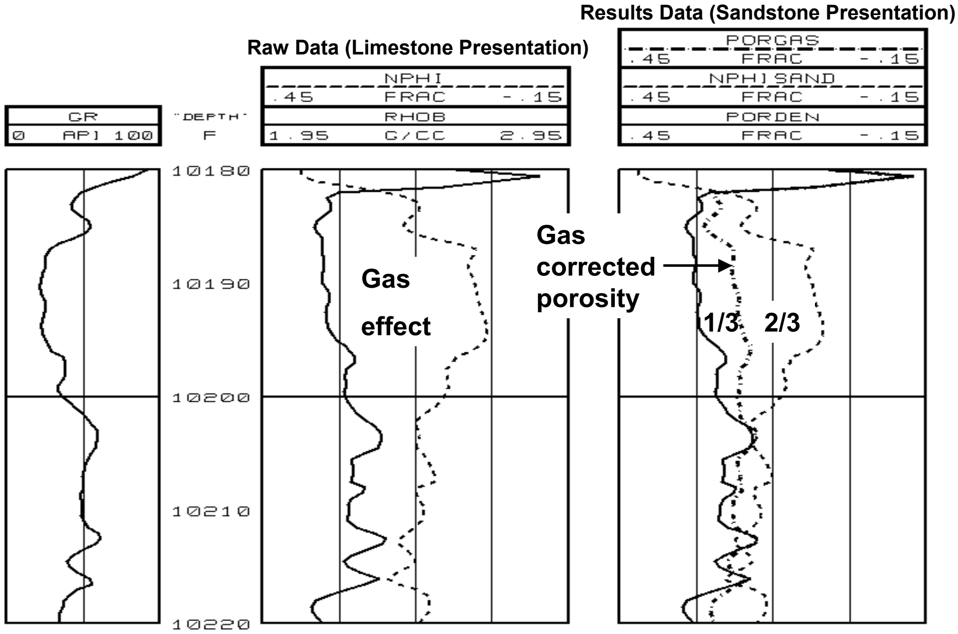


Figure 19 - Quicklook Porosity Determination in Gas Bearing Zones

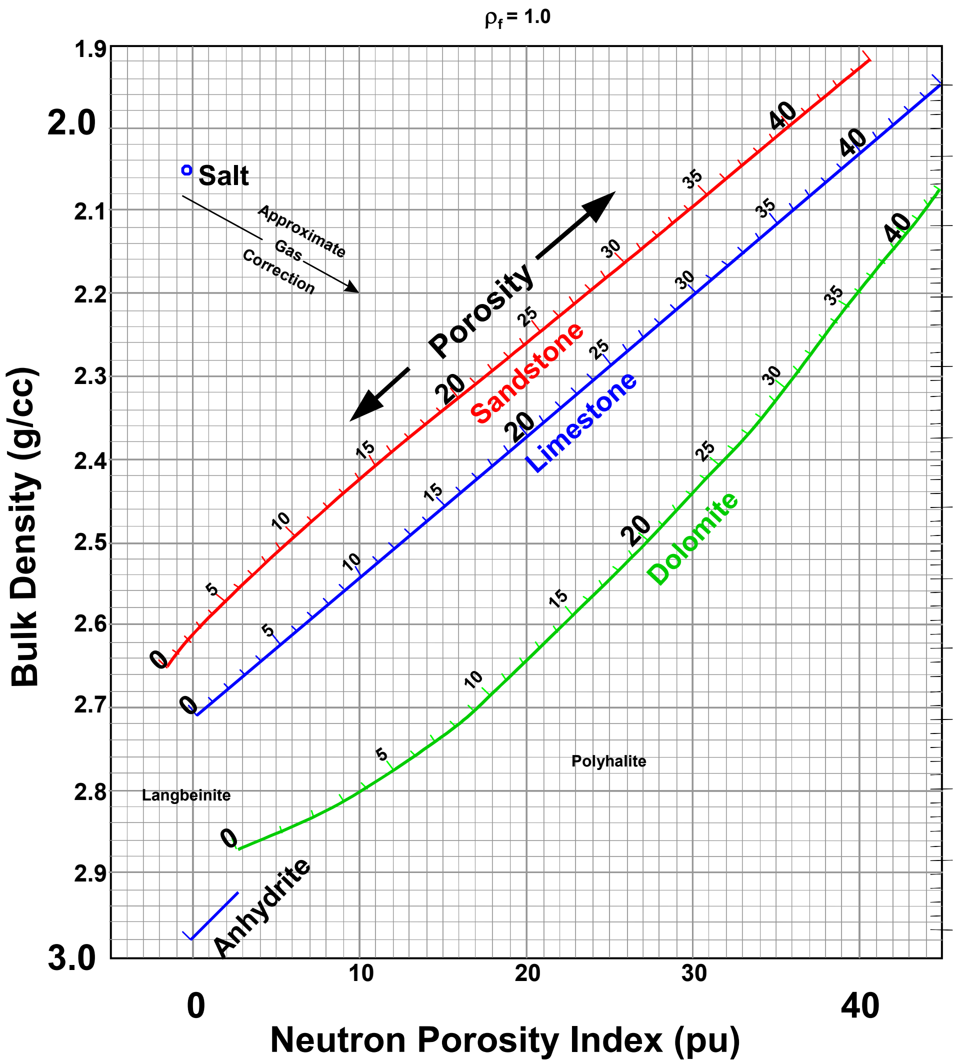


Figure 20 - Neutron / Density X-plot

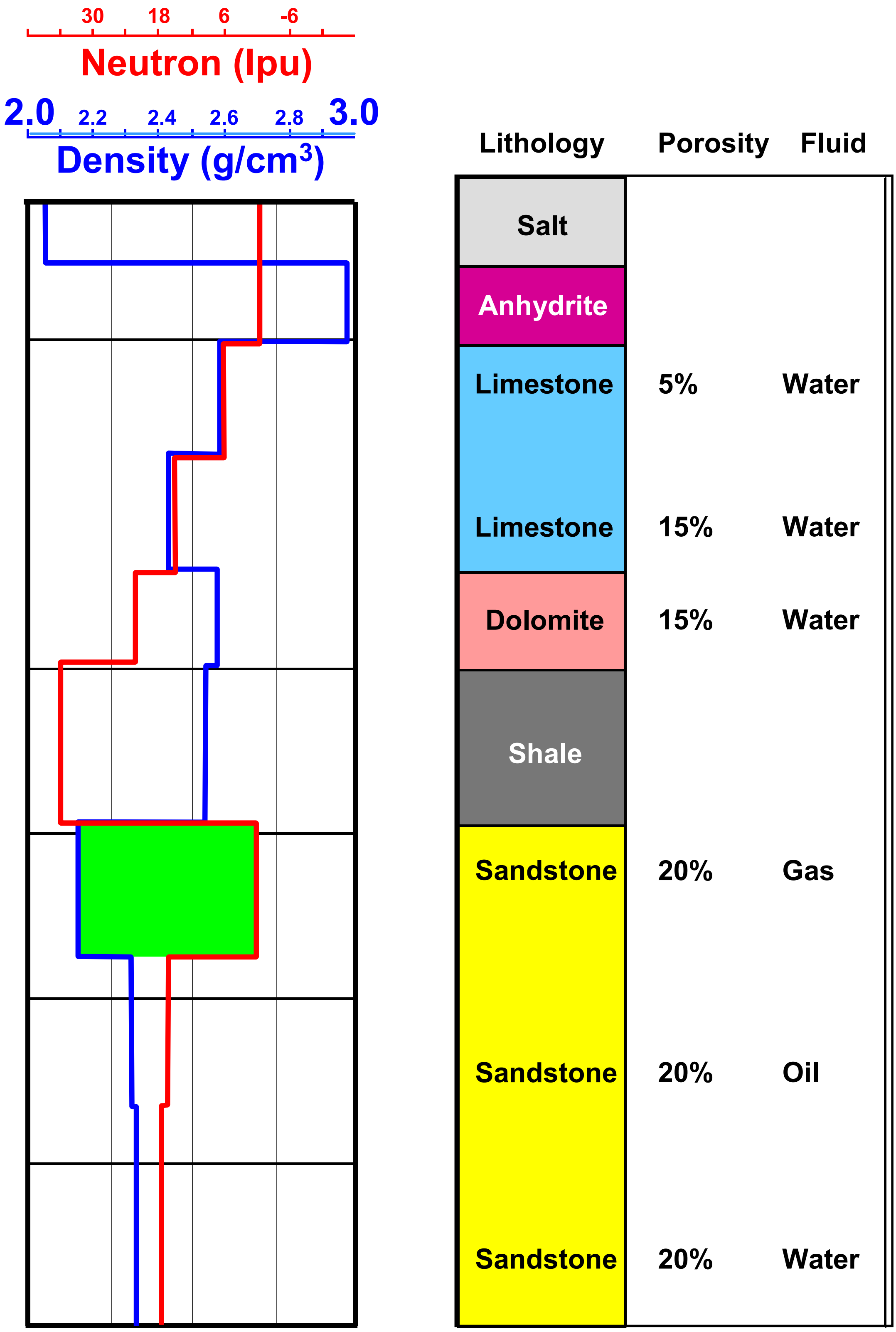


Figure 21 - Density/Neutron Response in Various Lithologies

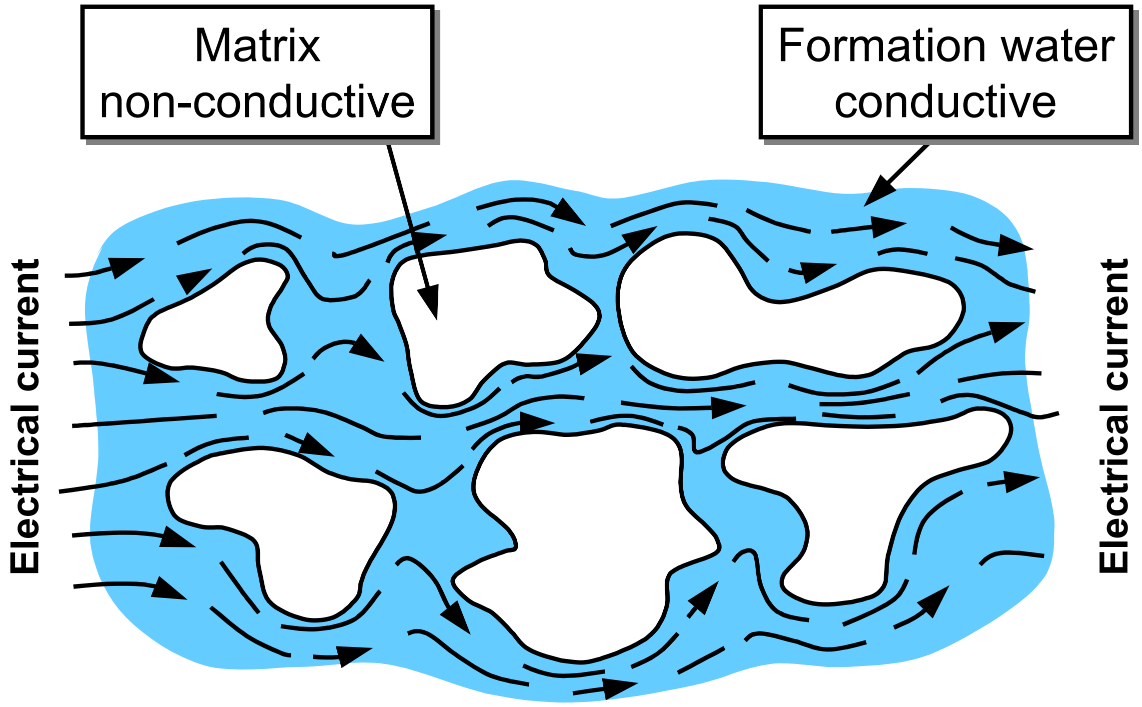


Figure 22 - Current Path Through Clean (non-shaly) Porous Rock

$$\boxed{F = R_o / R_w = \phi^{-m}}$$

F = Formation resistivity factor (FRF)
R_o = Resistivity of 100 % brine saturated rock
R_w = Brine resistivity (Ωm)
ϕ = Porosity
m = Cementation factor

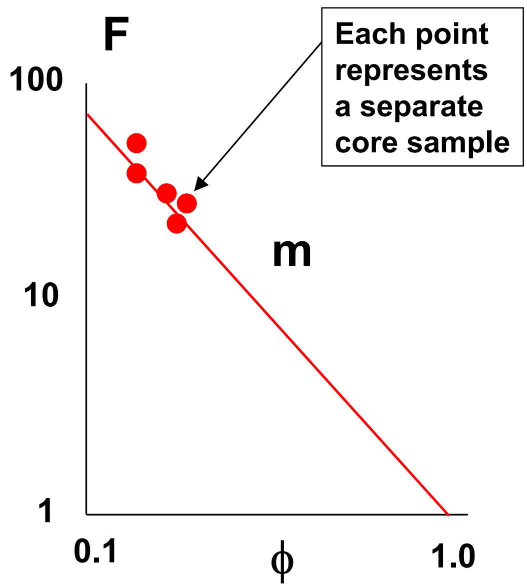


Figure 23 - First ARCHIE Equation: fully water-bearing rock

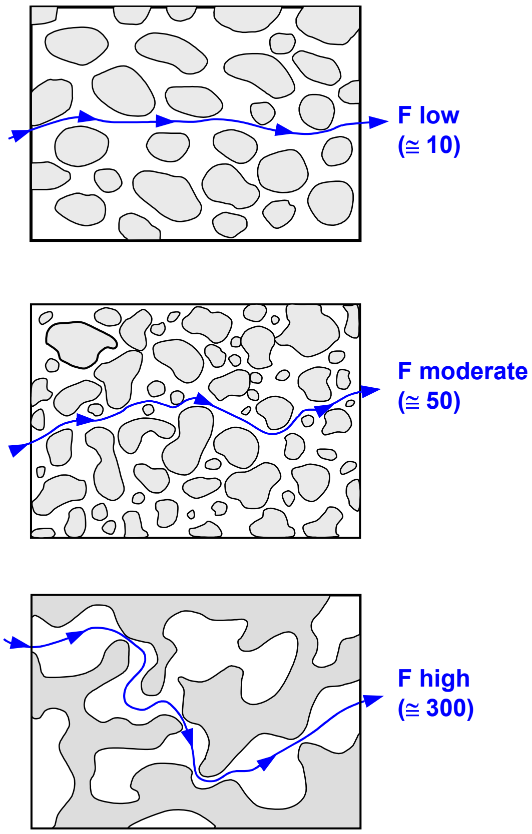


Figure 24 - Influence of pore structure on FRF

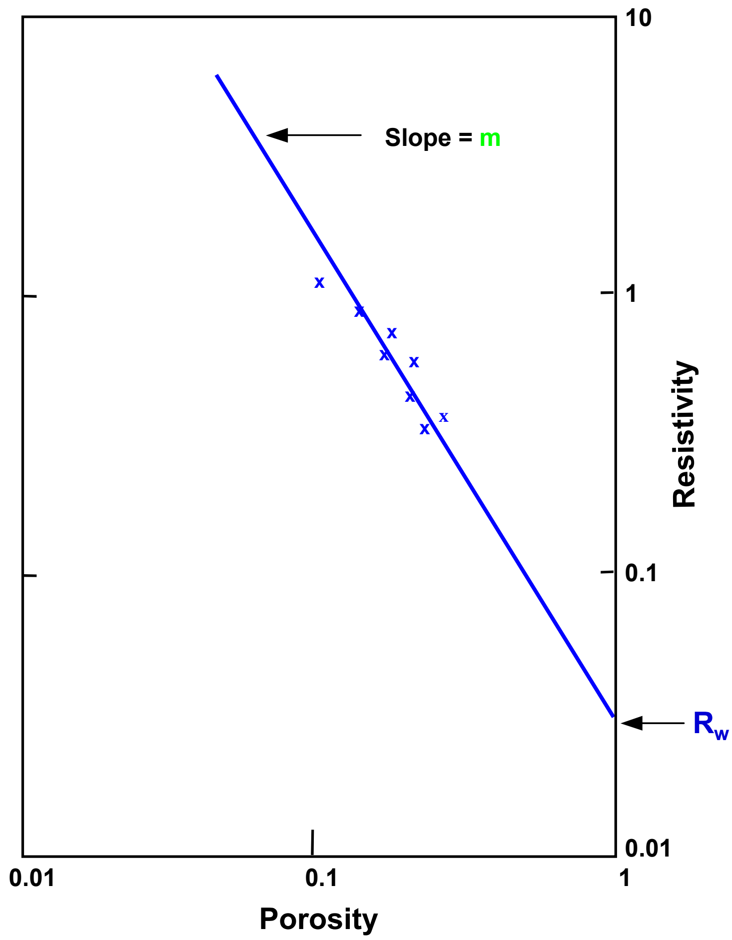


Figure 25 - "Pickett" Plot

$$\boxed{I = R_t / R_o = S_w^{-n}}$$

I	=	Resistivity index
R_t	=	Resistivity of partly brine saturated rock
R_o	=	Resistivity of fully brine saturated rock
S_w	=	Water saturation
n	=	Saturation exponent

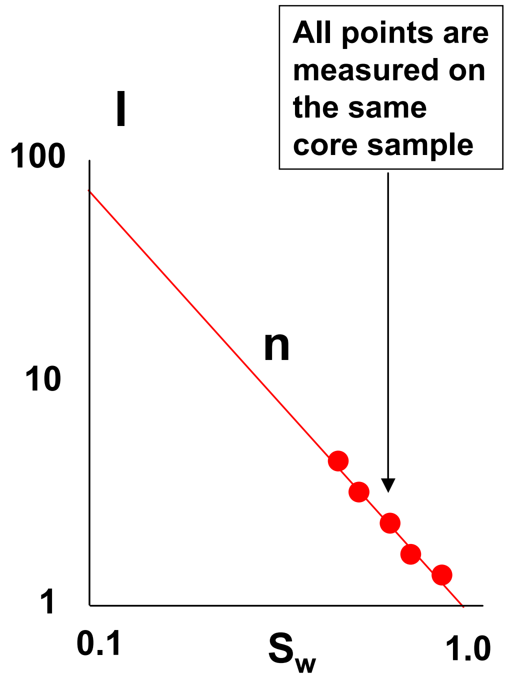


Figure 26 - Second ARCHIE Equation: partly water (hydrocarbon) bearing rock

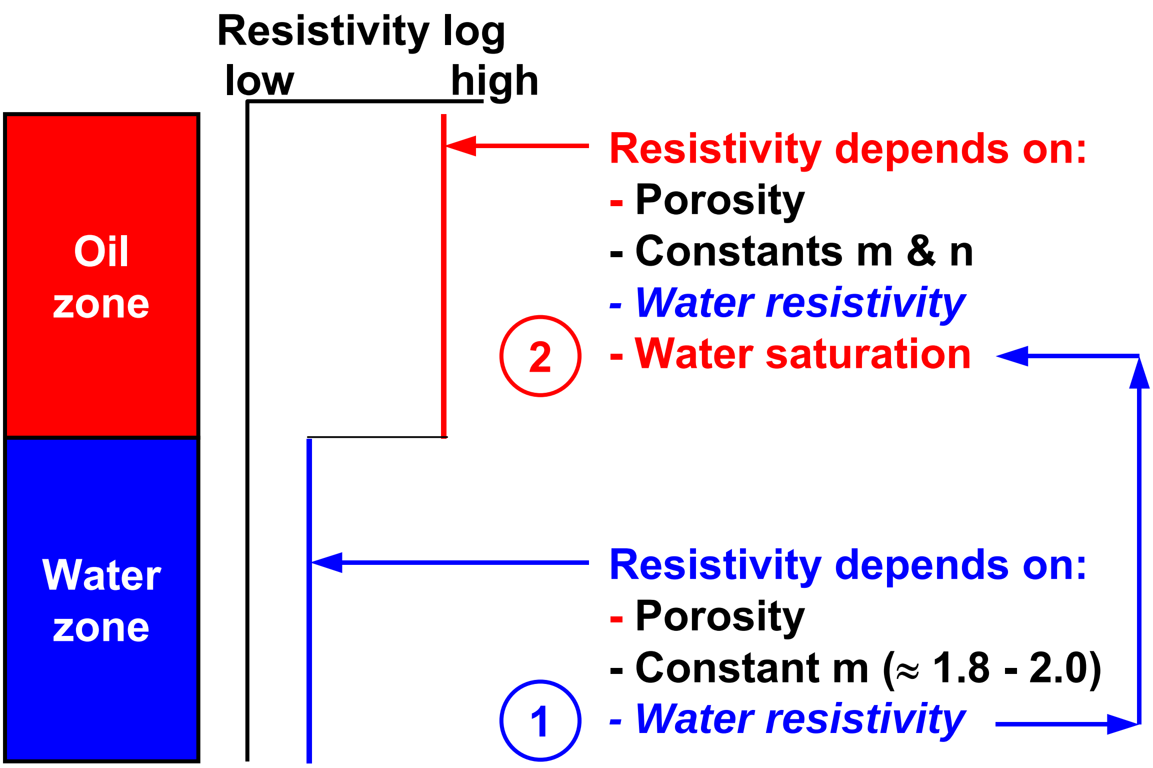


Figure 27 - Water Saturation from Resistivity Logs

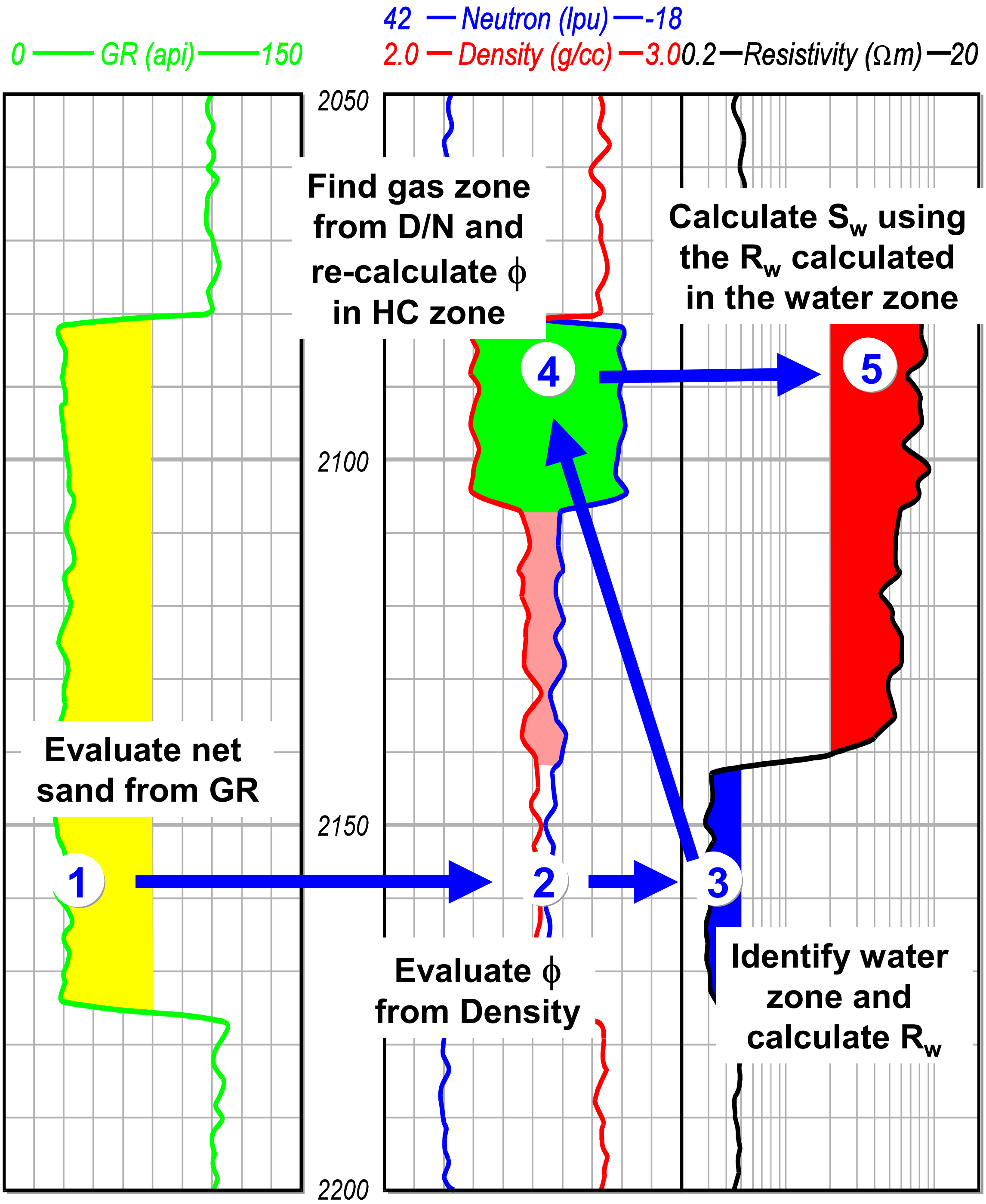


Figure 28 - Quicklook Evaluation Steps

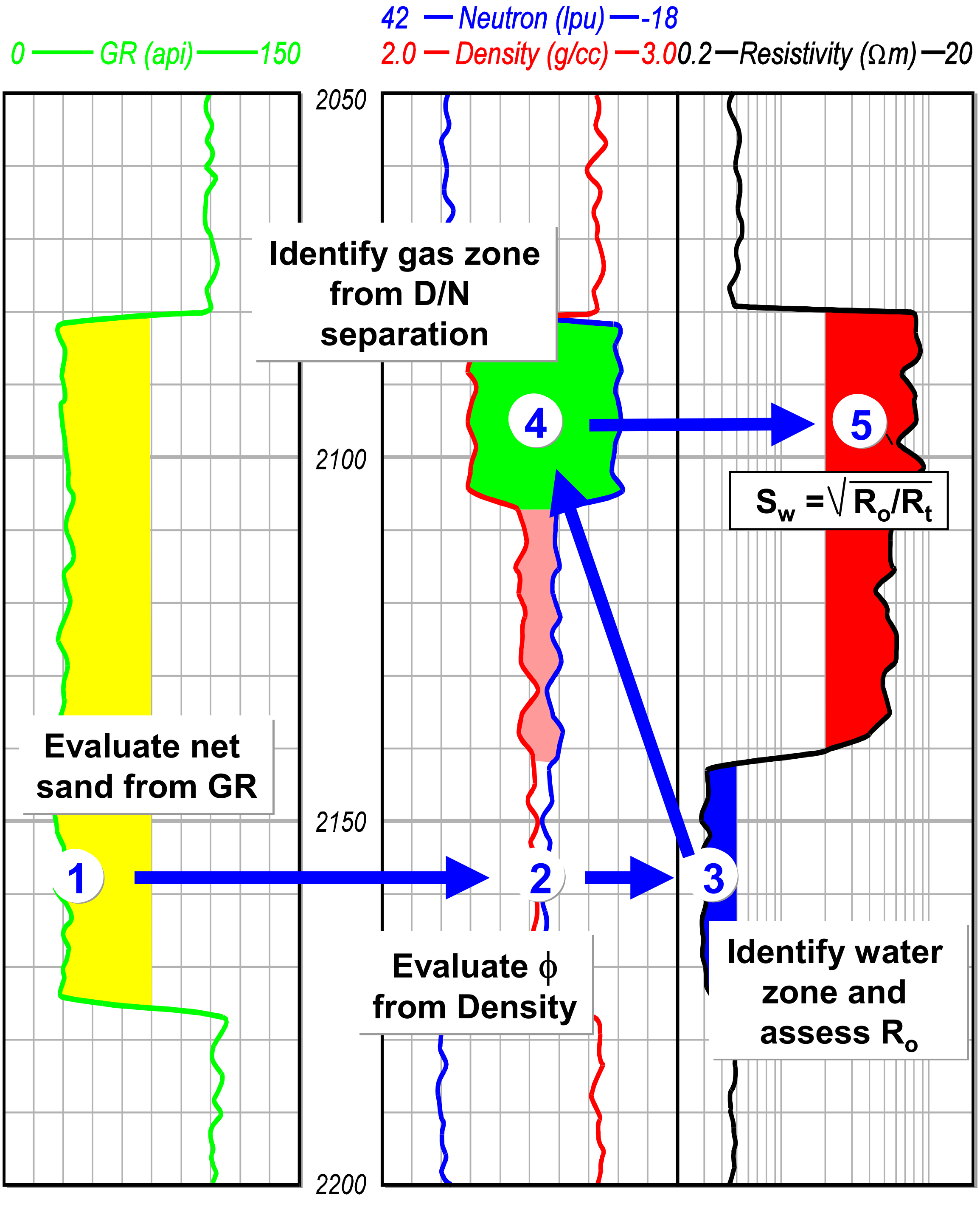


Figure 29 - Quicklook Evaluation Steps – Simplified Procedure

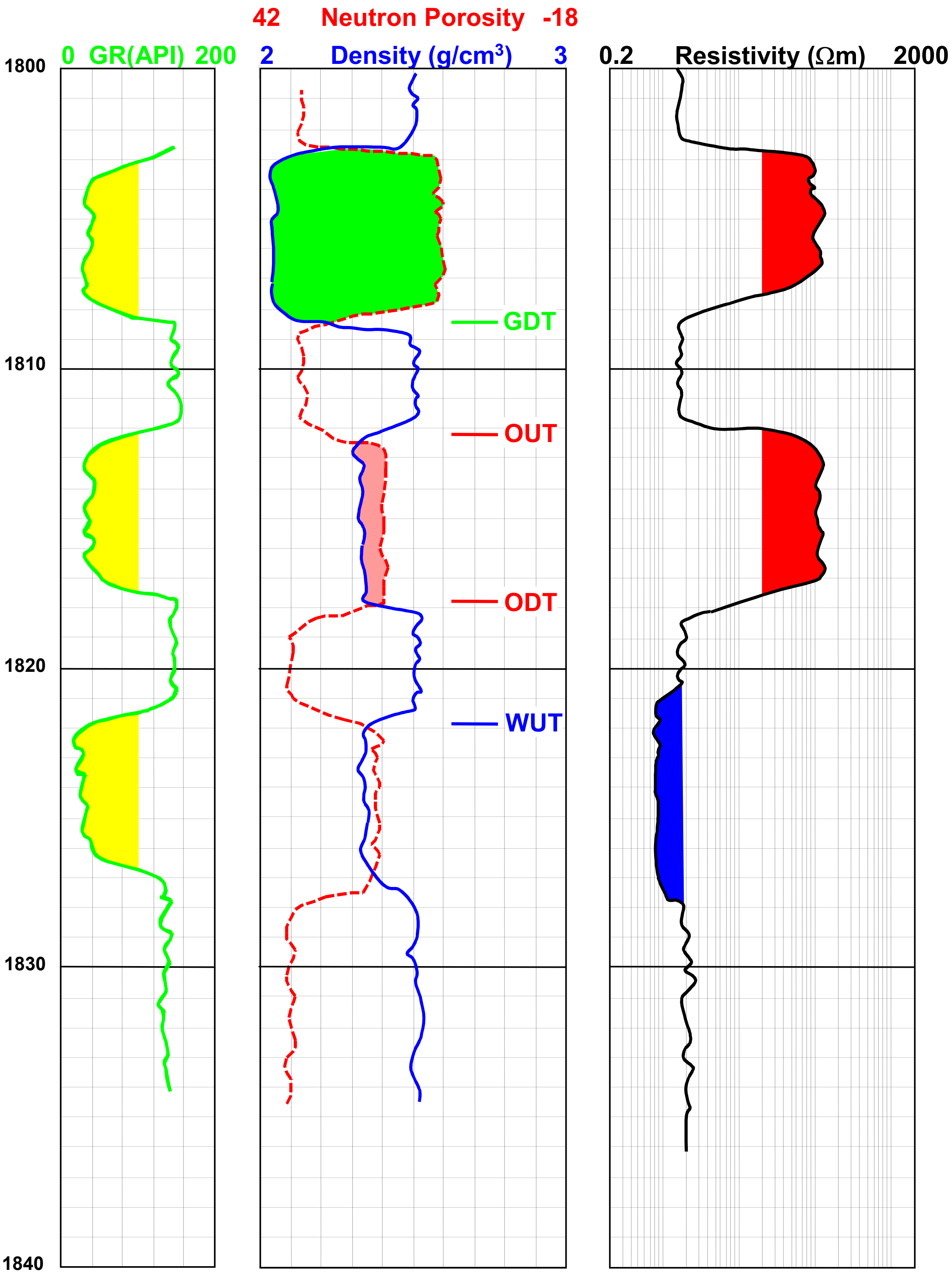


Figure 30 - Uncertain Fluid Contacts