Formation Evaluation In a Nutshell

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Contents

- What are well logs
- Why do we run logs
- The essential logs
  - Gamma Ray Log
  - Porosity Log
  - Resistivity Log
- Water saturation calculation
- Summary
- Conclusions

What Are Well Logs

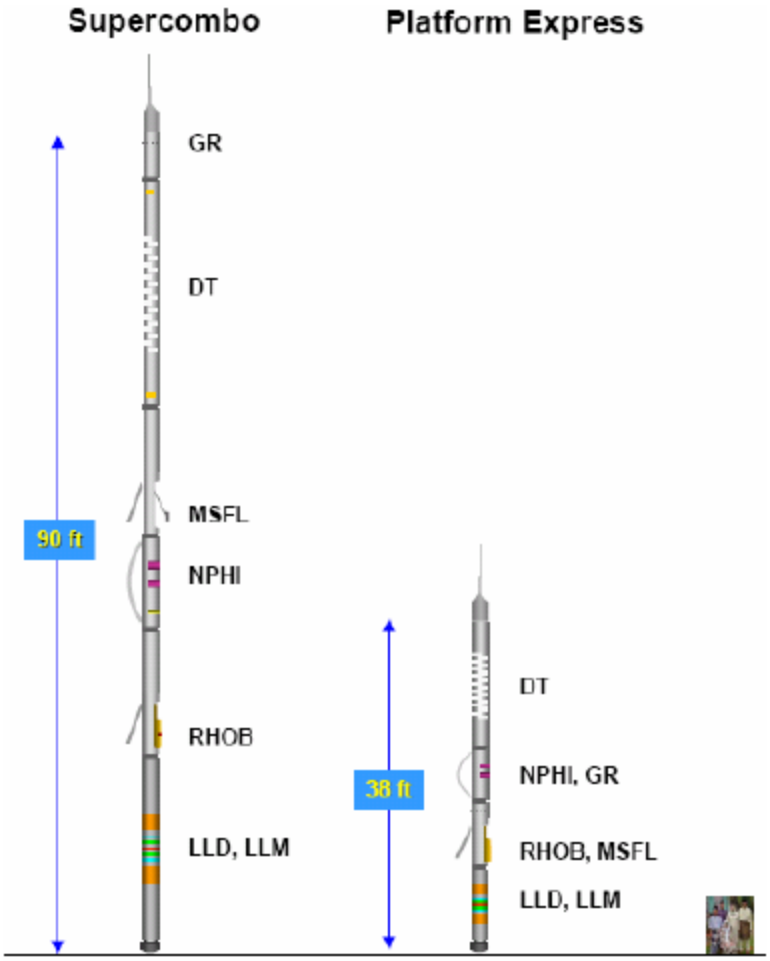
- Data recordings of formation rock properties
- Continuously recorded versus well depth
- Measured by logging tools lowered into the well
- Conveyed by electric cable (called Wireline Logging)
- Conveyed by drill pipes (TLC/PCL Logs)
- Recorded during drilling (called Logging While Drilling)
- Recorded by means of resistivity, nuclear, acoustic or magnetic measuring devices

Types of Well Logs

Two main types of well logs

- **Open hole logs**
  - Well logs run inside a well while the formation is still exposed or open
- **Cased hole logs**
  - Well logs run inside a casing or tubing, mainly for production/injection profiling and reservoir monitoring purposes
  - Casing and cement evaluation logs, corrosion monitoring logs

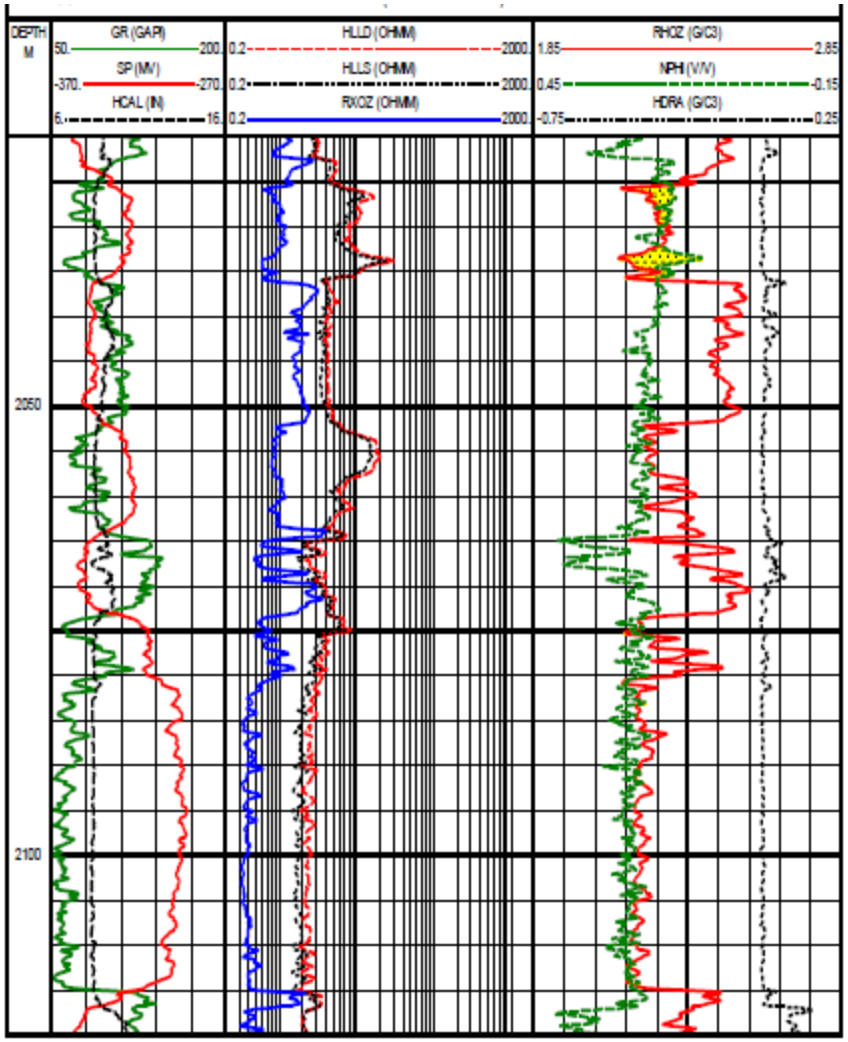
Typical Logging Tools



Comparison between the standard supercombo (triple combo) logging tools and the PEX (Platform Express) logging tools

Shorter tool length means less rat hole required

Less tool components means shorter rig up and rig down time

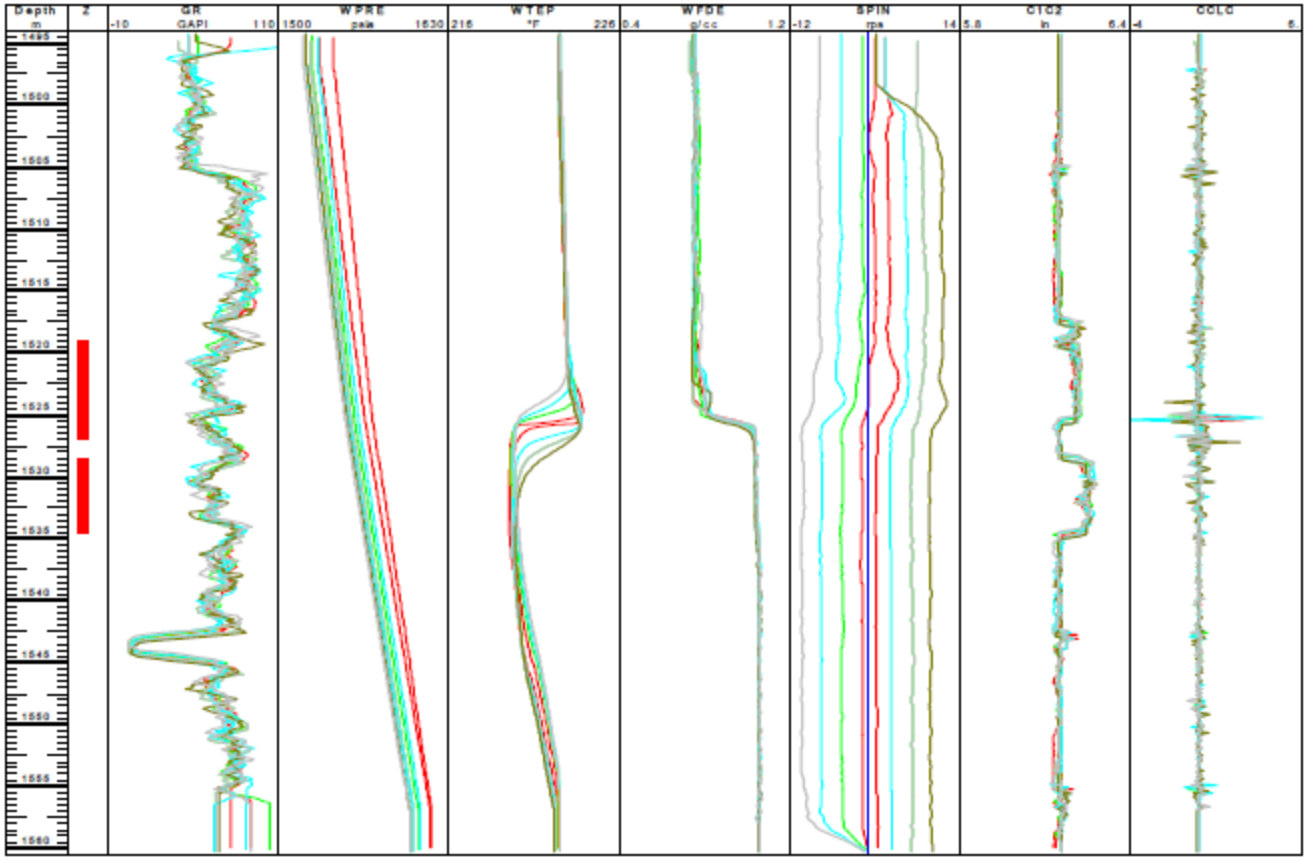


Well Log Example

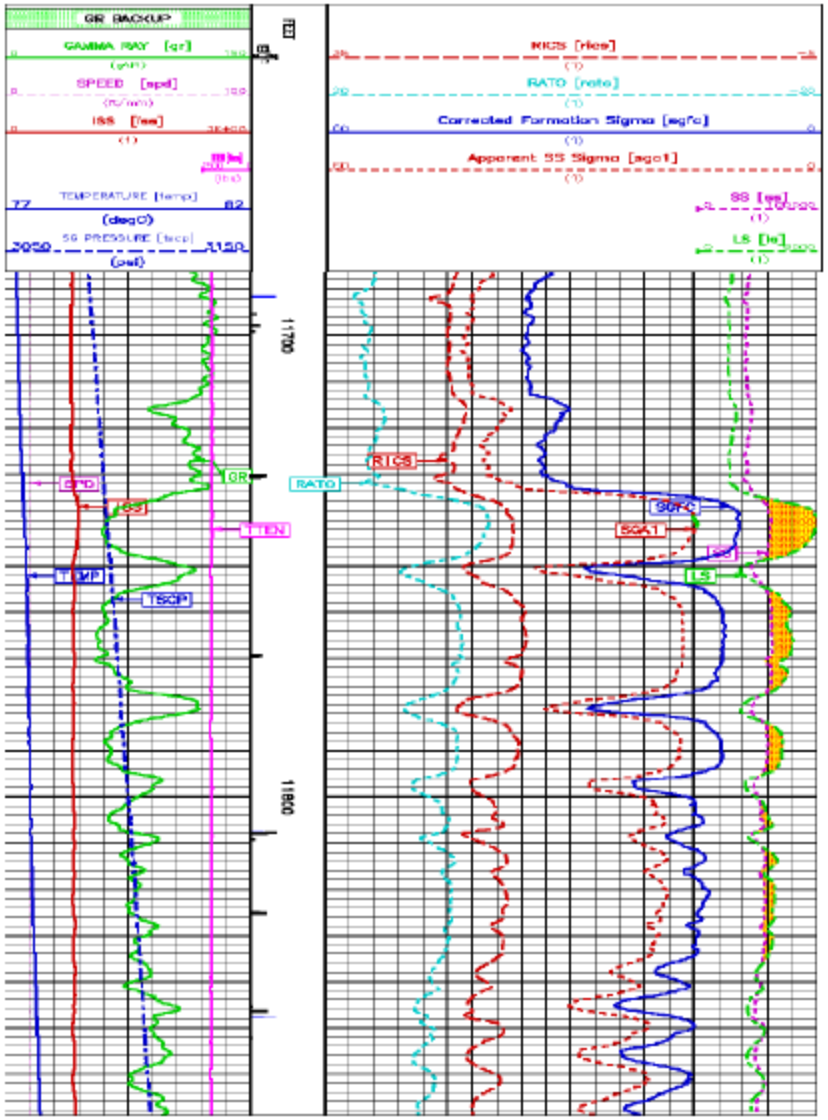
Open hole logs

- Gamma Ray
- Spontaneous potential
- Caliper
- Resistivity
- Bulk Density
- Neutron Porosity

Cased Hole Log Example

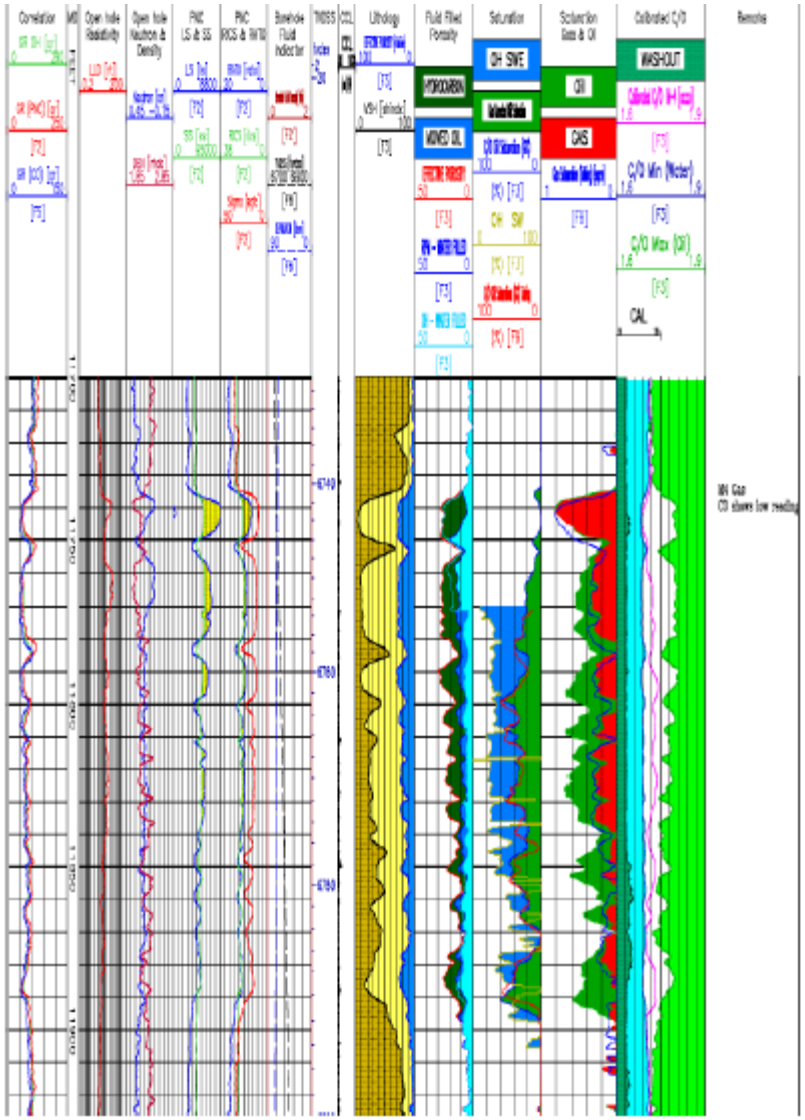


Production logs



Cased Hole Logs (Pulse Neutron Capture/Sigma) Raw Logs

- Mainly used for reservoir monitoring purposes
- Measures neutron capture cross section (Sigma Σ) of the formation
- Measures the ratio of carbon and oxygen molecules in the formation
- Used to identify fluid contacts



Cased Hole Logs

Carbon-Oxygen & PNC Interpreted Results

Carbon/Oxygen ratio is low in the M4 sand, indicating that it is gas bearing

GOC identified at 11798 ftMDDF (6777 ftTVDSS)

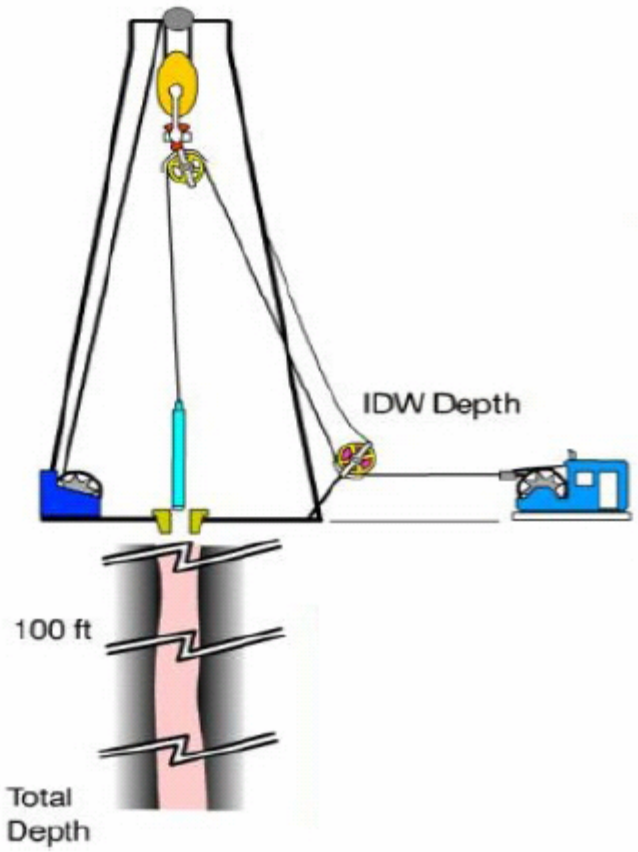
Methods of Tool Conveyance

- Wireline conveyed logging
- Drill pipe conveyed logging (TLC/PCL)
- Logging While Drilling (LWD)
- Coiled tubing conveyed logging
- Slick line (piano wire) conveyed logging

Modes of Well Logging

Wireline Logging

Wireline Logging Rig-up



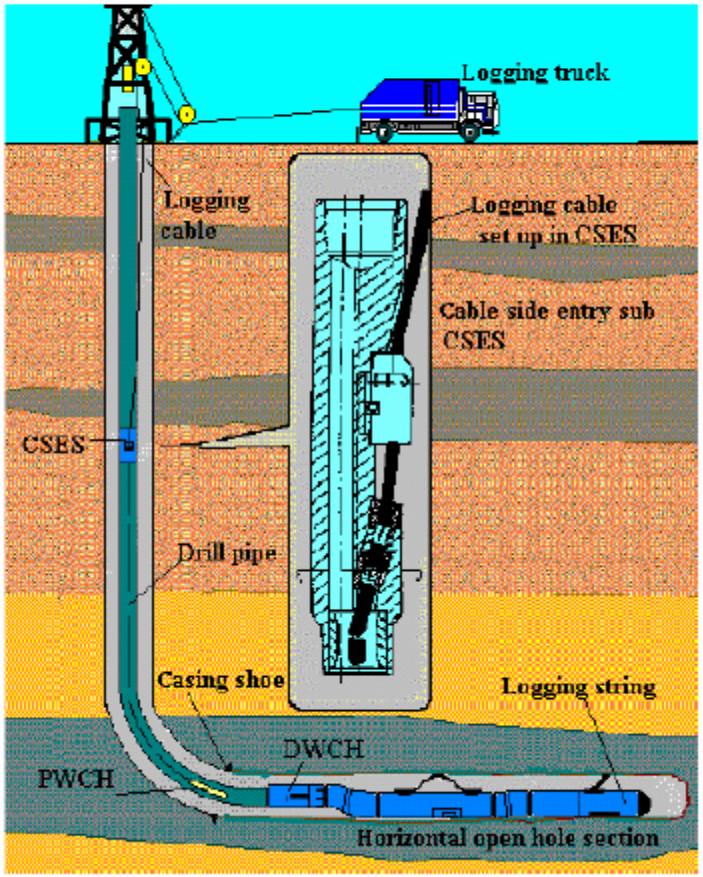
Well logging tools are lowered into the well by means of an electric cable attached to the head of the tool string.

Power and tool commands are sent downwards and data is transmitted upwards, by means of a telemetry sub.

IDW (Integrated Depth Wheel) measures the length of cable lowered into the well, thus providing depth measurement

Pipe Conveyed Logging System

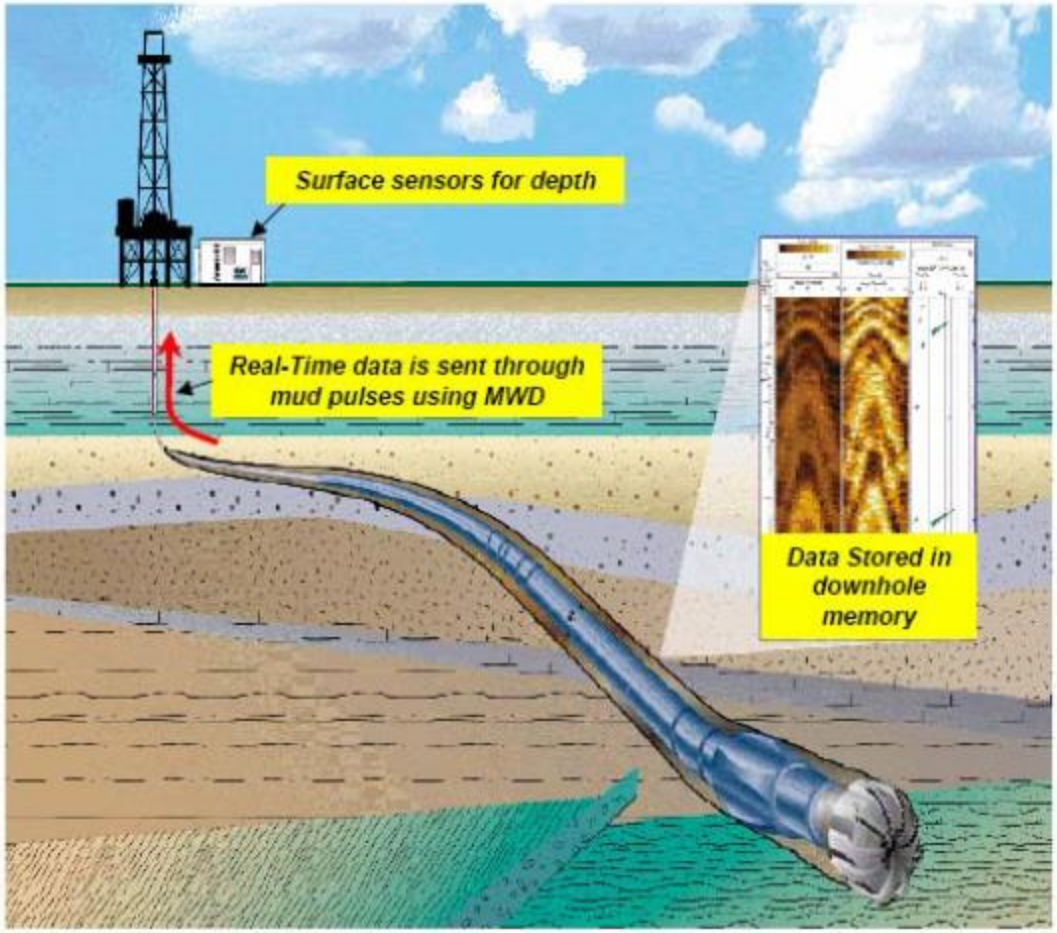
Tough Logging Conditions (TLC) System



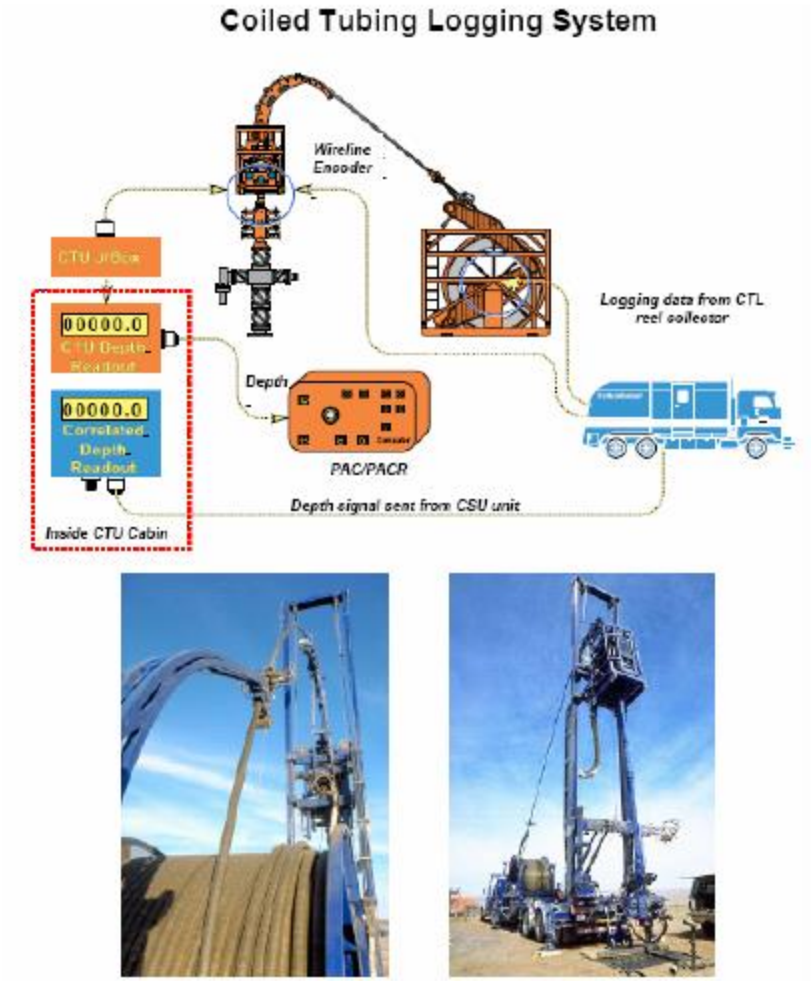
Normal wireline logging tools are attached to the drill pipe by means of a "side-entry sub" and lowered into the well.

Pipe Conveyed Logging System is used in wells where the logging tools cannot be lowered into the well using a logging cable, due to hole conditions.

Logging While Drilling LWD



Coiled Tubing Conveyance



Logging tools, usually cased hole logging tools, can be attached to the end of a coiled tubing and lowered into the well.

A special coiled tubing, with an electric cable inside, is required to transmit power and data to and from the logging tools.

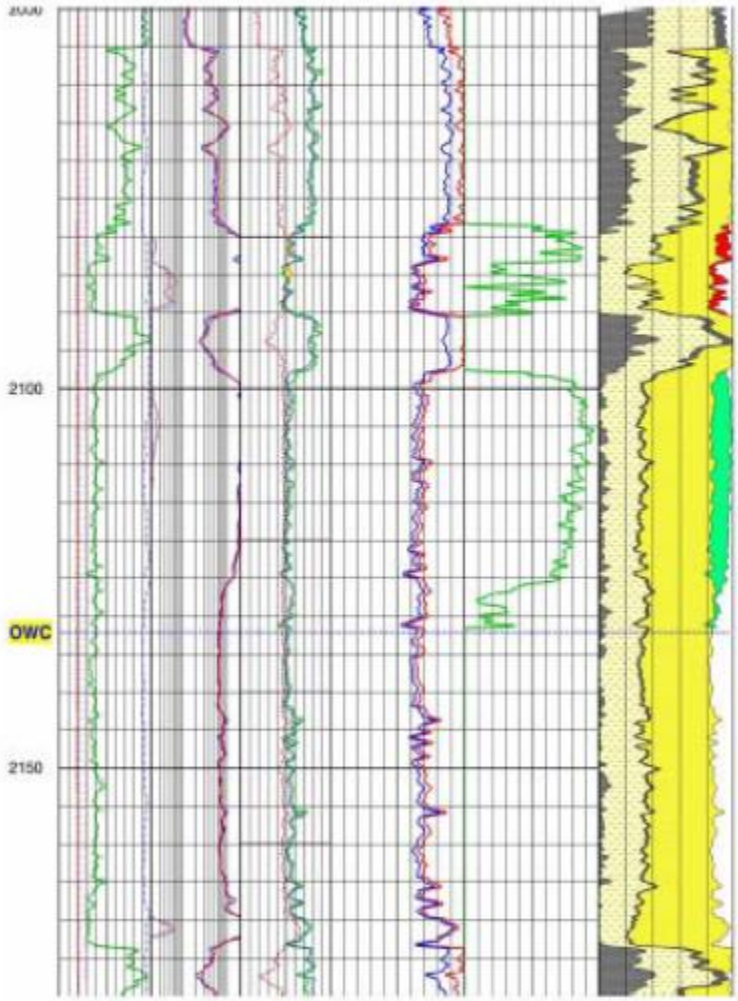
Why Do We Run Logs

To derive input parameters for calculating hydrocarbon volumes as follows:

$$HCIIP = GRV \times N/G \times \Phi \times S_h \times 1/FVF$$

GRV = Gross Rock Volume
N/G = Net to Gross Ratio
Φ = Formation Porosity
S_h = Hydrocarbon Saturation
FVF = Formation Volume Factor (shrinkage factor)

Example of Evaluated Well Logs



The Essential Well Logs

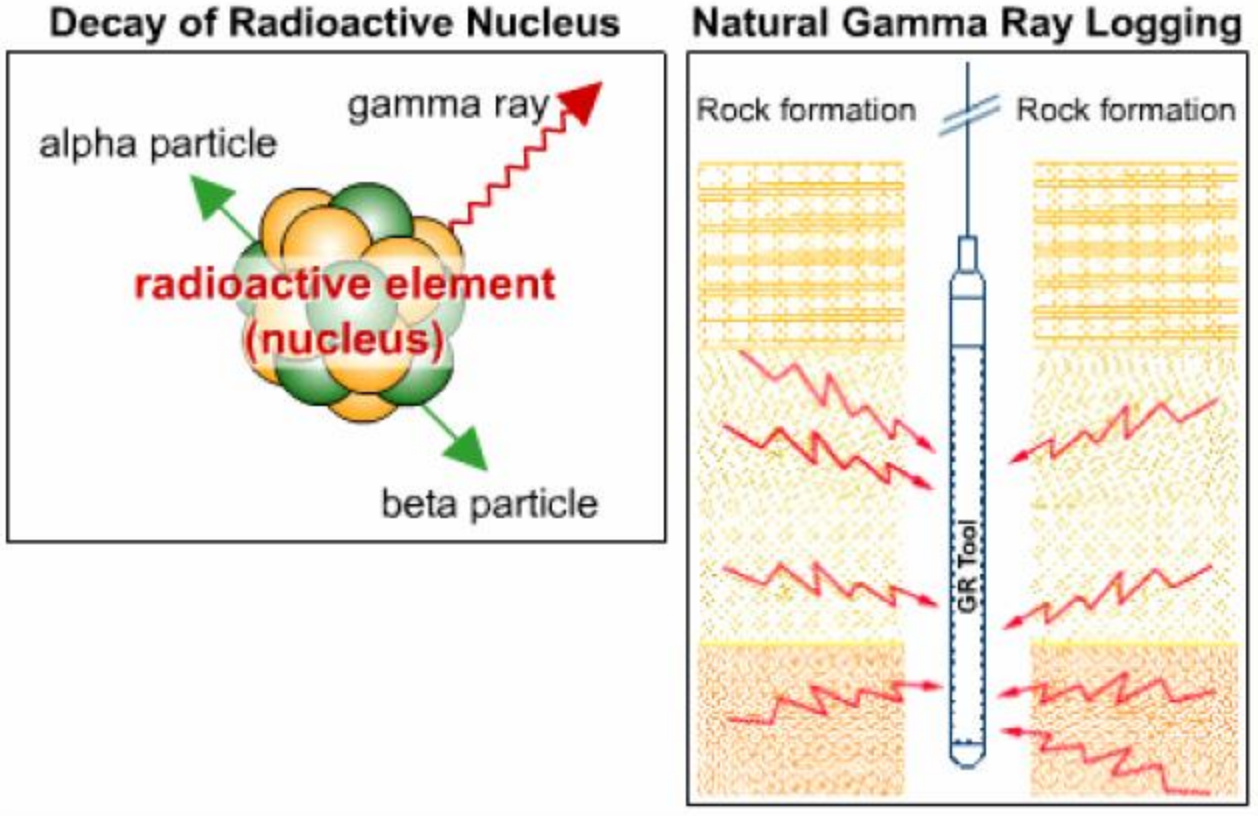
Gamma Ray logs: to differentiate reservoir rock from non-reservoir rock

Porosity logs: to determine net reservoir rock with potential to store hydrocarbons

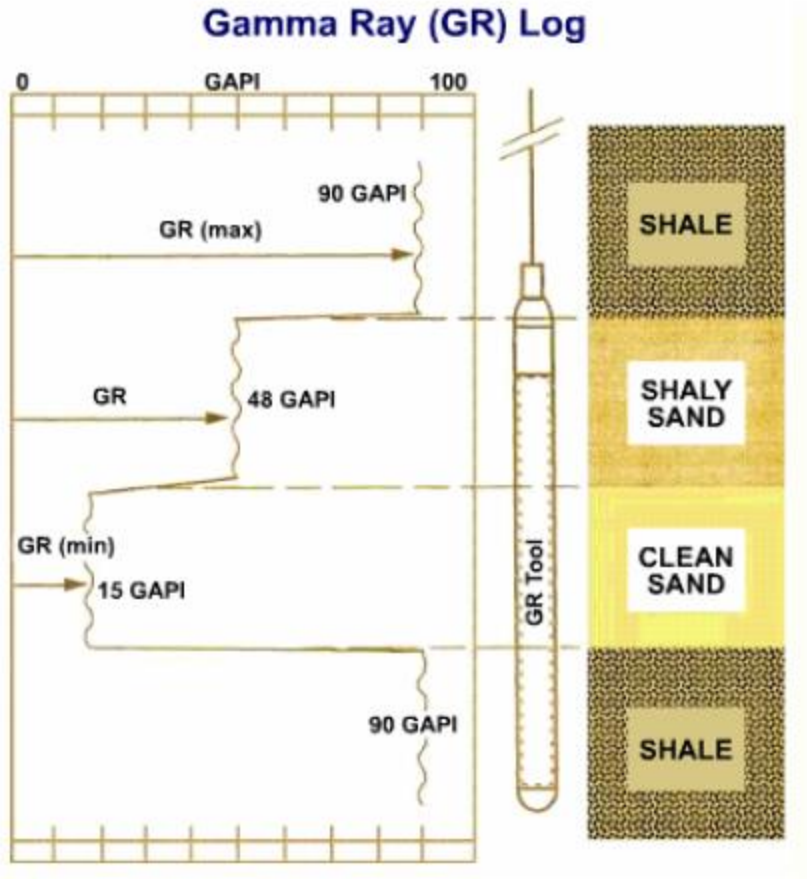
Resistivity logs: to calculate water saturation, which in turn provides hydrocarbon saturation

Gamma Ray Log

Natural Gamma Ray

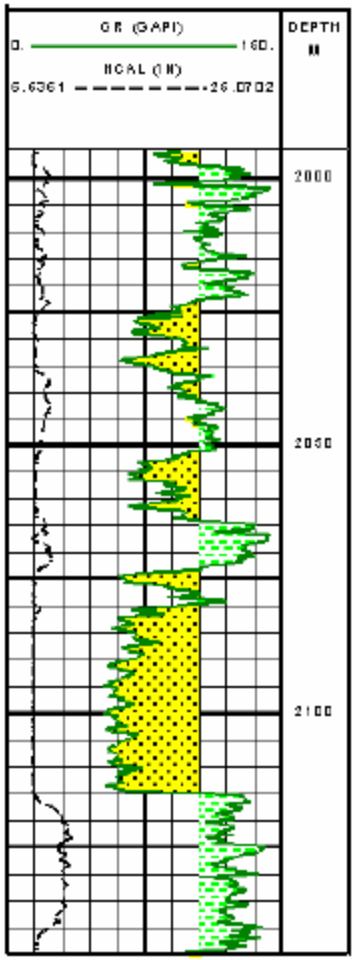


Gamma Ray Log



GR Log measures natural Gamma Rays and is used to differentiate between reservoir and non-reservoir rock

Gamma Ray Log



Gamma Ray Log is used to discriminate reservoir rock (sandstone) from non-reservoir rock (shales).

A cutoff value of 105 API has been imposed on the GR log to differentiate sands from shales.

Based on this cutoff criteria:

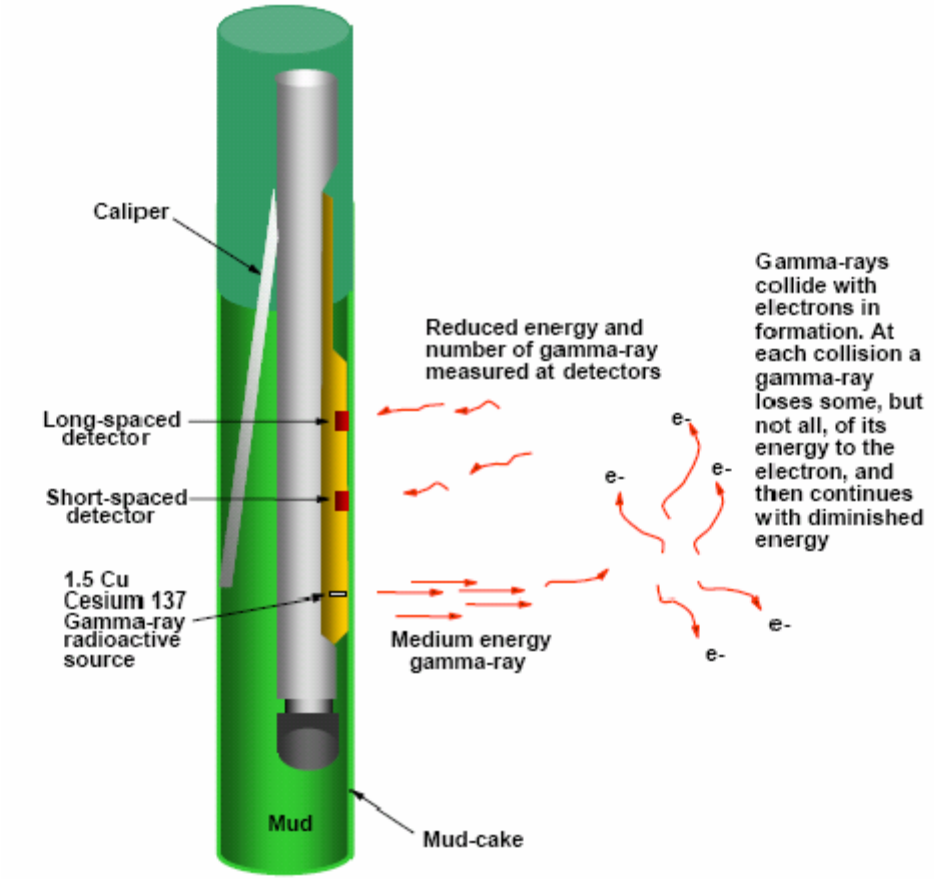
Net Sand Thickness : 65 meters

Uses of Gamma Ray Logs

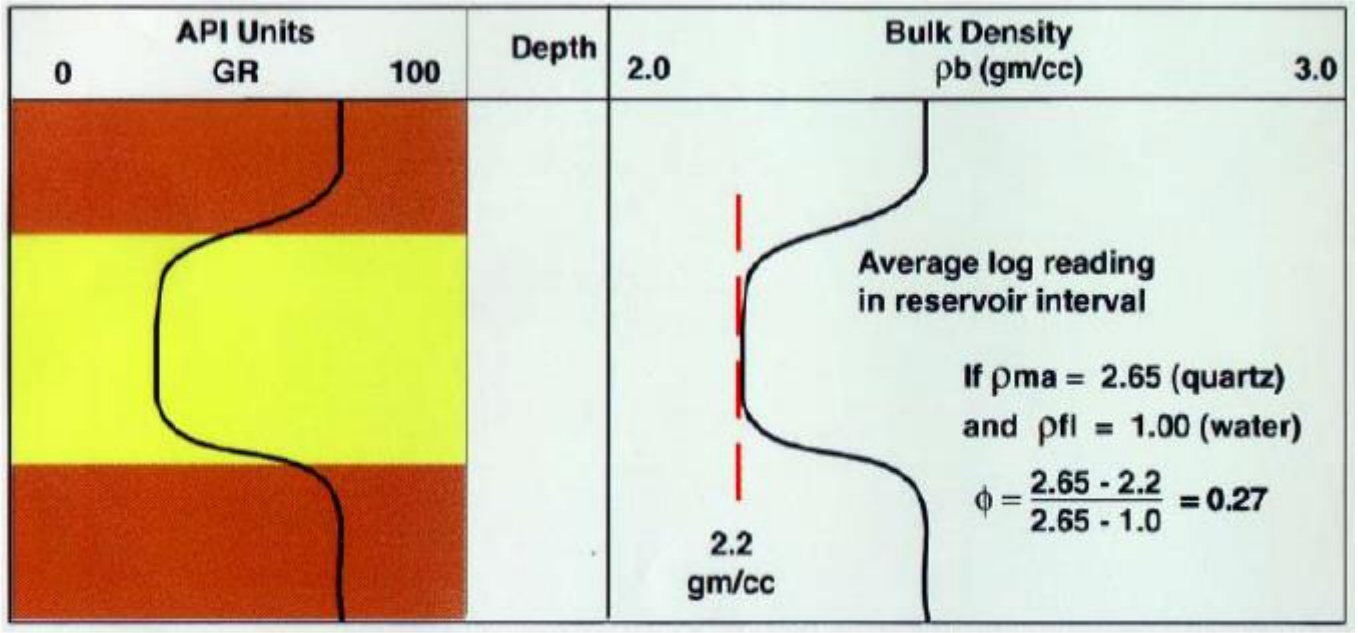
1. Discrimination between reservoir and non-reservoir rocks
2. Computation of clay content in reservoir rocks
3. Well to well correlation in a field
4. Identification of reservoir characteristics
5. Determination of depositional environment

Litho Density Tool

- How is ρ_B measured?

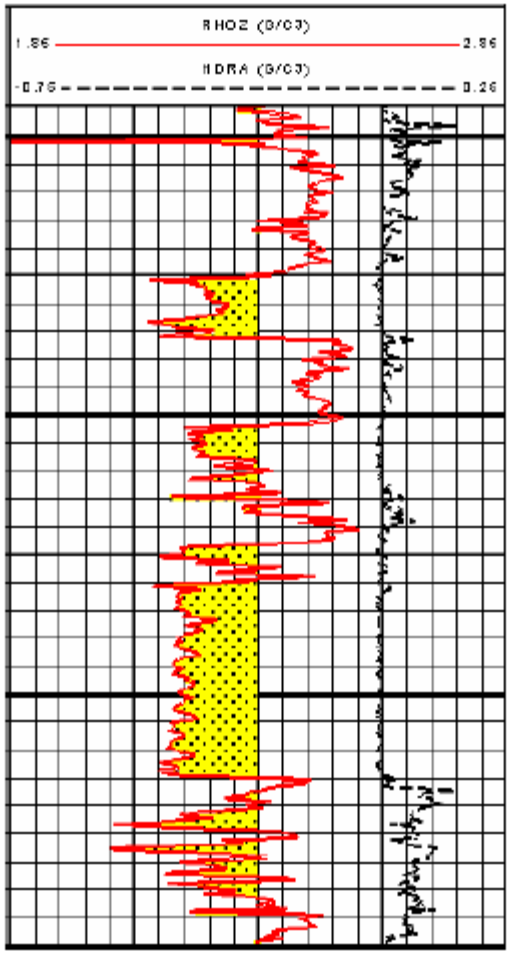


Bulk Density Log



Bulk density log measures formation density and is used to compute formation porosity

Litho Density Log



Litho density log provides bulk density of the formation and **PEF** (photo electric absorption factor)

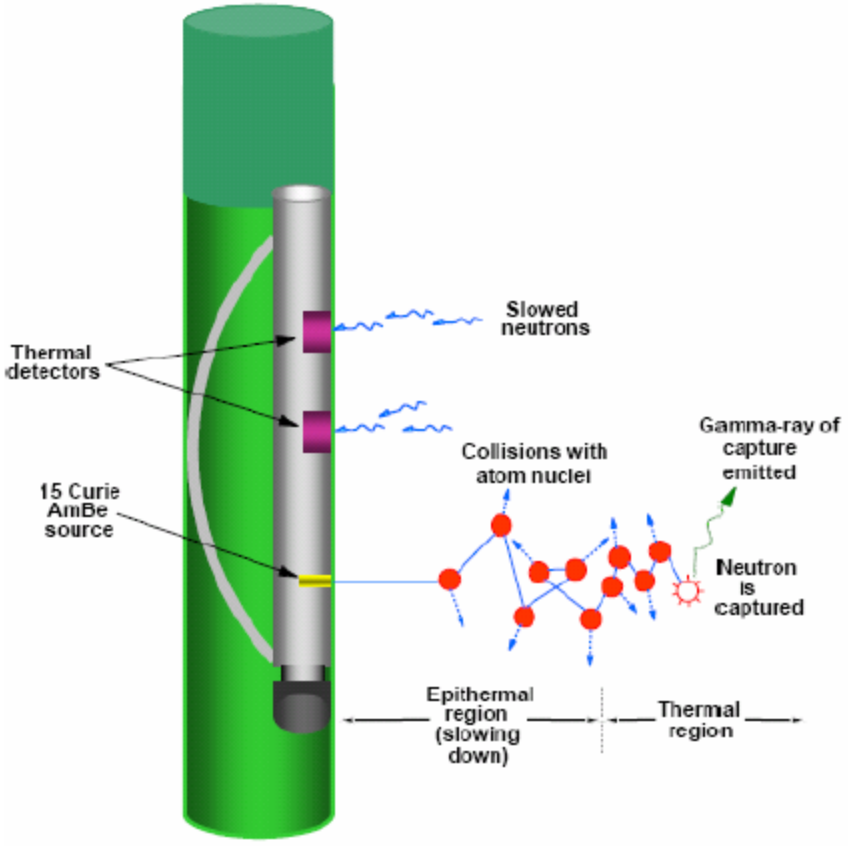
Bulk density log is used to compute formation porosity if grain density ρ_{ma} and fluid density are ρ_f known

PEF is used to identify the rock matrix

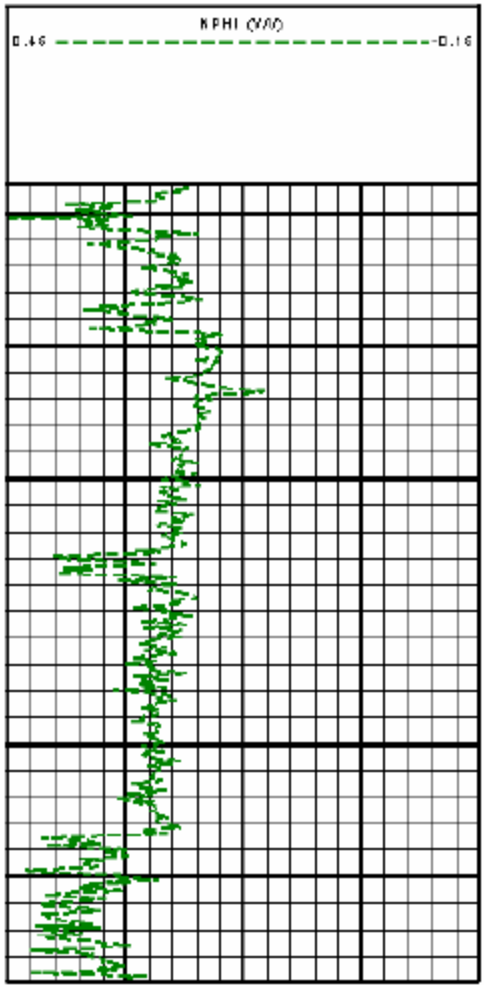
Litho density log is also used, together with the Neutron Porosity log, to identify formation fluid type

Neutron Porosity Tool

- How does the neutron tool work?



Neutron Porosity Log



Neutron porosity log detects the thermal neutrons which return after colliding with hydrogen atoms in the formation

The neutron porosity log measures the Hydrogen Index (HI) of the formation

Formation porosity is computed from the ratio of Near to Far detector counts

The neutron porosity log is used together with the bulk density log to identify the formation fluid

Uses of Porosity Logs

1. Computation of formation porosity using various porosity logs

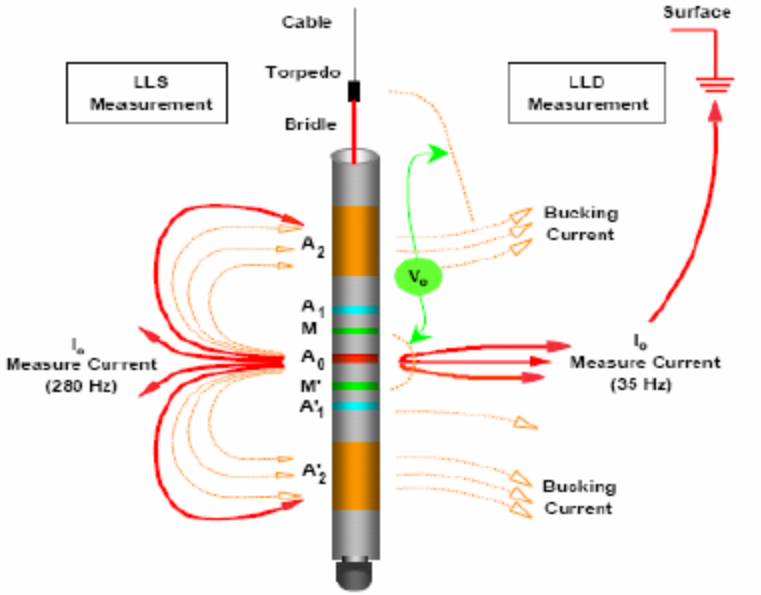
2. Three main types of porosity logs
   Bulk Density Log
   Neutron Porosity Log
   Sonic Porosity Log

3. Determination of Net Porous Reservoir Thickness

4. Identification of hydrocarbon type based on the combination of various porosity logs

Resistivity Logging Tool

Dual Laterolog tool configuration

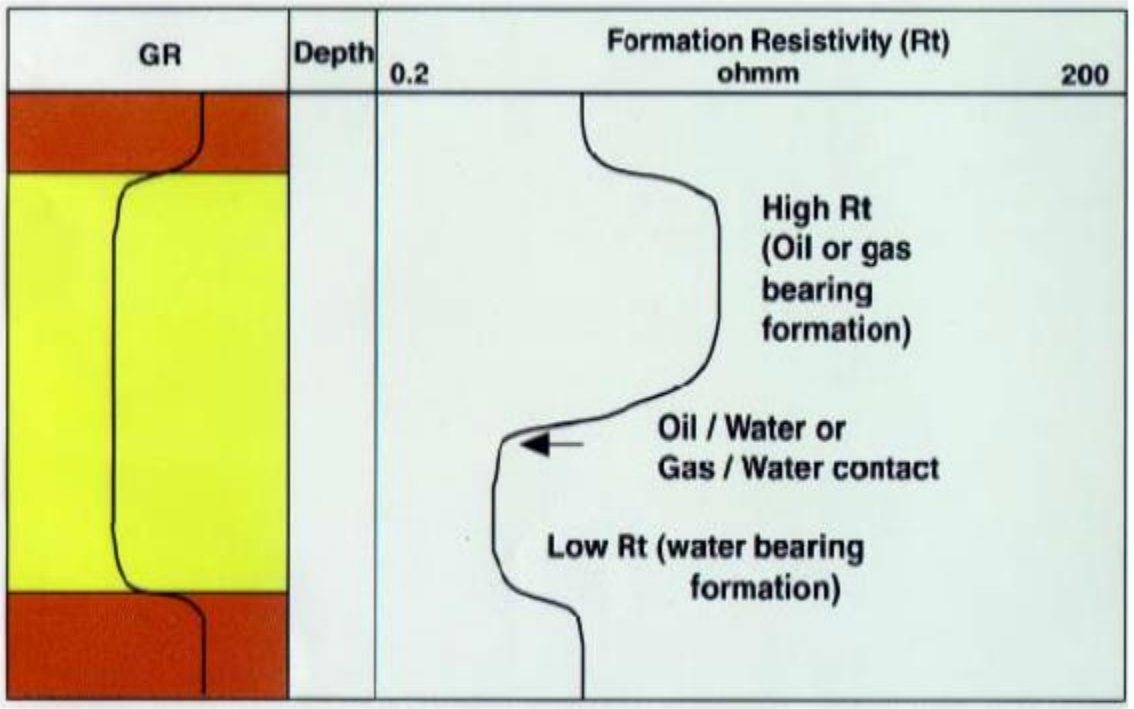


$$\text{Resistivity} = k * \text{Resistance} = k * \frac{V_o}{I_o}$$

where,

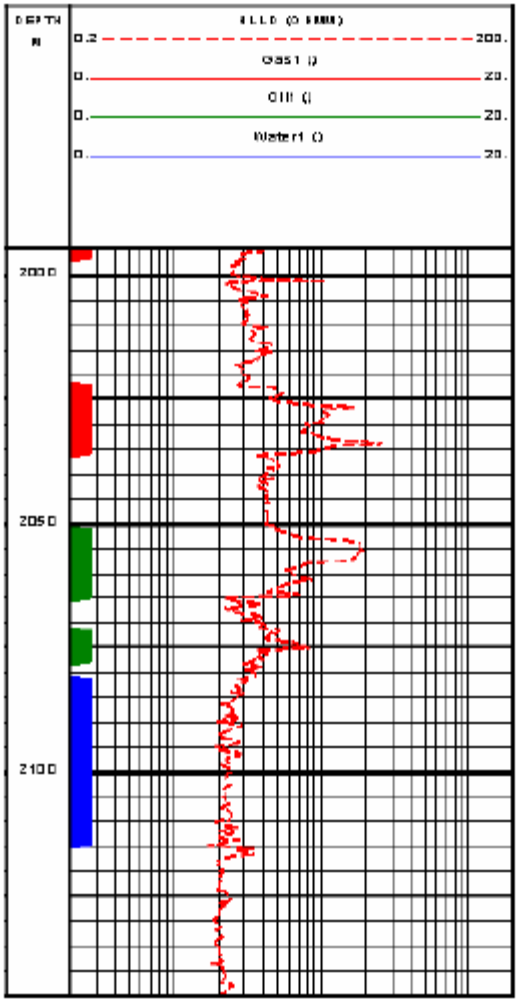
k = tool constant (K – factor)

Resistivity Log



Resistivity log measures formation resistivity and is used to determine hydrocarbon bearing zones and compute hydrocarbon saturation

Resistivity Log



Resistivity logs are used to differentiate hydrocarbon bearing zones from the water bearing intervals.

Hydrocarbon bearing zones usually have high resistivites accompanied by high or medium porosities.

Water bearing intervals usually have low resistivities accompanied by high or medium porosities.

Tight or non-permeable zones have high resistivities accompanied by low porosities.

Uses of Resistivity Logs

1. Identification of hydrocarbon bearing reservoirs
2. Determination of Net Pay thicknesses
3. Calculation of hydrocarbon saturation
4. Identification of productive reservoirs
5. Estimation of formation permeability

Water Saturation Calculation

Archie's equation may be used to compute water saturation:

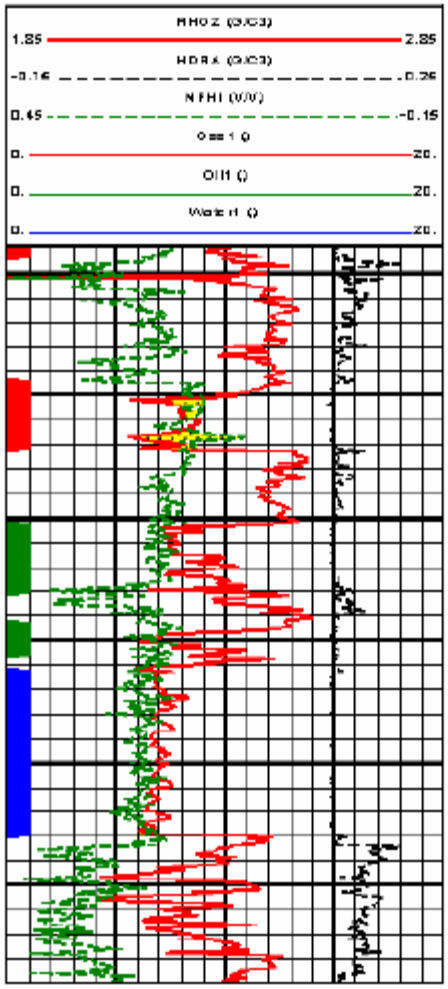
$$S_w^2 = aR_w/(\Phi^2 * R_t)$$

This can be modified as follows:

$$S_w^2 = R_o/R_t$$

Where: R_o = resistivity in the water bearing interval
R_t = resistivity in the hydrocarbon bearing zone
R_w = resistivity of formation water

Fluid Identification



Identification of formation fluids is carried out by using two or more porosity logs in combination.

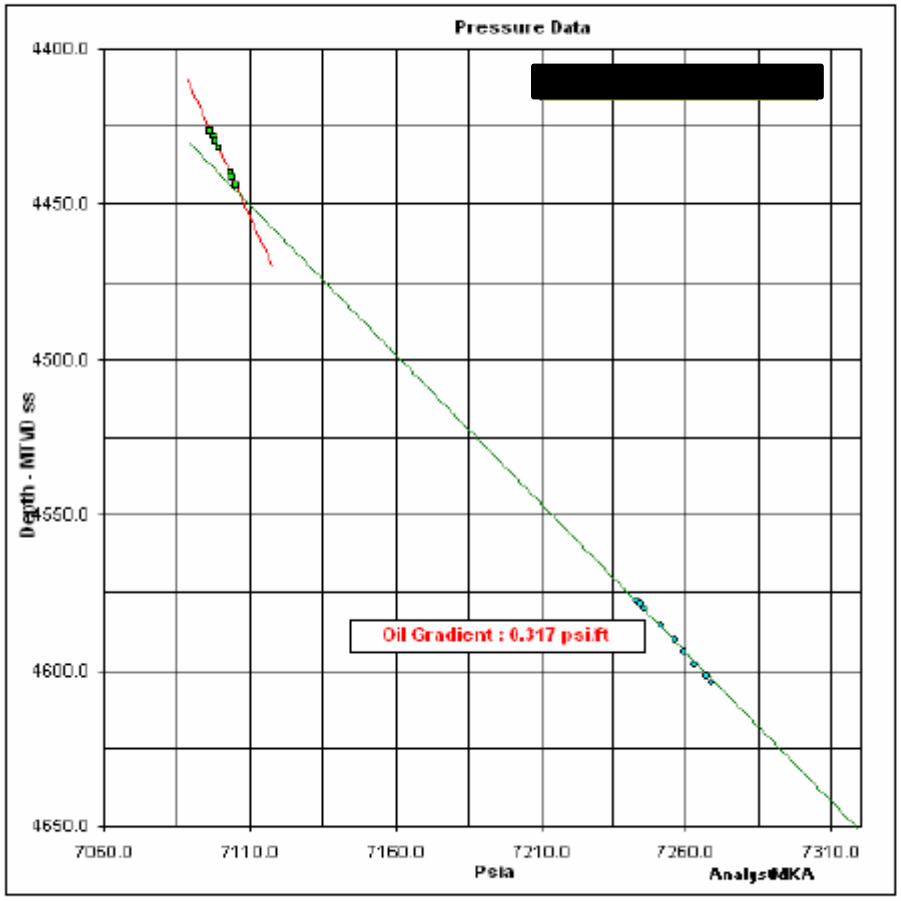
Usually the bulk density and neutron porosity logs are used in combination to detect gas bearing intervals.

Gas bearing intervals exhibit butterfly shape separation between neutron and density logs.

Generally, oil and water give similar responses on the neutron and density logs.

Oil can be differentiated from water by means of high resistivity readings, in combination with porosity logs.

Pressure Plot

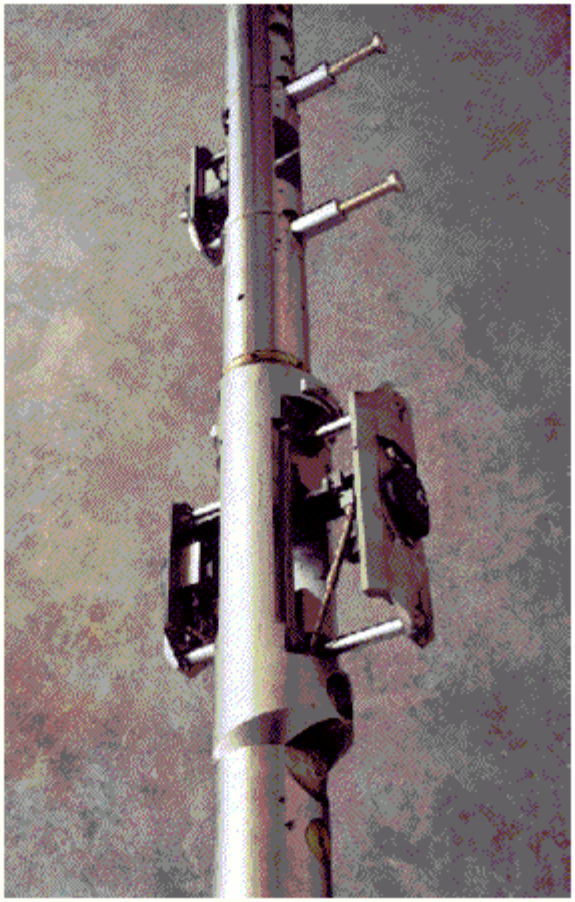


Fluid type and fluid contacts can be determined by using formation pressure and fluid sampling tools.

The intersection between the different fluid gradient lines indicates fluid contact.

Fluid type and fluid contact interpreted from well logs can be confirmed by using formation tester tools

Wireline Formation Tester



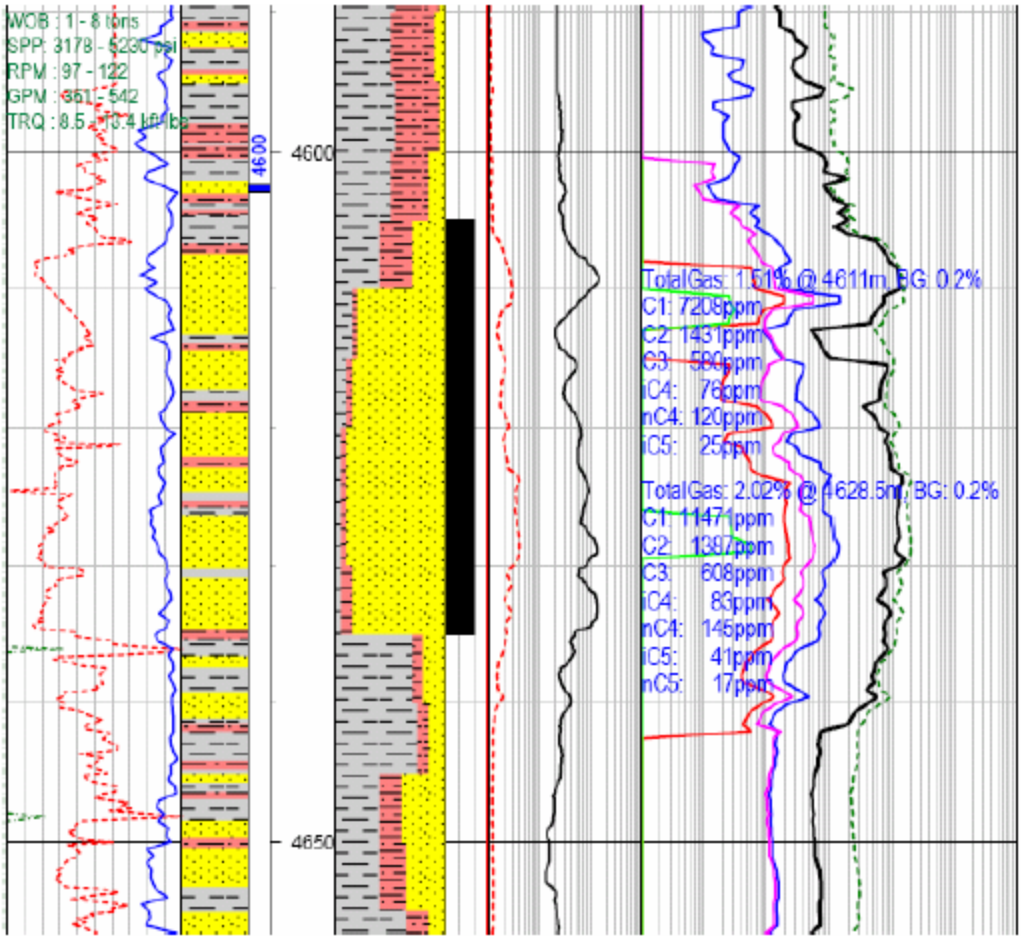
MDT (Modular Dynamics Tester) tool from Schlumberger

This wireline formation testing tool can take an unlimited number of pressure measurements

Depending on the tool configuration several formation fluid samples can be taken during one trip in the well

This tool is used for identification of formation fluids (from pressure gradient) and fluid contacts

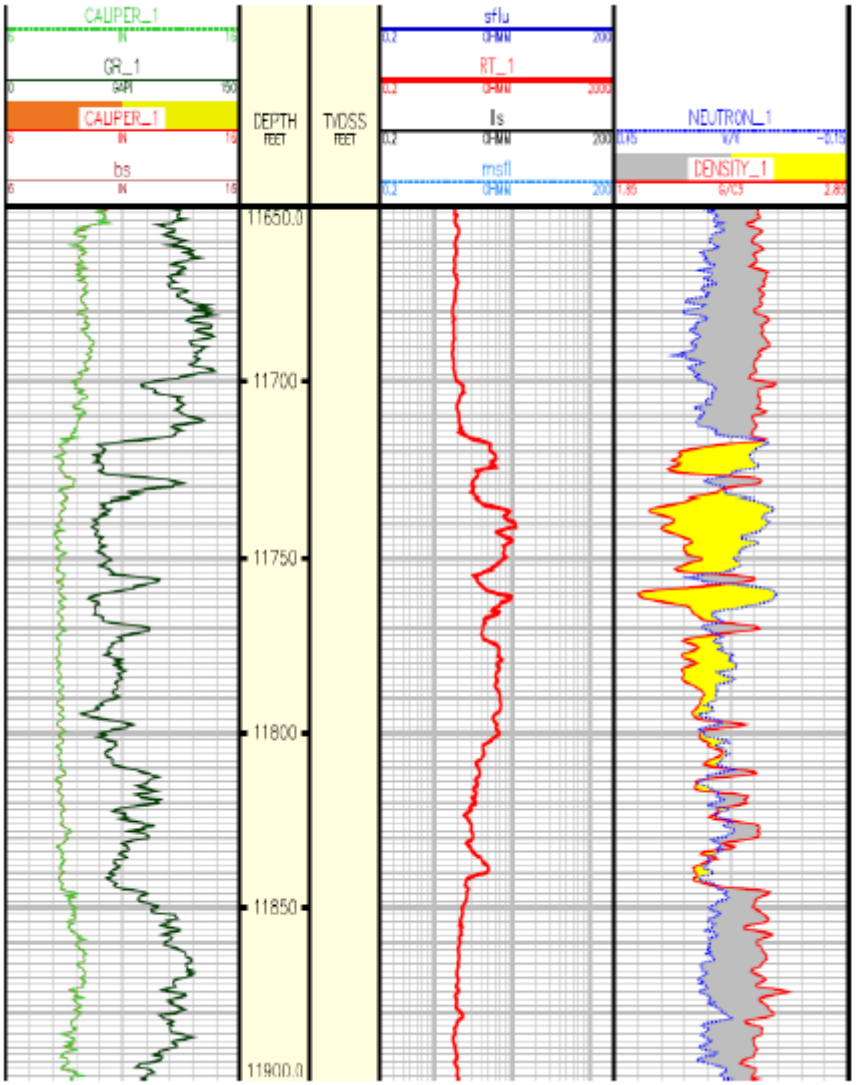
Mud Logs



Mud logs are very useful in fluid identification.

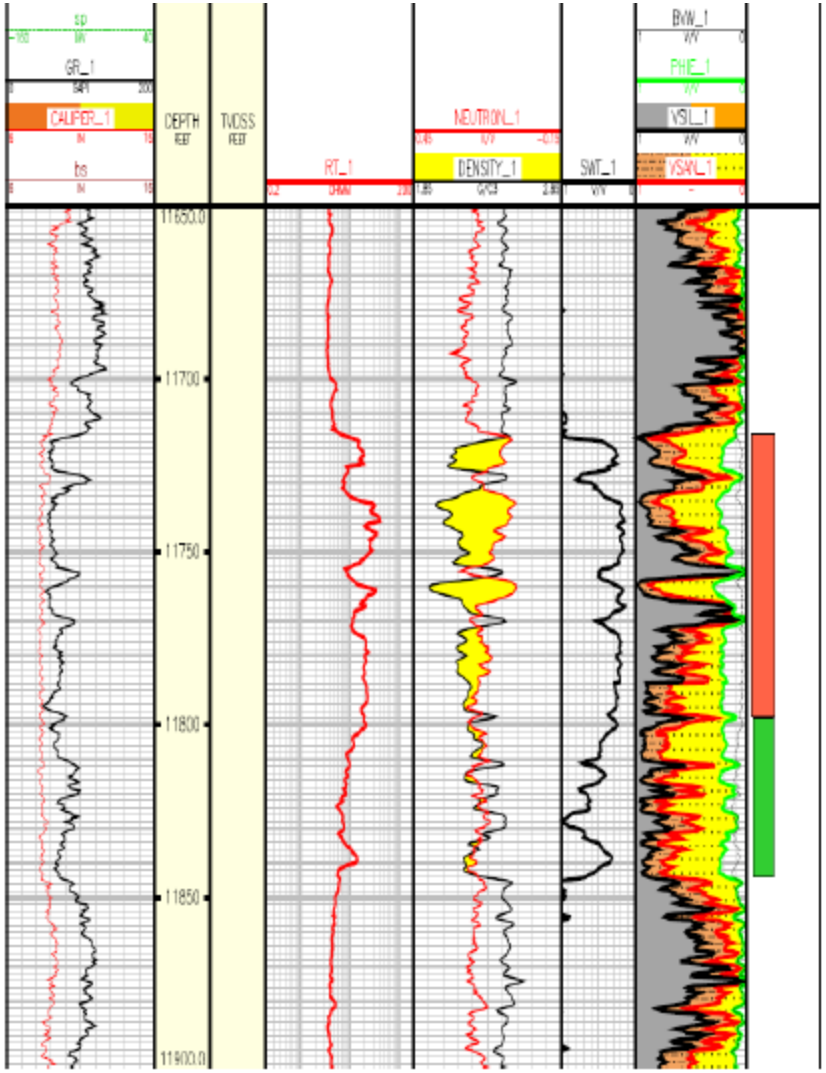
Gas and oil shows are used to corroborate fluid identification from well logs.

Mud logs are also very useful in rock typing and matrix identification.



Raw Open Hole Logs

- Gamma Ray
- Caliper
- True Resistivity
- Bulk Density
- Neutron Porosity



Interpreted OH Logs

- Hydrocarbon zones identified
- Gas-oil contact identified
- Porosity, water saturation and rock volumes computed
- Reservoir sums and averages computed for volumetrics

Log to Core Calibration

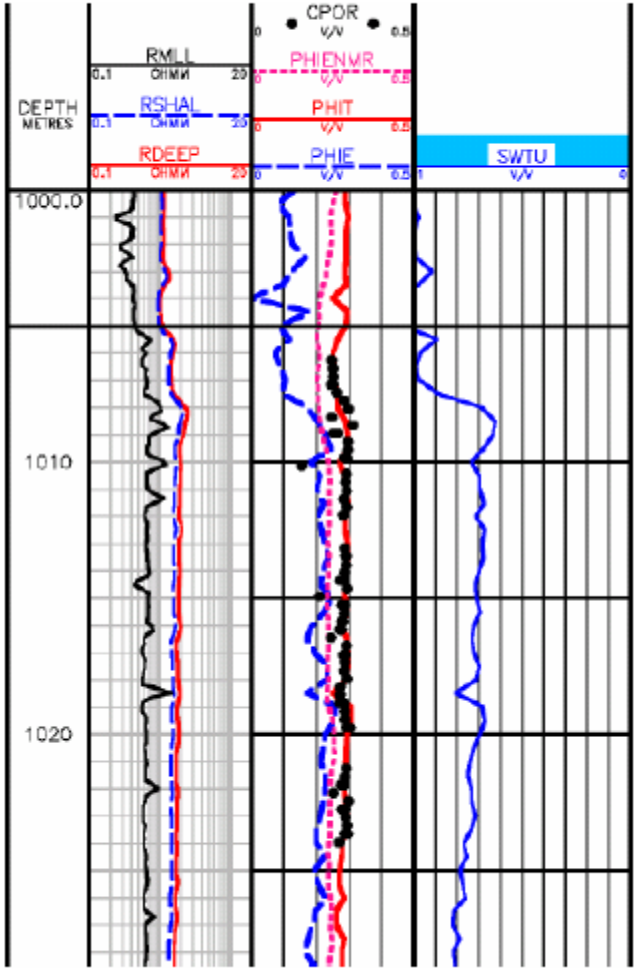
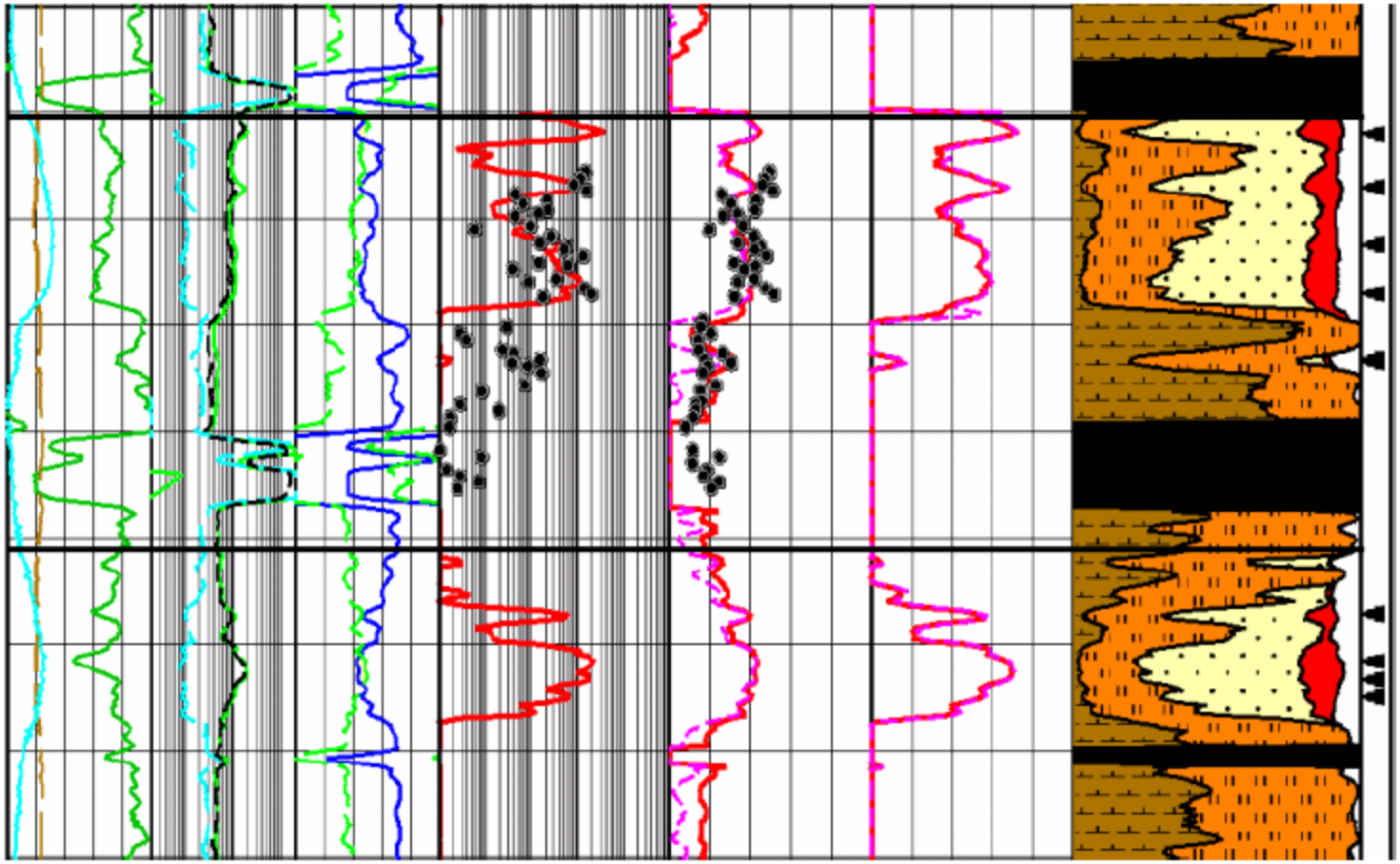


Illustration of calibration of log-derived porosity with measured core porosity.

Whenever available, log derived porosity and permeability should be calibrated with measured core porosity and permeability.

Log to Core Calibration



Summary

- Well logs acquired in oil and gas wells play a crucial role in assessment of hydrocarbon resources
- The parameters used in hydrocarbon volume calculation are derived from well logs
- Minimum three types of well logs, namely Gamma Ray log, porosity log and resistivity logs, are required to derive formation rock parameters.

Conclusions

- Gamma Ray log can be used to distinguish reservoir rock from non-reservoir by imposing a certain cutoff value on the log
- In a porous rock formation, hydrocarbon bearing zones will have higher resistivity values compared to the water bearing zones
- High resistivity accompanied by high porosity indicates hydrocarbon
- Low resistivity accompanied by high porosity indicates water

Thank you for your attention