Density Log

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DEFINITION

- Formation Density logging is a well logging tool that can provide a continuous record of a formation's bulk density along the length of a borehole.

- This is one of three well logging tools that are commonly used to calculate porosity, the other two being sonic logging and neutron porosity logging.

Density Log (Cont.)

- The density logging device is a contact tool which consists of a medium-energy gamma ray source that emits gamma rays into a formation.
- The gamma ray source is either Cobalt-60 or Cesium-137.
- Gamma rays collide with electrons in the formation ; the collisions result in a loss of energy from gamma ray particle.
- Tittman and Wahl (1965) called the interaction between incoming gamma ray particles and electrons in the formation, *Compton Scattering*.

Density Log (Cont.)

- Scattered gamma rays which reach the detector, located a fixed distance from the gamma ray source, are counted as an indicator of formation density.
- The number of Compton Scattering collisions is a direct function of the number of electrons in a formation (electron density).
- Consequently, electron density can be related to bulk density (ρ_b) of a formation in gm/cc.

TOOLS CONSISTS OF :

- A radioactive source: usually caesium-137 or cobalt-60, and emits gamma rays of medium energy (in the range 0.2 – 2 MeV). For example, caesium-137 emits gamma rays with a energy of 0.662 MeV.

- A short range detector. This detector is very similar to the detectors used in the natural gamma ray tools,and is placed 7 inches from the source.

- A long range detector. This detector is identical to the short range detector, and is placed 16 inches from the source.

PROCESS OF MEASURING

- The radiometric measurement of density is based on the Gamma transmission principle.
- The gamma rays enter the formation and undergo compton scattering by interaction with the electrons in the atoms composing the formation.
- **Compton scattering** reduces the energy of the gamma rays in a step-wise manner , and scatters the gamma rays in all directions.
- When the energy of the gamma rays is less than 0.5 MeV they may undergo photo electric absorption by interaction with the atomic electrons.

- The flux of gamma rays that reach each of the two detectors is therefore attenuated by the formation, and the amount of attenuation is dependent upon the density of electrons in the formation.

- The extent to which it is attenuated is directly proportional to the density of the measured material.

- Moreover the measurement performance is not affected by temperature, pressure, viscosity, color or chemical properties of the measured material.

- A formation with a **high bulk density, has** a **high number density of electrons. It** attenuates the gamma rays significantly, and hence **a low gamma ray count rate** is recorded at the sensors.

- A formation with a **low bulk density, has** a **low number density of electrons. It** attenuates the gamma rays less than a high density formation, and hence a **higher gamma ray count rate is** recorded at the sensors.

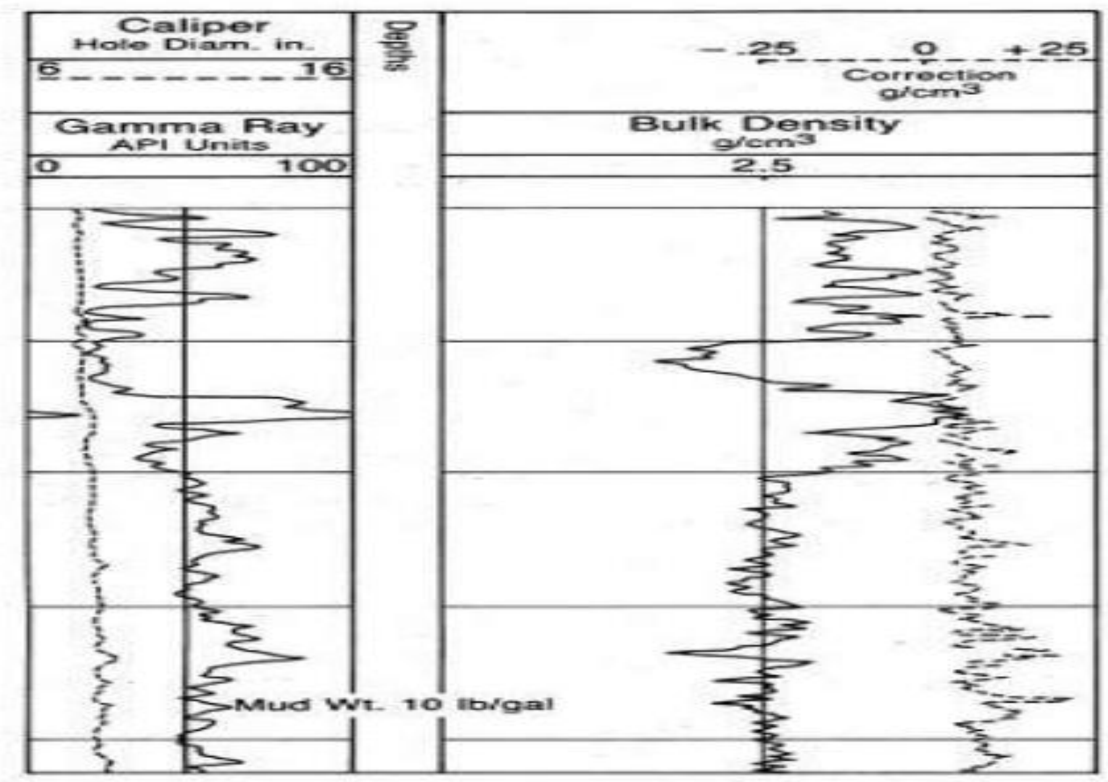
DEPTH OF INVESTIGATION

- About 80% signal of **short spacing detector** comes from within 5 cm of the borehole wall, which is commonly mainly mudcake .
- About 80% signal of the **long spacing detector** comes from within 10 cm of the borehole wall.
- Therefore the tool has a **shallow depth of investigation.**

Log Presentation

- The formation density log is recorded in **tracks 2 and 3 of the standard API log** presentation on a linear scale.

- The scale is usually spans **1.95 to 2.95 g/cm3** as this is the normal range for rocks.



THE FORMATION DENSITY TOOL IS MOST OFTEN RUN IN COMBINATION WITH

a) **Gamma ray log** : used in mining, mineral exploration, water-well drilling, for formation evaluation in oil and gas well drilling and for other related purposes.

b) **Caliper log :** provides a continuous measurement of the size and shape of a borehole along its depth.

c) **Neutron log** : responds primarily to the amount of hydrogen in the formation which is contained in oil, natural gas, and water.

DRILLING MUD EFFECT

- Drilling muds with high density or that absorb gamma rays efficiently, such as barite filled muds , will effect the detector readings.

- **Factors influencing to drilling :**

  - The change of drilling fluid viscosity.
  - The change of drilling fluid density.
  - The change of mud pH.

USES OF FORMATION DENSITY LOG

- This method is the most reliable porosity indicator for sandstones and limestones because their density is well-known.

- On the other hand the density of clay minerals such as mudstone is highly variable, depending on depositional environment, overburden pressure, type of clay mineral and many other factors.

- It can assist the geologist to (Schlumberger, 1972) :
  - detect gas-bearing zones,
  - determine hydrocarbon density,
  - evaluate shaly sand reservoirs and complex lithologies.

Density Log

- Advantage:

-- Automatically compensates for mudcake and minor borehole irregularities.

- Limitations:

-- Correction valid only if mudcake or standoff < 0.75” and is uniform along pad.

-- Abnormally low density (high porosity) in washed out (> 17”) hole or rough hole.

DETERMINATION OF POROSITY

- The porosity of a formation can be obtained from the bulk density if the mean density of the rock matrix and that of the fluids it contains are known.

Formula

- Formation bulk density is a function of matrix density, porosity and formation fluid density .
- Density porosity is defined as:

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

- Common values of matrix density (in g/cm³) are:

Quartz sand - 2.65
Limestone - 2.71
Dolomite - 2.87

- The matrix density and the fluid density need to be known

DERIVE DENSITY POROSITY BY FORMULA

- The formula for calculating density porosity is :

$$\phi_{den} = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f}$$

- Where :
- Φ_{den} = density derived porosity
- ρ_{ma} = matrix density (see Table)
- ρ_b = formation bulk density (= density log reading)
- ρ_f = fluid density
- (1.1 salt mud, 1.0 fresh mud, and 0.7 gas)

TABLE. MATRIX DENSITIES OF COMMON LITHOLOGIES

	ρ_b (gm/cc)
Sandstone	2.648
Limestone	2.710
Dolomite	2.876
Anhydrite	2.977
Salt	2.032

- Constants presented here are used in the Density Porosity Formula (after Schlumberger, 1972).

Grain (matrix) densities of some common rock forming minerals.

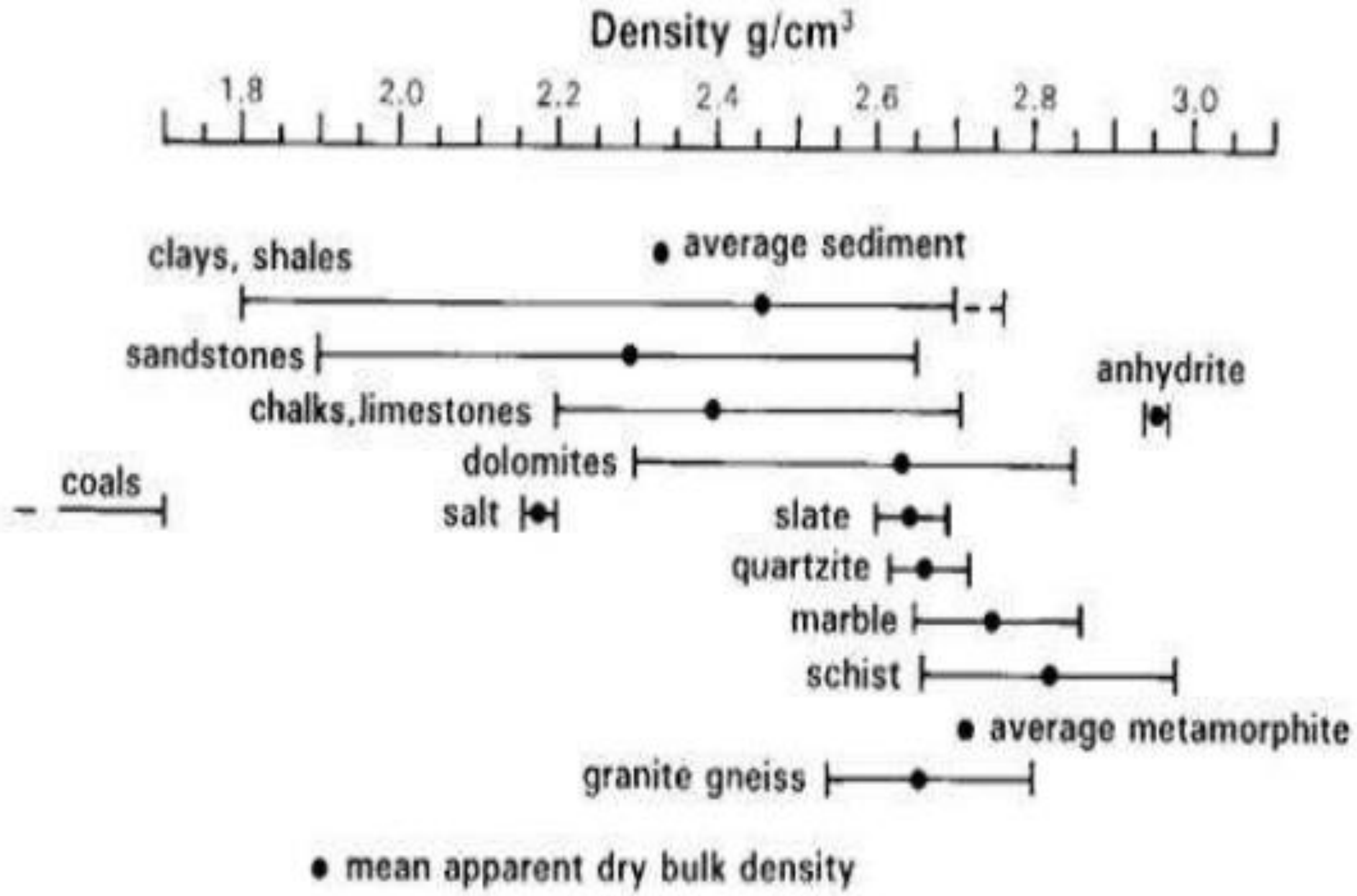
Mineral	Grain Density (g/cm^3)	Mineral	Grain Density (g/cm^3)
Quartz	2.65	Halite*	2.16
Calcite	2.71	Gypsum*	2.30
Dolomite	2.87	Anhydrite*	2.96
Biotite	2.90	Carnalite*	1.61
Chlorite	2.80	Sylvite*	1.99
Illite	2.66	Polyhalite*	2.78
Kaolinite	2.594	Glauconite	2.30
Muscovite	2.83	Kainite	2.13

*Evaporites

IDENTIFICATION OF LITHOLOGY

- Formation density is not a useful tool for identifying lithology alone since most sedimentary rocks can have a range of densities that commonly overlap.
- When used in combination with the neutron log, lithology can be determined.
- Evaporites are usually very pure and have consistent densities, making them more easily identifiable the other sedimentary rocks.

Lithology Determination



Shale effect in density measurement

- Shale undergoes progressive compaction and increasing density with depth of burial and age.

- If, within a given shale interval, there is a sudden change of density, the most likely explanation is that the formations above and below have been deposited in a completely different environment. The change is therefore an indication of a possible unconformity

- The density tool records the bulk density of the formation. The porosity derived from this will include all pores and fractures whether they are connected or not.
- Fracture identification and evaluation using conventional resistivity and compressional -wave acoustic logs is difficult, in part because fracture recognition is very dependent on the dip angle of fractures with respect to the borehole.

Fracture recognition

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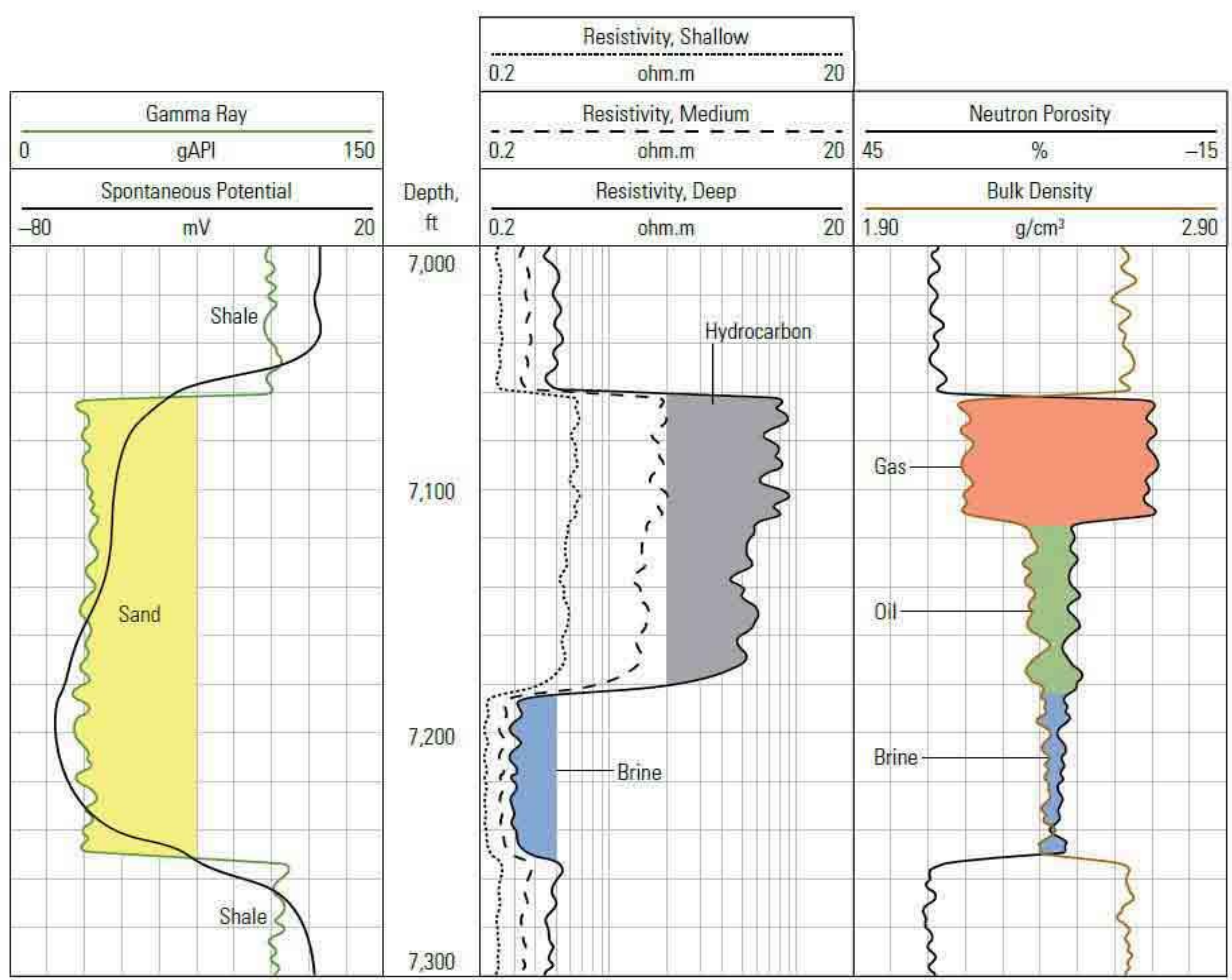
- The sonic tool can also be used to measure the porosity of the formation. However, the sonic tool is not sensitive to fracture porosity.
- Hence, the difference between the porosities derived from these two measurements can be used as an indicator of the extent of fracturing in a reservoir interval.

Organic Content of Source Rocks

- The presence of organic matter can reduce the density of shales by up to 0.5 g/cm3.It is possible to calculate the total organic carbon (*TOC)* content of a source rock from the change in bulk density.

Gas effect

- Where invasion of a formation is shallow, low density of the formation's hydrocarbons will increase density porosity.
- Oil does not significantly affect density porosity, but gas does (gas effect).
- Hilchie (1978) suggests using a gas density of 0.7 gm/cc for fluid density (ρ_f) in the density porosity formula if gas density is unknown.


Resistivity, Shallow
0.2
ohm.m
20
Gamma Ray
0
gAPI
150
Resistivity, Medium
0.2
ohm.m
20
Neutron Porosity
45
%
–15
Spontaneous Potential
–80
mV
20
Depth, ft
Resistivity, Deep
0.2
ohm.m
20
Bulk Density
1.90
g/cm³
2.90
7,000
7,100
7,200
7,300
Shale
Sand
Shale
Hydrocarbon
Brine
Gas
Oil
Brine

Overpressure Zone