University of Mosul
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Well Logging Engineering

Lecture Thirteen

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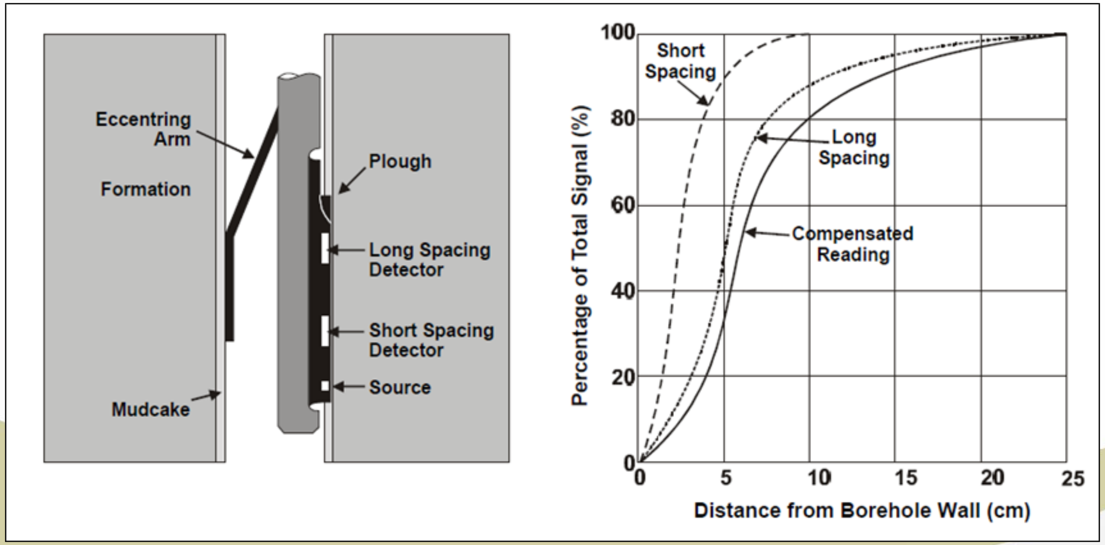
- **Formation density log**
- The formation density log is a porosity log that measures bulk density of the formation. In addition to the main use of density log in determining the total porosity of the formation, It can be used to:
- 1- Identify evaporate minerals.
- 2- Detect gas-bearing zones.
- 3- Determine hydrocarbon density.
- 4- Evaluate shaly sand reservoirs and complex lithologies.

- **Operation:**
- The early tools had only one detector, which was pressed against the borehole wall by a spring-loaded arm. Unfortunately, this type of tool was extremely inaccurate because it was unable to compensate for mudcake of varying thickness and densities through which the gamma rays have to pass if a measurement of true formation is to be achieved.
- All the newer tools have two detectors to help compensate for the mudcake problem. The newer two detector tools are called compensated formation density logs.

- **Operation:**
- Compensated formation density tools have one focussed radiation source, one short spacing detector at 7 inches from the source, and one long spacing detector 16 inches from the source (Figure 1). The source and both detectors are heavily shielded (collimated) to ensure that the radiation only goes into the mudcake and formation, and that detected gamma rays only come from the mudcake or formation. The tool is pressed against one side of the borehole using an arm with a force of 800 pounds force.



- **Principle:**
- The density logging device is a contact tool which consists of a radioactive 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 the gamma ray particle. The interaction between incoming gamma ray particles and electrons in the formation is called Compton scattering.
- 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 (ρb) of a formation in gm/cc.

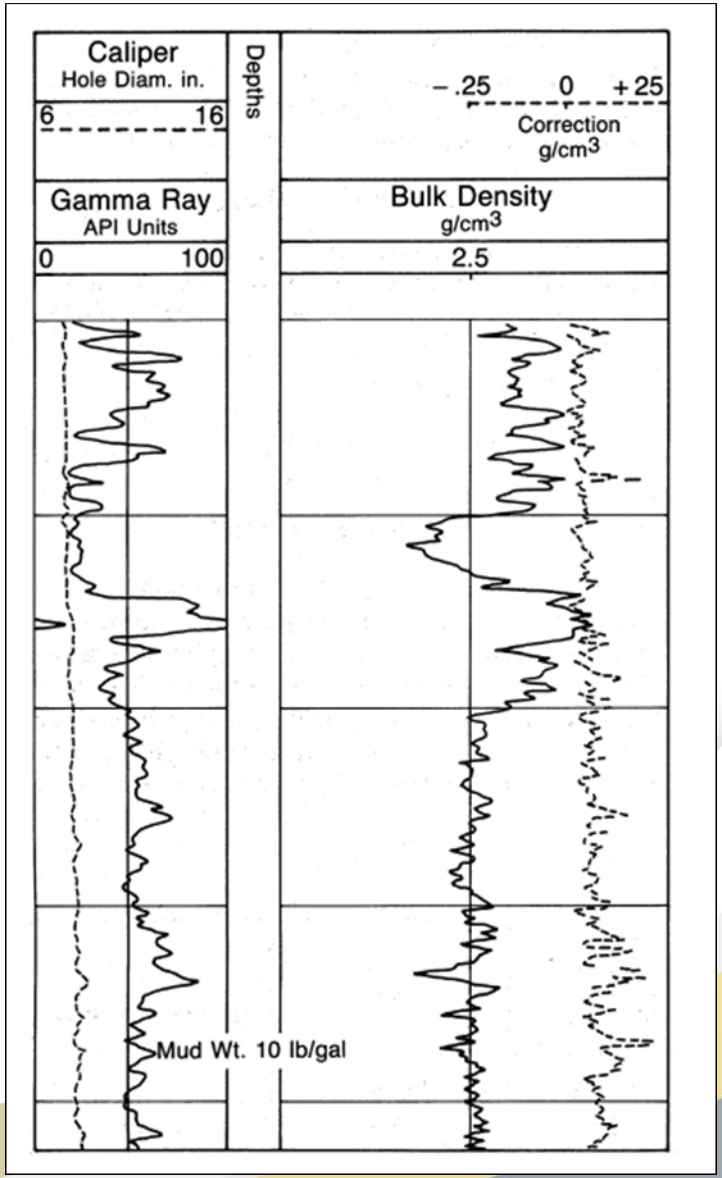
Principle:

- The bulk density curve is recorded in tracks #2 and #3 (Fig. 2), along with a correction curve (Δp). A density derived porosity curve is sometimes present in tracks #2 and #3 along with the bulk density (ρb) and correction (Δp) curves. Track #1 contains a gamma ray log and a calliper (Fig. 2).
- Formation bulk density (ρb) is a function of matrix density, porosity, and density of the fluid in the pores (salt mud, fresh mud, or hydrocarbon). To determine density porosity, either by chart (Figure 3) or by calculation, the matrix density (Table 1) and type of fluid in the borehole must be known. The formula for calculating density porosity is:
- $Ø_{den} = (\rho_{ma} - \rho_b)/(\rho_{ma} - \rho_f)$ ---------------------------- (1)
- Where:
- $Ø_{den}$: density derived porosity
- ρ_{ma}: matrix density (see table 1).
- ρ_b: formation bulk density.
- ρ_f: fluid density (1.1 salt mud, 1.0 fresh mud, and 0.7 gas).

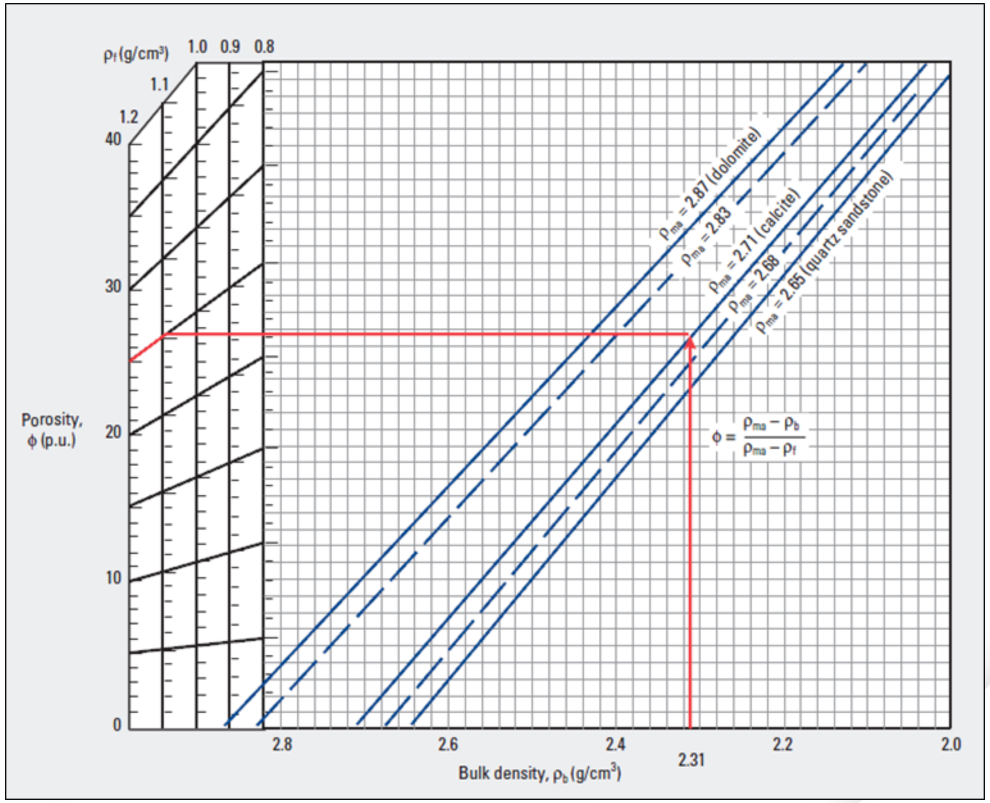
Lithology	ρma (gm/cc)
Sandstone	2.648
Limestone	2.710
Dolomite	2.876
Anhydrite	2.977
Salt	2.032

Table 1: Matrix densities of common lithologies.

- Figure 2: Example of a bulk density log with a gamma ray log and calliper.
- Where invasion of a formation is shallow, low density of the formation's hydrocarbon will increase density porosity. Oil does not significantly affect density porosity, but gas does (gas effect). A gas density of (0.7) gm/cc is used for fluid density (ρf) in the density porosity formula if gas density is unknown.



- Figure 3: Chart for converting bulk density (ρb) to porosity (Ø) using values picked from a density log.



- **Depth of investigation:**
- The depth of investigation of the tool is very shallow. For schlumberger's FDC tool 90% of the response comes from the first 13 cm (5 inches) from the borehole wall for a 35% porosity sandstone (which has low density compared with most reservoir rocks). In higher density rocks, the depth of investigation is even less, and a value of about 10 cm (4 inches) can be taken as an average value for reservoir rocks. Figure 1 shows the percentage of the signal that comes from different depths into the formation.
- The shallow depth of investigation also implies that in porous and permeable formations, where its main use lies, it only measures the invaded zone. This should be taken into consideration when only measures the invaded zone in porous formations makes the tool little use for distinguishing between formation oil and formation water. However, gas may still be detected because (i) the greater difference in density between gas and oil or water, and (ii) the fact that mud filtrate invasion into gas-bearing zones is never complete, and always leaves a significant amount of gas behind in the invaded zone.

- **Logging speed:**
- The typical logging speed for the tool is 1300 ft/hr (400 m/hr), although is occasionally run at lower speeds to increase the vertical resolution. The log quality is not as effected by logging speed as the natural gamma ray logs because much higher count rates are obtained with the radioactive source on the tool.

- **Borehole quality:**
- The log is run eccentered in the borehole, and therefore is prone to caving and rough borehole walls where the detectors or the source may not be pressed against the borehole wall. In this case the readings will be erroneous due to radiation leakage along the borehole between the detectors and bad measurement geometry. The sensitivity to bad hole quality is exacerbated by the shallow depth of investigation that the tool has. The formation density log should, therefore be run with a caliper tool, and the caliper reading should be used to judge the likely quality of the formation density log data.

- **Vertical resolution:**
- The vertical resolution at the typical logging speed (1300 ft/hr) is good (about 26 cm, 10 inches), which is defined by the distance between the two detectors. The measurement point is taken to be half way between the two detectors. Beds can be resolved down to about 60 cm (2 ft) with the density tool reading the true density value of the bed. The high vertical resolution means that the log is useful for defining formation boundaries.

- **The effect of gas:**
- If gas is present in the formation, porosities can be overestimated. The density of gases is very low (approximately 0.0001 g/cm3) compared to aqueous fluids. If the formation is gas-bearing a significant amount of gas is always left in the invaded zone. This gas will reduce the mean fluid density of the invaded zone, and will cause overestimations of the porosity if a fluid density of 1.0 or 1.1 g/cm3 is used.

Thank You