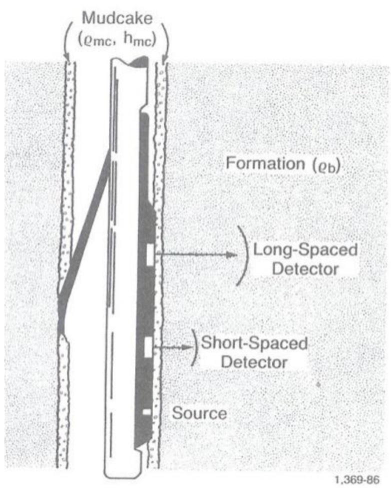
Density Log

Introduction

The density log belongs to the group of active nuclear tools, which contains a radioactive source and two detectors. the Gamma Ray tool, which is a passive nuclear tool, contains no source and can only measure the natural radiation in the formation.



The radioactive source is applied to the well bore wall in a shielded sidewall skid and emits medium gamma rays into the formation. See diagram of a dual spaced density tool.

The gamma ray waves may be thought of as energy particles. As these energy particles (photons) collide with the electrons in the formation, the gamma ray loses some of its energy to the electron. This is called Compton scattering. The denser the formation, the more electrons are presented, and more energy is lost due to collisions. If the matrix density is known, then the energy loss is directly related to porosity.

The discovery of Compton scattering led to the general concept that the behavior of electromagnetic waves could be both wave-like and particle-like, as explained in Reference 1 with a Wikipedia link.

Reference 2 appropriately refers to the density and photoelectric log as a "gamma ray absorption logs" because this, and not density is what is being measured. The measurement gamma rays are in counts per second, which after the tool is calibrated in a limestone pit, are translated into bulk density. Discussion on the PE log follows the density log discussion.

Similar to the other tools, the density log is a shallow reading tool, generally limited to 6 inches. (Ref 1, page V-250.

Calculation of Porosity from Density Log

The bulk density, ρ_b from the density log is considered to be the sum of the density of the fluid (ρ_f) times its relative volume, $\emptyset$, plus the density of the matrix (ρ_{ma}) times its relative volume $1 - \emptyset$, or:

$$\emptyset = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f}$$

Common densities are given below (Reference 1):

Material	Density(gm/cc)	Fluid	Density (gm/cc)
Quartz	2.65	Fresh Water	1.00
Calcite	2.71	Salt Water	1.15
Dolomite	2.87	Oil	0.85
Anhydrite	2.96		

There is some variation in grain density. Dolomites can vary from 2.83 to 2.87. Generally, the density tool will read mostly the flushed zone. Rrecommended density filtrate values are 1.0, 1.1 and 0.90 gm/cc for freshwater , saturated salt water, and oil based muds, respectively.

Environmental Effects

Modern tools use two detectors and is generally referred to as a compensated density log. Schlumberger adopted the nomenclature FDC, for formation density – compensated log. To prevent loss of the radiation, the skid mounted source (usually cesium 137) and detector are shielded.

Mudcake adsorption is a source of error. A plow shaped design of the skid allows it to cut through soft mudcakes. The dual detectors allow for correction for mudcake or well bore irregularities. The short detector, due to its distance to the source, is more affected by mudcake and borehole irregularities. By cross plotting the count rates from the short and long detectors, along with the other variables (mud cake density, % barite in mudcake, bulk density), a correction factor is identified. Further explanation can be found on page 5-10 of Reference 3. The correction is done automatically.

Additional borehole corrections may be needed for boreholes greater than 10” in mud and gas filled boreholes. See Reference 2, Figure 8.12, page 163 for this correction.

PE Log

The density reading is a function of both porosity and rock type. If the rock type is known, then porosity can be calculated. If there is a second log, whose readings are affected by both the porosity and rock type, then both variables can be solved. The cross plot is a graphical substitute for simultaneous equations. A final variable is fluid type, which since the log is reading mostly the flushed zone, is typically the density of fresh or saltwater mud.

The density tool measures electron density, ρ_e in terms of electrons per cubic centimeter. The relation between bulk density and electron density is:

$\rho_e = \rho_b \left({2Z}/{A} \right)$ where Z is the atomic number and A is the atomic weight.

A similar expression can be made for compounds, using molecular weight. In the above equation, the value in parenthesis is very close to 1 (see table 5-2, Reference 2), so for practical purposes, the electron density is the same as the bulk density.

The photoelectric absorption is obtained from the low energy spectrum of the gamma ray, as measured in keV. The variable measured, photoelectric absorption cross-section, is defined as a measure of the probability that a nuclear reaction will take place under specific conditions, between an incoming particle and its target.

The atomic number, Z, is the number of electrons and can be related to the photoelectric absorption cross section index as:

$$P_e = \left(\frac{Z}{10} \right)^{3.6}$$

where P_e is in barns/ electron.

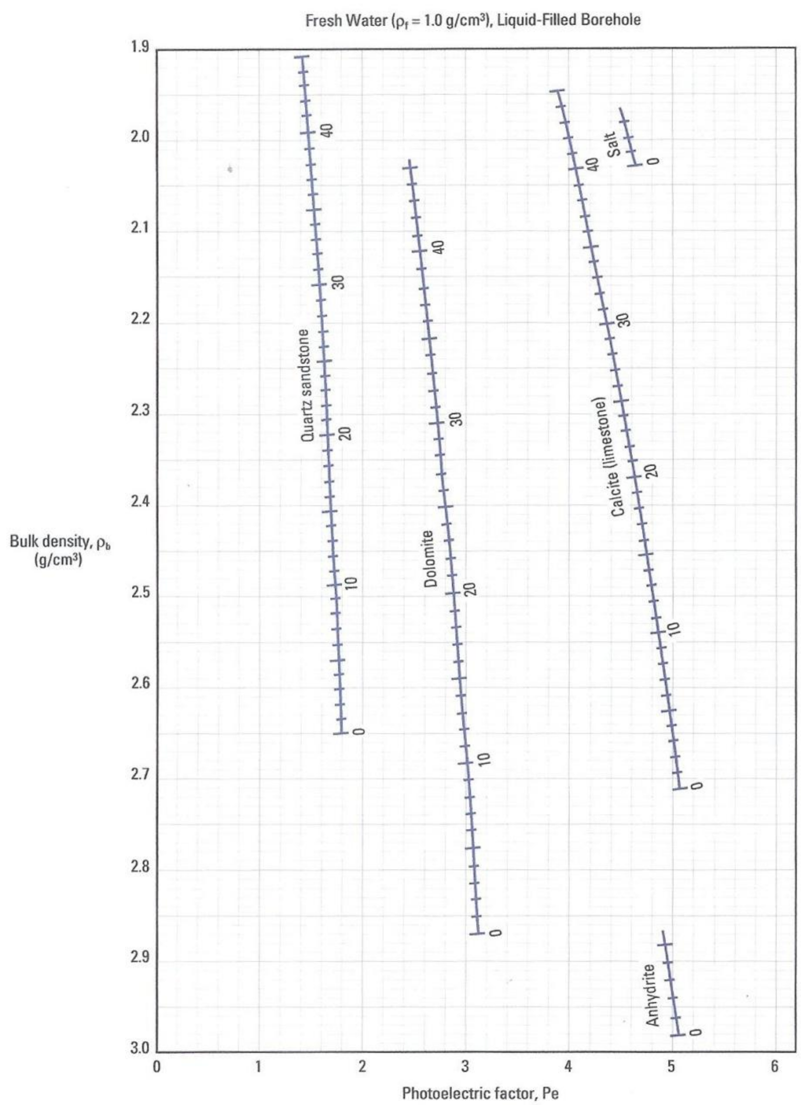
This can be converted into a PE factor in volumetric terms of barns/ cubic centimeter (U) by multiplying by the electron density:

$U = P_e \rho_e$

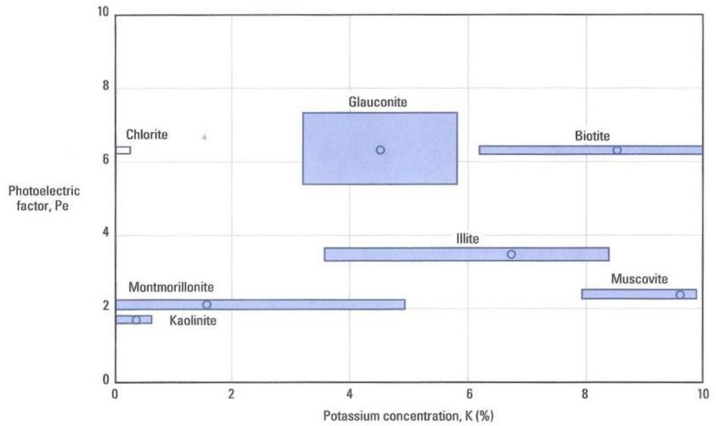
Now, since U is a density measure of the formation, we can use the familiar weighted average between rock and fluid, to obtain U as a function of porosity:

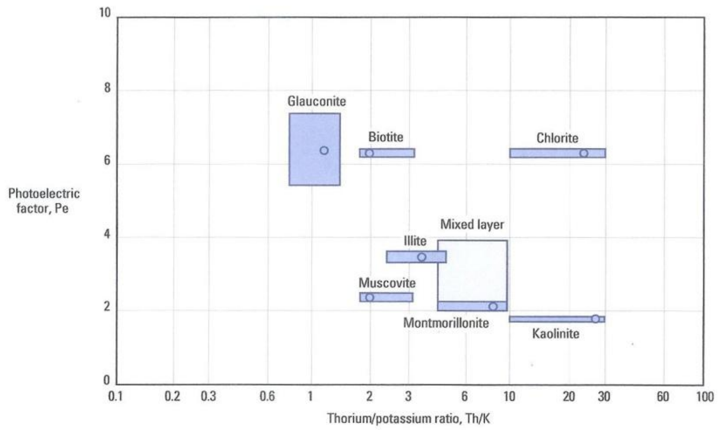
$U = \emptyset U_f + (1 - \emptyset) U_{ma}$ where U_f is the PE factor (barns/cc) for the fluid and U_{ma} is the PE factor (barns/cc) for the matrix

Since, since $\rho_b = \emptyset \rho_f + (1 - \emptyset)\rho_{ma}$ we have now two equations with two unknowns, porosity and matrix. The cross plot as shown below, shows that the Pe is more affected by lithology, while the density log is affect by both. This is helpful in complex lithologies.



Another very useful combination is the PE log with the Spectral Gamma Ray, to identify clay types:





Additional sections will describe other applications, including effect of shales and hydrocarbons on log readings, neutron-density cross plot and the use of the density log in detection of overpressured zones.

There are many excellent references on well log analyses. The recent Petroleum Engineering Handbook was particularly useful in this brief summary.

References:

1. Myers, Gary D., Nuclear Logging, Chapter 3D in Volume V(A), Reservoir Engineering and Petrophysics, E.D. Holstein, Editor, 2007.

2. Bassiouni, Z., Theory, Measurement and Interpretation of Well Logs, SPE Textbook Series, Volume 4, 1994.

3. Log Interpretation Principles/ Applications, Schlumberger, 1991.