Chapter 9 - Density logs

Lecture notes for PET 370
Spring 2011
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Density Log

1950s
• single detector tool developed initially to measure bulk density, $\rho_b$, insitu as an aid to geophysicists in gravity meter interpretation

Early 1960s
• accepted tool as a source for porosity

Late 1960s
• dual detector system, Compensated Formation Density (FDC) to correct for borehole effects

Early 1980s
• development of Lithodensity Tool (LDT) to measure photoelectric effect, $\text{Pe}$, with bulk density
Density Log

• Porosity/Lithology Determination
  – Mineral identification in evaporates
  – Gas detection (w/ other logs)
  – Estimate mechanical properties (w/ sonic)
  – Evaluation of shaly sands and complex lithologies

• Weak
  – Determination of hydrocarbon density
  – Determination of oil shale yield
  – Identify overpressured zones
Density Log

Logging speed:
15 to 30 fpm

Depth of investigation:
3 to 6”

Vertical Resolution ~ 1 ft
Bassiouni, 1994
Ejected gamma rays interact with matter and lose energy.

Upper limit of Z for common elements encountered in logging.
Density logging is based on measuring the attenuation of gamma rays caused by Compton scattering, (CPS per energy)
• Compton scattering depends only on the electron density of the formation (# of electrons/cc)

• The electron density is related to the bulk density by, \( \rho_e = \rho_b \left( \frac{2Z}{A} \right) \)

Where for common elements in sedimentary rocks, \( \left( \frac{2Z}{A} \right) \approx 1.00 \)

But for \( H_2 \) the ratio is double.

• Calibrated in freshwater filled limestone formation.

\[ \rho_{ba} = 1.0704 \rho_e - 0.1883 \]

Where \( \rho_{ba} \) is the apparent bulk density.

• \( \rho_{ba} \approx \rho_b \) for most common sedimentary rocks.
• Apparent bulk density (read by tool) = actual bulk density for ss, lms, and dols.

• For other formations (salt, anhydrite, coal) corrections are necessary.
**Density Log**

**Advantage:**
Automatically compensates for mudcake and minor borehole irregularities.

**Limitations:**
1. Correction valid only if mudcake or standoff < 0.75” and is uniform along pad.
2. Abnormally low density (high porosity) in washed out (> 17”) hole or rough hole.
Count rates at two detectors are:
f(spacing, $\rho_b, \rho_{mc}, h_{mc})$

Correction by:

$$\rho_b(\text{corr}) = \rho_{LS} + \Delta\rho$$

where, $\Delta\rho$ is density correction from *Spine and Rib* Plot.
Density Log

Teague (Mckee) Field
La Munyon #76

Incorrect Density Readings

Caliper
\[
\begin{aligned}
\{\text{Measured bulk density}\} &= \{\text{matrix contribution}\} + \{\text{pore fluid contribution}\} \\
\rho_b &= (1 - \phi)\rho_{\text{ma}} + \phi\rho_f \\
\text{or} \\
\phi &= \frac{\rho_{\text{ma}} - \rho_b}{\rho_{\text{ma}} - \rho_f}
\end{aligned}
\]

where \(\rho_{\text{ma}}\) \(\equiv\) matrix density

\(= 2.65\) for ss

\(= 2.71\) for lms

\(= 2.86\) for dolo
• Define $\rho_f$ as average density of fluid in pore space

• Depth of investigation of density tool is shallow (invaded zone), thus

$$\rho_f = S_{xo} \rho_{mf} + (1 - S_{xo}) \rho_h$$

• In practice,

<table>
<thead>
<tr>
<th>Mud Type</th>
<th>$\rho_{mf}$ (gm/cc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>oil</td>
<td>0.9</td>
</tr>
<tr>
<td>Fresh water</td>
<td>1.0</td>
</tr>
<tr>
<td>Salt water</td>
<td>1.1</td>
</tr>
</tbody>
</table>

• In water-bearing zones,

$S_{xo} = 1$ and $\rho_f = \rho_{mf}$

• In oil-bearing zones, use same $\rho_f = \rho_{mf}$ Assumes $S_{xo}$ is large and $\rho_h \approx \rho_{mf}$. 
The density porosity is usually calculated assuming $\rho_f = 1 \text{ gm/cc}$. Compare this apparent porosity, $\phi_a$, to the true porosity, $\phi_t$, that corresponds to a bulk density of 2.1 gm/cc in the following:

(1). a water-bearing sandstone invaded by a mud filtrate of 1.05 gm/cc density

(2). a 0.8 gm/cc oil-bearing sandstone characterized by $S_{or} = 30\%$.

(3). a low pressure gas-bearing sandstone with 30% residual gas saturation.

(4). a change in matrix density to 2.68 gm/cc.
Density Log

Example

Porosity?
• Photoelectric absorption depends on both $\rho_e$ and the average atomic number of the formation.

• Two independent parameters, $\rho_e$ and U, are measured in a low energy window.
Density Log

The absorption rate depends on the absorption coefficient per electron (Pe) and $\rho_e$:

$$U \left\{ \frac{\text{barns}}{\text{cm}^3} \right\} = Pe \left\{ \frac{\text{barns}}{\text{electron}} \right\} \ast \rho_e \left\{ \frac{\text{electrons}}{\text{cm}^3} \right\}$$

Substitute for electron density,

$$Pe = \frac{1.0704U}{\rho_b + 0.1883}$$
Density Log

**Advantage:**
The Pe curve distinguishes mineralogy regardless of porosity and fluid type in the pore space.

**Common Pe values:**
- quartz: 1.81
- calcite: 5.08
- dolomite: 3.14
- anhydrite: 5.05
Density Log

LDT - Example
**Density Log**

**LDT**
- Detector counts high energy gamma rays (Compton scattering) and low energy region (photoelectric effect)
- Measures both bulk density and Pe
- Pe is strong function of matrix
- Lower statistical variation
- Better vertical resolution

**FDC**
- Detects only high energy gamma rays
- Measures only bulk density
- Strong function of porosity, matrix, and fluids
Density Log

Overpressured shale

Normal Pressure gradient
Density Log


Chapter 2, Sec 6 – 8

Chapter 8


Western Atlas, *Log Interpretation Charts*, Houston, TX (1992)

Halliburton, *Log Interpretation Charts*, Houston, TX (1991)