Chapter 12 - Sonic logs

Lecture notes for PET 370
Spring 2012
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1) **Determine porosity of reservoir rock**

2) Improve correlation and interpretation of seismic records

3) Identify zones with abnormally high pressures

4) Assist in identifying lithology

5) Estimate secondary pore space

6) Indicate mechanical integrity of reservoir rocks and formations that surround them (in conjunction with density data)

7) Estimate rock permeability
Transmitter emits sound waves

Receivers pick up and record the various waves

Measure the first arrival of the compressional wave

Travel time is the difference in arrival of the compressional wave at the receivers

\[ \Delta t = \frac{(t_2 - t_1)}{L_s} \]

where \( L_s \) is span between receivers.
Span
• defined as distance between receivers
• determines vertical resolution, $h \sim \text{span}$

3 and 1-ft spacing sonic logs recorded in a west texas well (Bassiouni, 1994)
**Sonic Log**

**Depth of investigation**
- varies with wavelength, $\lambda$, which is related to formation velocity, $v$, and tool frequency, $f$. \( \lambda = \frac{v}{f} \)
- Depth of investigation, \( D_i \sim 3 \lambda \)
- Rule of thumb, 0.75 to 3.75 ft.
- indirectly related to T-R spacing

**Critical T-R Spacing**
- short enough for pulse to be detected
- long enough to allow 1st arrival to be compressional wave and not mud wave
- \( f(\text{standoff}, \frac{v_{\text{mud}}}{v_{\text{fm}}}) \)
- borehole enlargement effects
**Sonic Log**

**Cause:** Dampening of first arrival at far receiver

**Effect:**
Sonic curve shows spiking or an abrupt change towards a higher travel time

**Occurs in:**
- Unconsolidated formations (particularly gas bearing);
- fractured formations;
- transmitter weak and/or receiver poor
• Basic Sonic (obsolete)

• **BHC** - borehole compensated sonic (most common)

• LSS - Long spaced sonic

• Array Sonic or Full Waveform Sonic

• Dipole Shear Imager (DSI)
• One transmitter and two or three receivers, T-R1-R2-R3
• Borehole and sonde tilt problems

Single transmitter, two-receiver configuration
Western Atlas (1993)
West Texas acoustic log
Hilchie (1978)
Sonic Log

Borehole compensated Sonic (BHC)

- Automatically compensates for borehole effects and sonde tilt
- System of upper and lower transmitters bounding two sets of receivers.
Wyllie Eq. - linear time averaged relationship

\[ \Delta t = \frac{\sum L_f}{V_f} + \frac{\sum L_{ma}}{V_{ma}} \]

- empirically determined
- for clean and consolidated sandstones
- uniformly distributed small pores
Wyllie Equation

\[ \phi = \frac{\Delta t_{\log} - \Delta t_{ma}}{\Delta t_{f} - \Delta t_{ma}} \]

<table>
<thead>
<tr>
<th>(\Delta t_{ma}, \mu\text{sec/ft})</th>
<th>(\Delta t_{f}, \mu\text{sec/ft})</th>
</tr>
</thead>
<tbody>
<tr>
<td>ss</td>
<td>55.5</td>
</tr>
<tr>
<td>lms</td>
<td>47.6</td>
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<tr>
<td>dol</td>
<td>43.5</td>
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<tr>
<td>Anhy</td>
<td>50.0</td>
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</tbody>
</table>
**Sonic Log**

**Evidence:** when $\Delta t_{\log} > 100$ microsec/ft in overlying shale

**Result:** Estimated porosity too high

**Correction:** Observed transit times are greater in uncompacted sands; thus apply empirical correction factor, $C_p$

$$
\phi = \frac{t_{\log} - t_{ma}}{t_f - t_{ma}} \frac{1}{C_p}
$$

Estimate $C_p$ from overlying shale zone

$$
C_p = c \frac{\Delta t_{sh}}{100}
$$

where the shale compaction coefficient, $c$, ranges from $0.8 < c < 1.3$. 
• Sonic primarily independent of fluid type

• Know lithology, can calculate porosity

• Fluid Effect in high porosity formations with high HC saturation. Correct by:

\[
\begin{align*}
\text{oil: } & \phi_{\text{corr}} = 0.9 \phi_s \\
\text{gas: } & \phi_{\text{corr}} = 0.7 \phi_s
\end{align*}
\]

• Apply after compaction correction.
Cp = 1.44...from overlying shale

Ave zone
Core $\phi$
Transit time - porosity transform (Raymer-Hunt)

- based on field observation
- yields slightly greater porosity in the 5 to 25% range
- does not require compaction correction

\[ \phi = C \frac{t_{log} - t_{ma}}{t_{log}} \]

Where

C ranges from 0.625 to 0.700
Typical value used in practice is C = 0.67
C = 0.6 for gas-saturated formations
- Sonic ignores secondary porosity; i.e., vugs and fractures

- Result: Measured transit time < than would be calculated for given porosity

- Estimate Secondary porosity by:
  \[ \phi_2 = \phi_t - \phi_s \]

- Alternative: Develop specific empirical relationships for heterogeneous systems

Example of Porosity – Velocity Correlation in Dolomite
The example illustrates travel times which are consistently greater than predicted by the “time-average equation”. (Corelab)
- Chapter 3 – Acoustic Properties of Rocks
- Chapter 10 – Sonic Porosity Log

- Schlumberger, *Log Interpretation Charts, Houston, TX (1995)*
- Schlumberger, *Log Interpretation and Principles, Houston, TX (1989)*

- Western Atlas, *Log Interpretation Charts, Houston, TX (1992)*
- Western Atlas, *Introduction to Wireline Log Analysis, Houston, TX (1995)*

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