Why resistivity logs?

Estimate $R_t$

Why need $R_t$?

$$S_w = \sqrt[FR_w]{R_t}$$
## Resistivity Logs

<table>
<thead>
<tr>
<th>Classification</th>
<th>Flushed Zone 1-6 in.</th>
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<td><strong>Salt Mud</strong></td>
<td>Micro-laterolog (MLL)</td>
<td>Laterolog-7 Tool</td>
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<td>Shallow Laterolog</td>
<td>Deep Laterolog</td>
<td>DLL-MLL, DLL-MSFL</td>
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<td></td>
<td>MSFL</td>
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<td>(LLD)</td>
<td></td>
<td></td>
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</table>
Resistivity Logs

Example: Old ES

Bagley Penn Field
Chambers No. 2
Lea County, NM
<table>
<thead>
<tr>
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<td>Obsolete</td>
</tr>
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</table>

**Fresh Mud**

- Microlog (ML)
- Minilog
- Proximity (PL)

**R_{mf}>2R_w**

- Spherically Focused
- LL8/Short Guard
- Spherically Focused
- Spherically Focused

**Induction (6FF40)**

- Medium Induction
- Deep Induction
- Deep Phasor Induction

**Years**

- 1955-80
- 1970-85
- 1965
- 1975
- 1985

**Name**

- IES, IEL
- ISF
- DIL-LL8, DIFL, DISG
- DIL-SFL
- Phasor

**Comments**

- Obsolete
- Obsolete
- Current
- Current

**Array Induction Tool**

- 1990
- AIT

**Salt Mud**

- MicroLaterolog (MLL)
- MLL
- MSFL

**R_{mf}<2R_w**

- Shallow Laterolog (LLS)
- Deep Laterolog (LLD)

**Years**

- 1955-80
- 1972

**Name**

- LL7, LL3, guard
- DLL-MLL, DLL-MSFL

**Comments**

- Obsolete
- Current
Resistivity Logs

Example: IEL

IES or IEL; short normal or spherically focused curve with a deep induction.

*(No correction for invasion!)*
## Resistivity Logs

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### Salt Mud

| R_mf<2R_w Or        | Micro-laterolog (MLL) | Shallow Laterolog-7 / Guard | Laterolog-3 / Guard | 1955-80 | LL7, LL3, guard | Obsolete |
| R_t>200             | MLL MSFL             | Deep Laterolog (LLD)        | Deep Laterolog (LLD) | 1972  | DLL-MLL DLL-MSFL | Current |
Resistivity Logs

Example:
SFL-ILM-ILD

Replaced in the mid-1960s with a Dual induction tool (shallow, medium, and deep curves); DIL-LL8, DIFL, DISG

Improved DIL with the addition of the spherically focused shallow log; DISF

Big Lake (San Andres)
<table>
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Resistivity Logs

Example: High resolution or Phasor induction

Next improvement is known as the *Phasor Induction Tool* - better thin bed resolution and automatic corrections.
# Resistivity Logs Classification

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Resistivity Logs

Example: Array induction

DIL log

Ambiguous reading

Correct reading

AIT log

Source: Halliburton
Resistivity Logs

- where fresh mud or oil-base mud (or air-filled holes) is used,

- where the $R_{mf}/R_w$ ratio is greater than 2.5 to 3,

- where $R_t$ is less than 200 ohm-m
Resistivity Logs

Theory

Circumferential Current I

\[ \frac{1}{R_{ILD}} = \frac{G_m}{R_m} + \frac{G_{xo}}{R_{xo}} + \frac{G_t}{R_t} + \frac{G_s}{R_s} \]

or

\[ C_{ILD} = G_mC_m + G_{xo}C_{xo} + G_tC_t + G_sC_s \]
Resistivity Logs

Determination of Rt

Read apparent resistivity from well log, $R_a$

Correct for borehole effect (if necessary)

Correct for bed thickness effect (if necessary)

Correct for invasion effect (if three curves are present)

True formation resistivity, $R_t$
Resistivity Logs

Determination of $R_t$

Read **apparent** resistivity from well log, $R_{ILD}$ or $C_{ILD}$

$$C_{ILD} = G_m C_m + G_{xo} C_{xo} + G_t C_t + G_s C_s$$

Correct for **borehole** effect (if necessary)

$$C'_{ILD} = C_{ILD} - G_m C_m = G_{xo} C_{xo} + G_t C_t + G_s C_s$$
Resistivity Logs

**Given**
1.5” standoff in a 14.6” hole
Rm = 0.35 ohm-m
ILD = 50 ohm-m (20 mmho/m)

**Solution**
hole signal = 5.7 mmho/m
Ct (corr) = Ct - hole signal
Rt = 70 ohm-m
Resistivity Logs

- significant when:
  - mud is salty
  - hole size is large and/or oval
  - formation resistivity is high

- **Corrections** greatest for:
  - induction tool against borehole, standoff is zero.
  - ILM than ILD
  - holes > 12”
Read \textbf{apparent} resistivity from well log, $R_{ILD}$ or $C_{ILD}$

$$C_{ILD} = G_m C_m + G_{xo} C_{xo} + G_t C_t + G_s C_s$$

\[\downarrow\]

Correct for \textbf{borehole} effect (if necessary)

$$C'_{ILD} = C_{ILD} - G_m C_m = G_{xo} C_{xo} + G_t C_t + G_s C_s$$

\[\downarrow\]

Correct for \textbf{bed thickness} effect (if necessary)

$$C''_{ILD} = C'_{ILD} - G_s C_s = G_{xo} C_{xo} + G_t C_t$$
Resistivity Logs

• The bed thickness effect is a function of bed thickness, vertical resolution of tool, and resistivity contrast $R_t/R_s$.

• Corrections necessary for:
  – thick beds with $R_t/R_s >> 1$
  – thin beds with large $R_t/R_s$ contrast
Resistivity Logs

Bed thickness correction

Deep Induction Log Bed Thickness Correction (Schlumberger)
Resistivity Logs

Determination of \( R_t \)

Read **apparent** resistivity from well log, \( R_{ILD} \) or \( C_{ILD} \)

\[
C_{ILD} = G_m C_m + G_{xo} C_{xo} + G_t C_t + G_s C_s
\]

Correct for **borehole** effect (if necessary)

\[
C'_{ILD} = C_{ILD} - G_m C_m = G_{xo} C_{xo} + G_t C_t + G_s C_s
\]

Correct for **bed thickness** effect (if necessary)

\[
C''_{ILD} = C'_{ILD} - G_s C_s = G_{xo} C_{xo} + G_t C_t
\]

Correct for **invasion** effect (if three curves are present)

\[
C''_{ILD} = G_{xo(d_i)} C_{xo} + G_{t(d_i)} C_t
\]

\[
C''_{ILM} = \ldots
\]

\[
C''_{SFL} = \ldots
\]

**True** formation resistivity, \( R_t \)
Example 1

**Given**
R_t = 10 ohm-m  
Fresh mud, R_m = 1  
R_xo = 20  
d_i = 65”

**Solution**
G(ILD) = 0.2

R_a = 11 ohm-m  
(10% error)
Resistivity Logs

Example 1

**Given**
- \( R_t = 10 \text{ ohm}-\text{m} \)
- Salt mud, \( R_m = 0.05 \)
- \( R_{xo} = 1 \)
- \( d_i = 65'' \)

**Solution**
- \( G(ILD) = 0.2 \)
- \( R_a = 3.6 \text{ ohm}-\text{m} \)
  (Big error)
Resistivity Logs

Assume a step profile for invasion

Tornado charts to correct for invasion, determine $R_t$, $R_{xo}$, and $d_i$

- Rt correction factor between 0.75 and 1.0
- Depth of invasion is reflected by induction resistivity contrast:
  - $R_{im}/R_{id} > 1.5$ indicates deep invasion
  - $R_{im}/R_{id} < 1.2$ indicates shallow invasion
Resistivity Logs

Invasion Correction

Example

\[ R_{ILD} = 10 \, \Omega m \]
\[ R_{ILM} = 14 \, \Omega m \]
\[ R_{SFL} = 90 \, \Omega m \]

Solution:

(1). \[ \frac{R_{SFL}}{R_{ID}} = 9 \]

\[ \frac{R_{IM}}{R_{ID}} = 1.4 \]
Resistivity Logs

Invasion Correction

\[
\frac{R_t}{R_{ID}} = 0.89 \text{ from chart (2)}
\]

\[
R_t = \left(\frac{R_t}{R_{ID}}\right)^* R_{ID} = 8.9 \Omega - m \quad (3)
\]

\[
R_{xo} = 14 \Rightarrow \frac{R_{xo}}{R_t} = 14
\]

\[
R_{xo} = 125 \Omega - m \quad (4)
\]

\[
d_i = 50'' \quad (5)
\]
Resistivity Logs

Invasion Correction

Example

\[ R_{\text{ILD}} = 10 \text{ } \Omega \text{m} \]
\[ R_{\text{ILM}} = 14 \text{ } \Omega \text{m} \]
\[ R_{\text{SFL}} = 90 \text{ } \Omega \text{m} \]
Resistivity Logs

Example:
SFL-ILM-ILD

Big Lake (San Andres)
Resistivity Logs

Invasion Correction

Big Lake (San Andres)
### Big Lake (San Andres) Example

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<th>ILD</th>
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<th>SFL</th>
<th>SFL/ILD</th>
<th>ILM/ILD</th>
<th>Rt/RILD</th>
<th>Rt</th>
<th>Rxo/Rt</th>
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<th>di”</th>
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<td>1</td>
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<td>14</td>
<td>100</td>
<td>10.0</td>
<td>1.40</td>
<td>0.92</td>
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<td>45</td>
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<td>5</td>
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<td>90+</td>
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<td>6.8</td>
<td>8.3</td>
<td>50</td>
<td>7.35</td>
<td>1.22</td>
<td>0.99</td>
<td>6.7</td>
<td>12</td>
<td>80</td>
<td>35</td>
</tr>
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_Schlumberger Chart, Rxo/Rm = 20_
Resistivity Logs

Example: High resolution or Phasor induction

Improvements
(1). Thinner bed resolution (2 ft.)

(2). Comprehensive set of automatic corrections for:
- shoulder effect and thin bed resolution
- skin effect
- borehole and cave effect
- large boreholes
- invasion effects
Array Induction Image Tool (AIT) or High Resolution Imager (HRI)

Main features:

1. full borehole corrections over a range of $R_t/R_m$ contrasts

2. the ability to use short array information to solve for effective borehole parameters

3. Five log curves are presented at median depths of investigation of 10, 20, 30, 60 and 90 inches. Three vertical resolutions of 1, 2 and 4 ft.

4. improvement in invasion profiles for both oil- and water-based muds. This includes accurate $R_t$ estimate and a quantitative description of the transition zone.

5. Capability of producing resistivity and saturation images of the formation.
Resistivity Logs

Example: Array induction

DIL log

Ambiguous reading

Correct reading

Source: Halliburton
Resistivity Logs

Example: Array induction

Estimated invaded volumes from AIT log (Halliburton)
Resistivity Logs


Chapter 5, Sec 5 and 6

Schlumberger, Log Interpretation Charts, Houston, TX (1995)

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