Chapter 11
Clean Formation Interpretation

Lecture notes for PET 370
Spring 2012
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Clean Formation Interpretation

Applications

• porosity in formations with unknown and/or multiple minerals

• mineralogy determination

• secondary porosity detection

• evaluation of mineral deposits such as sulfur, coal, potash, uranium
Clean Formation Interpretation

• Clean formation; i.e., no shale fraction

• Formation composed of two discernable minerals, $V_1$ and $V_2$

• Pore space is liquid-filled.
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Idealized CNL-FDC response in common lithologies (Pirson, 1963)
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Example CNL-FDC response from Northern Rocky Mountain Well (Pirson, 1963)
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- Combine two porosity logs (density, neutron, or sonic) onto one chart.
- Use a reference scale, typically limestone, known as apparent limestone porosity units.
  - neutron from equivalence charts
  - sonic from transit time charts
  - density from mass balance equation
- Three equations for three unknowns
  \[ \rho_b = f(\phi, V_1, V_2) \]
  \[ \phi_n = f(\phi, V_1, V_2) \]
  \[ 1 = \phi + (1-\phi)*(V_1 + V_2) \]
  where \( V_1 \) and \( V_2 \) are volumetric mineral fractions as percent of grain volume.
- Isoporosity and constant mineral scales

Crossplot Technique
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Selection of crossplot:
1. based on tool types
2. Age of CNL tool (pre 1986)
3. fluid density, 
   \( \rho_f = 1.0 \) or 1.1 gm/cc
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Example No. 1
Determine the porosity and lithology of points A through E on the attached FDC - CNL log. The mud density is 1.1 gm/cc and the CNL was run before 1986.
Clean Formation I

Example no. 1
Determination of $\rho_{maa}$ from FDC and CNL logs
(Fresh mud)
Analytical solution

\[ U = \phi U_f + (1 - \phi) \sum_{i=1}^{3} V_i \times U_{ma_i} \]

\[ \phi_N = \phi(H_n)_f + (1 - \phi) \sum_{i=1}^{3} V_i \times H_{Nma_i} \]

\[ \rho_b = \phi \rho_f + (1 - \phi) \sum_{i=1}^{3} V_i \times \rho_{ma_i} \]

\[ \phi + (1 - \phi) \times \sum_{i=1}^{3} V_i = 1 \]
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Graphical
1. M/N plot - Combine sonic, density, and neutron readings to minimize porosity effect and maximize matrix effect.

2. MID plots
   a. Density-neutron-sonic
   b. Density-neutron-Pe

M/N Plot Limitations
- Separation between sandstone, limestone, and dolomite points is narrow, resulting in ambiguous answers.
- Tedious calculations
- M and N lack any physical meaning
- Multiple matrix points for varying porosity ranges.
- Readings affected by: shale, gas, secondary porosity, evaporates.

Best
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\[
\rho_b, \text{ Pe from LDT and } \phi_N
\]

\[
\phi_{xp} = \frac{\phi_n + \phi_d}{2} \quad \rho_{maa} = \frac{\rho_b - \phi_{xp} \rho_f}{1 - \phi_{xp}}
\]

\[
U = \frac{Pe (\rho_b + 0.1883)}{1.0704}
\]

\[
U_{maa} = \frac{U - Uf \phi_{xp}}{1 - \phi_{xp}} = \sum_{i=1}^{3} V_i * U_{maa_i}
\]

\(U_i\) is the fluid volumetric index
\(U_{maa}\) is the apparent matrix…index

Plot \(U_{maa}\) vs \(\rho_{maa}\)
Determine mineralogy

<table>
<thead>
<tr>
<th>Material</th>
<th>(Pe)</th>
<th>Sp.gr</th>
<th>(e_{blog})</th>
<th>(U)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>1.810</td>
<td>2.65</td>
<td>2.64</td>
<td>4.780</td>
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<tr>
<td>Calcite</td>
<td>5.080</td>
<td>2.71</td>
<td>2.71</td>
<td>13.800</td>
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<tr>
<td>Dolomite</td>
<td>3.140</td>
<td>2.85</td>
<td>2.85</td>
<td>9.000</td>
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<tr>
<td>Anhydrite</td>
<td>5.050</td>
<td>2.96</td>
<td>2.98</td>
<td>14.900</td>
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<tr>
<td>Halite</td>
<td>4.650</td>
<td>2.17</td>
<td>2.04</td>
<td>9.680</td>
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<tr>
<td>Siderite</td>
<td>14.700</td>
<td>3.94</td>
<td>3.89</td>
<td>55.900</td>
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<tr>
<td>Pyrite</td>
<td>17.000</td>
<td>5.00</td>
<td>4.99</td>
<td>62.100</td>
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<tr>
<td>Barite</td>
<td>267000</td>
<td>4.48</td>
<td>4.09</td>
<td>1065000</td>
</tr>
<tr>
<td>Water (fresh)</td>
<td>0.358</td>
<td>1.00</td>
<td>1.00</td>
<td>0.398</td>
</tr>
<tr>
<td>Water (100K ppm NaCl)</td>
<td>0.734</td>
<td>1.06</td>
<td>1.05</td>
<td>0.850</td>
</tr>
<tr>
<td>Water (200K ppm NaCl)</td>
<td>1.120</td>
<td>1.12</td>
<td>1.11</td>
<td>1.360</td>
</tr>
<tr>
<td>Oil (n(CH3))</td>
<td>0.119</td>
<td>(e_o)</td>
<td>1.22 (e_o - .118)</td>
<td>0.136 (e_o)</td>
</tr>
<tr>
<td>Gas (CH4)</td>
<td>0.095</td>
<td>(e_g)</td>
<td>1.33 (e_g - .188)</td>
<td>0.119 (e_g)</td>
</tr>
</tbody>
</table>
Clean Formation Interpretation

LDT Mid plot
Example no. 2

\[ \rho_{mf} = 1.1 \text{ gm/cc} \]
\[ U_f = 1.36 \]
\[ \rho_{ma} \text{ (reference) } = \text{Ims} \]
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Example No. 2

**Liquid-filled borehole** ($\rho_f = 1.190 \text{ g/cm}^3$ and $C_f = 250,000 \text{ ppm}$)

- Sulfur
- Salt

**Bulk density, $\rho_b$ (g/cm$^3$)**

- Anhydrite
- Dolomite
- Calcrete limestone
- Quartz sandstone

**Porosity**

- Approximate gas correction

**Density porosity, $\phi_b$ (p.u.)**

- ($\rho_{ms} = 2.71 \text{ g/cm}^3$, $\rho_f = 1.19 \text{ g/cm}^3$)

**Corrected apparent limestone neutron porosity, $\phi_{CNLcorr}$ (p.u.)**
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Example No. 2
Clean Formation Interpretation

Chapter 14

- 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)*