Log Interpretation Charts

2009 Edition
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This edition of the Schlumberger “chartbook” presents several innovations.

First, the charts were developed to achieve two purposes:

- Correct raw measurements to account for environmental effects
  Early downhole measurements were performed in rather uniform conditions (vertical wells drilled through quasi-horizontal thick beds, muds made of water with a narrow selection of additives, and limited range of hole sizes), but today wells can be highly deviated or horizontal, mud contents are diverse, and hole sizes range from 2 to 40 in. Environmental effects may be large. In addition, they compound. It is essential to correct for these effects before the measurements are used.

- Use environmentally corrected measurements for interpretation

Charts related to measurements that are no longer performed are not included in this chartbook. However, because many oil and gas companies use logs acquired years or even decades ago, the second chartbook, *Historical Log Interpretation Charts*, contains these old charts.

Why publish charts on paper in our electronic age? It is true that software may be more effective than pencil to derive results. Even more so, this chartbook cannot cope with the complex well situations that are encountered. Using software is the only way to proceed.

Thus, the chartbook has two primary functions:

- Training
  The chartbook is essential for educating junior petrophysicists about the different effects on the measurements. In the interpretation process, the chartbook unveils the relationships between the different parameters.

- Sensitivity analysis
  A chart gives the user a graphical idea of the sensitivity of an output to the various inputs (see Chart Gen-1). The visual presentation is helpful for determining if an input parameter is critical. The user can then focus on the most sensitive inputs.
Symbols Used in Log Interpretation

**Purpose**
This diagram presents the symbols and their descriptions and relations as used in the charts. See Appendixes D and E for identification of the symbols.

**Description**
The wellbore is shown traversing adjacent beds above and below the zone of interest. The symbols and descriptions provide a graphical representation of the location of the various symbols within the wellbore and formations.
Estimation of Formation Temperature with Depth

**Purpose**
This chart has a twofold purpose. First, a geothermal gradient can be assumed by entering the depth and a recorded temperature at that depth. Second, for an assumed geothermal gradient, if the temperature is known at one depth in the well, the temperature at another depth in the well can be determined.

**Description**
Depth is on the y-axis and has the shallowest at the top and the deepest at the bottom. Both feet and meters are used, on the left and right axes, respectively. Temperature is plotted on the x-axis, with Fahrenheit on the bottom and Celsius on the top of the chart. The annual mean surface temperature is also presented in Fahrenheit and Celsius.

**Example**
Given: Bottomhole depth = 11,000 ft and bottomhole temperature = 200°F (annual mean surface temperature = 80°F).
Find: Temperature at 8,000 ft.
Answer: The intersection of 11,000 ft on the y-axis and 200°F on the x-axis is a geothermal gradient of approximately 1.1°F/100 ft (Point A on the chart). Move upward along an imaginary line parallel to the constructed gradient lines until the depth line for 8,000 ft is intersected. This is Point B, for which the temperature on the x-axis is approximately 167°F.
Temperature gradient conversions:  
1°F/100 ft = 1.823°C/100 m
1°C/100 m = 0.5486°F/100 ft
Estimation of $R_{mf}$ and $R_{mc}$

**Fluid Properties**

**Purpose**
Direct measurements of filtrate and mudcake samples are preferred. When these are not available, the mud filtrate resistivity ($R_{mf}$) and mudcake resistivity ($R_{mc}$) can be estimated with the following methods.

**Description**

**Method 1: Lowe and Dunlap**
For freshwater muds with measured values of mud resistivity ($R_m$) between 0.1 and 2.0 ohm-m at 75°F [24°C] and measured values of mud density ($\rho_m$) (also called mud weight) in pounds per gallon:

$$\log \left( \frac{R_{mf}}{R_m} \right) = 0.396 - \left(0.0475 \times \rho_m\right).$$

**Method 2: Overton and Lipson**
For drilling muds with measured values of $R_m$ between 0.1 and 10.0 ohm-m at 75°F [24°C] and the coefficient of mud ($K_m$) given as a function of mud weight from the table:

$$R_{mf} = K_m \left( R_m \right)^{1.07}$$
$$R_{mc} = 0.69 \left( R_{mf} \right) \left( \frac{R_m}{R_{mf}} \right)^{2.65}.$$  

**Example**
Given: $R_m = 3.5$ ohm-m at 75°F and mud weight = 12 lbm/gal [1,440 kg/m$^3$].
Find: Estimated values of $R_{mf}$ and $R_{mc}$.
Answer: From the table, $K_m = 0.584$.
$$R_{mf} = (0.584) (3.5)^{1.07} = 2.23$$ ohm-m at 75°F.
$$R_{mc} = 0.69 (2.23) (3.5/2.23)^{2.65} = 5.07$$ ohm-m at 75°F.

<table>
<thead>
<tr>
<th>Mud Weight</th>
<th>lbm/gal</th>
<th>kg/m$^3$</th>
<th>$K_m$</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1,200</td>
<td>0.847</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>1,320</td>
<td>0.708</td>
<td></td>
</tr>
<tr>
<td>12</td>
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<td>13</td>
<td>1,560</td>
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<td>14</td>
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<tr>
<td>18</td>
<td>2,160</td>
<td>0.350</td>
<td></td>
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</tbody>
</table>
Equivalent NaCl Salinity of Salts

Purpose
This chart is used to approximate the parts-per-million (ppm) concentration of a sodium chloride (NaCl) solution for which the total solids concentration of the solution is known. Once the equivalent concentration of the solution is known, the resistivity of the solution for a given temperature can be estimated with Chart Gen-6.

Description
The x-axis of the semilog chart is scaled in total solids concentration and the y-axis is the weighting multiplier. The curve set represents the various multipliers for the solids typically in formation water.

Example
Given: Formation water sample with solids concentrations of calcium (Ca) = 460 ppm, sulfate (SO4) = 1,400 ppm, and Na plus Cl = 19,000 ppm. Total solids concentration = 460 + 1,400 + 19,000 = 20,860 ppm.

Find: Equivalent NaCl solution in ppm.

Answer: Enter the x-axis at 20,860 ppm and read the multiplier value for each of the solids curves from the y-axis: Ca = 0.81, SO4 = 0.45, and NaCl = 1.0. Multiply each concentration by its multiplier:

\[(460 \times 0.81) + (1,400 \times 0.45) + (19,000 \times 1.0) = 20,000 \text{ ppm.}\]
### Concentrations of NaCl Solutions

<table>
<thead>
<tr>
<th>g/L at 77°F</th>
<th>ppm</th>
<th>grains/gal at 77°F</th>
<th>Density of NaCl solution at 77°F [25°C]</th>
<th>Temperature Gradient Conversion</th>
<th>Oil Gravity</th>
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</thead>
<tbody>
<tr>
<td>0.15</td>
<td>150</td>
<td>10</td>
<td>1.00</td>
<td>2.0°F/100 ft</td>
<td>0.60°API</td>
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<tr>
<td>0.2</td>
<td>200</td>
<td>12.5</td>
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<td>3.5°F/100 ft</td>
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<tr>
<td>0.3</td>
<td>300</td>
<td>15</td>
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<td>1.9°F/100 ft</td>
<td>0.64°API</td>
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<tr>
<td>0.4</td>
<td>400</td>
<td>20</td>
<td></td>
<td>1.8°F/100 ft</td>
<td>0.66°API</td>
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<tr>
<td>0.5</td>
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<td>25</td>
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<td>1.7°F/100 ft</td>
<td>0.68°API</td>
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<tr>
<td>0.6</td>
<td>600</td>
<td>30</td>
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<td>0.80°API</td>
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<td>0.88°API</td>
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<td>1.00°API</td>
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<td></td>
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<tr>
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<td>100,000</td>
<td>850</td>
<td></td>
<td></td>
<td>1.06°API</td>
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<tr>
<td>125</td>
<td>125,000</td>
<td>1,000</td>
<td></td>
<td></td>
<td>1.08°API</td>
</tr>
</tbody>
</table>

\[^{\circ}API = \frac{141.5}{\text{sg at } 60^\circF} - 131.5\]

\[^{\circ}F/100 \text{ ft} = 1.822^{\circ}C/100 \text{ m}\]

\[^{\circ}C/100 \text{ m} = 0.5488^{\circ}F/100 \text{ ft}\]

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Resistivity of NaCl Water Solutions

**Purpose**
This chart has a twofold purpose. The first is to determine the resistivity of an equivalent NaCl concentration (from Chart Gen-4) at a specific temperature. The second is to provide a transition of resistivity at a specific temperature to another temperature. The solution resistivity value and temperature at which the value was determined are used to approximate the NaCl ppm concentration.

**Description**
The two-cycle log scale on the x-axis presents two temperature scales for Fahrenheit and Celsius. Resistivity values are on the left four-cycle log scale y-axis. The NaCl concentration in ppm and grains/gal at 75°F [24°C] is on the right y-axis. The conversion approximation equation for the temperature (T) effect on the resistivity (R) value at the top of the chart is valid only for the temperature range of 68° to 212°F [20° to 100°C].

**Example One**
Given: NaCl equivalent concentration = 20,000 ppm.
Temperature of concentration = 75°F.

Find: Resistivity of the solution.

Answer: Enter the ppm concentration on the y-axis and the temperature on the x-axis to locate their point of intersection on the chart. The value of this point on the left y-axis is 0.3 ohm-m at 75°F.

**Example Two**
Given: Solution resistivity = 0.3 ohm-m at 75°F.
Find: Solution resistivity at 200°F [93°C].
Answer 1: Enter 0.3 ohm-m and 75°F and find their intersection on the 20,000-ppm concentration line. Follow the line to the right to intersect the 200°F vertical line (interpolate between existing lines if necessary). The resistivity value for this point on the left y-axis is 0.115 ohm-m.

Answer 2: Resistivity at 200°F = resistivity at 75°F × [(75 + 6.77)/(200 + 6.77)] = 0.3 × (81.77/206.77) = 0.1186 ohm-m.

continued on next page
Resistivity of NaCl Water Solutions

Conversion approximated by:

\[ R_2 = R_1 \left( \frac{T_1 + 6.77}{T_2 + 6.77} \right) \]°F or

\[ R_2 = R_1 \left( \frac{T_1 + 21.5}{T_2 + 21.5} \right) \]°C

NaCl concentration (ppm or grains/gal)

Resistivity of solution (ohm-m)

Temperature

Grains/gal at 75°F
Purpose
These charts are for determination of the density (g/cm³) and hydrogen index of water for known values of temperature, pressure, and salinity of the water. From a known hydrocarbon density of oil, a determination of the hydrogen index of the oil can be obtained.

Description: Density of Water
To obtain the density of the water, enter the desired temperature (°F at the bottom x-axis or °C at the top) and intersect the pressure and salinity in the chart. From that point read the density on the y-axis.

Example: Density of Water
Given: Temperature = 200°F [93°C], pressure = 7,000 psi, and salinity = 250,000 ppm.
Answer: Density of water = 1.15 g/cm³.

Example: Hydrogen Index of Salt Water
Given: Salinity of saltwater = 125,000 ppm.
Answer: Hydrogen index = 0.95.

Example: Hydrogen Index of Hydrocarbons
Given: Oil density = 0.60 g/cm³.
Answer: Hydrocarbon index = approximately 0.91.
Purpose
This chart can be used to determine more than one characteristic of natural gas under different conditions. The characteristics are gas density ($p_g$), gas pressure, and hydrogen index ($H_{gas}$).

Description
For known values of gas density, pressure, and temperature, the value of $H_{gas}$ can be determined. If only the gas pressure and temperature are known, then the gas density and $H_{gas}$ can be determined. If the gas density and temperature are known, then the gas pressure and $H_{gas}$ can be determined.

Example
Given: Gas density = 0.2 g/cm$^3$ and temperature = 200°F.
Find: Gas pressure and hydrogen index.
Answer: Gas pressure = approximately 5,200 psi and $H_{gas}$ = 0.44.
Purpose
This chart is used to determine the sound velocity (ft/s) and sound slowness (μs/ft) of gas in the formation. These values are helpful in sonic and seismic interpretations.

Description
Enter the chart with the temperature (Celsius along the top x-axis and Fahrenheit along the bottom) to intersect the formation pore pressure.
**Purpose**
This chart illustrates the effect that gas in the formation has on the slowness time of sound from the sonic tool to anticipate the slowness of a formation that contains gas and liquid.

**Description**
Enter the chart with the compressional slowness time ($\Delta t_c$) from the sonic log on the y-axis and the liquid saturation of the formation on the x-axis. The curves are used to determine the gas effect on the basis of which correlation (Wood’s law or Power law) is applied. The slowing effect begins sooner for the Power law correlation. The Wood’s law correlation slightly increases $\Delta t_c$ values as the formation liquid saturation increases whereas the Power law correlation decreases $\Delta t_c$ values from about 20% liquid saturation.
**Purpose**
This chart is used to determine porosity from the compressional wave or shear wave velocity ($V_p$ and $V_s$, respectively).

**Description**
Enter $V_p$ or $V_s$ on the y-axis to intersect the appropriate curve. Read the porosity for the sandstone or limestone formation on the x-axis.
**Purpose**

*Longitudinal (Bulk) Relaxation Time of Pure Water*
This chart provides an approximation of the bulk relaxation time ($T_1$) of pure water depending on the temperature of the water.

*Transverse (Bulk and Diffusion) Relaxation Time of Water in the Formation*
Determining the bulk and diffusion relaxation time ($T_2$) from this chart requires knowledge of both the formation temperature and the echo spacing (TE) used to acquire the data. These data are presented graphically on the log and are the basis of the water or hydrocarbon interpretation of the zone of interest.

**Description**

*Longitudinal Relaxation Time*
The chart relation is for pure water—the additives in drilling fluids reduce the relaxation time ($T_1$) of water in the invaded zone. The two major contributors to the reduction are surfactants added to the drilling fluid and the molecular interactions of the mud filtrate contained in the pore spaces and matrix minerals of the formation.

*Transverse Relaxation Time*
The relaxation time ($T_2$) determination is based on the formation temperature and echo spacing used to acquire the measurement. The TE value is listed in the parameter section of the log. Using the $T_2$ measurement from a known water sand or based on local experience further aids in determining whether a zone of interest contains hydrocarbons, water, or both.
**Purpose**

**Longitudinal (Bulk) Relaxation Time of Crude Oil**

This chart is used to predict the $T_1$ of crude oils with various viscosities and densities or specific gravities to assist in interpretation of the fluid content of the formation of interest.

**Transverse (Bulk and Diffusion) Relaxation Time**

Known values of $T_2$ and TE can be used to approximate the viscosity by using this chart.

**Diffusion Coefficients for Hydrocarbon and Water**

These charts are used to predict the diffusion coefficient of hydrocarbon as a function of formation temperature and viscosity and of water as a function of formation temperature.

---

**Description**

**Longitudinal (Bulk) Relaxation Time**

This chart is divided into three distinct sections based on the composition of the oil measured. The type of oil contained in the formation can be determined from the measured $T_1$ and viscosity determined from the transverse relaxation time chart.

**Transverse (Bulk and Diffusion) Relaxation Time**

The viscosity can be determined with values of the measured $T_2$ and TE for input to the longitudinal relaxation time chart to identify the type of oil in the formation.
**Purpose**

**Methane Diffusion Coefficient**
This chart is used to determine the diffusion coefficient of methane at a known formation temperature and pressure.

**Longitudinal and Transverse Relaxation Times of Methane**
These charts are used to determine the longitudinal relaxation time ($T_1$) of methane by using the formation temperature and pressure (see Reference 48) and the transverse relaxation time ($T_2$) of methane by using the diffusion and echo spacing (TE), respectively.

**Hydrogen Index of Live Hydrocarbons and Gas**
This chart is used to determine the hydrogen index from the hydrocarbon density.
Purpose
The sigma value ($\Sigma_w$) of a saltwater solution can be determined from this chart. The sigma water value is used to calculate the water saturation of a formation.

Description
Charts Gen-12 and Gen-13 define sigma water for pressure conditions of ambient through 20,000 psi [138 MPa] and temperatures from 68° to 500°F [20° to 260°C]. Enter the appropriate chart for the pressure value with the known water salinity on the y-axis and move horizontally to intersect the formation temperature. The sigma of the formation water for the intersection point is on the x-axis.

Example
Given: Water salinity = 125,000 ppm, temperature = 68°F at ambient pressure, and formation temperature = 190°F at 5,000 psi.
Find: $\Sigma_w$ at ambient conditions and $\Sigma_w$ of the formation.
Answer: $\Sigma_w = 69$ c.u. and $\Sigma_w$ of the formation = 67 c.u.

If the sigma water apparent ($\Sigma_{wa}$) is known from a clean water sand, then the salinity of the formation can be determined by entering the chart from the sigma water value on the x-axis to intersect the pressure and temperature values.

continued on next page
**Purpose**

Chart Gen-13 continues Chart Gen-12 at higher pressure values for the determination of $\Sigma_w$ of a saltwater solution.
Purpose
Sigma hydrocarbon ($\Sigma_h$) for gas or oil can be determined by using this chart. Sigma hydrocarbon is used to calculate the water saturation of a formation.

Description
One set of charts is for measurement in metric units and the other is for measurements in “customary” oilfield units.

For gas, enter the background chart of a chart set with the reservoir pressure and temperature. At that intersection point move left to the y-axis and read the sigma of methane gas.

For oil, use the foreground chart and enter the solution gas/oil ratio (GOR) of the oil on the x-axis. Move upward to intersect the appropriate API gravity curve for the oil. From this intersection point, move horizontally left and read the sigma of the oil on the y-axis.

Example
Given: Reservoir pressure = 8,000 psi, reservoir temperature = $300^\circ$F, gravity of reservoir oil = $30^\circ$API, and solution GOR = 200.
Find: Sigma gas and sigma oil.
Answer: Sigma gas = 10 c.u. and sigma oil = 21.6 c.u.
**Purpose**
This chart is designed to determine the propagation time ($t_{pw}$) of saltwater solutions. The value of $t_{pw}$ of a water zone is used to determine the temperature variation of the salinity of the formation water.

**Description**
Enter the chart with the known salinity of the zone of interest and move upward to the formation temperature curve. From that intersection point move horizontally left and read the propagation time of the water in the formation on the y-axis. Conversely, enter the chart with a known value of $t_{pw}$ from the EPT Electromagnetic Propagation Tool log to intersect the formation temperature curve and read the water salinity at the bottom of the chart.
Purpose
This chart is designed to estimate the attenuation of saltwater solutions. The attenuation ($A_w$) value of a water zone is used in conjunction with the spreading loss determined from the EPT propagation time measurement ($t_{pl}$) to determine the saturation of the flushed zone by using Chart SatOH-8.

Description
Enter the chart with the known salinity of the zone of interest and move upward to the formation temperature curve. From that intersection point move horizontally left and read the attenuation of the water in the formation on the y-axis. Conversely, enter the chart with a known EATT attenuation value of $A_w$ from the EPT Electromagnetic Propagation Tool log to intersect the formation temperature curve and read the water salinity at the bottom of the chart.
Purpose
This chart is used to determine the apparent resistivity of the mud filtrate ($R_{mfa}$) from measurements from the EPT Electromagnetic Propagation Tool. The porosity of the formation ($\phi_{EPT}$) can also be estimated. Porosity and mud filtrate resistivity values are used in determining the water saturation.

Description
Enter the chart with the known attenuation and propagation time ($t_{pl}$). The intersection of those values identifies $R_{mfa}$ and $\phi_{EPT}$ from the two sets of curves. This chart is characterized for a sandstone formation at a temperature of 150°F [60°C].

Example
Given: Attenuation = 300 dB/m and $t_{pl}$ = 13 ns/m.
Find: Apparent resistivity of the mud filtrate and EPT porosity.
Answer: $R_{mfa}$ = 0.1 ohm-m and $\phi_{EPT}$ = 20 p.u.
Purpose
This chart provides a correction factor for measured values of formation gamma ray (GR) in gAPI units. The corrected GR values can be used to determine shale volume corrections for calculating water saturation in shaly sands.

Description
The semilog chart has the $t$ factor on the x-axis and the correction factor on the y-axis.

The input parameter, $t$, in g/cm², is calculated as follows:

$$
t = \frac{W_{\text{mud}}}{8.345} \left( \frac{2.54\left(d_h\right)}{2} - \frac{2.54\left(d_{\text{sonde}}\right)}{2} \right),
$$

where

$W_{\text{mud}}$ = mud weight (lbm/gal)
$d_h$ = diameter of wellbore (in.)
$d_{\text{sonde}}$ = outside diameter (OD) of tool (in.).

Example
Given: $GR = 36$ API units (gAPI), $d_h = 12$ in., mud weight = 12 lbm/gal, tool OD = $3\frac{3}{8}$ in., and the tool is centered.

Find: Corrected GR value.

Answer:

$$
t = \frac{12}{8.345} \left( \frac{2.54\left(12\right)}{2} - \frac{2.54\left(3.375\right)}{2} \right) = 15.8 \text{ g/cm}^2.
$$

Enter the chart at 15.8 on the x-axis and move upward to intersect the $3\frac{3}{8}$-in. centered curve. The corresponding correction factor is 1.6.

1.6 × 36 gAPI = 58 gAPI.
Purpose
These charts are used to further correct the GR reading for various borehole sizes.

Description
Two components needed to complete correction of the GR reading are determined with these charts: barite mud factor ($B_{mud}$) and borehole function factor ($F_{bh}$).

Example
Given: Borehole diameter = 6.0 in., tool OD = 3½ in., the tool is centered, mud weight = 12 lbm/gal, measured GR = 36 gAPI.
Find: Corrected GR value.
Answer: Enter the upper chart for $B_{mud}$ versus mud weight at 12 lbm/gal on the x-axis. The intersection point with the 3½-in. centered curve is $B_{mud} < 0.15$ on the y-axis.
Determine $(d_h - d_{sonde})$ as 6 − 3.375 = 2.625 in. and enter that value on the lower chart for $F_{bh}$ versus $(d_h - d_{sonde})$ on the x-axis. Move upward to intersect the 3½-in. curve, at which $F_{bh} = 0.81$.
Determine the new value of $t$ using the equation from Chart GR-1:
$$t = \frac{W_{mud}}{8.345} \left( \frac{2.54(d_h)}{2} - \frac{2.54(d_{sonde})}{2} \right)$$
$$= \frac{12}{8.345} \left( \frac{2.54(6)}{2} - \frac{2.54(3.375)}{2} \right) = 4.8 \text{ g/cm}^2.$$ The correction factor determined from Chart GR-1 is 0.95.
The complete correction factor is
$$(\text{Chart GR-1 correction factor}) \times [1 + (B_{mud} \times F_{bh})] = 1.12 \times [1 + (0.15 \times 0.81)] = 1.26.$$ Corrected GR = 36 × 1.26 = 45.4 gAPI.
**Purpose**

This chart is used to compensate for the effects of the casing, cement sheath, and borehole fluid on the GR count rate in cased holes for conditions of an eccentered 3¾-in. tool in an 8-in. borehole with 10-lbm/gal mud.

**Description**

In small boreholes the count rate can be too large, and in larger boreholes the count rate can be too small. The chart is based on openhole Chart GR-1, modified by laboratory and Monte Carlo calculations to provide a correction factor for application to the measured GR count rate in cased hole environments:

\[
t = \frac{2.54}{2} \left[ \frac{W_m}{8.345} \left( d_{\text{in}} - d_{\text{sonde}} \right)^2 + \rho_{\text{casing}} \left( d_{\text{ODcasing}} - d_{\text{IDcasing}} \right) + \rho_{\text{cement}} \left( d_{\text{h}} - d_{\text{IDcasing}} \right) \right].
\]

**Example**

Given: GR = 19 gAPI, hole diameter \(d_h \) = 12 in., casing OD \(d_{\text{ODcasing}} \) = 9¾ in. and 43.5 lbm/ft, casing ID \(d_{\text{IDcasing}} \) = 8.755 in., casing density \(\rho_{\text{casing}} \) = 7.96 g/cm³, tool OD \(d_{\text{sonde}} \) = 3¾ in., cement density \(\rho_{\text{cement}} \) = 2.0 g/cm³, and mud weight \(W_m \) = 8.345 lbm/gal.

Find: Corrected cased hole GR value.

Answer: The chart input factor calculated with the equation is \(t = 21.7 \text{ g/cm}^2\). Enter the chart at 21.7 on the x-axis. At the intersection point with the 3¾-in. curve, the value of the correction factor on the y-axis is 2.0. The GR value is corrected by multiplying by the correction factor: 19 gAPI \(\times 2.0 = 38\) gAPI.
Purpose
This chart is used to provide a correction factor for gamma ray values measured with the SlimPulse third-generation slim measurements-while-drilling (MWD) tool or the E-Pulse electromagnetic telemetry tool. These environmental corrections for mud weight and bit size are already applied to the gamma ray presented on the logs.

Description
Enter the chart with the mud weight on the x-axis and move upward to intersect the appropriate openhole size. Interpolate between lines as necessary. At the intersection point, move horizontally left to the y-axis to read the correction factor that the SlimPulse or E-Pulse gamma ray value was multiplied by to obtain the corrected gamma ray value in gAPI units.
**Purpose**
This chart is used to provide a correction factor for gamma ray values measured with the ImPulse integrated MWD platform. These environmental corrections for mud weight and bit size are already applied to the gamma ray presented on the logs.

**Description**
Enter the chart with the mud weight on the x-axis and move upward to intersect the appropriate bit size. Interpolate between lines as necessary. At the intersection point, move horizontally left to the y-axis to read the correction factor that the ImPulse gamma ray value was multiplied by to obtain the corrected gamma ray value in gAPI units.
This chart is used to provide a correction factor for gamma ray values measured with the PowerPulse 6.75-in. MWD telemetry system and TeleScope 6.75-in. high-speed telemetry-while-drilling service. These environmental corrections for mud weight and bit size are already applied to the gamma ray presented on the logs.

**Description**

Enter the chart with the mud weight on the x-axis and move upward to intersect the appropriate bit size. Interpolate between lines as necessary. At the intersection point, move horizontally left to the y-axis to read the correction factor that the PowerPulse or TeleScope gamma ray value was multiplied by to obtain the corrected gamma ray value in gAPI units.
Purpose
This chart is used to provide a correction factor for gamma ray values measured with the PowerPulse 8.25-in. normal-flow MWD telemetry system. These environmental corrections for mud weight and bit size are already applied to the gamma ray presented on the logs.

Description
Enter the chart with the mud weight on the x-axis and move upward to intersect the appropriate bit size. Interpolate between lines as necessary. At the intersection point, move horizontally left to the y-axis to read the appropriate correction factor that the PowerPulse gamma ray value was multiplied by to obtain the corrected GR value in gAPI units.
**Purpose**
This chart is used to provide a correction factor for gamma ray values measured with the PowerPulse 8.25-in. high-flow MWD telemetry system. These environmental corrections for mud weight and bit size are already applied to the gamma ray presented on the logs.

**Description**
Enter the chart with the mud weight on the x-axis and move upward to intersect the appropriate bit size. Interpolate between lines as necessary. At the intersection point, move horizontally left to the y-axis to read the correction factor that the PowerPulse gamma ray value was multiplied by to obtain the corrected gamma ray value in gAPI units.
**Purpose**
This chart is used to provide a correction factor for gamma ray values measured with the PowerPulse 9-in. MWD telemetry system. These environmental corrections for mud weight and bit size are already applied to the gamma ray presented on the logs.

**Description**
Enter the chart with the mud weight on the x-axis and move upward to intersect the appropriate bit size. Interpolate between lines as necessary. At the intersection point, move horizontally left to the y-axis to read the correction factor that the PowerPulse gamma ray value was multiplied by to obtain the corrected gamma ray value in gAPI units.
**Purpose**

This chart is used to provide a correction factor for gamma ray values measured with the PowerPulse 9.5-in. normal-flow MWD telemetry system. These environmental corrections for mud weight and bit size are already applied to the gamma ray presented on the logs.

**Description**

Enter the chart with the mud weight on the x-axis and move upward to intersect the appropriate bit size. Interpolate between lines as necessary. At the intersection point, move horizontally left to the y-axis to read the correction factor that the PowerPulse gamma ray value was multiplied by to obtain the corrected gamma ray value in gAPI units.
**Purpose**
This chart is used to provide a correction factor for gamma ray values measured by the PowerPulse 9.5-in. high-flow MWD telemetry system. These environmental corrections for mud weight and bit size are already applied to the gamma ray presented on the logs.

**Description**
Enter the chart with the mud weight on the x-axis and move upward to intersect the appropriate bit size. Interpolate between lines as necessary. At the intersection point, move horizontally left to the y-axis to read the correction factor that the PowerPulse gamma ray value was multiplied by to obtain the corrected gamma ray value in gAPI units.
Purpose
This chart is used to provide a correction factor for gamma ray values measured with the GVR resistivity sub of the geoVISION 6¾-in. MWD/LWD imaging system. These environmental corrections for mud weight and bit size are already applied to the gamma ray presented on the logs.

Description
Enter the chart with the mud weight on the x-axis and move upward to intersect the appropriate bit size. Interpolate between lines as necessary. At the intersection point, move horizontally left to the y-axis to read the correction factor that the GVR gamma ray value was multiplied by to obtain the corrected gamma ray value in gAPI units.
**Purpose**

This chart is used to provide a correction factor for gamma ray values measured with the RAB Resistivity-at-the-Bit 8.25-in. tool. These environmental corrections for mud weight and bit size are already applied to the gamma ray presented on the logs.

**Description**

Enter the chart with the mud weight on the x-axis and move upward to intersect the appropriate bit size. Interpolate between lines as necessary. At the intersection point, move horizontally left to the y-axis to read the correction factor that the RAB gamma ray value was multiplied by to obtain the corrected gamma ray value in gAPI units.
Purpose
This chart is used to provide a correction factor for gamma ray values measured with the arcVISION475 4¾-in. drill collar resistivity tool. These environmental corrections for mud weight and bit size are already applied to the gamma ray presented on the logs.

Description
Enter the chart with the mud weight on the x-axis and move upward to intersect the appropriate bit size. Interpolate between lines as necessary. At the intersection point, move horizontally left to the y-axis to read the correction factor that the arcVISION475 gamma ray value was multiplied by to obtain the corrected gamma ray value in gAPI units.
**Purpose**

This chart is used to provide a correction factor for gamma ray values measured with the arcVISION675 6¾-in. drill collar resistivity tool. These environmental corrections for mud weight and bit size are already applied to the gamma ray presented on the logs.

**Description**

Enter the chart with the mud weight on the x-axis and move upward to intersect the appropriate bit size. Interpolate between lines as necessary. At the intersection point, move horizontally left to the y-axis to read the appropriate correction factor that the arcVISION675 gamma ray value was multiplied by to obtain the corrected gamma ray value in gAPI units.
Purpose
This chart is used to provide a correction factor for gamma ray values measured with the arcVISION825 8¾-in. drill collar resistivity tool. These environmental corrections for mud weight and bit size are already applied to the gamma ray presented on the logs.

Description
Enter the chart with the mud weight on the x-axis and move upward to intersect the appropriate bit size. Interpolate between lines as necessary. At the intersection point, move horizontally left to the y-axis and read the appropriate correction factor that the arcVISION825 gamma ray value was multiplied by to obtain the corrected gamma ray value in gAPI units.
Purpose
This chart is used to provide a correction factor for gamma ray values measured with the arcVISION900 9-in. drill collar resistivity tool. These environmental corrections for mud weight and bit size are already applied to the gamma ray presented on the logs.

Description
Enter the chart with the mud weight on the x-axis and move upward to intersect the appropriate bit size. Interpolate between lines as necessary. At the intersection point, move horizontally left to the y-axis and read the appropriate correction factor that the arcVISION900 gamma ray value was multiplied by to obtain the corrected gamma ray value in gAPI units.
Purpose
This chart is used to provide a correction that is subtracted from the borehole-corrected gamma ray from the arcVISION475 4¾-in. tool. Environmental corrections for mud weight and bit size are already applied to the gamma ray presented on the logs.

Description
This chart is for illustrative purposes only. The indicated correction is already applied to the gamma ray log.

To determine the correction that was applied to the log output, enter the chart with the borehole size on the x-axis and move upward to intersect the downhole mud weight. From the intersection point move horizontally left to read the correction in gAPI units that was subtracted from the borehole-corrected data.

Charts GR-24 through GR-26 are similar to Chart GR-23 for different arcVISION tool sizes.
**Purpose**

This chart is used to provide a correction that is subtracted from the borehole-corrected gamma ray from the arcVISION675 63/4-in. tool. Environmental corrections for mud weight and bit size are already applied to the gamma ray presented on the logs.

**Description**

This chart is for illustrative purposes only. The indicated correction is already applied on the gamma ray log.

To determine the correction that was applied to the log output, enter the chart with the borehole size on the x-axis and move upward to intersect the downhole mud weight. From the intersection point move horizontally left to read the correction in gAPI units that was subtracted from the borehole-corrected data.
Purpose
This chart is used to provide a correction that is subtracted from the borehole-corrected gamma ray from the arcVISION825 8¼-in. tool. Environmental corrections for mud weight and bit size are already applied to the gamma ray presented on the logs.

Description
This chart is for illustrative purposes only. The indicated correction is already applied on the gamma ray log.

To determine the correction that was applied to the log output, enter the chart with the borehole size on the x-axis and move upward to intersect the downhole mud weight. From the intersection point move horizontally left to read the correction in gAPI units that was subtracted from the borehole-corrected data.
**Purpose**

This chart is used to provide a correction that is subtracted from the borehole-corrected gamma ray from the arcVISION900 9-in. tool. Environmental corrections for mud weight and bit size are already applied to the gamma ray presented on the logs.

**Description**

This chart is for illustrative purposes only. The indicated correction is already applied on the gamma ray log.

To determine the correction that was applied to the log output, enter the chart with the borehole size on the x-axis and move upward to intersect the downhole mud weight. From the intersection point move horizontally left to read the correction curve in gAPI units that was subtracted from the borehole-corrected data.
Purpose
This chart is used to provide a correction factor for gamma ray values measured with the EcoScope 6.75-in. Integrated LWD tool. These environmental corrections for mud weight and bit size are normally already applied to the gamma ray presented on the field logs.

Description
Enter the chart with the mud weight on the x-axis and move upward to intersect the appropriate bit size. Interpolate between lines as necessary. At the intersection point, move horizontally left to the y-axis to read the appropriate correction factor that the EcoScope 6.75-in. gamma ray value was multiplied by to obtain the corrected gamma ray value in gAPI units.
Purpose
This chart is used to illustrate the potassium correction that is subtracted from the borehole-corrected gamma ray from the EcoScope 6.75-in. Integrated LWD tool. Environmental corrections for mud weight, bit size, and potassium are normally already applied to the gamma ray presented on the field logs.

Description
This chart is for illustrative purposes only. The indicated correction is already applied on the gamma ray log. The chart shows the correction for a typical 5-wt% potassium concentration.

To determine the correction that was applied to the log output, enter the chart with the borehole size on the x-axis and move upward to intersect the downhole mud weight. From the intersection point move horizontally left to read the correction curve in gAPI units that was subtracted from the borehole-corrected data.
**Purpose**
This chart and nomograph are used to calculate the equivalent formation water resistivity ($R_{weq}$) from the static spontaneous potential ($E_{SSP}$) measured in clean formations. The value of $R_{weq}$ is used in Chart SP-2 to determine the resistivity of the formation water ($R_w$). $R_w$ is used in Archie’s water saturation equation.

**Description**
Enter the chart with $E_{SSP}$ in millivolts on the x-axis and move upward to intersect the appropriate temperature line. From the intersection point move horizontally to intersect the right y-axis for $R_{mfeq}/R_{weq}$. From this point, draw a straight line through the equivalent mud filtrate resistivity ($R_{mfeq}$) point on the $R_{mfeq}$ nomograph to intersect the value of $R_{weq}$ on the far-right nomograph.

The spontaneous potential (SP) reading corrected for the effect of bed thickness ($E_{SPcor}$) from Chart SP-4 can be substituted for $E_{SSP}$.

**Example**
First determine the value of $R_{mfeq}$:
- If $R_{mf}$ at $75^\circ F$ is greater than 0.1 ohm-m, correct $R_{mf}$ to the formation temperature by using Chart Gen-6, and use $R_{mfeq} = 0.85R_{mf}$.
- If $R_{mf}$ at $75^\circ F$ is less than 0.1 ohm-m, use Chart SP-2 to derive a value of $R_{mfeq}$ at formation temperature.

Given: $E_{SSP} = –100$ mV at $250^\circ F$ and resistivity of the mud filtrate ($R_{mf}$) = 0.7 ohm-m at $100^\circ F$, converted to 0.33 at $250^\circ F$.

Find: $R_{weq}$ at $250^\circ F$.
Answer: $R_{mfeq} = 0.85R_{mf} = 0.85 \times 0.33 = 0.28$ ohm-m.

Draw a straight line from the point on the $R_{mfeq}/R_{weq}$ line that corresponds to the intersection of $E_{SSP} = –100$ mV and the interpolated $250^\circ F$ temperature curve through the value of 0.28 ohm-m on the $R_{mfeq}$ line to the $R_{weq}$ line to determine that the value of $R_{weq}$ is 0.025 ohm-m.

The value of $R_{mfeq}/R_{weq}$ can also be determined from the equation

$$E_{SSP} = K_c \log \left(\frac{R_{mfeq}}{R_{weq}}\right),$$

where $K_c$ is the electrochemical spontaneous potential coefficient:

- $K_c = 61 + (0.133 \times \text{Temp}^\circ F)$
- $K_c = 65 + (0.24 \times \text{Temp}^\circ C)$.  

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Spontaneous Potential—Wireline

R_{weq} Determination from E_{SSP}

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Purpose
This chart is used to convert equivalent water resistivity ($R_{weq}$) from Chart SP-1 to actual water resistivity ($R_w$). It can also be used to convert the mud filtrate resistivity ($R_{mf}$) to the equivalent mud filtrate resistivity ($R_{mfeq}$) in saline mud. The metric version of this chart is Chart SP-3 on page 49.

Description
The solid lines are used for predominantly NaCl waters. The dashed lines are approximations for “average” fresh formation waters (for which the effects of salts other than NaCl become significant).

The dashed lines can also be used for gypsum-base mud filtrates.

Example
Given: From Chart SP-1, $R_{weq} = 0.025$ ohm-m at 250°F in predominantly NaCl water.
Find: $R_w$ at 250°F.
Answer: Enter the chart at the $R_{weq}$ value on the y-axis and move horizontally right to intersect the solid 250°F line. From the intersection point, move down to find the $R_w$ value on the x-axis. $R_w = 0.03$ ohm-m at 250°F.
Purpose
This chart is the metric version of Chart SP-2 for converting equivalent water resistivity ($R_{weq}$) from Chart SP-1 to actual water resistivity ($R_w$). It can also be used to convert the mud filtrate resistivity ($R_{mf}$) to the equivalent mud filtrate resistivity ($R_{mfeq}$) in saline mud.

Description
The solid lines are used for predominantly NaCl waters. The dashed lines are approximations for “average” fresh formation waters (for which the effects of salts other than NaCl become significant). The dashed lines can also be used for gypsum-base mud filtrates.

Example
Given: From Chart SP-1, $R_{weq} = 0.025$ ohm-m at 121°C in predominantly NaCl water.
Find: $R_w$ at 121°C.
Answer: $R_w = 0.03$ ohm-m at 121°C.
**Purpose**

Chart SP-4 is used to correct the SP reading from the well log for the effect of bed thickness. Generally, water sands greater than 20 ft in thickness require no or only a small correction.

**Description**

Chart SP-4 incorporates correction factors for a number of conditions that can affect the value of the SP in water sands.

The appropriate chart is selected on the basis of resistivity, invasion, hole diameter, and bed thickness. First, select the row of charts with the most appropriate value of the ratio of the resistivity of shale ($R_s$) to the resistivity of mud ($R_m$). On that row, select a chart for no invasion or for invasion for which the ratio of the diameter of invasion to the diameter of the wellbore ($d_i/d_h$) is 5. Enter the $x$-axis with the value of the ratio of bed thickness to wellbore diameter ($h/d_h$). Move upward to intersect the appropriate curve of the ratio of the true formation resistivity to the resistivity of the mud ($R_t/R_m$) for no invasion or the ratio of the resistivity of the flushed zone to the resistivity of the mud ($R_{xo}/R_m$) for invaded zones, interpolating between the curves as necessary. Read the ratio of the SP read from the log to the corrected SP ($ESP/ESP_{cor}$) on the $y$-axis for the point of intersection. Calculate $ESP_{cor} = ESP/(ESP/ESP_{cor})$. The value of $ESP_{cor}$ can be used in Chart SP-1 for $ESSP$. 

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**Purpose**
This chart is used to provide an empirical correction to the SP for the effects of invasion and bed thickness. The correction was obtained by averaging a series of thin-bed corrections in Reference 4. The resulting value of static spontaneous potential ($E_{SSP}$) can be used in Chart SP-1.

**Description**
This chart considers bed thickness ($h$) as a variable, and the ratio of the resistivity of the invaded zone to the resistivity of the mud ($R_i/R_m$) and the diameter of invasion ($d_i$) as parameters of fixed value. The borehole diameter is fixed at 8 in. and the tool size at 3¾ in.

To obtain the correction factor, enter the chart on the x-axis with the value of $h$. Move upward to the appropriate $d_i$ curve for the range of $R_i/R_m$. The correction factor on the y-axis corresponding to the intersection point is multiplied by the SP from the log to obtain the corrected SP.
**Purpose**

This chart is the metric version of Chart SP-5 for providing an empirical correction to the SP for the effects of invasion and bed thickness. The correction was obtained by averaging a series of thin-bed corrections in Reference 4. The resulting value of $E_{SSP}$ can be used in Chart SP-1.

**Description**

This chart considers bed thickness ($h$) as a variable, and $R_i/R_m$ and $d_i$ as parameters of fixed value. The borehole diameter is fixed at 203 mm and the tool size at 86 mm.
Porosity Effect on Photoelectric Cross Section

Purpose
This chart and accompanying table illustrate the effect that porosity, matrix, formation water, and methane (CH₄) have on the recorded photoelectric cross section (Pe).

Description
The table lists the data from which the chart was made. As the porosity increases the effect is greater for each mineral. Calcite has the largest effect in the presence of gas or water as the porosity increases.

Enter the chart with the total porosity (φₜ) from the log and move downward to intersect the angled line. From this point move to the left and intersect the line representing the appropriate matrix material: quartz, dolomite, or calcite minerals. From this intersection move upward to read the correct Pe.

<table>
<thead>
<tr>
<th>Matrix</th>
<th>φₜ</th>
<th>100% H₂O</th>
<th>100% CH₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>0.00</td>
<td>1.81</td>
<td>1.81</td>
</tr>
<tr>
<td></td>
<td>0.35</td>
<td>1.54</td>
<td>1.76</td>
</tr>
<tr>
<td>Calcite</td>
<td>0.00</td>
<td>5.08</td>
<td>5.08</td>
</tr>
<tr>
<td></td>
<td>0.35</td>
<td>4.23</td>
<td>4.96</td>
</tr>
<tr>
<td>Dolomite</td>
<td>0.00</td>
<td>3.14</td>
<td>3.14</td>
</tr>
<tr>
<td></td>
<td>0.35</td>
<td>2.66</td>
<td>3.07</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>—</td>
<td>1.00</td>
<td>0.10</td>
</tr>
</tbody>
</table>
**Purpose**

This chart is used to determine the true bulk density (\( \rho_b \)) from the “apparent” recorded log value (\( \rho_{\text{log}} \)).

**Description**

Enter the chart with the log density reading on the x-axis and move upward to intersect the mineral line that best represents the formation. At this point, move horizontally left to read the value to be added to the log density. The individual mineral points reflect the log-derived density and the correction factor to be added or subtracted from the log value to obtain the true density of that mineral.

The long diagonal lines representing zero porosity at the lower right and 40% porosity at the upper left are for dry gas in the formation. The three points at the lower right of the diagonal lines represent zero dry gas in the formation and are the endpoints for sandstone, limestone, and dolomite with water in the pores. This shows that there is a slight correction for water-filled formations from the log density value.

**Example**

Given: Log density = 2.40 g/cm³ in a sandstone formation (dry gas).

Find: Corrected bulk density.

Answer: Enter the x-axis at 2.4 g/cm³ and move upward to intersect the sandstone line. The correction from the y-axis is 0.02 g/cm³. The correction value is added to the log density to obtain the true value of the bulk density:

\[
2.40 + 0.02 = 2.42 \text{ g/cm}^3.
\]
This section contains interpretation charts to cover developments in compensated neutron tool (CNT) porosity transforms, environmental corrections, and porosity and lithology determination.

CSU® software (versions CP-30 and later) and MAXIS® software compute three thermal porosities: NPHI, TNPH, and NPOR.

NPHI is the “classic NPHI,” computed from instantaneous near and far count rates, using “Mod-8” ratio-to-porosity transform with a caliper correction.

TNPH is computed from deadtime-corrected, depth- and resolution-matched count rates, using an improved ratio-to-porosity transform and performing a complete set of environmental corrections in real time. These corrections may be turned on or off by the field engineer at the wellsite. For more information see Reference 32.

NPOR is computed from the near-detector count rate and TNPH to give an enhanced resolution porosity. The accuracy of NPOR is equivalent to the accuracy of TNPH if the environmental effects on the near detector change less rapidly than the formation porosity. For more information on enhanced resolution processing, see Reference 35.

Cased hole CNT logs are recorded on NPHI, computed from instantaneous near and far count rates, with a cased hole ratio-to-porosity transform.

**Using the Neutron Correction Charts**

For logs labeled NPHI:
1. Enter Chart Neu-5 with NPHI and caliper reading to convert to uncorrected neutron porosity.
2. Enter Charts Neu-1 and Neu-3 to obtain corrections for each environmental effect. Corrections are summed with the uncorrected porosity to give a corrected value.
3. Use crossplot Charts Por-11 and Por-12 for porosity and lithology determination.

For logs labeled TNPH or NPOR, the CSU wellsite surface instrumentation and MAXIS software have applied environmental corrections as indicated on the log heading. If the CSU and MAXIS software has applied all corrections, TNPH or NPOR can be used directly with the crossplot charts. In this case:
1. Use crossplot Charts Por-11 and Por-12 to determine porosity and lithology.
Neutron—Wireline

Compensated Neutron Tool
Environmental Correction—Open Hole

**Purpose**
Chart Neu-1 is used to correct the compensated neutron log porosity index if the caliper correction was not applied. If the caliper correction is applied, it must be “backed out” to use this chart.

**Description**
This chart is used only if the caliper correction was not applied to the logged data. The parameter section of the log heading lists whether correction was applied.

**Example 1: Backed-Out Correction of TNPH Porosity**
Given: Thermal neutron porosity (TNPH) from the log = 32 p.u. (apparent limestone units) and borehole size = 12 in.
Find: Uncorrected TNPH with the correction backed out.
Answer: Enter the top chart for actual borehole size at the intersection point of the standard conditions 8-in. horizontal line and 32 p.u. on the scale above the chart.
From this point, follow the closest trend line to intersect the 12-in. line for the borehole size.
The intersection is the uncorrected TNPH value of 34 p.u.
To use the uncorrected value on Chart Neu-1, draw a vertical line from this intersection through the remainder of the charts, as shown by the red line.

**Example 2: Environmentally Corrected THPH**
Given: Neutron porosity of 32 p.u. (apparent limestone units), without environmental correction, 12-in. borehole, ⅛-in. thick mudcake, 100,000-ppm borehole salinity, 11-lbm/gal natural mud weight (water-base mud [WBM]), 150°F borehole temperature, 5,000-psi pressure (WBM), and 100,000-ppm formation salinity.
Find: Environmentally corrected TNPH porosity.
Answer: If there is standoff (which is not uncommon), use Chart Neu-3. Then use Chart Neu-1 by drawing a vertical line through the charts for the previously determined backed-out (uncorrected) 34-p.u. neutron porosity value.
On each environmental correction chart, enter the y-axis at the given value and move horizontally left to intersect the porosity value vertical line.
For example, on the mudcake thickness chart the line extends from ¼ in. on the y-axis.
At the intersection point, move parallel to the closest blue trend line to intersect the standard conditions, as indicated by the bullet.
The point of intersection with the standard conditions for the chart is the value of porosity corrected for the particular environment. The change in porosity value (either positive or negative) is summed for the charts and referred to as delta porosity ($\Delta \phi$).

The $\Delta \phi$ net correction applied to the uncorrected log neutron porosity is listed in the table for the two examples.

### CNT Neutron Porosity Correction Examples

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Example 1</th>
<th>Example 2</th>
<th>$\Delta \phi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Log porosity</td>
<td>32 p.u.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Borehole size</td>
<td>12 in.</td>
<td>–2</td>
<td></td>
</tr>
<tr>
<td>Mudcake thickness</td>
<td>¼ in.</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Borehole salinity</td>
<td>100,000 ppm</td>
<td>+1</td>
<td></td>
</tr>
<tr>
<td>Mud weight</td>
<td>11 lbm/gal</td>
<td>+2</td>
<td></td>
</tr>
<tr>
<td>Borehole temperature</td>
<td>150°F</td>
<td>+4</td>
<td></td>
</tr>
<tr>
<td>Wellbore pressure</td>
<td>5,000 psi</td>
<td>–1</td>
<td></td>
</tr>
<tr>
<td>Formation salinity</td>
<td>100,000 ppm</td>
<td>–3</td>
<td></td>
</tr>
<tr>
<td>Standoff (from Chart Neu-3)</td>
<td>1 in.</td>
<td>–4</td>
<td></td>
</tr>
<tr>
<td>Net environmental correction</td>
<td></td>
<td>–1</td>
<td></td>
</tr>
<tr>
<td>Backed-out corrected porosity</td>
<td></td>
<td>34 p.u.</td>
<td>–3</td>
</tr>
<tr>
<td>Environmentally corrected porosity</td>
<td></td>
<td>33 p.u.</td>
<td></td>
</tr>
<tr>
<td>Net correction</td>
<td></td>
<td></td>
<td>–3</td>
</tr>
<tr>
<td>Backed-out, environmentally corrected porosity</td>
<td></td>
<td>31 p.u.</td>
<td></td>
</tr>
</tbody>
</table>
Neutron—Wireline
Compensated Neutron Tool
Environmental Correction—Open Hole

Neutron log porosity index (apparent limestone porosity in p.u.)

- Standard conditions

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**Purpose**

This chart is the metric version of Chart Neu-1 for correcting the compensated neutron tool porosity index.
Purpose
Chart Neu-3 is used to determine the porosity change caused by standoff to the uncorrected thermal neutron porosity TNPH from Chart Neu-1.

Description
Enter the appropriate borehole size chart at the estimated neutron tool standoff on the y-axis. Move horizontally to intersect the uncorrected porosity. At the intersection point, move along the closest trend line to the standard conditions line defined by the bullet to the right of the chart. This point is the porosity value corrected for tool standoff. The difference between the standoff-corrected porosity and the uncorrected porosity is the correction itself.

Example
Given: TNPH = 34 p.u., borehole size = 12 in., and standoff = 0.5 in.
Find: Porosity corrected for standoff.
Answer: Draw a vertical line from the uncorrected neutron log porosity of 34 p.u. Enter the 12-in. borehole chart at 0.5-in. standoff and move horizontally right to intersect the vertical porosity line. From the point of intersection move parallel to the closest trend line to intersect the standard conditions line (standoff = 0 in.). The standoff-corrected porosity is 32 p.u. The correction is –2 p.u.
Compensated Neutron Tool
Standoff Correction—Open Hole

Neutron—Wireline

Neutron log porosity index (apparent limestone porosity in p.u.)

Actual borehole size

6 in.
8 in.
10 in.
12 in.
18 in.
24 in.

Standoff (in.)

© Schlumberger

● Standard conditions
Purpose
This chart is the metric version of Chart Neu-3 for determining the porosity change caused by standoff.
Purpose
This chart is used to determine the porosity change caused by the borehole size to the neutron porosity NPHI and convert the porosity to thermal neutron porosity (TNPH). This chart corrects NPHI only for the borehole sizes that differ from the standard condition of 8 in. Refer to Chart Neu-1 to complete the environmental corrections for the TPNH value obtained.

Description
Enter the scale at the top of the chart with the NPHI porosity.

Example
Given: NPHI porosity = 12.5% and borehole size = 16 in.
Find: Porosity correction for nonstandard borehole size.
Answer: Enter the chart with the uncorrected porosity value of 12.5 at the scale at the top. Move down vertically to intersect the standard conditions line indicated by the bullet to the right. Enter the chart on the y-axis with the actual borehole size at the zone of interest and move horizontally right across the chart.

At the point of intersection of the vertical line and the standard conditions line, move parallel to the closest trend line to intersect the actual borehole size line.
At that intersection point move vertically down to the bottom scale to determine the TNPH porosity corrected only for borehole size. This value is also used to determine the change in porosity as a result of tool standoff. 
TNPH = 12.5 + 5 = 17.5 p.u.
Compensated Neutron Tool
Formation Σ Correction for Environmentally Corrected TNPH—Open Hole

**Purpose**
This chart is used to further correct the environmentally corrected TNPH porosity from Chart Neu-1 for the effect of the total formation capture cross section, or sigma (Σ), of the formation of interest. This correction is applied after all environmental corrections determined with Chart Neu-1 have been applied.

**Description**
Enter the chart with Σ for the appropriate formation along the y-axis and the corrected TNPH porosity along the x-axis. Where the lines drawn from these points intersect, move parallel to the closest trend line to intersect the appropriate fresh- or saltwater line to read the corrected porosity.

The chart at the bottom of the page is used to correct the Σ-corrected porosity for salt displacement if the formation Σ is due to salinity. However, this correction is not made if the borehole salinity correction from Chart Neu-1 has been applied.

**Example**
Given: Corrected TNPH from Chart Neu-1 = 38 p.u., Σ of the sandstone formation = 33 c.u., and formation salinity = 150,000 ppm (indicating a freshwater formation).

Find: TNPH porosity corrected with Chart Neu-1 and for Σ of the formation.

Answer: Enter the appropriate chart with the Σ value on the y-axis and the corrected TNPH value on the x-axis. At the intersection of the sigma and porosity lines, parallel the closest trend line to intersect the freshwater line. (If the water in the formation is salty, the 250,000-ppm line should be used.)

Move straight down from the intersection point to the formation salinity chart at the bottom.

From the point where the straight line intersects the top of the salinity correction chart, parallel the closest trend line to intersect the formation salinity line.

Draw a vertical line to the bottom scale to read the corrected formation sigma TNPH porosity, which is 35 p.u.
Compensated Neutron Tool
Formation Σ Correction for Environmentally Corrected TNPH—Open Hole

Neutron log porosity index

- Sandstone formation
  - Formation Σ (c.u.)
  - Fresh water
  - 250,000-ppm water

- Limestone formation
  - Formation Σ (c.u.)
  - Fresh water
  - 250,000-ppm water

- Dolomite formation
  - Formation Σ (c.u.)
  - Fresh water
  - 250,000-ppm water

Formation salinity
(1,000 × ppm)
Compensated Neutron Tool
Mineral $\Sigma$ Correction for Environmentally Corrected TNPH—Open Hole

**Purpose**
This chart is used to further correct the environmentally corrected TNPH porosity from Chart Neu-1 for the effect of the mineral sigma ($\Sigma$). This correction is applied after all environmental corrections determined with Chart Neu-1 have been applied.

**Description**
Enter the chart for the formation type with the mineral $\Sigma$ value along the y-axis and the Chart Neu-1 corrected TNPH porosity along the x-axis. Where lines drawn from these points intersect, move parallel to the closest trend line to intersect the freshwater line to read the corrected porosity on the scale at the bottom. The choice of chart depends on the type of mineral in the formation.

**Example**
Given: Corrected TNPH from Chart Neu-1 = 38 p.u., sandstone formation $\Sigma$ = 35 c.u., and formation salinity = 150,000 ppm (indicating a freshwater formation).

Find: TNPH porosity corrected with Chart Neu-1 and for the mineral $\Sigma$.

Answer: At the intersection of the $\Sigma$ and porosity value lines move parallel to the closest trend line to intersect the freshwater line. Move straight down to intersect the bottom porosity scale to read the TNPH porosity corrected for mineral $\Sigma$, which is 33 p.u.
Compensated Neutron Tool
Mineral $\Sigma$ Correction for Environmentally Corrected TNPH—Open Hole

Neutron log porosity index

Sandstone formation
Mineral $\Sigma$ (c.u.)

Limestone formation
Mineral $\Sigma$ (c.u.)

Dolomite formation
Mineral $\Sigma$ (c.u.)

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Compensated Neutron Tool
Fluid $\Sigma$ Correction for Environmentally Corrected TNPH—Open Hole

**Purpose**
This chart is used to correct the environmentally corrected TNPH porosity from Chart Neu-1 for the effect of the fluid sigma ($\Sigma$) in the formation. This correction is applied after all environmental corrections determined with Chart Neu-1 have been applied.

**Description**
Enter the appropriate formation chart with the formation fluid $\Sigma$ value on the y-axis and the Chart Neu-1 corrected TNPH porosity on the x-axis. Where the lines drawn from these points intersect, move parallel to the closest trend line to intersect the appropriate freshwater or saltwater line. If the borehole salinity correction from Chart Neu-1 has not been applied, from this point extend a line down to intersect the formation salinity chart at the bottom. Move parallel to the closest trend line to intersect the formation salinity line. Move straight down to read the corrected porosity on the scale below the chart.

**Example**

**Given:** Corrected TNPH from Chart Neu-1 = 30 p.u. (without borehole salinity correction), fluid $\Sigma$ = 80 c.u., fluid salinity = 150,000 ppm, and sandstone formation.

**Find:** TNPH corrected with Chart Neu-1 and for fluid $\Sigma$.

**Answer:** At the intersection of the fluid $\Sigma$ and Chart Neu-1 corrected TNPH porosity (30-p.u.) line, move parallel to the closest trend line to intersect the freshwater line. From that point go straight down to the formation salinity correction chart at the bottom. Move parallel to the closest trend line to intersect the formation salinity line (150,000 ppm), and then draw a vertical line to the bottom scale to read the corrected TNPH value (26 p.u.).
Compensated Neutron Tool
Fluid $\Sigma$ Correction for Environmentally Corrected TNPH—Open Hole

Neutron log porosity index

Sandstone formation
Fluid $\Sigma$ (c.u.)
- Fresh water
- 250,000-ppm water

Limestone formation
Fluid $\Sigma$ (c.u.)
- Fresh water
- 250,000-ppm water

Dolomite formation
Fluid $\Sigma$ (c.u.)
- Fresh water
- 250,000-ppm water

Formation salinity
(1,000 $\times$ ppm)
- 0
- 250
- 200
- 150
- 100
- 50
- 0

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Compensated Neutron Tool
Environmental Correction—Cased Hole

**Purpose**
This chart is used to obtain the correct porosity from the neutron porosity index logged with the compensated neutron tool in casing, where the effects of the borehole size, casing thickness, and cement sheath thickness influence the true value of formation porosity.

**Description**
Enter the scale at the top of the chart with a whole-number (not fractional) porosity value. Draw a straight line vertically through the three charts representing borehole size, casing thickness, and cement thickness. Draw a horizontal line on each chart from the appropriate value on the y-axis. At the intersection point of the vertical line and the horizontal line on each chart proceed to the blue dashed horizontal line by following the slope of the blue solid lines on each chart. At that point read the change in porosity index. The cumulative change in porosity is added to the logged porosity to obtain the corrected value. As can be seen, the major influences to the casing-derived porosity are the borehole size and the cement thickness. The same procedure applies to the metric chart.

The blue dashed lines represent the standard conditions from which the charts were developed: 8¾-in. open hole, 5½-in. 17-lbm casing, and 1.62-in. annular cement thickness.

The neutron porosity equivalence nomographs at the bottom are used to convert from the log standard of limestone porosity to porosity for other matrix materials.

The porosity value corrected with Chart Neu-9 is entered into Chart Neu-1 to provide environmental corrections necessary for determining the correct cased hole porosity value.

**Example**
Given: Log porosity index = 27%, borehole diameter = 11 in., casing thickness = 0.304 in., and cement thickness = 1.62 in.

Cement thickness is defined as the annular space between the outside wall of the casing and the borehole wall. The value is determined by subtracting the casing outside diameter from the borehole diameter and dividing by 2.

Find: Porosity corrected for borehole size, casing thickness, and cement thickness.

Answer: Draw a vertical line (shown in red) though the three charts at 27 p.u.

Borehole-diameter correction chart: From the intersection of the vertical line and the 11-in. borehole-diameter line (shown in red dashes) move upward along the curved blue line as shown on the chart.

The porosity is reduced to 26% by –1 p.u.

Casing thickness chart: The porosity index is changed by 0.3 p.u.

Cement thickness chart: The porosity index is changed by 0.5 p.u.

The resulting corrected porosity for borehole, casing, and cement is $27 - 1 + 0.3 + 0.5 = 26.8$ p.u.
### Customary

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<th>Neutron log porosity index (p.u.)</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
<th>0.6</th>
<th>0.7</th>
<th>0.8</th>
<th>0.9</th>
<th>1.0</th>
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<tbody>
<tr>
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<td>-1.0</td>
<td>0.304 in.</td>
<td>0.3</td>
<td>+0.3</td>
<td>0.5</td>
<td>0.7</td>
<td>0.9</td>
<td>1.0</td>
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<tr>
<td>Casing thickness (in.)</td>
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<td>0.3</td>
<td>0.4</td>
<td>0.5</td>
<td>0.6</td>
<td>0.7</td>
<td>0.8</td>
<td>0.9</td>
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<tr>
<td>Cement thickness (in.)</td>
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<td>-1.0</td>
<td>0.304 in.</td>
<td>0.3</td>
<td>+0.3</td>
<td>0.5</td>
<td>0.7</td>
<td>0.9</td>
<td>1.0</td>
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Borehole, casing, and cement correction = -1.0 + 0.3 + 0.5

### Metric

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<th>Neutron log porosity index (p.u.)</th>
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<tr>
<td>Diameter of borehole before running casing (mm)</td>
<td>222 mm</td>
<td>114</td>
<td>140</td>
<td>178</td>
<td>245</td>
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<tr>
<td>Casing thickness (mm)</td>
<td>7.7 mm</td>
<td>14</td>
<td>17</td>
<td>20</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>Cement thickness (mm)</td>
<td>41 mm</td>
<td>14</td>
<td>17</td>
<td>20</td>
<td>23</td>
<td></td>
</tr>
</tbody>
</table>

Neutron porosity equivalence

- **Calcite (limestone)**
- **Quartz sandstone**
- **Dolomite**

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APS* Accelerator Porosity Sonde  
Environmental Correction—Open Hole

**Purpose**
The Neu-10 charts pair is used to correct the APS Accelerator Porosity Sonde apparent limestone porosity for mud weight and actual borehole size. The charts are for the near-to-array and near-to-far porosity measurements. The design of the APS sonde resulted in a significant reduction in environmental correction. The answer determined with this chart is used in conjunction with the correction from Chart Neu-11.

**Description**
Enter the appropriate chart pair (mud weight and actual borehole size) for the APS near-to-array apparent limestone porosity (APLU) or APS near-to-far apparent limestone porosity (FPLU) with the uncorrected porosity from the APS log by drawing a straight vertical line (shown in red) through both of the charts. At the intersection with the mud weight value, move parallel to the closest trend line to intersect the standard conditions line. This point represents a change in porosity resulting from the correction for mud weight. Follow the same procedure for the borehole size chart to determine the correction change. Because the borehole size correction has a dependency on mud weight, even with natural muds, there are two sets of curves on the borehole size chart—solid for light muds (8.345 lbm/gal) and dashed for heavy muds (16 lbm/gal). Intermediate mud weights are interpolated. The two differences are summed for the total correction to the APS log value.

This answer is used in Chart Neu-11 to complete the environmental corrections for corrected APLU or FPLU porosity.

**Example**

Given: APS neutron APLU uncorrected porosity = 34 p.u., mud weight = 10 lbm/gal, and borehole size = 12 in.
Find: Corrected APLU porosity.
Answer: Draw a vertical line on the APLU mud weight chart from 34 p.u. on the scale above. At the intersection with the 10-lbm/gal mud weight line, move parallel to the trend line to intersect the standard conditions line. This point represents a change in porosity of $-0.75$ p.u.

On the actual borehole size chart, move parallel to the closest trend line from the intersection of the 34-p.u. line and the actual borehole size (12 in.) to intersect the 8-in. standard conditions line. This point represents a change in porosity of $-1.0$ p.u.

The total correction is $-0.75 + -1.0 = -1.75$ p.u., which results in a corrected APLU porosity of $34 - 1.75 = 32.25$ p.u.
**APS* Accelerator Porosity Sonde**

Environmental Correction—Open Hole

---

**APS near-to-array apparent limestone porosity uncorrected, APLU (p.u.)**

- Mud weight (lbm/gal)
  - 18
  - 16
  - 14
  - 12
  - 10
  - 8
  - 6

- Actual borehole size (in.)
  - 18
  - 16
  - 14
  - 12
  - 10
  - 8

**APS near-to-far apparent limestone porosity uncorrected, FPLU (p.u.)**

- Mud weight (lbm/gal)
  - 18
  - 16
  - 14
  - 12
  - 10
  - 8

- Actual borehole size (in.)
  - 18
  - 16
  - 14
  - 12
  - 10
  - 8

*Standard conditions*

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**Purpose**

This chart is used to complete the environmental correction for APLU and FPLU porosities from the APS log.

**Description**

Enter the left-hand chart on the x-axis with the temperature of the formation of interest. Move vertically to intersect the appropriate formation pressure line. From that point, move horizontally right to intersect the left edge of the formation salinity chart. Move parallel to the trend lines to intersect the formation salinity value. From that point, move horizontally to the left edge of the next chart. Move parallel to the trend lines to intersect the uncorrected APLU or FPLU porosity. At that intersection, move horizontally right to read the apparent porosity correction.

**Example**

Given: APLU or FPLU porosity = 34 p.u., formation temperature = 150°F, formation pressure = 5,000 psi, and formation salinity = 150,000 ppm.

Find: Environmentally corrected APLU or FPLU porosity.

Answer: Enter the formation temperature chart at 150°F to intersect the 5,000-psi curve. From that point, move horizontally right to intersect the left edge of the formation salinity chart. Move parallel to the trend lines to intersect the formation temperature of 150°F. At this point, again move horizontally to the left edge of the next chart. Move parallel to the trend lines to intersect the 34-p.u. porosity line. At that point on the y-axis, the change in porosity is +1.6 p.u.

The total correction for a corrected APLU or FPLU from Charts Neu-10 and Neu-11 is 34 + (–0.75 + –1) + 1.6 = 33.85 p.u.
Neutron—LWD

CDN* Compensated Density Neutron, adnVISION* Azimuthal Density Neutron, and EcoScope* Integrated LWD Tools

Mud Hydrogen Index Determination

**Purpose**
This chart is used to determine one of several environmental corrections for neutron porosity values recorded with the CDN Compensated Density Neutron, adnVISION Azimuthal Density Neutron, and EcoScope Integrated LWD tools. The value of hydrogen index (Hm) is used in the following porosity correction charts.

**Description**
To determine the Hm of the drilling mud, the mud weight, temperature, and hydrostatic mud pressure at the zone of interest must be known.

**Example**
Given: Barite mud weight = 14 lbm/gal, mud temperature = 150°F, and hydrostatic mud pressure = 5,000 psi.
Find: Hydrogen index of the drilling mud.
Answer: Enter the bottom chart for mud weight at 14 lbm/gal on the y-axis. Move horizontally to intersect the barite line. Move vertically to the bottom of the mud temperature chart and move upward parallel to the closest trend line to intersect the formation temperature. From the intersection point move vertically to the bottom of the mud pressure chart. Move parallel to the closest trend line to intersect the formation pressure. Draw a line vertically to intersect the mud hydrogen index scale and read the result.
Mud hydrogen index = 0.78.

*continued on next page*
Mud Hydrogen Index Determination

Mud hydrogen index, \( H_m \)

- Mud pressure (1,000 \( \times \) psi)
- Mud temperature (°F)
- Mud weight (lbm/gal)

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Purpose
This is one of a series of charts used to correct adnVISION475 4.75-in. Azimuthal Density Neutron tool porosity for several environmental effects by using the mud hydrogen index (H_m) determined from Chart Neu-30 in conjunction with the parameters on the chart.

Description
This chart incorporates the parameters of borehole size, mud temperature, mud hydrogen index (from Chart Neu-30), mud salinity, and formation salinity for the correction of adnVISION475 porosity.

The following charts are used with the same interpretation procedure as Chart Neu-31. The charts differ for tool size and borehole size.

Example
Given: adnVISION475 uncorrected porosity = 34 p.u., borehole size = 10 in., mud temperature = 150°F, hydrogen index = 0.78, borehole salinity = 100,000 ppm, and formation salinity = 100,000 ppm.

Find: Corrected adnVISION475 porosity.

Answer: From the adnVISION475 porosity of 34 p.u. on the top scale, enter the borehole size chart to intersect the borehole size of 10 in. From the point of intersection move parallel to the closest trend line to intersect the standard conditions line.

From this intersection point move straight down to enter the mud temperature chart and intersect the mud temperature of 150°F. From the point of intersection move parallel to the closest trend line to intersect the standard conditions line.

Continue this pattern through the charts to read the corrected porosity from the scale at the bottom of the charts.

The corrected adnVISION475 porosity is 17 p.u.
Purpose
This chart is used similarly to Chart Neu-31 to correct adnVISION475 borehole-invariant porosity (BIP) measurements.

Description
Enter the top scale with the BIP neutron porosity (BNPH) to incorporate corrections for mud temperature, mud hydrogen index, and mud and formation salinity.
Purpose
This chart is used similarly to Chart Neu-31 to correct adnVISION475 porosity.
Purpose
This chart is used similarly to Chart Neu-32 to correct adnVISION475 borehole-invariant porosity (BIP) measurements.
Purpose
This chart is used similarly to Chart Neu-31 to correct adnVISION675 porosity.
**Purpose**

This chart is used similarly to Chart Neu-32 to correct adnVISION675 borehole-invariant porosity (BIP) measurements.
Purpose

This chart is used similarly to Chart Neu-31 to correct adnVISION675 porosity.
Purpose
This chart is used similarly to Chart Neu-32 to correct adnVISION675 borehole-invariant porosity (BIP) measurements.
Purpose
This chart is used similarly to Chart Neu-31 to correct adnVISION825 porosity.
Neutron—LWD

Environmental Correction—Open Hole

Purpose
This chart is used similarly to Chart Neu-31 to correct CDN Compensated Density Neutron tool and adnVISION825s Azimuthal Density Neutron porosity.

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Neu-40 (former Por-24c)
Neutron—LWD

CDN* Compensated Density Neutron and adnVISION825s*
Azimuthal Density Neutron—8-in. Tool and 14-in. Borehole
Environmental Correction—Open Hole

Neutron porosity index (apparent limestone porosity) in 14-in. borehole

Borehole size (in.)

Mud temperature (°F)

Mud hydrogen index, $H_m$

Mud salinity (1,000 × ppm)

Formation salinity (1,000 × ppm)

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Neutron—LWD

CDN* Compensated Density Neutron and adnVISION825s*
Azimuthal Density Neutron—8-in. Tool and 16-in. Borehole
Environmental Correction—Open Hole

Neutron porosity index (apparent limestone porosity) in 16-in. borehole

- Borehole size (in.)
- Mud temperature (°F)
- Mud hydrogen index, $H_m$
- Mud salinity (1,000 × ppm)
- Formation salinity (1,000 × ppm)

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Standard conditions
Charts Neu-43 through Neu-46 show the environmental corrections that are applied to EcoScope 6.75-in. Integrated LWD Tool neutron porosity measurements. These charts can be used to estimate the correction that is normally already applied to the field logs.

**Purpose**
Charts Neu-43 through Neu-46 show the environmental corrections that are applied to EcoScope 6.75-in. Integrated LWD Tool neutron porosity measurements. These charts can be used to estimate the correction that is normally already applied to the field logs.

**Description**
The charts incorporate the parameters of borehole size, mud temperature, mud hydrogen index (from Chart Neu-30), mud salinity, and formation salinity for the correction of EcoScope 6.75-in. neutron porosity.

Select the appropriate chart based on both the hole size and the measurement type: thermal neutron porosity (TNPH) or best thermal neutron porosity (BPHI).

Enter the charts with the uncorrected neutron porosity data. Charts Neu-43 and Neu-44 are for use with BPHI_UNC, and Charts Neu-45 and Neu-46 are for use with TNPH_UNC. Because the borehole size correction is applied to the field logs, including the _UNC channels, do not include the borehole size correction, which is in the charts for illustrative purposes only.

A correction for eccentricity effects is normally also applied to the field BPHI measurement. Because this correction is not included in these charts, there may be a small difference between the correction estimated from the charts and that actually applied to the field data, depending on the tool position in the borehole.

The charts are used with a similar procedure to that described for Chart Neu-31.
### Purpose

This chart is used similarly to Chart Neu-31 to estimate the correction applied to EcoScope 6.75-in. Integrated LWD Tool best thermal neutron porosity (BPHI) measurements.

Use this chart only with EcoScope BPHI neutron porosity; use Chart Neu-45 with EcoScope thermal neutron porosity (TNPH) measurements.
**Purpose**

This chart is used similarly to Chart Neu-31 to estimate the correction applied to EcoScope 6.75-in. Integrated LWD Tool best thermal neutron porosity (BPHI) measurements.

Use this chart only with EcoScope BPHI neutron porosity; use Chart Neu-46 with EcoScope thermal neutron porosity (TNPH) measurements.

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**Environmental Correction—Open Hole**

EcoScope* Integrated LWD BPHI Porosity—6.75-in. Tool and 9.5-in. Borehole

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* Standard conditions

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**Back to Contents**
**EcoScope** Integrated LWD TNPH Porosity—6.75-in. Tool and 8.5-in. Borehole

Environmental Correction—Open Hole

**Purpose**
This chart is used similarly to Chart Neu-31 to estimate the correction applied to EcoScope 6.75-in. Integrated LWD Tool thermal neutron porosity (TNPH) measurements.

Use this chart only with EcoScope TNPH measurements. Use Chart Neu-43 with EcoScope best thermal neutron porosity (BPHI) measurements.
**Purpose**

This chart is used similarly to Chart Neu-31 to estimate the correction applied to EcoScope 6.75-in. Integrated LWD Tool thermal neutron porosity (TNPH) measurements.

Use this chart only with EcoScope TNPH neutron porosity; use Chart Neu-44 with EcoScope best thermal neutron porosity (BPHI) measurements.
Neutron—LWD
EcoScope* Integrated LWD—6.75-in. Tool
Formation Sigma Environmental Correction—Open Hole

Purpose
This chart is used to environmentally correct the raw sigma (RFSA) measurement for porosity, borehole size, and mud salinity. The fully corrected sigma (SIFA) measurement is normally presented on the logs.

Description
Chart Neu-47 includes (from top to bottom) the moments sigma transform, diffusion correction based on porosity, and borehole correction.

Example
Given: Raw sigma (24 c.u.), porosity (30 p.u.), borehole size (10 in.), and mud salinity (200,000 ppm).
Find: Corrected sigma (SIFA).
Answer: Enter the chart from the scale at the top with the raw sigma value of 24 c.u.

Moments Sigma Transform
Move parallel to the closest trend line to intersect the x-axis of the moments sigma transform chart. The difference between the x-axis value and the raw sigma value is the moments sigma transform correction (19.8 – 24 = –4.2 c.u.).

Diffusion Correction
Move down vertically from the scale at the top to intersect the 30-p.u. line on the porosity chart. At the intersection point, move parallel to the closest trend line to intersect the x-axis of the porosity chart.

The difference between the x-axis value and the raw sigma value is the diffusion correction (25.3 – 24 = +1.3 c.u.).

Borehole Correction
Move down vertically from the scale at the top to intersect the 10-in. borehole size line. At the intersection point, move parallel to the closest trend line corresponding to the mud salinity to intersect the x-axis of the borehole correction chart.

The difference between the x-axis value and the raw sigma value is the borehole correction (22.8 – 24 = –1.2 c.u.).

Net Correction
The net correction to apply to the raw sigma value is the sum the three corrections (–4.2 + 1.3 + –1.2 = –4.1 c.u.). The environmentally corrected sigma is the sum of the net correction and the raw sigma value (24 + –4.1 = 19.9 c.u.).

<table>
<thead>
<tr>
<th>EcoScope Sigma Correction Example</th>
<th>Correction</th>
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<tbody>
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<td>Raw sigma</td>
<td>24 c.u.</td>
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<tr>
<td>Porosity</td>
<td>30 p.u.</td>
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<tr>
<td>Borehole size</td>
<td>10 in.</td>
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<tr>
<td>Mud salinity</td>
<td>200,000 ppm</td>
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<tr>
<td>Moments sigma transform</td>
<td>–4.2 c.u.</td>
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<tr>
<td>Porosity correction</td>
<td>+1.3 c.u.</td>
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<tr>
<td>Borehole correction</td>
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<td>Net correction</td>
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<tr>
<td>Environmentally corrected sigma</td>
<td>19.9 c.u.</td>
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EcoScope* Integrated LWD—6.75-in. Tool
Formation Sigma Environmental Correction—Open Hole

<table>
<thead>
<tr>
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<th>Moments sigma transform</th>
<th>Porosity (p.u.)</th>
<th>Borehole size (in.)</th>
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<tr>
<td>60</td>
<td></td>
<td>60</td>
<td></td>
</tr>
</tbody>
</table>

Mud salinity
- 0 ppm
- 50,000 ppm
- 100,000 ppm
- 150,000 ppm
- 200,000 ppm

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Standard conditions
**Purpose**
This chart is used to determine the saturation of the flushed zone ($S_{xo}$) and hydrocarbon density ($\rho_h$) by using density ($\rho$) and CMR Combinable Magnetic Resonance data.

**Description**
The top chart has three components: ratio of total CMR porosity to density porosity ($\phi_{tCMR}/\phi_D$) on the y-axis, $(1 - S_{xo})$ values on the x-axis, and $\rho_h$ defined by the radiating lines from the value of unity on the y-axis. Enter the chart with the values for $(1 - S_{xo})$ and the $\phi_{tCMR}/\phi_D$ ratio. The intersection point indicates the hydrocarbon density value. The bottom charts are used to determine the $S_{xo}$ value in sandstone (left) and limestone (right).

**Example**
Given: CMR porosity = 25 p.u., $\phi_D = 30$ p.u., and $S_{xo} = 80\%$.
Find: Hydrocarbon density of the fluid in the formation.
Answer: $\phi_{tCMR}/\phi_D$ ratio = 25/30 = 0.83.
$1 - S_{xo} = 1 - 0.8 = 0.20$ or $20\%$.
For these values, $\rho_h = 0.40$. 
This page intentionally left blank.
Purpose
This chart is used to environmentally correct the ARI Azimuthal Resistivity Imager high-resolution resistivity ($LL_{hr}$) curve for the effect of borehole size.

Description
For a known value of resistivity of the borehole mud ($R_m$) at the zone of interest, a correction for the recorded log azimuthal resistivity ($R_a$) is determined by using this chart. The resistivity measured by the ARI tool is equal to or higher than the corrected resistivity ($R_t$) for borehole sizes of 8 to 12 in. However, the measured ARI resistivity is lower than $R_t$ in 6-in. boreholes and for values of $R_a/R_m$ between 6 and 600.

Example
Given: ARI $LL_{hr}$ resistivity ($R_a$) = 20 ohm-m, mud resistivity ($R_m$) = 0.02 ohm-m, and borehole size at the zone of interest = 10 in.

Find: True resistivity ($R_t$).

Answer: Enter the chart at the x-axis with the ratio $R_a/R_m = 20/0.02 = 1,000$.

Move vertically upward to intersect the 10-in. line. Move horizontally left to read the $R_t/R_a$ value on the y-axis of 0.86.

Multiply the ratio by $R_a$ to obtain the corrected $LL_{hr}$ resistivity:

$$R_t = 0.86 \times 20 = 17.2 \text{ ohm-m}.$$
Purpose
This chart is used to correct the HALS laterolog deep resistivity (HLLD) for borehole and drilling mud effects.

Description
Enter the chart on the x-axis with the value of HLLD divided by the mud resistivity (R_m) at formation temperature. Move upward to intersect the curve representing the borehole diameter (d_h), and then move horizontally left to read the value of the ratio R_t/HLLD on the y-axis. Multiply this value by the HLLD value to obtain R_t. Charts RLI-3 through RLI-14 are similar to Chart RLI-2 for different resistivity measurements and values of tool standoff.

Example
Given: HLLD = 100 ohm-m, R_m = 0.02 ohm-m at formation temperature, and borehole size = 10 in.
Find: R_t.
Answer: Ratio of HLLD/R_m = 100/0.02 = 5,000.
R_t = 0.80 \times 100 = 80\ ohm-m.
Purpose
This chart is used similarly to Chart RLI-2 to correct HALS laterolog shallow resistivity (HLLS) for borehole and drilling mud effects.
Purpose
This chart is used to similarly to Chart RLI-2 to correct the HALS high-resolution deep resistivity (HRLD) for borehole and drilling mud effects.
Purpose
This chart is used to similarly to Chart RLI-2 to correct the HALS high-resolution shallow resistivity (HRLS) for borehole and drilling mud effects.
### Purpose

This chart is used to similarly to Chart RLI-2 to correct the HALS laterolog deep resistivity (HLLD) for borehole and drilling mud effects at 0.5- and 1.5-in. standoffs.

---

**High-Resolution Azimuthal Laterolog Sonde (HALS)**

HLLD Borehole Correction—Eccentered in Open Hole

© Schlumberger
**Purpose**

This chart is used to similarly to Chart RLI-2 to correct the HALS laterolog shallow resistivity (HLLS) for borehole and drilling mud effects at 0.5- and 1.5-in. standoffs.
**Purpose**

This chart is used to similarly to Chart RLI-2 to correct the HALS high-resolution deep resistivity (HRLD) for borehole and drilling mud effects at 0.5- and 1.5-in. standoffs.
**Purpose**

This chart is used to similarly to Chart RLI-2 to correct the HALS high-resolution shallow resistivity (HRLS) for borehole and drilling mud effects at 0.5- and 1.5-in. standoffs.
**Purpose**

This chart is used to similarly to Chart RLI-2 to correct HRLA High-Resolution Laterolog Array resistivity for borehole and drilling mud effects. RLA1 is the apparent resistivity from computed focusing mode 1.
**Purpose**

This chart is used to similarly to Chart RLI-2 to correct HRLA High-Resolution Laterolog Array resistivity for borehole and drilling mud effects. RLA2 is the apparent resistivity from computed focusing mode 2.
Purpose
This chart is used to similarly to Chart RLI-2 to correct HRLA High-Resolution Laterolog Array resistivity for borehole and drilling mud effects. RLA3 is the apparent resistivity from computed focusing mode 3.
Purpose

This chart is used to similarly to Chart RLI-2 to correct HRLA High-Resolution Laterolog Array resistivity for borehole and drilling mud effects. RLA4 is the apparent resistivity from computed focusing mode 4.
Purpose
This chart is used to similarly to Chart RLI-2 to correct HRLA High-Resolution Laterolog Array resistivity for borehole and drilling mud effects. RLA5 is the apparent resistivity from computed focusing mode 5.
**Purpose**

This chart is used to derive the borehole correction for the GeoSteering bit-measured resistivity. The bit resistivity corrected to the true resistivity (R_t) is then used in the calculation of water saturation.

**Description**

Enter the chart on the x-axis with the ratio of the bit resistivity and mud resistivity (R_a/R_m) at formation temperature. Move upward to intersect the appropriate bit size. Move horizontally left to intersect the correction factor on the y-axis. Multiply the correction factor by the R_a value to obtain R_t. Charts RLI-21, RLI-23, and RLI-24 are similar to Chart RLI-20 for different tools and bit sizes.

Chart RLI-22 differs in that it is for reaming-down mode as opposed to drilling mode.
**Purpose**
This chart is used similarly to Chart RLI-20 to derive the borehole correction for the GeoSteering bit-measured arcVISION675 resistivity.
**Purpose**

This chart is used similarly to Chart RLI-20 to derive the borehole correction for the GeoSteering bit-measured resistivity while reaming down.
Purpose
This chart is used similarly to Chart RLI-20 to derive the borehole correction for the bit-measured resistivity from the GVR* resistivity sub of the geoVISION 6.75-in. tool. The bottom row of charts specifies the bit readout point (ROP) to the bit face.
Purpose
This chart is used similarly to Chart RLI-20 to derive the borehole correction for the bit-measured resistivity from the GVR* resistivity sub of the geoVISION 8.25-in. tool. The bottom row of charts specifies the bit readout point (ROP) to the bit face.

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**Purpose**
This chart is used to calculate the distance the GeoSteering bit must travel to return to the target formation.

**Description**
When drilling is at very high angles from vertical, the bit may wander out of formation. If this occurs, how far the bit must travel to get back into the formation must be determined.

Enter the chart with the known dip angle of the formation on the x-axis. Move upward to intersect the appropriate “buildup rate” (BUR) curve. Move horizontally left from the intersection point to the y-axis and read the distance back into the formation.

**Example**
*Given:* Formation dip angle = 6°, formation resistivity during drilling = 10 ohm-m, and buildup rate = 4°.
*Find:* Distance to return to the target formation.
*Answer:* Enter the chart at 6° on the x-axis. Move upward to the 10 ohm-m/4° BUR curve. Move horizontally left to the y-axis to read approximately 290 ft.
**Purpose**
This chart is used to correct the raw cased hole resistivity measurement of the CHFR Cased Hole Formation Resistivity tool (Rchfr) for the thickness of the cement sheath. The resulting value of true resistivity (Rt) is used to calculate the water saturation.

**Description**
Enter the chart on the x-axis with the ratio of Rchfr and the resistivity of the cement sheath (Rcem). The value of Rcem is obtained with laboratory measurements. Move upward to the appropriate cement sheath thickness curve, which represents the annular space between the outside of the casing and the borehole wall. Move horizontally left to the y-axis and read the Rt/Rchfr value. Multiply this value by Rchfr to obtain Rt.

Charts RLI-51 and RLI-52 are for making the correction in larger casing sizes.
Purpose

This chart is used similarly to Chart RLI-50 to obtain the cased hole resistivity of the CHFR Cased Hole Formation Resistivity tool corrected for the thickness of the cement sheath in 7-in.-OD casing.
**Purpose**

This chart is used similarly to Chart RLI-50 to obtain the cased hole resistivity of the CHFR Cased Hole Formation Resistivity tool corrected for the thickness of the cement sheath in 9.625-in.-OD casing.
**Purpose**
This chart is used to determine the limit of application for the AIT Array Induction Imager Tool measurement in a salt-saturated borehole.

**Description**
When the AIT tool logs a large salt-saturated borehole, the 10- and 20-in. induction curves may well be unusable because of the large conductive borehole. In a borehole with a diameter (dh) of 8 in., the 10- and 20-in. curve data are usable if Rt < 300Rm. The ratio of the true resistivity to the mud resistivity (Rt/Rm) is proportional to (dh/8)^2.

A general rule is that a 12-in. borehole must have a ratio of Rt/Rm ≤ 133 to have usable shallow log data. Additional requirements are that the borehole must be round and the AIT tool standoff is 2.5 in. The value of Rt/Rm is further reduced if the borehole is irregular or the standoff requirement is not met.

Chart RInd-1 summarizes these requirements. The expected values of Rt, Rm, borehole size, and standoff size are entered to accurately determine the usable resolution in a smooth hole. The lower chart summarizes which AIT resistivity tools typically provide the most accurate deep resistivity data.

**Example: Salt-Saturated Borehole**
Given: Borehole size = 10 in., Rt = 5 ohm-m, Rm = 0.0135 ohm-m, and standoff (so) = 2.5 in.
Find: Which, if any, of the AIT curves are valid.
Answer: From the x-axis equation:

\[
\left( \frac{R_t}{R_m} \right) \left( \frac{d_h}{8} \right)^2 \left( \frac{1.5}{so} \right) =
\]

\[
\left( \frac{5}{0.0135} \right) \left( \frac{10}{8} \right)^2 \left( \frac{1.5}{2.5} \right) =
\]

\[
(370)(1.5625)(0.6) = 346.
\]
Enter the chart on the x-axis at 346 and move upward to intersect Rt = 5 ohm-m on the y-axis. The intersection point is in an error zone for which the shallow induction curves are not valid even in a round borehole. The deeper induction curves are valid only with a 2-ft or larger vertical resolution.

The limits for the 1-, 2-, and 4-ft curves are integral to the chart. As illustrated, a 1-ft 90-in. curve is not usable in a large salt-saturated borehole. Also, under these conditions, the 1-, 2-, and 4-ft curves cannot have the same resistivity response.

**Example: Freshwater Mud Borehole**
Given: Borehole size = 10 in., Rt = 5 ohm-m, Rm = 0.135 ohm-m, and standoff (so) = 1.5 in.
Find: Which, if any, of the AIT curves are valid.
Answer: \( \frac{R_t}{R_m} = 37.0 \), \( (d_h/8)^2 = (10/8)^2 = 1.5625 \), and \( (1/so) = 1.5/1.5 = 1 \). The resulting value from the x-axis equation is \( 37.0 \times 1.5625 \times 1 = 57.9 \).

Enter the chart at 57.9 on the x-axis and intersect Rt = 5 ohm-m on the y-axis. The intersection point is within the limit of the 1-ft vertical resolution boundary. All the AIT induction curves are usable.
Resistivity Induction—Wireline

AIT* Array Induction Imager Tool
Operating Range—Open Hole

Limit of 4-ft logs
Possible large errors on shallow logs and 2-ft limit

Limit of 1-ft logs
Recommended AIT operating range (compute standoff method for smooth holes)

Salt-saturated borehole example
Freshwater mud example
Possible large errors on all logs

\[
\frac{R_t}{R_m} \left( \frac{d_m}{8} \right)^{1.5 \frac{80}{\text{ohm-m}}} 
\]

\[
R_t \quad \text{(ohm-m)} 
\]

AIT 4-ft limit
AIT 2-ft limit
AIT 1-ft limit

AIT tools
AIT and HRLA* tools
HRLA tools

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Introduction

The AIT tools (AIT-B, AIT-C, AIT-H, AIT-M, Slim Array Induction Imager Tool [SAIT], Hostile Environment Induction Imager Tool [HIT], and SlimXtreme® Array Induction Imager Tool [QAIT]) do not have chartbook corrections for environmental effects. The normal effects that required correction charts in the past (borehole correction, shoulder effect, and invasion interpretation) are now all made using real-time algorithms for the AIT tools. In reality, the charts for the older dual induction tools were inadequate for the complexity of environmental effects on induction tools. The very large volume of investigation required to obtain an adequate radial depth of investigation to overcome invasion makes the resulting set of charts too extensive for a book of this size. The volume that affects the logs can be tens of feet above and below the tool. To make useful logs, the effects of the volume above and below the layer of interest must be carefully removed. This can be done only by either signal processing or inversion-based processing. This section briefly describes the wellsite processing and advanced processing available at computing centers.

Wellsite Processing

Borehole Correction

The first step of AIT log processing is to correct the raw data from all eight arrays for borehole effects. Borehole corrections for the AIT tools are based on inversion through an iterative forward model to find the borehole parameters that best reproduce the logs from the four shortest arrays—the 6-, 9-, 12-, and 15-in. arrays (Grove and Minerbo, 1991). The borehole forward model is based on a solution to Maxwell’s equations in a cylindrical borehole of radius \( r \) with the mud resistivity \( R_m \) surrounded by a homogeneous formation of resistivity \( R_f \). The tool can be located anywhere in the borehole, but is parallel to the borehole axis at a certain tool standoff (so). The borehole is characterized by its radius \( r \). In this model, the signal in a given AIT array is a function of only these four parameters.

The four short arrays overlap considerably in their investigation depth, so only two of the borehole parameters can be uniquely determined in an inversion. The others must be supplied by outside measurements or estimates. Because the greatest sensitivity to the formation resistivity is in the contrast between \( R_m \) and \( R_f \), no external measurement is satisfactory for fitting to \( R_f \). Therefore, \( R_f \) is always solved for. This leaves one other parameter that can be determined. The three modes of the borehole correction operation depend on which parameter is being determined:

- compute mud resistivity: requires hole diameter and standoff
- compute hole diameter: requires a mud resistivity measurement and standoff
- compute standoff: requires hole diameter and mud resistivity measurement.

Because the AIT borehole model is a circular hole, either axis from a multiaxis caliper can be used. If the tool standoff is adequate, the process finds the circular borehole parameters that best match the input logs. Control of adequate standoff is important because the changes in the tool reading are very large for small changes in tool position when the tool is very close to the borehole wall. Near the center of the hole the changes are very small. A table of recommended standoff sizes is as follows.

### AIT Tool Recommended Standoff

<table>
<thead>
<tr>
<th>Hole Size (in.)</th>
<th>Recommended Standoff (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;5.0</td>
<td>—</td>
</tr>
<tr>
<td>5.0 to 5.5</td>
<td>—</td>
</tr>
<tr>
<td>5.5 to 6.5</td>
<td>0.5</td>
</tr>
<tr>
<td>6.5 to 7.75</td>
<td>1.0</td>
</tr>
<tr>
<td>7.75 to 9.5</td>
<td>1.5</td>
</tr>
<tr>
<td>9.5 to 11.5</td>
<td>2.0 + bowspring†</td>
</tr>
<tr>
<td>&gt;11.5</td>
<td>2.5 + bowspring†</td>
</tr>
</tbody>
</table>

† Only for AIT-H tool

Each type of AIT tool requires a slightly different approach to the borehole correction method. For example, the AIT-B tool requires the use of an auxiliary \( R_m \) measurement (Environmental Measurement Sonde [EMS]) to compute \( R_m \) or to compute hole size by using a recalibration of the mud resistivity method internal to the borehole correction algorithm. The Platform Express®, SlimAccess®, and Xtreme® AIT tools have integral \( R_m \) sensors that meet the accuracy requirements for the compute standoff mode.

Log Formation

AIT tools are designed to produce a high-resolution log response with reduced cave effect in comparison with the induction log deep (ILD) in most formations. The log processing (Barber and Rosthal, 1991) is a weighted sum of the raw array data:

\[
\sigma_{log}(z) = \sum_{n=1}^{N} \sum_{z=x_{min}}^{x_{max}} w_i(z') \sigma_a^{(n)}(z-z'),
\]

where \( \sigma_{log}(z) \) is the output log conductivity in mS/m, \( \sigma_a^{(n)} \) is the skin-effect-corrected conductivity from the \( n \)th array, and the weights \( w_i \) represent a deconvolution filter applied to each of the raw array measurements. The log depth is \( z \), and \( z' \) refers to the distance above or below the log depth to where the weights are applied. The skin effect correction consists of fitting the X-signal to the skin-effect-error signal (Moran, 1964; Barber, 1984) at high conductivities and the R-signal to the error signal at low conductivi-
Resistivity Induction—Wireline

AIT* Array Induction Imager Tool
Borehole Correction—Open Hole

ties, with the crossover occurring between 100 and 200 mS/m. The use of the R-signal at low conductivities overcomes the errors in the X-signal associated with the normal magnetic susceptibilities of sedimentary rock layers (Barber et al., 1995).

The weights \( w \) in the equation can profit from further refinement. The method used to compute the weights introduces a small amount of noise in the matrix inversion, so the fit is about \( \pm 1\% \) to \( \pm 2\% \) to the defined target response. A second refinement filter is used to correct for this error. The AIT wellsite processing sequence, from raw, calibrated data to corrected logs, is shown in Fig. 1.

There are only two versions of this processing—one for AIT-B, AIT-C, and AIT-D tools and one for all other AIT tools (AIT-H, AIT-M, SAIT, HIT, and QAIT) (Anderson and Barber, 1995). Only two versions are required because the tools were carefully designed with the same coil spacings to produce the same two-dimensional (2D) response to the formation.

Advanced Processing

Logs in Deviated Wells or Dipping Formations

The interpretation of induction logs is complicated by the large volume of investigation of these tools. The AIT series of induction tools is carefully focused to limit the contributions from outside a relatively thin layer of response (Barber and Rosthal, 1991). In beds at high relative dip, the focused response cuts across several beds, and the focusing developed for vertical wells no longer isolates the response to a single layer. The effect of the high relative dip angle is to blur the response and to introduce horns at the bed boundaries.

Maximum Entropy Inversion: MERLIN Processing

The maximum entropy inversion method was first applied by Dyos (1987) to induction log data. For beds at zero dip angle, it has been shown to give well-controlled results when applied to deep induction (ID) and medium induction (IM) from the dual induction tool (Freedman and Minerbo, 1991, 1993; Zhang et al., 1994). Maximum-Entropy Resistivity Log Inversion (MERLIN) processing (Barber et al., 1999) follows Freedman and Minerbo (1991) closely, and that paper is the basic reference for the mathematical formulation. The problem is set up as the simplest parametric model that can fit the data: a thinly layered formation with each layer the same thickness (Fig. 2). The inversion problem is to solve for the conductivity of each layer so that the computed logs from the layered formation are the closest match to the measured logs.

Figure 1. Block diagram of the real-time log processing chain from raw, calibrated array data to finished logs.

...
The flow of MERLIN processing is shown in Fig. 3. The borehole-corrected raw resistive and reactive (R- and X-) signals are used as a starting point. The conductivity of a set of layers is estimated from the log values, and the iterative modeling is continued until the logs converge. The set of formation layer conductivity values is then converted to resistivity and output as logs.

**Invasion Processing**

The wellsite interpretation for invasion is a one-dimensional (1D) inversion of the processed logs into a four-parameter invasion model \((R_{xo}, R_t, r_1, \text{and } r_2)\) shown in Fig. 4. The forward model is based on the Born model of the radial response of the tools and is accurate for most radial contrasts in which induction logs should be used. The inversion can be run in real time. The model is also available in the Invasion Correction module of the GeoFrame® Invasion 2 application, which also includes the step-invasion model and annulus model (Fig. 4).

**Figure 3.** Data flow in the MERLIN inversion algorithm. The output is the final set of model parameters after the iterations converge.

**Figure 4.** Parametric models used in AIT invasion processing. The slope profile model is used for real-time processing; the others are available at the computing centers. \(R_{xo} = \text{resistivity of the flushed zone, } R_t = \text{true resistivity, } r_1 = \text{radius of invasion, } R_{ann} = \text{resistivity of the annulus.} \)
Another approach is also used in the Invasion 2 application module. If the invaded zone is more conductive than the noninvaded zone, some 2D effects on the induction response can complicate the 1D inversion. Invasion 2 conducts a full 2D inversion using a 2D forward model (Fig. 5) to produce a more accurate answer for situations of conductive invasion and in thin beds.

References
Purpose
This chart is used to determine the borehole correction applied by the surface acquisition system to arcVISION475 and ImPulse phase-shift (Rps) and attenuation resistivity (Rad) curves on the log. The value of Rt is used in the calculation of water saturation.

Description
Enter the appropriate chart for the borehole environmental conditions and tool used to measure the various formation resistivities with the either the uncorrected phase-shift or attenuation resistivity value (not the resistivity shown on the log) on the x-axis. Move upward to intersect the appropriate resistivity spacing line, and then move horizontally left to read the ratio value on the y-axis. Multiply the ratio value by the resistivity value entered on the x-axis to obtain Rt.

Charts REm-12 through REm-38 are used similarly to Chart REm-11 for different borehole conditions and arcVISION* and ImPulse tool combinations.

Example
Given: Rps = 400 ohm-m (uncorrected) from arcVISION475 (2-MHz) phase-shift 10-in. resistivity, borehole size = 6 in., and mud resistivity (Rm) = 0.02 ohm-m at formation temperature.

Find: Formation resistivity (Rt).

Answer: Enter the top left chart at 400 ohm-m on the x-axis and move upward to intersect the 10-in. resistivity curve (green). Move left and read approximately 1.075 on the y-axis. Multiply 1.075 by 400 = 430 ohm-m.
arcVISION475* and ImPulse* 43⁄4-in. Array
Resistivity Compensated Tools—2 MHz
Borehole Correction—Open Hole

arcVISION475 and ImPulse Borehole Correction for 2 MHz, \( d_h = 6 \) in., \( R_m = 0.02 \) ohm-m

arcVISION475 and ImPulse Borehole Correction for 2 MHz, \( d_i = 6 \) in., \( R_m = 0.1 \) ohm-m

arcVISION475 and ImPulse Borehole Correction for 2 MHz, \( d_i = 6 \) in., \( R_m = 1.0 \) ohm-m

Resistivity spacing (in.)

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**Purpose**

This chart is used similarly to Chart REm-11 to determine the borehole correction applied by the surface acquisition system to arcVISION475 and ImPulse resistivity measurements. Uncorrected resistivity is entered on the x-axis, not the resistivity shown on the log.
**Purpose**

This chart is used similarly to Chart REm-11 to determine the borehole correction applied by the surface acquisition system to arcVISION475 and ImPulse resistivity measurements. Uncorrected resistivity is entered on the x-axis, not the resistivity shown on the log.
**Purpose**

This chart is used similarly to Chart REm-11 to determine the borehole correction applied by the surface acquisition system to arcVISION475 and ImPulse resistivity measurements. Uncorrected resistivity is entered on the x-axis, not the resistivity shown on the log.
Purpose
This chart is used similarly to Chart REm-11 to determine the borehole correction applied by the surface acquisition system to arcVISION675 resistivity measurements. Uncorrected resistivity is entered on the x-axis, not the resistivity shown on the log.
Purpose
This chart is used similarly to Chart REm-11 to determine the borehole correction applied by the surface acquisition system to arcVISION675 resistivity measurements. Uncorrected resistivity is entered on the x-axis, not the resistivity shown on the log.
Purpose

This chart is used similarly to Chart REm-11 to determine the borehole correction applied by the surface acquisition system to arcVISION675 resistivity measurements. Uncorrected resistivity is entered on the x-axis, not the resistivity shown on the log.
Purpose
This chart is used similarly to Chart REm-11 to determine the borehole correction applied by the surface acquisition system to arcVISION675 resistivity measurements. Uncorrected resistivity is entered on the x-axis, not the resistivity shown on the log.

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Purpose
This chart is used similarly to Chart REm-11 to determine the borehole correction applied by the surface acquisition system to arcVISION675 resistivity measurements. Uncorrected resistivity is entered on the x-axis, not the resistivity shown on the log.
**Purpose**

This chart is used similarly to Chart REm-11 to determine the borehole correction applied by the surface acquisition system to arcVISION675 resistivity measurements. Uncorrected resistivity is entered on the x-axis, not the resistivity shown on the log.
Purpose
This chart is used similarly to Chart REm-11 to determine the borehole correction applied by the surface acquisition system to arcVISION675 resistivity measurements. Uncorrected resistivity is entered on the x-axis, not the resistivity shown on the log.
Resistivity Electromagnetic—LWD

arcVISION675* 6¾-in. Array Resistivity Compensated Tool—2 MHz
Borehole Correction—Open Hole

Purpose
This chart is used similarly to Chart REm-11 to determine the borehole correction applied by the surface acquisition system to arcVISION675 resistivity measurements. Uncorrected resistivity is entered on the x-axis, not the resistivity shown on the log.
Resistivity Electromagnetic—LWD

arcVISION825* 8½-in. Array Resistivity Compensated Tool—400 kHz
Borehole Correction—Open Hole

Purpose
This chart is used similarly to Chart REm-11 to determine the borehole correction applied by the surface acquisition system to arcVISION825 resistivity measurements. Uncorrected resistivity is entered on the x-axis, not the resistivity shown on the log.
Purpose

This chart is used similarly to Chart REm-11 to determine the borehole correction applied by the surface acquisition system to arcVISION825 resistivity measurements. Uncorrected resistivity is entered on the x-axis, not the resistivity shown on the log.
Purpose
This chart is used similarly to Chart REm-11 to determine the borehole correction applied by the surface acquisition system to arcVISION825 resistivity measurements. Uncorrected resistivity is entered on the x-axis, not the resistivity shown on the log.
Purpose
This chart is used similarly to Chart REm-11 to determine the borehole correction applied by the surface acquisition system to arcVISION825 resistivity measurements. Uncorrected resistivity is entered on the x-axis, not the resistivity shown on the log.
Purpose
This chart is used similarly to Chart REm-11 to determine the borehole correction applied by the surface acquisition system to arcVISION825 resistivity measurements. Uncorrected resistivity is entered on the x-axis, not the resistivity shown on the log.
Purpose

This chart is used similarly to Chart REm-11 to determine the borehole correction applied by the surface acquisition system to arcVISION825 resistivity measurements. Uncorrected resistivity is entered on the x-axis, not the resistivity shown on the log.
**Purpose**

This chart is used similarly to Chart REm-11 to determine the borehole correction applied by the surface acquisition system to arcVISION825 resistivity measurements. Uncorrected resistivity is entered on the x-axis, not the resistivity shown on the log.
Purpose
This chart is used similarly to Chart REm-11 to determine the borehole correction applied by the surface acquisition system to arcVISION825 resistivity measurements. Uncorrected resistivity is entered on the x-axis, not the resistivity shown on the log.
**Purpose**

This chart is used similarly to Chart REm-11 to determine the borehole correction applied by the surface acquisition system to arcVISION900 resistivity measurements. Uncorrected resistivity is entered on the x-axis, not the resistivity shown on the log.
Purpose

This chart is used similarly to Chart REm-11 to determine the borehole correction applied by the surface acquisition system to arcVISION900 resistivity measurements. Uncorrected resistivity is entered on the x-axis, not the resistivity shown on the log.
Purpose

This chart is used similarly to Chart REm-11 to determine the borehole correction applied by the surface acquisition system to arcVISION900 resistivity measurements. Uncorrected resistivity is entered on the x-axis, not the resistivity shown on the log.
Purpose
This chart is used similarly to Chart REm-11 to determine the borehole correction applied by the surface acquisition system to arcVISION900 resistivity measurements. Uncorrected resistivity is entered on the x-axis, not the resistivity shown on the log.
Purpose
This chart is used similarly to Chart REm-11 to determine the borehole correction applied by the surface acquisition system to arcVISION900 resistivity measurements. Uncorrected resistivity is entered on the x-axis, not the resistivity shown on the log.
Purpose
This chart is used similarly to Chart REm-11 to determine the borehole correction applied by the surface acquisition system to arcVISION900 resistivity measurements. Uncorrected resistivity is entered on the x-axis, not the resistivity shown on the log.
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This chart is used similarly to Chart REm-11 to determine the borehole correction applied by the surface acquisition system to arcVISION900 resistivity measurements. Uncorrected resistivity is entered on the x-axis, not the resistivity shown on the log.
Purpose
This chart is used similarly to Chart REm-11 to determine the borehole correction applied by the surface acquisition system to arcVISION900 resistivity measurements. Uncorrected resistivity is entered on the x-axis, not the resistivity shown on the log.
Purpose
This chart is used to determine the correction factor applied by the surface acquisition system for bed thickness to the phase-shift and attenuation resistivity on the logs of arcVISION675, arcVISION825, and arcVISION900 tools.

Description
The six bed thickness correction charts on this page are paired for phase-shift and attenuation resistivity at different values of true ($R_t$) and shoulder bed ($R_s$) resistivity. Only uncorrected resistivity values are entered on the chart, not the resistivity shown on the log.

Chart REm-56 is also used to find the bed thickness correction applied by the surface acquisition system for 2-MHz arcVISION® and ImPulse® logs.

Example
Given: $R_t/R_s = 10/1$, $R_{ps}$ uncorrected = 20 ohm-m (34 in.), and bed thickness = 6 ft.
Find: $R_t$.
Answer: The appropriate chart to use is the phase-shift resistivity chart in the first row, for $R_t = 10$ ohm-m and $R_s = 1$ ohm-m. Enter the chart on the x-axis at 6 ft and move upward to intersect the 34-in. spacing line. The corresponding value of $R_t/R_{ps}$ is 1.6; $R_t = 20 \times 1.6 = 32$ ohm-m.
arcVISION675*, arcVISION825*, and arcVISION900*
Array Resistivity Compensated Tools—400 kHz
Bed Thickness Correction—Open Hole
arcVISION* and ImPulse* Array Resistivity Compensated Tools—2 MHz
Bed Thickness Correction—Open Hole

arcVISION and ImPulse 2-MHz Bed Thickness Correction for
\( R_t = 10 \text{ ohm-m and } R_s = 1 \text{ ohm-m at Center of Bed} \)

arcVISION and ImPulse 2-MHz Bed Thickness Correction for
\( R_t = 1 \text{ ohm-m and } R_s = 10 \text{ ohm-m at Center of Bed} \)

arcVISION and ImPulse 2-MHz Bed Thickness Correction for
\( R_t = 100 \text{ ohm-m and } R_s = 10 \text{ ohm-m at Center of Bed} \)

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Purpose
This chart is used to estimate the true resistivity ($R_t$) and dielectric correction ($\varepsilon_r$). $R_t$ is used in water saturation calculation.

Description
Enter the chart with the uncorrected (not those shown on the log) phase-shift and attenuation values from the arcVISION675 or ImPulse resistivity tool. The intersection point of the two values is used to determine $R_t$ and the dielectric correction. $R_t$ is interpolated from the subvertical lines described by the dots originating at the listed $R_t$ values. The $\varepsilon_r$ is interpolated from the radial lines originating from the $\varepsilon_r$ values listed on the left-hand side of the chart. Charts REm-59 through REm-62 are used to determine $R_t$ and $\varepsilon_r$ at larger spacings.

Example
Given: Phase shift $= 2^\circ$ and attenuation $= 8.45$ dB for 16-in. spacing.
Find: $R_t$ and $\varepsilon_r$.
Answer: $R_t = 26$ ohm-m and $\varepsilon_r = 70$ dB.
**Purpose**
Charts REm-59 through REm-62 are identical to Chart REm-58 for determining $R_t$ and $\varepsilon_r$ at larger spacings of the arcVISION675 and ImPulse 2-MHz tools.
Purpose
Charts REm-59 through REm-62 are identical to Chart REm-58 for determining $R_t$ and $\varepsilon_r$ at larger spacings of the arcVISION675 and ImPulse 2-MHz tools.
**Purpose**

Charts REm-59 through REm-62 are identical to Chart REm-58 for determining $R_t$ and $\varepsilon_r$ at larger spacings of the arcVISION675 and ImPulse 2-MHz tools.
Purpose
Charts REm-59 through REm-62 are identical to Chart REm-58 for determining $R_t$ and $\varepsilon_r$ at larger spacings of the arcVISION675 and ImPulse 2-MHz tools.
Dielectric Effects of Standard Processed arcVISION675 or ImPulse Log at 2 MHz with Dielectric Assumption

Dielectric assumption

\[ \epsilon_r = 5 + 10^{8.5R^{-0.35}} \]

\[ \epsilon_2 = 0.5\epsilon_1 \]

\[ \epsilon_3 = 2\epsilon_1 \]
Purpose

The charts in this chapter are used to determine the correction for invasion effects on the following parameters:

- Diameter of invasion (d_i)
- Ratio of flushed zone to true resistivity (R_xo/R_t)
- R_t from laterolog resistivity tools.

The R_xo/R_t and R_t values are used in the calculation of water saturation.

Description

The invasion correction charts, also referred to as “tornado” or “butterfly” charts, assume a step-contact profile of invasion and that all resistivity measurements have already been corrected as necessary for borehole effect and bed thickness by using the appropriate chart from the “Resistivity Laterolog” chapter.

To use any of these charts, enter the y-axis and x-axis with the required resistivity ratios. The point of intersection defines d_i, R_xo/R_t, and R_t as a function of one resistivity measurement.

Saturation Determination in Clean Formations

Either of the chart-derived values of R_t and R_xo/R_t are used to find values for the water saturation of the formation (S_w). The first of two approaches is the S_w-Archie (S_wA), which is found using the Archie saturation formula (or Chart SatOH-3) with the derived R_t value and known values of the formation resistivity factor (F_R) and the resistivity of the water (R_w). The S_w-ratio (S_wR) is found by using R_xo/R_t and R_out/R_w as in Chart SatOH-4.

If S_wA and S_wR are equal, the assumption of a step-contact invasion profile is indicated to be correct, and all values determined (S_w, R_t, R_xo, and d_i) are considered good.

If S_wA > S_wR, either invasion is very shallow or a transition-type invasion profile is indicated, and S_wA is considered a good value for S_w.

If S_wA < S_wR, an annulus-type invasion profile may be indicated, and a more accurate value of water saturation may be estimated by using

$$S_{wcor} = S_{WA} \left( \frac{S_wA}{S_wR} \right)^{1/4}$$

The correction factor of $(S_wA/S_wR)^{1/4}$ is readily determined from the scale.

For more information, see Reference 9.
**Purpose**

The resistivity values of HALS laterolog deep resistivity (HLLD), HALS laterolog shallow resistivity (HLLS), and resistivity of the flushed zone ($R_{xo}$) measured by the High-Resolution Azimuthal Laterolog Sonde (HALS) are used with this chart to determine values for diameter of invasion ($d_i$) and true resistivity ($R_t$).

**Description**

The conditions for which this chart is used are listed at the top. The chart is entered with the ratios of HLLD/HLLS on the x-axis and HLLD/R$_{xo}$ on the y-axis. The intersection point defines $d_i$ on the dashed curves and the ratio of $R_t/R_{xo}$ on the solid curves.

**Example**

Given: HLLD = 50 ohm-m, HLLS = 15 ohm-m, $R_{xo} = 2.0$ ohm-m, and $R_m = 0.2$ ohm-m.

Find: $R_t$ and diameter of invasion.

Answer: Enter the chart with the values of HLLD/HLLS = 50/15 = 3.33 and HLLD/R$_{xo}$ = 50/2 = 25.

The resulting point of intersection on the chart indicates that $R_t/R_{xo} = 35$ and $d_i = 34$ in.

$R_t = 35 \times 2.0 = 70$ ohm-m.
Purpose
The resistivity values of high-resolution deep resistivity (HRLD), high-resolution shallow resistivity (HRLS), and $R_{xo}$ measured by the HALS are used similarly to Chart Rt-2 to determine values for $d_i$ and $R_t$.

Description
The conditions for which this chart is used are listed at the top. The chart is entered with the ratios of HRLD/HRLS on the x-axis and HRLD/$R_{xo}$ on the y-axis. The intersection point defines $d_i$ on the dashed curves and the ratio of $R_t/R_{xo}$ on the solid curves.
Purpose
This chart is used to determine the correction applied to the log presentation of $R_t$ and $d_i$ determined from geoVISION675 ring ($R_{ring}$) and deep ($R_{bd}$) and medium button ($R_{bm}$) resistivity values.

Description
Enter the chart with the ratios of $R_{ring}/R_{bd}$ on the x-axis and $R_{ring}/R_{bm}$ on the y-axis. The intersection point defines $d_i$ on the blue dashed curves, $R_t/R_{ring}$ on the red curves, and $R_t/R_{xo}$ on the black curves. Charts Rt-11 through Rt-17 are similar to Chart Rt-10 for different tool sizes, configurations, and resistivity terms.

Example
Given: $R_{ring} = 30$ ohm-m, $R_{xo}/R_{m} = 50$, $R_{bd} = 15$ ohm-m, and $R_{bm} = 6$ ohm-m.
Find: $R_t$, $d_i$, and $R_{xo}$.
Answer: Enter the chart with values of $R_{ring}/R_{bd} = 30/15 = 2$ on the x-axis and $R_{ring}/R_{bm} = 30/6 = 5$ on the y-axis to find $d_i = 22.5$ in., $R_t/R_{ring} = 3.1$, and $R_t/R_{xo} = 50$. From these ratios, $R_t = 3.1 \times 30 = 93$ ohm-m and $R_{xo} = 93/50 = 1.86$ ohm-m.
Purpose
This chart is used similarly to Chart Rt-10 to determine the correction applied to the log presentation of $R_t$ and $d_i$ determined from geoVISION675 deep ($R_{td}$), medium ($R_{tm}$), and shallow button ($R_{ts}$) resistivity values.
Purpose
This chart is used similarly to Chart Rt-10 to determine the correction applied to the log presentation of \( R_t \) and \( d_i \) determined from geoVISION675 \( R_{ring} \), bit (\( R_{bit} \)), and \( R_{bd} \) resistivity values.
Purpose

This chart is used similarly to Chart Rt-10 to determine the correction applied to the log presentation of $R_t$ and $d_i$ determined from geoVISION675 $R_{ring}$, $R_{bit}$, and $R_{bd}$ resistivity values.
**Purpose**

This chart is used similarly to Chart Rt-10 to determine the correction applied to the log presentation of $R_t$ and $d_i$ determined from geoVISION825 $R_{ring}$, $R_{bd}$, and $R_{in}$ resistivity values.
Purpose
This chart is used similarly to Chart Rt-10 to determine the correction applied to the log presentation of $R_t$ and $d_t$ determined from geoVISION825 $R_{bd}$, $R_{bm}$, and $R_{bs}$ resistivity values.
Purpose
This chart is used similarly to Chart Rt-10 to determine the correction applied to the log presentation of $R_t$ and $d_i$ determined from geoVISION825 $R_{ring}$, $R_{bit}$, and $R_{bd}$ resistivity values.
Purpose
This chart is used similarly to Chart Rt-10 to determine the correction applied to the log presentation of \( R_t \) and \( d_i \) determined from geoVISION825 \( R_{\text{ring}} \), \( R_{\text{bit}} \), and \( R_{\text{bd}} \) resistivity values.
Purpose
This chart illustrates the resistivity response, as affected by sand and shale layers, of the arcVISION tool in horizontal wellbores. The chart is used to determine the values of $R_h$ and $R_v$. These corrections are already applied to the log presentation.

Description
The chart is constructed for shale layers at 90° relative dip to the axis of the arcVISION tool. That is, both the layers of shale and the tool are horizontal to the vertical. Other requirements for use of this chart are that the shale resistivity ($R_{sh}$) is 1 ohm-m and the sand resistivity is 5 or 20 ohm-m.

Select the appropriate chart for the attenuation ($R_{at}$) or phase-shift ($R_{ps}$) resistivity and values of resistivity of the shale ($R_{sh}$) and sand ($R_{sand}$). Enter the chart with the volume of shale ($V_{sh}$) on the x-axis and the resistivity on the y-axis. At the intersection point of these two values move straight downward to the dashed blue curve to read the value of $R_h$. Move upward to the solid green curve to read the value of $R_v$.

Chart Rt-32 is used to determine $R_h$ and $R_v$ values for the 2-MHz resistivity.
Purpose
This chart is used similarly to Chart Rt-31 for arcVISION and ImPulse 2-MHz resistivity. These corrections are already applied to the log presentation.
Purpose
This chart is used to determine arcVISION $R_{ps}$ and $R_{ad}$ for relative dip angles from 0 to 90°. These corrections are already applied to the log presentation.

Description
Enter the appropriate chart with the value of relative dip angle and move to intersect the known resistivity spacing. Move horizontally left to read $R_{ps}$ or $R_{ad}$ for the conditions of the horizontal resistivity ($R_h$) = 1 ohm-m and the square root of the $R_v/R_h$ ratio.
Purpose

This chart is used similarly to Chart Rt-33 for arcVISION and ImPulse 2-MHz resistivity. These corrections are already applied to the log presentation.
Purpose
This chart and Chart Rt-36 reflect the effect of anisotropy on the arcVISION resistivity response. These corrections are already applied to the log presentation. As the square root of the $R_v/R_h$ ratio increases, the effect on the resistivity significantly increases.

Description
Enter the appropriate chart with the value of the phase-shift or attenuation resistivity on the y-axis. Move horizontally to intersect the resistivity spacing curve. At the intersection point read the value of the square root of the $R_v/R_h$ ratio on the x-axis.
**Purpose**

This chart is used similarly to Chart Rt-35 for arcVISION and ImPulse for 2-MHz resistivity. These corrections are already applied to the log presentation.
**Purpose**
This log-log chart is used to determine the correction applied to the log presentation of the 40-in. arcVISION675 resistivity measurements, diameter of invasion \( (d_i) \), and resistivity of the flushed zone \( (R_{xo}) \). These data are used to evaluate a formation for hydrocarbons.

**Description**
Enter the chart with the ratio of the 16-in. \( R_{ps} / 40\text{-in. } R_{ad} \) on the y-axis and 28-in. \( R_{ps} / 40\text{-in. } R_{ad} \) on the x-axis. The intersection point defines the following:
- \( d_i \)
- \( R_{xo} \)
- Correction factor for 40-in. attenuation resistivity.

Chart Rt-38 is used for 2-MHz resistivity values. The corresponding charts for resistive invasion are Charts Rt-39 and Rt-40.

**Example**
Given: 16-in. \( R_{ps} / 40\text{-in. } R_{ad} = 0.2 \) and 28-in. \( R_{ps} / 40\text{-in. } R_{ad} = 0.4 \).
Find: \( R_{xo} \), \( d_i \), and correction factor for 40-in. \( R_{ad} \).
Answer: At the intersection point of 0.2 on the y-axis and 0.4 on the x-axis, \( d_i = 31.9 \text{ in.} \), \( R_{xo} = 1.1 \text{ ohm-m} \), and correction factor = 0.955.

The value of the 40-in. \( R_{ad} \) is reduced by the correction factor: 40-in. \( R_{ad} \times 0.955 \).
Purpose
This chart is used similarly to Chart Rt-37 for arcVISION675 and ImPulse 2-MHz resistivity. The corrections are already applied to the log presentation.
Purpose
This chart is used similarly to Chart Rt-37 to determine the correction applied to the arcVISION log presentation of di, Rxo, and 40-in. Rad for resistive invasion.
Purpose

This chart is used similarly to Chart Rt-39 to determine the correction applied to the arcVISION and ImPulse log presentation for 2-MHz resistivity.

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Purpose
Charts Rt-41 and Rt-42 are used to calculate the correction applied to the log presentation of Rt from the arcVISION tool at the approach to a bed boundary. The value of Rt is used to calculate water saturation.

Description
There are two sets of charts for differing conditions:
- shoulder bed resistivity ($R_{shoulder}$) = 10 ohm-m and $R_t$ = 1 ohm-m
- $R_{shoulder}$ = 10 ohm-m and $R_t$ =100 ohm-m.

Example
Given: $R_{shoulder}$ = 10 ohm-m, $R_t$ = 1 ohm-m, and 16-in. $R_{ps}$ = 1.5 ohm-m.
Find: Bed proximity effect.
Answer: The top set of charts is appropriate for these resistivity values. The ratio $R_{ps}/R_t = 1.5/1 = 1.5$.
Enter the y-axis of the left-hand chart at 1.5 and move horizontally to intersect the 16-in. curve. The corresponding value on the x-axis is 1 ft, which is the distance of the surrounding bed from the tool. At 2 ft from the bed boundary, the value of 16-in. $R_{ps}$ = 1 ohm-m.
arcVISION® Array Resistivity Compensated Tool—400 kHz in Horizontal Well

Bed Proximity Effect—Open Hole

Bed Proximity Effect for Horizontal Well: $R_{shoulder} = 10 \text{ ohm-m}$ and $R_t = 1 \text{ ohm-m}$

Bed Proximity Effect for Horizontal Well: $R_{shoulder} = 10 \text{ ohm-m}$ and $R_t = 100 \text{ ohm-m}$

Resistivity spacing

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Purpose
This chart is used similarly to Chart Rt-41 for arcVISION and ImPulse 2-MHz resistivity. The correction is already applied to the log presentation.
Purpose
This chart is a method for identifying the type of clay in the wellbore. The values of the photoelectric factor (Pe) from the Litho-Density* log and the concentration of potassium (K) from the NGS Natural Gamma Ray Spectrometry tool are entered on the chart.

Description
Enter the upper chart with the values of Pe and K to determine the point of intersection. On the lower chart, plotting Pe and the ratio of thorium and potassium (Th/K) provides a similar mineral evaluation. The intersection points are not unique but are in general areas defined by a range of values.

Example
Given: Environmentally corrected thorium concentration (ThNGScorr) = 10.6 ppm, environmentally corrected potassium concentration (KNGScorr) = 3.9%, and Pe = 3.2.
Find: Mineral concentration of the logged clay.
Answer: The intersection points from plotting values of Pe and K on the upper chart and Pe and Th/K ratio = 10.6/3.9 = 2.7 on the lower chart suggest that the clay mineral is illite.
Lithology—Wireline

Density and NGS* Natural Gamma Ray Spectrometry Tool

Mineral Identification—Open Hole

Potassium concentration, K (%)

Photoelectric factor, Pe

Thorium/potassium ratio, Th/K

Chlorite

Glauconite

Muscovite

Magnetite

Montmorillonite

Illite

Biotite

Mixed layer

Kaolinite

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Purpose
This chart is used to determine the type of minerals in a shale formation from concentrations measured by the NGS Natural Gamma Ray Spectrometry tool.

Description
Entering the chart with the values of thorium and potassium locates the intersection point used to determine the type of radioactive minerals that compose the majority of the clay in the formation.

A sandstone reservoir with varying amounts of shaliness and illite as the principal clay mineral usually plots in the illite segment of the chart with Th/K between 2.0 and 3.5. Less shaly parts of the reservoir plot closer to the origin, and shaly parts plot closer to the 70% illite area.
Purpose
This chart is used to determine the lithology and porosity of a formation. The porosity is used for the water saturation determination and the lithology helps to determine the makeup of the logged formation.

Description
Note that this chart is designed for fresh water (fluid density $[\rho_f] = 1.0 \text{ g/cm}^3$) in the borehole. Chart Lith-4 is used for saltwater ($\rho_f = 1.1 \text{ g/cm}^3$) formations.

Values of photoelectric factor (Pe) and bulk density ($\rho_b$) from the Platform Express Three-Detector Lithology Density (TLD) tool are entered into the chart. At the point of intersection, porosity and lithology values can be determined.

Example
Given: Freshwater drilling mud, Pe = 3.0, and bulk density = 2.73 g/cm$^3$.
Freshwater drilling mud, Pe = 1.6, and bulk density = 2.24 g/cm$^3$.

Find: Porosity and lithology.

Answer: For the first set of conditions, the formation is a dolomite with 8% porosity.
The second set is for a quartz sandstone formation with 30% porosity.
Fresh Water ($\rho_f = 1.0 \text{ g/cm}^3$), Liquid-Filled Borehole

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

- Quartz sandstone
- Dolomite
- Calcite (limestone)
- Salt
- Anhydrite

$\text{Photoelectric factor, } Pe$

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This chart is used similarly to Chart Lith-3 for lithology and porosity determination with values of photoelectric factor (Pe) and bulk density ($\rho_b$) from the Platform Express TLD tool in saltwater borehole fluid.
Density Tool
Apparent Matrix Volumetric Photoelectric Factor—Open Hole

**Purpose**
This chart is used to determine the apparent matrix volumetric photoelectric factor ($U_{maa}$) for the Chart Lith-6 percent lithology determination.

**Description**
This chart is entered with the values of bulk density ($\rho_b$) and Pe from a density log. The value of the apparent total porosity ($\phi_{ta}$) must also be known. The appropriate solid lines on the right-hand side of the chart that indicate a freshwater borehole fluid or dotted lines that represent saltwater borehole fluid are used depending on the salinity of the borehole fluid. $U_f$ is the fluid photoelectric factor.

**Example**
Given: $Pe = 4.0$, $\rho_b = 2.5 \text{ g/cm}^3$, $\phi_{ta} = 25\%$, and freshwater borehole fluid.
Find: Apparent matrix volumetric photoelectric factor ($U_{maa}$).
Answer: Enter the chart with the Pe value (4.0) on the left-hand x-axis, and move upward to intersect the curve for $\rho_b = 2.5 \text{ g/cm}^3$.

From that intersection point, move horizontally right to intersect the $\phi_{ta}$ value of 25%, using the blue freshwater curve.

Move vertically downward to determine the $U_{maa}$ value on the right-hand x-axis scale: $U_{maa} = 13$. 
Density Tool
Lithology Identification—Open Hole

**Purpose**
This chart is used to identify the rock mineralogy through comparison of the apparent matrix grain density ($\rho_{maa}$) and apparent matrix volumetric photoelectric factor ($U_{maa}$).

**Description**
The values of $\rho_{maa}$ and $U_{maa}$ are entered on the y- and x-axis, respectively. The rock mineralogy is identified by the proximity of the point of intersection of the two values to the labeled points on the plot. The effect of gas, salt, etc., is to shift data points in the directions shown by the arrows.

**Example**
Given: $\rho_{maa} = 2.74 \, \text{g/cm}^3$ (from Chart Lith-9 or Lith-10) and $U_{maa} = 13$ (from Chart Lith-5).
Find: Matrix composition of the formation.
Answer: Enter the chart with $\rho_{maa} = 2.74 \, \text{g/cm}^3$ on the y-axis and $U_{maa} = 13$ on the x-axis. The intersection point indicates a matrix mixture of 20% dolomite and 80% calcite.
Purpose
This chart is used to help identify mineral mixtures from sonic, density, and neutron logs.

Description
Because M and N slope values are practically independent of porosity except in gas zones, the porosity values they indicate can be correlated with the mineralogy. (See Appendix E for the formulas to calculate M and N from sonic, density, and neutron logs.)

Enter the chart with M on the y-axis and N on the x-axis. The intersection point indicates the makeup of the formation. Points for binary mixtures plot along a line connecting the two mineral points. Ternary mixtures plot within the triangle defined by the three constituent minerals. The effect of gas, shaliness, secondary porosity, etc., is to shift data points in the directions shown by the arrows.

The lines on the chart are divided into numbered groups by porosity range as follows:
1. $\phi = 0$ (tight formation)
2. $\phi = 0$ to 12 p.u.
3. $\phi = 12$ to 27 p.u.
4. $\phi = 27$ to 40 p.u.

Example
Given: $M = 0.79$ and $N = 0.51$.
Find: Mineral composition of the formation.
Answer: The intersection of the M and N values indicates dolomite in group 2, which has a porosity between 0 to 12 p.u.
Environmentally Corrected Neutron Curves
M–N Plot for Mineral Identification—Open Hole

- **Approximate shale region**
- **Anhydrite**
- **Calcite (limestone)**
- **Dolomite**
- **Quartz sandstone**
- **Gypsum**
- **Sulfur**

**Lithology—Wireline, LWD**

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Purpose
This chart is used to help identify mineral mixtures from APS Accelerator Porosity Sonde neutron logs.

Description
Because M and N values are practically independent of porosity except in gas zones, the porosity values they indicate can be correlated with the mineralogy. (See Appendix E for the formulas to calculate M and N from sonic, density, and neutron logs.)

Enter the chart with M on the y-axis and N on the x-axis. The intersection point indicates the makeup of the formation. Points for binary mixtures plot along a line connecting the two mineral points. Ternary mixtures plot within the triangle defined by the three constituent minerals. The effect of gas, shaliness, secondary porosity, etc., is to shift data points in the directions shown by the arrows.

The lines on the chart are divided into numbered groups by porosity range as follows:
1. \( \phi = 0 \) (tight formation)
2. \( \phi = 0 \) to 12 p.u.
3. \( \phi = 12 \) to 27 p.u.
4. \( \phi = 27 \) to 40 p.u.

Because the dolomite spread is negligible, a single dolomite point is plotted for each mud.

Example
Given: \( M = 0.80 \) and \( N = 0.55 \).
Find: Mineral composition of the formation.
Answer: Dolomite.
Environmentally Corrected APS* Curves

M–N Plot for Mineral Identification—Open Hole

- **Gypsum**
  - $v_{ma} = 5943 \text{ m/s} = 19,500 \text{ ft/s}$

- **Calcite (limestone)**
  - $v_{ma} = 5486 \text{ m/s} = 18,000 \text{ ft/s}$

- **Dolomite**
  - $v_{ma} = 5435 \text{ m/s} = 18,000 \text{ ft/s}$

- **Anhydrite**

- **Quartz sandstone**
  - $v_{ma} = 5813 \text{ m/s} = 19,000 \text{ ft/s}$

- **Sulfur**

- **Secondary porosity**

- **Gas or salt**

**Freshwater mud**
- $\rho_r = 1.0 \text{ Mg/m}^3$, $\tau_r = 620 \mu\text{s/m}$
- $\rho_r = 1.0 \text{ g/cm}^3$, $\tau_r = 189 \mu\text{s/ft}$

**Saltwater mud**
- $\rho_r = 1.1 \text{ Mg/m}^3$, $\tau_r = 607 \mu\text{s/m}$
- $\rho_r = 1.1 \text{ g/cm}^3$, $\tau_r = 185 \mu\text{s/ft}$

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Purpose
Charts Lith-9 (customary units) and Lith-10 (metric units) provide values of the apparent matrix internal transit time (t\text{maa}) and apparent matrix grain density ($\rho_{\text{maa}}$) for the matrix identification (MID) Charts Lith-11 and Lith-12. With these parameters the identification of rock mineralogy or lithology through a comparison of neutron, density, and sonic measurements is possible.

Description
Determining the values of t\text{maa} and $\rho_{\text{maa}}$ to use in the MID Charts Lith-11 and Lith-12 requires three steps.

First, apparent crossplot porosity is determined using the appropriate neutron-density and neutron-sonic crossplot charts in the “Porosity” section of this book. For data that plot above the sandstone curve on the charts, the apparent crossplot porosity is defined by a vertical projection to the sandstone curve.

Second, enter Chart Lith-9 or Lith-10 with the interval transit time (t) to intersect the previously determined apparent crossplot porosity. This point defines t\text{maa}.

Third, enter Chart Lith-9 or Lith-10 with the bulk density ($\rho_b$) to again intersect the apparent crossplot porosity and define $\rho_{\text{maa}}$.

The values determined from Charts Lith-9 and Lith-10 for t\text{maa} and $\rho_{\text{maa}}$ are cross plotted on the appropriate MID plot (Charts Lith-11 and Lith-12) to identify the rock mineralogy by its proximity to the labeled points on the plot.

Example
Given: Apparent crossplot porosity from density-neutron = 20%, $\rho_b = 2.4 \text{ g/cm}^3$, apparent crossplot porosity from neutron-sonic = 30%, and t = 82 $\mu$s/ft.
Find: $\rho_{\text{maa}}$ and t\text{maa}.
Answer: $\rho_{\text{maa}} = 2.75 \text{ g/cm}^3$ and t\text{maa} = 46 $\mu$s/ft.
Bulk Density or Interval Transit Time and Apparent Total Porosity
Apparent Matrix Parameters—Open Hole

Fluid Density = 1.0 g/cm³

Apparent matrix transit time, $t_{\text{maa}}$ (μs/ft)

Bulk density, $\rho_b$ (g/cm³)

Interval transit time, $t$ (μs/ft)

Apparent crossplot porosity

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Purpose

Charts Lith-9 (customary units) and Lith-10 (metric units) provide values of the apparent matrix internal transit time \( t_{\text{maa}} \) and apparent matrix grain density \( \rho_{\text{maa}} \) for the matrix identification (MID) Charts Lith-11 and Lith-12. With these parameters the identification of rock mineralogy or lithology through a comparison of neutron, density, and sonic measurements is possible.
Purpose
Charts Lith-11 and Lith-12 are used to establish the type of mineral predominant in the formation.

Description
Enter the appropriate (customary or metric units) chart with the values established from Charts Lith-9 or Lith-10 to identify the predominant mineral in the formation. Salt points are defined for two tools, the sidewall neutron porosity (SNP) and the CNL* Compensated Neutron Log. The presence of secondary porosity in the form of vugs or fractures displaces the data points parallel to the apparent matrix internal transit time (t mAa) axis. The presence of gas displaces points to the right on the chart. Plotting some shale points to establish the shale trend lines helps in the identification of shaliness. For fluid density ($\rho_f$) other than 1.0 g/cm$^3$ use the table to determine the multiplier to correct the apparent total density porosity before entering Chart Lith-11 or Lith-12.

<table>
<thead>
<tr>
<th>$\rho_t$</th>
<th>Multiplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>1.05</td>
<td>0.98</td>
</tr>
<tr>
<td>1.10</td>
<td>0.95</td>
</tr>
<tr>
<td>1.15</td>
<td>0.93</td>
</tr>
</tbody>
</table>

Example
Given: $\rho_{maa} = 2.75$ g/cm$^3$, t $maa = 56$ $\mu$s/ft (from Chart Lith-9), and $\rho_t = 1.0$ g/cm$^3$.
Find: The predominant mineral.
Answer: The formation consists of both dolomite and calcite, which indicates a dolomitized limestone. The formation used in this example is from northwest Florida in the Jay field. The vugs (secondary porosity) created by the dolomitization process displace the data point parallel to the dolomite and calcite points.
Density Tool
Matrix Identification (MID)—Open Hole

![Graph showing density versus sonic travel time for various lithologies: Calcite, Dolomite, Quartz, Anhydrite, and Salt. The graph includes density and sonic travel time axes, with points indicating different lithologies and their respective densities and times.]
Purpose

Chart Lith-12 is used similarly to Chart Lith-11 to establish the mineral type of the formation.
Purpose
This chart is used to convert sonic log slowness time (Δt) values into those for porosity (φ).

Description
There are two sets of curves on the chart. The blue set for matrix velocity (vma) employs a weighted-average transform. The red set is based on the empirical observation of lithology (see Reference 20). For both, the saturating fluid is assumed to be water with a velocity (vf) of 5,300 ft/s (1,615 m/s).

Enter the chart with the slowness time from the sonic log on the x-axis. Move vertically to intersect the appropriate matrix velocity or lithology curve and read the porosity value on the y-axis. For rock mixtures such as limy sandstones or cherty dolomites, intermediate matrix lines may be interpolated.

To use the weighted-average transform for an unconsolidated sand, a lack-of-compaction correction (Bcp) must be made. Enter the chart with the slowness time and intersect the appropriate compaction correction line to read the porosity on the y-axis. If the compaction correction is not known, it can be determined by working backward from a nearby clean water sand for which the porosity is known.

Example: Consolidated Formation
Given: Δt = 76 μs/ft in a consolidated formation with vma = 18,000 ft/s.
Find: Porosity and the formation lithology (sandstone, dolomite, or limestone).
Answer: 15% porosity and consolidated sandstone.

Example: Unconsolidated Formation
Given: Unconsolidated formation with Δt = 100 μs/ft in a nearby water sand with a porosity of 28%.
Find: Porosity of the formation for Δt = 110 μs/ft.
Answer: Enter the chart with 100 μs/ft on the x-axis and move vertically upward to intersect 28-p.u. porosity. This intersection point indicates the correction factor curve of 1.2. Use the 1.2 correction value to find the porosity for the other slowness time. The porosity of an unconsolidated formation with Δt = 110 μs/ft is 34 p.u.

<table>
<thead>
<tr>
<th>Lithology</th>
<th>vma (ft/s)</th>
<th>Δtma (μs/ft)</th>
<th>vma (m/s)</th>
<th>Δtma (μs/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandstone</td>
<td>18,000–19,500</td>
<td>55.5–51.3</td>
<td>5,486–5,944</td>
<td>182–168</td>
</tr>
<tr>
<td>Limestone</td>
<td>21,000–23,000</td>
<td>47.6–43.5</td>
<td>6,400–7,010</td>
<td>156–143</td>
</tr>
<tr>
<td>Dolomite</td>
<td>23,000–26,000</td>
<td>43.5–38.5</td>
<td>7,010–7,925</td>
<td>143–126</td>
</tr>
</tbody>
</table>
Sonic Tool
Porosity Evaluation—Open Hole

Porosity—Wireline, LWD

Porosity, $\phi$ (p.u.)

Interval transit time, $\Delta t$ (μs/ft)

$v_f = 5,300$ ft/s

$B_{\phi}$

Dolomite

Calcite/limestone

Quartz sandstone

$v_{ma}$ (ft/s)

21,000

19,500

18,000

26,000

22,000

Porosity, $\phi$ (p.u.)

© Schlumberger
Porosity—Wireline, LWD

Sonic Tool
Porosity Evaluation—Open Hole

Purpose
This chart is used similarly to Chart Por-1 with metric units.
Purpose
This chart is used to convert grain density (g/cm³) to density porosity.

Description
Values of log-derived bulk density ($\rho_b$) corrected for borehole size, matrix density of the formation ($\rho_{ma}$), and fluid density ($\rho_f$) are used to determine the density porosity ($\phi_D$) of the logged formation. The $\rho_f$ is the density of the fluid saturating the rock immediately surrounding the borehole—usually mud filtrate.

Enter the borehole-corrected value of $\rho_b$ on the x-axis and move vertically to intersect the appropriate matrix density curve. From the intersection point move horizontally to the fluid density line. Follow the porosity trend line to the porosity scale to read the formation porosity as determined by the density tool. This porosity in combination with CNL® Compensated Neutron Log, sonic, or both values of porosity can help determine the rock type of the formation.

Example
Given: $\rho_b = 2.31$ g/cm³ (log reading corrected for borehole effect), $\rho_{ma} = 2.71$ g/cm³ (calcite mineral), and $\rho_f = 1.1$ g/cm³ (salt mud).

Find: Density porosity.

Answer: $\phi_D = 25$ p.u.
Porosity—Wireline

APS* Near-to-Array (APLC) and Near-to-Far (FPLC) Logs
Epithermal Neutron Porosity Equivalence—Open Hole

Purpose
This chart is used for the apparent limestone porosity recorded by the APS Accelerator Porosity Sonde or sidewall neutron porosity (SNP) tool to provide the equivalent porosity in sandstone or dolomite formations. It can also be used to obtain the apparent limestone porosity (used for the various crossplot porosity charts) for a log recorded in sandstone or dolomite porosity units.

Description
Enter the x-axis with the corrected near-to-array apparent limestone porosity (APLC) or near-to-far apparent limestone porosity (FPLC) and move vertically to the appropriate lithology curve. Then read the equivalent porosity on the y-axis. For APS porosity recorded in sandstone or dolomite porosity units enter that value on the y-axis and move horizontally to the recorded lithology curve. Then read the apparent limestone neutron porosity for that point on the x-axis.

The APLC is the epithermal short-spacing apparent limestone neutron porosity from the near-to-array detectors. The log is automatically corrected for standoff during acquisition. Because it is epithermal this measurement does not need environmental corrections for temperature or chlorine effect. However, corrections for mud weight and actual borehole size should be applied (see Chart Neu-10). The short spacing means that the effect of density and therefore the lithology on this curve is minimal.

The FPLC is the epithermal long-spacing apparent limestone neutron porosity acquired from the near-to-far detectors. Because it is epithermal this measurement does not need environmental corrections for temperature or chlorine effect. However, corrections for mud weight and actual borehole size should be applied (see Chart Neu-10). The long spacing means that the density and therefore lithology effect on this curve is pronounced, as seen on Charts Por-13 and Por-14.

The HPLC curve is the high-resolution version of the APLC curve. The same corrections apply.

<table>
<thead>
<tr>
<th>Resolution</th>
<th>Short Spacing</th>
<th>Long Spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>APLC</td>
<td>FPLC</td>
</tr>
<tr>
<td>Enhanced</td>
<td>HPLC Epithermal neutron porosity (ENPI)*</td>
<td>HFLC</td>
</tr>
</tbody>
</table>

* Not formation-salinity corrected.

Example: Equivalent Porosity
Find: Porosity for sandstone and for dolomite.
Answer: Sandstone porosity from APLC = 28.5 p.u. and sandstone porosity from FPLC = 30 p.u.
Dolomite porosity = 24 and 20 p.u., respectively.

Example: Apparent Porosity
Given: Clean sandstone porosity = 20 p.u.
Find: Apparent limestone neutron porosity.
Answer: Enter the y-axis at 20 p.u. and move horizontally to the quartz sandstone matrix curves. Move vertically from the points of intersection to the x-axis and read the apparent limestone neutron porosity values.
APLC = 16.8 p.u. and FPLC = 14.5 p.u.
APS* Near-to-Array (APLC) and Near-to-Far (FPLC) Logs

Epithermal Neutron Porosity Equivalence—Open Hole

True porosity for indicated matrix material, \( \phi \) (p.u.)

Apparent limestone neutron porosity, \( \phi_{SNP_{cor}} \) (p.u.)

Apparent limestone neutron porosity, \( \phi_{APSCor} \) (p.u.)

*Mark of Schlumberger
© Schlumberger
Porosity—Wireline

Thermal Neutron Tool
Porosity Equivalence—Open Hole

Purpose
This chart is used to convert CNL* Compensated Neutron Log porosity curves (TNPH or NPHI) from one lithology to another. It can also be used to obtain the apparent limestone porosity (used for the various crossplot porosity charts) from a log recorded in sandstone or dolomite porosity units.

Description
To determine the porosity of either quartz sandstone or dolomite enter the chart with the either the TNPH or NPHI corrected apparent limestone neutron porosity ($\phi_{CNLcor}$) on the x-axis. Move vertically to intersect the appropriate curve and read the porosity for quartz sandstone or dolomite on the y-axis. The chart has a built-in salinity correction for TNPH values.

Example
Given: Quartz sandstone formation, TNPH = 18 p.u. (apparent limestone neutron porosity), and formation salinity = 250,000 ppm.

Find: Porosity in sandstone.

Answer: From the TNPH porosity reading of 18 p.u. on the x-axis, project a vertical line to intersect the quartz sandstone dashed red curve. From the y-axis, the porosity of the sandstone is 24 p.u.

*Mark of Schlumberger
© Schlumberger
Purpose
This chart is used similarly to Chart Por-5 to convert 2½-in. compensated neutron tool (CNT) porosity values (TNPH) from one lithology to another. Fresh formation water is assumed.
**Purpose**

This chart is used to determine the porosity of sandstone, limestone, or dolomite from the corrected apparent limestone porosity measured with the adnVISION475 4.75-in. tool.

**Description**

Enter the chart on the x-axis with the corrected apparent limestone porosity from Chart Neu-31 to intersect the curve for the appropriate formation material. Read the porosity on the y-axis.
**Purpose**

Chart Por-8 is used similarly to Chart Por-7 for determining porosity from the corrected apparent limestone porosity from the adnVISION675 6.75-in. tool.
**Purpose**

Chart Por-9 is used similarly to Chart Por-7 for determining porosity from the corrected apparent limestone porosity from the adnVISION825 8.25-in. tool.
Purpose
This chart is used to determine the porosity of sandstone, limestone, or dolomite from the corrected apparent limestone BPHI porosity measured with the EcoScope 6.75-in. LWD tool.

Use this chart only with EcoScope best thermal neutron porosity (BPHI) measurements; use Chart Por-10a with EcoScope thermal neutron porosity (TNPH) measurements.

Description
Enter the chart on the x-axis with the corrected apparent limestone BPHI porosity from Chart Neu-43 or Neu-44 to intersect the curve for the appropriate formation material. Read the porosity on the y-axis.
**Purpose**
This chart is used to determine the porosity of sandstone, limestone, or dolomite from the corrected apparent limestone TNPH porosity measured with the EcoScope 6.75-in. LWD tool.

Use this chart only with EcoScope thermal neutron porosity (TNPH) measurements; use Chart Por-10 with EcoScope best thermal neutron porosity, average (BPHI) measurements.

**Description**
Enter the chart on the x-axis with the corrected apparent limestone TNPH porosity from Chart Neu-45 or Neu-46 to intersect the curve for the appropriate formation material. Read the porosity on the y-axis.
Porosity—Wireline

CNL* Compensated Neutron Log and Litho-Density* Tool
(fresh water in invaded zone)

Purpose
This chart is used with the bulk density and apparent limestone porosity from the CNL Compensated Neutron Log and Litho-Density tools, respectively, to approximate the lithology and determine the crossplot porosity.

Description
Enter the chart with the environmentally corrected apparent neutron limestone porosity on the x-axis and bulk density on the y-axis. The intersection of the two values describes the crossplot porosity and lithology.

If the point is on a lithology curve, that indicates that the formation is primarily that lithology. If the point is between the lithology curves, then the formation is a mixture of those lithologies. The position of the point in relation to the two lithology curves as composition endpoints indicates the mineral percentages of the formation.

The porosity for a point between lithology curves is determined by scaling the crossplot porosity by connecting similar numbers on the two lithology curves (e.g., 20 on the quartz sandstone curve to 20 on the limestone curve). The scale line closest to the point represents the crossplot porosity.

Chart Por-12 is used for the same purpose as this chart for salt-water-invaded zones.

Example
Given: Corrected apparent neutron limestone porosity = 16.5 p.u. and bulk density = 2.38 g/cm$^3$.
Find: Crossplot porosity and lithology.
Answer: Crossplot porosity = 18 p.u. The lithology is approximately 40% quartz and 60% limestone.
Porosity—Wireline

CNL* Compensated Neutron Log and Litho-Density* Tool
(fresh water in invaded zone)

Porosity and Lithology—Open Hole

Liquid-Filled Borehole ($\rho_f = 1.000 \text{ g/cm}^3$ and $C_f = 0 \text{ ppm}$)

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

Density porosity, $\phi_D$ (p.u.)
($\rho_{ma} = 2.71 \text{ g/cm}^3$, $\rho_b = 1.0 \text{ g/cm}^3$)

Corrected apparent limestone neutron porosity, $\phi_{CNLcor}$ (p.u.)

*Mark of Schlumberger
© Schlumberger
Porosity—Wireline

CNL* Compensated Neutron Log and Litho-Density* Tool (salt water in invaded zone)
Porosity and Lithology—Open Hole

Purpose
This chart is used similarly to Chart Por-11 with CNL Compensated Neutron Log and Litho-Density values to approximate the lithology and determine the crossplot porosity in the saltwater-invaded zone.

Example
Given: Corrected apparent neutron limestone porosity = 16.5 p.u. and bulk density = 2.38 g/cm³.
Find: Crossplot porosity and lithology.
Answer: Crossplot porosity = 20 p.u. The lithology is approximately 55% quartz and 45% limestone.
Purpose
This chart is used to determine the lithology and porosity from the Litho-Density bulk density and APS Accelerator Porosity Sonde porosity log curves (APLC or FPLC). This chart applies to boreholes filled with freshwater drilling fluid; Chart Por-14 is used for saltwater fluids.

Description
Enter either the APLC or FPLC porosity on the x-axis and the bulk density on the y-axis. Use the blue matrix curves for APLC porosity values and the red curves for FPLC porosity values. Anhydrite plots on separate curves. The gas correction direction is indicated for formations containing gas. Move parallel to the blue correction line if the APLC porosity is used or to the red correction line if the FPLC porosity is used.

Example
Given: APLC porosity = 8 p.u. and bulk density = 2.2 g/cm³.
Find: Approximate quartz sandstone porosity.
Answer: Enter at 8 p.u. on the x-axis and 2.2 g/cm³ on the y-axis to find the intersection point is in the gas-in-formation correction region. Because the APLC porosity value was used, move parallel to the blue gas correction line until the blue quartz sandstone curve is intersected at approximately 19 p.u.
**Purpose**
This chart is used similarly to Chart Por-13 to determine the lithology and porosity from Litho-Density* bulk density and APS* porosity log curves (APLC or FPLC) in saltwater boreholes.

**Example**
Given: APLC porosity = 8 p.u. and bulk density = 2.2 g/cm³.
Find: Approximate quartz sandstone porosity.
Answer: Enter 8 p.u. on the x-axis and 2.2 g/cm³ on the y-axis to find the intersection point is in the gas-in-formation correction region. Because the APLC porosity value was used, move parallel to the blue gas correction line until the blue quartz sandstone curve is intersected at approximately 20 p.u.
Purpose
This chart is used to determine the crossplot porosity and lithology from the adnVISION475 4.75-in. density and neutron porosity.

Description
Enter the chart with the adnVISION475 corrected apparent limestone neutron porosity (from Chart Neu-31) and bulk density. The intersection of the two values is the crossplot porosity. The position of the point of intersection between the matrix curves represents the relative percentage of each matrix material.

Example
Given: $\phi_{ADNcor} = 20$ p.u. and $\rho_b = 2.24$ g/cm$^3$.
Find: Crossplot porosity and matrix material.
Answer: 25 p.u. in sandstone.
Purpose
This chart uses the bulk density and apparent limestone porosity from the adnVISION 6.75-in. Azimuthal Density Neutron tool to determine the lithology of the logged formation and the crossplot porosity.

Description
This chart is applicable for logs obtained in freshwater drilling fluid. Enter the corrected apparent limestone porosity and the bulk density on the x- and y-axis, respectively. Their intersection point determines the lithology and crossplot porosity.

Example
Given: Corrected adnVISION675 apparent limestone porosity = 20 p.u. and bulk density = 2.3 g/cm³.
Find: Porosity and lithology type.
Answer: Entering the chart at 20 p.u. on the x-axis and 2.3 g/cm³ on the y-axis corresponds to a crossplot porosity of 21.5 p.u. and formation comprising approximately 60% quartz sandstone and 40% limestone.
Purpose
This chart is used similarly to Chart Por-15 to determine the lithology and crossplot porosity from adnVISION825 8.25-in. Azimuthal Density Neutron values.
Purpose

This chart is used similarly to Chart Por-15 to determine the lithology and crossplot porosity from EcoScope 6.75-in. density and best thermal neutron porosity (BPHI) values.

Use this chart only with EcoScope BPHI neutron porosity; use Chart Por-19 with EcoScope thermal neutron porosity (TNPH) measurements.
Purpose

This chart is used similarly to Chart Por-15 to determine the lithology and crossplot porosity from EcoScope 6.75-in. density and thermal neutron porosity (TNPH) values.

Use this chart only with EcoScope TNPH neutron porosity; use Chart Por-18 with EcoScope best thermal neutron porosity (BPHI) measurements.
Purpose
This chart is used to determine crossplot porosity and an approximation of lithology for sonic and thermal neutron logs in freshwater drilling fluid.

Description
Enter the corrected neutron porosity (apparent limestone porosity) on the x-axis and the sonic slowness time ($\Delta t$) on the y-axis to find their intersection point, which describes the crossplot porosity and lithology composition of the formation. Two sets of curves are drawn on the chart. The blue set of curves represents the crossplot porosity values using the sonic time-average algorithm. The red set of curves represents the field observation algorithm.

Example
Given: Thermal neutron apparent limestone porosity = 20 p.u. and sonic slowness time = 89 $\mu$s/ft in freshwater drilling fluid.
Find: Crossplot porosity and lithology.
Answer: Enter the neutron porosity on the x-axis and the sonic slowness time on the y-axis. The intersection point is at about 25 p.u. on the field observation line and 24.5 p.u. on the time-average line. The matrix is quartz sandstone.
**Por-20**
(custamary, former CP-2c)

**Sonic and Thermal Neutron Crossplot**
Porosity and Lithology—Open Hole, Freshwater Invaded

\[ \Delta t = 190 \mu s/ft \text{ and } C_r = 0 \text{ ppm} \]

Corrected CNL* apparent limestone neutron porosity, \( \Phi_{CNL\text{cor}} \) (p.u.)

Sonic transit time, \( \Delta t \) (\( \mu s/ft \))

Porosity—Wireline

*Mark of Schlumberger
© Schlumberger
Porosity—Wireline

Sonic and Thermal Neutron Crossplot
Porosity and Lithology—Open Hole, Freshwater Invaded

Purpose
This chart is used similarly to Chart Por-20 for metric units.
Density and Sonic Crossplot
Porosity and Lithology—Open Hole, Freshwater Invaded

Purpose
This chart is used to determine porosity and lithology for sonic and density logs in freshwater-invaded zones.

Description
Enter the chart with the bulk density on the y-axis and sonic slowness time on the x-axis. The point of intersection indicates the type of formation and its porosity.

Example
Given: Bulk density = 2.3 g/cm³ and sonic slowness time = 82 μs/ft.
Find: Crossplot porosity and lithology.
Answer: Limestone with a crossplot porosity = 24 p.u.
Porosity—Wireline, LWD

Density and Sonic Crossplot
Porosity and Lithology—Open Hole, Freshwater Invaded

\[ t_s = 189 \mu s/ft \text{ and } \rho_b = 1.0 \text{ g/cm}^3 \]

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

Sonic transit time, \( \Delta t \) (\( \mu \)s/ft)

- Anhydrite
- Polyhalite
- Gypsum
- Trona
- Salt
- Sylvite
- Sulfur
- Dolomite
- Quartz sandstone
- Limestone
- Dolomite (limestone)
- Calcite (limestone)

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Purpose
This chart is used similarly to Chart Por-22 for metric units.
Density and Neutron Tool
Porosity Identification—Gas-Bearing Formation

**Purpose**
This chart is used to determine the porosity and average water saturation in the flushed zone ($S_{wo}$) for freshwater invasion and gas composition of $C_{1.1}H_{4.2}$ (natural gas).

**Description**
Enter the chart with the neutron- and density-derived porosity values ($\phi_N$ and $\phi_D$, respectively). On the basis of the table, use the blue curves for shallow reservoirs and the red curves for deep reservoirs.

**Example**
Given: $\phi_D = 25$ p.u. and $\phi_N = 10$ p.u. in a low-pressure, shallow (4,000-ft) reservoir.
Find: Porosity and $S_{wo}$.
Answer: Enter the chart at 25 p.u. on the y-axis and 10 p.u. on the x-axis. The point of intersection identifies (on the blue curves for a shallow reservoir) $\phi = 20$ p.u. and $S_{wo} = 62\%$.

<table>
<thead>
<tr>
<th>Depth</th>
<th>Pressure</th>
<th>Temperature</th>
<th>$\rho_w$ (g/cm$^3$)</th>
<th>$I_{Hw}$</th>
<th>$\rho_g$ (g/cm$^3$)</th>
<th>$I_{Hg}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow reservoir</td>
<td>~2,000 psi [~14,000 kPa]</td>
<td>~120°F [~50°C]</td>
<td>1.00</td>
<td>1.00</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Deep reservoir</td>
<td>~7,000 psi [~48,000 kPa]</td>
<td>~240°F [~120°C]</td>
<td>1.00</td>
<td>1.00</td>
<td>0.25</td>
<td>0.54</td>
</tr>
</tbody>
</table>

$p_w$ = density of water, $p_g$ = density of gas, $I_{Hw}$ = hydrogen index of water, and $I_{Hg}$ = hydrogen index of gas
Density and Neutron Tool
Porosity Identification—Gas-Bearing Formation

For shallow reservoirs, use blue curves.
For deep reservoirs, use red curves.

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Purpose
This chart is used to determine the porosity and average water saturation in the flushed zone ($S_{xo}$) for freshwater invasion and gas composition of CH₄ (methane).

Description
Enter the chart with the APS Accelerator Porosity Sonde neutron- and density-derived porosity values ($\phi_N$ and $\phi_D$, respectively). On the basis of the table, use the blue curves for shallow reservoirs and the red curves for deep reservoirs.

Example
Given: $\phi_D = 15$ p.u. and APS $\phi_N = 8$ p.u. in a normally pressured deep (14,000-ft) reservoir.
Find: Porosity and $S_{xo}$.
Answer: $\phi = 11$ p.u. and $S_{xo} = 39\%$.

<table>
<thead>
<tr>
<th>Depth</th>
<th>Pressure</th>
<th>Temperature</th>
<th>$\rho_w$</th>
<th>$I_{hw}$</th>
<th>$\rho_g$</th>
<th>$I_{hg}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow reservoir</td>
<td>~2,000 psi (~14,000 kPa)</td>
<td>~120°F (~50°C)</td>
<td>1.00</td>
<td>1.00</td>
<td>0.10</td>
<td>0.23</td>
</tr>
<tr>
<td>Deep reservoir</td>
<td>~7,000 psi (~48,000 kPa)</td>
<td>~240°F (~120°C)</td>
<td>1.00</td>
<td>1.00</td>
<td>0.25</td>
<td>0.54</td>
</tr>
</tbody>
</table>

$p_w =$ density of water, $p_g =$ density of gas, $I_{hw} =$ hydrogen index of water, and $I_{hg} =$ hydrogen index of gas.
Density and APS* Epithermal Neutron Tool
Porosity Identification—Gas-Bearing Formation

Density-derived porosity, $\phi_D$ (p.u.)

APS epithermal neutron-derived porosity, $\phi_N$ (p.u.)

For shallow reservoirs, use blue curves.
For deep reservoirs, use red curves.

*Mark of Schlumberger
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**Purpose**

This nomograph is used to estimate porosity in hydrocarbon-bearing formations by using density, neutron, and resistivity in the flushed zone ($R_{xo}$) logs. The density and neutron logs must be corrected for environmental effects and lithology before entry to the nomograph. The chart includes an approximate correction for excavation effect, but if hydrocarbon density ($\rho_h$) is $<0.25$ g/cm³ (gas), the chart may not be accurate in some extreme cases:

- very high values of porosity (>35 p.u.) coupled with medium to high values of hydrocarbon saturation ($S_{hr}$)
- $S_{hr} = 100\%$ for medium to high values of porosity.

**Description**

Connect the apparent neutron porosity value on the appropriate neutron porosity scale (CNL® Compensated Neutron Log or sidewall neutron porosity [SNP] log) with the corrected apparent density porosity on the density scale with a straight line. The intersection point on the $\phi_1$ scale indicates the value of $\phi_1$.

Draw a line from the $\phi_1$ value to the origin (lower right corner) of the chart for $\Delta\phi$ versus $S_{hr}$.

Enter the chart with $S_{hr}$ from $(S_{hr} = 1 - S_{xo})$ and move vertically upward to determine the porosity correction factor ($\Delta\phi$) at the intersection with the line from the $\phi_1$ scale.

This correction factor algebraically added to the porosity $\phi_1$ gives the corrected porosity.

**Example**

**Given:** Corrected CNL apparent neutron porosity = 12 p.u., corrected apparent density porosity = 38 p.u., and $S_{hr} = 50\%$.

**Find:** Hydrocarbon-corrected porosity.

**Answer:** Enter the 12-p.u. $\phi_{cor}$ value on the CNL scale. A line from this value to 38 p.u. on the $\phi_{Dcor}$ scale intersects the $\phi_1$ scale at 32.2 p.u. The intersection of a line from this value to the graph origin and $S_{hr} = 50\%$ is $\Delta\phi = -1.6$ p.u. Hydrocarbon-corrected porosity: $32.2 - 1.6 = 30.6$ p.u.
Porosity—Wireline

Density, Neutron, and R<sub>x0</sub> Logs

Porosity Identification in Hydrocarbon-Bearing Formation—Open Hole

*Mark of Schlumberger
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Purpose

This chart is used to estimate the hydrocarbon density ($\rho_h$) within a formation from corrected neutron and density porosity values.

Description

Enter the ratio of the sidewall neutron porosity (SNP) or CNL* Compensated Neutron Log neutron porosity and density porosity corrected for lithology and environmental effects ($\phi_{SNP\text{cor}}$ or $\phi_{CNL\text{cor}} / \phi_{D\text{cor}}$, respectively) on the y-axis and the hydrocarbon saturation on the x-axis. The intersection point of the two values defines the density of the hydrocarbon.

Example

Given: Corrected CNL porosity = 15 p.u., corrected density porosity = 25 p.u., and Shr = 30% (residual hydrocarbon).

Find: Hydrocarbon density.

Answer: Porosity ratio = 15/25 = 0.6. $\rho_h = 0.29 \text{ g/cm}^3$. 
Purpose
This chart is used for a variety of conversions of the formation resistivity factor ($F_R$) to porosity.

Description
The most appropriate conversion is best determined by laboratory measurement or experience in the area. In the absence of this knowledge, recommended relationships are the following:

- Soft formations (Humble formula): $F_R = 0.62/\phi^{2.51}$ or $F_R = 0.81/\phi^2$
- Hard formations: $F_R = 1/\phi^m$ with the appropriate cementation factor ($m$).

Example
Given: Soft formation with $\phi = 25$ p.u. Hard formation ($m = 2$) with $\phi = 8$ p.u.
Answer: $F_R = 13$ (from chart). $F_R = 160$ (from chart). $F_R = 156$ (calculated).
Purpose
This chart is used to identify how much of the measured porosity is isolated (vugs or moldic) or fractured porosity.

Description
This chart is based on a simplified model that assumes no contribution to formation conductivity from vugs and moldic porosity and the cementation exponent (m) of fractures is 1.0.

When the pores of a porous formation have an aspect ratio close to 1 (vugs or moldic porosity), the value of m of the formation is usually greater than 2. Fractured formations typically have a cementation exponent less than 2.

Example
Given: \( \phi = 10 \) p.u. and cementation exponent = 2.5.
Find: Intergranular (matrix) porosity.
Answer: Entering the chart with 10 p.u. and 2.5 gives an intersection point of \( \phi_{\text{iso}} = \) approximately 4.5 p.u.
Intergranular porosity = 10 – 4.5 = 5.5 p.u.
Saturation Determination
Open Hole

Purpose
This nomograph is used to solve the Archie water saturation equation:

\[ S_w = \frac{R_o}{R_t} = \frac{F_R R_w}{R_t}, \]

where
- \( S_w \) = water saturation
- \( R_o \) = resistivity of clean-water formation
- \( R_t \) = true resistivity of the formation
- \( F_R \) = formation resistivity factor
- \( R_w \) = formation water resistivity.

It should be used in clean (nonshaly) formations only.

Description
If \( R_o \) is known, a straight line from the known \( R_o \) value through the measured \( R_t \) value indicates the value of \( S_w \). If \( R_o \) is unknown, it may be determined by connecting \( R_w \) with \( F_R \) or porosity (\( \phi \)).

Example
Given: \( R_w = 0.05 \text{ ohm-m at formation temperature}, \phi = 20 \text{ p.u.} \) (\( F_R = 25 \)), and \( R_t = 10 \text{ ohm-m} \).

Find: Water saturation.

Answer: Enter the nomograph on the \( R_w \) scale at \( R_w = 0.05 \text{ ohm-m} \). Draw a straight line from 0.05 through the porosity scale at 20 p.u. to intersect the \( R_o \) scale. From the intersection point of \( R_o = 1 \), draw a straight line through \( R_t = 10 \text{ ohm-m} \) to intersect the \( S_w \) scale. \( S_w = 31.5\% \).
Saturation—Wireline, LWD

Saturation Determination
Open Hole

Clean Formations, \( m = 2 \)

\[
\begin{align*}
\text{\( R_w \)} & \quad \phi \quad \text{\( F_R \)} \quad \text{\( R_o \)} \quad \text{\( R_t \)} \\
\text{(ohm-m)} & \quad (%) & \quad & \text{(ohm-m)} & \text{(ohm-m)} \\
0.01 & 2.5 & 2,000 & 20 & 10 \\
0.02 & 3 & 1,000 & 16 & 8 \\
0.03 & 4 & 600 & 12 & 6 \\
0.04 & 5 & 400 & 10 & 5 \\
0.05 & 6 & 300 & 8 & 4 \\
0.06 & 7 & 200 & 6 & 3 \\
0.07 & 8 & 100 & 5 & 2 \\
0.08 & 9 & 80 & 4 & 2 \\
0.09 & 10 & 60 & 3 & 1 \\
0.1 & 11 & 50 & 2 & 1 \\
0.2 & 12 & 40 & 1.8 & 1.6 \\
0.3 & 13 & 30 & 1.6 & 1.4 \\
0.4 & 14 & 25 & 1.4 & 1.2 \\
0.5 & 15 & 20 & 1.2 & 1.0 \\
0.6 & 16 & 15 & 1.0 & 0.8 \\
0.7 & 17 & 10 & 0.8 & 0.7 \\
0.8 & 18 & 5 & 0.6 & 0.5 \\
0.9 & 19 & 4 & 0.5 & 0.4 \\
1 & 20 & 3 & 0.4 & 0.3 \\
1.5 & 21 & 2 & 0.3 & \text{...}
\end{align*}
\]

\[
F_R = \frac{1}{\phi^{2.0}}
\]

\[
R_o = F_R R_w
\]

\[
S_{w_o} = \frac{\sqrt{R_o}}{R_t}
\]
Purpose
This chart is used to determine water saturation ($S_w$) in shaly or clean formations when knowledge of the porosity is unavailable. It may also be used to verify the water saturation determination from another interpretation method. The large chart assumes that the mud filtrate saturation is

$$S_{xo} = \frac{5}{S_w}.$$

The small chart provides an $S_{xo}$ correction when $S_{xo}$ is known. However, water activity correction is not provided for the SP portion of the chart (see Chart SP-2).

Description
Clean Sands
Enter the large chart with the ratio of the resistivity of the flushed zone to the true formation resistivity ($R_{xo}/R_t$) on the y-axis and the ratio of the resistivity of the mud filtrate to the resistivity of the formation water ($R_{mf}/R_w$) on the x-axis to find the water saturation at average residual oil saturation ($S_{wa}$). If $R_{mf}/R_w$ is unknown, the chart may be entered with the spontaneous potential (SP) value and the formation temperature. If $S_{xo}$ is known, move diagonally upward, parallel to the constant-$S_{wa}$ curves, to the right edge of the chart. Then, move horizontally to the known $S_{xo}$ (or residual oil saturation [ROS], $S_{or}$) value to obtain the corrected value of $S_w$.

Example
Given: $R_{xo} = 12$ ohm-m, $R_t = 2$ ohm-m, $R_{mf}/R_w = 20$, and $S_{or} = 20\%$.
Find: $S_w$ (after correction for ROS).
Answer: Enter the large chart at $R_{xo}/R_t = 12/2 = 6$ on the y-axis and $R_{mf}/R_w = 20$ on the x-axis. From the point of intersection (labeled A), move diagonally to the right to intersect the chart edge and directly across to enter the small chart and intersect $S_{or} = 20\%$.
$S_w = 43\%$.

Description
Shaly Sands
Enter the chart with $R_{xo}/R_t$ and the SP in the shaly sand ($E_{SP}$). The point of intersection gives the $S_{wa}$ value. Draw a line from the chart’s origin (the small circle located at $R_{xo}/R_t = R_{mf}/R_m = 1$) through this point to intersect with the value of static spontaneous potential ($E_{SSP}$) to obtain a value of $R_{xo}/R_t$ corrected for shaliness. This value of $R_{xo}/R_t$ versus $R_{mf}/R_w$ is plotted to find $S_w$ if $R_{mf}/R_w$ is unknown because the point defined by $R_{xo}/R_t$ and $E_{SSP}$ is a reasonable approximation of $S_w$. The small chart to the right can be used to further refine $S_w$ if $S_{or}$ is known.

Example
Given: $R_{xo}/R_t = 2.8$, $R_{mf}/R_w = 25$, $E_{SP} = –75$ mV, $E_{SSP} = –120$ mV, and electrochemical SP coefficient ($K_c$) = 80 (formation temperature = 150ºF).
Find: $S_w$ and corrected value for $S_{or} = 10\%$.
Answer: Enter the large chart at $R_{xo}/R_t = 2.8$ and the intersection of $E_{SP} = –75$ mV at $K_c = 80$ from the chart below. A line from the origin through the intersection point (labeled B) intersects the $–120$-mV value of $E_{SSP}$ at Point C. Move horizontally to the left to intersect $R_{mf}/R_w = 25$ at Point D. Then move diagonally to the right to intersect the right y-axis of the chart. Move horizontally to the small chart to determine $S_{xo} = 0.9\%$, $S_w = 38\%$, and corrected $S_w = 40\%$.

For more information, see Reference 12.
Purpose
This chart is used to drive a value of water saturation ($S_w$) corrected for the bound-water volume in shale.

Description
This is a graphical determination of $S_w$ from the total water saturation ($S_{wt}$) and the saturation of bound water ($S_{wb}$):

$$S_w = \frac{S_{wt} - S_{wb}}{1 - S_{wb}}.$$

Enter the y-axis with $S_{wt}$ and move horizontally to intersect the appropriate $S_{wb}$ curve. Read the value of $S_w$ on the x-axis.

Example
Given: $S_{wt} = 45\%$ and $S_{wb} = 10\%$.
Find: $S_w$.
Answer: $S_w = 39.5\%$. 
Purpose
This chart is used to determine porosity ($\phi$) and gas saturation ($S_g$) from the combination of density and neutron or from density and resistivity measurements.

Description
Enter from the point of intersection of the matrix density ($\rho_{ma}$) and apparent bulk density ($\rho_b$). Move vertically upward to intersect either neutron porosity ($\phi_N$, corrected for lithology) or the ratio of true resistivity to connate water resistivity ($R_t/R_w$). This point defines the actual porosity and $S_g$ on the curves.

Oil saturation ($S_o$) can also be determined if all three measurements (density, neutron, and resistivity) are available. Find the values of $\phi$ and $S_g$ as before, and then find the intersection of $R_t/R_w$ with $\phi$ to read the value of the total hydrocarbon saturation ($S_h$) on the saturation scale for use in the following equations:

$$S_o = S_h - S_g$$
$$S_w = 100 - S_h.$$

Example
Given: Limy sandstone ($\rho_{ma} = 2.68 \text{ g/cm}^3$), $\rho_b = 2.44 \text{ g/cm}^3$, $\phi_N = 9 \text{ p.u.}$, $R_t = 74 \text{ ohm-m}$, and $R_w = 0.1 \text{ ohm-m}$.

Find: $\phi$, $S_h$, $S_b$, and $S_w$.

Answer: First, find $R_t/R_w = 74/0.1 = 740$.

$\phi = 12 \text{ p.u.}$ and $S_g = 25\%$.

$S_h = 70\%$ (total hydrocarbon saturation).

$S_b = 70 - 25 = 45\%$.

$S_w = 100 - 70 = 30\%$. 
Purpose
This nomograph is used to define flushed zone saturation ($S_{xo}$) in the rock immediately adjacent to the borehole by using the EPT Electromagnetic Propagation Tool time measurement ($t_{pl}$).

Description
Use of this chart requires knowledge of the reservoir lithology or matrix propagation time ($t_{pma}$), saturating water propagation time ($t_{pw}$), porosity ($\phi$), and expected hydrocarbon type. Enter the far-left scale with $t_{pl}$ and move parallel to the diagonal lines to intersect the appropriate $t_{pma}$ value. From this point move horizontally to the right edge of the scale grid. From this point, extend a straight line through the porosity scale to the center scale grid; again, move parallel to the diagonal lines to the appropriate $t_{pma}$ value and then horizontally to the right edge of the grid scale. From this point, extend a straight line through the intersection of $t_{pw}$ and the hydrocarbon type point to intersect the $S_{xo}$ scale. For more information, see Reference 25.
Purpose
This nomograph is used to determine the flushed zone saturation ($S_{xo}$) in the rock immediately adjacent to the borehole by using the EPT Electromagnetic Propagation Tool attenuation measurement. It requires knowledge of the saturating fluid (usually mud filtrate) attenuation ($A_w$), porosity ($\phi$), and the EPT EATT attenuation ($A_{EPTcor}$) corrected for spreading loss.

Description
The value of $A_w$ must first be determined. Chart Gen-16 is used to estimate $A_w$ by using the equivalent water salinity and formation temperature. EPT-D spreading loss is determined from the inset on Chart Gen-16 based on the uncorrected EPT propagation time ($t_{pl}$) measurement. The spreading loss correction algebraically added to the EPT-D EATT attenuation measurement gives the corrected EPT attenuation ($A_{EPTcor}$). These values are used with porosity on the nomograph to determine $S_{xo}$.

Example
Given: $EATT = 250$ dB/m, $t_{pl} = 10.9$ ns/m, $\phi = 28$ p.u., water salinity = 20,000 ppm, and bottomhole temperature = 150°F.

Find: Spreading loss (from Chart Gen-16 inset) and $S_{xo}$.

Answer: The spreading loss determined from the inset on Chart Gen-16 is $-82$ dB/m.

$A_{EPTcor} = 250 - 82 = 168$ dB/m.

$A_w$ (from Chart Gen-16) = 1,100 dB/m.

Enter the far-left scale at $A_w = 1,100$ dB/m and draw a straight line through $\phi = 28$ p.u. on the next scale to intersect the median line. From this intersection point, draw a straight line through $A_{EPTcor} = 168$ dB/m on the next scale to intersect the $S_{xo}$ value on the far-right scale. $S_{xo} = 56$ p.u.
Purpose
This chart is used to determine water saturation \((S_w)\) from capture cross section, or sigma \((\Sigma)\), measurements from the TDT\textsuperscript{a} Thermal Decay Time pulsed neutron log.

Description
This chart uses sigma water \((\Sigma_w)\), matrix capture cross section \((\Sigma_{ma})\), and porosity \((\phi)\) to determine water saturation in clean formations. The chart may be used in shaly formations if sigma shale \((\Sigma_{sh})\), the volume fraction of shale in the formation \((V_{sh})\), and the porosity corrected for shale are known.

Thermal decay time \((t\) and \(t_{sh}\) in shale) is also shown on some of the chart scales because it is related to \(\Sigma\).

Procedure

Clean Formation

The \(S_w\) determination for a clean formation requires values known for \(\Sigma_{ma}\) (based on lithology), \(\phi\), \(\Sigma_w\) from the NaCl salinity (see Chart Gen-12 or Gen-13), and sigma hydrocarbon \((\Sigma_h)\) (see Chart Gen-14).

Enter the value of \(\Sigma_{ma}\) on Scale B and draw a line to Pivot Point B. Enter \(\Sigma_{log}\) on Scale B and draw Line b through the intersection of Line a and the value of \(\phi\) to intersect the sigma of the formation fluid \((\Sigma_f)\) on Scale C. Draw Line 5 from \(\Sigma_f\) through the intersection of \(\Sigma_h\) and \(\Sigma_w\) to determine the value of \(S_w\) on Scale D.

Example: Clean Formation

Given: \(\Sigma_{log} = 20\) c.u., \(\Sigma_{ma} = 8\) c.u. (sandstone) from TDT tool, \(\Sigma_h = 18\) c.u., \(\Sigma_w = 80\) c.u. (150,000 ppm or mg/kg), and \(\phi = 30\) p.u.

Find: \(S_w\).

Answer: Following the procedure for a clean formation, \(S_w = 43\%\).

Shaly Formation

The \(S_w\) determination in a shaly formation requires additional information: sigma shale \((\Sigma_{sh})\) read from the TDT log in adjacent shale, \(V_{sh}\) from porosity-log crossplot or gamma ray, shale porosity \((\phi_{sh})\) read from a porosity log in adjacent shale, and the porosity corrected for shaliness \((\phi_{theor})\) with the relation for neutron and density logs in liquid-filled formations of \(\phi_{theor} = \phi_{log} - V_{sh}\phi_{sh}\).

Enter the value of \(\Sigma_{ma}\) on Scale B and draw Line 1 to intersect with Pivot Point A. From the value of \(\Sigma_{sh}\) on Scale A, draw Line 2 through the intersection of Line 1 and \(V_{sh}\) to determine the shale-corrected \(\Sigma_{cor}\) on Scale B. Draw Line 3 from \(\Sigma_{cor}\) to the value of \(\Sigma_{ma}\) on the scale to the left of Scale C. Enter \(\Sigma_{log}\) on Scale B and draw Line 4 through the intersection of Line 3 and the value of \(\phi\) to determine \(\Sigma_f\) on Scale C. From \(\Sigma_f\) on Scale C, draw Line 5 through the intersection of \(\Sigma_h\) and \(\Sigma_w\) to determine \(S_w\) on Scale D.

Example

Given: \(\Sigma_{log} = 25\) c.u. \(\Sigma_{ma} = 8\) c.u. \(\Sigma_{sh} = 18\) c.u. \(\Sigma_w = 80\) c.u. \(\Sigma_{sh} = 45\) c.u. \(\phi_{log} = 33\) p.u. \(\phi_{sh} = 45\) p.u. \(V_{sh} = 0.2\).

Find: \(\phi_{theor}\) and \(S_w\).

Answer: First find the porosity corrected for shaliness, \(\phi_{theor} = 33\) p.u. \(- (0.2 \times 45\) p.u.) = 24 p.u. This value is used for the \(\phi\) point between Scales B and C. \(S_w = 43\%\).
Saturation—Wireline

Capture Cross Section Tool
Cased Hole

SatCH-1
(former Sw-12)

$S_w = \frac{(\Sigma_{\text{sw}} - \Sigma_{\text{sw1}}) - \phi (\Sigma_{\text{sw}} - \Sigma_{\text{sw2}}) - V_{\text{sh}} (\Sigma_{\text{sh}} - \Sigma_{\text{sw3}})}{\phi (\Sigma_{\text{sw}} - \Sigma_{\text{sw}})}$
Purpose
This chart is used to graphically interpret the TDT* Thermal Decay Time log. In one technique, applicable in shaly as well as clean sands, the apparent water capture cross section ($\Sigma_{wa}$) is plotted versus bound-water saturation ($Sw_b$) on a specially constructed grid to determine the total water saturation ($Sw_t$).

Description
To construct the grid, refer to the example chart on this page. Three fluid points must be located: free-water point ($\Sigma_{wf}$), hydrocarbon point ($\Sigma_h$), and a bound-water point ($\Sigma_{wb}$). The free- (or connate formation) water point is located on the left y-axis and can be obtained from measurement of a formation water sample, from Charts Gen-12 and Gen-13 if the water salinity is known, or from the TDT log in a clean water-bearing sand by using the following equation:

$$\Sigma_{wa} = \frac{\Sigma_{log} - \Sigma_{ma}}{\phi} + \Sigma_{ma}.$$  \hspace{1cm} (1)

The hydrocarbon point is also located on the left y-axis of the grid. It can be determined from Chart Gen-14 based on the known or expected hydrocarbon type.

The bound-water point ($Sw_b$) can be obtained from the TDT log in shale intervals also by using the $\Sigma_{wa}$ equation. It is located on the right y-axis of the grid.

The distance between the free-water and hydrocarbon points is linearly divided into lines of constant water saturation drawn parallel to a straight line connecting the free-water and bound-water points. The $Sw_t = 0\%$ line originates from the hydrocarbon point, and the $Sw_t = 100\%$ line originates from the free-water point.

The value of $\Sigma_{wa}$ from the equation is plotted versus $Sw_b$ to give $Sw_t$. The value of $Sw_c$ can be estimated from the gamma ray or other bound-water saturation estimator.

Once $Sw_t$ and $Sw_c$ are known, the water saturation of the reservoir rock exclusive of shale can be determined using

$$Sw = \frac{Sw_t - Sw_c}{1 - Sw_b}.$$  \hspace{1cm} (2)

Example
Given: $\Sigma_{ef} = 61$ c.u. and $\Sigma_h = 21$ c.u. (medium-gravity oil with modest GOR from Chart Gen-14), and $\Sigma_{wb} = 76$ c.u. (from TDT log in a shale interval and the preceding Eq. 1).

Find: $Sw$ for Point 4.

Answer: $\Sigma_{wa} = 54$ c.u. (from Eq. 1) and $Sw_b = 25\%$ (from gamma ray).

$Sw_t = 72\%$ and $Sw = 63\%$ (from the preceding $Sw$ equation).

The grid can also be used to graphically determine water saturation ($Sw$) in clean formations by crossplotting $\Sigma_{log}$ on the y-axis and porosity ($\phi$) on the x-axis. The values of $Sw$ and $Sw_c$ need not be known but must be constant over the interval studied. There must be some points from 100% water zones and a good variation in porosity. These water points define the $Sw = 100\%$ line; when extrapolated, this line intersects the zero-porosity axis at $\Sigma_{ma}$. The $Sw = 0\%$ line is drawn from $\Sigma_{ma}$ at $\phi = 0$ p.u. to $\Sigma = \Sigma_h$ at $\phi = 100$ p.u. (or $\Sigma = \frac{1}{2}(\Sigma_{ma} + \Sigma_h)$ at $\phi = 50$ p.u.). The vertical distance from $Sw = 0\%$ to $Sw = 100\%$ is divided linearly to define lines of constant water saturation. The water saturation of any plotted point can thereby be determined.
Purpose
Charts SatCH-3 through SatCH-8 are presented for illustrative purposes only. They are used to ensure that the measured near- and far-detector carbon/oxygen (C/O) ratio data are consistent with the interpretation model. These example charts are drawn for specific cased and open holes and tool sizes to provide trapezoids for the determination of oil saturation ($S_o$) and oil holdup ($y_o$).

Description
Known formation and borehole data define the expected C/O ratio values, which are determined in water saturation and borehole holdup values ranging from 0 to 1. All log data for formations with porosity ($\phi$) greater than 10 p.u. should be within the trapezoidal area bounded by the limits of the $S_o$ and $y_o$ values. If data plot consistently outside the trapezoid, the interpretation model may require revision.

The rectangle within each chart is constructed from four distinct points determined by the intersection of the near- and far-detector C/O ratios:
- WW = water/water point
- WO = water/oil point
- OW = oil/water point
- OO = oil/oil point.

RST Reservoir Saturation Tool processing then determines the water saturation ($S_w$) of the formation.
**Saturation—Wireline**

**RST* Reservoir Saturation Tool—1.6875 in. and 2.5 in. in 6.125-in. Borehole**

Carbon/Oxygen Ratio—Open Hole

\[ \phi = 30\%, \text{ 6.125-in. Open Hole} \]

**RST-A and RST-C, limestone**

**RST-A, quartz sandstone**

**RST-B and RST-D, limestone**

**RST-B, quartz sandstone**

\[ \phi = 20\%, \text{ 6.125-in. Open Hole} \]

\[ \text{Near-detector carbon/oxygen ratio} \]

\[ \text{Far-detector carbon/oxygen ratio} \]

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*Mark of Schlumberger*
RST* Reservoir Saturation Tool—1.6875 in. and 2.5 in. in 9.875-in. Borehole
Carbon/Oxygen Ratio—Open Hole

φ = 30%, 9.875-in. Open Hole

φ = 20%, 9.875-in. Open Hole

*Mark of Schlumberger
© Schlumberger
RST* Reservoir Saturation Tool—1.6875 in. and 2.5 in. in 8.125-in. Borehole with 4.5-in. Casing at 11.6 lbm/ft

Carbon/Oxygen Ratio—Cased Hole

ϕ = 30%, 6.125-in. Borehole, 4.5-in. Casing at 11.6 lbm/ft

ϕ = 20%, 6.125-in. Borehole, 4.5-in. Casing at 11.6 lbm/ft

*Mark of Schlumberger
© Schlumberger
Saturation—Wireline

RST* Reservoir Saturation Tool—1.6875 in. and 2.5 in. in 7.875-in. Borehole with 5.5-in. Casing at 17 lbm/ft

Carbon/Oxygen Ratio—Cased Hole

φ = 30%, 7.875-in. Borehole, 5.5-in. Casing at 17 lbm/ft

φ = 20%, 7.875-in. Borehole, 5.5-in. Casing at 17 lbm/ft

*RST* Mark of Schlumberger
© Schlumberger
Saturation—Wireline

RST* Reservoir Saturation Tool—1.6875 in. and 2.5 in. in 8.5-in. Borehole with 7-in. Casing at 29 lbm/ft
Carbon/Oxygen Ratio—Cased Hole

\[ \phi = 20\%, \ 8.5\text{-in. Borehole, 7-in. Casing at 29 lbm/ft} \]

\[ \phi = 30\%, \ 8.5\text{-in. Borehole, 7-in. Casing at 29 lbm/ft} \]

*Mark of Schlumberger
© Schlumberger
SatCH* Reservoir Saturation Tool—1.6875 in. and 2.5 in. in 9.875-in. Borehole with 7-in. Casing at 29 lbm/ft

Carbon/Oxygen Ratio—Cased Hole

\( \phi = 30\% \), 9.875-in. Borehole, 7-in. Casing at 29 lbm/ft

\( \phi = 20\% \), 9.875-in. Borehole, 7-in. Casing at 29 lbm/ft

*Mark of Schlumberger
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Permeability from Porosity and Water Saturation

Purpose
Charts Perm-1 and Perm-2 are used to estimate the permeability of shales, shaly sands, or other hydrocarbon-saturated intergranular rocks at irreducible water saturation (Swi).

Description
The charts are based on empirical observations and are similar in form to a general expression proposed by Wyllie and Rose (1950) (see Reference 49):

\[ k^{1/2} = \left( \frac{C\phi}{S_{wi}} \right) + C'. \]  

(1)

Chart Perm-1 presents the results of one study for which the observed relation was

\[ k^{1/2} = \left( \frac{100\phi^{2.25}}{S_{wi}} \right). \]  

(2)

Chart Perm-2 presents the results of another study:

\[ k^{1/2} = \left( \frac{1-S_{wi}}{70\phi c^{2}} \right). \]  

(3)

The charts are valid only for zones at irreducible water saturation.

Enter porosity (\( \phi \)) and Swi on a chart. Their intersection defines the intrinsic (absolute) rock permeability (k). Medium-gravity oil is assumed. If the saturating hydrocarbon is other than medium-gravity oil, a correction factor (C') based on the fluid densities of water and hydrocarbons (\( \rho_w \) and \( \rho_h \), respectively) and elevation above the free-water level (h) should be applied to the Swi value before it is entered on the chart. The chart on this page provides the correction factor based on the capillary pressure:

\[ p_c = \frac{h(\rho_w - \rho_h)}{2.3}. \]  

(4)

Charts Perm-1 and Perm-2 can be used to recognize zones at irreducible water saturation, for which the product \( \phi S_{wi} \) from levels within the zone is generally constant and plots parallel to the \( \phi S_{wi} \) lines.

Example
Given: \( \phi = 23 \) p.u., \( S_{wi} = 30\% \), gas saturation with \( \rho_h = 0.3 \) g/cm\(^3\) and \( \rho_w = 1.1 \) g/cm\(^3\), and \( h = 120 \) ft.

Find: Correction factor and k.

Answer: First, find p_c to determine the correction factor if the zone of interest is not at irreducible water saturation:

\[ p_c = \frac{h(\rho_w - \rho_h)}{2.3} = \frac{120(1.1-0.3)}{2.3} = 42. \]

Enter the correction factor chart with \( S_{wi} = 30\% \) to intersect the curve for \( p_c = 40 \) (nearest to 42), for which the correction factor is 1.08. The corrected Swi value is \( S'_{wi} = 1.08 \times 30\% = 32.4\% \).

Chart Perm-1: \( \phi S_{wi} = 0.072\% \) and k = 130 mD.
Chart Perm-2: \( \phi S_{wi} = 0.072\% \) and k = 65 mD.
Permeability from Porosity and Water Saturation

Open Hole

Perm-1
(former K-3)
This chart is used similarly to Chart Perm-1 for the relation

$$k^{1/2} 70\phi_e^2 \left( \frac{1 - S_{wi}}{S_{wi}} \right).$$
**Purpose**
This chart is used to estimate ease of movement through a formation by a fluid.

**Description**
The mobility-added slowness, which is the difference between the Stoneley slowness and the calculated elastic Stoneley slowness, is plotted on the x-axis and the mobility of the fluid is on the y-axis. The membrane impedance curves represent the effect that the mudcake has on the determination of the mobility of the fluid in the formation. The membrane impedance is scaled in gigapascal per centimeter.
Purpose
This chart is used to determine the decibel attenuation of casing from the measured cement bond log (CBL) amplitude and convert it to the compressive strength of bonded cement (either standard or foamed).

Description
The amplitude of the first casing arrival is recorded by an acoustic signal-measuring device such as a sonic or cement bond tool. This amplitude value is a measure of decibel attenuation that can be translated into a bond index (an indication of the percent of casing cement bonding) and the compressive strength (psi) of the cement at the time of logging.

Enter the chart on the y-axis with the log value of CBL amplitude and move upward parallel to the 45° lines to intersect the appropriate casing size. At that point, move horizontally right to the attenuation scale on the right-hand y-axis. From this point, draw a line through the appropriate casing thickness value to intersect the compressive strength scale. The casing wall thickness is calculated by subtracting the nominal inside diameter (ID) from the outside diameter (OD) listed on the table for threaded nonupset casing and dividing the difference by 2.

Example
Given: Log amplitude reading = 3.5 mV in zone of interest and 1.0 mV in a well-bonded section (usually the lowest millivolt value on the log), casing size = 7 in. at 29 lbm/ft, casing thickness = 0.41 in., and neat cement (not foamed).

Find: Compressive strength and bond index of the cement at the time of logging.

Answer: Enter the 3.5-mV reading on the left y-axis of Chart Cem-1 and proceed to the 7-in. casing line. Move horizontally to intersect the right-hand y-axis at 8.9 dB/ft. Determine the casing thickness as \((7 - 6.184)/2 = 0.816/2 = 0.41\) in. Draw a line from 8.9 dB/ft through the 0.41-in. casing thickness point to the compressive strength scale. Cement compressive strength = 2,100 psi.

To find the bond index, determine the decibel attenuation of the lowest recorded log value by entering 1.0 mV on the left-hand y-axis and proceeding to the 7-in. casing line. Move horizontally to intersect the right-hand y-axis at 12.3 dB/ft. Divide the precisely determined decibel attenuation for the CBL amplitude in the zone of interest by this value for the lowest millivolt value: \(8.9/12.3 = 72\%\) bond index.

A 72% bond index means that 72% of the casing is bonded. This is not a well-bonded zone because a value of 80% bonding over a 10-ft interval is historically considered well bonded. Although the logging scale is a linear millivolts scale, the decibel attenuation scale is logarithmic. The millivolts log scale for the CBL value cannot be rescaled in percent of bonding. If it were, the apparent percent bonding would be 65% because most bond log scales are from 0 to 100 mV reading from left to right, over 10 divisions of track 1, or conversely 100% to 0% cement bonding for 0 mV = 100% bonding and 100 mV = 0% bonding.
<table>
<thead>
<tr>
<th>OD (in.)</th>
<th>Weight per ft(^t) (lbm)</th>
<th>Nominal ID (in.)</th>
<th>Drift Diameter(^t) (in.)</th>
<th>OD (in.)</th>
<th>Weight per ft(^t) (lbm)</th>
<th>Nominal ID (in.)</th>
<th>Drift Diameter(^t) (in.)</th>
<th>OD (in.)</th>
<th>Weight per ft(^t) (lbm)</th>
<th>Nominal ID (in.)</th>
<th>Drift Diameter(^t) (in.)</th>
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<td>3.303</td>
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<td>6.413</td>
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<td>9.228</td>
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<td>113.00</td>
<td>39.750</td>
<td>39.522</td>
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\(^t\)Weight per foot in pounds is given for plain pipe (no threads or coupling).
\(^t\)Drift diameter is the guaranteed minimum inside diameter of any part of the casing. Use drift diameter to determine the largest-diameter equipment that can be safely run inside the casing. Use inside diameter for volume capacity calculations.

continued on next page
## Cement Bond Log—Casing Strength

### Interpretation—Cased Hole

#### Cem-1 (former M-1)

<table>
<thead>
<tr>
<th>Casing thickness (mm)</th>
<th>Casing thickness (in.)</th>
<th>Attenuation (dB/m)</th>
<th>Casing size (mm)</th>
<th>Casing size (in.)</th>
<th>CBL amplitude (mV)</th>
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</thead>
<tbody>
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<td>15</td>
<td>0.6</td>
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<td>5</td>
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<td>2</td>
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**Compressive strength**

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<th>Standard cement</th>
<th>Foamed cement</th>
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<td>1,000</td>
<td>200</td>
</tr>
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<td>800</td>
<td>150</td>
</tr>
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<td>500</td>
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<tr>
<td>50</td>
<td>10</td>
</tr>
<tr>
<td>25</td>
<td>5</td>
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</tbody>
</table>

**Compressive strength (psi) (mPa)**

- **Standard cement**
  - 1,000 psi = 6,895 mPa
  - 800 psi = 5,436 mPa
  - 500 psi = 3,448 mPa
  - 300 psi = 2,068 mPa
  - 200 psi = 1,378 mPa
  - 100 psi = 689.5 mPa
  - 50 psi = 344.8 mPa
  - 25 psi = 172.4 mPa
  - 10 psi = 68.95 mPa
  - 5 psi = 34.48 mPa
  - 2 psi = 17.24 mPa
  - 1 psi = 6.895 mPa

- **Foamed cement**
  - 200 psi = 1,378 mPa
  - 100 psi = 689.5 mPa
  - 50 psi = 344.8 mPa
  - 25 psi = 172.4 mPa
  - 10 psi = 68.95 mPa
  - 5 psi = 34.48 mPa
  - 2 psi = 17.24 mPa
  - 1 psi = 6.895 mPa

* © Schlumberger*
For $F_R = \frac{0.62}{\phi^{2.15}}$

Resistivity scale may be multiplied by 10 for use in a higher range.
Water Saturation Grid for Resistivity Versus Porosity

For $F_R = \frac{1}{\phi^2}$

Resistivity scale may be multiplied by 10 for use in a higher range.
## Appendix B

### Logging Tool Response in Sedimentary Minerals

<table>
<thead>
<tr>
<th>Name</th>
<th>Formula</th>
<th>(\rho_{\text{mg}}) (g/cm³)</th>
<th>(\phi_{\text{SP}}) (p.u.)</th>
<th>(\phi_{\text{CNL}}) (p.u.)</th>
<th>(\phi_{\text{AP}}) (p.u.)</th>
<th>(\Delta t_{e}) (μs/ft)</th>
<th>(\Delta t_{s}) (μs/ft)</th>
<th>(P_e)</th>
<th>(U) (farad/m)</th>
<th>(\gamma) (μs/m)</th>
<th>(\Sigma) (gAPI Units)</th>
<th>(\Sigma) (c.u.)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Silicates</strong></td>
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<td></td>
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<td>−1</td>
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¹APS* Accelerator Porosity Sonde porosity derived from near-to-array ratio (APLC)
‡Mean value, which may vary for individual samples

For more information, see Reference 41.
### Appendix B

#### Logging Tool Response in Sedimentary Minerals

<table>
<thead>
<tr>
<th>Name</th>
<th>Formula</th>
<th>$\rho$ (g/cm³)</th>
<th>$\phi_{\text{SNP}}$ (p.u.)</th>
<th>$\phi_{\text{CNL}}$ (p.u.)</th>
<th>$\Delta \varepsilon$ (μs/ft)</th>
<th>$\Delta \varepsilon$ (μs/ft)</th>
<th>$\varepsilon$ (farad/m)</th>
<th>$\gamma$ (ns/m)</th>
<th>$\gamma$ (API Units)</th>
<th>$\Sigma$ (c.u.)</th>
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</tr>
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<td>$\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$</td>
<td>2.41</td>
<td>34</td>
<td>-37</td>
<td>-34</td>
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<td>4.4</td>
<td>-5.8</td>
<td>-8.0</td>
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<tr>
<td>Chlorite</td>
<td>$(\text{Mg,Fe}_2\text{Al}_4\text{Si}<em>4\text{O}</em>{10})\text{O}_2\text{(OH)}_2$</td>
<td>2.76</td>
<td>37</td>
<td>-52</td>
<td>-35</td>
<td>6.3</td>
<td>17</td>
<td>-5.8</td>
<td>-8.0</td>
<td>180–250</td>
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<td>Illite</td>
<td>$K_1\text{Al}_4(\text{Si}<em>4\text{O}</em>{10})\text{Al}_1\text{Si}_3\text{O}_7\text{(OH)}_6$</td>
<td>2.52</td>
<td>20</td>
<td>-30</td>
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<td>8.7</td>
<td>-5.8</td>
<td>-8.0</td>
<td>250–300</td>
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<td>Montmorillonite</td>
<td>$(\text{Ca,Na})_3\text{(Al,Fe}_2\text{Al}_4\text{Si}<em>8\text{O}</em>{20})\text{(OH)}_4\text{(H}_2\text{O)}_n$</td>
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<td>4.0</td>
<td>4.0</td>
<td>-5.8</td>
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<td>-2</td>
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<td>5.1</td>
<td>15</td>
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<td>8.4</td>
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<td>60+</td>
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<td>52</td>
<td>4.0</td>
<td>9.4</td>
<td>4.1</td>
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<td>50+</td>
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<td>7.2–7.3</td>
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<td>60+</td>
<td>41</td>
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<td>-220</td>
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1APS* Accelerator Porosity Sonde porosity derived from near-to-array ratio (APLC)

2Mean value, which may vary for individual samples

For more information, see Reference 41.
## Appendix C

### Acoustic Characteristics of Common Formations and Fluids

#### Nonporous Solids

<table>
<thead>
<tr>
<th>Material</th>
<th>Δt (µs/ft)</th>
<th>Sound Velocity (ft/s)</th>
<th>Acoustic Impedance (MRayl)</th>
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<td>Casing</td>
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<td>Halite</td>
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#### Water-Saturated Porous Rock

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<th>Porosity (%)</th>
<th>Δt (µs/ft)</th>
<th>Sound Velocity (ft/s)</th>
<th>Acoustic Impedance (MRayl)</th>
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<tr>
<td>Dolomite</td>
<td>5–20</td>
<td>50.0–66.6</td>
<td>20,000–15,000</td>
<td>6,096–4,572</td>
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<tr>
<td>Limestone</td>
<td>5–20</td>
<td>54.0–76.9</td>
<td>18,500–13,000</td>
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<td>Sandstone</td>
<td>5–20</td>
<td>62.5–86.9</td>
<td>16,000–11,500</td>
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<td>Sand</td>
<td>20–35</td>
<td>86.9–111.1</td>
<td>11,500–9,000</td>
<td>3,505–2,743</td>
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<td>Shale</td>
<td>58.8–143.0</td>
<td>17,000–7,000</td>
<td>5,181–2,133</td>
<td>12.0–4.3</td>
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</tbody>
</table>

#### Nonporous Solids

<table>
<thead>
<tr>
<th>Material</th>
<th>Δt (µs/ft)</th>
<th>Sound Velocity (ft/s)</th>
<th>Acoustic Impedance (MRayl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
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<td>4,800</td>
<td>1,463</td>
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<tr>
<td>Water + 10% NaCl</td>
<td>192.3</td>
<td>5,200</td>
<td>1,585</td>
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<tr>
<td>Water + 20% NaCl</td>
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<td>Seawater</td>
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<td>Kerosene</td>
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<td>Air at 15 psi, 32°F [0°C]</td>
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<td>1,088</td>
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<td>Air at 3,000 psi, 212°F [100°C]</td>
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### Appendix D

#### Conversions

##### Length

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<th>Feet</th>
<th>Inches</th>
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<th>Meters</th>
<th>Milis</th>
<th>Miles</th>
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##### Area

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<th>Square Feet</th>
<th>Square Inches</th>
<th>Square Kilometers</th>
<th>Square Meters</th>
<th>Square Miles</th>
<th>Square Millimeters</th>
<th>Square Yards</th>
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<td>10^-3</td>
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<td>2.590 × 10^-6</td>
<td>10^-6</td>
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### Appendix D

#### Volume

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<th>Cubic Centimeters</th>
<th>Cubic Feet</th>
<th>Cubic Inches</th>
<th>Cubic Meters</th>
<th>Cubic Yards</th>
<th>Gallons (Liquid)</th>
<th>Liters</th>
<th>Pints (Liquid)</th>
<th>Quarts (Liquid)</th>
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<td>2.832 × 10⁴</td>
<td>16.39</td>
<td>10³</td>
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<td>0.7646</td>
<td>3.785 × 10⁻²</td>
<td>0.001</td>
<td>4.732 × 10⁻⁴</td>
<td>9.464 × 10⁻⁴</td>
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<td>6.189 × 10⁻²</td>
<td>1.238 × 10⁻²</td>
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<td>Gallons (liquid)</td>
<td>2.642 × 10⁻⁴</td>
<td>7.481</td>
<td>4.329 × 10⁻³</td>
<td>264.2</td>
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#### Mass and Weight

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<th>Milligrams</th>
<th>Ounces¹</th>
<th>Pounds¹</th>
<th>Tons (Long)</th>
<th>Tons (Metric)</th>
<th>Tons (Short)</th>
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<td>28.35</td>
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<td>1.016 × 10⁰</td>
<td>10¹</td>
<td>9.072 × 10⁸</td>
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¹Avoirdupois pounds and ounces
### Density or Mass per Unit Volume

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<th>Kilograms per Cubic Meter</th>
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<th>Pounds per Cubic Inch</th>
<th>Pounds per Gallon</th>
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<td>Pounds per cubic inch</td>
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### Pressure or Force per Unit Area

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<th>Bayres or Dynes per Square Centimeter¹</th>
<th>Centimeters of mercury at 0°C¹</th>
<th>Inches of mercury at 0°C¹</th>
<th>Inches of water at 4°C</th>
<th>Kilograms per square meter∥∥</th>
<th>Pounds per square Foot</th>
<th>Pounds per square Inch‡‡</th>
<th>Tons (short) per square Foot</th>
<th>Pascals</th>
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<td>1.316 × 10⁻²</td>
<td>3.342 × 10⁻²</td>
<td>2.458 × 10⁻³</td>
<td>9.678 × 10⁻⁴</td>
<td>4.725 × 10⁻⁴</td>
<td>6.804 × 10⁻²</td>
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<td>9.869 × 10⁻⁴</td>
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<td>Bayres or dynes per square centimeter²</td>
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<td>1</td>
<td>1.333 × 10⁴</td>
<td>3.386 × 10⁴</td>
<td>2.491 × 10⁻³</td>
<td>98.07</td>
<td>478.8</td>
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<td>9.578 × 10⁵</td>
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<td>7.501 × 10⁻⁵</td>
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<td>2.540</td>
<td>0.1868</td>
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<td>5.171</td>
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<td>0.3937</td>
<td>7.355 × 10⁻²</td>
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<td>1.414 × 10⁻²</td>
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<td>29.53 × 10⁻⁴</td>
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<td>Inches of water at 4°C</td>
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<td>5.354</td>
<td>13.60</td>
<td>1.922</td>
<td>0.1922</td>
<td>27.68</td>
<td>384.5</td>
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<td>Kilograms per square meter¶¶</td>
<td>1.033 × 10⁴</td>
<td>1.020 × 10⁻²</td>
<td>136.0</td>
<td>345.3</td>
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<td>Pounds per square foot</td>
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<td>2.089 × 10⁻²</td>
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<td>47.88</td>
<td>6.895 × 10³</td>
<td>9.576 × 10⁴</td>
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</table>

1. One atmosphere (standard) = 76 cm of mercury at 0°C
2. Bar
3. To convert height \( h \) of a column of mercury at \( t \) °C to the equivalent height \( h_0 \) at 0°C, use \( h_0 = h \left(1 - \left[(m - l) t / (1 + mt)\right]\right)\), where \( m = 0.0001818 \) and \( l = 18.4 \times 10^{-6} \) if the scale is engraved on brass; \( l = 8.5 \times 10^{-6} \) if on glass. This assumes the scale is correct at 0°C; for other cases (any liquid) see International Critical Tables, Vol. 1, 68.
4. 1 gram per square centimeter = 10 kilograms per square meter
5. PSI = MPa × 145.038
6. psi/ft = 0.433 × g/cm³ = lb/ft³/144 = lb/gal/19.27

### Temperature

<table>
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<th>°C</th>
<th>°R</th>
<th>K</th>
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<td>5⁄9 (°F – 32)</td>
<td>°F + 459.69</td>
<td>°C + 273.16</td>
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<td>Traditional Symbol</td>
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<td>Standard Computer Symbol</td>
<td>Description</td>
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2 Used only if conflict arises between standard symbols used in the same paper.
3 The unit of kilograms per square centimeter to be replaced in use by the SI metric unit of the pascal
4 "DEL" in the operator field and "RAD" in the main-quantity field
5 Suggested computer symbol
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<thead>
<tr>
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<th>Standard Computer Symbol</th>
<th>Description</th>
<th>Customary Unit or Relation</th>
<th>Standard Reserve Symbol</th>
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<td>ϕ</td>
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<td>ϕ&lt;sub&gt;ig&lt;/sub&gt;</td>
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<td>ϕ&lt;sub&gt;ig&lt;/sub&gt; = (V&lt;sub&gt;b&lt;/sub&gt; - V&lt;sub&gt;gr&lt;/sub&gt;)/V&lt;sub&gt;b&lt;/sub&gt;</td>
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<th>Standard Computer Subscript$^*$</th>
<th>Explanation</th>
<th>Example</th>
<th>Standard Reserve Subscript$^*$</th>
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<td>mudcake</td>
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<td>noninvaded zone</td>
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<td>oil (except with resistivity)</td>
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<tr>
<td>or</td>
<td>or</td>
<td>OR</td>
<td>residual oil</td>
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<td>(F_0)</td>
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<td>p</td>
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<td></td>
<td>propagation</td>
<td>(t_{pw})</td>
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<td>pSP</td>
<td>PSP</td>
<td>pseudostatic SP</td>
<td>(E_{pSP})</td>
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<td>R</td>
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<td>(k_{r,o}, k_{r,w})</td>
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<td>R</td>
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<td>sand</td>
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<td>sandstone</td>
<td>sst</td>
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<td>secondary</td>
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<td>shale</td>
<td>(V_{sh})</td>
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<td>SP</td>
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<td>SSP</td>
<td>SSP</td>
<td>static spontaneous potential</td>
<td>(E_{SSP})</td>
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<td>sh st</td>
<td>SH ST</td>
<td>structural shale</td>
<td>(V_{shst})</td>
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<td>true (as opposed to apparent)</td>
<td>(R_t)</td>
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<td>t</td>
<td>T</td>
<td>total</td>
<td>(C_t)</td>
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<td>w</td>
<td>w</td>
<td>W</td>
<td>water, formation water</td>
<td>(S_w)</td>
<td>W</td>
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<td>wa</td>
<td>WA</td>
<td>formation water, apparent</td>
<td>(R_{wa})</td>
<td>Wap</td>
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<td>wf</td>
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<td>WF</td>
<td>well flowing conditions</td>
<td>(P_{wf})</td>
<td>f</td>
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<td>ws</td>
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<td>well static conditions</td>
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<td>s</td>
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<td>XO</td>
<td>flushed zone</td>
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<td>z, im</td>
<td>im</td>
<td>IM</td>
<td>intermatrix</td>
<td>(\phi_{im})</td>
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\(^\d\) Used only if conflict arises between standard symbols used in the same paper
## Subscripts

<table>
<thead>
<tr>
<th>Traditional Subscript</th>
<th>Standard SPE and SPWLA(^\dagger)</th>
<th>Subscript‡</th>
<th>Explanation</th>
<th>Example</th>
<th>Standard Reserve Subscript(^\ddagger)</th>
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</thead>
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<tr>
<td>0 (zero)</td>
<td>0 (zero)</td>
<td>ZR</td>
<td>100 percent water saturated</td>
<td>(R_0)</td>
<td>zr</td>
</tr>
<tr>
<td>AD</td>
<td>RAD</td>
<td>from CDR attenuation deep</td>
<td>(R_{AD})</td>
<td></td>
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</tr>
<tr>
<td>D</td>
<td>D</td>
<td>D</td>
<td>from density log</td>
<td>(\phi_D)</td>
<td>d</td>
</tr>
<tr>
<td>GG</td>
<td>GG</td>
<td>from gamma-gamma log</td>
<td>(\phi_{GG})</td>
<td>gg</td>
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<tr>
<td>IL</td>
<td>I</td>
<td>I</td>
<td>from induction log</td>
<td>(R_I)</td>
<td>i</td>
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<tr>
<td>ILD</td>
<td>ID</td>
<td>ID</td>
<td>from deep induction log</td>
<td>(R_{ID})</td>
<td>id</td>
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<tr>
<td>ILM</td>
<td>IM</td>
<td>IM</td>
<td>from medium induction log</td>
<td>(R_{IM})</td>
<td>im</td>
</tr>
<tr>
<td>LL</td>
<td>LL (also LL3, LL8, etc.)</td>
<td>LL</td>
<td>from laterolog</td>
<td>(R_{LL})</td>
<td>(\ell\ell)</td>
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<tr>
<td>N</td>
<td>N</td>
<td>N</td>
<td>from normal resistivity log</td>
<td>(R_N)</td>
<td>n</td>
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<tr>
<td>N</td>
<td>N</td>
<td>N</td>
<td>from neutron log</td>
<td>(\phi_N)</td>
<td>n</td>
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<tr>
<td>PS</td>
<td>RPS</td>
<td>from CDR phase-shift shallow</td>
<td>(R_{PS})</td>
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<tr>
<td>16&quot;, 16’N</td>
<td>from 16-in. normal Log</td>
<td>(R_{16’})</td>
<td></td>
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<td></td>
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<tr>
<td>1” × 1”</td>
<td>from 1-in. by 1-in. microinverse (MI)</td>
<td>(R_{1” \times 1”})</td>
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<tr>
<td>2”</td>
<td>from 2-in. micronormal (MN)</td>
<td>(R_2’)</td>
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</table>

\(^\dagger\) SPE Letter and Computer Symbols Standard (1986)

\(^\ddagger\) Used only if conflict arises between standard symbols used in the same paper
These unit abbreviations, which are based on those adopted by the Society of Petroleum Engineers (SPE), are appropriate for most publications. However, an accepted industry standard may be used instead. For instance, in the drilling field, ppg may be more common than lbm/gal when referring to pounds per gallon.

In some instances, two abbreviations are given: customary and metric. When using the International System of Units (SI), or metric, abbreviations, use the one designated for metric (e.g., m²/h instead of m³/hr). The use of SI prefix symbols and prefix names with customary unit abbreviations and names, although common, is not preferred (e.g., 1,000 lbf instead of klbf).

Unit abbreviations are followed by a period only when the abbreviation forms a word (for example, in. for inch).

### Appendix G Unit Abbreviations

<table>
<thead>
<tr>
<th>Unit</th>
<th>Abbreviation</th>
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<td>acre</td>
<td>ft²</td>
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<td>acre-foot</td>
<td>acre-ft</td>
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<tr>
<td>ampere</td>
<td>A</td>
</tr>
<tr>
<td>angstrom (10⁻⁸ cm)</td>
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<tr>
<td>atmosphere</td>
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<tr>
<td>atomic mass unit</td>
<td>amu</td>
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<tr>
<td>barrel</td>
<td>bbl</td>
</tr>
<tr>
<td>barrels of fluid per day</td>
<td>BFPD</td>
</tr>
<tr>
<td>barrels of liquid per day</td>
<td>BLPD</td>
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<tr>
<td>barrels of oil per day</td>
<td>BOPD</td>
</tr>
<tr>
<td>barrels of water per day</td>
<td>BWPD</td>
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<tr>
<td>bar</td>
<td>B/D</td>
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<tr>
<td>per minute</td>
<td>bbl/min</td>
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<tr>
<td>billion cubic feet (billion = 10⁹)</td>
<td>Bcf</td>
</tr>
<tr>
<td>billion cubic feet per day</td>
<td>Bcf/D</td>
</tr>
<tr>
<td>billion standard cubic feet per day</td>
<td>Bscf/D</td>
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<td>bits per inch</td>
<td>bpi</td>
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<tr>
<td>bits per second</td>
<td>bps</td>
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<tr>
<td>brake horsepower</td>
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<td>British thermal unit</td>
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<td>capture unit</td>
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<td>centistoke</td>
<td>cSt</td>
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<tr>
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<td>cps</td>
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<td>cubic feet per barrel</td>
<td>ft³/bbl</td>
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<td>ft³/D</td>
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<tr>
<td>cubic feet per pound</td>
<td>ft³/lbm</td>
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<td>cubic yard</td>
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<td>darcy, darcies</td>
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<td>degree (American Petroleum Institute)</td>
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<td>degree Rankine</td>
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<td>dots per inch</td>
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<td>electromagnetic force</td>
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<td>farad</td>
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<td>kips per square inch</td>
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Appendix G

lines per inch ....................................................... lpi
lines per minute .................................................... lpm
lines per second .................................................... lps
liter ................................................................. L
megabyte .......................................................... MB
megagram (metric ton) ............................................ Mg
megahertz ........................................................ MHz
megajoule ........................................................ MJ
meter ............................................................... m
metric ton (tonne) ................................................... t or Mg
mho per meter ...................................................... Ω/m
microsecond ......................................................... µs
mile ................................................................. Spell out
miles per hour ....................................................... mph
milliamperes ......................................................... mA
millicurie ........................................................... mCi
millidarcy, millidarcies ............................................ mD
milliequivalent ...................................................... meq
milligram ........................................................... mg
milliliter ............................................................. mL
millimeter ........................................................... mm
millimho ............................................................. mmho
million cubic feet (million = 10^6) .......................... MMcf
million cubic feet per day ................................. MMcf/D
million electron volts ............................................. MeV
million standard cubic feet per day ........................ MMcf/D (see “standard cubic foot”)
milliPascal ......................................................... mPa
millisecond ........................................................ ms
millisiemens ......................................................... mS
millivolt .............................................................. mV
mils per year ......................................................... mil/yr
minute .............................................................. min
mole ................................................................. mol
nanosecond ........................................................ ns
newton .............................................................. N
ohm ................................................................. ohm
ohm-centimeter .................................................... ohm-cm
ohm-meter ........................................................ ohm-m
ounce ............................................................... oz
parts per million ................................................... ppm
pascal .............................................................. Pa
picoFarad ........................................................ pF
pint ................................................................. pt
porosity unit ........................................................ p.u.
pound (force) ........................................................ lbf
pound (mass) ........................................................ lbm
pound per cubic foot ............................................. lbm/ft^3
pound per gallon .................................................. lbm/gal
pounds of proppant added .................................... ppa
pounds per square inch .......................................... psi
pounds per square inch absolute ......................... psia
pounds per square inch gauge .............................. psig
pounds per thousand barrels (salt content) ............ ptb
quarter .............................................................. qt
reservoir barrel ...................................................... res bbl
reservoir barrel per day .................................. RB/D
revolutions per minute ......................................... rpm
saturation unit ........................................................ s.u.
second .............................................................. s
shots per foot ........................................................ spf
specific gravity ....................................................... sg
square ............................................................... sq
square centimeter ................................................. cm^2
square foot ........................................................ ft^2
square inch ........................................................ in^2
square meter ......................................................... m^2
square mile ........................................................ sq mile
square millimeter .................................................. mm^2
standard ............................................................ std
standard cubic feet per day ................................. Use ft^3/D instead of scf/D (see “standard cubic foot”)
stock-tank barrel ................................................... STB
stock-tank barrels per day ................................... STB/D
stoke ............................................................... St
teragram ............................................................ Tg
thousand cubic feet ............................................. Mcf
thousand cubic feet per day ................................. Mcf/D
thousand pounds per square inch ......................... kpsi
thousand standard cubic feet per day .................... Use Mcf/D instead of Mscf/D (see “standard cubic foot”)
tonne (metric ton) ................................................ t
trillion cubic feet (trillion = 10^15) ......................... Tcf
trillion cubic feet per day ................................ Tcf/D
volt ................................................................. V
volume percent ...................................................... vol% 
volume per volume ............................................. vol/vol
watt ................................................................. W
weight percent ..................................................... wt%
yard ............................................................... yd
year (customary) ................................................... yr
year (metric) ........................................................ a
Appendix H

References

4. Segesman FF: “New SP Correction Charts,” *Geophysics* (December 1962) 27, No. 6, PI.


The Schlumberger “chartbook” was initially developed to correct raw measurements to account for environmental effects and to interpret the corrected measurements.

Although software may be more effective in deriving results, especially in complex well situations, the chartbook still serves two primary functions, for training and sensitivity analysis.

Entering the chartbook will take you to the contents, from where you can access any chart by clicking its entry.

You can also browse the PDF normally.

Enter the chartbook HERE.
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