GEO4250
Reservoir Geology

Basic Well Log Analysis

Determination of Saturation

Reminder

$$N_p = \phi_e S_{hc} hAr$$

$$S_w = \sqrt[n]{\frac{FR_w}{R_t}} = \sqrt[n]{\frac{R_o}{R_t}}$$

$$S_w = 1 - S_{hc}$$

$$\phi_s = \left(\frac{\Delta t_{log} - \Delta t_{matrix}}{\Delta t_f - \Delta t_{matrix}} \right)$$ **Sonic Porosity**

$$\phi_{den} = \frac{\rho_{matrix} - \rho_b}{\rho_{matrix} - \rho_f}$$ **Density Porosity**

ϕ_n **from log**

$$\phi_e = \phi_t \times (1 - V_{sh})$$ **Effective Porosity**

$$F = \frac{R_0}{R_w} = \frac{a}{\phi^m}$$

Reminder

- Determined R_w from the Spontaneous Potential
- Determined ϕ_t and ϕ_e from porosity and gamma ray logs

- The only parameter we lack now is the true resistivity of the formation

Resistivity

- The resistivity (specific resistance) of a substance is the resistance between opposite faces of a unit cube of that substance at a specific temperature
- Symbol R, measured in Ω·m (ohm·m^2/m)

$$R = \frac{r \times A}{L}$$

- With r = resistance in ohms; A = area in square meters; L = length in meters
- Resistivity is a basic measurement of a reservoir's fluid saturation and is a function of porosity, type of fluid, amount of fluid and type of rock
- Usually between 0.2 and 1000 ohm·m

Resistivity

- Dependent on:
  - Presence of Formation water / Hydrocarbons
  - Salinity of Formation water
  - Temperature of Formation water
  - Volume of water-saturated pore space
  - Geometry of the pore space
  - Morphology and species of clay minerals

Tools

- Conventional Electrical logs

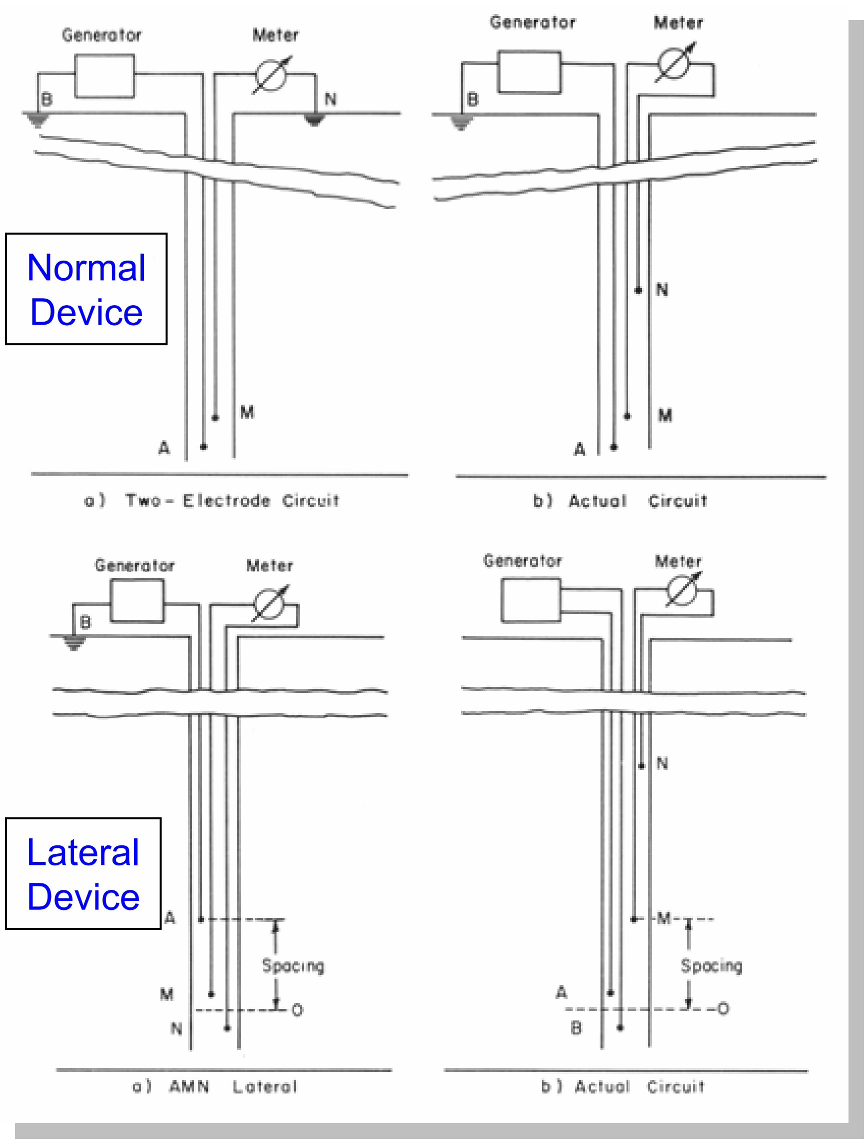
  First developed before 1950

  - Normal devices
    - Short Normal (SN)
    - Long Normal (LN)
  - Lateral devices
    - Laterologs (LL, e.g. LL3, LL7, LL8, LLD, LLS, SFL)
- Induction logging

  First developed after 1950

  - Induction devices
    - 6FF40 (combined tool: Induction, Normal and SP, 1960's)
    - DIL-LL8 (improved induction-normal combination)
    - Induction SFL
    - DIL-SFL
    - Phasor Induction SFL
    - Other abbreviations: ILD, ILM, ILS, RD, RM, RS, RT

Conventional Electrical Logging



- Current of constant intensity between A and B
- Resultant potential difference measured between M and N
- The larger the 'spacing', the deeper the measurement

Conventional Electrical Logging

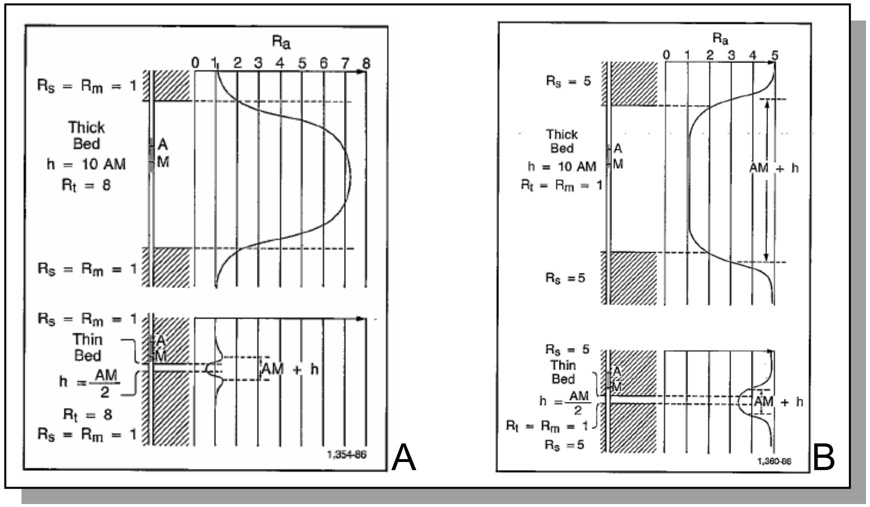
Normal and Lateral Curves

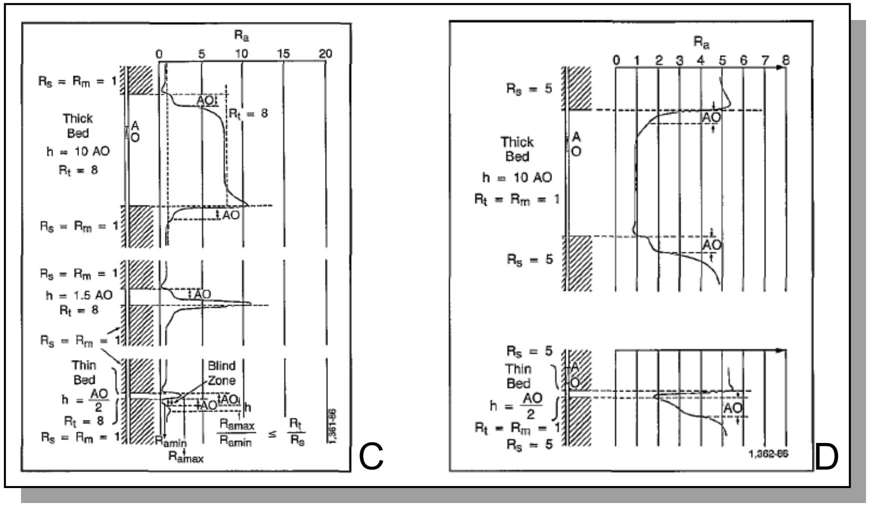
Normal Device

- A: Beds more resistive than surrounding beds
- B: Beds less resistive than surrounding beds

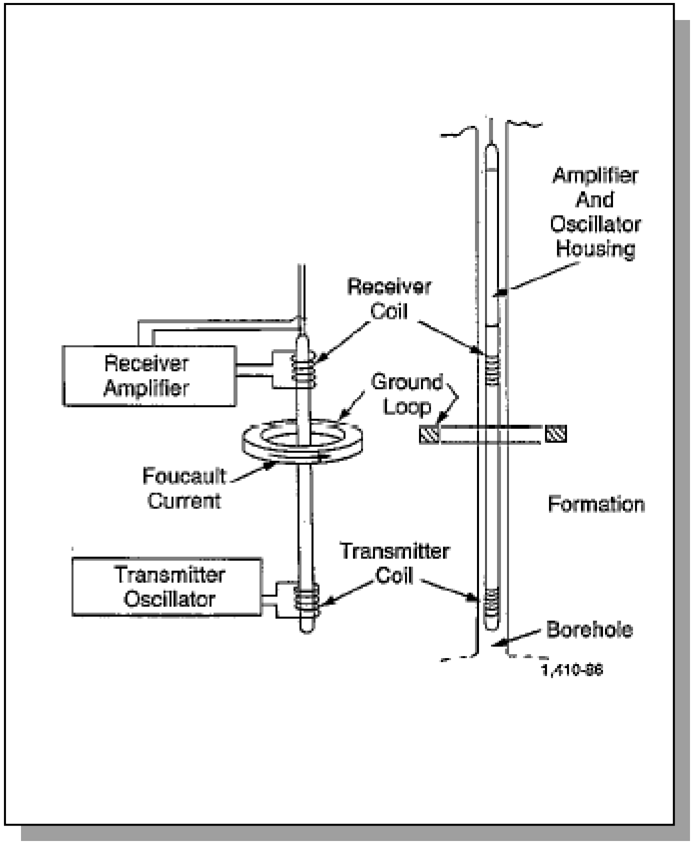
Lateral Device

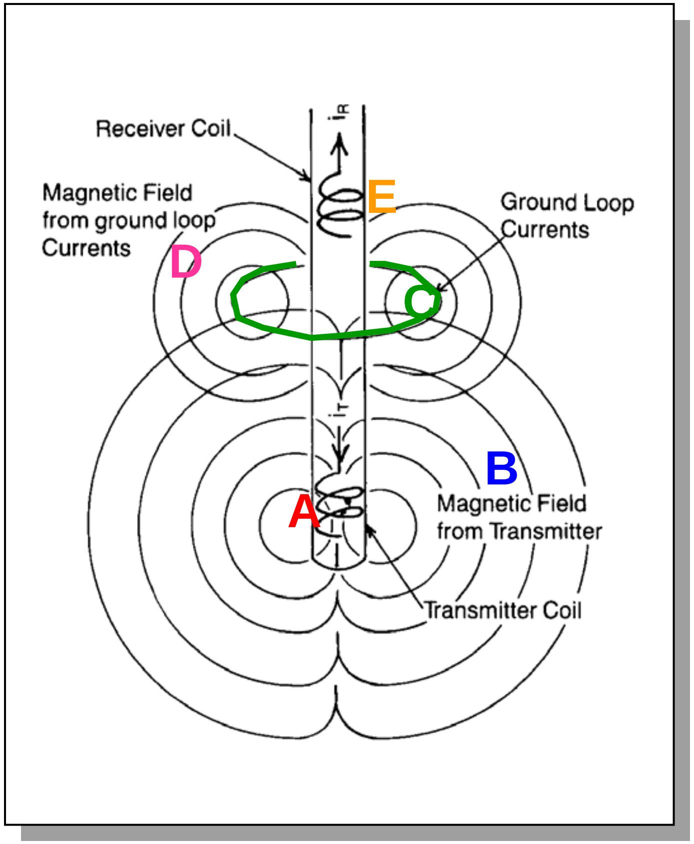
- C: Beds more resistive than surrounding beds
- D: Beds less resistive than surrounding beds





Induction Logging

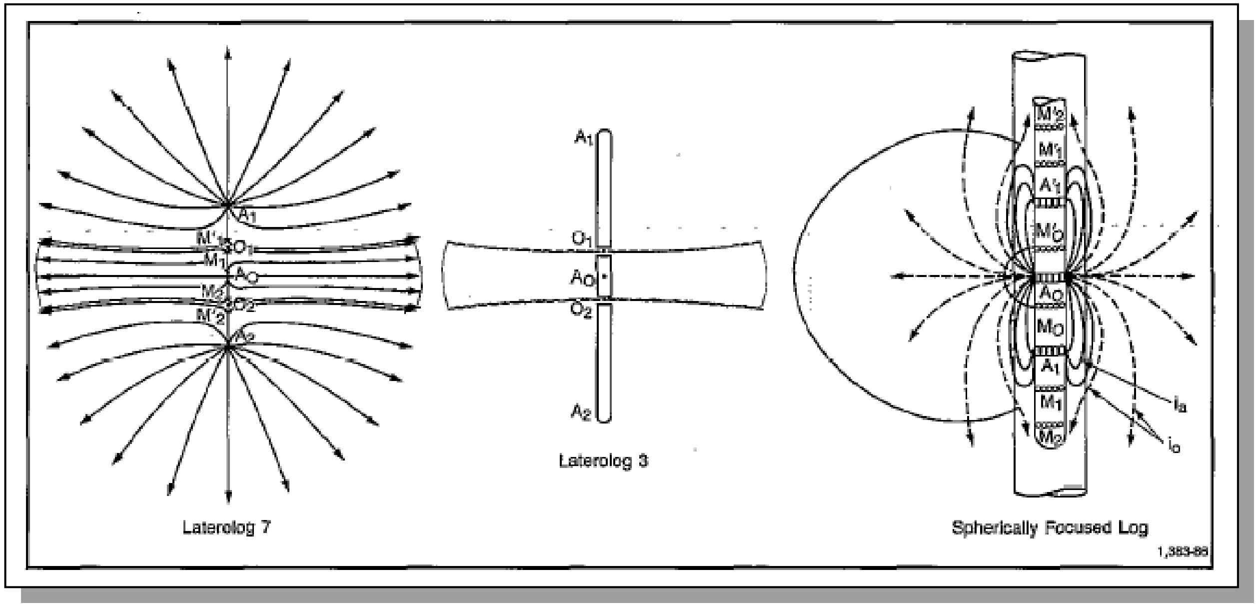




- High frequency, alternating current of constant intensity is sent through a transmitter coil (A)
- The alternating magnetic field (B) created, induces currents in the formation surrounding the borehole (C)
- These currents flow in circular ground loops coaxial with the transitter coil and create, is turn, a magnetic field (D) that induces a current in the receiver coil (E)

Resistivity Logging
Focusing

- Minimization of borehole and adjacent formation affects
- Focusing currents to control the path taken by the measure current



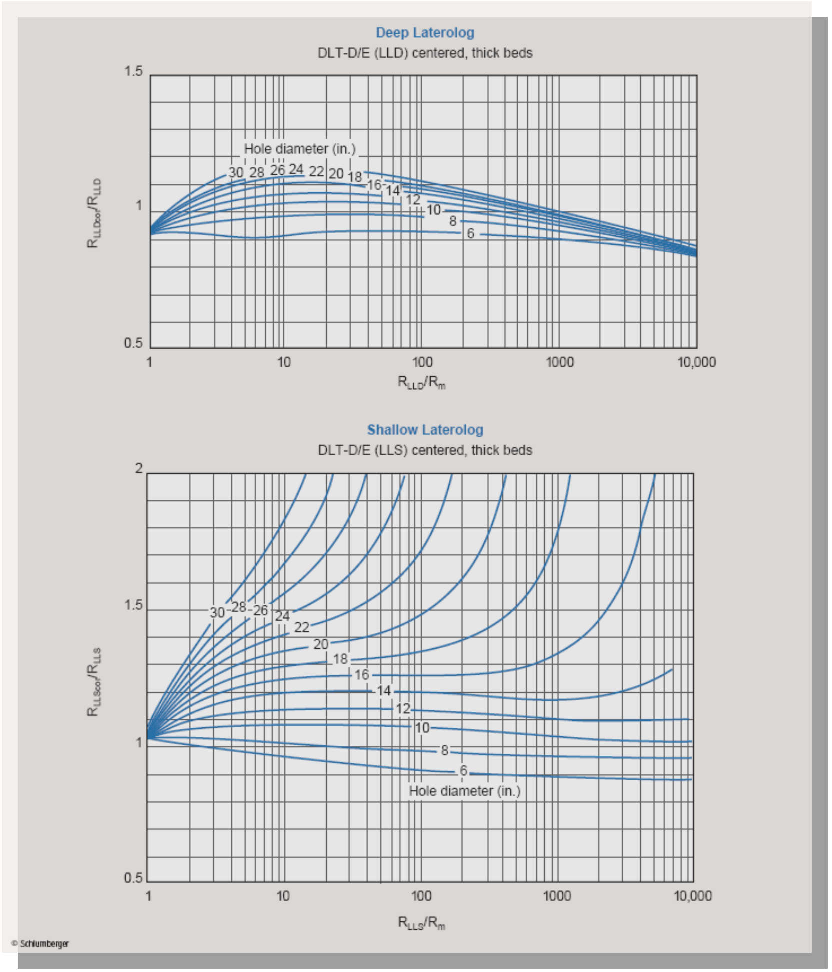
Resistivity Logging

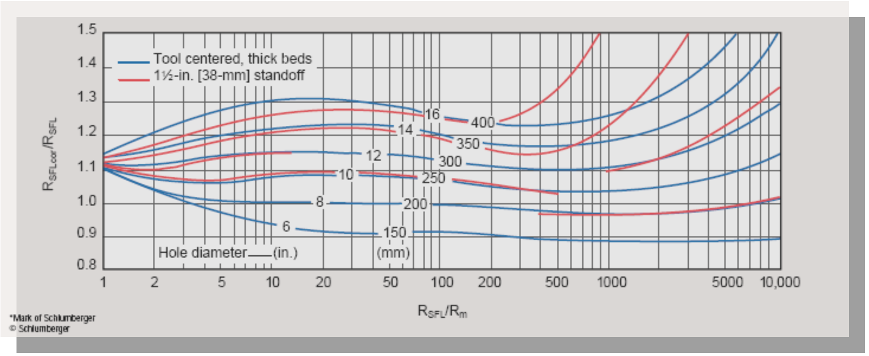
Influence of well bore variables and log correction

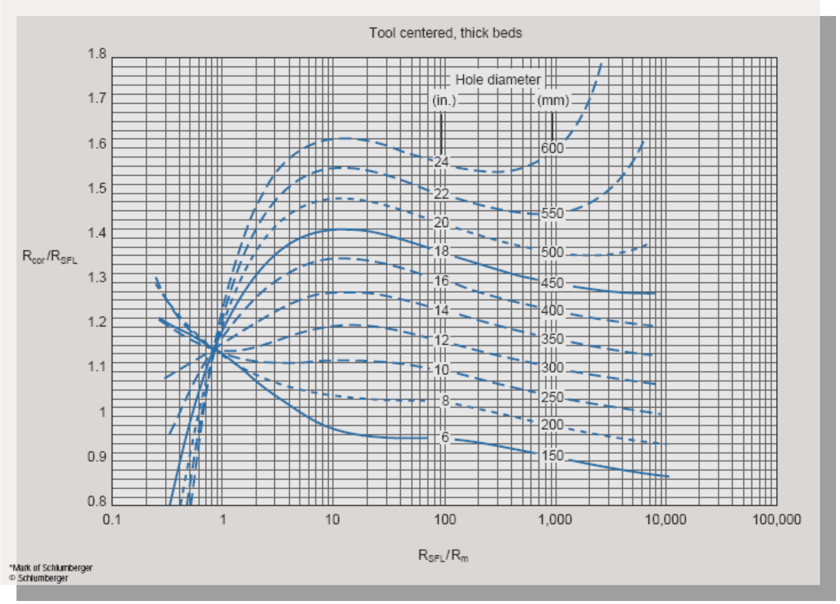
- Resistivity measurements are influenced by:
  - Borehole mud
  - Adjacent beds
  - Invaded zone
- Readings must be corrected, always in the following way:
  - Borehole effect
  - Adjacent bed effect
  - Invasion correction

Resistivity Logging

Corrections - Borehole Effect







Resistivity Logging

Corrections - Adjacent Bed Effect

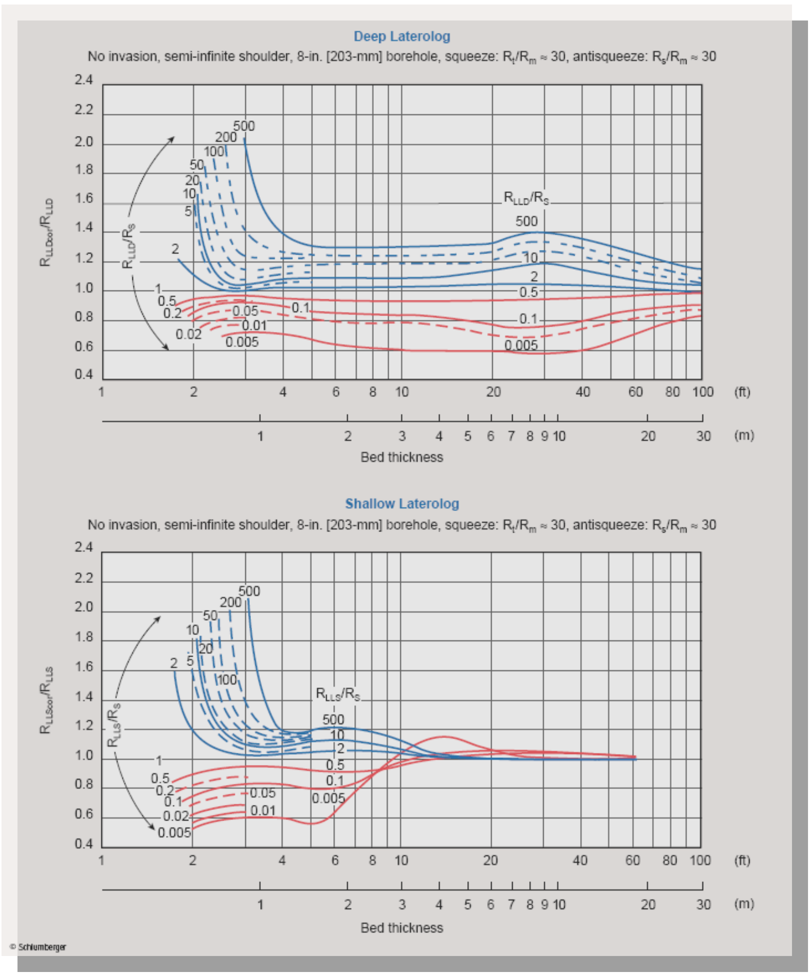


Chart Rcor-10 corrects the Dual Laterolog (LLD and LLS) for bed thickness.

To use, laterolog readings should first be corrected for borehole effects (see Charts Rcor-2b and -2c). Then, enter Chart Rcor-10 with the bed thickness and proceed upward to the proper R_{LL}/R_s ratio (apparent laterolog reading corrected for borehole/adjacent-bed resistivity) curve. Read the ratio of the corrected laterolog value (R_{LLcor}) to the apparent laterolog value (R_{LL}) in ordinate.

Example: R_{LLD} = 4.2 ohm-m
R_{LLS} = 3.0 ohm-m
R_S = 30 ohm-m
Bed thickness = 6 ft

Given $\frac{R_{LLD}}{R_S} = \frac{4.2}{30} = 0.14$

$\frac{R_{LLS}}{R_S} = \frac{3.0}{30} = 0.10$

Therefore, $\frac{R_{LLDcor}}{R_{LLD}} = 0.88$

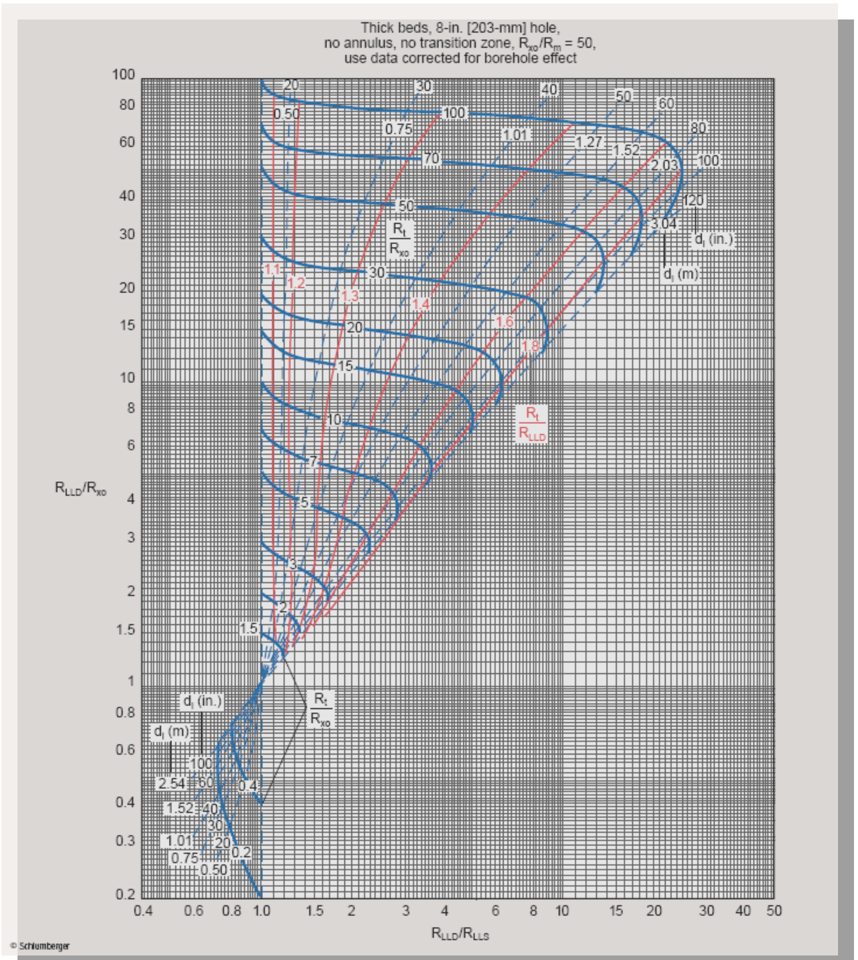
$\frac{R_{LLScor}}{R_{LLS}} = 0.80$

and R_{LLDcor} = 3.7 ohm-m
R_{LLScor} = 2.4 ohm-m

Resistivity Logging

Invasion Correction

'Tornado' or 'Butterfly' Chart



The invasion correction charts, sometimes referred to as "tornado" or "butterfly" charts, of the next several pages (labeled Rint-) are used to define the depth of invasion d_i, the R_{xo}/R_t ratio and the true resistivity R_t. All assume a step-contact profile of invasion and that all resistivity measurements have been corrected, where necessary, for borehole effect and bed thickness using the appropriate Rcor- chart, prior to entry.

To use any of these charts, enter the abscissa and ordinate 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 can be used to find values for S_w. One value, which is designated as S_{wA} (S_w-Archie), is found using the Archie saturation formula (or Chart Sw-1) with the R_t value and known values of F_R and R_w.

An alternate S_w value, designated as S_{wR} (S_w-Ratio), is found using R_{xo}/R_t with R_{mf}/R_w as in Chart Sw-2.

If S_{wA} and S_{wR} are equal, the assumption of a step-contact invasion profile is indicated to be correct, and all values found (S_w, R_t, R_{xo}, d_i) are considered good.

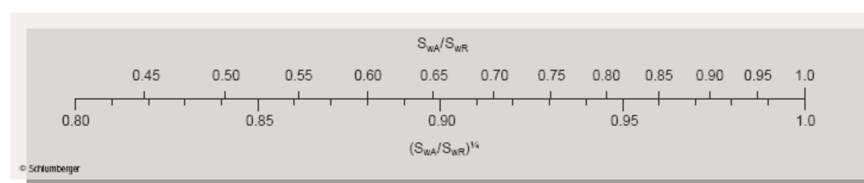
If $S_{wA} > S_{wR}$, either invasion is very shallow or a transition type of invasion profile is indicated, and S_{wA} is considered a good value for S_w.

If $S_{wA} < S_{wR}$, an annulus-type invasion profile may be indicated. In this case a more accurate value of water saturation may be estimated using the relation:

$$S_{wcor} = S_{wA}\left(\frac{S_{wA}}{S_{wR}}\right)^{\frac{1}{4}}$$

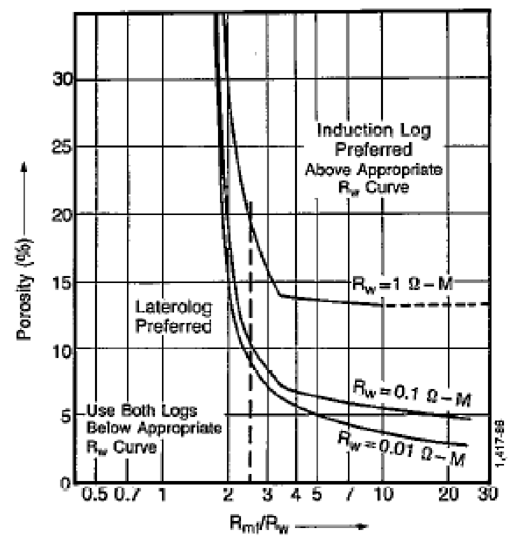
The correction factor $(S_{wA}/S_{wR})^{1/4}$ can be found from the scale below.

For more information see Reference 9.



Laterolog vs Induction

Both have unique characteristics that favor their use in specific, and often different, situations and application



Induction Log

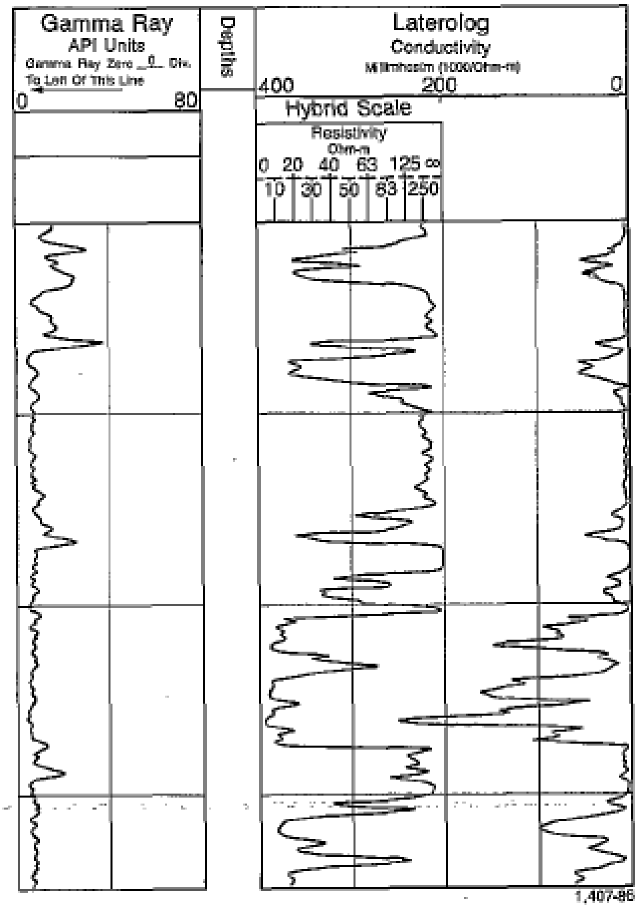
- Recommended in holes drilled with moderately conductive drilling muds, non-codunctive muds and in empty or air-drilled holes
- Most accurate in low- to medium-resistivity formations
- $R_{xo} > R_t$

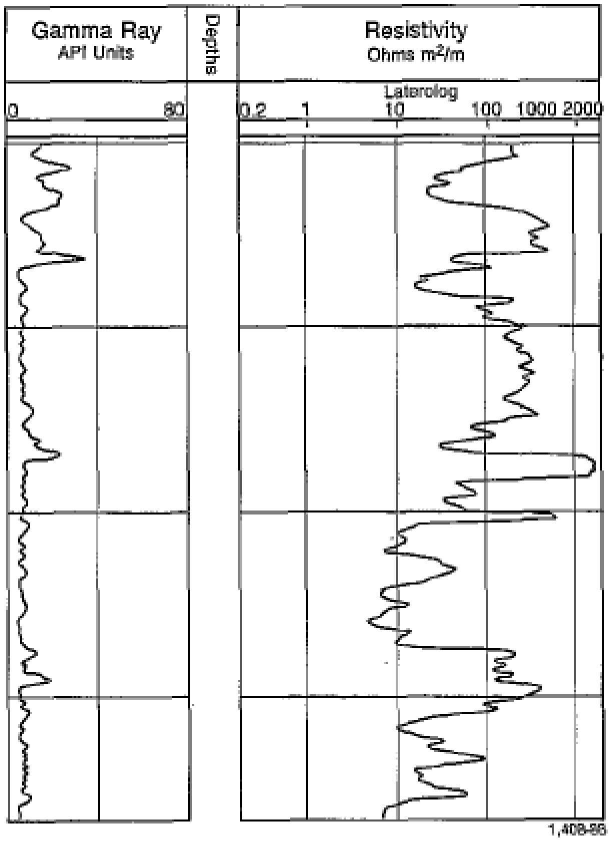
Laterolog

- Recommended in holes drilled with conductive muds (salt muds)
- Most accurate in medium- to high-resistivity formations
- $R_{xo} < R_t$

Resistivity

Scaling



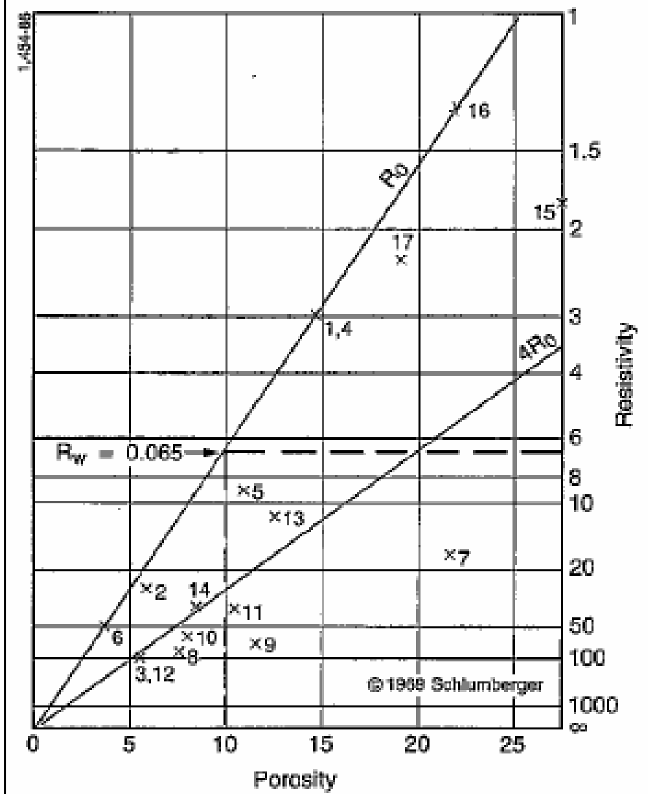


Determination of Saturation

$$S_w = \sqrt[n]{\frac{FR_w}{R_t}} \qquad F = \frac{R_0}{R_w} = \frac{a}{\phi^m}$$

$$S_w^n = \frac{aR_w}{\phi^m R_t} \xrightarrow{n=m=2,a=1} \phi S_w = \sqrt{\frac{R_w}{R_t}}$$

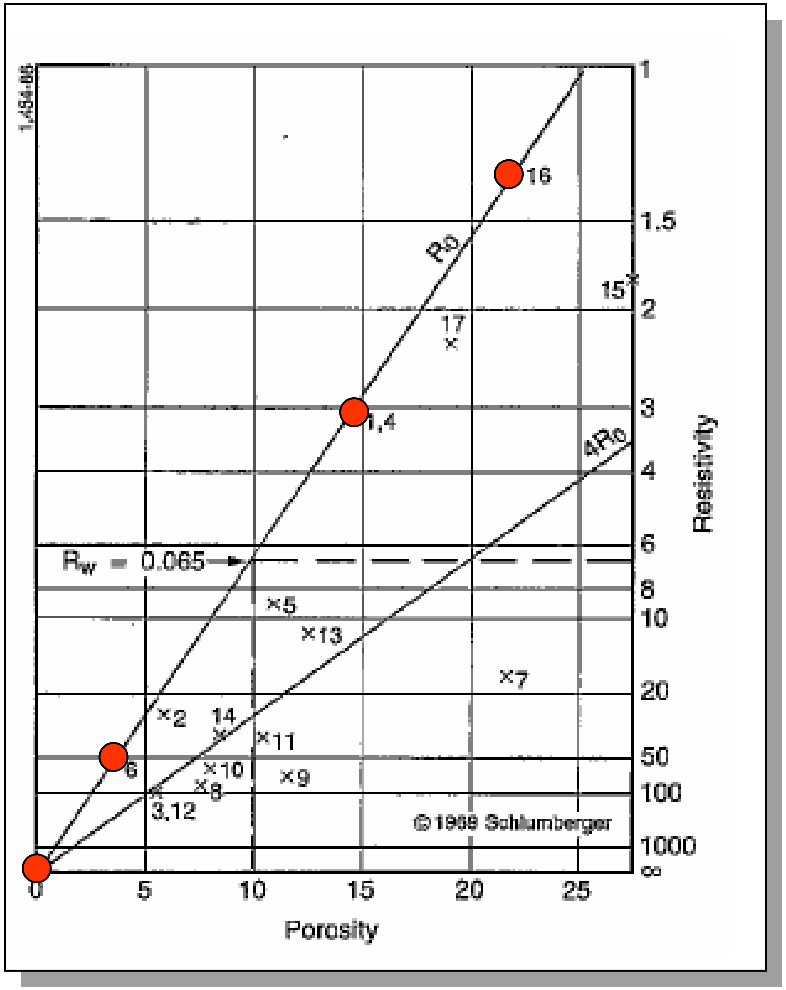
$$\rightarrow \phi = \frac{\sqrt{R_w}}{S_w}\frac{1}{\sqrt{R_t}}$$



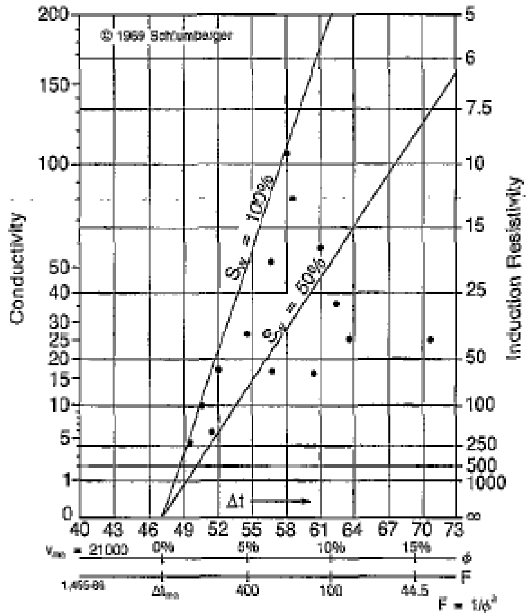
Determination of Saturation

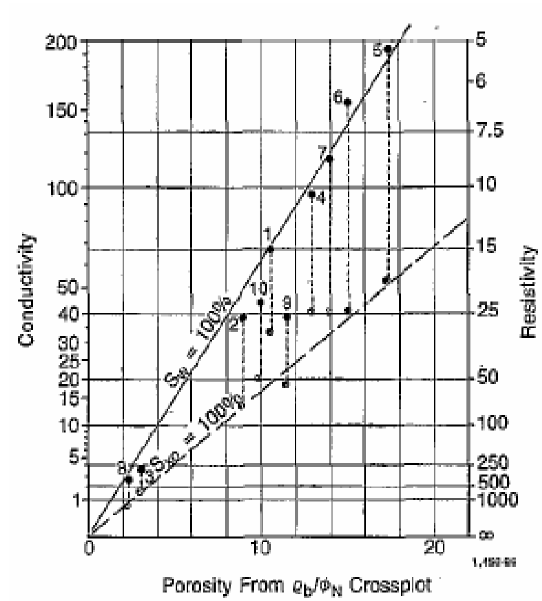
EXAMPLE

- 100% water saturated formation
- $S_w = 1$; $R_t = R_0$
- R_0 vs ϕ is a straight line; $\phi = \sqrt{R_w} / \sqrt{R_t}$
- If $S_w \neq 1$, but constant, all points also on a straight line
- From plotted points, assume some from 100% water saturated rock → line through f=0, R=∞ and through the most westerly plotted points
- Slope of this line defines the value of R_w
- For ϕ=10%, R_0 = 6.5 ohm·m
- For compacted formations:
  - **$F = 1 / \phi^2$**
- So, in this case F = 100
- We also now that:
  - **$R_w = R_0/F$**
- So, R_w = 6.5/100 = 0.065 ohm·m



Determination of Saturation





- Only possible for formations with constant matrix and for constant Formation Water Resistivities