

19. ELECTRICAL LOGGING

19.1 Introduction

Electrical logs are perhaps the most important tools available to a petrophysicist. This is because they provide a method for calculating the water saturation, upon which calculations of STOOIP are based. They were also some of the first logs to be used, with Marcel and Conrad Schlumberger testing out an electrical log for the first time in 1927 in the Pechelbronn field, France.

These first measurements were continuous recordings using 2 or 3 electrodes and a direct current. It was discovered that high quality recordings of apparent resistivity could be obtained under favourable conditions of small diameter boreholes, high mud resistivities and shallow invasion in thick reservoirs. These early tools are called *electric logging tools*.

The development of electrical tools has henceforward been intense. There are now tools that can cope with extremely highly resistive muds (oil-based muds or gas as the borehole fluid), which rely upon electromagnetic coupling and an induced alternating current (*induction logs*). The induction log actually measures conductivity, and hence is sometimes called the *conductivity log*. The modern tool for measuring resistivity in high salinity (low resistivity) muds is the *laterolog*, which focuses its current into a thin sheet to improve vertical resolution and penetration depth. The laterologs measure resistivity in the conventional sense, and are usually referred to as *resistivity tools*. Both the induction logs and the laterologs come in different types, which are sensitive to different depths of penetration into the borehole. Hence resistivity determinations for the invaded, partly invaded and undisturbed rock zones can be measured. In addition, there is a range of smaller electrical devices (*micro-resistivity tools*), which are designed to measure the resistivity of mudcake. There are also *Array Logs*, which are state of the art tools, and electrical measurements are used at high resolutions (small scale) to image the interior of the borehole electrically.

19.2 Principle Uses of Electrical Logs

The main use of the electrical tools is to calculate the water saturation of a reservoir formation, and hence the STOOIP. Chapter 17 covered most of the important theory for this application, and Chapter 1 introduced the use of the derived values when calculating STOOIP.

The electrical tools also have a number of qualitative uses, principle of which are (i) indications of lithology, (ii) facies and electro-facies analysis, (iii) correlation, (iv) determination of overpressure, (iv) determination of shale porosity, (v) indications of compaction, and the investigation of source rocks.

19.3 Typical Responses of an Electrical Tool

Figure 19.1 shows the typical response of an electrical tool in a sand/shale sequence. Note the lower resistivity in shales, which is due to the presence of bound water in clays that undergo surface conduction. The degree to which the sandstones have higher resistivities depends upon (i) their porosity, (ii) their pore geometries, (iii) the resistivity of the formation water, (iv) the water, oil and gas saturations (oil and gas are taken to have infinite resistivity).

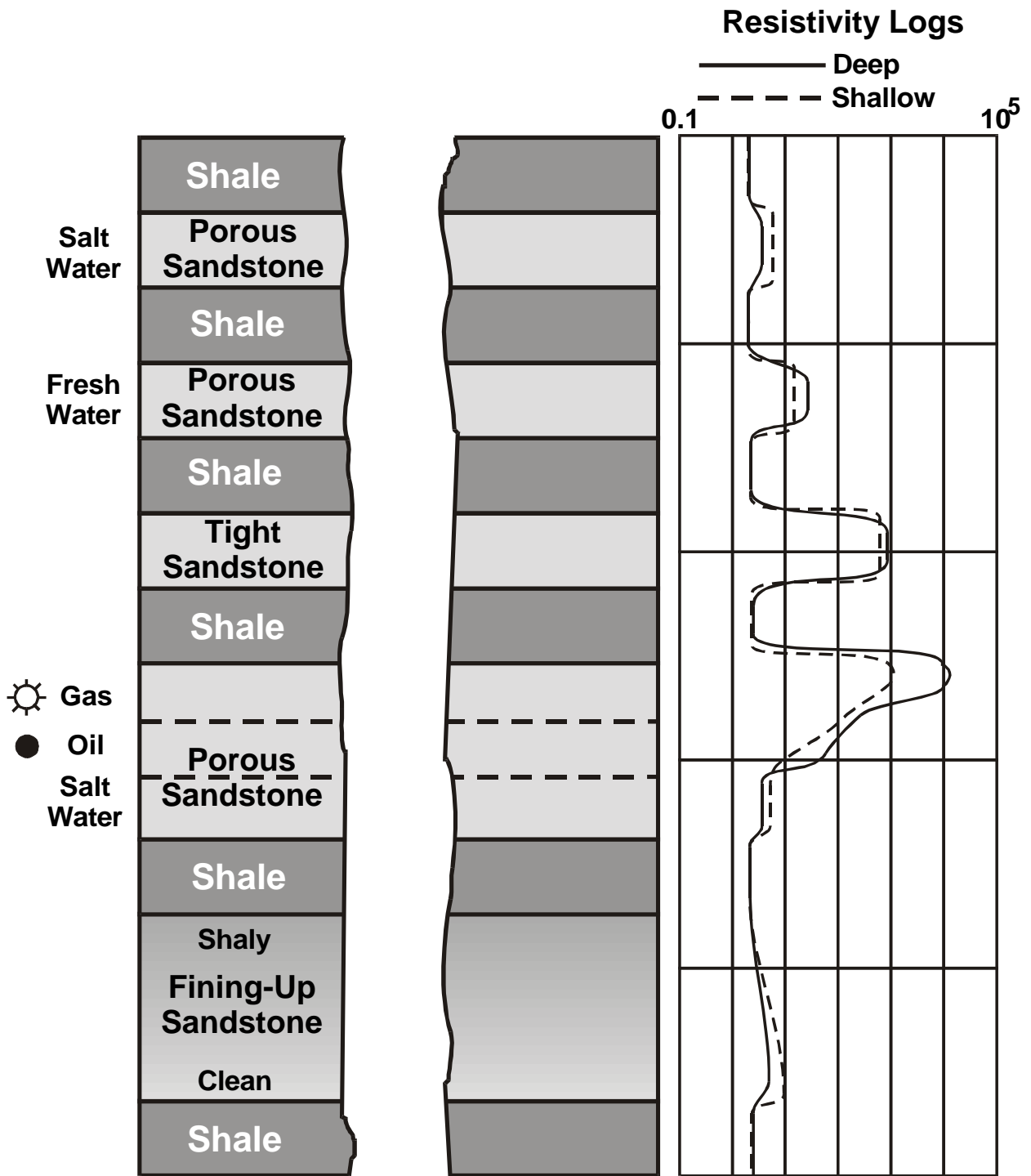


Fig. 19.1 Typical resistivity log responses.

19.4 Old Electrical Logs

These logs will be discussed briefly because data from them may still be encountered when reanalyzing mature fields.

Take an homogeneous and isotropic medium that extends to infinity in all directions. Now pass a current from an electrode A in the medium to another B infinitely distant. We take the potential of electrode A to be some value $V_A = V$, and that of electrode B to be zero, $V_B = 0$. The current will flow radially (Fig. 19.2), and generate spherical equipotential surfaces with electrode A at their centre. A third electrode M placed near A will lie on one of these equipotential surfaces, whose radius is r . If we connect electrode M to electrode B through a potential measuring device (voltmeter), it will show the value of the potential on the equipotential surface that passes through M, V_M . The resistivity of the material between A and M is the calculated as:

$$R = 4\rho r \frac{(V_A - V_M)}{I} = 4\rho r \frac{\Delta V}{I} \tag{19.1}$$

Here: $\Delta V =$ the potential difference between A and M, the factor $4\rho r$ is defined by the geometry of the system (spherical symmetry), and it is assumed that A and M are close enough together for the current I to be constant, even though it is spreading out with distance.

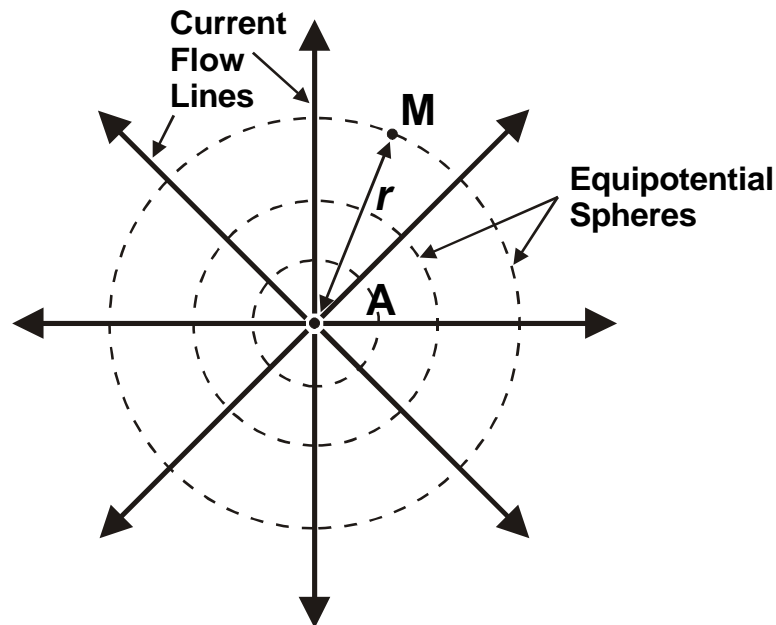


Fig. 19.2 Current flow in an homogeneous isotropic medium.

Different types of resistivity tool have different geometrical factors that depend on their electrode arrangements. These are calculated theoretically, and checked in tool calibration.

This theoretical scenario is the basis for the original tools: what are called the *normal* logging devices. The distance $AM = r$ is called the *spacing*. Two spacings were commonly used, a *short normal spacing* equal to 16 inches, and a *long normal spacing* equal to 64 inches. The longer the spacing, the greater the depth of penetration of the current into the formation, but the lower its vertical resolution.

Although the theory is developed for 3 electrodes, and this is how the first measurements were made, a four electrode arrangement soon became standard. This allows the current flow circuit (the generator circuit in Fig. 19.3) to be separated from the potential sensing circuit (the meter circuit in Fig. 19.3), which provides better quality results. In this arrangement a constant known current is flowed from A to B (or B to A), and the potential is measured between M and N. Electrode B and N are kept at a long

distance from electrodes A and M to provide quasi-infinite reference points for the current and potential measurements.

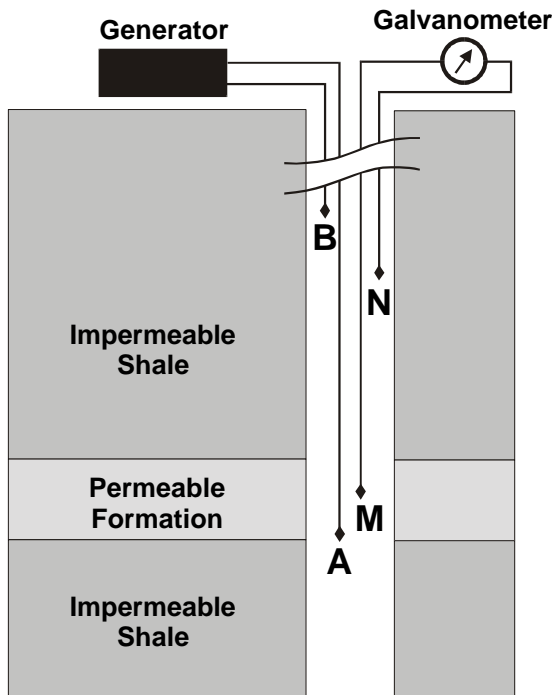


Fig. 19.3 The standard normal configuration.

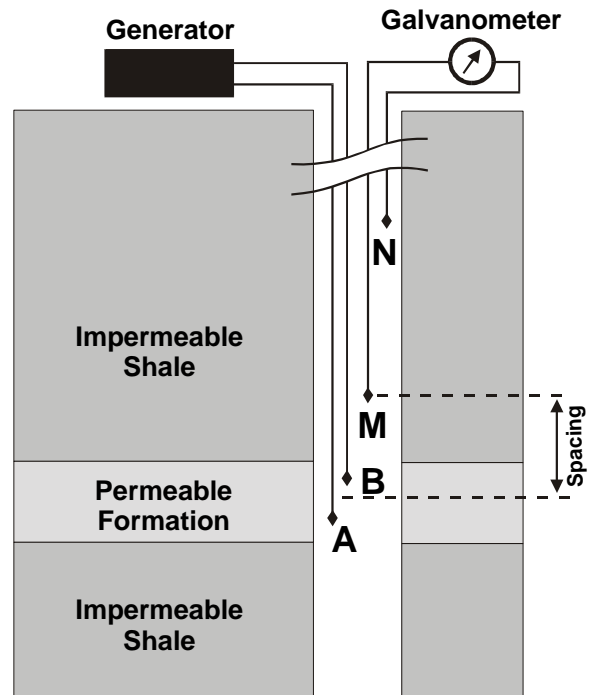


Fig. 19.4 The standard lateral configuration.

Another arrangement is possible, where electrodes A and B are placed close together with respect to the distance between A and M. This is shown in Fig. 19.4, and was called the *lateral configuration*.

19.5 Modern Resistivity Logs (Laterologs)

19.5.1 The Basic Laterologs

Figure 19.5 shows two of the earlier laterologs. Each have a number of electrodes. The LL3 has 3 current emitting electrodes. The middle one, which is 1 foot long emits the main current, while the 5 foot long electrodes either side of it emit a current that is designed to help keep the central current more focussed. This is called a *bucking current* and the electrodes are called *guard electrodes*. In this simple tool the bucking current is the same as that from the central electrode, and the potential of the central electrode is measured relative to the potential at infinity to give a potential difference. This potential difference and the known current from the central electrode are used to calculate the formation resistivity, using a known geometrical factor for the arrangement. The vertical resolution of the LL3 is 1 ft.

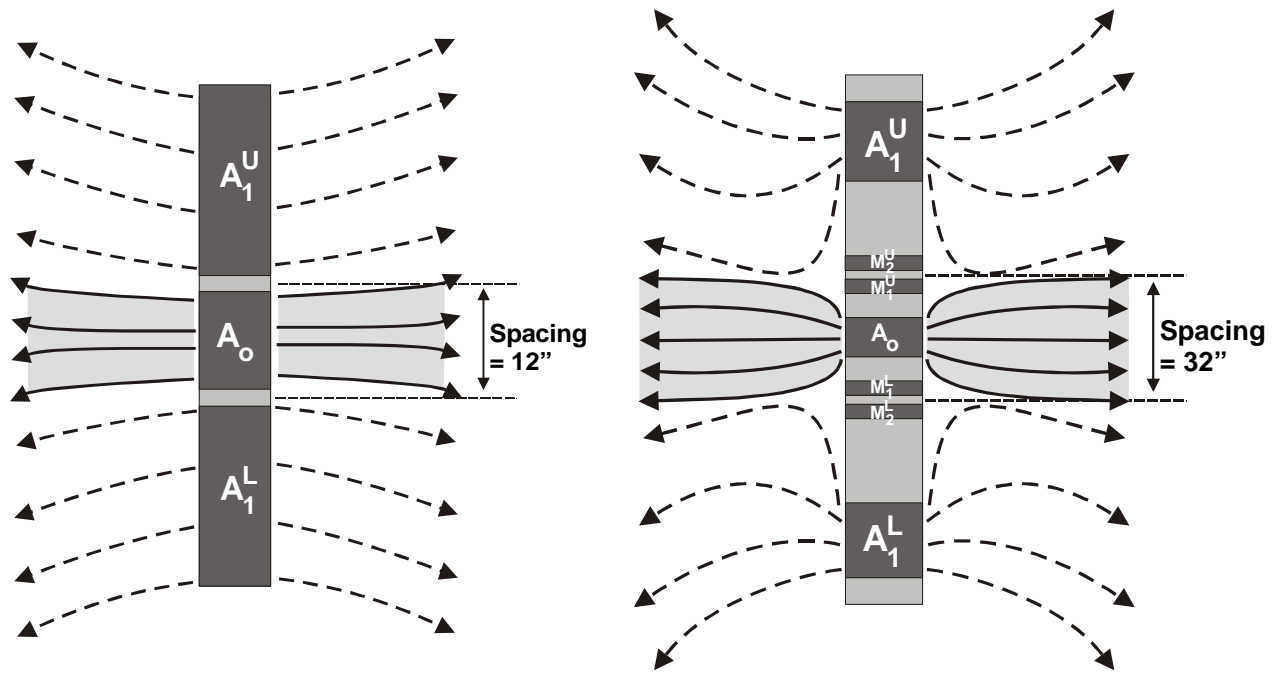


Fig. 19.5 The LL3 and LL7 tool electrode configurations.

The LL7 has 7 electrodes. A constant current is emitted from the centre electrode. A bucking current is emitted from the two far electrodes (80 inches apart), and is automatically adjusted such that the two pairs of monitoring electrodes are brought to the same potential difference. Then the current from the central electrode is focussed in a thin disk far out into the formation. The potential between one of the monitoring electrodes and the potential at infinity is then measured, and knowing the current from the central electrode allows the formation resistivity to be calculated providing the geometrical factor of the arrangement is known (calculated theoretically and tested in the calibration of the device). This electrode arrangement produces a thin disk of current that is confined between the two sets of measuring electrodes (32 inches apart). The strongly focussed beam is little affected by hole size, penetrates the invaded zone, and measures the resistivity of the virgin formation, R_t . The vertical resolution of the LL7 is 3 ft. and the sensitivity is 0.2 to 20,000 Ωm .

The LL8 is similar to the LL7, but has the current return electrode (which is not shown in Fig. 19.4 for the LL7 and LL3 because it is too far away) closer to the current emitting electrodes. This gives a current disk that does not penetrate as far into the formation before returning to the return electrode, and consequently the tool measures R_{XO} rather than R_t . The vertical resolution of the LL8 is about 1 ft and the sensitivity is 0.2 to 20,000 Ωm ..

Corrections for all of these tools for borehole size, effect of invasion and thin beds are available in the form of charts from the logging companies. However, the first two of these corrections are usually minor.

19.5.2 The Dual Laterolog

The *dual laterolog* (DLL) is the latest version of the laterolog. As its name implies, it is a combination of two tools, and can be run in a deep penetration (LLd) and shallow penetration (LLs) mode. These

are now commonly run simultaneously and together with an additional very shallow penetration device. The tool has 9 electrodes, whose operation are shown in Fig. 19.6.

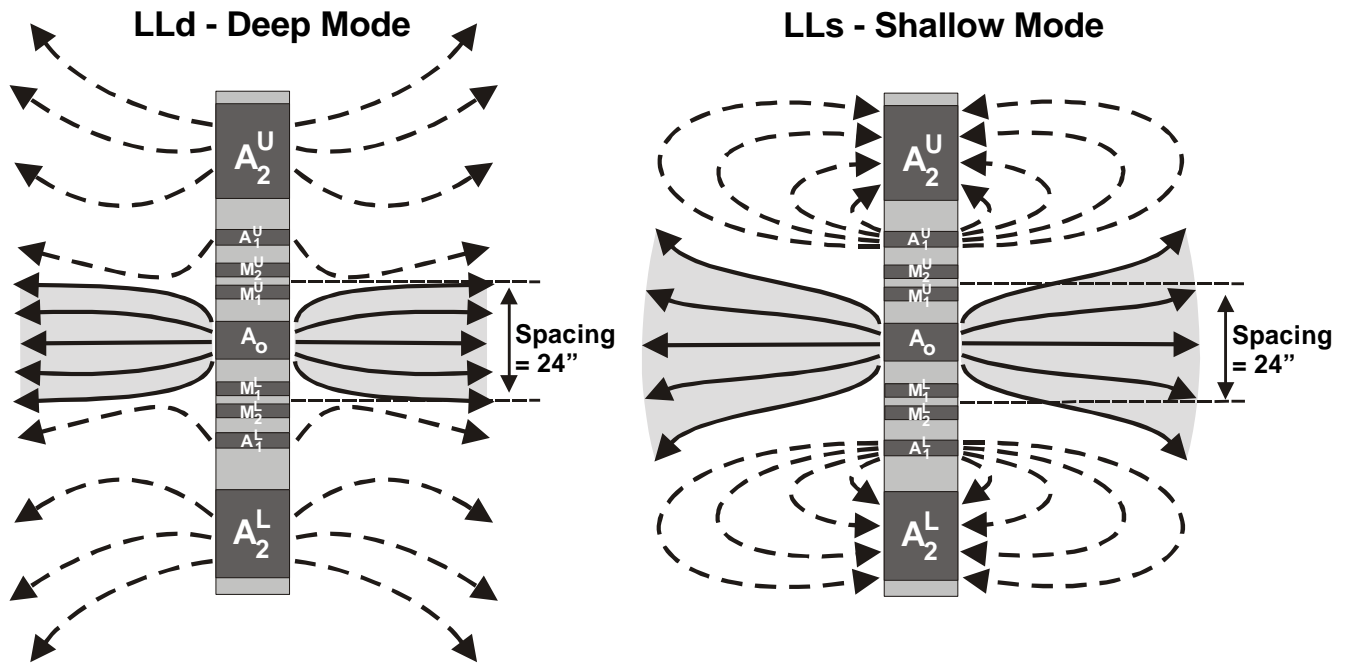


Fig. 19.6 The DLL electrode configuration in both the LLD and LLs modes.

In the LLD mode, the tool operates just like a LL7 tool but with the same bucking currents that are emitted from the A_1 electrodes also being emitted from the additional farthest electrodes, A_2 . The result of this is to focus the current from the central electrode even more than was the case for the LL7.

In the LLs mode, the A_1 electrodes emit a bucking current as they did in the LL7 device, but the A_2 electrodes are set to sink this current (i.e., the bucking current comes out of A_1 and into A_2 electrodes). This means that the bucking current must veer away from the pathway into the formation, and back towards the tool A_2 electrodes, and hence cannot constrain (focus) the current being emitted from the central electrode as much. The overall result is that the central electrode current penetrates less far into the formation before it dies away.

Both modes of the dual laterolog have a bed resolution of 2 feet, and a sensitivity of 0.2 to 20,000 Ωm . To achieve this sensitivity both the current and voltage are varied during the measurement, keeping their product (the power) constant.

The dual laterolog is equipped with centralizers to reduce the borehole effect on the LLs. A micro-resistivity device, usually the MSFL, is mounted on one of the four pads of the lower of the two centralists. Hence, this tool combination examines the resistivity of the formation at three depths of penetration (deep, shallow, and very shallow).

The resistivity readings from this tool can and should be corrected for borehole effects and thin beds, and invasion corrections can be applied using the three different depths of penetration. An example of dual laterolog data is shown as Fig. 19.7.

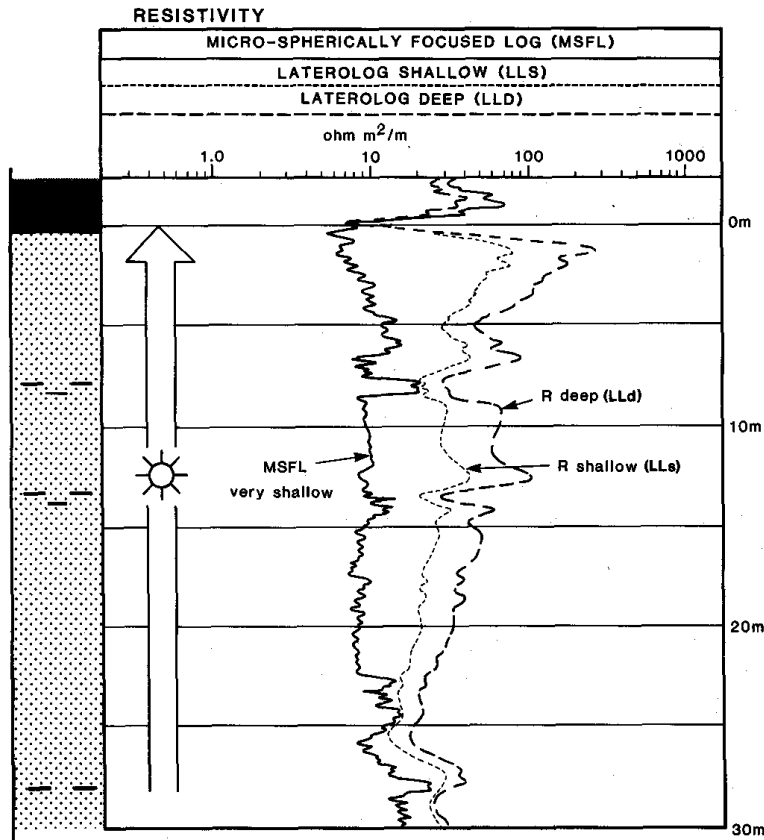


Fig. 19.7 An example of a DLL log. This shows good separation of the LLs and LLd from each other and from the MSFL, indicating the presence of a permeable formation with hydrocarbons (gas in this case in a formation of about 15% porosity). (Courtesy of Rider [1996]).

19.5.3 The Spherically Focussed Log

The *spherically focussed log* (SFL) has an electrode arrangement (Fig. 19.8) that ensures the current is focussed quasi-spherically. It is useful as it is sensitive only to the resistivity of the invaded zone.

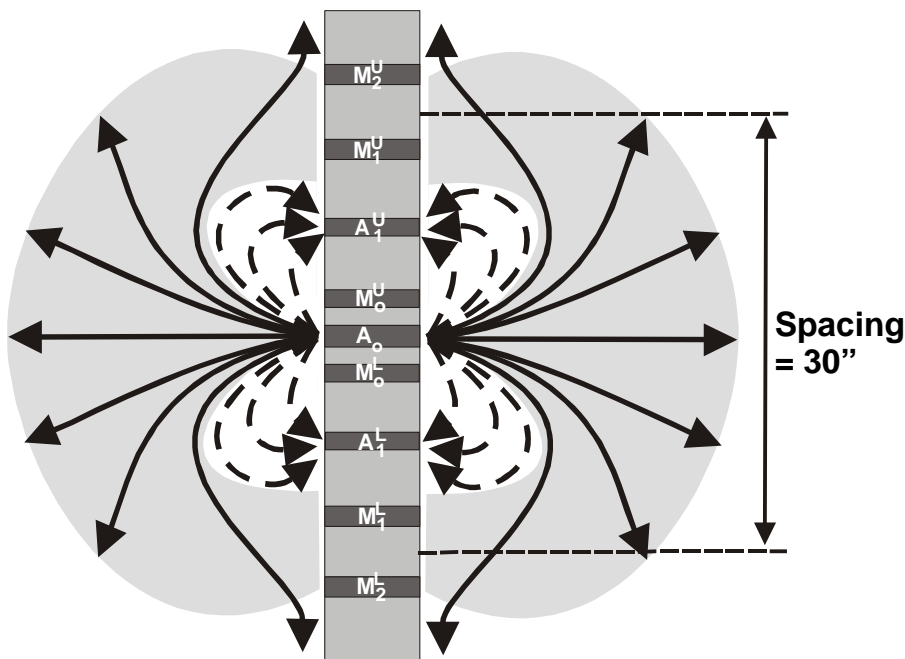
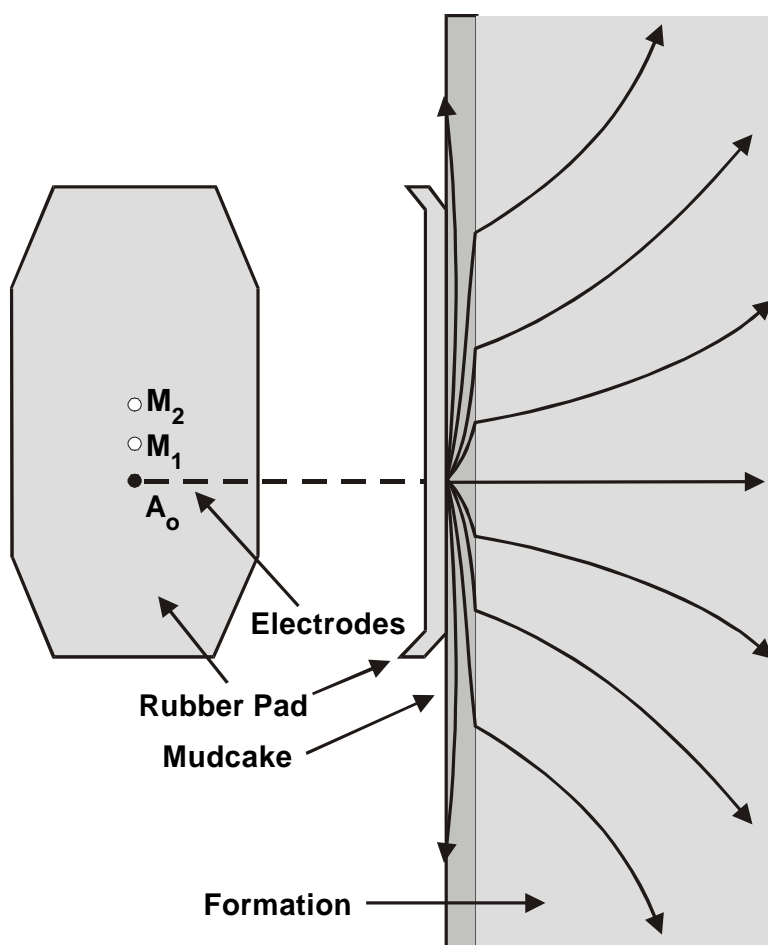


Fig. 19.8 The SFL electrode configuration.

19.6 Micro-Resistivity Logs

These are devices that often share the same sort of electrode arrangements as their larger brothers, but have electrode spacings of a few inches at most. Therefore, they penetrate the formation to a very small degree and most often do not penetrate the mudcake. They are all pad mounted devices that are pressed against the borehole wall, and often have the electrodes arranged coaxially. Combinations of these tools may be run together on the same sonde.

19.6.1 The Microlog



The *microlog* (ML) is a rubber pad with three button electrodes placed in a line with a 1 inch spacing (Fig. 19.9). A known current is emitted from electrode A, and the potential differences between electrodes M_1 and M_2 and between M_2 and a surface electrode are measured. The two resulting curves are called the 2" *normal* curve (ML) and the 1½" *inverse* curve (MIV). The radius of investigation is smaller for the second of these two curves, and hence is more affected by mudcake. The difference between the two curves is an indicator of mudcake, and hence bed boundaries. The ML tool is so good at this that it is used in making *sand counts*.

Fig. 19.9 The microlog electrode configuration.

The tool is pad mounted, and the distance across the pads is also recorded, giving an additional caliper measurement (the *micro-caliper* log). The arms of the caliper are kept in the fully collapsed state when inserting the tool into the hole. However, the microlog is recorded during this insertion to give a log of mud resistivity R_m with depth and at the BHT. Figure 19.10 shows an example of the *microlog-caliper* (MLC) showing beds clearly on both the microlog and the caliper traces.

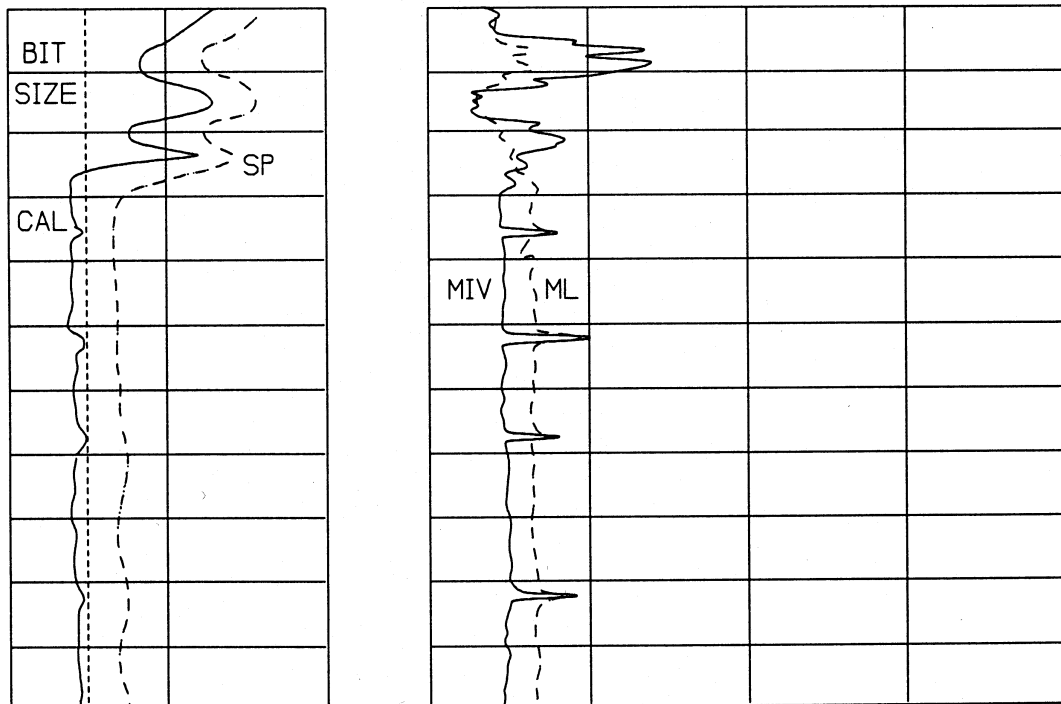


Fig. 19.10 An example of a MLC log showing mudcake from both the caliper and ML logs.

19.6.2 The Microlaterolog

The microlaterolog (MLL) is the micro-scale version of the laterolog, and hence incorporates a current focussing system. The tool is pad mounted, and has a central button electrode that emits a known measurement current surrounded coaxially by two ring-shaped monitoring electrodes, and a ring-shaped guard electrode that produces a bucking current as in the DLL (Fig. 19.11). The spacing between electrodes is about 1 inch.

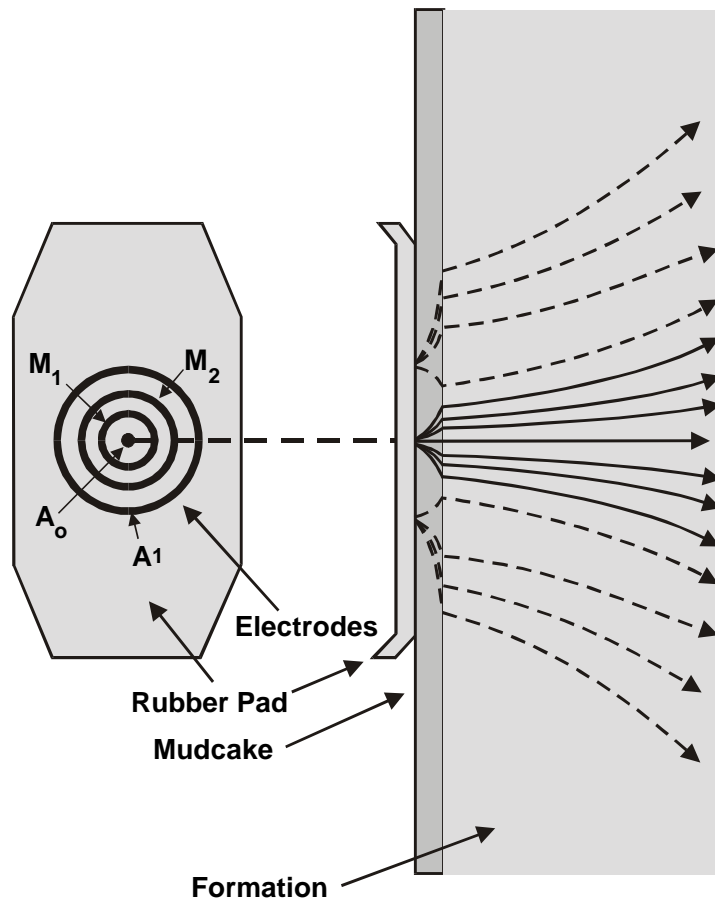
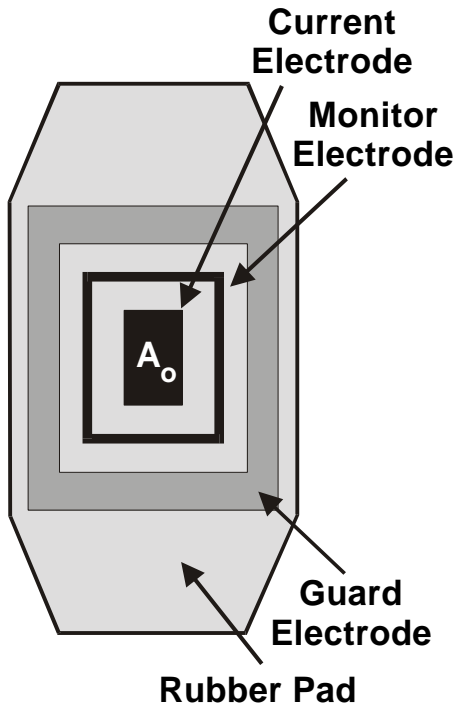


Fig. 19.11 The MLL electrode configuration.

The tool operates in the same way as the LL7. The focussed current beam that is produced from the central electrode has a diameter of about 1½ inches and penetrates directly into the formation. The influence of mudcake is negligible for mudcakes less than 3/8” thick, and in these conditions R_{XO} can be measured. The depth of investigation of the MLL is about 4 inches.

19.6.3 The Proximity Log



The *proximity log* (PL) was developed from the MLL to overcome problems with mudcakes over 3/8” thick, and is used to measure R_{XO} . The device is similar, except that it is larger than the MLL and the functions of the central electrode and the first monitoring ring electrode are combined into a central button electrode. The device has a coaxial oblong shape (Fig. 19.12). The tool operates in a similar fashion to the LL3. It has a depth of penetration of 1½ ft., and is not affected by mudcake. It may, however, be affected by R_i when the invasion depth is small.

Fig. 19.12 The PL electrode configuration.

19.6.4 The Micro Spherically Focussed Log

The *micro spherically focussed log* (MSFL) is commonly run with the DLL on one of its stabilizing pads for the purpose of measuring R_{XO} . It is based on the premise that the best resistivity data is obtained when the current flow is spherical around the current emitting electrode (isotropic conditions). The tool consists of coaxial oblong electrodes around a central current emitting button electrode (Fig. 19.13).

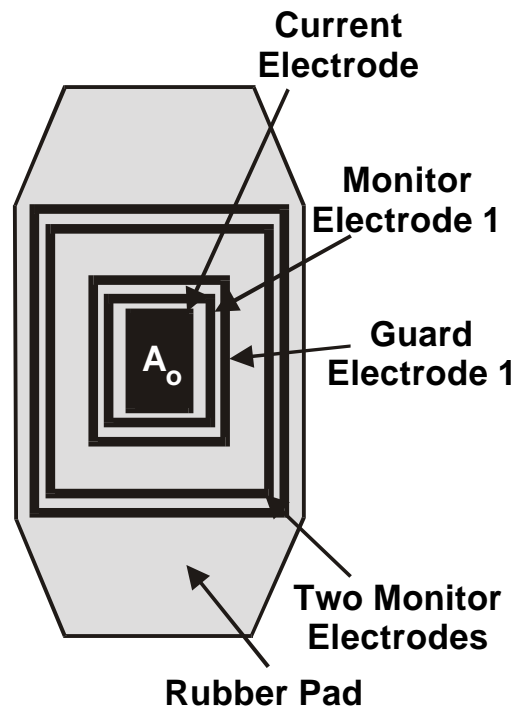


Fig. 19.13 The MSFL electrode configuration.

The current beam emitted by this device is initially very narrow (1"), but rapidly diverges. It has a depth of penetration of about 4" (similar to the MLL). The initial narrowness of the current beam means that its sensitivity to mudcake is somewhere between the MLL and the PL, and is not significantly affected by mudcake less than $\frac{3}{4}$ " thick.

19.7 Induction Logs

These logs were originally designed for use in boreholes where the drilling fluid was very resistive (oil-based muds or even gas). It can, however, be used reasonably also in water-based muds of high salinity, but has found its greatest use in wells drilled with fresh water-based muds.

The sonde consists of 2 wire coils, a transmitter (Tx) and a receiver (Rx). High frequency alternating current (20 kHz) of constant amplitude is applied to the transmitter coil. This gives rise to an alternating magnetic field around the sonde that induces *secondary currents* in the formation. These currents flow in coaxial loops around the sonde, and in turn create their own alternating magnetic field, which induces currents in the receiver coil of the sonde (Fig. 19.14). The received signal is measured, and its size is proportional to the *conductivity* of the formation. Clearly there will be direct coupling of the transmitter coil and the receiver coil signals. This is removed by additional coils, which also serve to improve the vertical and depth of penetration focussing of the tool.

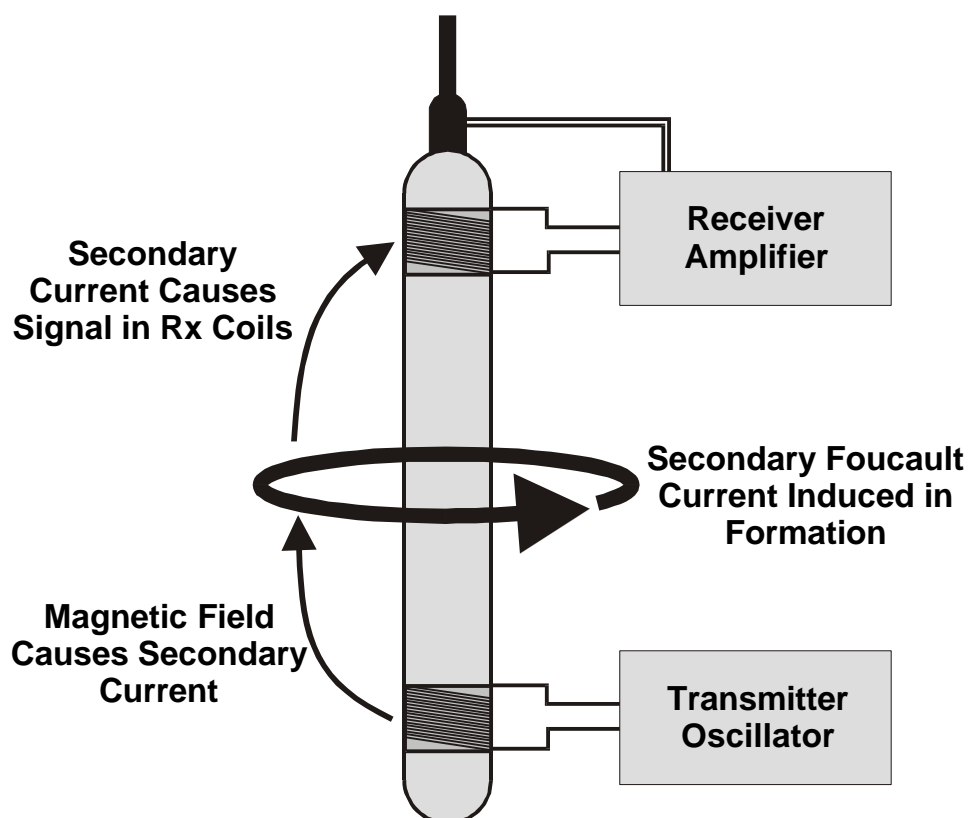
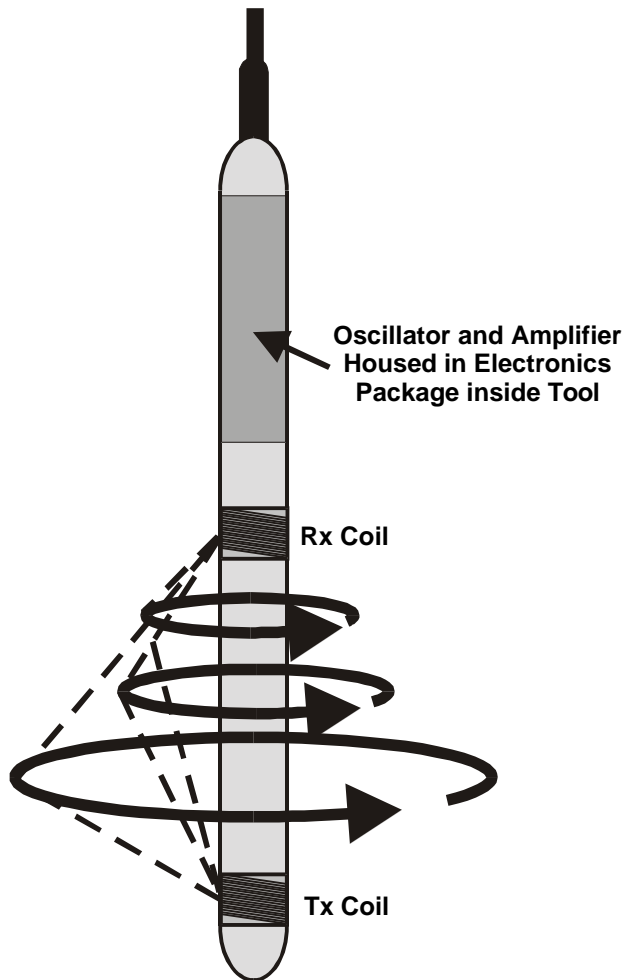


Fig. 19.14 The mode of operation of induction tools.

The intensity of the secondary currents generated in the formation depends upon the location in the formation relative to the transmitter and receiver coils. Hence there is a spatially varying *geometrical factor* to take into account. Figure 19.15 shows two ground loops of secondary current induced by the transmitter and sensed by the receiver. The actual signal recorded by the receiver will be the sum of all ground loops in the space investigated by the tool. Figure 19.16 shows the sensitivity map for this space for a homogeneous medium, showing that 50% of the total signal comes from close to the tool (borehole and invaded zone) between the transmitter and the receiver.

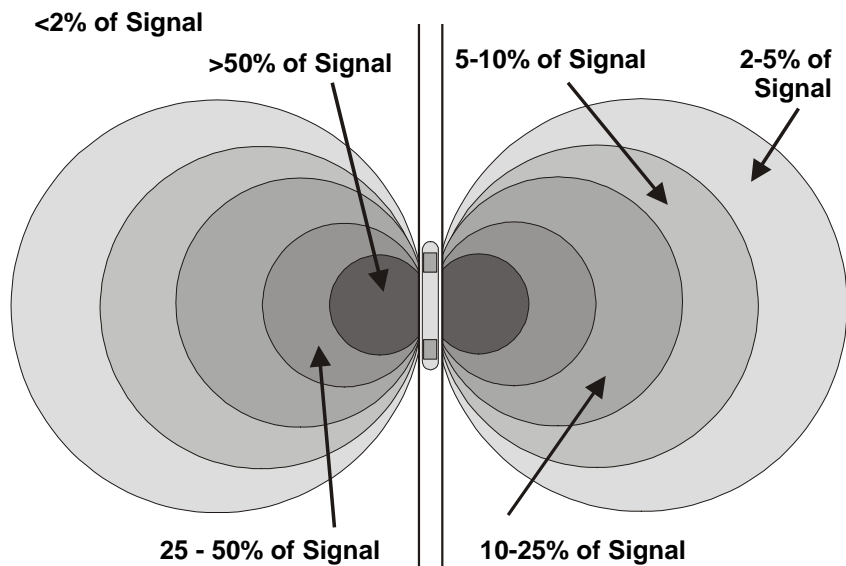


The *skin effect* is a problem that occurs with very conductive formations which results in the reduction of the signal. This is automatically corrected for during the logging run.

Induction logs are calibrated at the wellsite in air (zero conductivity) and using a 400 mS test loop that is placed around the sonde. The calibration is subsequently checked in the well opposite zero conductivity formations (e.g., anhydrite), if available.

Fig. 19.15 The integration of ground loop data in the construction of the received induction signal.

Fig. 19.16 Sensitivity map for induction tools.



The following tools are in common use today.

19.7.1 The 6FF40 Induction-Electrical Survey Log

The 6FF40 induction-electrical survey log (IES-40) is a 6 coil device with a nominal 40 inch Tx-Rx distance, a 16 inch short normal device and an SP electrode. An example of its data is given as Fig. 19.17.

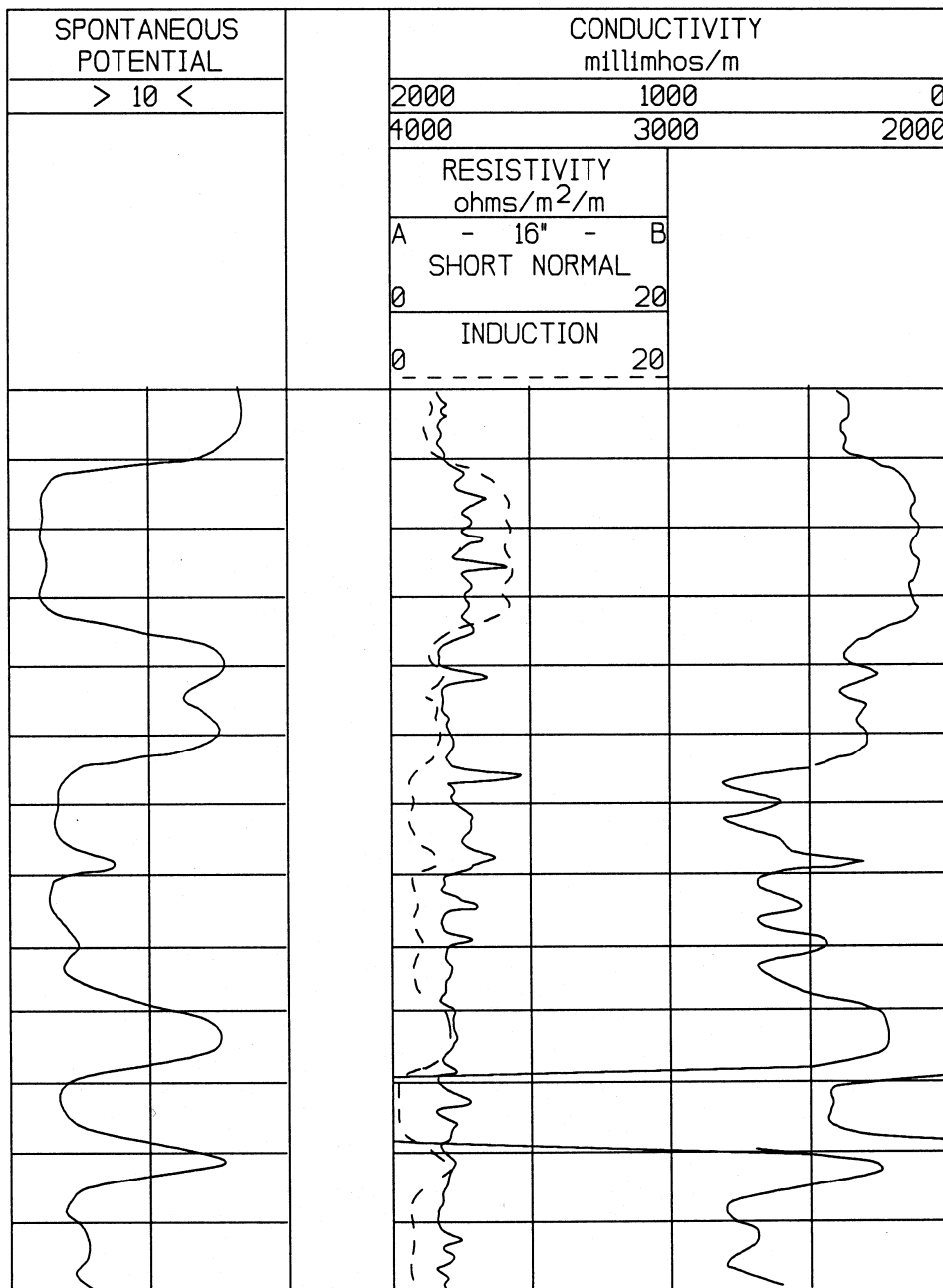


Fig. 19.17 An example of 6FF40 (IES-40) log data.

19.7.2 The 6FF28 Induction-Electrical Survey Log

The 6FF28 induction-electrical survey log (IES-28) is a smaller scale version of the IES-40. It is a 6 coil device with a nominal 28 inch Tx-Rx distance, a 16 inch short normal device and an SP electrode.

19.7.3 The Dual Induction-Laterolog

The dual induction laterolog (DIL) has several parts: (i) a deep penetrating induction log (ILd) that is similar to the IES-40, (ii) a medium penetration induction log (ILm), a shallow investigation laterolog (LLs) and an SP electrode. The ILm has a vertical resolution about the same as the ILd (and the IES-40), but about half the penetration depth. An example of its data is given as Fig. 19.18.

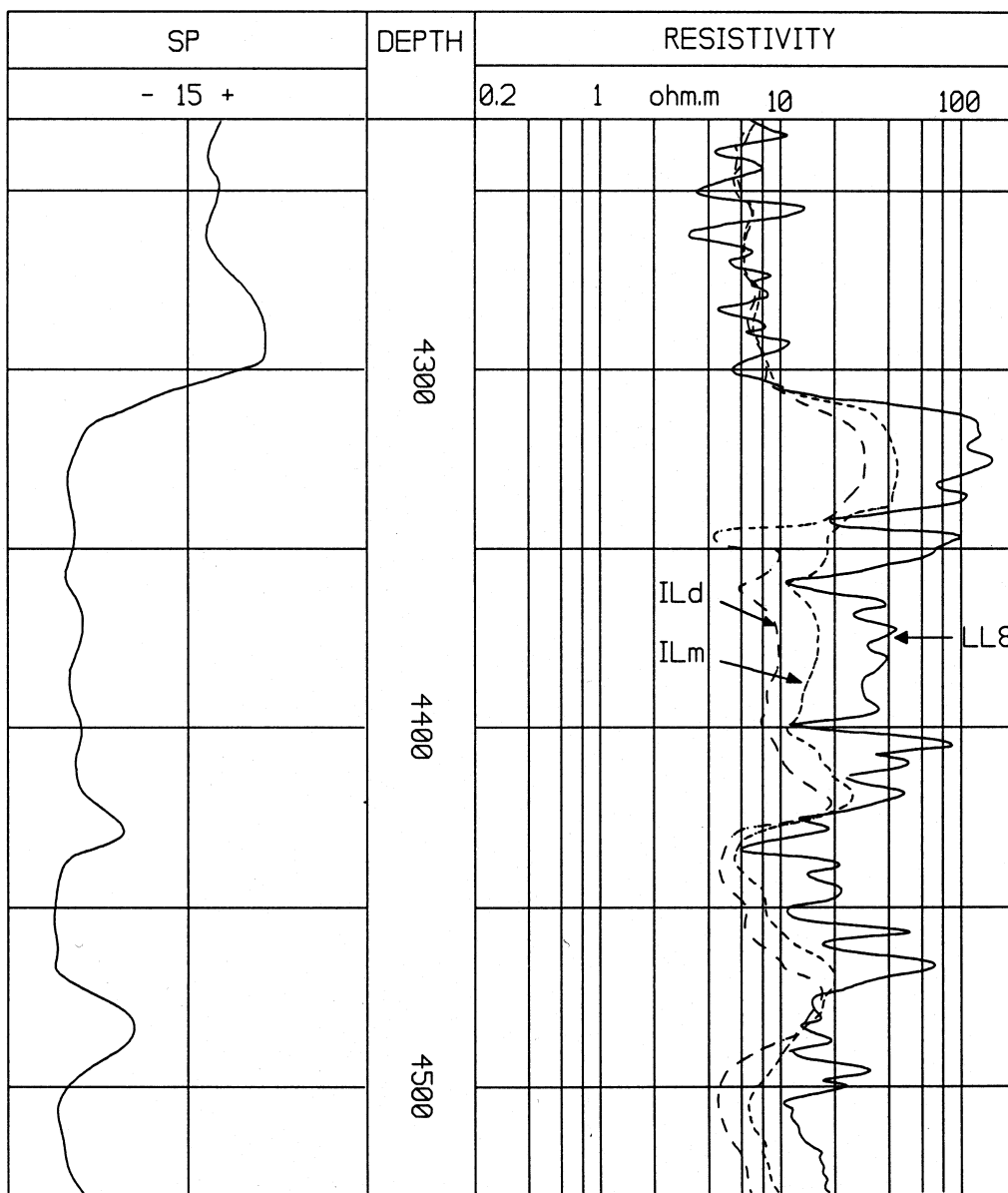


Fig. 19.18 An example of DLL log data.

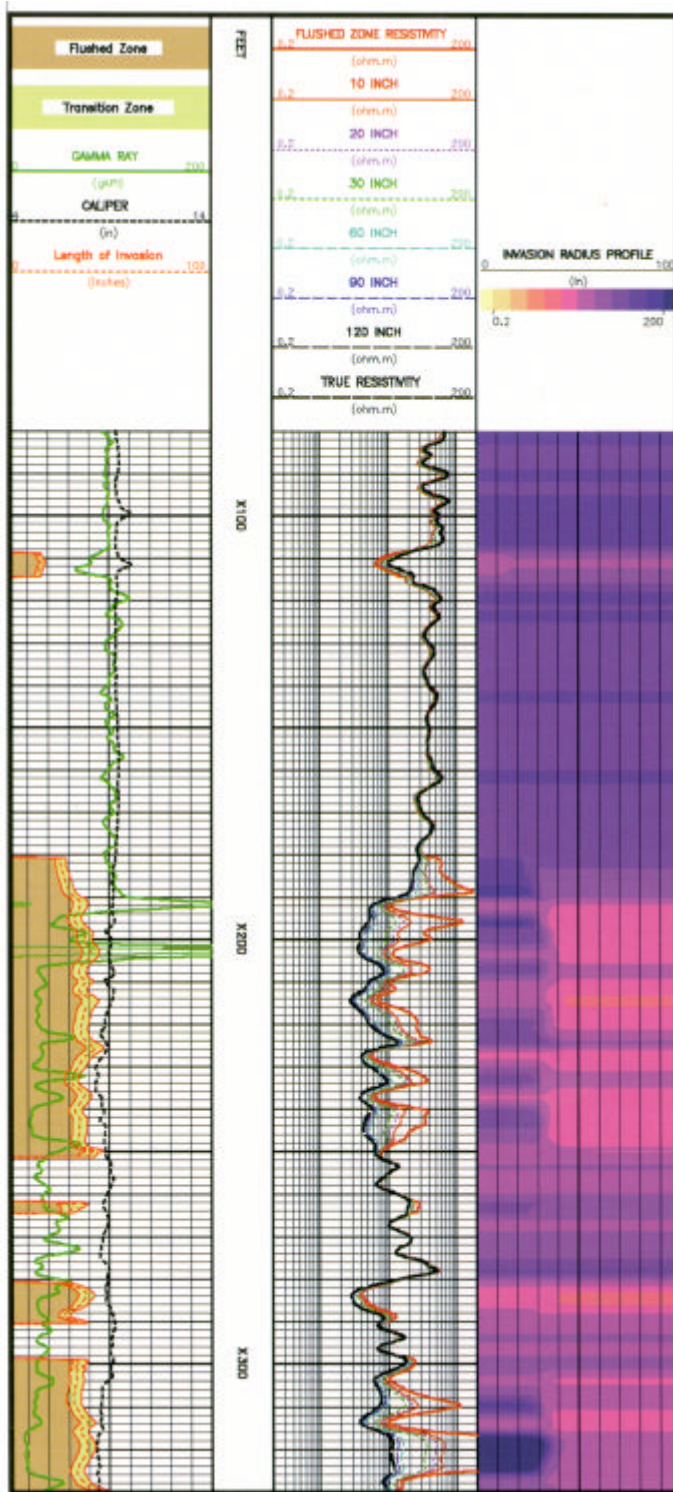


Fig. 19.19 An example of array induction log (HDIL) showing curves for different penetration depths as well as the calculated invasion profiles and extent of the flushed and transition zones in permeable beds (courtesy of Baker Atlas Ltd).

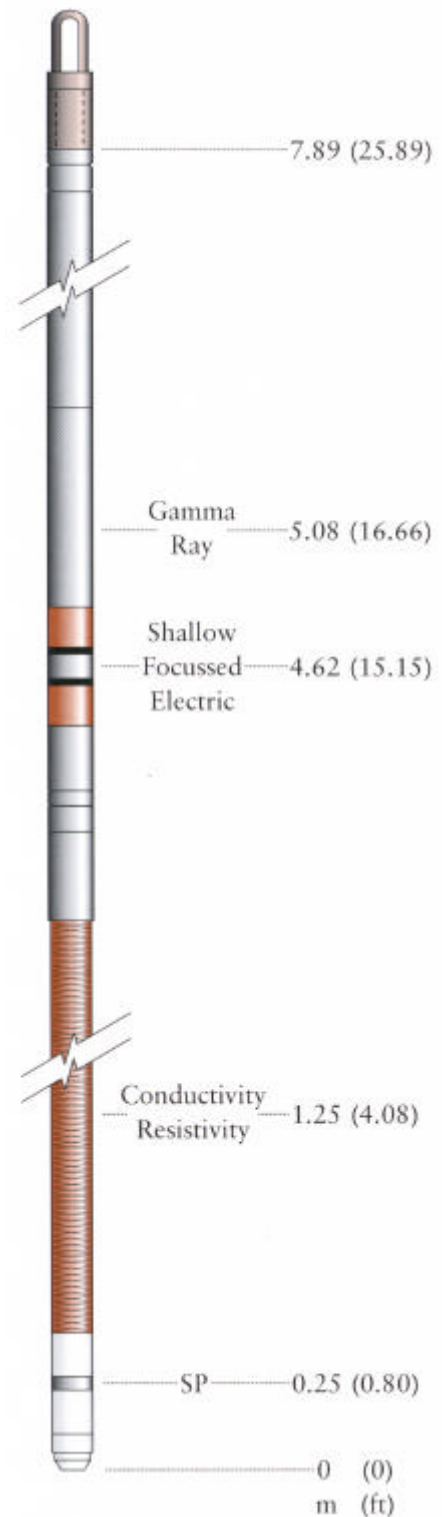


Fig. 19.20 The Array Induction data Sonde (AIS) of BPB Wireline Technologies Ltd. (BPB Wireline Technologies Ltd.).

19.7.4 The Induction Spherically Focussed Log

The induction spherically focussed log (ISF) combines (i) a IES-40, (ii) a SFL, and (iii) an SP electrode. It is often run in combination with a sonic log.

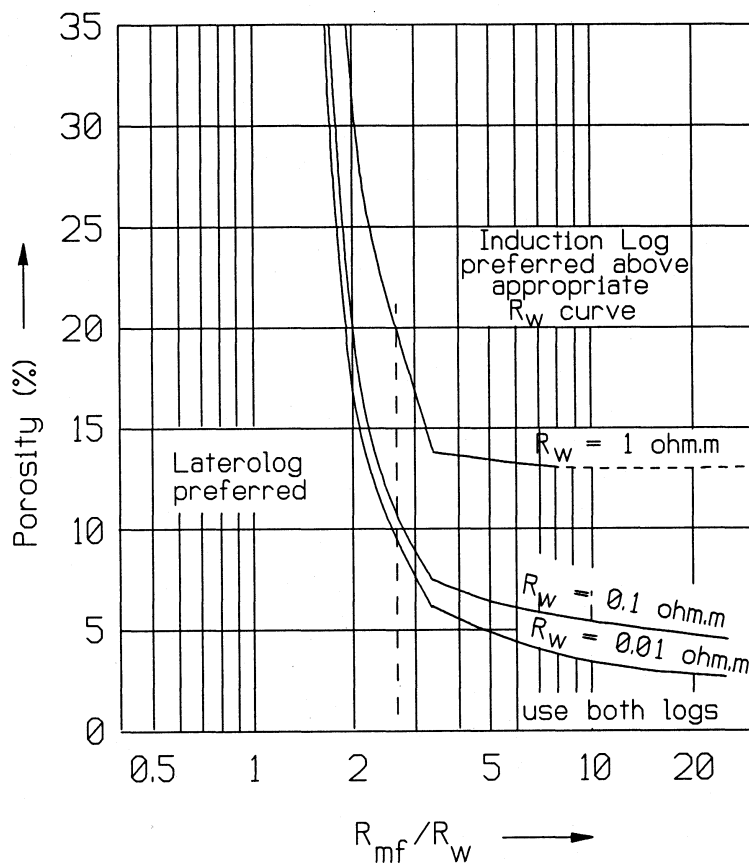
19.7.5 Array Induction Tools

The newest logs are array induction logs (AIS, HDIL). It consists of one Tx and four Rx coils. Intensive mathematical reconstruction of the signal enables the resistivity at a range of penetration depths to be calculated, which allows the complete invasion profile to be mapped. An example of array induction tool data is given as Fig. 19.19, while Fig. 19.20 shows a typical tool.

19.8 Comparing Laterologs and Induction Logs

At first sight it seems that induction logs and laterologs are complimentary:

- Induction logs provide conductivity (that can be converted to resistivity).
- Laterologs provide resistivity (that can be converted to conductivity).
- Induction logs work best in wells with low conductivity fluids.
- Laterologs work best in wells with low resistivity fluids.
- Both logs provide a range of depths of penetrations and vertical resolutions.



The decision to use one or the other depends upon the value of R_f/R_{XO} ratio, with the cut-off made at about 2.5 (Fig. 19.21).

Fig. 19.21 Chart showing the optimal tools to use as a function of R_w , R_{mf} and porosity.

19.9 Bed Resolution

The smaller the electrode spacing, the better the vertical and bed resolution. This is shown in Fig. 19.22. One should chose the tool for the purpose required, and this is related also to investigation depth. This is discussed further in the following section.

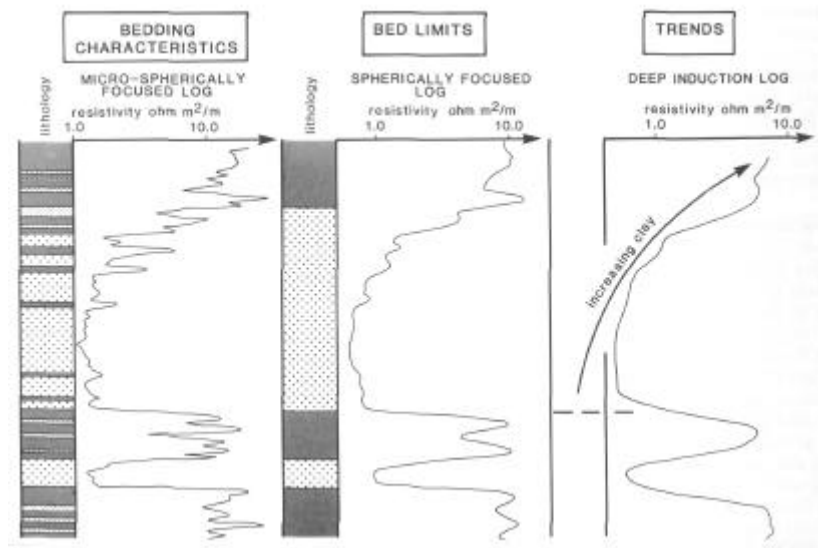


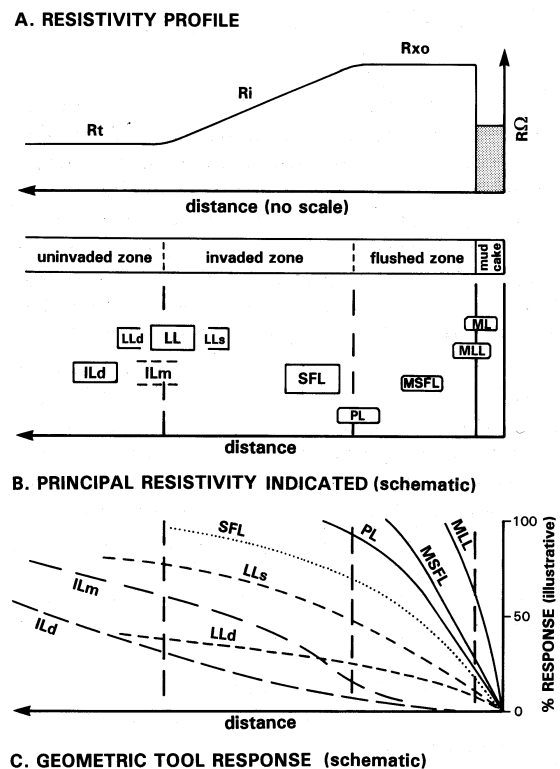
Fig. 19.22 Differences in bed resolution from different electrical tools (courtesy of Rider [1996]).

19.10 Investigation Depth

Figure 19.23 summarizes the depths of investigation of the various tools, and Table 19.1 summarizes the resistivity values commonly measured.

In general, the tool to use is that best suited for the purpose. If gross changes are needed, such as in certain types of correlation and shale compaction trends, the deeper looking tools should be used. If characteristics and values from formations which are relatively thin are needed, then a shallower looking tool with a better resolution should be used.

Fig. 19.23 Summary of the different depths of investigation for different electrical tools (courtesy of Rider [1996]).



Fine bed structure requires very shallow reading tools in order to obtain sufficient bed resolution. Changes in formation microstructure (texture) are best seen on logs that measure the invaded zone. This is because the texture of the rock is a significant parameter controlling the replacement efficiency of the formation fluids with the mud filtrate, and hence changes in the texture have a large effect on the degree of invasion, that is picked up by these medium depth penetration logs.

Table 19.1 Electrical tool penetration and resistivity measurements.

Tool	Mnemonic	Type	Commonly Measured	Possibly Measured
Laterolog3	LL3	Borehole	R_t	R_t
Laterolog7	LL7	Borehole	R_t	-
Dual Laterolog – deep	DLL-LLd	Borehole	R_t	-
Dual Laterolog – shallow	DLL-LLs	Borehole	R_t	R_t
Spherically Focussed Log	SFL	Borehole	R_i	R_t
Microlog - normal	ML	Pad	R_{mc}	R_{XO}
Microlog - inverse	MIV	Pad	R_{mc}	R_{XO}
Microlaterolog	MLL	Pad	R_{XO}	R_{mc}
Proximity Log	PL	Pad	R_{XO}	R_i
Micro Spherically Focussed Log	MSFL	Pad	R_{XO}	-
IES-40	IES-40	Borehole	R_t	-
IES-28	IES-28	Borehole	R_t	R_t
Dual Induction Log – deep	DIL-ILd	Borehole	R_t	-
Dual Induction Log - medium	DIL-ILm	Borehole	R_t	R_t
Induction Spherically Focussed Log	ISF	Borehole	R_t	-
Array Induction Tool	AIS, HDIL	Borehole	R_i to R_t	N/A

19.11 Log Presentation

Resistivity logs are presented in Track 2 or in Tracks 2 and 3 combined on a log scale. The units are Ωm , and sensitivity scales of 0.2-20 Ωm (3 log cycles) all the way up to 0.2 to 20,000 Ωm (6 log cycles) can be used. The scales are usually narrower if only Track 2 is used (e.g., 0.2-20 Ωm). A combination of deep, medium and shallow logs is usually available in the same track on the same scales so that a direct comparison can be made. It is possible to have data from both resistivity-type and induction-type tools shown together, and in this case it is usual to convert the conductivity readings from the induction devices to resistivities for display (although the opposite is also possible (converting resistivities to conductivities for display) it is rarely seen). If the conductivity from induction-type logs is displayed, the units are millimho per metre (mmho/m) and the scale is usually 0 – 2000 mmho/m (note the SI equivalent of mmho/m is millisiemens per metre, mS/m). The ML log is usually plotted in Track 2 over a range of 0 – 10 Ωm for both the micro-normal and micro-inverse curve. Array logs generally have six or seven curves, presented in terms of resistivity over an appropriate log scale. Figure 19.24 shows some typical log presentations for electrical logs.

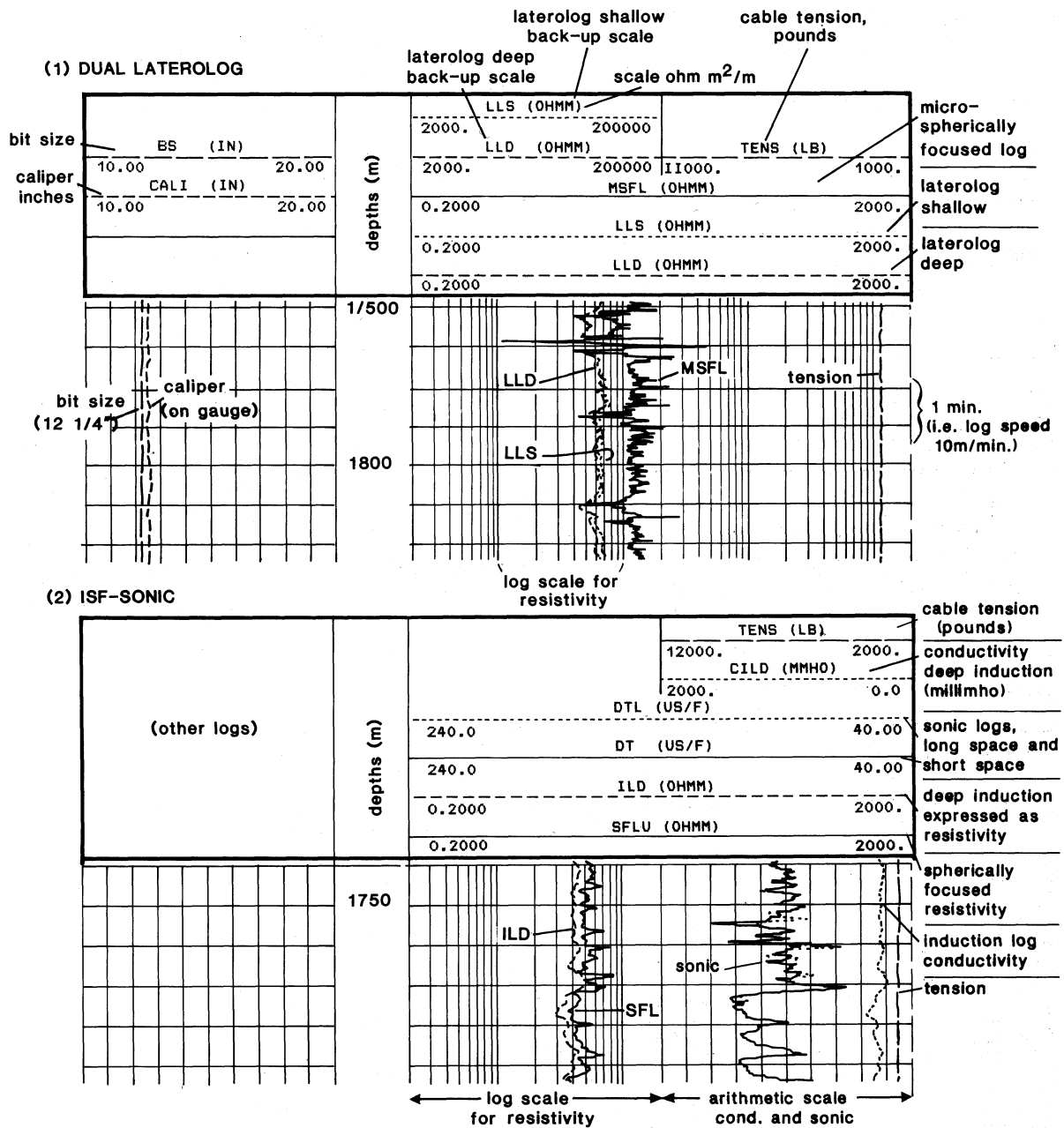


Fig. 19.24 The presentation of electrical logs (courtesy of Rider [1996]).

19.12 Uses of Electrical Logs

19.12.1 Recognition of Hydrocarbon Zones

Recognition of oil and gas in reservoir rocks is carried out by:

- Oil shows in the mud log.
- Noting a difference in the shallow, medium and deep resistivity tool responses.

Figure 19.25 shows the characteristics that are being looked for schematically.

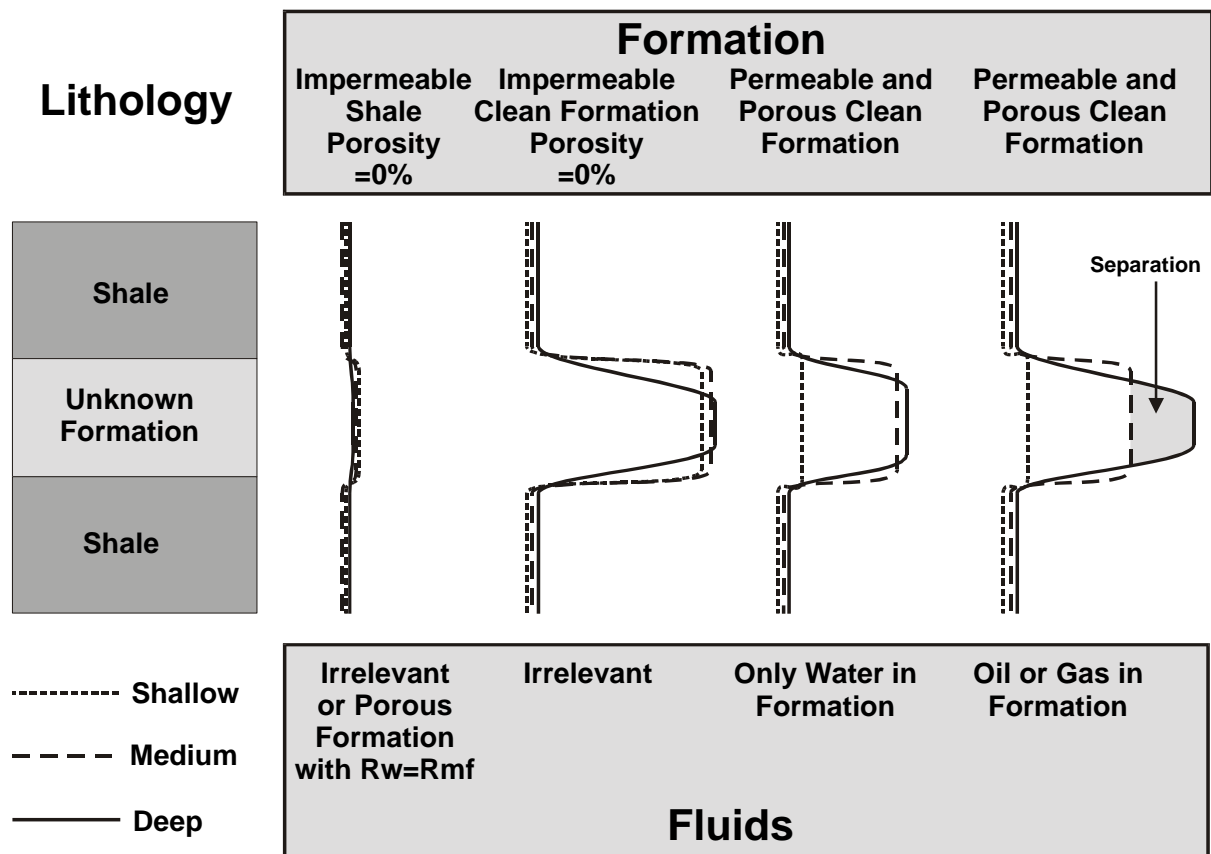


Fig. 19.25 The response of resistivity logs in formations with various fluids (recognition of hydrocarbon zones).

- If all three curves are low resistivity, and overlie each other, the formation is an impermeable shale, or, rarely, the formation is permeable and water-bearing but the mud filtrate has the same resistivity as the formation water.
- If all three curves are higher resistivity than the surrounding shales, and overlie each other, the formation is an impermeable cleaner formation (sandstone, limestone).
- If the shallow curve has low resistivity, but the medium and deep penetrating tools have a higher resistivity that is the same (they overlie each other), the formation is permeable and contains only formation water.
- If the shallow curve has low resistivity, the medium as a higher resistivity, and the deep one has an even higher resistivity (i.e., there is separation of the medium and deep tool responses), the formation is permeable and contains hydrocarbons.

Note 1: If the mud filtrate resistivity is constant, the effect is greater for formations with fresh formation waters than those for saline formation waters (Fig. 19.26), and in the case of extremely saline formation waters the deep resistivity in the formation can be smaller than that of the adjacent shale beds.

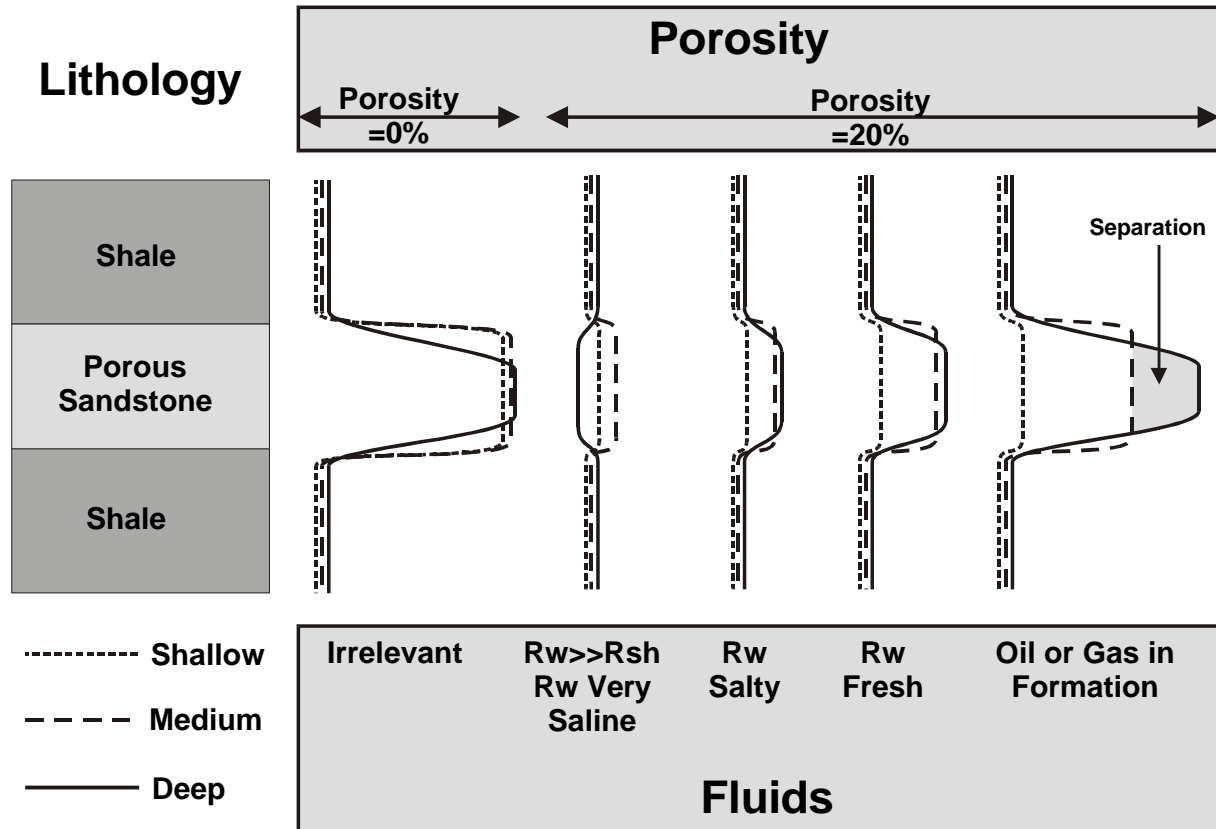


Fig. 19.26 The behaviour of the resistivity log responses for different formation water salinities.

Note that the effect is greater for oil-based drilling muds than fresh water-based muds and saline water-based muds in this order.

Some of the more advanced array type tools can now calculate the invasion profile of resistivity. An example of this is shown in Fig. 19.19, where the resistivity of the formation is shown as a function of depth into the formation in Track 3 as a colour coded map, and the interpreted flushed and transition zones are given in Track 1 for the permeable intervals.

Figures 19.25 and 19.26 are given as examples only. This is because there are too many variable parameters (mud filtrate resistivity, mudcake resistivity, formation water resistivity, water and hydrocarbon saturations, lithology and porosity etc.) to be comprehensive. In general, the best approach is to (i) see what type of tools have been used to create the logs, (ii) discover their penetration depths, (iii) discover the type of drilling mud and the resistivity of the mud filtrate used in the drilling, (iv) take account of information from other logs (caliper for mudcake, SP for permeable zones, gamma ray for shale volume, and sonic, neutron and density tools for porosity), and then interpret the resistivity curves from first principles!

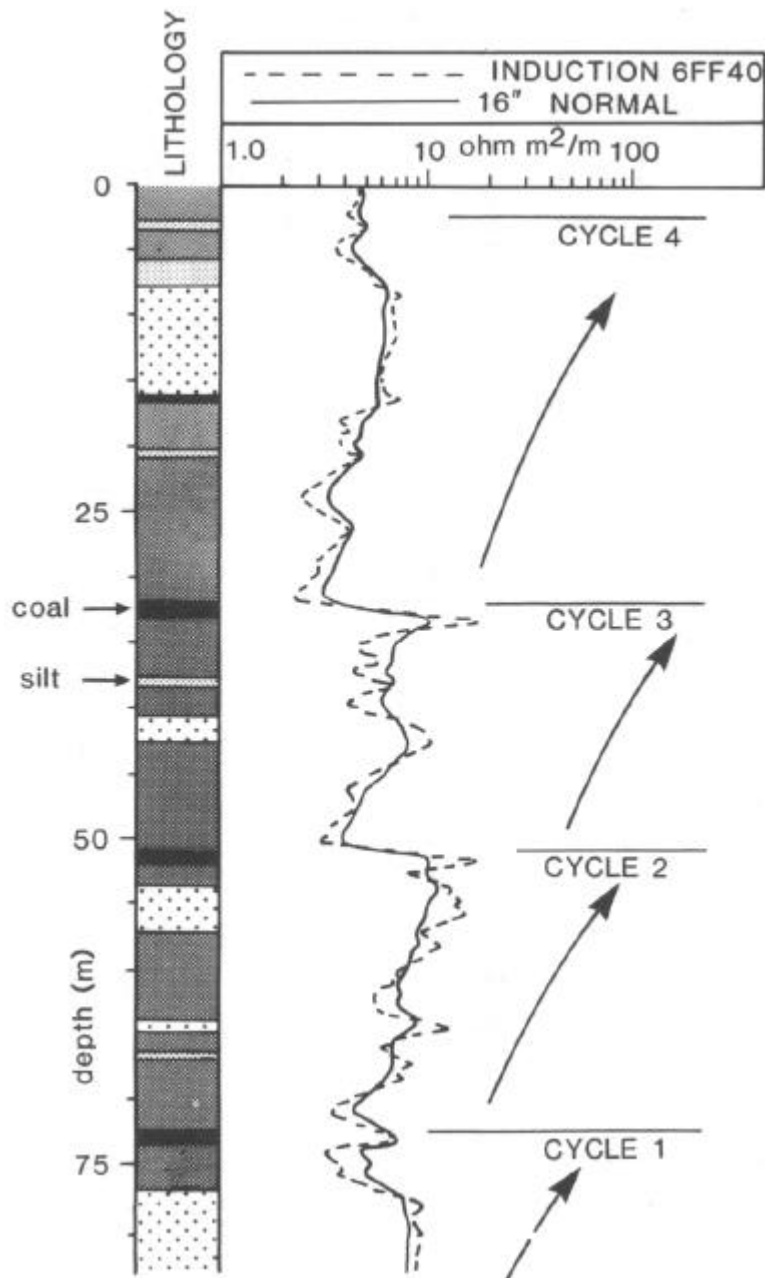
19.12.2 Calculation of Water Saturation

The theory behind the calculation of water saturation from resistivity logs was given in Chapter 17 in detail. In summary, the resistivity log values for the deep tools R_t in reservoir intervals can be used with a reliable porosity f , the formation water resistivity R_w , and m and n values that are derived from laboratory measurements on core, to calculate the water saturation in the zone. This is combined with

information about the reservoir thickness, its area and porosity, and fluid compression factors in STOOIP calculations to calculate the amount of oil in the reservoir (Chapter 1).

19.12.3 Textures and Facies Recognition

The texture of a rock has a great effect upon its electrical response, all other factors being equal. This is because the electrical flow through the rock depends upon the tortuosity of the current flow paths, which is described by the formation factor F .



However, we must always take into account the bed resolution and penetration depths of the various tools to understand how well we would expect the log to respond to changes in the log at various scales, as discussed in the sections above.

Figure 19.27 shows small scale deltaic cycles recorded by an IES-40.

The shapes electrical logs can be used to distinguish facies types as with other logs (e.g., sonic and gamma ray). These are sometimes called *electrofacies*, which are defined by Rider [1996] as “Suites of wireline log responses and characteristics sufficiently different to be able to be separated from other electrofacies.”. Note, in general the wireline logs characteristics that define a particular electrofacies will also include data from wireline logs other than electrical logs.

Fig. 19.27 Use of resistivity logs to track changes of lithofacies. In this case the log shows small scale deltaic cycles (courtesy of Rider [1996]).

19.12.4 Correlation

Electrical logs are often used for correlation. The deep logs (IES-40, ILd, LLd etc.) are the best to use, as they are sensitive to gross changes in the formations at a scale that is likely to be continuous with other wells. However, it must be noted that the resistivity of a formation also depends upon formation fluid pressure and formation water resistivity, which are non-stratigraphic variables, and changes in them from well to well may confuse correlations.

19.12.5 Lithology Recognition

Electrical logs are dramatically bad at indicating lithologies.

Sands shales and carbonates have no characteristic resistivity as their resistivities depend upon many factors including porosity, compaction, fluid resistivity, texture etc. However sequences of these rocks can usually be traced by using invariant characteristics from bed to bed, such as a similar resistivity reading as another set of beds or a characteristic roughness/smoothness of the curve within the bed. Thus if the basic lithologies can be defined from other logs, the electrical logs help progress them through the logged section. As the electrical logs are very sensitive to texture, they are extremely good at discriminating between lithologies of different types providing the types can be defined by some other log.

An example of this may include beds of shale separated by thin layers of siderite stringers and concretions. The shallow penetrating electrical tools will pick out each thin siderite bed as a sharp peak in resistivity.

However, electrical logs do provide characteristic responses for some lithologies (Fig. 19.28). The most common are:

- Gypsum – 1000 Ωm .
- Anhydrite – 10,000 - ∞ Ωm .
- Halite - 10,000 - ∞ Ωm .
- Coals – 10 – 10⁶ Ωm .
- Tight limestones and dolomites – 80 – 6000 Ωm .
- Disseminated pyrite - <1 Ωm (pyrite has a resistivity of 0.0001 – 0.1 Ωm).
- Chamosite - <10 Ωm .

19.12.6 Other Applications

Compaction of shales can be seen, as with other logs. In the case of electrical logs, the shale resistivity is seen to increase slowly but steadily in thick shale sequences. The deep tool should be used for this. Breaks in the compaction trend can then be used as indicators of unconformities and faults.

The beginning of *overpressure zones* can be seen by a sudden unexplained jump of the resistivity to lower values in a uniform lithology. This is best observed in shales and is associated with the higher porosity induced by the overpressure. Again, the best tools to use are the deep looking tools.

Source rocks may be recognized, and their maturity indicated by electrical logs. Immature sources have little effect upon electrical logs, but this effect grows with the degree of maturity. Hence, it

expected that it may be possible to calculate the TOC% from electrical logs under the correct conditions.

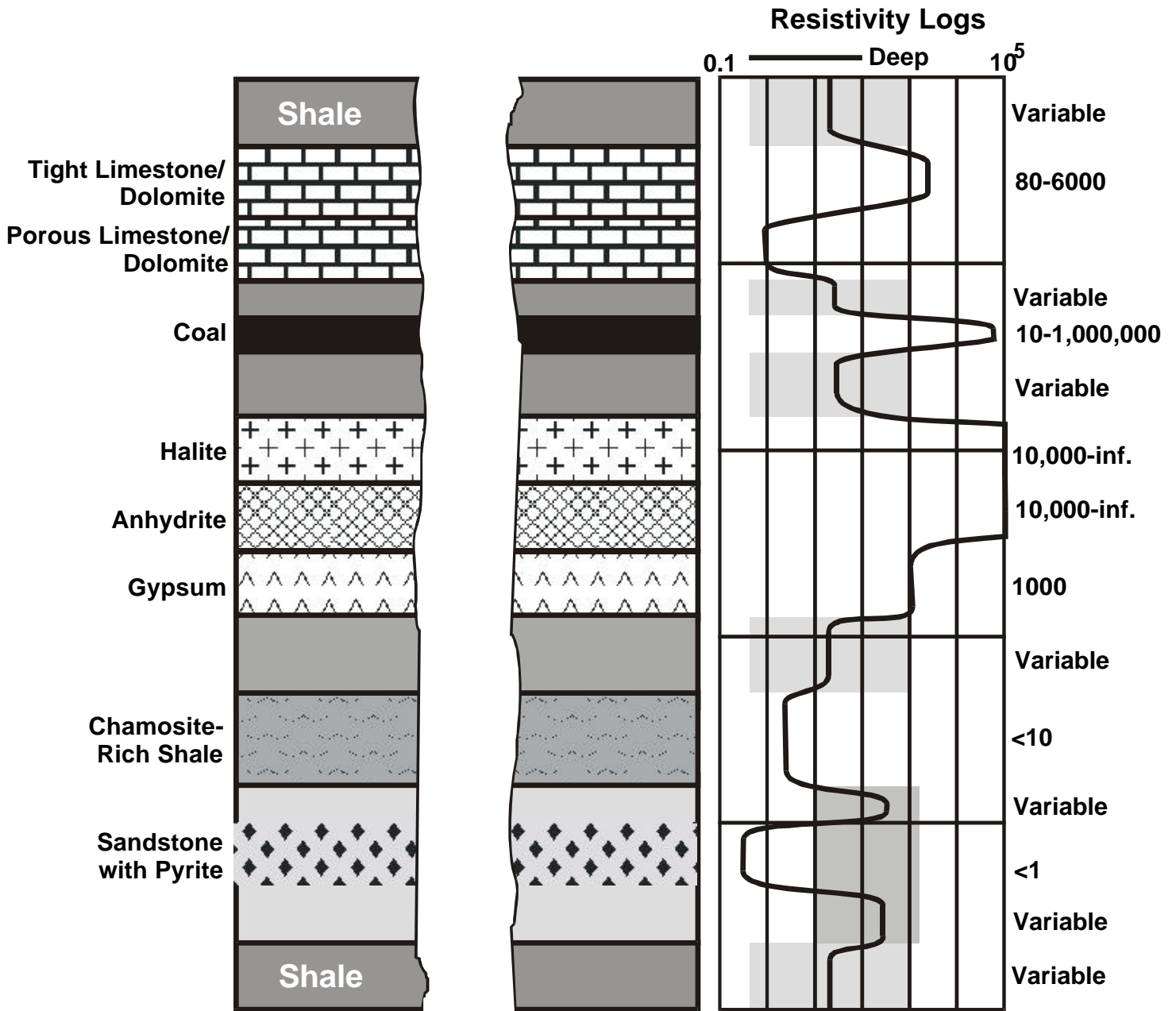


Fig. 19.28 Characteristic resistivities from various lithologies recorded by resistivity logs.