Optimum use of dual laterolog in the determination of formation resistivity

[1]Molua, O. C, [2]Ujuanbi, O, [3]Igharakpata, F. O.

[1]Physics department, College of Education, Agbor Delta state Nigeria.
[2]Physics department, Ambrose Alli University, Ekpoma Edo state Nigeria.
[3]Physics department, College of Education, Warri, Delta state Nigeria

A logging method called Dual laterolog is described which provides for better recording of formation resistivity. In this method a current is forced laterally into the formation in the shape of a thin sheet of current, by means of a special electrode arrangement and an automatic control system..By measuring the voltage needed to generate a given measuring current, the resistivity was deduced. By rapidly alternating the role of various returns, a simultaneous measurement of deep and shallow resistivity was achieved. Field example was used to illustrate the the effectiveness of this method in various types of formations.The results show that hydrocarbon saturation in the fresh water environment as in well 1 is 0.56 which is very significant in hydrocarbon exploitation.

Journal of Applied and Basic Sciences, 2005: 3(1&2): 95-104

***Keywords:** Dual Laterolog, Formation & Resistivity*

Introduction

The responses of conventional electrical Logging systems can be greatly affected by borehole and adjacent formations. These influences are minimized by a family of resistivity tools that uses focusing currents to control the path taken by the measured current. These currents are emitted from special electrodes on the Sondes[1].

A new member of this family is the dual laterolog. Actually the tool contains two devices. One of them has electrodes spaced in such a way as to push the measuring current as far away as possible and will measure the deep laterolog resistivity (lld). The other has electrodes spaced in such a way as to let the measuring current sheet open up a little, and it will measure in, the shallow laterolog resistivity (lls). Without concerning ourselves with the technology of these tools, their principles will however be discussed since many wells have been logged with these devices over the years. Two main benefits are expected from a resistivity log.

1. Obtaining geological information for mapping and other purposes, and
2. Obtaining petrophysical data, based on true rock resistivity.

The geological information can be derived from any resistivity curve having sufficient vertical detail, but true rock resistivities frequently are difficult to determine with desired accuracy because we do not have sufficient interpretation data. This is particularly true for the records given by the laterolog tools.Two major types of laterolog measuring systems which are now obsolete include LL3 and LL7. Although these tools are now obsolete, it is desirable to review the principles briefly in this paper in order to pinpoint the superiority of a new electrode device, which uses a dual focusing system known as the dual laterolog device. This combines the features of th LL3, LL7 and the spherical focused device, in an alternating sequence of measurements.

Theory

The evolution of electrical logging tools has lead to the implementation of current focusing which is illustrated in fig 1. It shows idealized patterns of current flow in the borehole and formation from central electrode. The left of the pattern is not of radial pattern because of the presence of a highly resistive bed. On the right is the desired flow, so that the resistivity of the bed of interest is sampled properly

---

Correspondence to: Molua, O. C
Physics Department,
College of Education, Agbor
Delta State,
Nigeria.

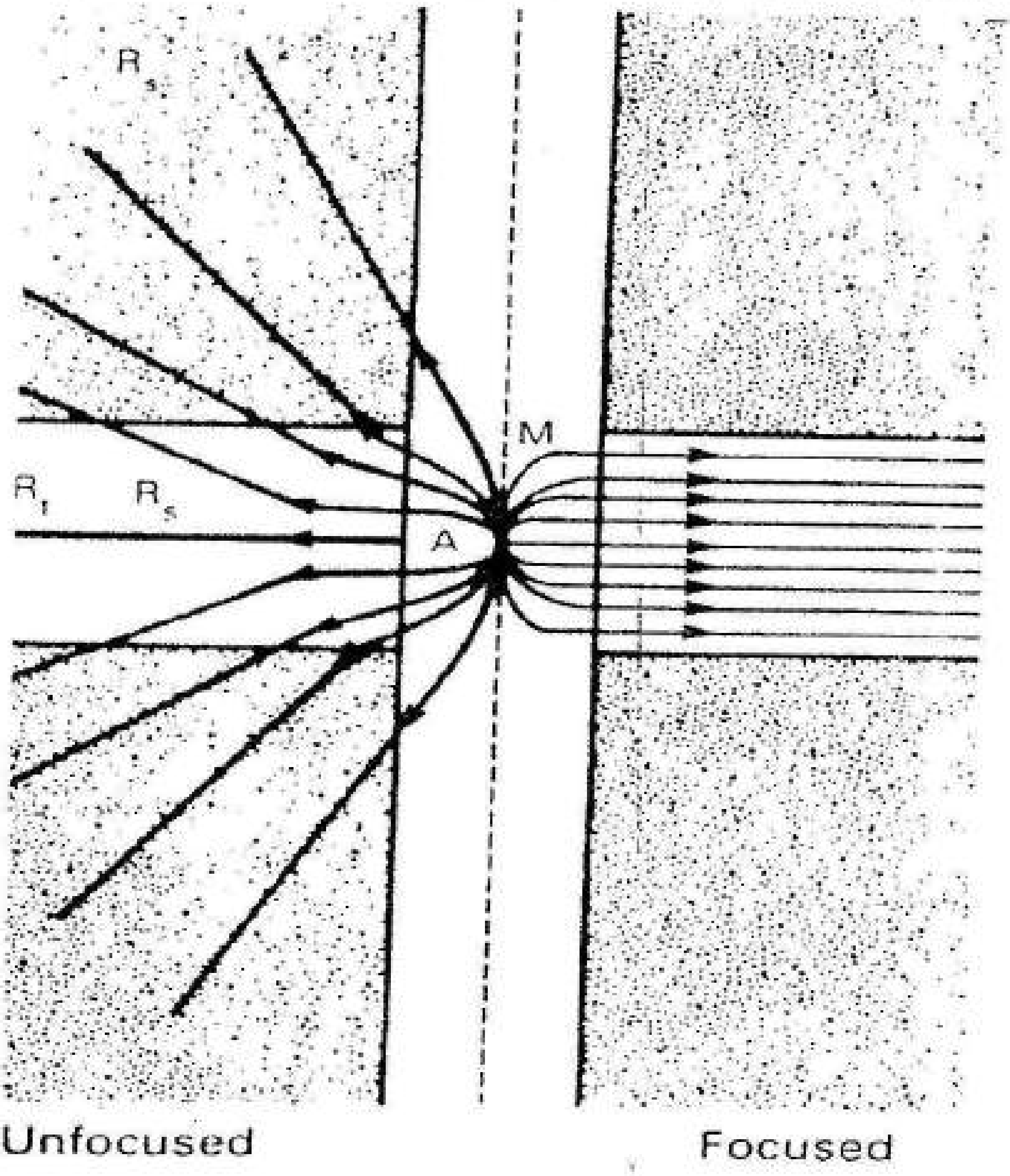


Fig 1- Ideal Pattern of current flow

The principle of focusing is shown in fig 2 where there are now three current - emitting electrodes. This type of array is known as guard focusing device and is commonly referred to as laterolog-3 or LL3 device. The potential of the electrodes marked A_1 and A_1 is held constant and at the same potential as the central electrode Ao. Since current flows only if a potential difference exists, there should, in principle, be no current flow in the vertical direction. The idealized current distribution from the laterolog 3 device with current focused into the formation is shown in fig. 3.

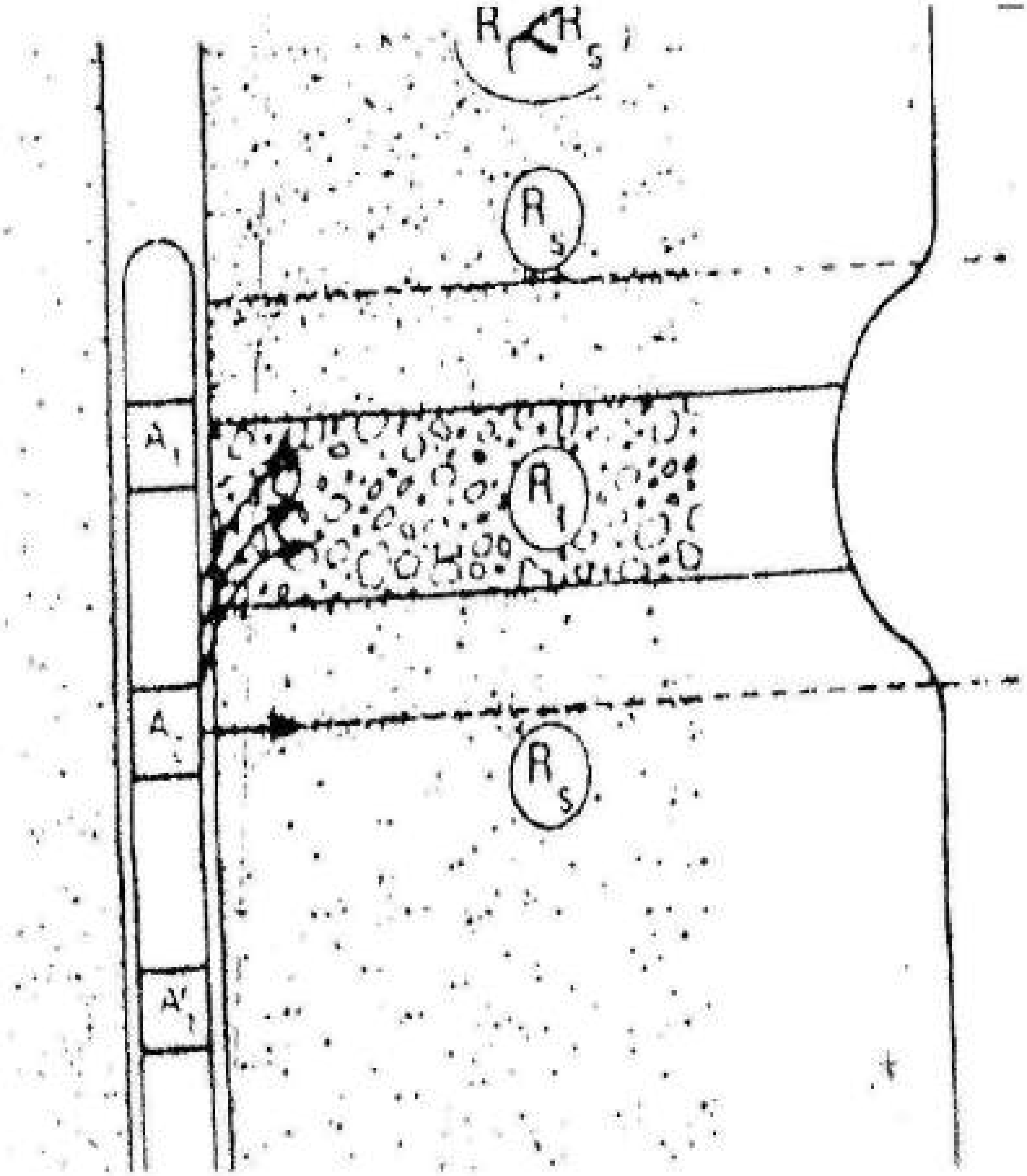


Fig 2- Principle of Focusing

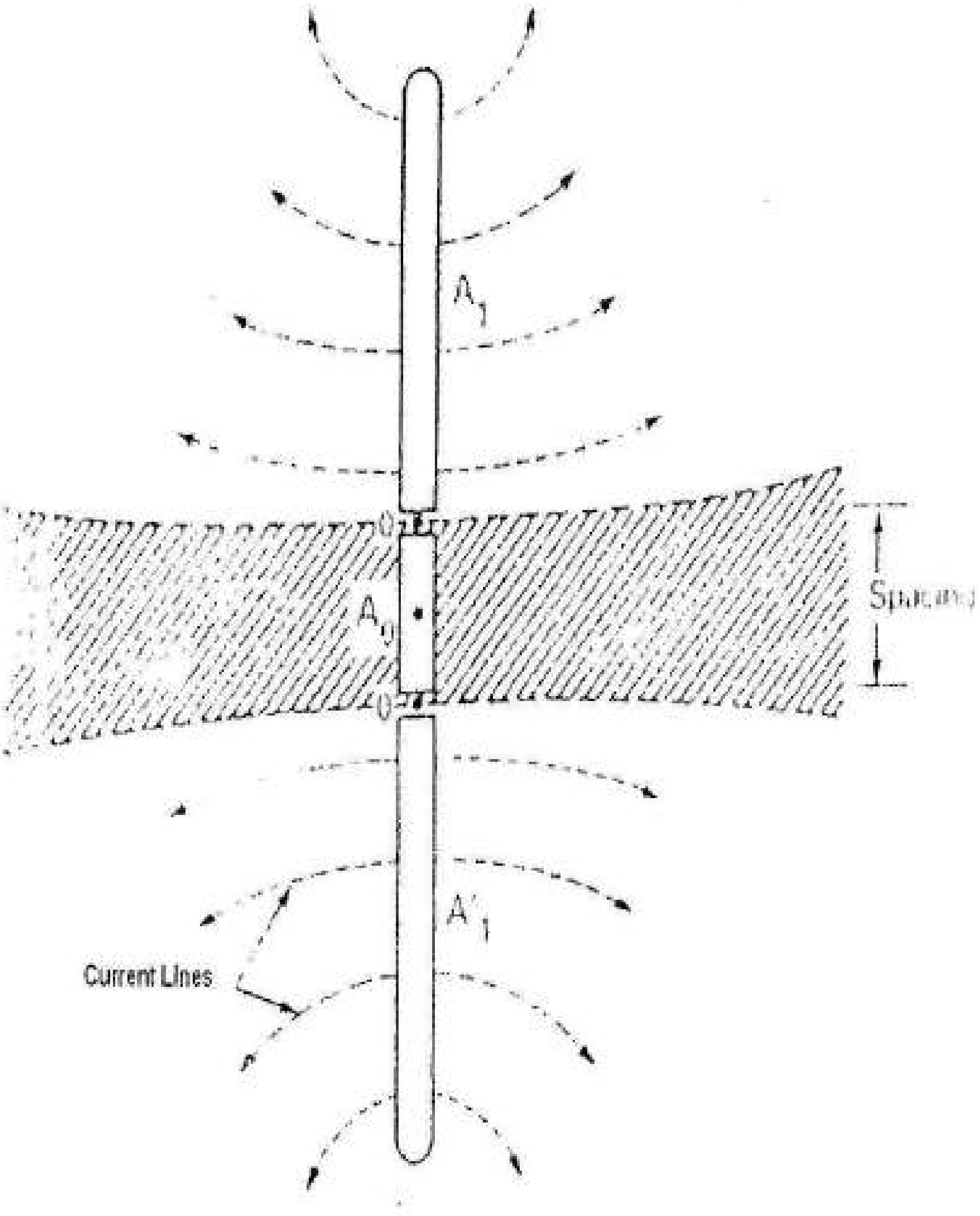


Fig 2- Idealized current distribution from the Laterlog-3 device, showing current focused into the formation

A sheet of current is shown to be emanating horizontally from the central measurement electrode. The current emitted from the focusing or "guard" electrode is often referred to as "bucking" current as its function is to impede the measured current from flowing in the borehole mud. It is the continuous adjustment of the bucking current, which keeps A_1 and A_2 at the same potential as Ao. The LL7 device comprises a center electrode, Ao and three pairs of electrode M_1 and M_2 M_1' and M'_2 A_1 and A_2 .The electrode of each pair is symmetrically located with respect to Ao which is the exploring electrode with the pairs being respectively short-circuited. In one version of the tool a current of constant intensity is sent through electrode Ao. Additional currents of the same polarity as the current flowing through Ao are feed through the outer electrodes A_1 and A_2. The difference of potential between M_1 and M_2 M_1' and M_2' is maintained substantially equal to zero by continuously automatically adjusting the intensities of the A_1 and A_2 current. Broadly, the LL7 and LL3 systems discussed so far are nearly the same: both use two outer electrodes whose currents are varied so that the difference of potential between various points along the tool remains essentially zero. Because of this similarity, the responds of the two tools are essentially the same. In particular, when the LL3 current beam is distorted, the LL7 beam is also distorted in a similar although somewhat exaggerated fashion. As a matter of fact the basic responses of the currently used tools are so similar that what is applicable to one of the tools are essentially applicable to the other tools except for thin resistive beds.

The advantages of the log given by these tools are.

1. Good vertical resolution except in resistive bed less than left thick (43) or 2-ft thick
2. No skin effect
3. A negligible annulus effect.
4. Good response when Rt is less than Ri
5. Good response when Rt is greater than Ri provided the invasion is moderate; and
6. An Rt value can be easily obtained from a guard log using a geometrical factor formula given by

$$Rg = GmRm + GiRi + GtRt \text{ ------------------------ } (1)$$

where Rg is a resistivity value

Gm, Gi and Gt are the geometrical factors and Rt is the true resistivity.

The above equation (1) is derived from a more formal and general expression

$$Rg = \int^{\infty} R\frac{dr}{A} \quad \text{..................................} (2)$$

where r_o is the radius of the tool at its center, r the distance from the tool axis, and A the beam cross section at distance r. The Rt solution obtained is reasonably correct except when both Rt/Ri and Di have high values. In such a case only a limit of Rt is obtained from the interpretation data available. Despite these good intensions, the LL3 and the LL7 tools have been found to posses the following short comings?

1. R_t cannot be obtained unless R_i and D_i are known or can be reasonable estimated. This is a short coming common to all resistivity logs.
2. Both tools shows some difficulty with bed boundaries, for example Rt cannot generally be determined with sufficient accuracy for resistive beds i.e. when $R_t > R_s$ (shallow resistivity) current will pass through the mud into the highly conductive shoulder similarly when $R_t < R_s$ there will be effect on a thin conductive bed.
3. Finally the LL3 and LL7 only measure the deep resistivity without due consideration of the borehole i.e. resistivity of the mud R m and the resistivity of the invaded zone Rro which are referred to as the shallow resistivity[7]. Because of the fact that no single measurement has yet succeeded in entirely eliminating the effect of the invaded zone. It became imperative therefore to measure the resistivity with several arrays having different depths of investigation which usually approximate the invasion profile well enough to determine R_t.This need has been taken care of by the introduction of this new resistivity measurement called the Dual laterolog DLL microsfL tool with simultaneous recordings[1]. Fig. 4 shows a schematic diagram of the DLL. It has a response range of 0.2 to 40,000 Ohm m which is a much wider range covered by previous laterolog devices. In the DLL long guard electrodes are needed and so the distance between the extreme ends of the guard electrodes is approximately 28ft. The nominal beam thickness of 2ft, however, insures good vertical resolution.The deep laterolog measurement (LLD) of the DLL tool has a deeper depth of investigation than previous laterolog devices thereby providing information for the determination of R_t using its extended range of formation conditions.

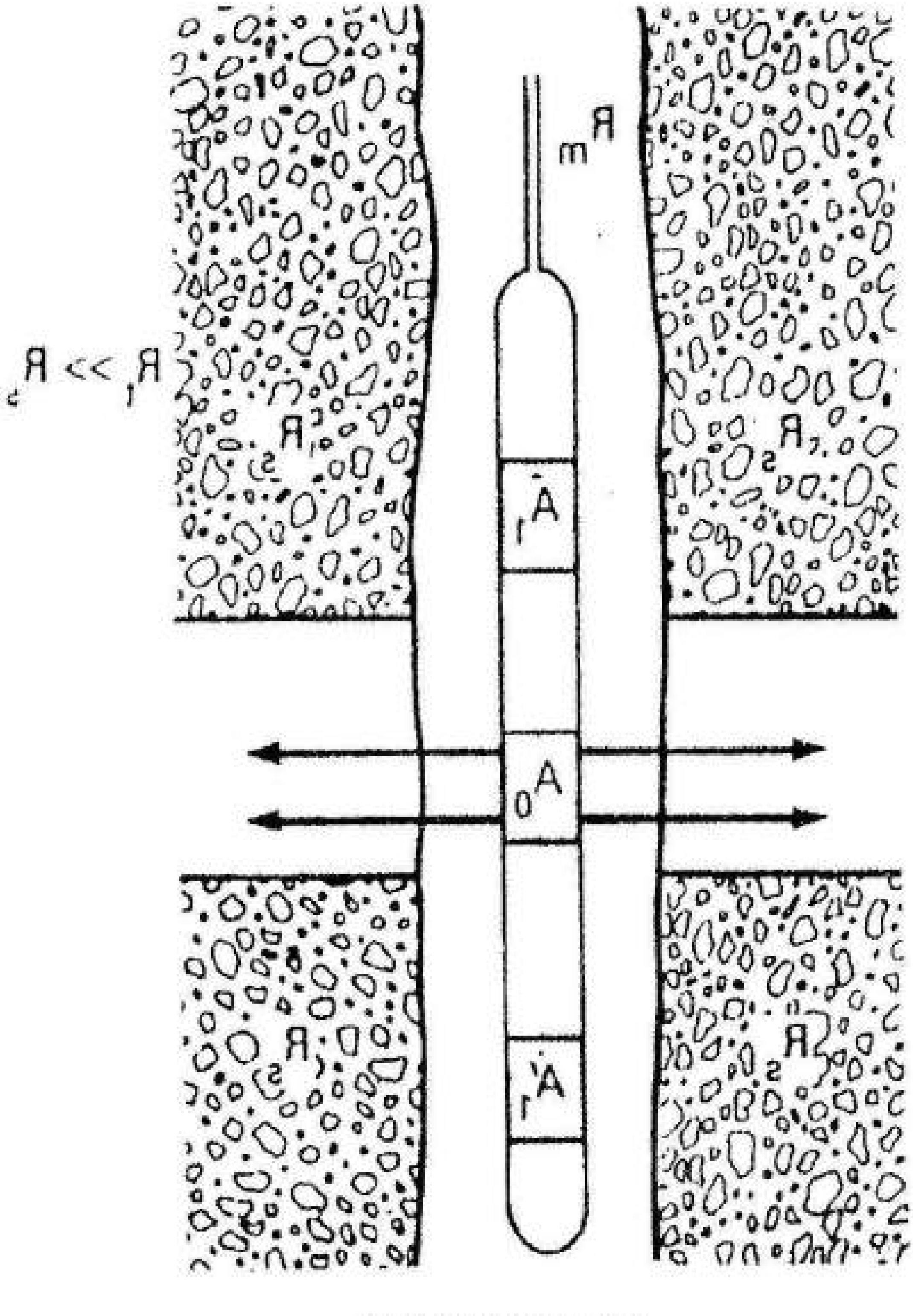


Fig 4- Dual lateralog tool

The shallow laterolog measurement (LLS) has the same vertical resolution as the deep laterolog device (2 ft), but it responds more strongly to that region around the borehole normally affected by invasion. It uses a type of focusing called ": pseudolaterolog" wherein the focusing current is returned to the nearby electrodes instead of to a remote electrode. This causes the measured current to diverge more quickly once it has entered the formations, thus producing a relatively shallow depth of investigation.

Warning-Groningen effect on LLD curve

The Warning Graningen effect occurs for about 100ft below a thick, highly resistive bed. When coming up into a formation with this infinite resistivity, the tool is no longer capable of forcing the current sheet to remain flat, since the measure and Bucking currents cannot flow easily through the highly resistive bed, it returns through the mud column and creates a negative potential on the zero reference electrode. Perhaps if a steel casing string has been set in the resistive zone, it helps to "short circuit" the current and this distorts the normal current pattern and results in a progressive increase in the LLd which reads too high. An induction log is recommended for serious formation evaluation in these "shielded" conductive beds[1].

Field example

In clean formations, if the water does not change between a hydrocarbon bearing zone and a water bearing zone, that is, if its salinity and hence its resistivity remains constant, reservoirs which contain hydrocarbons will exhibit resistivities which are higher than those of water bearing zones. At the same time, the ratio Rx_o/R_t will be lower in water zones, because filtrate invasion alters the fluid and lowers the hydrocarbon saturation in the invaded zone, and because of the different investigation depths of macro-resistivity and micro-resistivity devices. According to the Archie equation, the ratio Rx_0/R_t is given by $Rx_0/R_t = R_{mf}/R_w$ From which it follows that $R_w = R_{mf} R_t / Rx_0$

Similarly, the ratio $\frac{S_w^2}{S_{xo}^2} \leq 1$

where R_o is the Resistivity of non-shaly formation R_{xo} is flush- zone resistivity, R_t is true resistivity, R_w is formation water resistivity, R_i is resistivity of invaded zone, R_{mf} is resistivity of mud filtrate, S_w is water saturation and S_{xo} is mud filtrate saturation.

In water zones S_w and S_{xo}^2 are both in unity. In hydrocarbon-bearing zones S_w^2 less than S_{xo}. This water zones yield maximum values of this ratio, that is the maximum spread between the micro resistivity curve msfl and the macro resistivity curve LLD when R_{msfl}> Rμ or conversely, the minimum spread when R_{msfl}<RLL.

The Hydrocarbon zones are identified by a minimum spread in the second curve.

One can equally well overlay the micro-resistivity and macro-resistivity in the water zones and in that case the curves will be spread in the hydrocarbon zones. These methods are not recommended when there are frequent variations in water salinity and are of little use when the invasion is either very shallow or very deep.

This method i.e. (Rx_o/R_t) has the advantage of giving an indication of hydrocarbons mobility, and is little affected by shaliness or R_w variations[1].

Evaluations of shaly formations, usually shaly sands, are somewhat complex. All logging measurements are influenced by the shale and corrections for shale content are required. Regardless of the basic assumptions, most shale sand interpretation models employ a weighted average technique to evaluate the relative contributions of the sand and shale phases to the overall shaly sand response.

There are many formulae that relate resistivity to water saturation in shaly sands. Most are generally of the form:

$$1/R_t = S^2_w (1-V_x)/FR_w + C\ V_x/R_x \text{ -------- } (3)$$

where

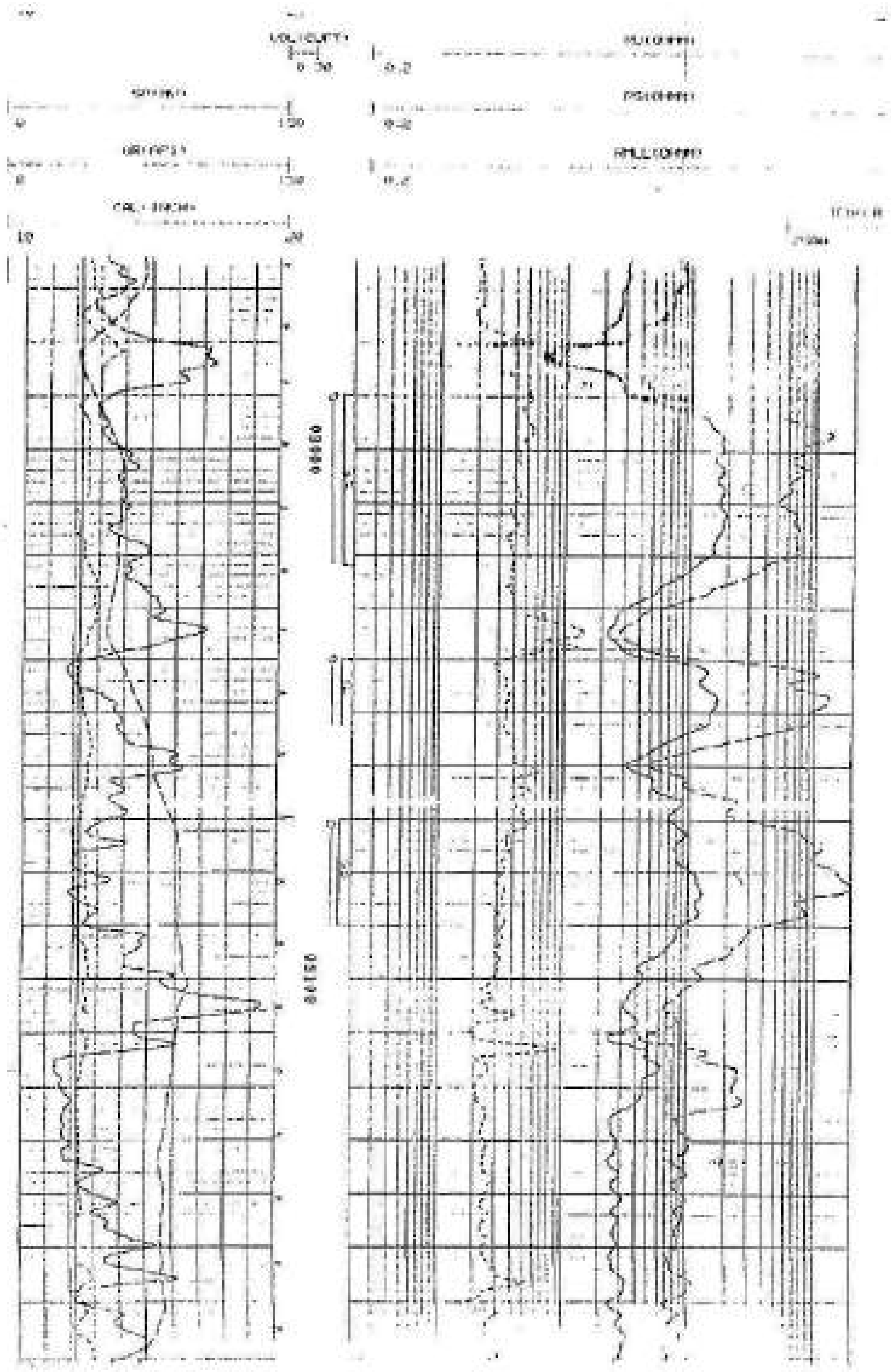
V_x = A term related to the volume or some specific volumetric characteristic of the shale or clay

R_x = A term related to the resistivity of the shale or clay

C = A term related to water saturation (S_w).

It should be noted that when the shale volume is zero (i.e. clean sand), the above equation reduces to the Archie water saturation equation (16). This is true for all shaly sand water saturation techniques.

Well 1 is a well logged between 08980-09160 Ft and shows curves of micro and macro resistivity devices logged in combination of Sp, caliper and GR curves, because, where the formation water is fresh, it is difficult to distinguish water and hydrocarbon bearing zones on the basis of resistivity logs alone. The well has been divided into four sand zones: A, B, C, and D.



WELL 1

For simplicity, a number of assumptions have been made in determining water saturation for each of the hydrocarbon zones of well 1

TABLE 1. Petrophysical evaluation worksheet

Sand Name	Interval L	Ä L	LLD Rt	$R_w/ö^m R_t$	$I^{-1/2}$ (S_w)	Ä L. S_w
A	8990-8992	2	120	0.480	0.693	1.386
	8992-9000	8	1,300	0.0443	0.210	1.680
	9000-9006	6	900	0.064	0.253	1.518
	9006-9012	6	600	0.096	0.400	2.40
	9012-9022	10	700	0.0823	0.287	2.87
	9022-9026	4	300	0.033	0.192	0.728
	9026-9030	4	120	0.48	0.693	2.772
B	9040-9046	6	1,000	0.0576	0.240	1.44
	9046-9052	6	1,500	0.0384	0.196	1.176
	9052-9056	4	500	0.1152	0.340	1.36
C	9064-9070	6	250	0.230	0.480	2.88
	9070-9078	8	1,000	0.0576	0.240	1.92
	9078-9084	6	2,000	0.0288	0.170	1.02
	9084-9090	6	900	0.064	0.253	1.518
	9090-9096	6	300	0.033	0.182	0.092
	9096-9102	6	150	0.384	0.620	3.720
D	9112-9116	4	160	0.360	0.600	2.40
	9116-9124	8	260	0.222	0.471	3.768

(1) $R_{(deep)} = R_t$

(2) Ro = 90(obtained from LLD reading over the water bearing interval 09140-09170 Ft of well).

(3) M = n = 2 (Constant)

(4) Φ = 0.25(quick look porosity)

(5) $Rw = \varphi^n R_o = 5.6$

These assumptions and other calculations are used for the evaluations of water saturation. (S_w) for each of the various randomly chosen sand intervals are shown in Table 1(Petrophysical evaluation worksheet).

Data analysis for well 1

Four sand intervals exist, these are:
Sand A (Intervals 08988-09030 Ft of well)
Sand B (Intervals 09040-09056 Ft of well)
Sand C (Intervals 09064-09102 Ft of well)
Sand D (Intervals 09112-09124 Ft of well)

Short lengths were taken of R_{deep} in the hydrocarbon bearing interval in order that R_t could be read off the logarithmic scale e.g. in sand A interval 8992-9000 Ft of length 8 was read off 1,300 approximately. Same was done for all the lengths of sad intervals of A, B, C, and D. From which the ratio I was calculated and obtained for all the interval lengths. From table $I^{-1/2} = S_w$. Consequently, S_w was calculated for all the chosen lengths of the sand intervals. From table 1.

For sand A, ÓÅL. S_w = 17.2333

For sand B ÓÅL. S_w = 4.0573

For sand C ÓÅL .S_w = 17.0655

For sand D ÓÅL .S_w = 7.6895

The average water saturation S_w (ave) for each sand is

Sand A, S_w(ave) = ÓÅL . S_w / ÓÅL = 17.2333/40 = 0.43

Sand B, S_w (ave) = ÓÅL. S_w / ÓÅ = 4.0573/16 = 0.25

Sand C, S_w(ave) = ÓÅL . S_w / ÓÅL = 17.0665/38 = 0.45

Sand D, S_w(ave) = ÓÅL. S_w / ÓÅL = 7.6895/12 = 0.64

Consequently, the hydrocarbon saturation can be estimated from the above values using S_h = (1- S_w) where S_w is the hydrocarbon saturation.

The total average water saturation ($S_{w(t)}$) for the four sand zones A, B, C and D of well 1 is
$S_{w(t)}$ = 0.43+0.25+0.45+0.64/ 4 = 1.77/ 4 = 0.44

Therefore Sh = (1- S_w)

= 1-0.44

= 0.56

Conclusion

A method for the measurement of resistivity in boreholes has been described which involves a controlled focusing system of electrodes, whereby the current used for the measurement is obliged to flow within a narrow slice of space, the boundaries of which are substantially horizontal up to a great distance from the borehole.

It has wider response range of 0.2 to 40,000 ohm, which is a much wider range than covered by previous laterolog devices.

Consequently, it has deeper depth of investigation than previous laterolog devices.

Recommendation

1. It is envisaged that for most formations, the best way to accomplish the determination of true resistivity both in case of thick and thin beds, will consist in simultaneously recording a Dual laterolog, micro-spherical log (MSFL) and an induction log.
2. When $R_{xo} < R_t$ and formation resistivity are high, the DLL is recommended for R_t determination. Adding microresistivity to the suit will permit a better evaluation of R_{xo} and R_t.

References

1. Pirson, Sylvain. J.Handbook of well analysis, New York, Prentice-Hill 1963; pp326
2. Archie G.E., The electrical resistivity log as an aid in determining, some reservoir characteristics: petrol. tech 1942; 5(1); pp115.
3. Schlumberger. Log interpretation principles/applications schlumberger educational service 1989; pp213.
4. Halliburton. Open hole log Analysis and Formation Evaluation. HES; 1991;pp99.
5. Frank. R.W, Prospecting with old Electric Log; Shlumberger Educational services Houston, 1986; pp120