THE CONDUCTIVITY OF A FORMATION AS A MEASURE OF INDUCED CURRENT (A CASE FOR INDUCTION LOG).

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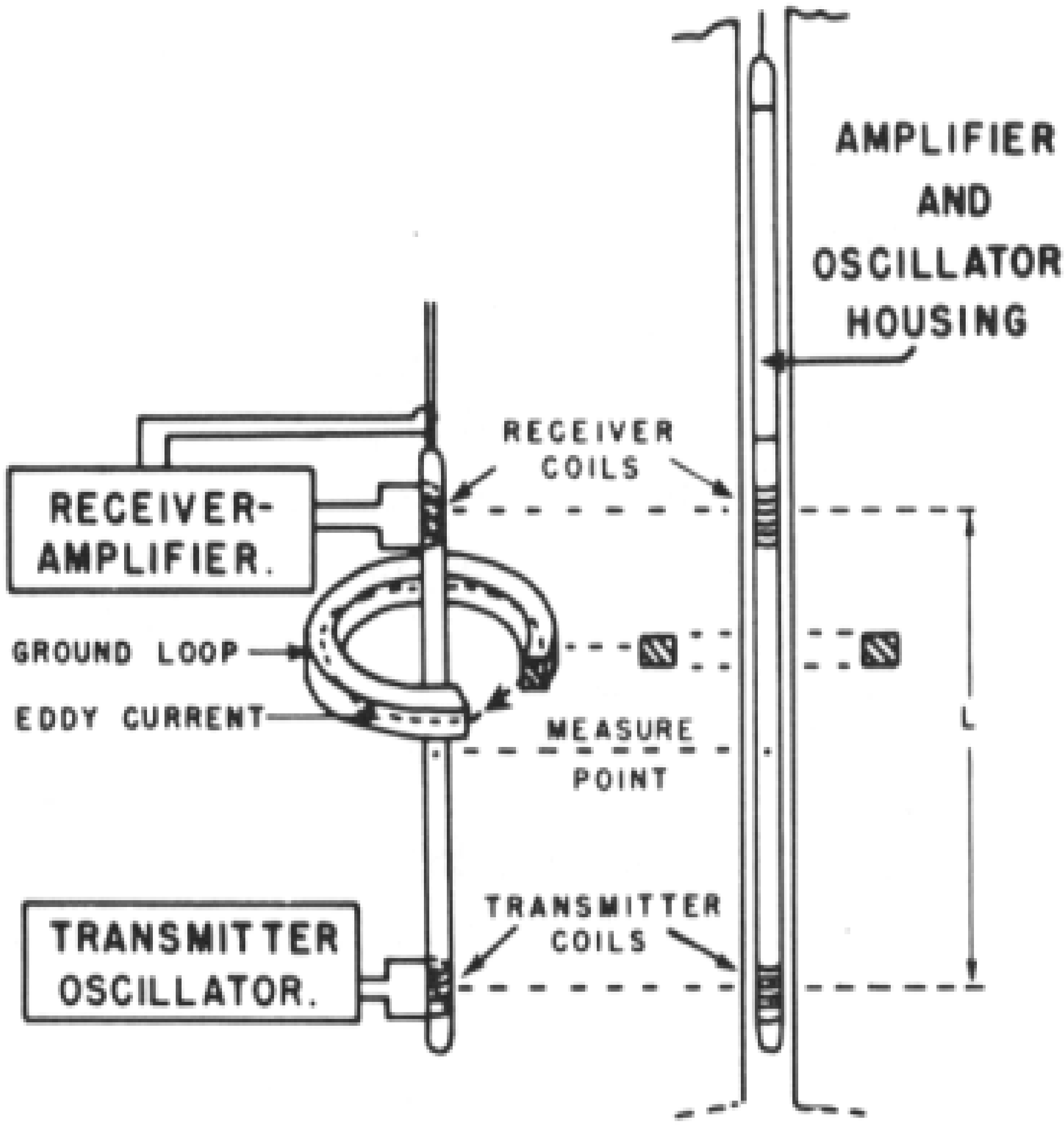
ABSTRACT

This work examined the viability of induction log as a measure of the conductivity of a formation by the use of induced current into the formation. Its use in the determination of water saturation was also examined. Induction logging is a method wherein the conductivity, ie reciprocal of resistivity is measured by means of induced current without the help of contact electrodes. It can be used in empty holes or in holes containing oil base, fresh water or other types of drilling fluid that is not conductive. We know that in formation evaluation, estimation of the quantity of formation water present in the pore space of a well leads to the evaluation of the quantity of the hydrocarbon present. And so for the geophysical well that was considered here, various assumptions made, and the water saturation for the two zones were found to be 33% and 20% respectively.

INTRODUCTION

Induction log is a log recorded in uncased boreholes, which involves the use of electromagnetic principles for the measurement of formation conductivity or resistivity. The Induction logging tool has advantages for use in nonconductive borehole fluids (air. oil gas) where other electrical resistivity logging tools cannot be easily used or should not be used. The Induction log is widely used in electrically conductive drilling mud's where it works well provided the formations are not too resistive and borehole effects are known and not too great (i.e., mud not too saline and hole diameter not too large). Practical Induction sondes include an array of several transmitter and receiver coils designed to provide focusing and deep investigation and to minimize borehole and adjacent-formation effects. A high-frequency alternating current, constant in magnitude, is passed through the transmitter coils. The resulting alternating magnetic field induces currents in the formation which flow in circular ground-loop paths coaxial with the sonde. Those ground-loop currents generate their own magnetic fields, which induce in the receiver coils signals, which at low conductivities are essentially proportional to formation conductivity. (Yuan et al 1999)



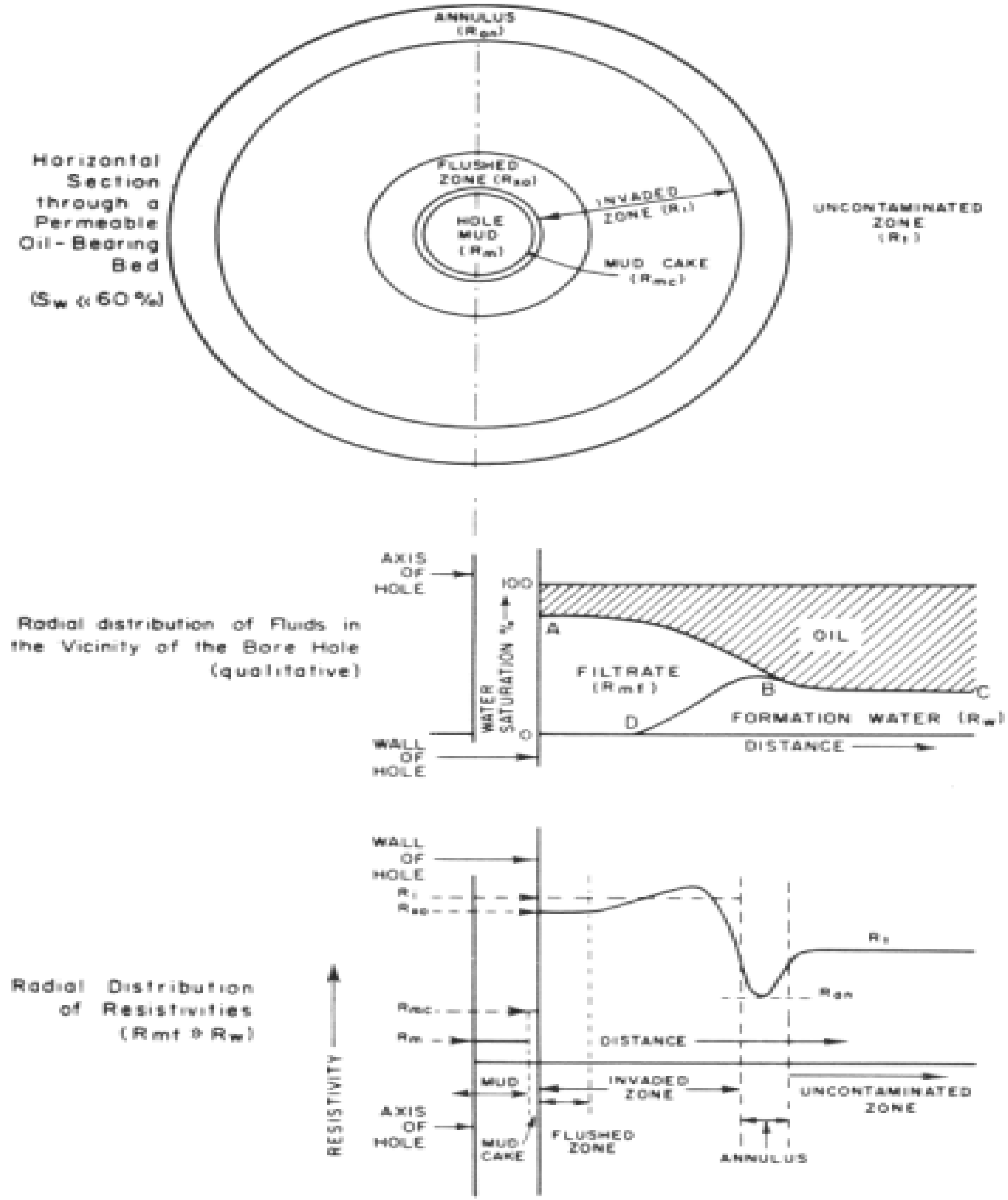
Induction Log Equipment

(Courtesy of Schlumberger)

Fig 1

At high conductivities, the reading may be affected by skin effect. Receiver-coil signals produced by direct coupling with the transmitter coil are balanced out by the measuring circuits. Induction tools can be run separately or can be combined with other devices to run combination services. Integrated tools, combining in one tool the devices necessary to perform different resistivity-measuring operations, are commonly used in the well-logging industry. Examples of such tools are the Induction device with a deep depth of investigation in combination with: another induction device having a shallower depth of investigation, invaded zone investigative devices (e.g., short normal device, short lateralog or guard log or Spherically Focused Logging device), long lateral, and SP. The portion of formation surrounding a well bore into which drilling fluid has penetrated. displacing some of the formation fluids. This invasion takes place in porous, permeable zones when the pressure of the mud is greater than that of the formation fluids. A mud filter cake builds on the formation wall, limiting further invasion into the formation by mud filtrate. Directly behind the mud cake is a flushed zone from which almost all of the formation water and most of the hydrocarbons have been displaced by filtrate. The invasion process alters the distribution of saturations and other properties and, consequently, alters the values, which are recorded on logs. The depth of invasion is the equivalent depth in an idealized model rather than the maximum depth (Molua O. C And Ujuanbi. O,2006)

reached by filtrate. In oil-bearing zones, the filtrate may push a bank of formation water ahead of it to produce what is referred to as an annulus.



Invaded Zone with Annulus
(Courtesy of Schlumberger)

Fig 2

STRATIGRAPHY OF THE STUDIED AREA

The Niger Delta occur at the southern end of Nigeria bordering the Atlantic ocean and extends from about longitude $3^{o}.9$ E and latitude $4^{o}.30'$ – $5^{o}.20'$N. The proto delta developed in the northern part of the basin during the capanian transgression and ended with the poleocene transgression.

It has been suggested that the formation of the modern delta basin which enhanced and controlled the development of the present day Niger delta, developed by rift faulting during the Precambrian . Sedimentological and funal data suggest that the modern Niger delta has a configuration similar to that of the past.(Molua & Ujuanbi,2006)

THEORETICAL CONSIDERATION

Formation evaluation is the application of any and all available borehole measurements to determine properties of interest of the in situ material surrounding the borehole.

Using the dual-water model, this involves the motion of bound water. In a formation unit volume, the clean matrix and the dry colloids represent the solids. The rest defines the porosity, which is the total porosity Φ_T .The accepted definition of "Formation water saturation" is as follows:

S_w = Fare water volume/ Effective porosity

$(S_{wt} - S_{wb}) \times \Phi_T$ = Fare water volume

$(1 - S_{wb}) \times \Phi_T$ = Effective porosity, therefore

$$Sw = \frac{(S_{wt} - S_{wb}) \times \Phi_T}{(1 - S_{wb}) \times \Phi_T}$$

$$Sw = \frac{S_{wt} - S_{wb}}{1 - S_{wb}}$$

Archie's saturation equation can be written:

$$Ct = (SwT \times \Phi_T)^2 \times C_{wm}$$

where $C_t = I/R_t$ Formation conductivity

C_{wm} Conductivity of mixed water (bound and free)

$$C_{wM} = \frac{S_{wb} + \varphi_T}{S_{WT} \text{ x } \Phi_T} \text{ x } C_w b + \frac{(S_{wt} - S_{wT}) \text{ x } \Phi_T}{S_{wT} \text{ x } \Phi_T} \text{ x } C_{wf}$$

$$C_{WM} = \frac{S_{wb} \text{ x } C_{wb} + (S_{wT} - S_{wb}) \text{ x } C_{wf}}{S_{WT}}$$

Substituting the expression of $C_W M$ in Archie's formula, we have a second-degree equation that can be solved for S_{WT}.

$$S_{WT} = X + \left(\frac{C_t}{S_{Wf} \text{ x } \Phi_T^{\,2}} + X^2 \right)^{1/2}$$

Where

$$X = \frac{S_{Wb} \text{ x } (C_{Wf} - C_{Wb})}{2C_{Wf}}$$

If there is no clay, then $S_{wB} = 0$, and X = and

$$S_{WT} = X + \left(\frac{C_t}{C_{Wf} \text{ x } \Phi_T^{\,2}} \right)^{1/2}$$

This is the standard Archie formula for clean formations.

Once we have S_WT, we may calculate:

$$S_w = \frac{S_{wT} - S_{wb}}{1 - S_{wb}}$$

Unfortunately, this expression tends to $\to 0$ for $S_{wB} \longrightarrow 1$ (which is in very shaly formations). This gives unreliable values of S_w, showing hydrocarbon in shale and clay. To solve this problem, another approach (empirical) has been retained: We consider a wet, shaly formation ($S_{wT} = 1$). In this case Archie's equation is written.

$$Co = \Phi_T^{\,2} \times C_{wm} \text{ and}$$

$$C_{wM} = S_{wb} \times C_{wb} + (1 - S_{wb}) \times C_{wf} \text{ then}$$

$$C_o = \Phi_T^{\,2} \times (S_{wb} \times C_{wb} + (1\text{-}S_{wb}) \times C_{wf})$$

Or, in resistivity,

$$\frac{1}{C_o} = R_o = \frac{R_{wf} \times R_{wb}}{\Phi_T^{\,2} \times [S_{wb} \times R_{wf} + (1 - S_{wb}) \times R_{wb}]}$$

R_O is a reconstructed resistivity curve, which depends on:

Φ_T useϕql from; DT-CNL (ϕD + ϕN)/2)

S_{wb} $S_{wB} = V_{cl}$ from clay indicators

R_{wf} from clean water zone

R_{wb} from 100% shale zone

R_{wf} From clean water zone

R_{wb} from 100% shale zone

And S_w is taken empirically as:

$$S_w = \sqrt{\frac{R_o}{R_t}}$$

Data Acquisition / Interpretation

In the determination of water saturation several methods abound. However one of the methods has been used in the determination of water saturation for well sections. While table 1 shows values of measures used in the evaluation of well A and B.

Table 1-Values of Measurements used in Evaluation, well sections A and B

Zone	Depth (IL)	C (mmho)	Rt (ohm-m)	R (SN)	SP (mv)	Den. (g/cc)	GR (s.d)
1	10,635-41	2900	0.34	1.60	70	2.12	6.3
2	10,646-52	4500	0.22	1.05	95	2.12	3.8
3	10,655-63	4400	0.225	1.00	90	2.11	3.7
4	10,670-73	1400	0.72	1.45	35	2.22	6.2
5	10,676-82	160o0	0.62	1.20	50	2.10	5.2
6	10,697-704	3200	0.31	1.00	65	2.10	4.6
7	10,743-48	1600	0.62	1.05	30	2.23	6.5
8	10,768-76	3500	0.28	1.30	85	2.17	4.5
9	10,781-85	1400	0.72	1.20	50	2.16	4.8
10	10,790-97	1400	0.72	1.00	40	2.13	5.1
11	11,548-52	350	2.80	3.35	45	2.13	4.7
12	11,554-57	300	3.50	4.50	65	2.06	4.4
13	11,570-74	330	3.60	3.50	55	2.11	5.0
14	11,577080	400	2.50	2.70	45	2.10	5.4
15	11,584-87	450	2.20	2.80	40	2.20	5.6
16	11,560-600	240	4.20	4.20	65	2.08-2.17	4.4

Table 2-Traditional Cookbook Evaluation Results

Zone	Ø	F	Rw	Ro	I	Sw(%)
1	32%	6.1	0.05	0.31	1.1	95
2	32	6.1	0.025	0.15	1.5	75
3	33	5.8	0.03	0.17	1.3	85
4	26	8.5	0.13	1.15	0.6	100
5	33	5.8	0.09	0.51	1.2	90
6	33	5.8	0.06	0.34	0.9	100
7	25	9.1	0.15	1.38	0.5	100
8	29	7.1	0.03	0.23	1.2	90
9	28	7.6	0.09	0.70	1.0	100
10	31	6.4	0.12	0.77	0.9	100
11	31	6.4	0.10	0.64	4.4	39
12	36	5.0	0.06	0.30	11.7	22
13	33	5.8	0.08	0.45	6.7	30
14	33	5.8	0.10	0.58	4.3	40
15	27	8.1	0.12	0.96	2.3	58
16	32	6.0	0.06	0.36	11.6	22

Zone	R(Sn)/R(IL)
1	4.7
2	4.8
3	4.4
4	2.0
5	1.9
6	3.2
7	1.85
8	4.6
9	1.7
10	1.4
11	1.25
12	1.3
13	0.97
14	1.1
15	1.3
16	1.0

Rwa Method for Saturation Estimates (Procedures for the Determination Saturation (S_w))

Equation: $R_{WA} = Rt.F$, $F = Ø^{-m}$

This flow chart shows the

What's Needed? →

- Rt from ES, LL, IL
- Ø from Δt, P_B, $Ø_N$, Ø core
- m from experience, lab, cross plot
- Δtm, B from experience (use Δt,)
- P_m, P_f from experience (use P_B)
- Water bearing zones for
- Comparison Sp if R_w not constant

Calculate R_{wa} →

$$\frac{Pm - PB}{Pm - Pf}$$

Or

ØN

$F = Ø^{-m}$

$R_{wa} = Rt/F$

<u>Example,Well sections Aand B,Zone 13</u>

3.6ohm-m (IL)

PB = 2.11 g/cc. (Den.)

1.6(guess based on past experience)

Pm = 2.65 (past experience, clean sand, Miocene)

Zones 1 – 10

$\frac{2.65 - 2.11}{2.65 - 1.00} = 0.33$ (Ø = 33%)

$0.33^{-1.6} = 5.8$

$\frac{3.6}{5.8} = \underline{0.62\text{ohm-m}}$

Estimate Sw

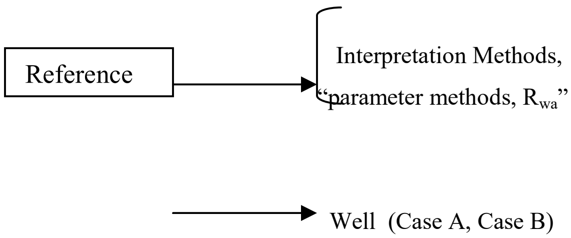
Case A Consistent Lower

Limit for RWA exists, implying constant RW

1. Determine consistent Minimum Rwa for Zones being compared.
2. I For Zone of interest = RWA, Zone of interest, divided By Consistent minimum R_{WA}.
3. Sw = 1 – 1/n

Case B SP (Sands) Used to Account for Variations in Rw

1. Plot RWA (Log Scale) Vs. (Linear Scale). See attached example.
2. Find MOS = 0 Trend. Criteria: Intercept on R_{WA} Axis At SP = 0 Numerically Equal to RmF at formation temperature. Change along MOS – 0 Trend in SP for 10/1 change In R_{WA}'s numerically equal to F of SP Equation.
3. I for zone of interest is Ratio of value of RWA from MOS = 0 Trend (at same SP as zone of interest) To RWA of zone of interest.
4. $S_W = 1^{-1/n}$



<u>Example Well sections A and B, Zone 13</u>

0.045 ohm-m Avg. (Avg RWA from Zones 1, 2, 3, 6, 8)

1 (Zone 13) = 0.62/0.045 = 13.8

Sw(Zone13)=13.8-1/1.6=0.20 20%)

Zones 1, 2, 4, 5, 6, 8, 9, 10

Rmf = 0.35 ohm-m BHT

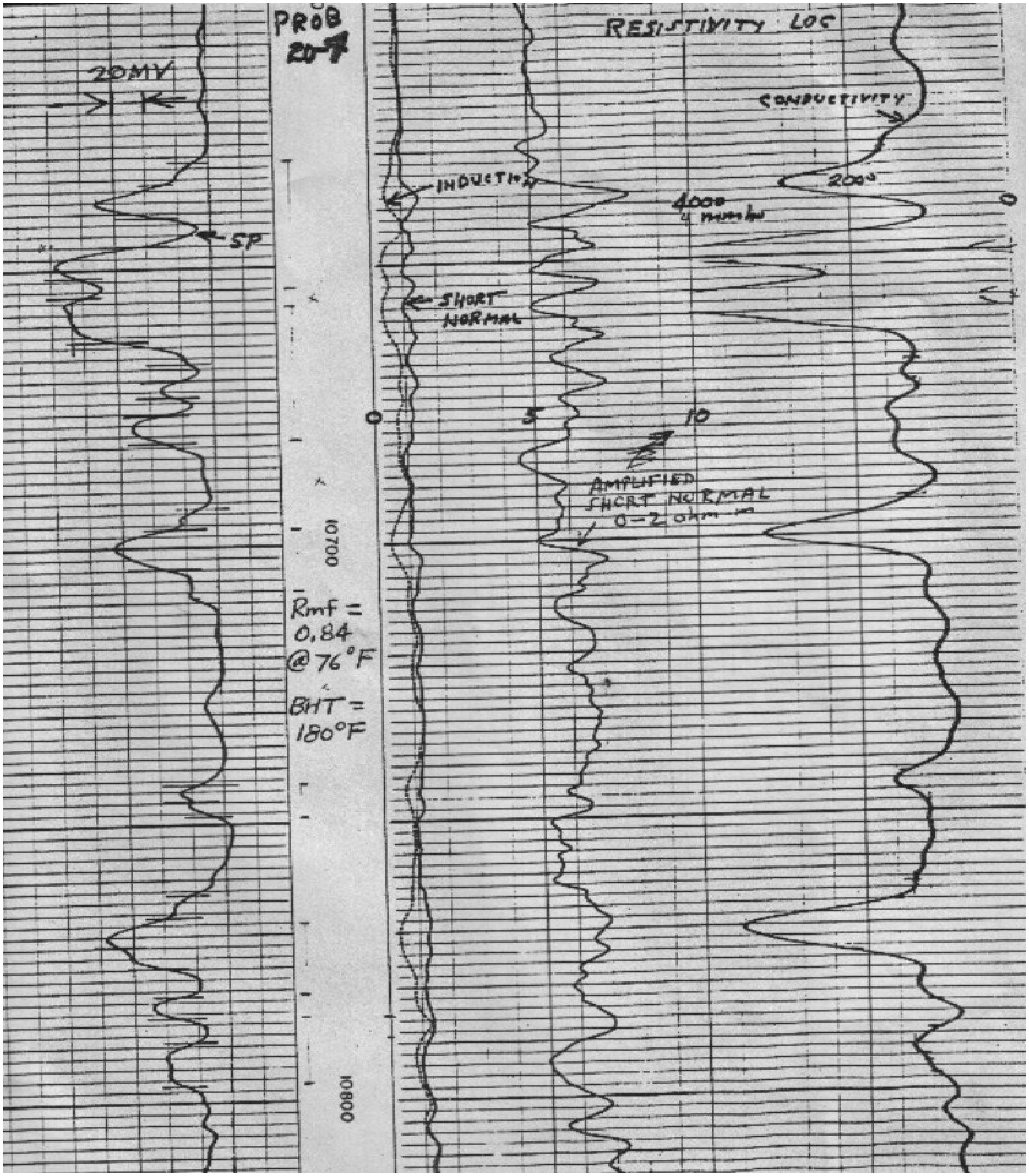
Apparent K = 85mv/cycle

0.52/0.083 = 6.5 – 1, Zon3 13

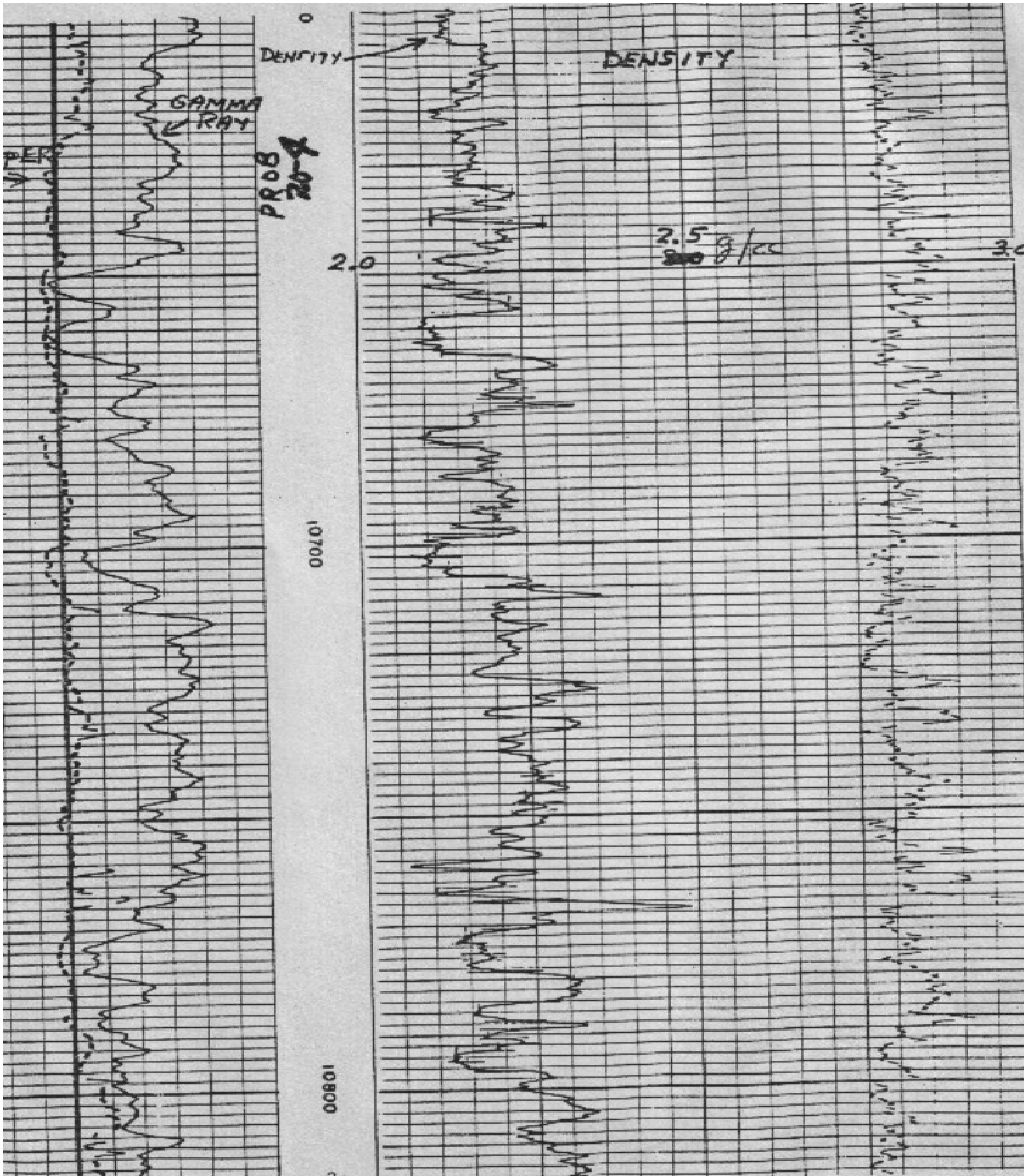
S_w = 6.5-1/1.6 = <u>0.32 (32%)</u>

Results and Conclusion

It can be seen that induction tools are better for low to medium resistivities for beds thicker than 5-6ft, and no more than 100 ohms. Its outstanding feature is that it will work in non-conductive fluids such as air and oil base mud. A new version of the Dual and no induction tool, the phasor induction or more than DIT-E make use of the directly coupled, 100 ohms or 'X' signal which makes it good for high resistivity formations. For the hypothetical well A, water saturation for zones 1 – 12 has been found to be 0.33 or 33% while for zone 13, water saturation is just 0.20 or 20%. Which means that for zones 1-12, using the relation1 1- S_w = S_h where S_h is the hydrocarbon saturation, we have that 1-0.33 gives 0.67, which shows that the zone is saturated with 67% hydrocarbon. While for zone 13, the hydrocarbon saturation is 80%. The implication of these findings is that the various zones are potential hydrocarbon productive zones. Although further productivity test and perforation are required to confirm this. Apart from oil industry, induction logging is also applicable in mineral exploration and water borehole.


PROB 20-4
RESISTIVITY LOG
20MV
CONDUCTIVITY
INDUCTION
200
4000
4 mmho
SP
SHORT NORMAL
0
5
10
AMPLIFIED SHORT NORMAL 0-2 ohm-m
10700
Rmf = 0.84 @76°F
BHT = 180°F
10800

Well A


DENSITY
DENSITY
GAMMA RAY
PER
PROB 20-4
2.5 g/cc
2.0
3.0
0
10700
10800
2

Well B

REFRENCES

Archie G.E., the electrical resistivity log as an aid in determining, some reservoir characteristics: petrol tecni. vol. 5 no. 1. 1942.

Dickey P.A, , natural potentials in sedimentary rock; trans. aime, vol. 164. pg. 256-266, 1945.

Molua O. C And Ujuanbi. O , “Microresistivity Log As A Viable Aid In Determining Hydrocarbon Saturation” Zuma Journal of pure & Applied science University of Abuja,pp129-133, 2006

N. Yuan, X. C. Nie, and Z. P. Nie, “Quantitative analysis and application of spontaneous potential log”, Well Logging Technology, vol.23, no.1, pp.9-14, 1999.

N. Yuan, Z. P. Nie, and X. C. Nie, “Numerical Simulation of spontaneous potential Log by Numerical Mode Matching Theory”, Antenna symposium of China. Hefei, Anhui, pp. 194~197, Aug., 1995.

Schlumberger,” log interpretation principles/applications” schlumberger educational service. 1989