J. Nig. Ass. Math. Phys.
Vol. 2 (1998)

CORRELATION BETWEEN RESISTIVITY SURVEY AND WELL LOGGING IN DELTA STATE

EGBAI, J. C. AND ASOKHIA, M. B.
DEPARTMENT OF PHYSICS, EDO STATE UNIVERSITY, EKPOMA.

ABSTRACT

A total of twenty one stations were recently investigated in parts of Delta State using vertical electrical sounding (VES) for detailed studies of hydrogeological setting in terms of static water level, lithology of the subsurface soil and the thickness of layers. The linear filter method was used in the interpretation of the resistivity soundings. Some boreholes were logged so as to correlate the surface resistivity survey with well logging. There was a high degree of correlation between drillers logs and spontaneous potential (SP) logs. These logs confirmed the results from surface resistivity survey in the area of research. Some useful recommendations are made on ways of avoiding unproductive boreholes.

INTRODUCTION

Electrical prospecting method makes use of a variety of techniques, each based on some different electrical properties or characteristics of materials in the earth. The resistivity method is designed to yield information or bodies having anomalous electrical conductivity. It is mainly employed in geophysics to map bedrock, in ground water studies and to determine salinity. The research is aimed at knowing the hydrogeological problems in terms of the static water levels and aquifers in Delta State.

In most cases near the surface, electric conductivity is mainly controlled by porosity, water content and water quality.

For resistivity measurements, various electrode arrays can be utilized. However, if the earth is assumed to be horizontally stratified, isotropic and homogeneous media such that the change of resistivity is a function of depth, the Schlumberger configuration is the most widely used array. As a result of this, the Schlumberger array has been chosen for the purpose of this research. It has added advantages over other arrangements. The array is less sensitive to the influence of near-surface lateral heterogeneities. Smoothing and interpretation techniques are much more developed for the Schlumberger array than other arrays.

Well logging involves probing the earth with instruments which give continuous reading recorded at the surface as they are lowered into boreholes. The result of resistivity survey carried out was confirmed by electrical logging of boreholes. All measurements were carried out during the dry season.

GEOLOGY OF DELTA STATE

Some information on the geology of Niger Delta, can be found in the works of Allen (1964, 1965a, 1965b), Nedeco (1950 and 1961) and Maron (1969). The geology comprises of rocks ranging from Tertiary clay-lignite information; the Quaternary coastal plain sands, Sobreiro-Warri deltaic plain, Mangrove swamp beaches and Alluvium deposits.

(i) **Tertiary**

These include the clay-lignite formations. They are made of dark shales, clays and lignite. They occur at Ogwashi-Uku and Asaba area of Delta State.

(ii) Quaternary

The Quaternary rocks consist of:

(a) Coastal sands:

These are very widespread in Agbor and Abraka. Parts of Asaba area lie on this formation. The formation is marked by top reddish earth, underlain by friable yellowish pebbly and clayey interbeds. It has gritty ferrugnized base where it makes contact with the lignite formation.

(b) Sombreiro-Warri deltaic formation:

This overlies the coastal sands. Parts of the Delta, Warri and Ughelli lie on this formation. It is characterized by its yellowish colour and consists of silt, sand and clays. Shallow boreholes at Warri and Ughelli tap their water from this formation

(c) Mangrove Swamp:

This is found around Burutu and is made up of dark-grey silt, clay and sands.

(d) Alluvium:

This is the youngest sedimentary deposit. It occurs at Asaba flood plane of the River Niger and is a very good source of borehole water.

THEORY

The apparent resistivity of an inhomogeneous formation is given by Habberjam (1975) as;

$$\rho_a = 2\pi(1/r_1 - 1/r_2)^{1}\,[1 + (\lambda^2 - 1)\sin^2\theta\sin^2\alpha]^{1\ 2}\,(\Delta\nabla/1) \quad (1)$$

$$= K(\Delta\nabla/1) \quad (2)$$

where K = geometric factor which depends on the array in use,

α = dip of the anisotropy

θ = angle of strike

λ = anisotropy = $(\rho_t/\rho_l)^{\cdot\ 2}$

ρ_l = longitudinal resistivity parallel to a bending plane

ρ_t = transverse resistivity normal to the bending plane,
ΔV = potential difference, and
r_1, r_2 = distances of surface electric potentials from a point source of current I.

The Schlumberger electrode array was used for the purpose of this research. The geometric factor for the Schlumberger array is given as:

$$K = \frac{\pi}{2\ell}(L^2 - \ell^2) \quad (3)$$

where L = distance from the centre of the array to the current electrode,
ℓ = distance from the centre of the array to the potential electrode,

The technique of data interpretation used involves seeking a solution to the inverse problem namely the determination of the subsurface resistivity distribution from surface measurements.

A very good solution to the inverse problem is the Kernel function. It is used in interpreting apparent resistivity measurements in terms of lithological variation with depth. The function assumes the earth to be locally stratified, inhomogeneous and isotropic layers and, unlike apparent resistivity function it is independent of electrode configuration. It cannot be measured in the field but has to be obtained from a transformation of measured apparent resistivities.

The Kernel function utilized in this work is derived after Ghosh, (1971). If the observed apparent resistivity is given by

$$\rho_a(r) = r^2 \int_0^\infty T(\lambda) J_1(\lambda_r) \lambda \, d\lambda \quad (4)$$

Then the Kernel function is given by Ghosh (1971) as:

$$T(\lambda) = \int_0^\infty (1/r) \rho_a(r) J_1(\lambda_r) dr \quad (5)$$

where J_1 is the first-order Bessel function of the first kind, and $T(\lambda)$ is the transformed resistivity data.

Dar-Zarrouk resistivity curve, unlike apparent resistivity curve is independent of any underlying layers. The basic mathematics for graphical construction of Dar-Zarrouk curves are given by Orellana (1963) and Zohdy (1973). The curves may be used to give true layer thickness h_i and resistivity ρ_1 by the equation

$$h_j = \rho_j ((L_{mj}/\rho_{mj}) - (L_{mj-1}/\rho_{mj-1})) \qquad j = 1, 2, 3, \ldots \quad (6)$$

where $h_j = L_{ml}$ and $\rho_l = \rho_{ml}$

where $h_i = L_{mi}$ and $\rho_i = \rho_{mi}$

$$\rho_{mj} = (T_j/S_j)^{1/2}; \; L_{mj} = (T_j/S_j)^{1/2}; \; T_j = \sum_{i=1}^{J} t_i; S_j = \sum_{i=1}^{J} S_i \qquad (7)$$

S = the total longitudinal conductance of a section of horizontal layers of thickness h_i and resistivity ρ_i.

T = total transverse resistivity of the same layer above.

The importance of Dar-Zarrouk function is that it is uniquely related to the apparent resistivity function.

In spontaneous potential logging, resistivity measurements are employed to determine formation resistivity in the non-invaded formation (called true resistivity, ρ_t). It is also used to determine the resistivity close to the borehole (called flush-zone resistivity, ρ_{xo}), where mud filtrate has largely replaced the original pore fluids.

Archie (1942) determined experimentally that the water saturation of a clean formation could be expressed in terms of its true resistivity as

$$S_w^n = F\rho_w/\rho_t \qquad (8)$$

where S_w = the fraction of the pore volume occupied by formation water.

F = formation resistivity factor, n = saturation exponent, ρ_w = resisitivity of water.

Though there exist some variations in the value of n, most formation samples yield a saturation exponent of about 2.

If n = 2, equation (8) becomes

$$S_w = \sqrt{F\rho_w/\rho_t} \qquad (9)$$

This equation is often referred to as the Archie water saturation equation.

Clays and shales do contribute to formation conductivity. Shale conducts because of the electrolyte that it contains and because of an ion-exchange process. All logging measurements are influenced by the shale, as such, and corrections for shale content are required.

There are many formulae that relate resistivity to water saturation in shale sands, most are generally of the form:

$$1/\rho_t = S_w^2(1-V_{sh})/F\rho_w + CV_{sh}/\rho_{sh} \qquad (10)$$

where V_{sh} = volume, or specific volumetric characteristic of shale or clay;

ρ_{sh} = resisitivity of the shale or clay and

C, if it occurs in the formula, is a term related to the water saturation, S_w.

If the shale volumes is zero (i.e, a clean sand), equation (10) reduces to the Archie water saturation equation (8). This is true for all shaly sand water saturation interpretation techniques.

EXPERIMENTAL WORK

Four electrode arrays are commonly used at the surface, one pair for introducing current into the earth, the other pair for measurement of the potential associated with the current, fig 1.

The field procedure in the Schlumberger electrode array system is to expand the current electrodes successively while the potential electrodes remain fixed . This process yields a rapidly decreasing potential difference across the potential electrodes which ultimately exceeds the measuring capabilities of the instrument. At this point a new value for potential electrode separation is selected, typically 2 to 4 times larger than the preceding value and survey is continued. The distance between the potential electrodes must never exceed 2/5 of AB/2 where AB is the distance between current electrodes, that is $CD \leq AB/5$. The field measurements are usually conducted at AB/2 equals 1.0, 1.47, 2.15, 3.16, 4.64, 6.81, 10.0, 14.7, 21.5 31.16, 46.4, 68.1. 100.00, 147.0, 215.0, 316.0, 464 .0, 681.0 and 1000m. The maximum separation depends on the geology of the area, the available space, and the depth of interest.

The corresponding potential electrode separation are 0.15, 0.5, 5.0 and 15.0m. Fig.1 illustrates the Schlumberger electrode array configuration. The geophysical instrument used was the Abem Terrameter SAS (Signal Averaging System) 300B manufactured in Sweden. The instrument operates in two modes: the resistivity surveying mode and the voltage measuring mode used for logging. It consists of about 200m of logging cables with a logging probe and potential reference electrode.

The cable with down-hole logging probe was lowered into the hole step by step (1 m at a time) and readings were taken. This simple logging system makes it possible to delineate formation boundaries with regards to infiltration, porosity and permeability. Water flow boundaries can be detected by measuring temperature changes. Total dissolved solids (TDS) can be estimated if the resistivity of the water can be measured. Zones of high salinity can thus be localized and sealed off by means of casing and cementing.

In case of heavy mound, the weight attached to the logging probe will enable the probe to penetrate through the obstacle
A total of 21 stations were covered for surface electrical survey, using the Schlumberger array, basically to determine the hydrogeology of the various areas of Delta State. Some of these were close to shallow hand-dug well sites where depth of water table could readily be determined by simple tape measurements.

An array of 200m for the current electrodes (AB) were mostly used as this provided enough subsurface information considering the depth of penetration in the Schlumberger array. It was only in stations, 1,2,19, 20 and 21 at Agbor and Ogwashi-Uku that arrays of 400m, were used.

Static water level was measured in eighty-one already existing boreholes in the state.

Geophysical well logging was carried out in four stations using the spontaneous potential (SP) method. These were 1,2,3, and 12. The aims were to correlate the result of surface survey with well logging.

RESULTS AND DISCUSSION

Low resistivity values indicate presence of water (or clay) in the formation. Resistivity depends on salinity of water, water saturation and occurrence of intercalation among formations.

The field curves obtained from these soundings were interpreted by applying the curve matching procedure and computer-based interpretation techniques. Koefoed, (1968).

The computer assisted interpretation used for this project is based on the algorithm which employs digital linear filters for the fast computation of the resistivity function for a given set of layers parameters.

All data collected in the field were very consistent and of good quality. The geometric factor for Schlumberger array system was used in converting the digital data obtained from the field into apparent resistivity values. These data with their corresponding electrode spacing data were fed into an automatic computer programme written in accordance with the theory above.

Logarithmic scale graphs of apparent resistivity versus $\frac{AB}{2}$ obtained from the computer results were plotted for all stations. Typical results are shown in Fig 2 and 3.

Table 1 shows the various stations and curves types. There was no station with Q – type ($\rho_1 > \rho_2 > \rho_3$)

Fig 4 is an example of a logging curve. It was carried out in Owa-Alero in Ika North L.G.A. of Delta State. High negative potential indicates presence of sand bed while low negative to low positive potential indicates shale or clay. The drillers' logs were compared with electrical resistivity logs and a high positive correlation was established.

The results of drilling logs and SP logs of some boreholes in Delta State confirm the results got from surface resistivity survey.

CONCLUSION

The research was carried out extensively in Delta State. Low resistivities were attributed to saline water. The highest resistivities were recorded in the northern Delta such as Ogwashi-Uku, Issele-Uku, Umunede, Owa-Alero and Abavo zones. The high resistivities of these areas correspond to the dry, unsaturated zones. There exists an area of low salinity resulting in higher resistivity. This area has the lowest acquifers as shown in table 2.

The general direction of ground water flow is coincident with topography though, obviously, having a lower gradient. Local ground water flow is radial and converges towards the main creeks of the area. The areas close to the river have higher aquifers when compared to areas far away from the river.

There was a high correlation between drillers' logs and SP logs. These logs confirm results obtained from surface resistivity survey in the area of research.

Table 1: Various stations and curve – types

Curve-type	Stations (and Resistivities)
1. K-type ($\rho_1 < \rho_2 > \rho_3$)	1, 3, 4, 6, 8, 9, 10 and 12 Lowest resistivity = 45Ωm. Highest = 5000Ωm
2. K-H type ($\rho_1 < \rho_2 > \rho_3 < \rho_4 < \rho_5$)	2, 19, 20 and 21 Lowest resistivity = 549Ωm Highest resistivity = 6783Ωm
3. A type ($\rho_1 < \rho_2 < \rho_3$)	7 Lowest resistivity = 158Ωm Highest resistivity = 3630Ωm.
4. H type ($\rho_1 > \rho_2 < \rho_3$)	11, 13, 14, 15,16, 17 and 18 Lowest resistivity = 140Ωm. Highest resistivity = 994Ωm.

Table 2 shows total number of sounding locations and results of survey, direct measurements and SP well logging

		STATIC WATER LEVEL (M) METHOD	
Station	Location	VES (M)	Direct Measurement
1	Charles St. Agbor	60.00	56.0
2	Coll. Of Education, Agbor	62.0	56.4
3	Okoh St. Agbor	20.0	18.0
4	New Road, Abraka	16.0	
5	Urhuoka-Abraka	15.0	15.20
6	Erho-Abraka	18.0	
7	Sapele-Agbor Rd. Sapele	6.0	
8	Warri-Sapele Rd., Sapele	5.0	5.5
9	AT&P Area Sapele	6.0	
10	Oleh 1, Isoko L.G.A.	10.0	8.50
11	Oleh 2, Isoko L.G.A.	9.0	
12	FCA Resort Ibusa	35.0	
13	Ughelli Loc. 1	4.5	4.6
14	Ughelli Loc. 2	5.0	
15	Ughelli Loc. 3	4.0	
16	Warri, Loc. 1	5.0	6.10
17	Warri, Loc. 2	6.0	
18	Warri, Loc. 3	6.50	
19	Ogwashi Uku Loc. 1	90.0	85.30
20	Ogwashi Uku Loc. 2	88.0	
21	Ogwashi Uku Loc 3	86.0	

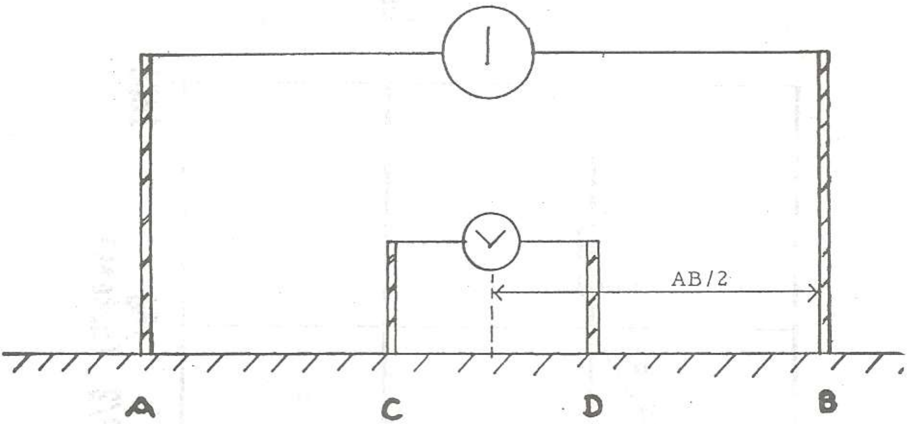

Fig 1. Schlumberger Electrode Array

I	=	Current
V	=	Voltage
A, B	=	Current Electrode
C,D	=	Potential Electrode

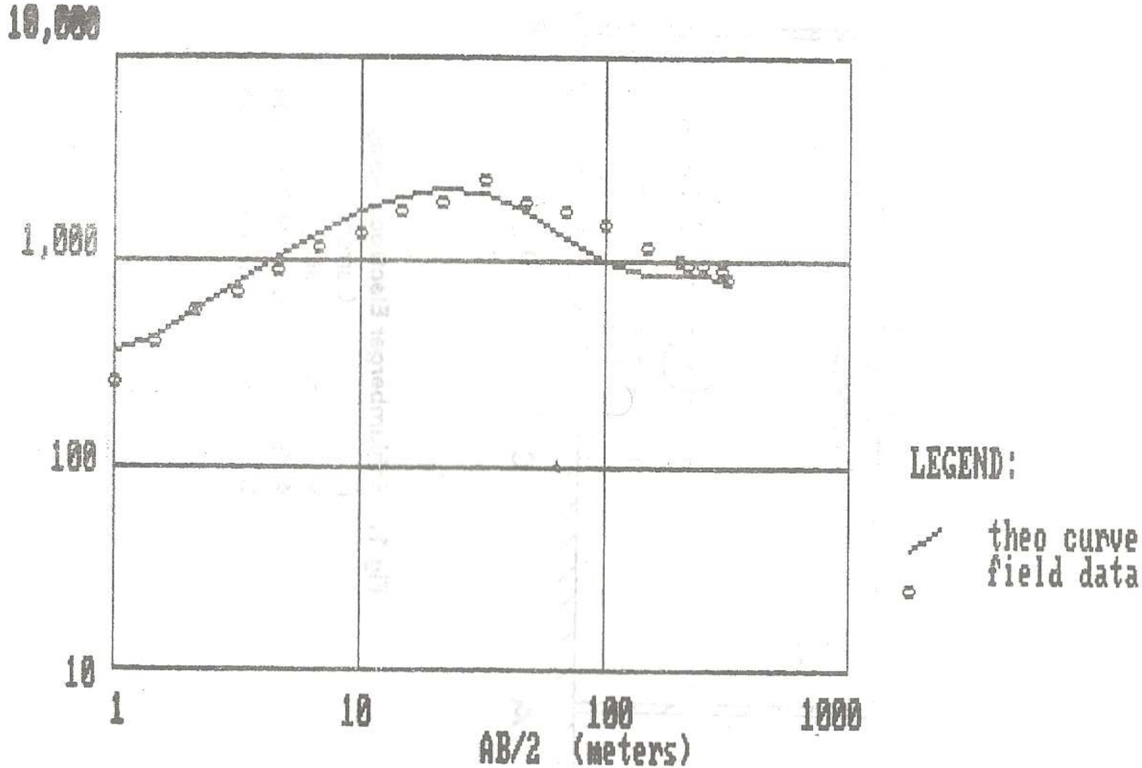

FIG 2. : RES VERSUS ELECTDRODE SPACING NEW RD ABRAKA LOC 4

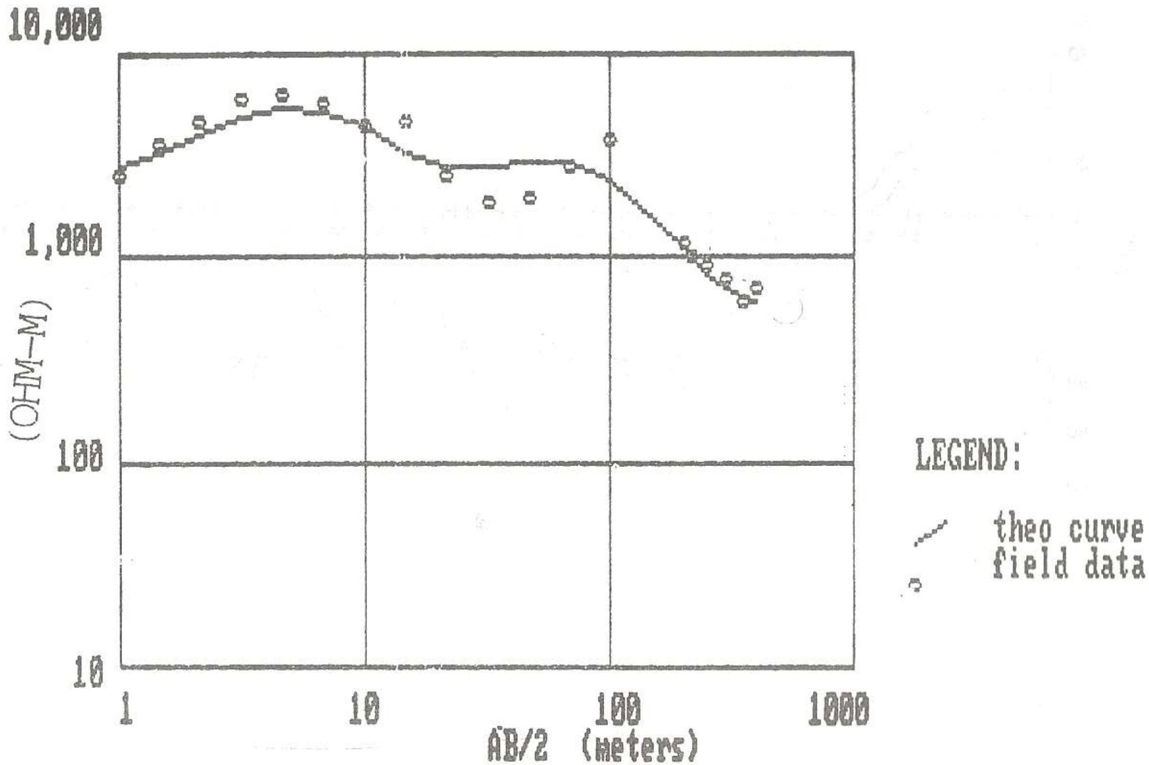

Fig 3 :RES VERSUS ELECTRODE SPACING COLL OF EDUC AGBOR LOC 2

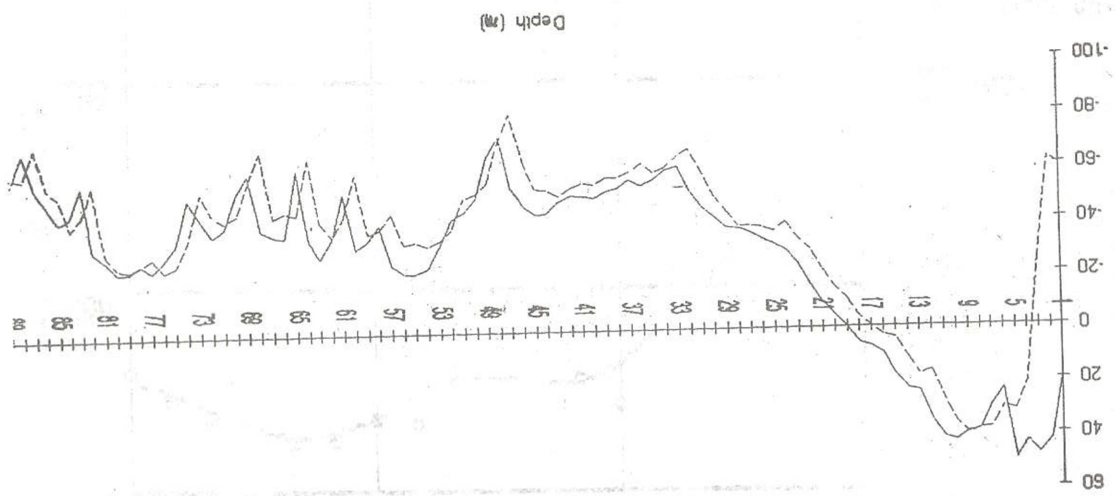

FIG. 4. SPONTANEOUS POTENTIAL LOGGING (OWA-ALERO, IKA NE LGA).

REFERENCES

1. Allen J.R.L. (1964): Nigerian continental margin. *Geol.* Vol 1 pp 289-322
2. _______ (1965a): Coastal geomorphology of eastern Nigerian beach ridge barrier islands and vegetated tidal flats. *Geol. Mijinbouw* Vol. 44, No. 1, pp 1-21.
3. _______ (1965b): Late Quaternary Niger delta and adjacent areas. *Am Assoc. Petroleum Geologists Bull.* Vol. 49 pp 547-600.
4. Archie, G.E. (1942): The electrical resistivity as an aid in determining reservoir characteristics:, *J. Pet Tech.* Vol. 5, No1.
5. Ghosh, D.P. (1971): Inverse filter coefficients for the computation of apparent resistivity standard curves for a horizontally stratified earth. *Geophys. Prosp.*, Vol. 19, No.14 pp 769-775
6. Habberjam, G.M. (1975): Apparent resistivity, anisotropy, and strike measurements . *Geophys. Prosp.*, Vol 23, No 2 pp. 211-247
7. Koefoed,O. (1968) The application of Kernal function in interpreting geoelectrical resistivity measurements. Gebruder Borntraeger. Berlin *Geoexploration Monographs series.* 1, No 2, p. 108.
8. Maron, P. (1969): Stratigraphical aspects of the Niger delta ; *Nigerian Journal Mining and Geology.* Vol. 4, p.1-2
9. NEDECO (Netherlands Engineering Consultants) (1959): River studies and recommendations on the improvement of Niger and Benue. Amsterdam, 1000pp.
10. _______ (1961) The waters of the Niger delta. The Hague, 317 pp.
11. Orellana, E. (1963): Properties and drawing of the so-called Dar-Zarrouk curves". *Geophs.* Vol 28, No 1 pp 99-110.
12. Zohdy, A.A.R. (1973): Automatic interpretation of resistivity sounding curves using modified Dar Zarrouk functions". *Geophysical prosp.* Vol. 38, No. 1, pp. 196-197