EFFECTIVENESS OF THE AJAYI - MAKINDE TWO - ELECTRODE ARRAY AS A GEOELECTRIC PROSPECTING METHOD IN DEPTH – TO - BASEMENT DETERMINATION

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ABSTRACT

A geoelectric investigation employing vertical electrical soundings (VES) using the Ajayi - Makinde Two-Electrode array and the conventional Schlumberger configuration was carried out in the Main Campus of Ahmadu Bello University (A.B.U.) Zaria with the aim of testing the reliability and effectiveness of the Ajayi-Makinde Two - Electrode array in depth - to - basement determinations. Interpretations of the two-electrode data and the Schlumberger data revealed that the geometry of the bedrock underlying the Main Campus is undulating. The depth – to - basement values for the Ajayi – Makinde Two – Electrode array ranges from 13.0 m in the central part of the study area to about 30.0 m around the southern end while that obtained from the Schlumberger configuration ranges from 11.0 m in the central part of the study area to about 29.0 m in the southern end. Results of the VES interpretation obtained in this work using the Ajayi - Makinde Two - Electrode array have compared very well with those obtained using the Schlumberger array at the same VES stations. The depth – to - basement values obtained in this work have also compared well with those obtained by previous researchers in the area. The Ajayi - Makinde Two - Electrode array is therefore reliable and effective and can be of use as a geoelectric prospecting method.

KEYWORDS: Two–Electrode Array, Vertical Electrical Sounding, Depth–to–Basement and "Bulk Resistivity"

INTRODUCTION

There are quite a number of different electrode arrangements used in electrical D.C. resistivity survey. These include the two - electrode arrangement, the three - electrode arrangement, the common four - electrode arrangement and the six - electrode arrangement (Jain and Roy, 1973).

The four - electrode arrangement is actually the most widely used electrode arrangement for electrical resistivity surveys. Of the different forms of the four - electrode arrays, the Wenner and Schlumberger Configurations are the most commonly used arrangements. Jain and Roy (1973) have discussed the theory of these arrangements, both of which employ four electrodes arranged along straight lines

Apparao and Roy (1973) and Kumar (1974), worked on a combination which consists of one current electrode and one potential electrode placed at sufficiently large distance that can approximate to infinity from the measuring environment. Gupta and Bhattacharya (1963) and Brizzolari and Bernabini (1979), reported on a combination that consists of two current electrodes both of which feed current into the ground with non acting as a return electrode.

The two - electrode method used in this work is that used by Makinde in 1996. The configuration is now referred to as the Ajayi - Makinde Two - electrode array (Ajayi and Makinde, 2000). The theory and arrangement of the method also referred to as the C-C mode is given in Ajayi and Makinde (2000)

AIM AND OBJECTIVES

The primary aim of this work is to test the reliability and effectiveness of the Ajayi - Makinde two - electrode method in depth – to - basement determinations. This aim will be achieved by:

➢ Carrying out vertical electrical D.C. resistivity surveys using the Ajayi – Makinde Two - electrode array and then followed by the Schlumberger array at the same VES stations.

➢ Comparing the results obtained from the VES interpretations of both sets of data and also with the results obtained by previous workers in the area.

The Main Campus of A.B.U. Zaria situated in the Kubanni River Basin was chosen as the project area in this work because the geology of the basin is well known.

LOCATION AND GEOLOGY OF THE STUDY AREA

The Main Campus of Ahmadu Bello University (A.B.U.) Zaria is the project area investigated in this work. It is part of the Kubanni River Basin which is situated in the north-central part of Nigeria (Fig. 1).

The Main Campus is located in the north - western part of the Kubanni Basin and occupies about 9% of the area of the basin. The Main Campus is approximately bounded by latitudes 11^0 09' N and 11^0 10' N and longitudes 7^0 38' E and 7^0 39' E (Fig.1). It is a built up area and the part investigated in this work is the western half of the Main Campus.

As reported by McCurry (1970), the Nigerian

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basement complex rocks are exposed over more than half of the land surface of Nigeria. The rocks are exposed mostly in the northern, western and eastern flank of Nigeria that has border with the Republic of Cameroun.

According to Thorp (1970), Zaria, which contains the Main Campus of A.B.U. Zaria, is a part of the gently undulating peneplain that extends east -west from Lake Chad to Sokoto and northwards from the southern parts of Kaduna to Tripoli in the Republic of Niger.
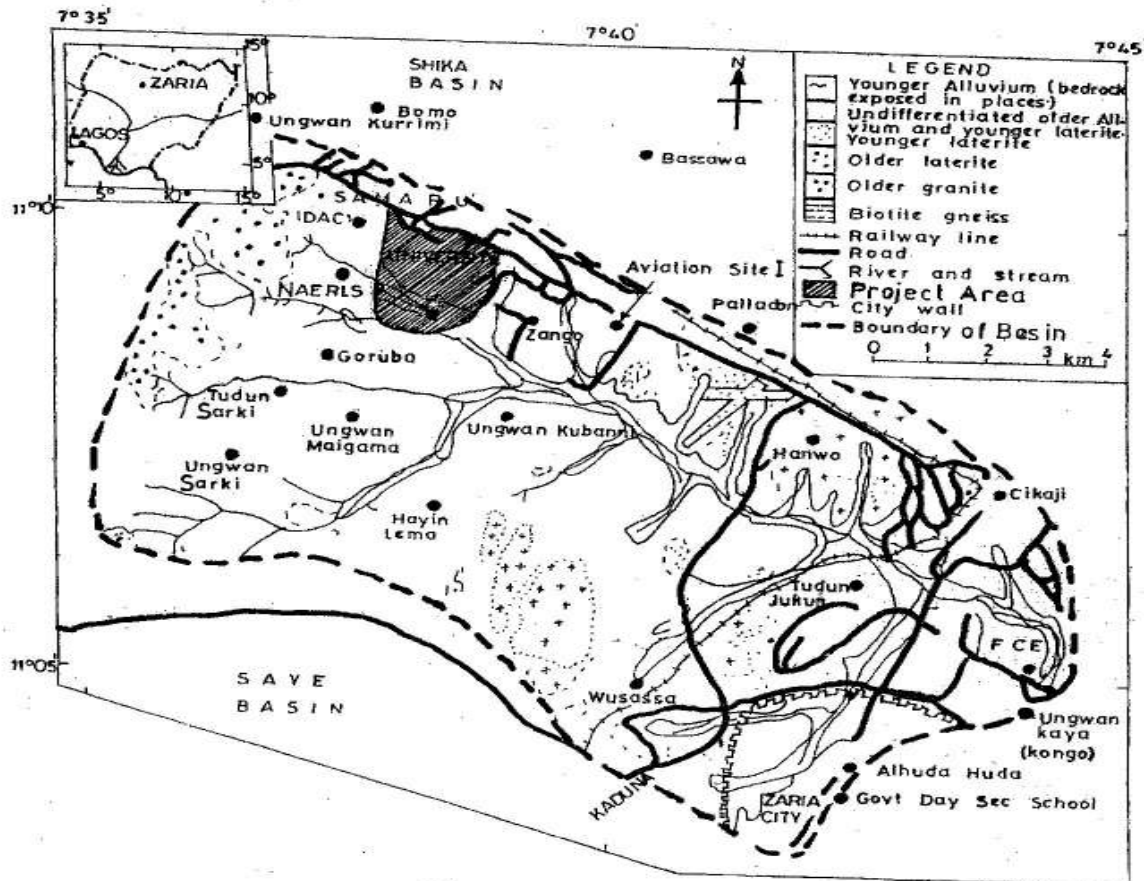

Fig. 1: Location of the Project Area within the Geological Map of the Kubanni Basin(Modified from Shemang, 1990).

As stated by Oyawoye (1964), the Nigerian basement complex is the end result of at least two major cycles. The last of the cycles probably extended from Late Cambrian to Lower Paleozoic. The cycles were believed to have been be initiated by the deposition of thick sands, mud and greywacke on igneous material cover and eroded metamorphic basement during the preceding cycle Oyawoye (1964).

As a result of the extensive re- metamorphism and partial mobilization of the underlying basement, the accumulated materials were developed into high-grade gneiss, migmatites and older granite (Trustwell and Cope, 1963; Wright and McCurry, 1970). The superficial deposits that cover most of the basement rocks in the

Kubanni Basin act as recharge areas where they are underlain by weathered basement (Eigbefo, 1978).

The Main Campus is underlain by Precambrian rocks of the Nigerian basement complex. Muscovite biotite-gneiss occupies the southern and western parts of the Campus while the northern and eastern parts are underlain by biotite granite-gneiss (Eigbefo, 1978).

The laterite contains little water which is mostly unconsolidated and, because they are shallow, they receive direct recharge from rainfall. The alluvial deposit in Zaria area consists of gravels, sands, silts and clay which are mostly found along stream channels.

According to Olowu (1967) and Eigbefo (1978), the weathered basement is the main storage element for groundwater in the Kubanni basin. As the case in the

entire basin, the aquifer in the Main Campus is covered by laterite loam (Wright and McCurry, 1970; Eigbefoh, 1978). Their thickness ranges from 5 – 15 m (Olowu, 1967).

A lot of geophysical studies have been carried out in the Kubanni Basin. Most of the researchers such as: Ososami (1968), Olugbemiro (1985), Hassan (1987), Shemang (1990), Bajeh (1992), Makinde (1996), Afolalu (2009),
Ameloko and Rotimi (2010), Ameloko and Omali (2011), Egwuonwu and Sule (2012), Fadele et al (2013), Osumeje and Kudamnya (2014) reported that the

bedrock in the Kubanni Basin is undulating with depth values ranging from less than a metre to a maximum of about 50 m.

DATA ACQUISITION, REDUCTION AND INTERPRETATION
The fieldwork in this research was carried out in the month of March, during the dry season. A total of thirty-seven (37) points were sounded. The points "sounded" or "stations established" were carefully selected to ensure adequate and uniform coverage of the study area as shown in Fig. 2.
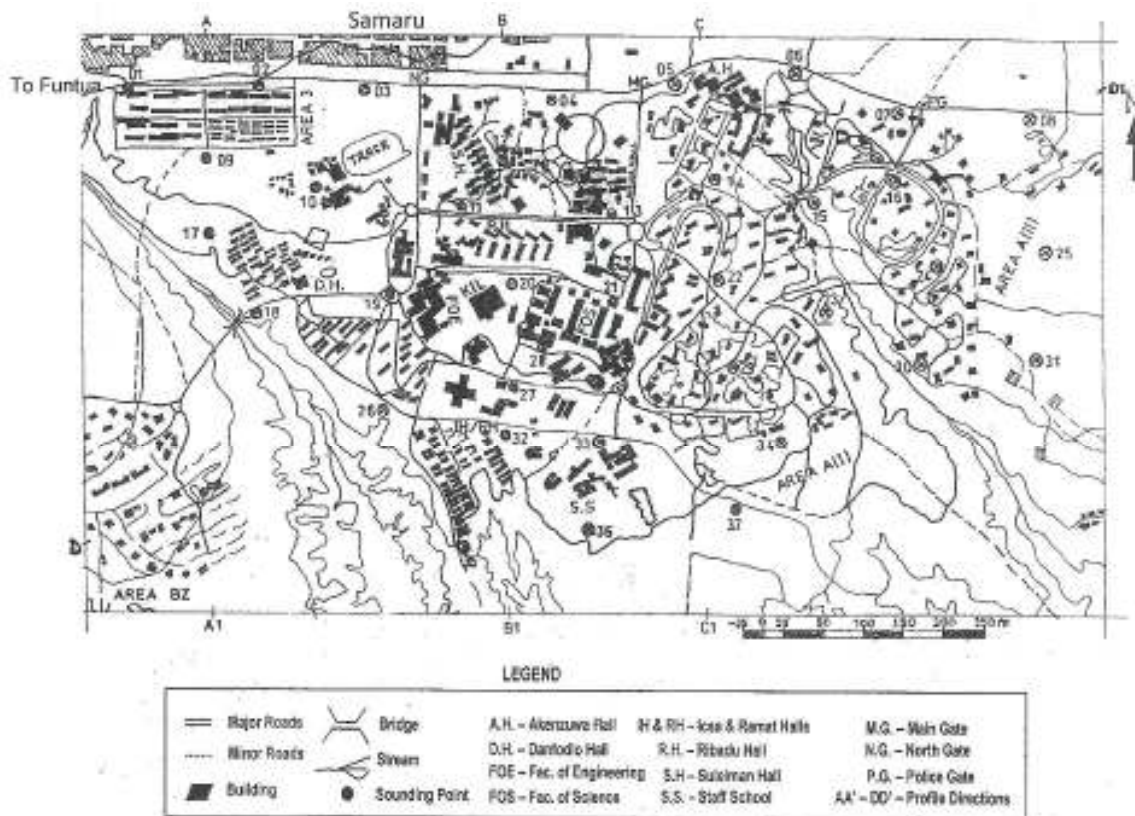

Fig. 2: Map of the Study Area Showing the Sounding Points (Courtesy Of U.R.P. Dept. ABU, Zaria)

Vertical electrical sounding (VES) were carried out at each of the 37 stations using the two - electrode array and then followed by the Schlumberger configuration. Thus a total of seventy- four (74) VES were conducted.

As the Ajayi - Makinde Two - electrode array is a new technique, no equipment had, as at the time of the fieldwork, been fabricated for it. Hence an arrangement which basically consist of an electric generator as the power source, a voltmeter, an ammeter, two copper electrodes, two reels of wire and connecting wires were used. The electric generator is an ET 500 YAMAHA with an output of 250 V, 50 Hz, capable of delivering a maximum current of 300 mA. A high tension laboratory power pack was used to convert the alternating current (A.C.) to direct current (D.C.),

which was then passed into the ground through the copper electrodes. A voltmeter with a range of 0-300 V was used to measure the potential difference (V) across the electrodes while an ammeter with a range of 0 - 300 mA measures the current (I) passed into the ground.

The field equipment used for the Schlumberger configuration consists of an ABEM Terrameter SAS 300, copper electrodes, four reels of wire and connecting wires.
For the two - electrode array, the field procedure involved the expansion of L/2 (half the current electrode spacing) symmetrically about the centre point or point being sounded. Half the current electrode spacing L/2 was expanded in steps from 0.5 m to a maximum of 100 m. For each measurement, I, V and the electrode spacing L were recorded.

Table 1: Typical Reduced Data Using the Two-Electrode Array for VES 25.

L (m)	L/2 (m)	V (Volts)	I (mA)	$\rho_b(\Omega\ m)$
1.0	0.50	188	42	659.2
2.0	1.00	174	32	1601.5
3.0	1.50	147	54	202.6
4.0	2.00	173	34	997.2
5.0	2.50	135	45	208.9
6.0	3.00	120	48	208.9
7.0	3.50	113	46	713.2
8.0	4.00	106	39	202.0
9.0	4.50	91	43	804.8
10.0	5.00	120	55	212.9
15.0	7.50	101	52	290.4
20.0	10.00	122	49	333.1
25.0	12.50	116	51	373.7
30.0	15.00	105	56	283.5
35.0	17.50	103	53	0016.6
40.0	20.00	72	44	9638.9
45.0	22.50	75	45	1044.7

Table 2: Typical Reduced Data Using the Schlumberger Array for VES 25.

MN (m)	AB/2 (m)	R (Ω)	$\rho_b(\Omega\ m)$
1.0	1.00	193.0240	454.8
	1.50	68.4525	430.1
	2.50	22.5050	424.2
	3.75	8.5013	368.9
	5.00	4.1271	320.9
	7.50	1.1890	209.2
	10.00	0.6111	191.5
3.0	7.50	3.9470	223.2
	10.00	1.6270	166.5
	15.00	0.5179	120.8
	25.00	0.1852	120.8
	37.50	0.1131	166.5
	50.00	0.0721	188.8
10.0	37.50	0.3890	168.9
	50.00	0.2830	220.1
	75.00	0.1677	295.1
	100.00	0.1194	374.1

In deriving the formula for calculating the apparent or "bulk" resistivity, ρ_b, Ajayi and Makinde (2000), assumed that: the portion of the earth material sounded by the electrodes is a hemisphere whose volume can be approximated by a horizontal cylinder of the same volume but whose diameter is L/2.

Applying the simple expression of Ohm's law (i.e. $R = \frac{V}{I}$) and by extension to the Ajayi - Makinde two- electrode sounding analog for a cylindrical load of uniform cross-section A and length l, the resistivity of the load is

$$\rho = \frac{RA}{l} \quad \dots\dots\dots\dots \quad (1)$$

Substituting for $R = \frac{V}{I}$ into equation (1) gives

$$\rho = \frac{A}{l}\frac{V}{I} \quad \dots\dots\dots\dots \quad (2)$$

The volume of a sphere of radius r is $(4/3)\pi r^3$, hence, the volume v, of the equivalent hemisphere is $(2/3)\pi r^3$. But $r = L/2$

Hence , $\quad v = \frac{2\pi(L/2)^3}{3} \quad \dots\dots\dots \quad (3)$

$$v = \frac{\pi L^3}{12} \quad \dots\dots\dots \quad (4)$$

The volume, v, in equation (4) is also the volume of the equivalent cylinder of the load, i.e.,

$$\pi \left(\frac{L}{4}\right)^2 l = \frac{\pi L^3}{12} \quad \dots\dots\dots(5)$$

Where l is the length of the cylinder. This implies that

$$l = \frac{4L}{3} \quad \dots\dots\dots \quad (6)$$

The cross-sectional area, A, of the cylinder is

$$A = \pi x^2 = \pi \left(\frac{L}{4}\right)^2$$

where $x = \frac{L}{4}$ = radius of cylinder.

Thus $\quad A = \frac{\pi L^2}{16} \quad \dots\dots\dots\dots \quad (7)$

Substituting for equations (6) and (7) into (3) gives

$$\rho - \left(\frac{3\pi}{32}\right)\left(\frac{L}{2}\right)\left(\frac{V}{I}\right) \quad \dots\dots \quad (8)$$

$$\rho = \frac{3\pi}{64}L\left(\frac{V}{I}\right) \quad \dots\dots\dots \quad (9)$$

or $\quad \rho = k\frac{V}{I} \quad \dots\dots\dots\dots \quad (10)$

where k = (3πL)/64 is the geometric factor of the array. Since the various layers being sampled as the electrode spacing increases are not of the same material, ρ in

equation (10) is actually the "bulk" or apparent resistivity ρ_b of the layers sounded. Hence equation (10) is better written as

$$\rho_b = k\frac{V}{I} \quad \dots\dots\dots\dots \quad (11)$$

From equation (11) a plot of ρ_b against L/2 is expected to give a set of straight lines whose slope is given by

$$S_n = \pm\frac{3\pi}{32}\left(\frac{V}{I}\right) \quad \dots\dots\dots \quad (12)$$

Keller and Frischknecht (1966) assumed that the resistivity of the earth ρ_z at depth z, is given by

$$\rho_z = \rho_1 e^{\pm\alpha z} \quad \dots\dots\dots\dots \quad (13)$$

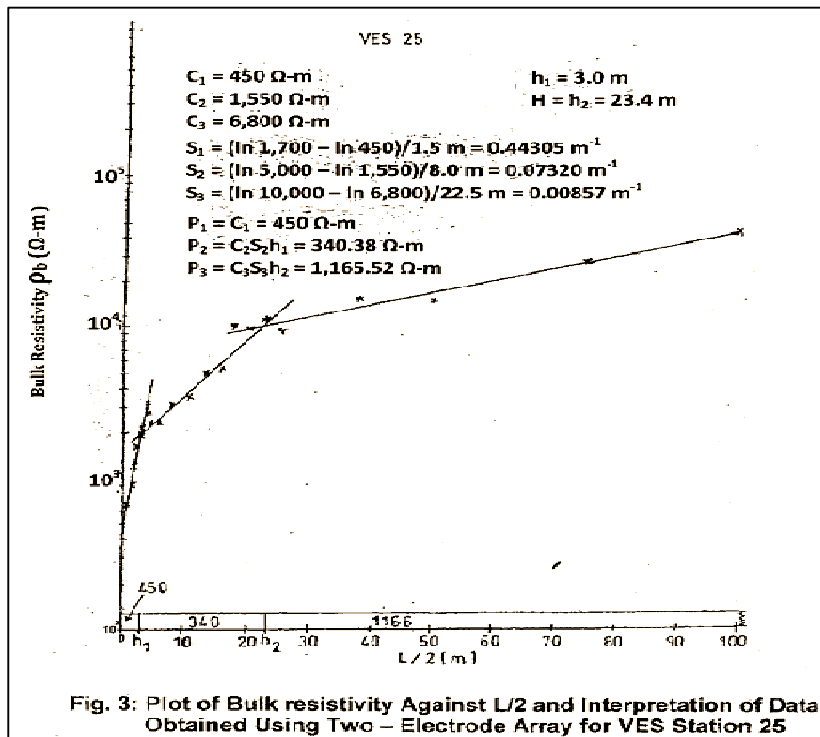where ρ_z is the resistivity at depth z, ρ_1 is the resistivity at the surface or top and α is a parameter defining the rate of increase or decrease with depth. Taking the logarithm of both sides of equation (13) gives

$$ln\rho_z = ln\rho_1 \pm \alpha z \quad \dots\dots\dots \quad (14)$$

It therefore follows that a plot of $ln\rho_z$ against z is expected to give a straight line whose slope is α and intercept $ln\rho_1$. The computed "bulk" resistivity ρ_b, values as in Table 1 were determined by equation (11).

The values of ρ_b and their corresponding values of L/2 plotted on a semi-log graph sheet is expected according to equation (13) to give a series of straight lines joined end-to-end. The intercepts on the L/2 axis at the points of intersection of the straight line segments gives the depth of the various layers. Fig. 3 is a typical example of such a plot for VES station 25.

As adopted by Makinde (1996), the intercept (i.e. h) values of the points of intersection of the segments of a plot on the horizontal (L/2) axis were read off. The intercept (h_1) of the first two segments gives the thickness of the first layer while the intercept (h_2) of the 2nd and 3rd segments gives the depth of the 2nd layer from the surface. The thickness of the 2nd layer is therefore ($h_2 - h_1$). The depth – to -basement value (H) is the value of the intercept of the last two segments of a plot. For VES station 25 (Fig. 3) the depth to the basement is H = h_2 = 23.4 m.

Fig. 3: Plot of Bulk resistivity Against L/2 and Interpretation of Data Obtained Using Two – Electrode Array for VES Station 25

For the Schlumberger array, the field procedure involved the expansion of AB/2 symmetrically about the centre of the spread while keeping the potential electrodes (MN) relatively fixed. The data collected consists of the resistance value read from the Terrameter, the current electrode AB and their corresponding MN values. The computed "apparent resistivity" values formed the resistivity data for that particular station. Table 2 is a typical reduced data for the Schlumberger array for VES station 25.

The data obtained using the Schlumberger configuration was interpreted by using a computer program (Offix Version 2.0), which performs an iterative curve matching process. The results of the interpretation are in terms of a layered - earth model. A typical example of such an interpretation carried out using the computer program, which shows the curve and model for VES station 25 is given in Fig 4.

Fig. 4: Interpretation of Apparent Resistivity from the Schlumberger Interpreted Data for VES 25.
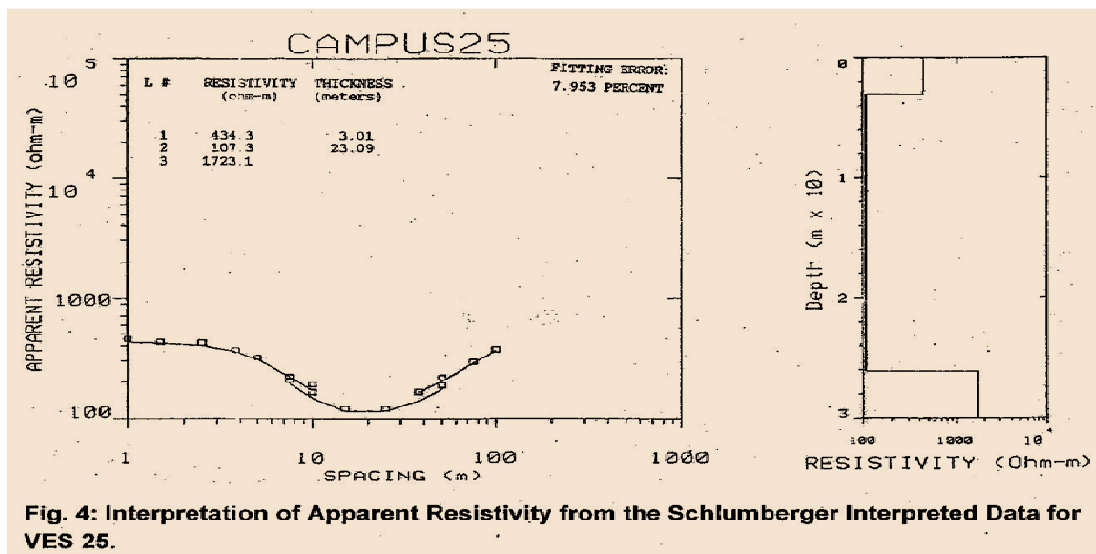
RESULTS AND DISCUSSION

Figs. 5 and 6 are the depth – to - basement contour maps for the Two-Electrode and Schlumberger arrays respectively

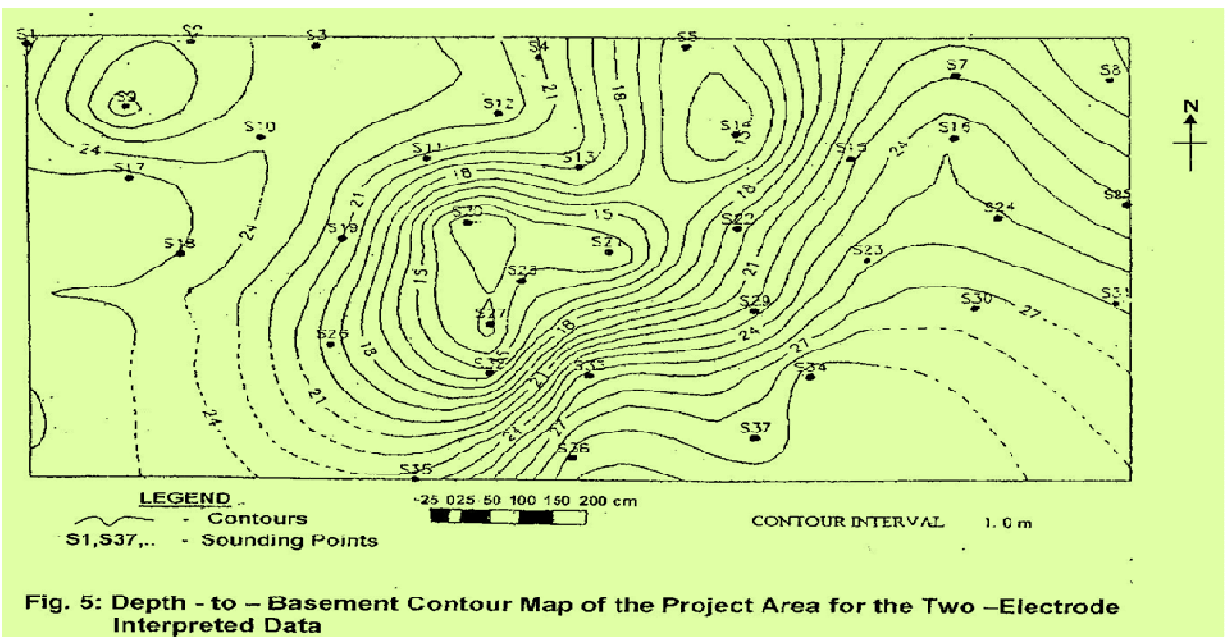Both contour maps (Figs. 5 and 6) are characterized by closures of low and high depth – to - basement values.

Fig. 5: Depth - to – Basement Contour Map of the Project Area for the Two –Electrode Interpreted Data
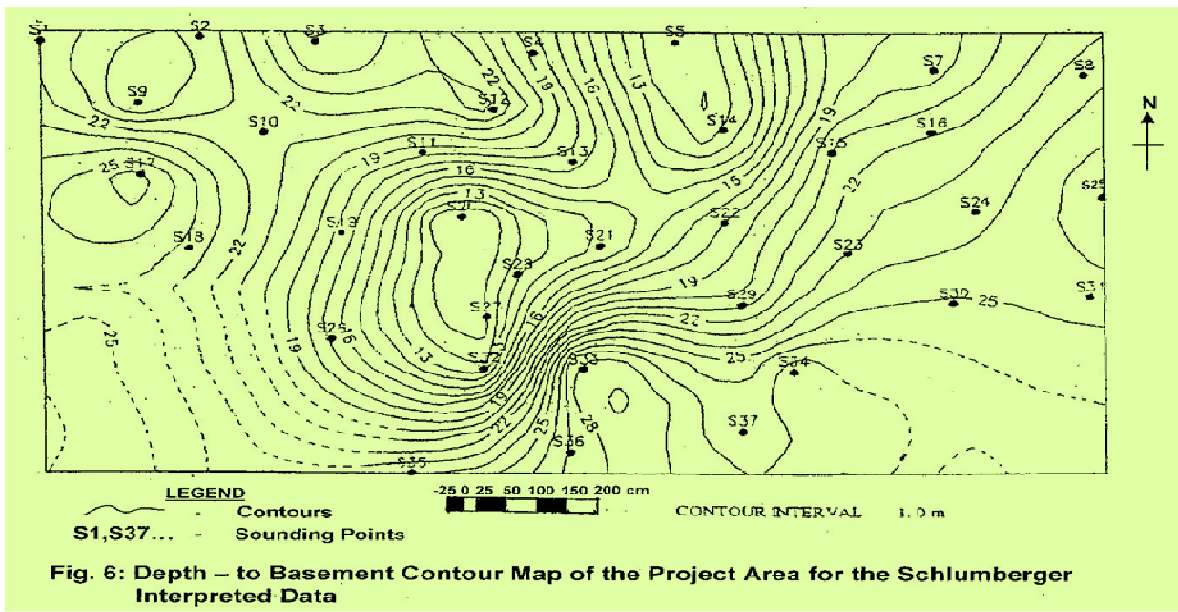

Fig. 6: Depth – to Basement Contour Map of the Project Area for the Schlumberger Interpreted Data

Figs. 7 and 8 are the 3-D cross-section diagrams respectively for the Two - Electrode and Schlumberger arrays.

Geoelectric sections from the interpretation of the two sets of data were drawn along four profiles AA', BB', CC' and DD' as given in Figs. 9, 10, 11 and 12 respectively.

The undulating nature of the basement underlying the Main Campus is shown in the diagrams.
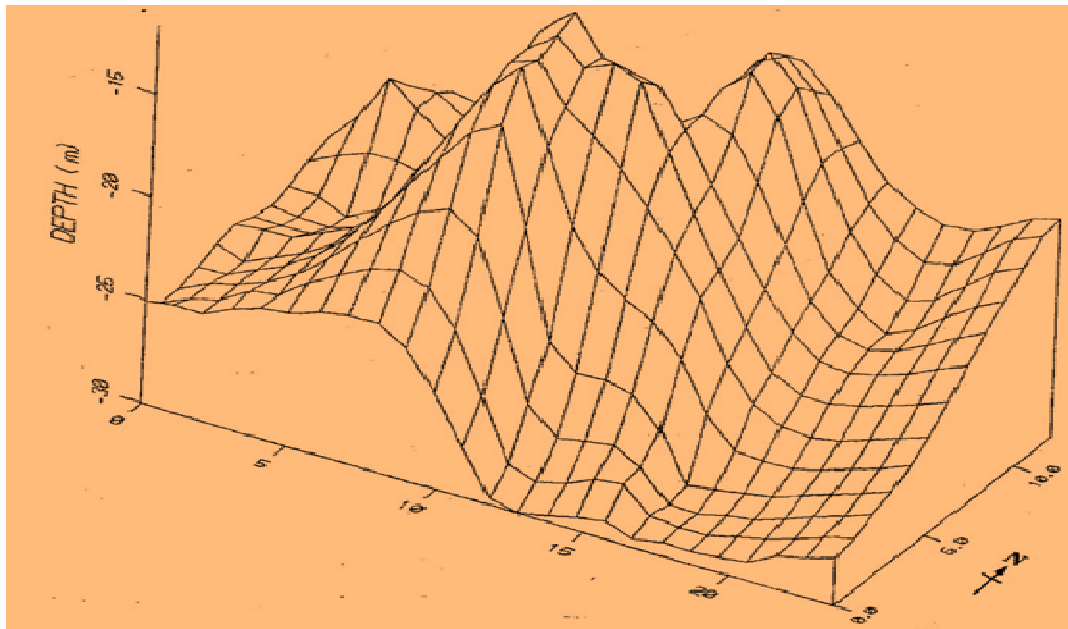
Fig. 7: 3 — D Cross Section View of the Basement Underlying the Project Area from the Two — Electrode Interpreted Data
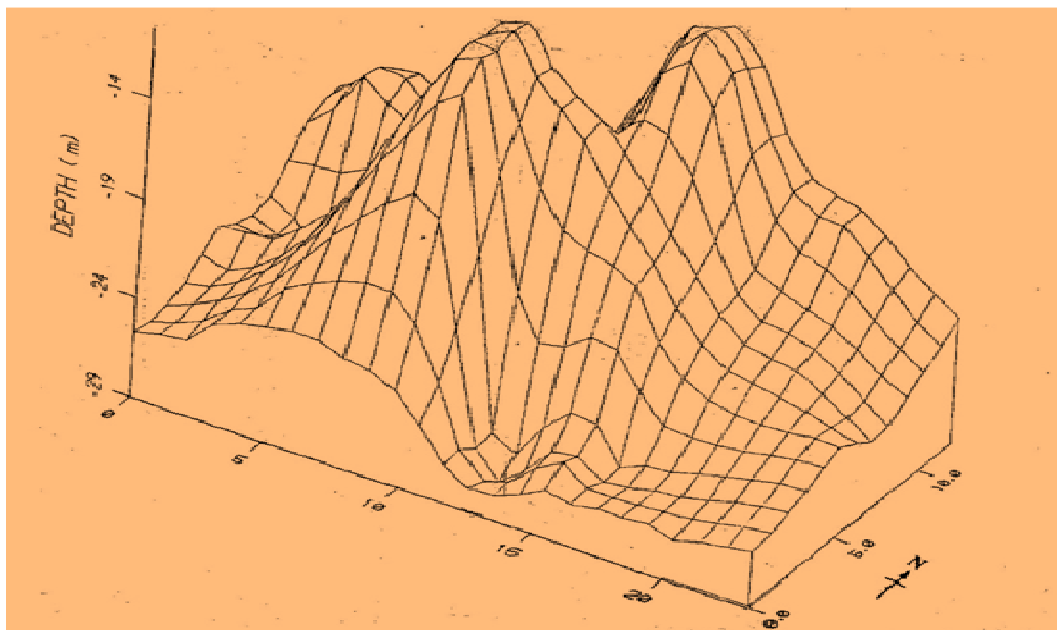

Fig. 8: 3 — D Cross Section View of the Basement Underlying the Project Area from the Schlumberger Interpreted Data
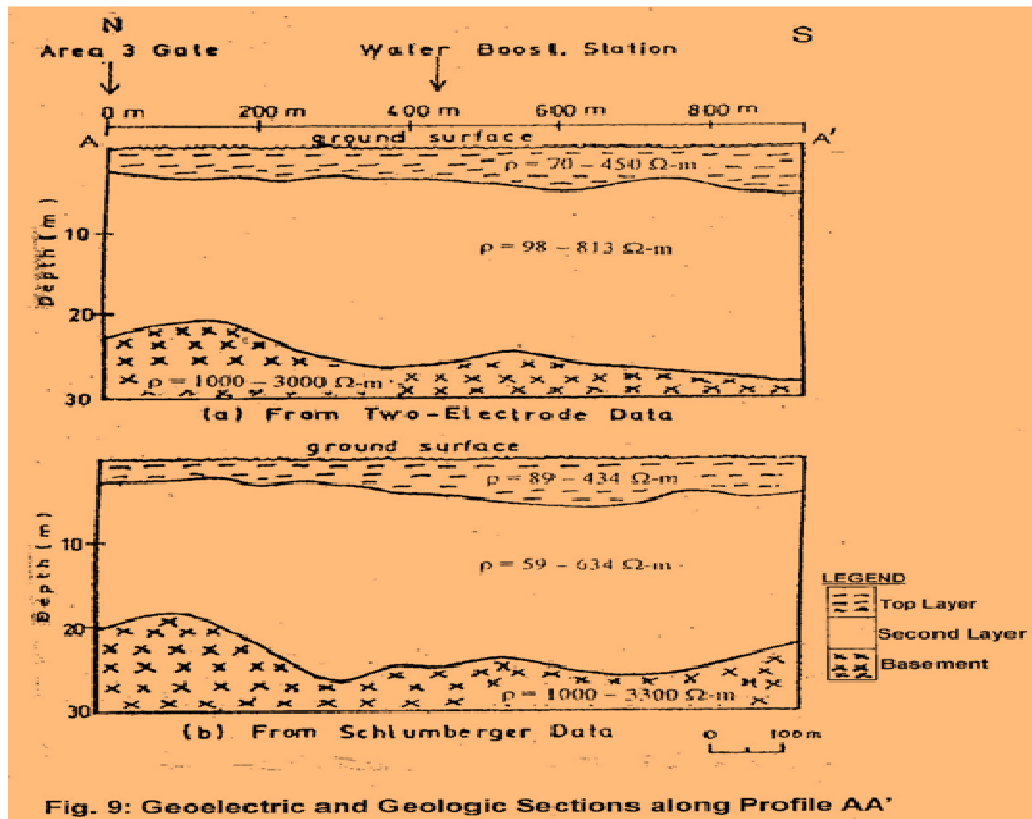
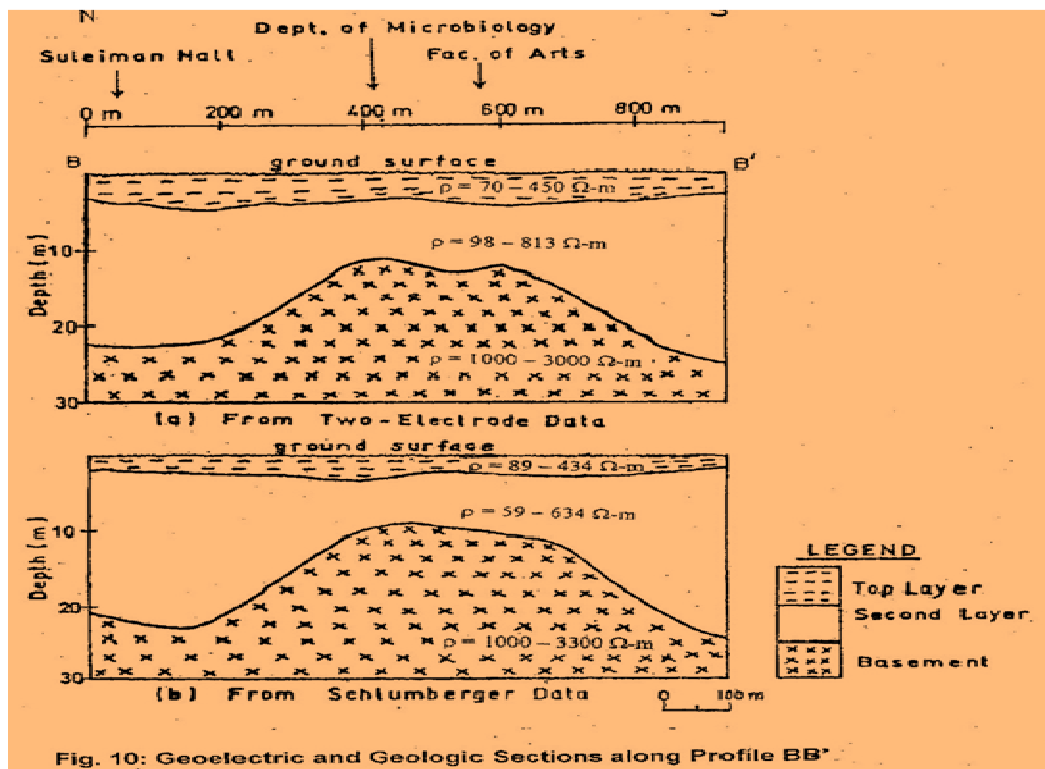Fig. 9: Geoelectric and Geologic Sections along Profile AA'

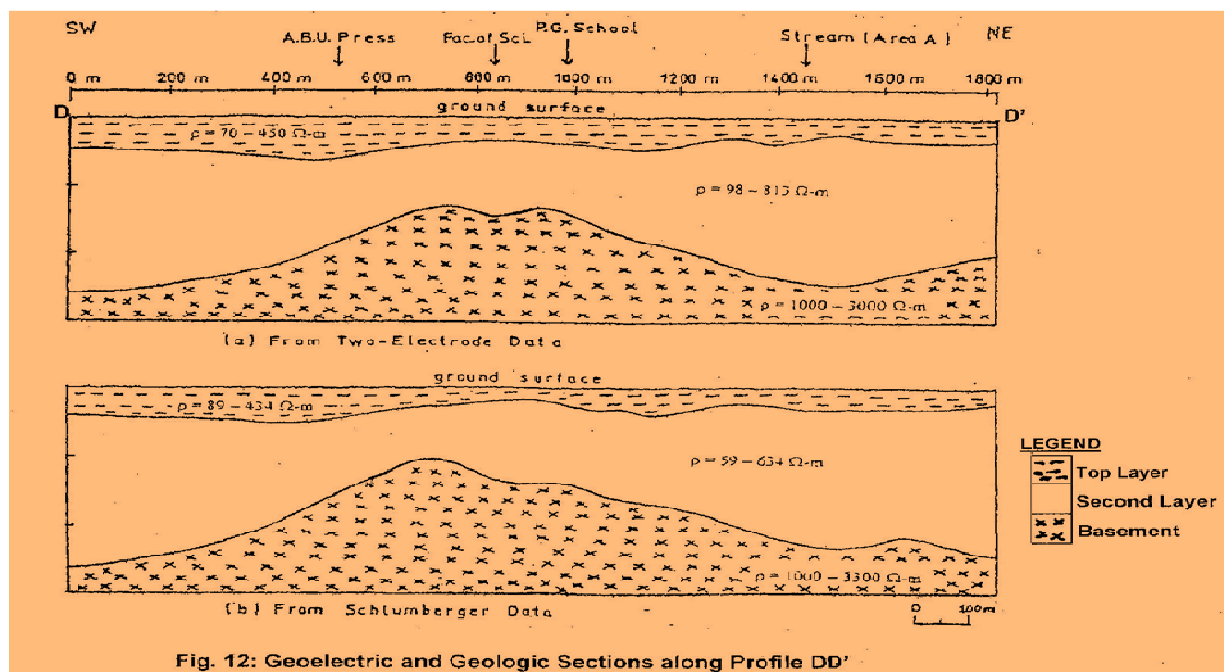Fig. 10: Geoelectric and Geologic Sections along Profile BB'

Fig. 12: Geoelectric and Geologic Sections along Profile DD'

Table 3: Depth – to - Basement Values for the Two Sets of Data

VES STATION No.	DEPTH-TO-BASEMENT VALUES (m)		VES STATION No.	DEPTH-TO-BASEMENT VALUES (m)	
	TWO-ELECTRODE ARRAY	SCHLUMBERGER ARRAY		TWO-ELECTRODE ARRAY	SCHLUMBERGER ARRAY
01	25.5	22.0	20	10.5	8.3
02	22.0	20.0	21	11.5	13.1
03	24.0	25.8	22	20.0	18.4
04	21.0	18.0	23	26.0	23.1
05	15.0	10.1	24	25.0	23.5
06	20.0	18.3	25	23.4	26.1
07	23.0	19.3	26	19.5	16.7
08	20.0	23.7	27	12.0	10.1
09	30.0	18.6	28	15.0	13.4
10	24.0	21.0	29	22.0	19.9
11	21.0	18.4	30	27.5	25.1
12	23.0	24.0	31	26.0	24.5
13	20.0	17.9	32	15.0	11.7
14	13.0	10.5	33	26.5	30.7
15	23.0	21.4	34	30.0	25.9
16	25.0	22.0	35	23.5	24.3
17	26.0	27.0	36	30.0	27.1
18	25.0	23.7	37	28.0	26.0

Results of the VES data interpretation of the two-electrode array and Schlumberger array have compared very well as shown in Figs. 5 to 12. The depth – to - basement values obtained from the two sets of interpreted results as given in Table 3 have agreed to about 86 %.

The depth – to - basement varies from about 13.0 m to 30.0 m for the two-electrode array while that of the Schlumberger array varies from about 11.0 m to 29.0 m. These values are also within the range of values obtained by previous workers, such as; Ososami (1968), Hassan (1987), Olugbemiro (1985) and Shemang

(1990) who reported that the depth –to - basement value in the Kubanni Basin varies from less than a metre to about 50.0 m.

A summary of the depth – to - basement values obtained from the interpretation of the two sets of data are given in Table 3.

CONCLUSION

An attempt was made in this work to determine the effectiveness of the Ajayi - Makinde two - electrode method as a geophysical method of investigation in depth – to - basement determination. The field procedure for the two - electrode array was faster and requires lesser hands as only two electrodes are used.

The interpretation of data for the two - electrode array was simple and straight forward as no computer analysis was involved. Results of the interpretation of the data in this work have also shown that the two - electrode array has a greater depth of penetration than the Schlumberger array.

This work has therefore proved that the Ajayi - Makinde two - electrode array is reliable and effective in depth – to - basement determinations and can be of use as a geoelectric prospecting method. More research should be carried out for computerized interpretation program and also fabrication of a device for the method.

ACKNOWLEDGEMENT

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