HYDROGEOLOGICAL INVESTIGATION FOR GROUNDWATER POTENTIALS IN AJAOKUTA AREA, KOGI STATE NIGERIA USING ELECTRICAL RESISTIVITY SURVEYS

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Abstract: The objective of this geophysical survey is to evaluate the hydrological characteristics of the study area. This includes the availability of groundwater, depth of aquifer, determining whether the underlying geology is competent basement/weathered basement or fractured bedrock and the delineation of the subsurface into various geo-electric layers. The availability of groundwater in an area is controlled by varying geological factors such as hydrogeological units, stratigraphical faults/folds, and geological sequences
The methodology used is the direct current method using the schlumberger configuration. In this electrical resistivity method, artificially-generated electric currents are introduced into the ground and the resulting potential differences are measured at the surface. Deviations from the expected pattern of potential differences from homogeneous ground provide information on the lithological formations and electrical properties of subsurface anomalies. A total of 10 vertical electric sounding was carried out on the study area, which covers the entire community and the data plotted and computer software designed by Vander Velpen BPA was used to iterate the result. This removes the noise and field errors incorporated in the data. The result of the VES curve reveals that there are three major geoelectric layers

The fist layer has an intermediate resistivity implying a sandy soil. Very low resistivity corresponds to clayey/clayey sand (VES 4, VES 5, and VES 6) while exceedingly high resistivity (VES 10) implies a lateritic cover. The second layer is the weathered layer sub-divided into minor geoelectric layers such as clays, gravels and weathered rocks. The weathered layers have low resistivity values, possibly due to the presence of conduction fluids such as water. The third layer is the basement or bedrock which may be fractured basement or fresh bedrock. Ajaokuta has more of fresh unfractured bedrocks except in some cases (VES 2 and VES 4)

The resistivity of topsoil varies from 12.6Ω to 3247.9Ω with a mean of 657.1Ω ± 947.7. The thickness of topsoil is within the range of 0.4m to 14.9m with a mean of 2.2m ± 4.2. The resistivity of weathered layer ranges from 27.9Ω to 175.5Ω with a mean of 59.2Ω ± 43.5. The thickness of the weathered layer is from minimum of 5.8m to maximum of 37.0 m having a mean of 12.4m ± 9.5. The depth to basement varies from 6.2m to 37.5m with a mean of 13.38 ± 9.07. The resistivity of the basement in the area varies from 183.3Ωm to 4294.2Ωm with a mean 0f 905Ωm ± 1170.The thickness of the topsoil is very low except for (VES 4) The average depth to basement is 13.38m±9.07.

Keywords: Boreholes, Ajaokuta, schlumberger configuration, resistivity, VES

INTRODUCTION

Ajaokuta is within the South/Western basement complex of Nigeria in Kogi State. The Kogi state landmass has over 50% crystalline rocks of basement complex. (Kogi state waterboard interim report, 1997). The study area in Ajaokuta is part of the Precambrian basement complex and cretaceous sediments of the south/western Nigeria (Jones and Hockey 1964, Kogbe, 1975, Rahaman, 1975)

The rocks of the basement complex comprises of migmatitic and granite gneiss. The rocks found in Ajaokuta are similar to rocks found generally in basement complex and it consists of slightly migmatized to unmigmatized paraschist and meta-igneous rock (Ajayi O, 1998). Certain factors controls the availability of groundwater potentials in the basement rocks but the most important is the presence of joints and fracturing in the basement rocks as well as the interconnectivity fractures and joints. This enables the capacity of the rocks to transmit, store and the general movement of water (Martins O E. 1999). Other factors include the extent of weathered material, parent rock type and fissures in the rock. If the basement is overlain by overburden of soil or weathered sediments, the factors that will contribute to groundwater availability includes

Thickness of the overburden

Porosity and permeability of weathered soil/sediments

In order to evaluate and estimate the Hydrogeological characters of the basement rocks, it is necessary to carry out geophysical surveys. Some known geological exploration techniques includes seismic, gravity, magnetic, electromagnetic and electrical resistivity survey methods. However for the purpose of this project, the electrical resistivity method is used to delineate the existence of water bearing formations and other related geological characteristics of the study area.

Ajaokuta is located in Ajaokuta Local Government of Kogi State. It is about 42km south of Lokoja, Kogi state capital. There is a major express road from the southwest, passing through Ajaokuta to Okene and linking the eastern part of the country. There are several major roads dissecting the area. One leads to Lokoja, which is a link to the northern part of the country. Ajaokuta is bounded to the east by river Niger. The study area is between latitude and longitudes 6̊40″- 6̊43″ and 7̊27″-7̊36″.

is guinea savannah, with dwarfed trees, shrubs, tall grasses all which makes less dense forest. There are seasonal rivers that dry up during the dry season. Most of the trees are xerophytes, which shed their leaves in the dry season to conserve water. The drainage pattern in the study area is structurally controlled by the hilly granitic terrain with hanging valleys. Occasionally, the area is characterized by radial drainage pattern. However with the influence of underlying geology, most of the drainage is dendritic and this indicates an alluvial cover on underlying basement of almost similar rock types.

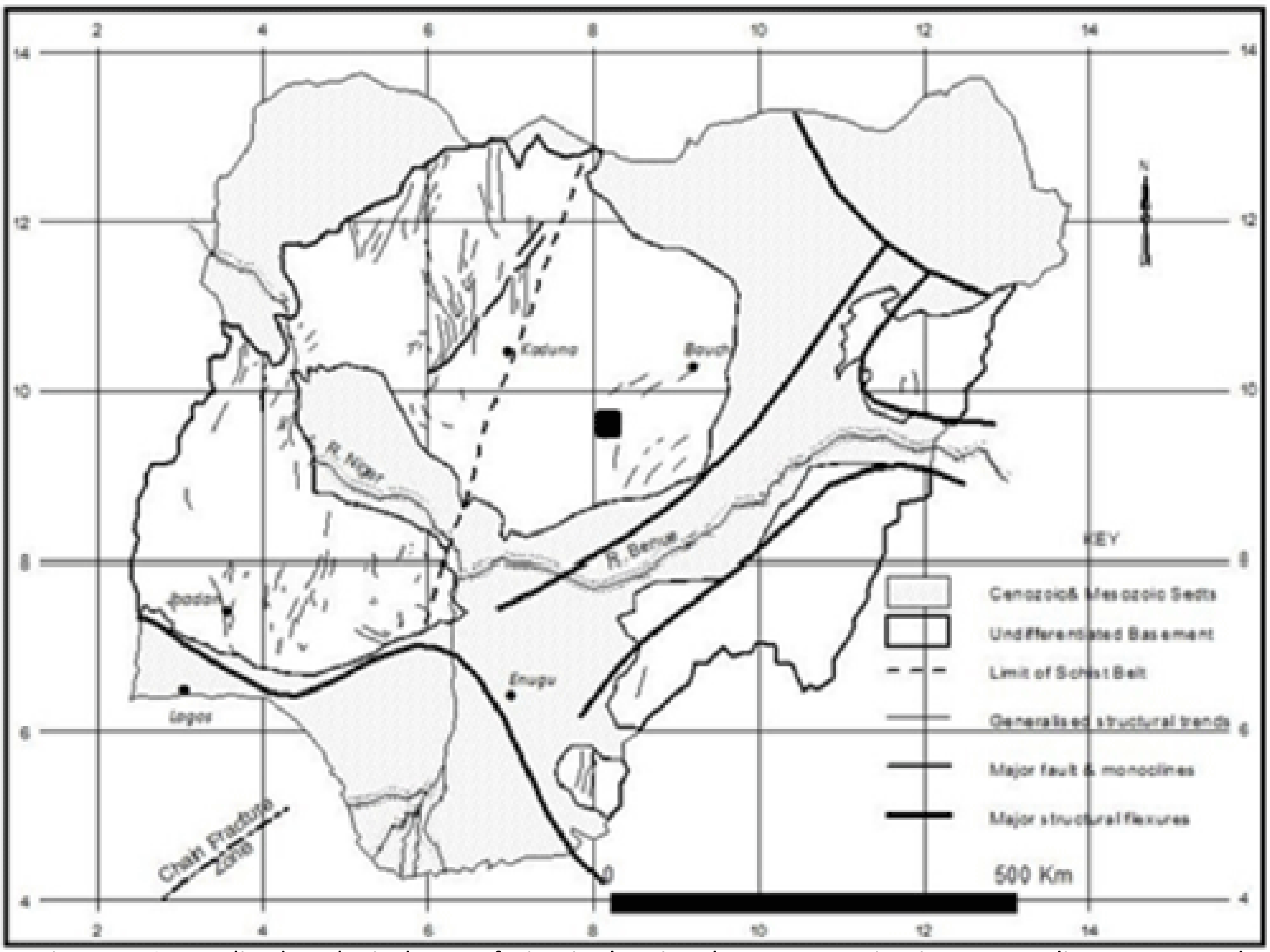


Figure 1: Generalized geological map of Nigeria showing the Western Nigerian metasedimentary Trend and three major basement complex after Oyawoye 1972

The topography of Ajaokuta is very rugged. It has numerous undulating hills and steep/scarp slopes. It might have derived its name from the gigantic masses of ridges scattered in the area. Amongst this high rise ridges and steep dipping slopes, there are presence of peneplain and expanses of flat plain land. Ajaokuta is in tropical hinterland with moderate rainfall between 1000-1500 per annum. The relative humidity is 40%-60% in January (dry season) and 60-80% in July in the morning, 50-70% in the afternoon. The vegetation

Most of the inhabitants of Ajaokuta (about 80%) are civil servants. The natives have been evacuated. There is no form of large scale farming. It is a planned and nucleated type of settlement with built up areas where workers dwell. Virtually, almost all language in Nigeria has a representative there (due to the large number of workers from every part of Nigeria). The language spoken there are Igala and Ebira. Ajaokuta is an Industrial Area with availability of social amenities.

LITERATURE REVIEW AND HYDROGEOLOGY

Little work has been done on the area. Most of the works done are well drilled (wild cats) to ascertain the availability and to know the thickness of depth of the minerals. Other well drilled are to determine the compressibility/shear test of the subsurface mainly for engineering and construction. In 2004, the Petrobras international limited was invited by Kogi state government to carry hydrogeophysical surveys on Wimpey and Ebiya in Ajaokuta. A number of individual bore holes has been dug by Kogi UNICEF assisted project.

The main source of water supply is surface water from rain and River Niger. The potential supply of groundwater is to be investigated. Well yields from the area vary considerably but generally, basement complex areas have credence as poor water yielding zones except for very few exceptions. The basement aquifers in the area of study are made up of fractured basement and weathered in situ materials which are characterized by quartz with partially altered minerals. The mode of aquifer occurrence in the area of study can be classified into

i. Occurrence in saprolite (in-situ weathered materials) overlying the freshwater basement
ii. Occurrence in joints and decomposed veins within the fresh basement.
iii. Occurrence in fractured basement.
iv. Occurrence in quartzites

The mode of occurrence in (i) and (ii) is most common for basement aquifers which are composed of clayey materials derived from the decomposition of mineral constituents in basement rocks. The recharge of basement aquifers is however low as a result of presence of clayey materials derived from the decomposition. The direct recharging of alluvium aquifer by river Niger has contributed to the increase of bore-hole yield in the area.

METHODOLOGY

Resistivity is one of the most variable of physical properties in evaluating the subsurface geology. The resistivity method is used in the study of horizontal and vertical discontinuities in the electrical properties of the ground, and also in the detection of three-dimensional bodies of anomalous electrical conductivity. It is generally used in the study of engineering and hydrogeology of shallow subsurface geology. Electrical methods utilize direct currents or low frequency alternating currents to investigate the electrical properties of the subsurface. Certain minerals such as native metals and graphite conduct electricity via the passage of electrons. Most rock-forming minerals are, however, insulators, and electrical current is carried through a rock mainly by the passage of ions in pore waters.

General survey and Instrumentation: There is a reconnaissance survey of the study area. This preliminary study was carried out as general survey on the site in concordance with the literature and the topographical map. Some few mappings are done to ascertain rock types, the strike and dip of the outcrops, etc. All this ensures certainty and conversance with the structure and topography of the area. The important instrument used here are SAS ABEM/DIGIT therameter. The instrument is used to measure the resistance of the sub-surface layer. The SAS (Signal Averaging System) make use of the mean of several measurements taken at about three to four times

Reels of Cables: It is usually called the ABEM cables. They are standard single conductor insulated cables usually wound on four steel cable drums to make four reels. Two of the reels connect current electrodes and the other two connect the potential electrode. Four cables of few length permanently attached to the therameter is used to connect to the four cable reel.

Stainless steel Electrode pegs: Four in number with a pointed end, they are used to peg the soil. The pointed end is driven a few centimeters into the soil a sledge hammer

Battery: A 12 volt DC battery provides current and potential difference which drives the therameter

Measuring tapes: They are two and are used to measure the distance between the electrodes. They are also used in gradation of electrode spacing. This makes the movement faster along the transverse lines

Hammers: Used to drive the electrodes properly into the ground.

Clamps: They are used for cable wire connections to the electrodes

There are several precautions taking in the VES includes using average values, not placing the therameter directly under power transmission lines, ensuring proper contact between the clip and the electrode as well as the ground and ensuring the therameter voltage is optimum to prevent spurious reading

FIELD PROCEDURE

A suitable site for carrying out geo-electric sounding was chosen. The points were picked randomly at about 500m interval. The factors

considered in picking the points include enough space to accommodate electrode spread in desired direction and presence of undulating or flat expanse of land. Some of the sites were located near dried up stream/water points mainly to validate some of the limitations of the electrical resistivity method.
Schlumberger array of vertical electric sounding (VES) was used. When using electrical resistivity surveys, it must be bear in mind that the extent to which electrical potentials is affected at the sub-surface depends on the size, shape, location and electrical conductivity of the sub-surface masses (Griffith and Kings, 1976). Also the porosity and chemical content in pore space is more determining than the rock mineral grain of which the rock is composed (Keller 1966). The ABEM therameter was placed at the centre of the spread very close to the midpoint area being investigated. A 12 volt DC battery was connected to the therameter. In addition, the current and potential cable reels are joined to the various wires from the electrodes. The other end of the cables was clipped to the electrodes which have been properly driven into the ground by hammer. If the area is very dried up, water is used to wet the soil around the electrode to establish a good connection.

Two main types of procedure are employed in resistivity surveys and this are;

(i) The horizontal profiling

(ii) Vertical electric sounding.

The horizontal electric profiling (HEP) is first used to determine lateral variations in resistivity. The horizontal electric profiling is otherwise known as Common Spread Profiling (CSP) or Constant separation traversing (CST). In this method, the current and potential electrodes are maintained at a fixed separation and progressively moved along a profile. The whole array is moved perpendicular to the strike along the transverse. A fixed constant separation between transmitting and receiving electrodes is ensured. The lateral variation in resistivity determine by the CSP may be cause by steep dipping fault or cavity which is filled with conducting fluids (water). This method is also employed in mineral prospecting to locate faults or shear zones and to detect localized bodies of anomalous conductivity. It is also used in geotechnical surveys to determine variations in bedrock depth and the presence of steep discontinuities.

Vertical electric sounding: also known as 'electrical drilling' or 'expanding probe', is employed mainly in the study of horizontal or slightly dipping interfaces. The current and potential electrodes are fixed at a corresponding spacing and the whole spread is continuously increased about a fixed central point. Average values of readings are taken as the current reaches progressively greater depths. The method has been used in geotechnical surveys to estimate overburden thickness and also in defining the various horizontal zones of porous and permeable strata which contains water.

In this study, the VES is done by schlumberger configuration, the sounding began with the electrodes close together, meaning that the resistance measurement always starts from the short electrode spacing and is spread to greater lengths. The schlumberger array of VES will reveal the variation of apparent resistivity with depth. In this VES survey, the potential electrodes remain fixed and the current electrodes are expanded symmetrically about the centre of the spread. With very large values of *L* it may, however, be necessary to increase *l* also in order to maintain a measurable potential.

For the Schlumberger configuration, the resistivity ρa is given by

$$Pa = \frac{\Pi (L^2 - x^2)^2 \Delta V}{2l (L^2 + x^2) I}$$

where L = AB/2 (AB = current electrode spacing)

l = MN/2 (MN = potential electrode spacing)

x is the distance between the mid-points of the potential and current electrodes. In this project, the electrodes are used symmetrically with a common midpoint so *x* = 0 and the resistivity becomes

$$Pa = \frac{\Pi L^2 \Delta V}{2l \; I}$$

In schlumberger array, five times the distance between potential electrodes (MN) must be equal to or less than the total spread length of the current electrode spacing (AB), 5MN ≤ AB. So the potential electrodes remain fixed while the current electrodes are expanded symmetrically about the centre of the spread. With very large values of AB, it is however necessary to increase MN in order to maintain a measurable potential. In this study, the maximum current spread L (AB/2) of 100m was reached. With increase in the current and potential spacing, current will travel through the ground and measure apparent resistivity to greater depths. With a single increase in current electrode, the potential electrodes are changed to measure four or five measurements.

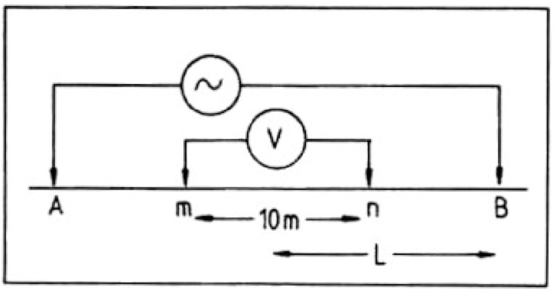


Figure 2: Diagram of schlumberger configuration

INTERPRETATION OF RESULTS

The interpretation of the horizontal electric profiling/common separation transverse involves the production of a pseudosection. This pseudosection determines the homogeneity of the topmost layer. Interpretation of the vertical electrical sounding data involves the determination of thickness and resistivity of various horizons quantitatively. There are various methods by which VES sounding curves can be interpreted. These methods are empirical methods, direct calculation, curve matching method and the computer iterative method. In this project the curve matching method, the computer iterative method and the statistical analysis of the geoelectric parameter was used to interpret the field data.

Curve matching method: This is a very simple and accurate. The convectional curve matching technique (Keller and frischknecht, 1966) is a very dependable and accurate method. It is most widely used because it can reduce the effect of geoelectrical equivalence and suppression upon interpretation of sounding data. The interpretation is based on comparing field data curves with theoretically generated curves. Two types of theoretical curves were used to tackle this problem.. Two layer curves of Orenella and Mooney 1966, and the corresponding auxiliary diagrams of AKHQ curves of Ebert, 1943. The partial curve matching interpretation techniques of VES data is segment-by-segment matching of field curves with two layer master curves and auxiliary curve. The procedure for the curve matching is as follows:

Select from the set of master curves a single sheet containing a two layer master curves

Super-impose the transparent paper containing the field curve into the master curve

S/no	Current Spacing AB/2(m)	Potential Spacing MN/2(m)	VES 1	VES 2	VES 3	VES 4	VES 5	VES 6	VES 7	VES 8	VES 9	VES 10
1	1.0	0.2	150	119	85	25	15	64	611	190	2308	1204
2	2.0		41	58	41	14	50	48	212	56	1370	1090
3	3.0		34	43	32	12	67	51	88	47	365	1012
4	5.0		31	31	36	11	98	64	76	44	61	669
5	6.0		32	30	39	10	103	66	87	45	54	495
6	6.0	1.0	32	30	41	10	109	63	74	44	45	465
7	8.0		41	29	43	11	125	64	93	51	51	265
8	10.0		46	30	44	12	133	74	99	58	55	164
9	10.0	2.0	55	33	42	13	136	66	111	51	61	175
10	15.0		69	35	56	14	137	92	154	67	68	69
11	18.0		75	41	62	14	136	107	162	78	81	92
12	20.0		78	42	68	17	133	114	173	86	83	96
13	25.0		97	47	74	19	137	139	197	96	125	111
14	30.0		119	50	87	22	158	165	217	118	181	131
15	35.0		134	53	103	23	161	188	252	138	198	155
16	40.0		137	58	165	25	167	205	283	140	162	172
17	40.0	7.5	143	58	169	26	168	198	294	140	162	172
18	50.0		186	74	235	30	194	263	372	146	167	203
19	60.0		250	89	240	35	186	281	481	151	185	219
20	70.0		295	90	175	37	199	316	450	162	215	234
21	80.0	15.0	315	87	205	50	230	375	493	174	267	241
22	100.0		315	121	264	71	250	390	510	216	339	368

Table 1: Field records of resistivity values for various VES stations

Move one sheet with respect to the other, keeping their vertical axis parallel until the field curves fit into the master curves. Interpolation between the two curves is permitted.

Trace into the transparent paper the cross of

the master curve sheet and the resistivity mark corresponding to the theoretical curve for which the match was obtained.

Table 1 shows the resistivity, thickness and depth corresponding to layers 1(topsoil/overburden), 2(weathered layer/fractured basement) and 3(fresh bedrock/basement) as generated from the curve matching

Computer iterative method: The results from the curve matching which are resistivity, no of layers and its thickness are the data/starting parameters for the computer iterative programme developed by Vander Velpen BPA of Netherlands. The computer now generates another set of theoretical apparent resistivity. This is compared with the curve matching. If there are two much differences, then it will be necessary to adjust the model parameters one at a time until the results are similar. For the purpose of this study, an r.m.s. error of less than or equal to 5 % was used. When the error is greater than 5 %, the model parameters is adjusted and the iteration process begins again.

Statistical analysis of the geoelectric parameter:

The mean as well as the range values can be used to infer some important characteristics of the rock/soil type. The geoelectric parameters analyzed includes resistivity and thickness of the topsoil and weathered layer as well as depth to the fresh basement

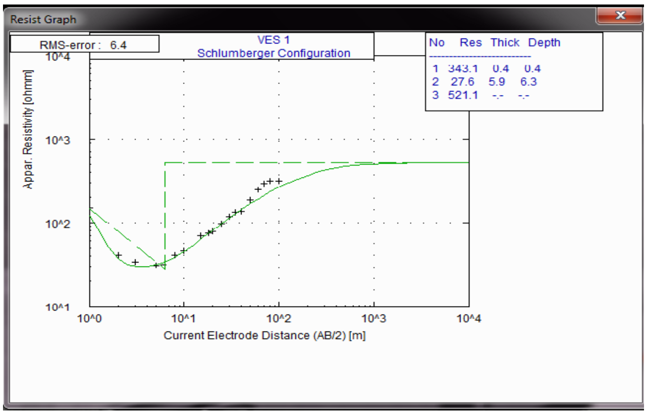
INTERPETATION OF RESULTS AND DISCUSSION

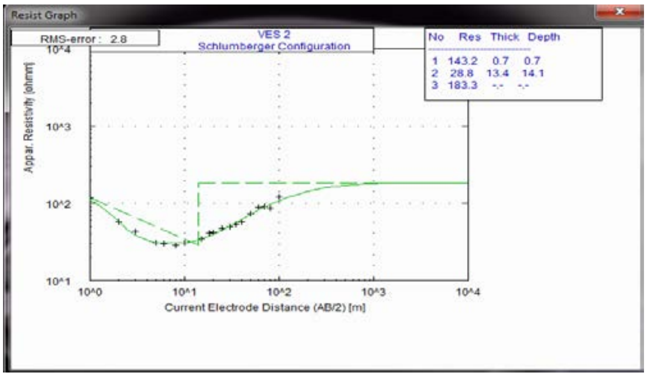
Data presentation

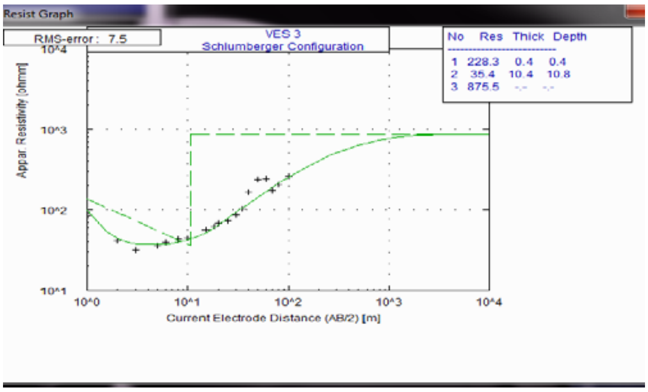
VES NO	LAYER NO	RESISTIVITY	THICKNESS/ DEPTH	DEPTH
VES 1	1	343.6	0.4	0.4
	2	27.9	5.8	6.2
	3	490.5		
VES 2	1	143.2	0.7	0.7
	2	28.8	13.4	14.1
	3	183.3		
VES 3	1	228.3	0.4	0.4
	2	35.4	10.4	10.8
	3	875.5		
VES 4	1	12.6	14.9	14.9
	3	81.8		
VES 5	1	13.2	0.5	0.5
	2	175.5	37.0	
	3	382.5		
VES 6	1	58.9	0.7	0.7
	2	54.6	7.9	8.6
	3	1016.6		
VES 7	1	969.6	0.6	0.6
	2	63.1	6.0	0.6
	3	947.2		
VES 8	1	324.9	0.5	0.5
	2	40.4	7.2	7.7
	3	472.5		
VES 9	1	3247.9	0.9	0.9
	2	37.0	6.5	7.4
	3	511.1		
VES 10	1	1229	2.6	2.6
		70.3	17.4	20.0
		4294.2		

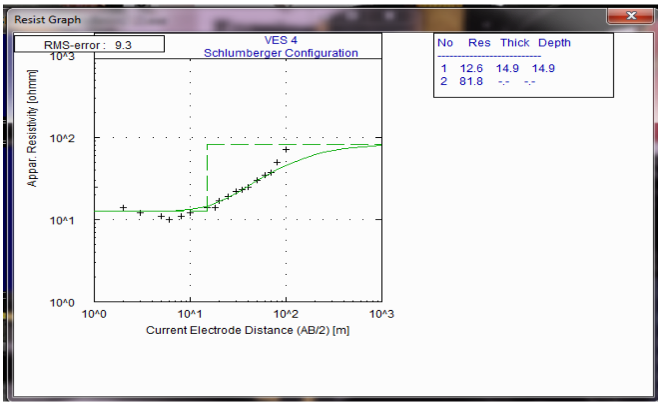
Table 2: Quantitative interpretation of resistivity thickness and depth corresponding to different layers

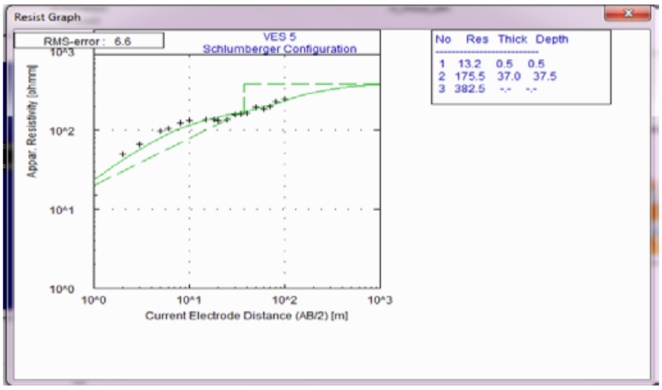
Figure 3: The VES curves of the ten locations after iteration

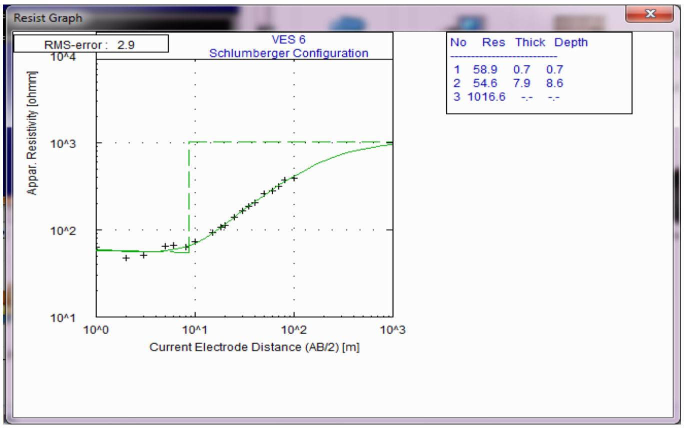


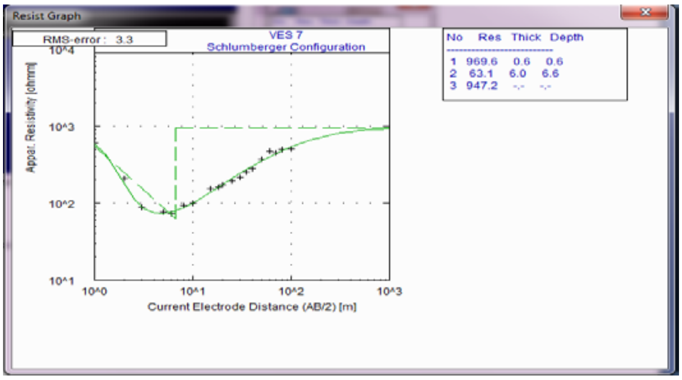


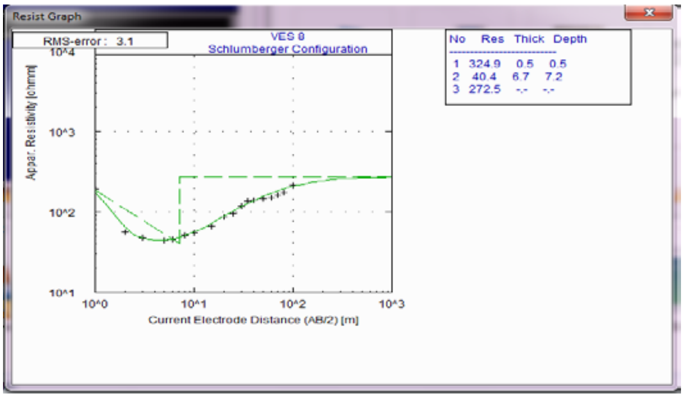


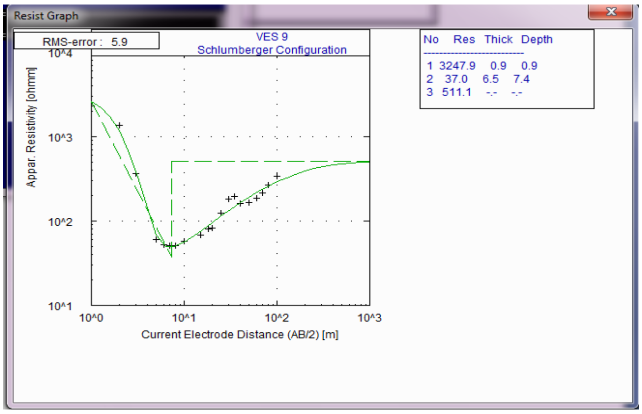


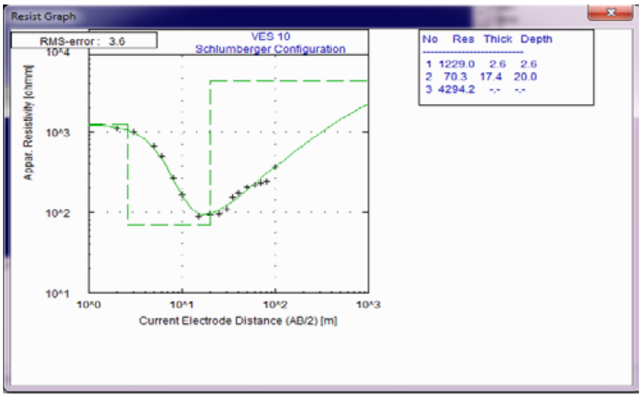












Generally, there are 4 basic types of curves given by the table 3 below

Table 3: Basic types of curves and their resistivity values

CURVE TYPES	RESISTIVITY VALUES
Q	$R_1 > R_2 > R_3$
H	$R_1 > R_2 < R_3$
A	$R_1 < R_2 < R_3$
K	$R_1 < R_2 > R_3$

Table 4: Different layers, resistivity variations and VES curves

VES NO	RESISTIVITY VARIATIONS	CURVE TYPE
1	$R_1 > R_2 < R_3$	H-curve
2	$R_1 > R_2 < R_3$	H-curve
3	$R_1 > R_2 < R_3$	H-curve
4	$R_1 < R_2$	2 layer curve
5	$R_1 < R_2 < R_3$	A-curve
6	$R_1 > R_2 < R_3$	H-curve
7	$R_1 > R_2 < R_3$	H-curve
8	$R_1 > R_2 < R_3$	H-curve
9	$R_1 > R_2 < R_3$	H-curve
10	R1 > R2 < R3	H-curve

Classification of curve types

For the VES 1-10, they can be classified based on the curve type as shown above provided it is a three layer. Two resistivity data VES are simply classified as a two-layer curve which is a distinct type of curve on its own. A four resistivity data will be grouped by first considering the first three resistivity values and then the last three. The type of curve is then written as the combination of both i.e. as KH, AH, QA etc. The interpretation of the 10 VES resistivity result is as summarized in the table 4.

From the curves in table for, it is estimated that 80% is H-curve, 10% is 2-layer curve and 10% is A curve. It will be observed that the generated curves for various VES stations shown varies considerably throughout the geoelectric layer but all the curves were characterized by a final segment of positive gradient which in many cases approximates 45° inclination. This indicates a semi-basal unit of relatively high resistivity which is considered to correspond to the basement complex of Nigeria (Olayinka and Olorunfemi 1992, Wortinton P. E. 1977)

An inspection of the computer iterated curve of each VES shown in figure 2 delineates the major/basic geo-electric units to be recognized (even though several geo-electric units have been merged together as the weathered layer). The H-curve type is most dominant around 80%. This is in concordance with the postulates that fresh basement complex areas have infinite resistivity with increase in depth(Olorunfemi and Oloruniwo 1985, Olayinka and Olorunfemi 1992, Ajayi and Hassan 1990)

The average resistivity and thickness of topsoil, weathered layer, depth to basement and basement resistivity shown in table 5 indicates that;
the resistivity of topsoil varies from 12.6Ω to 3247.9Ω with a mean of 657.1Ω ± 947.7. The thickness of topsoil is within the range of 0.4m to 14.9m with a mean of 2.2m ± 4.2. The resistivity of weathered layer ranges from 27.9Ω to 175.5Ω with a mean of 59.2Ω ± 43.5. The thickness of the weathered layer is from minimum of 5.8m to maximum of 37.0 m having a mean of 12.4m ± 9.5. The depth to basement varies from 6.2m to 37.5m with a mean of 13.38 ± 9.07. The resistivity of the basement in the area varies from 183.3Ωm to 4294.2Ωm with a mean 0f 905Ωm ± 1170. The basement rock is said to be fractured if its resistivity is < 1000m and fresh basement if its resistivity is > 1000m

Table 5: Mean and range of values for each geo-electric parameter

Geo-electric parameter	Mean	Standard deviation
Resistivity of topsoil	657.1	947.7
Thickness of topsoil	2.2	4.2
Resistivity of weathered layer	59.2	43.5
Thickness of weathered layer	12.4	9.5
Depth to basement	13.38	9.07
Resistivity of basement	905.5	1170

Table 6: Topsoil values in the study area

Range of topsoil thickness (m)	% area
0.4 – 0.6	50
0.6 – 0.8	20
0.8 -1.0	10
1.0 – 4.0	10
> 4.0	10

CONCLUSION

The interpretation of the sounding curves reveals three major geoelectric layers.

The resistivity values obtained for the first layer, the overburden is relatively high (with a mean value of 657.1Ω in table 5) which implies sandy soil. The exceptionally high value of the VES 9 and VES 10 is possibly due to the presence of the lateritic layer capping and anisotropy within the top layer. Generally the thickness of the topsoil in the study area is low (2.2m on average from table 5) and is an indicative of shallow weathering and proof of a crystalline basement terrain.

The resistivity of second layer is between 10Ωm - 200Ωm, which is weathered or highly fractured layer. This weathered/fractured layer constitute the aquifer and the water bearing unit by the virtue of its thickness (12.4m), presence of openings in form of joints and fractures.

The average resistivity of basement is relatively high. It is inferred that the basement is just slightly fractured because the value (905.5Ωm from table 5) is very close to that of fresh crystalline basement (>1000Ωm). However there are some exceptional VES stations (VES 2 and VES 4)with extremely low basement resistivity indicative of high fracturing

The depth to basement from the analysis is very small. This confirms the study area is of basement complex terrain of crystalline rocks. Groundwater availability in basement complex is very unpredictable. However from the interpreted data, observed structures such as fracturing, fissuring, joints, weathered layers there is provision for secondary porosity. VES 2 and VES 4 will make excellent points for bore hole drilling because of its extremely low basement resistivity values, thick overburden and will make excellent aquifers.

RECOMMENDATION

Though the spreadlength penetration is greater than the depth to basement, it is still recommended that greater spreadlength should be used for future geophysical surveys. Also more work should be done on the irregular lateritic topsoil of VES 10.

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