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HYDROGEOPHYSICAL INVESTIGATION IN NSUKKA AREA, SOUTHEASTERN, NIGERIA

A. E. Ofoma, O. S. Onwuka and O. C. Egbu
Department of Geology
University of Nigeria, Nsukka, Enugu State, Nigeria.

ABSTRACT

Resistivity surveys were carried out at seven stations within the University of Nigeria, Nsukka and its environs. The objective was to determine areas suitable for the drilling of boreholes for groundwater. The results generated from this survey were interpreted in terms of the number of subsurface layers, aquifer thickness, depth to aquifer and probable lithology/formations. However, lithologic interpretations were carried out using existing borehole data from the area. ABEM Terrameter SAS 300C instrument was used in obtaining the resistivity data. Partial manual curve matching technique was initially employed in interpreting the data and thereafter a computer iterated approach was used to arrive at the final result. The Schlumberger electrode configuration was employed. Results show that the depth to water table in the study area fall within the lower parts of layer 5, at a depth of about 110.0m. Thicknesses of the top soil vary between 0.8m and 1.2m, with their resistivities ranging between 50Ωm and 1120Ωm. The number of layers encountered is 6 and 7. Geological interpretation based on available borehole lithologs of the area shows that the subsurface comprises lateritic sandstone in the Nsukka Formation and coarse - medium grained sandstones in the Ajali Formation.

***Keywords:* Vertical Electrical Sounding, Resistivity, Water table, Aquifer depth/thickness, Geoelectric Section.**

INTRODUCTION

Vertical electric sounding or electrical drilling is designed to provide information on the variations in the results of the subsurface layers. The field procedure for this type of survey is to increase the current electrode spacing while the centre of the electrode spread remains fixed. The resistivity sounding method is useful for the deduction of the number of geoelectric layers, estimation of depth to bedrock, depth to water table as well as aquifer thickness (Telford et al, 1984). However due to considerable overlap of resistivity values among different rock types, identification of rock types is not possible solely on the basis of resistivity data. Hence, well logs or borehole/core data, where available, are combined to aid qualitative interpretation. For the present study the borehole data is used. Most geophysical surveys in the study area are carried out for private individuals, corporate organizations or government and information generated are seldom released for public use. However, some of the geophysical surveys that have been carried out in the area and neighboring towns include (Geoconsult, unpublished report, 2000; Ekoma Consultants, unpublished report, 2001; Selemo, A., unpublished report, 2001; Lithoprobe Services, unpublished reports, 2004). In this study attempts will be made to qualitatively and quantitatively interpret the profiles in terms of aquifer depth, number of layers with their thickness/depth and probable lithologies/formations.

Geology/Hydrogeology

The study area lies between latitudes $6^0 50'$N and $6^0 55'$N and longitudes $7^0 22'$E and $7^0 27'$E within the Anambra Basin (an onshore sedimentary basin in the Lower Benue Trough) of southeastern Nigeria (Fig. 1). Tectonic and depositional cycles in the Lower Benue trough resulted from the separation of the Afro-American plates during the Lower Cretaceous (Benkhelil, 1982). The Albian – Coniacian sedimentary phase which led to deposition of fluvio-deltaic to marginal marine offshore sediments ended with Santonian tectonism (Murat, 1972; Hoque and Nwajide, 1985). The second Campanian – Eocene phase filled the Anambra basin and Afikpo syncline and the third phase paved the way for the development of the Tertiary Niger Delta (Short and Stable, 1967; Burke et al., 1970; Murat, 1972). The Ajali Sandstone underlies the Nsukka Formation in the study area. It is the main aquiferous formation within the area, and consists of thick friable, poorly consolidated sandstones, typically white in colour, but sometimes pinkish due to post depositional iron staining with mudstones and shale as intercalations (Reyment, 1965; Hoque & Ezepue, 1977). Aquifer parameters of this formation calculated from grainsize data show that hydraulic conductivity is 2190.8m yr^{-1}, groundwater velocity is 49.9m yr^{-1}, specific discharge is 17.5m^3 m^{-2} yr^{-1}, total discharge is 9.6 x 10^5 m^3 yr^{-1} and transmissivity is 3.8 x $10^5 m^2$ yr^{-1} (Egboka, 1983). The Nsukka Formation overlies the Ajali Sandstone and is upper Maastrichtian in age. It constitutes the outliers, some of which are as high as 60m to 120m above the ground level. Numerous springs issue out from the flanks of the outliers and in some areas where permeable laterites overlie impermeable basal clay-shale beds that are superposed on sandy beds of the Ajali Formation, perched aquifers occur (Uma, 2003). This Formation consists of basal sandstone, shale, clay unit and intercalations of weathered sand and siltstone (Mamah & Ekine, 1989; Ofoma, 2001). The basal unit on which the University of Nigeria, Nsukka (UNN) stands is mineralogically mature with abundant quartz (75 – 95%) and (5 – 15%) matrix. Sieve analysis of quartz range between 27% in the gravel size to 63% on the sand range and about 8% silt. The void ratio ranges between 28 – 44%, while permeability is 2.0 – 20.7 x 10^{-10} cm/s (Mamah & Ekine, 1989). Borehole lithologic logs of sections within the study area (Agric Farm UNN and the new Nnamdi Azikiwe Library UNN) show two lithostratigraphic units, the Nsukka Formation and Ajali Sandstone. Red granular laterite (primary type) and ferruginized coarse sand with laterite (secondary type) fall within the Nsukka Formation. Porosities and permeabilities of the laterites range from 15% to 28% with a mean value of 18%, and from 0.0001 to 0.00001m/s (Egboka, 1983, Uma & Onuoha, 1992; Uma, 2003). White fine grain sand, sandstone, shale and pinkish clay characterize the Ajali Sandstone (Figs. 2 & 3).

Data acquisition

During the months of February to May, 2005, seven vertical electrical sounding (VES) surveys were carried out within the University of Nigeria, Nsukka and its neighboring communities. The ABEM terrameter SAS (signal averaging system) 300C instrument was used. The Schlumberger electrode configuration was used for this study. This configuration has been found to be convenient and reliable in most terrains. The measured field resistances (r) in ohms have been converted to apparent resistivity (ρ_a) in ohm-meters using the formula below (Telford et al, 1984).

$$\rho_a = \pi L^2 / 2l \, (\Delta V / I)$$

Where: $L = AB/2$ (m)

$l = MN/2$ (m)

$(\Delta V / I)$ = resistance in (Ω)

$\pi L^2 / 2l$ = geometric factor (K)

Note: AB = current electrode spacing (m)

MN = potential electrode spacing (m)

Maximum electrode spacing (AB/2) of 500m was used, except for VES 3, 6 and 7 which had maximum AB/2 of 200m. The observed field data were used to produce depth sounding curves. The preliminary quantitative interpretation of the curves was done with the aid of auxiliary diagrams (zohdy *et.al.*, 1974). This interpretation technique provided the layer thicknesses and resistivities, which served as input data for computer modeling and final interpretation (Ghosh, 1971). The vertical electrical sounding (VES) were processed using computer iterated resistivity software, RESIST. The RMS errors in the final models presented in this work are less than 2%.

DISCUSSION OF RESULTS

The adjusted values from the RESIST software for the VES are given in Table 1. The summary of the VES results are presented in Table 2, while the borehole lithologs of two different locations within the study area compared with the VES results of this study is given in Tables 3 & 4. The computer modeled curves is presented in Fig. 4, and the geoelectric sections for VES 2 – 4 and 6 – 10 is presented in Figs. 5 & 6. The resistivities of layer 1 is between 50Ωm & 1120Ωm (Tab. 2), and their thicknesses are between 0.8 & 1.2m. The average thickness of this layer is 1.0m. This layer is interpreted to be the top soil. Layer 2 shows resistivity values of between 325Ωm & 10225Ωm. Their thicknesses and depths are between 2.2m & 6.8m and 3.0 & 8.0m. Probable lithology for this layer may be lateritic sandstone. Layer 3 has resistivity values of between 1875Ωm and 6524Ωm and depths of between 8.0m and 25.0m. The thickest station in layer three is observed in VES 2; however, their thicknesses range from 4.8m to 22.0m. Medium – Coarse grained sandstones are the likely lithology in this layer (Tab. 2). The resistivities of layer 4 range between 1122Ωm & 78562Ωm. The depths of this layer for most VES stations vary between 25.0m & 102.0m. The thickest station in this layer is VES 10 and the least is VES 8, thicknesses of this layer vary between 17.0m & 87.0m, with an average value of 35.9m. Layer 5 shows relatively high resistivity values of between 4215Ωm & 99856Ωm with drop in resistivity values in layer 6 at VES stations 3, 7, 8 & 10 and in layer 7 at VES stations 4 & 8. Thicknesses of layers 5 and 6 are quite high. The probable lithology for layers 4 – 7 is sandstone. Aquiferous layers in this study may well be layers 5, 6 & 7. Thicknesses of these layers are between 22.0m & 120.0m for layer 5 and 75.0m & 106.0m for layer six, and their average thicknesses are

97.6m and 90.5m respectively. Depths of layer 5 are between 52.0m & 218.0m and that of layer 6 is between 158.0m & 220.0m. Approximate drill depths for VES 2 – 10 are 155.0m, 152.0m, 158.0m, 160.0m, 156.0m, 220.0m, and 218.0m respectively. In the study area regional water table ranges between 70.0m & 150.0m and depends on topography and time or season of acquiring the data (Uma, 2003). Geoelectric sections of the VES show six and seven layered earth (Figs. 5 & 6, Tab. 2). The geologic interpretation of the VES data was aided by the available borehole lithologs obtained for the area (Tables 3 & 4). The subsurface lithologies are feruginized, medium – coarse grained sandstone with laterites in the Nsukka Formation and predominantly sandstones in the Ajali Formation, these interpretations very well agree with each other (i.e. the borehole logs and VES results). The VES results, however, might have been affected by the effects of noise, instrumentation, computer error, suppression of thin lithologic beds or the 'lumping' effect etc, (David, 1994; Olayinka, 1996; Mamah, 1998; Uma, 2003; Obiora & Onwuka, 2005)

CONCLUSION

Geophysical survey is a useful investigation technique carried out at borehole sites prior to drilling. Some of the information obtained from such investigation may include aquifer depth and thicknesses, number of layers, overburden thickness, depth to bedrock and rock types which are interpreted in conjunction with seismic profiles, geophysical well logs or borehole/core data. These information, if available, will help in proper project evaluation and management and so reduce, or even eliminate completely, wastage of materials and finances. Geological interpretation based on available borehole lithologs of the area shows that the subsurface comprises lateritic sandstone in the Nsukka Formation and predominantly coarse - medium grained sandstones in the Ajali Formation. Six- and seven layer earth is deduced from the study. The aquiferous layers are from, five with an average thickness of 97.6m. Depths to water table fall within the lower parts of ρ_a 5 (Tab. 2), at the depth of 110.0m. This however, is seasonally dependent. These depth values are in agreement with the regional water table of the area. Depth of drilling within the study area should be above 160.0m, in order to allow for a water column of at least 50.0m below the water table. It is also important that down-the-hole geophysical logging be carried out to identify appropriate depth where screens can be installed.

REFERENCES

1. Benkhelil, J. 1982. "Benue Trough and Benue chain". Geological Magazine, V.119, p. 155-168.
2. Burke, K., Dessauvagie, T.F.J and Whiteman, A.J. 1970. "Geological History of the Benue valley and adjacent areas". In Dessauvagie, T. F.J and Whiteman, A.J. (Eds.) African Geology. Ibadan University Press, Ibadan. p. 187-206.
3. David, L. M. Jr. 1994. "Ambiquities in VES Interpretation: Case Histories in Southern Nigeria". Water Resources. Vol.4(1&2), p.43-48.
4. Egboka, B.C.E. 1983. "Analysis of groundwater resources of Nsukka area and Environs, Anambra State Nigeria". Nig. J. Min. Geol., Vol.20(1&2), p.1-16.
5. Ekoma Consultants 2001. Hydrogeological/geophysical investigation report for the location of borehole drilling sites at Aji and Umuogboagu communities in Igboeze North L.G.A. of Enugu State. Unpublished report.
6. GCU-UNN 2000. Baseline geological study at the site for the proposed Seismograph station at the University of Nigeria, Nsukka. Unpublished report
7. Ghosh, D.P. 1971. The application of linear filter theory to the direct interpretation of geo-electrical sounding measurements. Geophysical Prosp., Vol. 19, p. 192 -217.
8. Hoque, M. and Ezepue, M.C. 1977. "Petrology of the Ajali Sandstone". Nig. J. Min Geol. Vol. 14 (1) p.16-22.
9. Hoque, M., and Nwajide, C.S. 1984. "Tectono-sedimentological evolution of an elongate intracratonic basin (aulacogen); the case of the Benue trough of Nigeria" Nig. J. Min. Geol., Vol.21, p.19-25.
10. Lithprobe Services 2004. Vertical Electric Sounding (VES) for the location of borehole at Alo-Uno, Nsukka, Enugu State. Unpublished report.
11. Mamah, L.I. and Ekine, A.S. 1989. "Electrical Resistivity Anisotropy and Tectonism in Basal Nsukka Formation". Nig. J. Min. Geol., Vol.25(1&2), p.121-129.
12. Mamah, L.I. 1998. "Uncertainty in geosounding interpretation". Nig. J. Min. Geol., Vol.34 (1), p.37-42.

13. Murat, R.C. 1972. "Stratigraphy and paleogeography of cretaceous and lower Tertiary in Southern Nigeria". In Dessuvagie, T.F.J. and Whitman, A. J. (Eds.) African Geology. Ibadan University Press, Ibadan, p. 251-269.

14. Obiora, D.N. and Onwuka, O.S. 2005. "Groundwater Exploration in Ikorodu, Lagos-Nigeria: A surface Geophysical Survey contribution". Pacific J. Sci. Tech. Vol.6(1), p. 86 – 93.

15. Ofoma, A.E. 2001. Electrical resistivity and Magnetic surveys of some parts of Nsukka, L.G.A. unpublished M.Sc Thesis University of Nigeria, Nsukka. p.115

16. Ofoma, A.E. and O.C Egbu, (in Prep.) Grain size distribution and depositional processes of subsurface Maastrichtian sediments of the Anambra Basin

17. Olayinka, A.I. 1996. "Non-uniqueness in the interpretation of bedrock resistivity from sounding curves and its hydrogeological implications". Water Resources. Vol.7(1&2), p.49-55.

18. Reyment, R.A. (1965). Aspects of the Geology of Nigeria, Ibadan University Press, Nigeria, p. 210.

19. Selemo, A. 2001. Pre-drilling geophysical survey at Umumakashi, Nsukka, Enugu State. Unpublished report.

20. Short, K.C. and Stauble, A.J. 1967. Outline of Geology of Niger Delta. AAPG Bull. Vol. 51, No.5, pp 761 – 779.

21. Telford, W.M., Geldart, L.P. Sheriff, R.E and Keys, D.A. 1984. Applied Geophysics Cambridge University Press: London. 860p.

22. Uma, K. O. and Onuoha, K.M. 1989. "Groundwater Resources of the Lower Benue Trough: In Structure and Evolution of the Benue Trough and Ajacent regions". (Ed C. O. Ofoegbu) Earth Evaluation Sciences Monograph series, Vieweg Wiesbaden, Germany: 77-92.

23. Uma, K. O. 2003. "Hydrogeology of the Perched Aquifer systems in the Hilly Terrains of Nsukka Town, Enugu State, S. E. Nigeria". Water Resources Vol. 14 (2), p.85-92

24. Zohdy, A.A.R., Eaton, G.P and Mabey, D.R. (1974). Application of surface geophysics to ground water investigation: Techniques of water resources investigation of the US Geological Surveys Book 2 chapter D1, 116pp.

Table 1. Adjusted values from RESIST resistivity software for the Vertical Electrical Sounding (VES)

No	Current Electrode Spacing AB/2 (m)	VES 2 $\rho_a(\Omega m)$	VES 3 $\rho_a(\Omega m)$	VES 4 $\rho_a(\Omega m)$	VES 6 $\rho_a(\Omega m)$	VES 7 $\rho_a(\Omega m)$	VES 8 $\rho_a(\Omega m)$	VES 10 $\rho_a(\Omega m)$
1	1.00	10.46	84.0	305	536	124.1	244	149.7
2	2.00	29.3	258	894	1387	374	642	173.2
3	3.00	48.4	356	802	1089	447	588	209
4	5.00	82.8	567	998	3080	602	594	276
5	8.00	160.0	811	1169	4080	931	816	406
6	10.0	166.9	1015	1097	4970	971	1116	477
7	15.0	313	1144	1236	6000	1121	1522	716
8	20.0	326	1137	1352	5700	1021	1689	870
9	30.0	7480	1735	1032	6530	1871	1931	1328
10	40.0	7350	2330	1384	9890	2610	2460	1783
11	50.0	8380	2430	1444	8540	2620	4640	1859
12	75.0	13250	3840	2290	16240	4970	6720	3530
13	100	20980	4640	3450	22950	7890	8850	4790
14	150	27370	3970	3930	16340	7700	15140	7290
15	200	29300	9450	4210	35010	6880	22520	6510
16	300	43940		4860			43300	10010
17	400	109110		3810			46500	8980
18	500	164600		4560			36550	14070

Table 2. Summary of the Vertical Electric Sounding (VES) Results

VES	h_1 (m)	ρ_a 1 (Ωm)	D_1 (m)	h_2 (m)	ρ_a 2 (Ωm)	D_2 (m)	h_3 (m)	ρ_a 3 (Ωm)	D_3 (m)
2	0.8	50	0.8	2.2	1254	3.0	22.0	5487	25.0
3	1.2	180	1.2	6.8	1265	8.0	7.0	4687	15.0
4	0.8	1120	0.8	2.4	655	3.2	4.8	1875	8.0
6	1.2	1002	1.2	6.8	10225	8.0	7.0	6524	15.0
7	1.2	250	1.2	5.8	1290	7.0	11.0	4250	18.0
8	0.8	950	0.8	2.4	380	3.2	4.8	2154	8.0
10	0.8	108	0.8	4.2	325	5.0	10.0	3854	15
A_h	1.0			4.4			9.5		
LL	Top soil			Lateritic sandstone			Ferruginized. Medium – Coarse grained sandstone		

VES	h_4 (m)	$\rho_a 4$ (Ωm)	D_4 (m)	h_5 (m)	$\rho_a 5$ (Ωm)	D_5 (m)	h_6 (m)	$\rho_a 6$ (Ωm)	D_6 (m)	h_7 (m)	$\rho_a 7$ (Ωm)	D_7 (m)
2	20.0	2158	45.0	110.0	32015	155.0	-	85472	∞			
3	35.0	9886	50.0	102.0	13254	152.0	-	5547	∞			
4	22.0	1122	30.0	22.0	4215	52.0	106.0	13542	158.0	-	5545	∞
6	40.0	13245	55.0	105.0	78542	160.0	-	99857	∞			
7	30.0	10255	48.0	108.0	32150	156.0	-	2150	∞			
8	17.0	9985	25.0	120.0	99856	145.0	75.0	88547	220.0	-	32548	∞
10	37.0	78562	102.0	116.0	41258	218.0	-	7845	∞			
A_v	35.9			97.6			90.5					
LL_p	Sandstone			Sandstone			Sandstone			Coarse grained sandstone		

h (m) = thickness of layer (m), ρ_a (Ωm) = apparent resistivity (Ωm), A_v (m) = average thickness, LL_p = probable lithology of the layers, D (m) = depth

Table 3. Borehole lithologs of Agric farm University of Nigeria, Nsukka compared with the VES interpretation for this study

Depth (m)	Borehole litholog at Agric farm UNN (Fig. 2)	Probable lithology of the VES interpretation for this study (refer to Table 2)	F_{gp}
0 – 9	Red earth, sandy	LLp_1, LLp_2	Nsukka Formation
9 – 36	Red granular laterite (primary type)	LLp_3	..
36 – 57	Yellow coarse grained sandstone, ferruginized, lateritic (secondary type)	LLp_4	..
57 – 96	White fine grained, friable sandstone	LLp_4	Ajali Sandstone
96 – 144	White medium grained sandstone and friable	LLp_5	..
144 – 196	White friable fine grained sandstone with intercalation of thin shale clay beds	LLp_6	..
196 – 212	White friable, medium grained sandstone	LLp_7	..

LLp = probable lithology of the layers
F_{gp} = probable geologic Formations

Table 4. Borehole lithologs of Nnamdi Azikwiwe Library University of Nigeria, Nsukka compared with the VES interpretation for this study

Depth (ft)	Borehole litholog at Nnamdi Azikwiwe Library UNN (Fig. 3)	Probable lithology of the VES interpretation for this study (refer to Table 2)	F_{gp}
0 – 50	Deep reddish brown, weathered sandstone	LLp_1, LLp_2	Nsukka Formation
50 – 70	Dark brown ferruginized sand with lateritic sandstone	LLp_2	..
70 – 160	Light brown, coarse – medium sandstone	LLp_3	..
160 – 230	**Very light brown friable sandstone**	LLp_4	Ajali Sandstone
230 – 540	Light colour, medium grained sandstone	LLp_5	..
540 – 640	Light colour coarse – fine grained sandstone	LLp_5	..

LLp = probable lithology of the layers
F_{gp} = probable geologic Formations

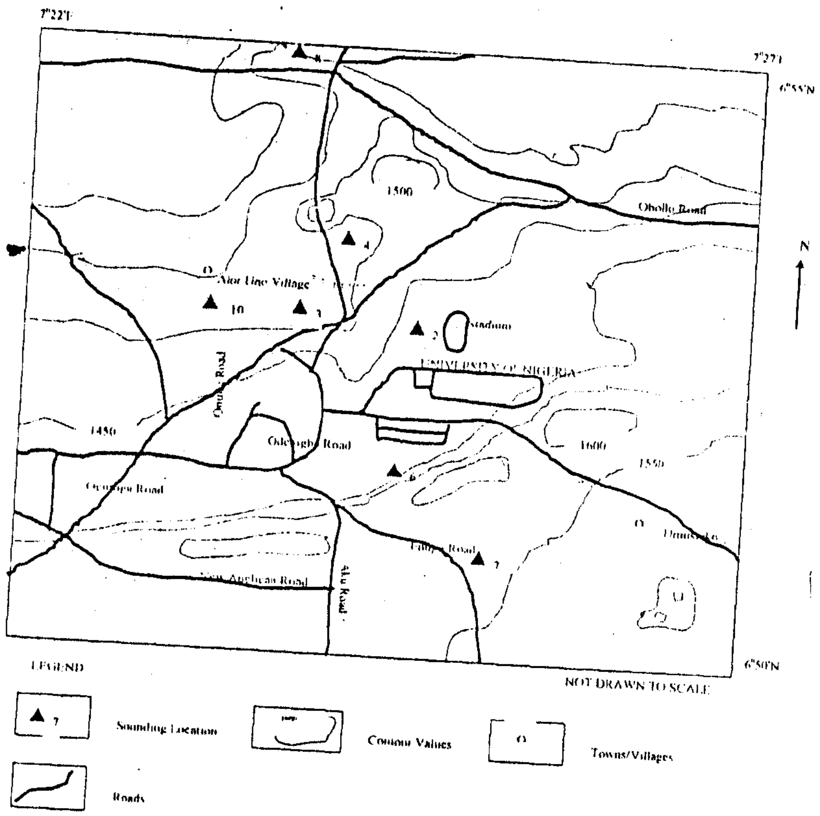


Fig. 1. Map of the study area showing sounding locations

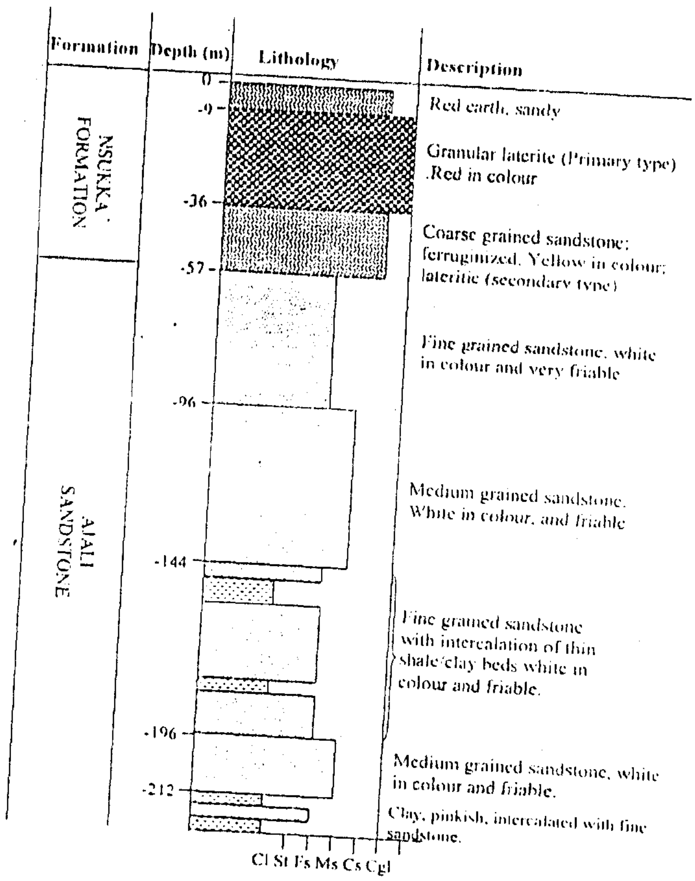


Fig. 2. Borehole Litholog at Agric. Farm, University of Nigeria, Nsukka (Compiled by the Works Department UNN)

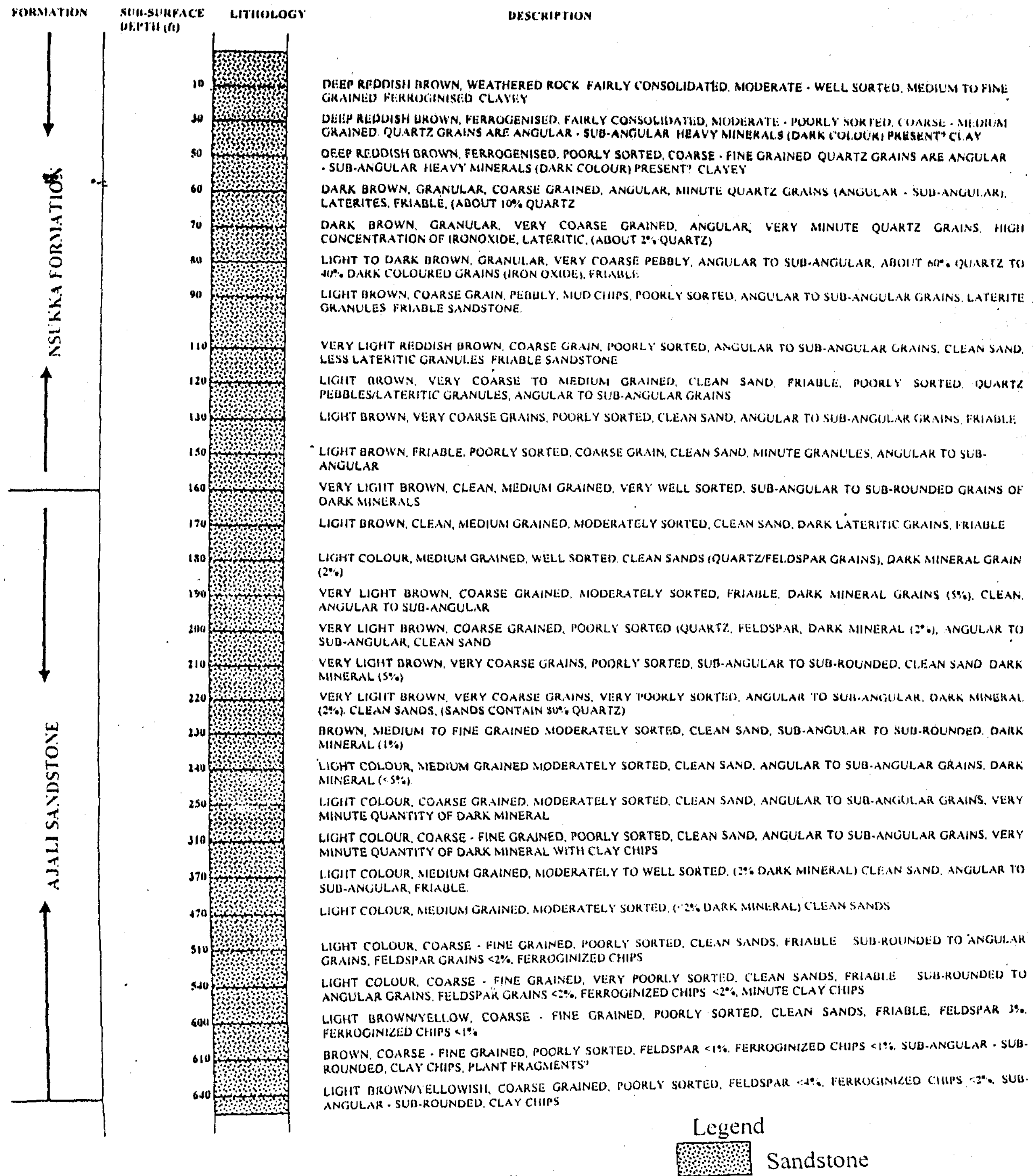
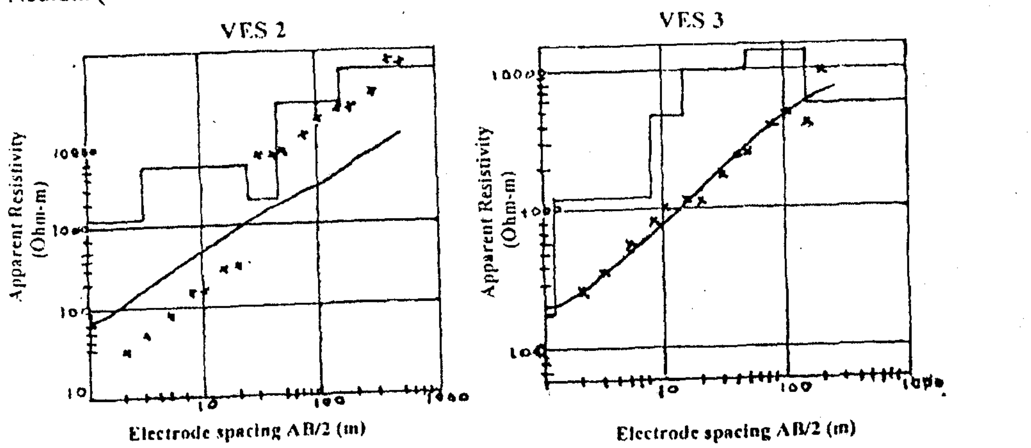


Fig. 3. Borehole Litholog at the New Nnamdi Azikiwe Library University of Nigeria, Nsukka (Modified from Ofoma & Egbu)



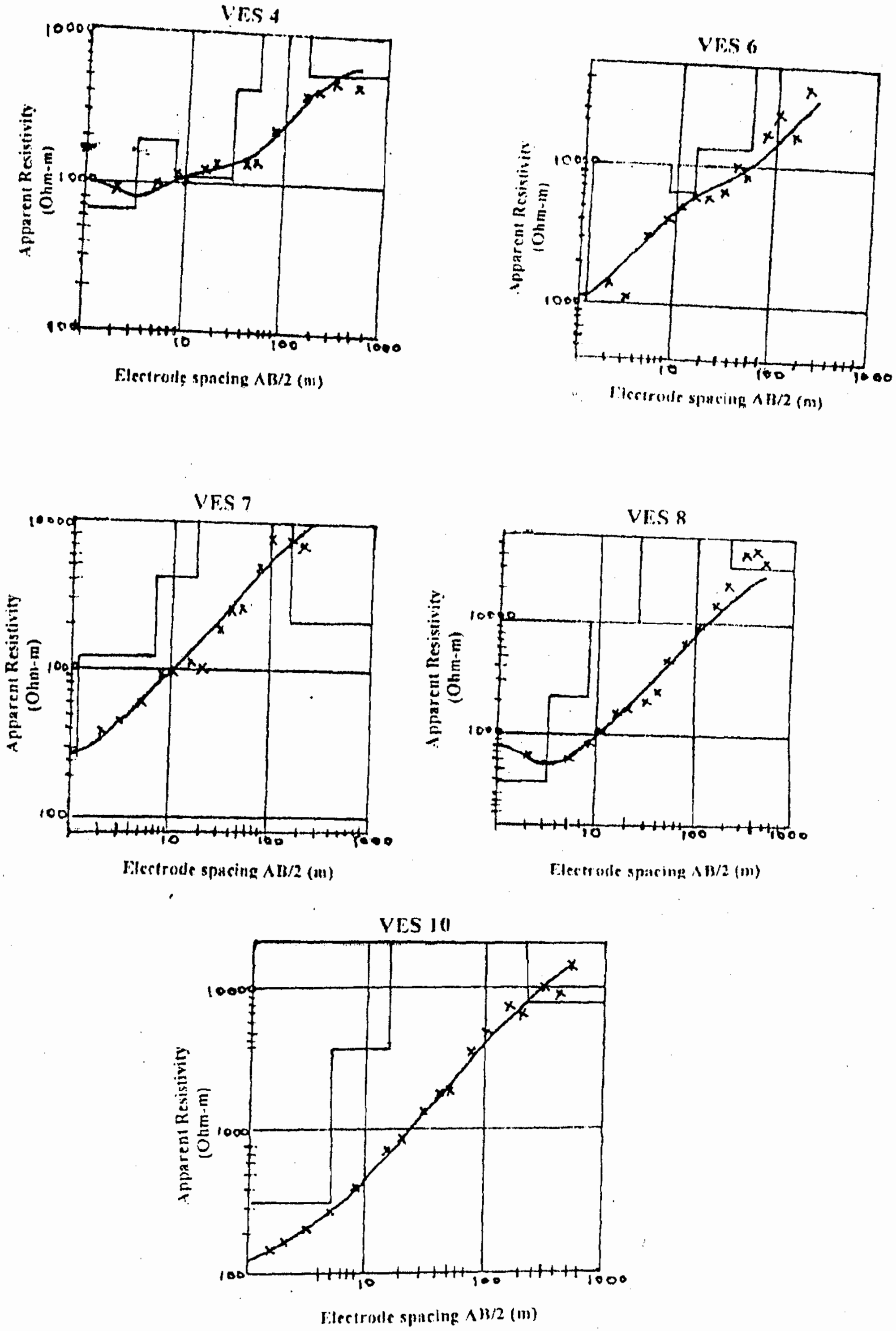


Fig. 4. Computer modelled curves for VES 2, 3, 4, 6, 7, 8 & 10

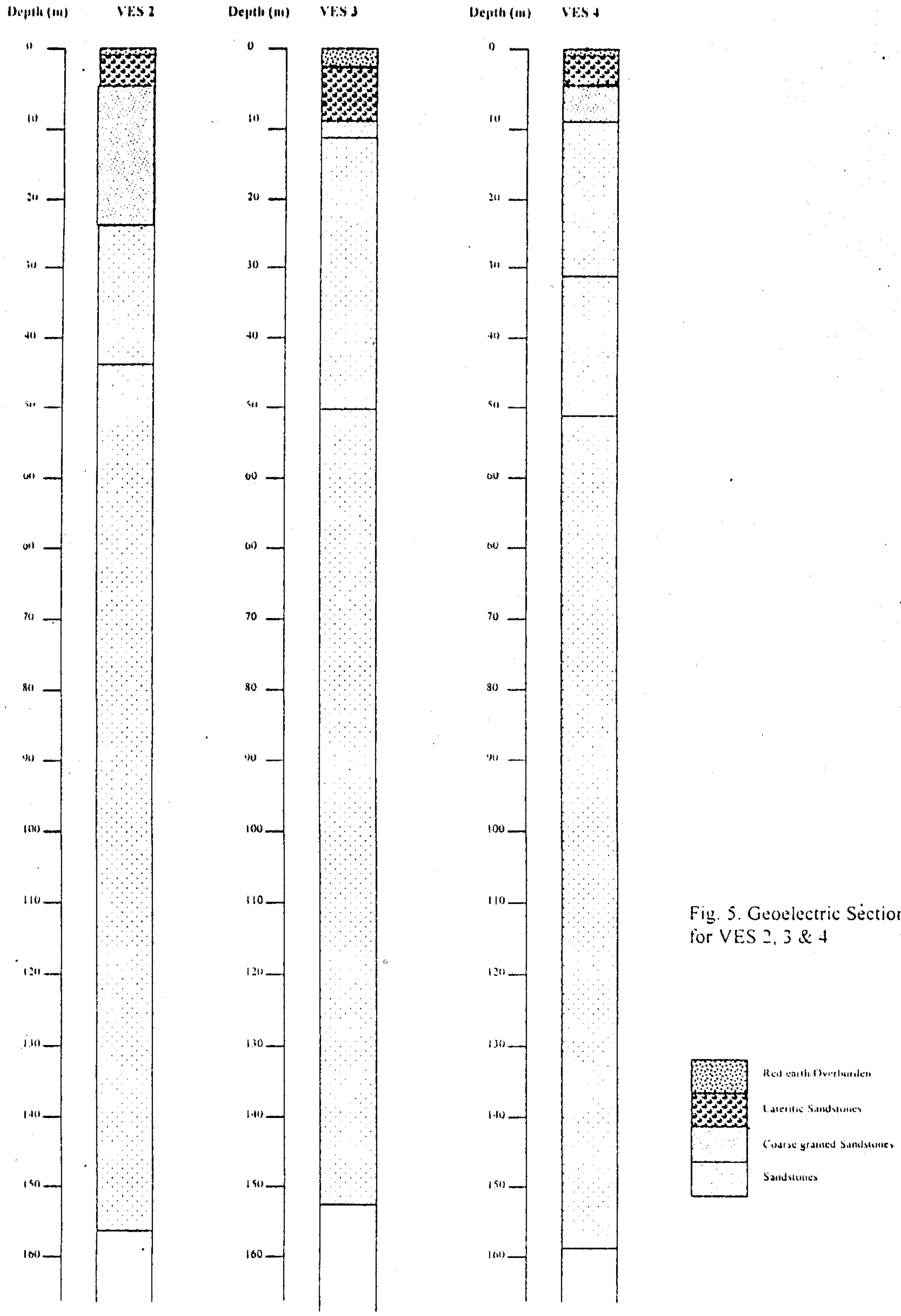


Fig. 5. Geoelectric Sections for VES 2, 3 & 4

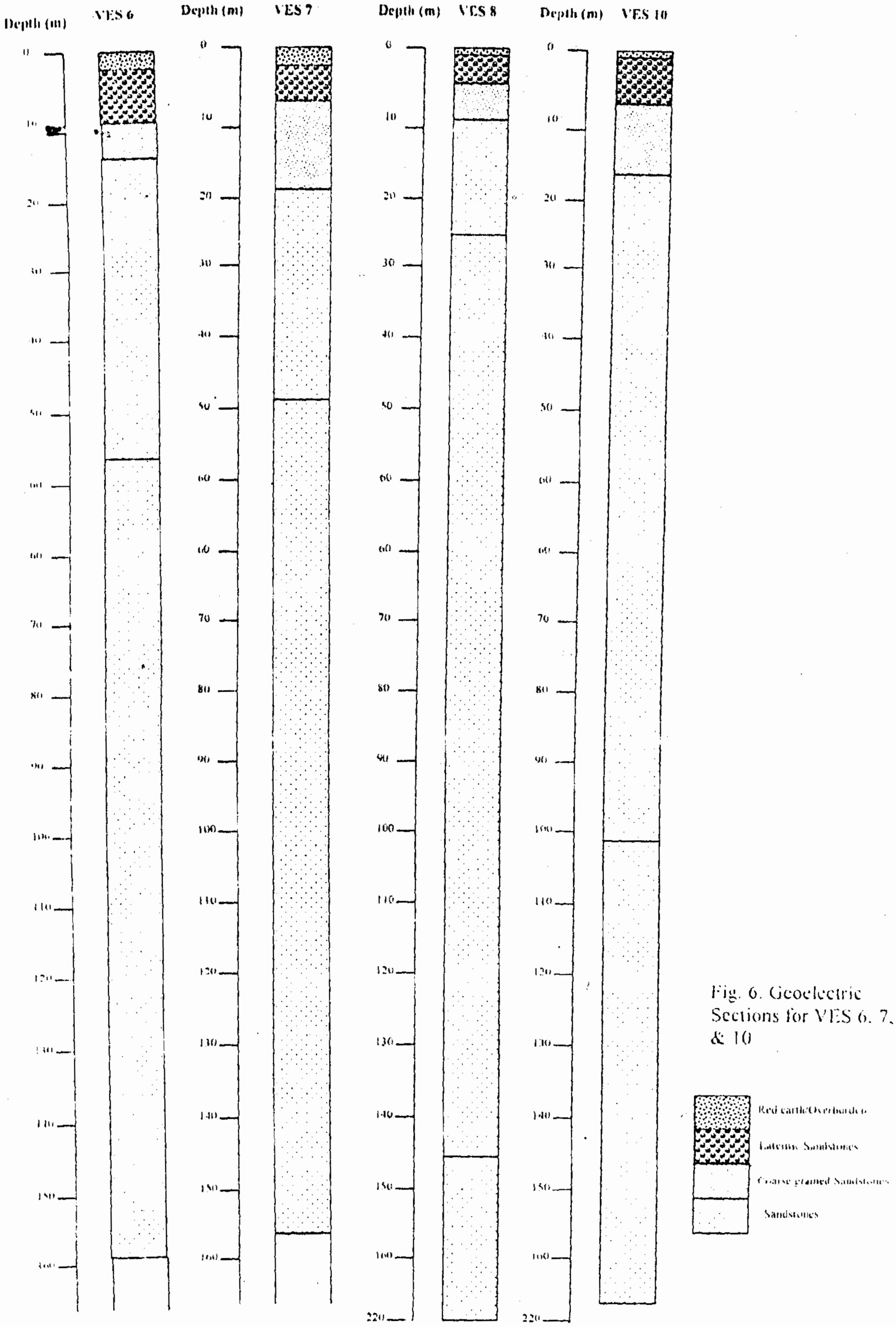


Fig. 6. Geoelectric Sections for VES 6, 7, 8 & 10

97.6m and 90.5m respectively. Depths of layer 5 are between 52.0m & 218.0m and that of layer 6 is between 158.0m & 220.0m. Approximate drill depths for VES 2 – 10 are 155.0m, 152.0m, 158.0m, 160.0m, 156.0m, 220.0m, and 218.0m respectively. In the study area regional water table ranges between 70.0m & 150.0m and depends on topography and time or season of acquiring the data (Uma, 2003). Geoelectric sections of the VES show six and seven layered earth (Figs. 5 & 6, Tab. 2). The geologic interpretation of the VES data was aided by the available borehole lithologs obtained for the area (Tables 3 & 4). The subsurface lithologies are feruginized, medium – coarse grained sandstone with laterites in the Nsukka Formation and predominantly sandstones in the Ajali Formation, these interpretations very well agree with each other (i.e. the borehole logs and VES results). The VES results, however, might have been affected by the effects of noise, instrumentation, computer error, suppression of thin lithologic beds or the 'lumping' effect etc, (David, 1994; Olayinka, 1996; Mamah, 1998; Uma, 2003; Obiora & Onwuka, 2005)

CONCLUSION

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REFERENCES

1. Benkhelil, J. 1982. "Benue Trough and Benue chain". Geological Magazine, V.119, p. 155-168.
2. Burke, K., Dessauvagie, T.F.J and Whiteman, A.J. 1970. "Geological History of the Benue valley and adjacent areas". In Dessauvagie, T. F.J and Whiteman, A.J. (Eds.) African Geology. Ibadan University Press, Ibadan. p. 187-206.
3. David, L. M. Jr. 1994. "Ambiquities in VES Interpretation: Case Histories in Southern Nigeria". **Water Resources.** Vol.4(1&2), p.43-48.
4. Egboka, B.C.E. 1983. "Analysis of groundwater resources of Nsukka area and Environs, Anambra State Nigeria". Nig. J. Min. Geol., Vol.20(1&2), p.1-16.
5. Ekoma Consultants 2001. Hydrogeological/geophysical investigation report for the location of borehole drilling sites at Aji and Umuogboagu communities in Igboeze North L.G.A. of Enugu State. Unpublished report.
6. GCU-UNN 2000. Baseline geological study at the site for the proposed Seismograph station at the University of Nigeria, Nsukka. Unpublished report
7. Ghosh, D.P. 1971. The application of linear filter theory to the direct interpretation of geo-electrical sounding measurements. Geophysical Prosp., Vol. 19, p. 192 -217.
8. Hoque, M. and Ezepue, M.C. 1977. "Petrology of the Ajali Sandstone". Nig. J. Min Geol. Vol. 14 (1) p.16-22.
9. Hoque, M., and Nwajide, C.S. 1984. "Tectono-sedimentological evolution of an elongate intracratonic basin (aulacogen); the case of the Benue trough of Nigeria" Nig. J. Min. Geol., Vol.21, p.19-25.
10. Lithprobe Services 2004. Vertical Electric Sounding (VES) for the location of borehole at Alo-Uno, Nsukka, Enugu State. Unpublished report.
11. Mamah, L.I. and Ekine, A.S. 1989. "Electrical Resistivity Anisotropy and Tectonism in Basal Nsukka Formation". Nig. J. Min. Geol., Vol.25(1&2), p.121-129.
12. Mamah, L.I. 1998. "Uncertainty in geosounding interpretation". Nig. J. Min. Geol., Vol.34 (1), p.37-42.

13. Murat, R.C. 1972. "Stratigraphy and paleogeography of cretaceous and lower Tertiary in Southern Nigeria". In Dessuvagie, T.F.J. and Whitman, A. J. (Eds.) African Geology. Ibadan University Press, Ibadan, p. 251-269.
14. Obiora, D.N. and Onwuka, O.S. 2005. "Groundwater Exploration in Ikorodu, Lagos-Nigeria: A surface Geophysical Survey contribution". Pacific J. Sci. Tech. Vol.6(1), p. 86 – 93.
15. Ofoma, A.E. 2001. Electrical resistivity and Magnetic surveys of some parts of Nsukka, L.G.A. unpublished M.Sc Thesis University of Nigeria, Nsukka. p.115
16. Ofoma, A.E. and O.C Egbu, (in Prep.) Grain size distribution and depositional processes of subsurface Maastrichtian sediments of the Anambra Basin
17. Olayinka, A.I. 1996. "Non-uniqueness in the interpretation of bedrock resistivity from sounding curves and its hydrogeological implications". Water Resources. Vol.7(1&2), p.49-55.
18. Reyment, R.A. (1965). Aspects of the Geology of Nigeria, Ibadan University Press, Nigeria, p. 210.
19. Selemo, A. 2001. Pre-drilling geophysical survey at Umumakashi, Nsukka, Enugu State. Unpublished report.
20. Short, K.C. and Stauble, A.J. 1967. Outline of Geology of Niger Delta. AAPG Bull. Vol. 51, No.5, pp 761 – 779.
21. Telford, W.M., Geldart, L.P. Sheriff, R.E and Keys, D.A. 1984. Applied Geophysics Cambridge University Press: London. 860p.
22. Uma, K. O. and Onuoha, K.M. 1989. "Groundwater Resources of the Lower Benue Trough: In Structure and Evolution of the Benue Trough and Ajacent regions". (Ed C. O. Ofoegbu) Earth Evaluation Sciences Monograph series, Vieweg Wiesbaden, Germany: 77-92.
23. Uma, K. O. 2003. "Hydrogeology of the Perched Aquifer systems in the Hilly Terrains of Nsukka Town, Enugu State, S. E. Nigeria". Water Resources Vol. 14 (2), p.85-92
24. Zohdy, A.A.R., Eaton, G.P and Mabey, D.R. (1974). Application of surface geophysics to ground water investigation: Techniques of water resources investigation of the US Geological Surveys Book 2 chapter D1, 116pp.

Table 1. Adjusted values from RESIST resistivity software for the Vertical Electrical Sounding (VES)

No	Current Electrode Spacing AB/2 (m)	VES 2 $\rho_a(\Omega m)$	VES 3 $\rho_a(\Omega m)$	VES 4 $\rho_a(\Omega m)$	VES 6 $\rho_a(\Omega m)$	VES 7 $\rho_a(\Omega m)$	VES 8 $\rho_a(\Omega m)$	VES 10 $\rho_a(\Omega m)$
1	1.00	10.46	84.0	305	536	124.1	244	149.7
2	2.00	29.3	258	894	1387	374	642	173.2
3	3.00	46.4	356	802	1089	447	588	209
4	5.00	82.8	567	998	3080	602	594	276
5	8.00	160.0	811	1169	4080	931	816	406
6	10.0	166.9	1015	1097	4970	971	1116	477
7	15.0	313	1144	1236	6000	1121	1522	716
8	20.0	326	1137	1352	5700	1021	1689	870
9	30.0	7480	1735	1032	6530	1871	1931	1328
10	40.0	7350	2330	1384	9890	2610	2460	1783
11	50.0	8380	2430	1444	8340	2620	4640	1859
12	75.0	13250	3840	2290	16240	4970	6720	3530
13	100	20980	4640	3450	22950	7890	8850	4790
14	150	27370	3970	3930	16340	7700	15140	7290
15	200	29300	9450	4210	35010	6880	22520	6510
16	300	43440		4860			43300	10010
17	400	109110		7810			46500	8980
18	500	164600		4560			36550	14070

Table 2. Summary of the Vertical Electric Sounding (VES) Results

VES	h_1 (m)	ρ_a 1 (Ωm)	D_1 (m)	h_2 (m)	ρ_a 2 (Ωm)	D_2 (m)	h_3 (m)	ρ_a 3 (Ωm)	D_3 (m)
2	0.8	50	0.8	2.2	1254	3.0	22.0	5487	25.0
3	1.2	180	1.2	6.8	1265	8.0	7.0	4687	15.0
4	0.8	1120	0.8	2.4	655	3.2	4.8	1875	8.0
6	1.2	1002	1.2	6.8	10225	8.0	7.0	6524	15.0
7	1.2	250	1.2	5.8	1260	7.0	11.0	4250	18.0
8	0.8	950	0.8	2.4	380	3.2	4.8	2154	8.0
10	0.8	108	0.8	4.2	325	5.0	10.0	3854	15
A_v	1.0			4.4			9.5		
LL_g	Top soil			Lateritic sandstone			Ferruginized. Medium – Coarse grained sandstone		