Journal of Environment and Earth Science
ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online)
Vol 2, No.7, 2012

Engineering Geophysical Investigation Around Ungwan Doka, Shika Area within the Basement Complex of North-Western Nigeria

*FADELE S.I (M.Sc), JATAU B.S (Ph.D) AND UMBUGADU A. (M.Sc)
Nasarawa State University, Keffi, Nigeria
*Email: fadeleidowu@yahoo.com +2348066035524; bsjatau@yahoo.co.uk +2348034529326

Abstract
Geophysical investigation for engineering or environmental studies was carried out around Ungwan Doka of Shika area which falls within the Basement Complex of North-Western Nigeria. The study is aimed at evaluating the competence of the near surface formation as foundation materials, and to unravel the subsurface profile which in turn determines if there would be any subsurface lithological variation(s) that might lead to structural failure at the site and evaluating the groundwater potential of the site and determining the level of safety of the hydrogeologic system. Vertical Electrical Sounding (VES), using Schlumberger configuration was adopted. A total of 18 VES was conducted. The data obtained were subjected to 1-D inversion algorithm to determine the layer parameters. The geoelectric section revealed two to four lithologic units defined by the topsoil, which comprises clayey-sandy and sandy lateritic hard pan; the weathered basement; partly weathered/fractured basement and the fresh basement. The resistivity values range from 26Ωm - 373Ωm; 77Ωm - 391Ωm; 473Ωm - 708Ωm; and 1161Ωm - 3600Ωm in the topsoil, weathered, fractured basement and fresh basement respectively. Layer thicknesses vary from 0.38m – 6.58m in the topsoil, 1.1m – 33.04m in the weathered layer, 5.86m – 34.1m in the fractured basement. Depth from the surface to bedrock/fresh basement generally varied between 2.65m and 37.75m. Based on the resistivity values, it is concluded that the subsurface material up to the depth of 25m is competent and has high load-bearing capacity. However, resistivity values less than 100Ωm at depths of 10m-15m indicate high porosity, high clayey sand content and high degree of saturation which are indications of soil conditions requiring serious consideration in the design of massive engineering structures. The hydrogeologic system at the site is vulnerable to contamination. Hence, the result reasonably provide a basis for which groundwater potential zones are appraised for safety in case potential sources of groundwater contamination sites such as septic tanks and sewage channels are planned for the area under study.
Key words: VES, Top soil, Weathered Basement, Partly weathered or Fractured Basement, Fresh ,Basement

1. Introduction

The failure statistic of structures such as buildings, tarred roads and bridges throughout the nation is increasing geometrically. Most of these failures were caused by swelling clays (Blyth and Freitas, 1988). In recent times, the collapse of civil engineering structures has been on the increase for reasons associated with subsurface geological sequence (Omoyoloye et al., 2008). The foundation of any structure is meant to transfer the load of the structure to the ground without causing the ground to respond to uneven and excessive movement. In order to achieve this, most buildings are supported on pads, strips and rafts or piles (Blyth and Freitas, 1988). Therefore the knowledge of the probable cause of rampant failure of building foundations due to subsurface movements giving rise to cracks or structural differential settlements has been a great concern to geoscientists. This has helped to distinguish between a continuing movement, which is often more likely to be a problem and those of single events, which may not require repair depending on the extent of damage. However, adequate insight on the types and patterns of foundation-based cracks and their evaluation has necessitated the need to consider the geological and geophysical basis for buildings' failure and adequate precaution taken to minimize such disaster. The amount, type and direction of foundation movement are commonly noted from the bulging of brick or masonry blocks. These in turn reveal the risk of vertical collapse or horizontal dislocation. The risk could be traced to the height of construction, materials used for the building, site factor, earth loading or water. Other factors include the seismic action, atmospheric disaster and accident (Omoyoloye et al., 2008). If cracks are old with no sign of continuing or recurrent movement, building inspectors accept monitoring rather than quickly recommending repairs. Most house settling cracks are basically caused by either the differences in expansion and compression coefficients of the construction materials, relative changes in the shapes and sizes of saturated soils or the dynamic earth. The need for subsurface geophysical investigation has therefore become very imperative so as to prevent loss of valuable properties and lives that always accompany such a failure. Foundation evaluation of a new site is necessary so as to provide subsurface and aerial information that normally assist civil engineers, builders and town planners in the design and siting of foundations of civil engineering structures (Omoyoloye, et al., 2008). Geophysical methods such as the Electrical Resistivity (ER), Seismic refraction, Electromagnetic

(EM), Magnetic and Ground Penetrating Radar (GPR) are used singly or in combinations for engineering site investigations. The applications of such geophysical investigation are used for the determination of depth to bedrock, structural mapping and evaluation of subsoil competence (Burland and Burbidge, 1981; Burger, 1992**).**
The engineering geophysical investigation was carried out at Ungwan Doka in Shika area, Kaduna State, North-Western Nigeria, aimed at determining the depth to the competent stratum in the subsurface, delineation of areas that are prone to subsidence or some form of instability, evaluating the groundwater potential of the site and determining the level of safety of the hydrogeologic system in the study area.

2. Location and Topography of the Study area

The study area lies between Latitudes 11^0 10**'** 49"N - 11^0 11**'** 05**"** N and Longitudes 7^0 35'40"E - 7^0 38**'** 50**"** E. The site is situated along the Sokoto road, North West of Zaria (Fig. 1). The topography is that of high plain (flat terrain) of Hausa land. The site is located within the tropical climatic belt with Sudan Savannah vegetation. The environment is Savannah type with distinct wet and dry season. The rainfall regime is simple but with slight variation which consists of wet season lasting from May to September and characterized by heavy down pour at the start and end of the rainy season. The annual rainfall varies between 800 mm to 1090 mm while the mean annual temperature ranges between 24^0C to 31^0C reaching a maximum of about 36^0C around April (Hore,1970; Goh and Adeleke, 1978).

3. Geology of Study Area

The study area is laid on undifferentiated Basement Complex. Though there were no rock out-crops within the site, observation however revealed that the weathered bedrock in some existing hand-dug wells within the site and environs indicates the occurrence of granitic rocks within the site which are porphiritic in texture. The study area falls within the Metasediments of the Basement Complex (McCurry, 1970). The Basement Complex in Kaduna state was affected by an Orogeny, which predated the emplacement of the Older Granite. During this event, deformation of the basement produced north-south trending basins of Metasediment in the form of Synclinoria. Tertiary earth movements tilted the Metasediments to north and warped the basement along the axis of the uplift pass through the present Kaduna state having northwest trend. They have a pronounced effect on the drainage pattern of the state. Through the process of metamorphism, migmatization and granitization that occurred within at least two tectono-metamorpic cycles, the rocks were largely transformed into migmatites and granite gneiss, with some relics of the original gneisses McCurry (1976). The Basement Complex was later intruded by series of intermediate and acid plutonic rocks during the Pan African Orogeny according to McCurry (1976). Oyawoye (1970), showed that there is structural similarity between the study area and the rest of West Africa. (MacLeod *et al* 1971), reported that newer basalts often overlie alluvial deposits. The Younger Granites are high level discordant intrusions in the Basement Complex and occupy approximately 8% of the total surface area of Nigeria according to Rahaman (1976).

4. Methodology

Vertical Electrical Soundings (VES) using Schlumberger array were carried out at eighteen (18) stations. A regular direction of N-S azimuth was maintained in the orientation of the profiles. Overburden in the basement area is not as thick as to warrant large current electrode spacing for deeper penetration (Oseji, et al., 2005; Okolie, et al., 2005), therefore the largest Current electrode spacing AB used was 200m, that is, 1/2AB=100m. The principal instrument used for this survey is the ABEM (Signal Averaging System, **(**SAS 300) Terrameter. The resistance readings at every VES point were automatically displayed on the digital readout screen and then written down on paper.

5. Results and Discussion

Shlumberger array shown in figure 2 was adopted for the survey. A and B are point current electrodes through which current is driven into the ground, while M and N are two potential electrodes to record the potential distribution in the subsurface within the two current electrodes.
From Ohm's law, the current I and potential V in a metal conductor at constant temperature are related as follows:

$$V = IR \qquad (1)$$

Where R is the constant of proportionality termed resistance and it is measured in ohms. The resistance R, of a conductor is related to its length L and cross sectional area A by;

$$R = \rho L / A \qquad (2)$$

Where ρ is the resistivity and it is a property of the material considered.
From equation (1) and (2),

$$V = I\rho L / A \qquad (3)$$

The vertical electrical sounding (VES) with Schlumberger array involves fixing the potential electrodes at point M and N, and symmetrically increasing the current electrode separation AB about the centre by displacing A and B outwardly in steps. This will increase the depth of penetration within the separation AB. Thus the varying resistivity measured when electrode array position is varied in an inhomogeneous medium is termed apparent resistivity.
For simple treatment, a semi-infinite solid with uniform resistivity, ρ, is considered. A potential gradient is measured at M and N when current electrodes located on the surface of the equipotential surface is semi-spheral downward into the ground at each electrode. The surface area will then be $2\pi L^2$, where L is the radius of the sphere. Thus

$$V = I\rho / 2\pi L \qquad (4)$$

By deduction then, the potential at M (V_M), due to the two current electrodes, is

$$V_M = I\rho/\{2\pi\ (1/r_1 - 1/r_2)\} \qquad (5)$$

Similarly, the potential at electrode N (V_N) is given by

$$V_N = I\rho/\{2\pi\ (1/r_3 - 1/r_4)\} \qquad (6)$$

where r_1, r_2, r_3 and r_4 are shown in Figure 2.

The potential difference, ΔV, acrss electrodes M and N is $V_M - V_N$. If the body is inhomogeneous like the study area, apparent resistivity (ρ_a) is considered,

$$\rho_a = K\ (\Delta V/ I) \qquad (7)$$

Where ρ_a is apparent resistivity in ohm-metre, and

$$K = 2\pi\ [(1/r_1 - 1/r_2) - (1/r_3 - 1/r_4)]^{-1} \qquad (8)$$

K is called the geometric factor whose value depends on the type of electrode array used.
For Schlumberger array, if MN =2b and 1/2AB = L then,

$$K = \pi\ (L^2/2b - b/2) \qquad (9)$$

The geometric factor, K, was first calculated for all the electrode spacings using the equation 9; $K= \pi\ (L^2/2b - b/2)$, for Schlumberger array with MN=2b and 1/2AB=L. The values obtained, were then multiplied with the resistance values to obtain the apparent resistivity, ρ_a, values (equation 7). Then the apparent resistivity, ρ_a, values were plotted against the electrode spacings (1/2AB) on a log-log scale to obtain the VES sounding curves using an appropriate computer software *IPI2win* in the present study. Some sounding curves and their models are shown in Fig.3. Similarly, geoelectric sections are shown in Figs. 4 and 5.Three resistivity sounding curve types were obtained from the studied area and these are the H ($\rho_1>\rho_2<\rho_3$), A ($\rho_1< \rho_2<\rho_3$) and KH ($\rho_1>\rho_2< \rho_3>\rho_4$) type curves. However, there are few points which show two geologic layer cases. The results of the interpreted VES curves are shown in Tables 1 and 2. The modeling of the VES measurements carried out at eighteen (18) stations has been used to derive the geoelectric sections for the various profiles (Figure 4 and 5). These have revealed that there are mostly four and three geologic layers beneath each VES station, and two layer cases at three different VES points. The geologic sequence beneath the study area is composed of top soil, weathered basement, partly weathered/fractured basement, and fresh basement. The topsoil is composed of clayey-sandy and sandy-lateritic hard crust with resistivity values ranging from 26Ωm to 391Ωm and thickness varying from 0.38m to 6.58m, thinnest at VES 12 and thickest at VES 13. It is however, observed from the geoelectric sections that VES 10, 11, 12 and 13 are characterized with low resistivity values varying between 26Ωm to 99Ωm suggesting the clayey nature of the topsoil in these areas and possibly high moisture content. The second layer is the weathered basement with resistivity values varying from 77Ωm to 391Ωm and thickness ranges between 1.1m to 33.04m, thinnest at VES 16 and thickest at VES 6. The third layer is the partly weathered and fractured basement with resistivity and thickness values varying between 473Ωm to 708Ωm and 5.86m to 34.1m respectively. The layer is extensive and thickest at VES 18 and thinnest at VES 16. The fourth layer is presumably fresh basement whose resistivity values vary from 1161Ωm to 3600Ωm with an infinite depth. Though the thickness of the bedrock is assumed to be infinite, the depth from the earth's surface to the bedrock surface varies between 2.65m to 37.75m. Quite a few of the profiles dipping and a negligible number of them show synclinal and fractured structure. These formations have some geological, physical and near-surface engineering significance.

6.1 Profile A-A'

Profile A-A' geoelectric section suggests that the site is characterized by lateritic hard pan at different consolidation levels within shallow depths, while gneiss and granites mainly, characterize the basements (Fig.4). The fresh basements have synclinal structure which cut across the profile. The weathered/fractured basement has a dipping layering. The probable feature that may cause building failure could be geologic feature like dipping bedrock or synclinal structure. This is because while overburden materials fill the synclinal structure, their columns undergo ground movement by subsidence and thereby could amount to uneven settlement at the foundation depths of buildings. In other words, uneven stress distribution may occur at the foundation depths of subsurface, that is one side of building structure may have a stronger support than the other adjacent of it. Another factor that could contribute to structural defect of building is the seasonal variation in the saturation of clay which causes ground movement and is caused by clay swells and shrinkages which are occasioned by alternate wet and dry seasons. The area is characterized by clay soils with lateritic patches at shallow depths with their thickness ranging between 1.06m and 4.14m.

6.2 Profile B-B'

The geoelectric section revealed clayey sandy topsoil having some lateritic hard crust patches (Fig. 5). The synclinal structure at VES point 11 is not well pronounced and may not pose any serious danger to building foundation. However, there is a deep weathering beneath VES point 17 and 18. The presence of laterite beneath the clayey topsoil which hardly extends beyond 2.5m reduces the danger posed by clay formation to large buildings. This area forms a good site for the erection of high-rise civil engineering structures.

6.3 Competence Evaluation

There are no indications of any major linear structure such as fracture or faults that could aid building subsidence. The geologic sequence beneath the area is composed of thin layer of topsoil, thick weathered layer, partly weathered/fractured basement and fresh bedrock. The topsoil constitutes the layer within which small civil engineering structures can be constructed. From the table of resistivity values Table 1, the topsoil is composed of sandy clay, clayey sand and patches of lateritic hard pans. Engineering competence of the subsurface can be qualitatively evaluated from the layer resistivity. The higher the layer resistivity value, the higher the competence of a layer; hence from the point of view of the resistivity value therefore, laterite is the most competent of the delineated topsoil, followed by clayey sand and sandy clay being the least competent. Based on the resistivity values, depths of about 8-10m can support small to medium size structures while depth in excess of 25m can support massive civil engineering structures in the study area.

6.4 Groundwater Potential

Even though experience has shown that there is no direct relationship between groundwater yield and borehole depth in a basement complex environment, studies (Bala and Ike, 2001; Omosuyi et al., 2008; Ariyo and Osinawo, 2007) revealed that areas with thick overburden cover in such basement complex terrain has high potential for groundwater. According to Ariyo and Oguntade (2009), in a basement complex terrain, areas with overburden thickness of 15m and above are good for groundwater development. The highest groundwater yield is often obtained from a weathered/fractured aquifer, or simply a subsurface sequence that has a combination of a significantly thick and sandy weathered layer and fractured aquifer. Where the bedrock is not fractured, a borehole can be located at a point having a relatively high layer resistivity greater than 150Ωm but less than 600Ωm (Olorunfemi, 2009). From the foregoing two parameters – overburden thickness and resistivity values, VES 1, 2, 3, 4, 5, 6, 7, 17 and 18 can be considered to be productive zones for groundwater development in the study area. Since the area is generally shallow to the water aquifer and groundwater in this area is vulnerable to pollution, the depth of sewage system should be <10m to the weathered basement (aquiferrous zone) in order to avoid groundwater contamination. It is suggested that potential sources of contamination site like sewage channels should be sited far away from viable aquifer units to ensure safety consumption of groundwater within the area.

7. Conclusion

The VES results revealed heterogeneous nature of the subsurface geological sequence. Though the geoelectric section showed complexity in the subsurface lithology, there is however, no indication of any major fracture/fault that could aid subsidence. The geologic sequence beneath the study area is composed of topsoil, weathered layer, partly weathered/fractured basement, and fresh basement. The topsoil is composed of clayey-sandy and sandy-lateritic hard crust with resistivity values ranging from 26Ωm to 391Ωm and thickness varying from 0.38m to 6.58m, thinnest at VES 12 and thickest at VES 13. It is however, observed from the geoelectric sections that VES 10, 11, 12 and 13 are characterized with low resistivity values varying between 26Ωm to 99Ωm suggesting the clayey nature of the topsoil in these areas and possibly high moisture content. The second layer is the weathered basement with resistivity values varying from 77Ωm to 391Ωm and thickness ranges between 1.1m to 33.04m, thinnest at VES 16 and thickest at VES 6. The third layer is the partly weathered and fractured basement with resistivity and thickness values varying between 473Ωm to 708Ωm and 5.86m to 34.1m respectively. The layer is extensive and thickest at VES 18 and thinnest at VES 16. The fourth layer is presumably fresh basement whose resistivity values vary from 1161Ωm to 3600Ωm with an infinite depth. Though the thickness of the bedrock is assumed to be infinite, the depth from the earth's surface to the bedrock surface varies between 2.65m to 37.75m. A-curve type which shows a continuous and uniform increase in resistivity predominates. This curve typifies an area showing characteristics of high load-bearing strength. This is followed by HK-curve showing that some areas have overburden saturation which recharges the main aquifer units. The rest of the curves are minority in number with H-type curve which has a minimum resistivity intermediate layer underlain and overlain by more resistant materials reminiscent of areas promising for groundwater development and also few 2-layer cases close to the bedrock are observed. Based on the resistivity values of the different geoelectric layers, the various geologic units up to depth of 25m are competent and can support massive civil engineering structures. The presence of laterite beneath the clayey topsoil which hardly extends beyond 2.5m reduces the danger posed by clay formation to large buildings. Other probable causes of foundation defects are the growth of tree roots, organic deposits, sink holes, cavities or ground surface saturation due to seepages and this should be taken care of during building project implementation to ensure that buildings erected at the site stands the test of time. In a basement complex terrain, areas with overburden thickness of 15m and above are good for groundwater development. The highest groundwater yield is often obtained from a weathered/fractured aquifer, or simply a subsurface sequence that has a combination of a significantly thick and sandy weathered layer and fractured aquifer. Where the bedrock is not fractured, a borehole can be located at a point having a relatively high layer resistivity greater than 150Ωm but less than 600Ωm (Olorunfemi, 2009). From the foregoing two parameters – overburden thickness and resistivity values, VES 1, 2, 3, 4, 5, 6, 7, 17 and 18 can be considered to be productive zones for groundwater development in the study area. To ensure safety appraisal of groundwater consumption in the area, potential sources of contamination site should be sited far away from viable aquifer units to ensure safety consumption of groundwater within the study area.

Acknowledgement
The field guide and contributions of Dr. B.S Jatau technically and financially cannot be over emphasized. His supports, corrections and guides are gratefully acknowledged, you are indeed a good mentor. Words of wisdom and encouragement from my fathers and mentors in geology matters, the likes of Prof. S. Abaa and Prof. N.G. Obaje also make this paper work a huge success.

References

Ariyo, S.O. and Oguntade, A.K. (2009). Geophysical Investigation for Groundwater Potential in Mamu Area, Southwestern Nigeria. Medwell Online Journal of Earth Sciences, Vol.3, no.1, pp.10-13.

Ariyo, S.O. and Osinawo, O.O. (2007). Hydrogeophysical Evaluation of Groundwater Potentials of Atan/Odosenbora. Medwell Online Journal of Earth Sciences, Vol.9, no.1, pp. 50-65.

Bala, A.E. and Ike, E.C. (2001). The Aquifer of the Crystalline Basement Complex Area of Africa. Quarterly Journal of Engineering Geology, Vol.18, pp. 35-36.

Burger, R.H (1992), 'Exploration Geophysics of the Shallow Subsurface'. Prentice Hall, U.S.A. pp. 30-56

Blyth, F.G.H and de Freitas, M.D., (1988). Geology for Engineers. Butler and Tannar Ltd, Frome and London. Pp. 292-293.

Burland, J.B and Burbidge, M.C (1981). Settlement of Foundations on Sand and Gravel Proceedings of the Institution of Civil Engineers, 78(1), pp. 1325- 1381.

Goh, C.L., and Adeleke, B.O., (1978). Certificate Physical and Human Geography' Oxford University Press, Ibadan,pp78-150.

Hore, P.N (1970). Weather and Climate of Zaria and its Region. (Ed.) By M.J. Mortimore, Department of Geography, Occasional Paper No4. A.B.U. Zaria. pp. 41-54

McCurry, P. O. (1970). The Geology of Zaria sheet 102 S.W and its Region in Mortimore, M.J. (Ed). Department of Geography occasional paper No.4, Ahmadu Bello University, Zaria. pp. 1-3.

McLeod W.N.; Turner D.C. and Wright, E.P. (1971). The Geology of Jos Plateau with 1:100,000 Sheets 147,148,168,169,189 and 190. Geol. Survey Nigeria Bulletin, 32.

Omosuyi, G.O., Ojo, J.S. and Enikanoselu, P.A. (2003). Geophysical Investigation for Groundwater around Obanla-Obakekere in Akure Area within the Basement Complex of South-western Nigeria. Journal of Mining and Geology, Vol.39, no.2, pp. 109-116.

Okolie, E.C., Osemeikhian, J.E.A., Oseji, J.O. and Atakpo, E. (2005). Geophysical Investigation of the Source of River Ethiope in Ukwuani Local Government Area of Delta State. Nigerian Institute of Physics, Vol.17, pp.30-45.

Olorunfemi M.O. (2009). Water resources, Groundwater Exploration, Borehole site selection, and Optimum Drill Depth in Basement Complex Terrain: Journal of the Nigerian Association of Hydrogeologists. Special Publication Series 1, pp. 1-20.

Omoyoloye, N.A., Oladapo, M.I. and Adeoye, O.O., (2008). Engineering Geophysical Study of Adagbakuja Newtown Development, Southwestern Nigeria. Medwell Online Journal of Earth Science; Vol. 2(2); pp. 55-63

Oseji, J.O., Atakpo, E. and Okolie, E.C. (2005). Geoelectric Investigation of the Aquifer Characteristics and Groundwater Potential in Kwale, Delta State. Nigerian Journal of Applied Sciences and Environmental Management, Vol.9, pp. 157-1600.

Oyawoye, M.O (1970). The Basement Complex of Nigeria. In: Dessauvagie, TFJ and White man, A.J (Eds) African Geology. University Press, Ibadan Nigeria pp. 91-97.

Rahaman, M.A. (1976).Review of the Basement Geology of South western Nigeria. In: Kogbe (Ed.). Geology of Nigeria, Elizabeth Publishing Company Lagos pp 41-58.

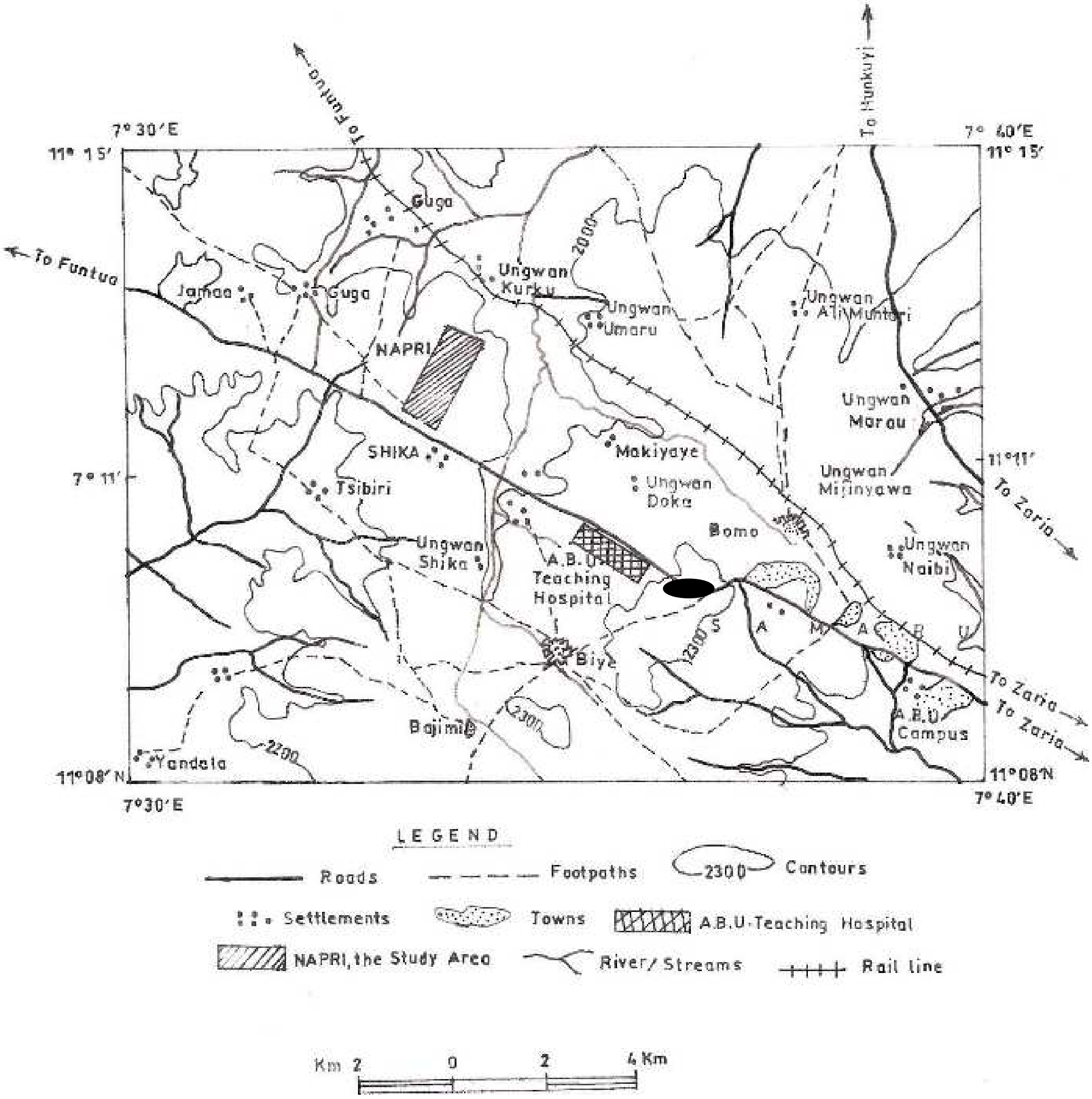


Figure 1: Location Map Showing the Study Area (From Northern Nigerian Survey Map)

Study Area

Table 1: The results of the interpreted VES curves

VES Stations	Thickness (m)	Layer resistivity (Ωm)	Remarks	Curve types	Numb of layers
1	1.43 6.8 17.0 -	373 221 473 1251	TP WB PWB FB	KH	4
2	1.65 15.7 20.4 -	370 77 503 1161	TP WB PWB FB	KH	4
3	1.06 12.8 11.0 -	276 251 522 1198	TP WB PWB FB	KH	4
4	2.02 5.51 17.4 -	304 293 835 2020	TP WB PWB FB	KH	4
5	2.64 32.36 -	257 144 1410	TB WB FB	H	3
6	2.96 33.04 -	256 391 1450	TP WB FB	A	3
7	1.87 17.13 -	272 298 1365	TP WB FB	A	3
8	4.14 3.85 -	367 298 1765	TP WB FB	A	3
9	1.54 6.58 -	353 708 1450	TP PWB FB	A	3
10	1.13 2.33 -	26 316 1251	TP WB FB	A	3
11	2.64 8.84 -	28 162 1410	TB WB FB	A	3
12	0.38 5.10 -	27 162 3600	TP WB FB	A	3

Table 2: The results of the interpreted VES curves

VES Stations	Thickness (m)	Layer resistivity (Ωm)	Remarks	Curve types	Numb of layers
13	6.58 -	99 2935	TP FB	2-Layer case	2
14	2.64 -	347 2593	TB FB	2-Layer case	2
15	6.08 -	261 3307	TB FB	2-Layer case	2
16	1.5 1.1 5.86 -	354 258 519 1519	TP WB PWB FB	K H	4
17	1.59 5.09 30.6 -	281 356 658 1614	TP WB PWB FB	KH	3
18	0.9 34.1 -	236 694 3511	TP PWB FB	A	3

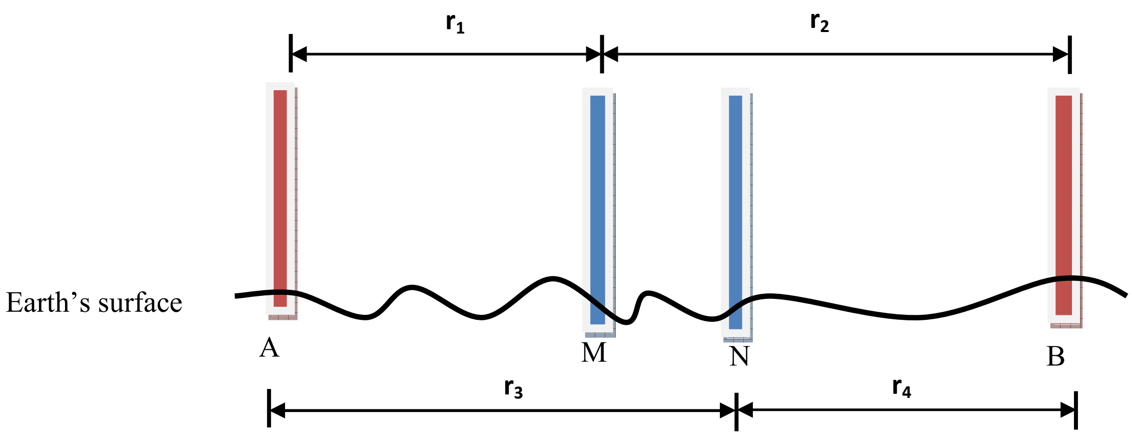
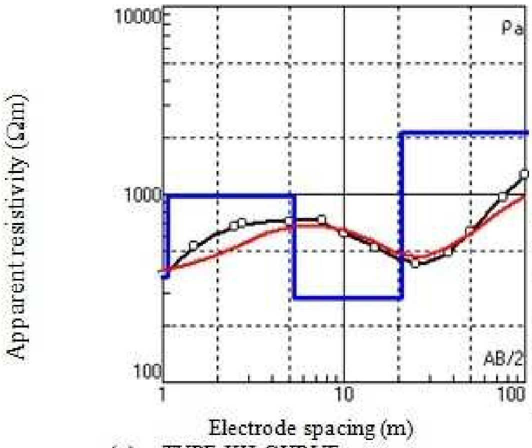


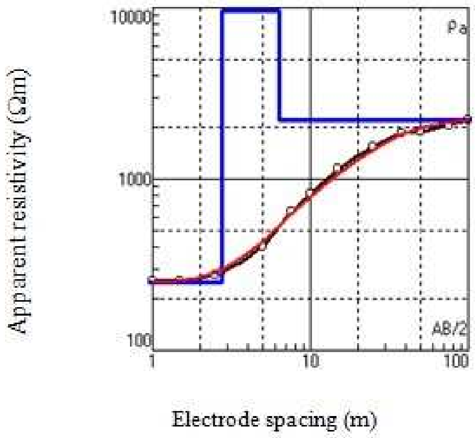
Figure 2: Four-general electrode configuration (Shlumberger Array).



N	ρ	h	d
1	370	1.65	1.65
2	410	15.7	17.4
3	503	20.4	37.8
4	1161		

Where,
N is the number of layers,
ρ is the apperent resistivity,
h is the thickness and
d is the depth to interface of each layer.

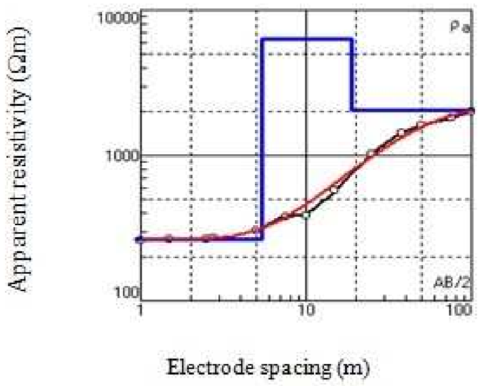
(a) TYPE KH CURVE



N	ρ	h	d
1	135	2.57	2.57
2	523	7.6	10.2
3	1520		

Where,
N is the number of layers,
ρ is the apperent resistivity,
h is the thickness and
d is the depth to interface of each layer.

(b) TYPE A CURVE



N	ρ	h	d
1	256	1.29	1.29
2	391	12.7	14
3	1450		

Where,
N is the layer number,
ρ is the apperent resistivity in ohm-metre,
h is the layer thickness and
d is the depth to interface of each layer

(c) TYPE A CURVE

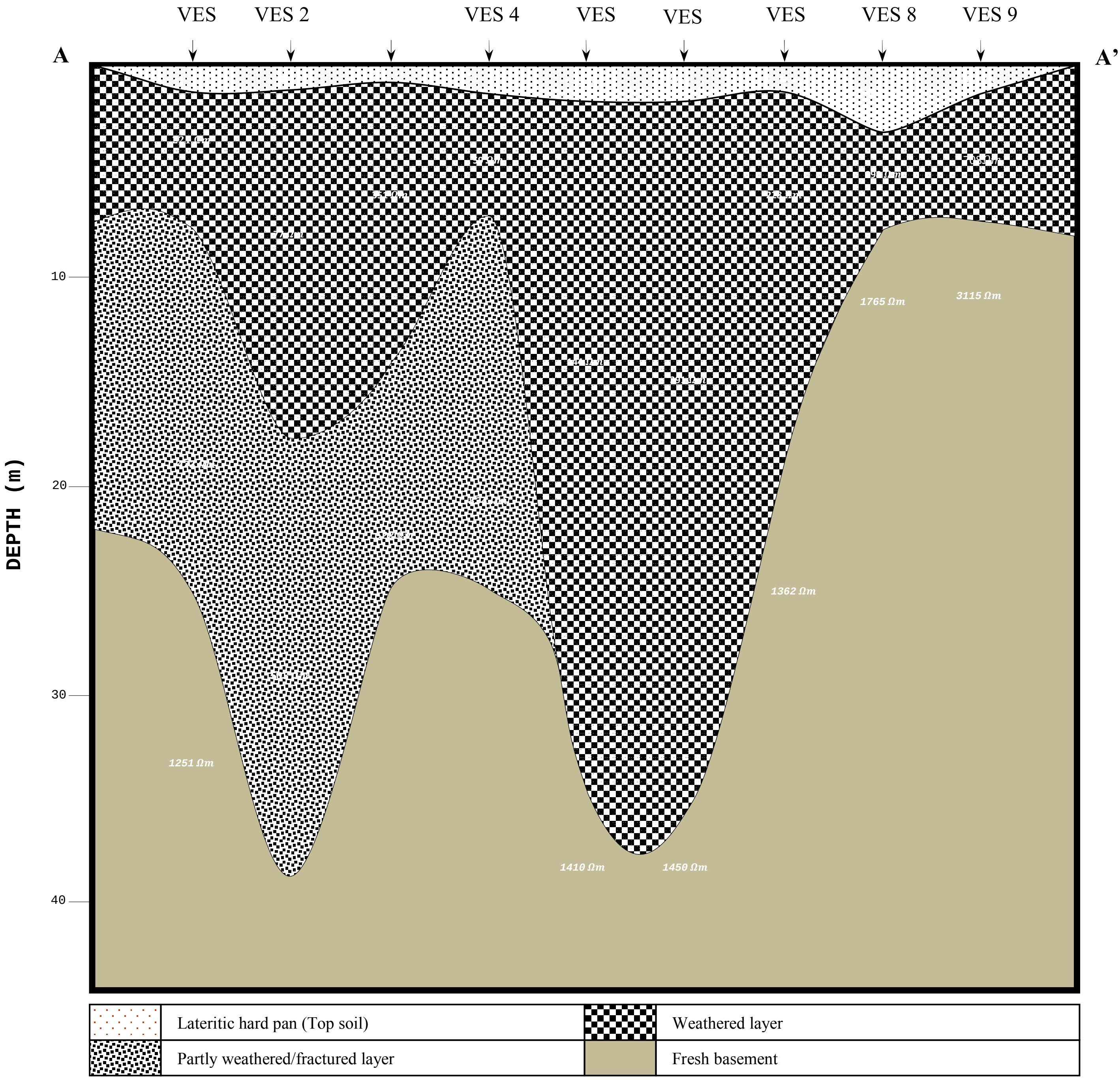

VES
VES 2
VES 4
VES
VES
VES
VES 8
VES 9
A
A'
DEPTH (m)
10
20
30
40
1251 Ωm
1410 Ωm
1450 Ωm
1362 Ωm
1765 Ωm
3115 Ωm
Lateritic hard pan (Top soil)
Weathered layer
Partly weathered/fractured layer
Fresh basement

Figure 4: Geoelectric section along profiles A-A[i]

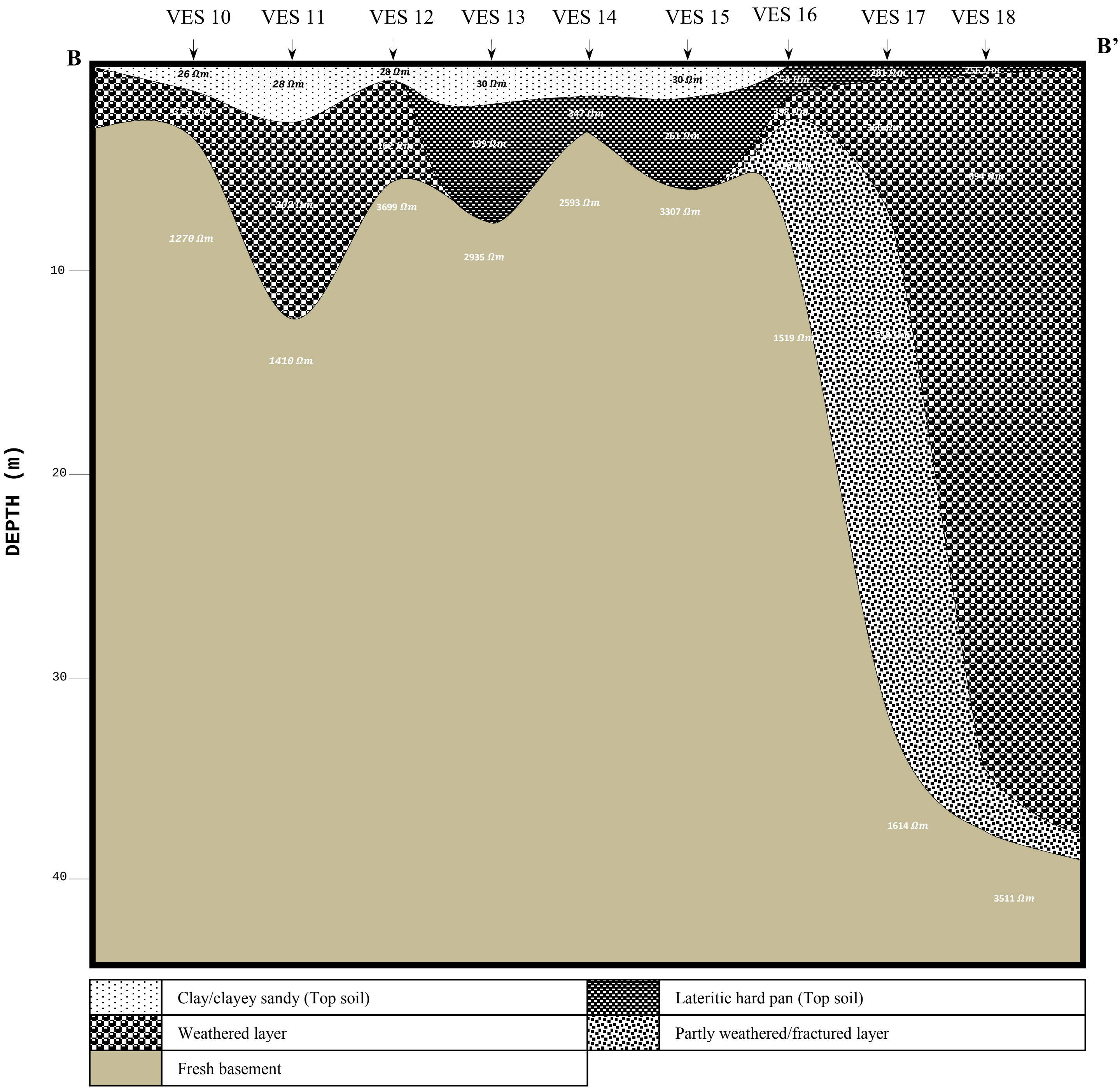


Figure 5: Geoelectric section along profiles B-B[i]