GEOPHYSICAL ASSESSMENT OF SUBSURFACE CONDITIONS AT PROPOSED BUILDING SITES: IMPLICATIONS FOR FOUNDATION FAILURE AND BUILDING COLLAPSE.

Stephen Oluwafemi ARIYO[1], Julius Ogunmola FATOBA[2], Olateju O. BAYEWU[1], Kamaldeen Olakunle OMOSANYA[3] and Muhedeen Ajibola LAWAL[4]

[1]Department of Earth Sciences, Olabisi Onabanjo University, Ago-Iwoye
[2]Department of Geophysics, Federal University of Oye, OyeEkiti
[3]Oasis Geoconsulting Limited, Ogun State. Nigeria.
[4]Leon H. Charney School of Marine Sciences - Marine Geosciences, University of Haifa
Corresponding author: S.O.Ariyo, ariyooluwafemi39@yahoo.com and
ariyo.o.stephen@oouagoiwoye.edu.ng +2348055132897

ABSTRACT

Building collapse has been a recurrent environmental hazard in Nigeria in the last two decades. This is a corollary of inadequate foundation investigation prior to construction, poor government policies, and general lack of awareness on the importance of geophysical and geotechnical investigations. In this study, geological mapping and detailed geophysical investigation using Electrical Resistivity Imaging (ERI) and Vertical Electrical Sounding (VES) were carried out to understand the suitability of proposed building sites at the main campus of the Olabisi Onabanjo University (OOU), Ago-Iwoye, Nigeria for construction. Both Wenner array and dipole-dipole were used for profiling and Schlumberger for sounding. Four transverses and VES were used in each of the three areas investigated. Our results show that the subsurface of the study areas is underlain by Precambrian basement rock of Nigeria. Rocks in the study area include banded gneiss, porphyroblastic gneiss, biotite-hornblende granite and quartzite schist. The sounding stations across the three areas and 2D resistivity imaging revealed three principal geoelectric layers, the topsoil, the weathered layer and the fractured/fresh basement with varied resistivity values for each layers. At the VES stations, the three geoelectric layers have resistivity values of 62 to 1182 Ωm, 3.2 to 1360Ωm and 87 to 4680 Ωm. On the 2D resistivity imaging profiles, the resistivity of the three layers varies from 2 to 1182 Ωm, 30to 1360 Ωm, and 40 to 2904 Ωm for the topsoil, the weathered basement, and fractured/fresh bedrock. Our work demonstrates that some of the proposed sites are structurally incompetent for engineering or foundation purposes. Excavation of the topsoil and reinforcement are required to sustain the proposed structures.

Keywords: Subsurface, Resistivity, Foundation, Failure, Site investigation.

1   INTRODUCTION

Building collapse and foundation failure have been a perpetual societal and environmental hazard in Nigeria for almost two decades [1, 2, 3 4]. Historically, one of the most devastating cases of building collapse in Nigeria includes collapse of an uncompleted building within the premises of the Synagogue church, Lagos on September 2014. The death toll stood at 115with over 100 others injured which involved sixty-seven South Africans. The event almost led to a diplomatic dispute between Nigeria and South Africa [5]. Other tragic building collapse include the Lekki building collapse of March 2016. Thirty-four people died and several others injured during this event. A woman, her six-month-old baby and her husband were among the dead. The collapse of an uncompleted building in Abuja, August 2010 in which twenty-one people died and nine others were injured. Also included was the Jos school building collapse of September 2014 with ten people dead, mostly below 10 years old [6]. The most recent of such events happened on the 13th May, 2016 in Itoku market area of Ogun State, southwestern Nigeria in which one person died and seven others were injured.

As a consequence of these environmental cum societal problem, several geophysical investigations have been conducted in many parts of Nigeria to forestall unforeseen and future building collapse [7, 8]. Most of these works used electrical geophysical techniques, which represent one of the oldest and cheapest geophysical techniques for investigating subsurface rocks and properties. Apart from using the method for foundation investigation, electrical resistivity methods have been used to resolve a variety of subsurface problems such as exploration and evaluation of groundwater potential and properties [9, 10, 11], characterization of geology and subsurface structures [12, 13], soil properties investigation [14], and hydrocarbon exploration [15], just to mention a few.

The aim of this study is to investigate the variability in the subsurface geology and properties, which could be harmful for the construction of the proposed buildings in the investigated areas. Our objectives are to

detect abrupt changes in lithology reflecting resistivity variation in the subsurface, identify and characterize fracture zones (faults, joints, etc.) and determine the suitability of the underlying materials to support such structures. This paper incorporates several techniques of electrical resistivity survey carried out at the proposed sites, thereby making it possible for our work to demonstrate the importance of using multiple approaches for investigating subsurface geology.

2   GEOLOGIC SETTING OF THE STUDY AREA

The study areas are located between longitude $3^0 52^1$E and $3^0 53^1$E and latitude $6^0 54.5^1$N and $6^0 56^1$N and include three proposed sites at the main campus of Olabisi Onabanjo University (Figure 1a & 1b). The physiography of the study area and its environs are as a result of the geomorphic processes that have shaped the rocks in the area. There are occurrences of rugged terrains with gently steeping hills of varying attitudes and aesthetic values around the main road from the gate towards the administrative building in OOU main campus (Figure1b). The study area is drained by a few seasonal rivers with dendritic drainage pattern flowing from northwest to southeast with the most popular river being River Omi (Figure 1a). The study area is situated within the tropical rain forest region of West Africa with the climate characterized by alternating dry and wet seasons with heavy rainfall, high temperature and humidity. The mean annual rainfall is between 1200mm and 1500mmreaching peaks in the months of June and July [16]. Annual temperature varies between 18°C to 34°C [17]. The wet season occurs between March and October or early November. The dry season is rather short with very hot days which commences in late November and continues until end of February. Relative humidity is averagely high throughout the year due to high rate of evaporation and dense vegetation cover [16].
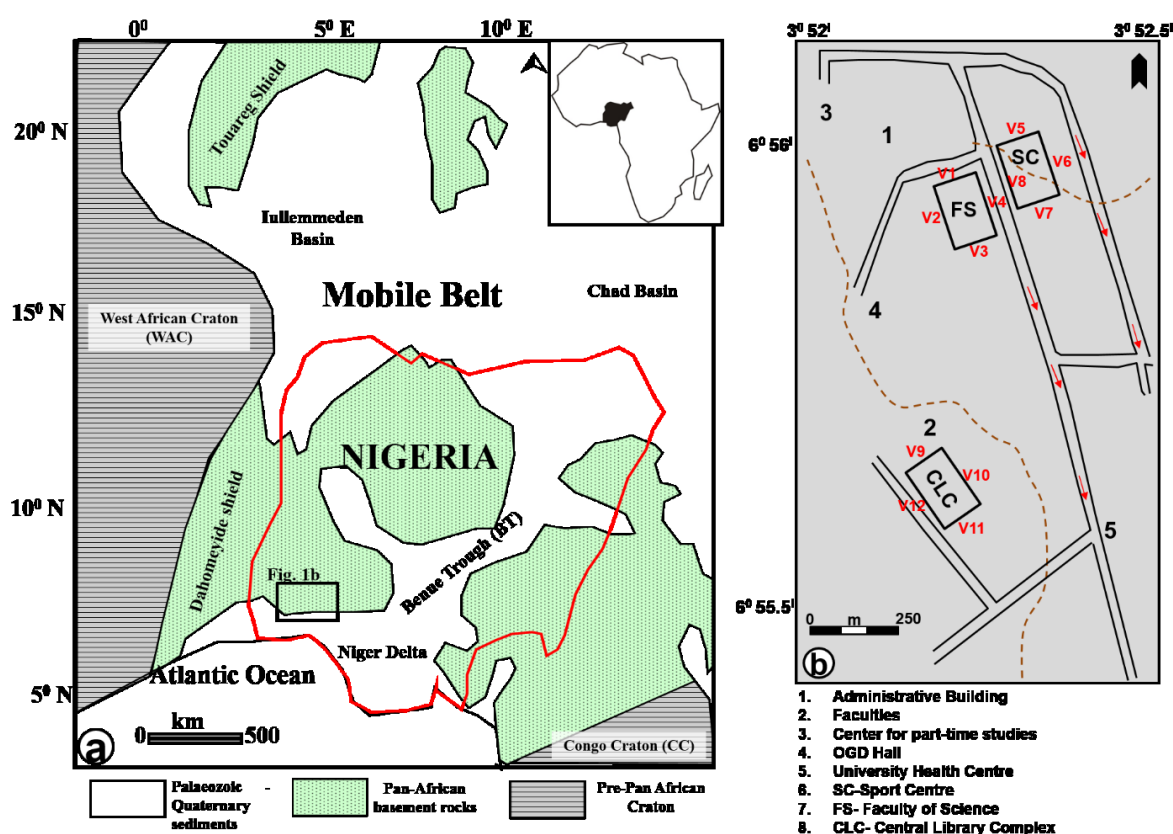

Figure 1: (a) Map of Nigeria showing the distribution of different rock types and the study area in the context of the Africa cratons.

The study area is underlain by rocks of the Precambrian basement complex of Nigeria (Figure 2). The geology of the basement complex has been studied extensively by several authors e.g. [18, 19, 20, 21 21, 22, 23, 24]. The crystalline rocks in Nigeria are distributed in a circular area in northcentral Nigeria, a triangular area in the west which runs into the Benin Republic, and a rectangular area broken into three parts by sedimentary rocks on the eastern border of Nigeria with Cameroun Republic (Figure 2). Rocks of the crystalline basement can be divided into basement complex, Younger granites and Cenozoic to Recent volcanic rocks. The Precambrian rocks of Nigeria are collectively known as the basement complex and they occupy nearly half of the total area of the country [19]. The other half is covered by the Cretaceous and younger sedimentary rocks (Figure 2).

Polycyclic Migmatite-Gneiss Complex (MGC) [19] recognized the following rock types as part of the MGC: banded gneisses, Augen gneisses and pegmatites. Recent petrological division of the MGC includes: A grey foliated biotite acid or biotite hornblende quartz feldspathic gneiss of tonalitic to granodioritic composition, which is also known as the "grey gneiss" [18]. Mafic and ultramafic components which when present, often outcrop as discontinuous boudinaged lenses or concordant sheets of amphibolites with minor amounts of biotite-rich ultramafic. Except where it constitutes the palaeosome to the migmatite, these are present in grossly subordinate amounts to the grey gneisses. Felsic components are a varied group of rocks consisting essentially of pegmatites, aplite, quartz-oligoclase veins, fine-grained granite gneiss, porphyritic granites etc. The three components may or may not be present together on a single outcrop. The migmatite-gneiss complexes are Archean [23]. Another important type of migmatite common in the Basement complex is the Agmatite, in which schistose or gneissic rocks (palaeosome) are dissected into irregular blocks by quartzofeldspathic dykes and pegmatites (metasome) [25]. Pan African Granitoid covers group of rocks that include biotite and biotite-muscovite granites, syenites, charnokites, diorites, monzonites (Bauchite), serpentines, anorthosites, etc. Pan African as a name was introduced by Falconer [26] to distinguish this rock type based on morphology and texture from Jurassic, anorogenic, peralkaline "Younger Granites" in north central Nigeria. The older granites, e.g. the coarse-grained biotite-hornblende granites, have concordant foliation with the MGC or schists [19] though they vary in composition, texture and colour.
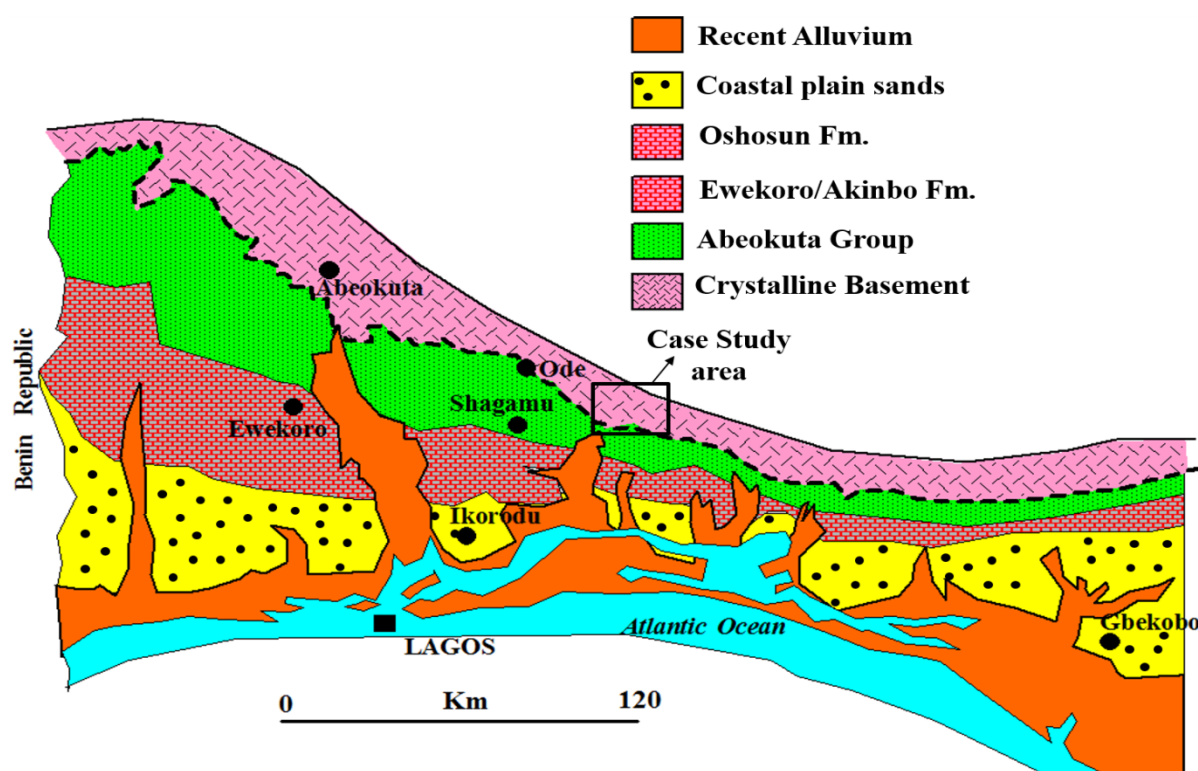

Figure 2: Geologic map of Ogun State showing the study area. Ago-Iwoye is characterized by both sedimentary and crystalline rocks. The study area lies on the crystalline part of Ago-Iwoye.

Rocks found in the study area are mainly metamorphic rocks belonging to the Migmatite-Gneiss Complex. The primary rock types include banded gneiss, which have a general NNW to SSE trend. The banded gneiss composed of felsic and mafic minerals which are distinctly segregated into alternating bands of light and dark coloured minerals. Orientation of the foliations is general NNW with angle of dips that vary from 16^0 to 64^0 SW (Figure 3). The second category of rocks common in the study are the porphyroblastic gneiss composed of porphyries of plagioclase. Other minerals identified in hand specimen include quartz, biotite, and muscovite. Lineation within the porphyroblastic gneisses shown northwestern strike and dips in SSW direction also (Figure3). Dips of lineations could vary from 34^0 in the northern part of the study area to 62^0 in the south. The gneisses to the north, northeast and southwest are bounded by biotite-hornblende granite and quartzite schist, respectively. The quartzite schists are composed mostly of quartz with some mica and/or tourmaline.
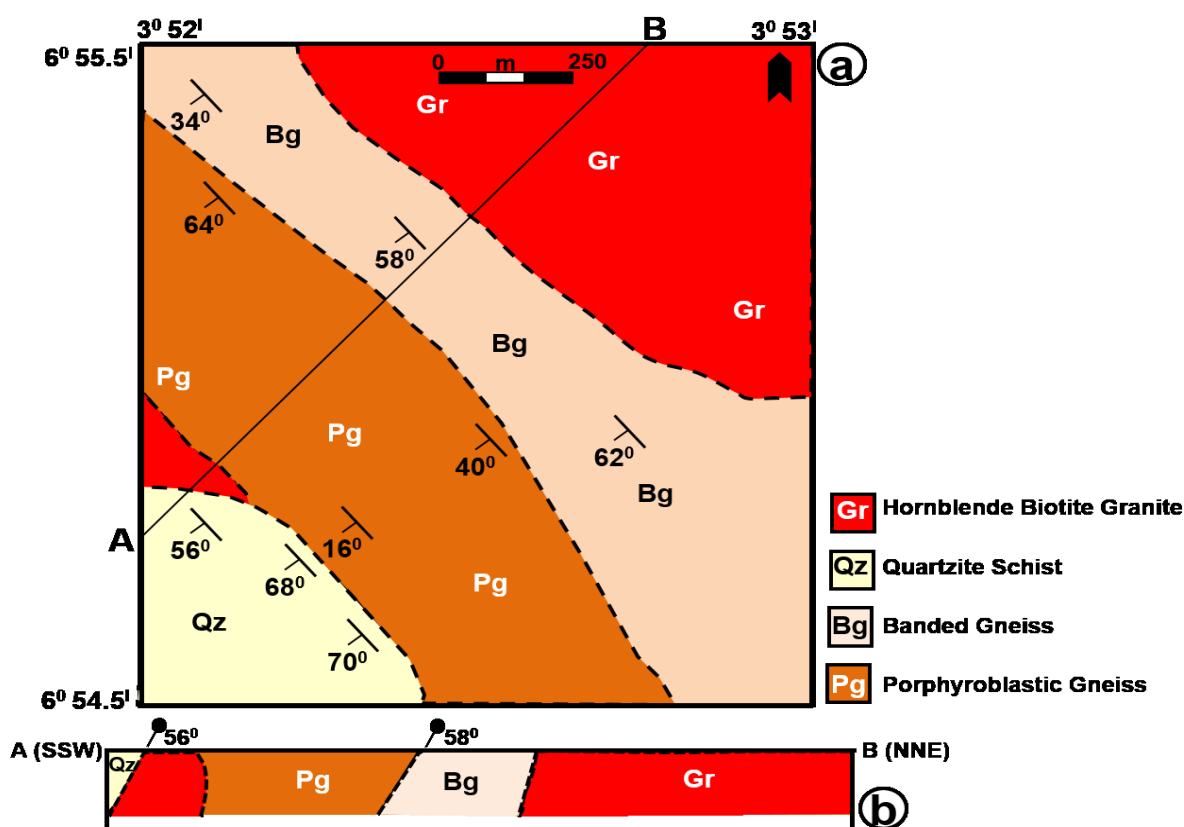
Figure 3: Geologic Map and Cross Section Through the Study Area.

3 MATERIAL AND METHODS

The electrical resistivity method comprising the Constant Separation Traverse (CST) and Vertical Electrical Sounding (VES) was used in this work. The CST was established using wenner array, with a minimum spacing of 5m while schlumberger array was used for the VES. Both the CST and VES were done to investigate the horizontal and vertical variations in subsurface geology. The electrode configurations for the different arrays are shown in figure 4. In using the Wenner array method to probe the subsurface, the electrodes were equidistant to each other (depending on the value of the 'a' spacing). The potential and current electrodes were moved at the same time when n=1 to 4 while a=5 to 20. The maximum profile length for the study area varies from 60 m to 150 m. Furthermore, four Vertical Electrical Sounding stations were probed using Schlumberger electrode array in each of the three proposed sites. The stations were taken at different locations along each of CST lines. Current was passed into the ground through a pair of current electrodes and the resultant resistances were obtained through a pair of potential electrodes. Basically, a station was chosen and an iron rod was driven into the ground, this marks the base station which was used as a mid-point from where MN/2 (potential electrode) and AB/2 (current electrode) spacing are measured in both directions using the marked midpoint and a measuring tape (Figure 4). The current and potential electrodes were progressively set out to achieve a well-defined profile during which the current electrode was set to be five times of the potential electrode at the start. With progressive increase in the current electrode separation, the potential electrodes spacing remained constant until potential reading became too small to be measured. The potential electrodes spacing was thus increased in order to have a meaningful reading. The maximum separation was 100m at depth, and maximum separation of potential electrode was 5m. The change in distance between the current electrodes increases the depth range at which the current penetrates.

The resistance measurements are on the field were converted to apparent resistivity values. To interpret the data from a 2-D imaging survey, a 2-D model for the subsurface consisting of a large number of rectangular blocks is usually used. To determine the resistivity of the blocks so that the calculated apparent resistivity values agree with the measured values from the field survey. DIPROfWin automatically subdivides the subsurface into a number of blocks, and then uses a least-squares inversion scheme to determine the appropriate resistivity value for each block. The location of the electrodes and apparent resistivity values were entered into a text file, which is read by the DIPROfWin program. Electrical surveys are among the most difficult to interpret quantitatively because of the complex theoretical bases of the technique. Several authors have proposed different methods

including numerical method of interpretation, interpretation by curve matching techniques and interpretation by an auxiliary point method [27]. This technique is fairly accurate and is a dependable one for interpretation. It involves the comparison of field obtained curves with characteristics standard curves. The construction of series of standard curves is based on the relationship between the hypothetical curves of resistivity against depth/thickness. Before interpretation is made with the master set of horizontal layer, it must be satisfied that the form of the sounding curve is sufficiently smooth and not distorted by sharp curves or discontinuities. Two different sets of curve are normally employed for this technique [28], and they are; theoretical 2-Layer master curves and auxiliary curves. The curves can further be classified as type H, A, K and Q curves. Type H curve shows that a low resistivity layer is sandwiched between two high resistivity layers. This is typical for a 3-layer case. Type A curve shows that the resistivity of the layers is increasing while Type K and Type Q curves shows a high resistivity layer was sandwiched between two low resistivity layers and resistivity that is decreasing with depth, respectively.
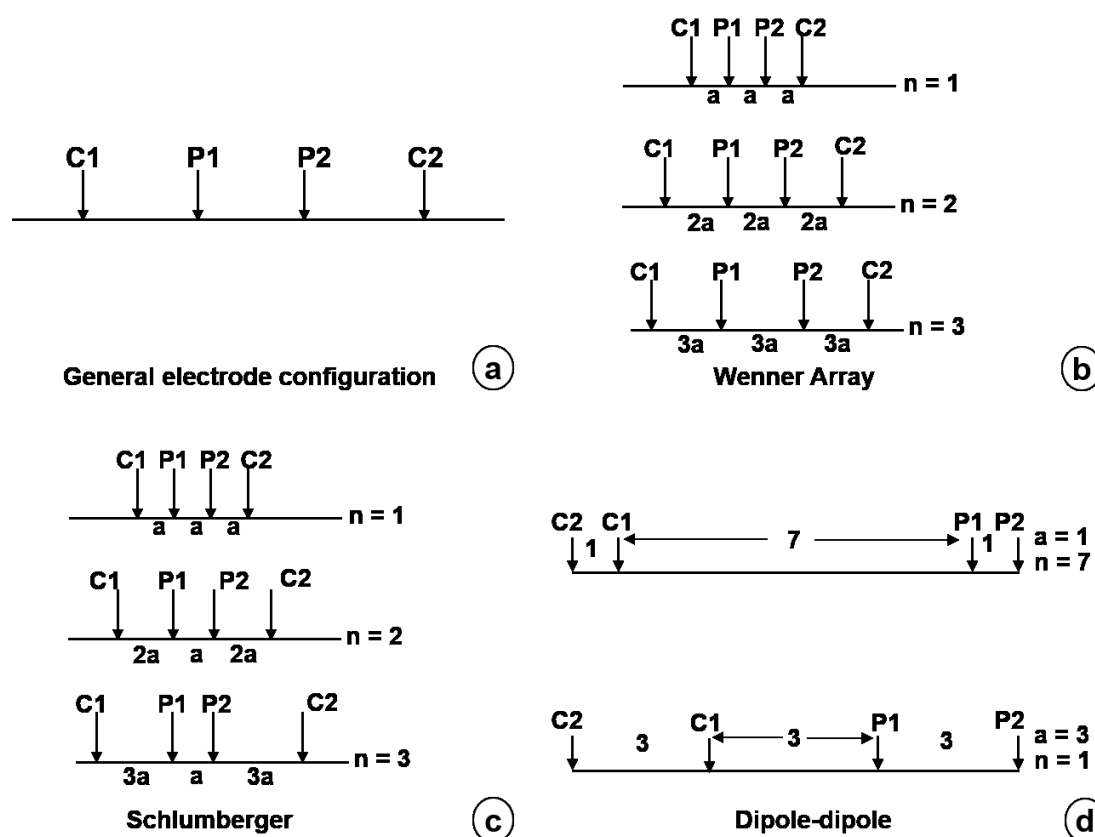

Figure4: (a) General electrode configuration for both VES and CST. (c)-(d) Electrode configuration for Wenner, Schlumberger and dipole-dipole, respectively.

4   RESULTS AND DISCUSSION

The results and discussions of the geophysical studies conducted at the three sites are hereby presented. Specifically, these include the geophysical measurements i.e., Vertical Electrical Sounding (VES) and the 2-Dimensional imaging survey. The results of the geophysical studies showed that three to four distinct geoelectrical layers underlie the site.

a.   Vertical Electric Sounding

Location One (Proposed Faculty of Science)

VES 1 reveals four (4) geoelectrical layers with resistivity values of 197.7Ωm, 462.9Ωm, 101.1Ωm, and 2070.4Ωm corresponding to topsoil, Sandy, sandy clay and fractured bedrock, respectively (Table 1, figures 1b and 5). The topsoil has a thickness of 0.7m, while the second layer has a thickness of 1.8m. The third and fourth layers have thicknesses of 7.2m and infinity respectively. The total depth is 9.6m and the curve type is KH. Consequently, VES 2 reveals three (3) geoelectrical layers with resistivity values of 465.0Ωm, 99.0Ωm and

2365.3Ωm corresponding to topsoil, clay, and fresh bedrock respectively (Table 1, Figures 1b and 5). The topsoil has a thickness of 1.1m while the second layer has a thickness of 13.3m. The thickness of the third layer is infinity. The total depth is 14.4m. Curve type is H. In addition, VES 3 reveals three (3) geoelectrical layers with resistivity values of 422.7Ωm, 205.9Ωm and 1967.8Ωm, corresponding to topsoil, sandy layer, and fresh bedrock, respectively (Table 1). The topsoil and sandy layers have thickness of 1.9m and 6.9m respectively, and the thickness of the last layer is infinity. The total depth is 8.8m. Curve type is H.

At VES 4 the geoelectrical layers include topsoil, clayey layer, and fresh bedrock with resistivity values of 61.7Ωm, 23.2Ωm and 4679.8Ωm respectively. The topsoil and clayey layers have thicknesses of 1.1m and 3.8m respectively, while the thickness of the last layer is infinity (Table 1 and Figure5a-5c). The total depth is 5.0m. Curve type is H. The resistivity curves obtained from the survey are the H and KH Types, with the H-Type being dominant at VES 2 to 4 (Table 1). The presence of clay in the subsurface configuration of VES 2 (2-14 m) and 4 (4-5 m) is particularly critical to the stability of the proposed structure. This is because clay swells as it absorbs water and retains soil in its complex chain structures and only releases the water slowly under pressure. Therefore, structures that rest on this type of materials are raised on swelling and drops when shrinking takes place. This process of raising and dropping contributes significantly to the failure of structures and will manifest in wall cracks and in severe cases leading to outright superstructure failure. We propose that the sandy and fresh bedrock layers can both sustain the structures effectively.

Location Two (Proposed Sport Centre)

At VES 1, 3 and 4, three geoelectrical layers are interpreted beneath the proposed the site while four geoelectrical layers are inferred at VES 2 (Table 2 and Figure 5). VES 1 shows three geo-electrical layers corresponding to the top soil, sandy layer and fresh bedrock with resistivity values of 648.2 Ωm, 193.3 Ωm, 946.4 Ωm, and thickness of 1.6m, 15.3 m and infinity, respectively. In contrast, VES 2 has characteristic HK type curve, which shows four geoelectrical layers. The layers correspond to the top soil, clay layer, fresh bedrock and fractured bedrock with resistivity values of 220.8 Ωm, 40.3 Ωm, 1161.3 Ωm and 381.7 Ωm. Corresponding thicknesses are 1.2 m, 4.8 m, 26.9 m and infinity. Furthermore, VES 3 exhibits a characteristic H type curve, showing three geoelectrical layers. The first layer has a resistivity value of 263.3Ωm with a thickness value of 1.8m while the second and third layers have resistivity value and thickness of 93.2Ωm, 1635.1 Ωm and 13.2m infinity, respectively. Conversely, VES 4 has the feature of an A curve type with three geoelectrical layers. The first layer with a resistivity value of 151.1Ωm and a thickness of 1.2m is identified as the top soil layer. The second layer has a resistivity value of 174.1Ωm, thickness of 6.6m and is identified as the sandy layer. The last layer is inferred to be the fresh bedrock which has a resistivity value of 907.4Ωm and an infinite thickness. Curve types include H, HK and A, with the H type being dominant at VES 1 and 3. Geo-electrical sections of the study area were produced revealing three to four geoelectrical layers; topsoil, clay, sandy clay, sand and the weathered/fresh basement as illustrated in Table 2. Three major layers are identified from figure 5b. The top soil has resistivity values ranging from 151.1 to 648.2 Ωm and thickness range from 1.2 to 1.8m. In contrast, the weathered basement has resistivity values of 193.3 Ωm at VES 1, 40.3 Ωm at VES 2, 93.2 Ωm at VES 3 and 174.1 Ωm at VES 4, with thickness of between 6m and 16.9 m. The fresh basement has resistivity values ranging from 907.4 Ωm to 1635.1 Ωm. The depth to the rock head is 16.9m, 32.9m, 15.0m and 7.8m at VES 1, 2, 3 and 4 respectively.

Table 1: Qualitative and quantitative interpretation of VES curves from Location One

VES No	No of Layers	Curve Types	Resistivity (Ωm)	Thickness (m)	Depth (m)	Inferred Lithology
1	1	KH	197.7	0.7	0.7	Top soil
	2		462.9	1.8	2.5	Sandy layer
	3		101.1	7.2	9.6	clayey Sandy
	4		2070.4	-	-	Fresh bedrock
2	1	H	465.0	1.1	1.1	Top soil
	2		99.0	13.3	14.4	Clay
	3		2365.3	-	-	Fresh bedrock
3	1	H	422.7	1.9	1.9	Top soil
	2		205.9	6.9	8.8	Sandy layer
	3		1967.8	-	--	Fresh bedrock
4	1	H	61.7	1.1	1.1	Top soil
	2		23.2	3.8	5.0	Clayey layer
	3		4679.8	-	-	Fresh bedrock

Table 2: Qualitative and quantitative interpretation of VES curves from Location 2

VES No	No of Layers	Curve Types	Resistivity (Ωm)	Thickness (m)	Depth (m)	Inferred Lithology
1	1	H	648.2	1.6	1.6	Top Soil
	2		193.3	15.3	16.9	Sandy
	3		946.4	∞	∞	Fresh bedrock
2	1	HK	220.8	1.2	1.2	Top Soil
	2		40.3	4.8	6.0	Clay
	3		1161.3	26.9	32.9	Fresh bedrock
	4		381.7	∞	∞	Fractured bedrock
3	1	H	263.3	1.8	1.8	Top Soil
	2		93.2	13.2	15.0	Clay
	3		1635.1	∞	∞	Fresh bedrock
4	1	A	151.1	1.2	1.2	Top Soil
	2		174.1	6.6	7.8	Sandy
	3		907.4	∞	∞	Fresh bedrock

Location Three (Proposed Central Library)

At VES 1, four (4) geoelectrical layers with resistivity values of 291.1Ωm, 129.2Ωm, 36.2Ωm and 2904.1Ωm were revealed (Figure 5c). These correspond to the topsoil, Sand, clay and fresh bedrock respectively (Table 3). The topsoil has a thickness of 1.8m while the sand layer has a thickness of 0.9m. Furthermore, the clay layer has a thickness of 2.8m, while the fresh bedrock is infinitely thick. The total depth is 5.4m and the curve type is QH. In contrast, at VES 2 the dominant curve type is H. This point reveals three (3) geoelectrical layers with resistivity values of 1182.1Ωm, 41.3Ωm and 1997.5Ωm corresponding to topsoil, clay and fresh bedrock respectively. Thicknesses of these layers are 1.1m, 2.3m, and infinity, respectively. The total depth is 3.5m. In addition, VES 3 reveals four (4) geoelectrical layers with resistivity values of 82.3Ωm, 39.1Ωm, 87.1Ωm and 1134.5Ωm corresponding to topsoil, clay layer and fresh bedrock, respectively. They have thicknesses of 1.0m,1.1m, 4.0m and infinity respectively. The total depth is 6.1m. Curve type is HA. In a similar manner, VES 4 reveals four (4) geoelectrical layers with resistivity values of 553.3Ωm, 1359.9Ωm, 53.2Ωm and 823.3Ωm corresponding to the topsoil, laterite, clayey layer and fractured bedrock respectively. Corresponding thicknesses are0.5m,0.7m, 3.8m and infinity, respectively (Table 3). The presence of clay here is critical to the stability of the proposed Central Library Complex. In contrast, the sandy and fresh bedrock layers can both sustain the proposed structures effectively. Overall results reveal the presence of three subsurface geologic units which comprise the topsoil, weathered layer, and fractured basement/fresh basement bedrock (Figure5c). The topsoil has resistivity values that vary from 82.3–1182.1 Ωm and thickness ranging from 0.5–1.8 m. The topsoil is composed of clay, sandy-clay, clayey-sand and sand. The second layer is the weathered layer. It is characterized by resistivity values ranging from 39.1–1359.9 Ωm and thickness varying from 0.7–2.3 m. It is composed of clay, clayey-sand, sandy-clay, laterite and sand. The basement bedrock which is fresh in most places has layer resistivity values of 823.3–2904.1 Ωm. The depth to the bedrock varies from 3.5m – 6.1m (Table 3).

Table 3: The geoelectrical parameters of VES curves for Location Three

| VES No	No of Layers	Curve Types	Resistivity (Ωm)	Thickness (m)	Depth (m)	Inferred Lithology
1	1	QH	291.1	1.8	1.8	Top soil
	2		129.2	0.9	2.6	Sand layer
	3		36.2	2.8	5.4	Clay
	4		2904.1	∞	∞	Fresh bedrock
2	1	H	1182.1	1.1	1.1	Top soil
	2		41.3	2.3	3.5	Clay
	3		1997.5	∞	∞	Fresh bedrock
3	1	HA	82.3	1.0	1.0	Top soil
	2		39.1	1.1	2.1	Clay layer
	3		87.1	4.0	6.1	Fractured bedrock
	4		1134.5	∞	∞	Fresh bedrock
4	1	KH	553.3	0.5	0.5	Top soil
	2		1359.9	0.7	1.3	Laterite
	3		53.2	3.8	5.1	Clay
	4		823.3	∞	∞	Fresh bedrock
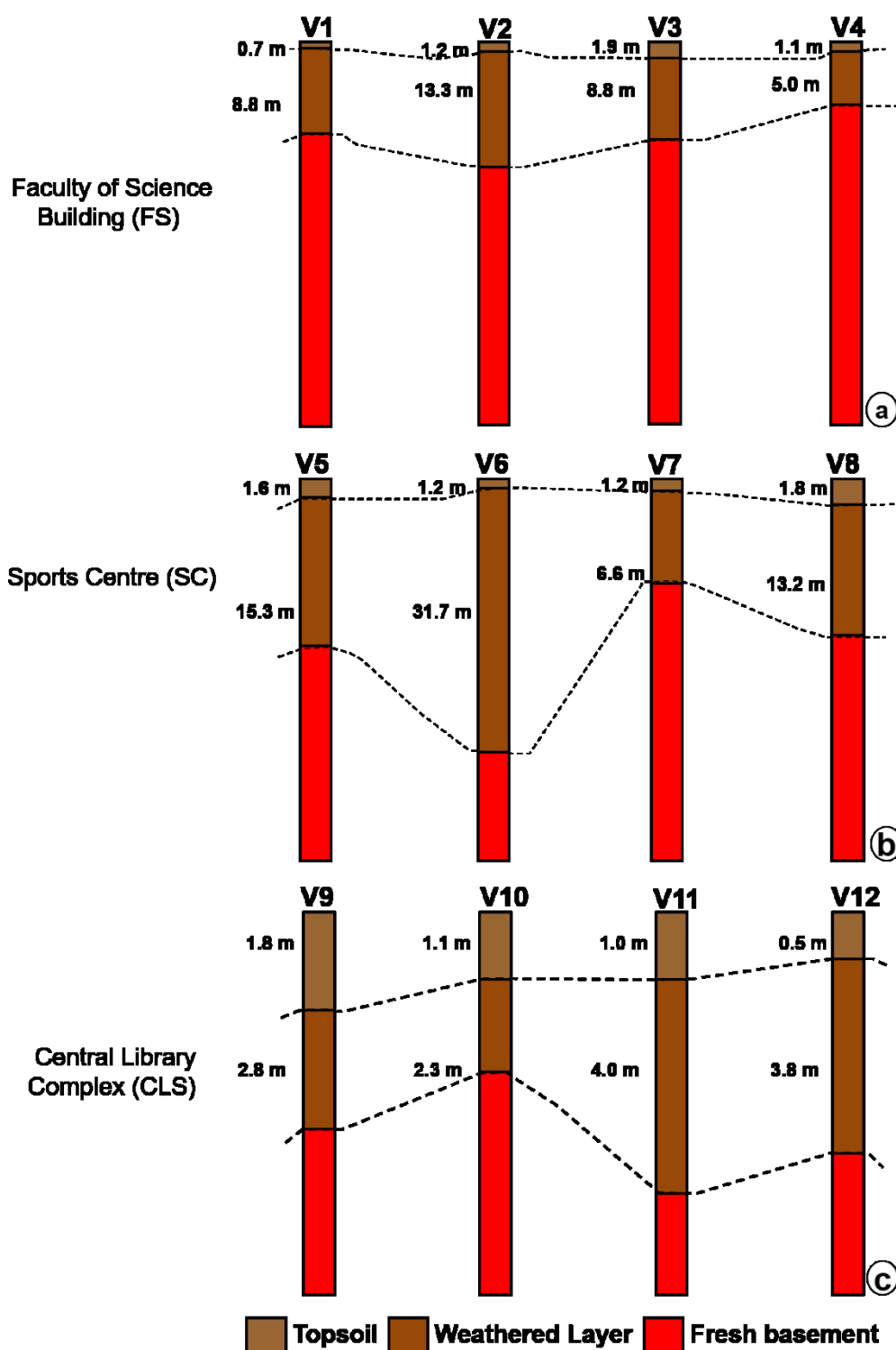
Fig. 5: Correlation panels showing the variation in resistivity and subsurface rock types across all the VES stations. The depths to the basement are estimated to infinity.

b. Electrical Resistivity Imaging

Location One

For traverse 1, the 2-D inverted resistivity shows three layers (Fig. 6a). The first layer (top soil) with reddish-greenish color shows variation in resistivity. At the western part, the resistivity value of this layer ranges from 0 to 100Ωm (station 10 to 65) and a high resistivity topsoil layer towards the eastern part with value ranging from 200 to 850Ωm (station 65 to 150), extending to a depth of 4m. The second layer (greenish coloration), which is a weathered layer has a resistivity value ranging from 56 to 190Ωm covering the whole area

and extending to a depth of 15m. The last layer (yellowish/reddish coloration) with high resistivity value ranging from 235 to 900Ωm has depths ranging from 7m to the rock head. The area towards the east can be adjudged competent for building foundation but towards the west, the topsoil needs to be excavated and then filled up with more competent materials that can support building foundation. Similarly, the 2-D inverted resistivity for traverse 2 shows three layers (Figure 6b). The topsoil has a relatively high resistivity value (ranging from 150 to 500Ωm) and covering almost the whole area and to a depth of 4m. The second layer (with greenish coloration) which is a weathered layer has resistivity value ranging from 40 to 150Ωm. The third layer (with yellowish/reddish) has a high resistivity value ranging from 150 to 800Ωm.

Similarly, traverse 3reveals three layers (Fig. 6c). The topsoil layer (yellowish/bluish) with resistivity values of 30 to 50Ωm toward the west and high resistivity values ranging from 250 to 700Ωm at the eastern part extending to a depth of 3m. The second layer (green color) which is a weathered layer has resistivity values ranging from 51 to 150Ωm and the last layer (with yellow/green coloration) has resistivity values ranging from 300 to 2026Ωm at a depth of 6m to the rock head. The foundation structure should be well reinforced at the western part of the profile to a depth of about 4m in order to avert subsidence at this location. In addition, traverse 4shows three layers as revealed in the figure6d. The first layer (bluish/reddish) which is the topsoil has a variation in resistivity which ranges from 38 to 90Ωm (station 10 to 55) toward the west and high resistivity values of 200 to 500Ωm (station 60 to 100) towards the east. The second layer (greenish/yellowish) has resistivity values of 90 to 200Ωm and the last layer (reddish coloration) has resistivity values ranging from 200 to 1144Ωm, extending from a depth of 5m to the rock head. The foundation structure should be well reinforced at the western part of the profile to a depth of about 5m in order to avert subsidence at this location.

Location Two

Transverse 1has a lateral extent of 180m (Figure 7a). The pseudosection and 2-D inverted resistivity were qualitatively interpreted to reveal three geoelectrical layers which are the top soil, weathered basement (clayey layer) and the fractured bedrock respectively (figure 7a). The resistivity of the first layer (top soil) ranges from 0-35Ωm terminating around station 20 at about 2m below the surface. The second layer which is the weathered basement (clayey), has resistivity values ranging from 35Ωm to 118Ωm and this extends through station 10 to 75 and also through station 160 to 180 at about 4m above the subsurface. In addition, the third layer which is the fractured bedrock has resistivity values ranging from 110Ωm to 570Ωm, extending through station 75 to 170 with depth of 9m. The 1-D resistivity survey was carried out around station 90. From the 1-D resistivity survey it was observed that the top soil in this particular profile has been excavated from station 20 through to 160. This signifies that the soil seen at the point where the 1-D resistivity survey was carried out is the 2nd and 3rd layer comprising of weathered basement rocks and the fractured/fresh bedrock. In contrast, the lateral extent of traverse 2 is 60m due to (Fig. 7b). The pseudosection and 2-D inverted resistivity were qualitatively interpreted to reveal the top soil and weathered basement (sandy layer) respectively. The resistivity of the top soil ranges from 0 to 111Ωm and extends through station 0 to 60 with a depth of 0 to 4m. The second layer which is the sandy layer has resistivity ranging from 111Ωm to 270Ωm, extending through station 15 to 60 with depth of 5 to 15m above the subsurface. In addition, the 1-D survey was carried out at station 30. From this, the first layer has a resistivity value of 220.8Ωm and thickness of 1.2m. The second layer has a resistivity value of 40.3Ωm and thickness of 4.8m. The third layer has a resistivity value and thickness of 1161.3Ωm and26.9m respectively. The last layer is identified as the fractured bedrock and has a resistivity value of 381.7Ωm with an infinite thickness. In this transverse the basement is not displayed. The point at which the survey was carried out still remains as the top soil. From the beginning (station 0 to 25) and towards the end of this traverse (station 55 to 60) very low resistivity values were observed. These are diagnostic of clayey weathered materials which are not good foundation materials. Resistivity values here are less than 50Ωm, extending to a depth of 13m from the surface.

Similarly, the pseudosection and 2-D inverted resistivity of traverse 3 revealed three geoelectrical layers. These layers are; the top soil, weathered basement (clayey layer) and the fresh bedrock respectively. The resistivity of the top soil ranges from 0 to 42Ωm extending through stations 0 to 10, 50 to 70 and also around station 115 to 140 with depth of 0.4m. The weathered basement (clayey/sand) has resistivity values ranging from 42Ωm to 216Ωm extending from station 10 to 130 with depth of 0 to 1.2m. The fresh bedrock has resistivity values ranging from 216Ωm to 1700Ωm and this extends from station 75 through to 105 at depth of 0.6 to 1.4m. The 1-D survey was carried out along station 70. The first layer has a resistivity value of 263.3Ωm with a thickness value 1.8m. The second layer has a resistivity value of 93.2Ωm with thickness of 13.2m. The third layer has a resistivity value of 1635.1Ωm with an infinite thickness. The first layer in this profile is not really in-situ signifying either excavation or erosion around the areas. At station 80 to 100, the foundation can be dug to about 0.6m to give a good base for the building. Lateral extent is 140 m (Fig. 7c). With a lateral extent of 95m (figure 7d) in traverse 4, the 2-D inverted resistivity revealed three geoelectrical layers which are the top soil, weathered basement (sandy layer) and the fractured bedrock respectively. The resistivity of the first layer (top soil) ranges from 0 to 130Ωm, extending through station 0 to 95 and with depth of 0 to 7m. The second layer is partially weathered basement (sandy) and has resistivity values ranging from 250Ωm to 710Ωm which extends

through station 40 to 90 with a depth of 3 to 7m (Fig. 7d). The third layer which is the bedrock has resistivity values ranging from 672Ωm to 1600Ωm; extending laterally from station 50 to 75 with depth of 5 to 7m. In addition, the 1-D survey was carried out around station 50. The first layer is with a resistivity value of 151.1Ωm and a thickness of 1.2m. The second layer has a resistivity value of 174.1Ωm with a thickness of 6.6m. It is identified as the sandy layer. The last layer is inferred to be the fresh bedrock with a resistivity value of 907.4Ωm and an infinite thickness. The top soil in this case is in-situ but shows varying depth along the transverse line as we move laterally from one end to the other. This profile which has a low resistivity weathered material to the depth of 7m with resistivity value of less than 100Ωm is incompetent for a foundation structure. The clay distress of the foundation here might appear less severe most likely because the thick clay layer is uniform along the traverse and may result in uniform settlement.

Location Three

Traverse 1 has a lateral extent of 100m.The 2-D inverted resistivity was interpreted revealing three geoelectrical layers which are topsoil, weathered basement, and the fresh basement respectively. The first layer is Topsoil in blue colour band which is clay, has resistivity value ranging from 28Ωm to 100Ωm at stations 12 and 65 and extends through station 83 to 100 at depth of about 5m below the subsurface (Fig. 8a). The second layer which is the weathered basement with green coloration has a resistivity value ranging from 100Ωm to 700Ωm extending through stations 10 to 100 with an average depth of 8m. The third layer is the fresh bedrock with yellowish/reddish/pinkish colour. It has resistivity values ranging from 700Ωm to 83677Ωm and it extends through stations 10 to about 100. It has a depth of 15m below the surface (Fig. 8a). With a lateral extent of 110m, the 2-D inverted resistivity of traverse 2 similarly reveals three geoelectrical layers which include the topsoil (clayey), weathered basement and fresh bedrock. The first layer (topsoil in blue colour band) has resistivity ranging from 22Ωm to 50Ωm, extending along stations 15 and 30 and also through stations 55 and 65. It is about 3m below the surface. The second layer is the weathered basement with greenish colour (Fig. 8b). It has resistivity values ranging from 50Ωm to 200Ωm and extends from station 10 to 100. It is about 6m below the surface. The third layer is the fresh bedrock with reddish/pinkish colour. This layer has resistivity values between 200Ωm to 4613Ωm and extends from stations 20 to 35, and proceeds at station 45 to 100 at depth of 8m below the surface (Fig. 8b).

In addition, traverse 3 extends laterally for 100m (Fig. 8c). The pseudosection revealed three geoelectrical layers. The first layer is the topsoil with blue coloration and resistivity ranging between 48Ωm to 160Ωm, extending from station 35 to 100. It has a depth of about 6m. The second layer is the weathered basement with greenish colour, and it has resistivity values of 168Ωm to 820Ωm extending from stations10 to 100. Its depth is about 10m. The third layer is the fresh bedrock with yellowish/reddish/pinkish colour. It has resistivity values of 820Ωm to25819Ωm extending from stations 20 to 90, with depth of 15m below the surface. The two results show that, the fresh basement is devoid of major geologic fissure that can jeopardize the life of building foundation/structure (Fig. 8c). Also, traverse 4 has a lateral extent of 100m. The pseudo-section delineated three geo-electrical layers (Fig. 8d). The first layer is the topsoil with resistivity values ranging from 85Ωm to 217Ωm extending along stations 10 to 100 to a depth of 6m. The second layer is the weathered basement with resistivity values from 80Ωm to 120Ωm extending from stations 10 to 100 and to a depth of 10m. The third layer is the fresh bedrock with resistivity values from 370Ωm to 14900Ωm extending from stations 15 to 95 with depth of 15m. The result shows that the fresh basement is devoid of major geologic fissure that can jeopardize the life of building foundation/structure (Fig. 8d). This place is of concern for building foundation as the topsoil which is clay may not support the foundation of the building because of the swelling behaviour of clay. This may cause fractures on the building after construction. This area therefore will not be good for building foundation except the clay layer is first excavated. From the foregoing discussion, it is recommended that a strip foundation within the lateritic zone should be adopted for the building and necessary fortification where needed.
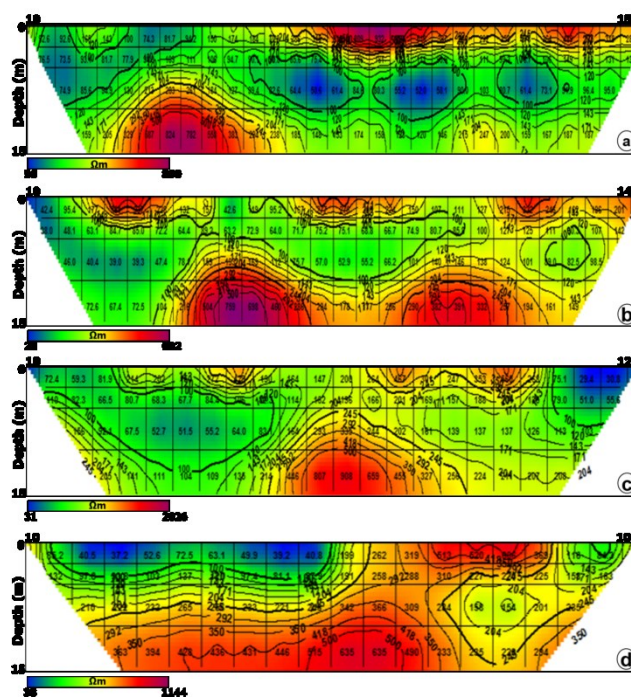
Figure 6: Resistivity Profiles or Pseudosections 1 to 4 at Location One Profiles 1 to 4 are taken along VES stations 1 to 4 in Figure 5.
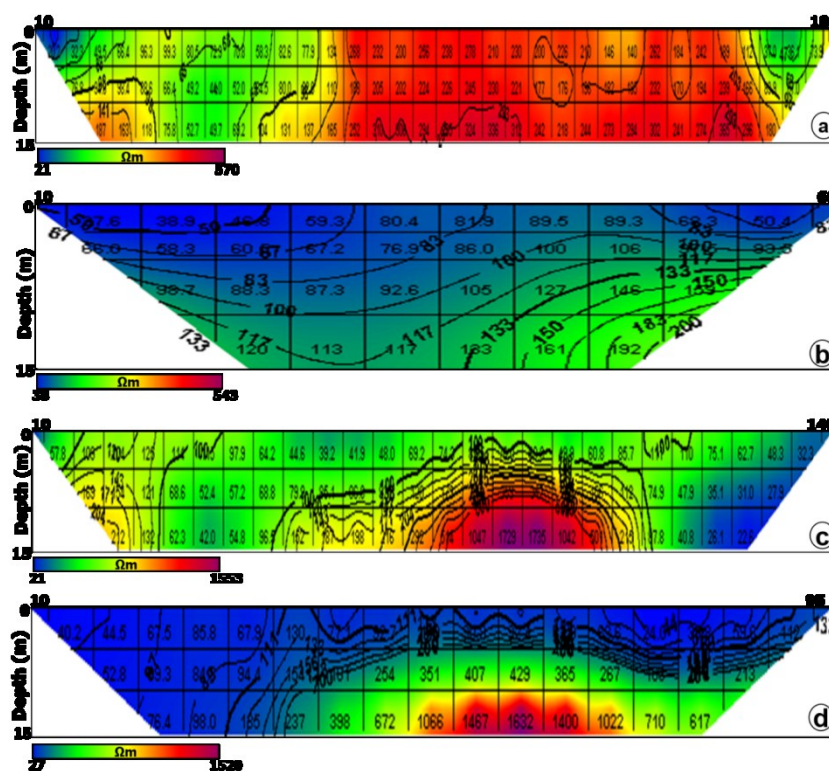

Figure 7: Resistivity Profiles or Pseudosections 1 to 4 at Location Two. Profiles 1 to 4 are taken along VES stations 5 to 8 in Figure 5.
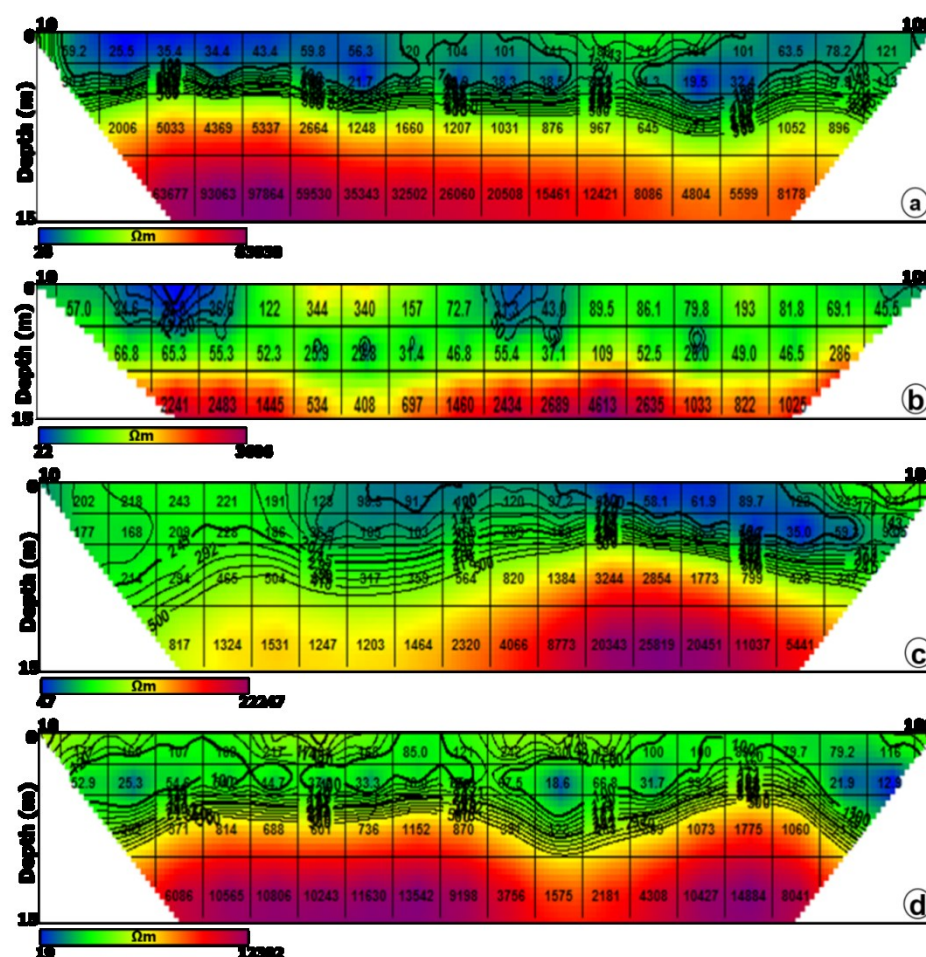
Figure 8: Resistivity Profiles or Pseudosections 1 to 4 at Location Three. Profiles 1 to 4 are taken across VES 9 to 12 in figure 5.

5   CONCLUSIONS

From the results of resistivity soundings and 2-D resistivity imaging, the sites are underlain by three layers from the ground surface to the fresh basement. The sounding stations and profiling across the three areas revealed three principal geoelectric layers, the topsoil, the weathered layer and the fractured/fresh basement. The two methods show that, the fresh basement is devoid of major geologic fissures that can jeopardize the building foundation/structure except for some excavations. In such areas, reinforcements will be required to make them competent to support building foundation.

REFERENCES

[1] OLABOSIPO, I., and O. ADEDAMOLA. Building failure and collapse in Nigeria: The influence of the informal sector. *Journal of Sustainable Development.* 2010, 3, 268–276.

[2] OLAGUNJU, R. E., S.C. AREMU and J. OGUNDELE. Incessant Collapse of Buildings in Nigeria: An Architect's View. *Civil and Environmental Research*. 2013, 3(4), 49-54.

[3] CHENDO, I.G and N.I. OBI. Building collapse in Nigeria: The Causes, Effects, Consequences and Remedies. I*nternational Journal of Civil Engineering, Construction and Estate Management*. 2015, Vol.3, No.4, 41-49.

[4] IFEDOLAPO, B.H. Building Collapse: Causes and Policy Direction in Nigeria. *International Journal of Scientific Research and Innovative Technolog*y. ISSN: 2313-3759. 2015, Vol. 2 No. 8.

[5] MOYELA, C. 67 South Africans killed in Nigeria building collapse. News24. [online]. 2014 [cit. 2015-04-14]. Available from: https://www.news24.com/SouthAfrica/News/67-South-African-killed-in-Nigeria-church collapse-20140916.

[6] EJEMBI, S. 10 tragic building collapses in Nigeria. *The Punch Newspaper,* 11th March, 2016. Punch news online. 21 March 2017.

[7] LATEEF, T.A. and J.A. ADEGOKE. Geophysical Investigation of Foundation Condition of a Site in Ikere- Ekiti, Ekiti State, South-Western Nigeria. *Australian Journal of Basic and Applied Sciences*. 2011, 5(9): 1852-1857.

[8] COKER, J.O. Geophysical and Geotechnical Assessment of Foundation Failure: A Case Study of Library Complex Area, Lagos State Polytechnic, Ikorodu, Lagos, Nigeria. *Research Journal in Engineering and Applied Sciences*. 2015, Vol.3, No 7.

[9] SIRHAN, A.M., A. HAMIDI and P. ANDRIEUX. Electrical resistivity tomography, an assessment tool for water resource: Case study of Al-Aroub Basin, West Bank, Palestine. *Asian J. Earth Sci*. 2011, 4: 38-45.

[10] EKINCI, Y.L, A. DEMIRCI and C. ERTEKIN. Delineation of the seawater-freshwater interface from the coastal alluvium of Kalekoy-Gokceada, NW Turkey. *J. Applied Sci.*, 2008, 8: 1977-1981.

[11] EHIRIM, C.N. and W. OFOR. Assessing aquifer vulnerability to contaminants near solid waste landfill sites in a coastal environment, Port Harcourt, Nigeria. *Trends Applied Sci. Res*. 2011, Vol. 6: 165-173.

[12] LEUCCI, G. Integrated geophysical, geological and geomorphological surveys to study the coastal erosion. *Int. J. Soil Sci.* 2006, 1: 146-167.

[13] SKJERNAA, L. and N.O. JORGENSEN. Evaluation of local fracture systems by Azimuthal resistivity surveys: Examples from South Norway. *Hydrogeology Journal.* 1993. 2: 19-25.

[14] MOLINDO, W.A and O.M. ALILE. Evaluation of the thermal conductivity of soils in Edo state, Nigeria. J*ournal of Applied Sciences*. 2007, 7 (4), 519-522.

[15] IKHANE, P.R., K.O. OMOSANYA and A.O. AFOLABI. Stratigraphy of Imobi Southwestern Nigeria. *Research Journal Earth Planetary Study*. 2011, 1: 33-45.

[16] ONAKOMAIYA, S. O., K. OYESIKU and F.J. JEGEDE. *Ogun State in maps*. Rex Charles Publications. 1992.

[17] ILOEJE, N.P. *A new geography of West Africa*. SheckWah Tong Printing Press Ltd. Hong Kong. 1980.

[18] RAHAMAN, M.A. Classification of Rocks in the Nigeria Precambrian Basement Complex. *Annual Conference of Nigerian Mining Geological and Metallurgical Society*. 1971. Dec. 1971. Kaduna, Nigeria.

[19] OYAWOYE, M.O. Geology of the Basement Complex. *Journal of Mining Geology.* 1965, vol. 2, pp 89 – 102.

[20] COORAY, P.G. A Note on the Charnockites of the Ado Ekiti Area, Western State, Nigeria. In: *Geology of Africa.* T.F.J Dessauvagie and A.J. Whiteman (eds.). 1972. 45-54. University Ibadan: Ibadan, Nigeria.

[21] ELUEZE, A.A. Petrography and geochemistry of metasedimentary rocks of the schist belt of Ilesha area, Southwestern Nigeria. *Journal of Nigeria Mining and Geosciences Society*. 1981, 18, 5-7.

[22] CABY, R. Precambrian terrains of Benin–Nigeria and northeast Brazil and the Late Proterozoic South Atlantic fit. *Geological Society America Special Paper*. 1989, 230, pp. 145-158.

[23] DADA, S.S., J.R. LANCELOT and L. BRIQUEU. Age and origin of the annular charnockitic complex at Toro, Northern Nigeria: U–Pb and Rb–Sr evidence. *Journal of African Earth Sciences*. 1989, Vol. 9, 227–234.

[24] OMOSANYA, K., G.O. MOSURO and L. AZEEZ. Combination of geological mapping and geophysical surveys for surface-subsurface structures imaging in Mini- Campus and Methodist Ago-Iwoye NE Areas, Southwestern Nigeria. *Journal of Geology and Mineral Resource.* 2012, 4, 105–117.

[25] OYAWOYE, M.O. The basement complex of Nigeria. In: *African geology.* University press Ibadan, Dessauvagier, T.F.J and Whiteman, A.J. (eds). 1970, pp. 67-103.

[26] FALCONER, J.D. *The geology and geography of northern Nigeria.* London: Macmillan, 1911.

[27] ZHODY, A. A. R. The auxiliary point method of electrical sounding data interpretation and its relation to the Dar Zarrouk parameters. *Geophysics*. 1965, 30(2).644–660.

[28] KELLER, G.V. and F.C. FRISCHKNECHT. *Electrical methods in geophysical prospecting*. Oxford: Pergamon Press, 1966.