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Geoelectrical Subsurface Characterization for Foundation Purposes in the College of Agricultural Sciences (CAS) Campus, Ebonyi State University, Abakaliki, Southeastern Nigeria

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Abstract
The study area is underlain by shales and volcanoclastics with subordinate lenses of sandstones and sandy limestone (Abakaliki Formation) of the Albian Asu River Group, southeastern Nigeria. Geophysical investigation was carried out at the College of Agricultural Sciences (CAS) Campus, Ebonyi State University (EBSU) to determine the structural competence of the subsurface geological strata for building construction and other foundation purposes, using vertical electrical sounding (VES) survey technique of the electrical resistivity method. From the result of the survey, two major zones have been established within the study area for building construction purposes. Zone A comprises of areas around the catholic church building, EBSU primary school up to the school of post graduate studies, while zone B is made up of areas around the EBSU secondary school, proposed student centre up to the main entrance gate which led to the Ogoja road. Zone A has been recommended for bungalows and other forms of low rising buildings, while zone B has been recommended for storey buildings and other heavy engineering structures. Overburden thickness for the two zones ranges from 1.3 m to 2.7 m, and 0.6 m to 2.7 m for zones A and B respectively. The cracks on walls of the buildings within the campus have been attributed to either the inability of the engineers to dig the foundation to the required depth or the construction of heavier structures on very weak subsurface layers which triggered off movement.
Keywords: Geoelectrical, Characterization, Foundation, Ebonyi State University, Nigeria.

1. Introduction

Investigation of proposed site(s) for foundation purposes by geophysicists, engineering geologists and geotechnical engineers provides subsurface information that assists the building professionals in the choice and design of civil engineering structures (Omoyoloye *et al.,* 2008; Akintorinwa and Adeusi, 2009). A building construction at a site without properly considering the underground geological strata or its load bearing capacity may settle excessively or differentially, causing development of cracks in the building which may ultimately lead to its failure and collapse (Scollar *et al.,* 1990). Subsurface geological features such as fractures, voids and nearness of water table to the surface are among the inconveniences which have been identified to pose considerable constraints to building constructions especially to their foundation (Andrews *et al.,* 2013). A number of geophysical techniques are available which enables an insight in obtaining a rapid nature of the underground strata or its load bearing capacity. Although these methods do not serve as a substitute for geotechnical investigations of the subsurface, they render quick and cheap preliminary approach to harnessing information about the subsurface layers.

Among the known geophysical techniques, the electrical resistivity method has found favour in the sight of many authors (Kearey *et al.,* 2002) for application in engineering studies, environmental assessment and hydro-geological investigation (Adeoti *et al.,* 2009; Akintorinwa and Abiola, 2011; Akintorinwa and Adesoji, 2009; Olorunfemi and Meshida, 1987; Oyedele and Ekpoette, 2011). Electrical resistivity method is based on the response of the earth to the flow of electrical current. Artificially generated electric currents are introduced into the ground and the resulting potential differences are measured at the surface (Loke, 1999; Telford *et al.,* 1990). All materials, including soil and rocks, have an intrinsic property- resistivity that governs the relation between the current density and the gradient of the electrical potential. Beside architectural factors, foundation cracks on building commonly occur due to resultant differential movements in the subsurface (Igboekwe *et al.,* 2006). Some buildings within the CAS campus have their walls cracked already only few years after construction (Fig. 1). Development of the site started without any form of subsurface investigation (whether geotechnical or geophysical), hence, the remote cause of the cracks could not be inferred. In order to ascertain the causes of such structural failure, a geophysical investigation was carried out with the aim of determining depth to stable geoelectrical layers which are geotechnically suitable for foundation purposes.

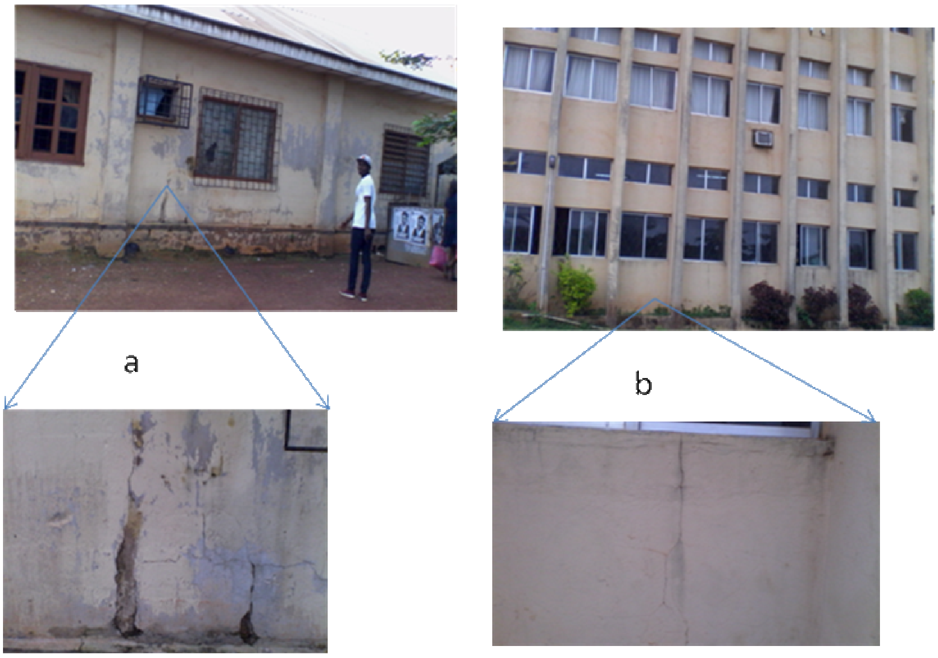

Fig. 1: Crack walls in the campus (a. Building at Pre-degree centre, b. Building at faculty of agriculture)

2. Geology of the Study Area

The study area is located within College of Agricultural Sciences (CAS) Campus of Ebonyi State University, Abakaliki, southeastern Nigeria, with latitudes $6^{0}15^{I}$ and $6^{0}25^{I}$ and longitudes $8^{0}00^{I}$ and $8^{0}10^{I}$ (Fig. 2). The area is underlain by the Abakaliki Formation of the Albian Asu River Group (Reyment, 1965). It is the oldest marine sedimentation in the southeastern Nigeria which followed the deposition of Aptian Ogoja Sandstone. The Asu River Group in the Abakaliki area consists mainly of poorly bedded, dark grey shale, volcanoclastics, mudstone with surbordinate lenses of sandstones, and sandy limestone. The geology of the study area is predominantly shale facies of the group otherwise known as the Abakaliki Shale (Agumanu, 1989). The sediments have been folded and fractured particularly following the series of tectonic episodes which have acted on them from the Albian times (Benkhelil, 1986). The lead – zinc mineralization in the Abakaliki – Benue Trough occur in the fractures. The evidence of igneous/volcanic activities in the Abakaliki area (southern Benue Trough) is represented by various intrusive deposits and volcanoclastics in the study area. Umeji (2000) has argued that the facture systems originated from movement resulting from the rising and cooling of magma, which intruded the sediments during the Santonian epirogeny which created uplifts in the Abakaliki and subsidence in both flanks of the Abakaliki Anticlinorium which resulted in the formation of Anambra and Afikpo Synclines. The high level of induration of the shales, which has made some people use them for construction works, have been interpreted as low grade metamorphism (Obiora and Charan, 2011).

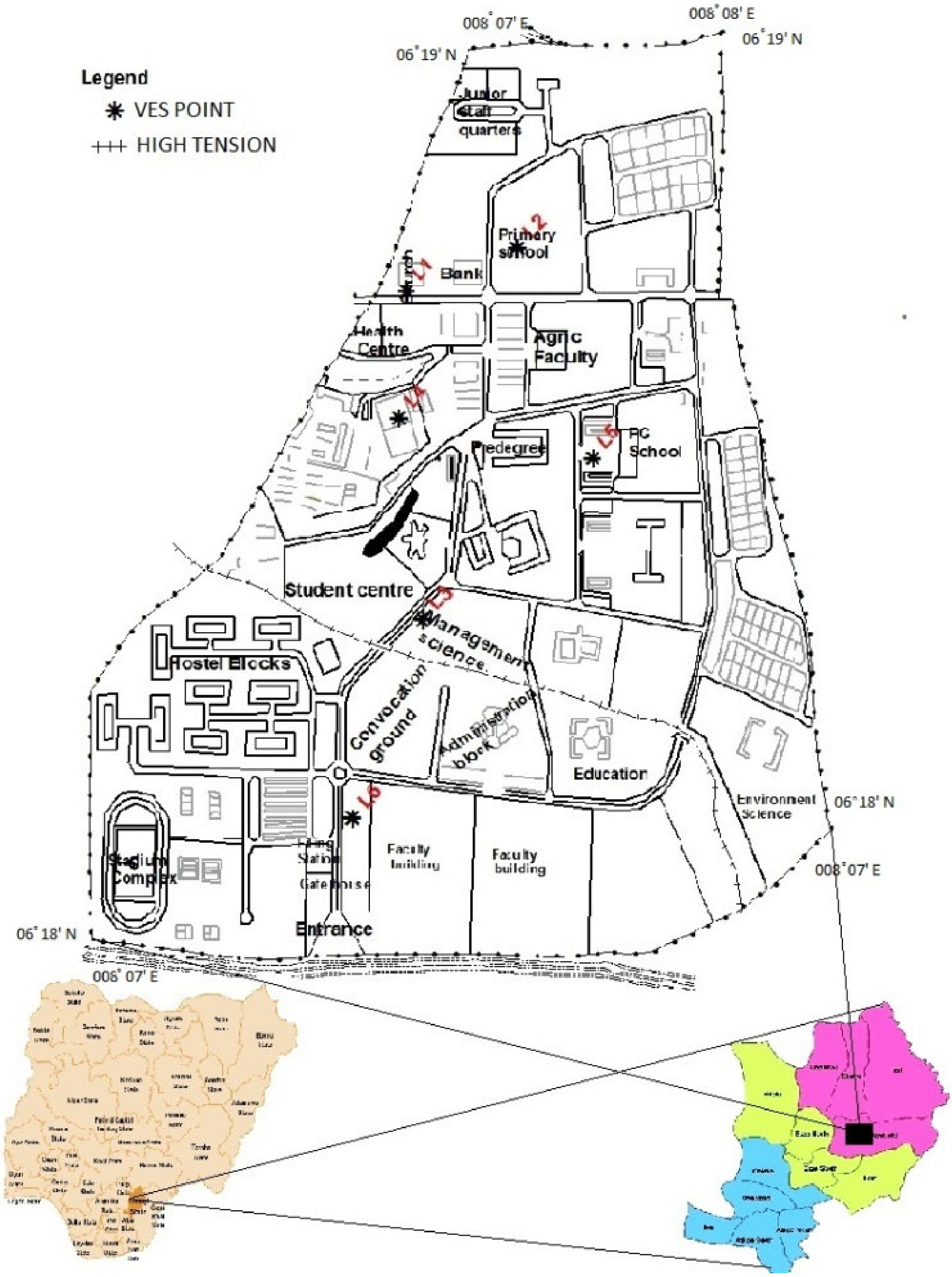

Figure. 2: Map of the study area.

3. Methodology

Equipment used for the geophysical survey include global positioning system (GPS), Abem Terrameter (SAS 1000), four electrodes, four reels of Cables, Direct Current Source (12 V Car battery), field Survey Data sheet and a Measuring tape. Geoelectrical resistivity measurements were performed using the Schlumberger electrode configuration (Fig. 3). Six (6) vertical electrical soundings (VES) were carried out at six different locations within the campus, with the half current electrode separation (AB/2) varying from 1m up to 100 m in successive steps, for the current electrodes, and 0.25 m to 10 m for the potential electrodes. The location and distribution of the VES stations were based on the available space and accessibility within the study area. At each VES point, the compass was used to get the direction of the point and GPS was used to record the coordinates of the area. The resulting resistance of each VES point were recorded in a survey data sheet and the resulting apparent resistivity were calculated respectively, using equation 1(Loke, 1999).

$$\rho_a = \left[\left(\pi/2I\right) X (L^2 - x^2)^2 / (L^2 + x^2)\right] x R \quad \ldots\ldots\ldots\ldots \quad (1)$$

Where: ρa = apparent resistivity, λ = constant (3.143), I = potential electrode spacing, L = current electrode spacing, x = separation of the mid-points of the potential and current electrodes, and R = resistance. The apparent resistivity data were plotted against the electrode spacing (AB/2) in order to generate the relevant geoelectric curves. The processing of the data was enhanced with the use of interpex IX1D software, which enabled the generation of the geoelectric layers. Corresponding lithologies for the geoelctric layers were inferred using the charts presented by (Loke, 1999 and Kearey *et al.,* 2002).

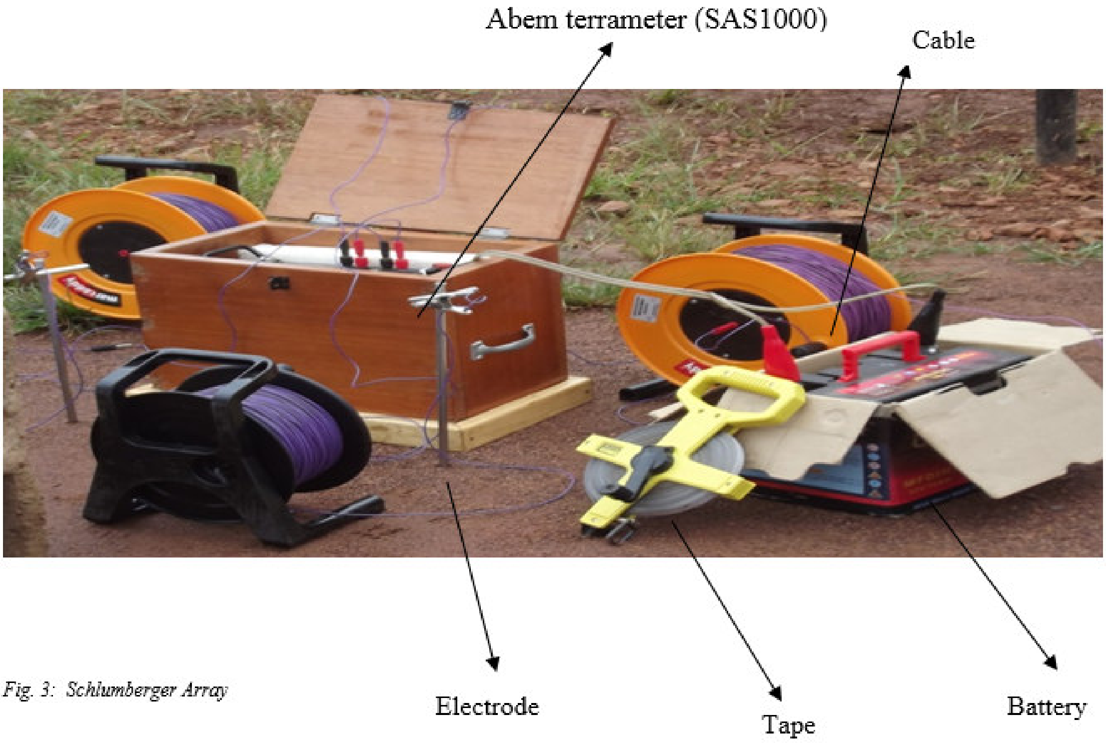

Fig. 3: Schlumberger Array

4. Results

4.1. Results of Vertical Electrical Sounding (VES) 1

The VES 1 was carried out in front of the Catholic Church at the left side after school gate (Fig. 2). It has the Q curve type (Fig. 4). It consists of six geoelectric layers (Table 1). The first layer has resistivity value of 51.05 Ωm and thickness of 0.267 m. Layer one was interpreted as organic top soil. The second layer has a resistivity value of 8968.3 Ωm and thickness of 0.0467 m. It was interpreted as sandy soil. The third layer has a resistivity value of 53.27 Ωm, thickness of 1.39 m and was interpreted as clay. The fourth layer with resistivity value of 43.00 Ωm, thickness of 0.940 m and was interpreted as moist clay. The fifth layer with resistivity value of 503.3 Ωm, thickness of 3.89 m. This layer was interpreted as baked shale. The sixth layer has resistivity value of 0.158 Ωm and has been interpreted as moist saturated clay.

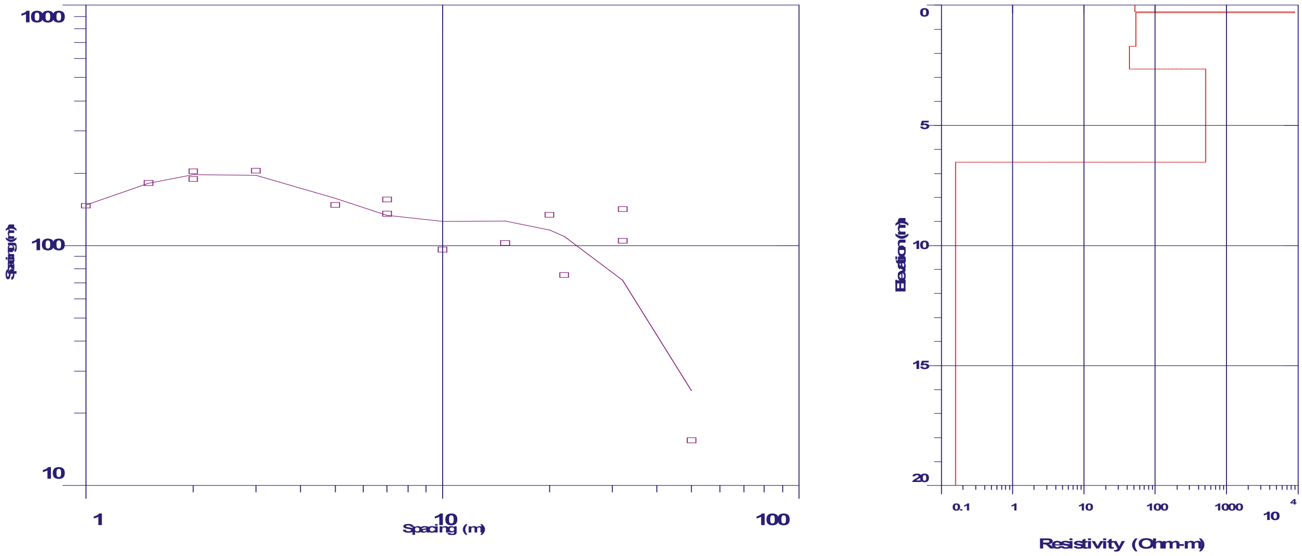

Fig. 4: Log-log Plot of VES 1 at the CAS campus

Table 1: Layer Model of VES 1

Layers	Resistivity(Ωm)	Thickness(m)	Depth (m)	Inferred Lithology
1	51.05	0.267	0.267	Organic Top soil
2	8968.3	0.0467	0.314	Sandy soil
3	53.27	1.39	1.70	Clay
4	43.00	0.940	2.64	Clay
5	503.3	3.39	6.54	Baked shale
6	0.158	-	-	Moist saturated Clay

4. 2. VES 2

The VES 2 was carried out at the premises of the Ebonyi State University (EBSU) primary school, precisely at their play ground. This VES has the Q curve type (Fig. 5) with six geoelectric layers (Table 2). The first layer has resistivity of 31.96 Ωm, thickness of 0.124 m. It has been interpreted as clay soil. The second layer has resistivity value of 11,114.2 Ωm, thickness of 0.0380 m and has been interpreted as fresh granite. The third layer has resistivity value of 36.87 Ωm and thickness of 1.03 m. It was also identified as clay. The fourth layer has resistivity value of 7.26 Ωm and thickness of 0.0282 m. It was interpreted as clay with high water content. The fifth layer has resistivity value of 579.9 Ωm, thickness of 2.38 m and was interpreted as baked shale. The sixth layer has resistivity value of 0.0189 Ωm.

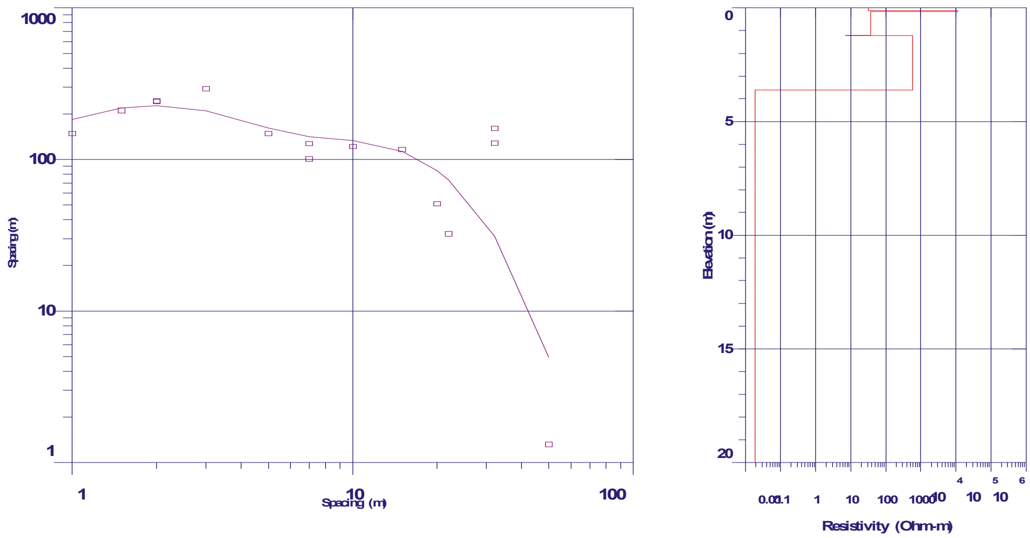

Fig. 5: Log-log Plot of VES 2 at the CAS Campus

Table 2: Layer Model of VES 2

Layers	Resistivity(Ωm)	Thickness(m)	Depth (m)	Inferred Lithology
1	31.96	0.124	0.124	clayey soil
2	11114.2	0.0380	0.162	Granite
3	36.87	1.03	1.19	Clay
4	7.26	0.0282	1.22	Clay
5	579.9	2.38	3.60	Baked shale
6	0.0189			Clay

4. 3. VES 3

The VES 3 was carried out in front of the proposed student centre (Fig. 3). This VES has a combination of H and K curve types (Fig. 6). It consists of five geoelectric layers (Table 3). The first layer, with resistivity value of 6.96 Ωm and thickness of 0.0308 m was interpreted as clay. The second layer has resistivity value of 991.7 Ωm, thickness of 0.497 m and was interpreted as silty clay. The third layer has resistivity value of 0.914 Ωm and thickness of 0.761 m. It was inferred as clay with high water content. The fourth layer has resistivity value of 1242.1 Ωm and thickness of 52.81 m. It was interpreted as baked shale. The fifth layer has resistivity value of 1.98 Ωm and was inferred as clay.

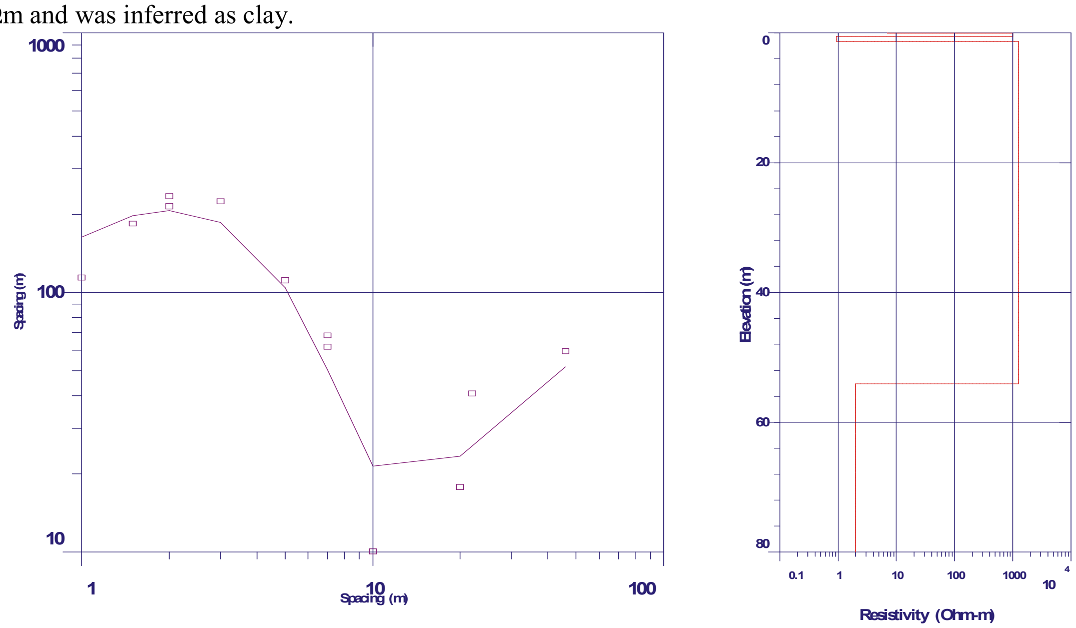

Fig. 6: Log-log plot of VES 3 at the CAS campus

Table 3: Layer model of VES 3

Layers	Resistivity(Ωm)	Thickness(m)	Depth(m)	Inferred lithology
1	6.96	0.0308	0.0308	Clay
2	991.7	0.497	0.528	Silty Clay
3	0.914	0.761	1.28	Clay (wet)
4	1242.1	52.81	54.10	Baked Shale
5	1.98			Clay

4. 4. VES 4

The VES 4 was carried out at the EBSU secondary school football field. This VES has a combination of H and K curve types (Fig. 7). It consists of five geoelectric layers (Table 4). The first layer with resistivity value of 0.939 Ωm and thickness of 0.00455 m has been interpreted as water saturated clay. The second layer has a resistivity value of 917.0 Ωm, with thickness of 0.291and has been interpreted as baked shale. The third layer has resistivity value of 1.07 Ωm and thickness of 0.268 m. it was interpreted as wet clay. , the fourth layer has resistivity value of 57,673.8 Ωm and is 205.0 m thick. This layer has been interpreted as fresh granite. The fifth layer has a resistivity value of 2.03 Ωm, with undefined thickness, and has been interpreted as wet clay.

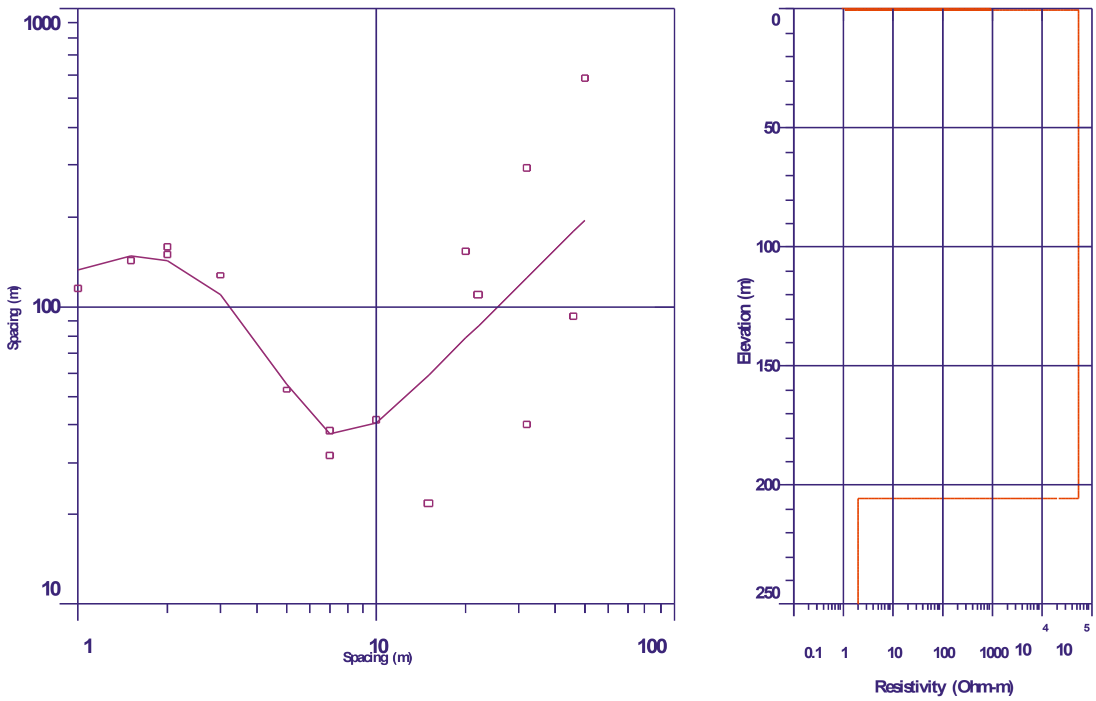

Fig. 7: Log-log plot of VES 4 at the CAS campus

Table 4: Layer model of VES 4

Layers	Resistivity(Ωm)	Thickness (m)	Depth (m)	Inferred Lithology
1	0.939	0.00455	0.00455	Water saturated Clay
2	917.0	0.291	0.295	Baked shale
3	1.07	0.268	0.563	Wet Clay
4	57673.8	205.0	205.5	Fresh granite
5	2.03			Wet Clay

4. 5. VES 5

The VES 5 was carried out in front of the new school of postgraduate studies (PG school) building. This VES has the H curve type (Fig. 8). It consists of four geoelectric layers (Table 5). The first layer has a resistivity value of 61.46 Ωm with thickness of 0.27 m and has been interpreted as soft, moisturized shale. The second layer has resistivity value of 662.4 Ωm and thickness of 0.423 m. it was interpreted as silty – clay. The third layer has resistivity value of 16.3 Ωm and thickness of 1.98 m. it was interpreted as wet clay. The fourth layer has a resistivity value of 84.74 Ωm, with undefined thickness, and has been interpreted as soft shale.

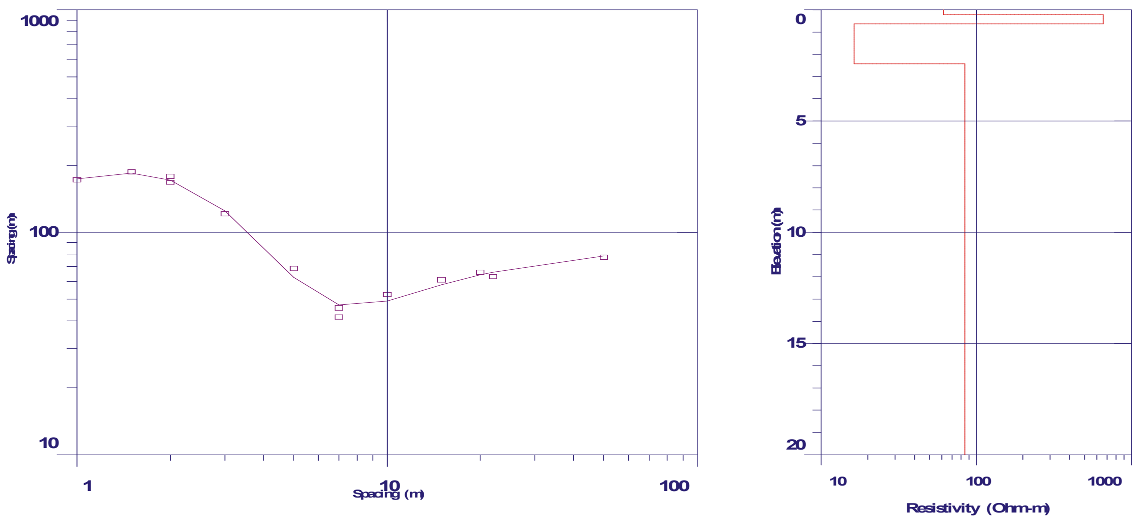

Fig. 8: Log-log plot of VES 5 at the CAS campus

Table 5: Layer model of VES 5

Layers	Resistivity (Ωm)	Thickness (m)	Depth (m)	Inferred Lithology
1	61.46	0.207	0.207	Soft shale
2	662.4	0.423	0.631	Silty-clay
3	16.3	1.78	2.41	Wet Clay
4	84.74			Soft Shale

4. 6. VES 6

The VES 6 was carried out along the road that leads to the CAS campus main gate, towards Ogoja road. This VES has the H curve type (Fig. 9). It consists of four geoelectric layers (Table 6). The first layer with resistivity value of 109.2 Ωm and thickness of 1.25 m is weathered shale. The second layer with the resistivity value of 0.456 Ωm and thickness of 0.0829 m is wet clay. The third layer has resistivity value of 77.09 Ωm with thickness of 1.33 m and was interpreted as soft shale. The fourth layer with resistivity value of 8621.4 Ωm and undefined thickness was interpreted as baked shale.

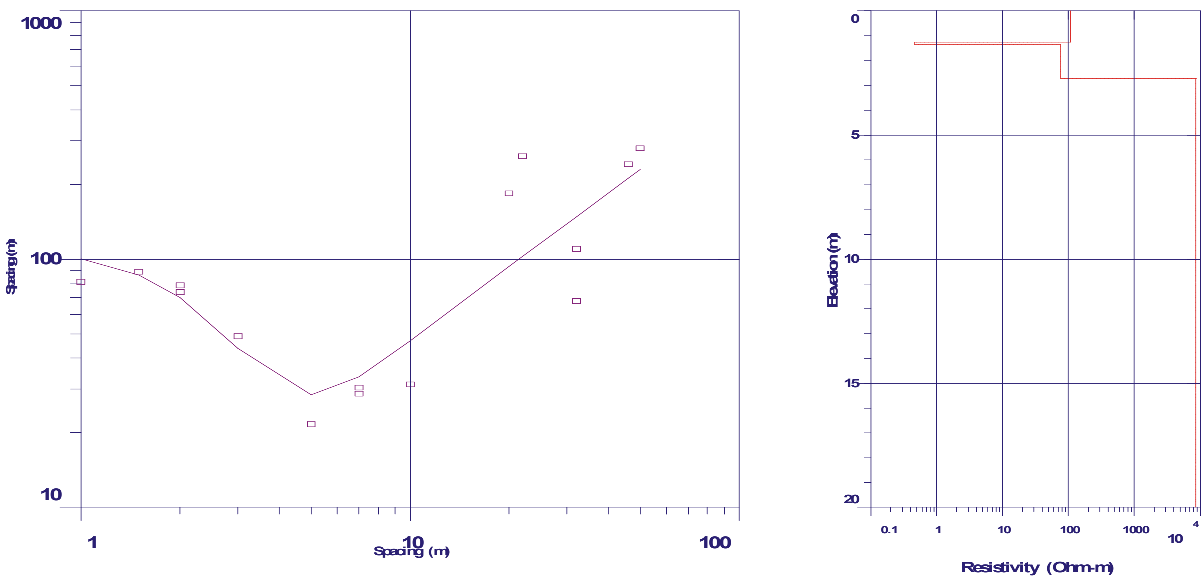

Fig. 9: Log-log plot of VES 6 at the CAS campus.

Table 6: Layer model of VES 6

Layers	Resistivity (Ωm)	Thickness (m)	Depth (m)	Inferred Lithology
1	109.2	1.25	1.25	Weathered shale
2	0.456	0.0829	1.33	Clay
3	77.09	1.33	2.71	Soft shale
4	8621.4			Baked Shale

5. Discussion

Considering the resistivity values of the layers and their corresponding thicknesses (Table 1), depth to bedrock has been interpreted as about 2.70 m. Hence, for buildings and similar foundations around the Catholic Church, minimum depth of excavation should be 2.7 m. However, it is recommended that high rising buildings should not be erected in this area owing to the fact that the thickness of the bedrock is moderately small, while it is underlain by a layer of very low resistivity.

On the basis of resistivity and thickness in Table 2, the 5th layer is considered most suitable for placement of foundation for engineering purposes. Although the second layer has a very high resistivity which tried to present it as a better geologic material for this purpose, its thickness is quite negligible. Hence, for building construction around the EBSU primary school, depth to foundation should not be less than 1.3 m. This is to ensure that the clay zones are completely exceeded. However, it is recommended that high rising buildings such as sky scrapers should not be constructed within this zone. This is based on the fact that the suggested 5th layer has a very weak layer under it which may likely trigger movement if a reasonable load is introduced, especially when considering the fact that the thickness of the 5th layer is just less than 3 m.

On the basis of resistivity and thickness in Table 3, the 4th layer has been recommended as a stable base for laying of foundations. Hence, a total overburden thickness of not less 1.30 m must be excavated before any foundation should be laid in areas around the proposed student centre. Although layer two appears promising, its thickness does not support the purpose. Around the student centre, both low and high rising buildings could as well be erected, since the average thickness of the recommended layer suggests that it would be geotechnically stable for heavy foundations.

Based on resistivity and thickness in Table 4, the fourth layer has been suggested to be suitable for laying of foundations. All kinds of foundations (both light and heavy structures) can be laid within and around the secondary school area, since the 4th layer can carry them. Although the resistivity of the second layer appears encouraging, its thickness is not, more so, the adjoining layers do not support foundation. A thickness of not less than o.6 m must be excavated before laying foundation in this area to ensure total passage of the overlying layers. Based on the resistivity and thickness of the geoelectric layers in Table 5, the 4th layer has been suggested as the stable layer for foundation laying. A total overburden thickness of about 2.50 should be evacuated before laying foundation. The result of resistivity and thickness Table 6 suggest a stable layer for foundation purposes. This implies that a total overburden thickness of not less than 2.7 m should be evacuated before foundation is laid on the baked shale. Based on the resistivity and thickness of the 4th layer, it is suggested that it is stable enough to carry both high and low rising buildings.

From the results of the VES data in the six locations, the EBSU College of Agricultural Science has been partitioned into areas of high and low rising buildings, and minimum depths to foundations have also been suggested. All construction works around Catholic Church, the EBSU primary school and the school of postgraduate studies should be low rising buildings (Fig. 10), while high rising buildings can be sited in areas around the proposed site for the students centre, EBSU secondary school and even towards the CAS main gate that led to the popular Abakaliki mechanic village. Depth of penetration for foundation laying in the area has been recommended based on the overburden thickness seen from the VES plots. Their thicknesses are catholic church (2.7 m), EBSU primary school (1.3 m), students centre (1.3 m), EBSU secondary school (0.6 m), PG school (2.5 m), and road to CAS gate (2.7 m). It can be observed from the discussion so far that the buildings with cracks (Fig. 1) are situated within the areas which were recommended for low rising buildings. It is also pertinent to note that the same environment mentioned above has its range of overburden thickness as 1.3 m – 2.7 m. Hence, the cracks on the walls of the both buildings (Fig. 1) could be attributed to either laying the foundation within the mobile layers, in which case it means the ideal depth to stable zone was not reached, or constructing a heavy structure, as in the case of the Faculty of Agricultural science building, on a weak subsurface layer which triggered off movement and consequently led to the tearing of the foundation of the building which appeared at the surface as cracks on the wall.

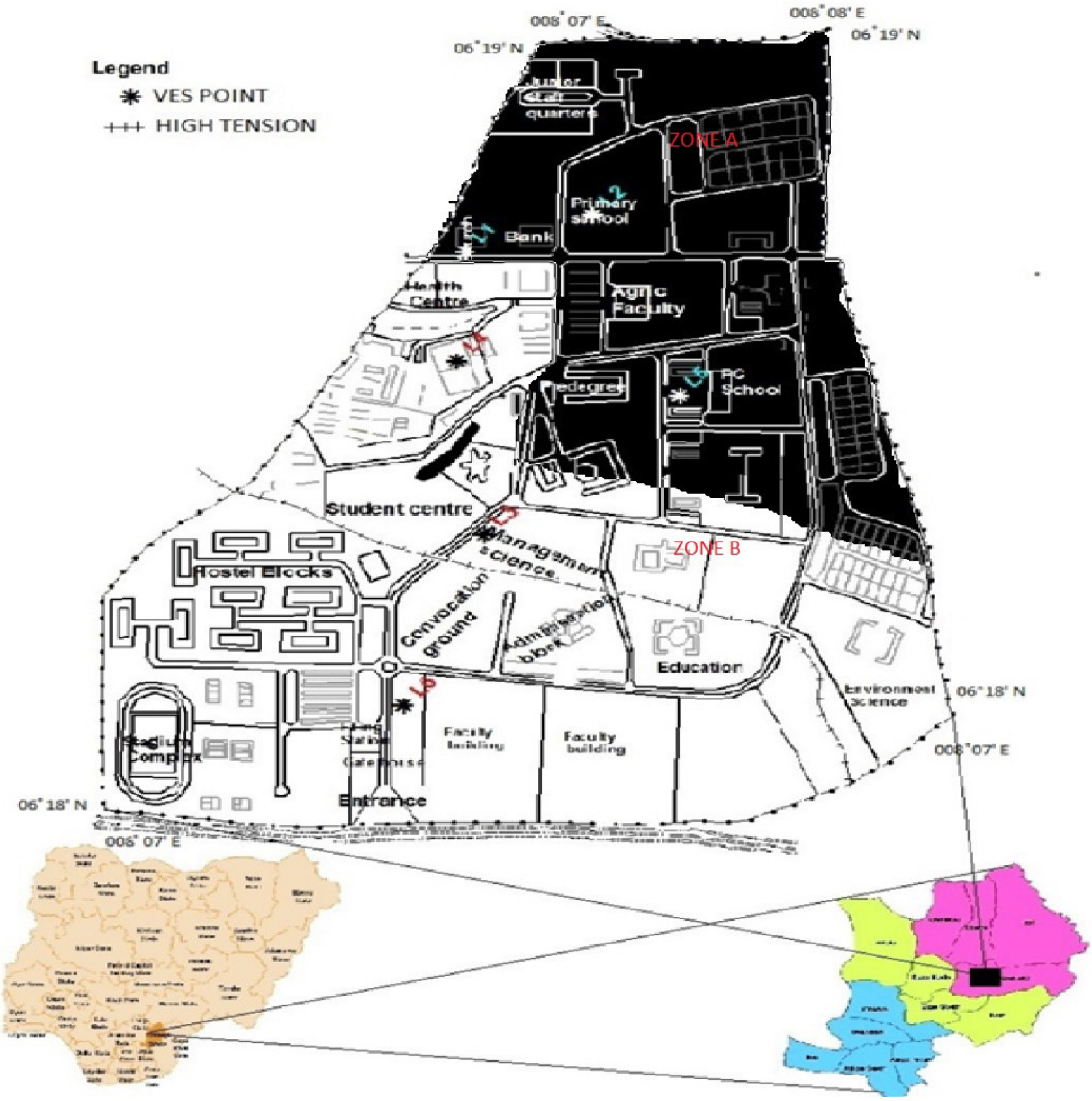

Fig. 10: Geoeletrical Zonation of the Study Area.

6. CONCLUSION

Two major zones have been established within the Ebonyi State University CAS campus based on the strength of the subsurface layers to form foundation for building construction. Zone 'A' (i.e. area with black colouration of Fig. 10) comprises of areas around the catholic church building, EBSU primary school up to the school of post graduate studies, while zone 'B' (i.e. area with white colouration of Fig. 10) is made up of areas around the EBSU secondary school, proposed student centre up to the main entrance gate which led to the Ogoja road. Zone A has been recommended for bungalows and other forms of low rising buildings, while zone B has been recommended for storey buildings. Overburden thickness within the zone 'A' ranges from 1.3 m to 2.7 m, while that of zone 'B' ranges from o.6 m to 2.7 m. The cracks on buildings within the campus have been attributed to either the inability of the engineers to dig the foundation to the required depth or the construction of heavier structures on very weak subsurface layers which triggered off movement thereby shaking the foundation of these structures.

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