Available online www.jsaer.com

Journal of Scientific and Engineering Research, 2020, 7(2):15-32

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Application of Geoelectric and Geotechnical Methods in Assessment of Occurrence of Ironstone in Okigwe Area of Imo State Nigeria

Nwosu, Leonard I.*, Onwuka, Chiemerie S.

Department of Physics University of Port Harcourt, Nigeria
E-mail: leowos@yahoo.com

Abstract A local mining site of Ironstone was identified at Amagu Okigwe during reconnaissance survey of the study area. Hence a combined geophysical and geotechnical techniques were employed to evaluate the occurrence of this natural economic resource in the area. Thirteen (13) vertical Electrical Soundings (VES) were carried out using OHMEGA-500 Resistivity meter and the field data interpreted using the Advanced Geosciences Incorporation (AGI) ID software and the Schlumberger automatic analysis version. The result revealed that the study area is underlain by exploitable ironstone deposit having highest resistivity values at each VES station. Also two lateral profiling using Wenner electrode array were run across the VES point stationed at the ironstone local mining site which gave 3 to 33m and 19m to 25m possible ironstone intervals along the traverses across the VES point. The resistivity values of the ironstone ranged from 5278Ωm to 181215.80Ωm. The thickness ranged from 0.6m to 38m. The ironstone samples were subjected to laboratory test for determination of basic geotechnical parameters. The results gave Optimum Moisture Content of 10%, Maximum Dry Density of 2.06g/cm^3, Specific gravity of 2.72 and Bulk density of 1.59g/cm^3. The area of the mining site, volume and mass of the ironstone reserve determined at Amagu were 180m^2, 12960m^3 and 2×10^{7}kg respectively. This study has shown that ironstone is geotechnically competent to be used as building and construction material and can be mined in the study area to generate revenue for both the host communities and the State.

Keywords mining site, resistivity, electrode array, bulk density, ironstone

1. Introduction

Reconnaissance survey of the study area revealed occurrence of ironstone deposits as can be observed from the outcrops. Such communities include Ihube, Isuochi, Isukwuato, Lokpanta and Uturu. Local mining of ironstone has been going on in some of these areas for the supply of building and construction materials especially for foundation of buildings in both rural communities and urban centers in Nigeria (Fig. 2). Hence this deposit is of economic importance to the host communities as it serves as means of livelihood for the owners of the sites. Truckload of onetonne of the material is soldat about one hundred and eight thousand Naira (500 USD).

No previous work on occurrence of ironstone deposit has been reported in the area. However, available literature sources show that geoelectrical methods are effective in delineating subsurface layers and lithological units. 1D resistivity inversion technique has been used in mapping of igneous intrusive for sustainable quarry development [1]. Similarly research reports show that geotechnical investigation is useful in characterization of soils and rocks [2-3, 24].

Integrated geophysical and geotechnical data therefore enhances evaluation of structural disposition of foundation beds [4-7]. The results of interpretation of such data when compared with standard values [9] are used to assess the competence of the near surface formation for foundation of engineering structures and also to predict remedial measures for structure foundation failures in areas [5-6]. Integration of geophysical and geotechnical methods has equally been applied in investigation of engineering properties and use of soil derived from maastritchian Ajali Formation in a part of Southeastern Nigeria; the study being necessitated by the move by Imo State Government of Nigeria to raise Okigwe town to urban status [10].

In this study, effort is made to apply electrical resistivity method to evaluate the occurrence of the rock mineral by carrying out Vertical Electrical Sounding (VES) in 13 communities within the study area. At Amagu local mining site, both the Schlumberger and Wenner electrode Configurations were adopted to determine the depth, thickness and lateral extent of the deposit.

The rock samples were taken to the laboratory for further analysis and characterization using geotechnical method. Estimates of area of site, mass and volume of the ironstone deposits at Amagu local mining site were made.

2. Location and Description of the Study Area

2.1. Location of the Study Area

The study area is located in the Northern parts of Imo State and parts of Abia State in the Southeastern Nigeria (Fig. 1) with coordinates 5°40'N to 6°10'N and 7°10'E to 7°30'E

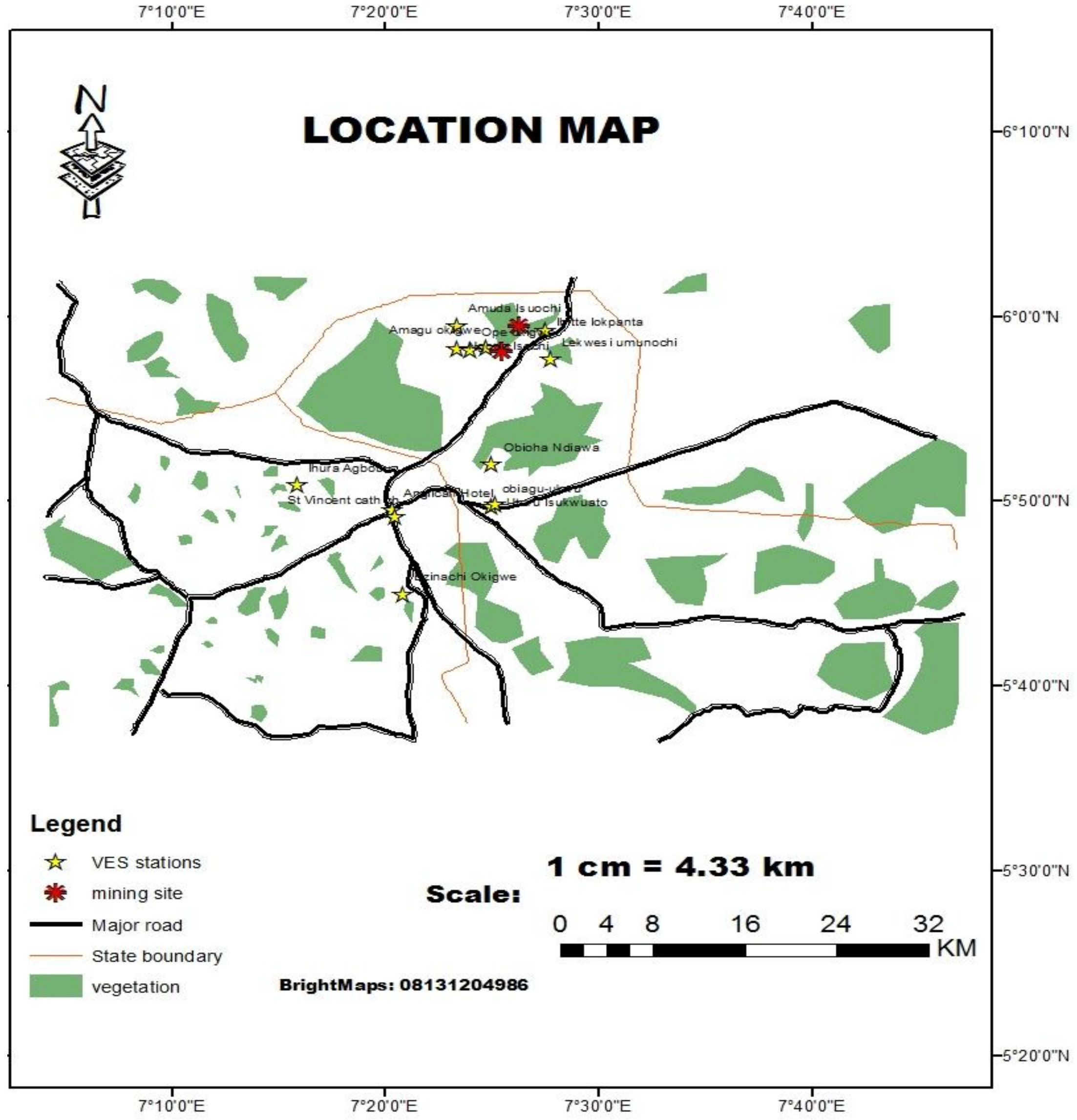


Figure 1: Location Map of Okigwe and environs showing the VES stations

2.2. Description of the Study Area

Major relief features of the study area include successive hills arranged in linear forms and separated from each other by valleys. This is the characteristic feature of Okigwe town and its environ. There are hills which range in height of about 60-90m. Between these hills are shallow valleys. The rocks such as ironstone, sandstone, and mudstone that make up the hills are resistant to weathering and erosion while soft rocks (finesand, silts, clay and shales make up the valley (Fig. 2)

Figure 2: Local mining site at AmaguOkigwe

The study area lies within the tropical rain forest belt of south-eastern Nigeria. However a change in vegetation from typical rain forest to transitional forest (Savannah type) is being noticed (Fig. 3). This is due to human activities such as farming, road construction and overgrazing that have resulted in extensive deforestation and hence change in natural vegetation. Savannah type is observed mainly in the areas overlain by Nsukka formation.

Figure 3: Typical Vegetation Cover in the study area

2.3. Geology of the Study Area

The study area is situated in a complex geological setting in the Imo River Basin (Figs 4a and 4b.). The basin is underlain by the following stratigraphic units: The Benin Formation, the Bende-Ameki Formation, Imo Shale Formation, Nsukka Formation and Ajali Formation.

The Benin Formation is overlain by lateritic overburden and underlain by the Ogwashi - Asaba Formation which is in turn underlain by the Ameki Formation of Eocene to Oligocene age [11]. The sand units are mostly coarse grained, pebbly and poorly sorted. As the sandy component in most areas form more than 90% of the sequence of the layers, permeability, transmissivity and storage coefficient are high [12].

The lmo Shale group is characterized by lateral and vertical variations in lithology. It is mainly a fine textural dark grey to bluish Shale with thick sandstone bands and ironstones. The formation becomes more sandy towards the top where it consists of alternation of sandstone and shale observed around Ugwuaku locality. It is underlain in succession by Nsukka Formation, Ajali Sandstones and NkporoShales. The Ajali Formation consists of thick, poorly sorted sandstones typically white in colour but sometimes iron- stained. A marked banding of coarse and fine layer is displayed [13]. The Ajali Formation is often overlain by a considerable thickness of red earth, which consists of red, earthy sand**.** This formation consists of alternations of sandstone, shale, mudstone and coal seams. There are few important coal seams in the lower horizons of Nsukka Formation.

Figure 4a: Map of Nigeria showing study area

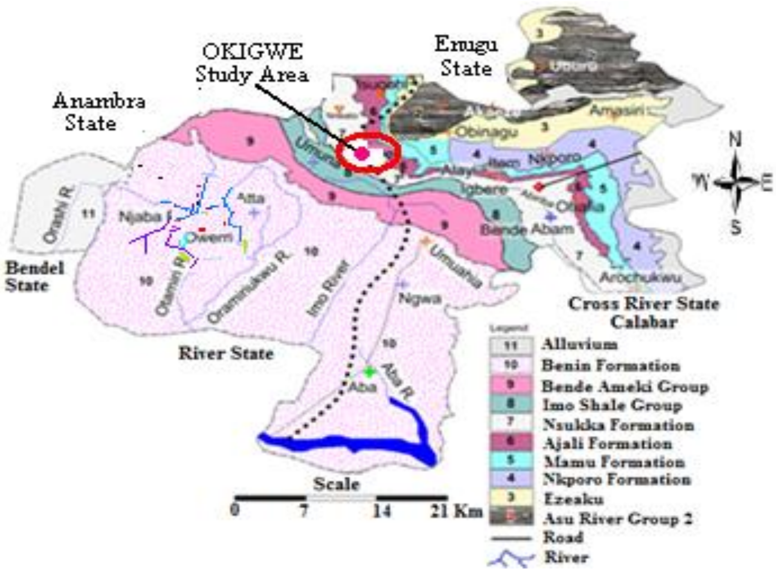
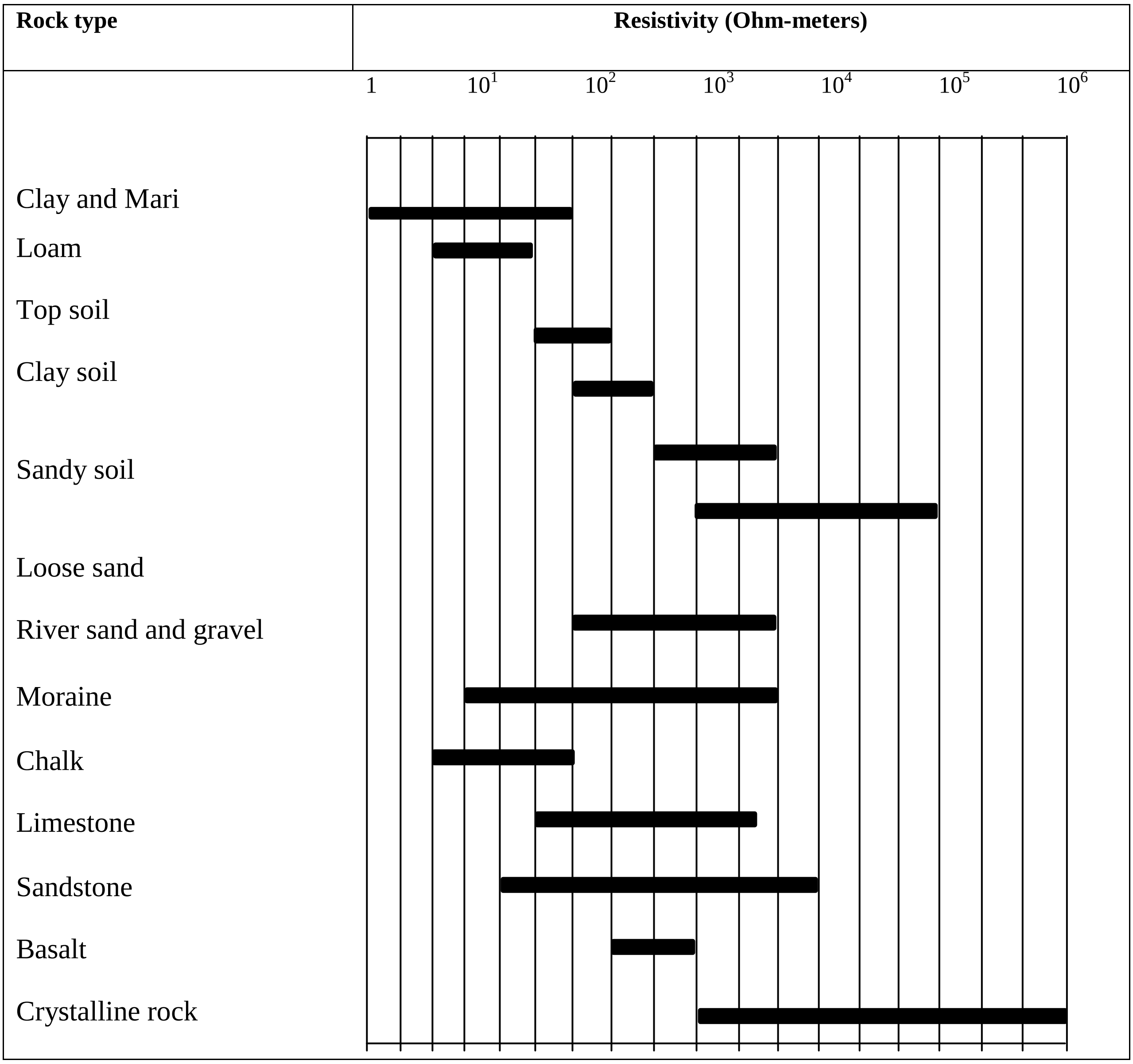


Figure 4b: Geologic Map of Imo River basin, showing the Study area [14]

2.4. Rock Resistivity

The resistivity of rocks and minerals displays a wide range (Table 1). Resistivity values for unconsolidated sediments commonly range from less than 1Ωm for certain clays or sands saturated with saline water, to several thousand ohm-m for dry basalt, dry sand and gravel. The resistivity of sand and gravel saturated with fresh water ranges from about 15 to 600Ωm. This table combined with available borehole information was useful in the interpretation of the VES data.

Table 1: Resistivities of some rock minerals [15]



3. Materials and Methods

3.1. Instrumentation for VES Data Acquisition

The instruments used for the field survey include:

Ohmega-500 electrical resistivity meter
Four stainless steel electrode (two potential and two current electrodes)
A 12 volts DC power supply
Four reels of cables

Harmers
Measuring tapes and
Clips

3.2. Field Procedure for VES Technique

Vertical electrical sounding (VES) using the Schlumberger electrode configuration and a total of 13 VES stations were occupied within the study area with maximum electrode spread of 700m. Four electrodes consisting of two current electrodes A and B, and two potential electrodes M and N were placed along a straight line on the ground surface such that the current electrode AB is greater than or equal to five times the potential electrode MN. This technique involves the measurement of variations in ground apparent resistivity with depth at a fixed point of expanding spread.

The Ohmega-500 electrical resistivity meter was placed in between the potential electrode M and N and its terminals P1 and P2 connected to the terminal M and N respectively using the ABEM sounding set. The current electrode A and B were connected to the C1 and C2 respectively using the ABEM sounding current cables wound on two separate metal reels mounted on the stand. After setting up the apparatus, the electrodes which were about 0.7m long were driven to a reasonable depth into the ground using a hammer. The potential electrodes were fixed while the current electrode spacing was expanded in opposite direction on a straight line for subsequent measurements. However, the potential electrode spacing was increased whenever the value of measured resistance became too small to be reliable while the length of the configuration was generally increased

3.3. Determination of Area, Volume and Mass of Ironstone Reserve

In order to determine the area of the local mining site, mass and volume of Ironstone reserve at AmaguOkigwe, a VES was run and two Wenner profiling were also run across the site (Fig. 5). These were aimed at establishing the depth and thickness of the ironstone with the VES and lateral spread with the profiling.

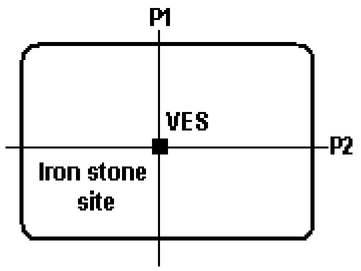


Figure 5: Field procedure at Amagu Local Mining Site

- VES = Vertical Electrical Sounding using Schlumberger electrode array.

P_1 and P_2 = Lateral profiling from area of low concentration to high concentration.

These parameters were determined as follows**:**

Area of site: The lateral spread obtained with the profiling P_1 and P_2 give the length and width dimensions from which the area of site is determined.

$$\text{Area of site} = P_1 \times P_2 \quad (1)$$

Volume of Ironstone reserve: Volume is estimated from the product of the area and the thickness of ironstone determined from VES.

$$\text{Volume} = P_1 \times P_2 \times h \quad (2)$$

where h = thickness of ironstone at the site

Mass of the Ironstone reserve: The mass of ironstone reserve is estimated from the product of the volume of ironstone obtained from geoelectric investigation and its Bulk density obtained from geotechnical method.

$$\text{Mass} = P_1 \times P_2 \times h \times BD \quad (3)$$

$$\text{Mass} = \text{Volume} \times BD \quad (4)$$

where BD is bulk density

3.4. VES Data Analysis

The field data was first subjected to manual computation and finally to computer processing techniques. The interpretation of the field data was carried out by applying the Advanced Geosciences Incorporation (AGI) ID resistivity analytical software.

The Analytical result presented by the AGI ID software and the Schlumberger Automatic analysis package revealed 12 layers with their various resistivity and depth and are later constrained to a certain number of layers depending on the significant value of the thicknesses.

3.5. Geotechnical Method

In the geotechnical phase of the study, the following laboratory tests were carried out on samples of ironstone collected from the local mining site at Amagu:

3.5.1. Specific Gravity Test: The weight of an empty bottle was determined using a weighing balance. The bottle was filled with water to the brim and its weight determined. One third of empty bottle was filled with the subgrade sample and its weight determined appropriately. Water was added to the latter to the brim and mixed thoroughly for few minutes before determining its weight.

The Specific gravity was calculated using the following steps:

Let weight of bottle = W_1

Weight of bottle + Sample = W_2

Weight of bottle + Sample + Water = W_3

Weight of bottle + Water (full) = W_4

Then,

Weight of water filling the bottle alone = $(W_4 – W_1)$ 5

Weight of water added to the Sample = $(W_3 – W_2)$ 6

Weight of Sample = $(W_2 – W_1)$ 7

Weight of water displaced by sample = $(W_4 – W_1) – (W_3 – W_2) = W$ 8

Specific gravity of sample particles = $(W_2 – W_1)/W$ 9

3.5.2. Bulk Density Test: Soil bulk density, ρ_b, is defined as the ratio of dry soil mass to bulk soil volume (including pore spaces). Since bulk density relates to the combined volume of the solids and pore spaces, soils with high proportion of pore spaces to solids have lower bulk densities than those that are more compacted and have less pore spaces. Consequently, any factor that influences soil pore space will affect bulk density.

Bulk density $\boldsymbol{\rho}_b$ which is also called wet density, is the mass per unit volume of the soil deposit including any water it contains.

$$\rho_b = \frac{W}{V} \qquad 10$$

Bulk density = Mass of soil divided by the internal volume of the cylinder.

The dimensions (mass, length, and internal diameter) of cylindrical cutter were measured and used to calculate the volume of the cylinder, since this will be the volume to be occupied by the sample (the volume of cylinder$=\pi r^2$h). The cutter was driven into the ironstone sample such that the sample fills it. Then the sample was emptied into a can of known mass (M_1) and weighed. This was recorded as M_2. The sample was dried in an oven, then weighed and recorded as (M_3). Hence, moisture content of the soil is calculated.

3.5.3. Compaction Test: This was carried out to determine the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD). Weights of cylindrical molds were determined using weighing balance. The sample of ironstone was divided into four different portions of about 6kg each. 100ml of water was added to the first portion and mixed thoroughly. Some parts of it were kept in two separate cans to determine weight of wet sample and weight of dry sample after spending 24 hours in the oven in order to know its moisture content. The first layer of a 4- layer cylindrical mold was filled with the sample and rammered 25 times with the aid of 4.5 kg rammer. The same was done on the remaining layers and rammered 25 times each. The weight of compacted wet sample was determined using weighing balance and wet density calculated. The same procedures were followed for the remaining three portions but with increment of 100ml of water on each portion to the first

100ml of water on each portion, that is, 200ml, 300ml, and 400ml of water respectively. Graph of moisture content against dry density was plotted and the compaction curve drawn. Optimum Moisture content (OMC) and Maximum Dry Density (MDD) were deduced from the graph {Fig 18}.

4. Results and Discussion

4.1. Geoelectrical Results

Typical model results obtained for the VES locations are shown in figures 6 to 14 while the corresponding analytical results obtained were displayed in Tables 2 to 8

The modeled results of lateral resistivity variations obtained using Wenner array which were run across the VES point from low to high concentration of the ironstone at the local mining site Amagu are shown in Fig. 7 and Fig, 8. The summary of geoelectrical data interpretation is shown in Table 9.

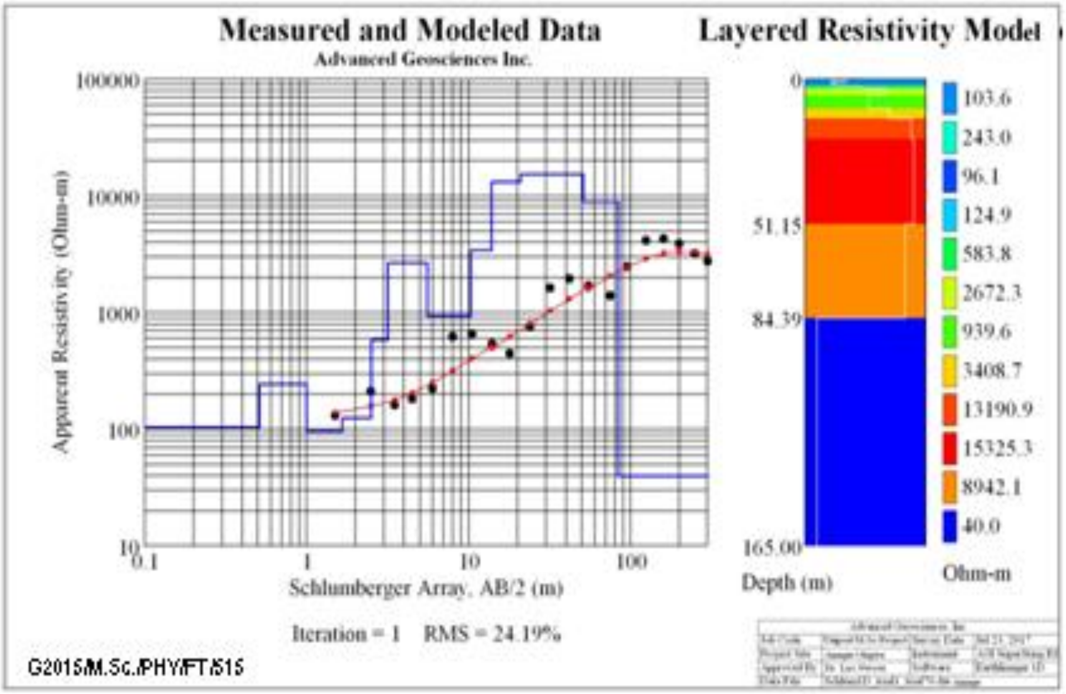


Figure 6: VES model result of Amagu

Table 2: Amagu VES analytical result

Layer	Depth (m)	Resistivity (Ohm-m)	Lithology	Colour
1	0.511	103.60	Top soil	Blue
2	0.998	243.05	Sandstone	Light blue
3	1.657	96.12	Silty	Blue
4	2.521	124.95	Sand	Light green
5	3.173	583.79	Sandy	Green
6	5.580	2672.33	Clay	Light yellow
7	10.305	939.59	Siltstone	Green
8	13.892	3408.68	Sandstone	Brown
9	21.046**	13190.94	Ironstone	Red
10	51.149**	15325.28	Sandstone/Ironstone	Yellow
11	84.386	8942.08	Mixed sand	Blue

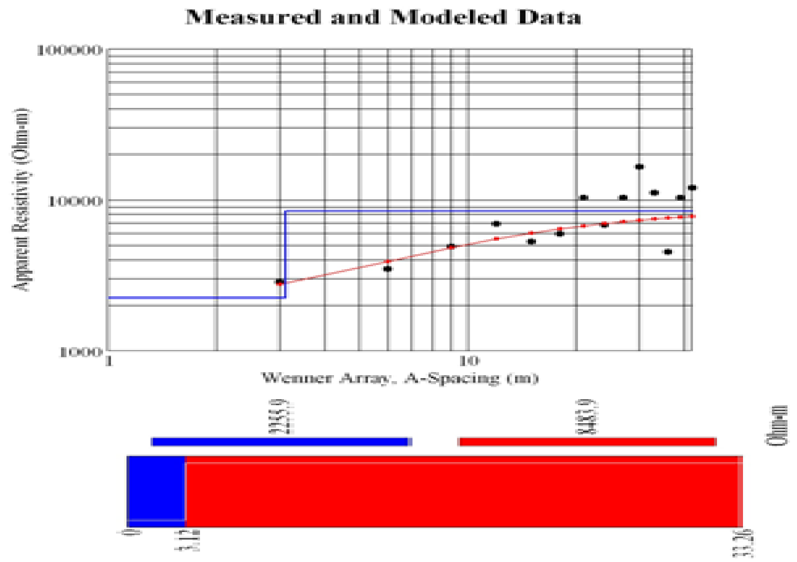


Figure 7: Wenner model result of Amagu (P_1 Ironstone interval = 3-33m)

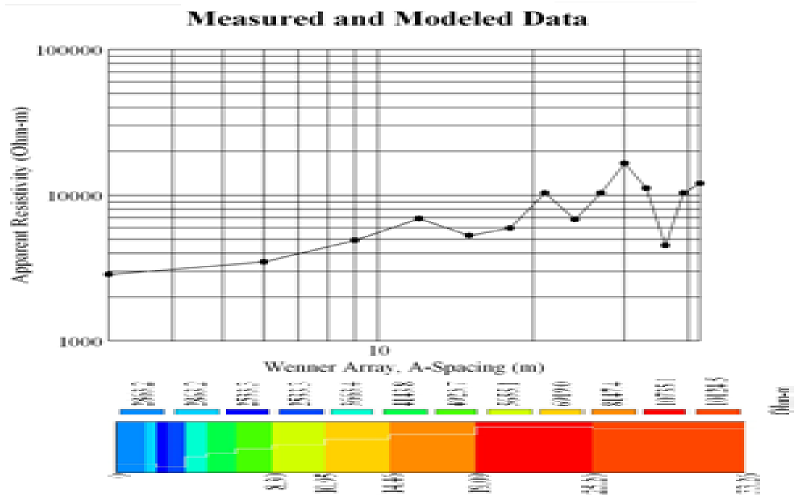


Figure 8: Wenner model result of Amagu (P_2 Ironstone interval = 19-25m)

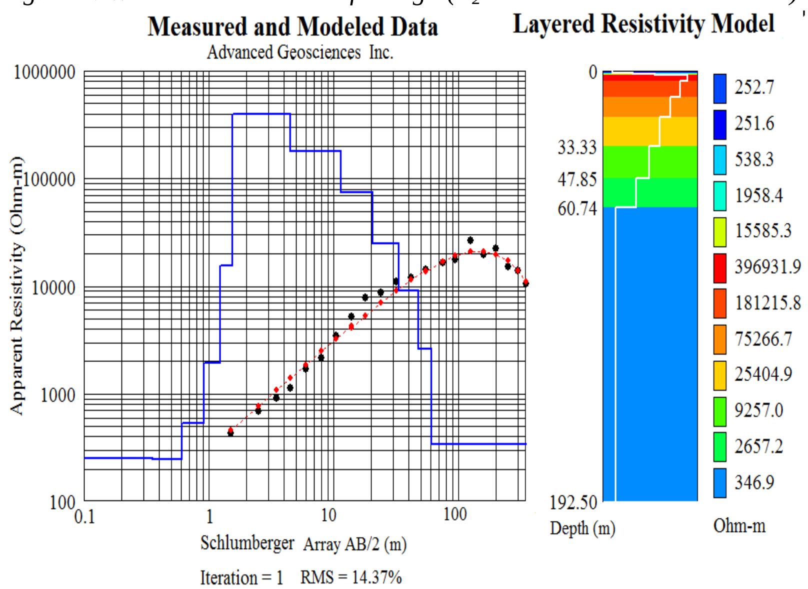


Figure 9: VES model result of Obiagu Ukwu Lokpanta

Table 3: ObiaguUkwuLokpanta Analytical Result

Layer	Depth (m)	Resistivity	Lithology	Color
1	0.6	251.6	Topsoil	Mixed Blue
2	4.5	396931.9	Ironstone-sandstone***	Red
3	11.4	181215.8	Sand stone/Ironstone**	Red
4	20.6	75266.8	Shale	Brown
5	33.3	25404.9	Siltstone	Yellow
6	47.9	9257.0	Shaly-Sand	Green
7	60.7	2657.2	Sandstone	Green
8	<192.50	346.9	Mixed Sand (Prospective)	Blue

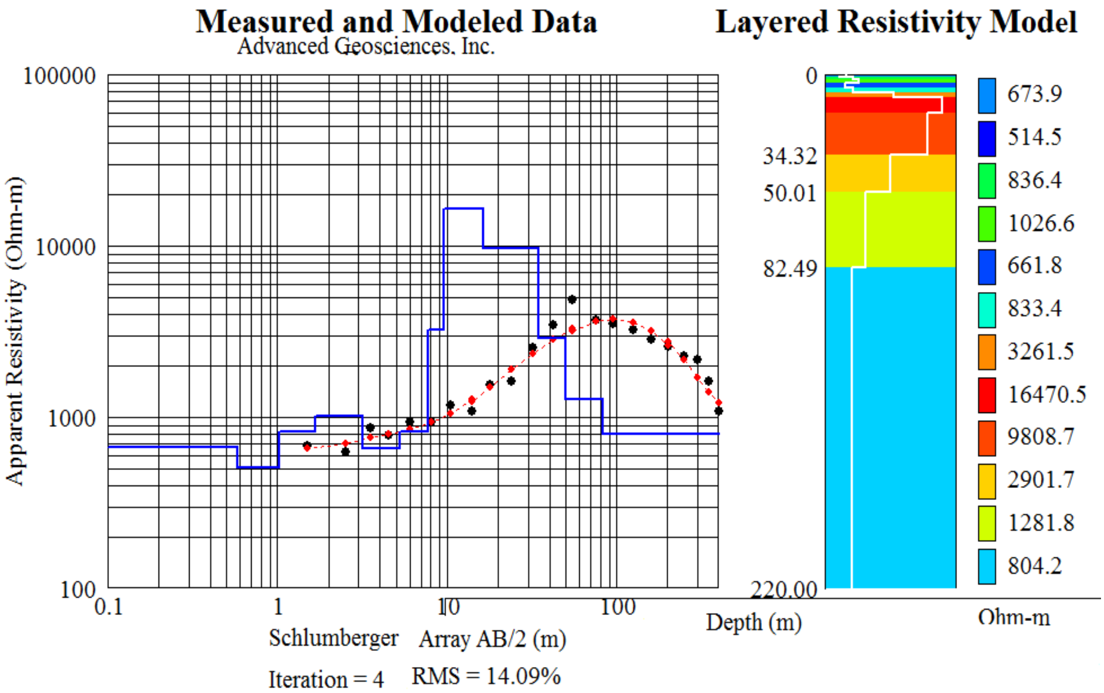


Figure 10: VES model result of Obiohia Ndiawa Isuochi

Table 4: Obiohia Ndiawa Isuochi Analytical Result

Layer	Depth (m)	Resistivity	Lithology	Color
1	0.5	737	Topsoil	Mixed Blue
2	1.6	855	Mixed sand	Green
3	3.1	1148	Siltstone	Blue
4	5.2	627	Sand	Light blue
5	9.2	3501	Sandstone	Blue
6	16.1	16470	Sand stone/Ironstone**	Red
7	34.3	9808	Sandstone	Red
8	50.0	2901	Shale-Siltstone	Yellow
9	82	1281	Sand –Siltstone	Light green
10	220	804	Prospective unit	Blue

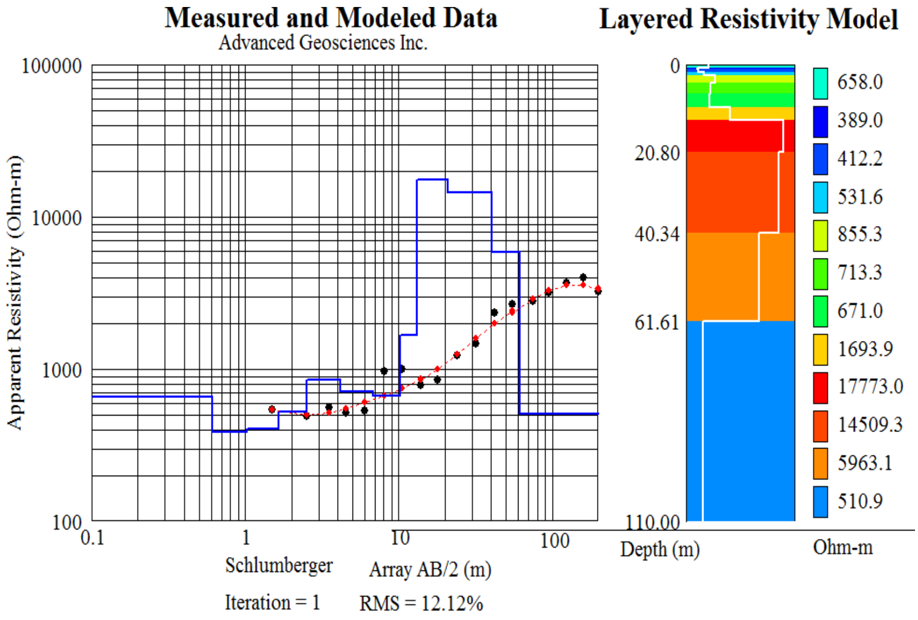


Figure 11: VES model result of UturuIsukwuato

Table 5: UturuIsukwuato Analytical result

Layer	Depth (m)	Resistivity (Ohm-m)	Lithology	Color
1	0.6	657	Topsoil	Mixed blue
2	2.5	531	Sand	Blue
3	6.7	713	Silty sand	Green
4	10.1	670	Sandy clay	Green
5	13.1	1693	Siltstone	Yellow
6	20.7	17772	Sandstone/Ironstone**	Red
7	40.3	14509	Shale-sandstone	Red
8	61.6	5963	Sandstone	Off Red
9	>110	510.9	Shale-Sand (prospective)	Blue

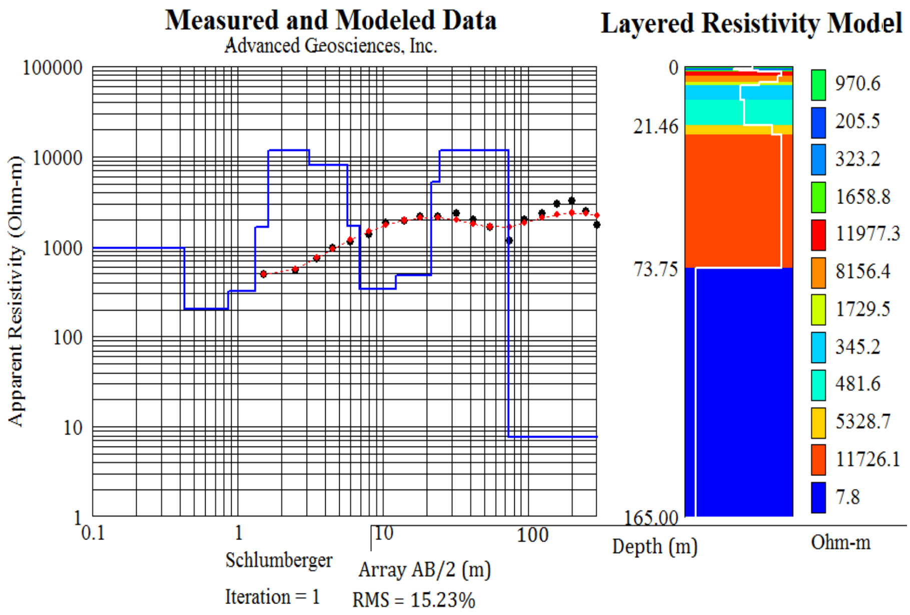


Figure 12: VES model result of Anglican Hostel Okigwe

Table 6: Anglican Hostel Okigwe Analytical result

Layer	Depth (m)	Resistivity (Ohm-m)	Lithology	Color
1	0.4	970.6	Topsoil	Mixed Green
2	2.3	11977	Ironstone-sandstone**	Red
3	4.6	8156.4	Shale	Red-Brown
4	6.9	1729.5	Siltstone	Orange
5	12.3	345	Sand	Blue
6	21.4	481.6	Sand	Light blue
7	24.7	5328.7	Sandstone	Yellow
8	73.7	11726	Shale-sandstone	Red
9	>165	7.8	Prospective sand unit *	Blue

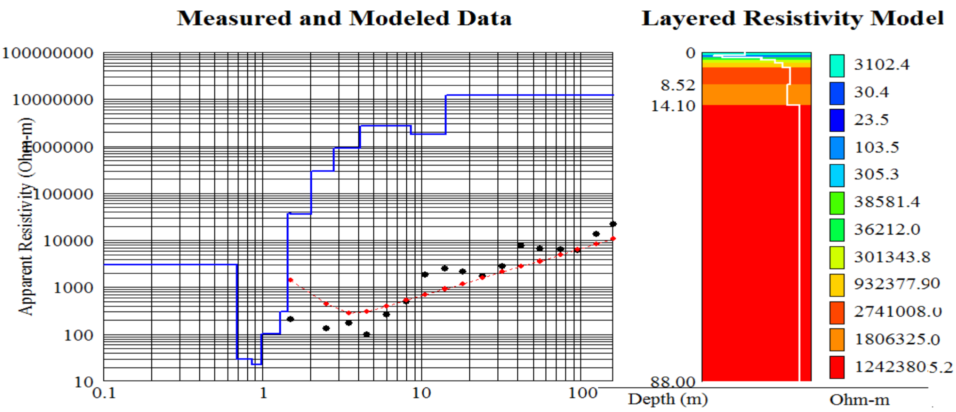


Figure 13: Modelled result for VES location at LekwesiUmunneochi

Table 7: Lekwesi VES analytical result

Prospect Layer	Thickness (m)	T. Depth (m)	B. Depth (m)	Ohm-m	Rock type	Color
1	4.5	4.0	8.5	2741008	Diabase	Red
2	5.5	8.5	14.1	1806325	Quartzite	Off-Red
3	---	14.1	>88	12423805	Ironstone	Red

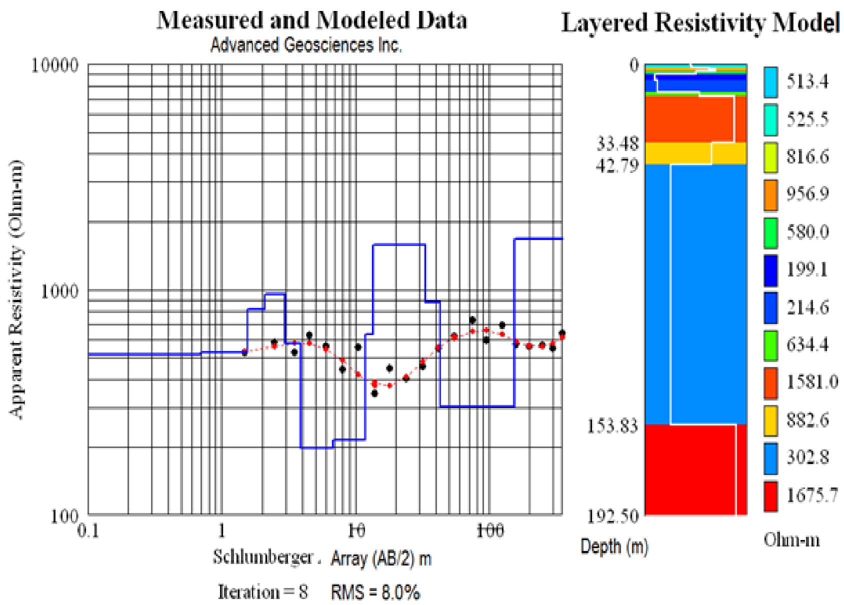


Figure 14: VES model result of IhiteLokpantaUmunneochi

Table 8: VES analytical result of IhiteLokpantaUmunneochi

Layer	Depth (m)	Resistivity (Ohm-m)	Lithology	Color
1	0.69	513.4	Topsoil	Mixed Blue
2	3.0	956.9	Sandstone/Ironstone	Red
3	6.8	199.1	Clay	Blue
4	11.9	214.6	Sandy clay	Blue
5	33.5	1581	Shale-sandstone	Red
6	42.8	882.6	Siltstone	Yellow
7	153.8	302.8	Clay – Sand (Prospective)	Blue
8	>192	1675.7	Shale-sandstone	Red

Table 9: Summary of Geoelectrical results

S/No	VES Location	Lat. N (Degree)	Long. E (Degree)	Elevation (ft)	Resistivity (Ωm)	Depth to Top Layer (m)	Thickness (m)
1	AmudaIsuochi	5.9916	7.3897	1035	5278.00	3.00-8.00	5.00
2	Anglican Hostel Okigwe	5.8252	7.3392	546	11977.00	0.40-4.00	5.20
3	ObiohaEzinachiOkigwe	5.7496	7.3472	404	9606.00	1.80-2.80	1.00
4	IhuraAgbobu	5.8476	7.2651	416	-	-	-
5	LekwesiUmunneochi	5.9614	7.4627	403	-	-	-
6	ObiohiaNdiawaIsuochi	5.8662	7.4170	445	16470.00	9.20-16.10	6.90
7	IhiteLokpantaUmunneochi	5.7873	7.4584	361	9569.00	0.69-3.00	2.31
8	ObiaguUkwuLokpanta	5.8289	7.4162	503	181215.80	0.60-11.40	10.80
9	St.Vincent Cathedral Church UmuowaIbuOkigwe	5.8790	7.3408	468	20060.00	0.40-1.00	0.60
10	OpeOkigwe	7.9700	7.4001	670	7417.00	1.50-4.50	3.00
11	AmaguOkigwe	5.9720	7.4127	1270	13190.94	13.00-51.00	38.00
12	UturuIsukwuato	5.8304	7.4201	487	17772.00	13.00-20.00	7.00
13	NgodoIsuochi	5.9704	7.3896	1072	5434.70	1.00-6.00	5.00

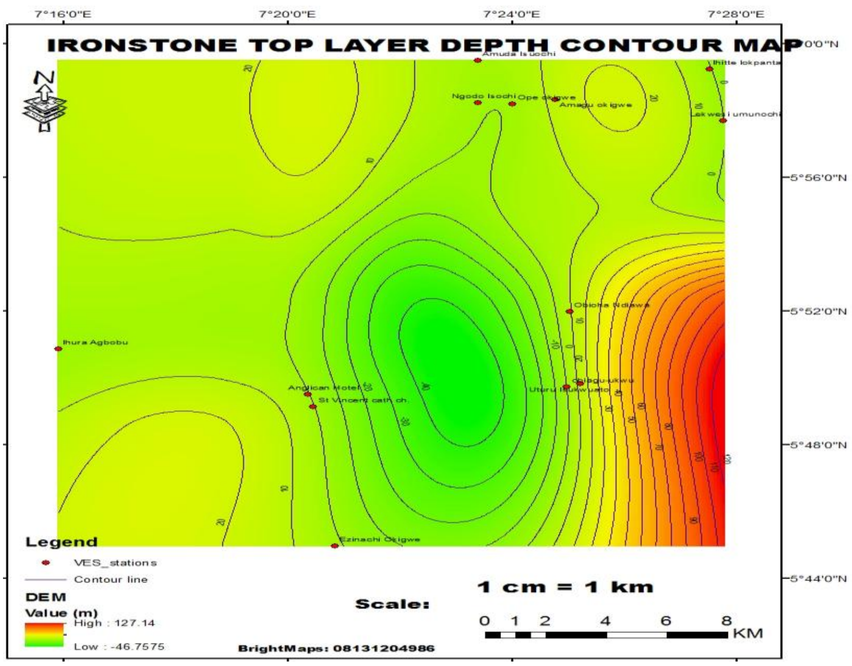


Figure 15: Top layer depth contour map

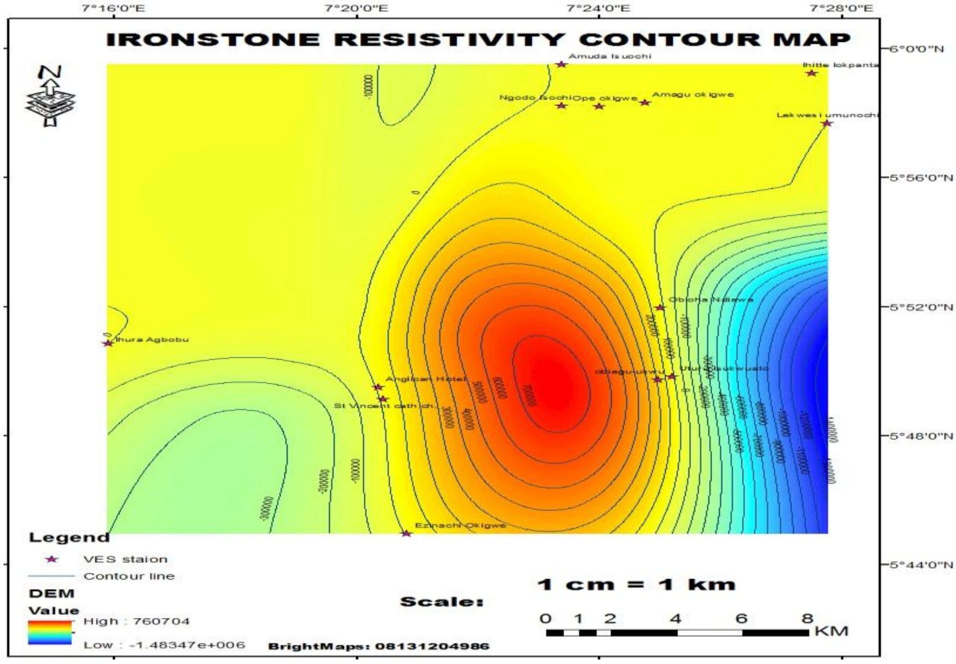


Figure 16: Ironstone resistivity map

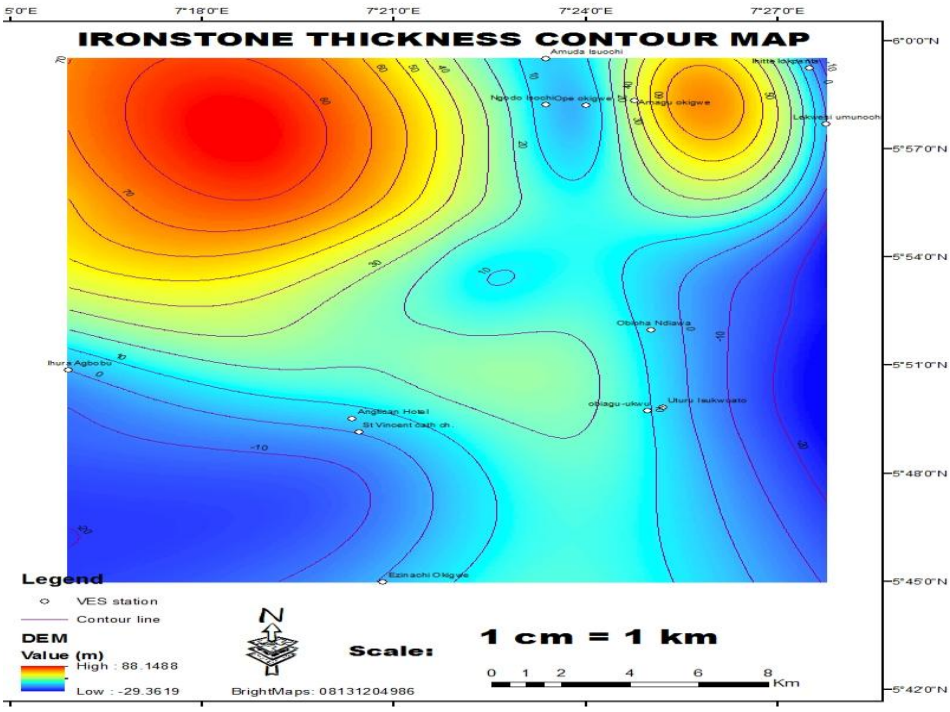


Figure 17: Isopach map of ironstone deposit

Ironstone was mapped out in some communities likeAmagu, ObiaguUkwuLokpanta, NdiawaIsuochi, Uturu, Okigwe and Umunneochi. At Ndiawa and ObiagukwuLokpanta, near surface ironstone deposites was mapped out with outcrops observed (Figs 9 and 10). At Umunneochi, the modeled result showed that almost the depth probed is composed of Ironstone (Fig. 13). However, there is no ironstone occurrence observed at VES number 4 and 5 located at IhuraAgbobu and LekwesiUmunneoch (Table 9).

The lateral profiling model result showed a lateral spread of ironstone deposits of 3 m to 33 m for P1 profile (Fig. 7) and 19 m to 25 m for P2 profile (Fig. 8). Generally, the study area is underlain by multi-geoelectric layers with the ironstone layer having highest resistivity values at each VES station. This is expected as resistivity of soil and rock materials increases as the degree of consolidation increases. Ironstone occurred within the 9th and 10th geoelectric layers at Amagu local mining site in Okigwe (Table 2) with resistivity values ranging from 13190.94 to 15325.28Ωm at a depth of approximately 21m. At ObiaguUkwuLokpanta, ironstone occurred within the 2nd to the 3rd geoelectric layers (Fig 4 and Table 3) with resistivity values ranging from 396931.9 to 181215.8Ωm at a depth beyond 1m. At ObiohaNdiawaIsuochi and UturuIsukwuato (Table 4 and 5), the ironstone occurred at the 6th geoelectric layer with resistivity values of 16470Ωm and 17772Ωm respectively. Thus, the resistivity of the ironstone layer varies with depth across the study area.

The variation of depth to top layer of ironstone deposits in the study area is shown by the contour map(Fig. 15). Shallow deposits occur in the central area while deeper deposits were observed in other areas with the deepest deposit recorded in the southeastern part of the study area. Isoresistivity map of ironstone deposit in the study area (Figure 16) shows that the central part has the highest resistivity value as well as the northern part of the study area than the southeastern and southwestern parts. The high resistivity values recorded imply that the ironstone is more consolidated and hence of good quality for use as building and construction material.

The Isopach map (Fig. 17) shows that the northwestern and northeastern parts as well as the central parts are underlain by relatively thick ironstone deposit. Therefore these areas are good prospect for mining. High thickness was recorded at Amagu which has more concentration of ironstone. Observation of high thickness was also made at ObiaguUkwu while medium thickness was recorded in UturuIsukwuato, ObiohiaNdiawa, Anglican Hostel Okigwe, NgodoIsuochi and AmudaIsuochi. Low thickness was noticed in ObiohiaEzinachiOkigwe, IhiteLokpantaUmunneochi, St. Vincent Cath.ChurchUmuowaIbuOkigwe and OpeOkigwe.

Generally, ironstone occurs more in the Northern part of the study area than the Southern part and mostly in the Northwestern part.

4.2. Geotechnical Results

The results of laboratory tests for density and specific gravity of ironstone samples are shown in Tables 10 and 11 respectively while Table 12 gives the summary of geotechnical results obtained for the study area.

Table 10: Bulk Density

S\No	Test Parameter		Result
1	Mass of bottle only (A)	(g)	4450
2	Volum of mould (B)	(cm^3)	939
3	Mass of bottle + Sample (C)	(g)	5944
4	BD $= \frac{(C)-(A)}{(B)}$	(g/cm^3)	1.59

Table 11: Specific gravity

S/No	Test Parameter	Result
1	Mass of Sample + Sample+ Water (M_3) (g)	21.38
2	Mass of bottle + Sample (M_2) (g)	1512
3	Mass of Bottle full of water (M_4) (g)	1456
4	Mass of bottle (M_1) (g)	434
5	$Gs= \frac{(M_{2-M_1})}{(M_4-M_1)-(M_3-M_2)}$	2.72

Table 12: Summary of Geotechnical results compared with other standards

S/No	Geotechnical Property	Quality/Quantity	Classification Standard Compared with	Description/Qualifying
1	Moisture Content	35.8%	Standard specification [16].	Prone to expansion and shrinkage
2	Lithology Field Descripion		Standard specification	
	Colour	Reddish brown		
	Texture	Fine/medium/coarse	[17]	Ironstone

	Soil type	grain Ironstone		
3	Bulk Density	1.59g/cm^3	Standard Specification [18]	Presence of Sand, Silt and Clay
4	Specific gravity	2.72	Typical values of soil specific gravity [19]	Presence of Inorganic clay and silt
5	Compaction		Standard specification for soil classification [20]	Presence of Silt, sand, gravel (A-2) Good material
	Maximum Dry Density (MDD)	2.06g/cm^3		
	Optimum Moisture Content (OMC)	10%		

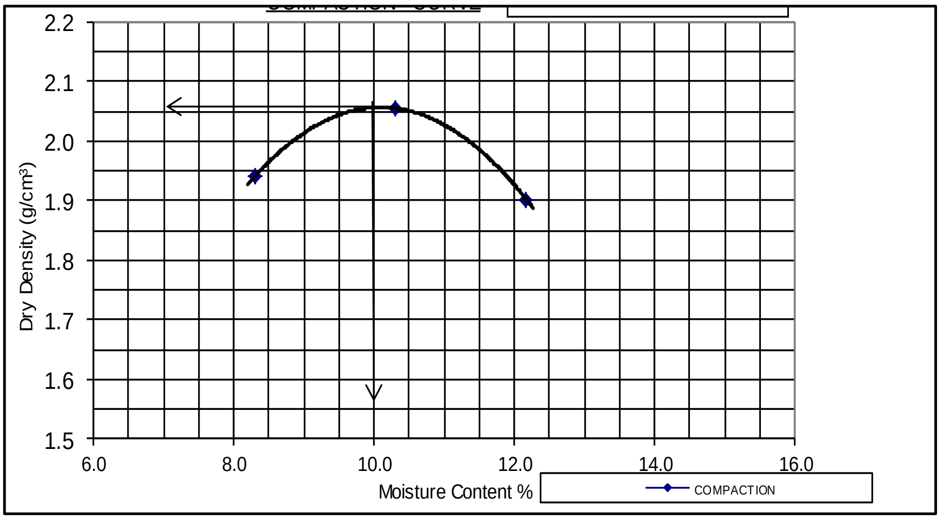


Figure 18: Graph of dry density against moisture content (Compaction curve)
MDD=2.06g/cm^3; OMC=10.0%

The moisture content ranges from 35.7% to 35.9% with an average value of 35.8. This value could be due to the presence of clay minerals that hold water. The percentage of water present in any earth material can determine the strength of the material. The large value of water content in the sample indicates that the sample will be prone to expansion and shrinkage when water is expelled from its pore spaces [20], since using this material could lead to cracks which will easily promote early failure of roads due to its ability to expand mainly in the dry season [22]. Hence there is need to fortify the foundation of buildings by addition of appropriate amount of cement and other building materials such as chippings.

The bulk density of the ironstone is 1.59g/cm^3 (Table 10). This is also referred to as total density, which includes, the solid particle, the void and water. This sample can also be classified as silt, clay and sand material [18].

Specific gravity

The laboratory test result displayed in Table 11 shows a specific gravity value of 2.72. Specific gravity varies according to soil type. The Standard range of specific gravity for soil is between 2.60 and 2.80 [21]. The value of specific gravity of the sample falls between 2.68 – 2.72 and so can be classified as inorganic clay and silt. Thus the sample is impervious and can be used as material for erosion resistant in canal construction [19]. Hence, the ironstone in the study area can be comfortably used in road construction and maintenance in cases of failure.

Compaction Test

The results displayed in Table 12 and Figure 18 show that the ironstone sample has Maximum Dry Density (MDD) value of 2.06mg/m^3 with an Optimum Moisture Content (OMC) of 10%. These values agree with the standard specifications for building of roads and bridges. The Federal Ministry of Works and Housing specification for building of Roads and Bridges, recommends values between 1.75 and 2.165mg/m^3[23] [24]. Hence, based on [9] the soil classification under A-2 [9], the ironstone deposit in the study area is good to be used as pavement material. In Nigeria, the Federal Ministry of Works and Housing, recommends that for a material to be used generally as fills, it should possess MDD greater than 0.0047 mg/m^3 and OMC less than 18%. Therefore the results of this study are very reliable.

4.3. Determination of the Area of the Mining Site, Volume and Mass of Ironstone Reserve

Applying equations 1, 2 and 3 under section 3.3, the area of the ironstone local mining site was calculated to be 180m^2 , the Volume of the Ironstone reserve is 12960m^3 and Mass of the ironstone reserve is estimated to be 2×10^7kg.

5. Conclusion

The combined electrical resistivity and geotechnical methods in this study have been effectively used to evaluate the ironstone occurrence in the study area. The results were able to identify potential sites for commercial mining of ironstone for building and construction. These sites include AmaguOkigwe, ObiaguUkwuLokpanta and UturuIsukwuato. Assessment of the suitability of the ironstone as building and construction material based on the geotechnical parameters determined showed that the deposit is of good grade and fit for building and construction.

Acknowledgement

We are grateful to GEOPROBE International consultancy limited for providing the instrumentation and crew during the field work. We are also grateful to Bough Resources Nigeria Limited for granting us access to their geotechnical laboratory which enabled us to characterize the ironstone samples.

References

[1]. Nwachukwu, M.A., Nwosu L.I., Uzoije P.A. and Nwoko C.A. (2017). 1D Resistivity Inversion Technique in the Mapping of Igneous Intrusives; A Step To Sustainable Quarry Development. *Journal of Sustainable mining*, Vol 16, pp 127 – 138.

[2]. Meju, M. (2006). Geoelectric Characterization of Covered Landfill Site: A process oriented model and investigation approach. *In applied hydro geophysics, H. Verecken et al., eds. Springer, Dordrecht, the Netherland*, pp.319-339.

[3]. Oghonyon, R. and Ekeocha, N.E (2015). The Geotechnical index properties of soil in Warri, Delta State, Nigeria. *International Journal of science Inventions today*. Vol 4(1), pp 085-091.

[4]. Adejumo, S.A, Oyerinde, A.O. and Aleem M.O. (2015). Integrated Geophysical and Geotechnical subsoil Evaluation for Pre-foundation Study of Proposed Site of Vocational Skill and Entrepreneurship center at the Polytechnic, Ibadan, Sw, Nigeria. *International Journal of Scientific and Engineering Research*, Vol. 6(6), pp 910-917.

[5]. Nwosu, L.I., Emujakporue, G.O. and Nwosu, B.O. (2017). Integration of Geoelectrical and Geotechnical Data for Evaluation of the Structural Disposition of the foundation Beds within the University of Port Harcourt, Nigeria. *International Journal of Science and Research Methodology*. Vol. 5(4), pp 95-110.

[6]. Adepelumi, A.A. and Olurunfemi, M.O. (2000). Engineering Geological and Geophysical investigation of the Reclaimed Lekki Peninsula, Lagos, South Western Nigeria. *Bull. Eng. And Env*. Pp. 125-131.

[7]. AASHTO. (2008). Standard specification for classification of soils and soil- Aggregate mixture for High way construction purposes, AASHTO.

[8]. Akintorinwa, O.J. and Adeusi, F.A. (2009). Integration of Geophysical and Geotechnical Investigation for a Proposed Lecture Room Complex at the Federal University of Technology, Akure, Sw, Nigeria. *Ozean Journal of Applied Sciences* Vol. 2(3), pp 241-254.

[9]. Aghamelu, O.P. and Okogbue, O.C. (2011). Geotechnical Assessment of Road Failures in the Abakiliki Area, South Eastern Nigeria. *International Journal of civil and Environmental Engineering*, Vol. 11(2), pp 12-19.

[10]. Onunkwo, A.A., Uzoije, A.P, Onyekuru, S.O. (2014). Engineering properties and uses of Soil Derive from MaastritchianAjali Formation in a Part of SE Nigeria. British *Journal of Environmental Sciences.* Vol 2(4). Pp 11-28.

[11]. Mbonu, P.D.C., Ebeniro, J.O., Ofoegbu, C.O. and Ekine, A.S. (1990). Geoelectric Sounding for the Determination of Aquifer Characteristics in Parts of the Umuahia Area of Ngeria. *Geophysics Journal*. Vol. 56(2), pp 284-291.

[12]. Nwosu, L.I., Nwankwo, C.N. and Ekine, A.S. (2013). Geoelectric Investigation of the Hydraulic Properties of the Aquiferous zones for Evaluation of Groundwater Potentials in the complex Geological Area of Imo State, Nigeria. *Asian Journal of Earth Sciences*. Vol. 6(1), pp 1-15.

[13]. Kogbe, C.A. (1989). *Geology of Nigeria*. 2nd revised edition. Rock view (Nigeria) Limited Jos, Nigeria. Pp 325-333.

[14]. Nwachukwu, M.A., Huan, F. and Ophori, D. (2010). Groundwater Flow Model and Particle Track Analysis for Selecting Water Quality Monitoring Well Sites, and Soil Sampling Profiles. *Journal of Spatial Hydrology*. Vol. 10(1): 23-34.

[15]. Vingoe, P. (1972). *Electrical resistivity Survey*, ABEM geophysics and electronics. Geophysical Memorandum. Vol 5(72), pp 1-15.

[16]. Oghonyon, R., Adeniran, A. and Opaimi, I. (2015). Geotechnical attributes of Niger Delta Soils, Warri Environs, Nigeria. *International Journal of Science Inventions Today*, 4(2), pp 213-225.

[17]. British Standard institution (BSI) 1377 (1990)."*Methods of testing Soils for civil engineering purposes*". British Standards institution, London.

[18]. U.S. Department of Agriculture (USDA). (1951). Soil survey manual, USDA Agriculture Handbook No. 18, US. Gorvernment printing office. Washington, DC.

[19]. Bowles, J.E. (1990). Physical and Geotechnical Properties of soil. (2nd ed). McGraw-Hill, inc. Pp 478.

[20]. AASHTO. (2008). Standard specification for classification of soils and soil- Aggregate mixture for High way construction purposes, AASHTO.

[21]. Wright, P.H. (1986). *Highway Engineering* sixth Edition John Willey and Sons: New York, NY.

[22]. Rogers, D.J., Oslshanky, R. and Rogers, R.B. (1993). Damage to Foundations from Expansive Soils Claims People.Vol3(4) p1-4

[23]. O'Flaherty, C.A. (1988). Highway Engineering vol.2, Edward Amold Publishers, London UK. of Petroleum Geologists Bulletin, Vol. 51, pp. 761-779.

[24]. Federal Ministry of works and Housing (1972). "General Specifications for roads and bridges. Volume 2, Federal Highway Department, FMH: Lagos Nigeria.