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Spatial variation and thickness determination of clay deposit using geo-electrical method at omi-adio, Ibadan, Southwestern Nigeria

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ABSTRACT

A geo-electric survey involving vertical electric sounding (VES) was carried out at the Nigeria Mining Corporation‘s quarry at Omi-adio near Ibadan Southwestern Nigeria, with a view to determinning the thickness and spatial variation of the clay deposit in the study area. Twenty VES were carried out in four traverses using a Geopulse Tigre terrameter within the vicinity of the study area with each traverse having four to six VES points. Quantitative interpretation of the data involved partial curve matching and computer assisted iteration method. A 3D contour map showing the variation of clay resistivity and thickness was also plotted. The results show that the deposit is made up of four lithological layers namely top soil, sandy clay, clay and weathered/fresh basement. The resistivity curves fall into five categories HA type (i.e. $\rho_1 > \rho_2 < \rho_3 < \rho_4$) KH type (i.e. $\rho_1 < \rho_2 > \rho_3 < \rho_4$), QH type (i.e. $\rho_1 > \rho_2 > \rho_3 < \rho_4$), A type (i.e. $\rho_1 < \rho_2 < \rho_3$), H type (i.e. $\rho_1 > \rho_2 < \rho_3$) with KH type dominant. Also the Geoelectric section shows that the top soil has resistivity between 11.5Ωm and 155.6Ωm and thickness between 0.7m and 3.8m. The sandy clay layer has thickness between 0.2m and 4.0m and resistivity between 71.5Ωm and 278.8Ωm. The clay layer has resistivity between 7.7Ωm and 33.5Ωm and thickness between 4.8Ωm and 31.0Ωm while the fresh/weathered basement has resistivity between 46.3Ωm and 871.7Ωm.The depth to bedrock is between 6.2m and 32.9m.The coefficients of anisotropy fall between 1.01 and 1.76 suggesting the presence of good quality clay.

1.0 Introduction

Clay is widely found and distributed in Nigeria. However, it is not always found in sufficient quantity or suitable quality for modern industrial purposes. Because of the many uses of clay in our society, there is an increasing need for better geologic and mineralogical data on industrial minerals. The electrical resistivity technique is best adapted for determining depth and resistivity of layered rock structures, sedimentary beds and aquifer depth because of its liability and accuracy [9]. This work focuses on the application of the electrical resistivity technique in determining the thickness and spatial variation of clay deposits in Omi Adio.

Clays and clay minerals have been mined since the Stone Age, today they are among the most important minerals used by manufacturing and environmental industries. The term “clay” is applied both to materials having a particle size of less than 2 micrometers and to the family of minerals that has similar chemical compositions and common crystal structural characteristics [12]. Clay occurs as sedimentary clay, primary clay produced by chemical weathering of the parent rock or as secondary clay transported from their point of origin. Clays and clay minerals are found mainly on or near the surface of the Earth. Clays and clay minerals occur under a fairly limited range of geologic conditions. The environments of formation include soil horizons, continental and marine sediments, geothermal fields, volcanic deposits, and weathering rock formations. Most clay minerals form where rocks are in contact with water, air, or steam. Examples of these situations include weathering boulders on a hillside, sediments on sea or lake bottoms, deeply buried sediments containing pore water, and rocks in contact with water heated by magma (molten rock). All of these environments may cause the formation of clay minerals from pre-existing minerals. Extensive alteration of rocks to clay minerals can produce relatively pure clay deposits that are of economic interest (for example, bentonites—primarily montmorillonite used for drilling muds and clays used in ceramics). Clay products derived from the weathering and hydrothermal reactions of rocks are a versatile industrial material that has amazing variety of uses and applications. They have found acceptance in ceramics porcelain, dinner wares, architectural tiles and enamel. Important uses have also been found for clay in petroleum cracking, cosmetic base and digestive coating remedy, paper, chalk, agro-allied and pharmaceutical industries. It has an appreciable applicability in the rubber industry where its reinforcing potential has been exploited since the early part of this century, particularly those with tolerable presence of silica (which serves as a reinforcing component in rubber compounding). In most third world countries like Nigeria clay products are imported whereas, clay deposits abound, but

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there is paucity of information about their potential. As a result of the usefulness of clay both at home and industries, this research becomes necessary at determining the existence, quality and quantities of clay deposits in Omi-Adio. In this research, the electrical method of geophysical survey was used. The electrical resistivity method is useful in depth to bedrock determination, structural mapping, determination of nature of superficial deposits etc. [1, 8]. It is very useful in groundwater quality study and mineral exploration, [1] used the method to investigate the reserve of kaolin deposit as well as the excavate overburden of the mineral. [5] used the vertical electrical sounding (VES) method to study kaolin deposit in Ozanogogo area in Ika South Area of Delta State. Several authors have carried out investigations on clay minerals [2]. The geological setting of the kaolin deposits in lower Cretaceous fluvial Chaswood formation, Nova Scotia, was interpreted from high resolution seismic-reflection profiles and boreholes, and mineralogical studies on one reference borehole [6].

For example, [2] carried out mineralogical analyses of primary clay deposits from seven localities representing different rocks in the Nigerian Basement Complex and found that the deposits that weathered from granites, gneisses, pegmatites and schists consisted mainly of kaolinite and trace proportions of montmorillonite and illitewhile deposits weathered from calc-silicate rocks contained high proportions of montmorillonite. Many sedimentary deposits have also been investigated in some detail e.g the Iguoba clay and Sokoto clay shales [10, 11] and the Ubulu-Uku clay [11].

By the 1970s, the clay minerals began to be widely studied for diagenesis and reservoir quality prediction due to the application of petrological analysis and quantitative mineralogical analysis by X-ray diffraction [3]. Since 1980s, the clay minerals analysis has been used to determine the hydrocarbon emplacement time and petroleum system analysis [7]. These intermittent clay minerals research progresses are the result of exploration demands of conventional reservoirs (sandstone and carbonate rocks) at different times.

2.0 Methodology

2.1 Geology and location of the study area

The sites is within the basement complex of south western Nigeria which is Precambrian to lower Palaeozoic age. The major rock types include granite, gneiss, schist and meta sediments. These rocks are characterized by low porosities and negligible permeability. The study area lies between latitudes 7°23ˈ58.7" and 7°24ˈ0.7" and longitudes 3°44ˈ51.0" and 3°44ˈ53.6" (Figure 1)

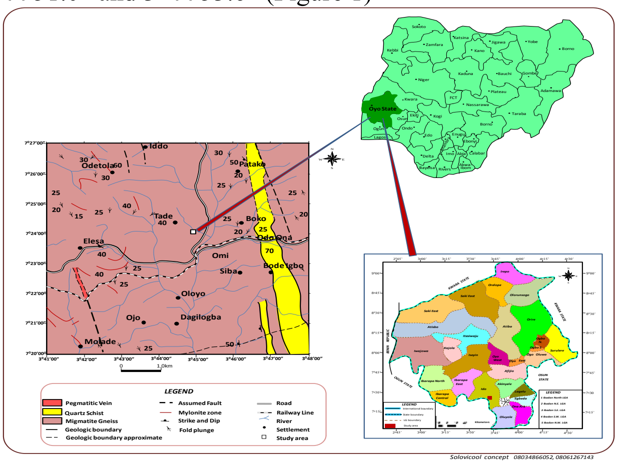

Figure 1. Geological Map showing the location of study area.

2.2 The Electrical survey and data acquisition

The instruments used in the survey include Geopulse Tigre resistivity metre, Batteries, Graduated tape rule, Electric cables, Electrodes, GPS metre and Clips. A total of twenty (20) VES were carried out in the study area (Figure 2). The elevation measurements of the area were made using a Global Positioning System (GPS), with a view to determine the spatial distribution of the rock mass. The GPS was also used in the location of the VES centre points. The field data were interpreted qualitatively using simple curve shape, semi-quantitatively using graphical model curves or quantitatively with computer models. The results obtained from the partial curve matching were processed using Winresist software. This was also used to produce smooth 1D model curve for each VES stations, contour maps and geo-electrical sections (Figures 4-16) using Surfer 9 software.

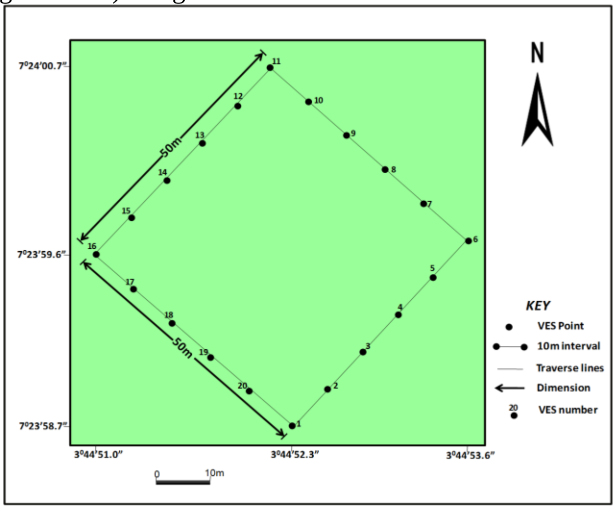

Figure 2. Location Map of the study area showing VES stations and layout.

2.3 Theory of Resistivity

The purpose of electrical surveys is to determine the subsurface resistivity distribution by making measurements on the ground surface. From these measurements, the true resistivity of the subsurface can be estimated. The ground resistivity is related to various geological parameters such as the mineral and fluid content, porosity and degree of water saturation in the rock. The fundamental physical law used in resistivity surveys is Ohm's Law that governs the flow of current in the ground. The equation for Ohm's Law in vector form for current flow in a continuous medium is given by:

$$J = \sigma E \quad (1)$$

where σ is the conductivity of the medium, J is the current density and E is the electric field intensity. In practice, what is measured is the electric field potential. We note that in geophysical surveys the medium resistivity ρ, which is equal to the reciprocal of the conductivity ($\rho = \frac{1}{\sigma}$) is commonly used. The resistivity of a material is defined as the resistance in ohms between the opposite faces of a unit cube of the material. The relationship between the electric potential and the field intensity is given by:

$$E = -\nabla\Phi \quad (2)$$

Combining equations (1) and (2), we get:

$$J = -\sigma\nabla\Phi \quad (3)$$

In almost all surveys, the current sources are in the form of point sources. In this case, over an elemental volume ΔV

surrounding the current source I, located at (x_s, y_s, z_s) the relationship between the current density and the current [4] is given by:

$$\nabla.\mathrm{J} = \left(\frac{1}{\Delta V}\right)\delta(x-x_s)\delta(y-y_s)\delta(z-z_s) \quad (4)$$

Where δ is the Dirac delta function. Equation (3) can then be rewritten as:

$$-\nabla.[\sigma(x,y,z)\nabla\phi(x,y,z)] = \left(\frac{1}{\Delta V}\right)\delta(x-x_s)\delta(y-y_s)\delta(z-z_s) \quad (5)$$

This is the basic equation that gives the potential distribution in the ground due to a point current source. A large number of techniques have been developed to solve this equation. Fully analytical methods have been used for simple cases, such as a sphere in a homogenous medium or a vertical fault between two areas each with a constant resistivity.

2.4 General Electrode configuration

In all surveys, the potential difference between two points (normally on the ground surface) is measured. A typical arrangement with 4 electrodes is shown in Figure 3.

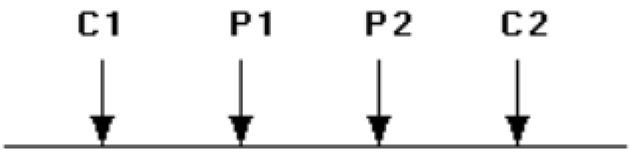

Figure 3. General Electrode configuration.

The potential difference is then given by:

$$\Delta\phi = \frac{\rho I}{2\pi}\left(\frac{1}{r_{c1p1}} - \frac{1}{r_{c2p1}} - \frac{1}{r_{c1p2}} + \frac{1}{r_{c2p2}}\right) \quad (6)$$

The above equation gives the potential that would be measured over a homogenous half space with a 4 electrodes array. Actual field surveys are invariably conducted over an inhomogenous medium where the subsurface resistivity has a 3-D distribution. The resistivity measurements are still made by injecting current into the ground through the two current electrodes (C1 and C2 in Figure 2), and measuring the resulting voltage difference at two potential electrodes (P1 and P2). From the current (I) and potential ($\Delta\phi$) values, an apparent resistivity (ρ_a) value is calculated.

$$\rho_a = k\frac{\Delta\phi}{I} \quad (7)$$

$$k = \frac{2\pi}{\frac{1}{r_{c1p1}} - \frac{1}{r_{c1p2}} - \frac{1}{r_{c2p1}} + \frac{1}{r_{c2p2}}} \quad (8)$$

k is a geometric factor that depends on the arrangement of the four electrodes. Resistivity measuring instruments normally give a resistance value, R =$\Delta\phi$/I, so in practice the apparent resistivity value is calculated by:

$$\rho_a = \mathrm{k\,R} \quad (9)$$

The calculated resistivity value is not the true resistivity of the subsurface, but an "apparent" value, that is the resistivity of a homogeneous ground that will give the same resistance value for the same electrode arrangement. The relationship between the "apparent" resistivity and the "true" resistivity is a complex relationship. To determine the true subsurface resistivity from the apparent resistivity values is called "inversion".

2.5 Vertical electrical sounding (VES) and Special electrode Configurations

As the distance between the current electrodes is increased, so the depth to which the current penetrates is increased. In the case of the dipole-dipole array, increased depth penetration is obtained by increasing the inter-dipole separation, not by lengthening the current electrode dipole. The position of measurement is taken as the midpoint of the electrode array. For a depth sounding, measurements of the resistance R are made at the shortest electrode separation and then at progressively larger spacing. At each electrode separation, a value of apparent resistivity ρ is calculated using the measured resistance in conjugation with the appropriate geometric factor for the electrode configuration and separation being used. The values of apparent resistivity are plotted on a graph the x- and y-axes of which represent the logarithmic values of the current electrode half-separation (AB/2) and the apparent resistivity ρ respectively. To interpret the data it is assumed that the subsurface consists of horizontal layers. Here, the subsurface resistivity changes only with depth but does not change in the horizontal direction. A number of different configurations are used for current and potential electrodes. The current electrodes are generally but not always placed on the outside of the potential electrode. These configurations are such that the general formula for the resistivity measured is simplified.

3.0 Results and Discussion

The results obtained from the preliminary interpretation served as initial estimates of the resistivity and thickness of the subsurface structure, which served as starting models for a computer-assisted interpretation. The results of the inversion of the field data and graphs obtained from the computer modelling technique were presented (Figures 4-16). It was observed that the starting apparent resistivities in the study area are low. This is due to the level of excavation in the area. Also it is observed that the curve types fall into five (5) categories summarised as follows:

i. HA curves (i.e. $\rho_1 > \rho_2 < \rho_3 < \rho_4$) which includes VES 2 and 3.

ii. KH curves (i.e. $\rho_1 < \rho_2 > \rho_3 < \rho_4$) which includes VES 5-12 and 15-20.

iii. QH curves (i.e. $\rho_1 > \rho_2 > \rho_3 < \rho_4$) which includes VES 13 and 14.

iv. A curve (i.e. $\rho_1 < \rho_2 < \rho_3$) which include VES 4.

v. H curve (i.e. $\rho_1 > \rho_2 < \rho_3$) which include VES 1.

Based on these results, four distinct geologic layers were identified namely: top soil, sandy clay, clay and fresh/weathered basement.

3.1 Geo-electrical Sections

3.1.1 Geo-electrical section of Traverse 1

This geo-electric section includes VES 1 to VES 6. The VES 1-4 are three-layered structures while VES 5 and 6 are four-layered structures (Figure 4). This geo-electric section consists of clayey top soil, sandy clay, clay and weathered/Fresh basement. The first two layers consist of clay with a mean resistivity of 35.3Ωm and thickness ranging from 2.1m to 21.7m. The resistivity of the third layers of VES 5 and 6 fall within the range for clay and their thickness range from 5.5m and 28.5m respectively. Weathered/Fresh basement constitute the lowest layer.

3.1.2 Geo-electrical section of Traverse 2

This section comprises of VES 6-11 all of which are four-layered structures (Figure 5). The resistivity of the top layer range from 29.6Ωm to 58.2Ωm while the thickness range from 1.0m to 1.4 m. The second layer is predominantly made up of sandy clay with a mean resistivity of 129.4 Ωm and thickness ranging from 0.7m to 3.6m. The third layer has a mean resistivity of 25.5 Ωm and mean thickness of 18.4 m. The lowest layer is made up of weathered/fresh basement with resistivity values ranging from 82.4Ωm to 846.3 Ωm.

3.1.3 Geo-electrical section of Traverse 3

It includes VES 11 to VES 16. This traverse shows a four-layered geologic section (Figure 6). The top layer has resistivity between 29.6Ωm and 278.8 Ωm with thickness between 0.9 m and 1.3 m. The second layer generally has resistivity values higher than the top layer with values between 59.0 Ωm and 278.8 Ωm with an average thickness of 2.0 m. The third layer is essentially clay with average resistivity of 21.3 Ωm and average thickness of 21.9 m. The lowest layers consist of clay, sandy clay and fresh basement with resistivity value ranging from 46.3 Ωm to 871.7 Ωm.

3.1.4 Geo-electrical section of Traverse 4

This geo-electric section consists of VES 16 to VES 20. A four-layer Geo-electric section characterises this profile (Figure 7). The top layer has resistivity between 29.0Ωm and 62.6Ωm and a mean thickness of 0.9m. The second layer is essentially characterised by lower resistivity values ranging from 11.3Ωm to 138.3Ωm. The thickness of this layer is between 0.2 m and 2.8 m. The third layer has the lowest values of resistivity with values between 7.7 Ωm and 19.8 Ωm and a mean thickness of 9.7 m. The resistivity of the lowest layer is between 52.9 Ωm and 290.6 Ωm and consists of clay, sandy clay and weathered/fresh basement.

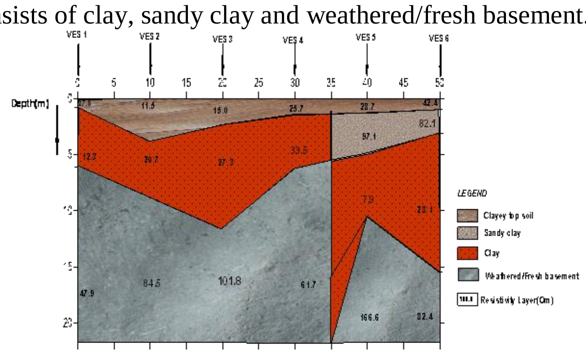

Figure 4. Geo-electric section of traverse 1.

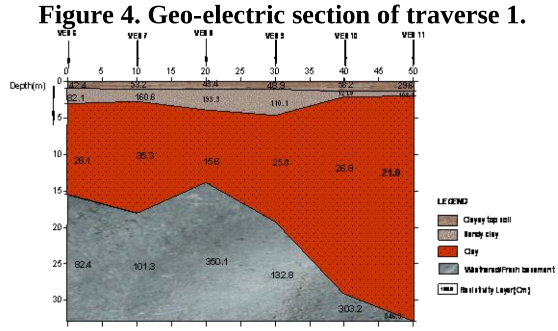

Figure 5. Geo-electric section of traverse 2.

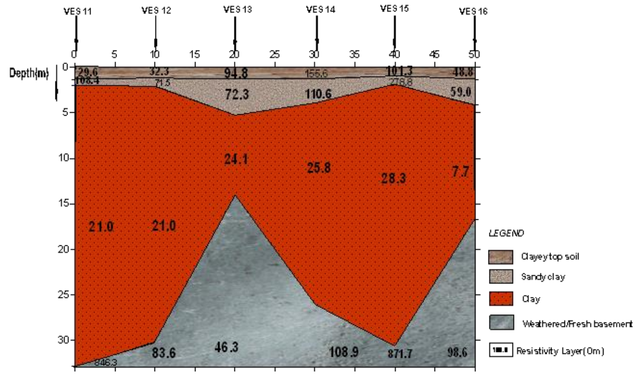

Figure 6. Geo-electric section of traverse 3.

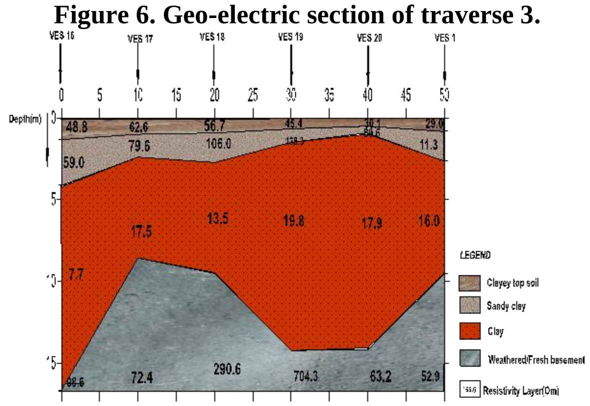

Figure 7. Geo-electric section of traverse 4.

3.2 Contour Mapping of the Clay Distribution

Clay distribution of Omi-Adio area was contoured using Surfer software and two types of contour maps were prepared for this research work. The clay overburden thickness (Figures 8-9) depicts clearly the depth to the kaolin in all the sections. The contour map shows the area of thick overburden/depression, indicated by dense contour closures. The clay thickness map (Figures 8-9) depicted various thicknesses of all sites sounded and revealed capacity of the clay deposit within the area. The resistivity contour map (Figure 8) however, depicted the spatial distribution of resistivity across the study area.

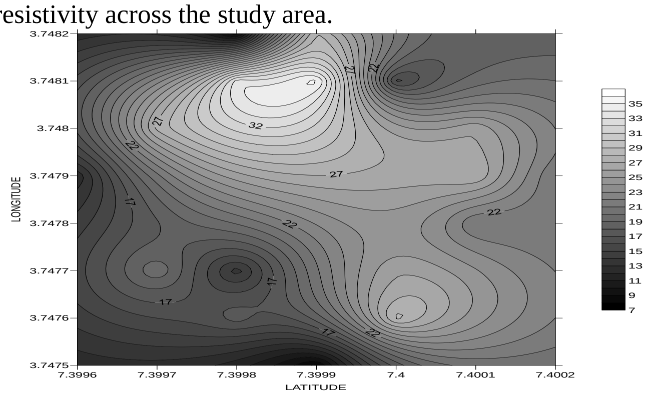

Figure 8. Contour map showing clay resistivity variation (in Ohm-metre) in the study area.

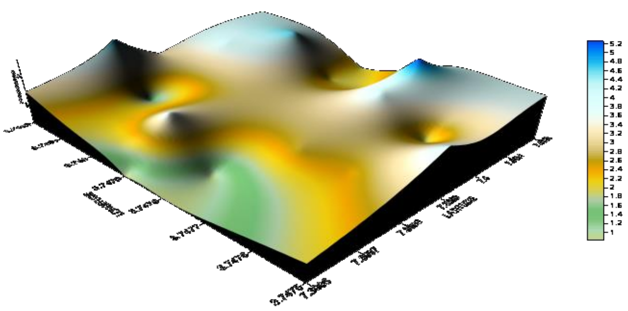

Figure 9. 3D contour map showing overburden thickness (in metres) in the study area.

3.3 Selected Model Curves for the VES Stations

The resistivity for the whole study area ranged from 7.7-846.3 mΩ with thickness ranging from 0.2-31.0 m and depth ranging from 0.7-32.9 m. These characteristic values are attributed to VES 16 (Figure 14) having the lowest resistivity and VES 11 highest resistivity and depth (Figure 13).

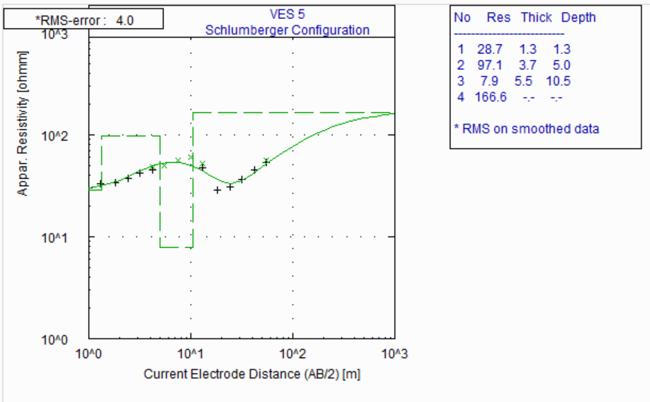

Figure 10. Layer model interpretation of VES 5.

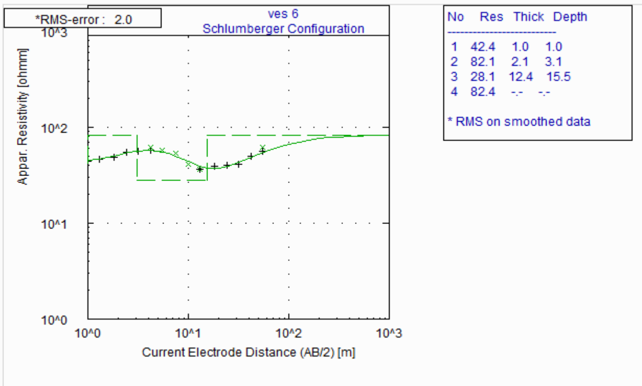

Figure 11. Layer model interpretation of VES 6.

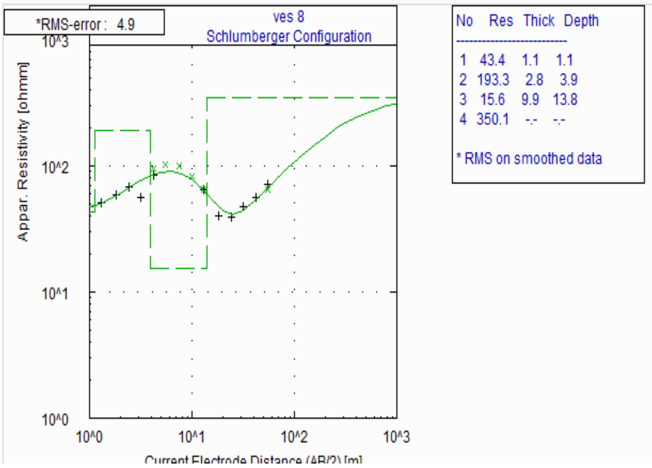

Figure 12. Layer model interpretation of VES 8

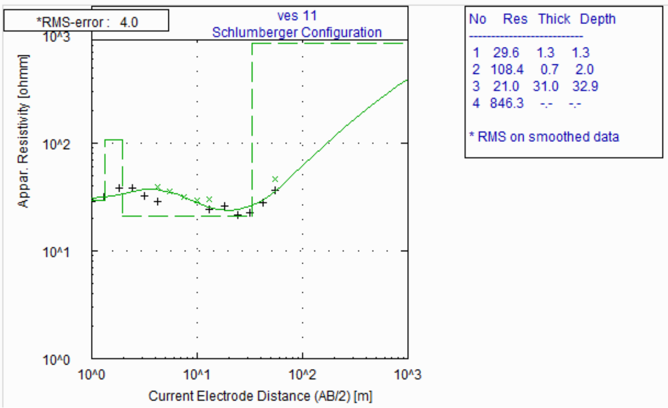

Figure 13. Layer model interpretation of VES 11.

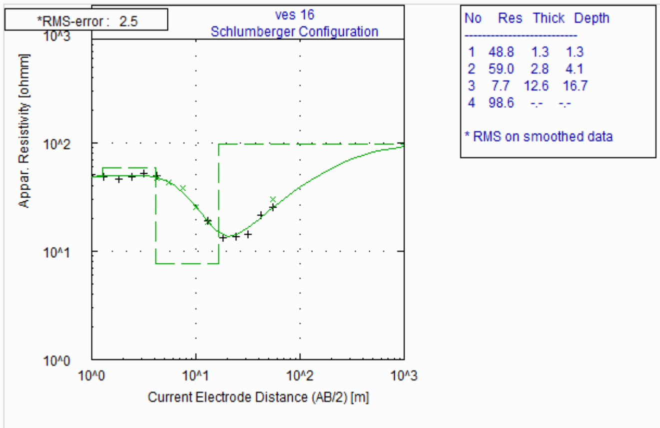

Figure 14. Layer model interpretation of VES 16.

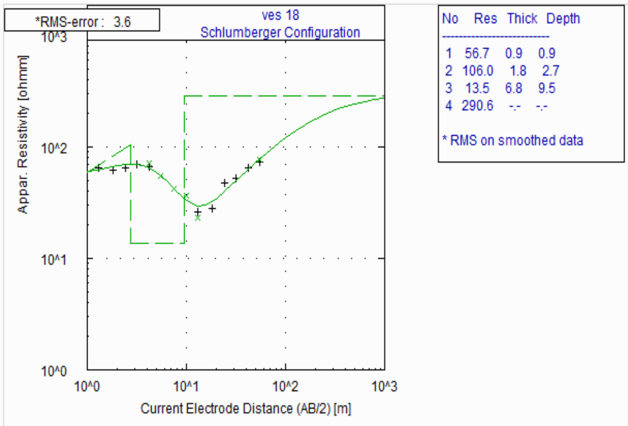

Figure 15. Layer model interpretation of VES 18.

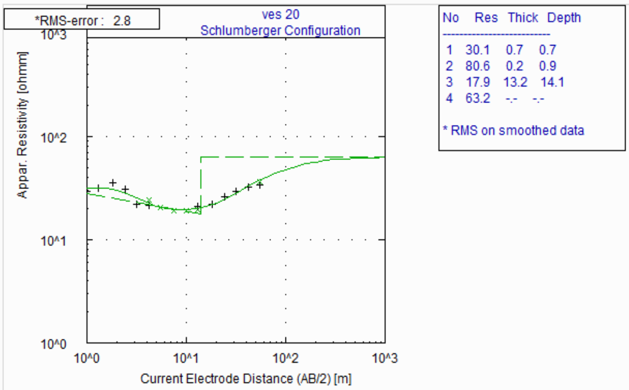

Figure 16. Layer model interpretation of VES 20.

3.4 .1 Total Transverse Resistance

It is represented by T, and defined as the summation of all the products of thickness and resistivity of each layer:

$$T=\sum_i^n (h_i\rho_i) \tag{10}$$

It is measured in Ohm-square metre (Ωm^2) and varies between 153.94Ωm^2 and 1132.08Ωm^2 for the study area.

3.4.2 Total Longitudinal Conductance

It is defined as the summation of the ratio of thickness of each layer to its resistivity. It is given by:

$$S=\sum_i^n \frac{h_i}{\rho_i} \tag{11}$$

Its unit is Siemens. It varies between 0.38339 and 1.71527 Siemens.

3.4.3 Coefficient of Anisotropy

This is expressed as the square root of the product of total transverse resistance across the layering and the total longitudinal conductance parallel to it divided by the thickness of the layer. It is commonly denoted by lambda (λ)

Table 1. Coefficient of Transverse Resistance, Longitudinal Conductance and Anisotropy.

VES no.	Total transverse resistance (Ωm^2)	Total longitudinal conductance(S)	Coefficient of anisotropy
1	97.3	0.52471	1.04
2	492.9	1.37874	1.02
3	351.2	0.57824	1.03
4	196.78	0.19776	1.01
5	440.03	0.77960	1.76
6	563.25	0.49044	1.07
7	871.63	0.46469	1.11
8	743.42	0.67445	1.62
9	824.25	0.61721	1.17
10	898.49	1.04095	1.05
11	765.36	1.52657	1.04
12	704.28	1.38754	1.04
13	622.11	0.43003	1.17
14	1062.6	0.89233	1.18
15	1132.08	1.03296	1.11
16	325.66	1.71046	1.41
17	288.75	0.38339	1.22
18	333.63	0.53656	1.41
19	393.88	0.66262	1.14
20	273.47	0.76317	1.02

where H is the total thickness:

$$\lambda = \frac{\sqrt{TS}}{H} \qquad (12)$$

The λ values for the VES stations range from 1.02 to 1.76. The coefficient of anisotropy is used in determining the quality of the clay. The more λ is closer to one, the better the quality of the clay. The values of the coefficient of anisotropy for the VES stations in the study area are closer to one except VES 5 and VES 8 (Figures 10 and 12). This suggests that the clay is of good quality.

4.0 Conclusion

Vertical Electrical sounding have been applied and established to be a valuable tool for the determination of thickness and spatial variation of clay deposit in Omi-Adio, Ibadan, Southwestern Nigeria. The results obtained showed that the deposit is made up of four (4) lithologic layers namely: clayey top soil, sandy clay, clay and fresh/weathered basement. The resistivity curves were observed to fall into five categories. These are HA type ($\rho_1 > \rho_2 < \rho_3 < \rho_4$) KH type ($\rho_1 < \rho_2 > \rho_3 < \rho_4$), QH type ($\rho_1 > \rho_2 > \rho_3 < \rho_4$), A type ($\rho_1 < \rho_2 < \rho_3$), H type ($\rho_1 > \rho_2 < \rho_3$) curves.

The geo-electric sections also showed that the top soil has resistivity between 11.5 Ωm and 155.6 Ωm and thickness between 0.7 m and 3.8m. The sandy clay layer has thickness between 0.2 m and 4.0 m and resistivity between 71.5 Ωm and 278.8 Ωm. The clay layer has resistivity between 7.7 Ωm and 33.5 Ωm and thickness between 4.8 Ωm and 31.0 Ωm while the fresh/weathered basement has resistivity between 46.3 Ωm and 871.7 Ωm.The depth to bedrock is between 6.2 m and 32.9 m. The total transverse resistance calculated is between 97 Ωm^2 and 1132 Ωm^2, the total longitudinal condictance is between 0.43003 and 1.71046 Siemen while the coefficients of anisotropy is between 1.01 and 1.76.

Taking into account the results of this research, it can be concluded that Omi-Adio area is a prospective source for clay exploitation and excavation.

It is therefore recommended that further investigations should be carried out on the clay deposit to determine the type of clay present in the study area and its industrial applications.

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