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INVESTIGATION OF THE VARIATION IN ELECTRICAL RESISTIVITY VALUES OF EARTH MATERIALS WITH DEPTH AT NARAYI AREA OF KADUNA STATE, NIGERIA

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ABSTRACT

The interpretation of 10 schlumberger vertical sounding (VES) data was carried out at Karji area of Kaduna state, Nigeria. It was an attempt to investigate the variation in the resistivity values of earth materials as it varies with depth within the area. Ohmega Resistivity Terrameter was the principal instrument used. No booster was used as the expected depth is within the range of penetration of the instrument. In this instrument consecutive reading are taken automatically and the result averaged continuously and display. The schlumberger electrode configuration was used in the data acquisition. The field procedure consist of expanding AB (distance between current electrodes) while MN (distance between potential electrodes) is fixed. This process yields a rapidly decreasing potential difference across MN, which eventually exceeded the measuring capacity of the instrument; therefore a larger vale for MN was taken to continue with the survey. The VES curves were interpreted using IP12Win resistivity computer software. The survey area is dominated mainly by four layers, namely; weathered basement, fractured basement and fresh basement. The Topsoil consists of laterites and clay sand with resistivity value of 90-110Ωm from the topsoil to a depth of 10m. The weathered layers constitutes of coarse grain sand with resistivity value of 190-250Ωm at a depth of 10-25m. The fractured layers contains gravels of resistivity value of 500-980Ωm at a depth of 25-44m, while the fresh bedrock is a fresh granitic rock of resistivity value of 1900-4000Ωm.

Keywords: Narayi, Resistivity, Depth, Granite rock

INTRODUCTION

The variation in electrical resistivity values of earth material helps in the determination of soil type within the weathered and fractured layer. The electrical resistivity method employing the vertical electrical sounding (VES) is the method used to determine different earth material which makes interpretation on the log-log graph sheet easier since every earth material has it resistivity value.

The use of vertical electrical sounding (VES) has become very popular with earth materials which are due to simplicity of the techniques. The purpose of electrical resistivity survey method is to detect the surface effect that produce by the flow of electric current inside the earth. These techniques have been used in a wide range of geophysical investigation such as mineral exploration, exploration, investigation, engineering studies, geothermal, archeological permafrost mapping and geological mapping. Electrical method are generally classified according to energy source involve that is either natural source method include self-potential (SP), telluric current and magneto tell-uric while those under artificial source method are resistivity, electromagnetic (EM) and induce polarization (IP) methods. This present research used one of the artificial methods which are the use of electric DC resistivity method using an instrument which were taken using schlumberger array. Vertical electrical sounding (VES) has been put to effective use in many earlier earth material studies and found to be extremely successful. In the present study, the vertical electrical sounding (VES) using schlumberger arrays were carried out. The study used electrode spacing of $1/_2 AB$=100m in which the potential electrode separation MN has maintain its order of increment. The sole purpose of this study is to determine the resistivity of the weathered layer, resistivity of the fractured layer and to determine the soil type within the weathered and fractured layer. Every earth material has its own resistivity value which helps in knowing or identifying the material. Variation in the electrical resistivity values of earth materials helps in determining site suitable for high-rise building construction, miming, agricultural, and industrial use. The science of geophysics applies the principles of physics to the study of the Earth. Geophysical investigations of the interior of the Earth involve taking measurements at or near the Earth's surface that are influenced by the internal distribution of physical properties. Analysis of these measurements can reveal how the physical properties of the Earth's interior vary vertically and laterally.

AIM AND OBJECTIVES

The aim of the study is to investigate the variation in electrical resistivity value of earth materials with depth using vertical electrical sounding at Narayi Area of Kaduna State.
The following objectives where use to achieved the aim of the work

i. Determination of the resistivity of the weathered layer
ii. To determine the resistivity of the fractured layer
iii. To determine the soil type within the weathered and fractured layer

Survey Area

The research project was conducted at Government Secondary School Narayi, Kaduna State. The coordinates of the study area: Latitude 10°28.275N - 10°29.15N and Longitude 07°28.649'E -07°29.14'E (Plate1). The specific location where the survey was done is an open field within the school premises. Students and other local football team play football at the study area.

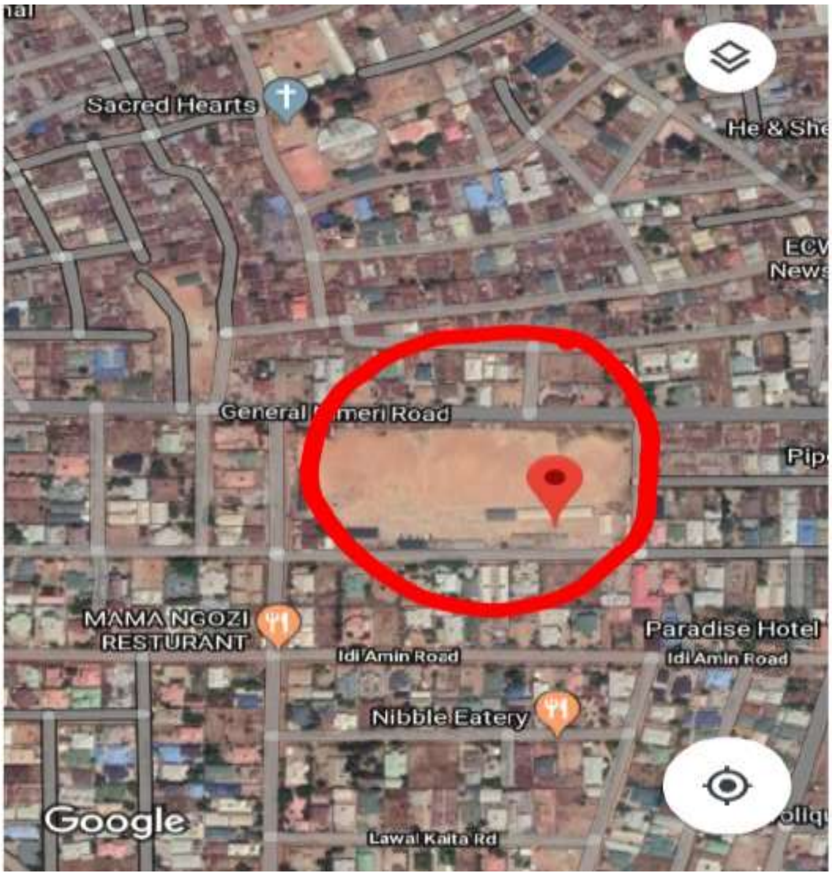


Plate1. Satellite image showing the survey area Government Secondary school narayi Kaduna

Geology of Narayi Area of Kaduna State

About 50% of Nigeria is covered by crystalline rocks and about 90% of this belong the basement complex which is said to be Precambrian in age. It is observed that the dominant rock types in the crystalline basement complex of Nigeria are Migmatites, gneisses, schists, quartzites and Granite (Afuwai, 2019). The study area lies within the basement complex of Nigeria (Figure1.) Narayi Area in Kaduna state is underlain by a basement complex of igneous and metamorphic rocks of mainly Jurassic and pre-Cambrian ages.

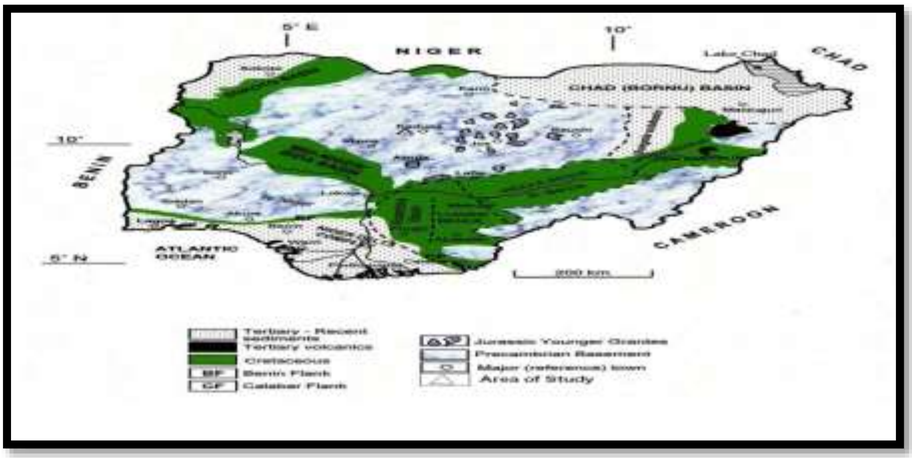


Fig. 1. Basement geological map of Nigeria showing the study area

Theory of the Electrical Resistivity Survey

In the DC resistivity surveying, an electric current is passed into the ground through two outer electrodes (current electrodes), and the resultant potential difference is measured across two inner electrodes (potential electrodes) that are arranged in a straight line, symmetrically about a centre point. The ratio of the potential difference to the current is displayed by the Terrameter as resistance. A geometric factor $\boldsymbol{K}$ in metres is calculated as a function of the electrode spacing. The electrode spacing is progressively increased, keeping the centre point of the electrode array fixed. A and B are current electrodes through which current is supplied into the ground, **M** and **N** are two potential electrodes to measure the potential differences between the two electrodes and P is the VES station to be sounded. The potential difference between the two potential electrodes is measured. The apparent resistivity is given by

$$\boldsymbol{\rho_a = k\left(\frac{\Delta V}{I}\right)} \qquad (1)$$

With K a geometric factor which only depends on electrode spacing and is given by

$$\boldsymbol{K = \pi\left(\frac{L^2}{2b} - \frac{b}{2}\right)} \qquad (2)$$

Electrical resistivity method is defined by their frequency of operation, the origin of the source signals and the manner by which the sources and receivers are coupled to the ground. The method is generally governed by Maxwell's equations of electromagnetism. In the direct-current (DC) frequency, the diffusion term is zero and the field is thus governed entirely by Poisson equation. Electrical methods of geophysical investigations are based on the resistivity (or its inverse, conductivity) contrasts of subsurface materials. The electrical resistance, $\boldsymbol{R}$ of a material is related to its physical dimension, cross-sectional area, $\boldsymbol{A}$ and length, $\boldsymbol{l}$ through the resistivity, $\boldsymbol{\rho}$ or its inverse, conductivity, $\boldsymbol{\sigma}$ by

$$\boldsymbol{\rho = \frac{1}{\sigma} = \frac{RA}{l}} \qquad (3)$$

Low-frequency alternating current is employed as source signals in the DC resistivity surveys in determining subsurface resistivity distributions. Thus, the magnetic properties of the materials can be ignored so that Maxwell's equations of electromagnetism reduced to:

$$\boldsymbol{\nabla . \vec{E} = \frac{1}{\varepsilon_\circ} q} \qquad (4)$$

$$\boldsymbol{\nabla \times \vec{E} = 0} \qquad (5)$$

Where $\boldsymbol{\vec{E}}$ is electric field in *V/m, q* is the charge density in *C/m*^{3} and $\boldsymbol{\varepsilon_\circ}$ (8.854 X 10^{-12} *F/m*) is the permittivity of free space. These equations are applicable to continuous flow of direct current; however, they can be used to represent the effects of alternating currents at low frequencies such that the displacement currents and induction effects are negligible. Usually, a complete homogeneous and isotropic earth medium of uniform resistivity is assumed. For a continuous current flowing in an isotropic and homogeneous medium, the current density $\vec{J}$ is related to the electric field, $\vec{E}$ through Ohm's law

$$\boldsymbol{\vec{J} = \sigma \vec{E}} \qquad (6)$$

The electric field vector $\vec{E}$ can be represented as the gradient of the electric scalar potential,

$$\boldsymbol{\vec{E} = \nabla \Phi} \qquad (7)$$

The apparent resistivity is the ratio of the potential obtained in-situ with a specific array and a specific injected current by the potential which will be obtained with the same array and current for a homogeneous and isotropic medium of 1Ωm resistivity. The apparent resistivity measurements give information about resistivity for a medium whose volume is proportional to the electrode spacing (Grant and West, 1965). Resistivity is affected more by water content and quality than the actual rock material in porous formations. While aquifers that are composed of unconsolidated materials their resistivity decreases with the degree of saturation and salinity of the groundwater (Afuwai and Lawal, 2013).

The apparent resistivity is the ratio of the potential obtained in-situ with a specific array and a specific injected current by the potential which will be obtained with the same array and current for a homogeneous and isotropic medium of 1Ωm resistivity. The apparent resistivity measurements give information about resistivity for a medium whose volume is proportional to the electrode spacing. Resistivity is affected more by water content and quality than the actual rock material in porous formations. Since the measured resistivity is usually a composite of the resistivity of several layers, the apparent resistivity may be smaller or larger than the real resistivities or in rare cases identical with one of the two resistivity values in a homogeneous surface. The apparent resistivity is the same as the real resistivity in a homogeneous subsurface, but normally a combination of contributing strata. The value of the apparent resistivity obtained with small electrode spacing is called the surface resistivity.

Ohmega Terrameter

The OHMEGA resistivity meter is a high quality earth resistance meter that gives accurate measurement over wide range of conditions. It has a minimum power output of 8watts. The manual selection set up is up to 200mA. This receiver incorporates automatic gain steps which provide a range of measurement from 0.001Ω to 360kΩ. This measurement is powered by large battery capacity which can take days before recharging. The OHMEGAterrameter is supplied with 4 stainless steel electrode for 100m cables on lightweight reels and battery charger (Plate1)

Plate 2. Terrameter, wire cables and reels

Data Collection

15 VES point along 3 profiles was taken within a maximum electrode spreading of 140m. The full schlumberger configuration was adopted with maximum half electrodes current spread ($1/_2 AB$) projected between 1m, 1.5m, 2m, 3m, 4m.5m, 7m, 7m, 10m, 15m, 20m, 30m, 45m, 45m, 70m. While the half potential electrodes separation was (MN/2) was increased from 0.3m, 1m and 5m (Table1).

The 15 VES were carried out, where the center electrodes were keep fixed while the electrodes spacing keep increasing outwardly in a linear array. The wider spacing the deeper information as possible of the surface structure and lithological disposition of the area. The resistances values are obtain from the Ohmega Terrameter by multiplying the geometric factor K which was the function of the electrodes spacing to obtain the apparent resistivity values. The electrode array use to obtain these values is the schlumberger array. Apart from the principal instrument use to acquire the data, that is the Ohmega Terrameter, other equipments includes the Four metallic electrodes, crocodile clips, wire cables, measuring tape, hammer and GPS.

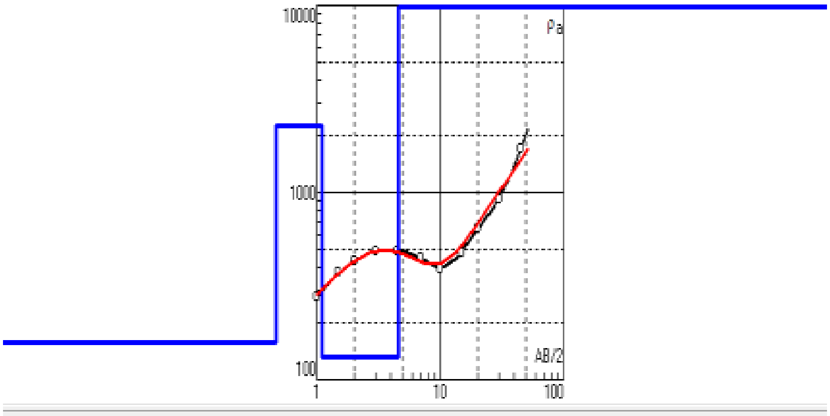
Table 1: Typical record of the field Data for VES 01 along Profile 1

S/N	AB/2 m	MN/2 m	Geometric factor (K) m	Resistance Readings (Ω)	Apparent Resistivity (Ωm)
1	1	0.30	4.76	36.49	173.7
2	1.5	0.30	11.31	20.53	232.2
3	2	0.30	20.47	13.11	268.4
4	3	0.30	46.65	6.485	302.5
5	4.5	0.30	105.56	2.876	303.6
6	7	0.30	256.1	1.036	2653.2
7	7	1.0	75.4	3.771	284.3
8	10	1.0	155.51	1.595	248
9	15	1.0	351.86	0.868	305.4
10	20	1.0	626.75	0.657	412.2
11	30	1.0	1412.15	0.414	585.6
12	45	5.0	3179.3	0.346	1101.9
13	45	5.0	628.32	2.754	1730.4
14	70	5.0	1531.53	3.171	4856.5

RESULTS AND DISCUSSION

Results of Profile 1 VES 01

Four (4) subsurface layers were found at VES01. The first layer has resistivity value of 353Ωm which is taken to be weathered sand. The second layer has resistivity value of 2254Ωm which is taken to be granitic rock. The third layer has a resistivity value of 131Ωm which is taken to be weathered layer. The fourth layer has a resistivity value 11000Ωm and is taken to be fresh bedrock (Figure 2).

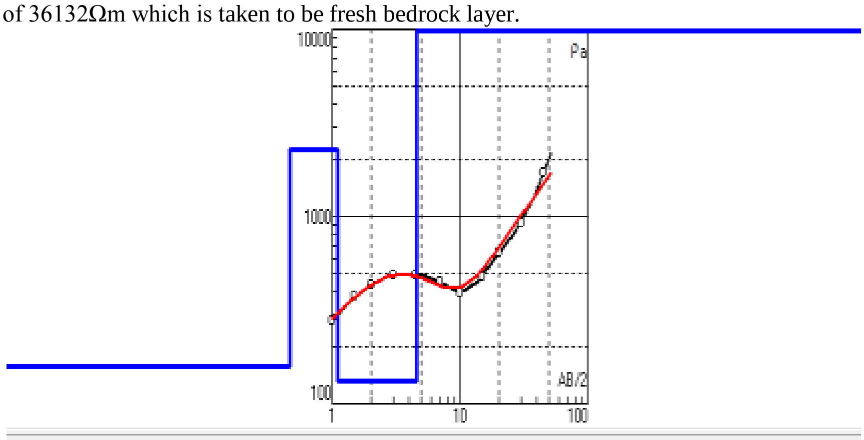


N	ρ	h	d	Alt
1	353	0.469	0.469	-0.469
2	2254	0.644	1.11	-1.11
3	131	3.44	4.55	-4.55
4	1.1E+5			

Fig. 2. The Sounding curve and interpretation model for VES01 along Profile 1.

Results of Profile 1 VES 02

Three subsurface layers were found at VES01 (Figure 3). The first layer has resistivity value of 131Ωm which is taken to be sandy clay. The second layer has resistivity value of 53.9Ωm which is taken to be clay. The third layer has a resistivity value of 36132Ωm which is taken to be fresh bedrock layer.

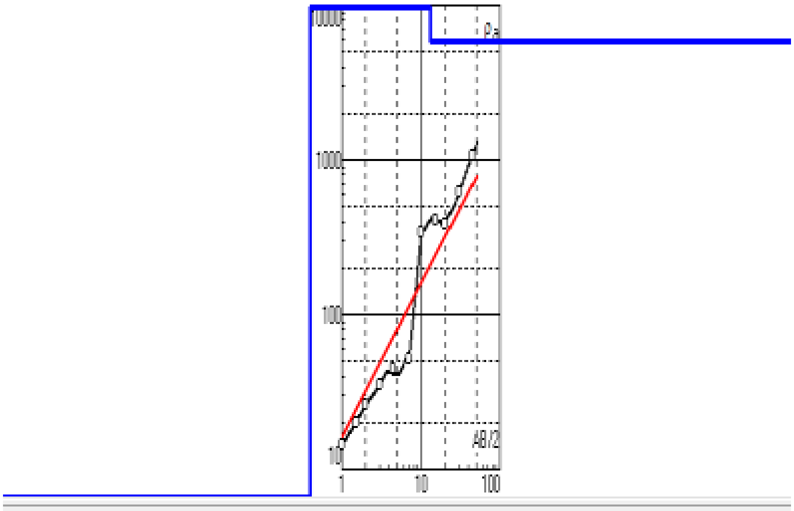


N	ρ	h	d	Alt
1	131	7.6	7.6	-7.59
2	53.9	2.78	10.4	-10.3
3	36132			

Fig. 3. The Sounding curve and interpretation model for VES02 along Profile 1

Results of Profile 1 VES 03

VES 03 was probed and four layers were detected. The first layer has resistivity value of 6.53Ωm and thickness of 0.39m at depth of 0.39m. The earth materials at this layer are found to be clay. The second layer has a resistivity value of 18393Ωm and thickness of 5.01m at a depth of 5.41m. The earth materials at this layer are found to be fresh granitic bedrocks. The third layer has a resistivity value of 18393Ωm and thickness of 7.51m at depth of 12.9m, which is the depth to Basement layer at VES 03. The earth materials at this layer are found to be Fresh Granitic Bedrocks. And the fourth layer has a resistivity value of 5783Ωm (Figure4). This layer is the fresh Basement at an infinite depth.

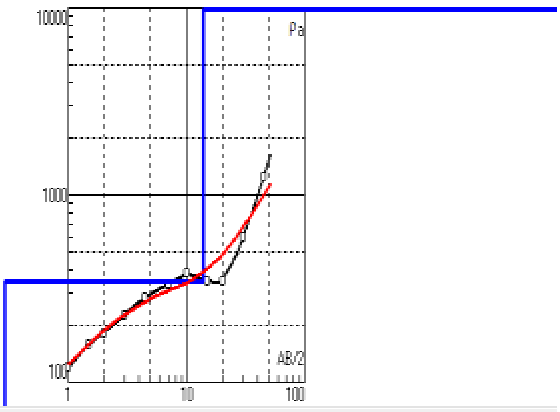


N	ρ	h	d	Alt
1	6.53	0.399	0.399	-0.399
2	18393	5.01	5.41	-5.40
3	18393	7.51	12.9	-12.9
4	5783			

Fig. 4. The Sounding curve and interpretation model for VES03 along Profile 1

Results of Profile 1 VES 04

VES 04 was probed and four layers were detected. The first layer has resistivity value of 50.5Ωm and thickness of 0.29m at depth of 0.29m. The earth materials at this layer are found to be clay. The second layer has a resistivity value of 345Ωm and thickness of 13.5m at a depth of 13.8m. The earth materials at this layer are found to be weathered sand. The third layer has a resistivity value of 220000Ωm and thickness of 20.7m at depth of 34.6m, which is the depth to Basement layer at VES 04. The earth materials at this layer are found to be Fresh Granitic rocks. And the fourth layer has a resistivity value of 220000Ωm (Figure5). The earth materials at this layer are found to be fresh granitic rocks. This layer is the fresh Basement at an infinite depth.

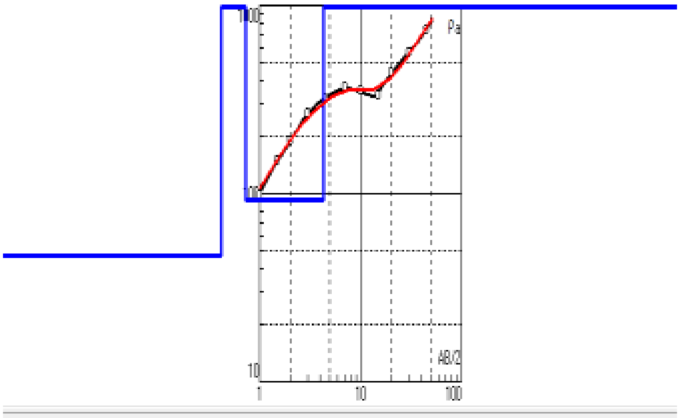


N	ρ	h	d	Alt
1	50.5	0.29	0.29	-0.289
2	345	13.5	13.8	-13.8
3	2.2E+5	20.7	34.6	-34.5
4	2.2E+5			

Fig. 5. The Sounding curve and interpretation model for VES04 along Profile 1

Results of Profile 1 VES 05

VES 05 was probed and four layers were detected. The first layer has resistivity value of 46.5Ωm and thickness of 0.42m at depth of 0.42m. The earth materials at this layer are found to be clay. The second layer has a resistivity value of 6028Ωm and thickness of 0.32m at a depth of 0.73m. The earth materials at this layer are found to be Granitic rocks. The third layer has a resistivity value of 91.9Ωm and thickness of 3.55m at depth of 4.28m, which is the depth to Basement layer at VES 05. The earth materials at this layer are found to be clay. And the fourth layer has a resistivity value of 3333Ωm (Figure6). The earth materials at this layer are found to be granitic rocks. This layer is the fresh Basement at an infinite depth.



N	ρ	h	d	Alt
1	46.5	0.415	0.415	-0.415
2	6028	0.317	0.732	-0.731
3	91.9	3.55	4.28	-4.28
4	3333			

Fig. 6. The Sounding curve and interpretation model for VES05 along Profile 1

Results of Profile 2 VES 01

VES 01 was probed and four layers were detected. The first layer has resistivity value of 44.5Ωm and thickness of 0.29m at depth of 0.29m. The earth materials at this layer are found to be clay. The second layer has a resistivity value of 44.5Ωm and thickness of 0.43m at a depth of 0.71m. The earth materials at this layer are found to be clay. The third layer has a resistivity value of 516Ωm and thickness of 15m at depth of 15.7m, which is the depth to Basement layer at VES 01. The earth materials at this layer are found to be Lateritic soil. And the fourth layer has a resistivity value of 42738Ωm (Figure7). The earth materials at this layer are found to be Fresh bedrocks. This layer is the fresh Basement at an infinite depth.

N	ρ	h	d	Alt
1	44.5	0.285	0.285	-0.285
2	44.5	0.428	0.713	-0.712
3	516	15	15.7	-15.7
4	42738			

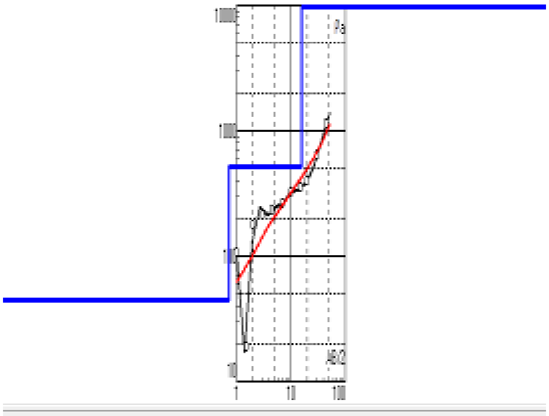
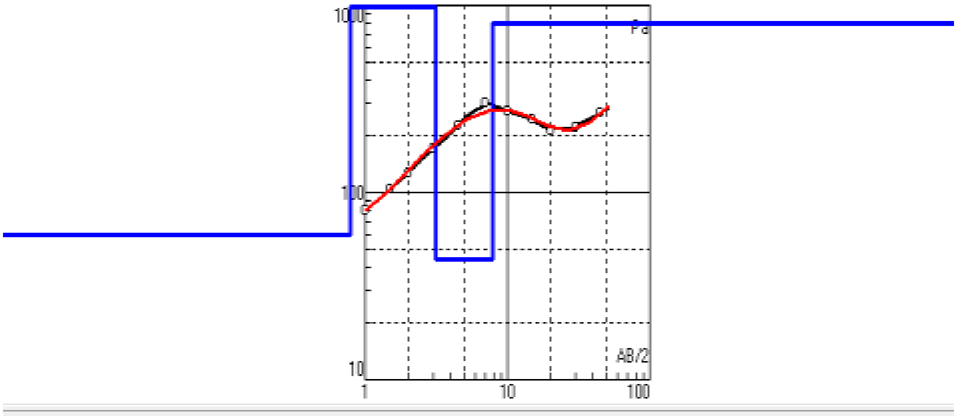


Fig. 7. The Sounding curve and interpretation model for VES01 along Profile 2

Results of Profile 2 VES 03

VES 03 was probed and four layers were detected. The first layer has resistivity value of 59.8Ωm and thickness of 0.79m at depth of 0.79m. The earth materials at this layer are found to be clay. The second layer has a resistivity value of 972Ωm and thickness of 2.33m at a depth of 3.11m. The earth materials at this layer are found to be Lateritic soil. The third layer has a resistivity value of 43.8Ωm and thickness of 4.81m at depth of 7.92m, which is the depth to Basement layer at VES 03. The earth materials at this layer are found to be Clay Sandy soil. And the fourth layer has a resistivity value of 809Ωm (Figure8). The earth materials at this layer are found to be gravels.

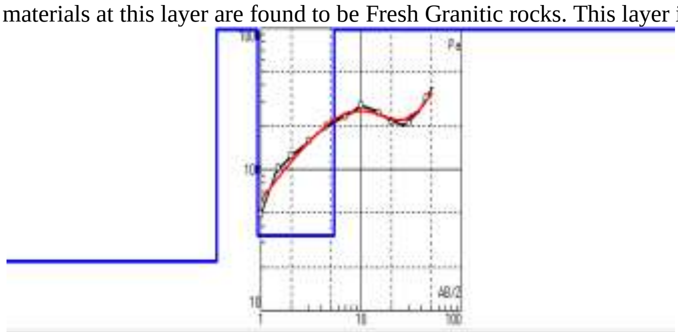


N	ρ	h	d	Alt
1	59.8	0.788	0.788	-0.787
2	972	2.33	3.11	-3.11
3	43.8	4.81	7.92	-7.92
4	809			

Fig. 8. The Sounding curve and interpretation model for VES02 along Profile 2

Results of Profile 2 VES 04

VES 04 was probed and four layers were detected. The first layer has resistivity value of 22.4Ωm and thickness of 0.36m at depth of 0.36m. The earth materials at this layer are found to be clay. The second layer has a resistivity value of 4067Ωm and thickness of 0.56m at a depth of 0.92m. The earth materials at this layer are found to be Granitic rocks. The third layer has a resistivity value of 33.8Ωm and thickness of 4.43m at depth of 5.35m, which is the depth to Basement layer at VES 04. The earth materials at this layer are found to be clay. And the fourth layer has a resistivity value of 19069Ωm (Figure9). The earth materials at this layer are found to be Fresh Granitic rocks. This layer is the fresh Basement at an infinite depth.

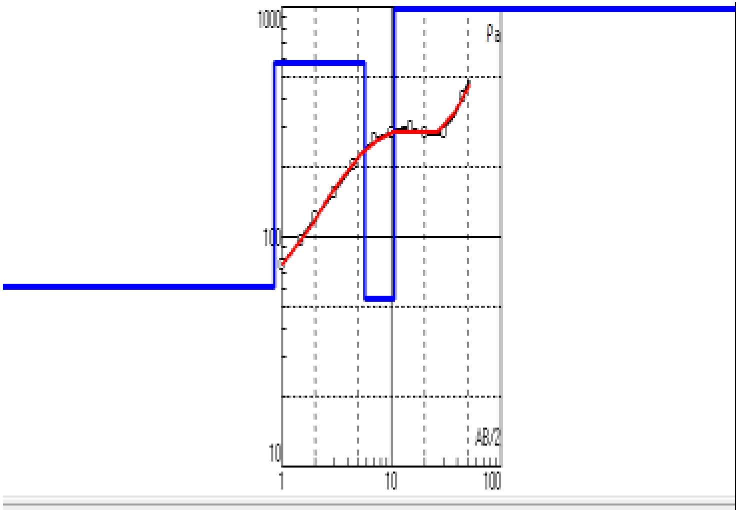


N	ρ	h	d	Alt
1	22.4	0.36	0.36	-0.359
2	4067	0.564	0.924	-0.923
3	33.8	4.43	5.35	-5.34
4	19069			

Fig. 9. The Sounding curve and interpretation model for VES04 along Profile 2

Results of Profile 2 VES 05

VES 05 was probed and four layers were detected. The first layer has resistivity value of 60.5Ωm and thickness of 0.85m at depth of 0.85m. The earth materials at this layer are found to be clay. The second layer has a resistivity value of 573Ωm and thickness of 4.82m at a depth of 5.67m. The earth materials at this layer are found to be Lateritic soil. The third layer has a resistivity value of 53.8Ωm and thickness of 4.88m at depth of 10.5m, which is the depth to Basement layer at VES 05. The earth materials at this layer are found to be Clay. And the fourth layer has a resistivity value of 38557Ωm (Figure10). The earth materials at this layer are found to be Fresh bedrocks. This layer is the fresh Basement at an infinite depth.

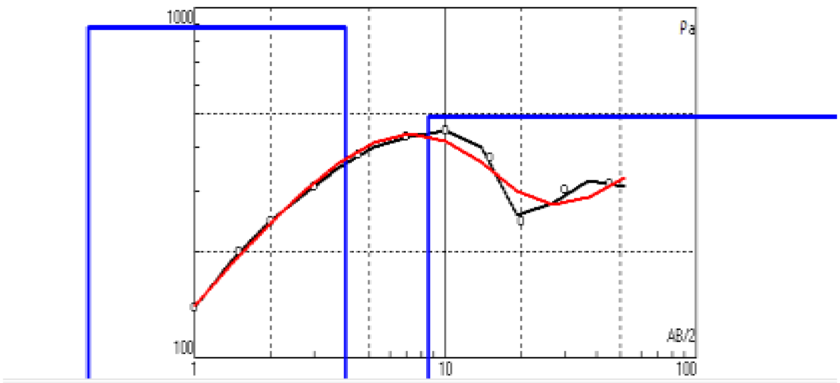


N	ρ	h	d	Alt
1	60.5	0.845	0.845	-0.844
2	573	4.82	5.67	-5.66
3	53.8	4.88	10.5	-10.5
4	38557			

Fig. 10: The Sounding curve and interpretation model for VES05 along Profile 2

Results of Profile 3 VES 01

VES 01 was probed and four layers were detected. The first layer has resistivity value of 61.4Ωm and thickness of 0.38m at depth of 0.38m. The earth materials at this layer are found to be clay. The second layer has a resistivity value of 878Ωm and thickness of 3.64m at a depth of 4.01m. The earth materials at this layer are found to be Lateritic soil. The third layer has a resistivity value of 71.4Ωm and thickness of 4.48m at depth of 8.49m, which is the depth to Basement layer at VES 01. The earth materials at this layer are found to be clay. And the fourth layer has a resistivity value of 488Ωm (Figure11). The earth materials at this layer are found to be Sandy soil.

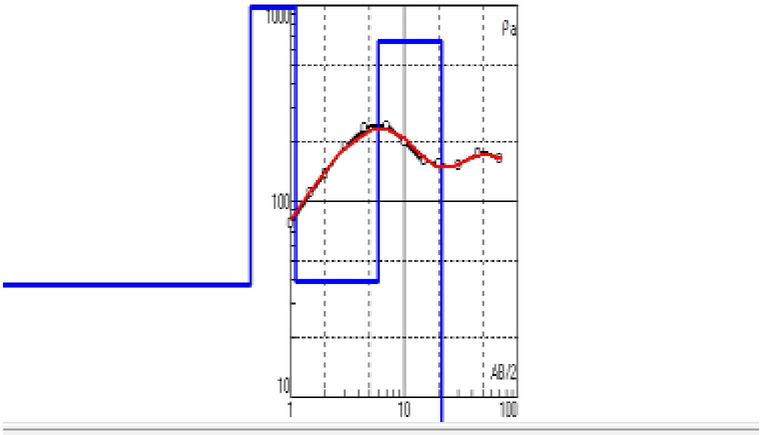


N	ρ	h	d	Alt
1	61.4	0.378	0.378	-0.377
2	878	3.64	4.01	-4.01
3	71.4	4.48	8.49	-8.49
4	488			

Fig. 11: The Sounding curve and interpretation model for VES01 along Profile 3

Results of Profile 3 VES 02

VES 02 was probed and five layers were detected. The first layer has resistivity value of 37.3Ωm and thickness of 0.44m at depth of 0.44m. The earth materials at this layer are found to be clay. The second layer has a resistivity value of 2074Ωm and thickness of 0.67m at a depth of 1.11m. The earth materials at this layer are found to be Granitic rocks. The third layer has a resistivity value of 38.8Ωm and thickness of 4.82m at depth of 5.94m. The earth materials at this layer are found to be clay. The fourth layer has a resistivity value of 660Ωm and thickness of 15.5m at depth of 21.5m. The earth materials at this layer are found to be Lateritic soil. And the fifth layer has a resistivity value of 6.58Ωm (Figure12). The earth materials at this layer are found to be clay.

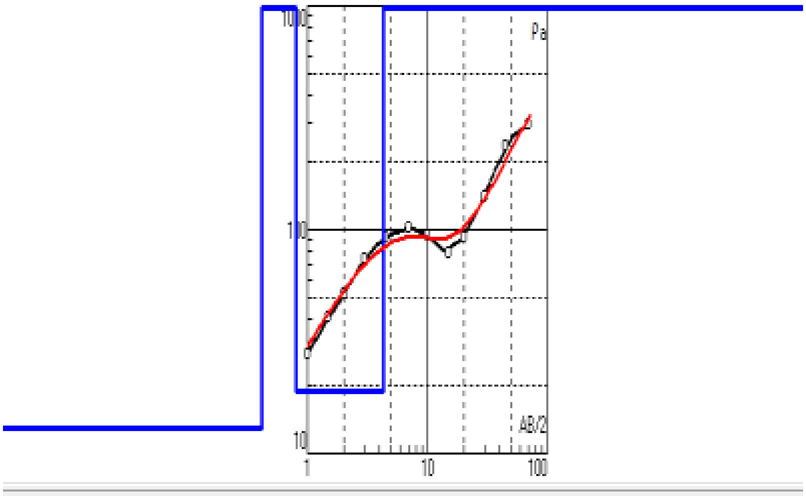


N	ρ	h	d	Alt
1	37.3	0.439	0.439	-0.439
2	2074	0.674	1.11	-1.11
3	38.8	4.82	5.94	-5.93
4	660	15.5	21.5	-21.4
5	6.58			

Fig. 12: The Sounding curve and interpretation model for VES02 along Profile 3

Results of Profile 3 VES 03

VES 03 was probed and four layers were detected. The first layer has resistivity value of 13Ωm and thickness of 0.41m at depth of 0.41m. The earth materials at this layer are found to be clay. The second layer has a resistivity value of 1380Ωm and thickness of 0.38m at a depth of 0.79m. The earth materials at this layer are found to be Lateritic soil. The third layer has a resistivity value of 18.9Ωm and thickness of 3.5m at depth of 4.3m, which is the depth to Basement layer at VES 03. The earth materials at this layer are found to be clay. And the fourth layer has a resistivity value of 14139Ωm (Figure13). The earth materials at this layer are found to be Fresh Granitic rocks. This layer is the fresh Basement at an infinite depth.



N	ρ	h	d	Alt
1	13	0.411	0.411	-0.410
2	1380	0.384	0.794	-0.794
3	18.9	3.5	4.29	-4.29
4	14139			

Fig. 13: The Sounding curve and interpretation model for VES03 along Profile 3

Results of Profile 3 VES 04

VES 04 was probed and four layers were detected. The first layer has resistivity value of 37Ωm and thickness of 0.47m at depth of 0.47m. The earth materials at this layer are found to be clay. The second layer has a resistivity value of 374Ωm and thickness of 4.11m at a depth of 4.58m. The earth materials at this layer are found to be Lateritic soil. The third layer has a resistivity value of 125Ωm and thickness of 2.93m at depth of 7.51m, which is the depth to Basement layer at VES 01. The earth materials at this layer are found to be Lateritic soil. And the fourth layer has a resistivity value of 324Ωm (Figure14). The earth materials at this layer are found to be sandy soil.

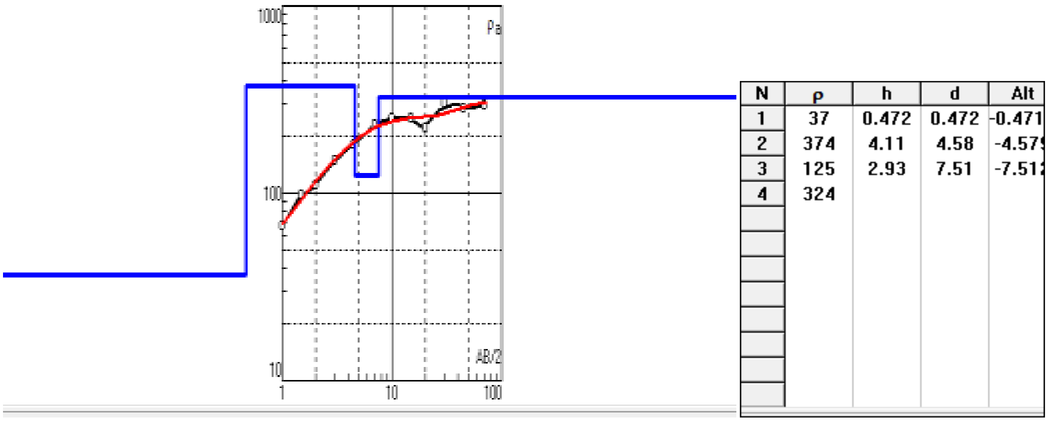


Fig. 14: The Sounding curve and interpretation model for VES04 along Profile 3

Results of Profile 3 VES 05

VES 05 was probed and three layers were detected. The first layer has resistivity value of 2.58Ωm and thickness of 0.47m at depth of 0.47m. The earth materials at this layer are found to be clay. The second layer has a resistivity value of 21.8Ωm and thickness of 8.2m at a depth of 8.67m. The earth materials at this layer are found to be clay. And the third layer has a resistivity value of 8168Ωm (Figure15). The earth materials at this layer are found to be granitic rocks. This layer is the fresh Basement at an infinite depth.

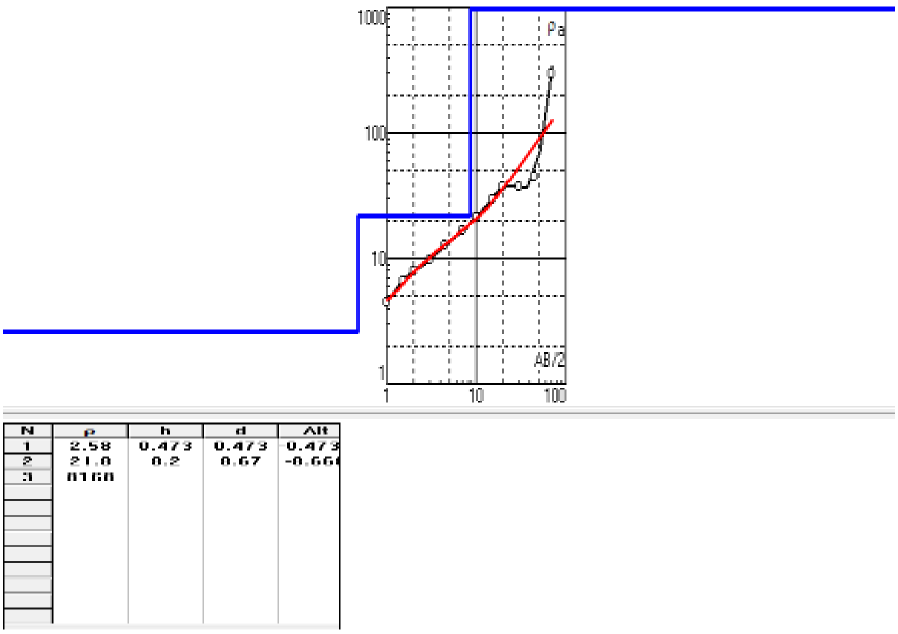


Fig. 15: The Sounding curve and interpretation model for VES05 along Profile 3

CONCLUSION

The survey area is dominated mainly by four layers, namely; weathered basement, fractured basement and fresh basement. The Topsoil consists of laterites and clay sand with resistivity value of 90-110Ωm from the topsoil to a depth of 10m. The weathered layers constitutes of coarse grain sand with resistivity value of 190-250Ωm at a depth of 10-25m. The fractured layers contains gravels of resistivity value of 500-980Ωm at a depth of 25-44m, while the fresh bedrock is a fresh granitic rock of resistivity value of 1900-4000Ωm.

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