GEOPHYSICAL INVESTIGATION OF THE SUBSURFACE CONDITION OF THE PERMANENT SITE OF FEDERAL UNIVERSITY LOKOJA, KOGI STATE

BY

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DECLARATION

I hereby declare that this work is the result of my research which was carried out under the supervision of Dr. M. O. Aku and has been presented and will not be presented elsewhere for the award of a degree or certificate. All sources have been duly acknowledged.

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CERTIFICATION

This is to certify that the research work for this thesis and the subsequent preparation of this thesis by (Lukman Inuwa Gani) with registration number (SPS/12/MPY/00035) were carried out under my supervision Dr. M.O. Aku and dully checked.

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APPROVAL PAGE

This is to certify that this dissertation titled Geophysical Investigation of the Subsurface Condition of the Permanent Site of Federal University Lokoja, Kogi State by Lukman Inuwa Gani, has met the requirement of the rules governing the award of Master of science degree (M.Sc) in Physics, Bayero University Kano and is approved for its contribution to the knowledge and literary presentation.

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DEDICATION

To my parents

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ABSTRACT

A geophysical investigation of the subsurface condition of the Permanent Site of Federal University Lokoja, Kogi-state was carried out using electrical resistivity method with the aim of studying the subsurface geologic layers, with a view to determing the aquiferious zones, their depth and the thickness of the geologic layers. Vertical electrical sounding (VES), using Schlumberger array, was conducted at twenty (20) VES stations along four profiles with the aid of ABEM SAS 300C terrameter and the field data obtained were analyzed using computer software, IPI2win. The VES results revealed the heterogeneous nature of the subsurface geological sequence to contain four layers; topsoil (sandy and clayey laterite), weathered layer, partly weathered or fractured basement and fresh basement with two aquiferous zones (weathered basement and fractured basement). The resistivity value of the topsoil layer varies from 20Ωm to 250Ωm with thickness ranging from 1.0m to 3.0m. The weathered basement has resistivity value ranging from 25Ωm to 300Ωm and thickness between 2.0m to 41.5m. The partial/fractured basement has resistivity value of 100Ωm to 600Ωm with thickness of 5.0m to 50m across most part of the area. Lastly the fresh basement has resistivity of 900Ωm and above with infinite depth. However, the depth from the earth's surface to the aquiferious zone varies from 10m to 50m and the overburden in the area is low.

CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION

Geophysical surveys are generally identified by the property being measured—namely, electrical, gravity, magnetic, seismic, thermal, or radioactive properties. The electrical method is also subdivided into resistivity, induced polarization, and self polarization methods. Electrical resistivity methods of geophysical survey have been used for many decades in hydro geological, mining and geotechnical investigations following the accessibility and availability of its instrument and interpretation software. It is used to determine the subsurface resistivity distribution through vertical electrical sounding (VES) techniques. Vertical electrical sounding (VES) is an electrical resistivity method for measuring vertical change of electrical resistivity (Todd, 2004 and Anomohanran, 2013). It detects the surface effects produced by the flow of electric current inside the earth.

The Felele community of Lokoja where the study area is situated is facing an increase in human population since the situation of the state polytechnic and the permanent site of Federal University Lokoja (study area) in the community. The area has no access to the township pipe-borne water as the residents of the area depend on untreated surface water, hand dug wells and private water supplies for their domestic activities. So to abate this problem of water scarcity and structural collapse in the permanent site of Federal University Lokoja (study area) which is a developing area, the need for a geophysical investigation of the subsurface condition arises.

Groundwater is an important source of freshwater. According to Philip Kearey (2001), groundwater is the water in porous rocks beneath the water table. It is water that is contained in aquifer and an aquifer is any geologically deposited material which is porous and permeable, saturated with water and allows pumping of water for economic use (Omali 2014). According to Alabi *et al*. (2010), about 53% of the world population depends on groundwater as a source of drinking water. Therefore, groundwater development is sine qua non to supplement the expensive surface water treatment and its exploitation can be achieved easily by performing a geophysical survey of the area under consideration. Electrical resistivity method was employed in this work to study the subsurface geologic layers of the basement complex terrain of the Permanent Site of Federal University Lokoja (study area).

1.2 STATEMENT OF THE PROBLEM

The permanent site of Federal University Lokoja is a new settlement situated in an area where scarcity of portable water is becoming severe, as it is already condemning residents to been restless. Residents of the area have no access to the township pipe-borne water and therefore are left with no option but to rely on surface water, handdug wells and private water supplies for their use. Thus, the need arises for comprehensive information of the subsurface conditions of the study area to avoid dotting the permanent site with unnecessary boreholes and to aid the construction process.

1.3 AIM

This study is aimed at evaluating the geophysical characteristics of the basement complex terrain of the permanent site of Federal University Lokoja.

1.4 OBJECTIVES

The following are objectives of this research.

i. To map out the groundwater pattern within Federal University Lokoja permanent site for future exploration.
ii. To identify the depth to the aquiferious layer of the Permanent Site.
iii. To delineate the various lithologies within the study area for construction purpose.

1.5 SCOPE AND LIMITATIONS OF THE STUDY

The study involves the use of electrical resistivity method of investigation and measurement of resistance. A number of vertical electrical sounding were conducted and The VES data were processed using the computer programs IPI2win and SURFER version 11. The processed data from the VES was used to generate resistivity pseudo sections of each profile. Using graphical software the sections were transformed into equivalent geological sections using other supplementary information, namely; geology of the area, collected borehole data and resistivity values of earth materials compiled in various literatures. The pseudo-sections were as well used to generate the basement topography. The overall results were used to identify locations of favourable groundwater exploration and heavy structure construction.

In achieving the aim and objectives of this research, the following limitations were observed.

i. The depth of penetration was limited by the strength of electrical power that was introduced into the ground.
ii. The various geoelectrical layers encountered were assumed to be electrically homogeneous. This is a possible source of error as the interpretation of the soundings took into cognizance homogeneity in lateral variation in resistivity of the respective layers.
iii. Lastly this work lacks the ability to delineate the regions of faults, fractures and to describe the recharging and discharging capacity of the study area.

1.6 LOCATION OF THE STUDY AREA

Federal University Lokoja permanent site is located along Lokoja-Okene road at the Felele area of Lokoja, Kogi state, Nigeria. It is at the north western part of mount Patti, it lies in between mount Patti and Agbaja plateau at latitude 07˚ 50 05 N to latitude 07˚ 54 04 N and longitude 06˚40 22 E to longitude 6˚42 02 E forming a rectangular like shape around the point in Figure 1.1.

1.7 GEOLOGY AND HYDROGEOLOGY OF THE STUDY AREA

The permanent site of Federal University Lokoja has almost the same geology as Lokoja in general. It is dominantly underlain by the Precambrian basement complex. However, part of the area is underlain by Cretaceous sediments (Omali, 2014) which uncomfortably overlie the basement complex. The study area is composed of the following fieldspathic sandstone and siltstones, biotite hornblende gneiss and magmatite. Fieldspathic sandstone refers to grains which are commonly converted to clay when granitic beddrock weathers. Siltstones are lithified silt whose components are mostly quartz and rarely clay.

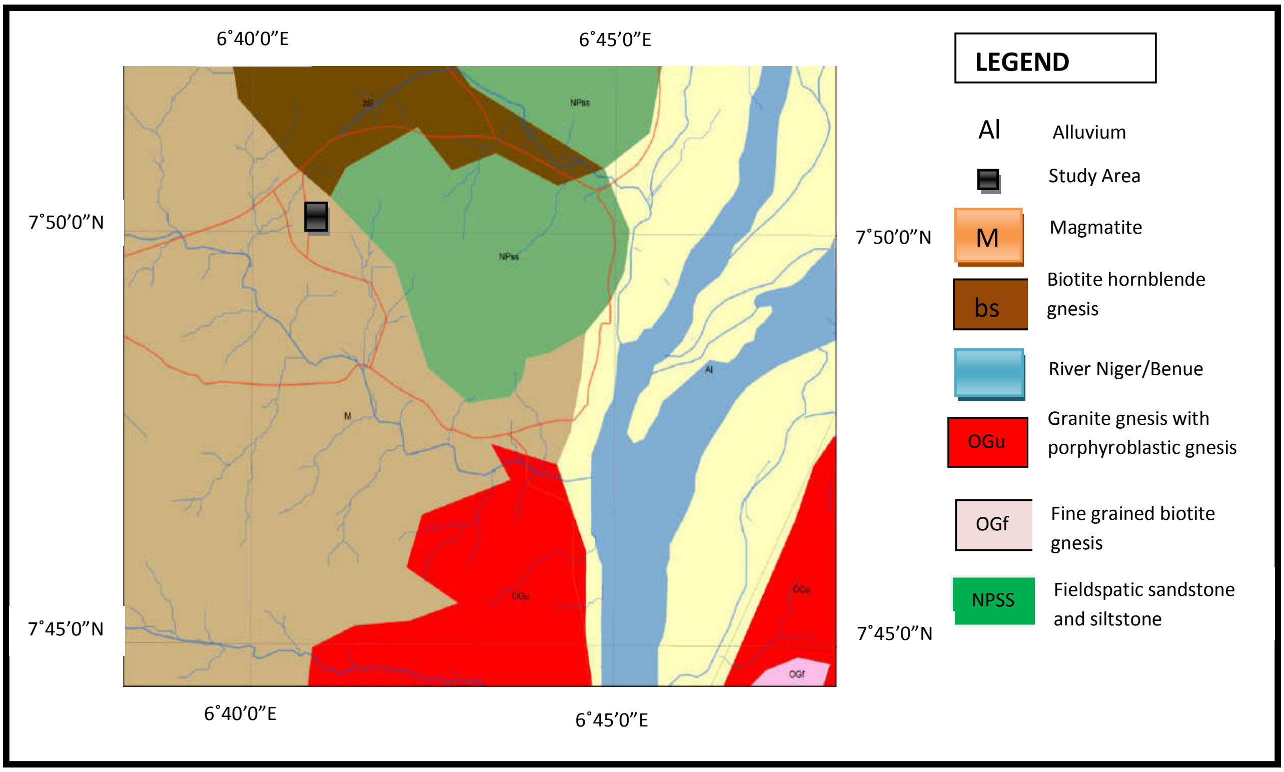


Figure 1.1: Geological Map of Lokoja Showing the Study Area (Omali, 2014)

The climatic data from the Nigeria metrological agency (NIMET, 2011) indicates that the study area falls within the tropical climate zone and is characterized by two distinct seasons; rainy season (April to October) and dry season (November to march). Mean annual rainfall in the dry season ranges from 0mm to 42mm; the mean annual rainfall during the rainy season ranges between 105mm to 1560mm while peak rainfall occurs between July to September annually. Mean annual temperature oscillates between 26 C (July or august) to 35 C in February or March while relative humidity ranges from 50- 63% (NIMET, 2011). The vegetation in the study area is classified as guinea savanna grassland characterized by shrubs with scattered orchard bush. The area is generally drained into river Niger due to the moderate sloping nature of the land.

CHAPTER TWO

LITERATURE REVIEW

2.0 INTRODUCTION

Geophysical survey method involves the exploration of the earth using geophysics. Geophysics is the study of the earth using quantitative physical methods, remote insight into the earth. In this chapter some related geophysical methods have been discussed.

2.1 REVIEW OF GEOPHYSICAL SURVEY METHODS

In this section, the geophysical methods listed above have been reviewed in order to derive more knowledge on geophysical methods.

2.1.1 GROUND PENETRATING RADAR

The ground penetrating radar (GPR) method provides subsurface information ranging in depth from several tens of meters to only a fraction of a meter. A basic understanding of the function of the GPR instrument, together with knowledge of the geology and mineralogy of the site, can help determine if GPR will be successful in the site assessment. When possible, the GPR technique should be integrated with other geophysical and geological data to provide the most comprehensive site assessment. The GPR method uses a transmitter that emits pulses of high-frequency electromagnetic waves into the subsurface. The transmitter is either moved slowly across the ground surface or moved at fixed station intervals. The penetrating electromagnetic waves are scattered at changes in the complex dielectric permittivity, which is a property of the subsurface material dependent primarily upon the bulk density, clay content and water content of the subsurface (Olhoeft, 1984). The electromagnetic energy is reflected back to the surface-receiving antenna and is recorded as a function of time. Depth penetration of GPR is severely limited by attenuation and/or absorption of the transmitted electromagnetic (radar) waves into the ground. Generally, penetration of radar waves is reduced by a shallow water table, high clay content of the subsurface, and in areas where the electrical resistivity of the subsurface is less than 30 ohm-meters.

2.1.2 MAGNETIC METHOD

Magnetic method is based on the measurement of susceptibility contrast between an anomalous body and the rock around it using magnetometers. A magnetometer is an instrument which measures magnetic field strength in units of gammas or nanoteslas (1 gammas = 1 nanotesla = 0.00001 gauss). Local variations, or anomalies, in the earth's magnetic field are the result of disturbances caused mostly by variations in concentrations of ferromagnetic material in the vicinity of the magnetometer's sensor. A buried ferrous object, such as a steel drum or tank, locally distorts the earth's magnetic field and results in a magnetic anomaly. The common objective of conducting a magnetic survey is to map these anomalies and delineate the area of burial of the sources of these anomalies. Analysis of magnetic data can allow an experienced geophysicist to estimate the regional extent of buried ferrous targets, such as a steel tank, canister or drum. Often, areas of burial can be prioritized upon examination of the data, with high priority areas indicating a near certainty of buried ferrous material. In some instances, estimates of depth of burial can be made from the data. Most of these depth estimates are graphical methods of interpretation, such as slope techniques and half width rules, as described by Nettleton (1976). The accuracy of these methods is dependent upon the quality of the data and the skill of the interpreting geophysicist. The magnetic method may also be used at a site to map various geologic features, such as igneous intrusions, faults, and some geologic contacts that may play an important role in the hydrogeology of a ground water pollution site. One of the advantages of using the magnetic method for the initial assessment of hazardous waste sites is the relatively low costs of conducting the survey, and the relative ease of completing a survey in a short period of time. There are certain limitations in the magnetic method. One limitation is the problem of "cultural noise" in certain areas. Man-made structures that are constructed using ferrous material, such as steel, have a detrimental effect on the quality of the data. Several types of magnetometers are commonly used in magnetic investigations. These include the total-field proton-precession magnetometer, the fluxgate magnetometer, and the magnetic gradiometer.

2.1.3 GRAVITY METHOD

The gravity method involves measuring the acceleration due to the earth's gravitational field. These measurements are normally made on the earth's surface. A gravity meter or gravimeter is used to measure variations in the earth's true gravitational field at a given location. These variations in gravity depend upon lateral changes in the density of the subsurface in the vicinity of the measuring point. Because density variations are very small and uniform, the instruments used are very sensitive. The acceleration due to the earth's gravity is approximately 980,000 milligal (the unit of measurement commonly used in gravity surveys). Many gravity meters have a sensitivity of 0.01 milligal. This allows the detection of a change of one part in 100 million of the earth's gravitational field. The gravity method is useful in delineating buried valleys, bedrock topography, geologic structure and voids. An advantage of using the gravity method for site assessment is that gravity measurements are not as susceptible to cultural noise and hence data can be acquired in heavily populated areas. The main source of interference or noise that may affect gravity data are vibrations, which may be caused by vehicular traffic, heavy equipment, low flying aircraft and wind. Nevertheless, gravity readings can be taken in virtually any location.

2.1.4 INDUCED POLARIZATION METHOD

The induced polarization (IP) method is an electrical geophysical technique, which measures the slow decay of voltage in the subsurface following the cessation of an excitation current pulse. Basically, an electrical current is imparted into the subsurface, as in the electrical resistivity method explained elsewhere in this work. Water in the subsurface geologic material (within pores and fissures) allows for certain geologic material to show an effect called "induced polarization" when an electrical current is applied. During the application of the electrical current, electrochemical reactions within the subsurface material take place and electrical energy is stored. After the electrical current is turned off the stored electrical energy is discharged which results in a current flow within the subsurface material. The IP instruments then measure the current flow. Thus, in a sense, the subsurface material acts as a large electrical capacitor. The induced polarization method measures the bulk electrical characteristics of geologic units; these characteristics are related to the mineralogy, geochemistry and grain size of the subsurface materials through which electrical current passes. Induced polarization measurements are taken together with electrical resistivity measurements using specialized IP instruments. Although the IP method historically has been used in mining exploration to detect disseminated sulfide deposits, it has also been used successfully in groundwater studies to map clay and silt layers which serve as confining units separating unconsolidated sediment aquifers. The Induced Polarization (IP) is a phenomenon which occurs with some types of minerals (mainly metallic particles, but also some clay minerals). It is equivalent to a charge / discharge behavior of capacitors when currents are switched on / off.

2.1.5 ELECTROMAGNETIC METHODS

The electromagnetic method is a geophysical technique based on the physical principles of inducing and detecting electrical current flow within geologic strata. Electromagnetic should not be confused with the electrical resistivity method. The difference between the two techniques is in the way that the electrical currents are forced to flow in the subsurface. In the electromagnetic method, currents are induced in the subsurface by the application of time-varying magnetic fields, whereas in the electrical resistivity method, current is injected into the ground through surface electrodes. The interaction of electrical & magnetic fields is governed by Maxwell's equation and well known laws of ampere & faraday. Geophysical methods make use of the interaction of electrical and magnetic fields with each other and their mutual interaction with matter to determine the properties of electrical conductivity or magnetic permeability of the earth. The electromagnetic method measures the bulk conductivity (the inverse of resistivity) of subsurface material beneath the instrument's transmitter and receiver coils. Electromagnetic readings are commonly expressed in conductivity units of millimhos/meter (pronounced "milly-moes per meter") or milliseimens/meter (1 millimho = 1 milliseimen). A "mho" is the reciprocal of an ohm. Electromagnetic can be used to locate pipes, utility lines, cables, buried steel drums, trenches, buried waste, and concentrated contaminant plumes. The method can also be used to map shallow geologic features such as lithologic changes, clay layers, and fault zones.

2.1.6 SEISMIC METHOD

Surface seismic techniques used in ground water pollution site investigations are largely restricted to seismic refraction and seismic reflection methods. The equipment used for both methods is fundamentally the same and both methods measure the travel-time of acoustic waves propagating through the subsurface. In the refraction method, the travel-time of waves refracted along an acoustic interface is measured. In the reflection method, the travel-time of a wave which reflects off an interface is measured. The interpretation of seismic data will yield subsurface velocity information, which is dependent upon the acoustic properties of the subsurface material. Their acoustic properties or velocities can categorize various geologic materials. Depth to geologic interfaces can be calculated using the velocities obtained from a seismic investigation. The geologic information gained from a seismic investigation can then be used in the hydrogeologic assessment of a ground water pollution site and the surrounding area. The interpretation of seismic data can indicate changes in lithology or stratigraphy, geologic structure, or water saturation (water table). Seismic methods are commonly used to determine the depth and structure of geologic and hydrogeologic units (for example, depth to bedrock or water table), estimate hydraulic conductivity, detect cavities or voids, determine structure stability, detect fractures/fault zones, and estimate rip ability. The choice of method depends upon the information needed and the nature of the study area. A geophysicist who is experienced in both methods, is aware of the geologic information needed by the hydro geologist, and is also aware of the environment of the study area must make this decision.

2.3 LITERATURE REVIEW

Geophysical data greatly helps in locating the groundwater potential in any hydro geological set up. This forms the basis of borehole geophysics (Kasonta, 1999). Electrical resistivity method happens to be the most applied method in geophysical exploration. It has been recognized to be more appropriate for hydro geological study of sedimentary basin (Todd, 2004).

A hydro geophysical investigation for groundwater in Lokoja metropolis, Kogi state, central Nigeria was carried out (Omali, 2014), two aquifer types were delineated. An unconfined aquifer was found within the weathered basement, the second aquifer was found at the weathered/fractured basement. These aquifers are thin in some of the localities while in others they are appreciably thick, hence enormous groundwater storage and discharge capacity was observed. Other researchers who investigated the subsurface conditions within lokoja area using electrical resistivity method include Gbemi (2007), Geo-Hydro Tech (2008), and Leo Flinch Nig Ltd (2008). This technique has been successfully used in the exploration for groundwater in sedimentary environment like Nnanka, Anambra (Emenike, 2001); for groundwater exploration in Ikorodu, Lagos (Obiora *et al*, 2005); and for groundwater exploration in the crystalline basement terrain around Onipe and adjoining areas, southwestern Nigeria (Anudu, 2011).

Subsurface geophysical investigation using vertical electrical sounding (VES) method was carried out around Bomo area, Kaduna state, Nigeria in other to study the subsurface geologic layer with view of determining the depth to the bedrock and thickness of the geologic layers. VES was carried out using schlumberger array at fifteen (15) VES stations. The field data obtained was analyzed using computer software (IP12Win) which gives an automatic interpretation of the apparent resistivity. The VES results revealed heterogeneous nature of the subsurface geological sequence. The geological sequence beneath the study area is composed of hard pan topsoil (clayey and sandy-lateritic), weather layer, partly weathered or fractured basement and fresh basement. The resistivity value for the topsoil layer varies from 40Ωm to 450Ωm with thickness ranging from 1.25 to 7.5m. The weathered basement has resistivity value ranging from 50Ωm to 593Ωm and thickness of between 1.37 to 20.1m. The fractured basement has resistivity values ranging from 218Ωm to 520Ωm and thickness of between 12.9 to 26.3m. The fresh basement (bedrock) has resistivity value ranging from 1215Ωm to 2150Ωm with infinite depth. However, the depth from the earth's surface to the bedrock surface varies between 2.63 to 34.99m and lastly the study further stressed the importance of the findings in civil engineering structures and ground water prospecting (Jatau *et al*, 2013). (Ezomo, *et al*. 2011), also conducted geophysical investigation of groundwater in Oluku village and its environs.

Linear schlumberger configuration was employed to delineate the formation strata and groundwater distribution in Ifon, Ondo state, Nigeria (Okolie *et al*, 2010). The aims were to identify variable sites for drilling borehole for long term supply of portable water in the town and its environs. Ten vertical electrical sounding VES were made using Schlumberger array six soundings were made along Orin-Oyin river road and four around the quarry. The obtained field data were subjected to analysis and interpretation by conventional curve matching and computer iteration techniques. The results reveal stations exhibits A, H and KH curves mainly. Also sites along the river road have their fifth and sixth layers consisting of medium to coarse grain and gravely sand which an indication of high water is bearing media (aquifer) within 25 to 30m, while sites around the quarry consist of rocks with far depth with no distinct aquifer. Sites along Orin-Oyin river road have formations of relatively high resistivity, the formation of site close to the river and around the quarry exhibits low resistivity.

Geoelectrical investigation of groundwater condition was carried out in Oleh, Nigeria to assess the groundwater condition of the area (Anomohanran, 2013). The method employed in the study was the vertical electrical sounding (VES) technique using Schlumberger configuration. The data obtained were interpreted by computer iteration process and the results when compared with lithologic log from existing borehole indicate a four layered formation. The first aquifer layer was identified along the second layer with resistivity values ranging from 347.4 to 1137Ωm and depth of 2.0 to 3.7m. Analysis of this layer revealed that this aquifer is unconfined and prone to pollution because it underlay's a loose sand and very thin clayey sand formation. The second aquifer located in the fourth layer is a viable portable water formation whose resistivity values ranged between 416.7 to 1459.2Ωm. The thickness of the aquifer was found to range between 12.0 to 14.9m while the depth was between 12.8 to 28.7m. Borehole for portable groundwater are therefore recommended within the forth layer.

A two dimensional shallow resistivity survey of the groundwater potential at the main campus of Nuhu Bamalli polytechnic, Zaria using electrical imaging technique was carried out (Olugbenga, 2009). Six results from the interpretation of the data collected suggest 2-4 layers in the area studied. However, there are patches of core rocks in some parts of the studied area. The resistivity value for the first layer (topsoil) varies from 10 to 400Ωm with thickness ranging from 1to 14m, the second layer (weathered basement) has resistivity values between 120 to 500Ωm and thickness ranging from 5 to 11m, the third layer (fractured basement) has resistivity value ranging from 500 to 1000Ωm and thickness between 3 to 6m, the fourth layer is the fresh basement (bedrock) has resistivity values greater than 1000Ωm and infinite thickness. The southwest of the study area thus, represent a promising aquifer with reasonable thickness of weathered basement and fractured zone. Also the area seems to be a zone of high hydraulic conductivity because of its low resistivity values. This area was recommended for possible groundwater exploration as it exhibited strong water bearing potential in the surface rocks.

A geophysical ground magnetic survey was carried out in eastern part of Ilesa town located in the southwestern part of Nigeria (kayode *et al*, 2013). Total field magnetic data was recorded using a proton precision geometric magnetometer along fifteen traverses. This research focused on delineation of subsurface geological structures that are suitable for mineral potential. The field data collected was qualitatively and quantitatively interpreted. The residual magnetic values were in the range of about 80nT to -330nT. The magnetic source depth was estimated using Peters half slope method which gave a maximum depth to basement of about 160m. The lateral extent of interpreted lithologies was estimated using the analytical signal. The results generated were used to delineate geological structures and to target areas with mineral potential.

Ground magnetic profiling was carried out around Oguta Lake in Imo State, Southeastern Nigeria (Chinyem, 2011). Seventy-Six stations in three profiles were established at five hundred meters intervals on major roads in the study area, a total distance of thirty five kilometers was covered. The result indicates that the highest field reading was 32835gamma while the lowest field was 28118gamma. Five anomalies were observed. The anomaly at the lake, was most prominent with magnetic readings of 28118 -29235 gamma and elevations of 17 -37 feet, all treading in the NE–SW direction. These anomalies, suggest that the lake has a tectonic origin.

CHAPTER THREE

MATERIALS AND METHODS

3.1 ELECTRICAL RESISTIVITY SURVEY

Electrical resistivity survey is used for studying horizontal and vertical discontinuities in the electrical properties of the subsurface materials. This technique employs an artificially generated electrical current which is introduced into the ground by two point electrode at the surface. The resulting potential difference that occurs between two additional measuring electrodes at the surface is then recorded (Telford *et al*, 1990). The resistivity of the ground can't be easily measured by just passing an electrical current through two grounded electrodes and then measuring the resulting voltage at these electrodes, but by measuring the resistance encountered by the electrical current passed through such electrode. Earth materials offer resistances to the passage of electrical current from one electrode point to another depending on the nature of subsurface materials. The positioning of the electrodes is an important factor in the measurement of the electrical field because an increase in the spacing between current electrodes results to a greater depth of current penetration and volumes of the earth measurement, both vertically and laterally. The resistance is a function of geometrical configuration of the electrodes and the electrical properties of the ground. Putting together the values of the measured output current, the resulting voltage and the electrode spacing will give the value of the resistivity (ρ) which is measured in ohm-meters (Ωm).

3.2ELECTRICAL RESISTIVITY THEORY

Electrical resistivity survey is one of the numerous methods used in the investigation of subsurface information. The method measures the subsurface resistivity by considering the flow of a continuous current through an isotropic homogenous media which forms an electric field **E** around the current source as in Figure 3.1. The current density **J** and electric field **E** are related through ohm's law.

$$\mathbf{J} = \sigma \boldsymbol{E} \qquad (3.01)$$

where **E** is the electric field (V/m) and also the potential gradient, σ is the conductivity (is the reciprocal of resistivity ρ) and is measured in Siemens per meter (S/m). Considering the flow of current around electrodes which introduces current *I* at the surface of a uniform half-space (Figure 3.1). Equation (3.01) gives

$$\boldsymbol{E} = \rho \boldsymbol{J} = \quad \nabla V = \quad \frac{dV}{\mathrm{dr}} \hat{\mathrm{r}} \qquad (3.02)$$

J is the current density and is equal to current *I* divided by the surface area, which is $2\pi r^2$ for a hemisphere of radius *r* formed around each electrode. Therefore the potential at any point in the medium or on the boundary is given by

$$V = \frac{I\rho}{2\pi r} \qquad (3.03)$$

r is the distance from the electrodes. For an electrode pair with current I at electrode A, and -I at electrode B (Figure 3.1), the potential at a point is given by the algebraic sum of the individual contributions equation (3.04).

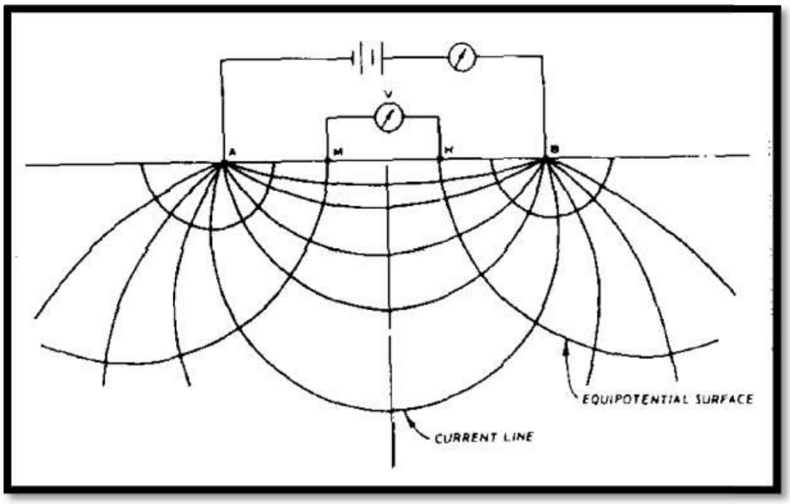


Figure 3.1**:** Equipotentials and Current Lines for Current Electrodes A and B on a Homogeneous Half-Space

$$V = \frac{\rho I}{2\pi r_A} \quad \frac{\rho I}{2\pi r_B} = \frac{\rho I}{2\pi}\left[\frac{1}{r_A} \quad \frac{1}{r_B}\right] \qquad (3.04)$$

r_A and r_B = distances from the point to electrodes *A* and *B.*

In addition to current electrodes A and B, Figure 3.1 shows a pair of electrodes M and N, which carry no current, but between which the potential difference V may be measured. Following the previous equation, the potential difference V may be written.

$$V = V_m \quad V_n = \frac{\rho I}{2\pi}\left(\frac{1}{AM} \quad \frac{1}{BM} + \frac{1}{BN} \quad \frac{1}{AN}\right) \qquad (3.05)$$

where V_m and V_n are potentials at M and N respectively. AM, BM, BN, AN, are distances between electrodes A and M, B and M, B and N, A and N respectively. Equation (3.05) can be written in terms of the resistivity ρ as

$$\rho = \frac{V}{I}\left[\frac{2\pi}{\frac{1}{AM} - \frac{1}{BM} + \frac{1}{BN} \quad \frac{1}{AN}}\right] = K\frac{V}{I} \qquad (3.06)$$

where k is the geometric factor from the bracket in equation 3.6 above that is

$$K = \frac{2\pi}{\frac{1}{AM} - \frac{1}{BM} + \frac{1}{BN} - \frac{1}{AN}} = \pi\left(\frac{AB^2}{MN} \quad \frac{MN}{4}\right) \qquad (3.07)$$

The resistivity in equation (3.06) above represents that of a homogeneous or uniform earth surface measurement. Whenever these measurements are taken over a real heterogeneous earth surface, equation (3.06) represents apparent resistivity of the earth with the symbol ρ_a which has no relation to the actual value of resistivity in a heterogeneous earth. The apparent resistivity may be greater, less or equal (in rare case) to the actual resistivity in a heterogeneous earth (Keller, 1966).

3.3 MATERIALS FOR DATA ACQUITION

The equipments for this geophysical survey are ABEM SAS 300C terrameter. The terrameter is equipped with two current transmission cables, two potential cables and four metal electrodes. Also we used three survey hammers for driving electrodes into the ground, measuring tapes, layout tapes and cutlass for clearing. The terrameter can operate in two modes; in the resistivity mode, it comprises a battery power, deep penetrating meter with an output sufficient for a current electrode separation of 2000 meters under good surveying conditions. Discrimination circuit and programming separate DC voltage, self potentials and noise from the incoming signal. The ratio between voltage and the current (V/I) is calculated automatically and displayed in digital form in ohms, milli-ohms, or kilo-ohms. This can be used to obtain the values of the apparent resistivity if the array geometry data is available.

Auxiliary equipment for the survey is a global positioning system (GPS), to determine the resistivity survey locations and elevation.

3.4 DATA ACQUISITION PROCEDURE

During the survey a total of twenty (20) vertical electrical soundings (VES) were carried out along four profiles with five VES on each profile using the Schlumberger electrode array at 20 VES points within the Permanent Site of Federal University Lokoja, with each VES point on a profile spaced 25m apart from each other. At each VES point a global positioning system (GPS) was used as a first step to measure the longitudes, latitudes and elevations. The terrameter was then powered using a 12v external cell which allows for at least ten sounding to be carried out at a stretch without running out of power, the wires were then connected to the four electrode (current and potential) and then to the terrameter also. With the aid of the terrameter, 10amp of current was sent into the ground at each $AB/2$ and $MN/2$ distance and the value of the resistance was recorded. The array geometry used is as follows: $AB/2$; 1.0, 3.0, 5.0, 8.0, 10.0, 15.0, 20.0, 20.0, 25.0, 30.0, 40.0, 50.0, 60.0, 80.0, 100.0, 100.0 and $MN/2$; 0.5, 0.5, 0.5, 0.5, 0.5,0.5, 0.5, 5.0, 5.0, 5.0, 5.0, 5.0, 5.0, 5.0, 5.0 and 10.0 respectively.

3.5 ELECTRODE CONFIGURATION

Electrodes array or configuration is the distribution pattern of electrodes on the earth surface during electrical resistivity survey. There are various types of standard configuration associated with different advantages and disadvantages over each other which can be applied during electrical resistivity survey work. The electrical resistivity method uses a series of electrodes nail to the ground about six inches deep along a straight profile or 3D grid. The distance between the electrodes depends on the desired depth of investigation and the target to be imaged. The farther apart the electrodes the "deeper" the electricity goes into the earth, at the expense of resolution; this is because the fraction of total current that flow at depth varies with the current-electrode separation. Usually the depth of penetration is about one-third of the current electrode spacing. The most commonly used configuration activates four electrodes at a time, two for passing current into the ground and two for measuring the potential difference; these are the Wenner, the Schlumberger and the dipole-dipole electrode layout.

3.6 ELECTRODE ARRAY CHOICE

Near-surface inhomogeneities are strong factor which influences the choice of array. When a Wenner or dipole–dipole array is expanded, all the electrodes are moved and the contributions from near-surface bodies vary from reading to reading. With a Schlumberger array, near-surface effects vary much less, provided that only the outer electrodes are moved, and for this reason the array is often preferred for depth sounding. Since depth-sounding involves expansion about a centre point, the instruments generally stay in one place. Instrument portability is therefore less important than in profiling. The Wenner array is very popular but for speed and convenience the Schlumberger array, in which only two electrodes are moved, is often preferred. Interpretational literature, computer programs and type curves are widely available for both arrays. Local near-surface variations in resistivity nearly always introduce noise with amplitudes greater than the differences between the Wenner and Schlumberger curves. Array orientation is often constrained by local conditions, i.e. there may be only one direction in which electrodes can be taken a sufficient distance in a straight line.

3.7 SCHLUMBERGER ELECTRODE CONFIGURATION

In this array, the current electrodes are spaced much further apart than the potential electrodes (Figure 3.2) below. The electric field is measured approximately. Thus, from the data obtained the apparent resistivities ρ_a are calculated using equation (3.06). In sounding, the potential electrodes are fixed while the current electrode separation is increased symmetrically about the centre of spread. These shows that Schlumberger soundings are carried out under the constraint that potential electrode spacing (MN) is small compared to the current electrode spacing (AB), that is (MN <AB/2). Where AB is the distance between the current electrodes and MN is the distance between the potential electrodes. In this research the Schlumberger electrode configuration was used to carried out the vertical electrical soundings because of the following reasons;

i. The effect of local and shallow inhomogeneities near the electrodes is constant for all measurements since the potential electrodes are kept fixed.

ii. Schlumberger array is faster in field operations, since only the current electrodes must be moved between all readings while the potential electrodes are moved only exceptionally. It is therefore more effective since the array saves time and manpower.

iii. The relative error resulting from the electrode effect is same for all measurement and these can be handled easily.

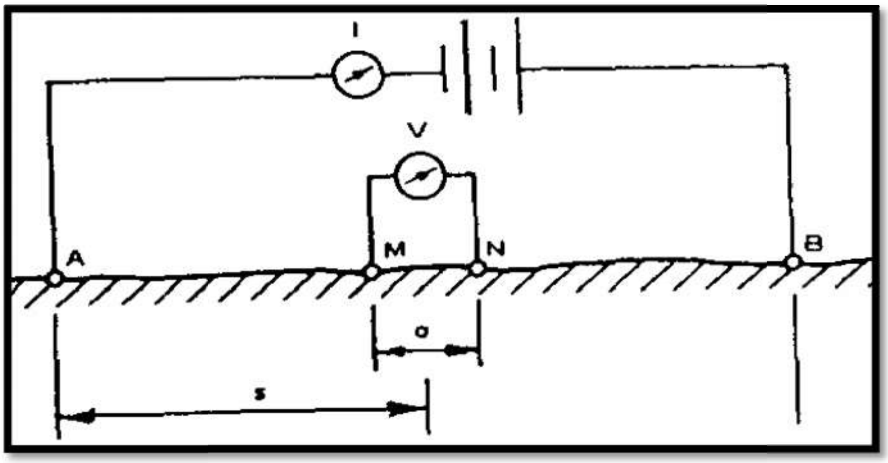


Figure 3.2: The Schlumberger Array

3.8 IPI2Win OVERVIEW

IP12Win is designed for vertical electrical sounding and or/induced polarization data curves 1D interpretation along a single profile (Bobachev, 2001).This special attention is paid to the user-friendly interactive interpreting. Due to handy control the interpreter is able to choose from a set of equivalent solutions, the best fitting both geophysical data (i.e. providing the least fitting error) and geologically sensible resistivity cross section. The main advantage of this program is comfortable manual interpretation. The parameters of the model could be change in different ways on the worksheet, on resistivity cross-section and through drag-and-drop of part of the resistivity curve (the blue one). The software capabilities are as follows:

i. Data Management through data file selection, topography input, data correction, viewing curves, models and cross-sections (Figure 3.3)

ii. Vertical electrical sounding (VES) Curve Interpretation through model creation, altering and automated & interactive interpretation (Figure 3.4).

iii. Managing Results through saving results, printing cross-sections and saving cross-section image (Figure 3.5)

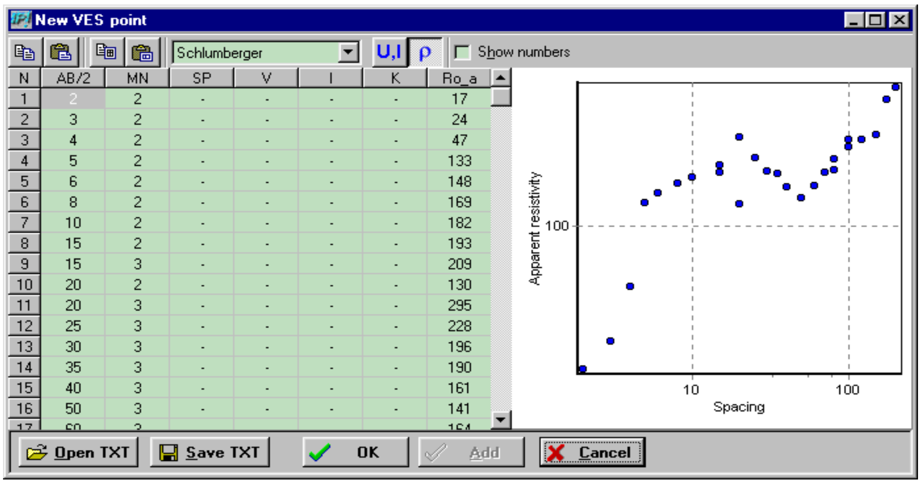


Figure 3.3: A Simple Worksheet for Data Management

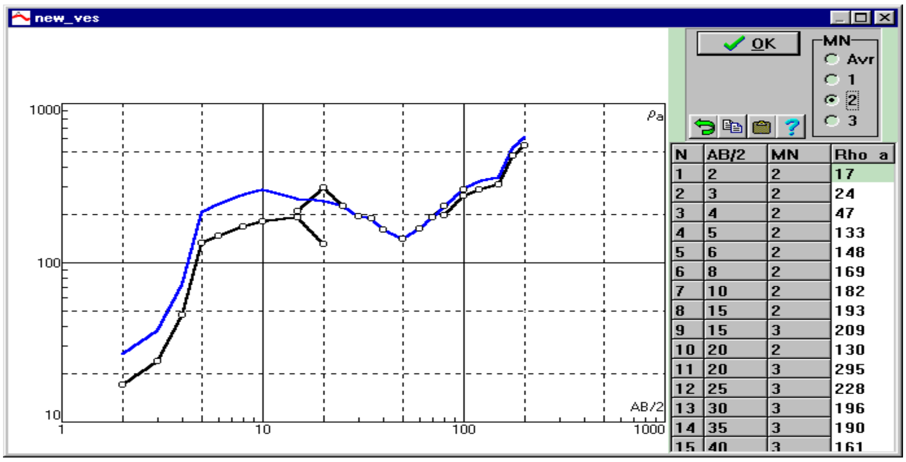


Figure 3.4: An Interface for Data Model Creation and Alteration.

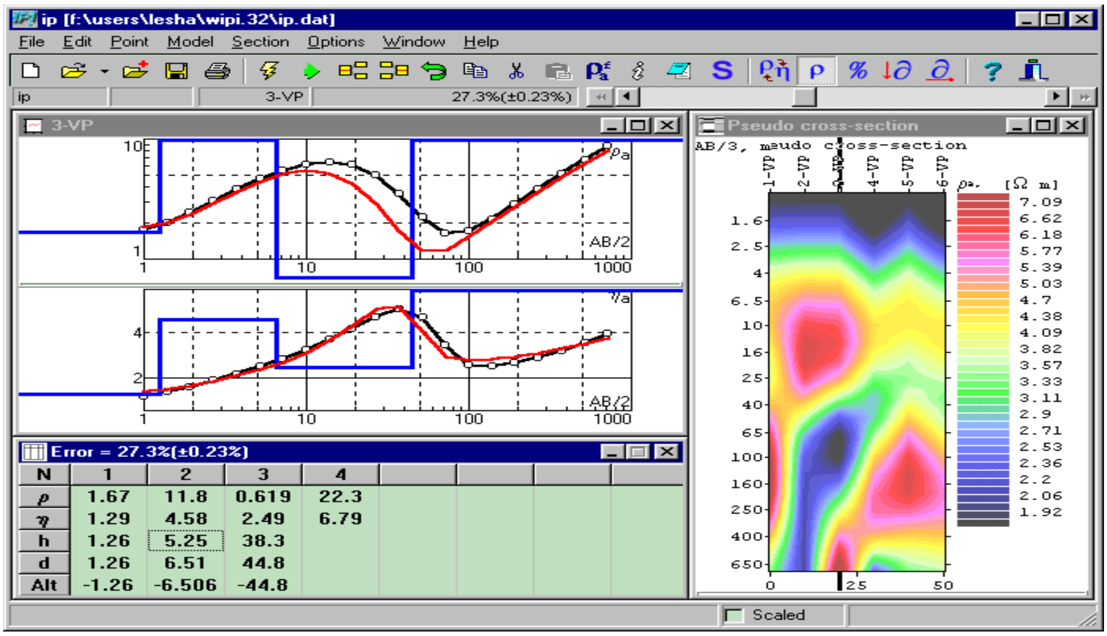


Figure 3.5: An Interface for Viewing, Saving and Printing Result.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

The interpretation of geophysical data involves expressing the information obtained from the surface measurement into geological section/form, from which both qualitative and quantitative deductions can be made. Generally, due to the advances in modern computers, software's are readily available for such interpretations and hence percentage of ambiguity is greatly reduced. There are so many methods of interpreting apparent resistivity data; they are the empirical methods which include Moore Cumulative Resistivity Method (Moore, 1945) and the Barnes Layer Method (Barnes, 1952).

Analytical Methods; this involves the curve matching, the computer-based etc. The computer-based approach was suggested by Zohdy (1989). Recently, due to the advancement in modern technology, different computer programs have being design to ease the ambiguity in the interpretation of apparent resistivity data.

4.2 INTERPRETATION OF RESISTIVITY DATA

An exclusively quantitative interpretation of apparent resistivity data is often difficult because of the wide variations in the resistivity possessed by geological materials and the difficulty in developing theoretical expressions for apparent resistivities of all but the simplest geometries (Burger and Burger, 1992). Zohdy produced a technique for the automatic inversion of resistivity sounding curves (Zohdy, 1989). The value of the apparent resistivity at each sounding point was calculated from the resistance values obtained in the field (Table 4.1).The apparent resistivity calculated were presented as sounding curves using IPI2Win, a software program version 3.0.1. Least-squares optimization was used in adjusting the starting model obtained successively until the difference between the observed and modeled pseudo-sections is reduced to a minimum. It was assumed that there are as many subsurface layers as there are data points on the field sounding curve and that the true resistivity of each of these assumed layers is that of the corresponding apparent resistivity value. The mean depth of each layer is taken as the electrode spacing at which the apparent resistivity was measured multiplied by some constant.

Table 4.1: Resistivity Data for VES 1, Profile 1.

S/No	AB/2	MN/2	R (Ω)	ρ(Ωm)
1	1	0.5	169.0	398.84
2	3	0.5	17.4	477.80
3	5	0.5	3.6	279.79
4	8	0.5	0.73	146.13
5	10	0.5	0.45	140.97
6	15	0.5	0.24	169.37
7	20	0.5	0.11	141.84
8	20	5.0	0.87	102.80
9	25	5.0	1.08	203.47
10	30	5.0	0.84	231.34
11	40	5.0	0.46	225.52

12	50	5.0	4.17	3240.72
13	60	5.0	0.32	353.60
14	80	5.0	0.39	784.69
15	100	5.0	0.41	1312.37
16	100	10	0.71	1108.22

4.3 DATA ANALYSIS

The geological sections of each of the four profiles were subsequently drawn based on the following information.

i. The layer resistivity and depth values obtained from the sounding curves of the respective VES station as shown in Figures 4.2(a,b,c,d,e), 4.4(a,b,c,d,e), 4.6(a,b,c,d,e), and 4.8(a,b,c,d,e).

ii. The nature of the superficial materials (rock types, outcrops and soil types) found within the study area was also considered in deriving the geologic sections.

By putting the above into consideration, thus, the first stage in obtaining the geologic sections was to input the modeled depth obtained from the sounding curves into surfer version 11(computer software). The geoelectrical subdivisions were then given their appropriate lithological unit based on their characteristic resistivities as in (Table 4.3) and compared with the lithology of the borehole log Table 4.2 available. It is however, not all the times that the geologic sections boundary will necessarily coincide with those of the geoelectric (Keller *et al*, 1966). The boundaries between the various layers are most often not so distinct (Aboh, 1996); broken lines are thus used to demarcate the boundaries of layers.

Table 4.2 Typical Resistivity Values of Rock Materials after (Aboh, 1996)

No	Rock Types	Resistivity Range (ohm-m)
1	Clay	1-100
2	Sand and Gravel	100-180
3	Lateritic Soil	200-500

4	Weathered Laterite	500-1000
5	Weathered Basement	20-400
6	Fractured Basement	135-900
7	Fresh Basement	> 1000

Table 4.3 Resistivity Values Adopted for this Work

No	Rock Types	Resistivity Range (ohm-m)
1	Clay	1-120
2	Sand and Gravel	100-180
3	Lateritic Soil	180-500
4	Weathered Laterite	500-1000
5	Weathered Basement	20-500
6	Fractured Basement	300-800
7	Fresh Basement	> 900

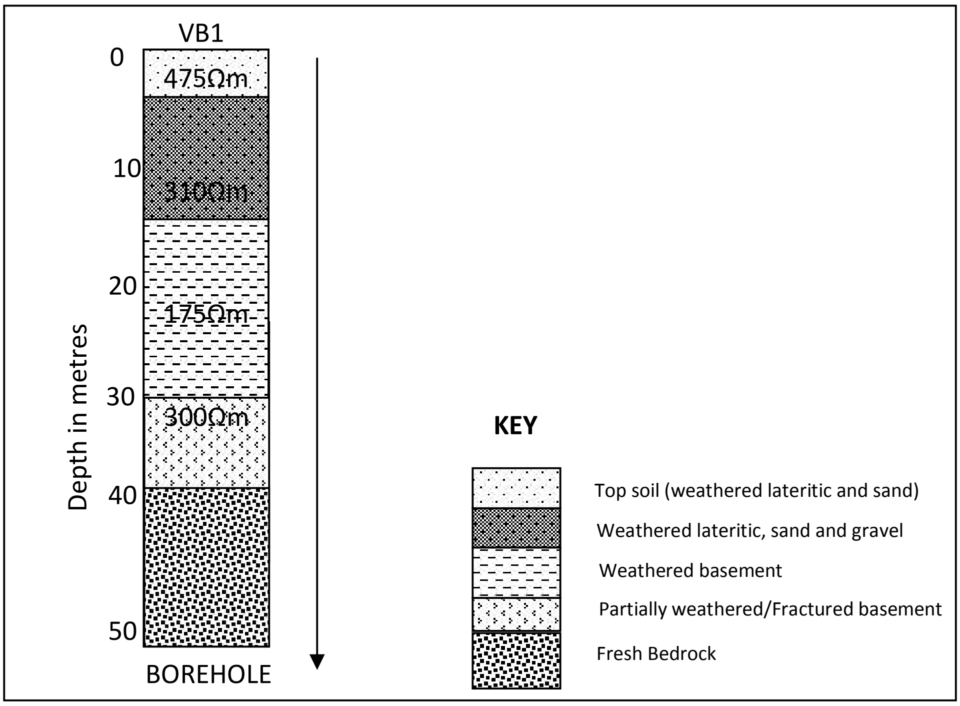
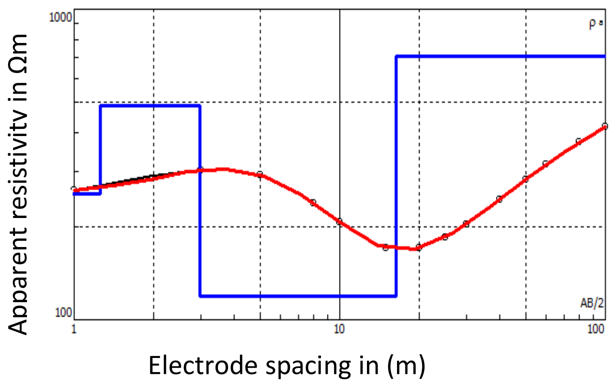


Figure 4.1 Log Data for the Borehole Located within Felele Community, Lokoja, Kogi State. Obtained from: VRS Drillers LTD, Lokoja, Kogi State

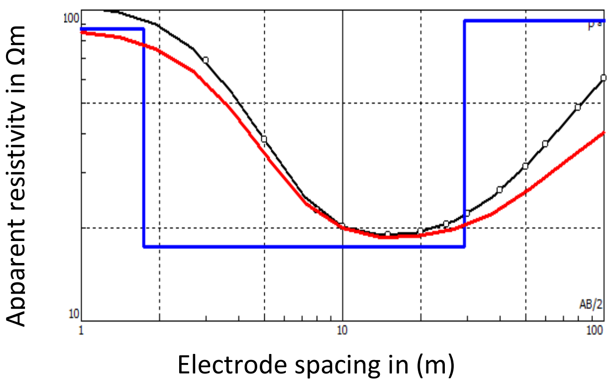
4.4 RESULTS

The data obtained from each VES point were recorded as in Table 1.0. Using the equation 3.07, the geometric factors K in meters were calculated as a function of electrode spacing and multiplied by the resistance values R recorded to obtain the apparent resistivities ρ_a in (Ωm). Thus, putting the values of the resistivity and electrode spacing into IPI2win (computer programs) the sounding curves Figures 4.2(a,b,c,d,e), 4.4(a,b,c,d,e), 4.6(a,b,c,d,e), and 4.8(a,b,c,d,e) were obtained. Lastly the geologic sections for each profile Figures (4.3, 4.5, 4.7and 4.9) were obtained by putting the information from the sounding curves in Surfer version.11 software.



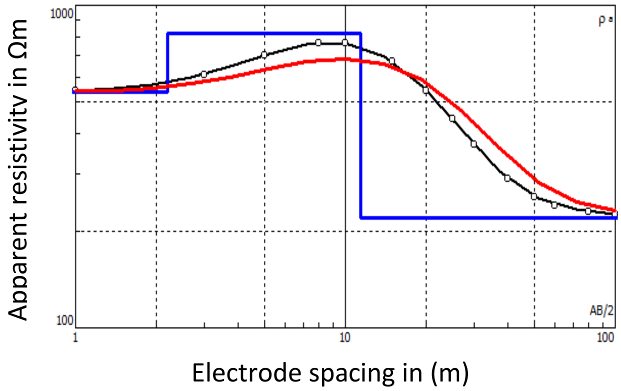
N	ρ	h	d	Alt
1	254.3	1.253	1.253	-1.2531
2	489.5	1.725	2.978	-2.9776
3	118.6	13.27	16.25	-16.248
4	704.7			

(a) VES 1Profile 1



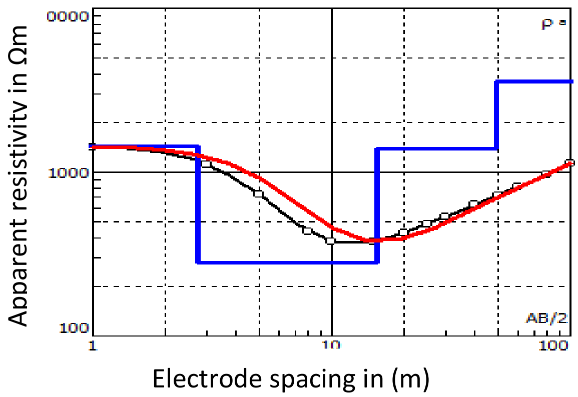
N	ρ	h	d	Alt
1	87	1.73	1.73	-1.732
2	17.3	27.5	29.2	-29.24
3	92.5			

(b) VES 2 Profile 1



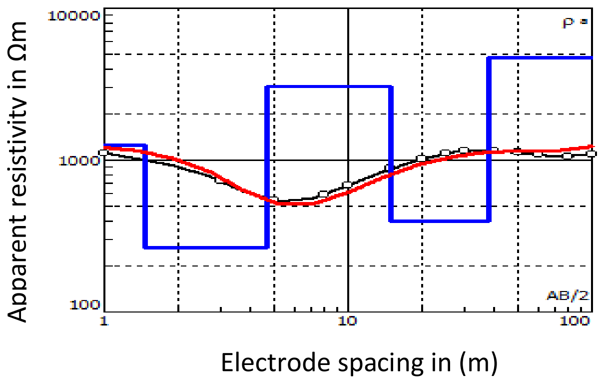
N	ρ	h	d	Alt
1	538	2.19	2.19	-2.19
2	818	9.21	11.4	-11.4
3	219			

(c) VES 3 Profile 1



N	ρ	h	d	Alt
1	1432	1.26	1.26	-1.255
2	1442	1.49	2.75	-2.75
3	280	12.7	15.5	-15.47
4	1393	33.4	48.9	-48.91
5	3573			

(d) VES 4 Profile 1



N	ρ	h	d	Alt
1	1255	1.47	1.47	-1.468
2	264	3.17	4.64	-4.642
3	3054	10.3	14.9	-14.94
4	397	22.7	37.7	-37.65
5	4723			

(e) VES 5 Profile 1

Figure 4.2 (a,b,c,d,e): Sounding Curves for Profile 1.

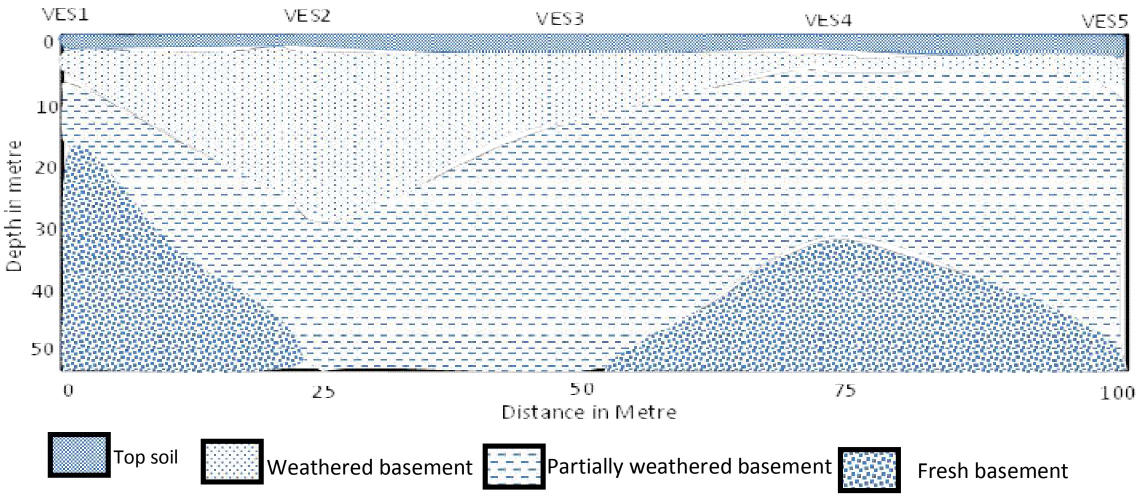
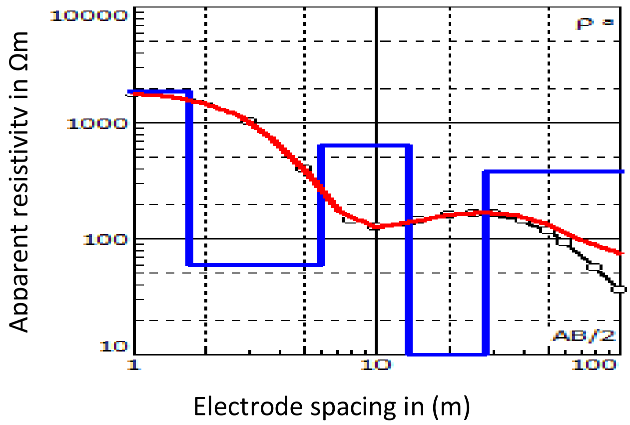
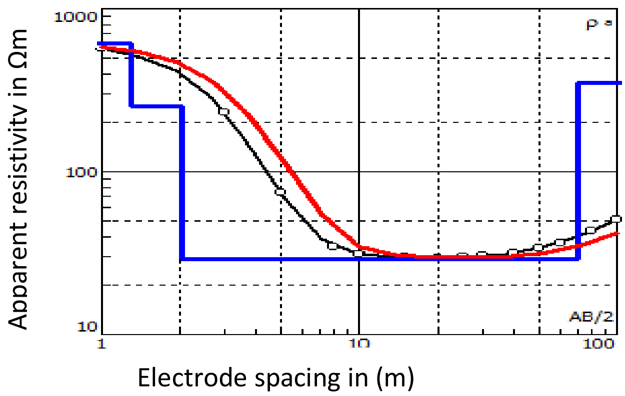


Figure 4.3: Geological Section along Profile 1



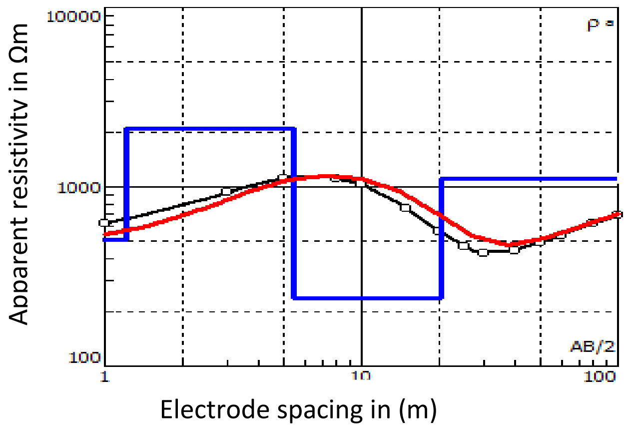
N	ρ	h	d	Alt
1	1859	1.7	1.7	-1.701
2	60	4.18	5.88	-5.878
3	642	7.34	13.2	-13.22
4	10	14.4	27.6	-27.63
5	380			

(a) VES 1 Profile 2



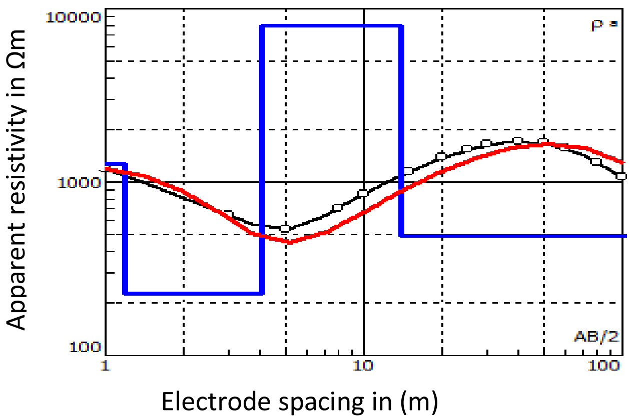
N	ρ	h	d	Alt
1	614	1.3	1.3	-1.299
2	253	0.746	2.04	-2.045
3	29	68.5	70.5	-70.55
4	354			

(b) VES 2 Profile 2



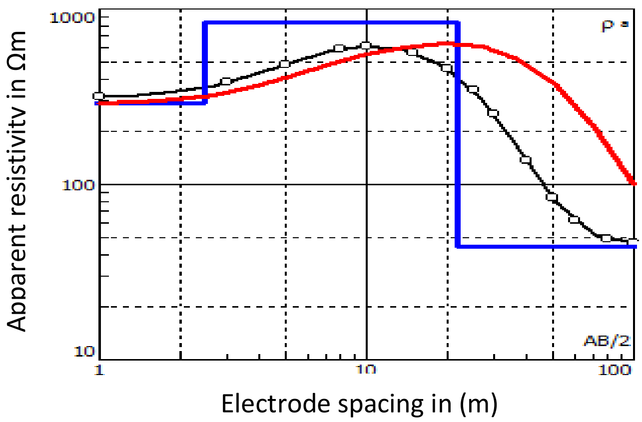
N	ρ	h	d	Alt
1	506	1.21	1.21	-1.212
2	2117	4.22	5.43	-5.431
3	239	15	20.4	-20.45
4	1110			

(c) VES 3 Profile 2



N	ρ	h	d	Alt
1	1285	1.19	1.19	-1.194
2	227	2.84	4.04	-4.037
3	7971	9.89	13.9	-13.93
4	489			

(d) VES 4 Profile 2



N	ρ	h	d	Alt
1	290	2.47	2.47	-2.473
2	840	19.5	21.9	-21.92
3	44.4			

(e) VES 5 Profile 2

Figure 4.4(a,b,c,d,e): Sounding Curves for Profile 2

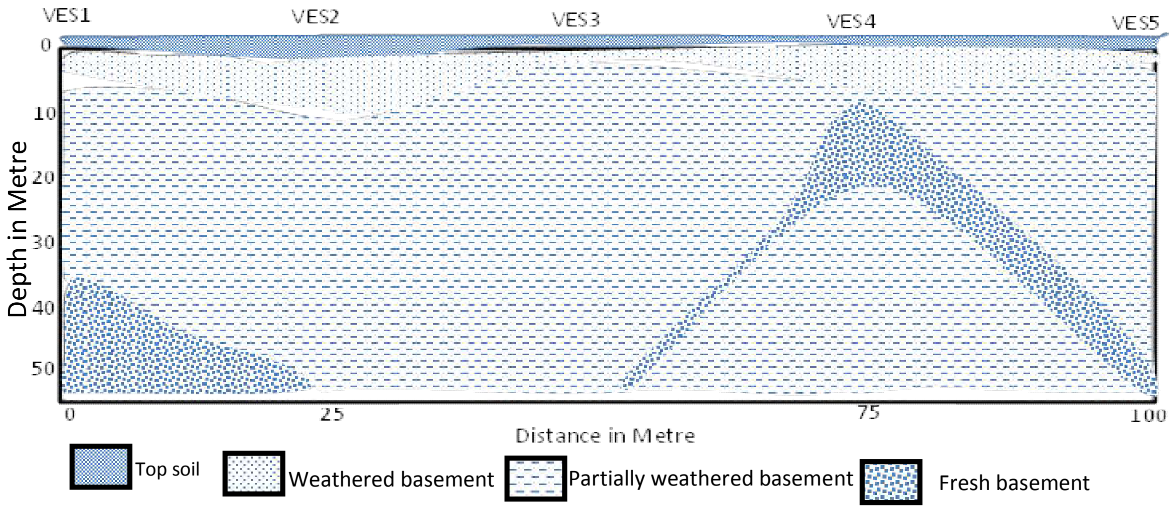
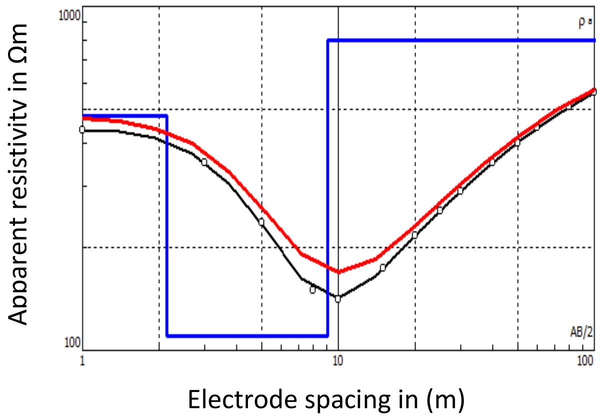
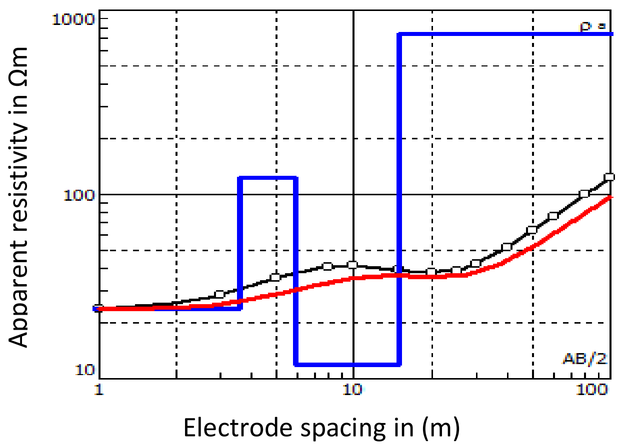


Figure 4.5: Geological Section along Profile 2



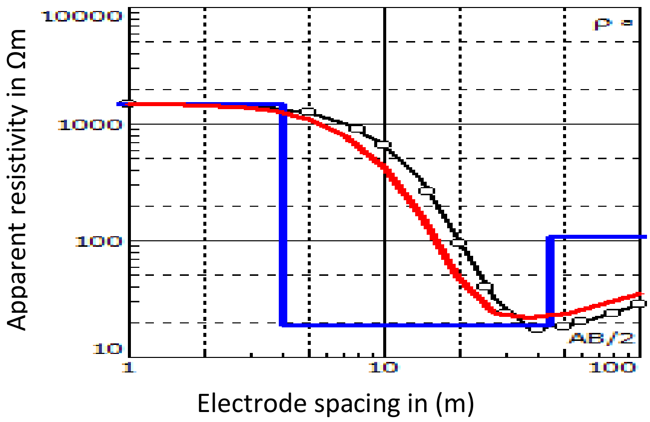
N	ρ	h	d	Alt
1	481	2.14	2.14	-2.136
2	110	6.95	9.09	-9.085
3	797			

(a) VES 1 Profile 3



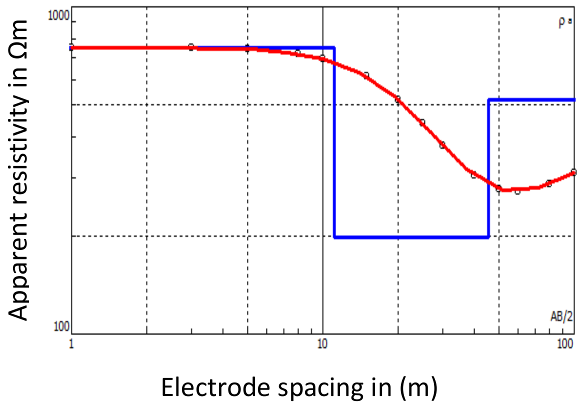
N	ρ	h	d	Alt
1	23.7	3.57	3.57	-3.573
2	124	2.35	5.93	-5.926
3	12	9.01	14.9	-14.94
4	743			

(b) VES 2 Profile 3



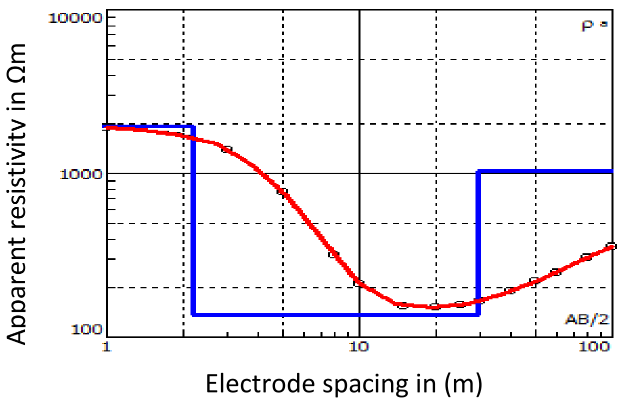
(c) VES 3 Profile 3

N	ρ	h	d	Alt
1	1481	4	4	-4.002
2	18.7	40.8	44.8	-44.83
3	108			



(d) VES 4 Profile 3

N	ρ	h	d	Alt
1	749.9	11.1	11.1	-11.1
2	197	34.5	45.6	-45.61
3	519.9			



(e) VES 5 Profile 3

N	ρ	h	d	Alt
1	1924	2.19	2.19	-2.192
2	137	27	29.2	-29.24
3	1027			

Figure 4.6 (a,b,c,d,e): Sounding Curves for Profile 3

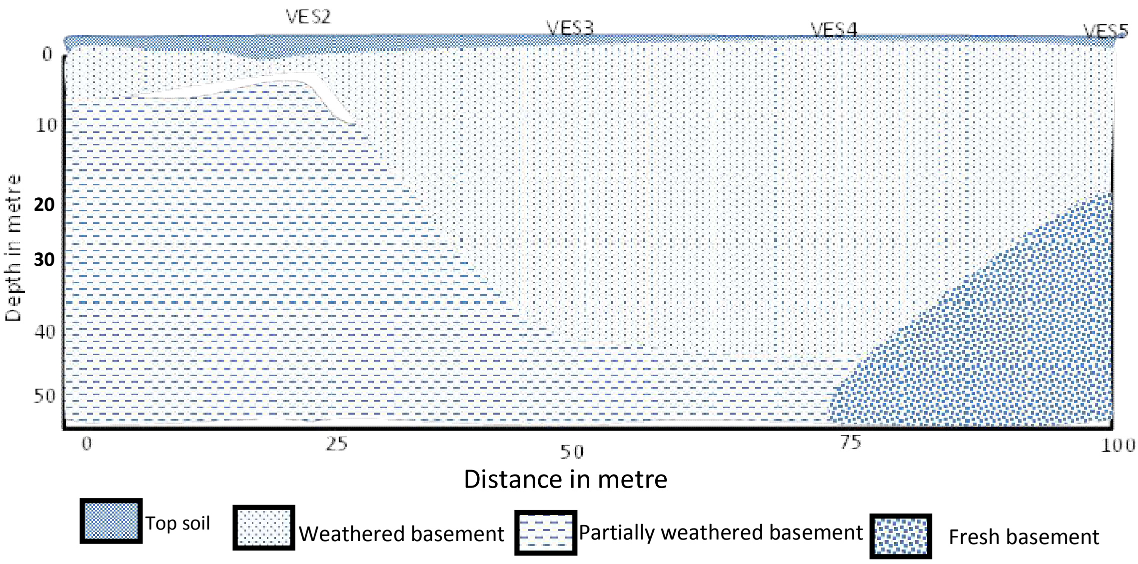
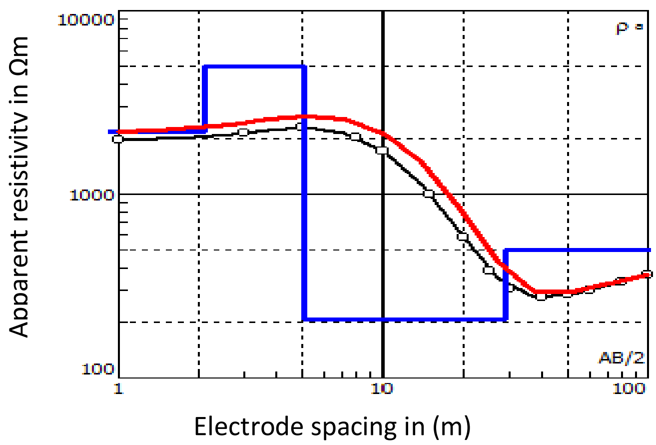
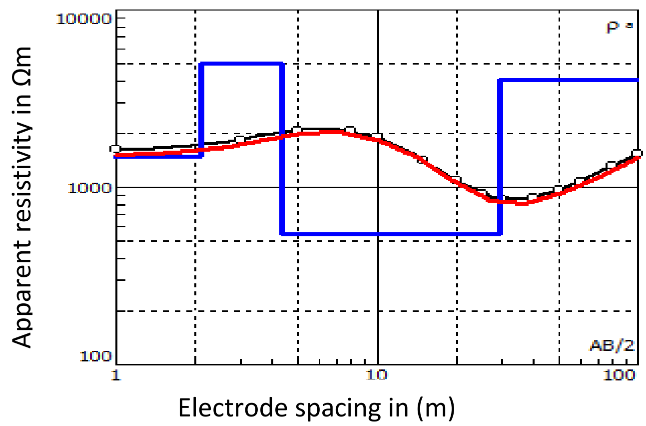


Figure 4.7: Geological Section along Profile 3



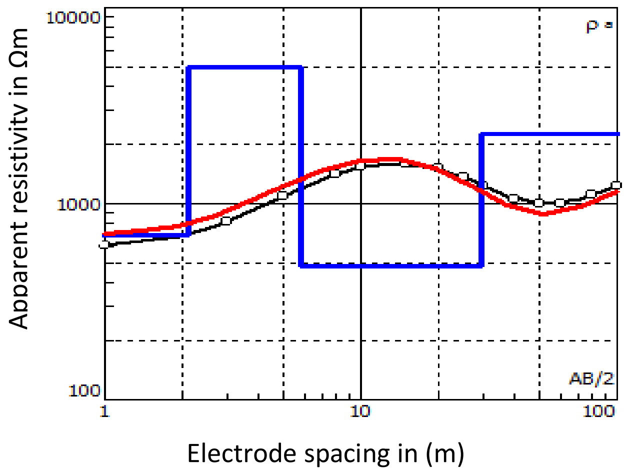
N	ρ	h	d	Alt
1	2192	2.12	2.12	-2.117
2	4977	2.95	5.06	-5.065
3	208	24.1	29.2	-29.21
4	498			

(a) VES 1 Profile 4



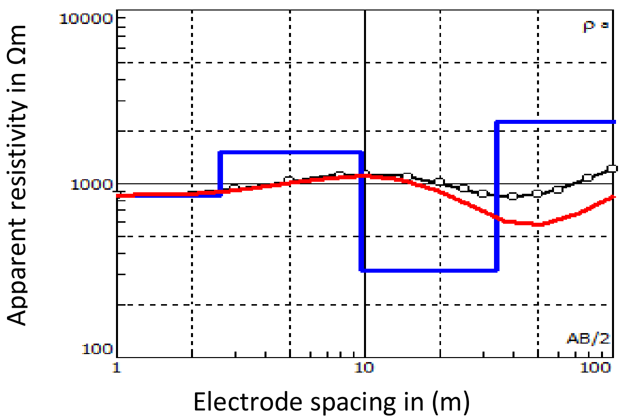
N	ρ	h	d	Alt
1	1494	2.13	2.13	-2.131
2	5009	2.18	4.31	-4.311
3	543	25.2	29.5	-29.49
4	4037			

(b) VES 2 Profile 4



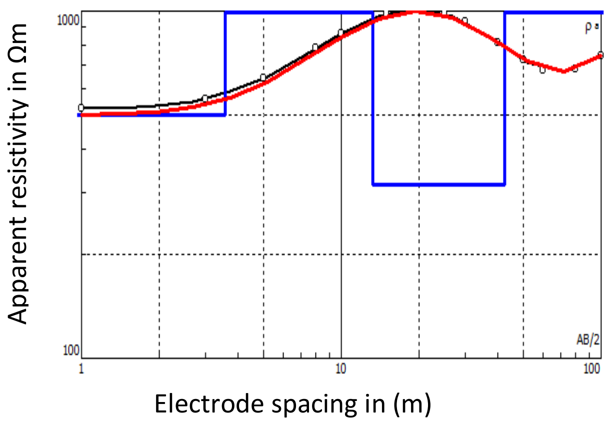
(c) VES 3 Profile 4

N	ρ	h	d	Alt
1	693	2.13	2.13	-2.131
2	5009	3.69	5.82	-5.823
3	481	23.7	29.5	-29.49
4	2270			



(d) VES 4 Profile 4

N	ρ	h	d	Alt
1	855	2.61	2.61	-2.61
2	1520	7.05	9.66	-9.657
3	316	24.3	33.9	-33.91
4	2270			



(e) VES 5 Profile 4

N	ρ	h	d	Alt
1	502	3.58	3.58	-3.584
2	1791	9.64	13.2	-13.22
3	316	29.3	42.5	-42.54
4	2298			

Figure 4.8 (a,b,c,d,e): Sounding Curves for Profile 4

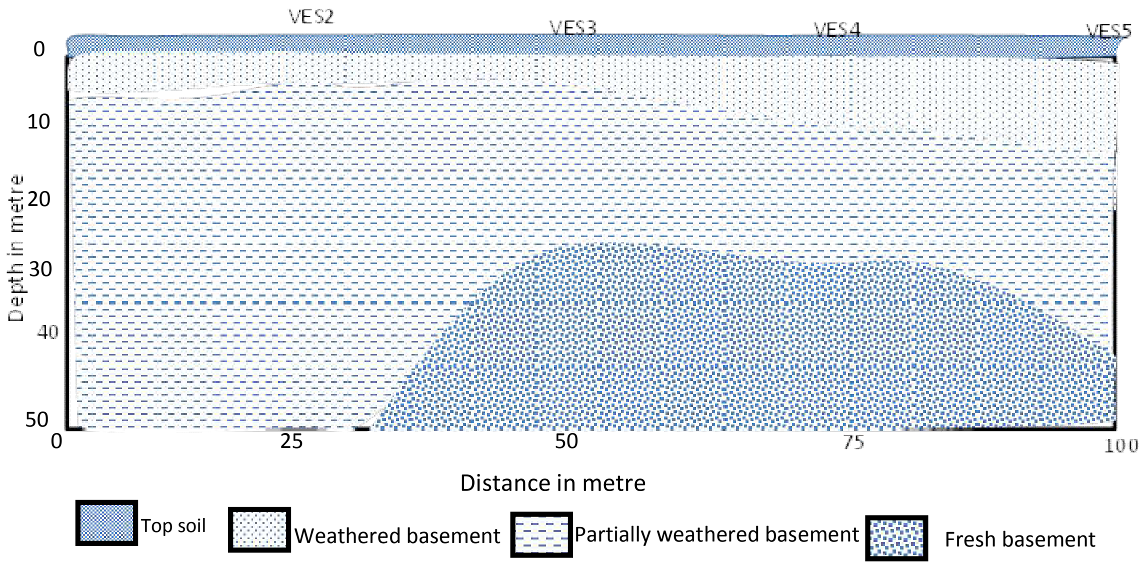


Figure 4.9: Geological Section along Profile 4

4.5 DISCUSSIONS

The geologic sections for the four profiles are shown in Figures 4.3, 4.5, 4.7 and 4.9 (the geologic section of each of the profiles is separated into four for clarity). Four geologic layers are suggested on these profiles. These layers will be interpretation based on the resistivity values adopted for the research (Table 4.3), the borehole log obtained from the study area and the nature of the outcrops within the study area.

Table 4.5 Resistivity Values of Different Layers in the Study Area and Their Description

Layers	**Resistivity Values (Ωm)**	**Description**
Surface Layer	20-120 120-250	Top soil, consists of saturated clay materials, and indicates high moisture content. Top soil, consists of sand and laterite material
Second Layer	25-150 160-450	Weathered Basement, highly saturated clay Weathered Basement, partially saturated, good as aquiferous layer
Third Layer	300-800	Partially weathered/Fractured Basement, considered as the aquiferous zone, as it indicates water accumulation
Fourth layer	>900	Fresh Bedrock, consists of gravel materials

In Profile 1 (Figure 4.3), the first layer which is the top soil has resistivity values ranging from 50-240Ωm. It is evident that this layer does not consist of the same material across the entire length of the profile. The thickness of this layer ranges from 1.0m - 2.6m. This layer composed mostly of sandy/clayey soil with rich in organic materials, hence the low resistivity within the layer. The second layer is the weathered basement which is composed mostly of loss gravel, sandy soil and clayey. The resistivity within this layer is about 100-240Ωm. And have an average thickness of 13.0m with wider depth at VES 2. The third layer is the partial weathered basement composed of mostly sand stone, gravel and sandy soil. This layer has a thickness of about 10-40m, at VES point 2 and 3, the layer extend beyond 50m. The resistivity value within this layer indicates that is it good for groundwater exploration. The last layer is the fresh basement (bedrock) with resistivity value of 1000Ωm and above. The layer is clearly seen at the first VES point and at a distance of 50-100m along the profile line.

In profile 2 (Figure 4.5), the first layer has thickness of about 1-3m with resistivity value of about 20-150Ωm. This is the top soil. The low resistivity within this layer indicates the high concentration of organic material. The second layer which is the weathered basement has an average resistivity value of about 240Ωm and thickness of about 4.0m. The third layer is the partial weathered basement composed mostly of gravel and sand stone. It has an average resistivity value of about 300Ωm. This layer is generally seen occupying the entire section. And it serves as a good groundwater aquifer within the area. The last layer is visible at a depth of about 35.0m at 0-25m along the profile, it is the fresh basement.

In profile 3, (Figure 4.7) the top soil has an average resistivity value of about 80Ωm and thickness of about 1.5m. This layer is rich in organic compounds, hence the low resistivity. The second layer is the weathered basement. Weathering of the basement is high in this section hence the deepening of the layer at a distance of about 25-75m along the profile line. The third layer is the partial weathered basement; it starts from the beginning of the profile at a depth of about 10.0m to a distance of 75.0m along the profile. It has average resistivity value of about 270Ωm. It will serve as a good aquifer for groundwater as it extends beyond 50m across most of the profile line. The last layer is the fresh basement visible at a distance of 75-100m along the profile line and at a depth of about 25.0m.

In profile 4 (figure 4.9), the first layer is the top soil composed mostly of loss sandy soil/clayey soil and gravels. It has average resistivity value of about 150Ωm and thickness of about 1.7m. The second layer has a thickness of 2.0m from the surface, this is the weathered basement. The resistivity values ranges from 100-250Ωm. The third layer has a thickness of about 30.0m at a distance of 25-100m along the profile line. This layer extends beyond 50.0m as shown in the section at a distance of 0-25m. The fresh bedrock is evidence at a distance of about 25-100m along the profile.

CHAPTER FIVE

(SUMMARY, CONCLUSION AND RECOMMENDATIONS)

5.1 SUMMARY

Using ABEM SAS 300C terrameter, twenty (20) vertical electrical soundings (VES) along four profiles with five VES points on each profile was conducted using the Schlumberger electrode array (Figure 3.2) with a half electrode spacing of about hundred meters at 20 VES points within the study area and each VES point on a profile spaced 25m apart from each other. The result were analyzed using relevant computer software as indicated and four profiles of various pseudo sections were shown indicating a four heterogeneous layer subsurface of the study area which are; topsoil (sandy and clayey laterite), weathered basement, fractured basement and fresh basement with different resistivities and thickness. Further analysis of the results shows that the fresh basement (bedrock) of the study area represents a small part across the profiles. It also delineates two aquifer types in the area, they are the weathered basement aquifer and fractured basement aquifer but most of the groundwater aquifers are located within the fractured basement at a good depth of about 40m with no major fractures within the area.

5.2 CONCLUSION

The survey shows that there are four geologic layers in the study area. The layers sequence delineated are the topsoil, weathered basement, partially weathered/fractured basement and fresh basement. The topsoil has a resistivity value of 20-250Ωm and thickness of 1.0m to 3.0m; the weathered basement (second layer) is 2.0m to 41.5m thick with a wide domination at profile 3 (figure 4.7) and resistivity value between 25-300Ωm; the third layer (partially weathered/fractured basement) has resistivity value ranging from 100-600Ωm with thickness of 5.0m to 50m across most part of the area and the fourth layer is the fresh basement with resistivity of 900Ωm and above with infinite depth. It forms the bedrock of the study area but represents a small part of the area across the profiles. So exploration of groundwater, structure construction of all kinds without serious excavation of the subsurface can be done.

5.3 RESEARCH FINDINGS

At the end of this research, the following information was observed from the survey;

i. The subsurface of the permanent site (study area) constitutes four geological layers, two aquifer zones and low overburden.
ii. The research has also been able to ascertain the applicability of schlumberger array in the determination of depth to basement.
iii. Lastly, the research has also confirmed the role of ohm's law in an electrical resistivity survey.

5.4 RECOMMEDATION

In the area, groundwater exploration especially within the weathered basement is highly recommended at a minimum depth of 35m and maximum depth of 60.0m. Also building of any structure can be done in the area as the subsurface tends to show adequate stability since no major geological threat was observed within the area. For a proper understanding of the subsurface, it is also recommended that further geophysical and geotechnical survey should be conducted within the area like gravity, electrical tomography and magnetic survey. This will bring out more information about the subsurface.

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APPENDIX

VES 1, PROFILE 1

S/No	AB/2	MN/2	R (Ω)	ρ(Ωm)
1	1	0.5	169.0	398.84
2	3	0.5	17.4	477.80
3	5	0.5	3.6	279.79
4	8	0.5	0.73	146.13
5	10	0.5	0.45	140.97
6	15	0.5	0.24	169.37
7	20	0.5	0.11	141.84
8	20	5.0	0.87	102.80
9	25	5.0	1.08	203.47
10	30	5.0	0.84	231.34
11	40	5.0	0.46	225.52
12	50	5.0	4.17	3240.72
13	60	5.0	0.32	353.60
14	80	5.0	0.39	784.69
15	100	5.0	0.41	1312.37
16	100	10	0.71	1108.22

VES 2, PROFILE 1

S/No	AB/2	MN/2	R (Ω)	P (Ωm)
1	1	0.5	146.00	344.56
2	3	0.5	10.60	291.29
3	5	0.5	3.05	237.05
4	8	0.5	0.85	171.15
5	10	0.5	0.47	149.72
6	15	0.5	0.23	168.67
7	20	0.5	0.30	386.61
8	20	5.0	0.76	89.84
9	25	5.0	0.72	136.03
10	30	5.0	0.70	193.70
11	40	5.0	0.69	343.71
12	50	5.0	0.57	442.98
13	60	5.0	0.48	539.95
14	80	5.0	0.28	97.41

15	100	5.0	0.03	156.98
16	100	10	0.10	234.12

VES 3, PROFILE 1

S/No	AB/2	MN/2	R (Ω)	P (Ωm)
1	1	0.5	673.00	1588.28
2	3	0.5	43.90	1206.37
3	5	0.5	13.10	1018.13
4	8	0.5	1.58	316.65
5	10	0.5	0.90	495.42
6	15	0.5	0.70	782.00
7	20	0.5	0.62	174.27
8	20	5.0	1.48	322.16
9	25	5.0	1.71	387.40
10	30	5.0	1.41	1023.72
11	40	5.0	2.07	1632.02
12	50	5.0	2.10	1414.41
13	60	5.0	1.26	2742.40
14	80	5.0	1.37	4353.69
15	100	5.0	1.39	3839.12
16	100	10	2.47	3442.32

VES 4, PROFILE 1

S/No	AB/2	MN/2	R (Ω)	P (Ωm)
1	1	0.5	402.00	948.72
2	3	0.5	21.10	579.83
3	5	0.5	5.64	438.34
4	8	0.5	4.21	842.76
5	10	0.5	3.88	1215.29
6	15	0.5	4.44	3133.40
7	20	0.5	4.48	5623.39
8	20	5.0	5.41	637.03
9	25	5.0	2.23	866.64
10	30	5.0	4.74	670.39
11	40	5.0	4.50	2344.17
12	50	5.0	1.29	3494.18
13	60	5.0	1.92	1448.36
14	80	5.0	0.73	2286.47
15	100	5.0	2.72	4225.98

16	100	10	3.22	4342.11

VES 5, PROFILE 1

S/No	AB/2	MN/2	R (Ω)	P (Ωm)
1	1	0.5	0.0011	2501.60
2	3	0.5	4.90	134.64
3	5	0.5	1.06	82.38
4	8	0.5	1.25	250.23
5	10	0.5	0.003	0.93
6	15	0.5	0.210	148.20
7	20	0.5	0.270	338.91
8	20	5.0	0.358	95.81
9	25	5.0	0.577	67.45
10	30	5.0	0.805	158.53
11	40	5.0	2.740	398.11
12	50	5.0	1.670	2139.39
13	60	5.0	1.360	1874.66
14	80	5.0	0.957	2722.38
15	100	5.0	1.430	2997.47
16	100	10	1.773	2222.65

VES 1, PROFILE 2

S/No	AB/2	MN/2	R (Ω)	P (Ωm)
1	1	0.5	265.0	625.40
2	3	0.5	14.1	387.47
3	5	0.5	0.17	13.91
4	8	0.5	0.48	96.09
5	10	0.5	0.29	92.71
6	15	0.5	0.18	131.97
7	20	0.5	0.18	232.21
8	20	5.0	0.43	51.34
9	25	5.0	0.412	77.62
10	30	5.0	0.31	86.00
11	40	5.0	0.344	170.13
12	50	5.0	0.97	753.84
13	60	5.0	0.24	272.78
14	80	5.0	0.28	574.50

15	100	5.0	0.28	903.06
16	100	10	0.62	966.78

VES 2, PROFILE 2

S/No	AB/2	MN/2	R (Ω)	P (Ωm)
1	1	0.5	279.00	658.44
2	3	0.5	55.40	1522.39
3	5	0.5	18.50	1437.82
4	8	0.5	6.86	1373.24
5	10	0.5	1.03	322.62
6	15	0.5	0.217	153.14
7	20	0.5	0.163	204.60
8	20	5.0	0.528	62.17
9	25	5.0	0.792	149.21
10	30	5.0	7.670	2107.33
11	40	5.0	0.205	101.38
12	50	5.0	7.390	5743.14
13	60	5.0	0.202	226.76
14	80	5.0	0.096	192.17
15	100	5.0	0.139	435.37
16	100	10	0.483	750.73

VES 3, PROFILE 2

S/No	AB/2	MN/2	R (Ω)	P (Ωm)
1	1	0.5	402.00	948.72
2	3	0.5	25.10	689.75
3	5	0.5	7.06	548.70
4	8	0.5	4.04	808.73
5	10	0.5	3.05	955.32
6	15	0.5	4.21	2971.08
7	20	0.5	4.58	5686.15
8	20	5.0	5.21	708.86
9	25	5.0	3.52	981.56
10	30	5.0	4.83	967.12
11	40	5.0	4.64	2388.68
12	50	5.0	1.28	3605.98
13	60	5.0	1.56	1436.86

14	80	5.0	0.68	3122.73
15	100	5.0	2.57	2129.86
16	100	10	2.09	3994.55

VES 4, PROFILE 2

S/No	AB/2	MN/2	R (Ω)	P (Ωm)
1	1	0.5	36	109.16
2	3	0.5	2.08	15.52
3	5	0.5	2.37	87.52
4	8	0.5	1.12	125.13
5	10	0.5	0.47	157.41
6	15	0.5	1.41	249.13
7	20	0.5	1.67	342.15
8	20	5.0	2.65	224.90
9	25	5.0	1.71	322.15
10	30	5.0	1.19	335.51
11	40	5.0	2.50	741.83
12	50	5.0	1.41	979.21
13	60	5.0	1.61	2100.0
14	80	5.0	1.97	2121.86
15	100	5.0	2.66	3272.31
16	100	10	1.61	2569.54

VES 5, PROFILE 2

S/No	AB/2	MN/2	R (Ω)	P (Ωm)
1	1	0.5	106.09	244.76
2	3	0.5	10.60	191.49
3	5	0.5	3.05	237.37
4	8	0.5	1.12	125.13
5	10	0.5	0.47	157.41
6	15	0.5	1.41	249.13
7	20	0.5	1.67	342.15
8	20	5.0	2.65	224.90
9	25	5.0	1.71	322.15
10	30	5.0	1.19	335.51
11	40	5.0	0.69	343.71
12	50	5.0	1.00	344.19
13	60	5.0	10.60	391.17
14	80	5.0	3.05	237.05
15	100	5.0	1.12	225.13

16	100	10	1.47	357.31

VES 1, PROFILE 3

S/No	AB/2	MN/2	R (Ω)	P (Ωm)
1	1	0.5	1.25	250.23
2	3	0.5	0.003	0.93
3	5	0.5	0.210	148.20
4	8	0.5	0.270	338.91
5	10	0.5	0.358	95.81
6	15	0.5	0.577	67.45
7	20	0.5	0.805	158.53
8	20	5.0	2.740	398.11
9	25	5.0	1.670	2139.39
10	30	5.0	0.62	174.27
11	40	5.0	1.48	322.16
12	50	5.0	1.71	387.40
13	60	5.0	1.41	1023.72
14	80	5.0	2.07	1632.02
15	100	5.0	0.62	174.27
16	100	10	1.48	322.16

VES 2, PROFILE 3

S/No	AB/2	MN/2	R (Ω)	P (Ωm)
1	1	0.5	1.37	106.52
2	3	0.5	0.63	125.11
3	5	0.5	0.47	147.31
4	8	0.5	0.49	349.33
5	10	0.5	1.01	1569.32
6	15	0.5	0.57	67.45
7	20	0.5	0.80	158.53
8	20	5.0	2.74	398.11
9	25	5.0	1.67	2139.54
10	30	5.0	0.62	174.27
11	40	5.0	1.48	322.16
12	50	5.0	1.71	387.40
13	60	5.0	1.12	125.13

14	80	5.0	0.47	157.41
15	100	5.0	1.41	249.13
16	100	10	1.67	342.15

VES 3, PROFILE 3

S/No	AB/2	MN/2	R (Ω)	P (Ωm)
1	1	0.5	4.90	134.64
2	3	0.5	1.06	82.38
3	5	0.5	1.25	250.23
4	8	0.5	0.003	0.93
5	10	0.5	0.21	148.20
6	15	0.5	0.27	338.91
7	20	0.5	0.35	95.81
8	20	5.0	0.57	67.45
9	25	5.0	0.47	157.41
10	30	5.0	1.41	249.13
11	40	5.0	1.67	342.15
12	50	5.0	2.65	224.90
13	60	5.0	1.71	322.15
14	80	5.0	1.19	335.51
15	100	5.0	0.69	343.71
16	100	10	0.47	157.41

VES 4, PROFILE 3

S/No	AB/2	MN/2	R (Ω)	P (Ωm)
1	1	0.5	5.64	438.34
2	3	0.5	4.21	842.76
3	5	0.5	3.88	1215.29
4	8	0.5	4.44	3133.40
5	10	0.5	5.64	438.34
6	15	0.5	4.21	842.76
7	20	0.5	1.12	125.13
8	20	5.0	0.47	157.41
9	25	5.0	1.41	249.13
10	30	5.0	1.67	342.15
11	40	5.0	2.65	224.90
12	50	5.0	1.71	322.15
13	60	5.0	1.19	335.51

14	80	5.0	0.69	343.71
15	100	5.0	1.00	344.19
16	100	10	1.12	125.13

VES 5, PROFILE 3

S/No	AB/2	MN/2	R (Ω)	P (Ωm)
1	1	0.5	6.86	1373.53
2	3	0.5	1.03	322.62
3	5	0.5	0.22	153.14
4	8	0.5	0.16	204.77
5	10	0.5	0.53	62.17
6	15	0.5	6.86	1373.51
7	20	0.5	7.06	548.70
8	20	5.0	3.14	808.10
9	25	5.0	3.05	955.32
10	30	5.0	5.64	438.11
11	40	5.0	4.21	842.76
12	50	5.0	3.88	1215.29
13	60	5.0	4.44	3133.10
14	80	5.0	5.64	438.34
15	100	5.0	1.00	344.17
16	100	10	1.12	125.24

VES 1, PROFILE 4

S/No	AB/2	MN/2	R (Ω)	P (Ωm)
1	1	0.5	0.47	149.72
2	3	0.5	0.23	168.67
3	5	0.5	0.30	386.61
4	8	0.5	0.76	89.84
5	10	0.5	0.72	136.03
6	15	0.5	0.70	193.70
7	20	0.5	1.41	249.13
8	20	5.0	1.67	342.15
9	25	5.0	2.65	224.90
10	30	5.0	1.71	322.15
11	40	5.0	1.19	335.51
12	50	5.0	0.69	343.71
13	60	5.0	1.00	344.19

14	80	5.0	10.60	391.17
15	100	5.0	3.05	237.05
16	100	10	1.12	225.13

VES 2, PROFILE 4

S/No	AB/2	MN/2	R (Ω)	P (Ωm)
1	1	0.5	381.00	899.16
2	3	0.5	3.84	105.52
3	5	0.5	1.37	106.52
4	8	0.5	0.63	125.11
5	10	0.5	1.37	106.52
6	15	0.5	361	799.42
7	20	0.5	3.84	105.52
8	20	5.0	1.67	342.15
9	25	5.0	2.65	224.90
10	30	5.0	1.37	106.52
11	40	5.0	28.43	199.71
12	50	5.0	3.84	105.52
13	60	5.0	0.47	147.84
14	80	5.0	0.49	349.33
15	100	5.0	1.01	1569.84
16	100	10	1.64	2147.84

VES 3, PROFILE 4

S/No	AB/2	MN/2	R (Ω)	P (Ωm)
1	1	0.5	3.88	1215.3
2	3	0.5	3.21	2143.7
3	5	0.5	5.64	438.34
4	8	0.5	4.21	842.8
5	10	0.5	1.12	125.13
6	15	0.5	1.13	557.41
7	20	0.5	3.84	105.52
8	20	5.0	1.67	342.15
9	25	5.0	3.05	237.37
10	30	5.0	1.12	125.13
11	40	5.0	1.17	1257.13
12	50	5.0	1.41	249.13
13	60	5.0	1.67	342.15

14	80	5.0	2.65	224.90
15	100	5.0	1.71	322.15
16	100	10	1.19	335.51

VES 4, PROFILE 4

S/No	AB/2	MN/2	R (Ω)	P (Ωm)
1	1	0.5	0.72	136.03
2	3	0.5	0.70	193.70
3	5	0.5	0.69	343.71
4	8	0.5	0.57	442.98
5	10	0.5	0.48	539.95
6	15	0.5	0.28	97.41
7	20	0.5	3.05	237.37
8	20	5.0	1.12	125.13
9	25	5.0	0.47	157.41
10	30	5.0	1.41	249.13
11	40	5.0	1.67	342.15
12	50	5.0	0.63	125.11
13	60	5.0	0.47	147.84
14	80	5.0	0.49	349.33
15	100	5.0	1.01	1569.84
16	100	10	0.63	125.11

VES 5, PROFILE 4

S/No	AB/2	MN/2	R (Ω)	P (Ωm)
1	1	0.5	0.76	89.84
2	3	0.5	0.72	136.03
3	5	0.5	0.70	193.70
4	8	0.5	0.69	343.71
5	10	0.5	0.57	442.98
6	15	0.5	0.48	539.95
7	20	0.5	3.05	237.37
8	20	5.0	1.12	125.13
9	25	5.0	10.60	291.29
10	30	5.0	3.05	237.05
11	40	5.0	0.85	171.15
12	50	5.0	0.47	149.72
13	60	5.0	0.23	168.67

14	80	5.0	0.30	386.61
15	100	5.0	3.05	237.37
16	100	10	1.12	125.13