GEO-ELECTRIC SOUNDINGS FOR GROUNDWATER EXPLORATION IN PART OF PORT HARCOURT, RIVERS STATE, SOUTH-EASTERN NIGERIA.

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CERTIFICATION

I hereby certify that this project was carried out by Onayemi Ayomide Oluwatobi, Matric no: GPY/11/0297 in the department of geophysics, faculty of Science, Federal University, Oye, Oye-Ekiti, Ekiti State under my supervision.

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DATE

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DEDICATION

This project is dedicated to the almighty God; the alpha and Omega, protector and provider, who has proved to me that He is indeed God and for being there for me throughout my stay in this university.

It is also dedicated to my mum; Mrs. Aderonke Onayemi and my grand uncle; Mr Kolawole for their financial support, moral words of encouragement and prayers throughout my stay in this university.

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TABLE OF CONTENTS

Chapter one

Chapter two

Chapter three

Chapter four

Chapter five

List of tables

List of figures

ABSTRACT

Groundwater is the water that exists in pore spaces and fractures in rocks and sediments beneath the water table. The need for groundwater has increased tremendously due to the unavailability and the contamination of surface water bodies by the intrusion of saline water and human activities.

The geo-electric soundings were carried out in Eleme Port Harcourt, capital of Rivers state in order to delineate the subsurface geo-electric layers and the depth to the aquifer unit for groundwater development.

Ten (10) vertical electrical sounding stations were occupied within the study area using the schlumberger electrode configuration. The Pasi Earth Resistivity Meter (16EL Model) was used. The sounding curves were classified into five (5) curve types: KH, HKH, QHK, HKQH and QQ curves. The quantitative interpretation of the geo-sounding curves by partial curve matching and computer iteration revealed 5 geo-electric layers based on characteristic resistivity ranges. The layers are; topsoil, lateritic sand, sand, coarse sand and clay. The major aquifer units in the area are the sand and the coarse sand formations.

Virtually all the VES points are good for groundwater development, because of the dominant sand and coarse sand formations, which is the major aquifer unit in the study area.

CHAPTER ONE

1.0 INTRODUCTION

1.1 GENERAL STATEMENT

Groundwater is water that exists in the pore spaces and fractures in rocks and sediments beneath the water table. It originates as rainfall or snow, and then moves through the soil and rock into the groundwater system, where it eventually makes its way back to the surface streams, lakes, or oceans. Groundwater makes up about 1% of the water on the Earth (most water is in oceans). Groundwater is found within the saturated zone where all the open spaces between sedimentary materials or in fractured rocks is filled with water and the water has a pressure greater than atmospheric pressure. To understand the ways in which groundwater occurs, it is needed to think about the groundwater bearing formation properties such as porosity and permeability. The water bearing formation is termed aquifer.

The occurrence of groundwater resources in a basement complex depends mainly on the secondary porosity (after deposition of sediments) and also permeability arising from weathering and fracturing of parent rocks and also the pattern of the fracture (Carruthers, 1984).

Fractures in rock are very important pathways for the flow of groundwater and the transportation of contaminants. In fractured rock systems, groundwater occupies voids that are formed by fractures, fissures, faults and joint planes which are constantly distributed inside the rock formation. Due to their nature, they exhibit unique problems in their investigation, evaluation and management largely because of their heterogeneous nature and the dependence of aquifer properties on fracture distribution and connectivity.

A relatively inexpensive way to prospect for groundwater, both on a small and large scale is by using electrical resistivity method of geophysical prospecting; this method is fast, relatively cheap and non-intrusive, thus making it a practical alternative to traditional approaches. The electrical resistivity of rocks depend on several factors, some of which include; the presence of conductive minerals such as base metal sulphides or oxides and graphites in the rock. Most rocks without these minerals are usually poor conductors and their resistivity is determined primarily by their porosity, degree of fracturing and the degree of saturation of the pore spaces (Cook et al., 2001).

Electrical methods have been successfully employed to monitor groundwater occurrence and have also provided information on fluid electrical conductivity, fracture orientation and overall bulk porosity (Dailey et al., 1992, Slater et al., 1996).

1.2 LOCATION AND ACCESSIBILITY

The research was carried out at Eleme, Port Harcourt, Rivers state. The study area lies within the sedimentary terrain of southern Nigeria between longitudes E: 007° 06.215' to E: 007° 06.564' and latitudes N: 04° 49.480' to N: 04° 49'793. The study area is accessible as a result of the availability of roads; the terrain is generally low-lying with elevation between 8 -17m above mean sea level and slopes unperceptively towards the Atlantic Ocean (Iloeje, 1979). Ten (10) Vertical Electrical stations were occupied in the study area, (see figure 1.0)

1.3 AIM AND OBJECTIVES

The aim of the research is to use the electrical resistivity method to prospect for groundwater development in the study area. The objectives of the study are;

- To determine the geo-electric parameters of the different geologic units.

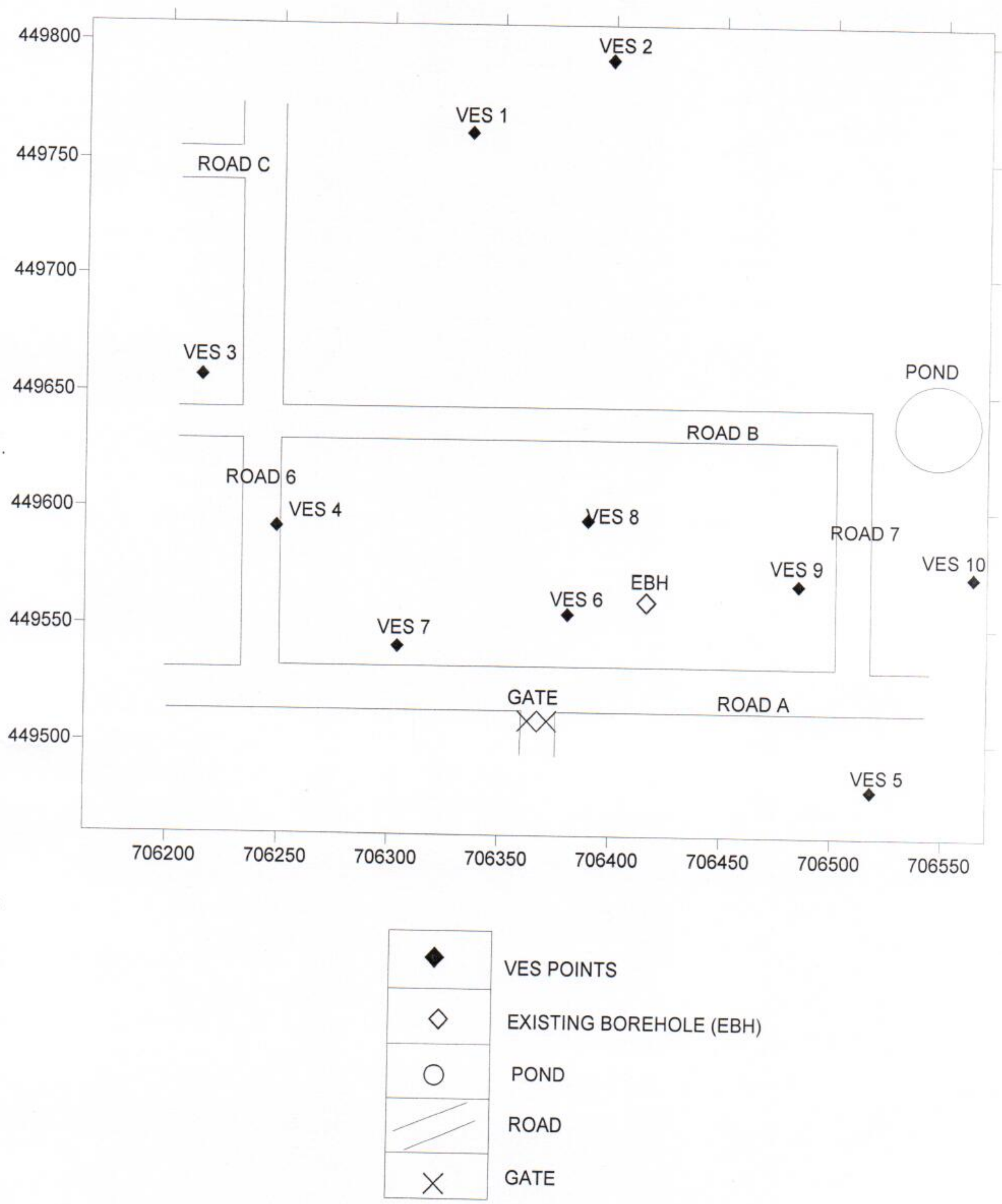

FIG 1.0: MAP OF THE STUDY AREA SHOWING THE VES LOCATIONS.

- To delineate the geo-electric layers, their thicknesses and lateral extent.
- To determine the depth to the aquifer unit
- From the above objectives, to locate feasible borehole point.

1.4 PHYSIOGRAPHIC SETTING

The area lies within the subequatorial region of Nigeria. This region is characterized by two major seasons; wet and dry seasons (Iloeje, 1979). The wet season begins in March and ends in October, with a peak in June and July. There is a period of little or no rain in August, popularly called "August Break". Annual mean rainfall in the area is over 3000mm (Ojo et al, 1992). The study area is characterized by high temperature and humidity as is common with humid tropical climate. Average annual temperature in the area is about 27°C (Inyang, 1975), with maximum values in the months of april, and lowest in July and August (Amali et al). The climatic conditions have an intimate relationship with vegetation type in the area. The high rainfall and humidity promote thick vegetation termed tropical rainforest (Iloeje, 1979).

Rainfall is high in Port Harcourt with annual mean of 240cm. the rainfall exhibits double maxima regime with peaks in July and September. The area falls within the humid tropics with humidity of 63- 79%, (Korean Report, 1980). The physiography conforms to the geomorphic features of the Niger Delta governed by several factors which influence transport and ultimate deposition of the sediment load, shape and growth of the delta. The Niger Delta comprises five geomorphic sub-environments (Osakumi and Abam 2004); the undulating lowlands of the coastal plain sands, the flood plain of the lower Niger with extensive sand deposits, the meander belts consisting of wooded freshwater swamps, the mangrove swamps and estuary complexes and the beach ridges. These sub-environments are zones where a vast amount of sediments are deposited by rivers in their search for lines of flow, (Osakumi and Abam 2004).

The drainage pattern is largely controlled by the Bonny River and its tributaries and creeks which together drain various outcrops of relatively higher land which are largely surrounded by mangrove swamps, (Bell-Gam 2002).

1.5 REVIEW OF PREVIOUS WORKS

The electrical resistivity method has been used by many researchers to detect bedrock fractures, overburden thicknesses, geoelectric layers, groundwater potential and so on.

Lane (1995) used square array electrical resistivity method to detect fracture and estimate hydraulic property of fractured bedrock in Grafton county, New Hampshire, US.

Onabanjo (2001) carried out geophysical survey using resistivity method in Ago-iwoye southwestern Nigeria and discovered two types of subsurface zones which are associated with groundwater exploration namely the weathered basement and fractured basement in which both are separated by barriers of unaltered rocks tending to reduce the possibility of groundwater accumulation.

Olasehinde and Bayewu (2011) used evaluation of electrical resistivity anisotropy to report the potency of combination of anisotropy polygon and isoresistivity map in reducing ambiguity inherent in a single geophysical parameter in Odo Ara west,central Nigeria.

Ajibade, et al (2012) used Azimuthal Resistivity Survey (ARS) to investigate the groundwater potentials and anisotropic properties of fractures for sustainable groundwater development within Ibadan metropolis. Result of groundwater head contouring showed that groundwater flow is dominantly in directions which are associated to fracture-controlled flow.

Isifile and Obasi (2012) used Radial Vertical Electrical Sounding carried out around Ifon, south western Nigeria to determine the electrical anisotropy and map the trend of concealed structures. They discovered that the major structural elements responsible for the structures include joints, foliations and the fracture system. The trend of the fracture system is along N-S, NW-SE and NE-SW, while that of the W-E is occasional. Hence, they recommended that any engineering structures imposed on the area must have a firm and broad base foundation in order to avoid settlement problems due to the subsurface fractures that abound in Ifon area.

CHAPTER TWO

2.0 BASIC THEORY OF THE ELECTRICAL RESISTIVITY AND GEOLOGY OF THE STUDY AREA

2.1 BASIC THEORY OF THE ELECTRICAL RESISTIVITY METHOD

The electrical resistivity method of geophysical prospecting involves the passing into the ground of a DC or low frequency AC through two (2) electrodes referred to as *current electrodes* while the resulting potential ΔV is measured between another pair of electrodes designated potential electrode array system.

The ground resistivity can be calculated using parameters I, V and K

I = current

ΔV = Potential difference

K = Geometric factor of the array system

Resistivity methods involves the study of horizontal and vertical discontinuities in the electrical properties of the ground and also the detection of 3-Dimentional bodies of anomalous conductivity and it is also the most important method in groundwater exploration and accounted for about 80% of the total groundwater in Nigeria.

The electrical resistivity method involves various physical parameter of the area study which include the resistivity and geoelectrical parameter; it is affected by various factors which include porosity and salinity (Olayinka). To obtain resistivity of subsurface formations four electrode array were used; two current electrodes and two potential (voltage) electrode.

2.1.1 PRINCIPLES OF ELECTRICAL RESISTIVITY METHOD

The electrical resistivity method measures both lateral and vertical variation in ground resistivity from different points on the earth surface. The electrical resistivity prospecting method involves the passage of electric current (usually direct current or low frequency alternating current) into the subsurface, through two electrodes (the current electrodes). The potential difference is measured between another pair of electrodes, which may or may not be within the current electrodes depending on the electrode array in use. Apparent resistivity value is determined by multiplying with an appropriate geometrical factor. Actual resistivity of subsurface layer is determined from ground apparent resistivity, which is computed from the measurement of current and potential difference between the electrodes pair placed on the surface.

The electrical resistivity methods adopt the use of three fundamental properties of rocks which are:

i. The resistivity, or its inverse conductivity, governs the amount of current that passes through the rock when a specified potential difference is applied.

ii. The electrochemical activity with respect to electrolytes in the ground is the basis for self-potential and induced- potential methods.

iii. The dielectric constant gives information on the capacity of a rock material to store electric charge and governs in part the response of rock formation to high-frequency alternating currents introduced into the earth by conductive or inductive means

2.1.2 FACRORS AFFECTING RESISTIVITY OF EARTH MATERIALS

There are several factors that influence electrical resistivity of the earth materials. These include: The chemistry or salinity of the saturating fluid: Earth resistivity decreases with increase in the concentration or salinity of the saturating fluid.

- Porosity: Generally resistivity of earth materials deceases with increase in porosity for a clean sediment.
- Temperature: This influences viscosity, the higher the temperature the lower the viscosity, the higher the ion mobility, the higher the conductivity and the lower the resistivity.
- Rock texture: Well sorted sandstone with large void will exhibit lower resistivity. Poorly sorted sandstone with small void will display high resistivity.
- Rock types: The resistivity of rocks varies with rock types e.g. the resistivity of granite will be higher than that of clay.
- Geological processes: The resistivity of rocks is influenced by geological processes such as: Fracturing; here resistivity decreases while conductivity increases.
- Water saturation: The resistivity of earth materials increases with decrease in the degree of fluid saturation.
- Permeability: Ideally, when permeability increases resistivity decreases but, reverse is the case in clay materials i.e. clay has high porosity, low permeability, but yet low resistivity. (I.e. high conductivity).

2.1.3 THEORY OF ELECTRICAL RESISTIVITY METHOD

Ohm's law forms the foundation for electrical resistivity theory. The law governs the development of equations, which expresses the potential about a single point source of currents.

Consider a current flowing in a cylindrical conductor of length L, cross-sectional area A, with current I, flowing through in it (Fig, 2.0).

The resistance R from ohm's law is expressed as:

$R \propto L$ 1

$R \propto I/A$..2

Combining equations 1 and 2

$R \propto L/A$..3

$R = \rho L/A$..4

Where ρ is the constant of proportionality called resistivity.

But from ohms law:

$R = \frac{\Delta V}{I}$ 5

By substituting for 'R' in equation 4

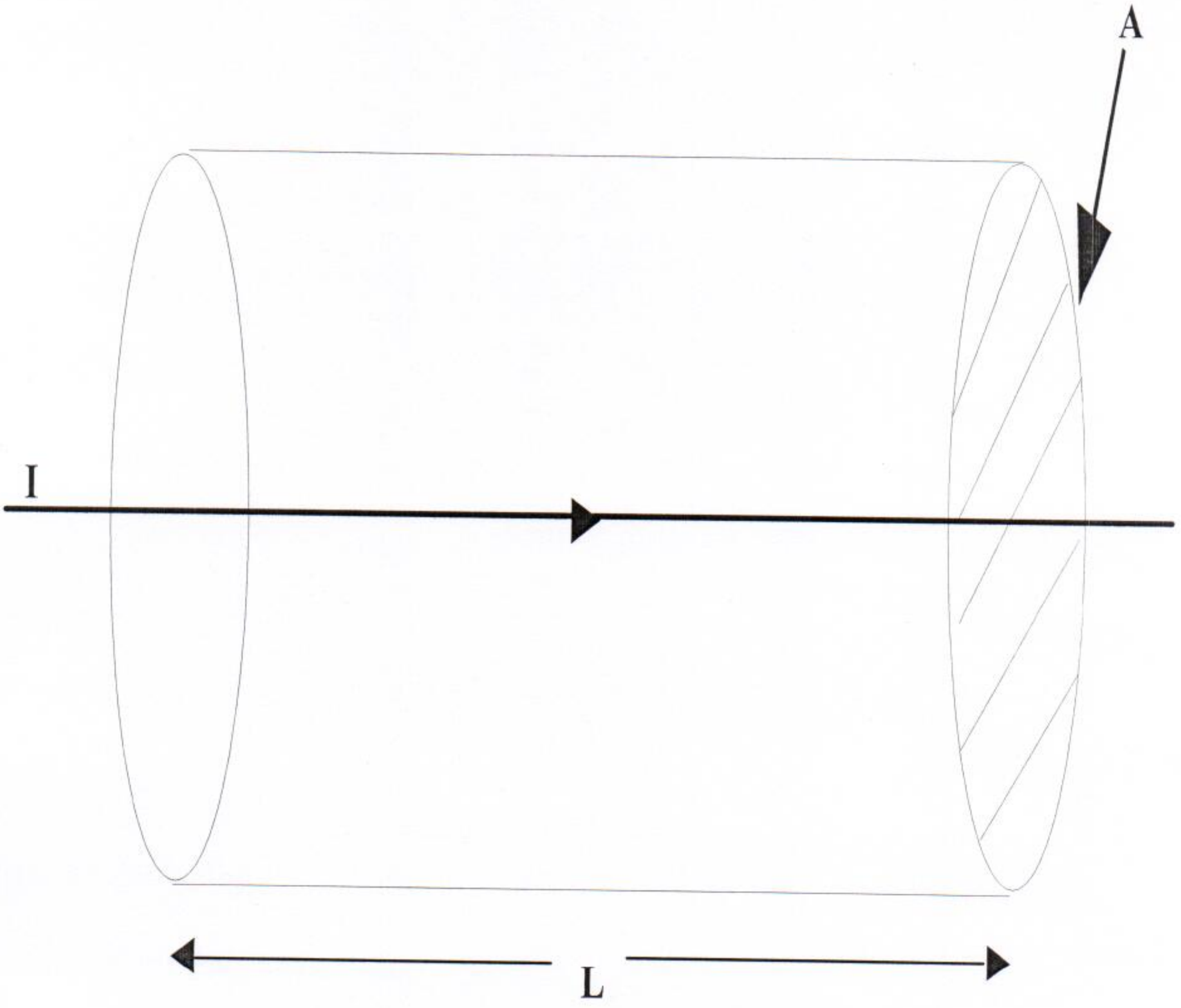

Figure 2.0: Schematic Diagram of the Flow of Current through a Cylindrical Model.

$$\frac{\Delta V}{I} = \rho \, {}^{L}\!/_{A} \quad \text{......6}$$

$$\frac{\Lambda VA}{I} = \rho L$$

$$\therefore \rho = \frac{\Lambda VA}{IL} \quad \text{......7}$$

Where:

ΔV = Potential difference between any two points measured in volts.

I = Current flowing in the conducting medium between points measured in amperes

R = Resistance of medium between two points measured in ohms.

ρ = The resistivity in (Ω m)

Equation 7 can be used to determine the resistivity of any homogenous medium provided the geometry is simple. But when the medium is semi-infinite, equation 7 needs to be modified before it can be applicable.

If we allow parameters A and I/L to shrink to infinitesimal size.

Then:

$$\frac{\rho = Lim L \rightarrow 0 \frac{\Lambda V}{L}}{Lim A \rightarrow 0 \frac{I}{A}} \quad \text{......8}$$

$$\rho = \frac{E}{J} \quad \text{......9}$$

Where E is the electric field and J is the current density.

From Equation 9

$$J = \frac{E}{\rho}$$

$\therefore E = JP$ 10

Imagine that the source is located at the centre of a spherical body of radius ‘r’ (Fig. 2.1)

The current density at the spherical surface is:

$J = \frac{I}{A}$ 11

Where A = area of the spherical surface,

Given; $A = 4\pi r^2$

$\therefore J = I/A = \frac{I}{4\pi r^2}$ 12

Substitute equation 12 into 10

$E = \frac{I\rho}{4\pi r^2}$ 13

But E is the gradient of scalar potential i.e.

$E = -\nabla V = \frac{-\delta V}{\delta r}$ 14

Equate equations 13 and 14

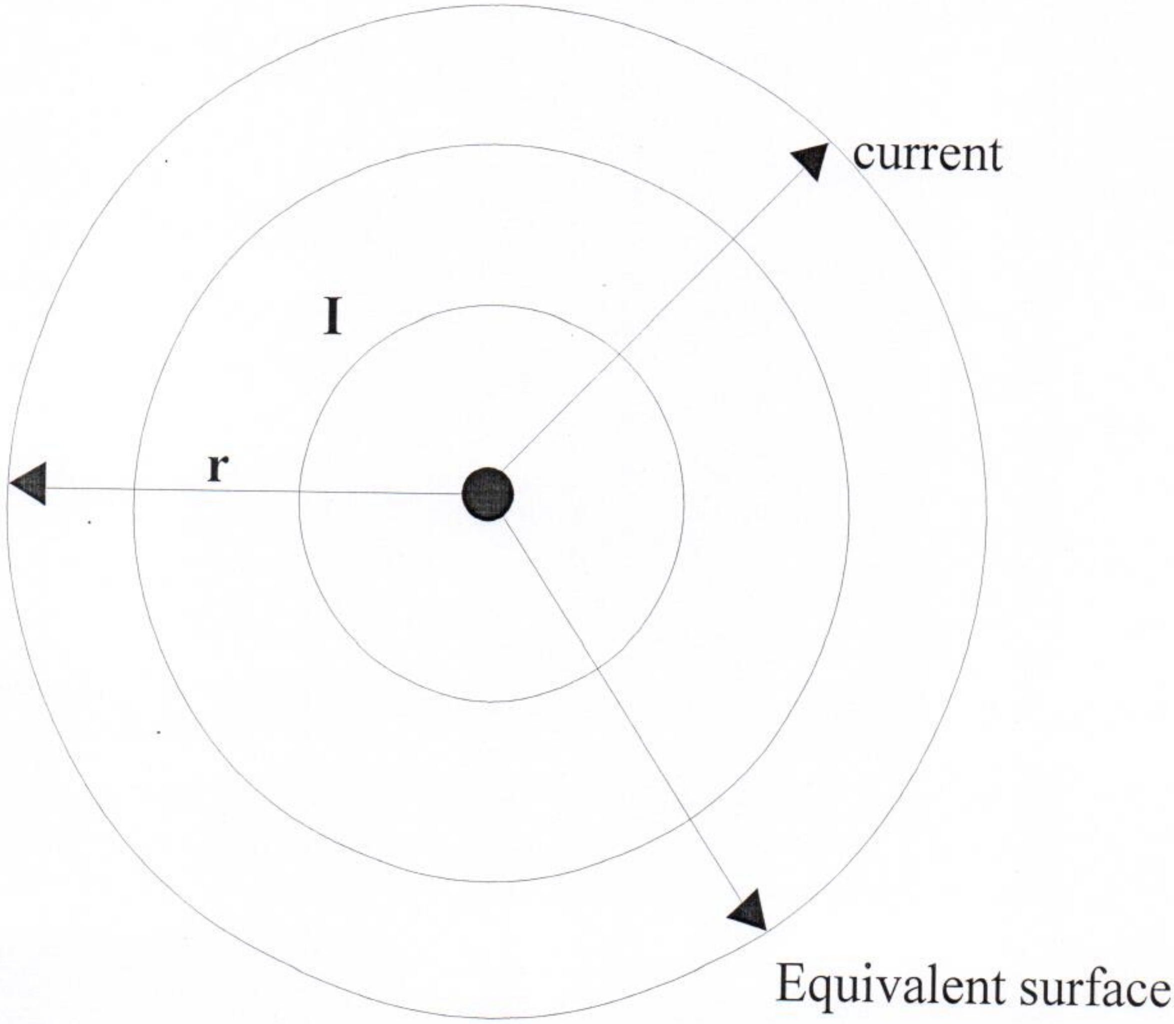

Figure 2.1: Spherical Body of Radius ‘r’

$\frac{I\rho}{4\pi r^2} = \frac{-\delta V}{\delta r}$

$\frac{\delta V}{\delta r} = \frac{-I\rho}{4\pi r^2}$

$\therefore \frac{\delta V}{4\pi r^2} = -I\rho\delta r$ 15

Taking the integral of both sides:

$\int \delta V = \int \frac{-I\rho\delta r}{4\pi r^2}$

$\int \frac{\delta V}{4\pi r^2} = I\rho \int 1\delta r$

$\therefore V = \frac{I\rho}{4\pi r}$ 16

In practice the earth surface structure is taken as an approximate hemisphere (Fig. 2.2). The current density (J) is defined as

$J = \frac{l}{A}$ 17

The area of a hemisphere is $2\pi r^2$

$\therefore$ Equation 17 becomes

$J = \frac{1}{2\pi r^2}$ 18

$\therefore E = \frac{I\rho}{2\pi r^2}$ 19

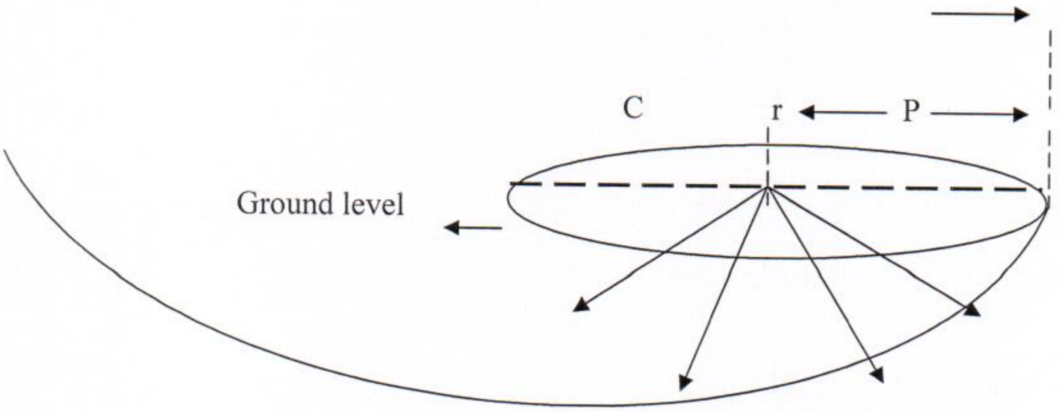

Figure 2.2: Current Source at the Hemispherical Surface

$$But\ E = -\nabla V = \frac{-\delta V}{\delta r}$$

$\therefore \frac{\delta V}{\delta r} = \frac{-I\rho}{2\pi r^2}$ 20

Taking the integral of both sides:

Equation 18 becomes:

$$\int \frac{\delta V}{\delta r} = \int \frac{-I\rho}{2\pi r^2}$$

$$\int \frac{\delta V}{\delta r} = \frac{-I\rho}{2\pi} \int \frac{1}{r^2}$$

$$\int \delta V = \frac{-I\rho}{2\pi} \int \frac{1\delta r}{r^2}$$

$$V = \frac{I\rho}{2\pi r^2}\left(-\frac{1}{r}\right)$$

$V = \frac{-I\rho}{2\pi r}$ 21

This is the potential at point P due to current at point C on the surface of the earth.

2.1.4 GENERALIZED APPARENT RESISTIVITY EQUATION

Consider the diagram in Figure. 2.3: The diagram illustrates a simple current source at the surface of the earth. The potential 'V' is at a distance 'R' from the current source. From figure 2.2, the potential at point P_1 due to current at point C_1 at the current surface is given as:

$$V = \frac{I\rho}{2\pi r}$$

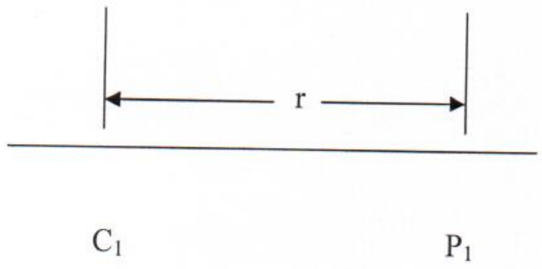

Figure 2.3: A simple current source

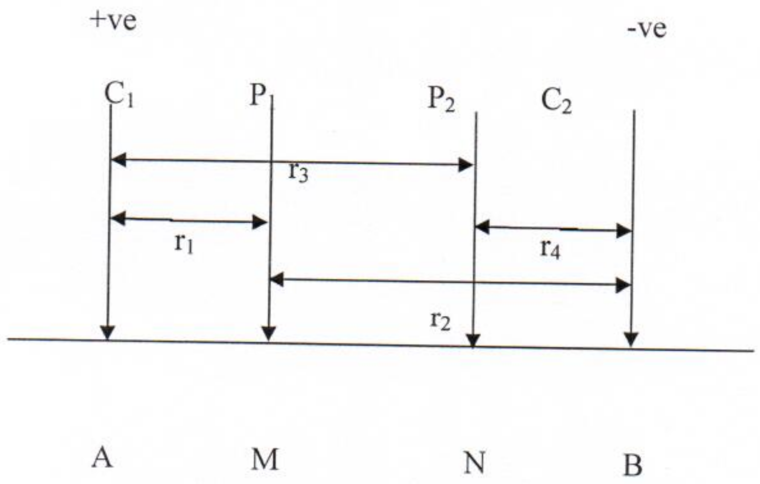

Figure 2.4: Generalized Electrode Configuration for Resistivity Survey

Where;

r_1 is the Distance between P_1 and C_1

r_2 is the Distance between P_1 and C_2

r_3 is the Distance between P_2 and C_1

r_4 is the Distance between P_2 and C_2

C_1 and C_2 are Current Electrodes

P_1 and P_2 are Potential Electrodes

AB = Current Electrode Distance

MN = Potential Electrode Distance

The potential at P_1 due to current at C_1 is;

$$V_{11} = \frac{I\rho}{2\pi r_1}$$

The potential at P_1 due to current at C_2 is;

$$V_{12} = \frac{I\rho}{2\pi r_2}$$

The sum total of potential at P_1 due to current at C_1 and C_2 is;

$$V_{11,12} = \frac{I\rho}{2\pi r_1} + \frac{(-I\rho)}{2\pi r_2}$$

$$V_{11,12} = \frac{I\rho}{2\pi r_1} - \frac{I\rho}{2\pi r_2}$$

$$V_{11,12} = \frac{I\rho}{2\pi}\left[\frac{1}{r_1} - \frac{1}{r_2}\right] \quad \text{...} 22$$

Similarly, Potential at P_2 due to current at C_1 is;

$$V_{21} = \frac{\rho I}{2\pi r_3}$$

The potential at P_2 due to current at C_2 is;

$$V_{22} = \frac{-\rho I}{2\pi r_4}$$

The sum total Potential of P_2 due to current at C_1 and C_2 is;

$$V_{21,22} = \frac{I\rho}{2\pi r_3} - \frac{I\rho}{2\pi r_4}$$

$$V_{21,22} = \frac{I\rho}{2\pi}\left[\frac{1}{r_3} - \frac{1}{r_4}\right] \quad \text{...} 23$$

But the potential difference ΔV between P_1 and P_2 can be obtained by subtracting equation 22 and 23

$$\Delta V = V_{11,12} - V_{21,22}$$

$$= \left[\frac{\rho I}{2\pi r_1} - \frac{\rho I}{2\pi r_2}\right] - \left[\frac{\rho I}{2\pi r_3} - \frac{\rho I}{2\pi r_4}\right]$$

$$\text{But } \rho = \frac{2\pi\Delta V}{I}\left[\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4}\right]^{-1} \quad \text{..} 24$$

Therefore, $\rho = KR$

Where; K is the Geometric Factor

2.1.5 ELECTRICAL RESISTIVITY METHOD ARRAYS

The various electrical resistivity method arrays are;

i. Wenner array

ii. Schlumberger array

iii. Dipole-dipole array

iv. Pole-dipole array

v. Pole-pole array

vi. Gradient array

vii. Lee partition

The electrode configuration or array is defined by the mode of arrangement of both the current and the potential electrodes. There are several types of electrode array used in electrical resistivity method and the schlumberger electrode array was used for this study.

• SCHLUMBERGER ELECTRODE ARRAY

Schlumberger electrode array also utilizes four electrodes system like wenner array but they are arranged linearly with different inter-electrode spacing as shown in the figure 2.5.

The electrodes are arranged such that the distance AB between the current electrodes is greater or equal to five times the distance MN, between the potential electrodes. The potential electrodes are fixed about the data station in which the current electrodes are spread until the required maximum separation is attained.

Where:

AB = Current Electrode Distance
MN = Potential Electrode Distance
AB = 2L

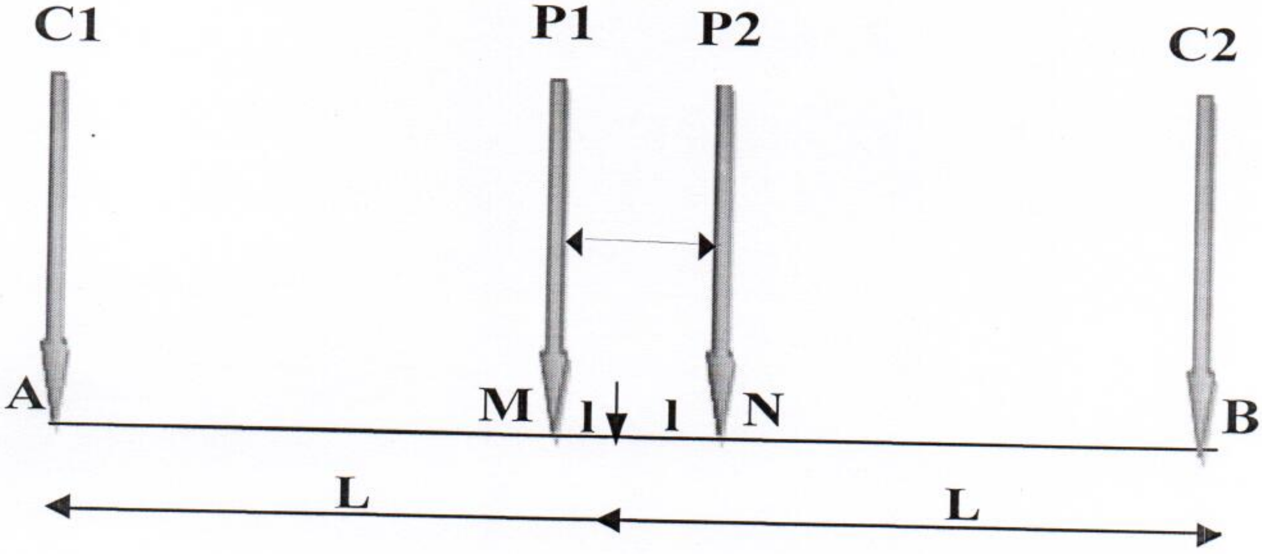

Figure 2.5: Typical Schlumberger Configuration

MN = 2l

AB ≥ 5MN

The apparent resistivity equation for schlumberger array is derived as:

$$\rho_a = 2\pi R \left[\frac{1}{AM} - \frac{1}{MB} - \frac{1}{AN} + \frac{1}{NB}\right] \quad \text{......25}$$

Consider the array in Figure 2.5

If AM = L – l

MB = L + l

AN = L + l

NB = L – l

By substituting into equation (25)

$$\rho_a = 2\pi R \left[\frac{1}{L+1} - \frac{1}{L+1} - \frac{1}{L+1} + \frac{1}{L-1}\right]^{-1}$$

$$\rho_a = 2\pi R \left[\frac{L+1 - L+1 - L+1 + L-1}{L^2 - 1^2}\right]^{-1}$$

$$\rho_a = 2\pi R \left[\frac{41}{L^2 - 1^2}\right]^{-1}$$

$$\rho_a = 2\pi R \left[\frac{L^2 - 1^2}{41}\right]$$

$$\rho_a = 2\pi R \left[\frac{L^2 - 1^2}{41}\right] \quad \text{......26}$$

But, l^2 is negligible when comparing with L^2 therefore, equation (2.29) becomes;

$$\rho_a = \frac{\pi R L^2}{2l} \quad \text{......27}$$

Equation 27 is the apparent resistivity for Schlumberger electrode array. Finally, in vertical sounding, the potential electrodes remain fixed while the current electrodes spacing is expanded symmetrically about the center of the spread. For large value of L_1 it is necessary to increase 'l' also in order to maintain a measurable potential. The assumption is that, the wider the current electrode spacing, the deeper the earth is being probed. For schlumberger method, apparent resistivity is plotted against AB/2 or half the spread length.

2.1.6 FIELD TECHNIQUES FOR ELECTRICAL RESISTIVITY METHOD

Geophysical traverses are established along directions normal or perpendicular to the general strike of the target, the traverse to traverse separation and the station interval are determined by the length, width and depth extent of the target.

Three survey techniques are commonly used in resistivity method to examine changes within the subsurface, these are:

- **HORIZONTAL PROFILING (HP)**

This is used to measure the lateral variation in relation to electrical resistivity method with respect to a specific depth extent or datum determined by the electrode spacing. The electrode spacing is kept constant, while the entire electrode array is moved after each measurement. The common electrode array used in HP includes; Wenner, Pole-pole, pole dipole and gradient array. Horizontal profiling technique is adopted in mineral exploration, geological mapping, groundwater, environmental and engineering geophysics.

- **VERTICAL ELECTRICAL SOUNDING (VES)**

The vertical electrical sounding measures vertical variation in ground resistivity effect with respect to a fixed center of electrode array used. The survey is carried out by gradually expanding the electrode spacing with respect to the fixed center. The common electrode array used for VES technique is the wenner and schlumberger array. Vertical electrical sounding technique is applied in groundwater exploration, environmental and engineering geophysics and to some extent in mineral exploration.

- **COMBINED HORIZONTAL PROFILING AND VERTICAL ELECTRICAL SOUNDING**

This measures both lateral and vertical variation in ground resistivity beneath a specific traverse line. The dipole-dipole array is commonly used for this survey technique but wenner and pole dipole array can also be adopted. The combined HP\VES technique is relevant in mineral exploration, groundwater, environmental and engineering geophysics.

2.1.7 DATA PRESENTATION IN ELECTRICAL RESISTIVITY METHOD

HP data are presented as profiles and maps in electrical resistivity method. Profiles are generated by plotting resistivity value against station position along a particular traverse line; the station position is determined by the electrode configuration used. Profiles give location of the targets and qualitatively its altitude.

Maps are generated by posting of apparent resistivity value on each station along individual traverses and contoured. Maps give location of the target, it gives geometry, and it can give strike length and the width extent.

VES data are presented as a sounding curve, i.e. plot of apparent resistivity against spacing on log-log (bi-log) graph paper.

Combine HP\VES data are presented as pseudosection. The resistivity value are plotted at the point of intercession and then contoured to give a pseudosection. The result is in form of 2-D. It gives the location of the target, strike lines, width extent, geometry and altitude of the target.

2.1.8 DATA INTERPRETATION OF ELECTRICAL RESISTIVITY METHOD

Interpretation of resistivity data can be qualitative, semi-quantitative or quantitative depending on the field procedure. The interpretation of resistivity profiles, maps, and pseudosections are usually qualitative or at best semi-quantitative.

The qualitative interpretation involves; visual inspection of profiles, maps and pseudosections for signatures or pattern diagnostic of a particular target. For example;

- Very low resistivity anomalies are typical of saline water intruded area or conductive mineralized zone, saline water based hydrocarbon impacted area or corrosive (aggressive) soil.

- Highly resistive anomalous area diagnostic of hydrocarbon or refined oil-impacted zone, areas polluted by organic compound, areas with shallow basement or sand\gravel deposit in a clay host rock.

A quantitative interpretation is applied to combine HP\VES. Quantitative interpretation of HP\VES pseudosection involves automatic direct 2-D inversion of the data or 2-D modeling involving simultaneous iterative reconstruction technique.

On VES, the interpretation is quantitative and it involves;

- Empirical\ semi-empirical technique which is used mostly for wenner array.
- Analytical method which involve partial curve matching and complete curve matching.
- Direct interpretation which is computer based.

2.1.9 FACTORS AFFECTING ELECTRICAL RESISTIVITY METHOD

There are various factors that influence the electrical resistivity method which include:

i. Mode of conduction of rocks and soils
ii. Rock texture
iii. Rock types
iv. Temperature
v. Degree of water saturation
vi. Permeability and porosity

Vii. Geological processes e.g. weathering, jointing, faulting etc.

2.1.10 APPLICATION OF ELECTRICAL RESISTIVITY METHOD

i. Groundwater Exploration

ii. Engineering Study

iii. Environmental Study

iv. Geological Mapping

v. Mineral Exploration

2.1.11 FACTORS FAVOURABLE TO THE USE OF ELECTRICAL RESISTIVITY METHOD FOR SITE INVESTIGATION

- Existence of simple geologic features.
- Existence of sufficient geophysical contrast between the bedrock and the overlying deposit.
- Existence of suitable contrast in the electrical property of the targeted feature.
- Absence of fill materials over the site, scattered metal and brick, buried Pipes and wire, fences, buried and overhead power lines and nearby Industries using electrical plant that adversely affect electrical sounding.

2.2 GEOLOGIC SETTINGS

2.2.1 REGIONAL GEOLOGY

Nigeria is a country in the African continent; the African continent is as a result of the separation of the African plate from the South American plate. Nigeria is bounded by the Atlantic Ocean to the south, by the republic of Benin to the West, by the Niger Republic to the North, the Republic of Chad to the North and the republic of Cameroon to the East (figure 2.6). The country lies between latitude 4^0-14^0N and longitude 3^0-14^0E and it is located in the western part of the African continent. Hence, the geologic frame work of Nigeria is genetically related to the global process and episodes that affected the African continent (Rahaman et al., 1988).

Geologically, about half of the total area of Nigeria is covered by igneous and metamorphic rocks of which about 80% of it is of Precambrian age, and the remaining 20% are younger intrusions and volcanic lava. These crystalline rocks are collectively called the Basement Complex (the basement complex is made up of Precambrian rocks and the younger granite of Jurassic age); the remaining half are made of sedimentary rocks accumulated in various sedimentary basins within the country. All over the world, below the oldest sedimentary rocks of any region are found crystalline rocks to have been extensively altered by heat, such heated-rocks (constitute the basement complex) lies below the oldest sedimentary rock. It forms part of the African crystalline shield and consist of West African Craton, which occurs predominantly in the west and in the Congo Craton that occur in the East. The rocks evolve through four major Orogenetic events and radiometric data have been used to delineate at least four major Orogenetic belts in the Precambrian of Africa. They include;

- The Liberian Orogeny rock emplaced about 2500-2800Ma

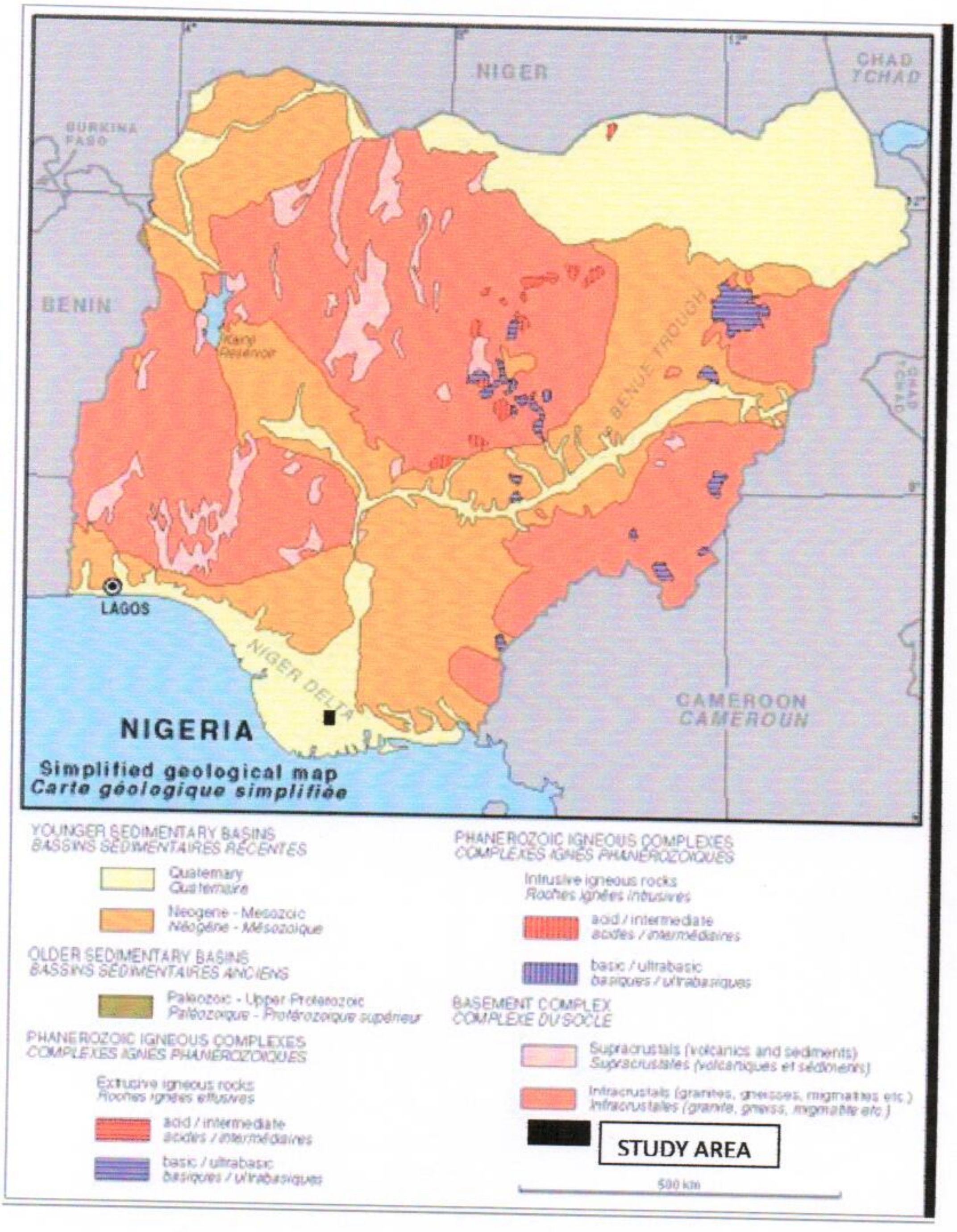

FIG 2.6: SIMPLIFIED GEOLOGICAL MAP OF NIGERIA (AFTER OYAWOYE, 1972)

- The Eburnean Orogeny rock emplaced about 2200-1800Ma
- The Kiberian Orogeny rock emplaced about 1300-900Ma
- The Pan African Orogeny rocks emplaced about 600-150Ma

Out of all these Orogenic belts, Pan African is the most recent and the most wide spread (even most significant) in Nigeria, since it is only part of a vast area in Africa that experiences a major thermostectonic upheaval that occur about 600-180M years ago emplacing rocks of this age (Rahaman, 1976).

The rocks of the basement complex of Nigeria consist mainly of the following:

- The migmatite-Gneiss complex
- The metasediments which include the older and younger metasediments
- Charnockitic rocks
- Older granites

The sedimentary basins of Nigeria consist of sedimentary rocks of ages younger than the Jurassic. There is a long gap in the geologic history of Nigeria between the Precambrian and oldest sedimentary rocks, which are Cretaceous. These sedimentary basins belong generally to the Hercynian basin of West Africa and can be grouped into two broad basinal classes using the kingston et al, 1983 classification scheme.

- Marginal Sag Basins: they were formed in response to the generalized tensionsal regime which accompanied the opening of the central and south Atlantic in the middle Jurassic and the Equatorial Atlantic by Aptian/Albian times. The Niger Delta and Benin basin belongs to this group.

- Intra Continental Basins: they show complete cycle development, characterized by marine facies and continental sediments. Some basins show retreated cycles. The Bida basin, Benue trough and Chad basin belong to this group.

Sedimentary rocks are evenly distributed over eleven sedimentary basins but the major ones are:

- Chad or Borno basin
- Anambra basin
- Sokoto basin
- Dahomey/Benin embayment
- Bida/Nupe basin
- Niger Delta
- Benue Trough, which is made up of lower, middle and upper Benue Trough.

2.2.2 GEOLOGY OF THE STUDY AREA

Geologically, the study area lies within the Niger Delta sedimentary Basin. Lithostratigraphically, these rocks are divided into the oldest Akata formation (Paleocene), the Agbada formation (Eocene) and the youngest Benin formation (Miocene to recent). The present knowledge of the geology of the Niger Delta was derived from the works of the following researchers (Reyment, 1965; Short and Stauble, 1967 Murat, 1970) as well as the exploration activities of the oil and gas companies in Nigeria. The formation of the so called proto-Niger Delta occurred during the second depositional cycle (Campanian- Maaxtrichtian) of the southern

Nigerian Basin. However, the modern Niger Delta was formed during the third and last depositional cycle of the southern Nigeria basin which started in the Paleocene.

The geologic sequence of the Niger Delta consists of three main tertiary subsurface lithostratigraphic units (Short and Stauble. 1967), which are overlain by various types of Quaternary deposits. (Table 1.0)

The major aquiferous formation in the study area is the Benin Formation. It is about 2100m thick at the basin centre and consists of coarse-medium grained sandstones, thick shales and gravels. The upper section of the Benin Formation is the quaternary deposits which is about 40-150m thick and comprises of sand and silt/clay with the later becoming increasingly more prominent seawards (Etu-Efeotor and Akpokodje, 1990). The formation consists of predominantly freshwater continental friable sands and gravel that have excellent aquifer properties with occasional intercalations of claystones/shales (Olobaniyi and Owoyemi, 2006).

TABLE 1: QUATERNARY DEPOSITS OF THE NIGER DELTA (AFTER ETU-EFEOTOR AND AKPOKODJE, 1990)

GEOLOGIC UNIT	LITHOLOGY	AGE
ALLUVIUM	GRAVEL, SAND, CLAY, SILT	RECENT
FRESHWATER BACKSWAMP, MEANDER BELT	SAND, CLAY, SOME SILT, GRAVEL	QUATERNARY
SALTWATER MANGROVE SWAMP AND BACKSWAMP	MEDIUM-FINE SANDS, CLAY AND SOME SILT	QUATERNARY
ACTIVE/ABANDONED BEACH RIDGES	SAND, CLAY, AND SOME SILT	QUATERNARY
SOMBREIRO-WARRI DELTAIC PLAIN	SAND, CLAY, AND SOME SILT	QUATERNARY

According to Etu-Efeotor (1981), Etu-Efeotor and Akpokodje, (1990), Offodile (2002), Udom et al (2002), the Benin formation is highly permeable, prolific productive and is most extensively tapped aquifer in the Niger Delta. The Benin formation consists of fluvial and lacustrine deposits whose thicknesses are variable but generally exceed 1970m (Asseez, 1989). According to Onyeagocha (1980), the rocks of the Benin formation are made up of about 95-99% quartz grains, Na+K Mica 1-2.5%, feldspar 0.5-1.0% and dark minerals 2.3%. These minerals are loosely bound by calcite and silica cement. The clayey intercalations have given rise to multi-aquifer systems in the area.

The main source of recharge is through direct precipitation where annual rainfall is as high as 2000-2400mm. The water infiltrates through the highly permeable sands of the Benin formation to recharge the aquifers. Groundwater in the study area occurs principally under water table conditions in the study area and the upper aquifers are generally unconfined (Etu-Efeotor, 1981; Offodile, 2002; Edet, 1993; and Udom, 2004).

CHAPTER THREE

3.0 METHODOLOGY AND INSTRUMENTATION

3.1 METHODOLOGY

For the purpose of this research, ten (10) Vertical Electrical Sounding stations were occupied within the study area. These stations were taken at different locations within the study area. The schlumberger array was employed. Current was passed into the ground through a pair of current electrode and the resultant resistance were obtained through pair of potential electrode and then recorded on the resistivity recording sheets. The study was carried out by using Pasi Earth Resistivity meter (16GL Digital Model), measuring tapes, current and potential electrode, crocodile clips and hammers.

Basically, a station is chosen and an iron rod is driven into the ground, this marks the base station which is used as a mid-point from where MN/2 (potential electrode) spacing are measured in both directions using the marked mid-point and measuring tape.

The potential electrodes are driven in either side of the base stations at a specified distance. The current electrodes were driven in on either side and the spacing is given as AB/2, a straight line is maintained by the configuration of all the electrodes.

The measurement are repeated and recorded with MN fixed at its initial distance and AB/2 is symmetrically increased where the resistance measured becomes too small MN/2 is increased symmetrically. The maximum spread of AB/2 in this study is 300m, while the maximum spread of MN/2 is 10.0m.

3.1.1 DATA PRESENTATION AND INTERPRETATION

The apparent resistivity is plotted against the corresponding half electrode spacing (AB/2) on a bi-log paper. The curve types were interpreted qualitatively and quantitatively. The quantitative interpretation involved the partial curve matching; which is used to determine an initial model from the field data, after which the computer iteration method was done by the Winresist software, while the qualitative interpretation involved the inspection of the curve types.

3.1.1.1 PARTIAL CURVE MATCHING

This technique is fairly accurate and dependable for interpretation. It involves the comparism of field curves with characteristics standard curves. The construction of series of standard curves is based in the hypothesis field curves of resistivity against depth.

Before interpretation is made with the master set of horizontal layer, it must be satisfied that the form of the sounding curve is sufficiently smooth and not distorted by sharp curves or discontinuities.

Two different set of curves are usually employed for this technique and they are:

- Theoretical 2-layer master curves.
- Auxiliary curves:
  - ❖ Ascending type; where p2>p1.
  - ❖ Descending type; where p1>p2

Also used in conjunction with the theoretical master curves are the four auxiliary curves designed for use in more than two layer interpretations.

3.1.1.2 COMPUTER ITERATION METHOD

This method involves the use of geophysical software called Winresist. Field data are input and then modeled. Curve matching gets cumbersome where there are many layers; hence the computer iteration makes the interpretation of such problems easier.

A fast observation is allowed based on the iteration intense of the program. The layer parameters are altered until s good fit is achieved between the observed and the calculated values. The iteration process of a curve could go as far as 30 times before achieving an effect match, after which the computer displays the final result of the iteration and the layer parameters.

This method is the most effective method of all the interpretation method in terms of speed and accuracy.

3.2 INSTRUMENTATION

The instrumentations used for the vertical electrical sounding includes the Pasi Earth Resistivity Meter and its accessories like the connecting cables, four electrodes (steel rods), measuring tapes, hammers and the Global Positioning system (GPS).

- **TERRAMETER**

It is a compact digital resistivity meter that contains a transmitter and receiver functions packed in one unit. It is designed to measure extremely weak electrical signal. The instrument can transmit up to 2900mA or less 200V, which is sufficient enough for ordinary resistivity surveying. It is highly sophisticated, compact lightweight equipment with inbuilt power source, signal receiver. It takes consecutive resistivity in several cycles and averaging the values obtained at each cycle to give the final resistivity.

- **ELECTRODES**

The four electrodes used were made of steel and are driven into the surface of the earth to the subsurface (few cms) with the aid of a hammer for good contact. These electrodes are connected to their respective cables.

- **CABLES**

There are four cables used on the field, two of which are about 500m in length used in connecting current electrodes (C1 and C2) while the other two cables of about 100m in length are used in connecting potential electrodes (P1 and P2)

- **MEASURING TAPE**

The measuring tapes are of various lengths used to mark off the electrode spread.

- **HAMMER**

The hammer is used in driving in the electrode into the ground for proper electrical contact.

- **GLOBAL POSITIONING SYSYTEM**

This is a very compulsory geologic instrument in any geophysical survey. It is used to mark the position of one's location on the globe which is the X,Y and Z, longitude, latitude and the elevation above the sea level which is also known as the altitude at that point.

CHAPTER FOUR

RESULTS AND DISCUSSION

A total of ten (10) electrical sounding measurements were taken in the study area using the schlumberger electrode configuration, the data acquired were interpreted by partial curve matching and computer iteration by the WINRESIST software to obtain VES curves which shows a vertical variation in resistivity value with depth.

The interpretation of the sounding curves was done both quantitatively and qualitatively. The quantitative interpretation reveals 5 curve types, which are: KH, HKH, QHK, HKQH and QQ curves, occurring in the proportion of 4:2:2:1:1 respectively. Table 2 shows the resistivity values of the layers with their corresponding thicknesses.

The geo-electric parameters obtained from the quantitative interpretation of the sounding curves assisted in the generation of the geo-electric sections (see figures 3a-3d), which shows the variation of the layer resistivities in 2-D with respect to the depth.

Figure 3a (geo-section 1) comprises of VES 3, 1 and 2. The geo-electric section delineated five geo-electric layers; the topsoil, which has resistivity values of 660Ωm to 1129Ωm and an average thickness of 5m and it is made up of sand. The second layer is the lateritic sand formation, which has resistivity values of 171Ωm to 3830Ωm and an average thickness of 15m. The third layer is the sand formation, which has resistivity values of 202Ωm to 473Ωm and an average thickness of 60m. The fourth layer is the clay formation, which has resistivity value of 39Ωm and thickness of 73.8m. The fifth layer is the coarse sand formation, which has resistivity values of 903Ωm to 8765Ωm, and the depth to the top of the formation is about 100m.

TABLE 2: INTERPRETED VERTICAL ELECTRICAL SOUNDING RESULTS

VES STATIONS	NO. OF LAYERS	RESISTIVITY (Ωm)	CURVE TYPE	THICKNESS (m)	DEPTH (m)
VES 1	5	686/173/2082/274/903	HKH	13.6/6.9/18.7/71.4	13.6/20.5/39.2/110.6
VES2	6	1129/171/3830/202/39/1037	HKQH	1.4/2.2/7.9/100.5/73.8	1.4/3.6/11.5/112/186
VES 3	4	659.7/2190/472.8/8764.6	KH	0.8/4.5/79.5	0.8/5.2/84.8
VES 4	4	389.5/1054.5/446/2887.2	KH	0.3/20.8/56.1	0.3/21.0/77.1
VES 5	4	1065.8/2280.6/987.4/18925.5	KH	0.6/11.1/59.8	0.6/11.7/71.5
VES 6	4	2645.2/1319.5/223.4/38.6	QQ	1.9/4.7/83.8	1.9/6.5/90.3
VES 7	5	1152.8/461.2/1839/354/628	HKH	0.5/7.9/35.7/66.6	0.5/8.4/44.2/100.8
VES 8	5	1036/263/184/1084/281.5	QHK	2.5/5.1/6.7/18.5	2.5/7.7/14.3/32.8
VES 9	5	1684/1277/423/2309/228	QHK	1.3/22/43.0/20.9	1.3/23/67/87.5
VES 10	4	1499/469/785/80.4	KH	1.8/4.5/99.5	1.8/6.3/105.8

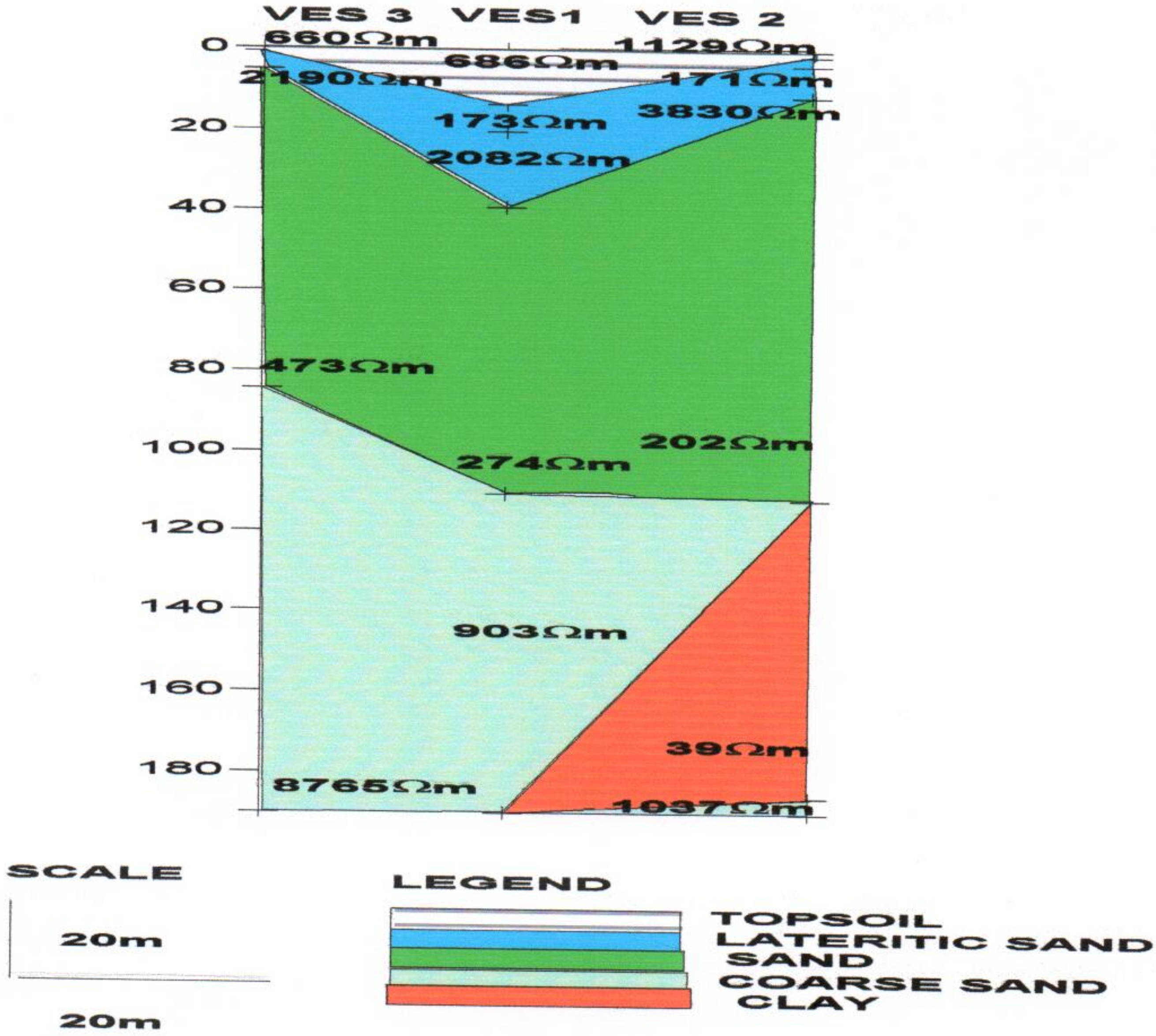

FIGURE 3a: GEO-ELECTRIC SESSION SHOWING VES 3, 1 AND 2.

Figure 3b (geo-section 2) comprises of VES 4, 6 and 5. The geo-electric section delineated five major geo-electric layers which are; the topsoil, which has resistivity values of 390Ωm to 2645Ωm and an average thickness of 2m and it is made up of sand. The second layer is the lateritic sand formation, which has resistivity values of 1056Ωm to 2281Ωm and an average thickness of 10m. The third layer is the sand formation, which has resistivity values of 223Ωm to 987Ωm and an average thickness of 60m. The fourth layer is the coarse sand formation, which has resistivity values of 2887Ωm to 18926Ωm and an average thickness of 30m. The fifth layer is the clay formation which has resistivity value of 39Ωm, the depth to the top of the formation is about 90m.

Figure 3c (geo-section 3) comprises of VES 7, 8 and 10. The geo-electric section delineated four geo-electric layers which are; the topsoil, which has resistivity values of 1036Ωm to 1499Ωm and an average thickness of 1m and it is made up of sand. The second layer is the lateritic sand formation, which has resistivity values of 184Ωm to 1839Ωm and an average thickness of 30m. The third layer is the sand formation, which has resistivity values of 281Ωm to 785Ωm and an average thickness of 70m. The fourth layer is the clay formation, which has resistivity values of 81Ωm and the depth to the top of the formation is about 100m.

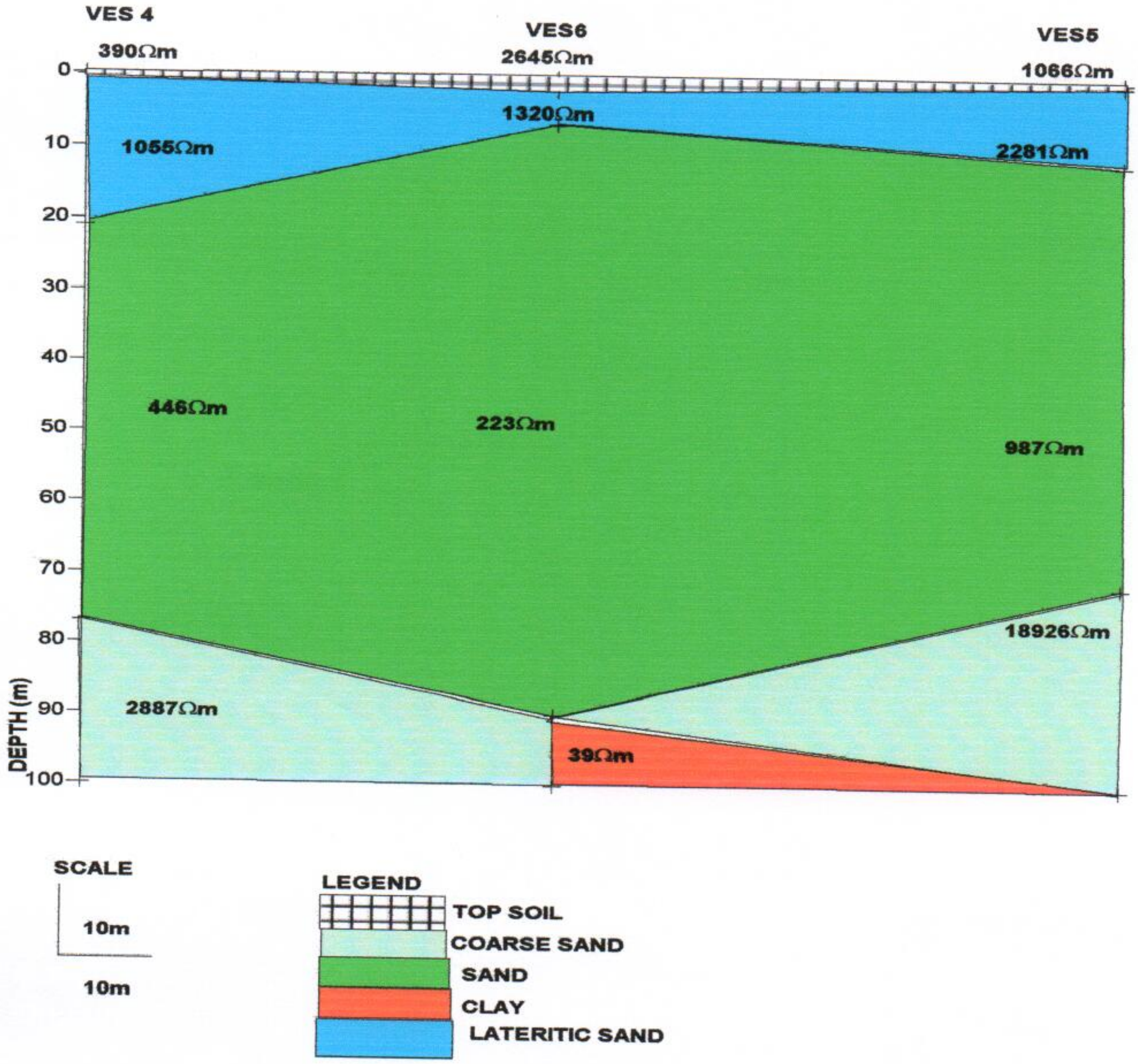

FIG 4b: GEO-ELECTRIC SECTION SHOWING VES 4,6 and 5.

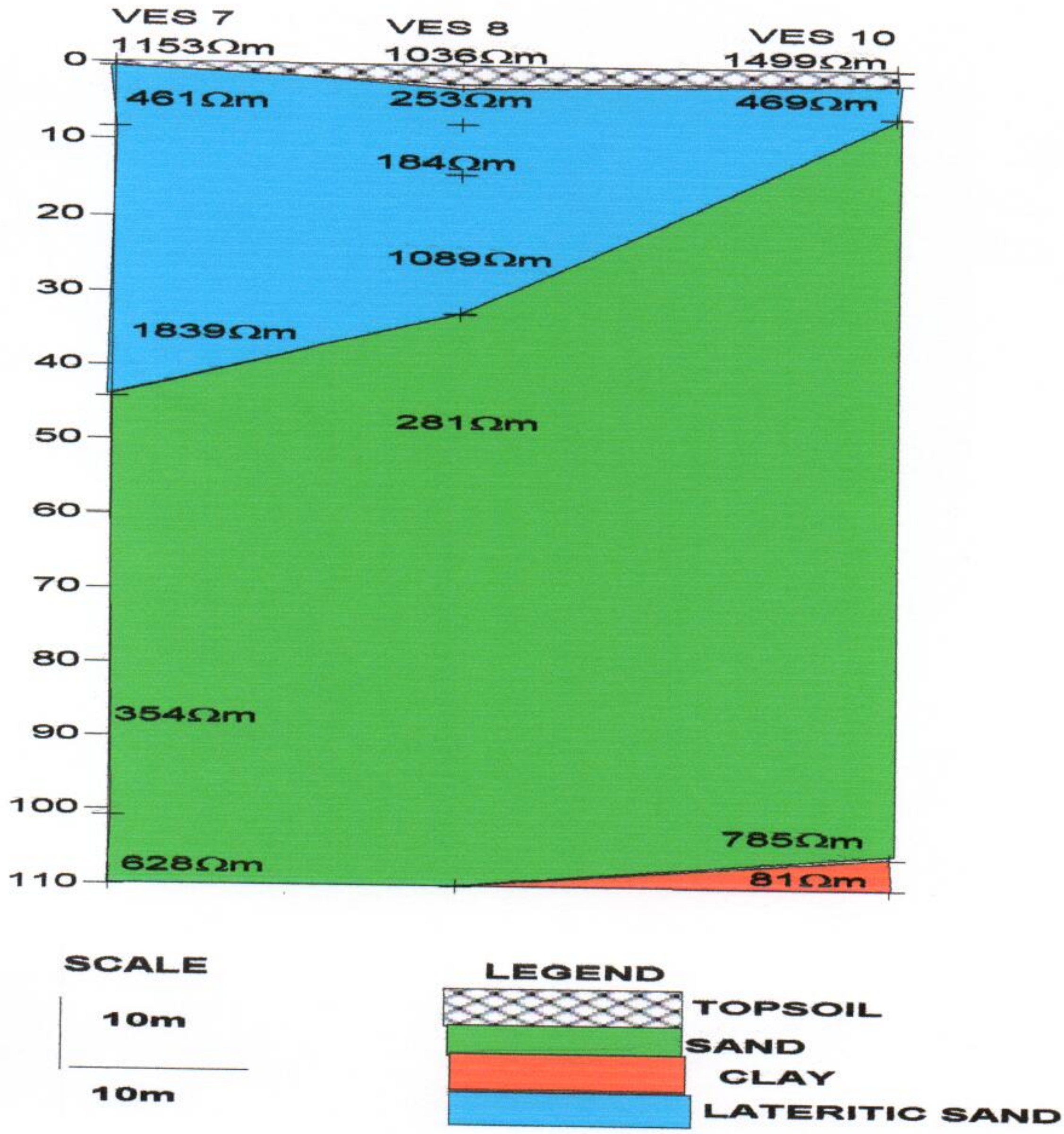

FIG 3c: GEO-ELECTRIC SESSION SHOWING VES 7, 8 and 10

Figure 3d (geo-section 4) comprises of VES 7, 6, 9 and 10. The geo-electric section delineated four geo-electric layers which are; the top soil, which has resistivity values of 1151Ωm to 2654Ωm and an average thickness of 0.5m and it is made up of sand. The second layer is the lateritic sand formation, which has resistivity values of 461Ωm to 2809Ωm and an average thickness of 20m. The third layer is the sand formation, which has resistivity values of 223Ωm to 785Ωm and an average thickness of 80m. The fourth layer is the clay formation, which has resistivity values of 39Ωm to 80Ωm and the depth to the top of the formation is about 90m.

Generally, the geo-electric sections showed a total of 4-5 layers; which is the topsoil, lateritic sand formation, sand formation, coarse sand formation and clay formation. The formation beneath the VES points is dominantly sand, which is highly prolific and permeable and it is the major aquifer unit in the area.

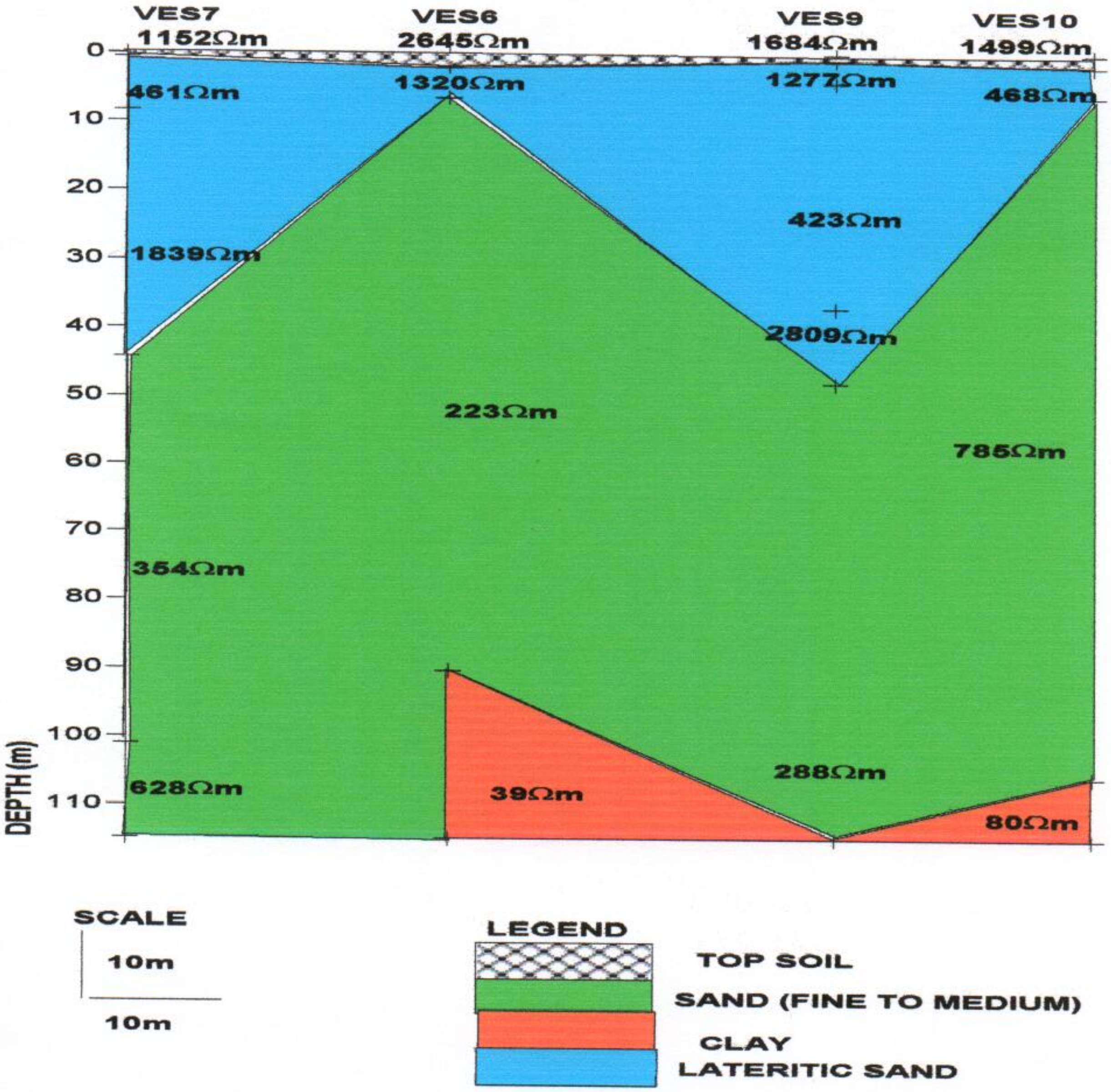

FIG 3d: GEO-ELECTRIC SECTION SHOWING VES 7, 6, 9 AND 10

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

Geophysical resistivity sounding method has enabled us to prospect for groundwater development in Eleme, Port Harcourt.

The geo-sections revealed the lithologic layers beneath the VES points, which is dominantly sand, which is highly prolific and permeable, thus making the study area good for the development of groundwater.

Based on the above discussion, virtually all the VES points are good for groundwater development due to the dominant sand formation, which is the major aquifer in the study area, because of its high prolificacy and permeability.

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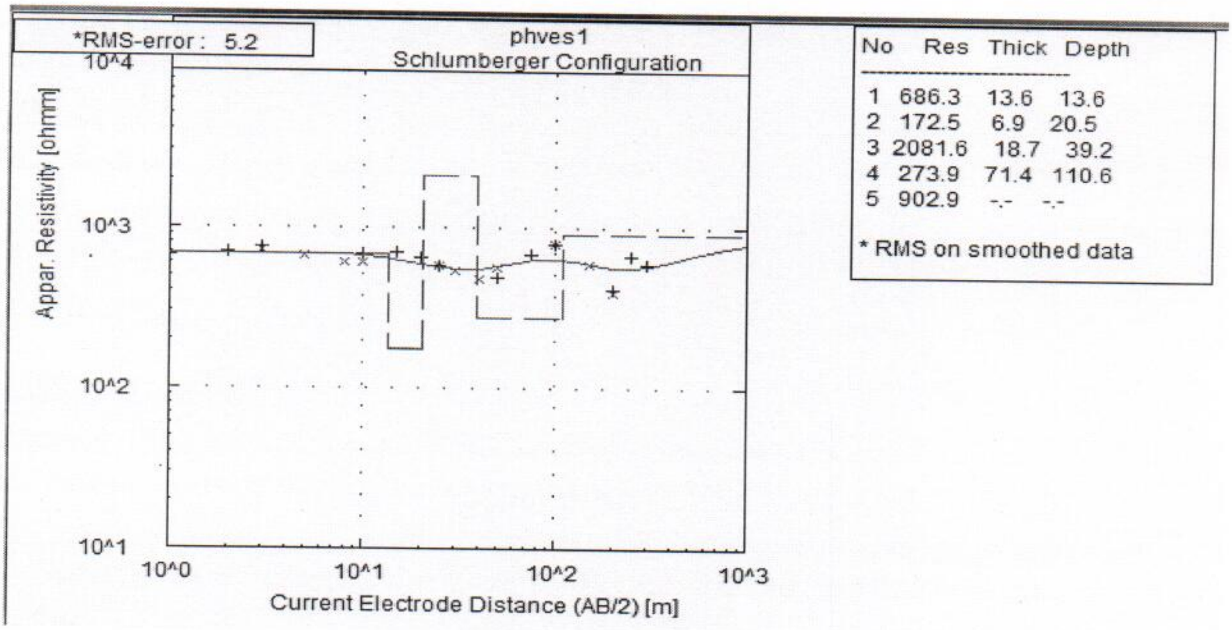
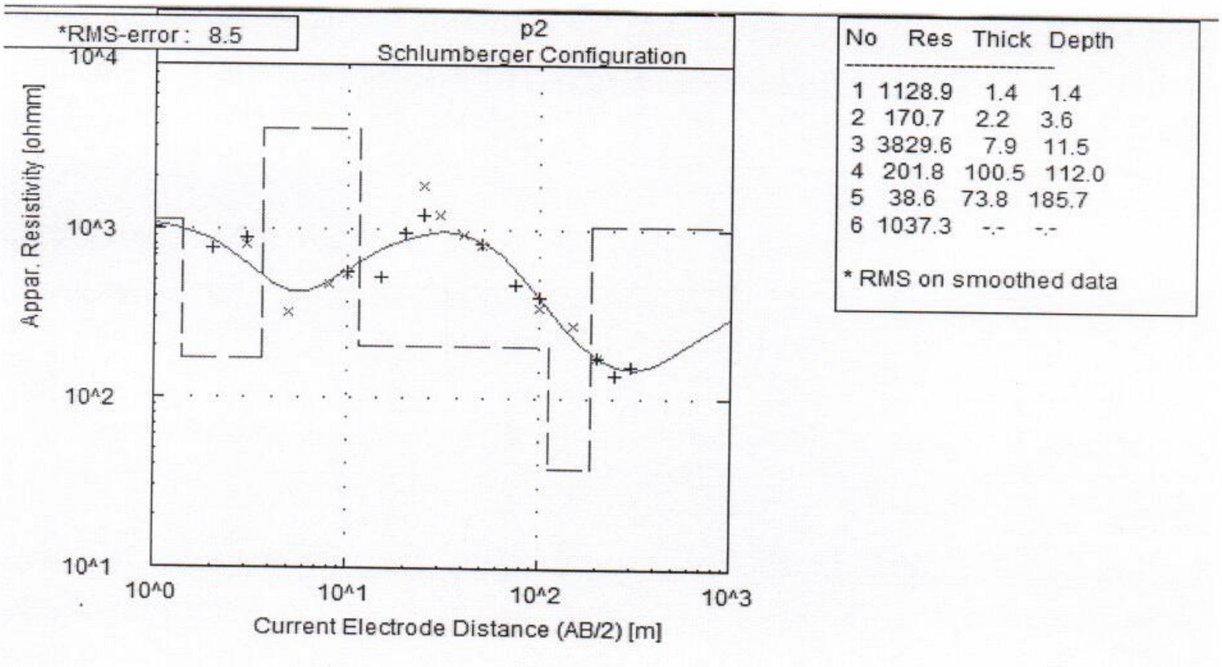
APPENDIX



No	Res	Thick	Depth
1	686.3	13.6	13.6
2	172.5	6.9	20.5
3	2081.6	18.7	39.2
4	273.9	71.4	110.6
5	902.9	-.-	-.-

* RMS on smoothed data

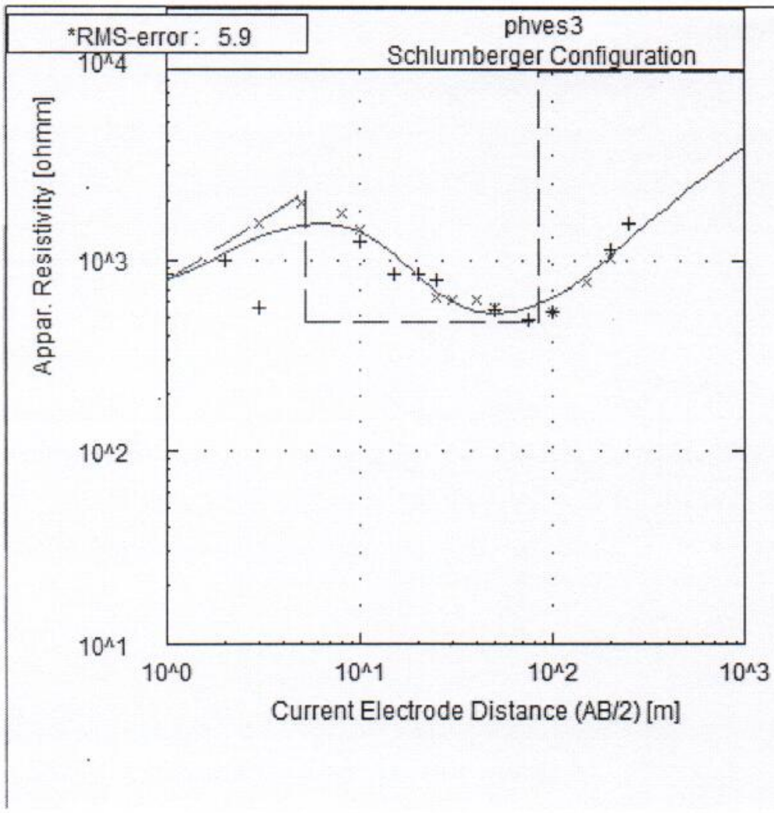
A TYPICAL HK CURVE (VES1)



No	Res	Thick	Depth
1	1128.9	1.4	1.4
2	170.7	2.2	3.6
3	3829.6	7.9	11.5
4	201.8	100.5	112.0
5	38.6	73.8	185.7
6	1037.3	-.-	-.-

* RMS on smoothed data

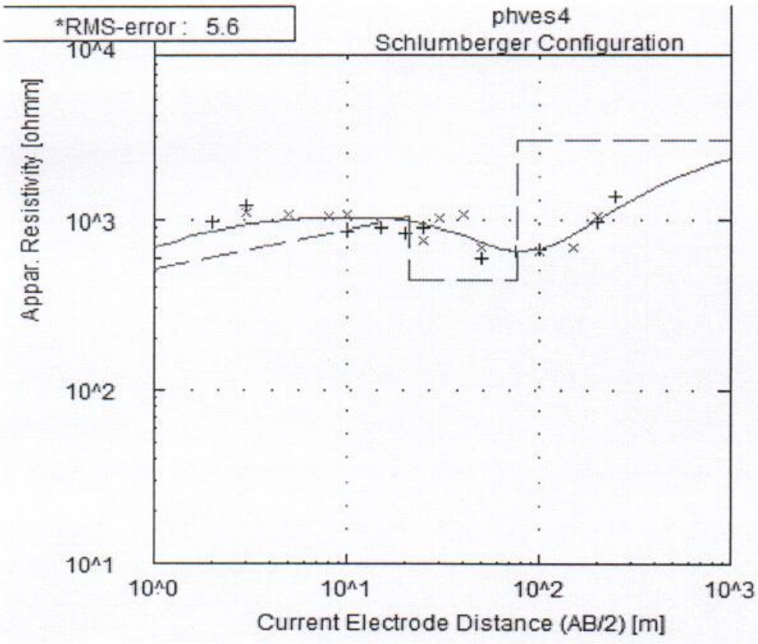
A TYPICAL HKQ CURVE (VES2)



No	Res	Thick	Depth
1	659.7	0.8	0.8
2	2190.0	4.5	5.2
3	472.8	79.5	84.8
4	8764.6	-.-	-.-

* RMS on smoothed data

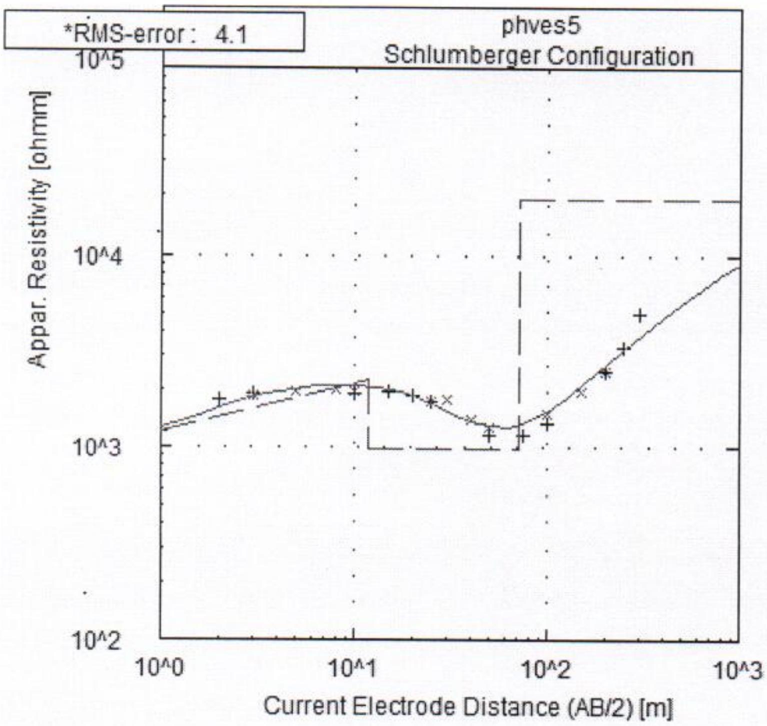
A TYPICAL KH CURVE (VES 3)



No	Res	Thick	Depth
1	389.5	0.3	0.3
2	1054.5	20.8	21.0
3	446.0	56.1	77.1
4	2887.2	-.-	-.-

* RMS on smoothed data

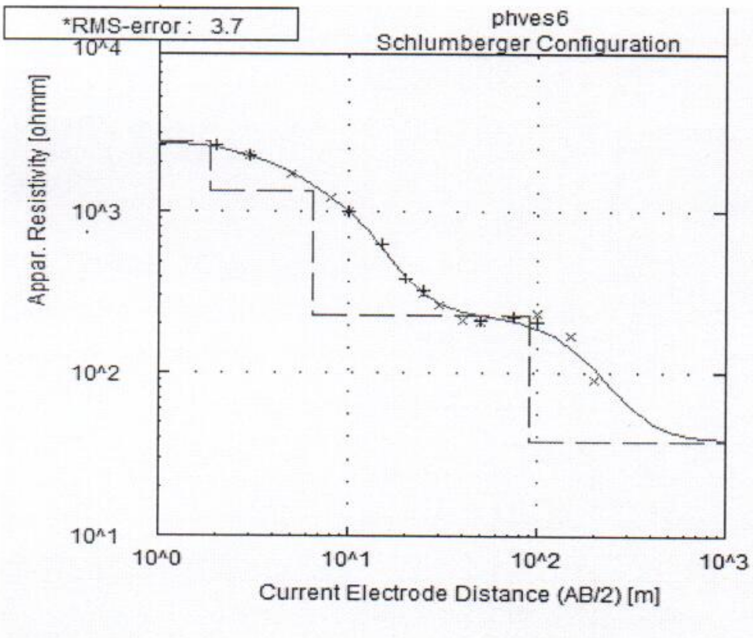
A TYPICAL KH CURVE (VES 4)



No	Res	Thick	Depth
1	1065.8	0.6	0.6
2	2280.6	11.1	11.7
3	987.4	59.8	71.5
4	18925.5	-.-	-.-

* RMS on smoothed data

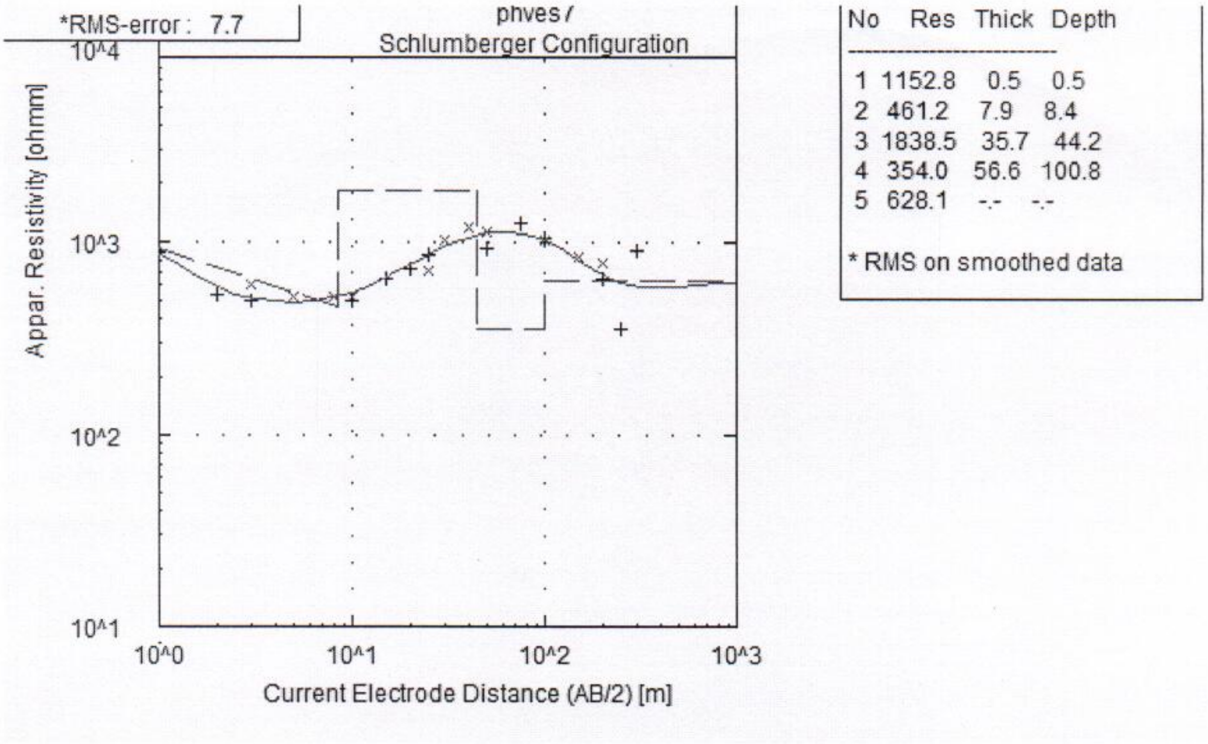
A TYPICAL KH CURVE (VES 5)



No	Res	Thick	Depth
1	2645.2	1.9	1.9
2	1319.5	4.7	6.5
3	223.4	83.8	90.3
4	38.6	-.-	-.-

* RMS on smoothed data

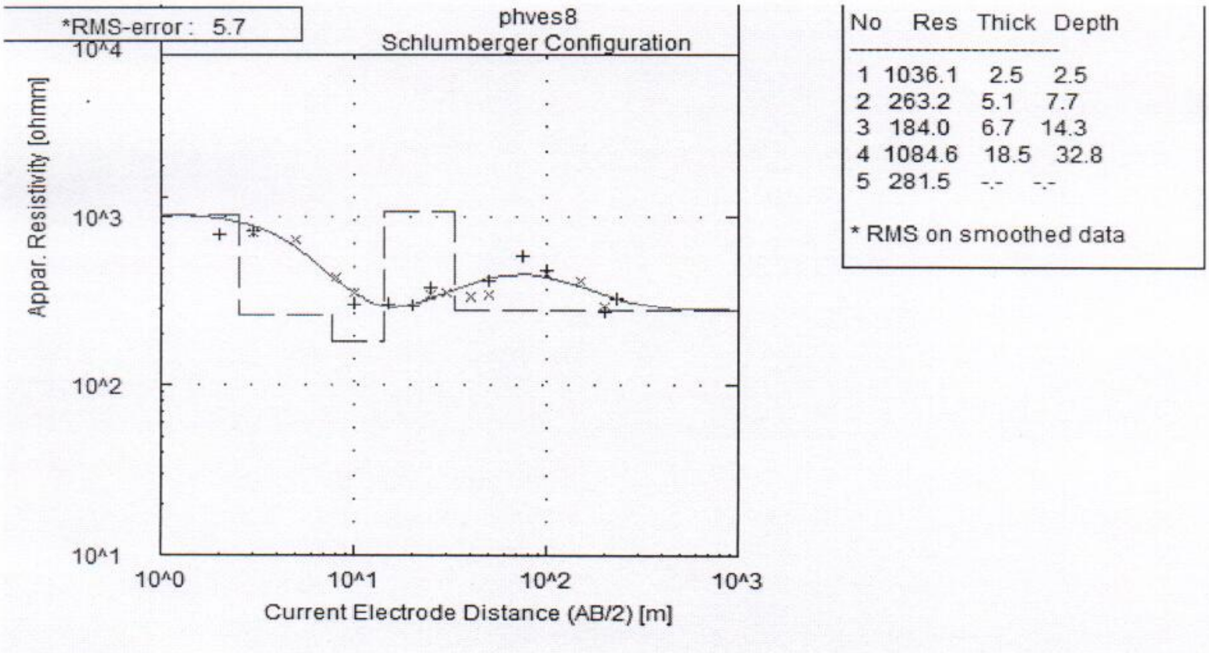
A TYPICAL QQ CURVE (VES 6)



No	Res	Thick	Depth
1	1152.8	0.5	0.5
2	461.2	7.9	8.4
3	1838.5	35.7	44.2
4	354.0	56.6	100.8
5	628.1	-.-	-.-

* RMS on smoothed data

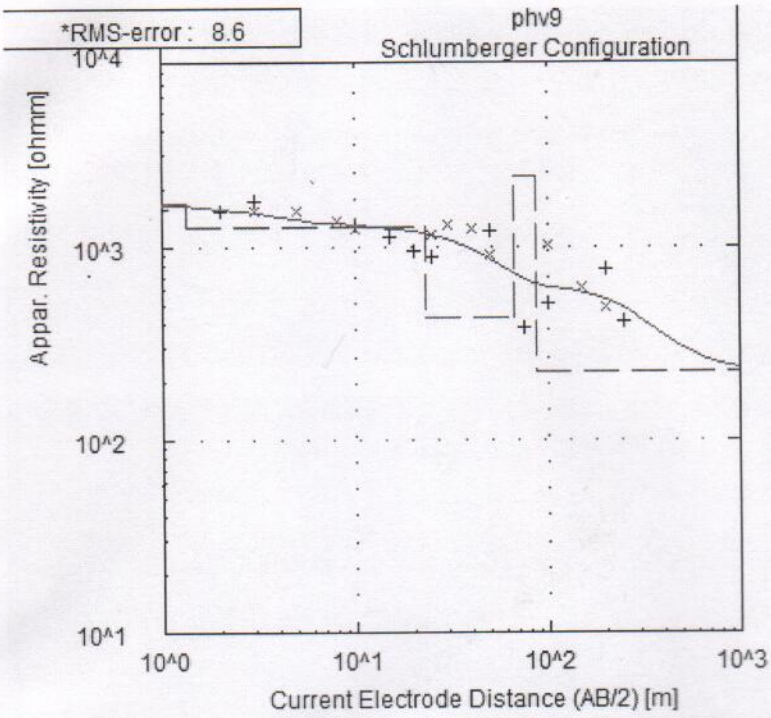
A TYPICAL HKH CURVE (VES 7)



No	Res	Thick	Depth
1	1036.1	2.5	2.5
2	263.2	5.1	7.7
3	184.0	6.7	14.3
4	1084.6	18.5	32.8
5	281.5	-.-	-.-

* RMS on smoothed data

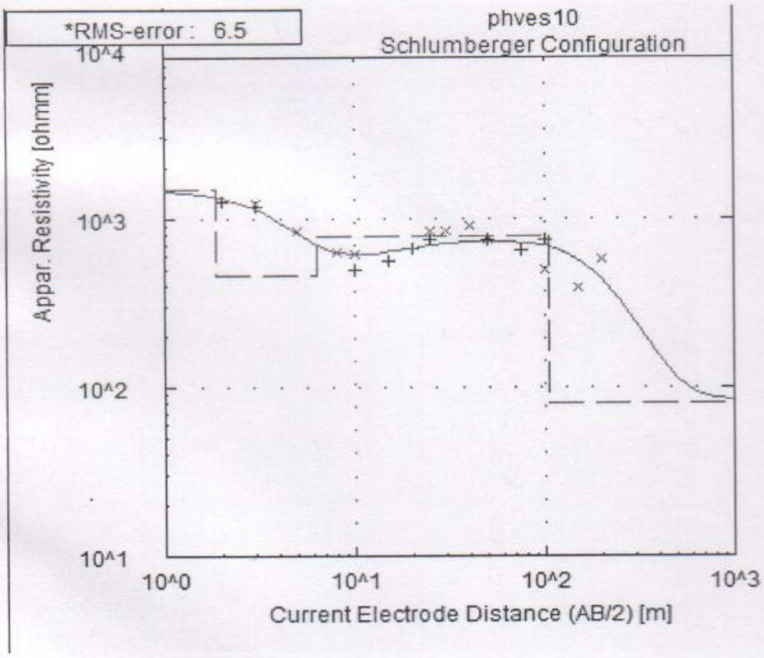
A TYPICAL QHK CURVE (VES 8)



No	Res	Thick	Depth
1	1683.8	1.3	1.3
2	1277.4	22.0	23.3
3	433.7	43.3	66.6
4	2309.4	20.9	87.5
5	228.3	-.-	-.-

* RMS on smoothed data

A TYPICAL QHK CURVE (VES 9)



No	Res	Thick	Depth
1	1498.8	1.8	1.8
2	468.7	4.5	6.3
3	785.0	99.5	105.8
4	80.4	-.-	-.-

* RMS on smoothed data

A TYPICAL KH CURVE (VES 10)