DELINEATION OFANISOTROPY PROPERTIES OF FRACTURE IN PART OF FEDERAL UNIVERSITY OYE-EKITI CAMPUS SOUTHWESTERN NIGERIA, USING RADIAL VERTICAL ELECTRICAL SOUNDING (RVES) METHOD

BY

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A PROJECT WORK SUBMITTED TO THE DEPARTMENT OF GEOPHYSICS, FACULTY OF SCIENCE, IN PARTIAL FULFILMENT OF THE REQUIRMENT FOR THE AWARD OF DEGREE OF BARCHELOR OF SCIENCE IN GEOPHYSICS.

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CERTIFICATION

This is to certify that this project work was carried out by Master Eniola Adeyemi Olamide with matriculation number GPY/11/0293 of the department of Geophysics, Faculty of Science, Federal university Oye Ekiti, Ekiti State, Under my supervision.

……………………… 30/11/2015

Supervisor **Date**

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DEDICATION

I dedicate this work to God Almighty for keeping me till this present time and for seeing me through my course of study and to my parents, brothers and my church members for their support, advice and words of encouragement.

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I thank Almighty God for His unconditional Love towards me and for His faithfulness even in all my faithlessness

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ABSTRACT

Electrical resistivity survey was used to investigate the anisotropic properties with the view of understanding the major direction of fractures as well as the behavioural patterns of the structures in part of Federal University Oye Ekiti, south western Nigeria. The area lies within the south-western Basement complex of Nigeria underlain by migmatite, granite gneiss.

Five Radial Vertical Electrical Soundings (RVES) were carried out along four different azimuths (0^0, 45^0, 90^0, and 135^0) to determine the electrical anisotropy. The quantitative interpretation of RVES curves involved the use of partial curves matching and computer iteration using WINRESIST software.

Polygons produced from eight radial sounding showed the dominant structural trends of fractures on the banded gneiss. The radial resistivity survey results show that there is significant anisotropy between 0 – 40 m depth generally striking NE-SW, NW-SE and N-S showing the major structural trend of basement fractures. Variation of apparent resistivity is strongest at the eastern and southern parts of the study area with coefficients of 1.1, and 2.0 this high coefficient of anisotropy implies higher- permeability anisotropy.

The orientation of geologic structures from the study area showed an NE-SW, and NW-SE directions of the structures depicted by the anisotropic polar plot. The fractures are known to be complex and in turn interconnected. Hence a fracture controlled flow.

The main water – bearing unit in the area of study is the weathered basement and the fractured basement which are within the second and third geo-electric layers respectively. The weathered/fractured basement resistivity values vary from 57 Ohm-m and 1282 Ohm-m with thickness values ranging from 0.1m to7.9m.

CHAPTER ONE

INTRODUCTION

1.1 GENERAL STATEMENT

The presence of aligned vertical features and vertical to subvertical thin beds causes anisotropic and inhomogeneity in rocks. Observed changes in apparent resistivity with azimuth are typically interpreted to indicate fracture anisotropy. There has been growing need and interest in anisotropy to locate, characterize and identify the directional properties of fractured rock mass in the subsurface. Electrical anisotropy has not been extensively utilized despite of its relevance in electrical technique for detecting fluid filled fracture. This need has compelled the geophysicist to use the method to characterize the fractures economically, quantitatively, and non-invasively and to relate these fractures to their fluid flow properties. For instance, a fractured rock mass has a preferential direction for bulk fluid flow along the major fracture directions. A relatively inexpensive way to characterize a fractured rock remotely and on a larger volume is by using geophysics, for example resistivity method. Information about fracture orientation, intensity of porosity and permeability obtained non-invasively is particularly useful to an earth scientist (Boadu et al., 2005).

The model of a dipping anisotropic half-space is proposed for the first time by Bhattacharya and Patra (1968). The most advanced model considered so far is that of Gurevich (1975). It consists of a layered half-space with dipping anisotropy, the only restriction being that the horizontal strike direction is the same in all layers. Pal and Mukherjee (1986) calculated the electrical potential due to a point current source over a two-layer earth with a dipping anisotropic top layer. Negi and Saraf (1989) review the research on electrical anisotropy, which has been the subject of much attention in electrical prospecting (e.g. Kunz and Moran, 1958; Asten 1974; Moranand Gianzero, 1979, 1982).

The term anisotropy is used to describe the difference in vertical and horizontal resistivity within a formation and at the scale of the resistivity measurement. Although there are several types of anisotropy, the term usually is used when the electrical properties are the same in all horizontal direction, but different in the vertical direction, (Wikipedia definition).

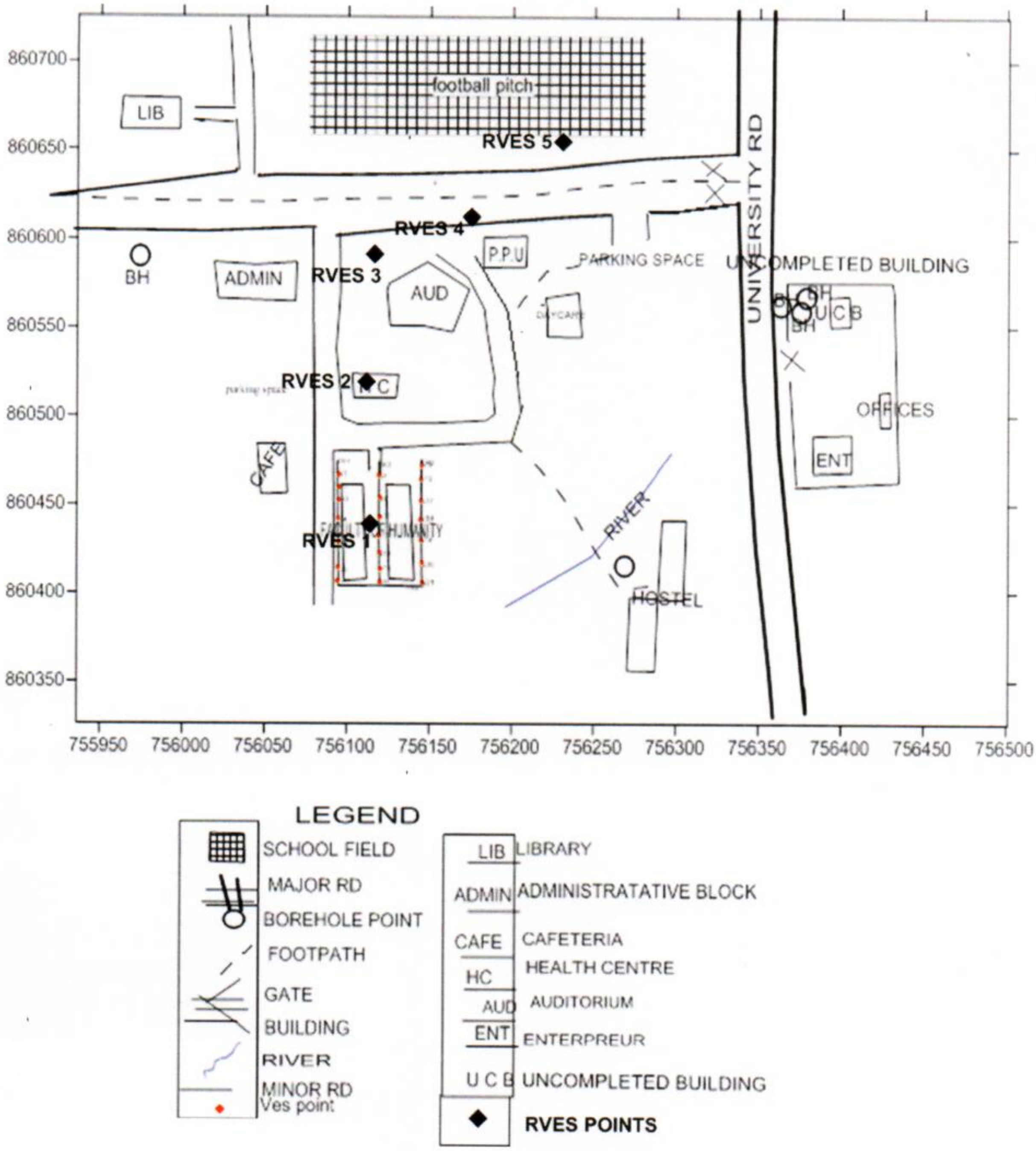
A complex problem in hydrology is the determination of fluid transport behavior such as flow pathways, flow velocity and hydraulic conductivity in a heterogeneous and anisotropic subsurface. Information on fluid flow behavior (both present and predicted) is needed to assess the contamination impact of spills and plumes and the planning and assessment of remediation efforts. Geophysical methods may provide a relatively low-cost approach to hydrogeological characterization. Numerous papers illustrate the utility of, notably geophysical methods in defining subsurface heterogeneity in aquifer properties (Kelly and Mares 1993). Other methods azimuthal resistivity (Ritzi and Andolsek, 1992), or electromagnetic azimuthal resistivity (Slater et al., 1998) provides information on aquifer anisotropy. In field conditions, clean fracture and fault planes manifest themselves on geoelectrical sounding curves as cusps marking lateral inhomogeneity (Zohdy et al., 1974). The cusps become more pronounced as the angle of inclination of the fracture approaches 90^0. When groundwater flow in shallow depths is to be traced, radial electrode configuration exhibits maximum infiltration potential in the direction of fluid flow (Ogilvy, 1970; Mamah and Ekine, 1989; Sauk and Zabik, 1972). Azimuthal resistivity measurement is a modified resistivity method where the magnitude and direction of the electrical anisotropy are determined. An electrode array is rotated about its center so that the apparent resistivity is observed for several directions (Taylor and Fleming, 1988). It is generally assumed that the anisotropy is caused by presence of fluid – filled fractures in a relatively resistive rock or soil. Azimuthal resistivity has been used to determine fracture geometry in crystalline rocks and glacial till by Lane *et al*. (1995), Carlson *et al*. (1996), Ritzi and Andolsek (1992), Jansen and

Taylor (1996) and chapman and Lane (1996). One of the key problems with azimuthal resistivity method is its sensitivity to lateral heterogeneities. A site exhibiting significant lateral changes in resistivity can produce azimuthal resistivity measurements where the effects of anisotropy are entirely masked by the effects of heterogeneity.

Electrical anisotropy is an important subject, not only to Geophysicist and Geologist, but also to the Petrophysicist, Drillers, Stratigraphers, as well as Reservoir Engineers. Where electrical anisotropy exists, convenient assumption fails, actual geological depths and structures are wrongly imaged, petrophysical parameters are wrongly estimated and drilling activities become more problematic because of loss of circulation of drilling fluids. There has been growing need and interest in the application of azimuthal resistivity surveys (ARS) using various electrode adaptations to locate, characterize, and identify the directional properties of anisotropic rock mass in the earth surface. In using azimuthal resistivity survey, any observed change in apparent resistivity ρ_a is interpreted as an indication of fractured anisotropy, which in most cases might also be produced by the presence of a dipping bed or inhomogeneities or lateral change in apparent resistivity (Waton and Baker, 1999, Busby, 2000). Fracture anisotropy is associated with electrical and hydraulic variation resulting from the preferred orientation of fracture sets (Slater et al., 2006).

1.2 LOCATION AND AREA EXTENT

Federal University Oye Ekiti is located in the South Western part of Nigeria and falls within the basement complex terrain of South Western Nigeria. The study area lies within latitude $N7^{0}48^{1}04.54^{11}$ and Longitude $8^{0}35^{1}07.45^{11}$. (Figure 1.0a)



(FIG 1.0a) MAP OF FEDERAL UNIVERSITY OYE EKITI, PHASE ONE SHOWING THE RVES LOCATION.

1.3 AIM AND OBJECTIVES OF STUDY

The aim of this research is to understand the electrical resistivity anisotropic characteristics of the basement rock of Federal university Oye Ekiti campus. The following objectives help in achieving the aim of the research.

1. To determine the depth to the bedrock or weathering profile .

2. Determine the subsurface layering, their thickness as well as their resistivity with respect to different azimuth.

3. Investigating the hydrogeological condition of the study area with a view to delineating the potential fracture zone in the basement.

4. Identifying the type of fault and fractures in the study area, which in turn gives an insight to the depth of the water table and flow pattern of the groundwater.

1.4 PHYSIOGRAPHY SETTING

1.4.1 ACCESSIBILITY

The study area is accessible through interconnected series of minor roads, foot paths and few major roads. The minor roads serve as the main access for the movement of Federal university Oye Ekiti student and staff. The foot paths leads to areas that are not accessible by cars, the minor roads are used to transport people and goods with the uses of automobiles or Cabs within the study area. The major roads serve as a link between the study area and Oye Community.

1.4.2 RELIEF, CLIMATE AND VEGETATION

Ekiti State is mainly an upland area. In the main, the relief is rugged with undulating areas and granitic outcrops in several places. The notable ones among the hills are Ikere Ekiti Hills in the southern part of the state; Efon Alaye Hills to the western boundary of the state and the Ado Ekiti Hills in the central part of the state. Most of these hills are well over 250m above sea level. The drainage system over the areas of basement complex rocks is usually marked with the proliferation of many small river channels. The channels of these smaller streams are dry for many months, especially from November to May.

However, the state serves as the watershed and source region for three major rivers that flow into the Atlantic Ocean. These are the Rivers Osun, Owena and Ogbese. Other rivers are Ero, Ose and Oni. Another important aspect of the relief of Ekiti state is the prevalence of erosion gullies along hill slopes and valleys. The gullies are very common in Efon Alaye and in the northern part of the state. Indeed, in Efon Alaye, the gullies could be devastating. (Ekiti State Ministry of Environment, 1999).

The climate is of the Lowland Tropical Rain Forest type with distinct wet and dry seasons. The dry season comes up between November and April while the wet season prevails between May and October. In the south, the mean monthly temperature is about 28Atmospheric condition with a mean monthly range of 3Atmospheric condition while the mean relative humidity is over seventy five percent. However, in the northern part of the state, the mean monthly temperature may be over 30Atmospheric condition while the mean monthly range may be as high as 8Atmospheric condition. The mean monthly relative humidity here is about 65 percent. The mean annual total rainfall in the south is about 1800mm while that of the northern part is hardly over 1600mm. (Ekiti state ministry of environment 1999). As indicated under climate, the expected climax vegetation is the evergreen high forest composed of many varieties of hardwood timber.

1.4.3 DRAINAGE PATTERN

The drainage pattern of the study area is characteristically dendritic which is probably related to the structures of the underlying rock. The main rivers in the study area are river Atirin close to the University Hostel and river Egburu in the University road that leads to Are town both of which are tributaries to River Awere close to the University ICT in phase 2. The river Awere is the main river found in the south Western part of the study area while River Atirin and Egburu is found in the eastern part of the study area.

1.5 LITERATURE REVIEW

In the last few years, a great number of interpretation methods with variable isotropic electrical conductivity have been developed, but not enough attention has been paid to the effects of anisotropy, especially the arbitrary anisotropy of the earth.

The effect of anisotropy on apparent resistivity was mentioned earlier in the geophysical literature by Slichter (1933) and Pirson (1935), but their research concentrated on the uniform transverse isotropic half-space only. In that case, the solution for the potential is usually obtained by replacing the anisotropic resistivity by an isotropic medium with the resistivity being the geometric mean of the vertical and radial resistivity. Also for the layered transverse isotropic earth, one can use the equivalent isotropic models to replace the anisotropic resistivity. (Niwas and Upadhyaya, 1974; Pal and Das Gupta

A lot of work has been done in the studied area and similar areas. Such work includes, Rahaman (1988), Odeyemi (1977) and Oyawoye (1964), Grant (1978) and Anifowose (2006) among others have given a vivid account of the geology of this area.

Numerous geological research works has been carried out in Ekiti State by different geologist ranging from geophysical, petrological research. The electrical resistivity anisotropy research has also been carried out by diverse geologist in different part of Nigeria and the world in general. Anisotropy properties of an area can be used in delineating not only the potential fracture zone but also the fracture trend, and also in studying the geological set up of an area as well as in the study of concealed structured.

Olasehinde and Bayewu (2011) used the electrical resistivity anisotropy properties of Odo Ara near Egbe, west central Nigeria to resolve its geological set up. They concluded that the amphibolite and schist in the area are characterized by low resistivity of less than 100 ohms and the banded gneiss has higher resistivity greater than 100 ohms. The resistivity parameters showed that the amphibolite and the schist have NE-SW anisotropy direction while the banded gneiss has NW-SE direction which agrees significantly with the geology of Nigeria.

Odo (2010) employed the azimuthal resistivity survey to determine the anisotropy properties of fracture in parts of Abakaliki in Ebonyi State University, Nigeria for groundwater development within the area. He arrived at the conclusion that the fractured intensity and density is more in the country NW and SE (mainly in 135^0 orientation) of the study area which suggest higher porosity. He also gave an insight to the net groundwater flow of the area which is controlled by dominant fracture direction.

Isife and Obasi (2012) used Radial Vertical Electrical Sounding carried out at Ifon, south western Nigeria to determine the electrical anisotropy and map the trend of conceal 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-SW and NW-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 problem due to the subsurface fractures that abound in Ifon area.

Omosanya, et al (2012) combined electrical resistivity imaging and geologic mapping to delineate geological structures and azimuthal resistivity survey to determine the subsurface fractures in the north-western part of Ago-iwoye.

case in clay materials i.e. clay has high porosity, low permeability, but yet low resistivity. (i.e. high conductivity).

2.3 BASIC THEORY OF ELECTRICAL RESISTIVITY METHODS

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:

$$R \propto L \quad (2.1)$$

$$R \propto I/A \quad (2.2)$$

Combining (2.1) and (2.2)

$$R \propto L/A \quad (2.3)$$

$$R = \rho L/A \quad (2.4)$$

Where ρ is the constant of proportionality called resistivity.

But from ohms law:

$$R = \frac{\Delta V}{I} \quad (2.5)$$

By substituting for 'R' in equation (2.4)

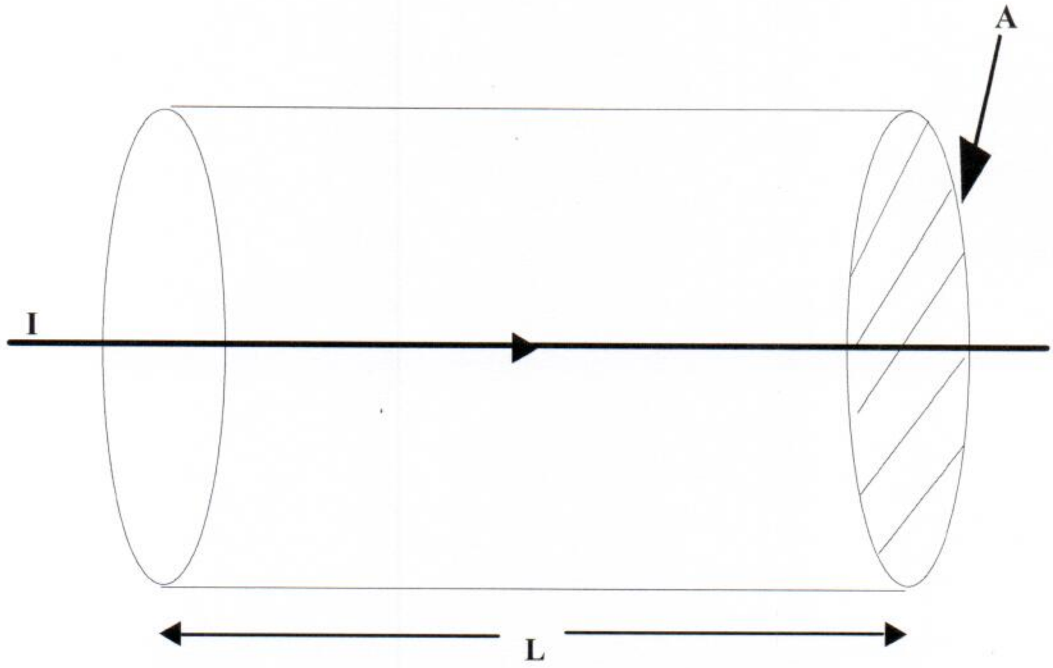


Figure 2.0: Schematic Diagram of the Flow of Current through a Cylindrical Model.

$$\frac{\Delta V}{I} = \rho \, {}^{L}\!/_{A} \qquad (2.6)$$

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

$$\therefore \rho = \frac{\Lambda VA}{IL} \qquad (2.7)$$

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 (2.7) can be used to determine the resistivity of any homogenous medium . provided

the geometry is simple. But when the medium is semi-infinite, equation (2.7) needs to be modified before it can be applicable.

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

Then:

$$\rho = \frac{LimL \to 0\frac{\Lambda V}{L}}{LimA \to 0\frac{I}{A}}. \qquad (2.8)$$

$$\rho = \frac{E}{J} \qquad (2.9)$$

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

From Equation (2.9)

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

$$\therefore E = JP \qquad (2.10)$$

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:

$$J = \frac{I}{A} \qquad (2.11)$$

Where A = area of the spherical surface, Given; $A = 4\pi r^2$

$$\therefore J = I/A = \frac{I}{4\pi r^2} \qquad (2.12)$$

Substitute equation (2.12) into (2.10)

$$E = \frac{I\rho}{4\pi r^2} \qquad (2.13)$$

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

$$E = -\nabla V = \frac{-\delta V}{\delta r} \qquad (2.14)$$

Equate equations (2.13) and (2.14)

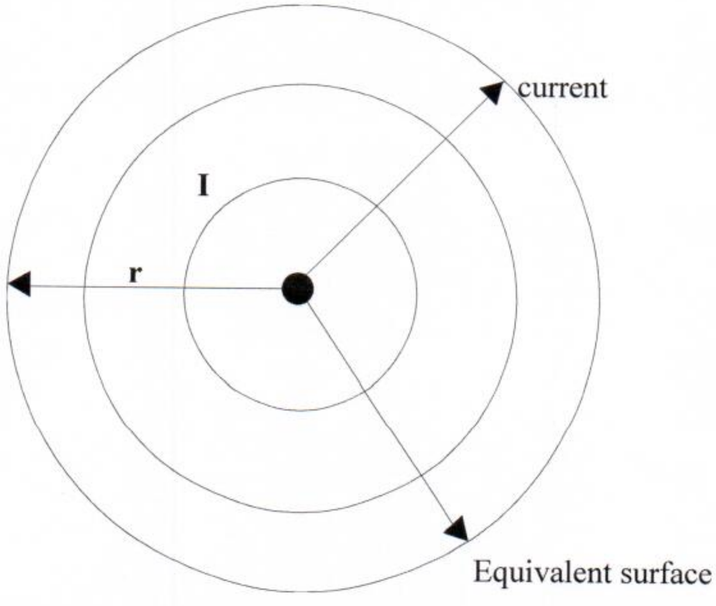


Figure 2.1: Spherical Body of Radius 'r'

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

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

$$\therefore \frac{\delta V}{4\pi r^2} = -I\rho\delta r \quad (2.15)$$

Taking the integral of both sides:

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

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

$$\therefore V = \frac{I\rho}{4\pi r} \quad (2.16)$$

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

$$J = \frac{I}{A} \quad (2.17)$$

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

∴Equation (2.17) becomes

$$J = \frac{1}{2\pi r^2} \quad (2.18)$$

$$\therefore E = \frac{I\rho}{2\pi r^2} \quad (2.19)$$

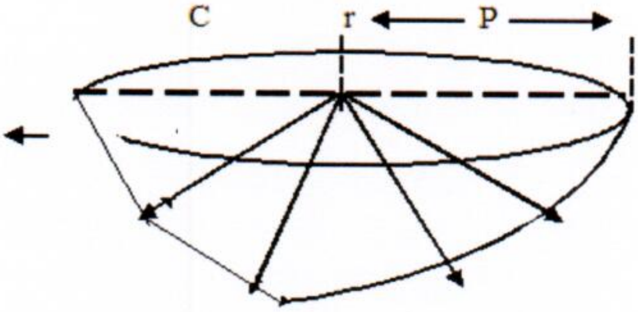


Figure2.2: Current Source at the Hemispherical Surface (Telford *et al.*, 1990).

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

$$\therefore \frac{\delta V}{\delta r}$$

$$= \frac{-I\rho}{2\pi r^2} \qquad (2.20)$$

Taking the integral of both sides:

Equation (2.18) becomes:

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

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

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

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

$$V$$

$$= \frac{-I\rho}{2\pi r} \qquad (2.21)$$

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

2.4 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 2.4, the potential at point P_1 due to current at point C_1 at the current surface is given as:

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

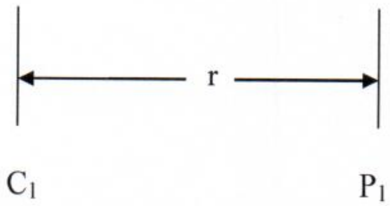


Figure 2.3: A simple current source

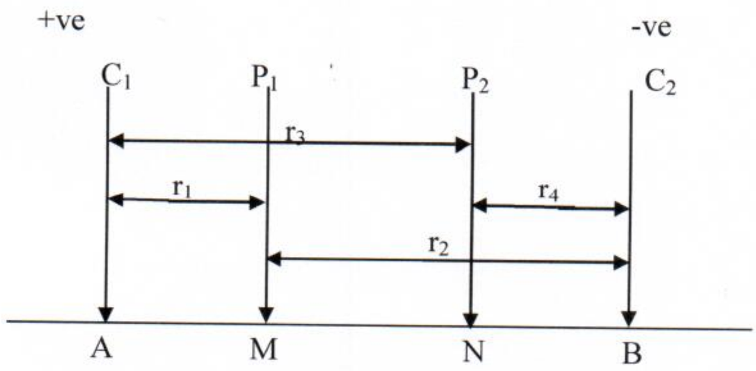


Figure 2.4: Generalized Electrode Configuration for Resistivity Survey.

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;

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

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

$$V_{11,12} = \frac{I\rho}{2\pi}\left[\frac{1}{r_1} - \frac{1}{r_2}\right] \quad (2.22)$$

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;

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

$$V_{21,22} = \frac{I\rho}{2\pi}\left[\frac{1}{r_3} - \frac{1}{r_4}\right] \quad (2.23)$$

But the potential difference ΔV between P_1 and P_2 can be obtained by subtracting equation (2.22) and (2.23)

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

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

$$\text{But } \rho = \frac{2\pi\Delta V}{I}\left[\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4}\right]^{-1} \quad (2.24)$$

Therefore, $\rho = KR$

Where;

K is the Geometric Factor

2.5 ELECTRODE ARRAY OR CONFIGURATION

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.

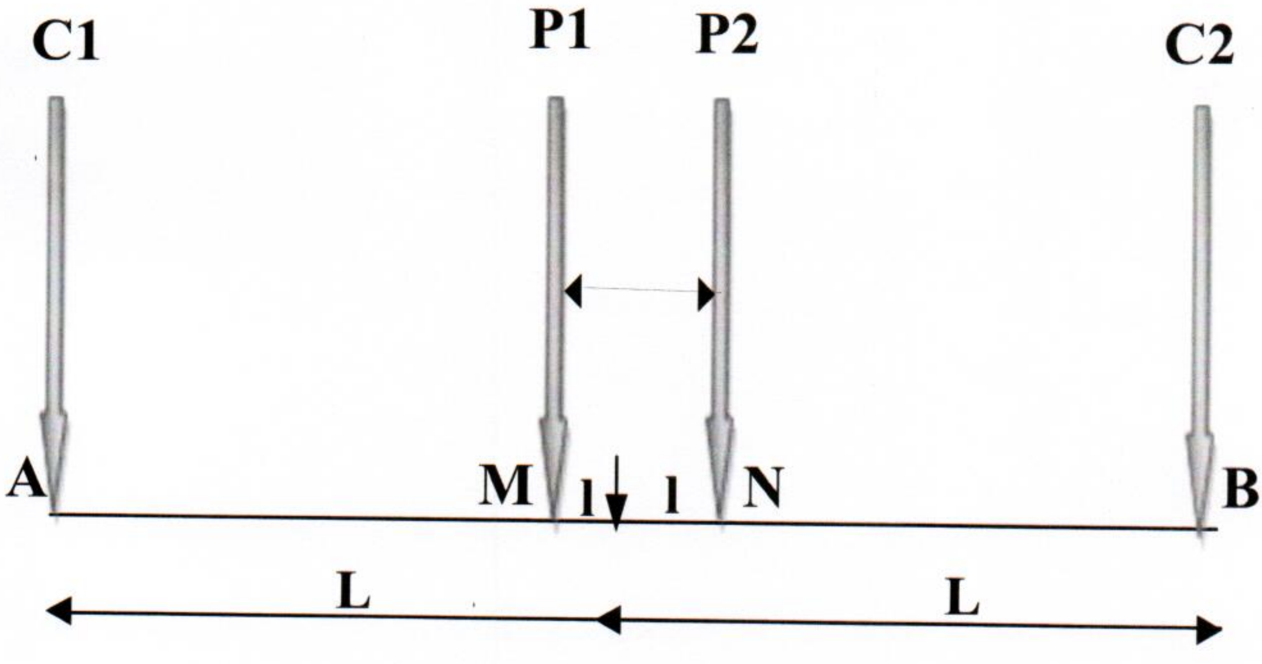
2.6 SCHLUMBERGER ELECTRODE ARRAY

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 2.5a.

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 2.5a): Typical Schlumberger Configuration

MN = 2l

AB ≥ 5MN

The apparent resistivity equation for schlumberger array is derived as:

$$\rho_a = 2\pi R \left[\frac{1}{AM} - \frac{1}{MB} - \frac{1}{AN} + \frac{1}{NB}\right] \qquad (2.28)$$

Consider the array in Figure 2.8

If AM = L – 1

MB = L + 1

AN = L + 1

NB = L – 1

By substituting into equation (26)

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

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

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

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

$$\rho_a = 2\pi R \left[\frac{L^2-1^2}{41}\right] \qquad (2.29)$$

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

$$\rho_a = \frac{\pi R L^2}{2l} \qquad (2.30)$$

Equation (2.18) 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.

2.7 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:

i. Horizontal Profiling (HP);

Ii. Vertical Electrical Sounding (VES);

iii. Combined horizontal profiling and vertical electrical sounding.

i. 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.

ii. 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.

Iii .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.

2.8 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.

2.9 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;

i. 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.

ii. 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;

i. Empirical semi-empirical technique which is used mostly for wenner array

ii. Analytical method which involve partial curve matching and complete curve matching

iii. Direct interpretation which is computer based.

2.2.1 ADVANTAGES OF ELECTRICAL RESISTIVITY METHOD

A principal advantage of the electrical resistivity method is that quantitative modeling is possible using either computer software or published master curves. The resulting models can provide accurate estimates of depth, thickness and electrical resistivity of subsurface layers. The layered electrical resistivity can then be used to estimate the electrical resistivity of the saturating fluid, which is related to the total concentration of dissolved solids in the fluids.

2.2.2 APPLICATION OF ELECTRICAL RESISTIVITY METHOD

(a) Groundwater Exploration: The relevance of this method to groundwater exploration involves:

i. Direct location of subsurface water through mapping of the water table. Indirect location of potential aquifer such as weathered zone, porous and permeable sandstones, alluvium deposits and sand gravel within clay deposit, Etc.
ii. Determination of saline zones and fresh/saline water interface in the coastal areas.
iii. Mapping of groundwater flow direction
iv. Mapping of geological structures that are favorable to groundwater accumulation, such as fractures, basement depressions, buried channels, Sand lenses and network of joints.

(b) Engineering Study: Application of this method in engineering study is relevant in various areas;

i. Determination of the depth to bedrock at construction site this may include building highway roads, bridges and dam sites.

i. Mapping of sea page zones across contaminated structures such as dam embankment or Reservoir floors.
ii. Mapping of subsurface structures inimical to Engineering foundations such as bedrock depression, fault and fracture and joint.
iii. Location of buried pipes, cables, mine shafts etc.
iv. Evaluation of volume of hydraulic sand fills in recline area e.g. Lagos, Port Harcourt and Warri.
v. Determination of nature of superficial deposits for corrosion study and electrical system earthening.
vi. Mapping of construction materials such as granite, gravel deposits, laterite etc.

(c) Environmental Study: Application of this method in environmental study is relevant in the following areas:

i. Mapping of chemical pollution plumes arising from Industrial waste disposal or oil well blowout, spilled oil from failed oil pipes.
ii. Delineation of saline water and mapping of fresh/saline water interphase
iii. Detection of buried waste dung, delineation of their margins and physical characteristics.
iv. Exploration of new landfill or disposal sites.
v. Delineation of geological features such as ground subsidence, landslide, gravity and sink holes.

(d) Geological Mapping: This method is used in the mapping of geological contact zones, fractures, faults, shear zones, buried channels etc. it is also applicable in the determination of geological trends such as strike, foliation, particularly in the area where the bedrock is conceal.

(e) Thermal/geothermal study: This method is used in mapping of fault and fracture zone associated with a geothermal fields and delineation of geothermal reservoir. It is also used in the mapping of coal mine fire.

(f) Mineral Exploration: This method is limited in its application to mineral exploration. However, it can be used in location or mapping of massive mineral deposits; non-metallic or metallic such as pyrite, chalcopyrite, graphite, chalcocite, salt etc.

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

i. Existence of sufficient geophysical contrast between the bedrock and the overlying deposit.

ii. Existence of simple geologic features.

iii. Existence of suitable contrast in the electrical property of the targeted feature.

iv. Existence of large expanse of hand to work with little or no restriction.

v. Availability of electrolyte in formation.

vi. 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.

2.2.4 LIMITATIONS OF ELECTRICAL RESISTIVITY METHOD

Limitations of using the electrical resistivity method in ground water pollution investigations are largely due to site characteristics, rather than in any inherent limitations of the method. Typically, sites are located in industrial areas that contain an abundance of broad spectrum electrical noise. In conducting an electrical resistivity survey, the voltages are relayed to the receiver over long wires that are grounded at each end. These wires act as an antenna receiving the radiated electrical noise that in turn degrades the quality of the measured voltages.

Electrical resistivity surveys require a fairly large area, far removed from power lines and grounded metallic structures such as metal fences, pipelines and railroad tracks. This requirement precludes using this technique at many ground water pollution sites. However, the electrical resistivity method can often be used successfully off-site to map the stratigraphy of the area surrounding the site.

Another consideration in the electrical resistivity method is that the fieldwork tends to be more labour intensive than some other geophysical techniques. A minimum of three crew members is required for the fieldwork.

2.2.5 FIELD OPERATIONAL PROBLEMS AND AMBIGUITIES

Field Operational Problems: This includes;

i. Lateral in homogeneity: This usually occurs in the upper layer of the earth and can degrade the quality of our resistivity sounding data by creating cusp conductive/resistive lateral inhomogeneity. The problem could be reduced by employing a special land of configuration called Tri-potential array system.

ii. Poor electrical contact: This could lead to acquisition of erroneous data especially if the poor contact is at current electrodes position. It may be due to a very dry ground surface, hard ground or fossil ground. The problem could be solved by creating saline water medium around the electrodes or by just increasing the moisture content of the point where the electrode is to be inserted

i. **Dip effect:** In a situation where the horizontal interface is dipping, the quality of data is seriously affected likewise the interpretation. However, if the dip angle is less than 10^{o} then it is negligible.

Ambiguities: These arise from the following;

i. **Equivalence:** This is a phenomenon whereby a multiple layer resistivity curve can correspond to a great number of different geo-electrical models. This problem is most relevant to H-type curve. To correct this ambiguity, a drilling information is needed which will reveal the lithological sequence.

ii. **Suppression:** This occurs when the layers are having a resistivity, which is intermediate between those of enclosing layers. It may be suppressed and not having any significant influence on the appreciable thickness.

2.6 GEOLOGY OF THE STUDY AREA

The geology of the study area is that of a typical basement terrain with four different rock types ranging from Granite gneiss, Migmatites, Gneiss to pure Granitic rocks. The rock type that were discovered during our field exercise carried out in Oye and her surrounding are two rock type:

1. IGNEOUS ROCK
2. METAMORPHIC ROCK

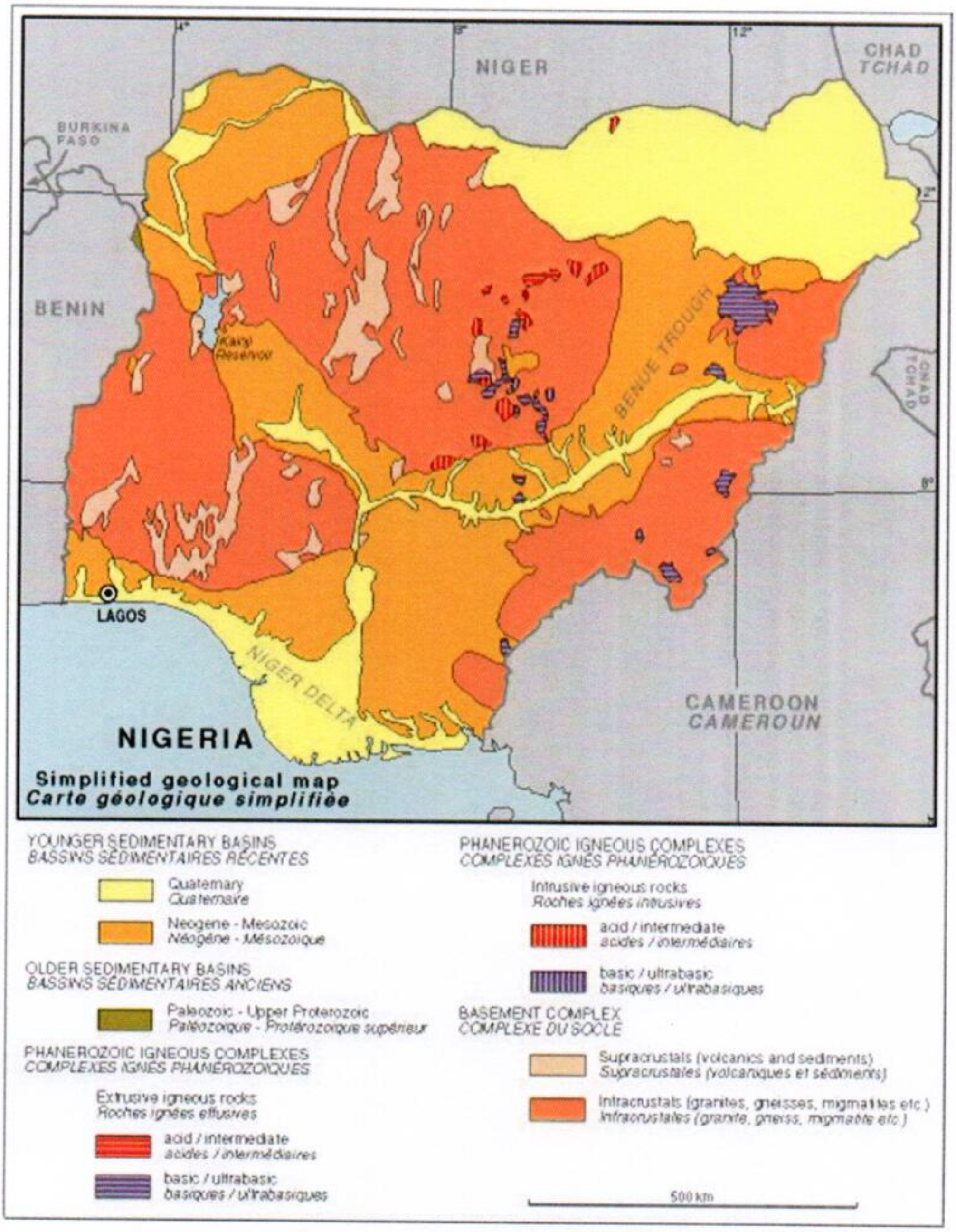
1. **IGNEOUS ROCK:** This is a rock that has crystallized or solidifies from molten or partially molten material. The type of igneous found in the study area is a granitic rock which is coarse grain rich in quartz feldspar. Granite is also formed by plutonic activities which is formation at depth.
2. **METAMORPHIC ROCK:** Metamorphic rocks are rocks that undergoes metamorphism which is a solid state transformation of a pre-existing rock due to changes in physical conditions (temperature and pressure) that were different from those under which it was originally formed.

It is well known fact that igneous rocks are formed by the crystallization of molten materials which arises from within the earth surface. We also know that metamorphic rocks are formed from the metamorphism of pre-existing rock.

Oye lies within the basement complex of south-western Nigeria, the study area is covered by Precambrian igneous and metamorphic rocks which extend over the state. The major lithologic units in Oye are granite, granite-gneiss,migmatite-gneiss and charnockite.

The migmatite-gneiss is a highly metamorphosed rock that occurs in white and dark bands showing the alignment of the mineral. The major minerals in the rock is quartz, feldspar, biotite, muscovite, plagloclase, they majorly occur in hilly or low-lying form.

The granite-gneiss rock is a metamorphosed granite rock and has a gneissic texture, the rock has light and dark coloured bands that show the way the mineral are aligned and the rocks are usually massive as shown in the geological map of Nigeria in (Fig 2.5b)



(Fig 2.5 b) GEOLOGICAL MAP OF NIGERIA (after Oyawoye 1972) .

CHAPTER THREE

3.0 MATERIAL AND METHOD

The apparent resistivity was measured along four different azimuths N-S, NE-SW, NW-SE for a given AB/2 separations and were plotted along there corresponding azimuths. Lines of the resistivity of the same value along different azimuths were joined together, thus resulting in a polygon. A set of such polygons obtained corresponding to different AB/2 separations is known as polar diagram or anisotropy polygon. For an isotropic homogenous formation, this polygon will assume a circular shape. Any deviation from a circle to an ellipse is indicative of anisotropic nature of the formation (Mallik et al., 1983). The major or longest axis of the ellipse, which can fit any of such anisotropic polygons, gives the strike direction of the fracture. The co-efficient of apparent anisotropy (πa) (designated here as the degree of fracturing) is calculated from each anisotropy ellipse (fitted through each polygon) using the relationship πa= a/b, where a and b are the semi major and semi minor axes of the element. All calculated πa values are then plotted against the corresponding AB/2 separations. The behavior of rock fracturing at various depth equivalents to different AB/2 separation can thus be understood qualitatively from the variation of πa (Habberjam, 1975).

From the 10 RVES survey carried out, the apparent resistivity anisotropy polygon was plotted and coefficient of anisotropy were calculated for each station, using the methods of Habberjam (1972, 1975, 1979), Lane et al. (1995), Mallik et al. (1983), Olasehinde (1984), and Okurumeh and Olayinka (1998).

3.1 INTERPRETATION OF VERTICAL ELECTRICAL SOUNDING

For many decades of application of VES method, an important tool in the interpretation of the data has been the comparison of the apparent resistivity curves computed for assumed models of subsurface stratification (Bhattachnya & Patra, 1968).

The data of Vertical Electrical Sounding (VES) are usually presented as a series of graphs expressing the variations of apparent resistivity with increasing electrode separation. These curves represent the variation of the resistivity with depth and as such, the curve may be qualitatively interpreted by inspection.

The procedure of interpretation of VES data is quantitative and it involves the determination of thickness and resistivity of different subsurface layers and number of layers.

Various methods like empirical methods, direct calculation methods, computerized technical methods, complete curve matching and partial curve matching can be used to interpret VES data but only partial curve matching and computer iteration methods were used to interpret VES data in this work.

3.2 PARTIAL CURVE MATCHING

The field apparent resistivity for the four azimuth directions was plotted against AB/2 on transparent double-logarithm scale graph. The use of this scale opens up the possibility of determining p_1 and h_1 from theoretical and field curves. On the logarithmic scale, the conditions of limiting values are satisfied. The problem of negative depths is eliminated and the asymptotic nature of the apparent resistivity is preserved (Bhattachnya and patra, 1968).

The field curve was superimposed on the appropriate two-layer master curves. Thus resistivity of the first layers (p_1) and its thickness h are thus obtained.

The resistivity of the subsequent layers can be computed from the parameters on the appropriate master curve used.

There are two types of two layer master curves.

1. The descending type where $p_1 < p_2$
2. The ascending type where $p_1 > p_2$

The set of auxiliary point charts have been designed to be of use in the multitude layers cases.

i. The minimum type (H) where $p_1>p2<p_3$

ii. The double ascending type (A) where $p_1<p_2<p_3$
iii. The maximum type (K) where $p_1<p_2>p_3$
iv. The double descending type (Q) where $p_1>p_2>p_3$

3.3 THE COMPUTER ITERATION

The computer interpretation comprises two stages;

a) Determination of an initial model of the field data. This is achieved by partial curve matching.

b) The result of this curve matching provides starting models for computer modeling which gave the final accepted geometric structures. Before interpretation, it was ascertained that VES curve where sufficiently smothered. Layers parameters are obtained from curves matching and were supplied in the input. The iteration nature of the program afforded fast observation and alternating nature of the layer parameter.

3.4 INSTRUMENTATION

The equipment used in this survey includes;

a. Omega Terrameter and its accessories
b. Steel electrodes/center iron rods
c. Reel of cable
d. Measuring tape and hammer
e. Global positioning system (GPS)
f. Compass clinometers

OMHEGA TERRAMETER

This is used in measuring the electrical resistance of the different layers in the subsurface. The instrument is tested and trusted over the years, it is highly sophisticated, compact, lightweight with inbuilt power source, transmitter or signal sender, receiver and microprocessor.

The instrument takes consecutive resistivity value in several cycles and averages the value obtained at each cycle to give the final resistivity readings. The transmitter signals current, the receiver moves and measures the voltage correlated with the transmitted current signal in the resistivity survey mode while the microprocessor monitors and control the terminal which includes the ON/OFF switch, circuit selector, range selector, power indicator and display screen, all these units are housed in a single casing which is mounted on a dry cell battery. It gives the resistance value as the electrodes are moved on the field.

STEEL ELECTRODES/IRON RODS

The electrodes are four in number and are made of steel i.e. aluminum or stainless steel which are driven into the earth surface for few centimeters with the aid of hammer for good electrical contact.

REEL OF CABLE

Electrical wires which are water and heat resistant with crocodile clips at the top and attached to the electrodes are needed. There are four reels used on the field, two of which are big reels with cables of about 750-1000 meters in length used in connecting the current electrodes (c1 and c2) while the other two small reels with cables of about 250-500 meters in length are used for connecting potential electrodes (p1 and p2).

MEASURING TAPE AND HAMMER

The measuring tapes are of various length used to mark off the electrode spread and the hammer is used to drive the electrode into the ground for proper electrical contact. Hammer was used to drive the steel electrodes and iron rods into the ground.

GLOBAL POSITIONING SYSTEM (GPS)

This was used to locate bearing and determine the elevation above sea level of different points in the study as well as the exact point or location on the map. It measures the longitude, latitude and altitude of the VES location.

COMPASS CLINOMETER

The instrument was used to determine our true north and also to determine the various azimuthal directions which were 0^o,45^o, 90^o and 135^o.

3.5 PRECAUTIONS TAKEN DURING FIELD SURVEY

During the course of field study, the following precautions were taken:

1. The possibility of leakage from current circuit to the potential circuit during measurement was avoided by connecting the circuit in series.
2. The electrodes were hammered deep into the ground to ensure good contact of electrode with ground and easy flow of electric circuit.
3. It was ensured that connection and disconnection of current cables were done only when the switch was off, else the current electrode might have constituted a point of physical hazard.
4. Excessive temperature exposures were avoided since weather changes can affect the readings and equipment.
5. Proper inspection was done to ensure the stations were located away from any conducting material such as underground pipes and electric poles to avoid noise.
6. Crocodile screws used to connect cables to the meter were not allowed to touch the conducting meter reel and cables were adequately insulated.
7. All metals should be taken away when locating the different azimuthal direction, this is because it affects the measurements of the compass clinometers which deflect the true north and thus a wrong azimuth is read.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 GEOPHYSICAL INVESTIGATION

A thorough geophysical investigation was carried out in the study area making use of Radial Vertical Electrical Sounding (RVES) method. A total of five RVES point were sounded using the schlumberger array which was distributed across the study area. Table 1.0 shows the parameters of values gotten from the sounding curves interpretation. The interpretation of the data was carried out both qualitatively and quantitatively. The data was obtained through the use of OmHega resistivity meter, but after the multiplication of resistivity with the geometric factor, the apparent resistivity value was obtained.

4.2 ITERATED RVES CURVE

Partial curve matching using two-layer master curves in conjunction with auxiliary diagram were employed to obtain initial model parameters. The curves were interpreted quantitatively by partial curve matching and computer iteration with WINRESIST software. The iteration program uses the results of the partial curve matching as starting model.

Two to four lithological sections were delineated. These are the Topsoil, Weathered Basement, Partly Weathered Basement, and Fresh Basement. The table gives details of the thickness of each layer as well as the depth of the bedrock for all locations. It also gives detail of the curve types as well as the inferred lithology of each layer.

Table 1.0 PARAMETER OF VALUES GOTTEN FROM THE CURVE INTERPRETED

VES NUMBER	RESISTIVITY(Qm)	THICKNESS(m)	DEPTH(M)	PROBABLY LITHOLOGY	CURVE TYPE
1	92 121 168	0.5 6.2 0.8	0.5 6.7 7.4	Top soil Weathered Sandy clay	A
2	117 60 520 1282	0.6 4.8 0.0	0.6 5.4 5.4	Top soil Weathered Basement	H
3	109 61 925	1.2 2.7	1.2 3.9	Top soil Weathered Basement	H
4	137 57 243	1.7 3.0	1.7 4.7	Top soil Weathered Sandy clay	H
5	114 116 444	0.0 0.0 0.3	0.0 0.1 0.3	Top soil Weathered Basement	HK
6	252 122 406	0.5 1.7	0.5 2.2	Top soil Weathered Basement	H
7	313 461 147	0.5 0.2 4.3	0.5 0.6 4.9	Top soil Weathered Sandy clay	KH
8	298 275 134	0.1 0.7 3.8	0.1 0.8 4.6	Top soil Weathered	QH

RADIAL VERTICAL ELECTRICAL SOUNDING

A consistent increase in the apparent anisotropy coefficient was observed for AB/2 around 10 m and this behaviour of increase in resistivity with depth may be due to the presence of the fracture effect at the corresponding true depths.

Figure 2.7a shows the polar plots for the variation of ρa data at four azimuths (0^0,45^0, 90^0, 135^0) at various depths corresponding to the fractured basement at the five radial sounding locations. The observed changes in the apparent resistivity were interpreted as an indicator of fracture anisotropy. The fracture strikes at different depths are indicated as the polar plot trends. The apparent resistivity measured along different azimuths for a given AB/2 separations at each location were plotted along their corresponding azimuths. Lines of the resistivity of the same value along different azimuths were joined together, thus resulting in a polygon. A set of such polygons obtained corresponding to different AB/2 separations is known as a polar diagram or anisotropy polygon. For an isotropic homogeneous formation, this polygon will assume a circular shape. Any deviation from a circle to an ellipse is indicative of anisotropic nature of the rock formation (Mallik *et al.*, 1983; Busby, 2000; Senos Matias, 2002).

LOCATION ONE

Figure 2.7a – 2.7c shows the display polar plot for the variation of apparent resistivity data at the four azimuth at various depth corresponding to the five radial sounding. The observe changes in the apparent resistivity was interpreted as an indicator of fracture anisotropy of the fracture strike at different depth at the polar trend. The dominant fracture trend display by the polar diagram is from W –E direction.

The observed changes in apparent resistivity (pa) with azimuth were interpreted as an indicator of fracture anisotropy and the presence of aligned vertical or sub-vertical fractures causes a fractured rock mass to exhibit azimuthal anisotropic behaviour.

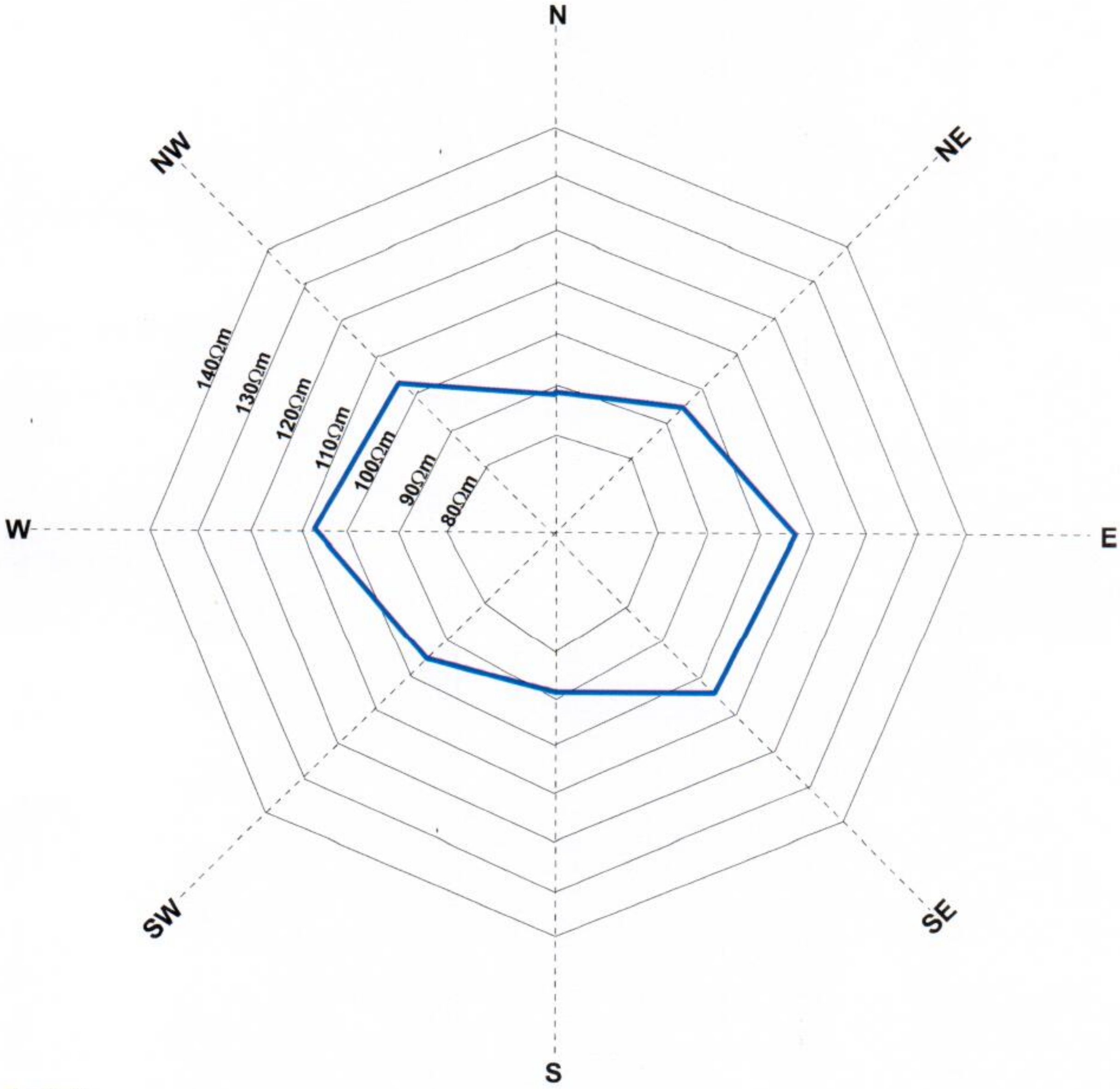


Fig 2.7a

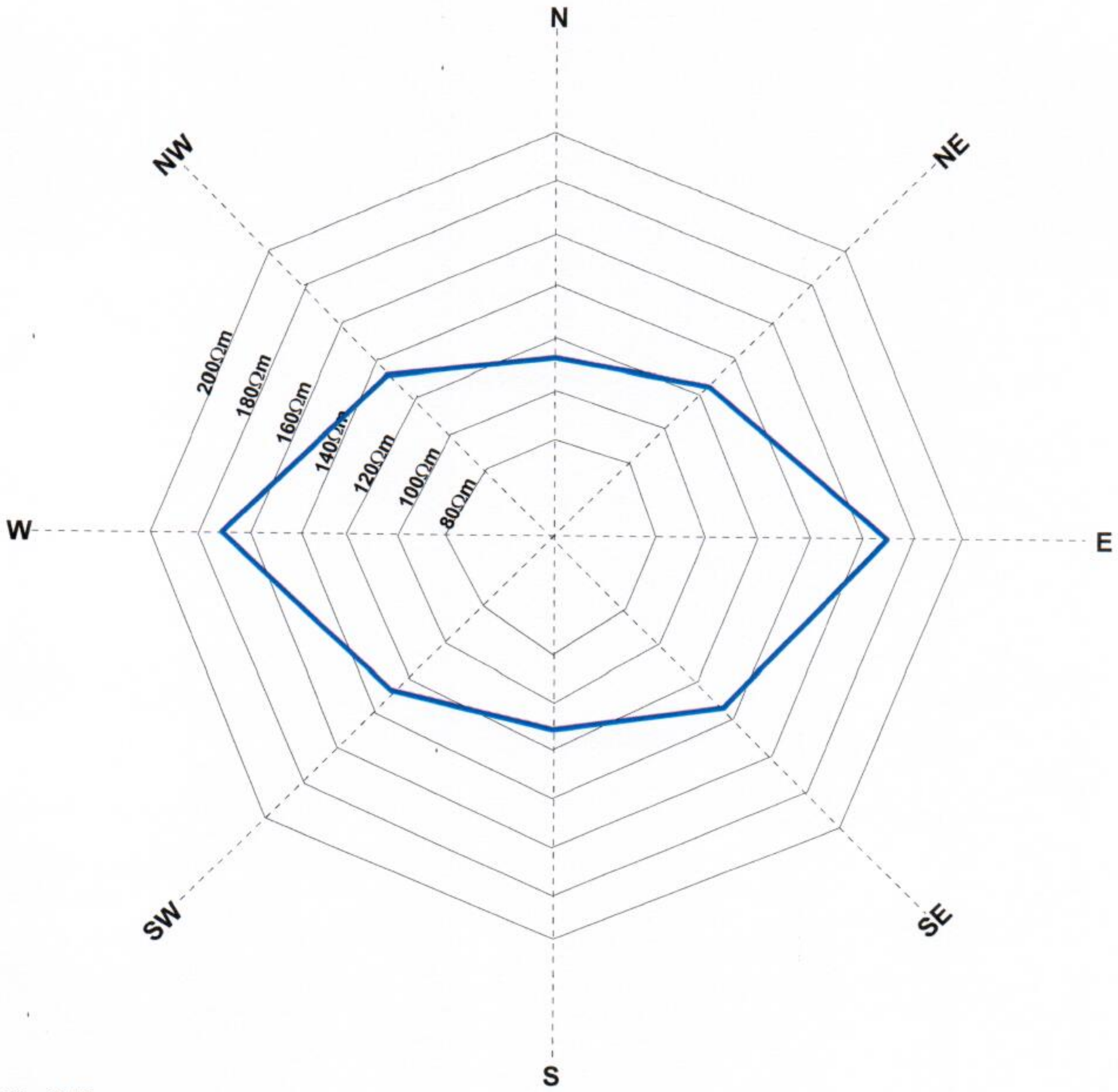


Fig 2.7b

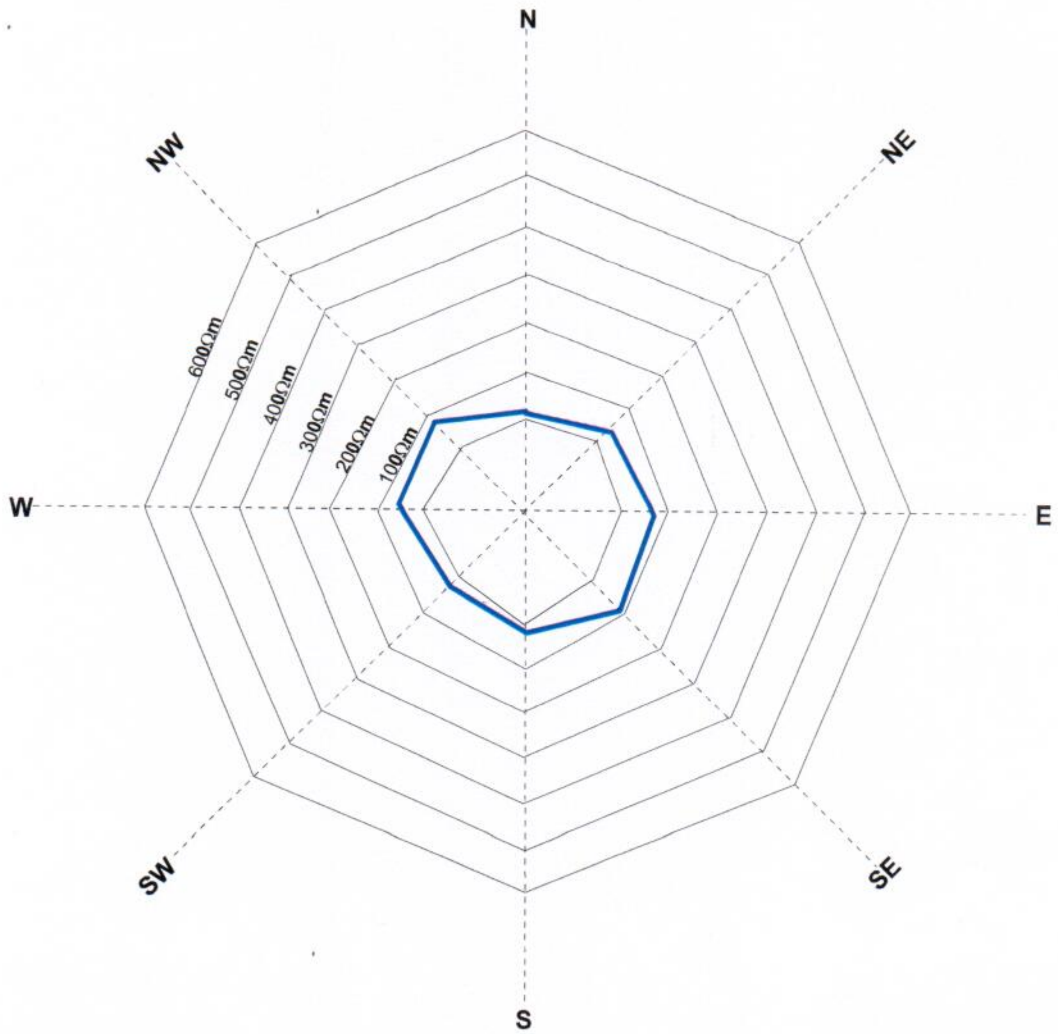


Fig 2.7c

LOCATION TWO

Figure 2.7d – 2.7e shows the polar plot for the variation of apparent resistivity data at the four azimuth at various depth. The observe changes in the apparent resistivity was interpreted as an indicator of fracture anisotropy of the fracture strike at different depth at the polar trend. The dominant fracture trend display by the polar diagram is from NE -SW direction.

The observed changes in apparent resistivity (pa) with azimuth were interpreted with the presence of fracture anisotropy and an indicator of aligned vertical or sub-vertical fractures causes a fractured rock mass to exhibit azimuthal anisotropic behaviour.

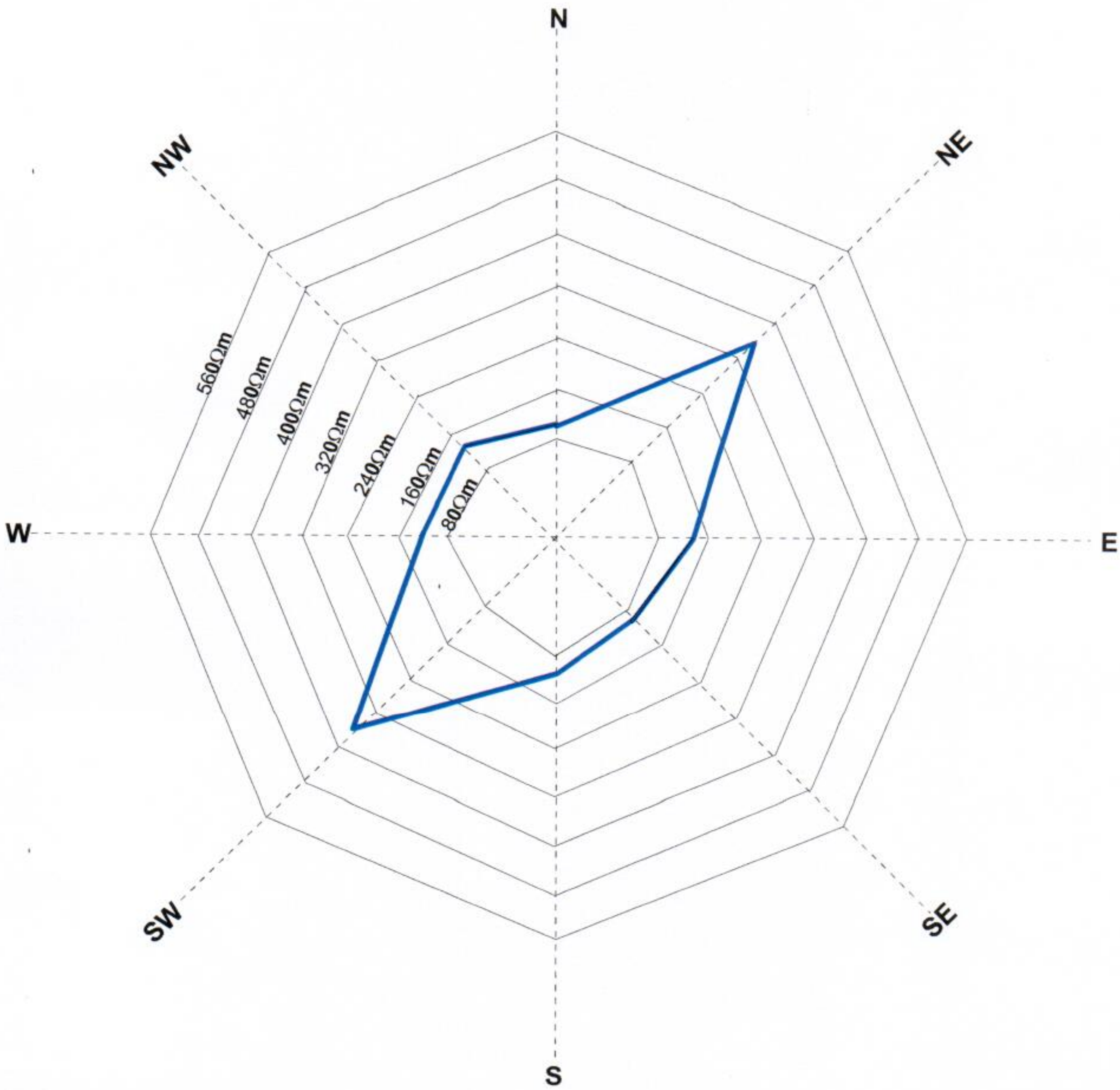


Fig 2.7d

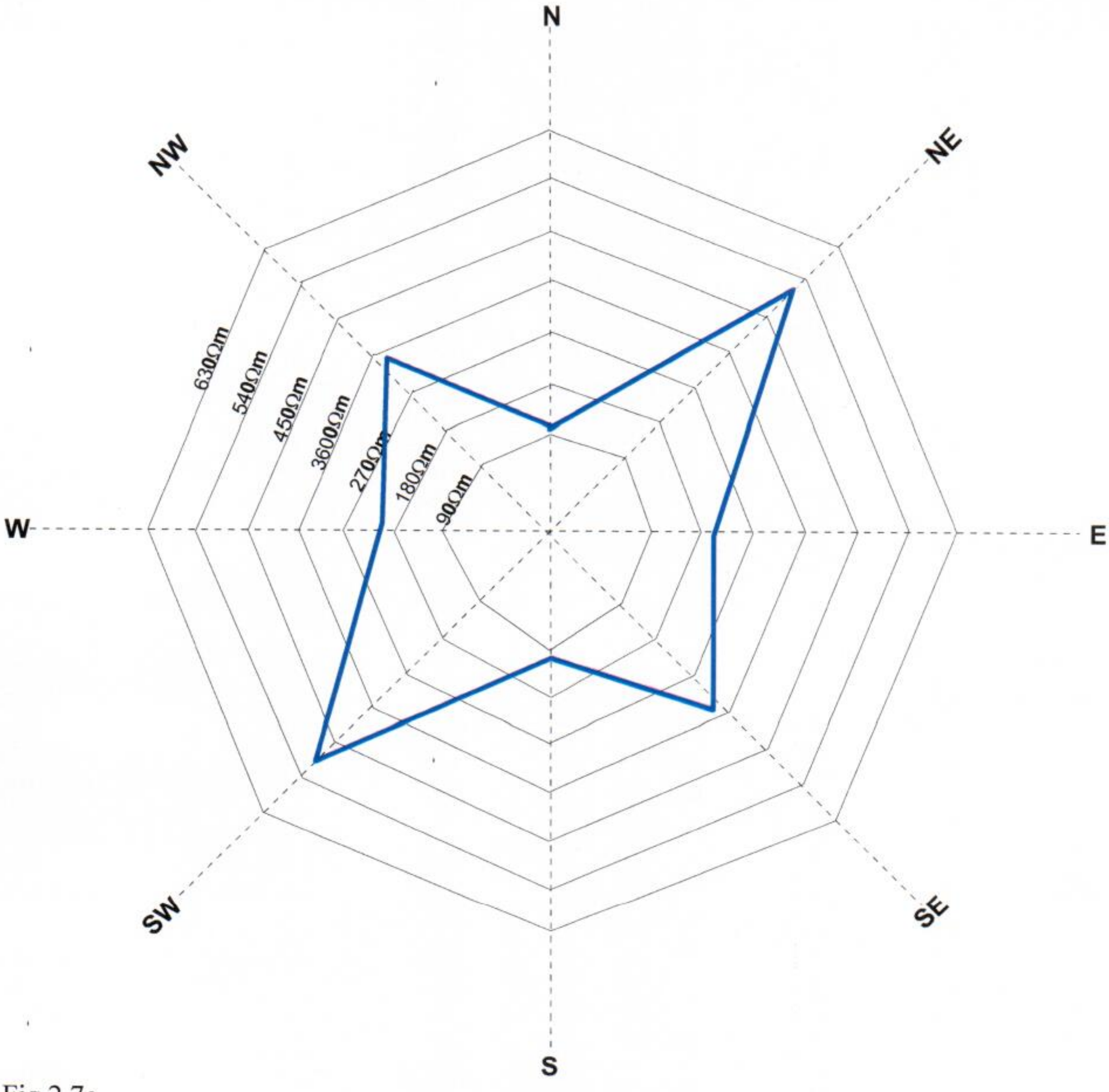


Fig 2.7e

LOCATION THREE

Figure 2.7f – 2.7h shows the display polar plot for the variation of apparent resistivity data at the four azimuth at various depth corresponding to the five radial sounding. The observe changes in the apparent resistivity was interpreted as an indicator of fracture anisotropy of the fracture strike at different depth at the polar trend. The dominant fracture trend display by the polar diagram is from N- S direction.

The observed changes in apparent resistivity (pa) with azimuth were interpreted as an indicator of fracture anisotropy and the presence of aligned vertical or sub-vertical fractures causes a fractured rock mass to exhibit azimuthal anisotropic behaviour.

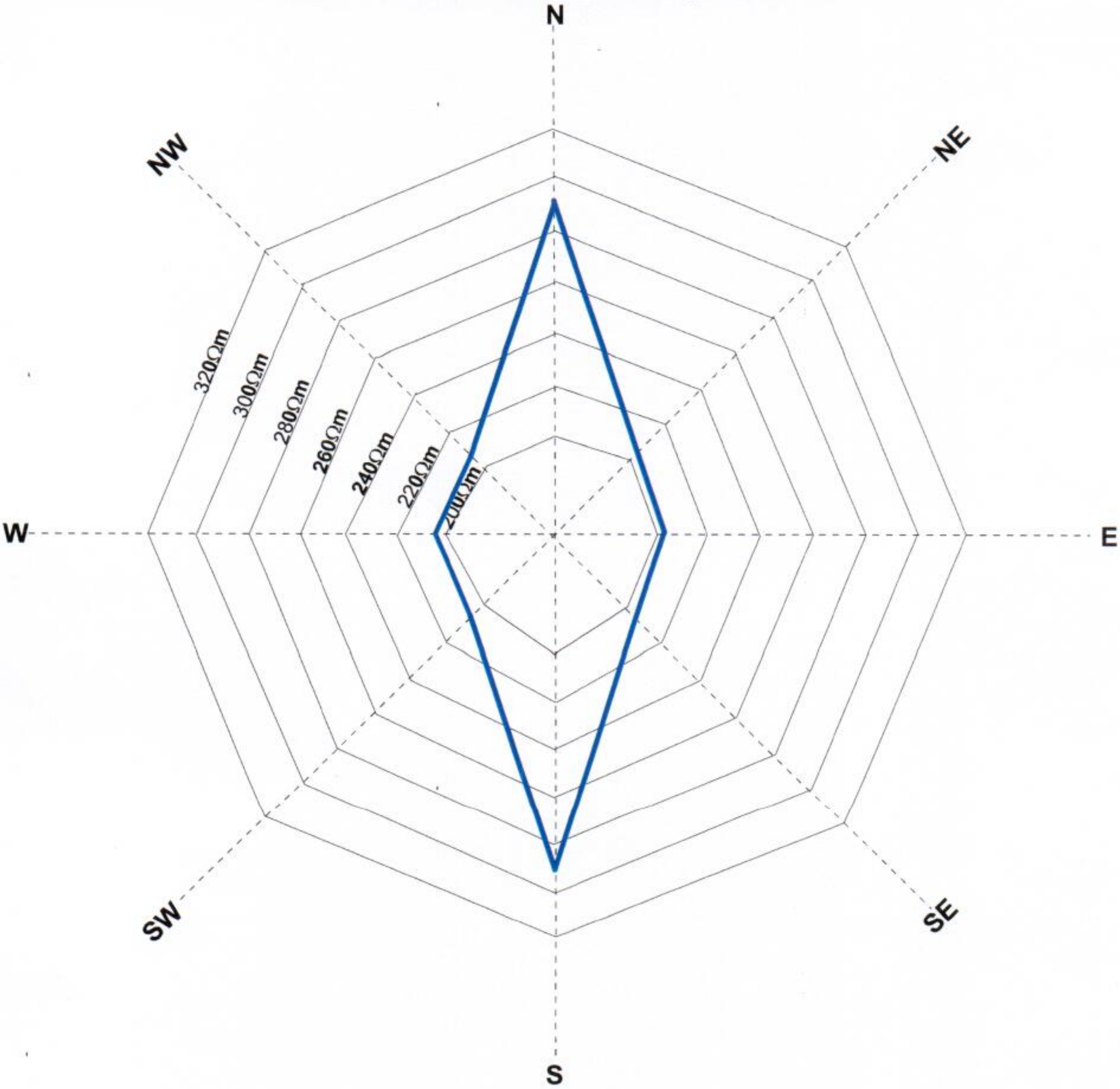


Fig 2.7f

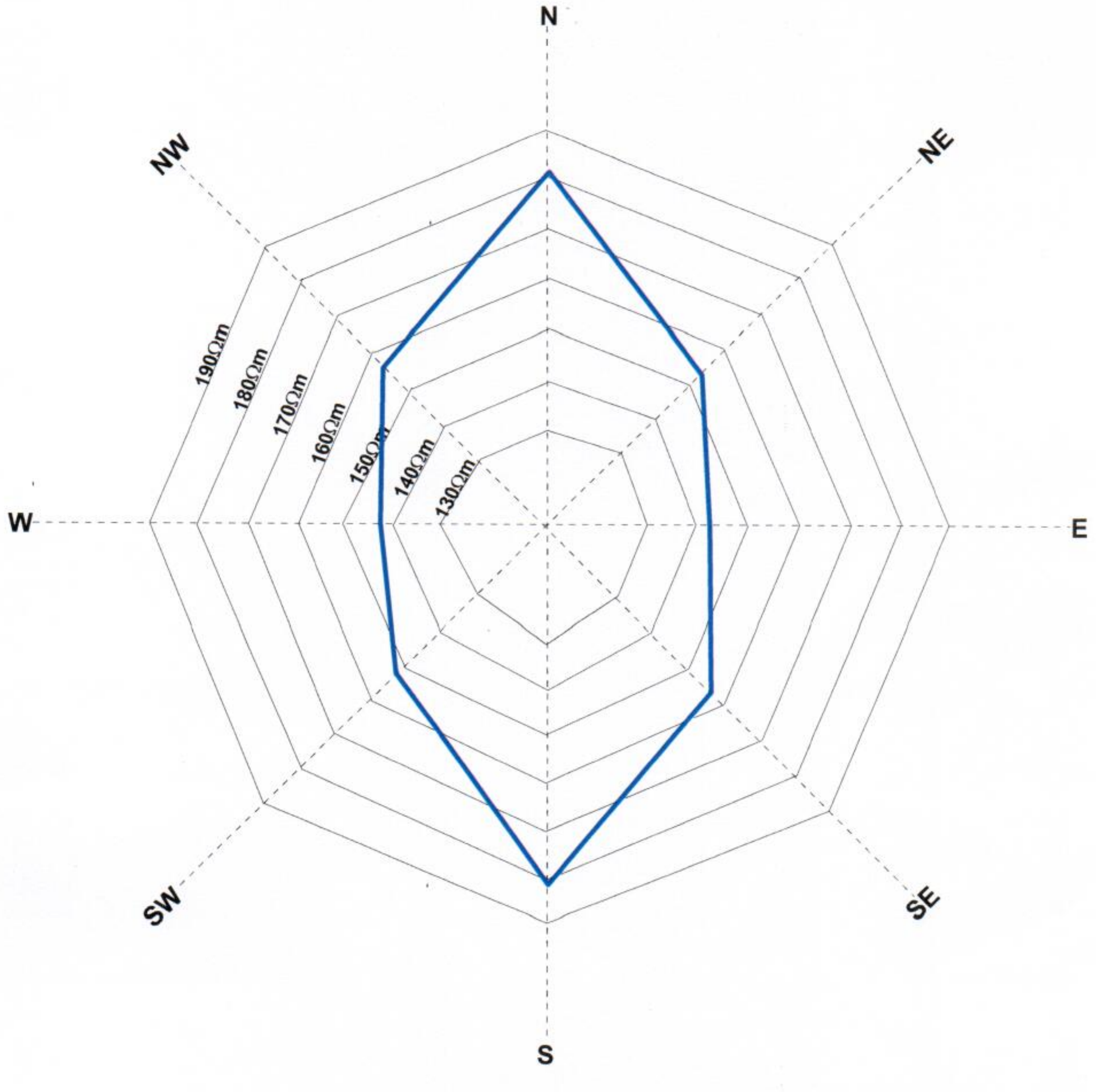


Fig 2.7g

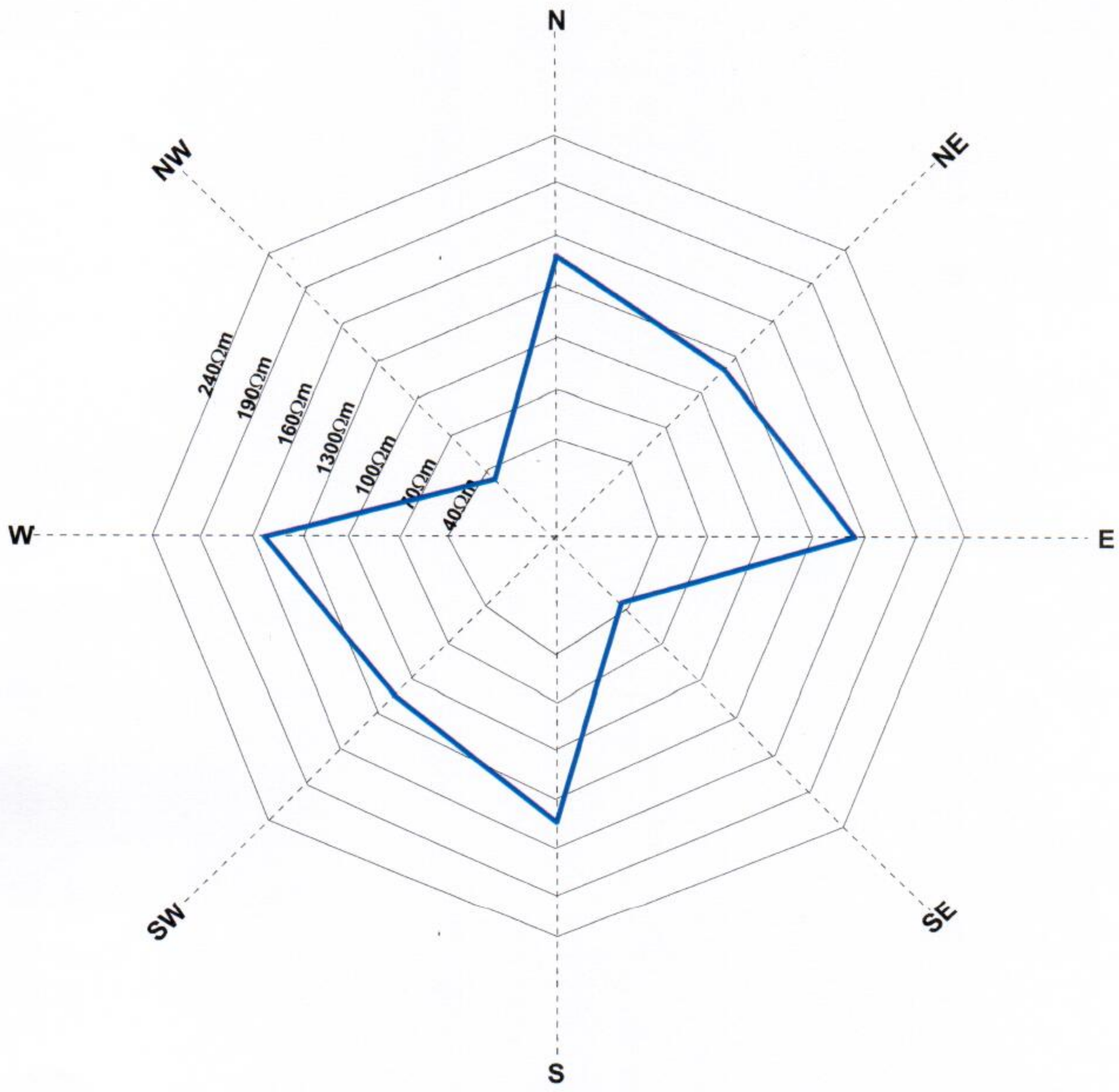


Fig 2.7h

LOCATION FOUR

Figure 2.7i – 2.7j shows the display polar plot for the variation of apparent resistivity data at the four azimuth at various depth corresponding to the five radial sounding. The observe changes in the apparent resistivity was interpreted as an indicator of fracture anisotropy of the fracture strike at different depth at the polar trend. The dominant fracture trend display by the polar diagram is from N- S direction.

The observed changes in apparent resistivity (pa) with azimuth were interpreted as an indicator of fracture anisotropy and the presence of aligned vertical or sub-vertical fractures causes a fractured rock mass to exhibit azimuthal anisotropic behaviour.

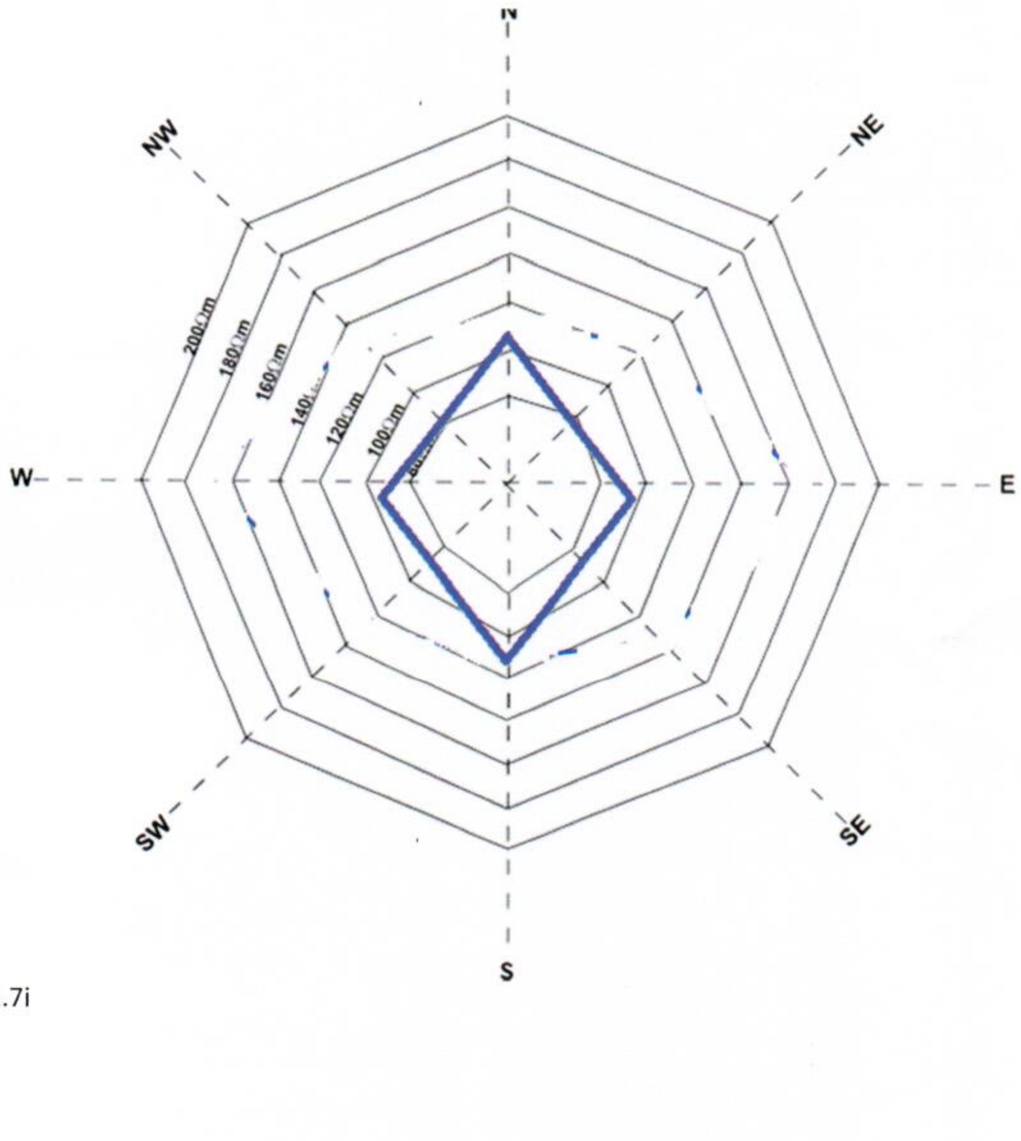


Fig 2.7i

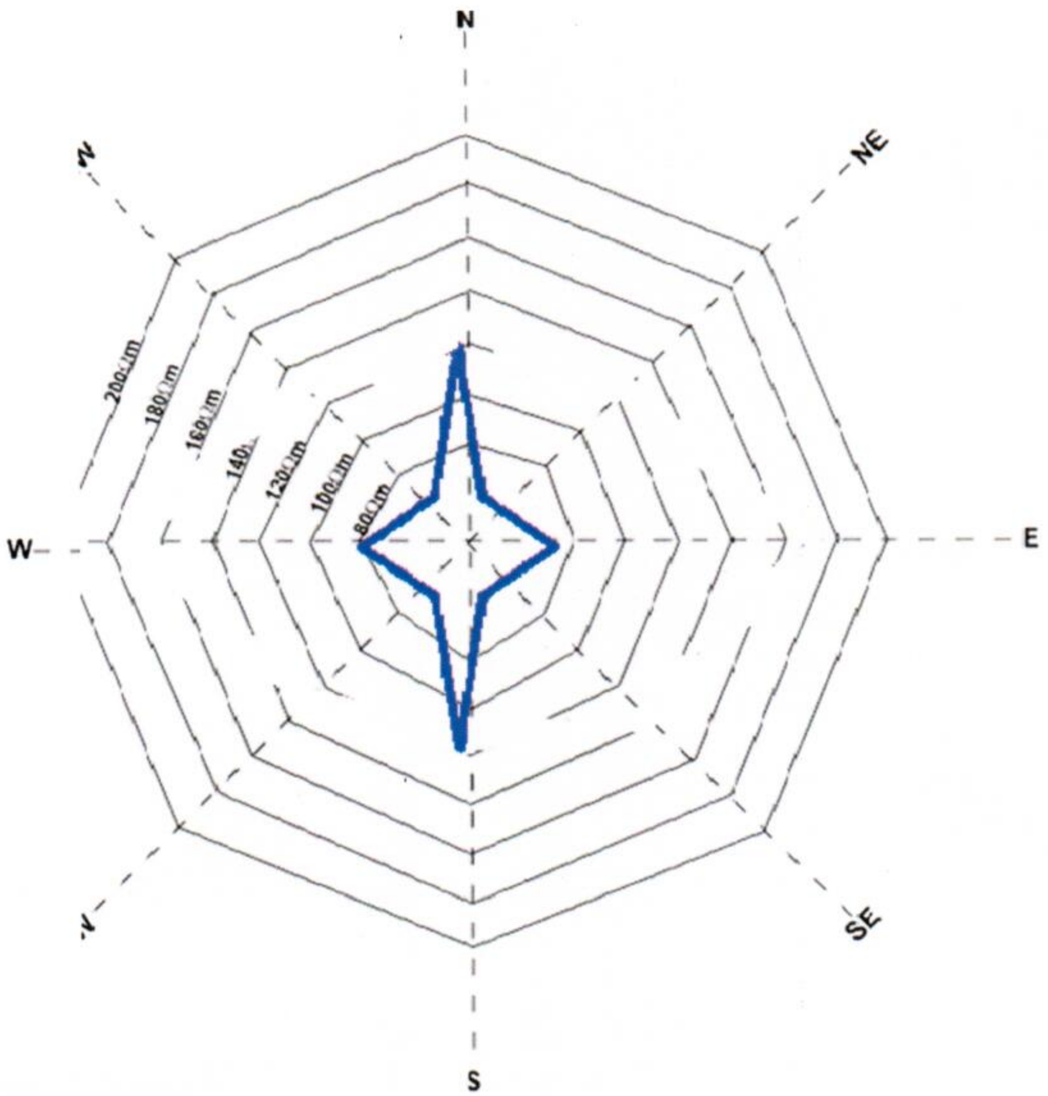


Fig 2.7j

LOCATION FIVE

Figure 2.7k – 2.7L shows the display polar plot for the variation of apparent resistivity data at the four azimuth at various depth corresponding to the five radial sounding. The observe changes in the apparent resistivity was interpreted as an indicator of fracture anisotropy of the fracture strike at different depth at the polar trend. The dominant fracture trend display by the polar diagram is from N- S and W-E direction.

The observed changes in apparent resistivity (pa) with azimuth were interpreted as an indicator of fracture anisotropy and the presence of aligned vertical or sub-vertical fractures causes a fractured rock mass to exhibit azimuthal anisotropic behaviour.

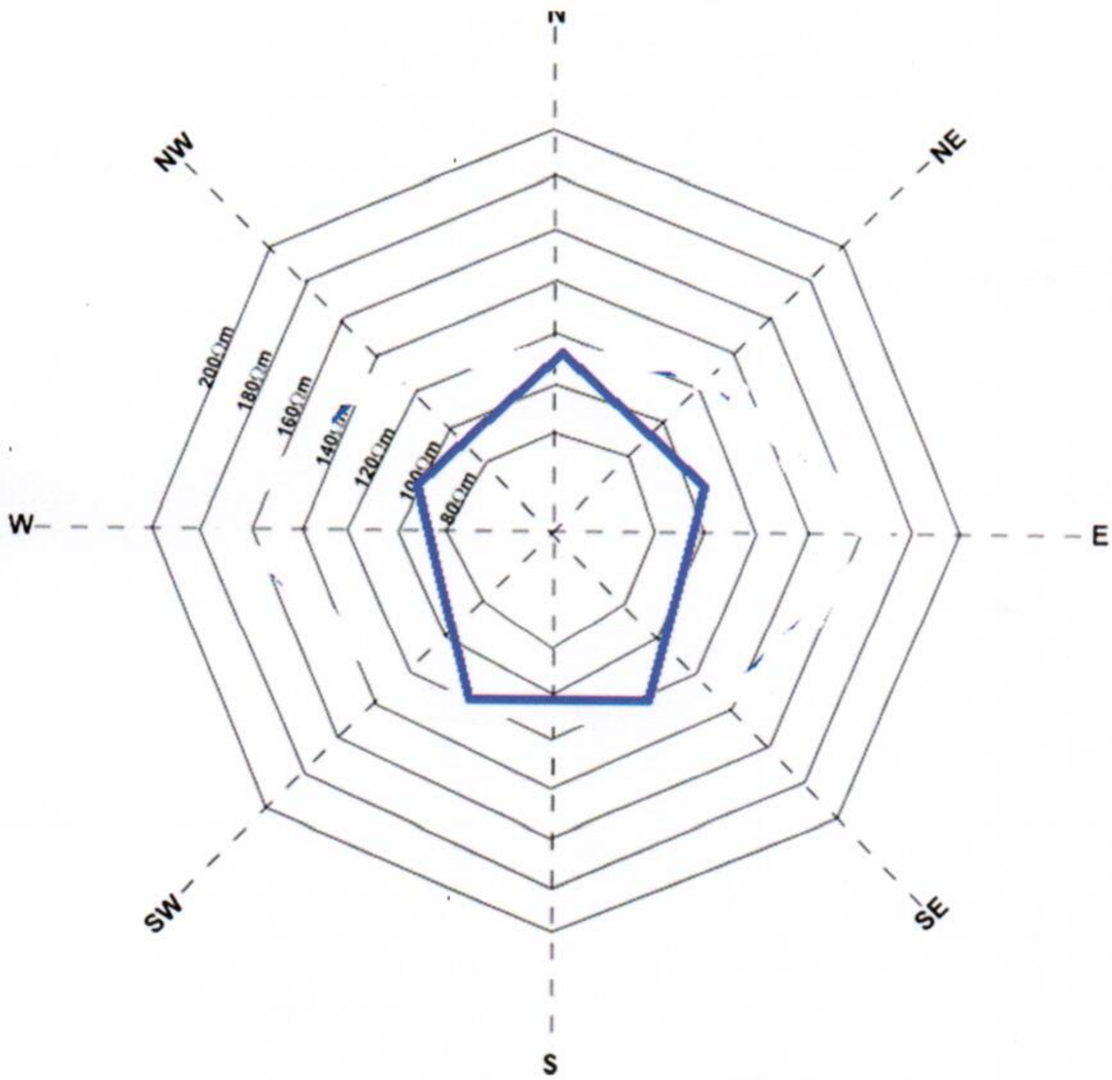


Fig 2.7k

Table 2. Coefficient of Anisotropy parameters at each subsurface obtained from analysis of azimuthal resistivity data obtained from the study area.

AB/2	COEFFICIENT OF ANISOTROPY
1	1.1
2	1.1
3	1.3
4	1.7
6	1.2
8	2.0
12	1.1
15	1.8
25	1.3
40	1.8

The coefficient of anisotropy (λ) has been shown to have the same functional form as permeability anisotropy to a first order (Bespalov et al., 2002). Thus, a higher coefficient of anisotropy (λ) implies higher permeability anisotropy. The values of λ ranges from a minimum of 1.1 at Location one to 2.0 at Location three.

CHAPTER FIVE

CONCLUSION

The survey has been used to determine and characterized the anisotropic properties in Part of Federal University, Oye Ekiti, south western Nigeria for evaluation of structural trend. Measured apparent resistivity was found to have varied with orientation of arrays and depth, which signifies fracture anisotropy. The interpretation of RVES data indicate the area is underlain by three geo-electric layers with the depth to fractured basement ranging from 6.3 to 54m. The azimuthal polar diagrams plotted for apparent resistivity against different azimuthal depths ranging from 15-100m revealed NW-SE, E-W and N-S directions as the dominant electrical anisotropy directions while NE-SW directions is less prominent.

The implication of this complex fracturing pattern is that the fractures will be disconnected and hence will form a good groundwater channel ways. It should be noted that any engineering structure imposed on the area must have a firm and broad base foundation although little problem would arise from the fractures in the subsurface, since most of this fractures occurred at greater or deeper depth.

Coefficient of anisotropy in the study area ranges between 1.1 and 2.0 Localities with low mean bedrock resistivity and a high coefficient of anisotropy may indicate intense fracturing and such localities are potential sites for borehole. The depressions and the fractures zones whose direction are delineated from the radial soundings are the likely groundwater collecting centres and are priority areas for groundwater development.

The relation of geological structures in outcrops such as orientation of joints and foliations in outcrop from the study area showed an E-W and NW-SE direction respectively and this corresponds to the direction of the fracture depicted by the anisotropic polar plot which in turn corresponds to the groundwater flow pattern. Hence giving rise to a fracture controlled flow.

The technique has increased the rate of success for location of site for borehole drilling and consequently the cost effectiveness of groundwater exploration.

RECOMMENDATION

The research work had given us an insight on the anisotropic properties of the study area with great understanding on the depth to the bedrock, the types of layers as well as the fractures found in the study area. The properties of the fractures are also known and the magnitude was estimated from the values of the coefficient of anisotropy. Based on all this findings we recommend the following:

- The borehole point should be sited along the orientation of the fracture zones which is dominantly along the NW-SE direction
- Suitable foundations must be laid on different kind of engineering structures imposed on the study area. More specifically for high rising building because the fractural behaviour of most location sampled in the study area are closing to the surface.
- More work should be done to further understand the anisotropy properties of the study area with other azimuthal resistivity survey method.

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APPENDIX

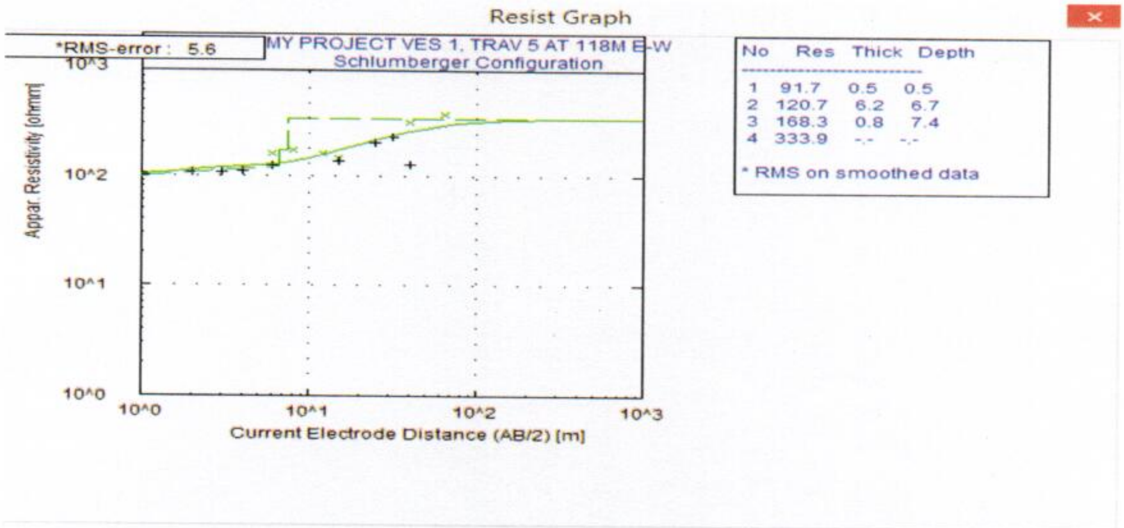


Fig 2.8a

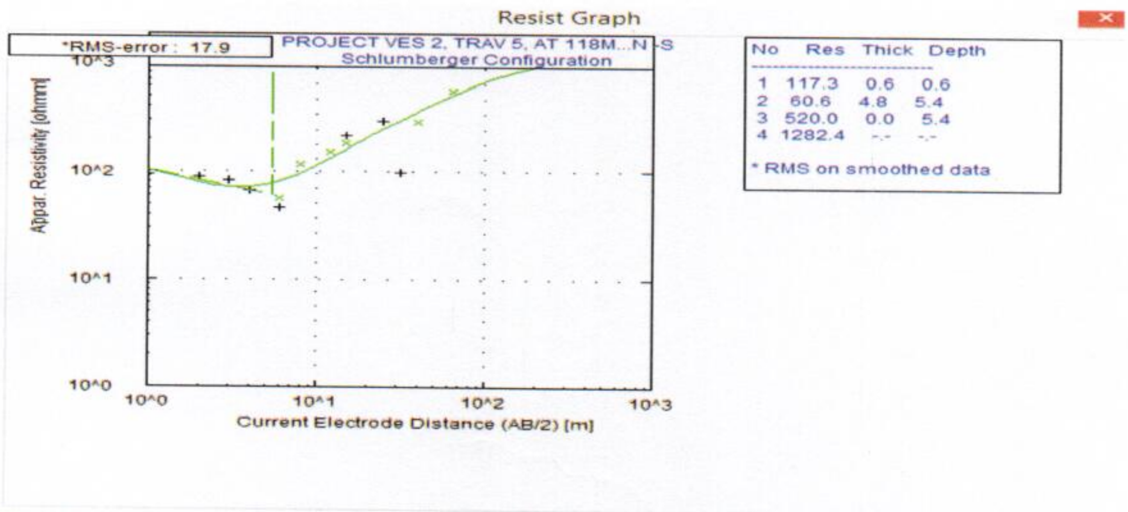
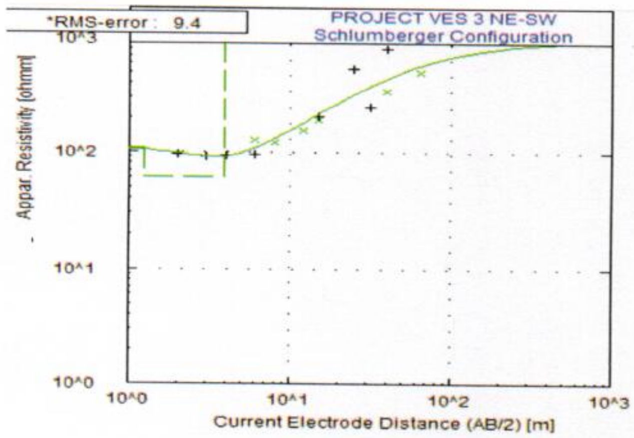


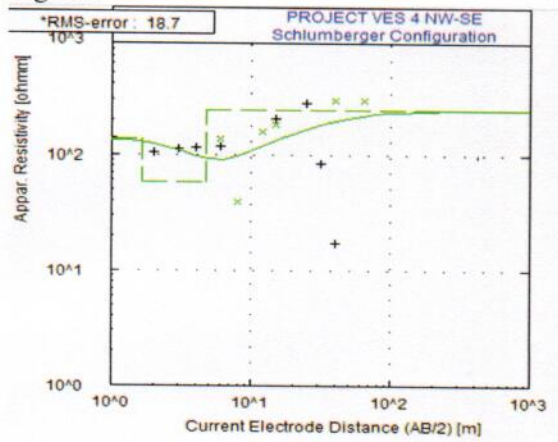
Fig 2.8b



No	Res	Thick	Depth
1	108.5	1.2	1.2
2	60.8	2.7	3.9
3	925.1	-.-	-.-

* RMS on smoothed data

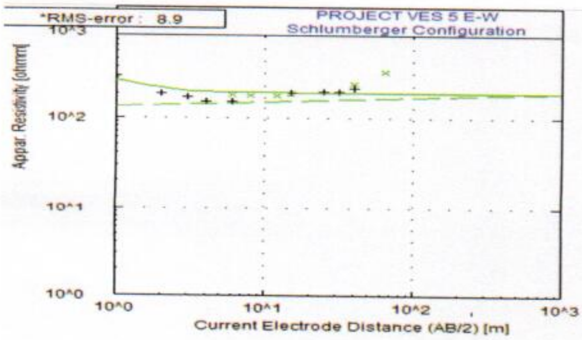
Fig2.8c



No	Res	Thick	Depth
1	137.4	1.7	1.7
2	57.0	3.0	4.7
3	243.4	-.-	-.-

* RMS on smoothed data

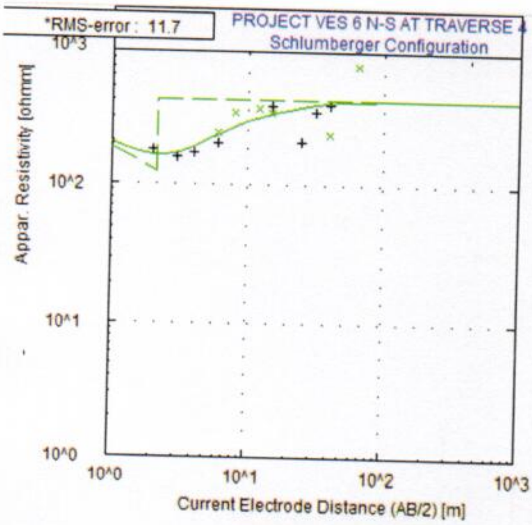
Fig2.8d



No	Res	Thick	Depth
1	114.4	0.0	0.0
2	111.6	0.0	0.1
3	444.3	0.3	0.3
4	202.5	-.-	-.-

* RMS on smoothed data

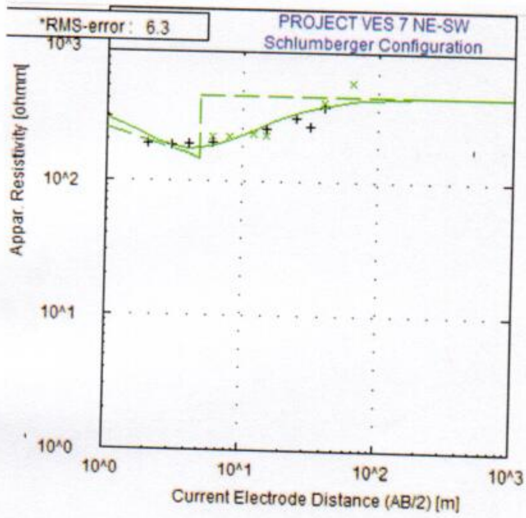
2.8E



No	Res	Thick	Depth
1	252.0	0.5	0.5
2	122.4	1.7	2.2
3	402.5	-.-	-.-

* RMS on smoothed data

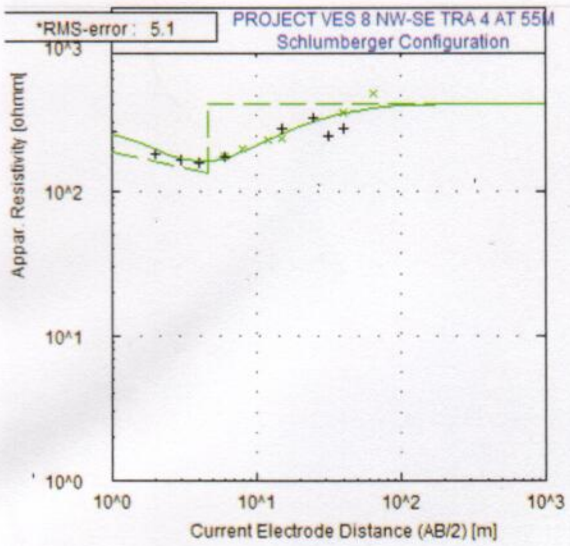
Fig 2.8f



No	Res	Thick	Depth
1	312.7	0.5	0.5
2	461.1	0.2	0.6
3	147.0	4.3	4.9
4	421.3	-.-	-.-

* RMS on smoothed data

Fig 2.8g



No	Res	Thick	Depth
1	298.3	0.1	0.1
2	274.8	0.7	0.8
3	133.6	3.8	4.6
4	403.0	-.-	-.-

* RMS on smoothed data

Fig2.8h

Figure (2.8a -2.8h) are the representative Layer model interpretation for different VES curves obtained from the study area.