D.C RESISTIVITY INVESTIGATION OF THE GROUNDWATER POTENTIAL IN ROMI CHUKUN LOCAL GOVERNMENT KADUNA STATE,NIGERIA.

BY

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A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL, AHMADU BELLO UNIVERSITY, ZARIA, IN PARTIAL FULFILMENT FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN APPLIED GEOPHYSICS.

DEPARTMENT OF PHYSICS

FACULTY OF SCIENCE

AHMADU BELLO UNIVERSITY, ZARIA

SEPTEMBER, 1995

DECLARATION

I, hereby declare that, this thesis is an original work carried out by the author under the supervision of Dr. B.B.M. Dewu and Professor C.O. Ajayi.

To the best my knowledge no part thereof has been submitted elsewhere for the award of a degree.
The work of others are duly acknowledged and referenced.

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SEPTEMBER, 1995.

DEDICATION

This work is earnestly dedicated to my grandmother (KABDAN) who taught me 'Love' whose earthly departure means a lot to my family. I sincerely wish her safe journey yonder.

CERTIFICATION

This Thesis entitled: D.C. RESISTIVITY INVESTIGATION OF THE GROUNDWATER POTENTIAL IN ROMI, CHIKUN LOCAL GOVERNMENT, KADUNA STATE, NIGERIA, by Dogara Matoh Dary meets the regulations governing the award of the degree of Master of Science (Applied Geophysics) of Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

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ACKNOWLEDGEMENT

I wish to express my profound gratitude to Dr. B.B.M. Dewu, my supervisor who suggested this work, for his encouragement, support, advice and strong scientific critism during the write up. I am also deeply indebted to Professor C.O. Ajayi, my co-supervisor, for his useful comments and suggestions that were of immense help in the write up.

My special thanks go to the Steel Raw Materials Exploration Agency (Steel Council) Malali, Kaduna for making the instrument used in this work available. The entire staff of the geophysics section of Steel Council, Kaduna, I say a BIG THANK YOU. May Almighty God reward you accordingly.

Professor S.B. Ojo, the Head of Physics Department, ABU, Zaria, whose advice and administrative dynamism added to his dedication to work and transparent honesty challenges and spurs me up to greater heights. It is my prayer to be like him or a little better. To Dr. M.N. Umego, Dr. Olatinwo, Mr. Kaka and the entire staff members of Physics Department, I also say a big thank you for your helpfull suggestions and pieces of advice in period of academic difficulties. Dr. B.W. Jimba greatly helped me in the course of this work. Without him, this work would have been delayed longer than necessary. I wish to, therefore, sincerely acknowledge his assisting me with the use of the computer in his office even at odd hours. Mr. Sule, Amoor and Family, I say thank you for your

secretarial expertise. Doo, Kunle and Aboye, thank you for your friendly support and encouragement.

I gracefully, acknowledge the support and concern of my dear family. Unyyem, 'Thank you' for drawing my attention whenever you cried in the midst of my resistivity interpretation. To my wife (Niyanka) I say THANK you for your understanding. Above all, I acknowledge the Almighty God for the treasures stored in me.

ABSTRACT

A geoelectrical survey employing the conventional Vertical Electrical Sounding (VES) was carried out at 36 stations in the Basement Complex of Romi village, south of Kaduna town. The survey was carried out to determine the groundwater potentials of the area.

Results from the interpretation of the data collected led to the production of some geoelectric and geologic sections and maps from which conclusions were drawn. The result of the study indicate a layering of two to three in the region. The range in resistivities for the first, second and third layer are 95-2187 ohm-m, 32-558 ohm-m and 585-8810 ohm-m, respectively depending on the lithological formation. The investigation showed that the aquifer occurs in the weathered and fractured basement which is characterized by relatively low resistivity values, 35-160 ohm-m for the weathered basement.

From the analysis of the maps and other information in the study, the most promising region for underground water exploitation in the area was delineated and this was found to be the region around VES L3/3. The dimension of this region measures about 1.68 xlO^6 nr^3 . Furthermore, the overburden thickness map suggests that the drainage pattern in the Romi stream is controlled by the basement topography.

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GLOSARRIES

Abbreviation	Description
D.C	Direct Current
°C	Degree Celsius

CHAPTER ONE

INTRODUCTION

1.1. Background

For a country such as Nigeria where rural industrialization is on the increase, the need to explore for suitable and productive reservoirs of groundwater for domestic, industrial and agricultural purposes cannot be over-emphasised. This is of particular importance in some parts of Northern Nigeria where, for many months of the year, there is no rainfall and surface water sources are often inadequate or non existent (Du Preez and Barber,1965; Baimba,1978). This situation taking into account the growing population of Northern Nigeria, suggests that intensive exploitation for groundwater is indispensable to make living condition more meaningful for the people in this region.

1.2. The Study Area

The area under investigation is located at Romi village in Chikun Local Government Area of Kaduna State. The area is approximately centred on Latitude 10° 27' N and Longitude 07° 26' E. It is about 5km east of the Command Secondary School Kaduna on the Kaduna-Kachia Road via bye-pass. The area is situated in the NE quadrant of the 1:50,000 Kakuri NE sheet No. 144. The total area covered in this work measures about

2km^2. The area can be accessed through a trunk road joining Kawo and Sabon-Gari via bye-pass in Kaduna town. Within the area itself, motorable tracks and minor footpaths exist (Fig.1.1). Thus accessibility within the area is very good.

1.3. Relief, Climate, Vegetation and Economic Activities

Romi is part of the extensively gentle undulating peneplain, the Hausa plains, which stretches East-West from Lake Chad to Sokoto and Northwards from the Southern parts of Kaduna State to the Tigueddi scarp near Agades in Niger Republic (Thorp, 1970). This area is at a height of 610m (Kakuri NE sheet No. 144, 1:50,000) above sea level. It has a rugged topography with an adjoining Kujama hill by the East. The hills are considerably high and are generally being reduced by quarrying activities taking place in the region.

The study area falls within part of Kaduna township (about 17km from the centre of the town) in the Northern part of Nigeria. It has a tropical Savannah climate with very distinct wet and dry season. The wet season normally starts in April/May and ends in September/October (Adanu, 1991). The mean daily maximum temperature shows a major peak of about 38°C in April and a minor one of about 26°C in October (Danladi, 1985).

The vegetation of the area lies within a transitional zone, between the Guinea Savannah belt and the Sudan Savannah belt. The Guinea Savannah belt is characterised by a mixture of

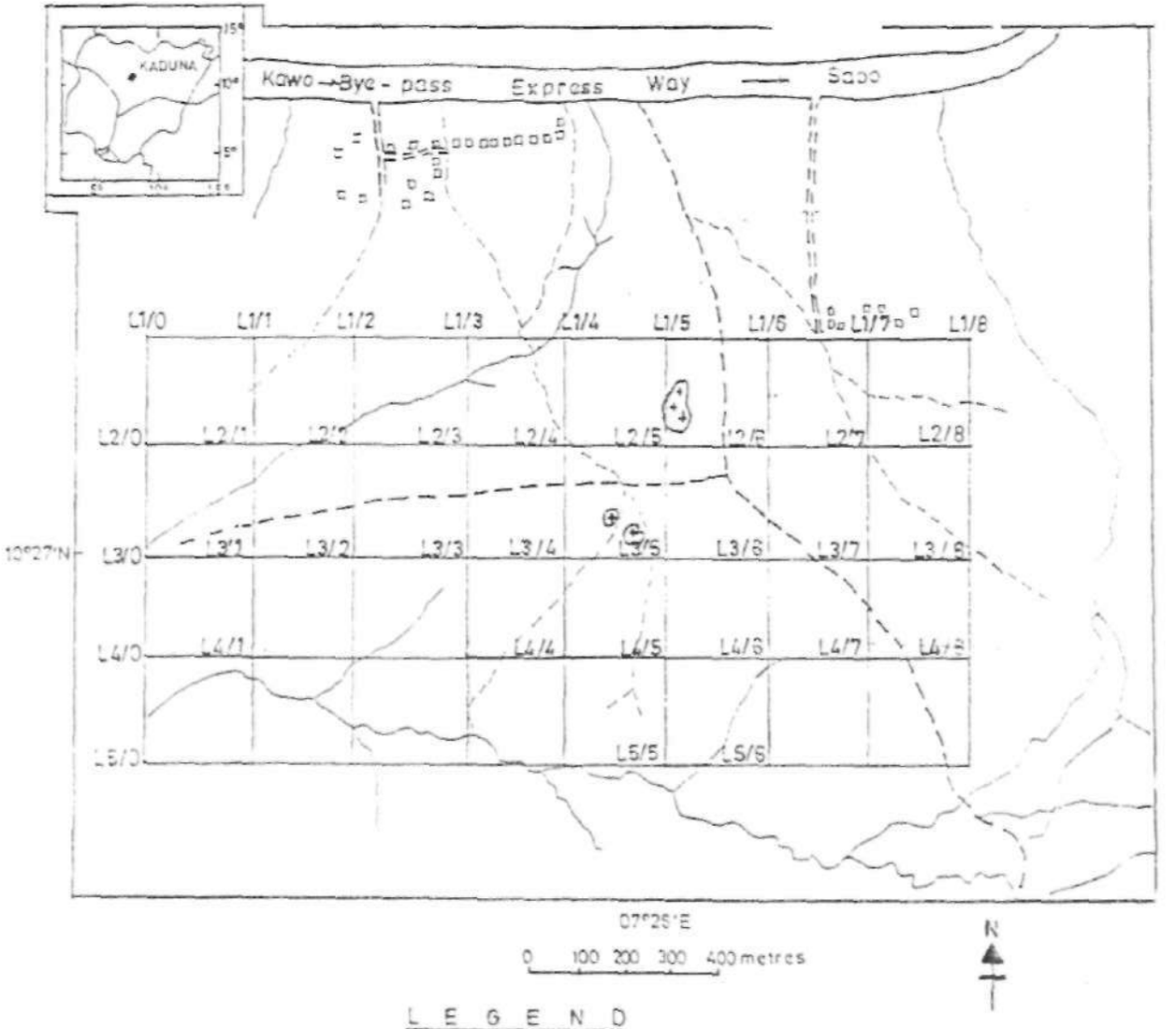


Fig.1:Map of the study area

grassland and woodland while the Sudan Savannah belt is drier with a less humid climate, characterised by grass and thorn bush with boabab trees (Adanu, 1991). Agriculture is the main economic activity of the people in this area. The people cultivate subsistence crops such as maize, guinea corn, millet, potatoes, etc. Near the streams sugar cane and vegetables are cultivated as part of the Fadama farming in the dry season. Rearing of cattle and goats by the nomadic Fulanis is also substantial in the area, especially in the South-Eastern part of the area where water supply is more regular all the year round.

The main water source of the inhabitants around the area, for the purpose of irrigation in the dry season is in the form of manmade ponds. These ponds normally dry up before the dry season runs out. To sustain the irrigation activities in the area, there is therefore, the need for regular water supply. It is apparent that the system of crude ponds can be improved upon to provide the needed water supply. Geophysical methods provide the best means of achieving such objectives. Hence, there is the need to study the area properly in order to determine the water potentials in the region thus the need for the study reported in this work.

1.4. Previous Work Done Around The Area

In the past, a lot of geologic, hydrogeologic and

geophysical investigations have been carried out around the area. Most of the works are localised and, therefore, information is generally inadequate as the result of such works are not published. However, some of the little available are informative. They include works by Webb (1972) who studied the geology of the area between Zaria and Kaduna. The study revealed that the contact between the Zaria batholith with the schists to the West of the area is sharp and that there is no apparent metamorphism along the contacts. Danladi (1985), in his hydrogeophysical investigations in the shallow basement area of Zaria and Kaduna reported that groundwater in the Zaria-Kaduna region mostly occurs in joints, decomposed zones of the Basement Complex and the overlying alluvium. Ajayi and Hassan (1990), delineated the aquifer overlying the Basement Complex in the Western part of the Kubanni Basin of Zaria (Nigeria). Their work showed that the decomposed (Weathered) basement most likely forms the main aquifer component within the area of study thus confirming the findings of Danladi (1985). The decomposed basement layer is characterised by relatively low resistivity values. Amadi and Nurudeen (1990), from their work on the Electromagnetic survey for the search of groundwater in the Crystelline Basement Complex of Nigeria, identified an integrated network of fractures usually hidden by a suite of overburden materials overlying the Crystalline Basement. Also Annor et al. (1990) in their work in the Basement Complex Area of Central Nigeria showed that drainage patterns could serve as remote sensors for unexposed

fractures in poorly exposed gneiss-granite terrains. In an investigation of the source and recharge of groundwater, in the basement terrain in the Zaria/Kaduna area, Adanu (1991), found that both the groundwater and river water showed very low dissolved constituents with low electrical conductivities.

1.5 Aims and Objectives of the Present Work

Most if not all, of the geophysical investigations carried out in Kaduna town were concerned with either civil works or groundwater exploration for individuals or companies (personal communication with some staff of Steel Council, Kaduna State Water Board and Kaduna State Agricultural Development Project). This implies the localised nature of these investigations. The present work was carried out because there is a need for regular water supply in Romi Village which would serve both agricultural and domestic needs of the populace. In view of this, therefore, the study was primarily meant to determine the groundwater potentials of the area using d.c. resistivity technique. From the study, details such as, the zones around the area most suitable for borehole siting were obtained.

The objectives pursued to achieve the above aim included:

i. The production of a geoelectric section at each sounding

point in order to determine the subsurface layering (that is the lithology) structures (if any) and the depth to basement within the study area.

ii. The determination from the geoelectric sections, the components of the aquifer and the thickness of each component in the study area.

iii. The production of a depth to basement map for the study area with the aim of getting a good knowledge of the basement geometry (topography).

CHAPTER TWO

GEOLOGY AND HYDROGEOLOGY OF THE AREA

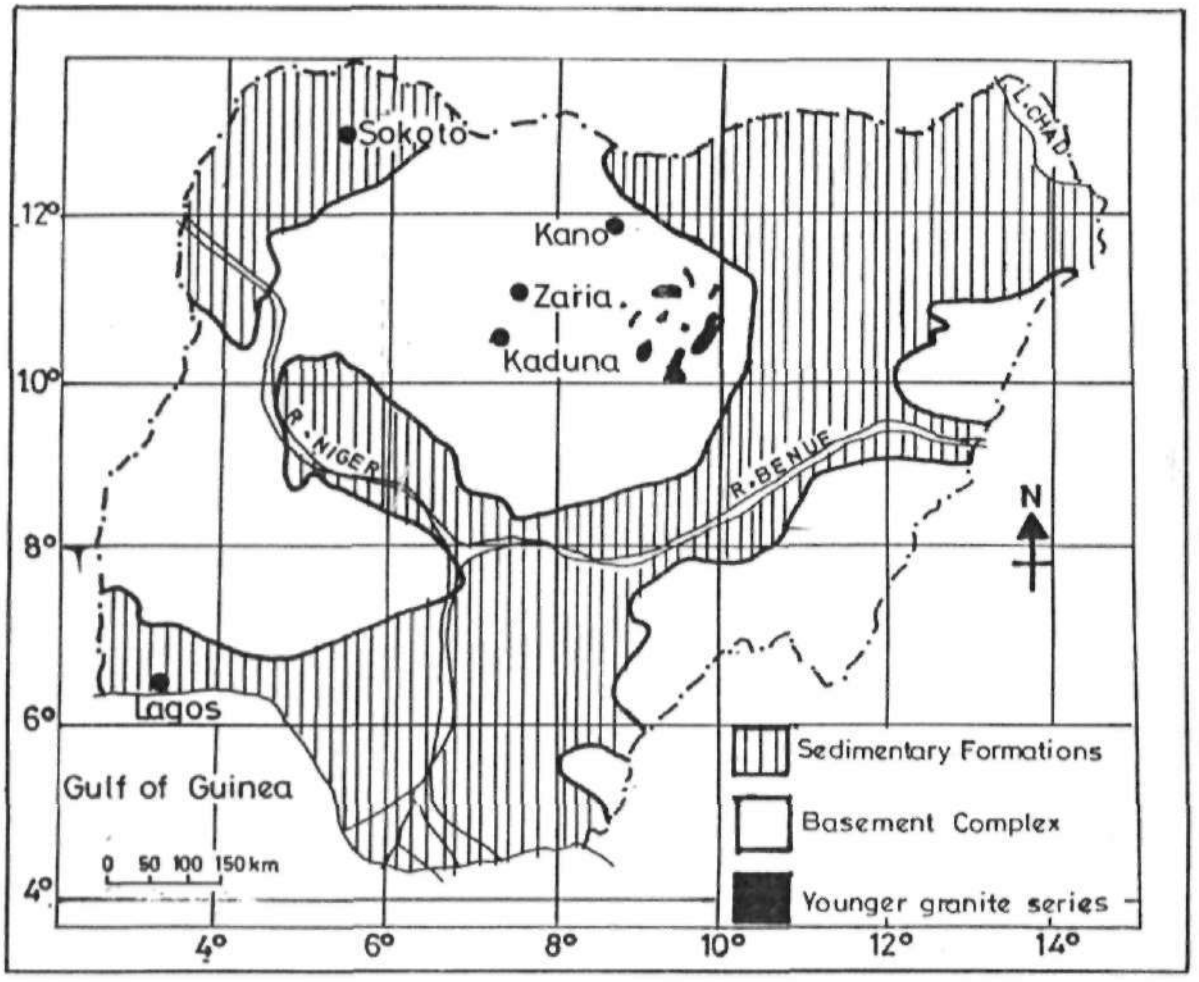
2.1. General Geology of the Study Area

Romi Village is underlain by Precambrian rocks typical of the Nigerian Basement complex which bears the imprints of thermotectonic events dating from Archean to early Paleozoic times (Oyawoye, 1979; Mccurry, 1976). Fig. 2.1 shows the distribution of the Basement complex and the sedimentary formation within Nigeria.

The Basement complex (crystalline rocks) are granites and gneisses, migmatites, peltic schist and metaconglomerates, marbles and calc- silicate rocks, basic schist, amphibolites and basalts, quartzites and quartz schist, charnockites and fayalite granites.

The sedimentary rock types are sandstones, shales and mudstones, limestones, siltstones and ironstones.
The crystalline stone are further sub-divided into the following groups, depnding on their ages.

i. Precambrian basement complex which characteristically yields radiometric ages in excess of 50 million years, occupies 40% of the total surface area of Nigeria (Grant, 1971). As can be seen in Fig. 2.1., these rocks are exposed in three sections of Nigeria; namely, the northern, southern



FIG·2·1·SIMPLIFIED GEOLOGICAL MAP OF NIGERIA (Courtesy of GSN)

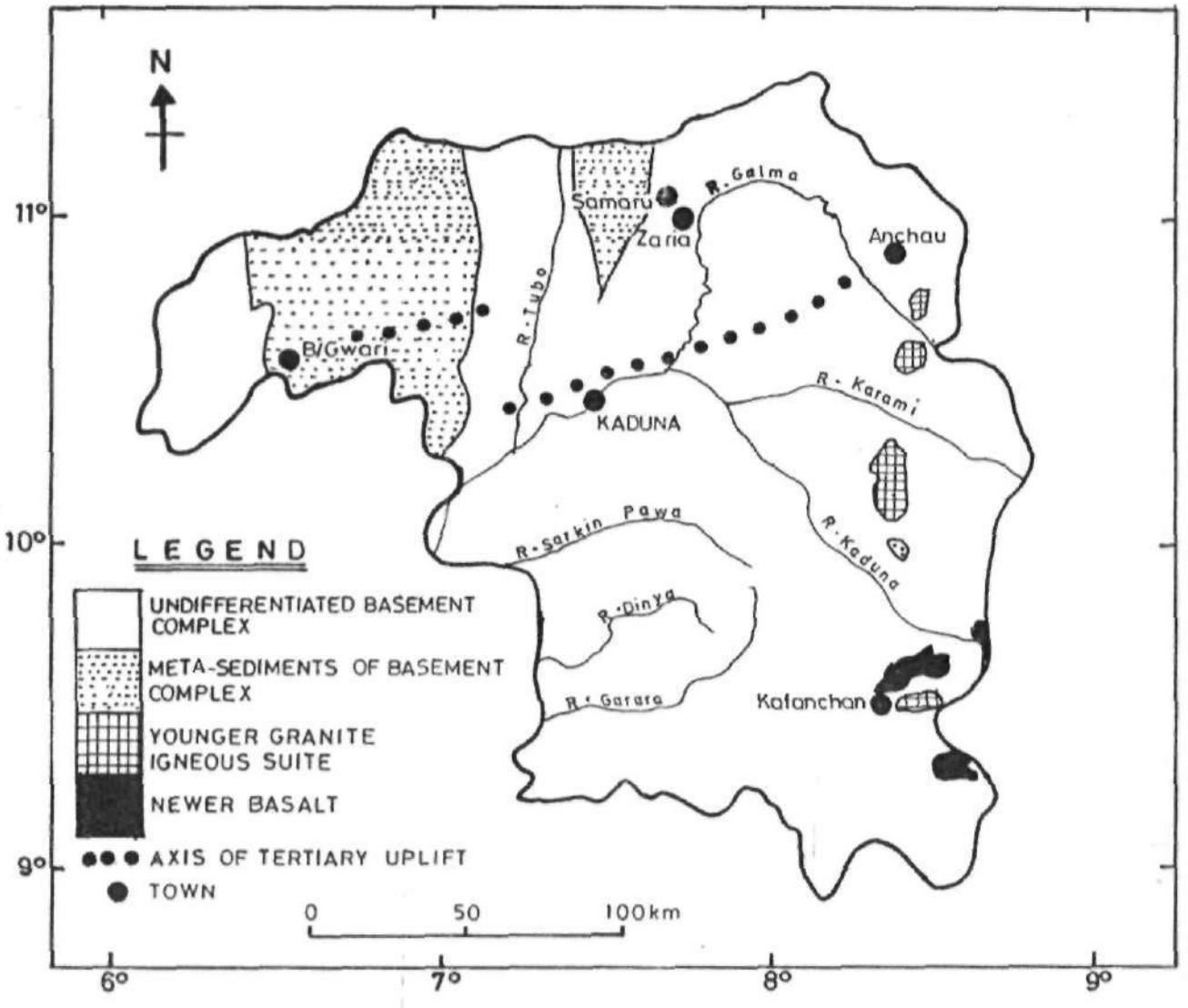
and eastern regions. The oldest of these rocks include the Older metasediments believed to be Birrimian (greater than 1000 million years) in age and gneisses which have suffered at least two episodes of tectono-metamorphic deformations resulting in widespread occurrences of migmatitic and granite gneisses (McCurry, 1976). Simply, it is underlain by igneous and metamorphic rocks of variably migmatized undifferentiated biotite and biotite-hornblende gneiss (Adanu, 1991).

ii. The younger granites, which are high level discordant intrusions in the basement complex, occupy about 8% of the total surface area of Nigeria (Bowden, 1976;Rahaman, 1976). They are a group of anorogenic rocks of Jurrassic age. The major tectonic event which took place principally,in the Jos Plateau around the Jurrassic period, resulted in the emplacement of the Younger granites and associated rock assemblage (Grant, 1971) and;

iii. The Younger metasediments are found in relatively narrow well defined belts, particularly in the western part of Northern Nigeria and in South Western Nigeria (Coorey, 1974). They are believed to have been deposited on the originally granitized basement around 1800 million years ago putting them as Katangan in age. They were then folded during the pan-African thermotectonic event (Kennedy, 1964).

2.2. Basement Geology Around the Study Area

Fig. 2.2. shows a detailed geological map of Kaduna State. The basement complex in the state was affected by an



FIG·2·2: GEOLOGICAL MAP OF KADUNA STATE
(Courtesy of KSADP)

orogeny which predated the emplacement of the older granites (Trustwell and Cope, 1963). During this event deformation of the basement produced north-south trending basins of metasediments in the form of synclinoria (Trustwell and Cope,1963).

Tertiary earth movements tilted the metasediments to the north and warped the basement along the axis of the uplift (Russ, 1957). Two of Russ's axes of tertiary uplifts pass the present Kaduna State trending west-north (Fig. 2.2.). They have a marked effect on the drainage pattern of the state.

Basically, the different basement rocks found around the undifferentiated basement complex can be summarised as given by Adanu 1991 to be:

a. Medium-coarse grained granite
b. Undifferentiated schist, including gneisses
c. Granite gneiss
d. Fine grained biotite and biotite-hornblende granite.
e. Coarse porphyritic biotite and biotite-hornblende granite including quartz manorzite, and;
f. Quartz diorite granodiorite.

2.3. General Hydrogeology

The hydrogeology of an area is controlled by factors such as the geology and climate of the region. This is because the geological formations underlying the area and

their structures determine the type of aquifers that would be developed and the means by which they would be recharged and the climate determines the amount and the rate of recharge of the aquifer. Thus, the hydrogeology of Kaduna State like that of any other place is, to a large extent, a function of the geologic setting. The climatic and the hydrogeologic conditions control the surface and the sub-surface waters in the area. The surface water, which is directly governed by the underlying geology, has its infiltration, evaporation, run-off and other flow components as major factors responsible for ground water recharge and accumulation in the area.

2.3.1. Hydrogeology of the Basement Complex

The basement complex consist of crystalline rocks which may be either altered, jointed or fractured. The process of alteration may give rise to loose aggregates above fresh basement or may create a laterite cover and a clayey horizon above loose altered bedrock. Primary porosities of fresh basement rocks are very low, usually less than 3% (Krymine and Judd, 1957). Permeabilities are also very low because the few pores present are normally not interconnected. However the weathered profile covering the fresh and fractured basement rocks, consisting of clayey and lateritic material changes down profile to unweathered bedrock. This material forms the body of the aquifer, its porosities and permeabilities are generally varied in region (Adanu, 1991).

From hydrogeological viewpoint, the basement complex may be regarded as having minimal groundwater potential (Egboka and Nwogute, 1985) as the decomposed region is usually thin in some areas of the basement complex to harbour large quantities of water and is usually too clayey to be permeable (Du Preez and barber, 1965; Baimba, 1978). However, boreholes and dugwells, if carefully sited, will normally provide an adequate supply of water for a small community within such geological terrain. Among the superficial formations found in the basement area, only sands and gravel have high permeabilities. River bed deposits, such as alluvium and wind deposited aeolian drift, on the basement provide other water bearing layers within the terrain.

The surface of the fresh basement is usually undulating. Hence the aquifer, in most cases, is divided into isolated pockets. Thus the movement of groundwater and drainage of aquifer is limited. Major sources of recharge to the aquifer in the basement complex are rainfall, nearby rivers and streams.

CHAPTER THREE

THEORY OF METHOD, DATA COLLECTION AND REDUCTION

3.1 Introduction

The method employed in any geophysical survey, is to a large extent determined by the nature of the problem at hand. Most of the geophysical methods can give useful information in connection with groundwater problems (Kolhert, 1969) but the most frequently used method is the D.C. resistivity technique. It can be used to map bedrock topography, delineate clayey and sandy layers and to locate aquifers. It has also been successfully used to map groundwater salinity. This technique was employed in this work. A brief description of the theoretical basis of the D.C. resistivity method is given below:

3.2. The Theory of D.C. Resistivity Method

The simplest approach to the theoretical study of the resistivity of the earth materials is to consider first the case of the completely homogeneous earth. Two basic equations govern the electrical method (Telford et al, 1976; Keller and Frischknecht, 1976). These are:

(i) Ohms law

$$\frac{1}{r^2}\frac{\partial(r^2\frac{\partial U}{\partial r})}{\partial r}+\frac{1}{r^2}\sin\theta\frac{\partial(\sin\theta\frac{\partial U}{\partial\theta})}{\partial\theta}+\frac{1}{r^2}\sin^2\theta\frac{\partial^2 U}{\partial\phi^2}=0.....(4)$$

where θ is the radial polar coordinate and ϕ is the azimuthal angle. If only single source of current I is considered to have been introduced into an infinite homogeneous medium and assuming complete current flow with respect to θ and ϕ directions then, equation (4) becomes a function of r only. Thus,

$$\frac{1}{r^2}\frac{\partial(r^2\frac{\partial U}{\partial r})}{\partial r}=0;\ since\ r\neq 0\ then,\ \frac{d}{dr}(r^2\frac{dU}{dr})=0$$

$$which\ gives\ r^2\frac{dU}{dr}=a.....(5)$$

and

$$U=-\frac{a}{r}+b$$

and where a and b are constants and r is the distance from the current electrode.

$$since\ U=0\ when\ r\to\infty,\ then\ b=0$$

$$\therefore U=-\frac{a}{r}\ .....(6)$$

The current flows radially through a hemispherical surface in the lower medium.

$$I = 2\pi r^2 J, \text{ but, } J = \frac{1}{\rho}\nabla U = -\frac{1}{\rho}\frac{dU}{dr}$$

$$\therefore I = -2\pi r^2 . \frac{1}{\rho}\frac{dU}{dr} = -\frac{2\pi}{\rho} r^2 \frac{dU}{dr} = -\frac{2\pi}{\rho} a$$

$$\Rightarrow a = -\frac{I\rho}{2\pi} \quad \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

substituting equation (7) in (6) we get

$$U = \frac{I\rho}{2\pi r} \quad \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

In case of several sources of current, instead of the single source assumed so far, the total potential at an observation point is the algebraic sum of the potential distributions from each source considered independently. Thus for n sources of current, equation (8) becomes:

$$U_n = \rho/2\pi \left[\frac{I_1}{r_1} + \frac{I_2}{r_2} + \frac{I_3}{r_3} + \ldots\ldots + \frac{I_n}{r_n}\right] \ldots\ldots\ldots\ldots (9)$$

From equation (8) the resistivity ρ, can be expressed as:

$$\rho = \frac{U}{I} 2\pi r = \frac{U}{I} . K \quad \ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Where K is the `geometrical factor' that depends on the electrode configuration used in the field measurements. The geometrical factor, K for a Schlumberger array (Fig. 3.1) is given by Keller and Frischknecht (1976) as:

$$K = 2\pi/\left(\frac{1}{AM} - \frac{1}{BM} - \frac{1}{AN} + \frac{1}{BN}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots (11)$$

Since, AM = L - b/2, BM = L + b/2, AN = L + b/2

and BN = L - b/2, then,

$$K = \frac{2\pi}{\frac{1}{L-b/2} - \frac{1}{L+b/2} - \frac{1}{L+b/2} + \frac{1}{L-b/2}}$$

$$K=\pi\left[\frac{L^2}{b}-\frac{b}{4}\right]=\pi b\left[\left(\frac{L}{b}\right)^2-\frac{1}{4}\right]$$

$$K = \pi\left[\frac{L^2}{b}-\frac{b}{4}\right] = \pi b\left[\left(\frac{L}{b}\right)^2-\frac{1}{4}\right]$$

Where L = seperation between a current electrode and the centre of configuration (AB/2)

b = seperation of the potential electrode MN (Fig.3.1).

The apparent resistivity ρ_a (combination of potential, current and electrode geometrical factors which would equal true earth resistivity if the earth were uniform) of the earth for a Schlumberger array can therefore, be obtained from equation (10) and (11) as:

$$\rho_a = \pi b\left[\left(\frac{L}{b}\right)^2-\frac{1}{4}\right]\frac{U}{I} \quad \ldots\ldots\ldots\ldots (12)$$

3.3 Data collection

Vertical Electrical Sounding (VES) data were collected in 36 stations on profiles of varying length. These stations were established on a grid pattern. The station interval used was 200m. At each VES station, the maximum seperation of current electrodes (AB/2) was 150m.

3.3.1 Choice of Electrode Configuration

The manner in which electrodes are positioned or arranged while performing a resistivity survey depends largely on the interest. Whether the interest is finding lateral variation in resistivity or finding the variation of resistivity with depth. Although, there are different types of arrays, the Schlumberger array was chosen for this work because of the advantages it enjoys over other arrays. One of such advantages is that it is convenient to use in the field, in that the potential electrodes are moved a minimum number of times during a given sounding compared to the frequent movement of electrodes required by other next popular array - Wenner array. The Schlumberger array saves time and man power. Infact, a minimum of 3 people are required to execute the survey comfortably when the Schlumberger array is used compared to a minimum of 5 people required in using the Wenner array.

Another advantage of the Schlumberger array over the Wenner is that it is less sensitive to undetected lateral variation in resistivity. This is because the potential difference is measured between two points which are close together compared with Wenner array where such two points are about one-third the interval of the current electrodes. The electrode effect on the resistivity curve is greatly minimized in using the Schlumberger array. This effect comes about because of the perturbations caused by the passage of

the potential electrodes over a superficial inhomogeneity which is much greater than those due to the current electrodes (Kunetz, 1966; Parasnis, 1972). Since the movements of the potential electrodes are minimized this electrode effect is also minimized.

3.3.2. Instrumentation

A Geohmeter model 10, a Gish-Rooney type of electrical resistivity apparatus, was used in this work. The apparatus consists of the measuring instrument assembly, battery power supply and associated cables, reels and copper rods (electrodes). The measuring instrument assembly contains a current measuring circuit, potential measuring circuit, commutator and a reversing system. The assembly was connected to the power supply through cables provided with plugs to prevent wrong connections. The flow of current was determined by means of a multirange current milliammeters with a single scale reading (0-50) and a selector switch, which indicated the multiplication factor to be applied to the meter reading.

The potential circuit included a galvanometer, a potentiometer and circuit control devices which permitted the selection of any fraction of the total voltage for comparison and balancing against the potential difference being measured. The potential difference was determined by a null method. The instrument was designed such that no current flows in the galvanometers whenever the potentiometer output

was exactly equal to the input potential. The potential difference was then read in millivolts on the potential dials. From the current and potential values, the resistance was determined. The rotation of the commutator periodically reversed the flow of the current. A rheostat was to control the speed of the commutator.

3.3.3 The Field Procedure

Fig. 3.1. shows the arrangement of electrodes in the Schlumberger array employed in this work. In the Figure, A and B represent the current electrodes through which the current was passed into the ground while M and N represent the potential electrodes across which the potential difference caused by the current was measured.

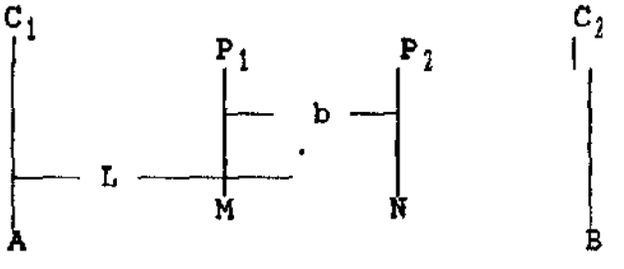


Fig. 3.1: Schematic Diagram of the Schlumberger Array.

The field procedure used involved expanding the current electrodes AB while keeping the potential electrodes MN relatively fixed. For each reading, the current was sent into the ground through A and B which set up the potential difference between the potential electrodes M and N. The magnitude of the potential difference developed was a measure

of the electrical resistance of the ground between the potential electrodes. This resistance is, in turn, a function of the geometrical configuration of the electrodes and the electrical parameters of the ground (Bhattacharya, 1968).

As the separation AB gets larger, the potential between MN decreases rapidly and ultimately becomes negligible, below the measuring capabilities of the instrument. This is because the field at the centre of the configuration normally varies inversely as the square of the length of the configuration AB (Kunetz, 1966). Mooney (1980) suggested that whenever the situation discussed above occurs, the separation of the potential electrodes, MN, should be enlarged such that the new value is larger than the preceeding value.

In this work, the magnitude of AB was chosen to be about six points per decade as required by the computer program used for the interpretation of the data. Thus, a new value of L was chosen to be more or less equal to the previous value multiplied by 1.47 or $10^{1/6}$ (Mooney, 1980). Using this procedure, 36 points were sounded. The survey in the study area was established on five profiles of varying lengths with each profile running East-West (Fig. 1.1). The maximum AB/2 value reached was 150m.

3.4. Data Reduction.

The data collected during the field work was processed using equation (12). The management of the data was made simple by the fact that the readings were computed in Ohms. The resistances obtained for each reading was multiplied by the corresponding geometrical factor, thus obtaining the value of the apparent resistivity.

The computed apparent resistivity values were then plotted against the half current electrodes separation (AB/2) on log-log graph sheets. A typical example of such resistivity curves for VES L1/2 is shown in Fig. 3.2. The plot was made such that AB/2 is on the abscissa and the corresponding apparent resistivity plotted on the ordinate. The plots of the field data for other VES stations are shown with their corresponding interpreted curves in Appendix A.

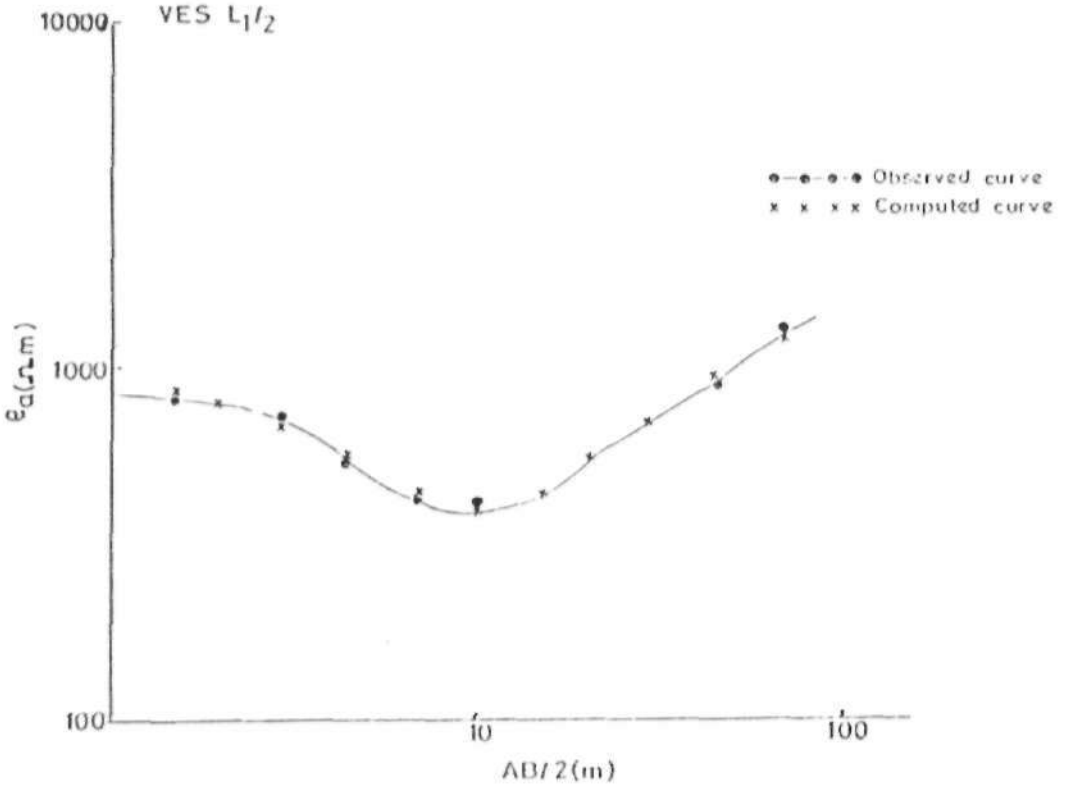


FIG. 3.2 : A TYPICAL CURVE FOR VES L1/2

CHAPTER FOUR

INTERPRETATION AND DEDUCTIONS FROM INTERPRETED DATA

4.1. Introduction

The interpretation of vertical electrical sounding (VES) data just like any other geophysical data obtained from such as magnetics, gravity and others involve expressing the information obtained from the surface measurements in geological terms. It is the aim, in interpretation of VES data to determine some combination of parameters of the subsurface structure (resistivities and thicknesses of the layers) that give the values of the surface measurements. In such interpretations, allowances for assumptions are made. However, the interpretation of VES data suffers from non-uniqueness arising from problems of equivalence and suppression.

The problems of equivalence is the difficulty in distinguishing between two resistive beds of different thicknesses and resistivities where products of these two parameters are the same. Similarly two conductive beds may not be distinguished if the ratios of their thickness to resistivity are the same. This is the `eqivalence problem'. Also, the problem of `suppression' is associated to those beds whose resistivities are intermediate between the resistivities of the enclosing beds. Such beds as long as

they do not have a great enough thickness have practically no influence on the resistivity curve for sounding (Kunetz, 1966).

It is conventional practice in VES interpretations to make the assumption that layers are homogeneous and isotropic. Any deviation from these ideal situations adds to the error in the final interpretation (Keary and Brooks, 1984; Aminudeen, 1990).

The problems of `equivalence' and suppression are ambiguous. This ambiguity can be minimised depending on the interpreter's experience with the method and his knowledge of the geology of the region under study.

4.2. Interpretation

The method employed in the interpretation of the data collected, as discussed in chapter three, involved finding some initial parameters which were later fed in a computer program. The computer program called `program Inverse' written by Phillip A. Davis of the University of Minnesota and published by Mooney (1980), was used. The program essentially produces a model that best fits the observed resistivity values. This is achieved by executing the following steps incorporated in the program.

i. Designing a trial model based on the field results by the author;
ii. Computing the theoretical field curve expected from the

trial model;

iii. Comparing the computed resistivity curve with the observed (field) resistivity curve and;

iv. Modifying the model, where necessary, to improve upon the match between the computed and the observed data until the best possible fit was achieved.

By supplying parameters of the trial model to the program, steps (ii) and (iii) are automatically executed; while step (iv) is carried out only where it is necessary to improve upon the agreement between the computed and the observed data by altering one or more of the parameters (layer resistivities and/or thicknesses) of the subsurface structure of the initial or last model. The parameters of the initial model were approximately determined using the conventional method of curve matching (Keller and Frischnecht, 1976; Telford et al., 1976).

The Petrowski and the Moor's cumulative plot methods were used to supplement the curve matching. The cumulative plot and curve matching are detailed in Telford et al (1976). The Petrowski method of interpretation works through the use of resistivity transform, the formula of which is given by

$$P_T = (L_{i+1} - L_i)/((L_{i+1}/P_{i+1})-(L_i/P_i))$$

Where, P_T = The transformed resistivity

L_i = AB/2

P_i = Apparent Resistivity

The values of P_T obtained from these calculations are plotted

on a billogarithmic graph using the average seperation of the distance $(L_{i+1} + L_i)/2 = L_0$.

The interpretation of these curves is based on the principle that all points of maxima, minima and points of inflection are indicators of existence of boundaries. Where the values tend to infinity is an indication of a fresh rock. This method is detailed in Danladi (1985).

The computer program is designed in such a way that it uses the trial model to compute a theoritical apparent resistivity curve. This is then compared with the observed field curve and then iteratively modifies the initial layer parameters until the `best' fit between the observed field curve and the computed one was obtained. The iterative process terminates when the process must have gone through a specified number of iterations or a given rms value is obtained. An IBM Micro-computer of the Centre for Energy Research and Training, Ahmadu Bello University, Zaria, was used for this aspect of the work. A typical result of such an interpretation is discussed in section 4.2.2.

4.2.1. Precautions Taken

The direct current (D.C) resistivity method with an inherent inverse problem has a lot of difficulties associated with it, especially when it comes to the delimitation of

aquifer horizons in prospecting for groundwater. The interpretation of resistivity data aims at the correct delimitation of the subsurface geological structures of the region of survey.

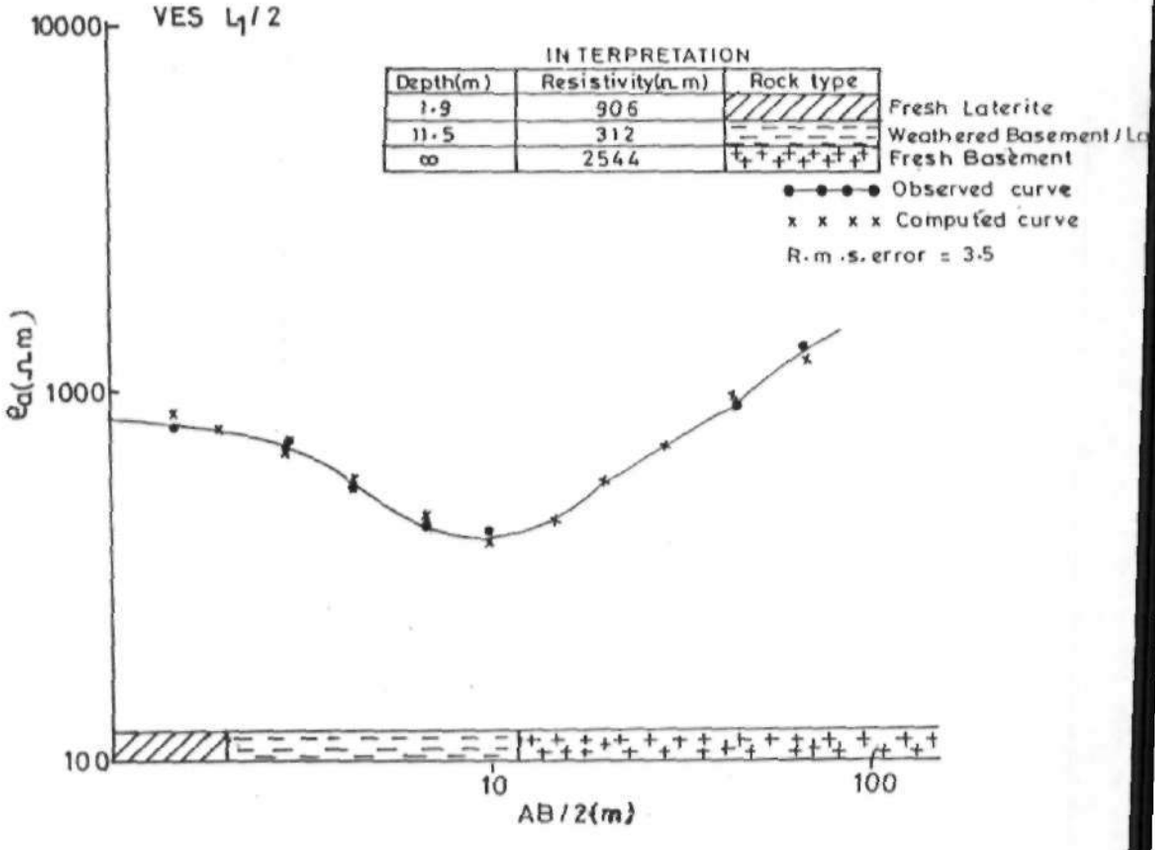
The computer program used in the interpretation of this work is very versatile but extra care had to be taken in using it as it can produce models which are totally implausible geologically (Mooney, 1980) if the initial model is not properly chosen. Hence, the following precautions and procedures were adopted to safeguard against the production of models that are geologically meaningless.

i. The electrode spacings were increased at approximately logarithmically equal intervals at the data collection stage as discussed in section 3.3. Also for an efficient use of the program, six data points were made to lie within each decade of AB/2 axis.

ii. As required by the program, an approximate interpretation of the data collected from each VES point was carried out using the conventional curve matching (Compagnie General De Geophysique, 1963) and the Petrowski method described by Danladi (1985).

4.2.2. Typical Interpretation

Fig.4.0 shows the interpretation for the VES point L1/2 which is used as a typical example of the interpreted VES



FIG·4·0:INTERPRETATION OF VES DATA AT POINT $L_1/2$

data. Shown in the Figure are the observed resistivity data, the computed data for the final model as well as the interpreted geologic section and its corresponding resistivity values for the VES point.

The shape of the observed resistivity curve at the VES point (VES L1/2) shown in Fig.4.0 suggests that three layers of the earth were sampled beneath that point. Hence, a three layer model was employed in the interpretation. The computed resistivity values for the final model (h_1=1.9m, ρ_1=906 ohm-m; h_2=9.6m, ρ_2=312 ohm; ρ_3=2544 ohm-m) are shown in the Figure by crosses, while the resistivity observed data are shown by dots joined by a smooth curve. At points where dots are not shown, the observed and theoritical values are exactly the same. Hence only the cross signs are shown at such points. The root mean square (rms) value, is the measure of the degree of fit between the computed and observed curve. For this Figure the r.m.s value is 3.5. The final model suggests that the total depth to the third layer is 13.4m (Fig.4.0)

All the remaining VES points were interpreted following the same procedure discussed above for VES L1/2. The computed resistivity data for the final model and the interpreted geologic sections for the various VES points are shown in Appendix A.

In interpreting d.c. resistivity data, just like any other geophysical method, geoelectric and geologic sections of the various profiles sounded were prepared.
Also, the isoresistivity and isopach maps were prepared by

contouring. These are discussed in section 4.3. and 4.4.

4.2.3. Resistivity Values

Tables 4.1 and 4.2 show the resistivity values of rock types in basement areas compiled from previous works around the area and the resistivity values used in deriving the geologic sections in this work respectively.

Table 4.1: Resistivity values of Rock Types in Basement Areas (Compiled from Shemang (1990), Aminudeen (1990), Ajayi and Hassan (1990), Hassan (1987) and Baimba (1979)).

Rock Type	Resistivity (ohm-m)
Fadama loam	30-90
Sandy clay and sandy silt	100-200
Sand and gravel laterite	150-10
Weathered Basement	20-200
Fractured basement	500-1000
Fresh basement	> 1000

Table 4.2: Resistivity values used in deriving the Geologic sections in this work.

Rock Type	Resistivity (ohm-m)
Fadama loam	30-90
Sandy clay and sandy silt	91-200
Weathered laterite	201-850
Fresh laterite	851-3500
Weathered basement	20-160
Fractured basement	500-1000
Fresh basement	> 1000

4.3. Geoelectric and Geologic Sections

The interpretation of the collected geoelectrical sounding data is generally not meaningful without some reliable geological control or some data relating to the intrinsic resistivities of the various geoelectric units at several places within the surveyed area (Worthington, 1977). As discussed earlier, in section 3.3.3., the VES stations in this work were established on three main profiles labelled L1, L2 and L3. Each of the profiles had nine sounding points located on it while two other profiles, L4 and L5, had 7 and 2 sounding points respectively located on them (Fig.1.1). In Figures 4.2a, 4.2b, 4.3a, 4.3b, 4.4a and 4.4b are shown the geoelectric and geologic sections derived for the profiles L1, L2 and L3 respectively. These sections were based on the interpretations discussed in section 4.2.2. above. The geologic sections are determined using the geoelectric sections and the geological information obtained from the Table of resistivity values (Table 4.2) and a well log (Fig.4.1) obtained for a borehole (well) located around the study area. A brief description of each of the resulting geoelectric and geological sections is presented below. Table 4.2 was largely used in deriving all geologic sections for all profiles in this work.

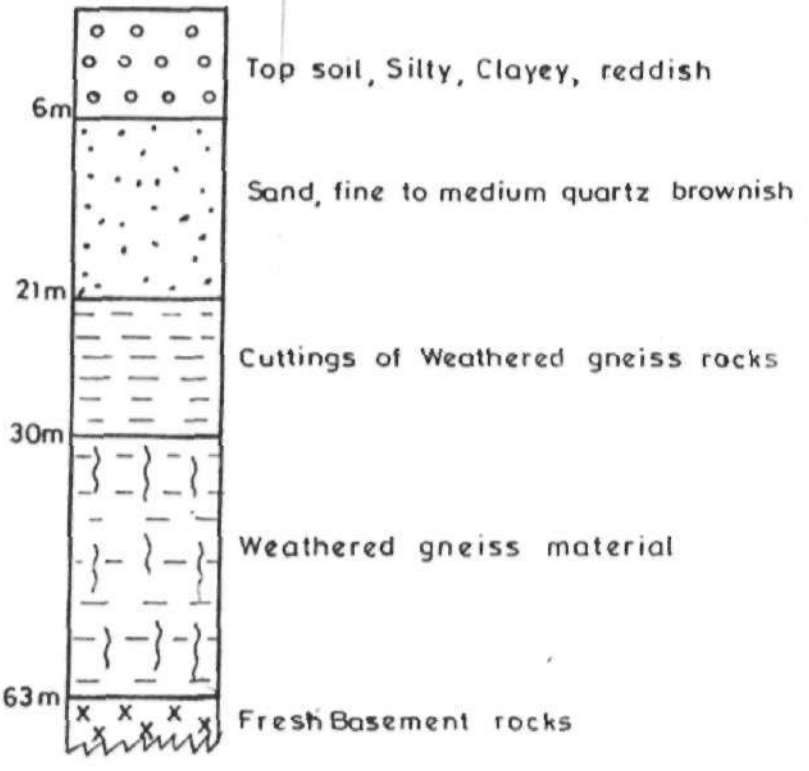


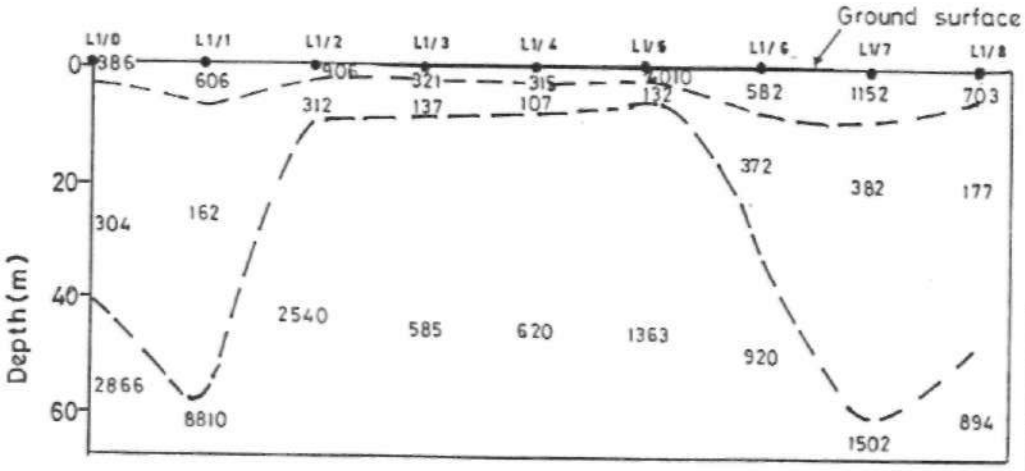
Fig.4.1: Geological well-log obtained by preussag Ltd at Kaduna (Courtesy of Kaduna state water board)

4.3.1. The Geoelectric and Geologic Sections for Profile L1

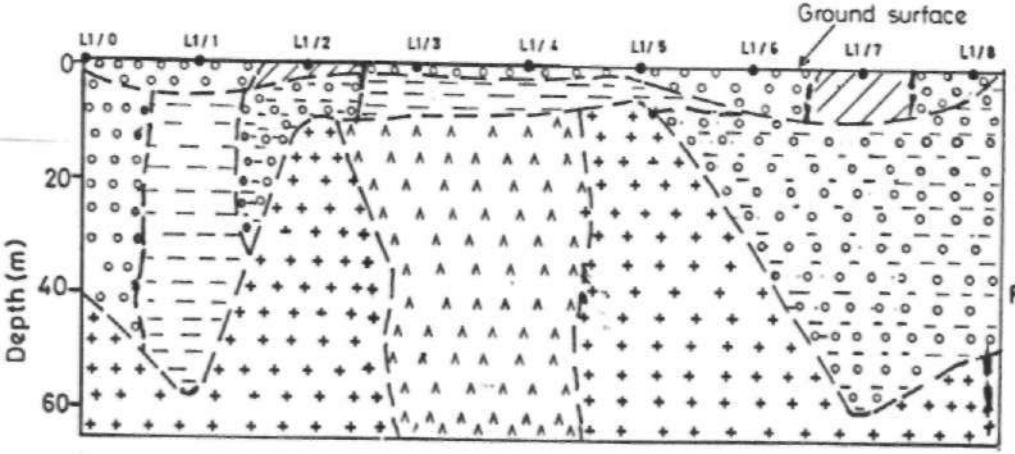
The composite geoelectric section derived for all the VES point established along profile L1 is shown in Fig.4.2a. The geoelectric section suggests that the subsurface along the profile is made up of 3-layers. Along this profile, the resistivity of the upper layer ranges from 315-2010ohm-m with an average of 776 ohm-m. The thickness of this layer varies from 1.2 to 8.8m at around VES L1/5 and L1/7 respectively.

The second layer has a resistivity in the range of 107 to 382 ohm-m. This layer has the lowest resistivity values and, hence, the likely most conductive layer under the profile. The thickness of the layer varies from 5.5m to 60.8 m.

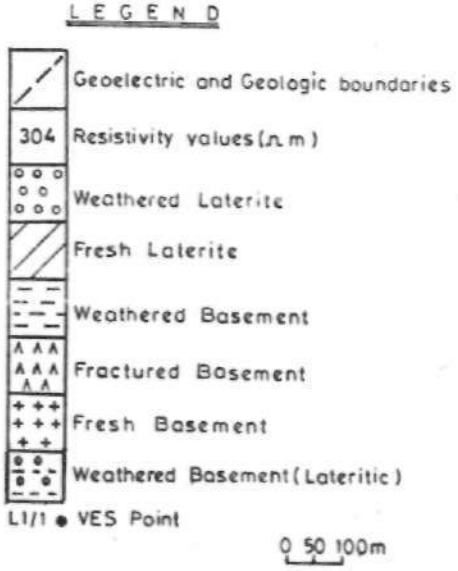
The third layer, which is the deepest layer, has relatively high resistivity values throughout the length of the profile. The resistivity values of this layer ranges from 585 to 8810ohm-m. The geologic section derived for this profile is shown in Fig.4.2b. The section suggests that the top layer must probably consist of two different soil types. The high resistivity zone (906-1152 ohm-m) of the layer occurring around VES L1/2 and L1/7 is considered to be fresh laterite. On the other hand, the zone with relatively medium resistivity values (321-703 ohm-m) occurring between VES L1/0 and L1/1, L1/3 and L1/6 and around VES L1/8 is considered to be a layer of weathered laterite based on Table 4.1. The Figure also suggests that the second layer also most probably



FIG·4.2(a):GEOELECTRIC SECTION



FIG·4.2(b): GEOLOGIC SECTION



FIG·4·2: GEOELECTRIC AND GEOLOGIC SECTIONS FOR PROFILE L_1

consists of two rock types. The first type found around VES L1/0 and L1/2 and between L1/6 and L1/7, with a range of resistivity values between 304 and 382 ohm-m suggests a likely layer of lateritic weathered basement. The second type which lies around L1/1 and between L1/3 and L1/5, is considered to be a layer of the weathered basement. The resistivity values in this zone suggest that this layer could have been highly weathered and likely to be clayey and partly gravelly with relatively low resistivity values (107-162 ohm-m).

The third layer whose resistivity values range from 585-8810 ohm-m is considered fresh basement, that is likely fractured at some points, example L1/3 and L1/4.

4.3.2. The Geoelectric and Geologic Sections for Profile L2

The composite geoelectric section obtained for all the VES stations on profile L2 is shown in Fig. 4.3a. The Figure suggests that the area around VES point L2/5 is underlain by 2-layers while the rest of the profile is underlain by 3-layers.

The resistivity of the first layer in both the 2 and 3 layer zones varies from 140 to 667 ohm-m while its thickness varies from 1.2 to 9.9m. The thinnest part (1.2m) of the layer occurs around VES L2/7. The second layer shows up between VES L2/4 and become absent around VES L2/5. It then emerges from L2/6 to L2/8. The resistivity of this area varies from 112-

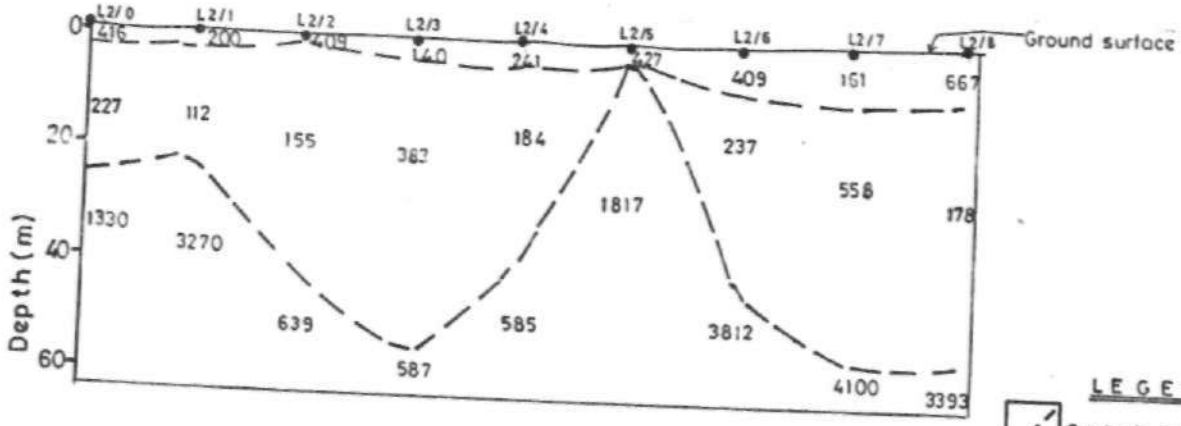


FIG.4.3(a): GEOELECTRIC SECTION

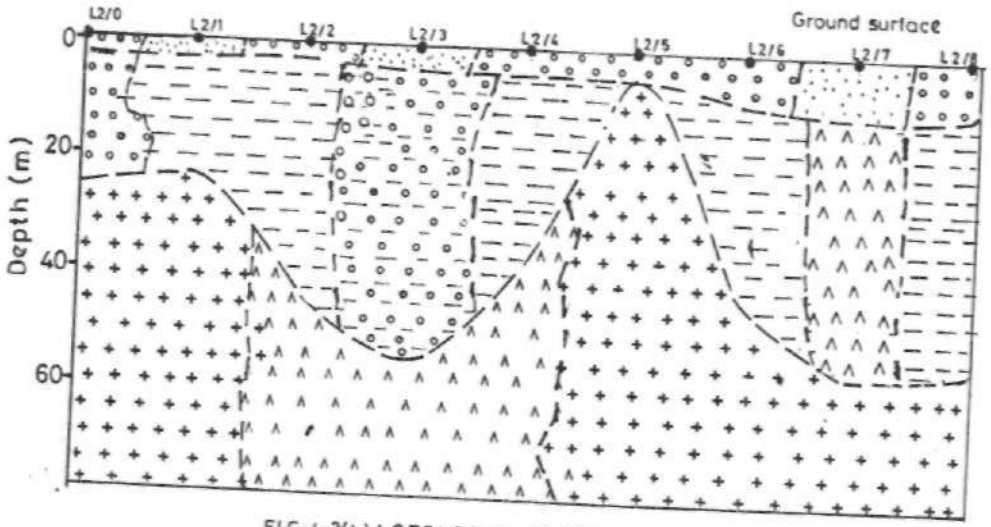


FIG.4.3(b): GEOLOGIC SECTION

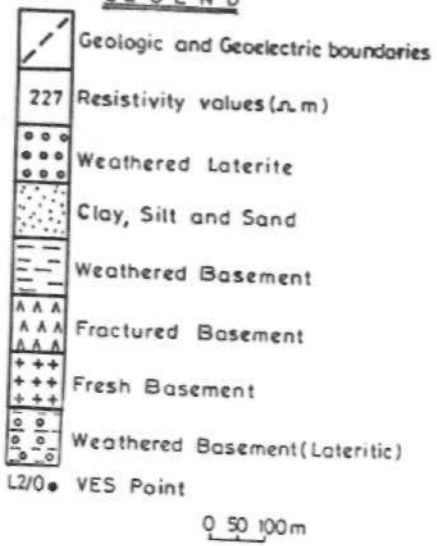


FIG.4.3: GEOELECTRIC AND GEOLOGIC SECTIONS FOR PROFILE L_2

558 ohm-m. The lowest resistivity value (112 ohm-m) of the layer occurs around VES L2/1 and the maximum resistivity value (558 ohm-m) occurs around VES L2/7. The third layer which is relatively resistive has resistivity values which range from 585 to 4100 ohm-m. This area underlies the entire profile.

Figure 4.3b shows the geologic section obtained for profile L2. The first layer suggests, it probably contains two soil types as in the case of profile L1. The zone where the resistivity values range between 161 and 241 ohm-m is most likely a layer of sandy clay or sandy silt. This occurs at VES L2/1, between L2/3 and L2/4 and around VES L2/7. The second zone is probably a zone of weathered laterite because it has resistivity values between 409 to 667 ohm-m. This zone occurs around VES L2/2 between L2/5 and L2/6 and around L2/8.

The second layer can be geologically divided into two segments. The first segment lies between VES L2/0 and L2/4, with resistivity values ranging from 112 to 383 ohm-m. this portion is believed to contain 2 soil formations, at VES L2/0 and around L2/3 is lateritic weathered basement, while the portion around L2/6 and L2/8 suggests a weathered basement rock formation. Between them is lateritic weathered basement formation as can be seen from the well log (Fig.4.1). Directly below the weathered basement is the third layer whose resistivity values range from 585 to 4100 ohm-m. This layer is believed to be fractured between VES L2/2 and L2/4.

Hence, implying a region of possible water saturation. The rest of the layer is thought to be fresh basement.

4.3.3. The Geoelectric and Geologic Sections for Profile L3

Figure 4.4a shows the composite geoelectric section obtained for the VES points on profile L3. The Figure suggests that the region between VES L3/4 and L3/6 is underlain by 2-layers while the rest of the profile is underlain by 3-layers. The region of 2-layers is an area where there is an outcrop of gneiss (Fig.1.1).

The resistivity of the first layer varies from 95-2187 ohm-m with its thickness varying from 1.9-12.6m. The thinnest part of the layer is around VES L3/2 and thickest around VES L3/6. The second layer occurs between VES L3/0 and L3/3. The layer is absent between VES L3/4 and L3/6. It then continues from VES L3/8. The resistivity of this layer varies from 73 to 1152 ohm-m. The lowest resistivity value (73 ohm-m) of the layer occurs at VES L3/3 and an abnormal maximum resistivity of 1152 ohm-m occurs in the vicinity of VES L3/8. The third layer, which is the last layer, has relatively high resistivity values throughout the length of the profile. The resistivity values of this layer ranges from 500 to 5400 ohm-m.

The geologic section along profile L3 is shown in Fig.4.4b. The first layer suggest the possibility of 3 soil types. The zones of resistivity values ranging between 204

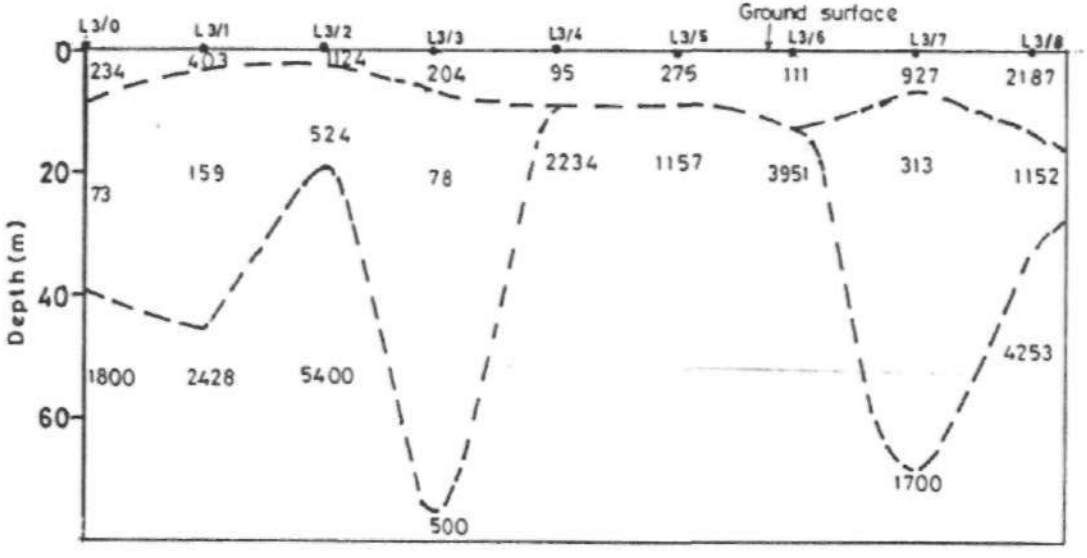


FIG.4.4(a):GEOELECTRIC SECTION

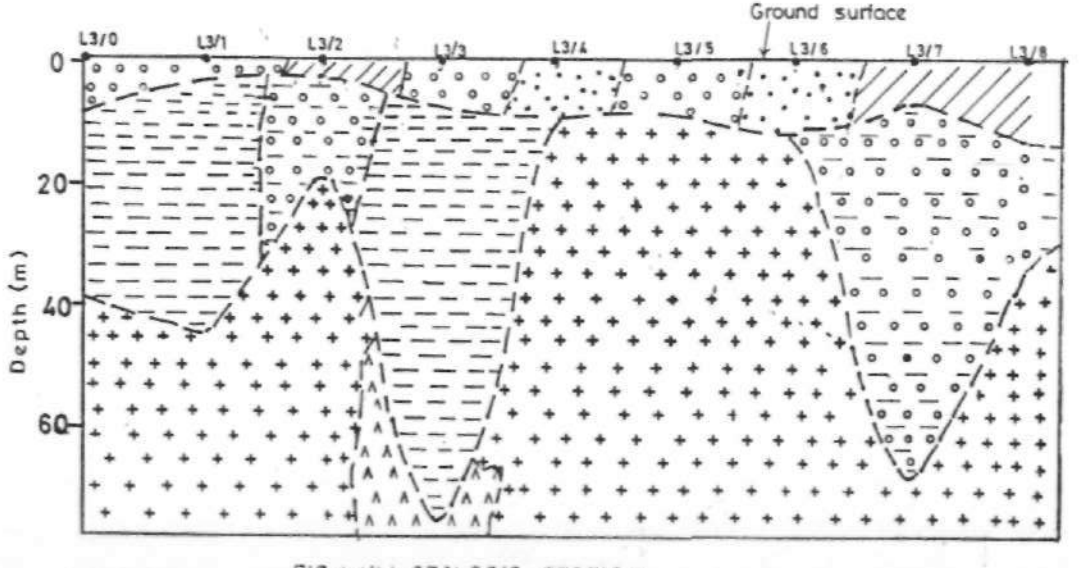


FIG.4.4(b):GEOLOGIC SECTION

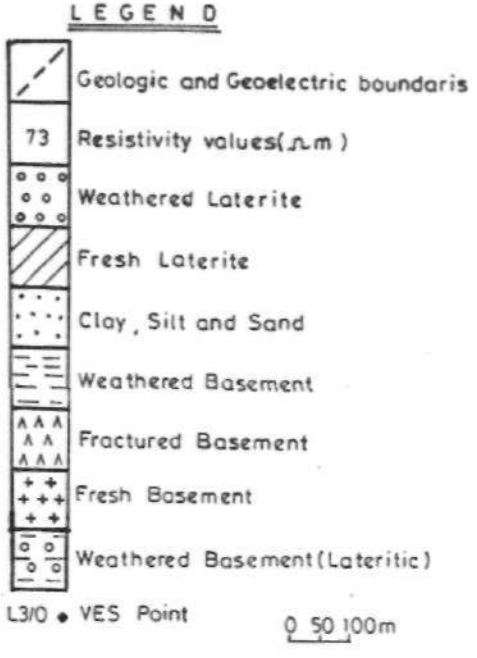


FIG.4.4:GEOELECTRIC AND GEOLOGIC SECTIOINS FOR PROFILE L3

and 403 Ohm-m are most likely weathered laterite zones. These zones occur around VES L3/0, L3/1, L3/3 and occurs around VES L3/8. This zone is considered a probable area of fresh laterite. The third zone lies around VES L3/4 and VES L3/6 with resistivity values of 95 ohm-m and 111 ohm-m respectively. This zone is likely an area of clayey and sandy silt.

The second layer experiences an intrusion of the whole basement. In the intrusion, there are some localised depressions which are due to weathering along fractures. This intrusion seems to occupy quite a reasonably large area within the profile. At L3/0, L3/1 and L3/3,the resistivities are low, suggestive of regions of weathered basement. VES L3/2 and between L3/7 and L3/8 suggest regions of lateritic weathered basement. Under the second layer or first layer, as the case may be (Fig.4.4b), lies the layer of high resistivity. Resistivity values in this layer reach up to 5400 ohm-m.

4.4. Maps Produced from Interpreted Data.

In order to look at certain aspects of the study area, certain specialized maps were produced from the interpreted resistivity data of the whole area. Though, possible interpretations have been given in the profiles discussed, however, each of the maps discussed below show the whole area at a glance including profiles L4 and L5 which are not

discussed in section 4.3. because readings were not taken completely along them (Fig.1.1). The specialized maps produced include:

i. The isoresistivity map of the surface layer.

ii. The isoresistivity map at AB/2 = 30m and at AB/2 =45m.

iii. The isoresistivity map of the fresh basement.

iv. A map of the overburden thickness (topography) and

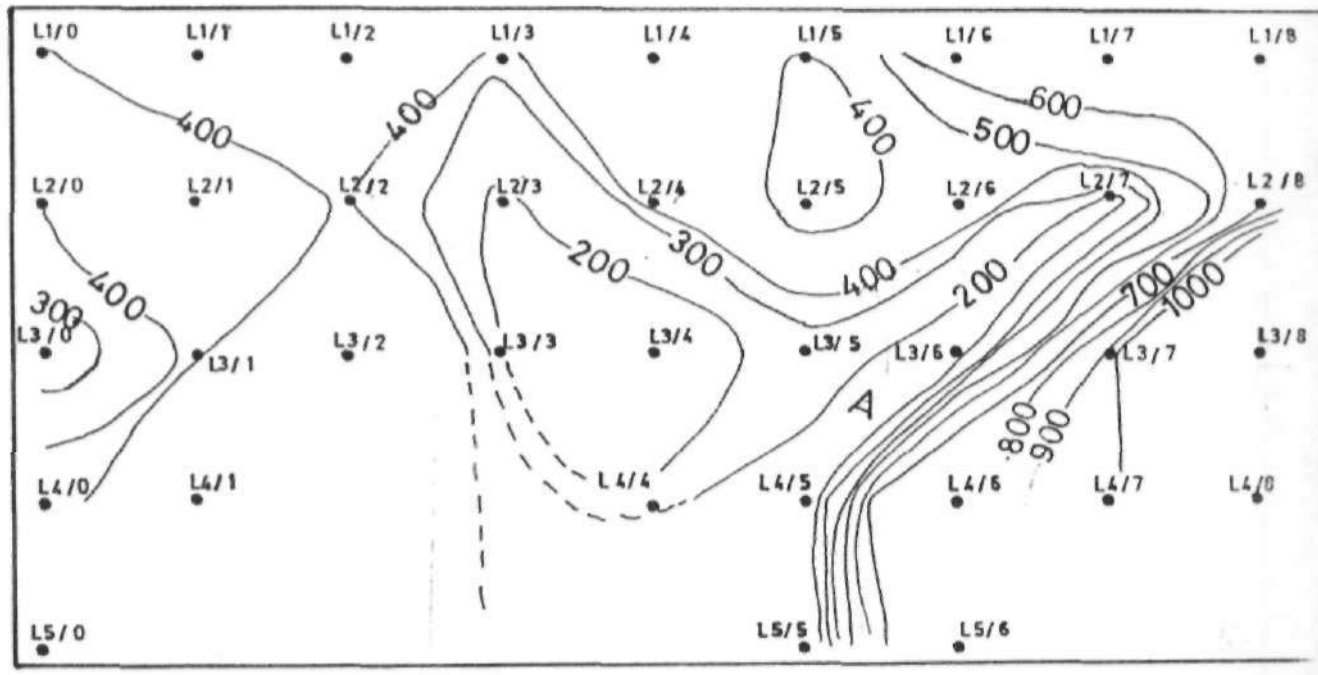
v. The aquifer thickness map.

The method of producing such maps and deductions made from them are discussed below.

4.4.1. Isoresistivity Map of the Surface Layer.

This map was produced by contouring the resistivity values obtained for this layer at all the VES points. The resulting map (Fig.4.5) was drawn with a contour interval of 100 ohm-m. This map is meant to show the variation of resistivity of the topmost layer, which could be used to compare with the surface features (such as the stream and the outcrop exposed). This would elucidate whether there exist some water saturation in the top soil.

The Figure shows that the resistivity values of the topmost layer in the study area range from 111 ohm-m at around VES L3/4 to 2187 ohm-m at around VES L3/8. VES points L3/4 and L3/6 have the lowest resistivity value on the map, which suggests the soil cover in this area to be likely made up of



0 50 100 m

Contour interval = 100 Ω.m

LEGEND

VES point

Contour line

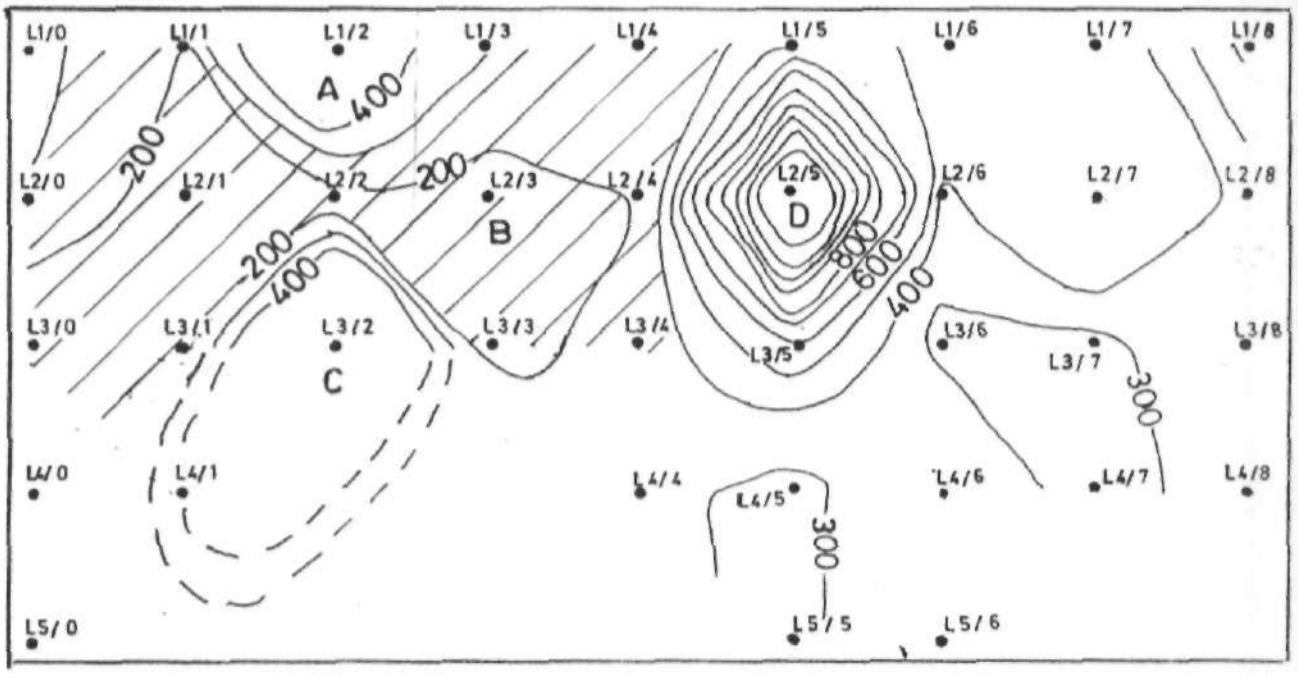
FIG. 4-5: ISORESISTIVITY MAP OF THE SURFACE LAYER

sandy clay and silt. The contour lines (labelled A) stretch from VES L2/7 to VES L4/5 in NE - SW direction and Southwards to VES L5/5 terminating at the stream (Fig.4.5). At the eastern side of this low resistivity region is the high resistivity region that may be likely occupied by fresh laterite.

4.4.2. Isoresistivity Maps at AB/2 =30m and AB/2 =45m

The maps (Fig.4.6a and b) were prepared using resistivity values obtained for AB/2 =30m and AB/2 =45m for various VES points. These maps were prepared at these depths to see how the resistivity of the major component (weathered basement) of the aquifer in the area varies from place to place at this depth with the aim of delineating the most favourable area(s) for groundwater exploitation as well as delineating possible structural trends (if any) within the layer of the weathered basement.

The appendix A shows the plotted apparent resistivity (versus AB/2) curves in the region. The curves show that the lowest resistivity values are usually recorded between AB/2 =30m and AB/2 =45m. This is suggestive that the region is most likely saturated with water. Hence the decision to investigate this region with more detail through the production of the maps shown in Figs. 4.6 (a) and (b). The two figures are approximately similar to each other. Each of the Maps suggest the existence of four anomalies which have



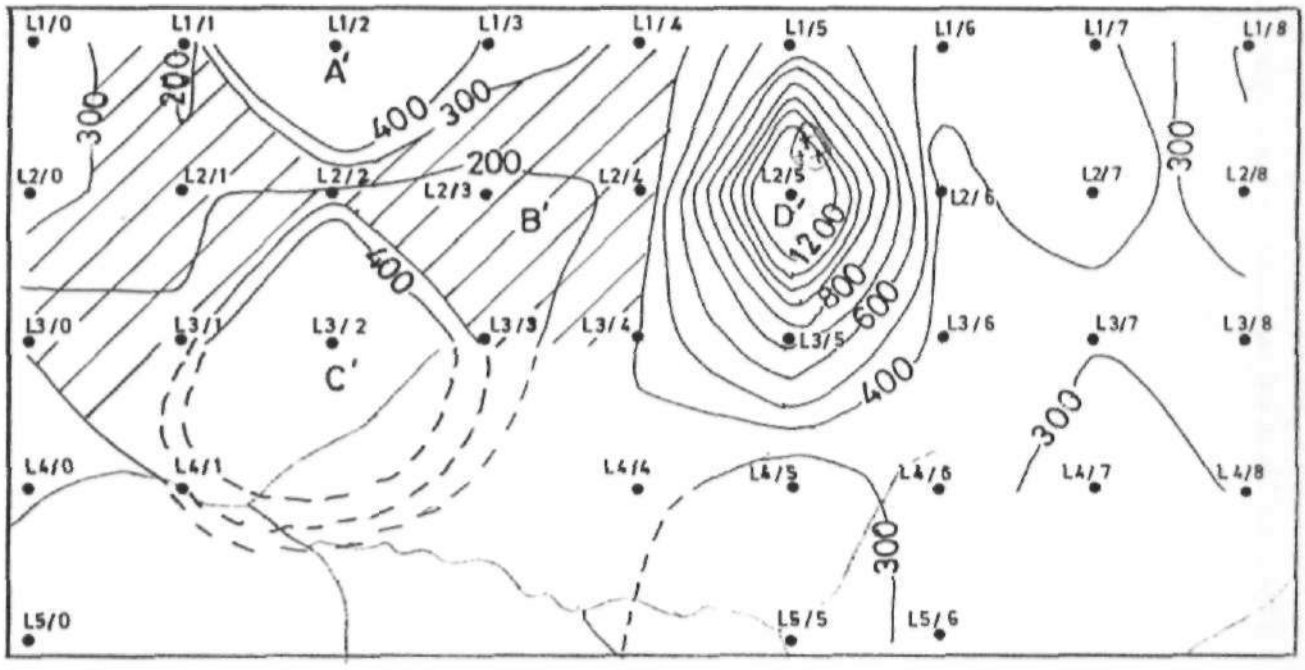
0 50 100m

Contour interval = 100 Ωm

LEGEND

- VES point
- Area of low resistivity values
- Contour line

FIG 4.6(a): ISORESISTIVITY CONTOUR MAP OF THE STUDY AREA AT AB/2 = 30m



0 50 100 m

Contour interval = 100 Ωm

LEGEND

- VES point
- Area of low resistivity values
- Contour line
- Stream

FIG-4.6(b): ISORESISTIVITY CONTOUR MAP OF THE STUDY AREA AT AB/2 = 45 m

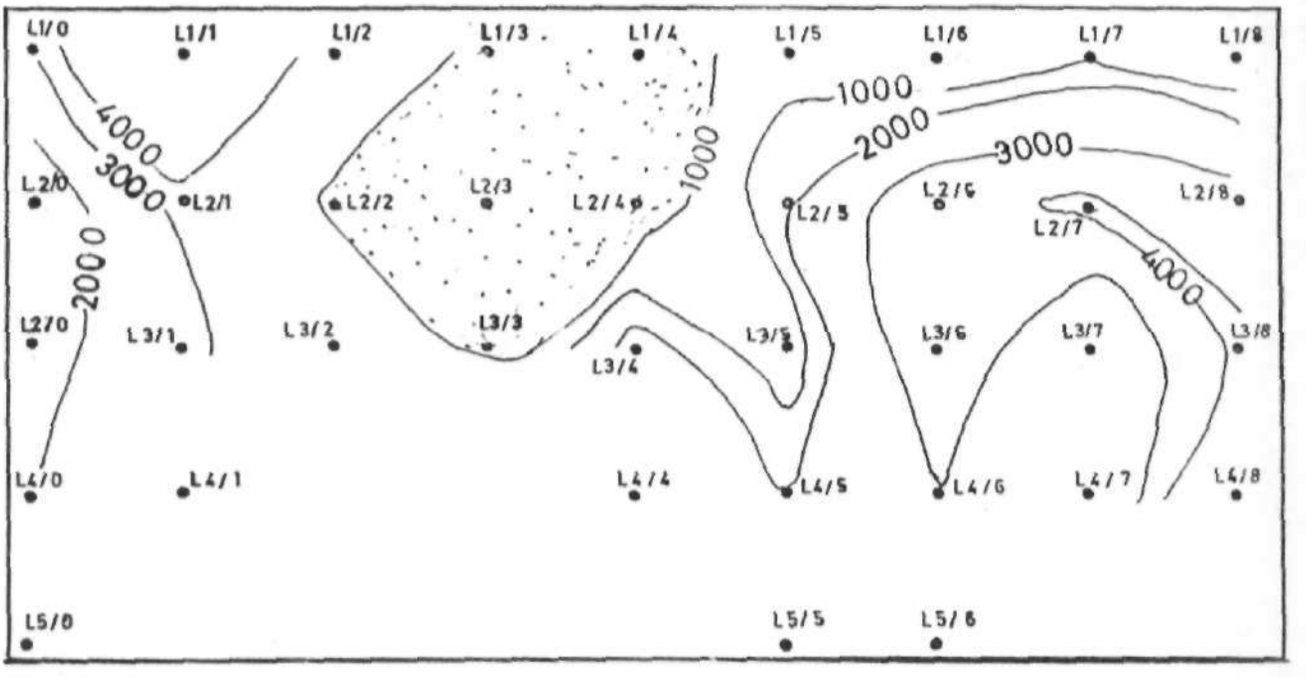
been labelled A,B,C and D in Figure 4.6(a) and A',B',C' and D' in Figure 4.6(b).

Zones A,C and D in Figure 4.6(a) and A',C' and D', in Figure 4.6(b) are zones of high resistivity values. The resistivity values in these regions range between 737 and 1629 ohm-m in the two maps. Zones D and D' correspond to the area of the gneiss outcrop. Hence, the zone is not suitable for water exploitation. The shaded zone labelled B in Figure 4.6(a) and (zone B') in Figure 4.6(b). The region is considered to be the most favourable for water exploitation because of its low resistivity values (less than 300 ohm-m) which is most probably due to the highly saturated nature of the weathered basement layer within the region.

4.4.3. Isoresistivity Map of the Fresh Basement

The resistivity map of the fresh basement underlying the area is shown on Figure 4.7. This map was produced by contouring the interpreted resistivity values for the basement beneath all the VES points. The map was produced with the primary aim of seeing how the resistivity of the basement varies within the study area. From which, could be inferred on the distribution of fractured and unfractured fresh basement rocks within the study area.

The Table of resistivity values (Table 4.1.) used to derive the geologic sections shows that the resistivity range of 500-1000 ohm-m are obtained in fractured basement terranes, while a resistivity value of greater than 1000 ohm-



0 50 100m

Contour interval = 1000 Ω m

LEGEND

VES point

Contour line

Area of minimum resistivity value

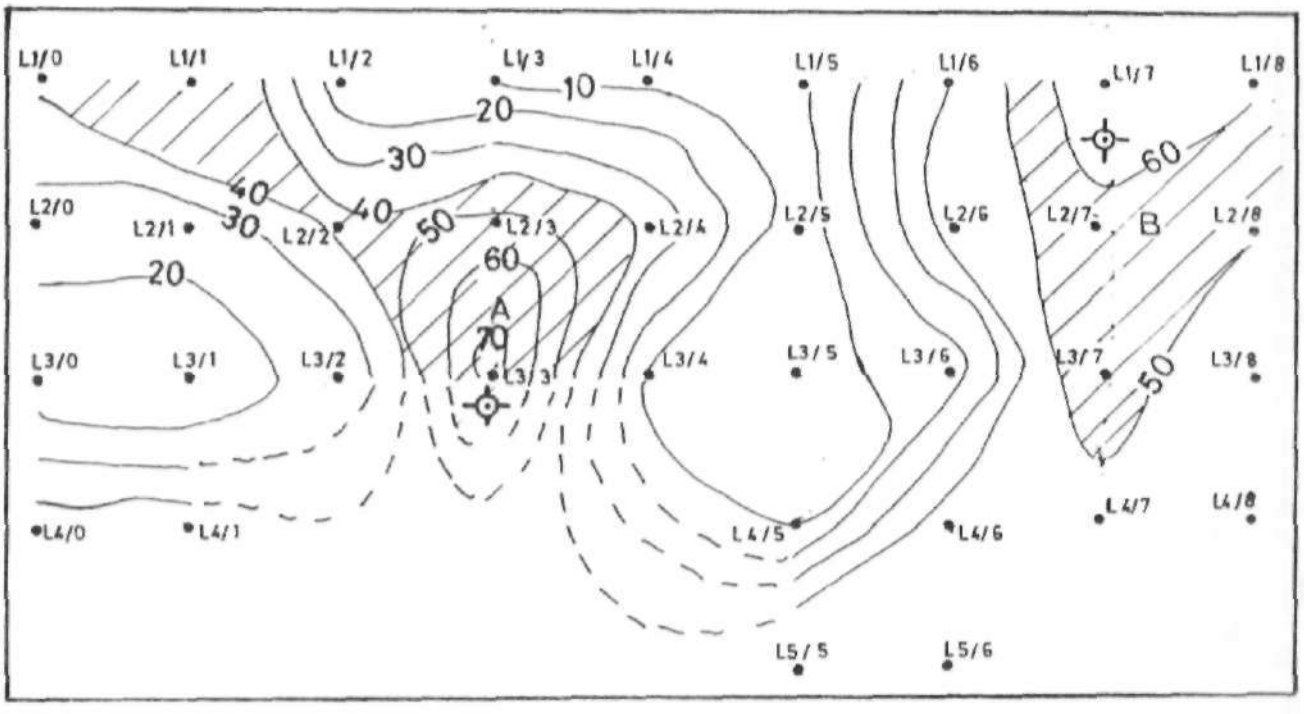
FIG·4·7:ISORESISTIVITY CONTOURED MAP OF THE FRESH BASEMENT

m are mainly due to fresh basement rock. Figure 4.7 suggests that a part of the study area is most likely underlain by fresh basement rock. The average resistivity obtained for the fresh basement (both fractured and unfractured) in the area is 2332 ohm-m. The dotted region in Fig.4.7 represents the area that most probably contains fractured basement because its resistivity values are less than 1000 ohm-m. Part of this area falls within the area earlier designated in this work (Section 4.4.2.) as the zone to exploit groundwater (Figures 4.6(a) and (b)).

4.4.4. Depth to Basement (Overburden Thickness) Map

The overburden thickness map was prepared from the interpreted depth to basement at each sounding point. This was contoured at an interval of 10m. This was done to enable a general view of the geometry or topography of the basement under the study area as well as the variation in overburden thickness. By so doing, the deepest part of the study area was delineated.

The overburden thickness map of the area is shown in Fig.4.8. The Figure suggests that the depths-to-basement in the study area range from about 10m around VES L2/5 to 76m around VES L3/3 near the stream. The average depth to the basement in the area is about 33.7m. The shallowest depth occurs around VES L3/5, while the deepest part of the area



0 50 100 m

Contour interval = 10m

LEGEND

- Recommended B·H·point
- VES point
- Contour line
- Area of maximum aquifer thickness
- Axis of basement depression

FIG.4·8: OVERBURDEN THICKNESS MAP

is around VES L3/3 (Fig.4.8). Figure 4.8. suggests two regions A and B (shaded) where the depths to the basement are about 55m on the average for both regions. A comparison of these regions with Figures 4.6(a) and 4.6(b), shows that these regions have resistivity values less than 300 ohm-m for region A and less than 400 ohm-m for region B. This is suggestive of probable water saturation. Hence, the area could be favourable for the exploitation of groundwater. A close examination of the map suggests that the geometry of the basement may serve as a form of structural control on the flow direction of the streams in the region. This is because the stream tributries flows approximately along regions labelled A and B in Figure 4.8.

4.4.5. Weathered Basement Thickness Map

The map shown in Figure 4.9 represent a map of the aquifer thickness. This was produced from the thickness of the second layer obtained in the course of the interpretation of the data in this work (section 4.2.2.). The map was produced to find out how the thickness of the weathered layer , considered the main aquifer component in the area, varied from place to place within the study area.

The weathered basement thickness map (Fig,4.9) is very similar to the depth to basement map (Fig.4.8), though the thickness of the first layer was removed from Figure 4.8. to

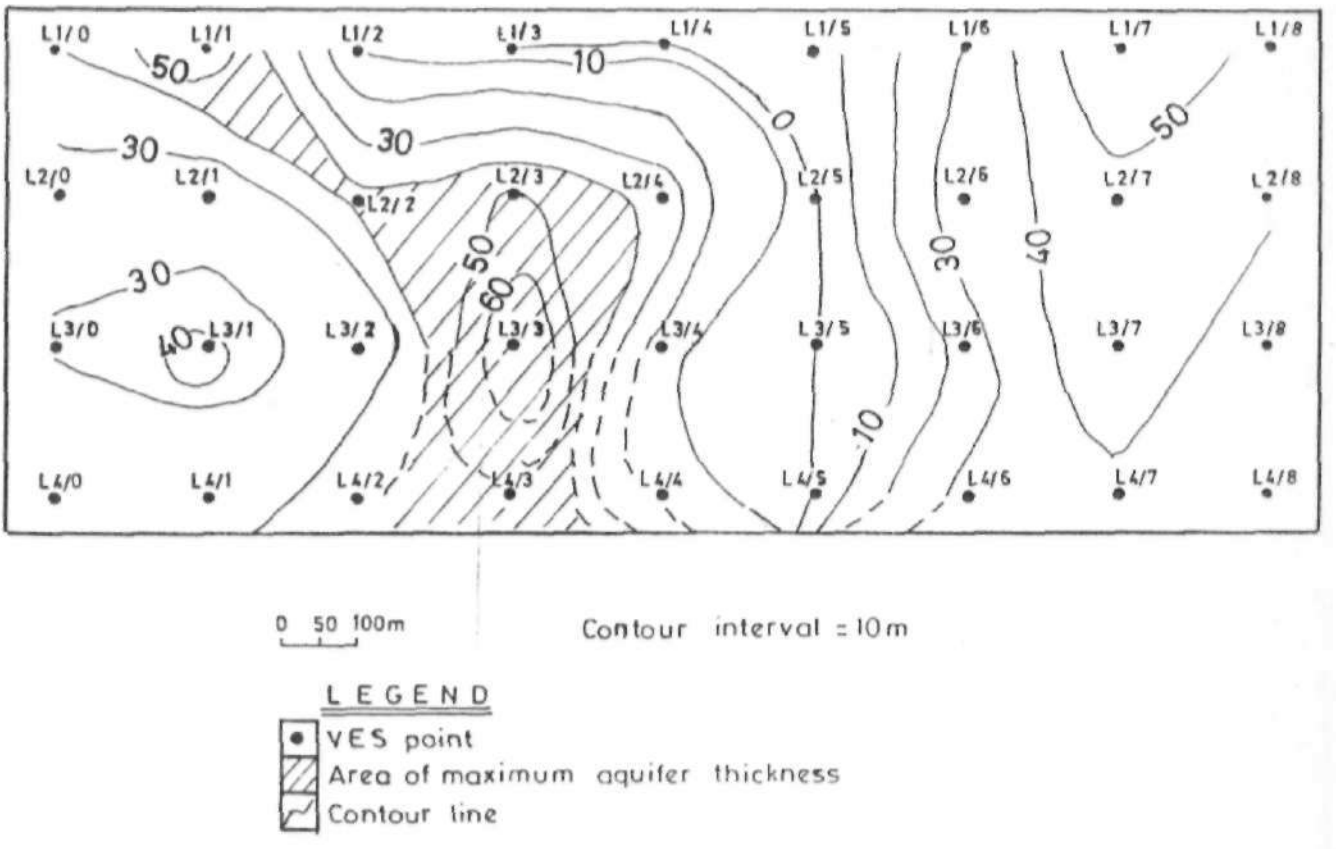


FIG. 4.9: AQUIFER THICKNESS MAP

produce Fig.4.9. As can be seen from the map, the thickness of the weathered basement layer varies from 6m to 68m with an average value of 26.5m. Around VES L2/5, L3/5 and L3/6, this layer is virtually absent. This is the region of the gneiss outcrop. The map, as in the case of the overburden thickness map, also suggest the existence of a weathering induced structure or an ancient buried erosional surface.

CHAPTER FIVE

DISCUSSION OF RESULTS AND CONCLUSIONS

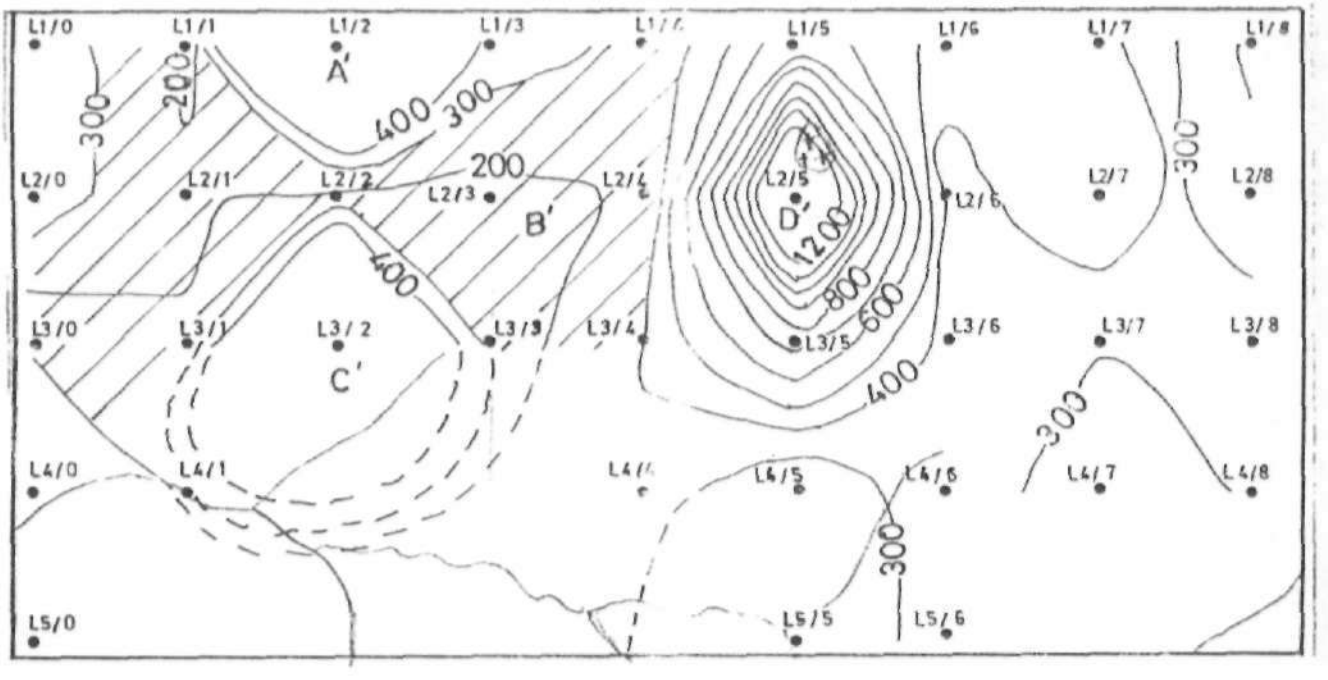
5.0 Introduction

The interpretation of the Vertical Electrical Sounding (VES) data discussed and presented in Chapter four, gives a basis for making a number of deductions regarding the aquifer underlying the study area. These deductions will be used in selecting the best points for locating boreholes in the study area. The deductions made are discussed in the foregoing;

5.1 Groundwater Potential in the Area

The components of aquifer in the basement areas are generally classified into weathered basement fractures and alluvial deposits (Ajayi and Hassan, 1990; Amadi and Nurudeen, 1990; Hassan, 1987). The weathered basement and fractured basement is believed to be the major components of the aquifer system in this study. Fig. 4.9, which is the weathered basement thickness map could be taken to represent the aquifer thickness map of the study area.

To determine the region with the greatest groundwater potentials in the study area, the physiographic map (Fig. 1.1) was superimposed on the isoresistivity map for AB/2 = 45m to produce Figure 5.1. The isoresistivity map for AB/2



0 50 100 m

Contour interval = 100 Ωm

LEGEND

- VES point
- Area of low resistivity values
- Contour line
- Stream
- Rock exposure

FIG. 5.1: ISORESISTIVITY CONTOURED MAP OF THE STUDY AREA AT AB/2= 45m SUPERPOSED ON THE PHYSIOGRAPHIC MAP.

= 45m indicates the region of weathered basement resistivity. From this map (Fig. 5.1.), the areas that look most promising for underground water exploitation, based on information from such other maps as overburden thickness (Fig. 4.8) and weathered basement thickness (Fig. 4.9) are shaded and labelled A and B in the Figure. The regions A and B were identified because, the weathered basement resistivity value in those zones is less than 300 ohm-m which suggests that the aquifer in those areas are most probably saturated with water. Also, in Chapter four it was shown that the aquifer thickness in those regions are high (around 40-60m in zone A, and around 40-50m in zone B). Furthermore, these zones A and B are the regions where the stream tributries tend to pass. This in effect means the aquifer thickness around these regions are almost water saturated.

5.2. Suggestions for Future Work

The study area which is about 2km^2 is quite localised for major structures to be revealed hence, it is suggested that an electrical resistivity survey of this form be conducted possibly in a regional pattern around the whole town. This may reveal the extent and overall nature of the fault noted around Kaduna town by Adanu (1991).

In the present work, profiles L4 and L5 were not completely investigated because the area had unharvested sugar cane and vegetables. It is, therefore, suggested that

such profiles if investigated would give more light to the most suitable area within the present study area to exploit groundwater.

5.3. Conclusion.

This work determined the subsurface lithology and structure underlying the area of study with the sole aim of investigating the groundwater potentials and delineating the extent of the aquifer under the area. The conclusions deduced from the results of the work are as follows:

1. The geologic sections in Figures 4.2(b), 4.3(b) and 4.4(b) derived for profiles L1, L2 and L3 respectively suggest that the profiles are underlain by 2-3 layers of different lithological units.

2. The Figures discussed above also suggest that the overall thickness of the formations overlying the basement range from 3m to 76m.

3. The basement topography map of the area (Fig. 4.7) suggests that the bedrock is undulating with its deepest point (76m) occurring at VES L3/3.

4. The aquifer thickness map under the study area showed in Fig. 4.9 suggests that the thickness of the aquifer varies between 3m to 68m. The aquifer is thin or even absent around

the central part of the studied area while it has significant thickness around the western and eastern parts of the area investigated.

5. The maps produced from the resistivity data, especially the isoresistivity map at AB/2 = 30m and AB/2 = 45m (Figs. 4.6(a) and 4.6(b)), the isoresistivity map of the surface layer (Fig. 4.5) and the overburden thickness map (Fig. 4.8) suggest that the drainage pattern in the Romi stream is controlled by the basement topography.

6. Generally, it can be concluded that, the best region in the area of study of great groundwater potentials, hence recommended for siting of a borehole with accessibility taken into consideration is the region of VES L3/3.

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APPENDIX A

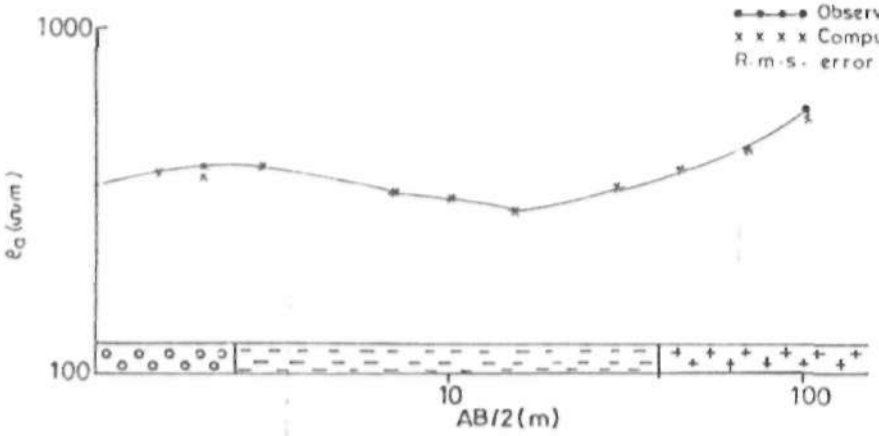
Interpreted Vertical Electrical Sounding (VES) Curves

VES $L_1/0$

INTERPRETATIONS

Depth(m)	Resistivity(Ωm)	Rock type
2·5	386	Weathered Laterite
43·2	304	Weathered Basement / Laterite
∞	2866	Fresh Basement

Observed curve
x x x x Computed curve
R.m.s. error = 4.9

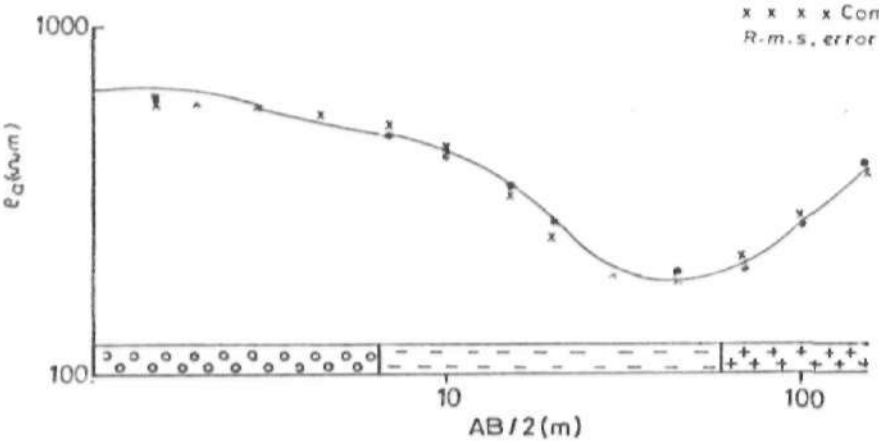


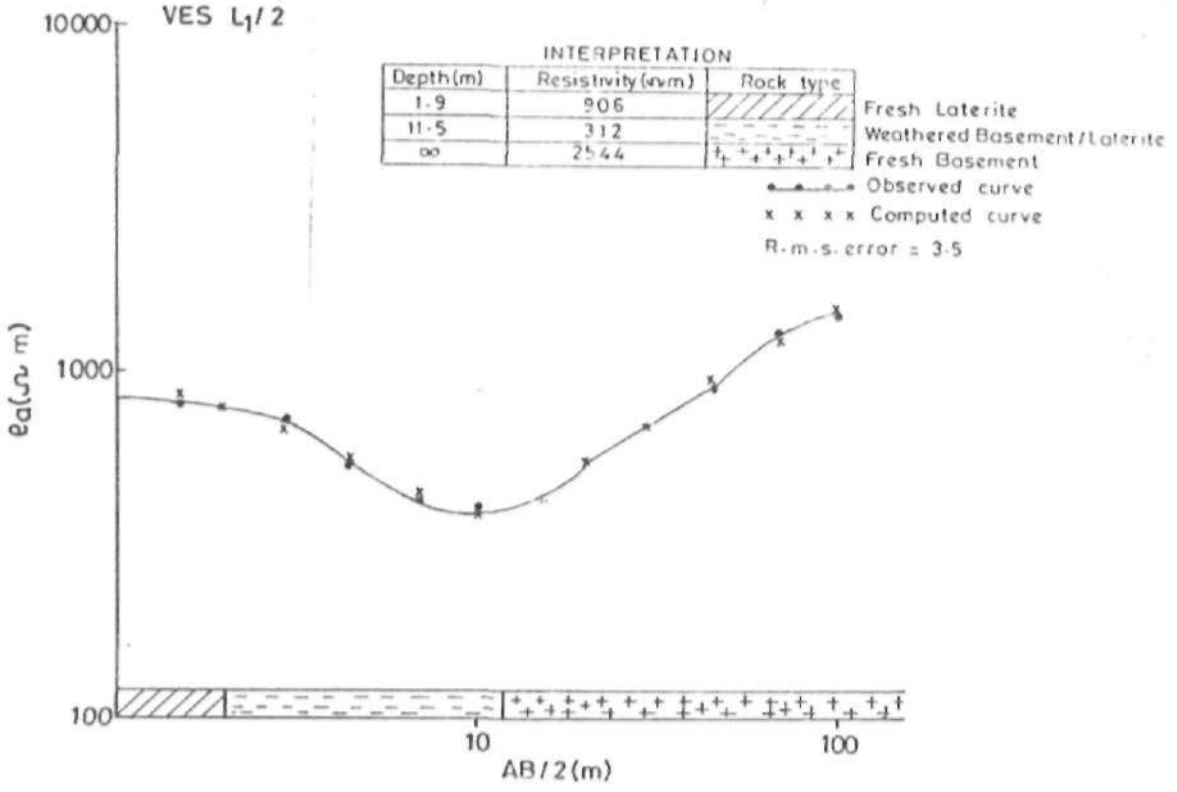
VES $L_1/1$

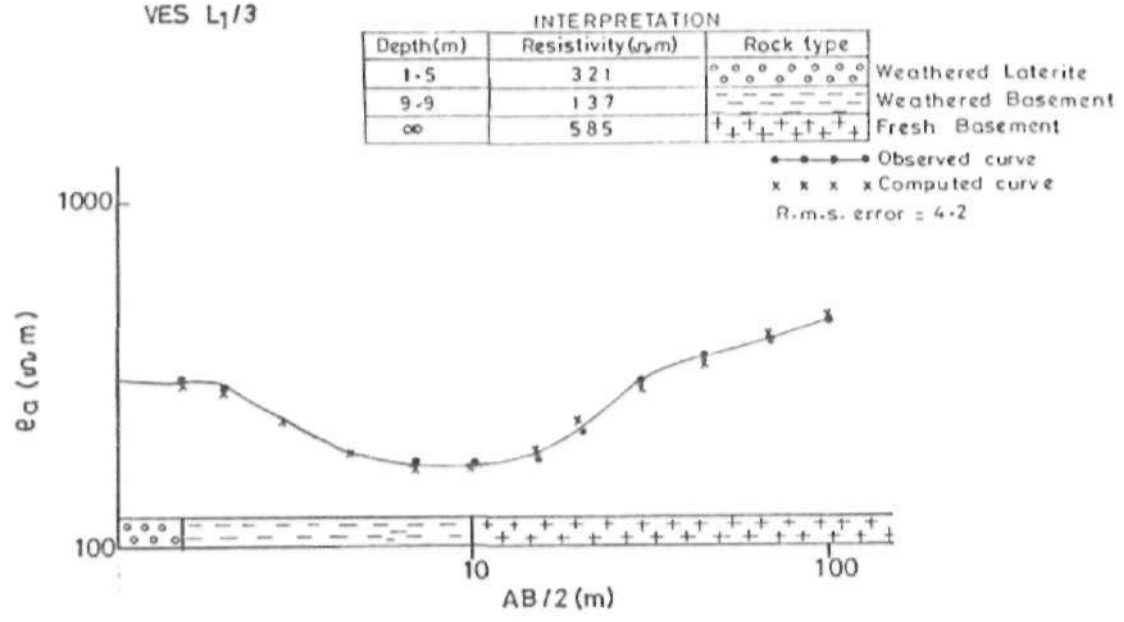
INTERPRETATIONS

Depth(m)	Resistivity(Ωm)	Rock type
6·2	606	Weathered Laterite
63·8	162	Weathered Basement
∞	8810	Fresh Basement

Observed curve
x x x x Computed curve
R.m.s. error = 8.1




VES L1/2
INTERPRETATION
Depth(m) | Resistivity(Ωm) | Rock type
1·9 | 906 | Fresh Laterite
11·5 | 312 | Weathered Basement/Laterite
∞ | 2544 | Fresh Basement
Observed curve
Computed curve
R.m.s. error = 3·5
10000
1000
100
ρa(Ω m)
10
100
AB/2 (m)


VES L1/3
INTERPRETATION
Depth(m) | Resistivity(Ωm) | Rock type
1·5 | 321 | Weathered Laterite
9·9 | 137 | Weathered Basement
∞ | 585 | Fresh Basement
Observed curve
Computed curve
R.m.s. error = 4·2
1000
100
ρa (Ω m)
10
100
AB/2 (m)

VES L1/4

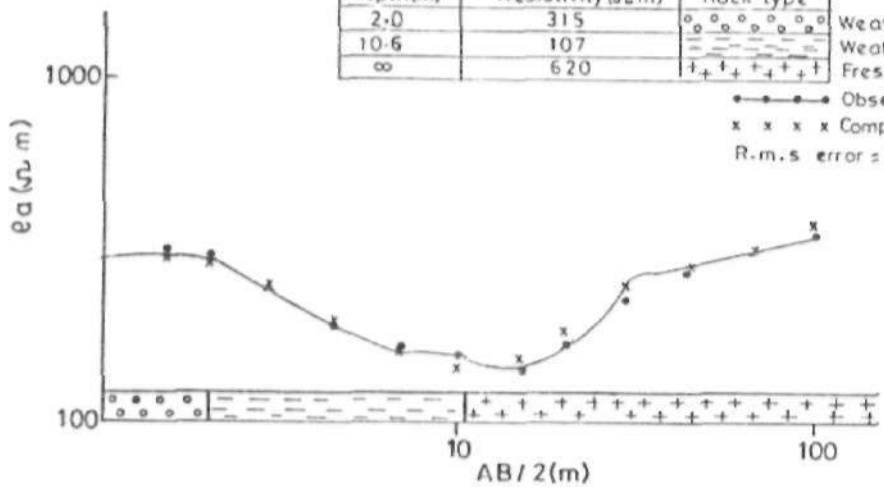
INTERPRETATION

Depth(m)	Resistivity(Ω m)	Rock type
2·0	315	Weathered Laterite
10·6	107	Weathered Basement
∞	620	Fresh Basement

Observed curve

x x x x Computed curve

R.m.s error = 6·2



VES L1/5

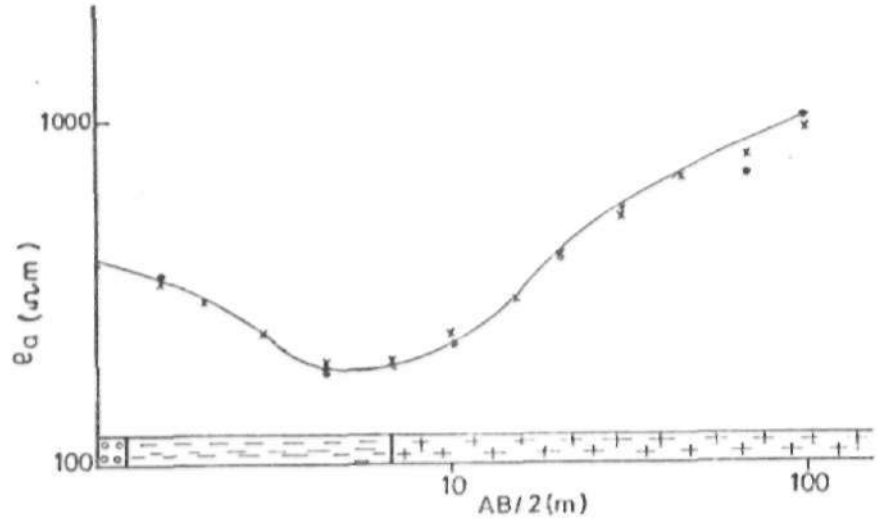
INTERPRTATION

Depth(m)	Resistivity(Ω m)	Rock type
1·2	410	Weathered Laterite
6·7	152	Weathered Basement
∞	1363	Fresh Basement

Observed curve

x x x x Computed curve

R·m·s·error = 6·9

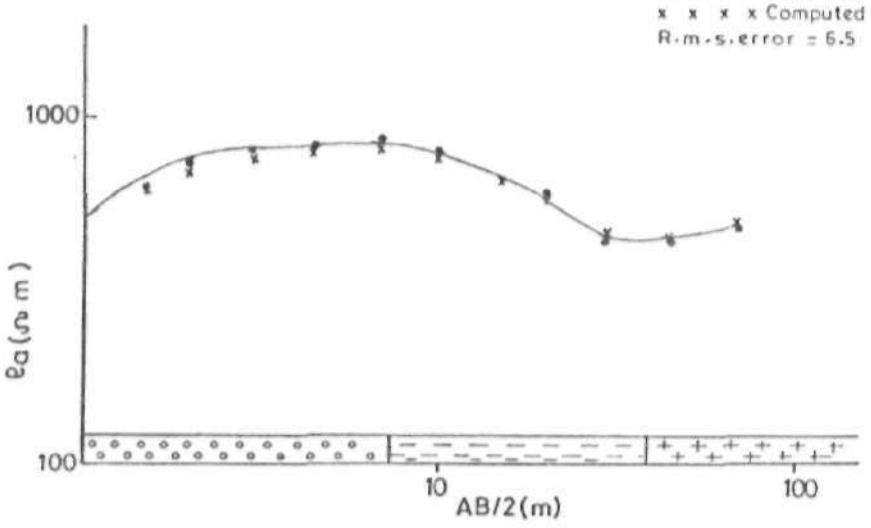


VES $L_1/6$

INTERPRETATION

Depth(m)	Resistivity(Ω m)	Rock type
7·3	582	Weathered Laterite
38·7	372	Weathered Basement / Laterite
∞	920	Fresh Basement

Observed curve
x x x x Computed curve
R.m.s.error = 6.5

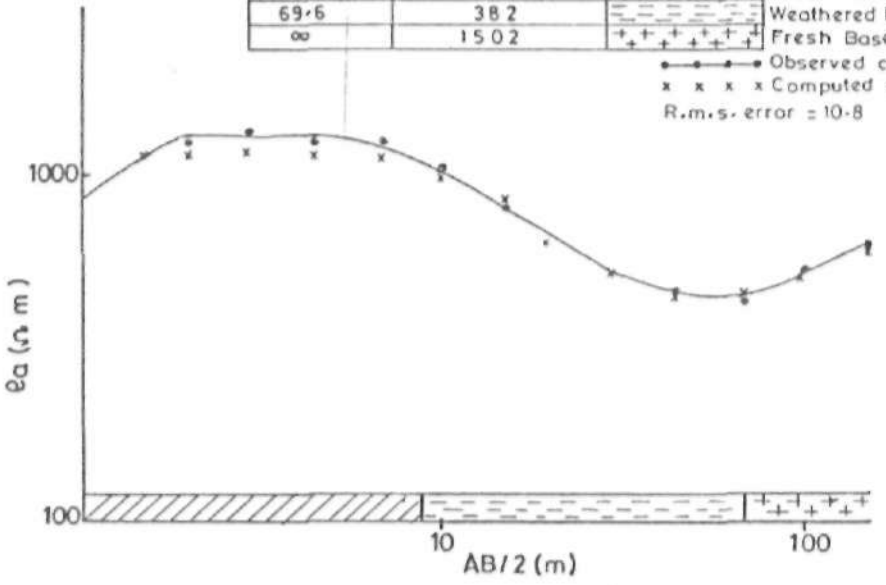


VES $L_1/7$

INTERPRETATION

Depth(m)	Resistivity (Ω m)	Rock type
8·8	1157	Fresh Laterite
69·6	382	Weathered Basement / Laterite
∞	1502	Fresh Basement

Observed curve
x x x x Computed curve
R.m.s. error = 10·8

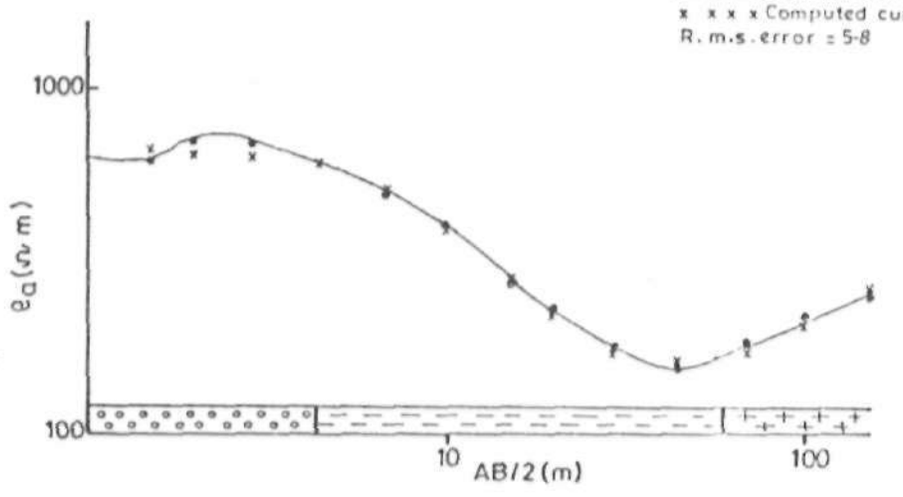


VES $L_1/8$

INTERPRETATION

Depth(m)	Resistivity(Ω m)	Rock type
4·3	703	Weathered Laterite
52·4	177	Weathered Basement
∞	894	Fresh Basement

•—•—• Observed curve
x x x Computed curve
R.m.s.error = 5·8

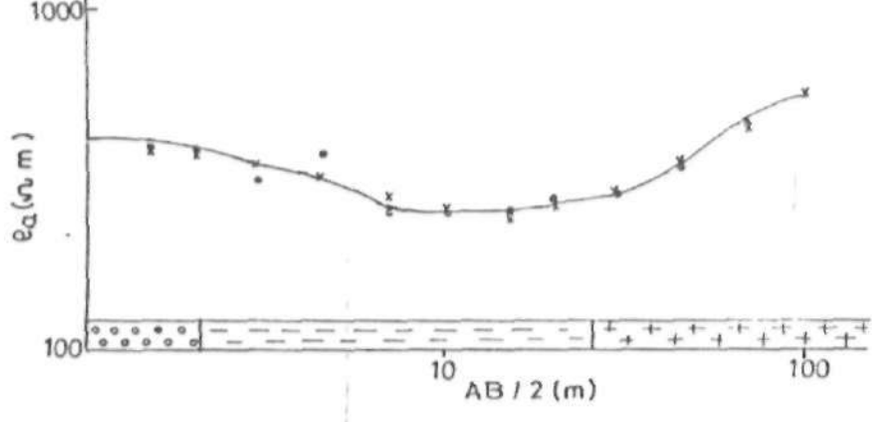


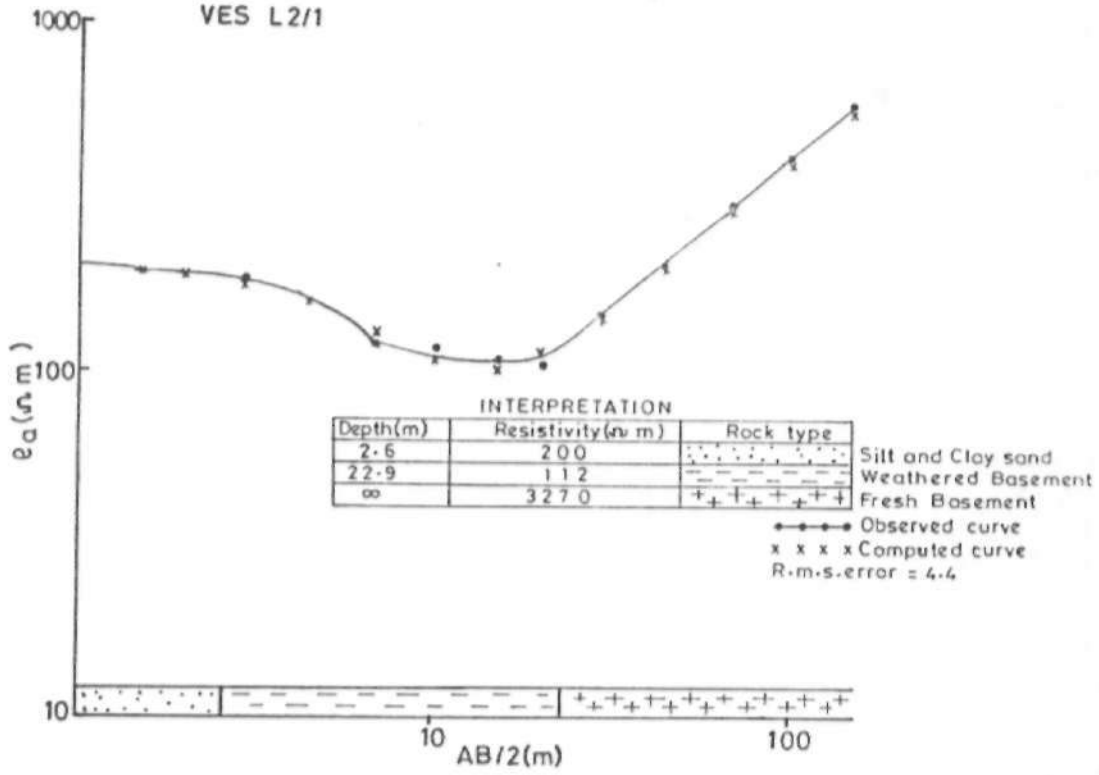
VES $L_2/0$

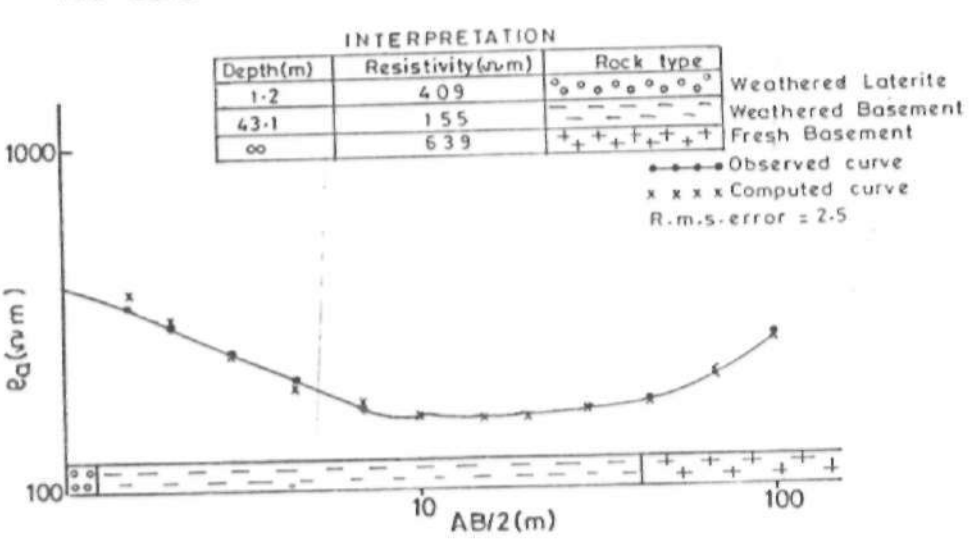
INTERPRETATION

Depth(m)	Resistivity(Ω m)	Rock type
2·1	416	Weathered Laterite
25·3	227	Weathered Basement/Laterite
∞	1330	Fresh Basement

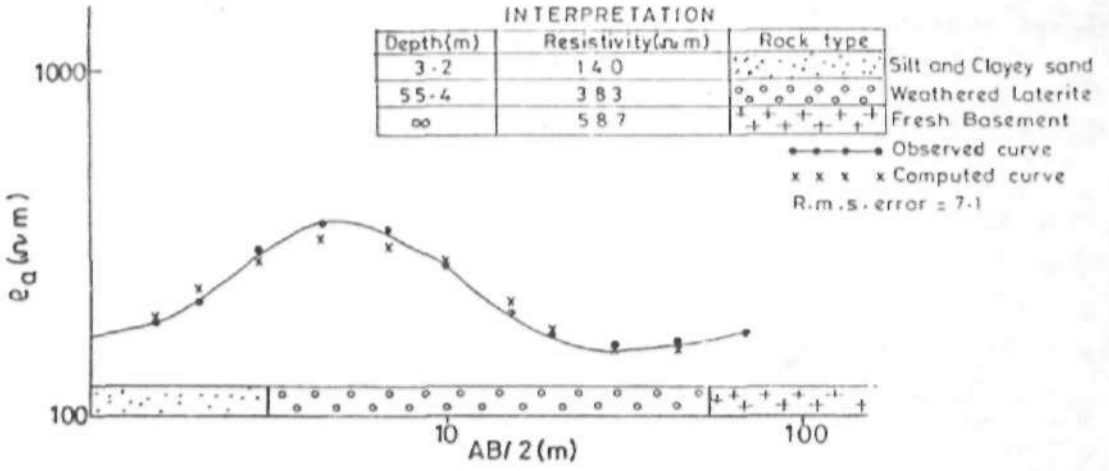
•—•—• Observed curve
x x x x Computed curve
R.m.s.error = 6.9



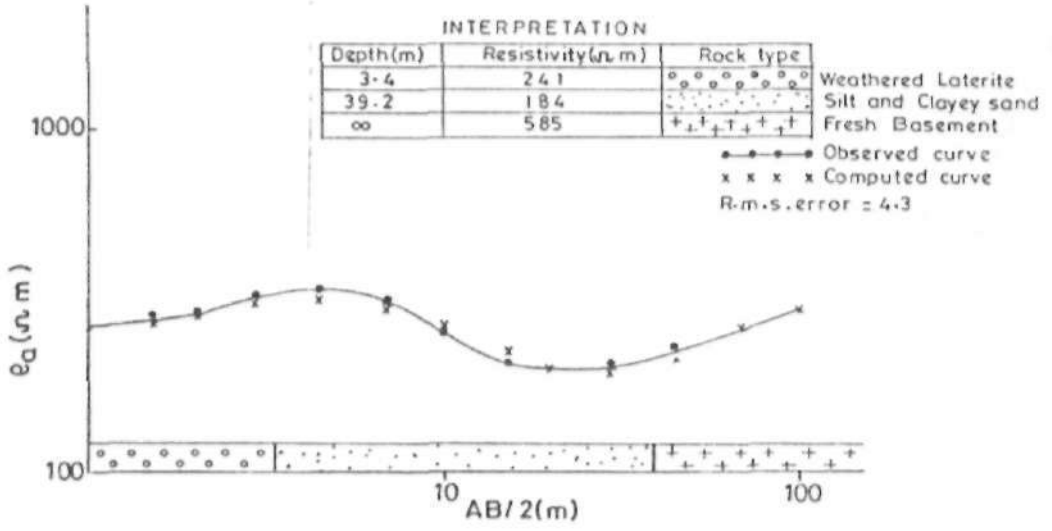

VES L2/1
1000
100
10
ρa(Ω m)
INTERPRETATION
Depth(m) | Resistivity(Ω m) | Rock type
2·6 | 200 | Silt and Clay sand
22·9 | 112 | Weathered Basement
∞ | 3270 | Fresh Basement
Observed curve
x x x x Computed curve
R·m·s·error = 4.4
10
AB/2(m)
100

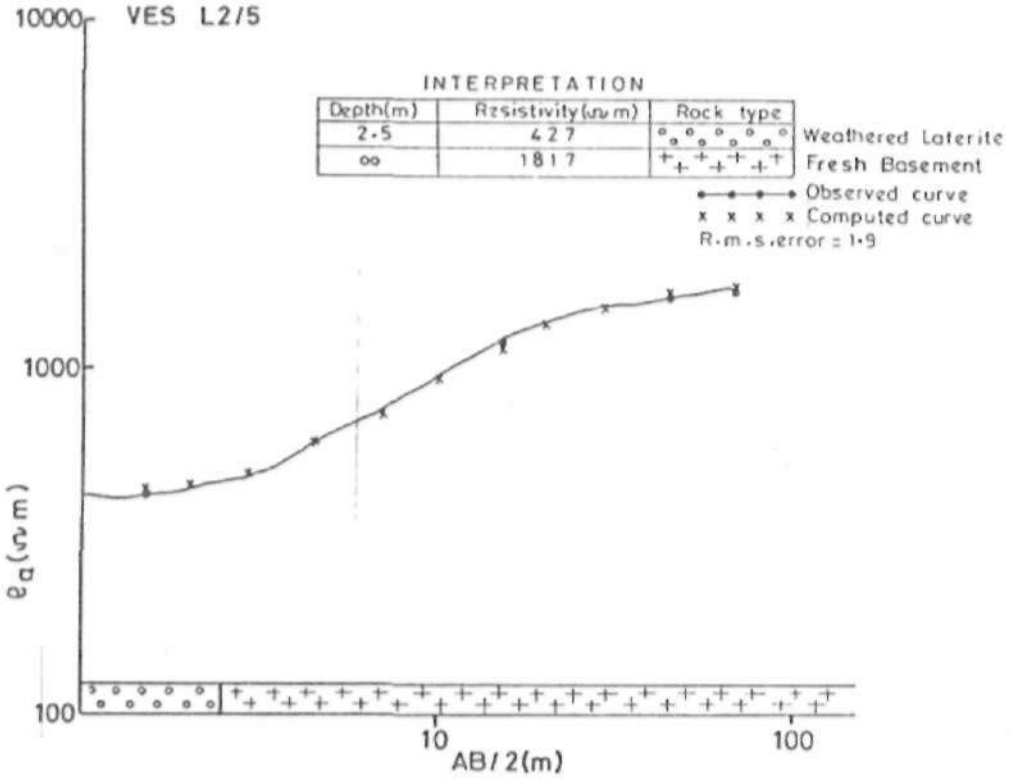

VES L2/2
INTERPRETATION
Depth(m) | Resistivity(Ω m) | Rock type
1·2 | 409 | Weathered Laterite
43·1 | 155 | Weathered Basement
∞ | 639 | Fresh Basement
Observed curve
x x x x Computed curve
R.m.s.error = 2·5
1000
100
ρa(Ω m)
10
AB/2(m)
100

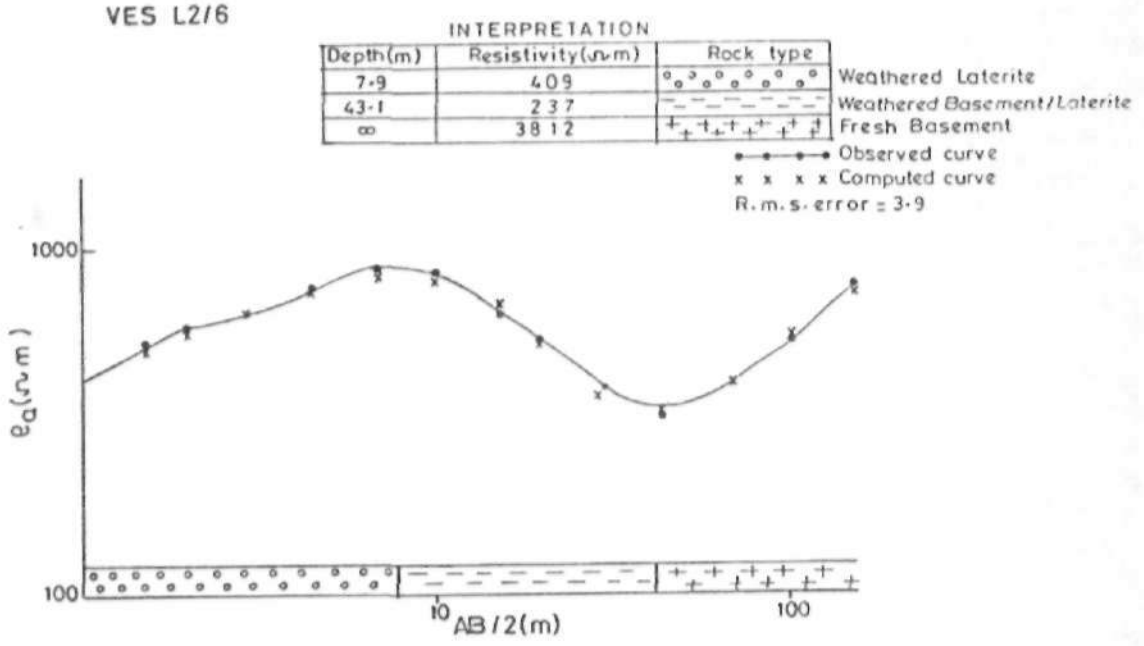
VES L2/3

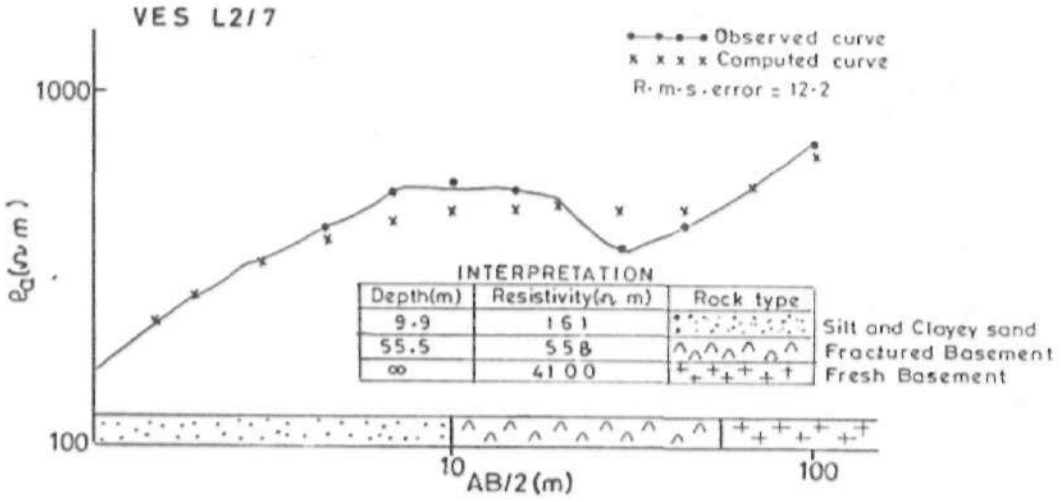


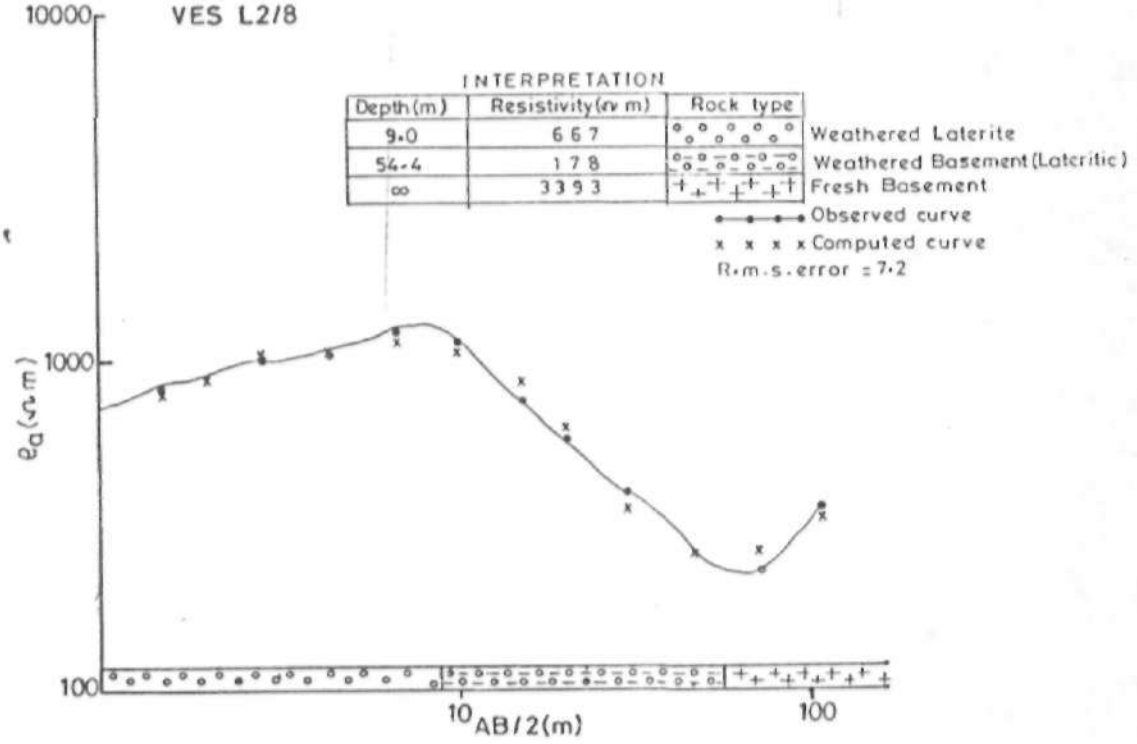
VES L2/4



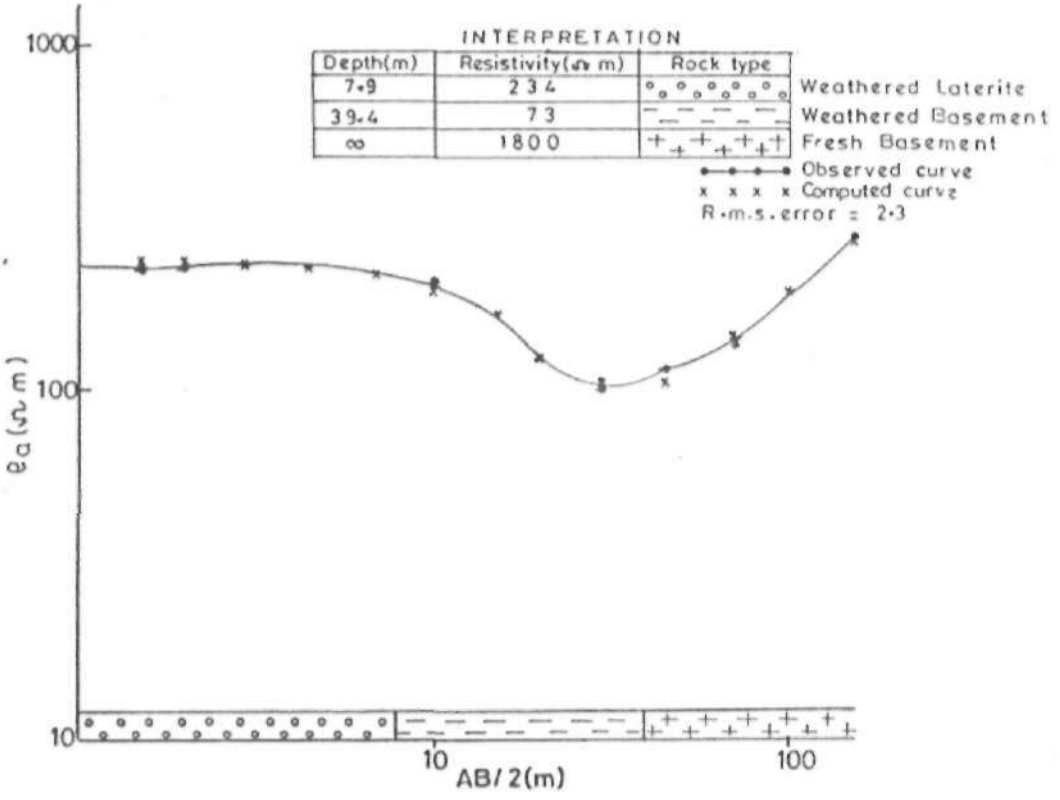

VES L2/5
INTERPRETATION
Depth(m) | Resistivity(Ω m) | Rock type
2·5 | 427 | Weathered Laterite
∞ | 1817 | Fresh Basement
Observed curve
Computed curve
R.m.s.error = 1·9
10000
1000
100
ρa(Ω m)
10
100
AB/2(m)


VES L2/6
INTERPRETATION
Depth(m) | Resistivity(Ω m) | Rock type
7·9 | 409 | Weathered Laterite
43·1 | 237 | Weathered Basement/Laterite
∞ | 3812 | Fresh Basement
Observed curve
Computed curve
R.m.s.error = 3·9
1000
100
ρa(Ω m)
10
100
AB/2(m)

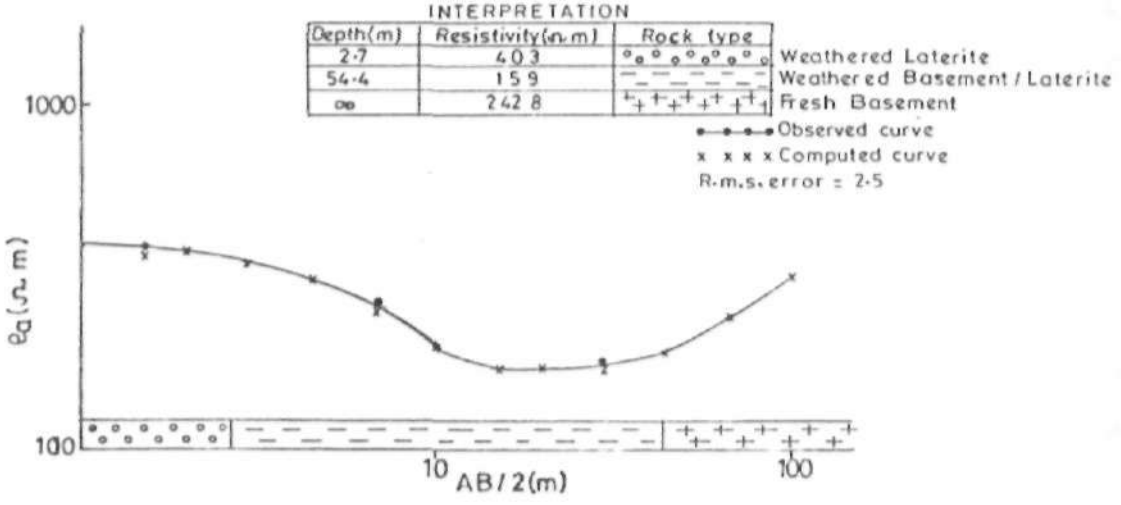

VES L2/7
Observed curve
Computed curve
R.m.s.error = 12·2
1000
100
ρ_a(Ω m)
10
AB/2 (m)
100
INTERPRETATION
Depth(m) | Resistivity(Ω m) | Rock type
9·9 | 161 | Silt and Clayey sand
55.5 | 558 | Fractured Basement
∞ | 4100 | Fresh Basement

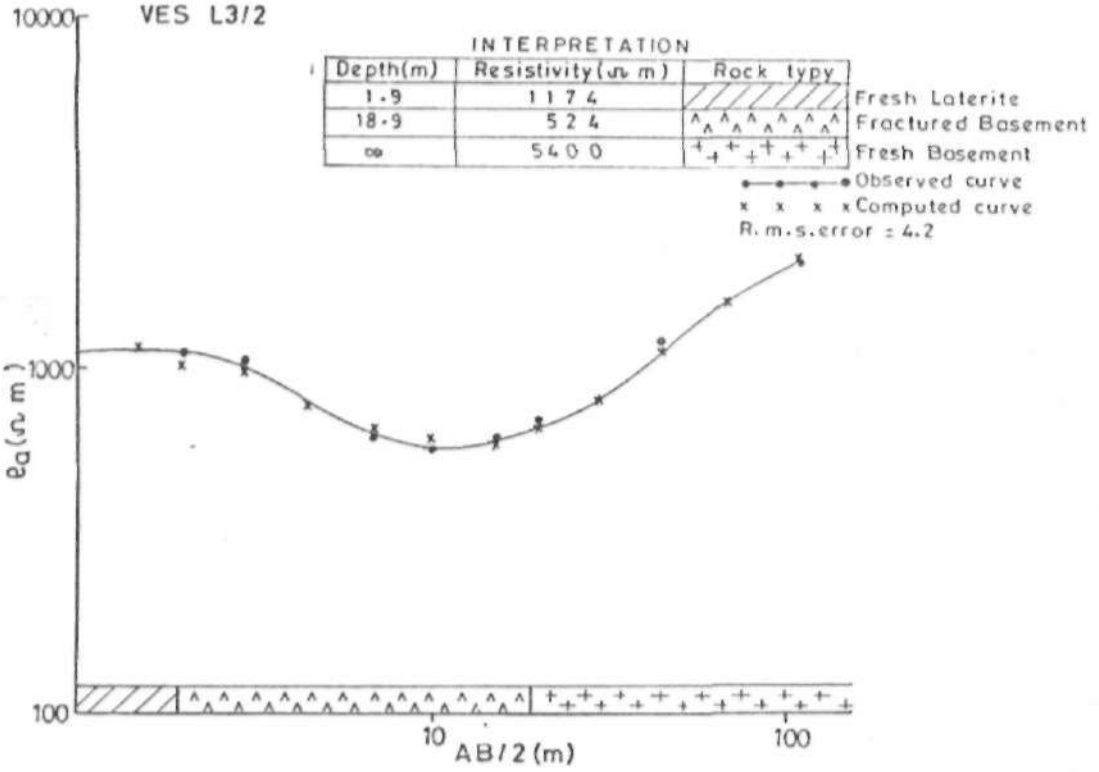

VES L2/8
10000
1000
100
ρ_a(Ω m)
10
AB/2(m)
100
INTERPRETATION
Depth(m) | Resistivity(Ω m) | Rock type
9·0 | 667 | Weathered Laterite
54·4 | 178 | Weathered Basement (Lateritic)
∞ | 3393 | Fresh Basement
Observed curve
Computed curve
R.m.s.error = 7·2

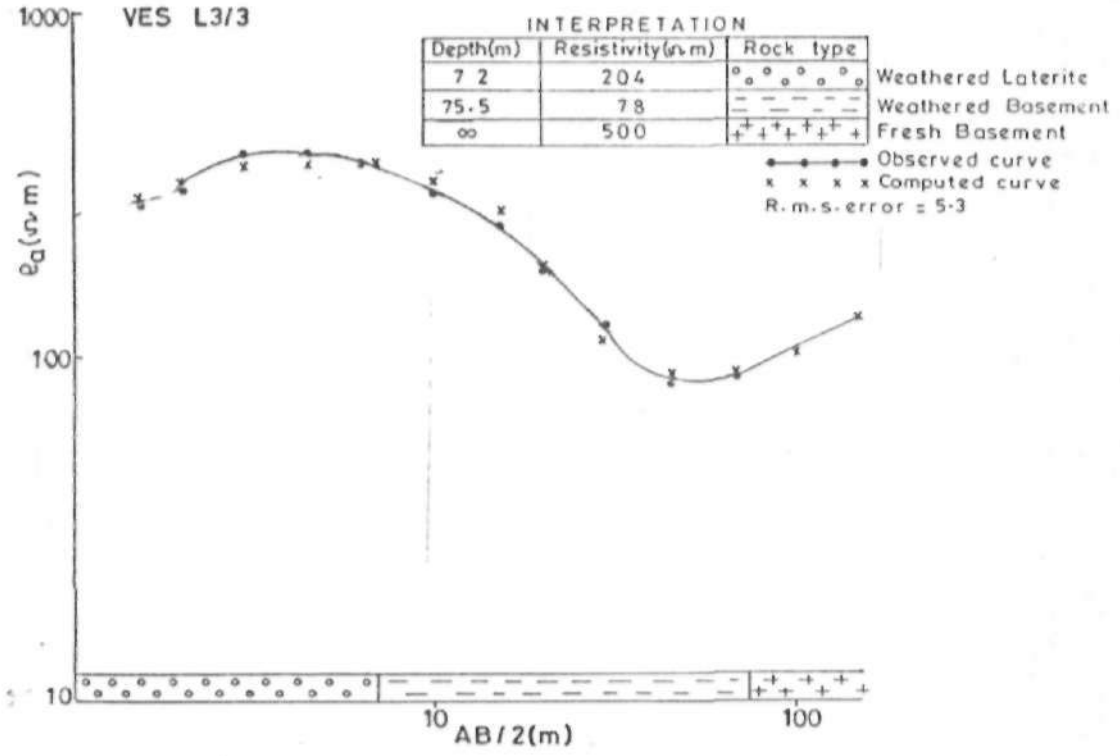
VES L3/0

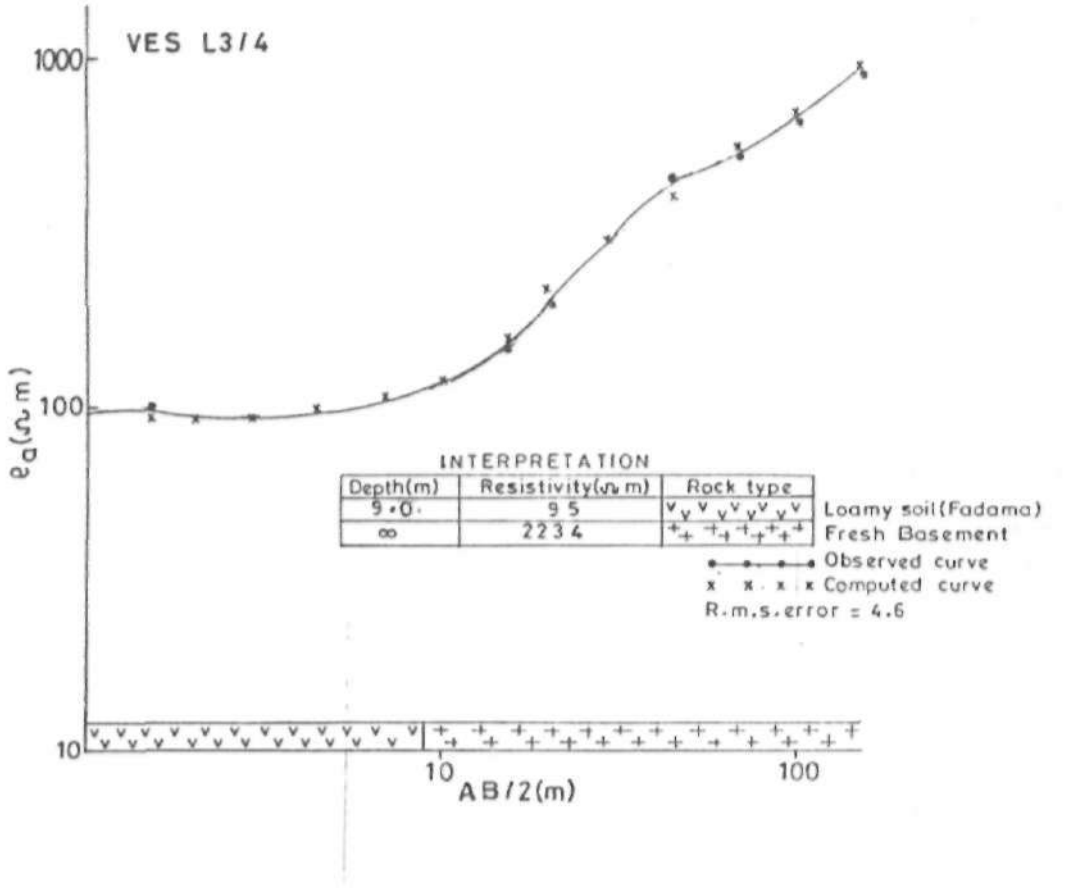


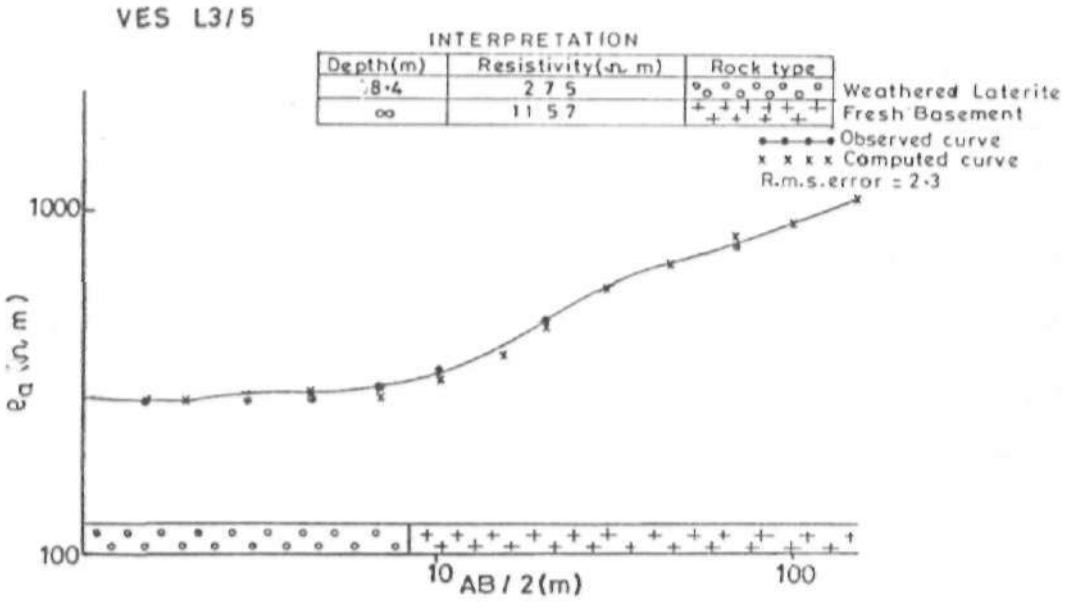
VES L3/1

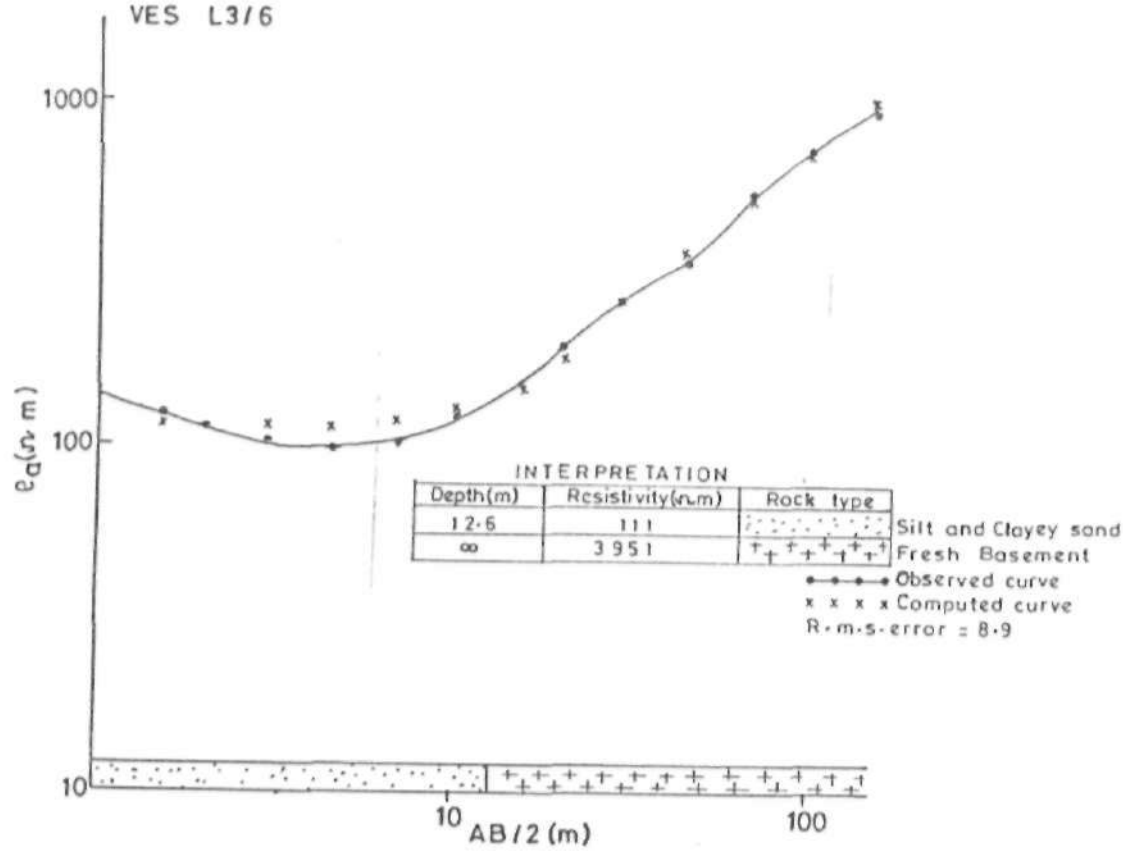


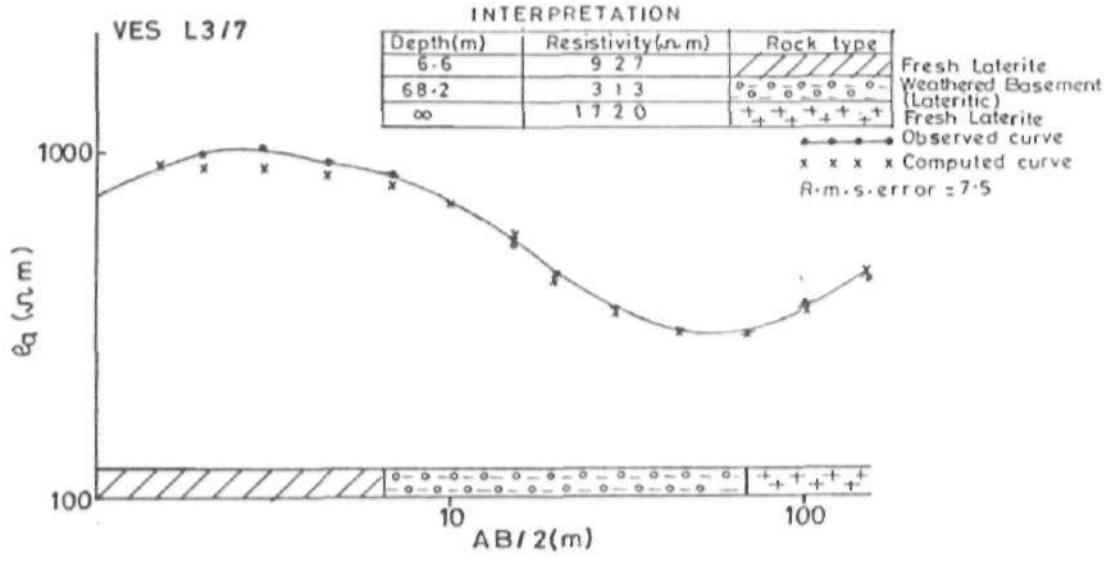

VES L3/2
INTERPRETATION
Depth(m) | Resistivity(Ω m) | Rock typy
1·9 | 1174 | Fresh Laterite
18·9 | 524 | Fractured Basement
∞ | 5400 | Fresh Basement
Observed curve
Computed curve
R.m.s.error = 4.2
10000
1000
100
ρa(Ω m)
10
AB/2 (m)
100

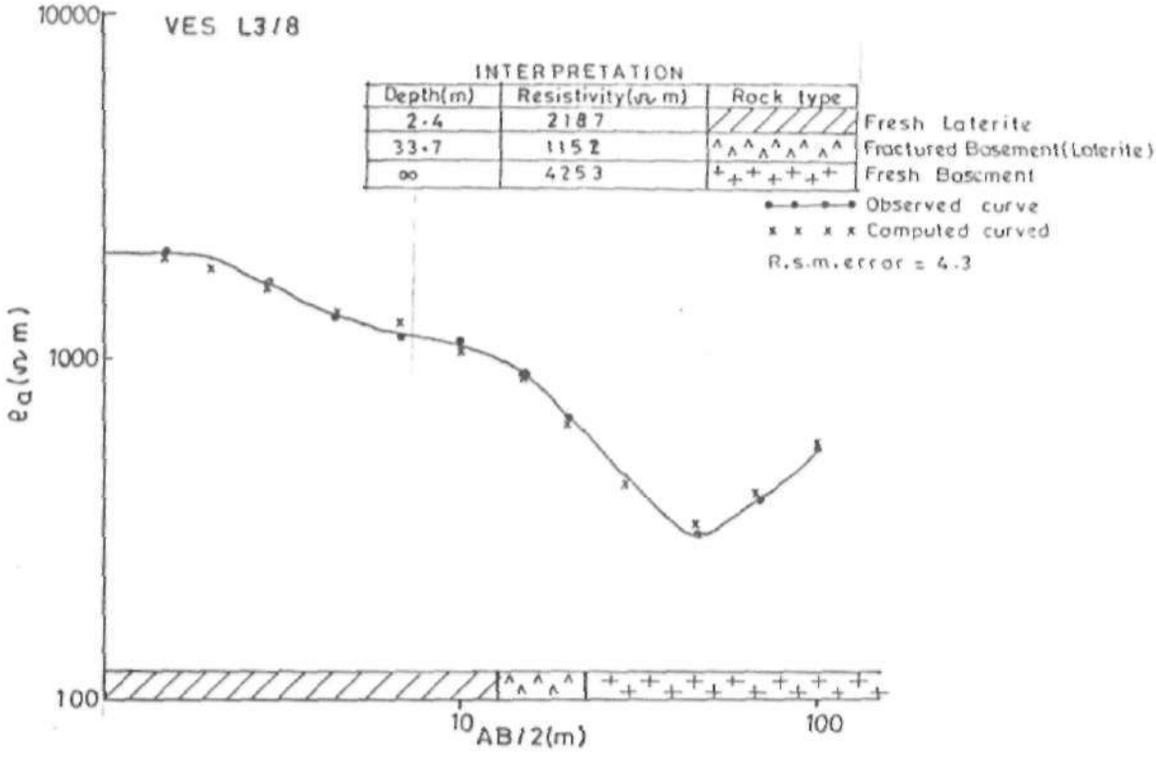

VES L3/3
INTERPRETATION
Depth(m) | Resistivity(Ω m) | Rock type
7 2 | 204 | Weathered Laterite
75.5 | 78 | Weathered Basement
∞ | 500 | Fresh Basement
Observed curve
Computed curve
R.m.s.error = 5·3
1000
100
10
ρa(Ω m)
10
AB/2(m)
100

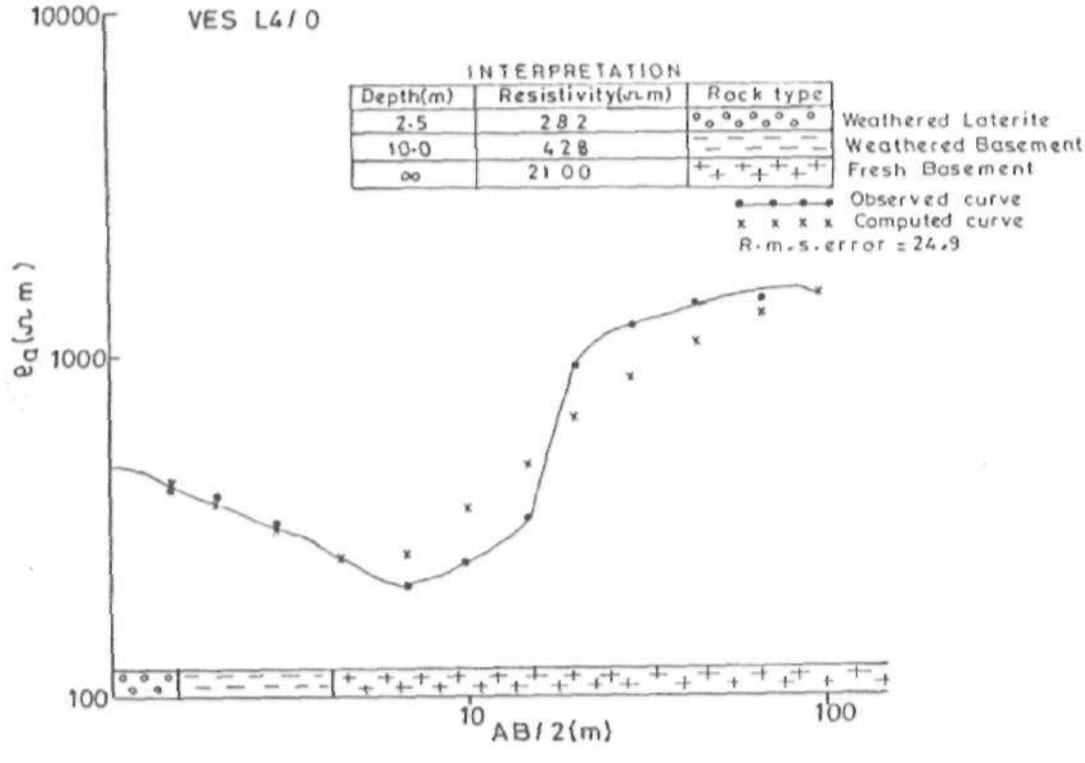

VES L3/4
1000
100
10
ρa(Ω m)
INTERPRETATION
Depth(m) | Resistivity(Ω m) | Rock type
9·0 | 95 | Loamy soil(Fadama)
∞ | 2234 | Fresh Basement
Observed curve
Computed curve
R.m.s.error = 4.6
10
100
AB/2(m)

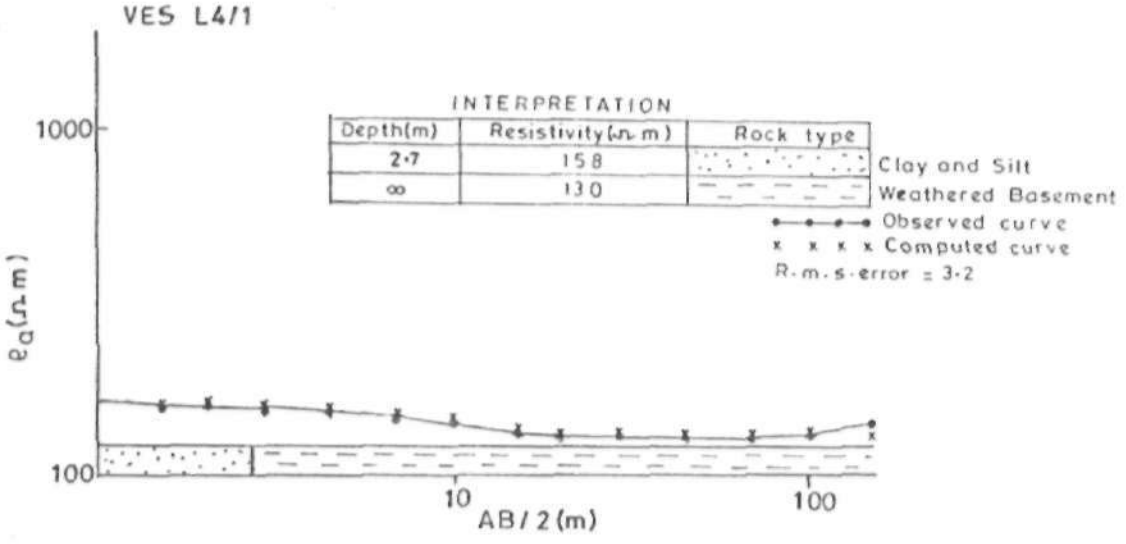

VES L3/5
INTERPRETATION
Depth(m) | Resistivity(Ω m) | Rock type
8·4 | 275 | Weathered Laterite
∞ | 1157 | Fresh Basement
Observed curve
Computed curve
R.m.s.error = 2·3
1000
100
ρa (Ω m)
10
AB/2(m)
100

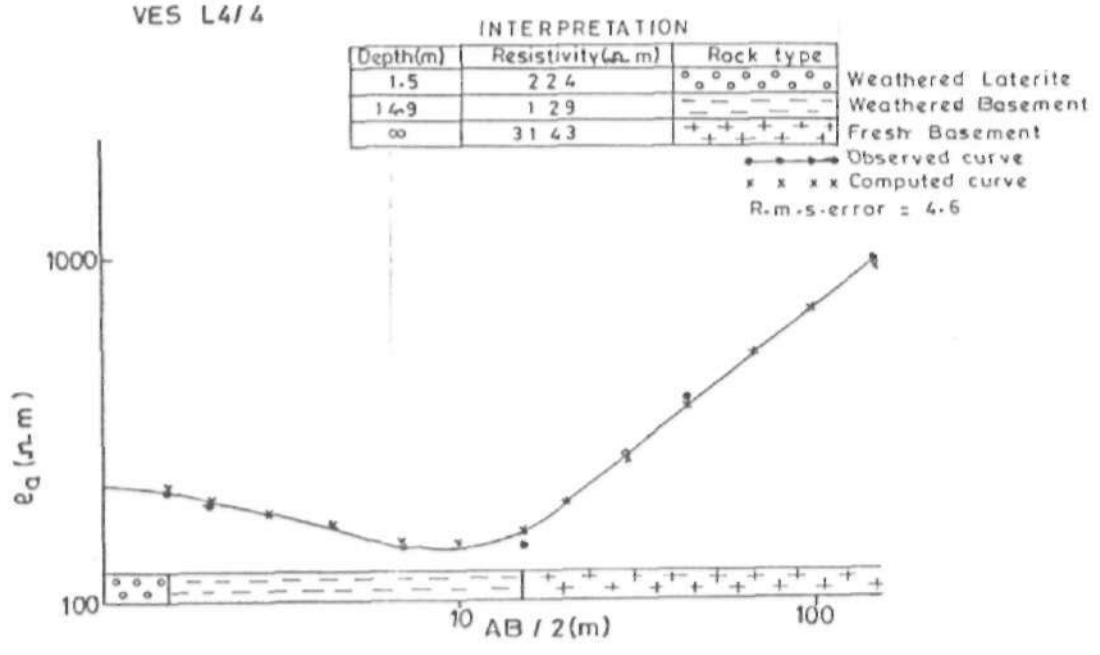

VES L3/6
1000
100
10
ρa(Ω m)
10
AB/2 (m)
100
INTERPRETATION
Depth(m) | Resistivity(Ω m) | Rock type
12·6 | 111 | Silt and Clayey sand
∞ | 3951 | Fresh Basement
Observed curve
Computed curve
R·m·s·error = 8·9

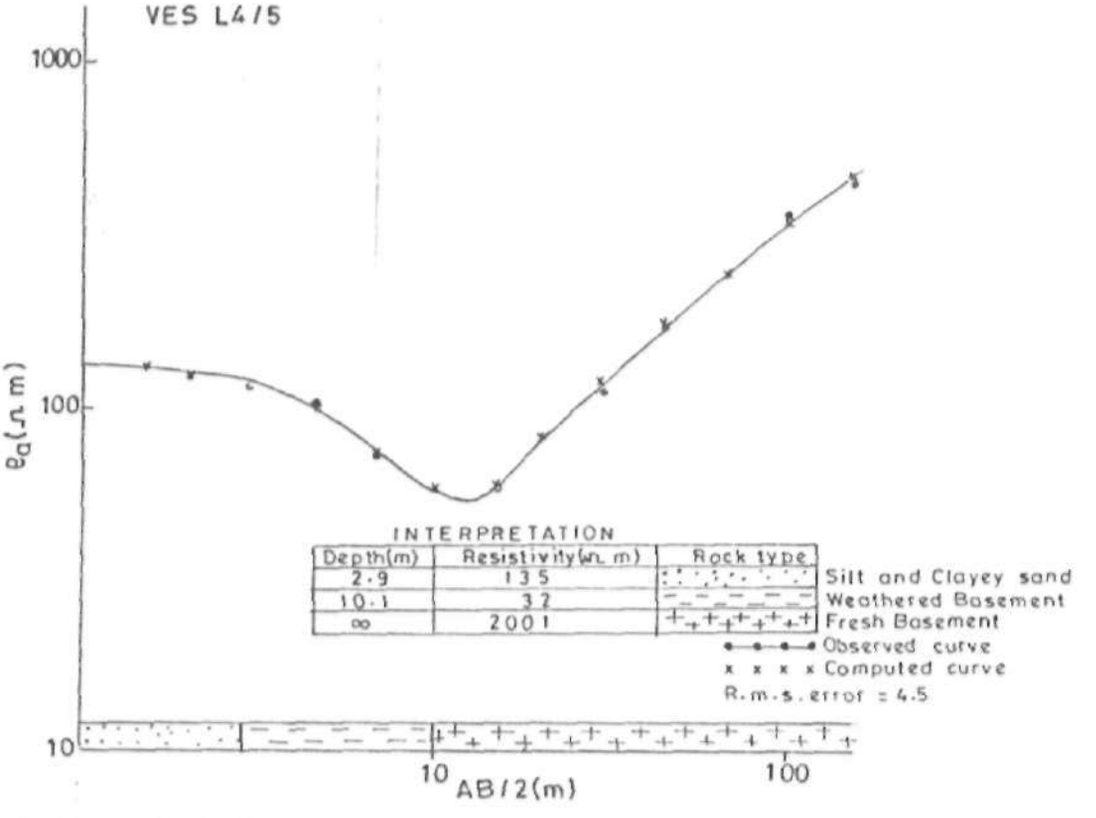

VES L3/7
INTERPRETATION
Depth(m) | Resistivity(Ω m) | Rock type
6·6 | 927 | Fresh Laterite
68·2 | 313 | Weathered Basement (Lateritic)
∞ | 1720 | Fresh Laterite
Observed curve
Computed curve
R·m·s·error = 7·5
1000
100
ρa (Ω m)
10
AB/2(m)
100

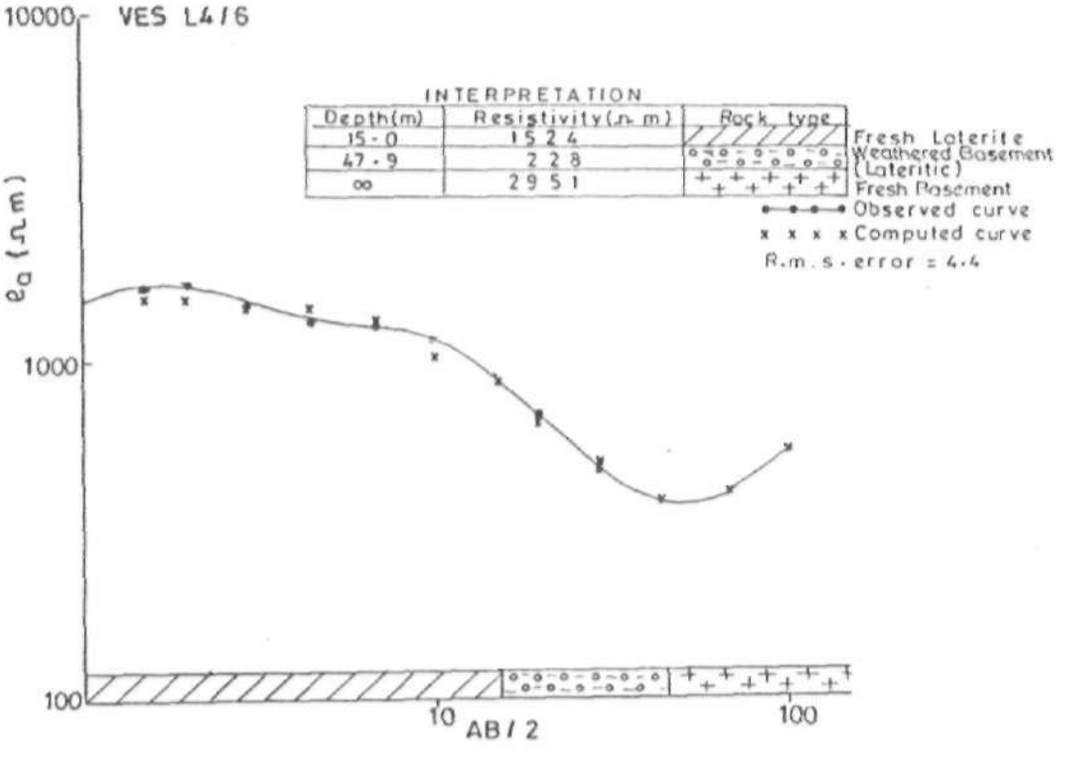

VES L3/8
INTERPRETATION
Depth(m) | Resistivity(Ω m) | Rock type
2·4 | 2187 | Fresh Laterite
33·7 | 1152 | Fractured Basement(Laterite)
∞ | 4253 | Fresh Basement
Observed curve
Computed curved
R.s.m.error = 4.3
10000
1000
100
ρa(Ω m)
10
AB/2(m)
100

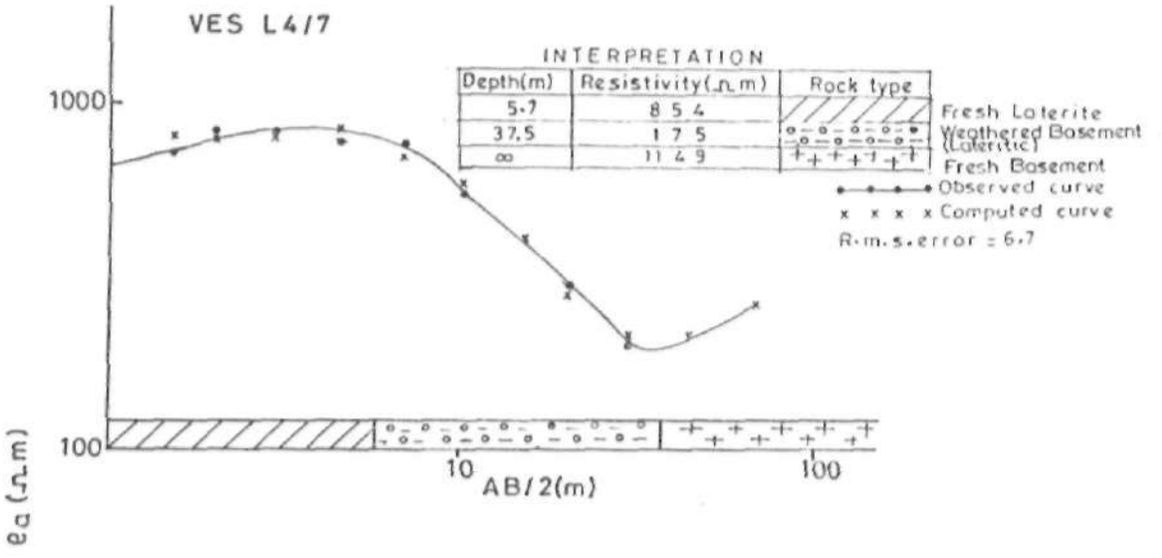

VES L4/0
INTERPRETATION
Depth(m) | Resistivity(Ω m) | Rock type
2·5 | 282 | Weathered Laterite
10·0 | 428 | Weathered Basement
∞ | 2100 | Fresh Basement
Observed curve
Computed curve
R·m·s·error = 24·9
10000
1000
100
ρa(Ω m)
10
AB/2(m)
100

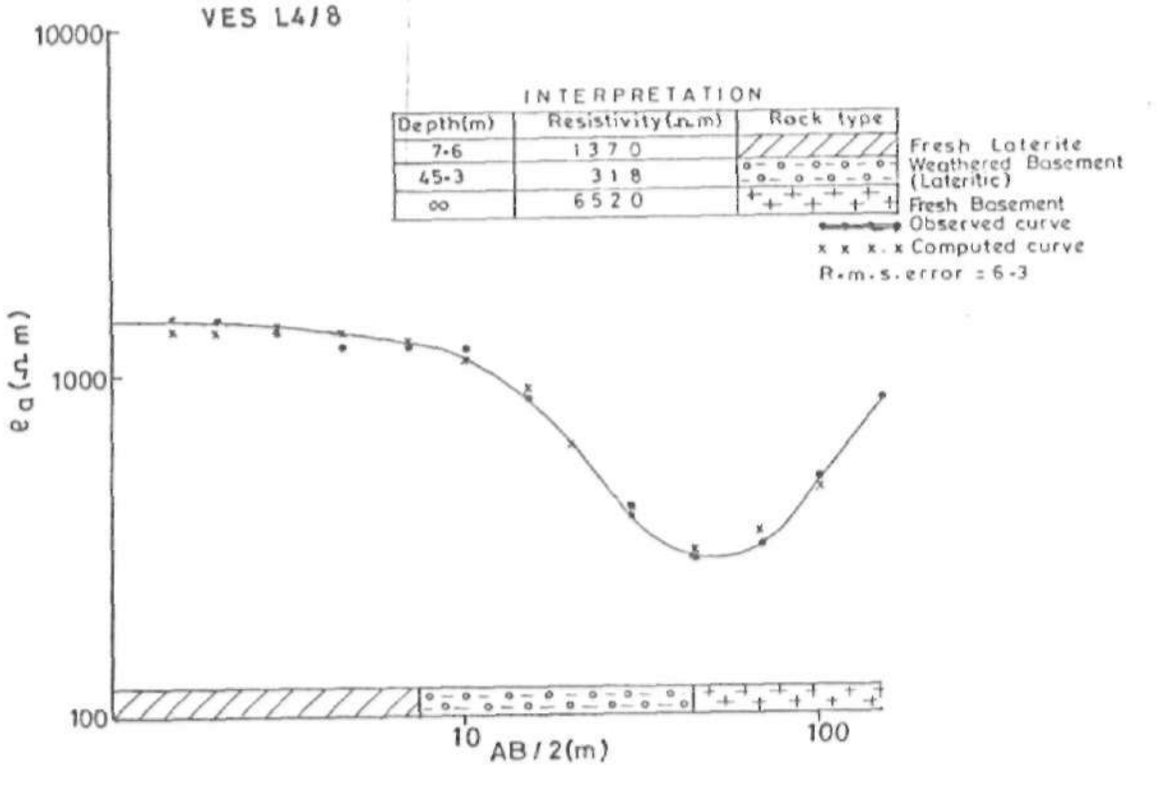

VES L4/1
INTERPRETATION
Depth(m) | Resistivity(Ω m) | Rock type
2·7 | 158 | Clay and Silt
∞ | 130 | Weathered Basement
Observed curve
Computed curve
R.m.s.error = 3·2
1000
100
10
100
AB/2 (m)
ρa (Ω m)


VES L4/4
INTERPRETATION
Depth(m) | Resistivity(Ω m) | Rock type
1.5 | 224 | Weathered Laterite
14·9 | 129 | Weathered Basement
∞ | 3143 | Fresh Basement
Observed curve
Computed curve
R.m.s.error = 4·6
1000
100
10
100
AB/2 (m)
ρa (Ω m)

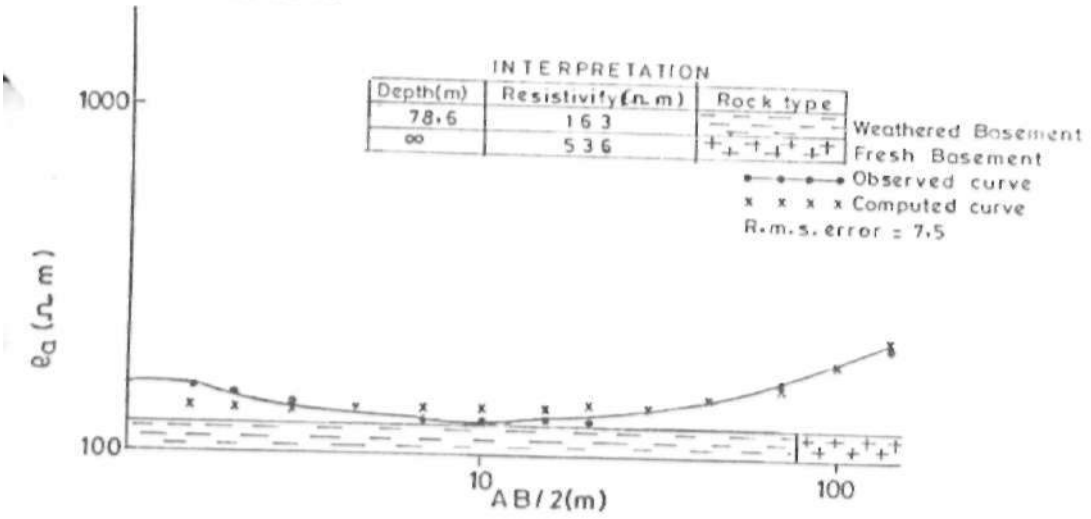

VES L4/5
1000
100
10
ρ_a(Ω m)
INTERPRETATION
Depth(m) | Resistivity(Ω m) | Rock type
2·9 | 135 | Silt and Clayey sand
10·1 | 32 | Weathered Basement
∞ | 2001 | Fresh Basement
Observed curve
Computed curve
R.m.s. error = 4.5
10
AB/2(m)
100


10000
VES L4/6
ρ_a (Ω m)
1000
100
INTERPRETATION
Depth(m) | Resistivity(Ω m) | Rock type
15·0 | 1524 | Fresh Laterite
47·9 | 228 | Weathered Basement (Lateritic)
∞ | 2951 | Fresh Basement
Observed curve
Computed curve
R.m.s. error = 4.4
10
AB/2
100


VES L4/7
INTERPRETATION
Depth(m) | Resistivity(Ω m) | Rock type
5·7 | 8 5 4 | Fresh Laterite
37.5 | 1 7 5 | Weathered Basement (Lateritic)
∞ | 1 1 4 9 | Fresh Basement
Observed curve
x x x x Computed curve
R·m.s.error = 6·7
1000
100
10
100
AB/2(m)
ρa (Ω m)


VES L4/8
INTERPRETATION
Depth(m) | Resistivity(Ω m) | Rock type
7·6 | 1 3 7 0 | Fresh Laterite
45·3 | 3 1 8 | Weathered Basement (Lateritic)
∞ | 6 5 2 0 | Fresh Basement
Observed curve
x x x x Computed curve
R·m.s.error = 6·3
10000
1000
100
10
100
AB/2(m)
ρa (Ω m)

VES L5/5



VES L5/6

