APPLICATION OF VERTICAL ELECTRICAL SOUNDING (VES) TO GROUND WATER EXPLORATION AROUND RUDUYAUSA VILLAGE NEAR GUBI, BAUCHI L.G.A. BAUCHI STATE

BY

MUHAMMAD BASHIR NUHU

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SUBMITTED TO THE DEPARTMENT OF PHYSICS, FACULTY OF SCIENCE IN PARTIAL FULFILMENT FOR THE AWARD OF BACHELOR OF TECHNOLOGY (B. Tech) IN APPLIED GEOPHYSICS. ABUBAKAR TAFAWA BALEWA UNIVERSITY BAUCHI NIGERIA

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DECLARATION

I Muhammad Bashir Nuhu hereby declared that this project was written by me and it is a record of my research effort under the supervision of Mal. A. D. Shehu

....

MUHAMMAD BASHIR NUHU

DATE 08/03/2016

CERTIFICATION

This research project has been read, corrected and approved as meeting the requirement of Physics department, Abubakar Tafawa Balewa University, Bauchi for the award of B. Tech (Hons) degree in Applied Geophysics

Mal. A. D. SHEHU

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Date:

Name: 20-06-16.

External Supervisor

Date:

DEDICATION

This project is dedicated to Almighty Allah the most Beneficient the most Merciful for His mercy, protection and for making this research work a success. Alhamdulillah

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My profound gratitude goes to Almighty Allah for His mercy and protection throughout my stay at ATBU Bauchi and may His peace and blessing be upon the best of mankind, Holy prophet Muhammad (S.A.W). My deepest appreciation also goes to my project supervisor, Mal A. D. Shehu for being there for me as a father, encouraging and putting me through. I will not forget my lecturers as well: Prof M.F. Haque, Prof. O.K. Likkason, Prof. Abdulazeez, Prof. F.W.Burari, Dr. Sani Ali, Dr. A. Tijjani, Dr. S.B. Mbang, Dr. A. Abdurrahman, Mal. Garba and all the staff of the Physics department.

My deepest gratitude also goes to my parents Alh Nuhu Shehu, Haj Fatima Ja'afar, Haj Fatima Nuhu and to my siblings: Hadiza, Halima, Dr. J.N. Ja'afar, Dr. S.U. Nuhu, Habiba, Aminu, Mustapha, Hauwa'u, Aisha, Amina, Isma'il, Radiya, Rabi'a, Adnan, Iman, Aunty Safeenah, and Aunty Saheebat.

I will not forget the role played by Prof. A.D. Ribadu, vice chancellor Jigawa State University Kafin Hausa, Alahji J.U. Shehu and my classmates Sunday, Rimam, and John for their immense contribution.

Finally I will also say a big thank you to my bride Nabila Isma'il Shehu for her care. May Almighty Allah bless you all.

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ABSTRACT

Geophysical survey using the vertical electrical sounding (VES) method was carried out at Ruduwasa village Gubi to investigate ground water potential using the ABEM (SAS4000) terrameter. The study area is underlain by the pre-cambrian basement rock. VES technique using the schlumberger electrode configuration was used to determine the thickness of individual layers and depth to the basement rock. Global Positioning System (GPS) was also used to determine the position and height of each VES station. The result of the interpreted data shows a four (4) layer geoelectric section which is normally encountered in a crystalline basement areas. The layers comprise the top soil (mainly alluvium), weathered zone, fractured zone and the highly resistive basement rock. The weathered/fractured zones are characterized by relatively low resistivity values but these layers are not deeply buried. Fifteen (15) soundings were conducted in the area out of which only VES 10, 11, 12 and 14 were found to indicate the weathered and fractured zone that is thick enough to constitute potential ground water zone.

Contents

CHAPTER ONE

1.0 INTRODUCTION

One of the basic necessities for the sustenance of life on earth is water; it is so important that it is second only to air and the largest available source of fresh water lies underground. Increased demand for water has stimulated development of underground water supplies.

Ground water simply implies water occupying the entire void within a geologic stratum or within a fractured zone and is known to occur more widely than surface water (Offodile 1992).

Ground water supply like every other kind of buried natural resources of the earth is becoming progressively more difficult to locate, it is so because of the fact that more than half of the country is underlain by the crystalline basement rock of Precambrian era. Also because of the population growth the need for ground water is increasing by the day. The main rock type in this geologic terrain includes igneous and metamorphic rocks such as migmatite and granite gneiss (carter et al1963). Generally in their unaltered form these rocks are characterized by low porosity and permeability.

Methods for investigating the occurrence and movement of ground water have been improved, better means of extracting ground water have been developed, principles of conservation have been established and research of several types has contributed to a better understanding of the subject. Complementing the traditional water finding method are the modern geophysical investigation techniques.

Each of the main methods of geophysical prospecting i.e. magnetic, gravimetric, seismic, and electrical method and other geophysical method are capable of furnishing useful information in connection with ground water problems when applied in areas in which the physical condition satisfy the necessary requirement. This research project employed the use of electrical resistivity method using the vertical electrical sounding (VES) to search for productive aquifer for ground water exploration.

1.1 CLIMATE AND VEGETATION

The area under study is of tropical continental (Sudan) climate. These types of climate consist of two seasons. A rainy/wet season and a dry season, the rainy season mostly starts in May and ends in October. During this season humidity and temperature are high 32°C (90°F) (Burnette, ends in October. During this season humidity and temperature are high 32°C (90°F) (Burnette, 1965) the rainy season is the period when the tropical maritime air mass travels northward, over the study area from the gulf of guinea progressively dropping to moisture in form of precipitation, consequently rainfall diminishes from south to north (Illopje 1982) the dry season usually start from November to April. This is a long period of weather with high temperature during the day and low temperature at night. Average temperature during this season is about 12°C (about 70°F) (Burnette, 1965). There is severe harmattan period from December to February. This is the period when the north-east trade wind begins to blow southwards into the country from the Sahara belt. At this period it is generally cooler than normal and less humid, also visibility at certain times is restricted as a result of airborne dust.

Vegetation in this area is of the savannah type and sporadic thorny bushes, scattered shrubs and a few isolated trees.

1.2 LOCATION AND ACCESSIBILITY

The study area is located at Ruduyausa village a suburb of Bauchi along Bauchi-Ningi road, Bauchi State, North East Nigeria, the study area is located at 10°28'N and 9°50'E. The study area is accessible through major roads such as Bauchi – Ningi road and old Maiduguri road. The area is around the Gubi campus of ATBU Bauchi.

1.3 RELIEF AND DRAINAGE

The study area is characterized by a hilly topography with high elevation, the hill are formed by Inselbergs of medium coarse-granites (Dike et al 1994). As inselbergs, the hills may have conical, elongated or irregular stapes.

Generally, the drainage system of Bauchi and environments has a dendrite pattern with radially flowing streams, the major rivers in the area river are Kabuya and Misau the surface drainage in the area is seasonal and provides head waters for rivers Kabuya and Misau both of which flow Northward during the rainy season and dry out with isolated ponds during the dry season (Dike et al, 1994). Gubi Dam is also around the study area.

1.4 SETTLEMENT AND LAND USE

Bauchi metropolis is characterized by both linear and nucleated settlement. The Ruduyausa village is partially developed. The principal land use in the area is farming during the rainy wet

1.5 AIM AND OBJECTIVES

The objective and expected benefit of the research work include:-

- To identify and delineate the conductive zones within the basement rock based on their resistivity values.
- To identify the most favorable areas for locating productive borehole in the area.
- To contribute to research work on the area as the contribution of a reference material in the archive of the physics department.
- To fulfill one of the academic requirements for the award of bachelor in technology (B tech) in applied Geophysics of the Abubakar Tafawa Balewa Unversity.
- To provide subsurface information in terms of geo-electric sections that may indicate areas with shallow/deeper basement.

1.6 PREVIOUS WORK

The earlier geologic work was carried out by (Falconer 1911) as a reconnaissance survey during the mineral survey of Northern Nigeria. He recognized an old crystalline basement represented mainly by granitic rocks.

Du-preez and Barber (1965) worked on the distribution and chemical quality of ground water in Northern Nigeria, while Schpetes (1977) described the hydrogeologic conditions found in Bauchi State and concluded that water is found in the superficial weathered material derived from the basement complex which forms an aquifer of poor quality.

The earlier geophysical; exploration work in the area was done by Edok Eter Mandilas limited between 1976. They undertook the geophysical survey and construction of borehole and installation of mechanized pumps in Bauchi and environs.

Other works in the area include exploration by water survey Nigeria limited (August 1952), Pressaug Drilling Engineering L.td (May, June, 1990) and Dike et al 1994.

CHAPTER TWO

2.0 GEOLOGY AND HYDROGEOLOGY

2.1 GEOLOGY OF BAUCHI STATE

The geology of Nigeria is generally divided in to three units. The basement complex, the sedimentary environment and the volcanic rocks which have being described in detail by various workers (Buchanan et al, 1963, Oyawoye 1970, Anner 1998)

Bauchi state is underlained by crystalline rocks which belong to the Nigeria basement complex thought to be mostly precambrian in age (Oyawoye 1970) and occurrence of tertiary sedimentary environment. The rocks of the basement complex are the migmatite and the migematite gneiss, quartzite and granite gneiss. The older granite and the charnokitic rock (Bauchite). There is also the Younger Granite ring complex which comprises Ningi-Burra, Kila-Warji and Bauchi-Zaranda.

The granites of the basement complex were first investigated by Falconer (1911) and were mapped and examined by Bain (1926) and Oyawoye (1958, 1961, 1962).

The gneiss occurs as pendants or xenoliths in the granite and are generally a medium grained granublastic aggregate of quarts, plagioclase and potash feldspar (Oyawoye 1958, 1961, 1962 and Oyawoye and Makanjuola 1972).

The granites are coarse grained and are composed essentially of quartz, alkali feldspar, biotitic and some muscovite with accessory hornblende and haematite. Many stages of granitization and magmatic activity show diverse contact relationship with the metasediments (Oyawoye, 1962).

A charnockitic rock occurs around the margin while it forms a small outcrop. The older granite suits are predominantly of porphyrytic biotite granite or biotite hornblende granite. They are usually foliated due to the mafic mineral present in them (Truswell and Cope, 1963).

2.1.1 OLDER BASEMENT ROCKS

a. GRANITE GNEISS

The granite gneiss occurs at the southern zone of the state, comprising eastern and western parts of Bauchi local government, some parts in Ganjuwa local government.

The granite gneiss are fine to medium grained biotite rich granitic rock. In general, they have uniform appearances and are relatively constant in composition. They are composied of white plagioclase and some quartz and fairly abundant biotite humblende is also present in varying amounts. The rocks are finely foliated.

b. MIGMATITES

The migmatites cover part of the southern parts of the state which include some villages in Dass and Toro Local Government. Migmatites are variable in texture from medium to coarse grined and they represent a high grade metamorphosed series with excellent bonding. Generally the migmatite are foliated with flakes of biotite defining the foliation as parallel to the general trend.

The migmatite is a composite rock of hornblende bearing gneiss and granite rock. The granite rock is usually biotite granite alternating with the horneblende bearing gneiss. (Rahunan 1981).

c. FAYALITE QUARTZ MONZONITE (BAUCHITE)

Fayalite quartz Monzonite (Bauchite) occurs in areas around Bauchi, Dandango, and Gwaskwaram.

Bauchite was described as coarse grained augite by Falconer (1911) and later Bain (1962). The distributive features of quartz and Bauchite were first described by Oyawoye (1958, 1961) who named the complex Bauchite.

Fresh sample of Bauchite is dark green due to the green or Brown color of quartz and feldspar, (Rahman, 1981). The rocks are massive, homogeneous and unfolited with few joint, the mineral assemblage of Bauchite includes Fayalite, Biotite Orthoclase Oligoclase. Accessory minerals include iron titanium; apatite, zircon and are epidote (Rahman 1981). Clear occurrence of Bauchite was seen at Wambai, Guni and underlying Bauchi town.

d. QUARTZ DIORITE

Quartz diorite occurs as veins and dykes within the migmatites and granites. The dykes vary in thickness from 10cm to as much as 100cm and also about 1km across. They generally cut across the structure in the host rock having a sharp contact with them.

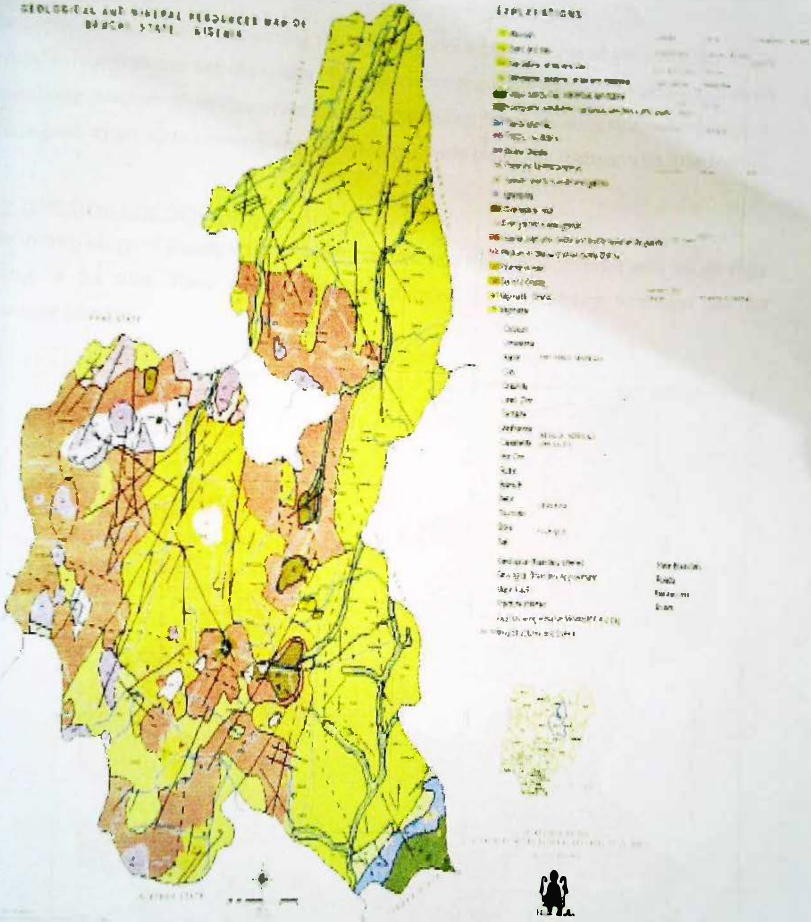

Fig. 1 Map of Bauchi showing different rock types and drainage pattern.

f. PEGMATITES

The pegmatites are found cross-cutting the country rocks within the area of interest. They can be divided in to concordant and discordant. The concordant pegmatite are those found parallel to the pre-existing structure while discordant are those truncating the pre existing structure in the rock. The pegmatites are up to coarse quartz and feldspar mostly potassium feldspar with little biotite.

2.2 HYDROGEOLOGY OF BAUCHI STATE

The hydrogeology of Bauchi state is broadly divided into three in accordance with the geologic setting of the state. These are the basement complex, the sedimentary formation and the basement foreland.

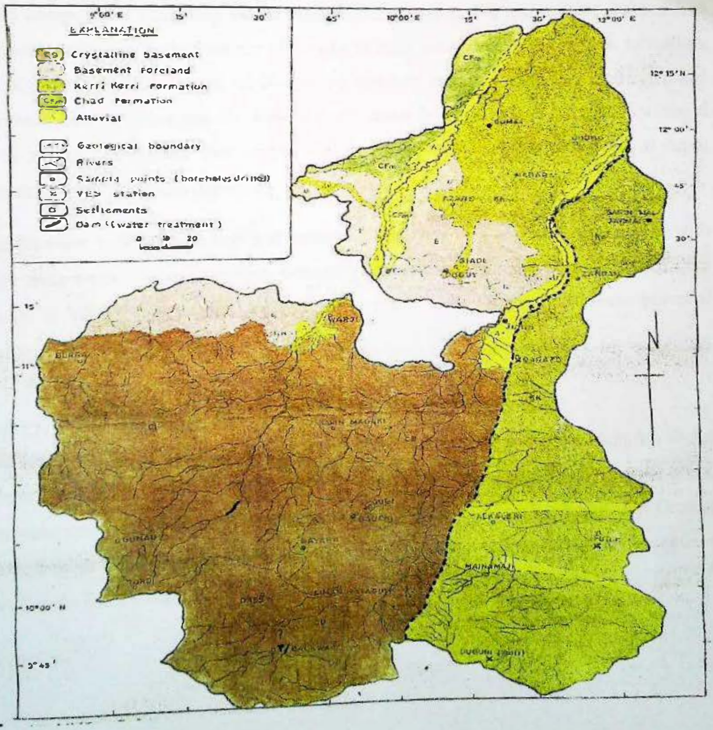

Fig.2 Hydrogeology map of Bauchi State

(a) BASEMENT COMPLEX

Considering the basement complex portion of the state, the weathered zone forms an aquifer with limited resources. The fractured zones occurring within the fresh basement on the other hand constitutes the richer aquifer with water yield tend to be constant depending on the rock type.

Since the thickness of the weathered and fractured layer forming the aquifer determine the size of its water bearing capacity, therefore the maximum ground water potential in this basement complex part of the state is to be found along the fractured and fissured lines which constitute the preferential flow paths of ground water.

(b) KERI-KERI FORMATION

It is chiefly composed of permeable clayed sandstone of coarse to fine grained size, brownish in color. Ground water is the main source of supply in most areas underlined by this formation. Wardrop engineering (1989) further subdivided the keri-keri formation in to four hydrogeolocal units Borehole data indicated that the water bearing zones in areas around Alkaleri Northward are fine to coarse quartz sand, fine quartz sand and lateritic or ferrogenised gravel at depth ranging between 20-115 meters depending on topographic location.

Estimated borehole yield here are high and capable of supplying over 400 litters per minute, with an average static water level of 36 meters. Generally the keri-keri formation despite the existence of few areas of low yielding capacity can be considered as having high ground water potential compared the basement complex areas of the state.

(c) THE CHAD FORMATION

The Chad formation portion of the state possesses both confined and unconfined aquifer. Water supply from the areas can normally be obtained from wells and water bone holes. In some areas, depths to water level are excessively deeper and consequently well yields are low. The Ground water in most areas is supplied by the top aquifer of fine to medium sand at an average depth of 40 meters (Edok- Eter- Mandilas, 1976).

2.3 GEOLOGY OF THE STUDY AREA

Ruduyausa village is located on the Precambrian to early Paleozoic (600-2000ma) crystalline rock of the basement roçk terrain of Nigeria which is overlain by recent alluvial sediments comprising fine to coarse-grained sands, silts and clay.

There are inselberges of medium-coarse grained granites belonging to the older granite series of Nigeria which intruded granite and migmatite usually exposed as flat outcrops in low land areas. Laterite and alluvium cover the crystalline rocks weathered and decompose to form sands or clayed sand depending on the local variation of the mineralogy of the granite, gneiss and migmatites.

2.4 HYDROGEOLOGY OF THE STUDY AREA

Generally during the rainy season the ground water level is very close to surface but during the dry season the ground water level drops considerably below the ground surface. Most wells dry up on the dry season. It is believed that if the depth of weathering is sufficiently thick, the weathered mantle contains water in storage large enough to produce successful borehole. Fractured partially decomposed rock and fresh rock underlying the weathered mantle have large store capacity and transmissivity to be potential sites of successful borehole the granitic basement aquifer with deeply weathered mantle and fractured rock in hydraulic continuity will yield appreciable water if thickly developed and laterally extensive.

In some areas joints tend to store and transmit water fairly well near the surface but become tighter with depth. Below a depth of 100m, there is effectively no storage. The basement rock has no primary porosity and apart from the joint and fractures it is impermeable. The permeability of the weathered mantle in location where the gneisses have high content of ferromagnesian minerals (hornblende and biotite) which weathered into clays is inadequate for borehole supply.

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.1 GENERAL INTRODUCTION

3.2 DATA ACQUISITION AND INTERPRETATION

Geologic method is employed at the initial stage of this research which includes collection of previous data. This was followed by a reconnaissance survey of the study area to locate major outcrops, drainage pattern and where the basement is believed to be deeply buried by the over burden. This is to provide prior information for proper assessment of the hydrologic potential of the study area at the early stage of the project.

Geophysical methods can be grouped into two, the surface geophysics approach in which measurements are taken at the surface i.e. electrical resistivity, seismic refraction method, electromagnetic method, magnetic method, and gravity methods etc, and the geophysical methods i.e. borehole logging, electrical resistivity tomography (ERT), etc. In this research work, the surface geophysics involving the electrical method was employed to delineate zones of ground water potentials.

Geoelectric surveys are basically the interpretation of variation in responses to the measured electrical properties of the earth either naturally or artificially generated within the Earth crust. Such variation result from difference in electrical resistivity of the sub-surface materials.

In this work, the field data was interpreted quantitatively and by means of computer software (win RESIST) and the final results was then used to deduce and locate viable sites for portable water supply in the area. Surfer software is also used to make contour maps as another means of interpretation.

3.3 ELECTRICAL METHOD

Electrical method in which current is applied by conduction to the ground through electrodes depend on their operation for the fact that any subsurface variation in conductivity alters the form of the current flow within the earth and this affect the distribution of electrical potential. The degree to which the potential at the surface is affected depend on the size, shape location resistivity of the subsurface masses, it is therefore possible to obtain information about the subsurface distribution of bodies from potential measurement made at the surface.

Basically, electrical prospecting involves the detection of subsurface effects produced by electric current flow in the ground. Using the electrical method one may measure potential, current and electromagnetic fields which occur naturally or are introduced artificially in the earth.

Furthermore, the electrical measurement can be made in a variety of ways to determine a variety of result. However it is the enormous variation in the electrical properties found in different rocks and minerals that are greatly exploited in these methods.

Electrical methods includes self potential (sp), telluric current and magneto telluric, audio-frequency magnetic field (AFMAG), resistivity, electromagnetic (EM) and induced polarization (IP), they are often classified by the type of energy sources involved that is natural or artificial.

3.4 ELECTRICAL RESISTIVITY METHOD

The most commonly used electrical methods is the direct-current (DC) resistivity method. It is employed conducting vertical electrical sounding or horizontal/lateral profiling to effectively locate ground water sources and geotechnical studies due to its simplicity and easy interpretation. The technique is widely used in soft and hard rock areas (Sharma and Baranwal 2005).

The usual practice is to pass the current in to the ground by means of two electrodes and to measure the potential drop between them with a second pair of electrode placed in line between them. From the magnitude of the potential drop and current, knowledge of the electrode separation quantity known as the appearance resistivity (ρ_a) can be calculated. If the ground is homogenous this is the true ground resistivity, but in general it is a weighted average of the resistivity of formation through which the current passes.

Electrical conduction in majority of rocks is essentially electrolytic. This is because most mineral grains are insulators, conduction being through the interstitial water which is usually present and which invariably contains some dissolved salts. Hence the resistivity of a formation generally depends on the resistivity of the contained electrolyte and is invariably related to the effective porosity and the degree of saturation.

In crystalline rocks and weathered basement which have very low porosities conduction takes place mainly along cracks and will control the resistivity.

In porous rocks, especially in arid and semi- arid environments, degree of saturation is the most important parameter.

The resistivity of formation varies widely not only from formation to formation but even within a particular formation especially for near surface unconsolidated materials.

Nevertheless some generalizations are possible and it is true to say the order of increasing resistivity is clay, sand, gravel, and limestone. The value for crystalline rocks being higher when partly dry the resistivity may increase by a factor of 10 or more.

3.5 ELECTRICAL RESISTIVITY THEORY

All resistivity methods employ an artificial source of current which is introduced into the ground through point electrodes or long line contacts.

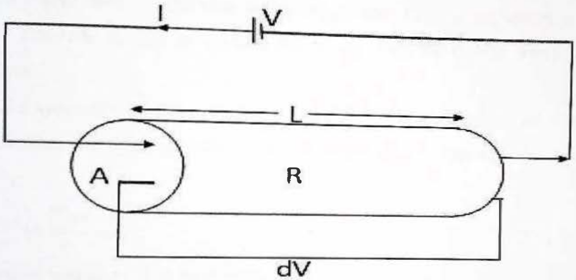

Fig. 3 *Schematic diagram describing Ohm's law*

The procedure is to measure potentials dV at other electrodes in the neighborhood of the current flow. Electrical methods of geophysical investigations are based on the resistivity or its inverse (i.e.) conductivity of materials. The electrical resistance, R of a material is related to its physical dimension, cross sectional area A, length L, through the resistivity ρ or its inverse, conductivity σ, and is given by

$$\rho = \frac{1}{\sigma} = \frac{RA}{L} \quad (3.1)$$

Low frequency alternating current is employed as source signals in the DC resistivity surveys in determining subsurface resistivity distribution.

Usually a complete homogeneous and isotropic medium is considered. For homogeneous medium, the current density J and electric field E are related through Ohm's law.

$$J = \sigma E \quad (3.2)$$

Where E is in volts per meter and σ is the conductivity of the medium in Siemens per meter. The electric field E can be represented as gradient of a scalar potential,

$$E = \nabla V$$

$$J = \sigma \nabla V \qquad (3.3)$$

But $\nabla . J = 0$, $\nabla . (\sigma \nabla V) = 0 \qquad (3.4)$

By combining equations 3.2 and 3.3, we obtained fundamental Laplace's equation for electrostatic fields which is given by

$$\nabla^2 V = 0 \qquad (3.5)$$

3.5.1 SINGLE CURRENT ELECTRODE AT DEPTH

There are several field configurations used in resistivity. The first of these is the electrode of small dimensions buried in a homogeneous isotropic medium. This is where the single electrode is down a drill hole or otherwise under the ground. The current circuit is completed through another electrode usually at surface, but in any case far enough away that its influence is negligible.

From the symmetry of the system the potential will be a function of r only, where r is the distance from the first electrode. Under these conditions Laplace's in spherical coordinate is given by:

$$\nabla^2 V = \frac{d^2 V}{dr^2} + \frac{\left(\frac{2}{r}\right) dV}{dr} = 0 \qquad (3.6)$$

Multiplying equations (3.6) by r^2 yield,

$$\frac{dv}{dr} = \frac{A}{r^2} \qquad (3.7)$$

On integrating, equation (3.7) yields,

$$V = \frac{-A}{r} + B \qquad (3.8)$$

Where A and B are constant.

When the current flows radially outward in all direction from the point electrode, the total current crossing a spherical surface is given by

$$I = 4\pi r^2 J = -4\pi r^2 \sigma \frac{dV}{dr} = -4\pi \sigma A \qquad (3.9)$$

Combining (6) and (3), yields

$$A = -\frac{I_P}{4\pi}$$

Hence,

$V = \left(\frac{I\rho}{4\pi}\right)\frac{1}{r}$ $or\ \rho = \frac{4\pi rV}{I}$

(3.1.0)

3.5.2 SINGLE CURRENT ELECTRODE AT THE SURFACE

If the point electrode delivering current is located at the surface of the homogeneous isotropic medium, the single probe or three-point system is used in surface resistivity layout and the return current electrode is at a great distance.

By applying Laplace's equation, the solution will be

$V = \frac{A}{r} + B$ with B = 0

(3.1.1)

The current flows through a hemispherical surface in the lower medium is given by

$V = \left(\frac{I\rho}{2\pi}\right)$ $or\ \rho = \frac{2\pi rV}{I}$

(3.1.2)

3.5.3 TWO CURRENT ELECTRODES AT THE SURFACE

When the distance between the two current electrodes is finite, the potential

$V_1 = -\frac{A_1}{r_1} where\ A_1 = -\frac{I\rho}{2\pi}$

The potential due to C2 at P2 is $V_2 = -\frac{A_2}{r_2}\ where\ A_2 = \frac{I\rho}{2\pi}$

Thus,

$V_1 + V_2 = \frac{I\rho}{2\pi}\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$ (3.1.3)

Introducing a second potential electrode at P2, the difference in potential between P1 and P2 can be measured which is given by,

$\nabla V = \frac{I\rho}{2\pi}\left(\frac{1}{r_1} - \frac{1}{r_2}\right) - \left(\frac{1}{r_3} - \frac{1}{r_4}\right)$ (3.1.4)

3.6 APPARENT RESISTIVITY

The purpose of electrical survey is to determine the subsurface resistivity distribution by making measurements on the ground surface. From these measurements, the true resistivity of the subsurface can be estimated. The ground resistivity is related to various geological parameters such as the mineral and fluid content, porosity and degree of water saturation in the rock. Electrical resistivity surveys have been used for many decades in hydrogeological, mining and geotechnical investigations. More recently, it has been used for environmental studies.

The resistivity measurements are normally made by injecting current into the ground through two electrodes (C1 and C2), and measuring the resulting voltage difference at two potential electrodes (P1 and P2).

From the current (I) and Voltage (V) values, an apparent resistivity (ρ_a) value is calculated.

$$\rho_a = K \frac{V}{I} \qquad (3.1.5)$$

Where K is the geometric factor which depend on the arrangement of the four electrodes .The figures below show the common arrays used in resistivity surveys together with their geometric factors. Resistivity meters normally give a resistance value, $R = \frac{V}{I}$, so in practice the apparent resistivity value is calculated by $\rho_a = KR$

The calculated resistivity value is not the true resistivity of the subsurface, but an apparent value which is the resistivity of a homogeneous ground which will give the same resistance value for the same electrode arrangement. The relationship between the ''apparent'' resistivity and the "true'' resistivity is a complex relationship. To determine the true subsurface resistivity, an inversion of the measured apparent resistivity values using a computer program software package will be used.

3.7 ELECTRODE ARRAY

An electrode array is determined by the mode of arrangement of the current and potential electrodes. The typical arrays used in resistivity measurement include the following.

i Schlumberger array

ii Wenner array

iii Dipole-dipole array

iv Pole-dipole array

v Pole-pole array

The electrode arrays that are commonly used (schlumberger, wenner, and dipole -dipole) are illustrated below;

3.7.1 SCHLUMBERGER ARRAY

It is a collinear array with the four electrodes arranged along a straight line. The inner electrode spacing is not constant. In usual field operations, the inner (potential) electrodes remain fixed, while the spacing between the outer (current) are moved farther.

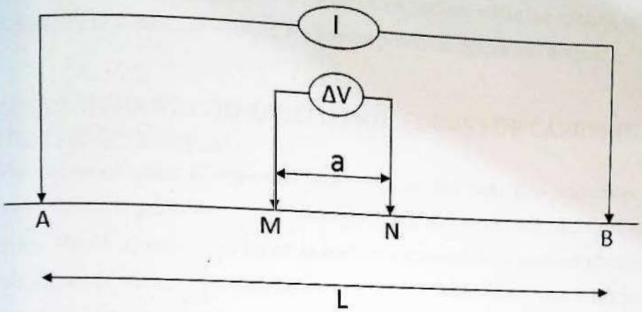

Fig.4 Schlumberger Electrode Configuration

Where L is the distance between the current electrodes A and B

The theoretical depth of investigation for Schlumberger array is approximately given as $Z = 0.125AB$, where $AB = L$ is the distance from C_1 to C_2 as $AB \geq 5MN$, $MN = a$ = distance between P_1 and P_2.

The Schlumberger configuration is known to have the following advantages:

i. Less man power is required to perform sounding.
ii. Problem of electrolytic contact potential is overcome.
iii. Relatively short cables are used.
iv. Not very sensitive to lateral resistivity variations
v. High signal-to-noise ratio.

3.8 FIELD PROCEDURE

Vertical Rlectrical Sounding (VES) is adopted in the electrical resistivity survey.

3.8.1 VERTICAL ELECTRICAL SOUNDING (VES)

This method furnishes detail information on the vertical succession of different conducting zones and their individual thickness and true resistivities. For this reason, the method is valuable for horizontally or nearly horizontally stratified ground. In electrical sounding the midpoint of the electrode configuration is fixed at an observation station, while the spacing of the configuration is gradually increased. As a result, the current penetrate deeper and deeper.

3.9 INSTRUMENTATION/FIELD PROCEDURE FOR CARRYING OUT RESISTIVITY SURVEY

The resistivity meter (Terrameter) was used for the field data collection. This instrument measures and displays the apparent resistivity of the subsurface averaged over a number of cycles. This is accomplished by an in-build microprocessor controlled electronic circuit which nulls displayed voltage by manipulation of a resistor bank. Other instrument include; measuring tapes, hammers, Global Positioning System (G.P.S), set of metal electrodes, reels of wire and connecting cables.

Below is a general procedure for carrying out vertical electrical sounding in the field;

I. A good location for the midpoint of electrodes spread was found.

II. The survey was oriented along the strike of the bedding plane and at least enough space of 200m on either side was ensured.

III. Measuring tapes were spread out on either sides of the midpoint which the lines were collinear.

IV. Electrodes were hammered at required locations.

V. The resistivity meter, cables and reels of wire were connected appropriately.

VI. Readings were taken at various electrodes locations.

VII. Small current (<5mA) was used.

VIII. The current electrode and the potential electrodes spacing were increased at the internal AB ≥ 5MN.

IX. The geometric factor for Schlumberger array K was multiplied by the value of resistance displayed by the resistivity meter to obtain the apparent resistivity.

X. Data were plotted along side of the survey to check the curves for anomaly.

XI. When moving to larger potential electrodes separation, at least two cross over point would be ensured for Schlumberger array.

3.10 FIELD DATA ACQUISITION

In this research work, the VES using Schlumberger electrode configuration was employed throughout. The method uses collinear expanding array of electrodes with fixed potential electrodes MN nested between the two current electrodes AB which are moved symmetrically outward. As the current .electrodes spread are expanded farther apart, the current penetrate progressively deeper into the Earth.

The data acquisition was aided using a Terrameter. It contains three main units housed in a single casing; the transmitter, receiver and the microprocessor. The electrically isolated transmitter sends out regulated signal currents. The receiver on the other hand, discriminate noise and measures voltages correlated with transmitted signal current. The microprocessors monitor and control operations and calculate result of the Earth's geoelectric response to the given separation.

3.11 FIELD DATA PROCESSING

The value of the resistance obtained from the Terrameter at each locality was recorded on a field data sheet. This value is then multiplied by the corresponding geometric factor appropriately to the electrode configuration and separation. This result is the apparent resistivity. Subsequently, a plot of apparent resistivity (ρ_a) versus half current electrode separation (AB/2) was done on a log-log graph sheet. The resulting curve yielded a rough estimate of the number of layers, andresistivity variation of the subsurface. The curves are attached in appendix 1.

CHAPTER FOUR

4.0 RESULTS AND INTERPRETATION

4.1 RESISTIVITY MEASUREMENT

Geophysical investigations consisting of (15) vertical electrical sounding (VES) points were conducted in the study area using the Schlumberger four electrode array.

4.2 INTERPRETATION OF RESULTS

Since the instrument measures the apparent resistivity the data were interpreted quantitatively with a computer aided program called Win-resist where the field curves were correlated with the computer fitted curves to deduce the layer depth (m), layer thickness (m), and apparent resistivity values (Ωm) for each plotted model.

The algorithm determine the model whose theoretical geo-electric curve best fits the field data by successive iterations dictated by the numerical program in which estimate of input parameter is made for each layer and curves of the apparent resistivity versus electrode spacing was plotted for each set of data.

The assumption made during the interpretation is that the underlying formations are horizontal and parallel to the earth's surface. The interpreted results of the 15 vertical electrical sounding for the study area are presented in the appendix.

Four geo-electric layers were established from all the VES points and were given in the table below along with their coordinates, and inferred lithology of each layer.

In addition to the win-resist software interpretation, contour mapping is also adopted using the surfer software to make more interpretations. The contour maps for the study area are also presented in the appendix.

4.3 RESULT OF THE INTERPRETED DATA

The results are presented in table 1.

Table I: showing interpreted VES field data

VES No.	COORDINATES/ ELEVATION (M)	LAYER No.	LAYER RESISTIVITY (Ωm)	LAYER THICKNESS (M)	APPROX. DEPTH (M)	INFERRED LITHOLOGY
1	10°46.388N	1	294.8	0.8	0.8	Top soil
	09°83.500E	2	96.1	3.4	4.2	Slightly weathered
	559m	3	7494.8	28.2	32.4	Fractured basement
		4	3848.2	∞	∞	Fresh basement
2	10°46.235N	1	22.9	2.0	2.0	Top soil
	09°84.297E	2	199.1	2.9	4.9	Highly weathered unit
	550m	3	2744.0	22.6	27.5	Fractured basement
		4	10763.0	∞	∞	Fresh basement
3	10°28,551N	1	2431.1	1.1	1.1	Top soil
	09°50.013E	2	525.8	0.7	1.8	Weathered unit
	565m	3	65.2	4.0	5.8	Fractured rock
		4	585.5	∞	∞	Highly fractured rock
4	10°28.538N	1	1570.4	1.2	1.2	Top soil
	09°49.983E	2	452.0	0.8	2.0	Highly weathered unit
	590m	3	217.1	9.8	11.8	Slightly weathered
		4	1194.3	∞	∞	Fractured rock
	10°28.569N	1	1589.9	1.1	1.1	Topsoil
	09°49.976E	2	312.0	1.9	3.0	Weathered unit
	587m	3	200.1	51.0	54.0	Fractured unit
		4	6306.2	∞	∞	Fresh crystalline unit
	10°28.556N	1	263.9	2.1	2.1	Top soil
	09°49.940E	2	746.6	7.1	9.2	Weathered unit
	586m	3	1062.2	92.8	102.0	Fractured rock unit
		4	1613.3	∞	∞	Highly fractured rock
	10°28.525N	1	1004.2	0.9	0.9	Top soil
	09°49.957E	2	860.8	4.9	5.8	Weathered unit
	585m	3	1064.1	17.9	23.7	Fractured rock
		4	1901.7	∞	∞	Highly fractured unit

	10°28.542N	1	290.8	0.9	0.9	Top soil
	09°49.070E	2	252.1	12.7	13.6	Weathered unit
	584m	3	541.6	55.5	69.1	Slightly fractured rock
		4	2515.7	∞	∞	Highly fractured rock
	10°28.512N	1	2166.6	1.2	1.2	Top soil
	09°49.917E	2	892.3	4.3	5.4	Weathered unit
	583m	3	652.2	17.3	22.8	Fractured unit
		4	262.9	∞	∞	Fractured unit
0	10°28.479N	1	889.7	1.8	1.8	Top soil
	09°49.927E	2	558.6	14.6	16.4	Fairly weathered unit
	584m	3	178.6	37.2	53.6	Fractured rock
		4	2009.5	∞	∞	Highly fractured rock
1	10°28.456N	1	906.2	1.1	1.1	Top soil
	09°49.940E	2	553.1	6.2	7.4	Weathered rock
	582m	3	199.3	26.2	33.6	Lightly weathered
		4	984.1	∞	∞	Slightly fractured rock
2	10°28.487N	1	973.2	1.0	1.0	Top soil
	09°49.958E	2	740.5	8.0	9.0	Weathered unit
	581m	3	326.2	80.0	89.0	Fractured rock unit
		4	560.9	∞	∞	Slightly fractured rock
3	10°28.462N	1	890.9	1.0	1.0	Top soil
	09°49.969E	2	740.4	5.3	6.3	Weathered unit
	581m	3	383.3	63.7	70.0	Fractured rock
		4	591.0	∞	∞	Slightly fractured rock
4	10°28.493N	1	1318.4	1.0	1.0	Top soil
	09°49.982E	2	687.4	15.6	16.5	Weathered unit
	585m	3	219.1	50.0	66.6	Fractured unit
		4	2300.7	∞	∞	Highly fractured rock
5	10°28.468N	1	888.1	1.2	1.2	Top soil
	09°49.991E	2	864.6	9.9	11.1	Weathered unit
	585m	3	272.7	39.0	50.1	Fractured rock
		4	981.4	∞	∞	Slightly fractured rock

From the table above, the results indicate that generally the area is composed of 4-layers. The sequence of the rock that typified each layers are top soil, highly weathered/decomposed crystalline rock, fractured crystalline rock and fresh crystalline rock.

4.3.1 Top soil

The top soil from the area is characterized by sand, laterite and alluvium. This zone has resistivity values that range from 20 to 2400 Ωm and their thickness ranges from 0.8 to 2.1 m.

4.3.2 Highly weathered/decomposed unit

This zone underlies the top soil, the zone consist of deeply weathered mantle. They are characterized by very low resistivity values which range from 96 to 200 Ωm and their thickness range from 0.7 to 16 m. The high resistivity values occur in areas where the basement is believed to be buried at very shallow depth.

4.3.3 Fractured crystalline rock

The resistivity values of this layer range from 300 to 2500 Ωm and their thickness range from 15 to 105 m. This layer is sufficiently thick and could provide appreciable water supplies from boreholes because of its low to moderate resistivity values. The layer together with the weathered zone is the only potential ground water zones in the basement rock as they constitute the major aquifer.

4.3.4 Fresh crystalline rock

This constitutes the basement rock having very high resistivity values above 3000 Ωm and they are unweathered. This zone is normally devoid of groundwater which influences the resistivity.

4.4 APPARENT RESISTIVITY CONTOUR MAP OF THE STUDY AREA

In order to consider the hydro-electrical characteristics of the study area, the results of the apparent resistivity for all the VES points were then used to develop series of resistivity contour maps at a particular depth from the raw field data so that formations with the same depth having different resistivity value are contoured and given a unique label as illustrated in the appendix. The purpose of generating these resistivity contours is to distinguish and identify the possible depth to which lower values of apparent resistivity can be obtained so that we can infer the possible depth to which water could be stored in the study area. From the results obtained, it is found that the apparent resistivity of water in a basement rock that is well fractured and saturated with water ranges from 90 to 300 Ωm. Hence, areas at a given depth with this range of resistivity values were contoured purple to blue in color. While areas that have fewer values than that of water in a basement rock were inferred to be made up of highly decomposed basement, laterite and clay with a resistivity range of 5 to 89 Ωm and were labeled grey in the contour map. For those formations that have higher values of apparent resistivity than that of the basement water were labeled red as illustrated in the appendix.

5.1 SUMMARY, DISCUSSION AND CONCLUSION

The study area (Ruduyausa village) is underlain by crystalline basement rocks which normally have no porosity or permeability. However there are areas of reasonably thick weathered rock which have enough water in storage. The results of the resistivity revealed that the curves obtained are in agreement with those obtained by Dike et al (1994). The shapes of the sounding curves for the study area basically are the H A and QH types. VES 1 has an AH-type curve and VES 9 has a Q-type curve. The area is characterized by rock exposures.

The curves show a typical four layered earth. In some cases, the points begin with lower apparent resistivity values while in other cases the points begin with higher resistivity values. The resistivities of the first layers are mostly of poor conducting overburden.

The second intermediate layer is of low resistivity. It represents the weathered portion of the basement complex. Below this weathered zone are mostly areas of low resistivity values that are believed to be associated to the fracturing of the crystalline rock which is also a potential groundwater zones. The fresh intact crystalline rocks in the area are characterized by high resistivity values.

Based on the geophysical survey, the interpretation of the contour mapping and considering the thickness of the intermediate layer which is believed to constitute the major aquifer VES 10, 11, 12 and 14 have been determined that may be good areas for drilling of borehole. The results obtained correlate with earlier work of Dike done on adjacent area. Although the thickness of the weathered/fractured zones on these points are relatively thick compared to others, VES 11 is regarded as the most favourable because the aquiferous zone is thicker than all the other VES points.

5.2 RECOMMENDATION AND CONCLUSION

The electrical resistivity technique have proved to be extremely cost effective, fast and hazard free in the location and delineation of zones of weathering and fracture which are the main groundwater potential zones in crystalline basement.

Although the method adopted (resistivity sounding using VES) cannot discover water directly by itself, it offers helpful assistance in determining subsurface conditions that are favourable for the occurrence of groundwater.

In conclusion, the need to conduct adequate geophysical survey and selective siting of boreholes cannot be over emphasized as the basement complex areas are generally characterized by their limited groundwater potential with geologic factors such as the nature and extent of the aquiferous zones.

Based on the resistivity sounding in the area, it is strongly recommended that a more detailed work should be carried out in the study area employing the electromagnetic method to complement the extent of regolith and its associated fracture zones for optimal water yield.

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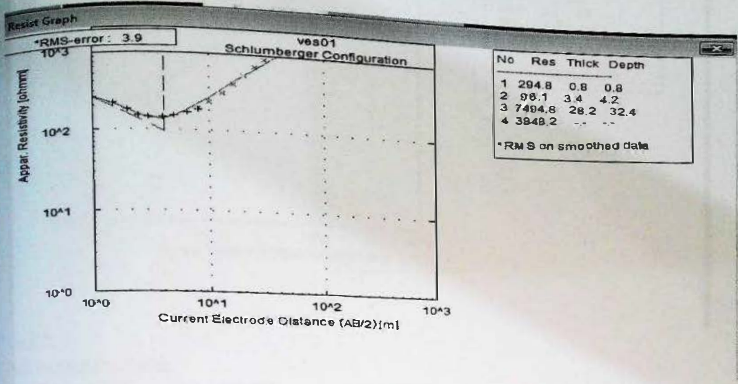
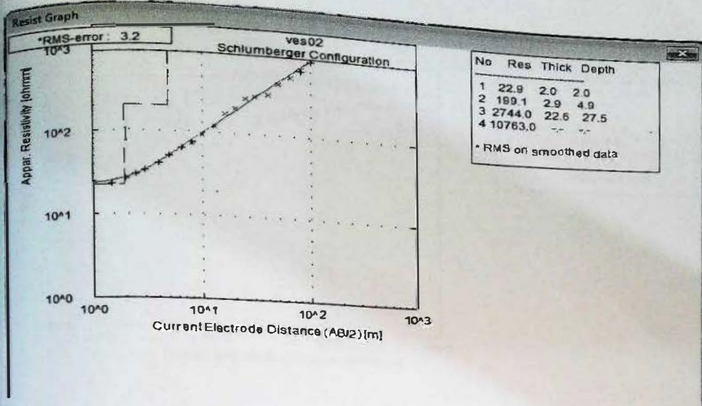
APPENDIX I



ves01

Schlumberger Array

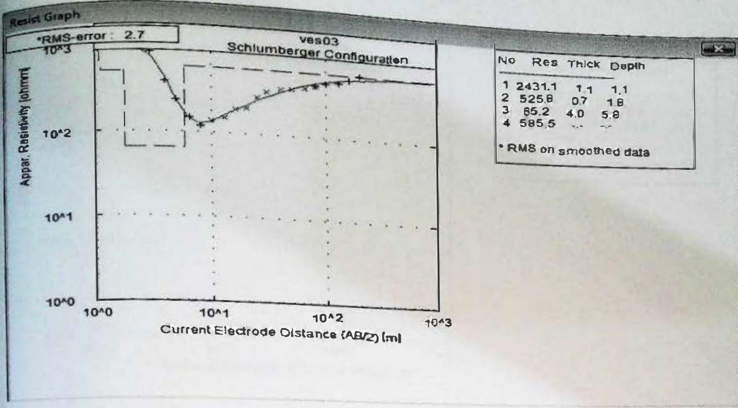
AB/2	RES	LATITUDE	LONGITUDE	ELEVATION
1.0000	254.1000	N10°.463888	E9°.835000	559m
1.5000	214.2200			
2.0000	176.5700			
2.5000	151.1400			
3.0000	142.1100			
4.0000	142.0500			
5.0000	151.2700			
6.5000	166.7400			
8.0000	183.5900			
8.0000	187.7300			
10.0000	225.0700			
13.0000	296.2300			
16.0000	379.9900			
20.0000	500.4900			
25.0000	646.2500			
30.0000	802.5300			
40.0000	1086.0000			
50.0000	1292.9000			
65.0000	1582.7000			
80.0000	1643.5200			
80.0000	1683.1000			
100.0000	1523.5000			
130.0000	2156.3000			
160.0000	2443.6000			
200.0000	2657.7000			



ves02

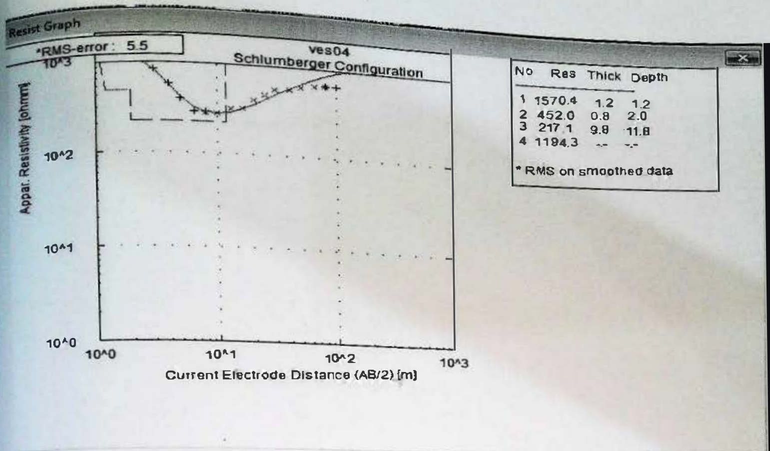
Schlumberger Array

AB/2	RES	LATITUDE	LONGITUDE	ELEVATION
1.0000	24.9900	N10°.462358	E9°842972	550m
1.5000	23.3500			
2.0000	26.7500			
2.5000	30.0100			
3.0000	34.3600			
4.0000	41.1000			
5.0000	51.4300			
6.5000	63.4800			
8.0000	74.2400			
8.0000	72.7000			
10.0000	92.8200			
13.0000	118.6100			
16.0000	170.8900			
20.0000	199.0100			
25.0000	266.9600			
30.0000	284.5800			
40.0000	305.7200			
50.0000	419.3600			
65.0000	528.5300			
80.0000	669.5500			
80.0000	636.4400			
100.0000	848.7400			
130.0000	1200.1000			
160.0000	1403.5000			
200.0000	1749.3600			



ves03
Schlumberger Array

AB/2	RES	LATITUDE	LONGITUDE	ELEVATION
1.0000	1991.4000	N10°.285510	E9°.500130	565m
1.5000	1908.8000			
2.0000	1574.8000			
2.5000	1168.3000			
3.0000	856.7000			
4.0000	394.2000			
5.0000	238.1000			
6.5000	146.3000			
8.0000	118.8000			
8.0000	121.6000			
10.0000	135.4000			
13.0000	150.2000			
16.0000	189.8000			
20.0000	200.7000			
25.0000	271.8000			
30.0000	320.8000			
40.0000	353.7000			
50.0000	369.2000			
65.0000	381.3000			
80.0000	412.1000			
80.0000	420.4000			
100.0000	455.6000			
130.0000	480.2000			
160.0000	520.4000			
200.0000	600.2000			



ves04

Schlumberger Array

AB/2	RES	LATITUDE	LONGITUDE	ELEVATION
1.0000	1359.0000	N10°.285380	E9°.499830	590m
1.5000	1310.4000			
2.0000	1185.1000			
2.5000	957.7000			
3.0000	764.5000			
4.0000	539.0000			
5.0000	374.1000			
6.5000	275.1000			
8.0000	271.3000			
8.0000	270.1000			
10.0000	265.6000			
13.0000	298.4000			
16.0000	311.7000			
20.0000	379.1000			
25.0000	443.2000			
30.0000	507.9000			
40.0000	527.1000			
50.0000	566.4000			
65.0000	590.3000			
80.0000	602.8000			
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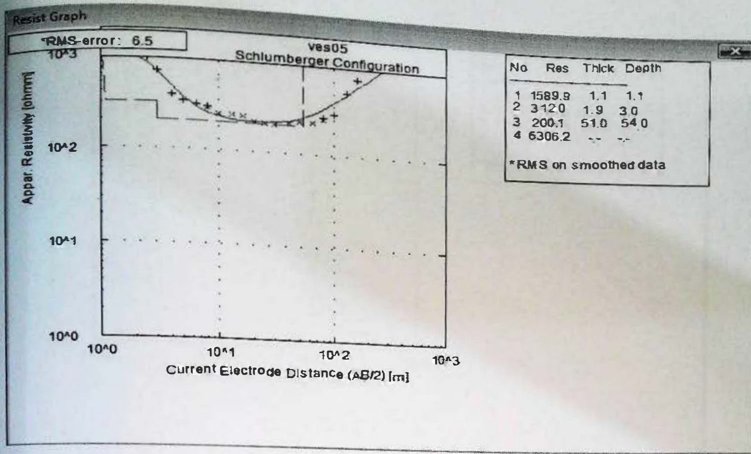
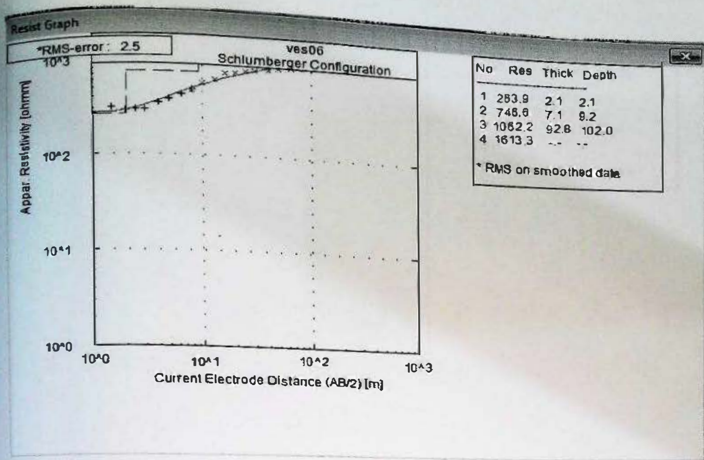
100.0000	610.7000			
130.0000	961.7000			
160.0000	1162.5000			
200.0000	1348.0000			



ves05

Schlumberger Array

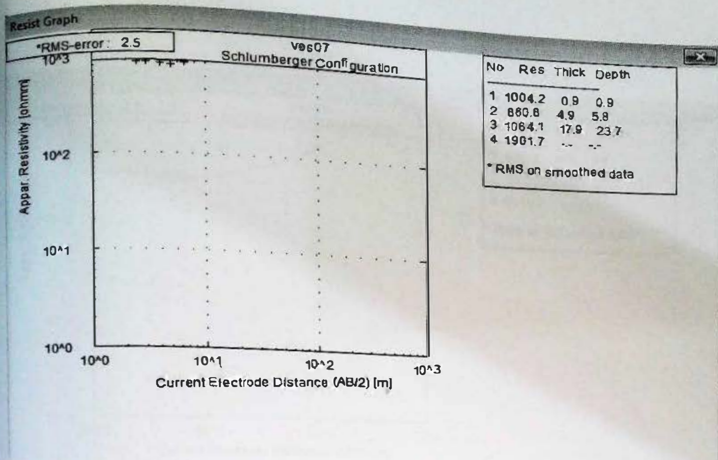
AB/2	RES	LATITUDE	LONGITUDE	ELEVATION
1.0000	1250.6000	N10°.285699	E9°.499760	587m
1.5000	1291.5000			
2.0000	1176.8000			
2.5000	911.4000			
3.0000	663.2000			
4.0000	371.2000			
5.0000	320.1000			
6.5000	300.5000			
8.0000	285.0000			
8.0000	277.3000			
10.0000	244.5000			
13.0000	240.4000			
16.0000	237.1000			
20.0000	210.0000			
25.0000	204.8000			
30.0000	202.4000			
40.0000	208.7000			
50.0000	218.6000			
65.0000	222.7000			
80.0000	240.5000			
80.0000	255.3000			
100.0000	282.3000			
130.0000	482.6000			
160.0000	703.5000			
200.0000	995.6000			



ves06

Schlumberger Array

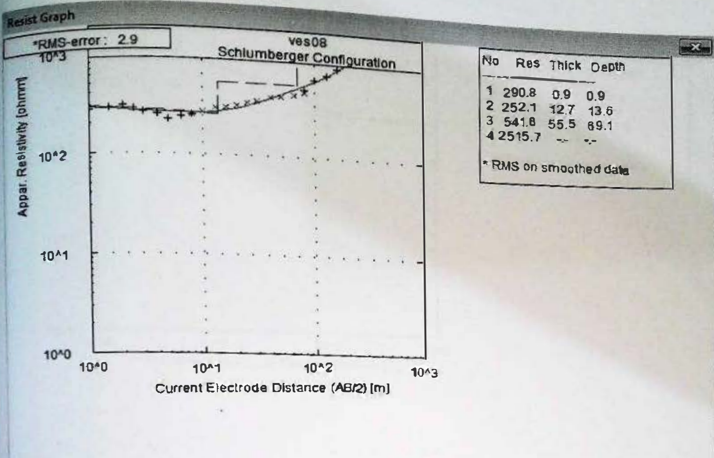
AB/2	RES	LATITUDE	LONGITUDE	ELEVATION
1.0000	274.1000	N10°.285560	E9°.499400	586m
1.5000	310.1000			
2.0000	287.2000			
2.5000	293.8000			
3.0000	295.7000			
4.0000	347.8000			
5.0000	386.7000			
6.5000	434.2000			
8.0000	491.7000			
8.0000	480.3000			
10.0000	577.6000			
13.0000	635.0000			
16.0000	745.4000			
20.0000	770.3000			
25.0000	810.2000			
30.0000	825.2000			
40.0000	850.6000			
50.0000	886.2000			
65.0000	905.4000			
80.0000	920.1000			
80.0000	950.4000			
100.0000	1073.5000			
130.0000	1100.3000			
160.0000	1147.8000			
200.0000	1286.0000			



ves07

Schlumberger Array

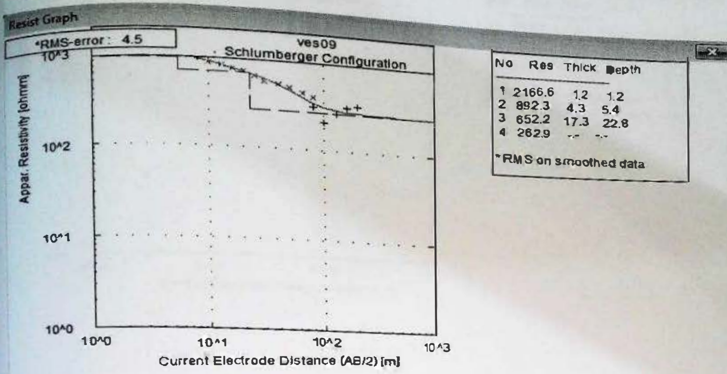
AB/2	RES	LATITUDE	LONGITUDE	ELEVATION
1.0000	1010.4000	N10°.285250	E9°.499570	585m
1.5000	1004.0000			
2.0000	952.5000			
2.5000	870.0000			
3.0000	861.2000			
4.0000	846.4000			
5.0000	825.5000			
6.5000	873.0000			
8.0000	940.7000			
8.0000	977.4000			
10.0000	1025.3000			
13.0000	1031.3000			
16.0000	1045.0000			
20.0000	1057.5000			
25.0000	1079.0000			
30.0000	1107.1000			
40.0000	1125.3000			
50.0000	1206.7000			
65.0000	1322.6000			
80.0000	1340.0000			
80.0000	1402.3000			
100.0000	1510.0000			
130.0000	1601.0000			
160.0000	1805.1000			
200.0000	1970.2000			



ves08

Schlumberger Array

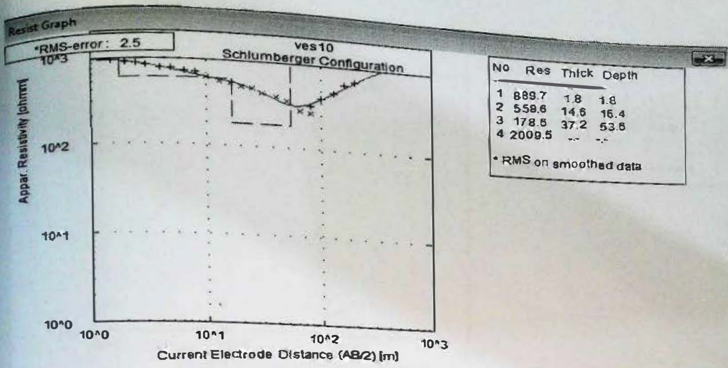
AB/2	RES	LATITUDE	LONGITUDE	ELEVATION
1.0000	271.6000	N10°.285420	E9°49070	584m
1.5000	290.7000			
2.0000	298.8000			
2.5000	278.5000			
3.0000	261.4000			
4.0000	247.5000			
5.0000	223.1000			
6.5000	239.5000			
8.0000	251.4000			
8.0000	250.4000			
10.0000	265.6000			
13.0000	291.4000			
16.0000	304.3000			
20.0000	317.8000			
25.0000	339.6000			
30.0000	354.2000			
40.0000	391.4000			
50.0000	405.6000			
65.0000	420.4000			
80.0000	455.1000			
80.0000	490.8000			
100.0000	618.9000			
130.0000	702.7000			
160.0000	817.4000			
200.0000	991.5000			



ves09

Schlumberger Array

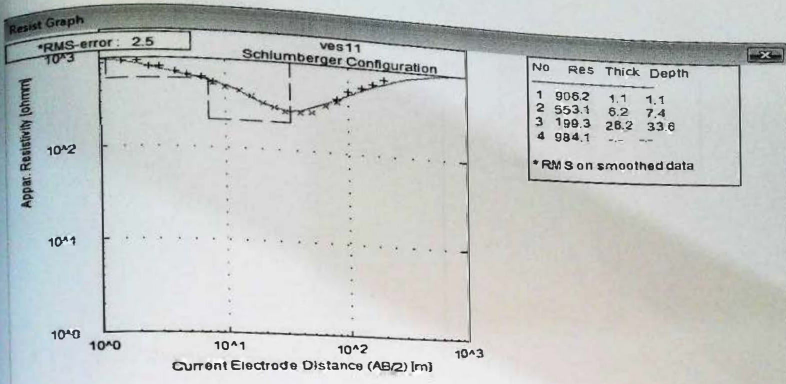
AB/2	RES	LATITUDE	LONGITUDE	ELEVATION
1.0000	1990.0000	N10.285129	E9.499170	583m
1.5000	1943.0000			
2.0000	1798.0000			
2.5000	1522.0000			
3.0000	1336.1000			
4.0000	1151.4000			
5.0000	1042.6000			
6.5000	950.4000			
8.0000	901.2000			
8.0000	915.3000			
10.0000	800.2000			
13.0000	766.7000			
16.0000	710.2000			
20.0000	675.3000			
25.0000	600.3000			
30.0000	541.4000			
40.0000	513.3000			
50.0000	480.6000			
65.0000	425.4000			
80.0000	384.1000			
80.0000	302.7000			
100.0000	207.3000			
130.0000	259.7000			
160.0000	307.4000			
200.0000	327.5000			



ves10

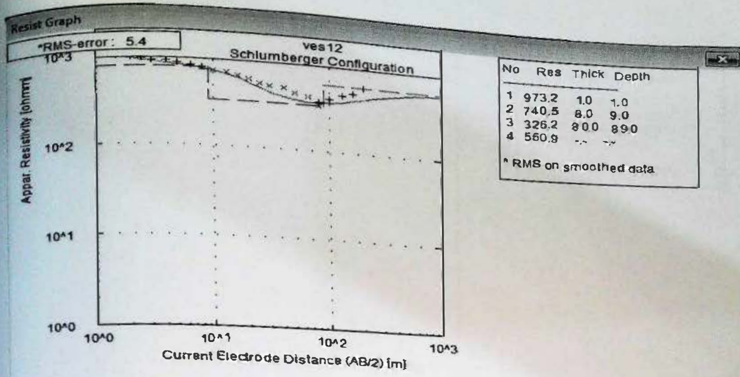
Schlumberger Array

AB/2	RES	LATITUDE	LONGITUDE	ELEVATION
1.0000	891.2000	N10̊.284790	E9̊.499270	584m
1.5000	873.0000			
2.0000	835.3000			
2.5000	800.5000			
3.0000	766.0000			
4.0000	721.7000			
5.0000	710.4000			
6.5000	671.2000			
8.0000	643.5000			
8.0000	636.2000			
10.0000	581.0000			
13.0000	520.0000			
16.0000	500.9000			
20.0000	464.2000			
25.0000	455.3000			
30.0000	400.1000			
40.0000	375.2000			
50.0000	336.3000			
65.0000	270.2000			
80.0000	254.3000			
80.0000	310.7000			
100.0000	386.4000			
130.0000	450.2000			
160.0000	582.7000			
200.0000	641.2000			



ves11
Schlumberger Array

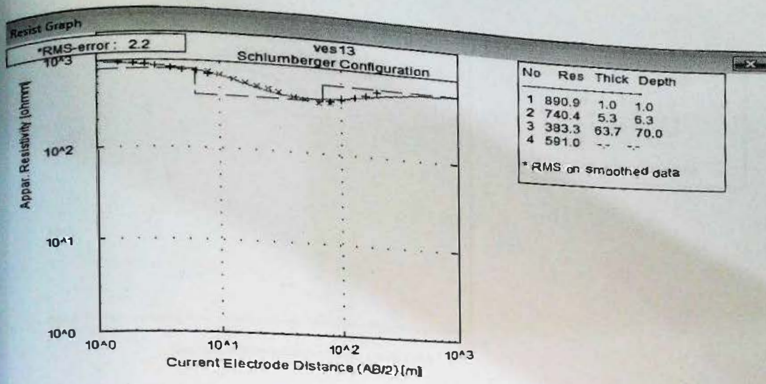
AB/2	RES	LATITUDE	LONGITUDE	ELEVATION
1.0000	802.0000	N10°.284561	E9°.499400	582m
1.5000	854.7000			
2.0000	837.7000			
2.5000	730.0000			
3.0000	733.5000			
4.0000	647.2000			
5.0000	610.1000			
6.5000	571.3000			
8.0000	510.1000			
8.0000	496.0000			
10.0000	450.3000			
13.0000	418.6000			
16.0000	372.4000			
20.0000	313.2000			
25.0000	290.4000			
30.0000	258.2000			
40.0000	261.1000			
50.0000	270.5000			
65.0000	320.1000			
80.0000	367.2000			
80.0000	393.2000			
100.0000	491.3000			
130.0000	550.2000			
160.0000	621.2000			
200.0000	715.9000			



ves12

Schlumberger Array

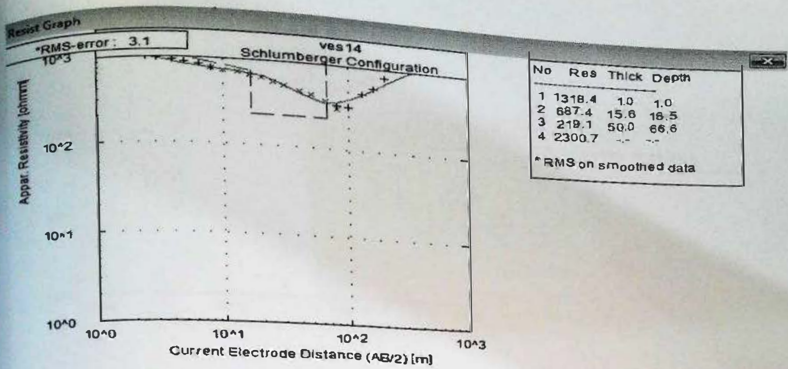
AB/2	RES	LATITUDE	LONGITUDE	ELEVATION
1.0000	973.2000	N10°.284871	E9°.499580	581m
1.5000	952.4000			
2.0000	900.1000			
2.5000	884.5000			
3.0000	851.0000			
4.0000	843.7000			
5.0000	812.3000			
6.5000	773.2000			
8.0000	740.5000			
8.0000	721.3000			
10.0000	688.6000			
13.0000	672.5000			
16.0000	619.3000			
20.0000	571.8000			
25.0000	519.4000			
30.0000	501.3000			
40.0000	483.2000			
50.0000	433.1000			
65.0000	400.7000			
80.0000	326.2000			
80.0000	353.2000			
100.0000	390.1000			
130.0000	440.3000			
160.0000	476.7000			
200.0000	560.9000			



ves13

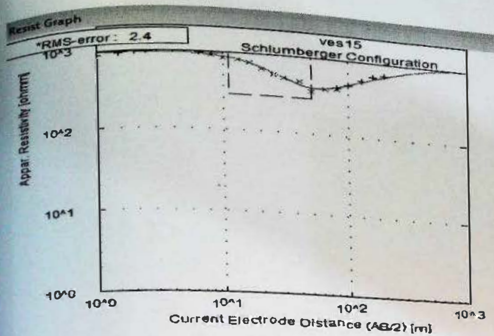
Schlumberger Array

AB/2	RES	LATITUDE	LONGITUDE	ELEVATION
1.0000	881.5000	N10°.284622	E9°.499690	581m
1.5000	869.0000			
2.0000	850.5000			
2.5000	822.7000			
3.0000	780.4000			
4.0000	750.0000			
5.0000	722.2000			
6.5000	697.4000			
8.0000	645.2000			
8.0000	697.4000			
10.0000	653.5000			
13.0000	584.0000			
16.0000	551.4000			
20.0000	515.4000			
25.0000	481.7000			
30.0000	450.8000			
40.0000	410.6000			
50.0000	388.8000			
65.0000	361.2000			
80.0000	370.5000			
80.0000	391.6000			
100.0000	415.2000			
130.0000	453.2000			
160.0000	491.5000			
200.0000	550.7000			



ves14
Schlumberger Array

AB/2	RES	LATITUDE	LONGITUDE	ELEVATION
1.0000	1250.5000	N10°.284930	E9°.499820	585m
1.5000	1192.8000			
2.0000	983.0000			
2.5000	904.3000			
3.0000	886.4000			
4.0000	845.4000			
5.0000	812.6000			
6.5000	766.5000			
8.0000	700.1000			
8.0000	693.3000			
10.0000	659.2000			
13.0000	648.9000			
16.0000	610.7000			
20.0000	575.1000			
25.0000	520.8000			
30.0000	486.2000			
40.0000	431.2000			
50.0000	402.8000			
65.0000	345.2000			
80.0000	290.7000			
80.0000	316.4000			
100.0000	310.2000			
130.0000	450.2000			
160.0000	537.7000			
200.0000	724.8000			



No	Res	Thick	Depth
1	888.1	1.2	1.2
2	864.6	9.9	11.1
3	272.7	39.0	50.1
4	981.4	-.-	-.-

* RMS on smoothed data

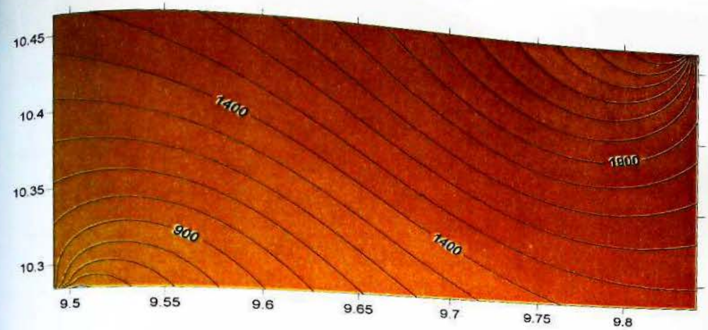
ves15

Schlumberger Array

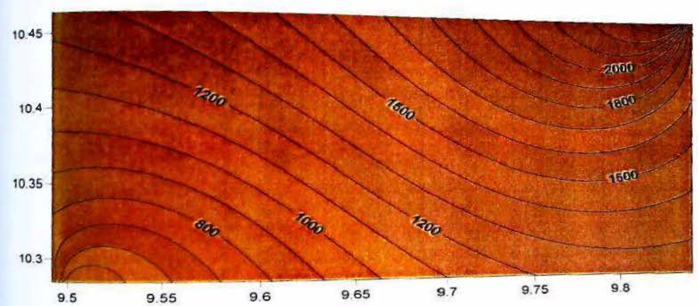
AB/2	RES	LATITUDE	LONGITUDE	ELEVATION
1.0000	805.7000	N10°.284680	E9°499910	585m
1.5000	840.1000			
2.0000	886.0000			
2.5000	910.4000			
3.0000	932.5000			
4.0000	950.7000			
5.0000	930.2000			
6.5000	885.2000			
8.0000	870.5000			
8.0000	820.0000			
10.0000	761.0000			
13.0000	742.5000			
16.0000	697.4000			
20.0000	584.5000			
25.0000	516.2000			
30.0000	479.3000			
40.0000	440.8000			
50.0000	338.7000			
65.0000	370.2000			
80.0000	380.3000			
80.0000	406.1000			
100.0000	441.3000			
130.0000	521.7000			
160.0000	598.6000			
200.0000	650.7000			

APPENDIX I

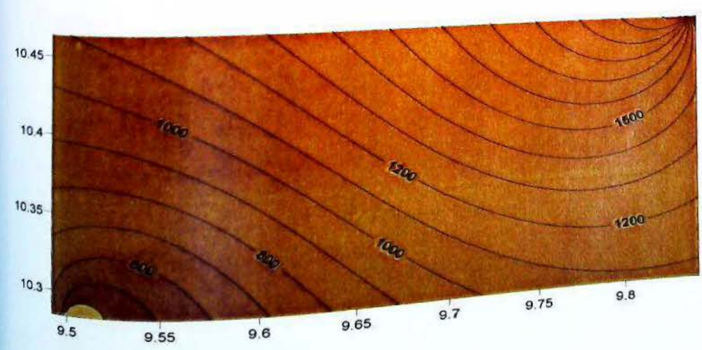
AB/2=200m



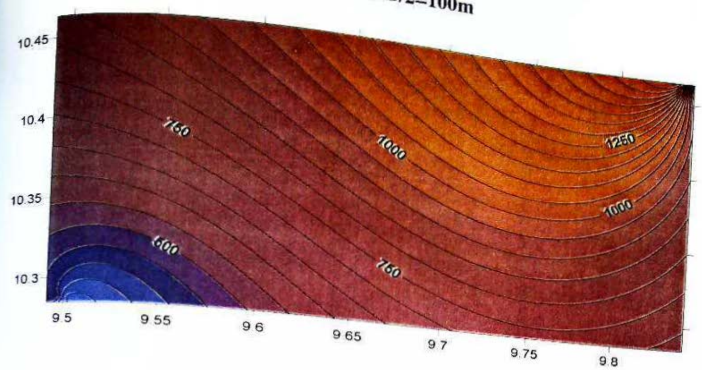
AB/2=160m



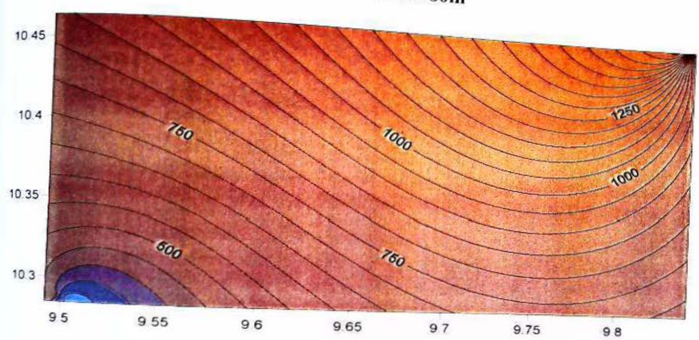
AB/2=130m



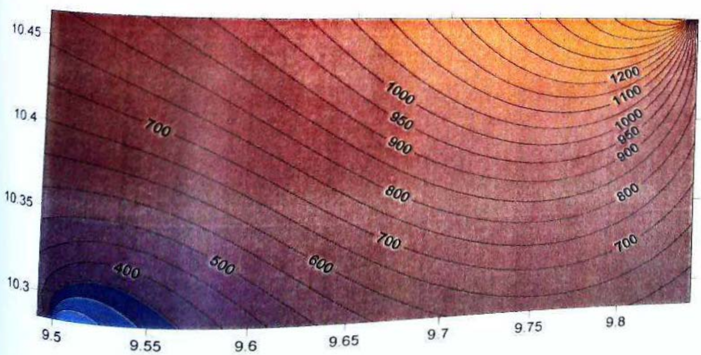
AB/2=100m



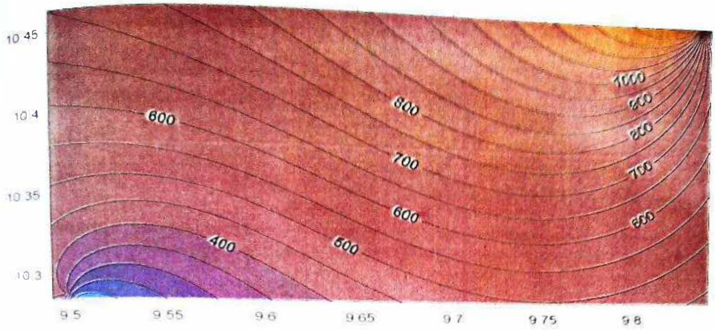
AB/2=80m



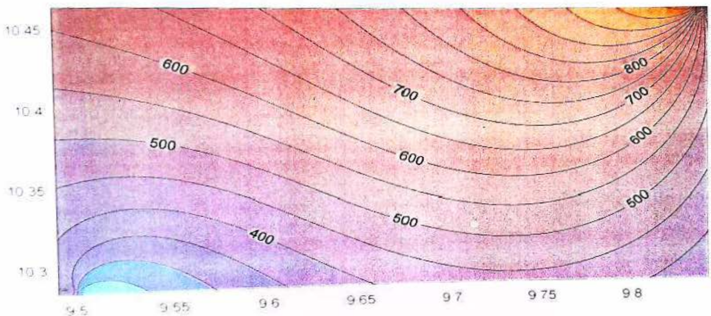
AB/2=65m



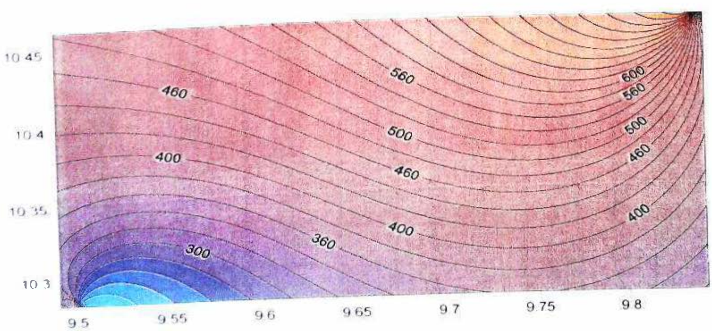
AB/2 50m



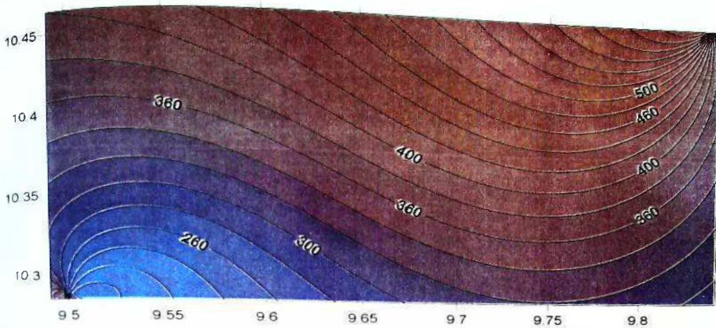
AB/2=40m



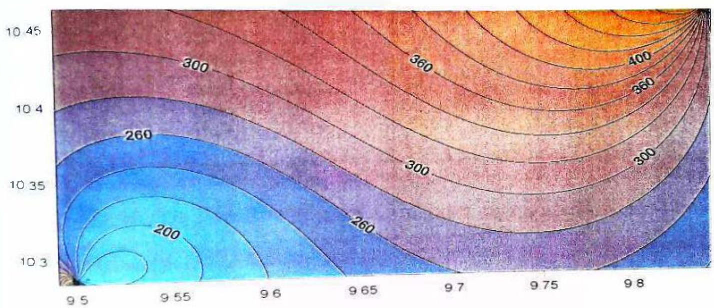
AB/2=30m



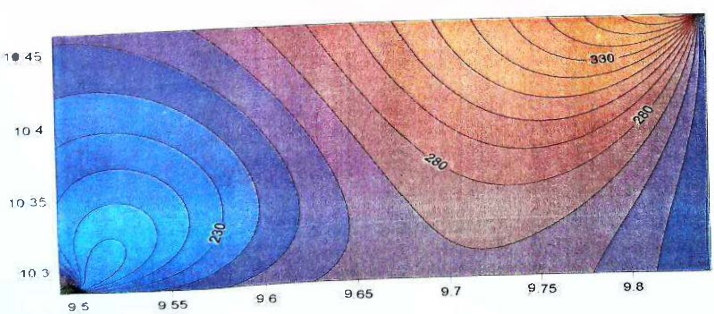
AB/2=25m



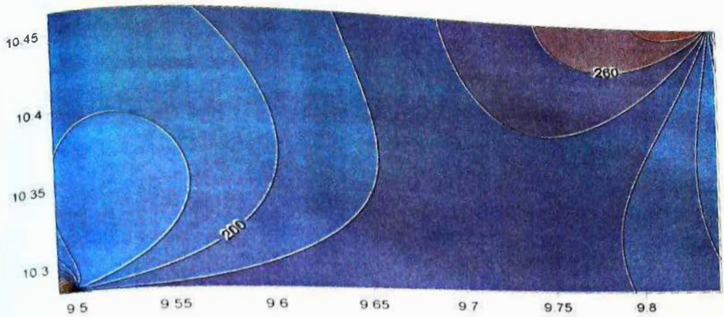
AB/2=20m



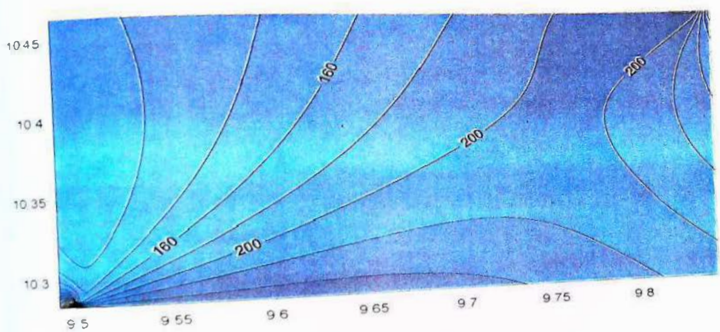
AB/2=16m



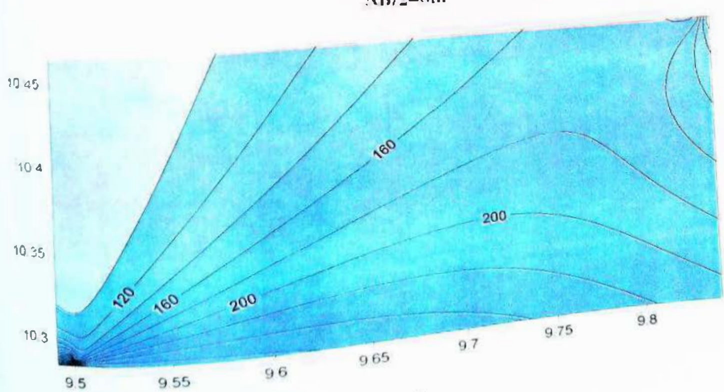
AB/2=13m



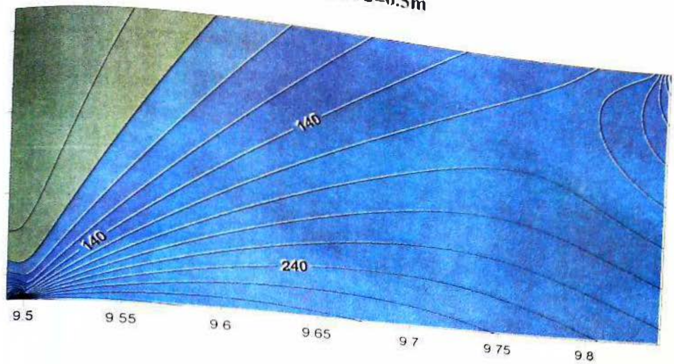
AB/2=10m



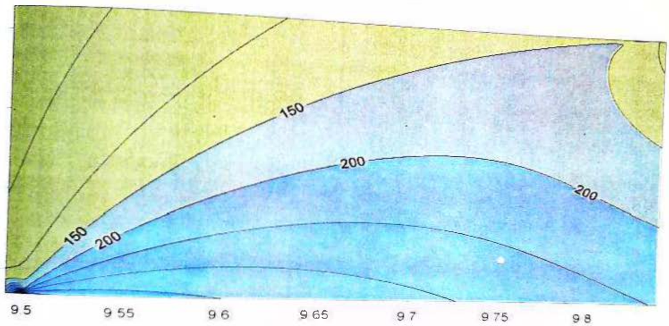
AB/2=8m



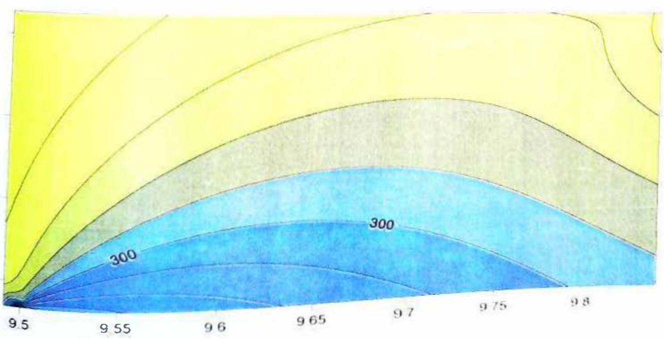
AB/2=6.5m



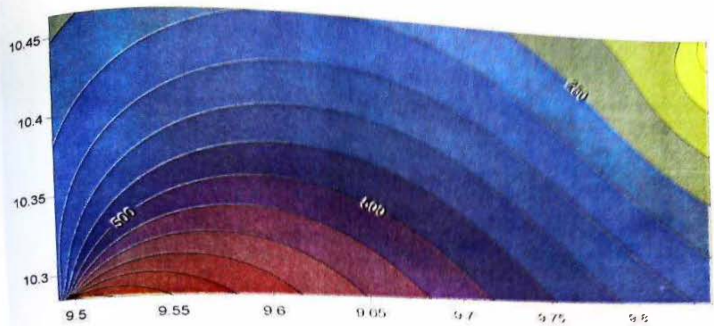
AB/2=5m



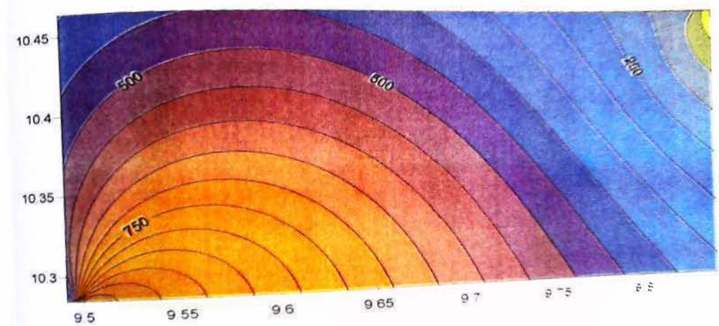
AB/2=4m



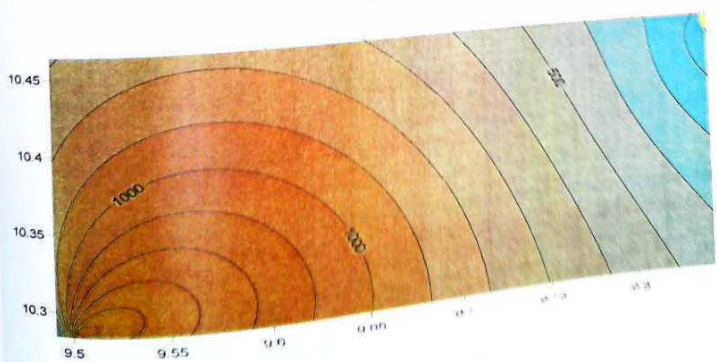
AB/2=3m



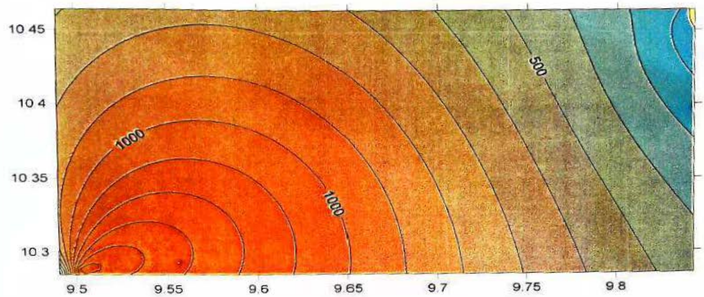
AB/2=2.5m



AB/2=2m



AB/2=1.5m



AB/2=1.0m