APPLICATION OF VERTICAL ELECTRICAL SOUNDING (VES) TO HYDROGEOPHYSICAL INVESTIGATION: A CASE STUDY OF BILLIRI AND ENVIRONS GOMBE STATE

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A CASE STUDY OF BILLIRI AND ENVIRONS,

GOMBE STATE.

BY

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(11/26995/U/1)

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AWARD OF B.TECH DEGREE IN APPLIED GEOPHYSICS

SUPERVISOR: MAL. A. D. SHEHU

FEBURARY, 2017

DECLARATION

I, Shehu Aliyu (11/26995/U/1), hereby declare that, except for other people's work, which have been duly acknowledged, this particular project has never been presented anywhere and stands a result of my research work carried out in the department of Physics, Abubakar Tafawa Balewa University, Bauchi, under the supervision of Mal. A.D. Shehu.

Shehu Aliyu (Student)

.... 10/02/2017

(Signature) date

CERTIFICATION

This is to certify that this research work meets the requirement and the regulation governing the award of a degree of Bachelor of Technology in Applied Physics (Geophysics) of Abubakar Tafawa Balewa University Bauchi.

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Date: 08/02/17..

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Professor A. M. Tijjani

Signature...

Date: 08/02/17..

EXTERNAL EXAMINER

Prof. Osita C. Meludu

Signature...

Date: 08/02/17..

DEDICATION

This research work is dedicated to the cherished and evergreen memory of my late Father Alh. Shehu Muhammed Azarema. May the most Gracious and merciful Allah grant you jannatul firdaus (Amin), and to my beloved mother Haj. Maryam Mohammed Wabi for her love, care and support. Indeed, having you is a blessing, may you live much longer! Once again, I acknowledge your contribution to my life.

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Praise is to Almighty Allah (SWT) who has made it possible for me despite the rough road. May He continue to clear all obstacles (natural and man made) on our ways to success (Amen).My profound gratitude goes to the Almighty Allah for His divine guidance and protection throughout my life to this level.

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ABSTRACT

The study area is part of sheet 173 Kaltungo North West and is about 30sqkm. It lies between latitude $9^{0}51^{1}40^{11}$ N and $9^{0}54^{1}46^{11}$ N Longitude $11^{0}12^{1}2^{11}$ E and $11^{0}15^{1}00^{11}$E. *The rock units encountered during the field mapping are: Porphyritic Granite, Biotite Granite and Bima Sandstone. Twenty Vertical Electrical Sounding (VES) were conducted around Billiri and environs, employing Schlumberger array with maximum electrode separation of AB/2 = 100 to determine locations favourable for sitting boreholes. The data obtained were interpreted using a computer software (WinResist) for resistivity data interpretation. From the result, it was found that 15 VES points are four layers while 5 VES points are three layers. The first layers have thickness ranging from 0.4 to 12.7m, the second and third layers have thicknesses ranging from 5.8 to 39.3m and 25.7 to 64.5m, respectively while the forth layers had thickness that extended beyond the probing depth. Six different curve types obtained from the study area,* AH, KA, KQ, AA, QH and HK. *The Geoelectrical layers for the VES layer ranges in thickness between* 0.4-60.8m, *with recommended drilling depth of 40- 70m.The study area therefore has potential of moderate yield from borehole but such project must be preceded by a proper geologic/geophysical survey.*

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CHAPTER ONE

INTRODUCTION

1.1 General Introduction

The study area is part of sheet 173 Kaltungo North West. It lies between latitude $9^{0}51^{1}40^{11}$ N and $9^{0}54^{1}46^{11}$ N Longitude $11^{0}12^{1}2^{11}$ E and $11^{0}15^{1}00^{11}$E. The study area forms part of the Gongola Arm of the Upper Benue Trough of North Eastern Nigeria. Geophysical methods have been a very useful tool in determining the geological characteristics of the underlying rocks by measurement of their physical properties. There are various techniques employed in groundwater exploration, electrical resistivity method is reliable in identifying zones of relatively low resistivity which might be indicative of saturated strata in various conducted geophysical surveys.

Vertical electrical sounding (VES) is a geophysical method for investigation of a geological medium. It is by far the most used method for geoelectric surveying, because it is one of the cheapest geophysical method and it gives very good results in many area of interest. The field measurements technique is adjustable for the different topographic conditions and the interpretation of the data can be done with specialized software, with a primary interpretation immediately after the measurements. The results of VES measurements can be interpreted qualitatively as well as quantitatively. The quantitative interpretation, in the case of mineral exploration, can give the chance to evaluate the reserves in a certain area of interest. The principle of this method is to insert an electric current, of known intensity, through the ground with the help of two electrodes (power electrodes – AB) and measuring the electric potential difference with another two electrodes (measuring electrodes – MN). The investigation depth is proportional with the distance between the power electrodes. The method is based on the estimation of the electrical conductivity or resistivity of the medium. The interpretation of the measurements can be performed based on the apparent resistivity values. The depth of investigation depends on the distance between the current electrodes. In order to obtain the apparent resistivity as the function of depth, the measurements for each position are performed with several different distances between current electrodes.

1.2 Aim and Objectives of the research

The aim of this research is to carry out a detailed Hydro-geophysical investigation of Billiri and environs. This aim is achievable through the following objectives:

i. Determining the pattern of resistivity variation with depth in various locations.

ii. Relate the resistivity and thickness to water bearing zones.

iii. Identify units that are favourable for ground water development in the study area.

1.3 Location and Accessibility of the Study Area

The study area is located in Billiri Local Government area of Gombe State (Figure 1) and forms part of sheet 173 Kaltungo North West, It lies between latitude $9^{0}51^{1}40^{11}$ N and $9^{0}54^{1}46^{11}$ N Longitude $11^{0}12^{1}2^{11}$ E and $11^{0}15^{1}00^{11}$E and covers an area of about 30 square km (Figure 2). The area is accessed through a network of major roads, minor roads and foot paths. The major road is the Gombe to Yola highway. The minor roads include roads leading to Banganje, Bare, Billiri Mai palace, General Hospital road and by-pass to Filiya road.

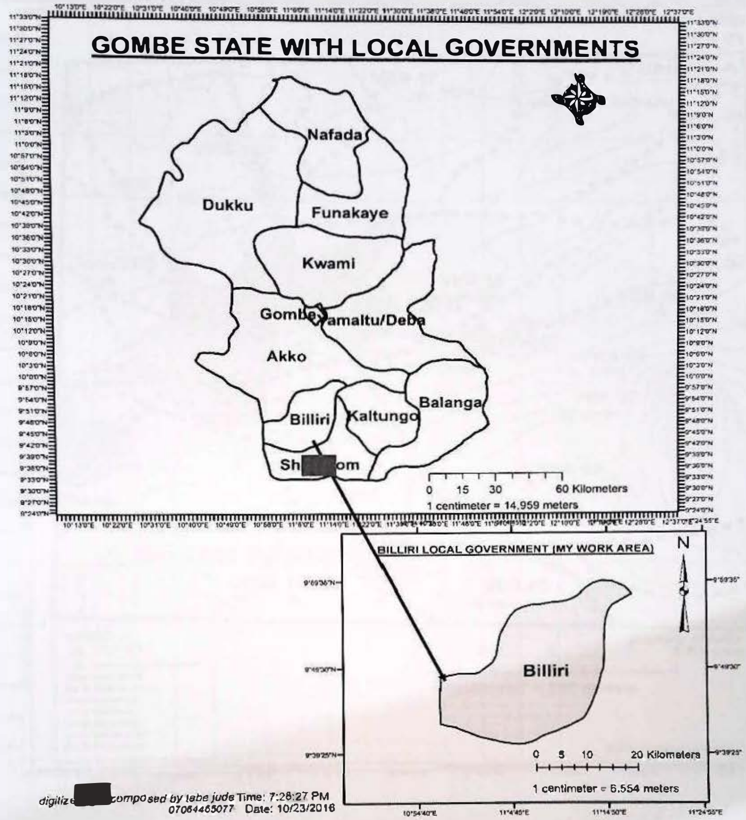


Fig. 1: Map of Gombe State showing the Location of the study area

Source: Ministry of Land and survey Gombe State 2010

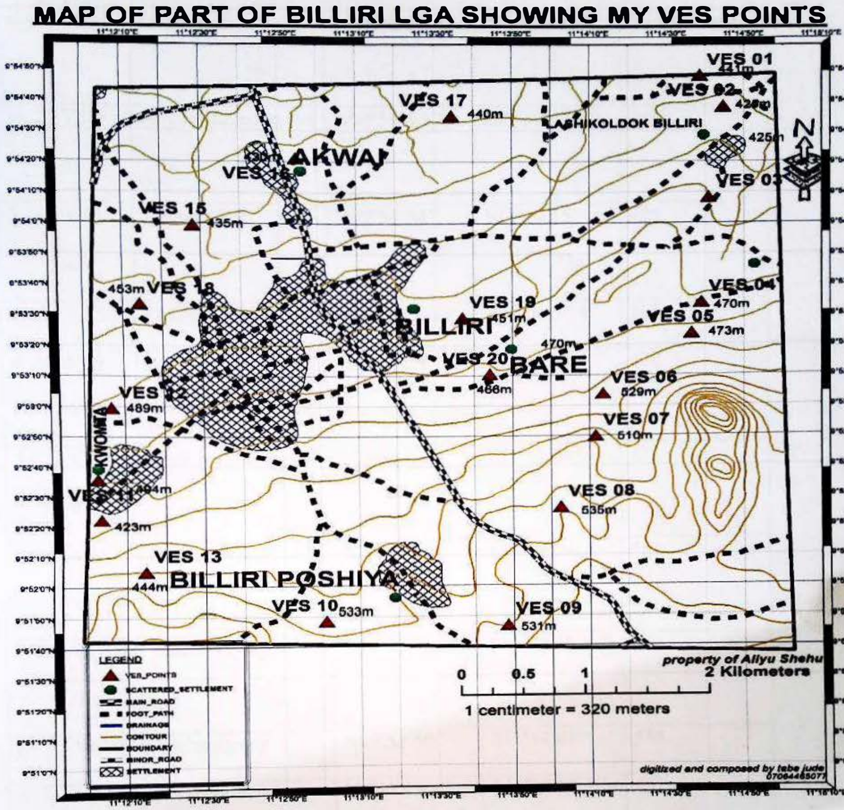


Figure 2: Topographical map of the Study area showing the VES points

Table 1: The Vertical Electrical Sounding (VES) Location and their coordinates

s/no	VES No	Location	Latitude	Longitude	Elevation(m)
1	VES 01	AnguwanZazzagawa	N09°54'6.5"	E11°13'11"	441
2	VES 02	Lashikoldok	N09°54'34"	E11°14'55"	425
3	VES03	Lashikoldok	N09°50'30.8"	E11°04'57.4"	364
4	VES 04	Lasiklc	N09°53'23"	E11°13'54"	470
5	VES 05	Lasikle	N09°53'20.8"	E11°12'48.8"	473
6	VES 06	Kentengereng	N9°53'11"	E11°13'24"	529
7	VES 07	Kentengereng	N09°53'40.59"	E11°05'30.83"	510
8	VES08	Kentengereng	N09°52'50"	E11°14'41"	535
9	VES 09	Poshiya	N9°51'49.2"	E11°13'37.5"	531
10	VES 10	Poshiya	N09°51'48.1"	E11°13'38.2"	533
11	VES 11	Kwomta	N09°52'30.9"	E11°12'19.6"	494
12	VES 12	Kwomta	N09°52'36.4"	E11°12'36.7"	489

13	VES 13	Kalmai	N09°56'40.2"	E11°07'17.2"	444
14	VES14	Kalmai	N09°55'29.3"	E11°10'15.3"	423
15	VES 15	Akwai	N09°53'56"	E11°13'16"	435
16	VES 16	Akwai	N09°54'45"	E11°12'34"	430
17	VES 17	Akwai	N09°54'2.5"	E11°13'5.3"	440
18	VES 18	Kilikkilik	N09°53'24.2"	E11°12'31.4"	453
19	VES 19	Bare	N09°53'56.6"	E11°13'33.1"	451
20	VES 20	Bare	N09°53'48.5"	E11°13'30.9"	466

1.4 Topography and Drainage

Numerous geological units often demarcated their topographic patterns such that, Basement rocks and Cretaceous Bima sandstone constitute prominent topographic features ranging from 20-150m in height. The Granites of the Basement Complex form isolated, rocky hills in the southeastern part, and in the northern Part around Akwai, The Bima Sandstone form most of the part of Billiri. The topography (i.e. hills and valleys) in the study area has influence the drainage pattern (Figure 2). The study area is underlain predominantly by Basement rocks.

There is North-East and South-West structural trend which is related to the directional flow of the Stream, Rivers and Valleys thus fonning a dendritic drainage pattern.

1.5 Climate and Vegetation

The area is tropical continental [Sudan] climate. The climate consists basically of two Seasons, a rainy season and dry season. The onset of rainy season is from April-June and ceases at the end of October, with average Rainfall of about 2.38mm annually. This season is also characterized by humidity and Temperature of about 25 ^{0}C while in the dry season, temperature of about 32 ^{0}C is usually recorded. The vegetation is of Sudan Savannah type which covers more than half of northern Nigeria. It is characterized by the short grasses of 1.2-2.0 meters high sporadic thorny bushes and scattered trees.

1.6 Settlement and Land Use

Billiri town, being the administrative headquarters of Billiri local government area is inhabited by many people, especially the Tangales. It is a developing town and has a population of about 202,144 (2006 census).

The majority of the people practice agriculture; growing crops like maize, guinea corn, beans, groundnut and rearing of animals like pigs, goats, and cattle. Crops like groundnut, guinea corn are grown mainly in the southern part of the study area (which is underlain by Basement rocks).

1.7 Justification of the Study

i. The study will provide information on depth to which ground water can be exploited.

ii. The study will reveal the geo-electrical properties of layers one may encounter in the study area.

iii. It will also provide data base for government agencies, private individuals and non-governmental organization that intent to locate productive bore hole in the study area.

CHAPTER TWO

LITERATURE REVIEW

Various geoscientists have carried out researches on the different aspect on Nigerian geology. The earliest of them was Falconer (1911) who introduced the terms and differentiates between Younger Granites and Older Granites.

In the aspect of structural and tectonic studies Grant (1971) carried- out isotopic age determination which indicated that the Basement Complex of Nigeria has been subjected to not less than three successive Orogenic cycles that include; Pan African Orogeny (650 _+150 million years ago),

The Nigerian geological survey agency in 1923, carried out a hydrogeological investigation of Northern Nigeria, this has led to the drilling of the first Bore hole in Misau town (Misau 1) in Bauchi State.

Benkhelil (1986) conclude that in the upper Benue trough the Precambrian basement crops out in this area which is an inlier within the cretaceous sediment.

Barber et al (1957) differentiated the Bima Sandstone; which they called Bima grits. According to Carter et al (1963) the Bima Formation consist of coarse grained thick bedded feldspathic sandstone with intercalation of thin bands of siltstone and mudstone. The Formation attains maximum development in the Lamurde anticline. The sediments were deposited in a fluvial and deltaic environment in Albian to Cenomanian time.

Carter et al (1963) summarized the geology of the study area as consisting of crystalline Basement represented mainly by granitic rocks, overlain by Cretaceous to Recent sediment and some intrusive volcanic rocks.

The Continental Bima group comprise the sediment in the Upper Benue Trough directly overlain the crystalline basement rocks, Falconer (1911) Carter et al. (1963) and Allix (1983) gave description of the sequence exposed at Bima hill recognised a threefold subdivision.

Allix (1983) proposed a twofold sub-division consisting of a lower shale unit deposited in lacustrine environment and an Upper thickly bedded feldspathic sandstone unit deposited in a fluviarite environment. Petters (1982). Nwajide (1990). Idowu and Ekweozor (1993) were of the opinion that Benue trough is sediment filled with N-E trending depression in Nigeria it is arbitrurity sub- divided into lower middle and upper region. Allix and Popoff (1983) assigned an Upper Aptian to Mid Albian age to the lower and middle unit, Albian to Turonian age for the upper series.

Akande et al (1998) and Obaje et al (1999) proposed that Gongola arm and Yola arm Albian Bima sandstone formation lies unconformably on the Cambrian basement which was deposited in continental condition.

2.1 Regional Geology

The study area is part of the Gongola Arm of the Upper Benue Trough northeast, Nigeria. The Benue Trough was understood to be a trough that was formed due to rifting (Carter et al.1963; Catchley and Jones, 1965).

The Benue Trough (Fig. 3) is an elongated rift basin in central West Africa filled with Cretaceous-Tertiary sediment. The Benue Trough is one of the most important of all the Cretaceous sedimentary basins in Nigeria, Benkhalil, (1989). It stretches in the NE-SW direction for about 1000Km over a Precambrian Basement Complex. The southern limit is northern boundary of Niger Delta, while the northern limit is the southern boundary of the Chad Basin. The Trough is bordered on each side by Crystalline Basement Complex, (Carter et. al, 1963; Oyawoye, 1972, McCurry, 1971).

The Basin which is geographically divided into three parts; The Upper or North-East region; Middle region or Lafia-Muri area; and the Lower or Southern Benue Trough, which is the area south and west of Makurdi. The study area falls strictly within the Upper Benue Trough.

2.2 Upper Benue Trough

The upper Benue Trough is divided into two branches trending N-S and E-W and named Gongola and Yola arm respectively, Carter, et.al. (1963) produced the foundation work of the geology of the Upper Benue Trough. The two arms are separated by NE-SW trending ridge called the Zambuk Ridge. The Cretaceous sedimentary deposits of the two sub basins are characterized by the deposition of a continental deposit and overlain by marine deposits.

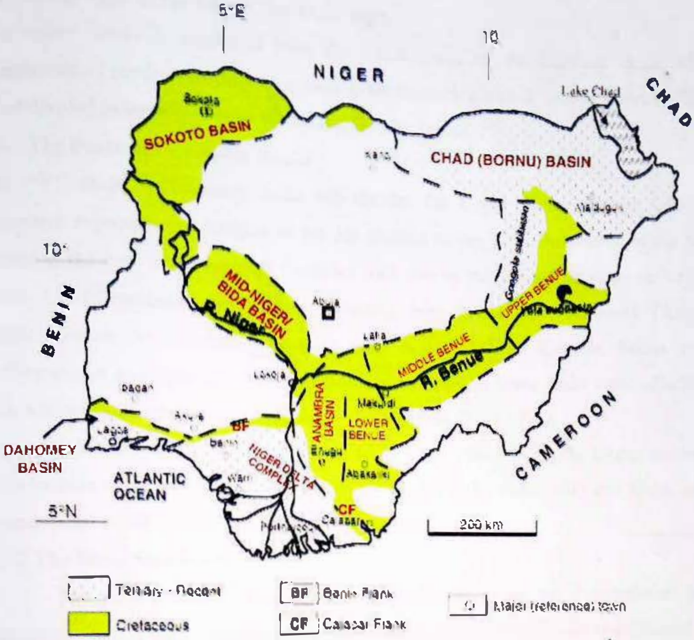


Fig. 3: Map of Nigeria showing Benue Trough and other Sedimentary Basins (After Obaje (2009)

The stratigraphic succession of the Benue trough is shown in (Fig.4 :). The study area lies within the Gongola sub basin which is characterized by the following stratigraphic sub units, the :Bima sandstone, Yolde Formation, Pindiga Formation and Gombe sandstone (Carter et al. 1963).

2.3 Stratigraphy of the Upper Benue Trough

The upper Benue is separated from the Chad basin by the Zambuk ridge which runs approximately north-eastwards from near town through Zambuk to Biu Plateau. This region is subdivided sedimentary basins; Lau and Gombe basins.

2.3.1 The Basement Complex Rocks

The "Y" shape sedimentary basin sub divides the Upper Benue Trough into three (3) Basement exposure; the margins of the Jos plateau to the West, Adamawa to the South and Hawul to the east. The Basement Complex rock can be subdivided into two major lithologic units; Un-differentiated Migmatite, including high grade Meta-sediment (Amphibolitic Schist, Garnet Mica-Schist, Quartzite etc.) and an Older Granite Series containing Orthogneisses and Granites. It is commonly assumed that these units were affected by the Pan-African thermotectonic event (600+- 70 MY) (Mc Curry 1971).

Volcanic rocks are particularly abundant in this position of the Upper Benue Trough with basaltic lava flow forming characteristic plateaus (Biu-Lunguda) and plugs, especially concentrated South and West of the Kaltungo inlier.

2.3.2 The Bima Sandstone

The Albian Bima Sandstone lies unconformably on the Precambrian Basement Complex. This Formation was deposited under continental conditions (fluvial, deltaic, lacustrine) and is made up of coarse to medium grained sandstones, intercalated with carbonaceous clays, shales, and mudstones.(Carter et al 1963). The Bima Sandstone was subdivided by Carter et al. (1963) into a Lower, Middle and Upper Bima. The Middle Bima is reported to be shaley in most parts with some limestone intercalations and was assumed to be deposited under a more aqueous anoxic condition (lacustrine, brief marine). There is exposure of carbonaceous shales within the Bima Sandstone in the section along the river channel to the south of the bridge, 20m (just) before the village of Bambam. Similar shales also occur within units of the Bima Sandstone that outcrop extensively on the Lamurde anticline (2 km) to the town of Lafiya, on the Gombe – Yola road). Good exposures of the Bima Sandstone can be observed around Billiri, Filiya and Cham.

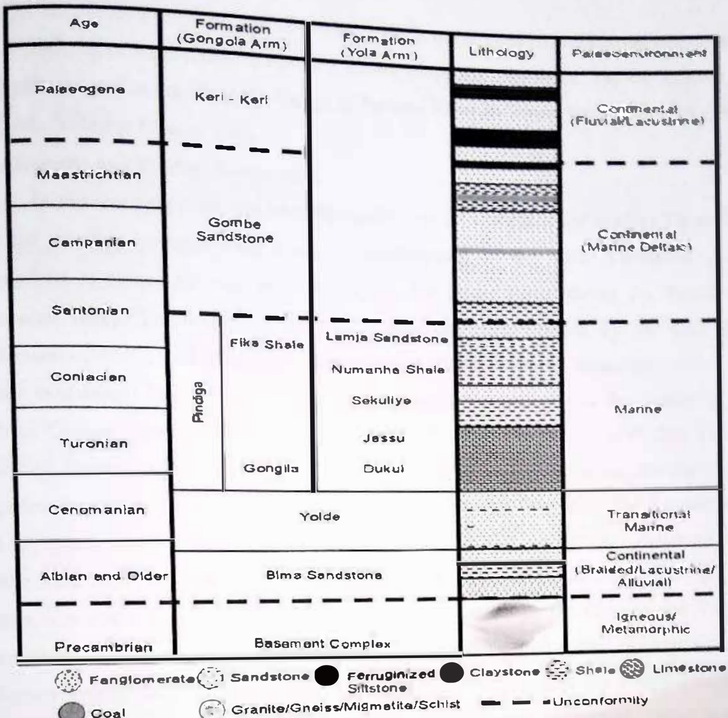


Fig.4: The Stratigraphic Succession of the upper Benue trough (After Abubakar, 2006).

2.3.3 The Yolde Formation

The Yolde Formation lies conformably on the Bima Sandstone. This Formation of Cenomanian age represents the beginning of marine incursion into this part of the Benue

Trough. The Yolde Formation was deposited under a transitional/coastal marine environment and is made up of sandstones, limestones, shales, clays and claystones. Typical localities of the Yolde Formation are along the Valley of Pantami River in Gombe town and in the village of Yolde, 50 km to Numan town.

2.3.4 Gongila and Pindiga Formations

In the Gongola Arm, the laterally equivalents of Gongila and Pindiga Formations and the possibly younger Fika Shale lie conformably on the Yolde Formation. These Formations represent full marine incursion into the Upper Benue during the Turonian – Santonian times. Lithologically, these formations are characterized by the dark/black carbonaceous shales and limestones, intercalating with pale colored limestones, shales and minor sandstones. The typical locality of the Gongila Formation is at the Quarry of the Ashaka Cement Company at Ashaka while that of Pindiga Formation is at Pindiga village. The Fika Shale is lithologically made up of bluish-greenish carbonaceous, sometime pale gypsiferous, highly fissile Shale sand occasional limestones in places. The Formation is entirely marine and has its typical locality at Nafada village on the Gombe – Potiskum road. In the Yola Arm, the Dukul, Jessu and Sekuliye Formations, the Numanha Shale, and the Lamja Sandstone are the Turonian – Santonian equivalents of the Gongila and Pindiga Formations. The Turonian – Santonian deposits in the Yola Arm are lithologically and palaeoenvironmentally similar to those in the Gongola Arm, except the Lamja Sandstone which has a dominant marine sandstone lithology. The recovery of diversed assemblages of arenaceous alongside planktonic foraminiferal samples obtained from the Dukul, Jessu and Sekuliye Formations indicate deposition in shallow marine – neritic – shelfal environments. The type locality of the Dukul Formation is in the village of Dukul with good exposures also at Bambam and Lakun on the Gombe – Yola road. All the other Formations have their type localities in the villages named after them. The Santonian was a period of folding and deformation in the whole of the Benue Trough. (Benkhelil, M.J 1982.)

2.3.5 Gombe Sandstone

Post-folding sediments are represented by the continental Gombe Sandstone of Maastrichtian age. The Gombe Sandstone is lithologically similar to the Bima Sandstone, attesting to the re- establishment of the Albian palaeoenvironmental condition. The Gombe Sandstone Formation, however, contains coal, lignite, and coal shale intercalations which in places are very thick. The type locality of the Gombe Sandstone is along the bank of Pantami River in Gombe town. Good exposures are also encountered in many parts of Gombe town and Birin Fulani village

2.3.6 The Keri–Keri Formation

The Keri–Keri Formation is made up of whitish grey sandstones, siltstones, and claystones with the claystones dominating the lithology in most places, typical sections are exposed in Gombe Aba, Dukku and Alkaleri. The Kerri-Kerri Fonnation is characterized by fining upwards sequence in most part but coarsening upward sequence have been obtained at Maimaji and Duguri (Dike, 1993).

2.4 Local Geology of the Study Area

The study area which covers an area of 30sqkm is underlain by four lithologies (Figure 5); the Basement Complex rocks which include: Coarsed-porphyritic granite, and Medium – Coarse Grained Biotite Granite. The cretaceous sedimentary rock outcrop is the Bima sandstone and lastly the Basalt. The Basement Complex is Precambrian in age and Bima sandstone is Albian in age.

2.4.1 The Basement Complex

The Basement Complex is highly fractured and weathered. The rock units in the study areas belong to those of the crystalline Basement Complex rock of the upper Benue trough collectively known as the older granite (Falconer, 1911) and covers about 40% of the study area which is to the Southern part of the Study area. The rocks include coarse porphyritic pegmatite and medium – coarse grained biotite granite.

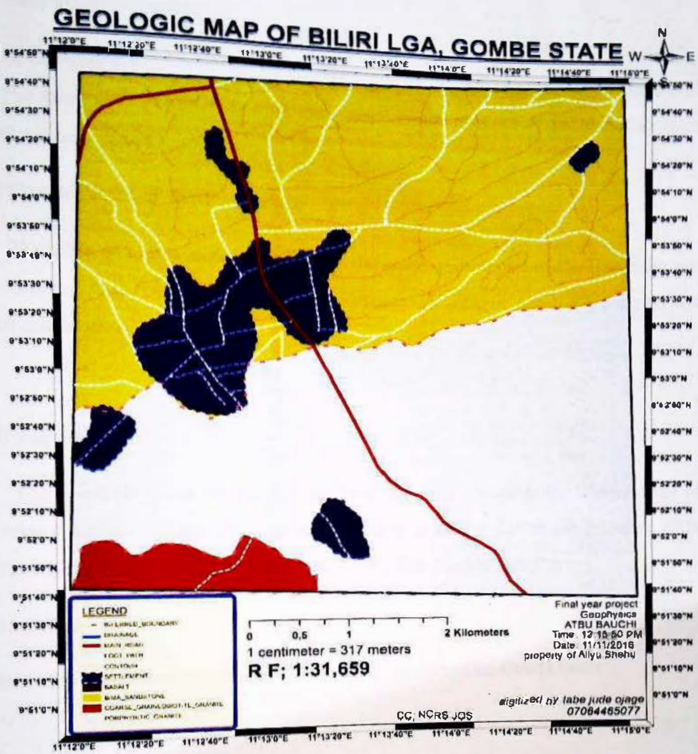


Fig.5: Geologic map of the study area

2.4.1.1 Porphyritic Granite

This rock occupies a portion of the south eastern part of the Basement portion (which is about 40%). The mineral grains are Coarse in size with feldspar phenocryst and the other minerals are mainly quartz, and Biotite.

2.4.1.2 Coarse Grained Biotite Granite

This rock occupies extreme portion of the south eastern part of the Basement portion (which is about 5%). The mineral grains are Medium – Coarse in size and are mainly quartz, feldspar and Biotite.

2.4.2 Basalt Plugs

The basalt plugs out crop within the Bima Sandstone towards the Western part of the study area, it occurs in form of plugs and it is dark in colour due to the presence of mafic minerals such as Olivine and Pyroxenes and is very fine grained in texture.

2.5 Structures

The structures are graded bedding ,cross bedding, Ripple marks, Quartz veins.

2.5.1 Graded Bedding

Grading occurs within the sandstone beds and contain a variety of sediments sizes .some of the beds are well graded but majority are poorly graded suggesting a turbidite environment of deposition.

2.5.2 Ripple Marks

This is produced by fluid movement over sediments. Oscillating current produces symmetrical ripples where as a well-defined current direction produces asymmetrical ripples. The crest lines of the ripples may be straight or sinuous.

2.5.3 Cross Bedding

This is one of the most oblivious sedimentary structures in the study area consist of sets of bed that are inclined relative to one another. The beds are inclined in the direction that the wind or water was moving at the time of deposition.

2.5.4 Quartz Veins

These are tabular bodies that occur within the rocks of the study area. The veins contain quartz dominantly, as principal vein mineral and with feldspar as secondary minerals. They have been formed by infilling of pre-existing joints or newly developed joint. They occur in varying sizes and width of about 1 – 30cm. The quartz vein stands higher indicating resistance to physical processes like erosion and weathering.

CHAPTER THREE

METHODOLOGY

3.1 Geological mapping Field Procedure

The field work was achieved in two (2) phases.

a. A reconnaissance survey was done which established the extent of the study area and strategy to be employed during the field study.

b. A detailed survey which entailed ground traversing along foot paths, cattle tracks, farm lands, streams channels and other paths forming the access route in the study area.

3.2 Detailed Survey

The field work phase involves mapping by traverse, in the course of traversing, detailed identification description, delineation of boundaries measurement of different lithologies and structures were made. Features like weathering effects, textures and structures were observed and recorded. Where there is rock exposure, detailed examination of the exposure was carried out and description made.

Essential Equipments used in the field includes;

1. Base map: this was used for locating geologic information observed in the field.
2. GPS for locating positions
3. Tape for taking measurements

3.3 The Electrical Resistivity Method

The electrical resistivity technique using Vertical Electrical Sounding (VES) was used to obtain information on the ground water potential of the study area. This method is designed to identify subsurface features in which ground water can be found, and has proved very much useful in the exploration for ground water (Offodile, 1991). The electrical resistivity method can be used to obtain, quick and economic details about the location; depths and resistivity of subsurface Formations.

The basis of the method is that when current is applied by conductor into the ground through electrodes, any subsurface variation in conductivity (water content) alters the current flow within the earth and this in turn affects the distribution of electric potential. The degree to which the potential at the surface is affected depends upon the size, location, shape and conductivity of the material within the ground. It is possible to obtain information about the subsurface distribution of this material from measurement of the electric potential made at the surface (i.e. by Vertical Electrical Sounding (VES). The VES follows preliminary geological assessment, based on local wells, outcrop information and location map of the study area.

3.4 Basic Principles of Electrical Resistivity Survey

In the resistivity method an electric current is introduced into ground by means of two current electrodes, and the potential difference between two potential electrodes is measured. However, the electrical survey is based on Ohm's law which explains how current (I) in a given conducting material varied with the potential differences (V) across it and that the potential difference is proportional to the current with respect to the resistance of the conducting material. The relationship is expressed as:

$$V = IR \quad \ldots\ldots (1)$$

Where, R is the resistance offered by the conducting material which is a constant independent of V or I. The electrical resistivity (ρ) of a medium is the resistance offered by a unit cube of the medium when a unit current passes normal to its surface of cross-sectional area (A). This is expressed by the equation:

$$\rho = RA/L \quad \ldots\ldots (2)$$

Where, ρ = resistivity

R = resistance offered by the medium

A = cross-sectional area of the medium

L = length of the material.

3.4.1 Vertical Electrical Sounding (VES)

The Vertical Electrical Sounding (VES) method was used for depth investigation. The objective of this method is to obtain resistivity variation with depth and more information with the hope of determining the thickness of subsurface layers. In this method, the depth of investigation depends on current electrode separation. The middle point of the array is kept constant while the current electrodes are moved outward symmetrically thereby increasing their distance apart. This leads to deeper penetration in the subsurface. The data is recorded and is multiplied by a factor appropriate to the electrode configuration and separation to obtain the apparent resistivities (ρa) of the various layers in the subsurface (Roy and Apporas, 1978).

3.4.2 General Four – Elecrodes Configuration for Resistivity Measurement

The figure below (Fig. 6) is an arrangement consisting of a pair of current electrodes and a pair of potential electrodes. Current enters into the earth at point A and leaves at point B. at the detector electrode C, the potential due to A is $+\rho I/(2\pi r_{AC})$ while the potential due to B is $-\rho I/(2\pi r_{CB})$. The combined potential C is:

$$V = \rho I/2\pi (1/r_{AC} - 1/r_{CB}) \quad (3)$$

Similarly, the resultant potential at D is:

$$V = \rho I/2\pi (1/r_{AD} - 1/r_{DB}) \quad (4)$$

The potential difference measured by a voltmeter connected between C and D is:

$$V = \rho I/2\pi [(1/r_{AC} - 1/r_{CB}) - (1/r_{AD} - 1/r_{DB})] \quad (5)$$

From equation (5), the resistivity is given by:

$$\rho = 2\pi V/I [(1/r_{AC} - 1/r_{CB}) - (1/_{AD} - 1/r_{DB})] \quad (6)$$

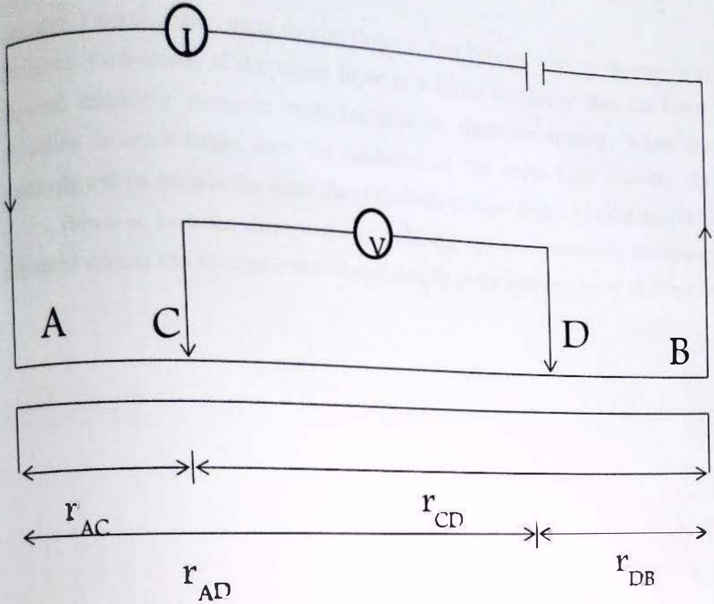


Fig. 6: General four electrodes configuration for resistivity measurement consisting of pair of current electrodes (A, B) and pair of potential electrodes (C, D), (After Lowrie, 1997).P_1<P_1

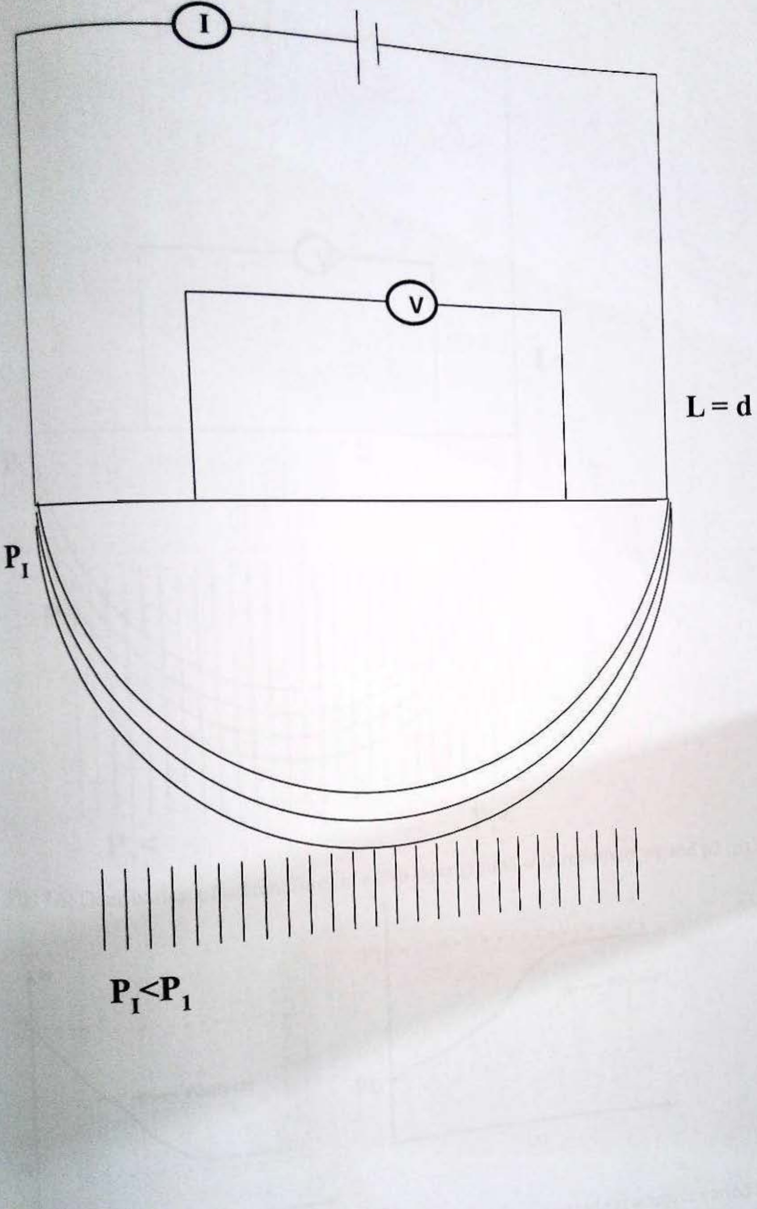
3.4.3 Apparent Resistivity (ρa)

In the idealized case of perfectly uniform conducting half space, the current flow lines resemble a dipole pattern (Fig.7a) and the resistivity determined with a four-electrode configuration is the true resistivity of the half space. But in real situations, the resistivity is determined from different lithologies and geological structures and so may be inhomogeneous. This complexity is not taken into account when measuring resistivity in a four- electrode method, which assumed that the ground is uniform. The result of such measurement is the apparent resistivity of an equivalent uniform half space and general by not representing the resistivity of any part of the ground (Kullert, 1980).

Consider a horizontally layered structure of two layers in which a layer of thickness (d) and the resistivity (pl) overlies a conducting half- space within lower resistivity (Fig. 7a). If the current electrode are close together, so that l<<d, all or most of the current flow in the top upper layers, so that the measured resistivity is close to the true value of the upper layer (pl). With increasing expansion of the current electrodes, the depth reached by the current

increases. Proportionally, more current flows in less bottom layer, so the measured resistivity decreases. Conversely, if the upper layer is a better conductor than the lower layer, the apparent resistivity increases with increase in electrode spacing. When the electrode separation is much larger than the thickness of the upper layer (L>>D), the measured resistivity will be close to the value *P*a of the bottom layer (Fig 3.1). (Kullert,1980).

However, between these extreme ends, the apparent resistivity determined from the measured current and voltage is not related simply to the true resistivity of either layer.


I
V
L = d
P_I
P_I<P_1

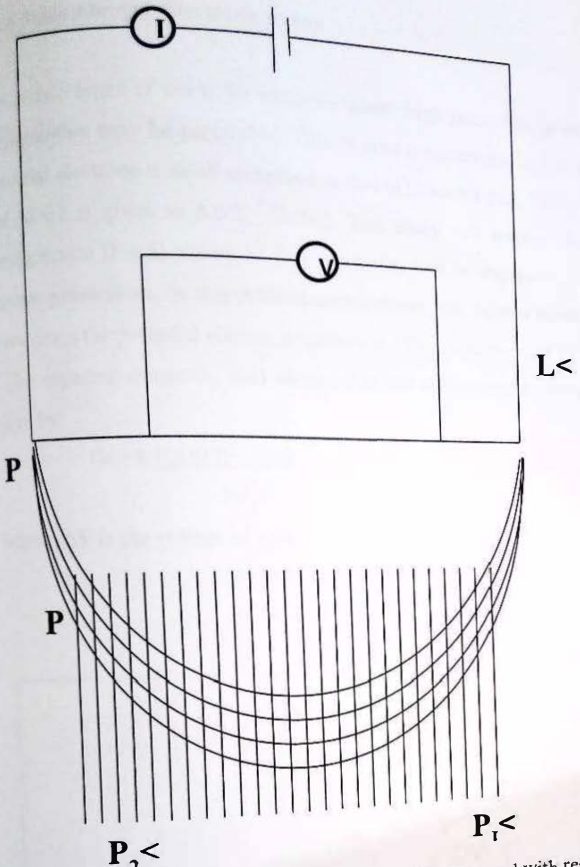


Fig. 7A: Distribution of current lines in a two layer ground with resistivity p1 and p2 (p1>p2

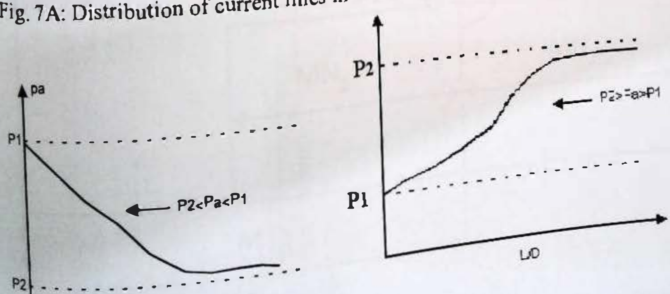


Fig.7B: The variation of apparent resistivity as the current electrode spacing is varied for the two cases of $\rho_1>\rho_2$ and $\rho_1<\rho_2$.

3.4.4 Schlumberger Electrode Array

For certain types of work, for example where high resolution is required, the schlumberger configuration may be preferable. This is also symmetrical layout but the separation of the potential electrode is small compared to that of the outer pair. The relationship between AB/2 and MN/2 is given as AB/2≥ 5MN/2. This study will employ the schlumberger electrode configuration (Fig.8) where all four electrodes will be expanded thereby resulting in deeper current penetration. In this AMNB arrangement, the current separation AB is usually 5 or more times the potential electrode separation MN (Deperman, 1954).

The apparent resistivity (pa) obtained in the schlumberger arrangement is approximately given by:

$$Pa = \pi \frac{[(AB/2)^2 - (MN/2)^2]}{2MN} . \Delta V/I \quad \text{...} (7)$$

Where, ΔV is the voltage in volts

I is current in amperes

ΔV is the measured resistant in Ohm's

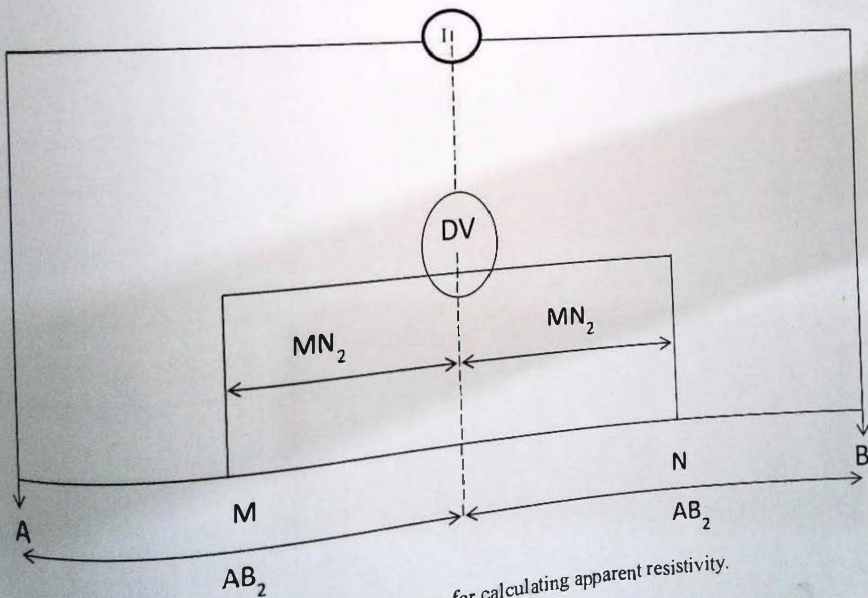


Fig. 8: Electrode arrangement defining parameters for calculating apparent resistivity.

4.5Limitations of the Method

Although resistivity surveying is an effective method for delineating shallow layered sequences or vertical discontinuities involving changes of resistivity, it has limitations:

1. Interpretations are ambiguous; consequently independent geophysical and geological controls are necessary to discriminate between valid alternative interpretations of the resistivity data.

2. Interpretations are limited to simple structural configuration. Any deviations from this simple situation may be impossible to interpret.

3. Topography and the effects of near surface resistivity variations can hide the effect of deeper variations.

3.5 Data Processing

This simply refers to detailed examination of the resistivity data obtained in the field as well as processing it for easy interpretation of the resulting data.

This involves calculating apparent resistivities data (ρ_a), which is done by multiplying the resistivities by their respective geometric constant K, (i.e. $\rho_a = R \times K$). For Schlumberger configuration, K can be obtained by using any of the following formulas;

1. $K = [(AB^2 - MN^2)/MN]\ \pi/4$.
2. . $K = (AM.AN/MN)\ \pi$.
3. $K = [(AB/2)^2 - (MN/2)^2]\ \pi / 2(MN/2)$. Where A and B are current electrodes; M and N are potential electrodes, Fig 3.4.

The processed data were interpreted using computer Software called WinResist where the field curves were compared with the computer modeled curves to deduce the layer thickness (m), true resistivity values (ohm) for each layer and the percentage fitting error of each plot mode.

3.6 Materials Needed For Effective VES Operation

1. Terrameter
2. Cable wires I.e. two potential and two current cables
3. Electrodes (at least six stainless electrodes)
4. Hammer i.e. at least two
5. Crocodiles clip

7. Measuring tapes at least of 50 metres
8. GPS (Global position system)
9. Manpower (at least three men)

3.7. Uses of the Materials

1. **Terrameter**

This is the equipment that is used to measure the resistivity of the ground after inducing electric current via electrodes(Plate 1.)

Plate 1: Ohmega Terrameter

2. **Electrodes**

These are steel conductive spikes that serve as a media through which induced electric currents are introduced the ground also serve as paths through which induced potential are detected and sent (Plate 2). Two pairs of electrode (C_1 and C_2) are the points through which the current is passed and received by the potential electrodes (P_1 and P_2).

Plate 2: Current /potential electrodes

3. Cable wires

These are four wires connecting the electr●des and the Terrameter. They are 200m in length and 0.2m in diameter rolled in a wheel- like shape made up of plastic material .During the field operation,the four rolled wires are extended by turning the wheel while spreading of electrode.

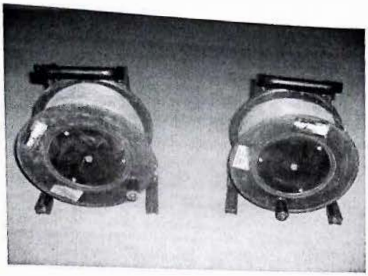


Plate 3: Cable wire

4. Crocodiles Clips

These are used to connect cable wires and the electrodes.

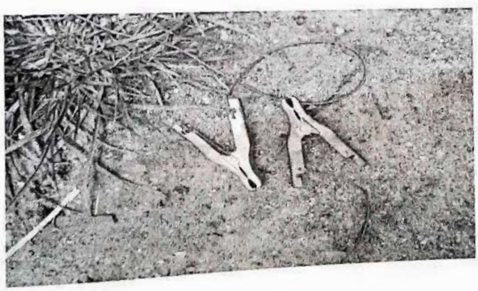


Plate 4: crocodile clips

5. Hammer

In the course of fixing the electrodes into the ground, two Hammers are used to hit them down, until when a meaningful reading is observed on the Terramcter.

Plate 5: Hammers

6. **Measuring Tape**

This is used to measure the separation of electrodes from one point to another of both currents and potential electrodes.

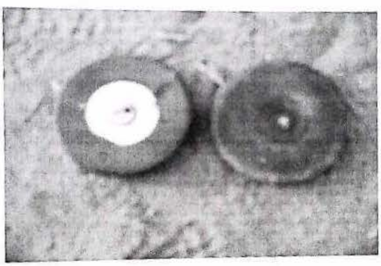


Plate 6: Measuring Tapes

7. **Man Power**

Field operation of the Vertical electrical sounding (VES) requires at least three men, one at the center i.e. the operator of the Terrameter and other two that shifts the electrodes as well as the cable wires during spreading on either sides of the device.

CHAPTER FOUR

DISCUSSION AND INTERPRETATION OF RESULT

4.1 Qualitative Interpretation

The apparent resistivity curves from the study area are presented. (table 2). Also the curves gives information concerning resitivity and thickness of the layers in the area. Quantitative interpretation of the data was done with winresist interpretation software. Basically winresist is a forward and inverse modeling program for interpreting resistivity sounding data taken with the various resistivities sounding method such as the Schlumberger Sounding System. DC resistivity sounding method is designed to be interpreted in terms of a layered earth solution. The algorithm determines the model whose theoretical geo-electric curves best fit the field data by successive iteration dictated by the numerical program in which estimate of input parameter is made for each layer and the observed and theoretical curves were calculated during the analysis. Further iteration reduces the discrepancies to a predetermined value or less as the case may be.

The assumption during the interpretation is that the underlying formation is horizontal and parallel to the earth's surface. The result of interpreted data shows that the fitting error in the study area ranges from 2.4% - 26.4% shown on the data sheets.

However, four geo-electric layers were established at 15 VES points and three geo-electric layers at 5 VES points, with resistivity values ranging from 0.4 – 1749.2.9 Ωm (Table 2). The measured electrical resistivity is reliable when the percentage fit is very low and vice-versa. This may influence the data processing/interpretation and may give negative result. Table 2 present the summary of the interpretation of VES curves.

Table 2: Result of Interpretation of VES Curves from the Study area

VES No.	Layers No.	Resistivity (Ω)	Layer Thickness (m)	Depth to Interface(m)	Inferred Lithology	Curves Types	Error (%)
01 Anguwan Zazzagawa	1	290.6	4.7	4.7	Dry Topsoil	AH	9.8
	2	8.6	14.5	19.2	Clays		
	3	18.7	--	--	Weathered Sandstone		
02 Lashikoldok	1	10.9	9.7	9.7	Dry Topsoil	AH	10.9
	2	2.8	13.7	23.4	Clays		
	3	160.2	--	--	Weathered Sandstone		
03 Lasikoldok	1	8.3	0.6	0.6	Dry Topsoil	KA	26.4
	2	480.5	6.8	7.3	Clayey Sand		
	3	545.2	35.9	43.2	Consolidated Sandstone		
	4	172.6	--	--	Weathered Sandstone		
04 Lasikle	1	755.3	0.4	0.4	Dry Topsoil	KQ	
	2	12.6	23.5	23.9	Clays		
	3	0.4	46.7	70.7	Consolidated Sandstone		

	4	1.1	--	--	Weathered Sandstone		13.3
05 Lasikle	1	19.0	2.1	2.1	Dry Topsoil		
	2	50.5	14.8	16.9	Clays		
	3	52.2	42.7	59.7	Consolidated Sandstone	AA	
	4	64.1	--	--	Weathered Sandstone		2.9
06 Kentengereng	1	616.2	3.6	3.6	Dry Topsoil		
	2	24.3	5.1	8.7	Weathered Basement	HK	
	3	274.3	28.2	36.9	Fractured Basement (Possibly auriferous)		15.9
	4	81.5	--	--	Fresh Basement		
07 Kentengereng	1	85.0	12.7	12.7	Dry Topsoil		
	2	282.2	14.2	26.9	Clays		
	3	553.9	37.8	64.8	Consolidated Sandstone	AA	
	4	505.7	--	--	Weathered Sandstone		6.1

8 Kentengereng	1	419.7	5.3	5.3	Dry Topsoil		
	2	14.5	13.4	18.7	Clays	AH	
	3	63.2	40.0	58.7	Consolidated Sandstone		
	4	58.2	--	--	Weathered Sandstone		3.3
09 Poshiya	1	206.7	4.8	4.8	Dry Topsoil		
	2	142.7	14.8	19.5	Clays	KH	
	3	555.8	45.4	65.0	Consolidated Sandstone		6.2
	4	362.4	--	--	Weathered Sandstone		
10 Poshiya	1	405.7	1.7	1.7	Dry Topsoil		
	2	49.6	10.0	11.7	Clays		
	3	218.0	42.2	53.8	Consolidated Sandstone	QH	
	4	183.6	--	–	Weathered Sandstone		2.4
11 Kwomta	1	212.7	1.0	1.0	Dry Topsoil		
	2	27.5	12.2	13.2	Weathered Basement	HA	
	3	601.6	64.5	77.8	Fractured Basement		2.5

					(Possibly auriferous)		
	4	308.6	--	--	Fresh Basement		
12 Kwomta	1	304.8	4.3	4.3	Dry Topsoil	KH	2.5
	2	662.3	15.0	19.3	Weathered Basement		
	3	183.7	60.8	80.2	Fractured Basement		
	4	251.1	--	--	Fresh Basement		
13 Kalmai	1	19.5	0.9	0.9	Dry Topsoil	AA	3.2
	2	39.4	9.6	10.5	Weathered Basement		
	3	54.2	44.1	54.6	Fractured Basement		
	4	44.4	--	--	Fresh Basement		
14 Kalmai	1	20.2	5.7	5.7	Dry Topsoil	KH	
	2	14.4	14.4	20.2	Weathered		

					Basement		
	3	30.5	41.8	62.0	Fractured Basement		4.3
	4	28.1	--	--	Fresh Basement		
VES 15 Akwai	1	109.5	0.7	0.7	Dry Topsoil	HA	7.3
	2	13.8	16.5	17.3	Weathered Basement		
	3	97.1	--	--	Fractured Basement		
VES 16 Akwai	1	916.5	0.7	0.7	Dry Topsoil		
	2	13.8	39.3	17.3	Clays		

	3	89.1	--	--	Weathered Sandstone	QH	6.5
S 17 wai	1	49.3	1.3	1.3	Dry Topsoil	AH	12.1
	2	7.6	25.3	26.3	Clays		
	3	50.8	--	--	Weathered Sandstone		
ES 18 Kilikkilik	1	291.5	0.8	0.8	Dry Topsoil	HK	10.8
	2	7.0	3.5	4.3	Clays		
	3	152.9	13.7	18.0	Consolidated Sandstone		
	4	8.1	--	--	Weathered Sandstone		
VES 19 Bare	1	61.9	11.7	11.7	Dry Topsoil		
	2	89.3	5.8	17.4	Clays		

	3	89.1	--	--	Weathered Sandstone	QH	6.5
VES 17 Akwai	1	49.3	1.3	1.3	Dry Topsoil	AH	12.1
	2	7.6	25.3	26.3	Clays		
	3	50.8	--	--	Weathered Sandstone		
VES 18 Kilikkilik	1	291.5	0.8	0.8	Dry Topsoil	HK	10.8
	2	7.0	3.5	4.3	Clays		
	3	152.9	13.7	18.0	Consolidated Sandstone		
	4	8.1	--	--	Weathered Sandstone		
VES 19 Bare	1	61.9	11.7	11.7	Dry Topsoil		
	2	89.3	5.8	17.4	Clays		

	3	532.0	41.5	58.9	Consolidated Sandstone	HA	10.0
	4	203.9	--	--	Weathered Sandstone		
VES 20 Bare	1	207.7	4.4	4.4	Dry Topsoil	AK	3.8
	2	1749.2	10.7	15.2	Clayey Sand		
	3	1220.3	25.7	40.9	Consolidated Sandstone		
	4	623.8	--	--	Weathered Sandstone		

4.1.1 Geologic Units Identified Based On the Interpretation of VES Data

Based on the interpretation of the geo-electric data, the following geo-electric units have been identified from the study area: high, fairly high, medium and low resistivity layers which also correspond to their respective inferred lithologies (Table 2)

4.1.2 High Resistivity Layers

High resistivity values characterize the unweathered, fresh crystalline bedrock in the study area and are generally identified by higher values, while on the sedimentary portion, the high resistivity value is a characteristic of highly consolidated sandstone. The weathered layer usually underlies low, medium, or fairly high resistivity layers. The crystalline basement and highly compacted sedimentary rocks normally have low porosity and permeability, except where they are faulted, fractured or jointed. Thus, they are devoid of groundwater which influences the resistivity. Non-fractured crystalline rocks have a porosity of < 3% (Offodile,1991).

4.1.3 Fairly High Resistivity Layer

This unit represents the slightly weathered and fractured zone, and the nearly porous and permeable rocks underlying the weathered mantle. The extent of weathering and fracturing is generally limited in crystalline rocks (Offodile,1991). As a result, groundwater may occur only in small pocket or basins depending on the extent of weathering.

4.1.4 Medium Resistivity Layers

This is considered to be topsoil which consists of conductive materials varying in composition from clay, laterite and sand, derived from chemical weathering of basement rocks.

4.1.5 Low Resistivity Layers

This unit is characterized by low resistivity values relative to the medium and high resistivity units. The units were interpreted as the highly weathered and fractured portion, and highly porous and permeable sandstones composed of sands, clays or clayey sands depending on the local variation of the mineralogy of the basement and sedimentary rock. This unit may contain water in storage large enough to produce a successful borehole where thickly developed.

4.2 Vertical Electrical Sounding (VES) Curves

The twenty VES points carried out in the study area showed various types of resistivity curves including type HK, AH, KA,KQ and some combinations of H, A, K and Q as shown in the figures below:

i. HK Types: Where P1>P2<P3>P4. The first layer has higher resistivity when compared to the second layer. The second layer has lower resistivity when compared to the first and third layers. The forth layers have lower resistivity compared to first three layers.

ii. AH Types: Where P1>P2<P3. The first layer has higher resistivity than the second layer. The second layer has lower resistivity when compared to the third layer.

iii. KA Types: Where P1<P2<P3>P4. The first layer has lower resistivity when compared to the second layer. The second layer has lower resistivity when compared to the third layer. The third layer has higher resistivity than the forth layer.

iv. KQ Types: Where P1>P2>P3>4. The first layer has higher resistivity than the second layer. The second layer has higher resistivity than the third layer. The third layer has higher resistivity than the forth layer

v. H types: where P1>P2<P3. The first layer has higher resistivity when compared to the second layer. The second layer has lower resistivity when compared to the third layer.

vi. A types: where P1<P2<P3. The first layer has low resistivity when compared to the second layer. The second layer has lower resistivity when compared to the third layer.

vii. K types: where P1<P2>P3. The first has low resistivity when compared to the second layer so also third layer has low resistivity than the second layer

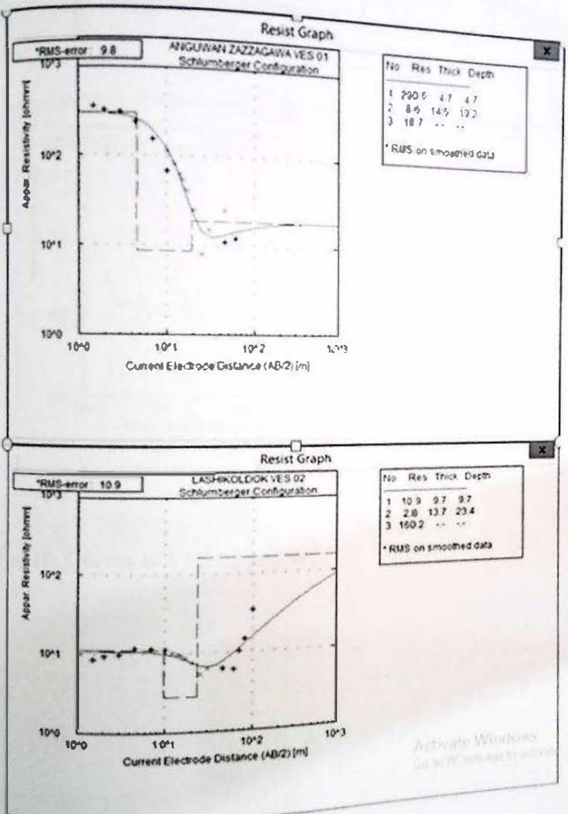


Fig. 9: Curves of VES 01 and 02

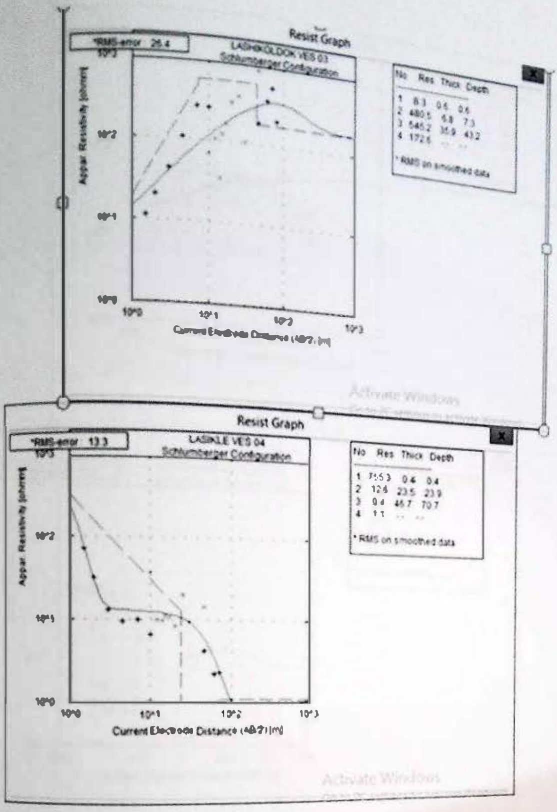


Fig. 10: Curves of VES 03 and 04

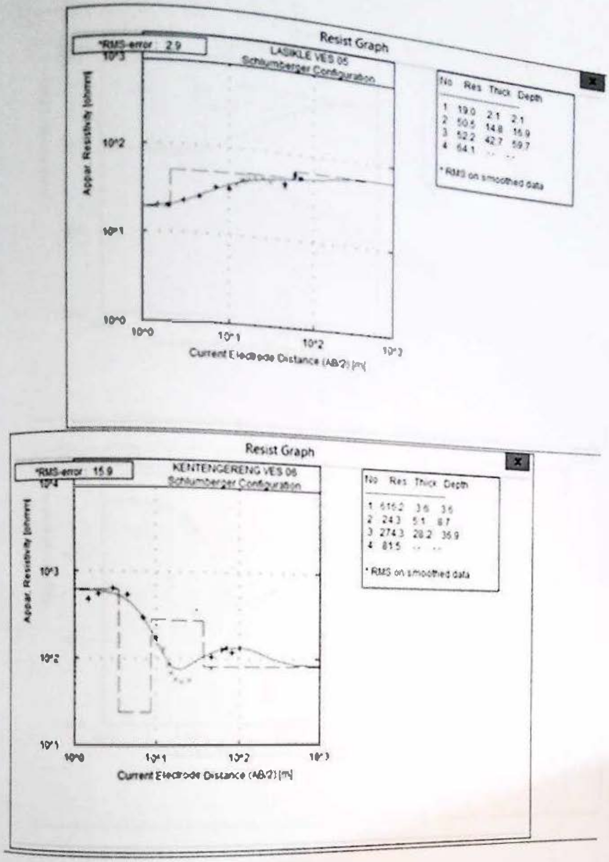


Fig. 11: Curves of VES 05 and 06

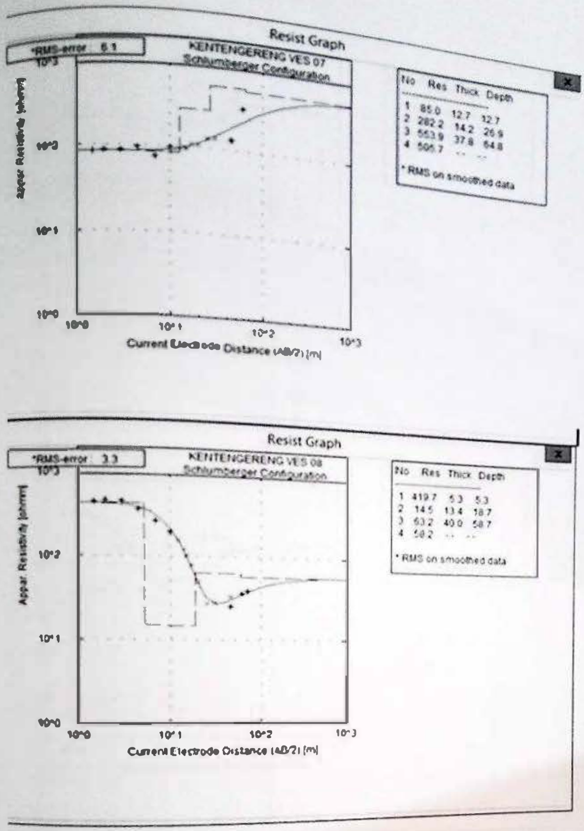


Fig. 12: Curves of VES 07 and 08

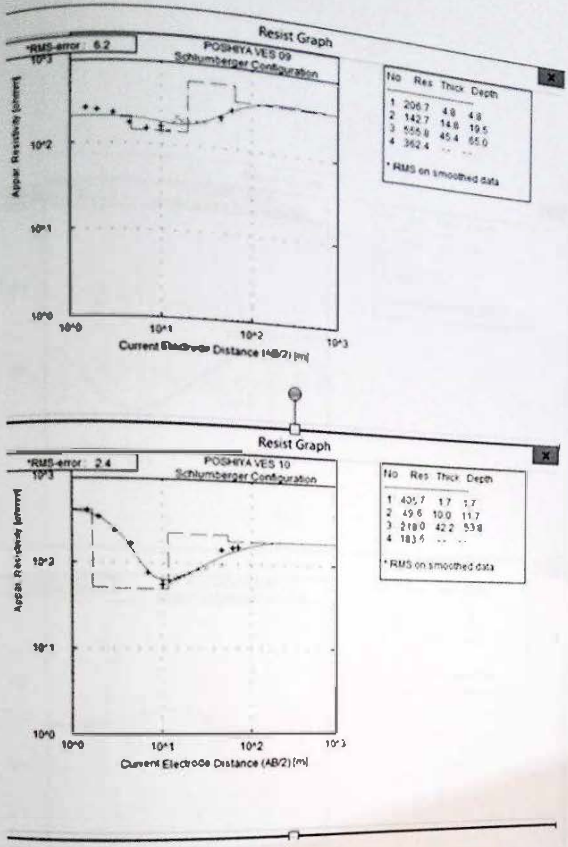


Fig. 13: Curves of VES 09 and 10

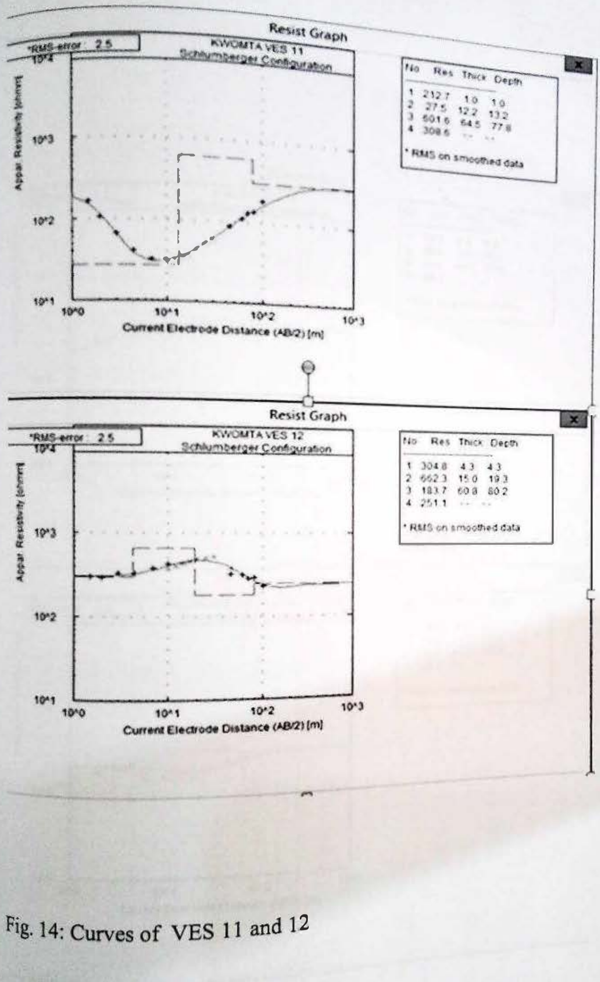


Fig. 14: Curves of VES 11 and 12

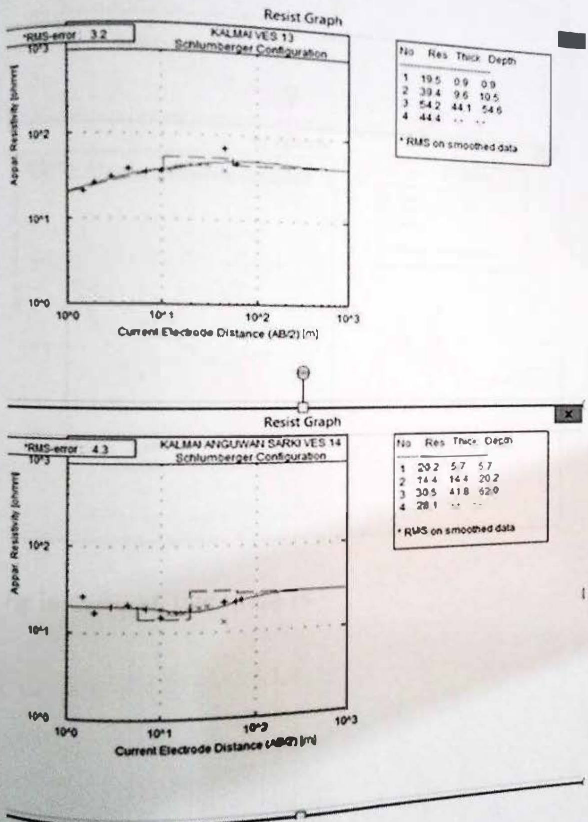


Fig. 15: Curves of VES 13 and 14

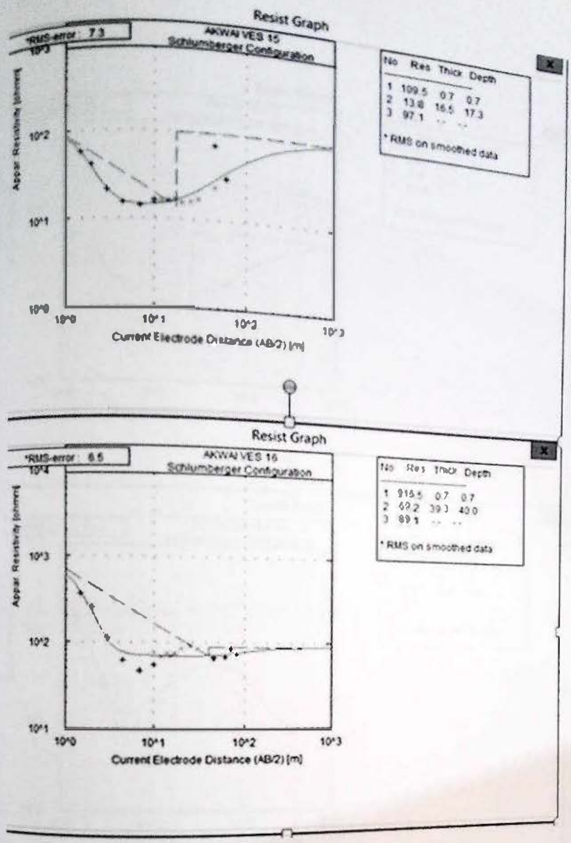


Fig. 16: Curves of VES 15 and 16

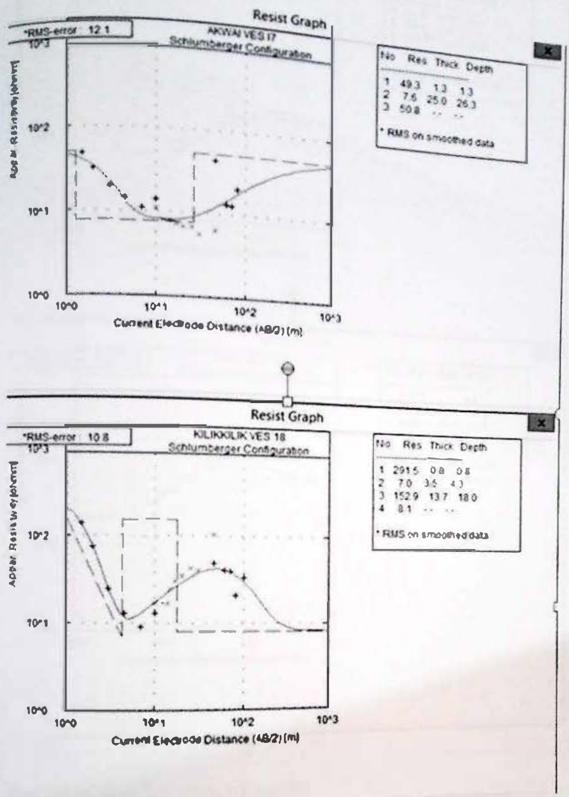


Fig. 17: Curves of VES 17 and 18

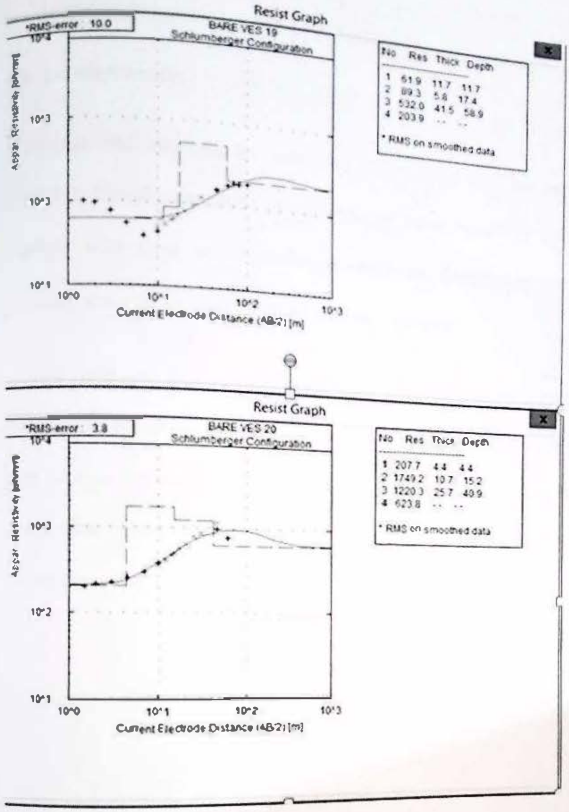


Fig. 18: Curves of VES 19 and 20

4.3 Iso-Resistivity:

A contour map showing Iso-resistivity of the study area has been produced using surfer 9 (Fig. 19). Resistivity values of the areas of equal resistivity from the various VES station together with their corresponding co-ordinate (longitudes and latitudes) were used to delineate areas of low and relatively higher resistivity.

Low resistivity infers high conductivity which, in this case, may be due to the presence of water in the subsurface. Therefore, areas of low resistivity at depth are considered as potential sites for locating successful borehole in the study area. From the Iso-Resistivity contour map of the areas around South Western to North eastern parts of the map can be considered as potential site for locating successful borehole in the study area.

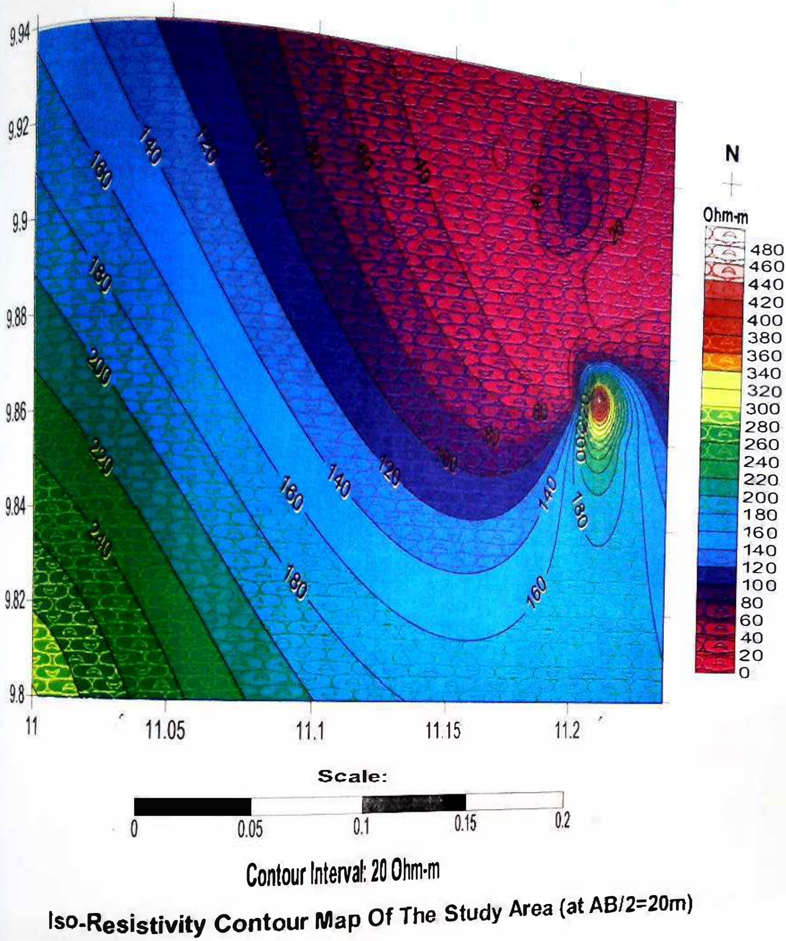
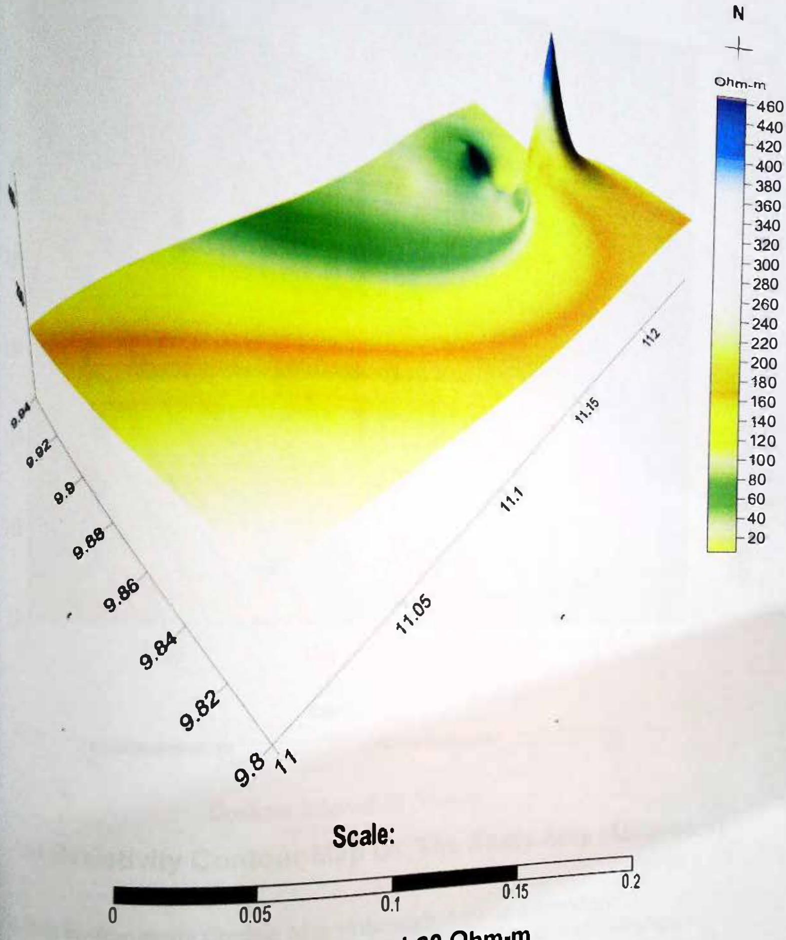


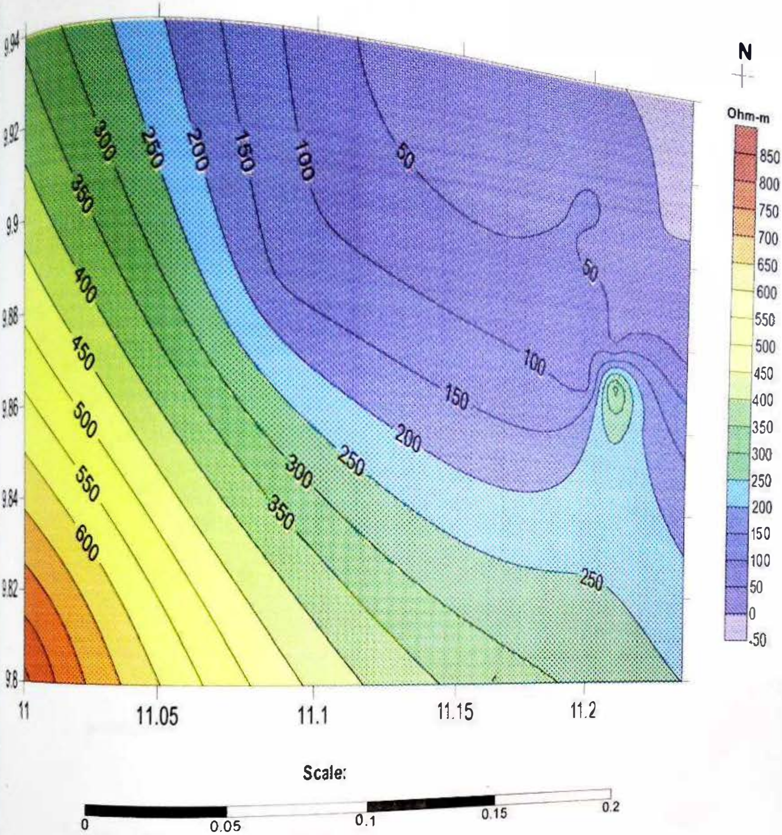
Fig. 19A: Iso-Resistivity Contour Map of the study Area (at AB/2=20m)



Contour Interval:20 Ohm-m

3-D View Surface Iso-Resistivity Contour Map Of The Study Area (at AB/2=20m)

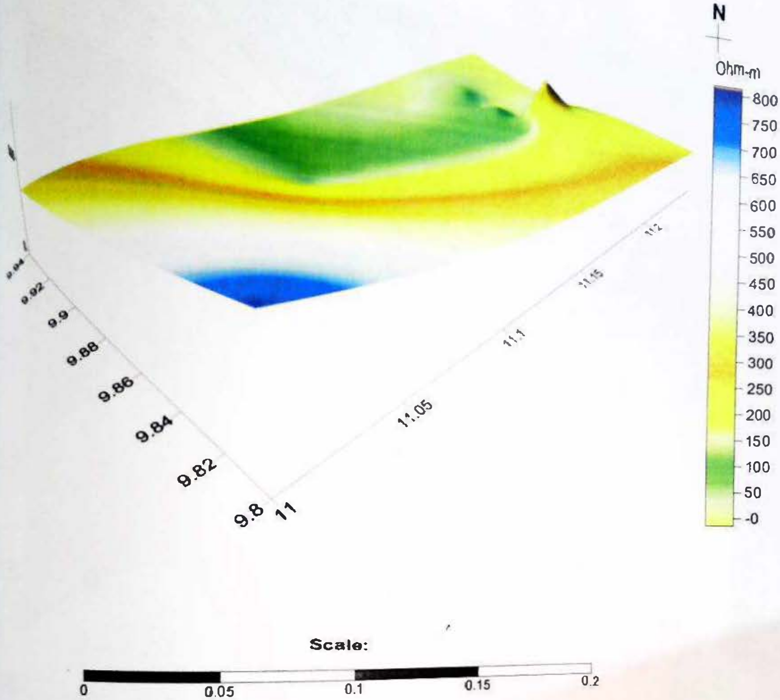
Fig. 19B: 3D view of Iso-Resistivity Contour Map of the study Area (at AB/2=20m)



Contour Interval:50 Ohm-m

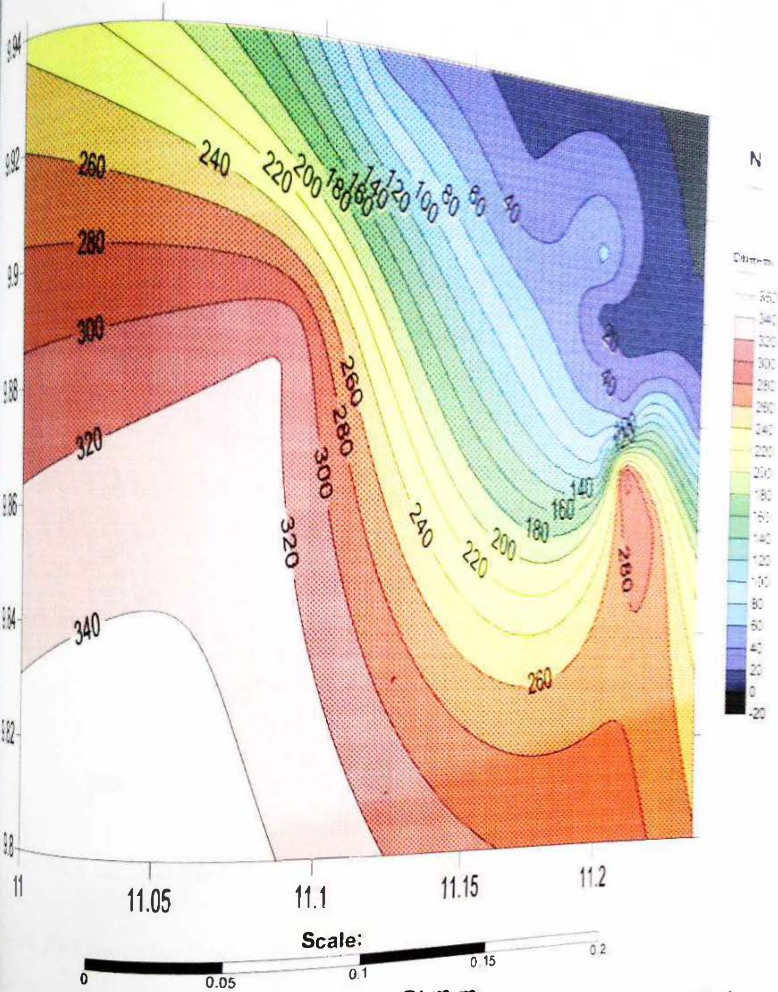
Iso-Resistivity Contour Map Of The Study Area (AB/2=45m)

Fig. 20A: Iso-Resistivity Contour Map of the study Area (at AB/2=45m)



3-D View Surface Iso-Resistivity Contour Map Of The Study Area (at AB/2=45M)

Fig. 20B: 3D view of Iso-Resistivity Contour Map of the study Area (at AB/2=45m)



Contour Interval:20 Ohm-m

Iso-Resistivity Contour Map Of The Study Area (at AB/2=60m)

Fig. 21A: Iso-Resistivity Contour Map of the study Area (at AB/2=60m)

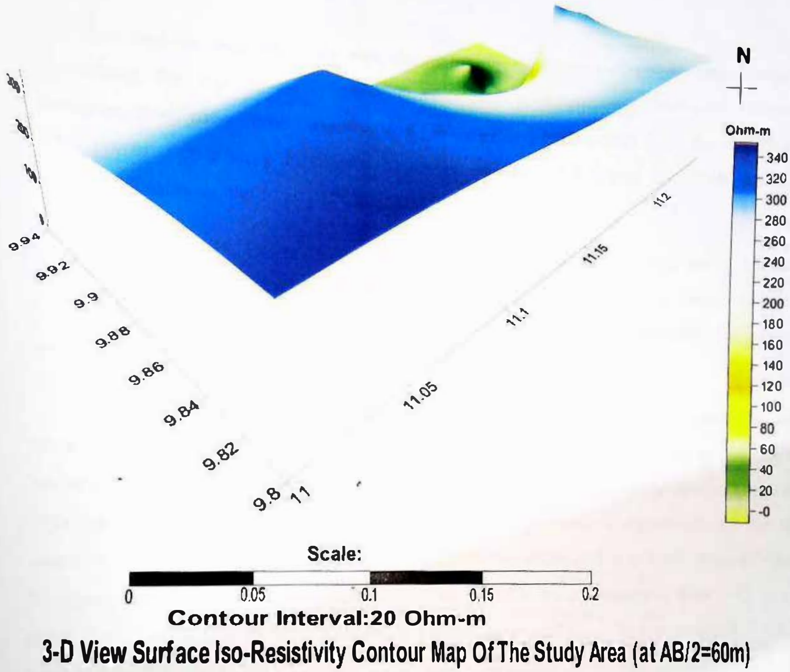


Fig. 21B: 3D View of Iso-Resistivity Contour Map of the study Area (at AB/2=60m)

4.4 Quantitative Interpretation

4.4.1 Geo-Electric Section

The data analysis from the study area shows mainly four layers of geo-electric succession comprising dry topsoil, clayey sand, consolidated sandstone, and fractured sandstone. However, three geo-electric layers were established at 5 VES points from the twenty total VES points. Some other lithologies identified at few VES points are fresh basement, weathered basement and fractured basement.

Weathered and fractured zones represented by low and fairly high resistivity units, respectively, which are considered to be the potential groundwater bearing zones. Dike *et al.* (1994) suggested a thickly developed weathered mantle (>30m) as adequate for borehole water supply.

However, based on the above suggestions, the following VES stations have been recommended as viable sites for siting successful borehole: The sub-surface underlying the investigation site revealed four geo-electric units (sections) at 15 points of investigation and three geo-electric units at five points. From the analysis and interpretation of the data acquired, drilling at VES 01 Anguwan Zazzagawa is recommended to a depth range of 45m – 50 meters depth, VES 03 Lashikoldok is recommended to a depth range of 40m – 45 meters depth, VES 04 Lasikle is recommended to a depth range of 65m – 70 meters depth, VES 05 Lasikle is recommended to a depth range of 60m – 65 meters depth, VES 07 Kentengereng is recommended to a depth range of 65m – 70 meters depth, VES 08 Kentengereng is recommended to a depth range of 62m – 65 meters depth, VES 10 Poshiya is recommended to a depth range of 54m – 65 meters depth, VES 16 Akwai is recommended to a depth range of 40m – 45 meters depth.

CHAPTER FIVE

SUMMARY AND CONCLUSION

5.1 Summary

Twenty Vertical Electrical Soundings (VES) were conducted around Billiri and environs, employing Schlumberger array with maximum electrode separation of AB/2 = 100 to determine locations favorable for siting boreholes. The data obtained were interpreted using software (WinResist) for resistivity data interpretation. From the result, it was found that 15 VES points are characterized by four Geo-electric section layers and five are characterized by three. Six different curve types were obtained from the study area, which are: AH, KA, KQ, AA, QH and HK. The Geo-electrical layers for the VES points range in thickness from 0.4-60.8m, with recommended drilling depth range of 40 - 70m.The study area therefore has potential of moderate yield from borehole but such project must be preceded by a proper geologic/geophysical survey.

5.2 Conclusion

An electrical resistivity sounding survey has proved very efficient in identifying areas with high potentials for ground water development through borehole drilling within the study area. The western part of the study area is identified of excellent potential of groundwater development

In conclusion, the need to conduct adequate geophysical survey and selective sitting of a borehole cannot be overemphasized as the basement complex areas are characterized by limited groundwater potential which is limited by geologic factors such as nature and extent of the water bearing zones.

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