GEOELECTRICAL INVESTIGATION IN THE NORTHERN PART OF KADUNA STATE, NIGERIA

BY

MUFUTAU OLATUNDE OLATINWO

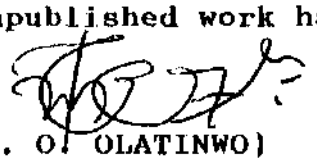
A Thesis submitted to the Postgraduate School, Ahmadu Bello University, Zaria in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Geophysics.

DEPARTMENT OF PHYSICS,
AHMADU BELLO UNIVERSITY,
ZARIA.

MAY 1994.

DECLARATION

I certify that this thesis is based on the result of research carried out by me; that it has not been previously presented for a higher degree. Information derived from published and unpublished work has been dully acknowledged.



(M. O. OLATINWO)

MAY 1994

CERTIFICATION

This thesis entitled "Geoelectrical Investigation in the northern part of Kaduna State" by M. O. Olatinwo, meets the regulations governing the award of the degree of Doctor of Philosophy in Geophysics of Ahmadu Bello University, and is approved for its contribution to scientific knowledge and literary presentation.

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ABSTRACT

This work spells out the mode of execution and the results of the geoelectrical investigation within the Northern Part of Kaduna State, Nigeria. The project is located within Latitude **10°** 40' and 11° 20' North and Longitude 7° 0' and 8° 0' East. The Schlumberger 4 - array was used in the Vertical Electrical Sounding (VES) methods with a maximum half current electrodes separation of 156 m. A total of 118 VES points was occupied. Majority of the VES curves obtained are the 4 - layer types though there are both 3 - and 5 - layer types. The Zohdy method has been used for the interpretation of the field curves. The beginning of each geoelectric section was found to be influenced by the dry soil or laterite or fadama loam. The thicknesses of the layers also vary from location to location depending on the processes that have taken place and the type of parent rock. The top layers give resistivity values as large as a few hundreds of ohm-meters for laterites and loose sands or as low as 100 ohm-m or less for fadama loams and clays, and varies in thickness from 1 m to 20 m.

The weathered basement rock is made up of various materials due to the weathering of the parent rock. They could contain mixed sands with varying degree of coarseness with clays. The thickness varies from 1 m to 60 m, but on the average the thickness is around 45 m while the resistivity is between 50 to 200 ohm-m. Under favourable structural setting this layer could serve as good aquifer.

The fractured rock has high resistivity which is greater than 500 ohm-m. Where the fractures/joints are connected and open, this layer could serve as a good aquifer.

The solid bedrock has high resistivity, it is about 1000 ohm-m and sometimes running up to tens of thousands of ohm-meters.

The structural trend maps delineate a series of bedrock ridges (most especially around Zaria) and depressions within the survey area. The bedrock depressions being groundwater collecting centers are priority areas for groundwater deve]opment.

DEDICATION

This thesis is dedicated to my father, Alhaji T.A. Olatinwo and his descendants.

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CHAPTER ONE

INTRODUCTION

1.1 General Introduction

In several parts of Africa underlain by crystalline basement complex rocks, the major rock types include quartzo-feldspathic granites, migmatites, gneisses and schists. These rocks typically show a bulk uniformity in their mineralogy and as a result, there is a broad similarity in the gross weathering of materials from place to place (Jones, 1985). Arising from this, the basement aquifers could be expected to have predictable hydrogeological characteristics on a regional basis. However, it has also been observed that on a local scale differences in bedrock mineralogy and structure may produce significant variations in the physical and chemical characteristics of the aquifer (Chitton and Smith-Carington, 1984).

Nigeria as a nation, has been striving hard to solve some of her many social, economic and political problems by employing scientific methods. As part of these scientific approaches to National planning and the increasing demand for water for domestic, industrial and agricultural purposes which has become more compelling due to a ten-year drought cycle in Nigeria, geophysical data collection, analysis and interpretation were undertaken to cover the topographic map sheets 102 (Zaria) and part of 104 (Igabi), latitude 10^0 40'N to 11^0 20'N and longitude 7^0 0'E to 8^0 0'E (hereafter referred to as Zaria area (Kaduna North)) (figure 1.1). The location of

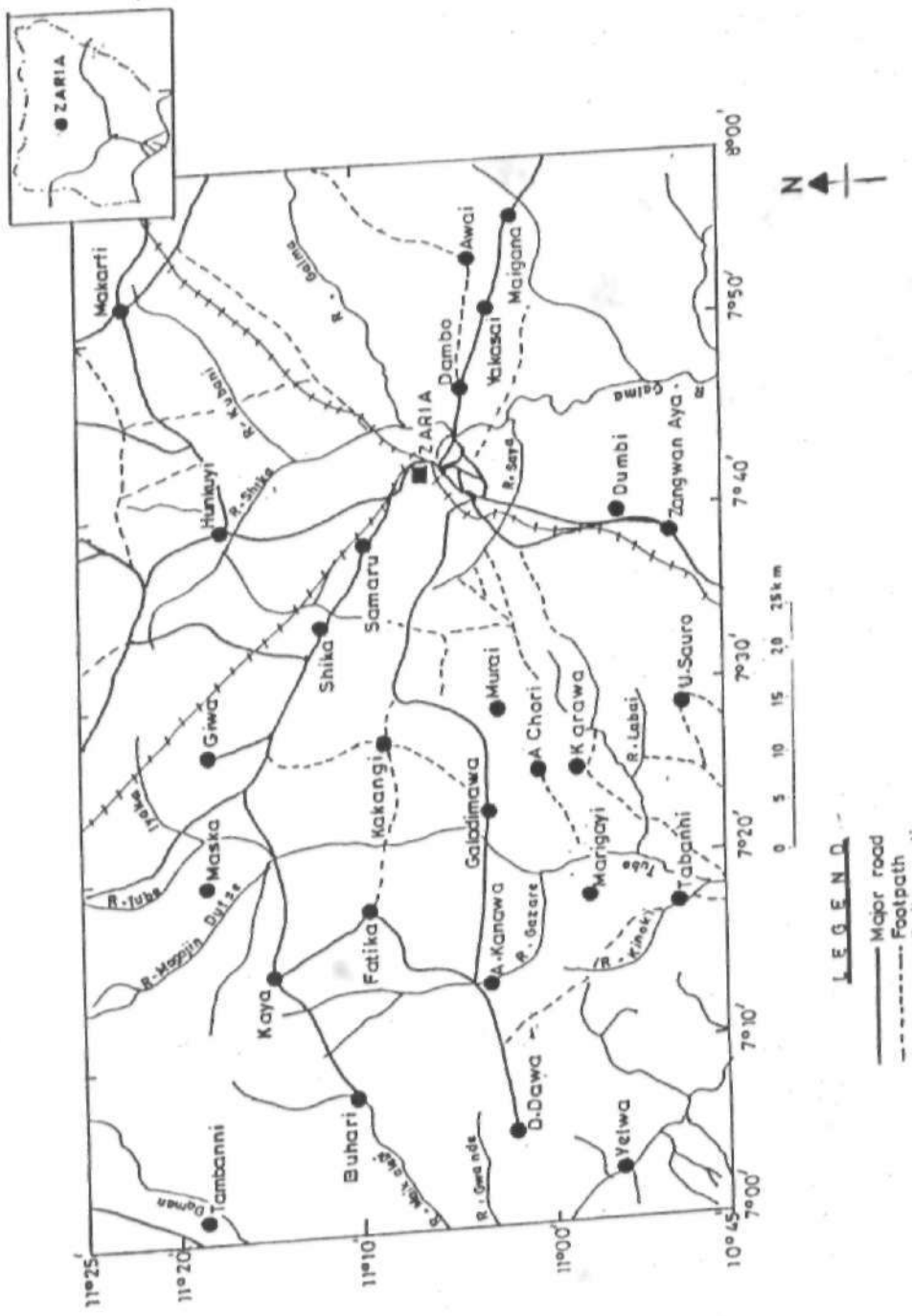


FIG1.1: A SKETCH MAP OF THE SURVEY AREA

Kaduna State, on the fringes of the Sahel region, has particularly compelled Government to turn to the search for ground-water as a remedy for the scarcity. The large number of people required to be served, and the dwindling financial resources has led to a greater need for efficiency in the siting of boreholes (water-wells) to sustain yields of good quality water.

The geophysical method has found useful applications in groundwater investigation, geologic mapping and engineering site investigation. These include bedrock determination, determination of the superficial deposits, structural mapping, aquifer delineation, saline water mapping, lithological boundary differentiation, and determination of structural trends among others (e.g. Kurthenecker, 1934; Early and Dyer, 1964; Page, 1968; Zohdy, 1974; Van-Overmeeren, 1981; Olatinwo, 1981; Olorunfemi, 1985; Olorunfemi and Olorunniwo, 1985; Olorunfemi and Mesida, 1987; Olorunfemi and Opadokun, 1987 and Mbipom et al., 1990; Shemang et al., 1992).

In most parts of the lowland area, where the present study is concentrated, the basement rocks are not exposed. Hence, the geology and the lithological boundaries are in most cases inferred. Unexposed rocks are sometimes identifiable using surface geophysical measurements (Dobrin and Savit, 1988).

A detailed geoelectric survey covering about 72000 square km has been carried out within Zaria area (fig. 1.1). The area is accessible with the Kaduna - Zaria - Kano motor roads, rail

line and foot paths running through it in a south - north direction. The Kaduna - Jos road runs in the Southern part, while the Funtua - Zaria - Pambegua runs in the middle, in a West - East direction. There are other secondary but motorable roads (at least during the dry season) in this area due to the agricultural activity of the inhabitants. The data collection spread over 2 years due to logistic problems such as the size of the survey, and availability of equipment.

1.2 Physiography and Drainage

The Zaria - Kaduna plains are part of an extensive peneplain developed on crystalline metamorphic rocks of the Nigerian Basement complex. It extends almost unbroken from Sokoto to Lake Chad and from South of Kaduna to Agades (Thorp, 1970). At first sight, these monotonous plains appear to be geomorphologically simple, but a closer examination reveals considerable variations in both surface form and composition.

Within the range of 80 km from Zaria, the plains vary in height from 600 m to 800 m above mean sea level reflecting both a regional slope to the south and a local relief of 180 m (Thorp, 1970). The plains are surmounted by hilly features such as inselbergs (e.g. Kufena and Turunku) and laterite mesas.

The Southward flow of river Galma and its tributaries into river Kaduna in the extreme south, and the westward flow of the tributaries of river Tubo drain the whole area. The watershed runs from south to north, towards the Funtua modal point. A

major East-West axis of warping (Russ, 1957) forms the main watershed between the Kaduna drainage basin and the rivers to the north.

Thorp (1970) has reported the possible existence of two types of drainage basins in the area in terms of stream frequency and drainage density. One type is characterised by a large number of unbranched first order tributaries, producing high stream frequencies and drainage densities, for example, Kubanni and Saye rivers. Such basins are characterised also by gullying and intense headwater erosion. River captures are suspected to have occurred along the watershed north and east of Zaria. The second type of drainage basin is characterised by low stream frequencies and drainage densities. Awai river, east of the surveyed area is a good example.

The drainage patterns are commonly dendritic reflecting an absence of structural control over the drainage lines on these deeply weathered plains. Metasedimentary beds such as the quartzite ridges occurring in the south - west of Shika, do impart a rectilinear pattern. Valley bottoms contain wide marshy flood plains often with intricately developed river meanders.

1.3 Climate, Vegetation, Soils and Land Use

The region has dry (October to April) and wet (May to September) seasons with rains falling mainly during the wet season, with an average annual rainfall of 45 inches. It also

experiences cold and hot weather with the coldest months (the hamatan period) from November to February (when a minimum of 57°F and a maximum of 95°F) have been recorded (I.A.R. Weather Station Report). Evaporation is highest during the hamatan period due mainly to south westerly wind from the Sahara desert north of this region.

Soil properties in this region show a rather sandy topsoil and a clayey subsoil in which concretions are common. Once the vegetative cover is removed through over - cultivation, overgrazing and periodic bush burning, the top soils are readily washed off by rain water. Gully erosion is common along the slopes of cliffs bordering the river valleys, and it has been observed that gullies in such areas cut back very rapidly. The areas bordering the rivers are the most densely settled due to the need to establish settlements near water sources, and the fact that the increasing height of floodwaters in the basin has resulted in a retreat of settlements from the flood plains to the edge of the plateau surfaces. Footpaths leading from these settlements to the streams have often provided initial flow channels which have developed into large gullies. Gullies have also been known to originate at the downward end of furrows in field where ridging is along the slope instead of along the contours.

The area lies within the Guinea Savannah supporting a tropical bushland vegetation of few scattered trees and shrub bushes characterised by isoberlinia doka in alluviated areas

and by isoberlinia tormentosa in laterised regions (Jackson, 1970). This is undergrown by a vegetation of tall herbs and grasses. But because this area is intensely cultivated the remnant of this vegetation can only be observed in lateritised areas and near or at the foot of inselbergs.

The soils which occur along the extensive fadamas (or seasonally flooded river valleys) differ from the general description given above in that, firstly they provide more fertile farmlands, except where the drainage is very poor and only swamp rice can be cultivated. Secondly, the fadamas are very close to the sources of water for dry - season irrigation, their major handicaps being the erratic nature of the flood height which may destroy crops and habitations. There are patches of uncultivated areas which are mainly in the laterite and the inselberg areas. All the vegetation have been affected such that there is no where that the natural vegetation can be observed.

1.4 Geology

Almost half the surface of Nigeria (fig. 1.2) is covered with granitoids which are mostly Precambrian in age. These are collectively known as the basement complex. The rocks of the basement complex have been recognized to belong to three groups, viz; group I the older metasediments; group II the gneisses, migmatites and older granites and group III the younger metasediments. The rocks of these three groups have undergone at least two major phases of orogenessis (Oyawoye

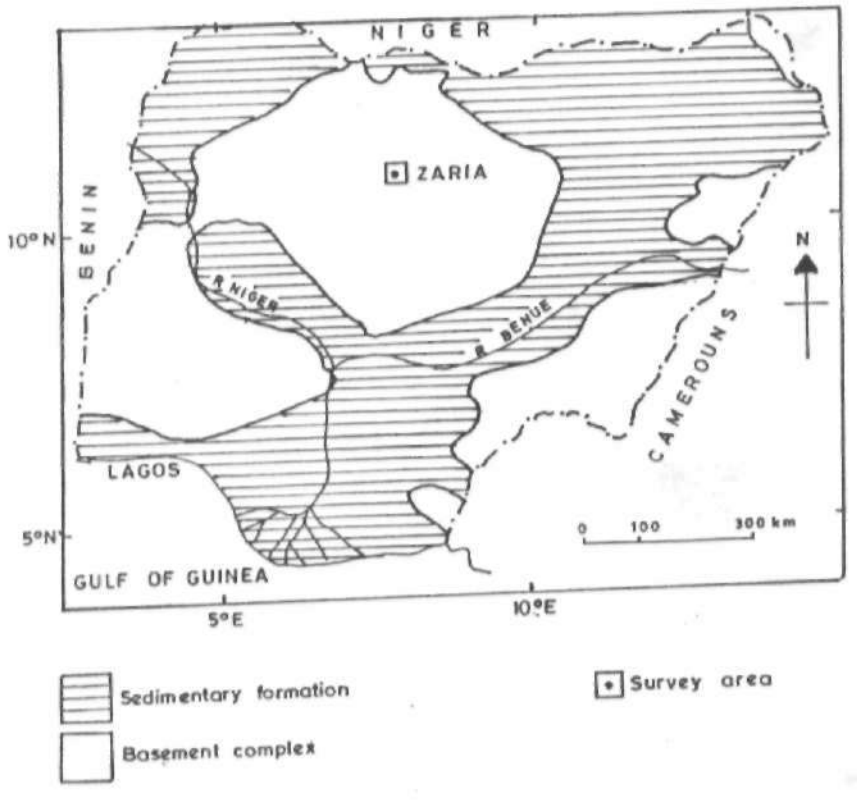


FIG.1-2:GEOLOGY MAP OF NIGERIA

1964), the last of which was initiated by deposition of sands, muds, greywackes and igneous material on an eroded metamorphic basement.

Erosion and weathering of the Basement must have commenced from Precambrian and terminated by quaternary deposition. Folding and low to medium grade metamorphism of these eroded materials may have led to the development of gneisses, migmatites and older granites.

The rocks of Zaria area (Figure 1.3) belong to group II which can be further classified into three major subdivisions viz: (1) a Crystalline complex which includes gneisses and migmatites; (2) a late Proterozoic suite of sediments, folded and metamorphosed into phyllites, quartzite, pelitic and psammitic schists; (3) intrusive rocks of late Proterozoic to Cambrian age, including synorogenic to late Orogenic granites, minor basic and Ultra basic dyke rocks, pegmatites and aplites. The rocks vary rapidly in texture with the metamorphosed low grade pelitic schists and ferruginised micaceous schists located in the western part, being separated from the other rock types by a line running north - south. The gneisses and granites are mostly in the central and eastern parts, but the contacts between them is gradational.

1.4.1 Structures

The Basement complex in this area together with its supracrustal younger metasediments suffered two phases of tight

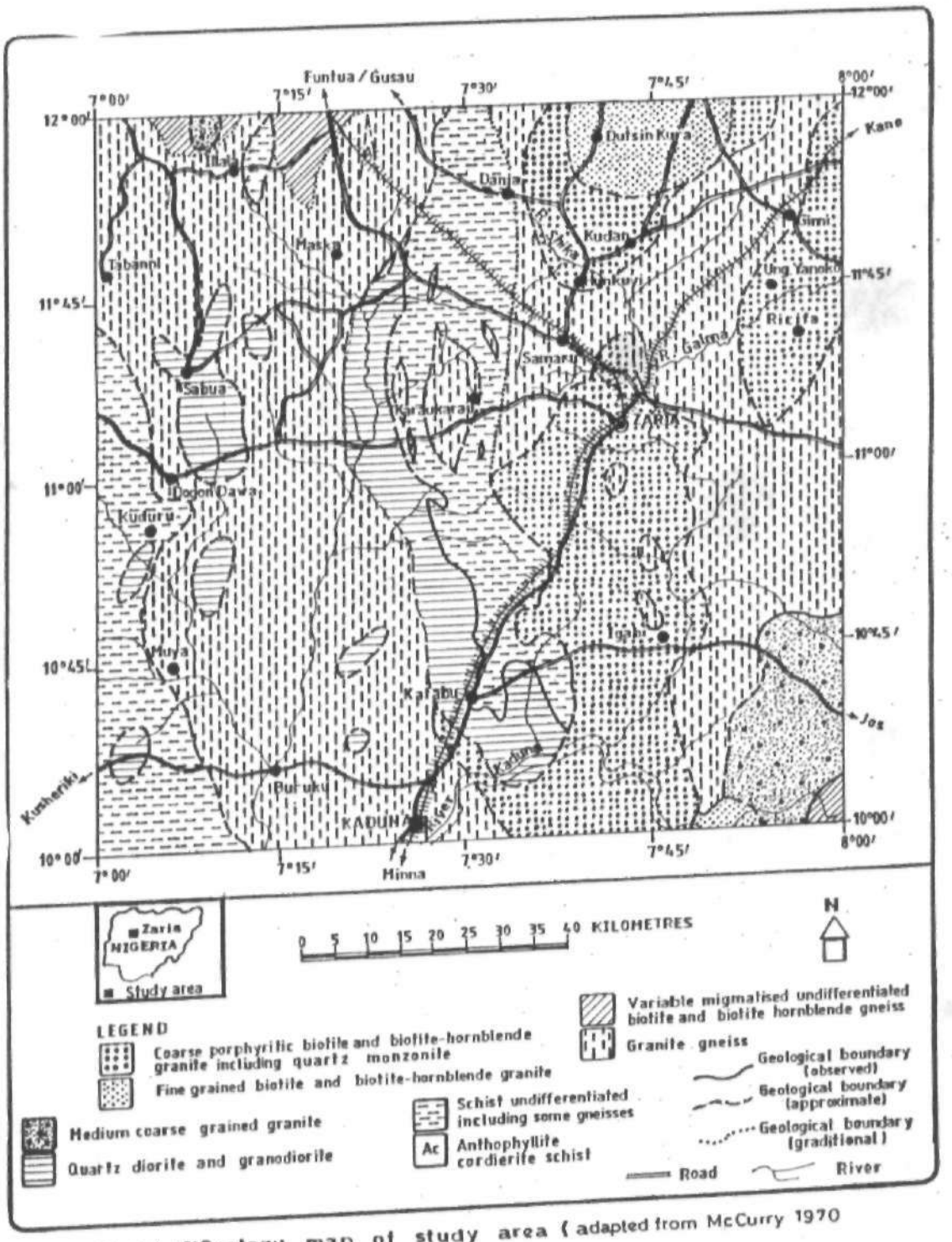


Fig : 1.3 Geology map of study area (adapted from McCurry 1970 and Adanu, 1991).

isoclinal folding during the Pan - African episode (McCurry, 1975). During the early deformation episode, ENE - WSW (40^0 to 50^0) trending structures predominated. Here fold axial planes and foliations dip slightly north or south. The later deformation episode produced the north - south trending steeply dipping structures. Joints-sets and fractures formed here are frequently filled with aplite - pegmatite veins in granites or vein quartz (Adanu, 1989).

Another joint set is between 120^0 - 130^0 (ESE to WNW) usually showing small sinistral displacements. These have been observed on exposed bedrocks. Both deformation episodes produced tectonic foliation defined by parallel alignment of play, prismatic tabular minerals such as mica, amphibole and microcline megacrysts, which are essentially parallel to lithological boundaries (Wright and McCurry 1970).

Groundwater flow direction obtained from construction of groundwater levels observed in boreholes do not seem to show any discrimination in favour of the dominating linearment direction; instead these flows show topographic controls in the direction of drainage channels such as rivers and streams. That means that, on the regional scale, linearment trends do not coincide with the regional direction of groundwater flow; but at local levels of first order streams and tributaries flow directions are virtually controlled by structural features, which eventually cumulatively produce the regional direction of flow.

Linearments which are observed on areal photos do not all represent fractures and joints. Even when they do they may not be interconnected or not anymore extend deep enough to the water table due to elimination by weathering process which though previously have been enhanced by these structural traces. The obliteration of these structural traces by weathering activities within the weathered material mars any structurally controlled groundwater flow in this layer. These lineaments have been found to be important when present around producing wells. Transmissivity values are always greatly influenced by the fractures. Fracture density and interconnectibility around a producing well in a terrain are more important factors in the determination of local aquifer properties than regional fracture length and orientation (Olowu, 1967).

1.4.2 Hydogeology

According to Olowu (1967) the crystalline rocks of the Basement complex, by virtue of their lithological composition and texture, are generally poor in groundwater content except, however, where exists fracture systems or where weathering has attained advanced stage that it results in thick permeable product. To contain significant aquifers with exploitable groundwater, the weathered layer must attain a minimal areal extent and thickness with sufficient porosity and permeability to store and to yield it to wells from season to season (UNESCO, 1979). It is therefore the most extensive and thickly

weathered layers that are likely to contain the most viable productive aquifers.

The superficial deposits, which contain partly the products of weathered rocks and partly alluvial deposits serve as media of infiltration and recharge of the aquifers. The areal extent and location of these superficial deposits will encourage or inhibit infiltration. The river valleys and the "fadama" usually contain alluvial materials such as clayey and silty products deposited during floods. Their composition and porosity make them good reservoirs of groundwater which serve as source of water for the wells during the dry season. Rivers loose their water during the dry season in three major ways, viz run off of the water, evaporation and recharge of the aquifer through the fadama. In the heart of the dry season when the river may have dried up (which is very common in Zaria area) the fadama "cakes" up thus preventing the loss of water in the aquifer through evaporation of water from the pores. Although the aquifer level within the fadama region may have fallen slightly there is still an appreciable amount of water retention within it, thus wells dug within the fadama area still give good yield. On the other hand Kaduna north area is geographically a savannah region characterised by dry and wet seasons. Most of the rain water received during the short wet season (May to September) is held up in the superficial covering and in the weathered basement. Since this region is dissected by numerous streams (fig. 1.3), the total surface discharge is likely to be more than the amount of infiltrated

water. This small amount of infiltrated water is unevenly distributed among the rock units (McCurry, 1970), a factor which depends both upon the state of weathering and the permeability of the rocks. Field evidences show that the country rock units (mainly granites and the gneisses) are more fractured, faulted and folded than the fresher more extensive batholithic granites (Tokarski, 1972). Wright and McCurry (1970) have suggested that the batholithic granites may extend in weathered form beyond 30 feet. This means the gneiss are likely to be weathered to a greater depth than this.

In conclusion, it is suggested that despite the fact that groundwater may be contained in crystalline rocks under favourable conditions, location of wells for use based on the physical and structural states of the rocks as well as the hydrogeological conditions in a given area must be preceded by careful geophysical investigation.

1.5 Previous Work

Although detailed geophysical mapping of this area as a unit has never been done, but some geological, hydrogeology, geographical and geophysical survey have been carried out in isolated localities within this area. Between 1928 and 1946, a total of 2000 hand dug and concrete lined wells were sunk in Northern Nigeria.

Du Preez (1952) gave a short account of the groundwater occurrence in the Zaria area. This was followed by the

geophysical investigation of the Regional Technical College site, Zaria by Jones (1952 and 1954) for water supply. Barber and Phoenix (1963) prepared a report on water supply for Ahmadu Bello University, Zaria in which it was pointed out that groundwater occurred in superficial deposits and in decomposed bed-rock.

The most extensive study on groundwater in this area (sheet 102 SW) is that carried out by Olowu (1967), in which he has attempted to give a regional outline of the conditions governing groundwater occurrence in the basement complex. According to him, groundwater occurs in water table conditions in joints, decomposed zones of the basement complex and the overlying alluvium. Olowu (1967) in a report on groundwater conditions in Zaria produced a small scale geological sketch map delineating the major rock types. Bankole (1983) and Ogunjobi (1983) also worked in the Shika Basin and part of the Galma Basin respectively, all within the Zaria Sheet 102 (Scale 1:100,000) and they gave some account of the groundwater conditions in the area.

Previous geophysical works are limited both in scope and objective, even when the scope is wide the objective is still restricted. The regional aeromagnetic mapping which covered the whole of Nigeria including Zaria area was carried out by the Geological Survey of Nigeria for the purpose of producing aeromagnetic maps only. For example the gravity interpretation by Osazuwa et al., (1992) focused on macrostructures such as

batholiths. The works of Olowu, (1967), Ajayi and Hassan, (1990) focused mainly on the thickness of the aquifer and the depth to water table in limited areas within Zaria sheet 102. Of all the series of isolated Electrical resistivity surveys (Ososami, 1968; Messrs Pressuag Ltd, 1982; Ajayi and Hassan, 1990; and Shemang et al., 1992) none was carried out outside the Kubanni basin and Ahmadu Bello University main campus. Even within the basin where they worked they could not provide a complete picture of the basement structure.

Structurally the resistivity work carried out by Du Preez (1952) within the Kubanni basin revealed the presence of steep dipping joints in some granite outcrop, however the location of these joints were not clearly stated. Adeniyi (1987) and Osazuwa et al., (1992) carried out gravity survey and interpretation respectively of the older granite pluttons in Zaria area, they deduced that there are multiple batholiths within this area. However Adeniyi (1987) recommended the use of other geophysical methods.

Drilling of Water Well boreholes in this area was carried out by the Geological Survey of Nigeria between 1954 and 1965. Messrs Strojexport (1980) also carried out some groundwater study in the Northern part of Old Kaduna State. At present both the Kaduna State Water Board and Directorate of Food, Road and Rural Infrastructure (DFRRI) are drilling in some rural settlements within this area. This exercise was carried out relying on chance, luck and the experiences of the drillers

(wild cat drilling) without preliminary geophysical survey to locate correctly the borehole points.

1.6 Objectives of the Research Work

In response to the ever increasing demand for water and the awareness on the part of both the State and Federal governments of the problems of provision of water, and coupled with the fact that no attempt has yet been made by previous workers to extend their studies and use the informations obtained therefrom to evaluate the water resources of the whole Zaria sheeet 102. Also no detailed geotechnical studies have been carried out to assess subsurface geotechnical parameters that are of importance to the construction industry. These data inadequacies have resulted in two major problems. Viz; (i) non-realistic estimation of the water balance of the reservoirs and catchment areas, especially during the dry season and (ii) Ineffective or non-existence legislative scheme for proper surface structural layout such as bridges, dams, high-rise buildings etc.

In view of the deficiencies and limitations of previous works,this project is aimed at (i) determining the geoelectric parameters (layer resistivities and thicknesses) of the subsurface layers and their hydrogeologic implications, (ii) mapping the bedrock relief and hence the subsurface structural disposition, (iii) assessing the probable groundwater potential and hence determine the aquifer profile, (iv) examining the utilization of the electrical anisotropy coefficient and the

weathered layer resistivity as indices for lithological differentiation with particular reference to areas where the basement rocks are concealed. The final results of the study could be used

(1) to formulate a clear conceptual hydrogeological and geophysical model for the area,

(2) to obtain subterranean structural map of the area.

In addition to the above objectives, efforts will be made to examine the electrical anisotropy coefficient and the weathered layer resistivity as indices for lithological differentiation with particular reference to areas where the basement rocks are concealed.

CHAPTER TWO

2. GEOPHYSICAL INVESTIGATION

2.1 Introduction

The geophysical investigation was carried out by the author employing the DC resistivity method in January/February, 1992 using the DC Terrameter 300.

The choice of the Villages and locations for VES measurements was done by the author in collaboration with the Kaduna State Water Board based on the present and earlier geophysical and hydrogeological works and with the present objectives in mind. The Schlumberger array was employed (for reasons stated later in section 3.2) in all the VES stations with the distance between the current electrodes continuously being increased until the desired maximum separation (AB/2 = 156) was attained. From some geophysical survey carried out within some areas of the northern part of old Kaduna State Strojexport (1980) has shown that the overburden in the basement area is not so thick as to warrant wider current electrode spacing. The separation of the potential electrodes MN was also increased in order to maintain a measurable potential but it did not exceed one-fifth of AB/2 as suggested by Dobrin & Savit (1988).

2.2 Principle and Theory of Geoelectric Sounding

As resistivity is a fundamental electrical property of rock materials closely related to their lithology, the determination of the subsurface distribution of resistivity

from measurements on the surface can yield useful information on the structure or composition of buried formations. A common method is the geoelectric sounding. Four - electrode arrays are generally used at the surface; one pair for introducing current into the earth, the other pair for measuring the potential associated with the current. The vertical electrical sounding (VES) or the geoelectrical sounding is based on the principle that a fraction of electric current injected into the ground, penetrating below a given depth increases with the separation of the current electrodes. Thus as the current electrodes separation is increased, the depth of penetration will increase. Therefore any anomalous body lying between the ground surface and the last depth of penetration will have great influence on the electrical potential field at depth.

This method is based on Ohm's Law given by

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

where: I = Current (amps)

V = Impressed Voltage (Volts)

R = Electrical Resistance (in Ohms, (Ω))

The resistance R of a conductor with a length (l) and a cross-sectional area A is given by

$$R = \rho l/A \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where ρ is the resistivity of the unit under consideration

Combining equations (1) and (2) and for unit length and unit cross-sectional area,

$$V = \frac{IPL}{A}$$

If R is expressed in Ohm (Ω) ρ will be expressed in Ω-m a commonly used unit in VES measurements.

The problem in VES measurement is to determine the specific resistivity of the subsoil by measurements at the surface.

Most resistivity techniques define a response function called apparent resistivity ρ_a which can be deduced or estimated from surface measurements. These apparent resistivities are usually functions of a variable that is related to the depth of penetration.

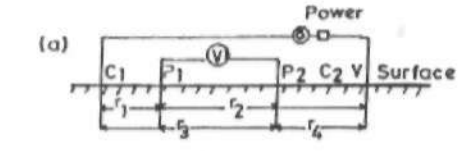
Consider a semi - infinite solid with uniform resistivity ρ. Assuming that a current I is introduced into this material through electrodes at positions A and B on its surface, and that the potential gradient associated with this current is measured across two other electrodes at positions M and N on the same surface (fig. 2.1),

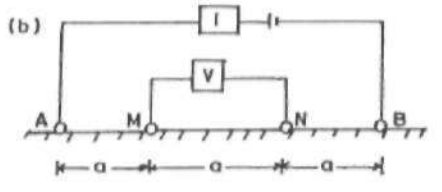
the potential at electrode M will be

$$V_M = (I\rho/2\pi)*(1/r_1 - 1/r_2).....(3)$$

where r_1 = distance from potential electrode M to current electrode A and r_2 = distance from electrode M to current electrode B.

Similarly the potential at electrode N is given by





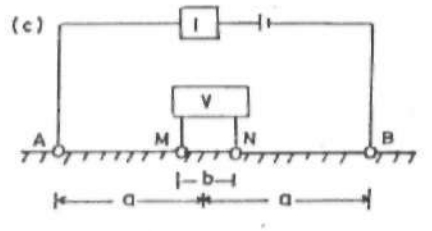


FIG.2.1: ELECTRODE CONFIGURATION

(a) General electrode configuration in resistivity survey
(b) Wenner array
(c) Schlumberger arrary

$V_N = (I\rho/2\pi)*(1/r_3 - 1/r_4)$.....(4)

where r_3 is the distance from N to A and r_4 the distance from N to B.

Potential difference ΔV across electrodes M and N is $V_M - V_N$.

Subtracting equation (4) from equation (3) and solving for ρ one obtains

$\rho_a = (2\pi\Delta V/I)*(1/(1/r_1 - 1/r_2 - 1/r_3 + 1/r_4))$.....(5)

The result is independent of the position of the electrodes and is not affected when the current and potential electrodes are interchanged.

The apparent resistivity is equal to the true resistivity only when the subsurface is isotropic. In practice this is difficult to obtain, however the subsurface is assumed to be divided into thin strata with each stratum regarded as completely homogeneous and isotropic. This is a convenient way to represent a response of the actual distribution of lateral resistivities in the subsurface on the basis of surface measurements. If the electrodes are laid out along a profile and their separations are increased in a systematic manner, the change in the apparent resistivity will be a function of electrode spacing [as defined in Equation (5)]. Also it has been shown by Dobrin and Savit, (1988) that depth of penetration of current increases with electrode spacing. Therefore it is possible to determine the variation of resistivity with increasing depth within the limits of

instrumental resolution which depends to a greater degree on the subsurface resistivity/layering and data quality.

In actual practice a number of different conventional surface configurations are used for the current and potential electrodes placement. In many arrangements, both sets of electrodes are laid out along a line . The current electrodes are generally placed on the outside of the potential electrodes. The most widely used configurations are Wenner arrangement, Schlumberger arrangement and Dipole Methods.

Two general approaches are used for making resistivity measurements in the field. With the first, the electrode spacing are fixed, and the array of electrodes is moved laterally along a profile with constant separation, the apparent resistivity being plotted at the midpoints. This is called continuous profiling or electric trenching. Any body having anomalous conductivity and which is shallower than and extends beyond the depth of maximum effective penetration should show up as an anomaly on the resulting map. In the second type of measurement the center of the electrode spread remains fixed, but the separation of electrodes is progressively increased. This is called Vertical Electrical Sounding (VES). Continuous profiling with a fixed configuration is more cost effective for detection of anomalies along a traverse but is inadequate for exploration objectives requiring depth control which can only be achieved through expanding the geometry of the electrode configuration.

As mentioned earlier the vertical electrical sounding measurements can be executed using different approaches, among which are the Wenner Arrangement and the Schlumberger Arrangement. In Wenner configuration, the electrodes are uniformly spaced in a line.

From equation (5)

$r_1 = r_4 = 1$ and $r_2 = r_3 = 2a$.

Thus, the apparent resistivity is given by

$$\rho_a = 2\pi aV/I \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

where a = distance between the electrodes

I = Current passed through the ground.

V = Potential difference Measured.

Despite the straight forward geometry, this configuration is often quite inconvenient for field work, and has some disadvantages from a theoretical point of view as well (Telford et al., 1976). For depth soundings, the electrodes are expanded about a fixed center, increasing the spacing 'a' in steps.

In the Schlumberger Configuration, the current electrodes are spaced much further apart than the potential electrodes. The array is often used symmetrically, i.e.

$$\rho_a = (\pi L^2/2l)*(\Delta V/I) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

where L = half the separation of the current electrodes

l = half the distance of the potential electrodes

ΔV = Potential difference measured.

In depth probing, the potential electrodes remain fixed while the current electrode spacing is expanded symmetrically about the center of the spread. Sometimes it may be necessary to increase 'l' when measuring large 'L' values in order to maintain a measurable potential, but usually not exceeding one - fifth of L.

CHAPTER THREE

3. INSTRUMENTATION AND FIELD PROCEDURE

3.1 Instrumentation

3.1.1 Terrameter SAS 300

The TERRAMETER SAS SYSTEM consists of a basic unit called the Terrameter SAS 300 which can be supplemented as desired with the SAS 2000 Booster. SAS stands for Signal Averaging System - a method whereby consecutive readings are taken automatically and the results are averaged continuously. The continuously updated running average is presented automatically on the display. This continues until the operator is satisfied with the stability of the result. SAS results are more reliable than those obtained using single-shot systems. The SAS 300 (basic unit) can be used for Self Potential surveys and resistivity surveys.

The SAS 2000 Booster (optional) supplements the SAS 300 in situations where the voltage and/or current must be increased. The booster is normally slaved to the SAS 300, but it can also be operated separately in special applications such as charge-potential studies and dipole-dipole surveys.

The Terrameter SAS 300 can operate in two modes:

(1) In the resistivity surveying mode, it comprises a battery powered, deep-penetration resistivity meter with an output sufficient for a current electrode separation of 2000 metres under good surveying conditions. Discriminatory circuitry and programming separates DC voltages, self potentials and noise

from the incoming signal. ΔV/I is calculated automatically and displayed in digital form in kilohms, ohms or milliohms. The overall range thus extends from 0.5 milliohms to 1999 kilohms. The range can be extended down to 0.02 milliohms by means of the SAS 2000 Booster.

(2) In the voltage measuring mode, the SAS 300 comprises a self potential instrument that measures natural DC potentials. The result is displayed in V or mV. The overall range extends from 0.01 mV to 500 V.

The Terrameter SAS 300 contains three main units, all housed in a single casing: the transmitter, the receiver and the microprocessor. The electrically isolated transmitter sends out well-defined and regulated signal currents. The receiver discriminates noise and measures voltages correlated with transmitted signal current (resistivity surveying mode) and also measures uncorrelated DC potentials with the same discrimination and noise rejection (Voltage measuring mode). The microprocessor monitors and controls operations and calculates results.

In geophysical surveys, the SAS 300 permits natural or induced signals to be measured at extremely low levels, with excellent penetration and low power consumption. Moreover, it can be used in a wide variety of applications where effective signal/noise discrimination is needed.

3.1.2 Transmitter Designation

The transmitted current is commutated in a time pattern suitable for resistivity surveying. The transmitted signal is measured by the receiver at discrete time intervals when the eddy currents, the IP and the cable transients have decayed to low levels.

Standard factory current-output programming (in combination with the receiving principle) provides skin impedance effects equivalent to approximately 0.4 Hz for 3.6 seconds of current flow. The operator can, however, select two other time scales equivalent to 0.2 and 0.1 hz. These should only be used under extreme conditions since the corresponding time cycle (7.2 and 14.4 seconds of current flow) increase power consumption. For normal use, the standard factory programming is equivalent to DC surveying.

The current amplitude is set by the operator to suit the actual survey conditions. It can be set to 0.2, 0.5, 1, 2, 5, 10 and 20 mA at 150 V maximum current electrode potential. The range can be extended to 500 mA or to 500 V by using the optional SAS 2000 Booster.

3.1.3 Receiver Designation

Penetration and accuracy limits are imposed mainly by noise caused by telluric currents, power transmission lines and electrochemical variations at the potential electrodes. A unique integrator combined with an ingenious measurement

strategy permits the Terrameter SAS 300 receiver to extract the signal from man-made and natural noise, even when using low, safe signal voltage levels. This measurement strategy includes signal stacking, logical and analog filtering, rejection of induced polarization (IP) effects and rejection of transient phase of the signal current.

3.1.4 DC Potential Measurement

Four receiver ranges for DC potential can be selected manually: ±1 V, ±10 V, ±100 V and ±500 V. The linear circuits allow the voltage to be read and displayed to 3 or 4 significant decimal places. An automatic shift of scale from volts to millivolts in lower ranges allows surveys to be carried out with s significant resolution of ±0.05 mV at an electrode impedance of 100 kilohms. Power line noise is effectively suppressed. At low railway frequencies (15-20 Hz), noise suppression is 70 dB while suppression in the 50 - 60 Hz range is 85 dB (operation's manual for SAS 300).

The aforesaid noise suppression figures are for single signal reading. However, when the Terrameter SAS 300 is used in the signal averaging mode, the microprocessor takes repeated readings and calculated the running average (up to 64 readings). Statistically distributed noise voltages are thus reduced by a factor of square root N, where N is the number of readings.

3.1.5 Resistance Measurement

In the resistance measuring mode, the Terrameter SAS 300 measures signal voltages created by the transmitter signal current while rejecting both DC voltages and noise. ΔV/I is automatically calculated and displayed digitally in kilohms, ohms or milliohms. Four ranges can be selected manually: 1 ohm, 100 ohms, 10 kilohms and 1 megohm. The result is displayed to 3 or 4 decimal places. When the transmitter is operating at 20 mA, the Terrameter SAS 300 has a significant resolution of 0.5 milliohms (operation's manual for SAS 300) for a single reading. Meticulous care was always observed in the arrangement of cables and electrodes used in the field so as to disallow current leakage and creep which can substantially reduce the attainable accuracy and sensitivity and thus the depth penetration.

3.1.6 Measurement Operations

The microprocessor controls and monitors all measurements to ensure optimal accuracy and sensitivity and to make certain that the instrument is used correctly. When the operator presses the MEASURE button, the microprocessor runs a thorough check on circuits and switch positions. It also checks the battery condition and the useability of selected parameters. The complete check-up procedure takes only one second and, if necessary, warnings and information comprising beeper signals and error codes tell the operator to change parameters or to check circuits. When satisfied, the microprocessor

automatically starts the measurement cycle, and after all readings have been taken it puts the instrument into the standby mode with the final result displayed.

3.2 Field Procedure

3.2.1 Choice of Electrode Configuration

In choosing the type of electrode configuration to be used for this survey, it is noted in the first place that in both the Wenner and Schlumberger configurations the depth penetration of the current is predominantly controlled by the distance between the current electrodes: with equal values of the current electrode spacing, the depth penetrations reached in the two electrode configurations are thus nearly equal. However the potential difference between the potential electrodes in these conditions is considerably larger in Wenner configuration than in Schlumberger, because the distance between the potential electrodes is larger in the Wenner configuration. This tends to make the reading accuracy of the voltage better in Wenner configuration than it is in the Schlumberger configuration for comparable depth penetration. There is, however, another consideration which is to the advantage of the Schlumberger configuration and which, in my opinion, outweighs the disadvantage of the smaller measuring accuracy. One of the assumptions on which the interpretation of resistivity sounding measurements is based is that each of the subsurface layers is electrically homogeneous. This differs in reality in that in many areas, inhomogeneity of relatively

Schlumberger array saves time and manpower, i.e.,it is more cost effective than other configurations.

3.2.2 Data Collection

The sounding locations (Appendix I) were chosen by the author in collaboration with Kaduna State Water Board based on the present borehole drilling programme of DFRRI and earlier geophysical and hydrogeological works and the present objectives. There are a total of 118 VES stations including 14 soundings close to existing boreholes with known lithologies within the different geologically identified formations within the survey area. The initial intention was to have VES on a 2 km X 2 km grid station but due to lack of access roads, built up areas and the large size of the survey area, only top priority areas with a fair degree of even spread have been considered. The locations and elevations of the VES stations were extrapolated from topographic maps of Zaria, Igabi, Maska and Kaduna.

The maximum length attained for the current electrode spacing is 312 m while that for the potential electrode is 25.6 m. The values of half the current electrode separation and the distance between the potential electrodes are given in Appendix II.

CHAPTER FOUR

4. INTERPRETATION TECHNIQUE AND DATA PROCESSING

4.1 General

Much of our knowledge of the Earth's interior is based on the interpretation of measurements made at the surface, rather than direct sampling of the material in the interior. In the past few years there have been great advances in the mathematical aspects of this problem, and the technique has come to be called geophysical inverse methods. To apply these ideas, there must be a valid mathematical model of the physics of the system under study, so that one would be able to calculate the values of observations made on an exactly known structure: the calculation of the behaviour of a specified system is the solution of the "forward" or "direct" problem. Frequently it is the forward problem that presents a difficult challenge to the theoretical geophysicist. Illustrations include the mechanism of earthquake rupture or the generation of the earth's magnetic field; in problems like these, inverse theory is normally quite inappropriate. When the forward problem has been completely solved, there are of course unknown parameters in the mathematical model representing physical properties of the earth such as Lame' parameters, density or electrical conductivity. The goal of inverse theory is to determine the parameters from observations or, in the face of the inevitable limitations of actual measurement, to find out as much as possible about them. The quality that distinguishes inverse theory from the parameter estimation problem of

statistics is that the unknown are functions, not merely a handful of real numbers. This means that the solution contains in principle an infinite number of variables, and therefore with real data the problem is as underdetermined as it can be. Naturally, there are geophysical problems containing a relatively small number of free parameters. Sometimes, however, unknown structures are conceived in terms of small numbers of homogeneous layers for reason of computational simplicity rather than on any convincing geophysical or geological grounds. Such simplification may lead to false confidence in the solution because the true amount of freedom has not been allowed in the parameters.

The inverse theory falls into two distinct parts. One part deals with the ideal case in which the data are supposed to be known exactly and as densely as desired, and is of course mainly the domain of the applied mathematics. The other part treats the practical problem that are created by incomplete and imprecise data. It might be thought that an exact solution to an inverse problem with perfect data would prove extremely useful for the practical case. Actually, this often turns out to be untrue because geophysical inverse problems are almost always unstable in a sense to be defined more precisely later; when this is so, the solution obtained by the analytic technique is very sensitive to the way in which the data set is completed and to the errors in it.

of the first and last branches of the sounding curve to their respective asymptotes. The number of layers is equal to the number of digitised points, and the layer boundaries are spaced uniformly on a logarithmic depth scale. For field sounding curves, this method provides the geophysicist with a theoretical curve that fits the observed curve as closely as possible and produces a corresponding, well-behaved layering model (with no extremely thin layers of unusually high or unusually low resistivities). The geophysicist may accept, simplify, complicate, or modify the resulting solution to satisfy known geologic information using other equivalent layering models (Zohdy, 1974).

4.3 Outline of Zohdy Method

The iterative procedure used in the interpretation of all the Schlumberger VES curves in which a layering model is obtained directly from a digitised sounding curve follows from Zohdy, (1989). The outline of the method is given below.

The study of Schlumberger theoretical sounding curves for horizontally stratified, laterally homogeneous, and isotropic media shows that regardless of the number of layers or resistivity distribution with depth, the following properties are observed:

(1) Computed apparent resistivities are always positive

(2) The form of a sounding curve follows the form of the true resistivity-depth curve. As the true resistivities increase (or decrease) with greater depth, the apparent resistivities

(i) The electrode spacings do not adequately approximate the depths to various layers. Therefore, the assumed depths must be shifted to the left in order to bring the assumed layering more or less in phase with the resistivity-depth curve.
(ii) The apparent resistivities do not adequately approximate the true resistivities; and, therefore, the assumed resistivities must be adjusted to approximate the amplitude of the true resistivities.
(iii) Property (5) can be used for the required resistivity adjustments.

Determining the appropriate amount to horizontally shift the depths and vertically adjust the resistivities without prior knowledge of the true resistivity depth distribution, is the essence of the new iterative method.

4.4 Initial Data Preparation

Unlike a theoretical curve, a field Schlumberger sounding curve is composed of several overlapping segments. The segmented Schlumberger field curve is processed and reduced to a continuous curve prior to its interpretation in terms of a horizontally stratified model (Koefoed, 1979; Kunetz, 1966; Mundry, 1980; Zohdy et al., 1973).

The processed Schlumberger sounding curve is digitised at a logarithmic interval equal to (or equal to a multiple of) the sampling interval of the filter to be used in calculating the theoretical sounding curve. The purpose of digitising the

sounding curve is to speed up the computations of the succession of theoretical sounding curves used in the iterative process. A sampling interval of six points per logarithmic cycle (O'Neill, 1975) is considered commensurate with the electrode spacing interval used in the field and is considered optimal for defining the form of a sounding curve.

When a processed field Schlumberger sounding curve is digitised, it is ready for interpretation by the iterative method. In the following sections, the processed and digitised Schlumberger field curve is referred to as the "observed" curve.

4.5 Iterative Procedure

The iterative procedure relies on the following initial assumptions:

(i) The number of layers in the model equals the number of digitised points on the observed curve. This assumption remains unchanged throughout the iterative process.

(ii) The depths of the model layers are equal to the digitised electrode spacings which are equally spaced on a logarithmic depth scale.

(iii)The true resistivities of the model equal the apparent resistivities.

With the aforementioned assumptions in mind, a theoretical sounding curve was calculated for a multilayer model by convolution and the percentage root-mean-square deviation (ϕ) was computed from the equation

$$\phi = \sqrt{\frac{\sum_{j=1}^{N} (\bar{\rho}_{oj} - \bar{\rho}_{cj})^2}{N}} \cdot 100$$

where $\bar{\rho}_{oj}$ = jth "observed" apparent resistivity

$\bar{\rho}_{cj}$ = jth calculated apparent resistivity, and

N = number of digitised apparent resistivity points (with j = 1,N).

The depths are then multiplied by a constant factor (fraction) to decrease all the layer depths and successively reduced until ϕ is minimum bearing in mind the geology and borehole lithology/resistivity sounding relation of the area. Having calculated a theoretical sounding curve using shifted depths and apparent resistivities, the amplitudes of those resistivities are adjusted iteratively to obtain a better fit between observed and calculated sounding curves. The ratio of observed to calculated apparent resistivity is multiplied by the corresponding layer resistivity to adjust it to a higher or lower value. A new sounding curve is then calculated using the adjusted layer resistivities. These steps are repeated until a prescribed minimum ϕ (less than 2 percent) is obtained.

The advantage of the n-layers model over the other layering models is that it can provide additional information about the subsurface variations within any suggested geoelectric layer

4.6 Ambiguity in The Relation Between The Resistivity Curve and The Subsurface Layer Distribution

Strongly differing layer resistivity distributions in the subsurface may yield apparent resistivity curves that are not strictly equal but differ so slightly that they cannot be separately distinguished as different formations with the accuracy of the resistivity measurements/instrument. This ambiguity lies entirely in the relation between the resistivity transform and the parameters of the subsurface layer distribution.

These ambiguities are generally referred to as "equivalence" and or "suppression". The term "equivalence" is used either in cases where $\rho_{i-1} > \rho_i < \rho_{i+1}$ (i.e. the so called "bowl-type" resistivity sequences), or where $\rho_{i-1} < \rho_i > \rho_{i+1}$, (i.e. "bell-type" resistivity sequences). In the bowl-type case two resistivity stratifications can be equivalent, i.e., distinguishable on the apparent resistivity curves, if they have the same value for the quotient t_i/ρ_i. For bell-type cases this situation arises for two resistivity stratifications which have the same value for the product $t_i*\rho_i$. The term "suppression" is used either where $\rho_{i-1} < \rho_i < \rho_{i+1}$, (i.e., "ascending-type" resistivity sequences) or where $\rho_{i-1} > \rho_i > \rho_{i+1}$, (i.e., "descending-type" resistivity sequences). In both the ascending and descending types the effect of the phenomena is such that it may be impossible to detect the existence of the intermediate layer at all from the apparent resistivity curve.

These limitations were resolved by sounding at some borehole locations where the resistivities and thicknesses obtained were verified with the corresponding stratification in the borehole lithology log within the area of survey.

4.7 OPTIONS AND CHARACTERISTICS APPLIED

Different options and characteristics were used to generate equivalent models and to impose constraints so that the eventual model chosen actually represents the resistivity and layering sequence for each of the sounding locations apart from the borehole lithology used for resistivity/formation identification. The options are discussed below.

1) Fixed Shift Factor: Each sounding curve has its unique depth shift factor that yields a minimum root-mean-square percentage. The value of this shift factor depends on (a) the curve type, i.e., $H(\rho_1>\rho_2<\rho_3)$, $K(\rho_1<\rho_2>\rho_3)$, $KH(\rho_1<\rho_2>\rho_3<\rho_4)$, $A(\rho_1<\rho_2<\rho_3)$, $KH(\rho_1<\rho_2>\rho_3<\rho_4)$, etc (Zohdy et al., 1974). (b) The completeness of the left and right branches of the field curve; and (c) the amount of noise present. It was found, however, that because of equivalence, determining the optimum shift factor is not critical for the final fitting of the curve. Thus a fixed shift factor was selected within the range between 0.3 and 0.6 (approximately) as suggested by Zohdy (1989) and used for almost all the Schlumberger curves; and the observed curve always matched when the resistivity amplitude adjustment was applied.

The use of a fixed shift factor eliminates a few iterations that would have been necessary to find the optimum shift factor for each curve type. However, the number of iterations saved in using a fixed shift factor results in a larger number of amplitude adjustment iterations. Furthermore, if the selected fixed shift factor is too small (layering is shifted too far to the left), overshoots and undershoots develop at shallow depths, and the depth to the last layer is defined by an abrupt change in resistivity. Conversely, if the selected fixed shift factor is too large (layering is shifted too far to the right), then overshoots and undershoots develop at large depth, and the depth to the shallow layers are defined by abrupt changes in resistivity.

2) Layer Compression: Layer compression becomes necessary where severe K-type curves are encountered. A severe K-type curve is a curve that rises steeply at an angle of nearly 45^0, continues to rise for nearly two logarithmic cycles, forms a somewhat sharp maximum, and then falls to low resistivity values. Interpreting observed curves of the severe K-type results in situations in which the curves cannot be fitted within 2 percent probably because the distribution of layer depths obtained from digitised electrode spacings, extends over a much larger depth profile than does the true (or any equivalent) layer-depth profile. Hence the layer depths are compressed so that the resistivity adjustment procedure may succeed to yield a good fit.

Layer compression is achieved by increasing the number of layers per decade, i.e., greater than six. The total number of layers is still the same as the number of digitised points and the thicknesses of all layers beneath the first layer still increase at a uniform logarithmic rate, but now the depth interval is less than the electrode spacing interval from which it was originally derived.

3) Layer Expansion: This is a direct converse of layer compression, it results from decreasing the value of the number of layers per decade.

4) Fixed Last Layer Resistivity: The resistivity of the last layer was fixed for all sounding curves within the same geologically identified formations that show a rising right branch and interpreted in terms of a constant resistivity value for geoelectric basement and hence geoelectric cross-sections are produced with a common basement resistivity; the last layer's resistivity does not change during the iterations process.

5) Interpretation of Incomplete Curves: Most field sounding curves are incomplete, i.e. a sounding curve in which the left and (or) right asymptotes to the resistivity of the first and (or) last layer, respectively, are not measured. A field sounding curve whose last right branch rises at an angle 45^0 for at least three or four points (sampled at the rate of six

points per decade) is considered to have a complete right-hand branch (Zohdy, 1989). Provided the curve is not distorted, the resistivity value of the first point will fit because the depth to the bottom of the first layer is always less than the first electrode spacing, and similarly for the last layer.

4.7 Adjustment of the Apparent Resistivity Curves in Schlumberger Measurements

In Schlumberger Configuration it is necessary to increase the distance between the potential measuring electrodes as the distance between the current electrodes increases. Without this step the potential difference would become too small to allow a reliable measurement. When the distance between the potential electrodes is changed, measurements at both the measuring electrode spacings were made at two values of current electrode spacing. The apparent resistivity graph obtained then consists of a few segments that correspond with the different values of the measuring electrode spacing. These segments fail to tie in with each other within the accepted error limit for some of the soundings (e.g. figure 4.1). The reasons for these are, firstly the measurements are made with a symmetrical electrode configuration in which the ratio of the measuring electrode spacing to the current electrode spacing has a finite value, i.e. "eccentricity" of the electrode configuration (Koefoed, 1979). Changing the distance between the measuring electrodes entails a change in the eccentricity of the configuration which depends on the apparent resistivity of a given layer

UNGWAN MAKERA 84 (FIELD DATA)

AB/2	App. Res.	AB/2	App. Res.
1.00	100.88	12.60	75.45
1.26	83.87	15.60	61.47
1.56	77.64	15.80	62.02
2.00	85.53	20.00	48.98
2.00	103.75	25.10	39.15
2.51	118.39	31.60	31.53
3.16	125.79	31.60	43.48
3.98	133.01	39.80	36.93
3.98	142.96	50.10	42.42
5.01	125.35	63.10	48.36
6.31	112.08	63.10	60.91
7.91	97.66	79.40	74.38
7.94	104.27	100.00	78.46
10.00	87.63	126.00	85.19
		156.00	107.24

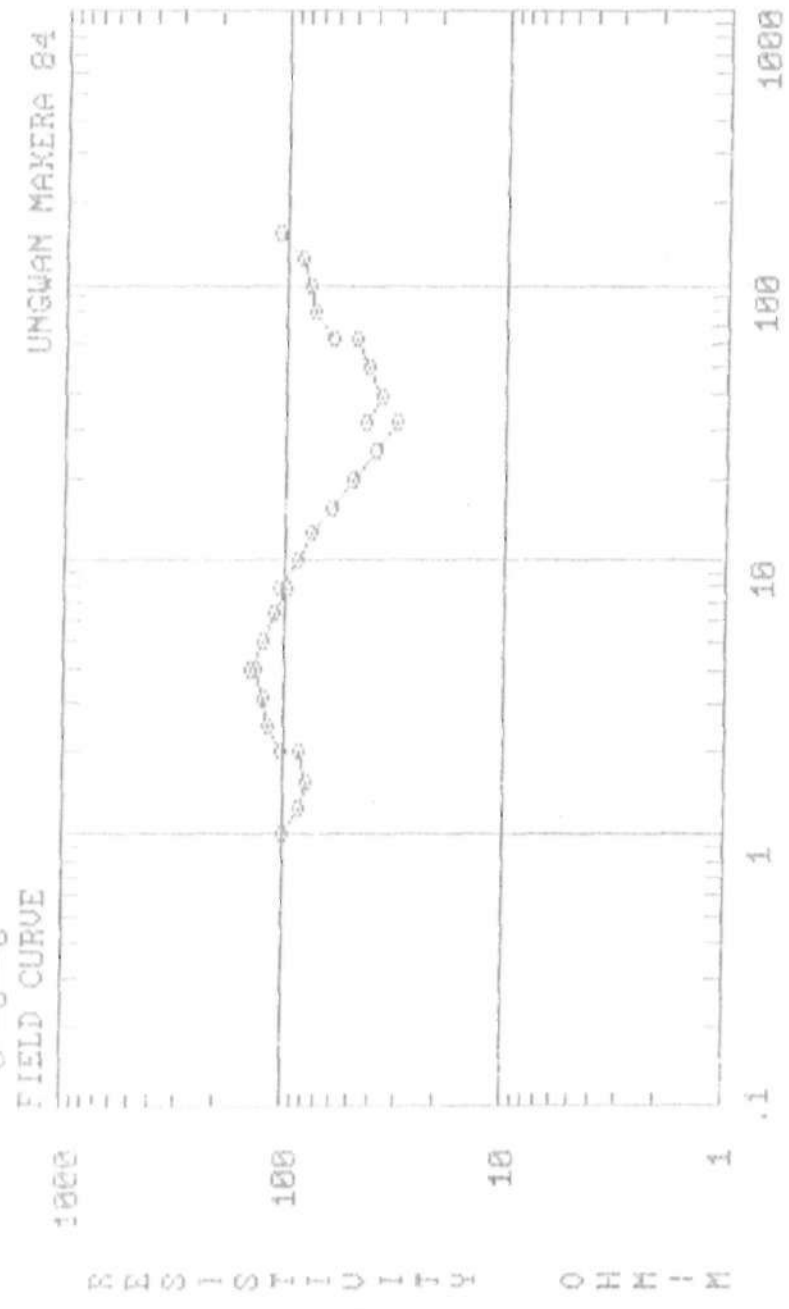


Fig. 4.1 An Example of Tie-in problem

stratification. The second reason for lack of tie-in between the segments of an apparent resistivity curve is the occurrence of near-surface inhomogeneities in the ground. These inhomogeneities affect the current distribution pattern, and the relative change in the current density which they cause depends on the position of the measuring points with respect to the inhomogeneity.

Distortions could also be caused by errors in measurements, current leakages, man-made structures (fences with grounded metal poles, metallic pipe lines, railings, etc). These distortions affect the resulting model even if the theoretical sounding curve fits the observed sounding with an acceptable rms percentage. This results in an unacceptable anomalous layer(s) within the model.

To eliminate the tie-in problem and anomalous layer(s) the apparent resistivity values in a segment were initially multiplied by the same factor, i.e., by a parallel shift of the whole segment on logarithmic scales as suggested by Koefoed, (1979) and later, manual smoothing was applied before entering the data into the computer program. Zohdy, (1989) suggested that manual smoothing is much faster and more efficient than assigning fitting tolerance to each point.

4.8 Influence of Slope of Boundary Plane

The effect of the dip of the boundary plane may be neglected for dip angles less than 10^0 or less than 15^0.

Considering that in practice the ratio of the relevant value of the half-distance between the current electrodes over the depth of the boundary is rarely greater than 5, this effect was considered not to be very important in this work, hence correction for the slope of boundary plan was not effected.

CHAPTER FIVE

5. RESULTS

5.1 General Statement

The data analysis was performed using Zohdy's method, which allows the performance of automatic interpretation of the Schlumberger sounding curves to obtain the equivalent n-layer model from the apparent resistivity curve of each sounding (fig. 5.1a). The resulting true resistivity layer models from the application of this method is illustrated in fig. 5.1b. Moreover the equivalent true resistivity models of each sounding were used to produce a comprehensive subsurface resistivity contour section for analysis along some profiles (figs. 5.2a-d). The contour sections were achieved by plotting the resistivity value of each n hypothetical layers of each sounding at a point in the mid-thickness of this layer beneath the sounding locations, and hence the resistivity values were contoured in the vertical plane of these sections.

The interpretations of the VES data were carried out using the subsurface resistivity sections instead of the individual sounding (these were done only at borehole locations corresponding to VES stations at those locations). Such interpretation can deal with the comprehensive picture of the subsurface configuration of the geoelectric layers since the total number of sounding (118) is considered to be quite dense for the area. Accordingly, a discussion of each sounding section is provided and the correlation between them was made

SAKADADI SOUTH 103 (FIELD DATA)

AB/2	App. Res.	AB/2	App. Res.
1.00	501.40	12.60	34.96
1.26	452.16	15.60	37.23
1.56	320.53	15.60	39.48
2.00	261.88	20.00	51.27
2.00	259.82	25.10	62.67
2.51	204.95	31.60	76.41
3.16	165.53	31.60	77.09
3.98	122.11	39.80	101.50
3.98	101.48	50.10	126.05
5.01	74.83	63.10	160.75
6.31	51.23	63.10	170.07
7.94	37.74	79.40	218.53
7.94	42.28	100.00	277.63
10.00	33.58	126.00	321.40
		156.00	373.05

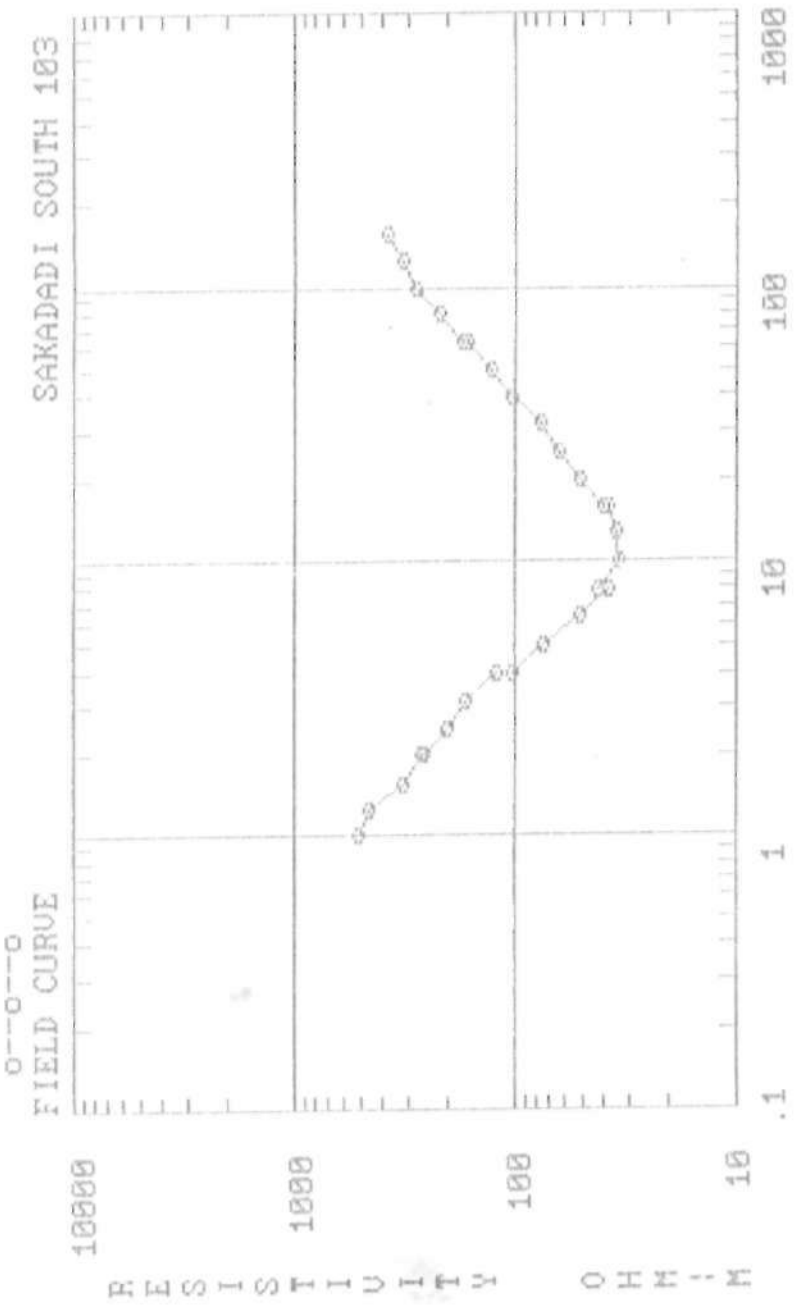


Fig. 5.1a A typical VES Curve

SAKADADI SOUTH 103 (INTERPRETATION)

DEPTH	RESIS.	DEPTH	RESIS.
0.52	850.88	7.58	19.99
0.76	234.20	11.13	57.55
1.11	171.28	16.33	158.55
1.63	235.46	23.98	405.58
2.40	186.76	35.19	946.45
3.52	54.81	51.65	2045.62
5.17	13.83	99999.00	4294.72

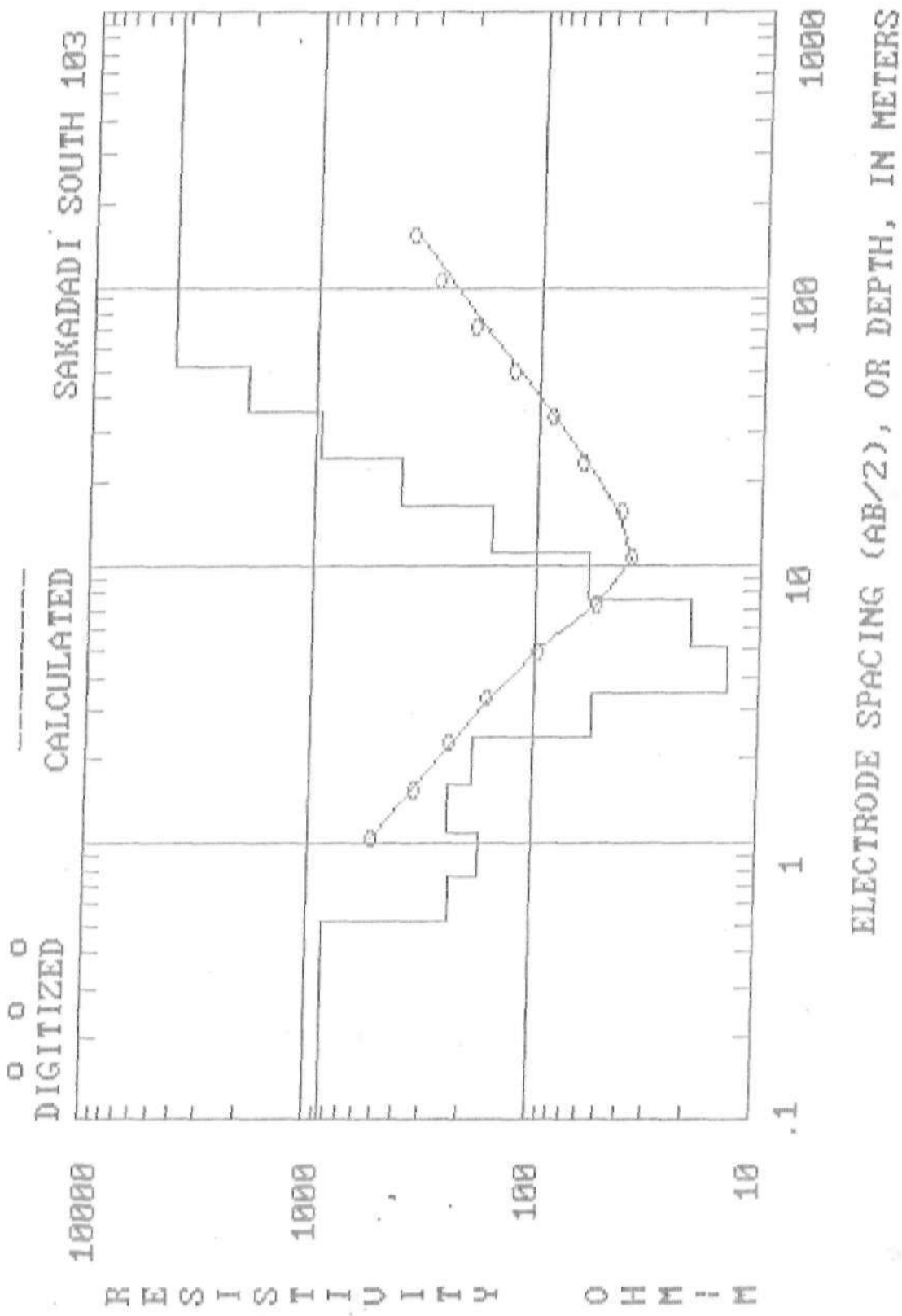


Fig. 5.1b: Interpretation of a VES Curve

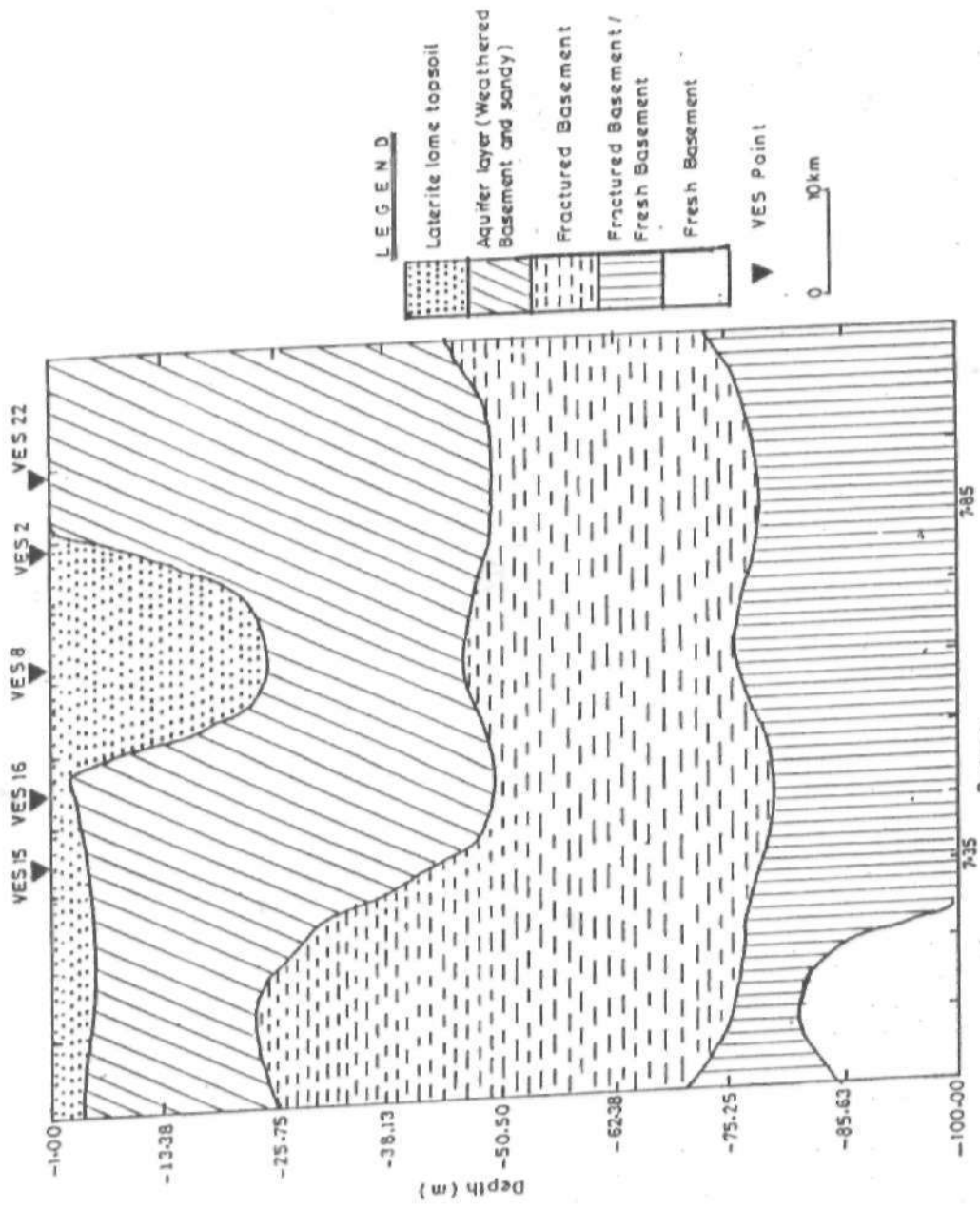


FIG.5-2a:SUBSURFACE GEOLOGIC SECTION EQUIVALENT TO RESISTIVITY CONTOUR SECTION ALONG AR

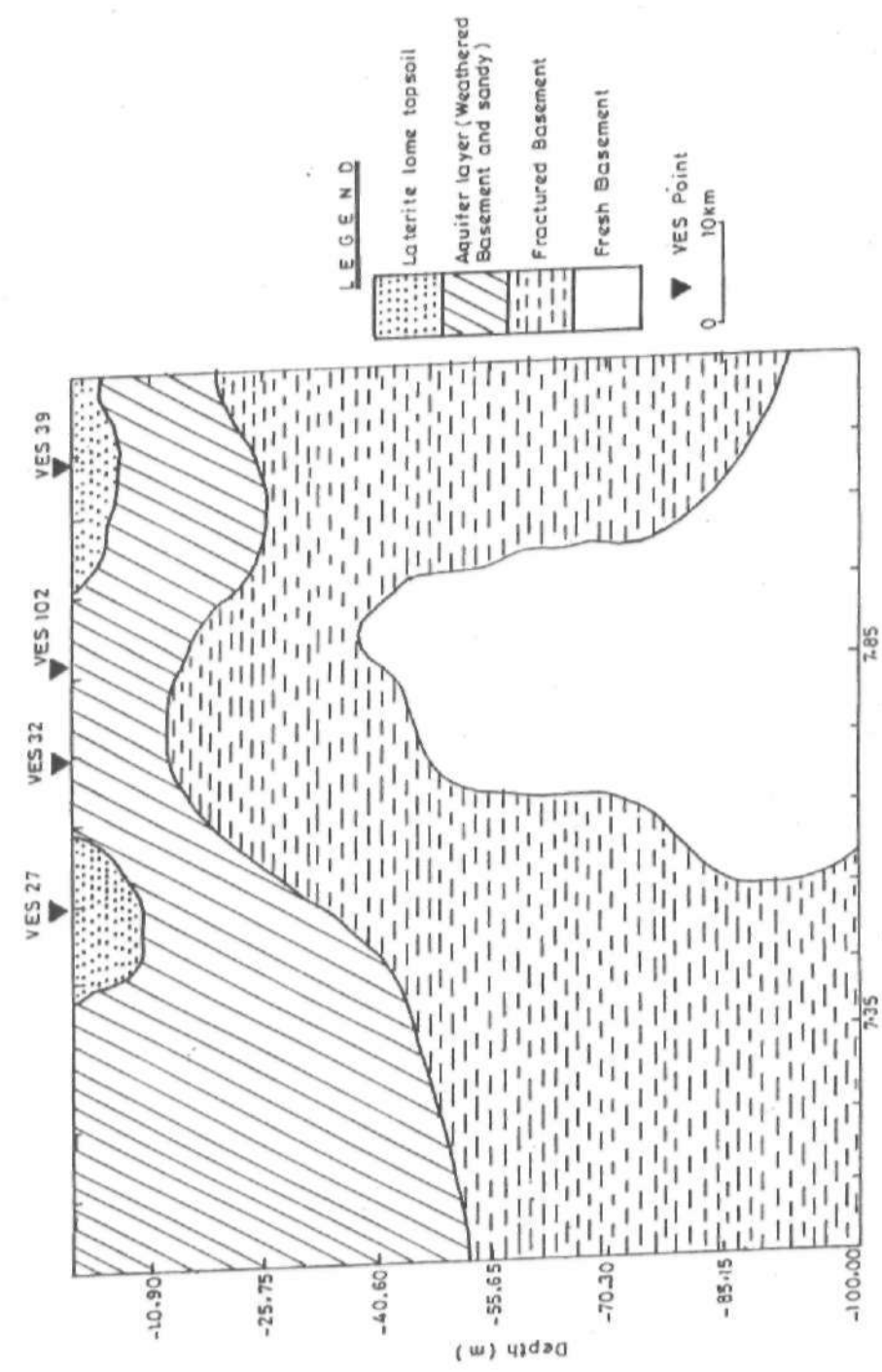


FIG.5.2b: SUBSURFACE GEOLOGIC SECTION EQUIVALENT TO RESISTIVITY CONTOUR SECTION ALONG CD

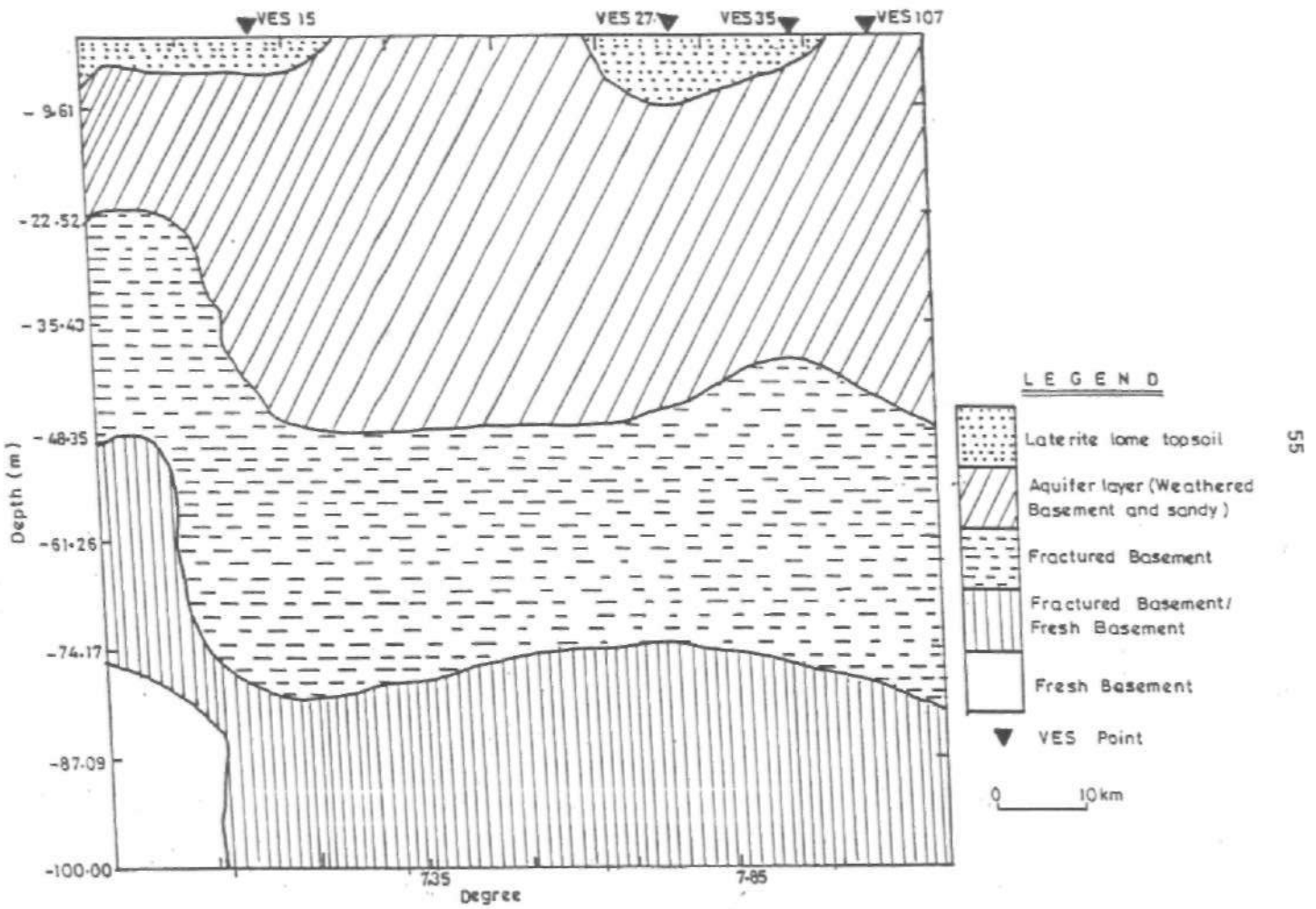


FIG-5-2c:SUBSURFACE GEOLOGIC SECTION EQUIVALENT TO RESISTIVITY CONTOUR SECTION ALONG E F

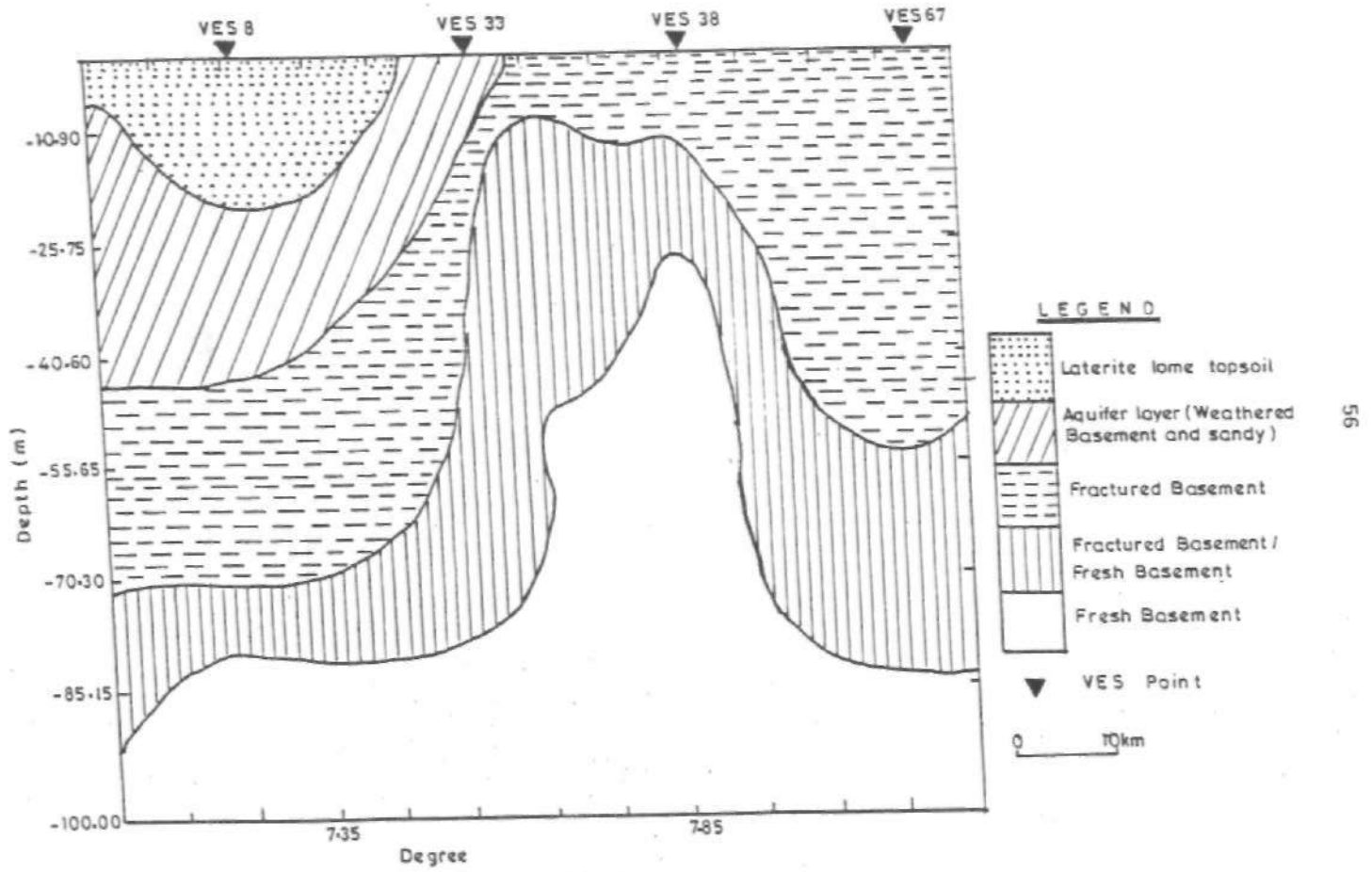


FIG.5-2d: SUBSURFACE GEOLOGIC SECTION EQUIVALENT TO RESISTIVITY CONTOUR SECTION ALONG GH

to stress the additional information provided by the resistivity contour section in fig. 5.3a-j.

5.2 Electrical Resistivity Sounding

The field VES curves for the 118 locations were generally of 4 layer type though there are 2, 3 and 5-layer curves. These are of different shapes and characteristics depending on the formation layering.

Signs of minor distortion of some of the curves can be observed by sudden jumps (fig. 5.4) in values which may be caused by the effects of near surface heterogeneities which are also apparent on the iso-resistivity contour maps. Many sources of errors can contribute to distortion of the field curves in such a way that, quite often, quantitative analysis of them cannot be made or, at best, made with large uncertainty. These include errors in measurements or calculation, current leakage and effect of topography. Errors in measurements were minimised during the field work by often repeating them for increased accuracy. Consequently, it is believed that main source of distortion in the present work could be attributed to occurrence of surface or sub-surface inhomogeneities with marked resistivity contrasts. In all the sounding, smoothening was carried out prior to running the program designed by Zohdy (1989) as earlier mentioned so as to overcome distortion effects. A reasonable control of these sources of error was also the correlation with borehole records where the sounding were done close to borehole locations.

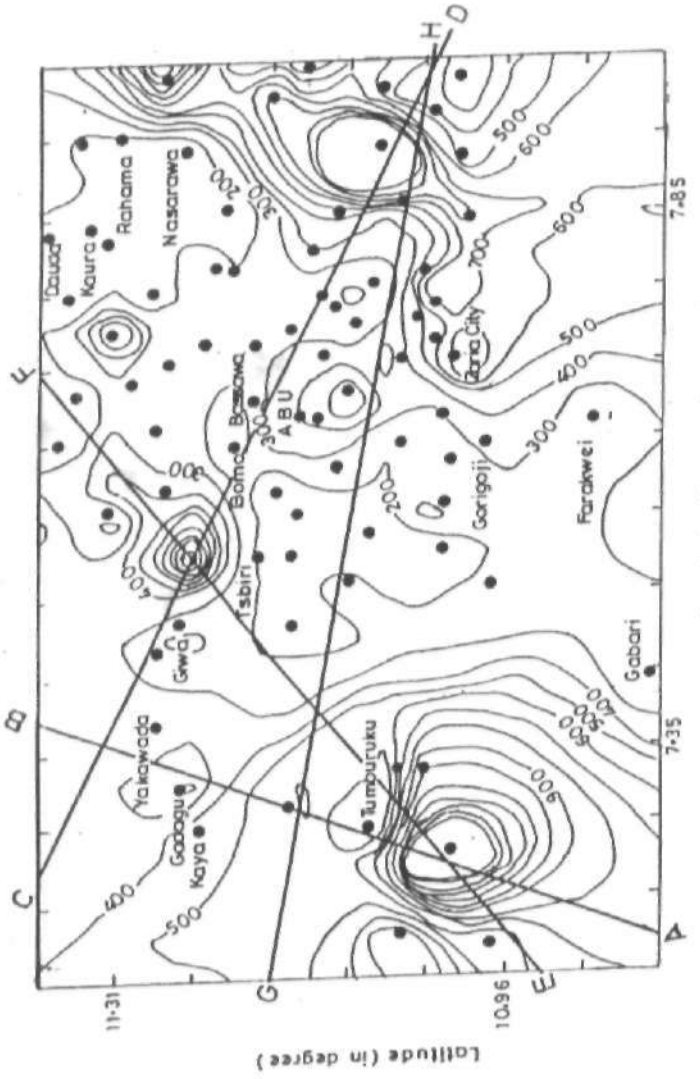


FIG-5-3a: ISORESISTIVITY CONTOUR MAP OF ZARIA AT THE SURFACE

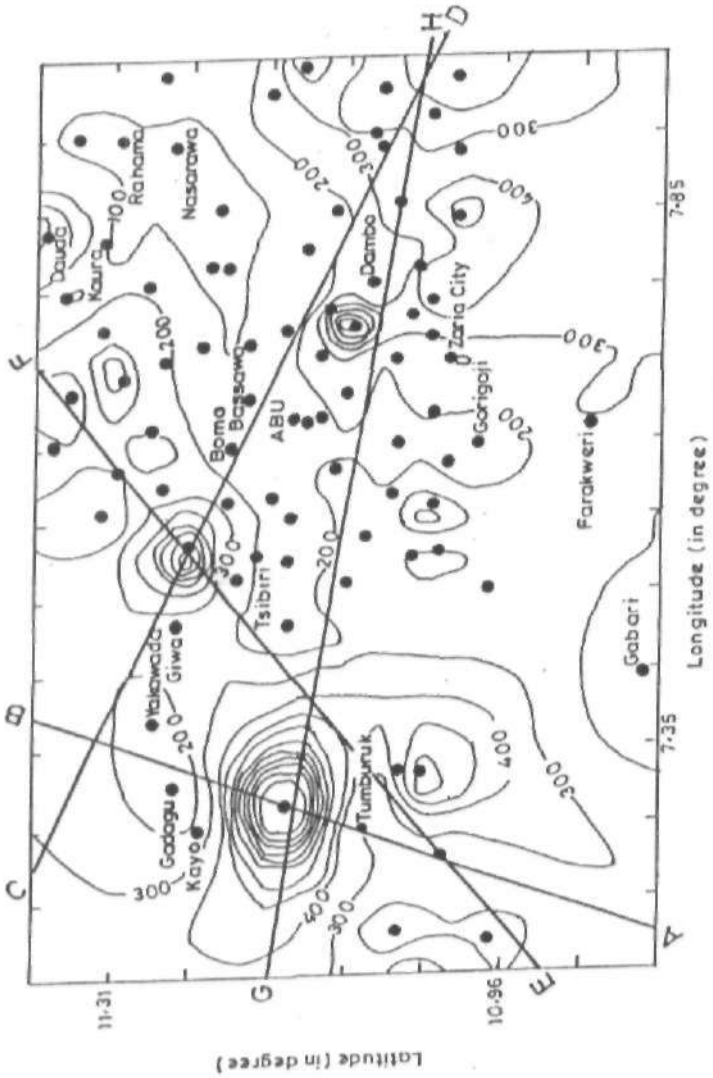


FIG-5-3b : ISORESISTIVITY CONTOUR MAP OF ZARIA AREA AT 5 METER DEPTH

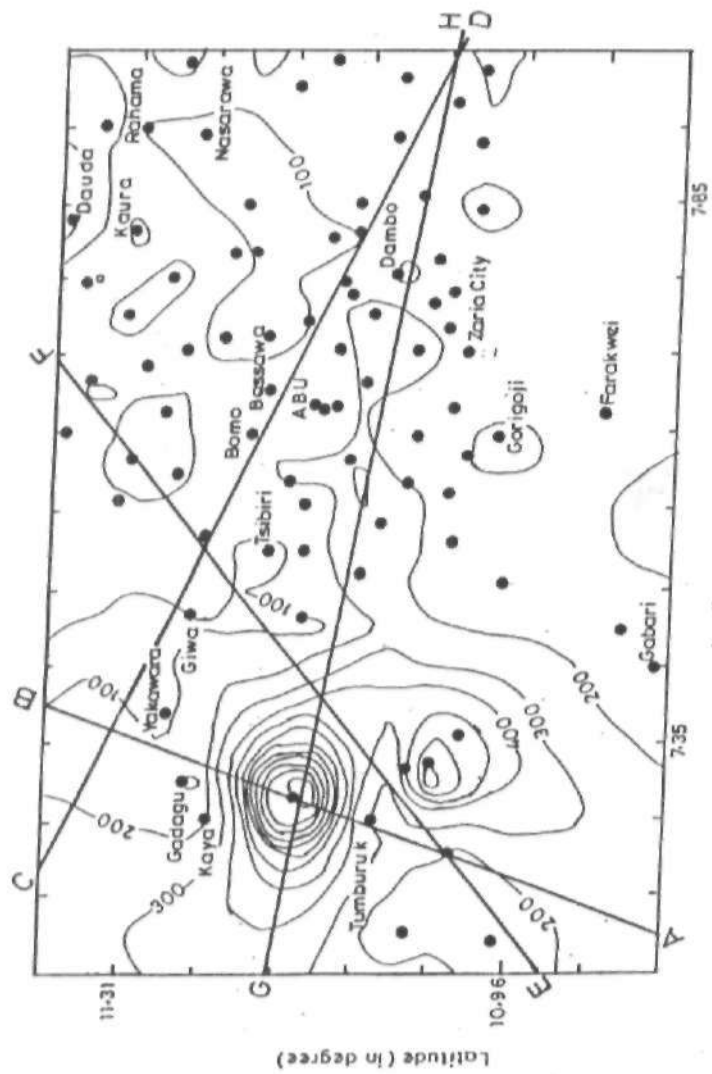


FIG-53c:ISORESISTIVITY CONTOUR MAP OF ZARIA AREA AT 10METER DEPTH

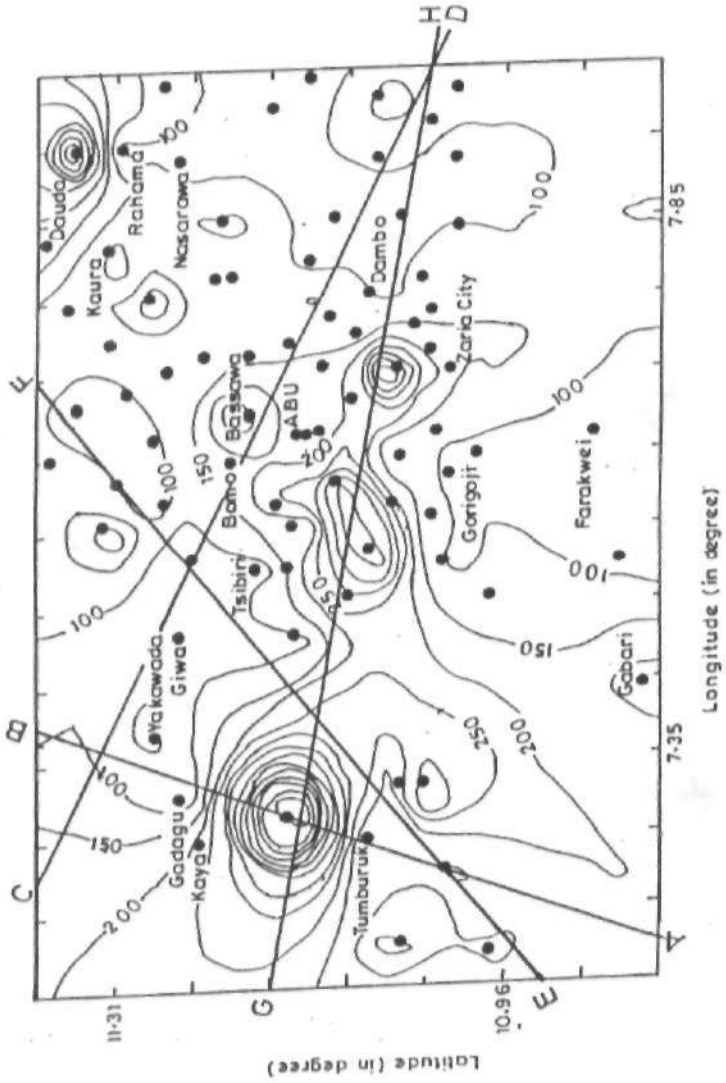


FIG.53d:ISORESISTIVITY CONTOUR MAP OF ZARIA AREA AT 15 METER DEPTH

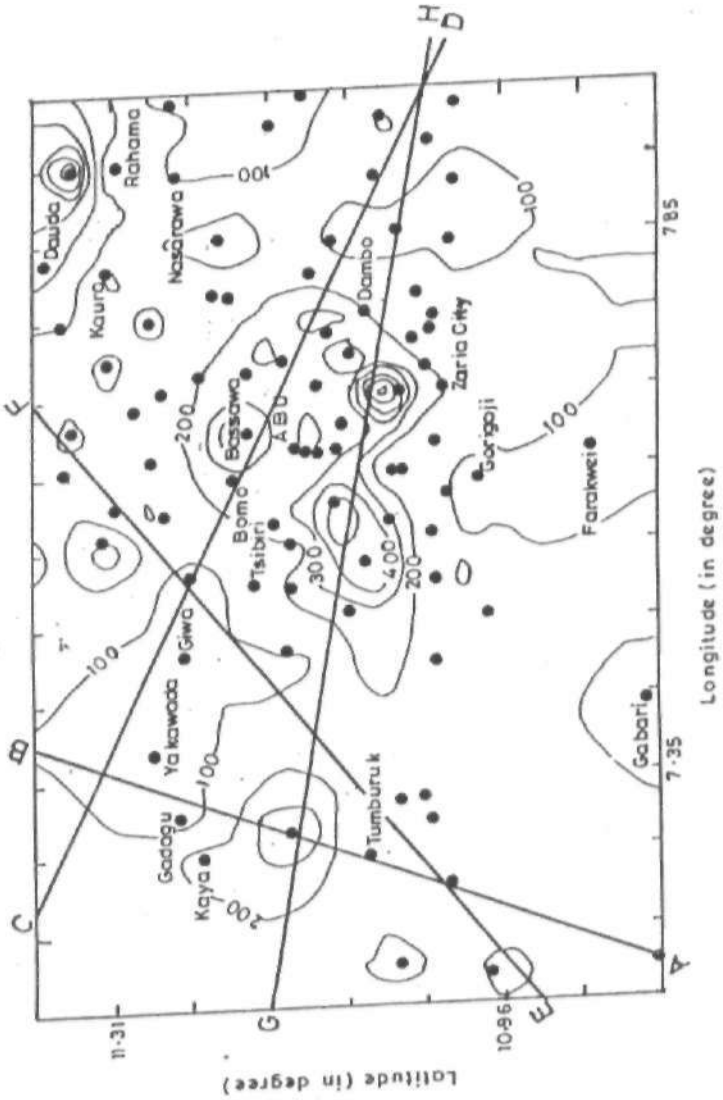


FIG-5.3c:ISORESISTIVITY CONTOUR MAP OF ZARIA AREA AT 20 METER DEPTH

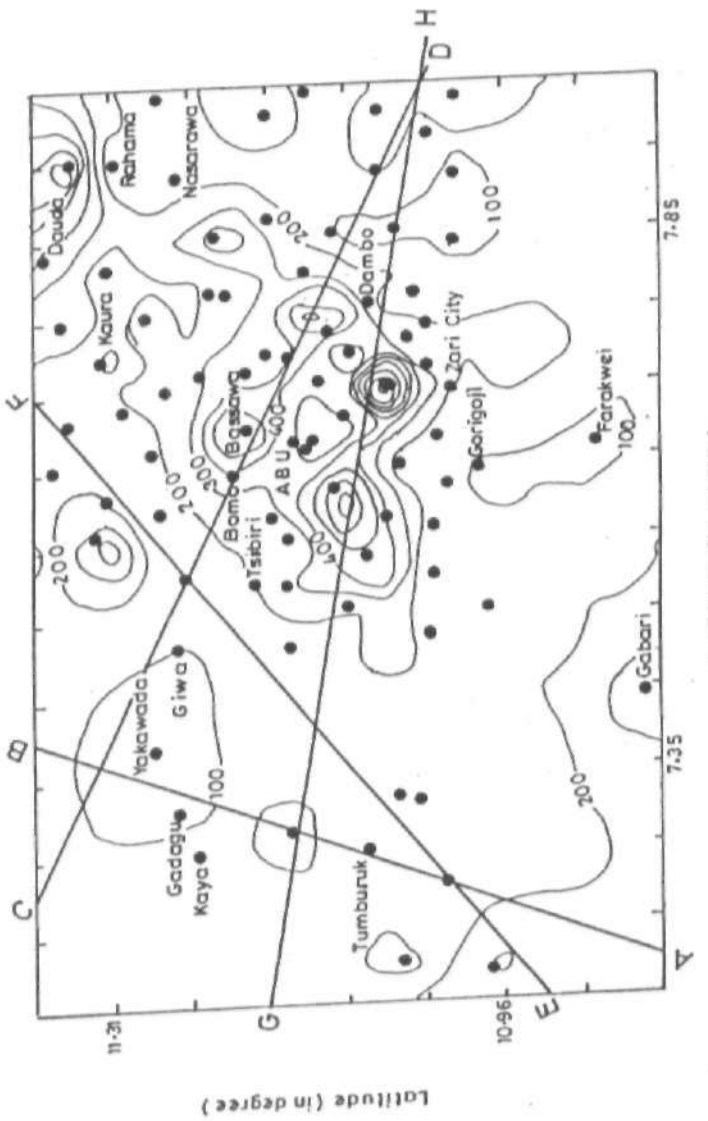


FIG-5.3f : ISORESISTIVITY CONTOUR MAP OF ZARIA AREA AT 25 METER DEPTH

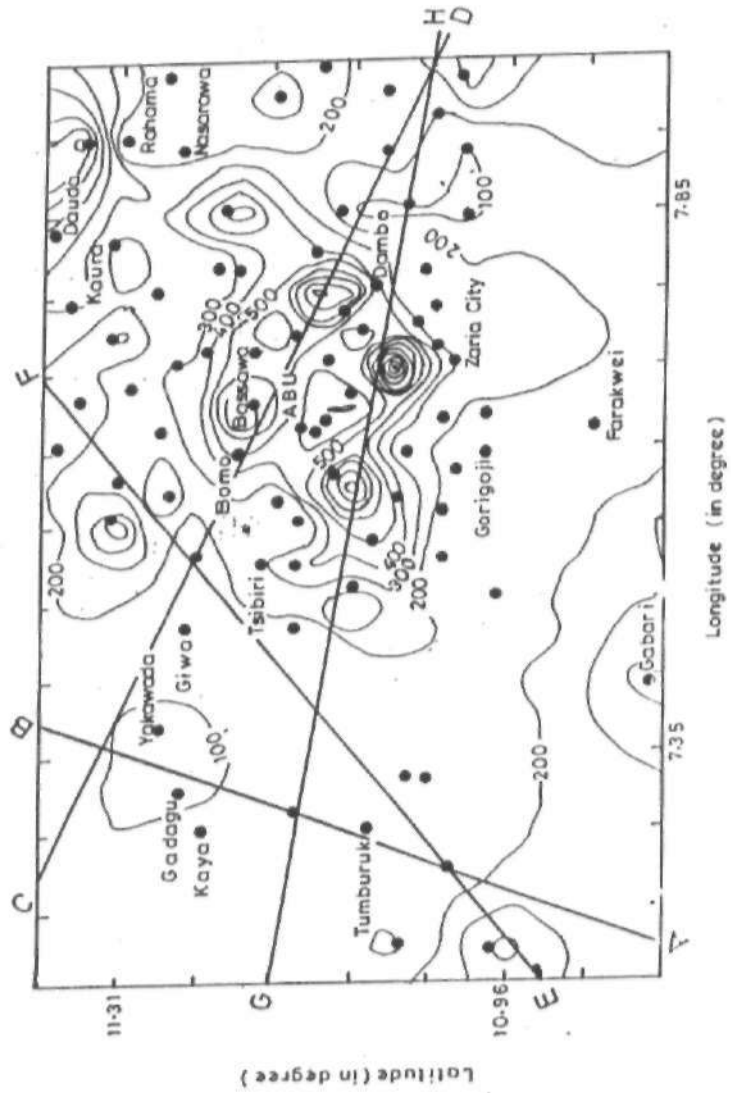


FIG.5·3g : ISORESISTIVITY CONTOUR MAP OF ZARIA AREA AT 30 METER DEPTH

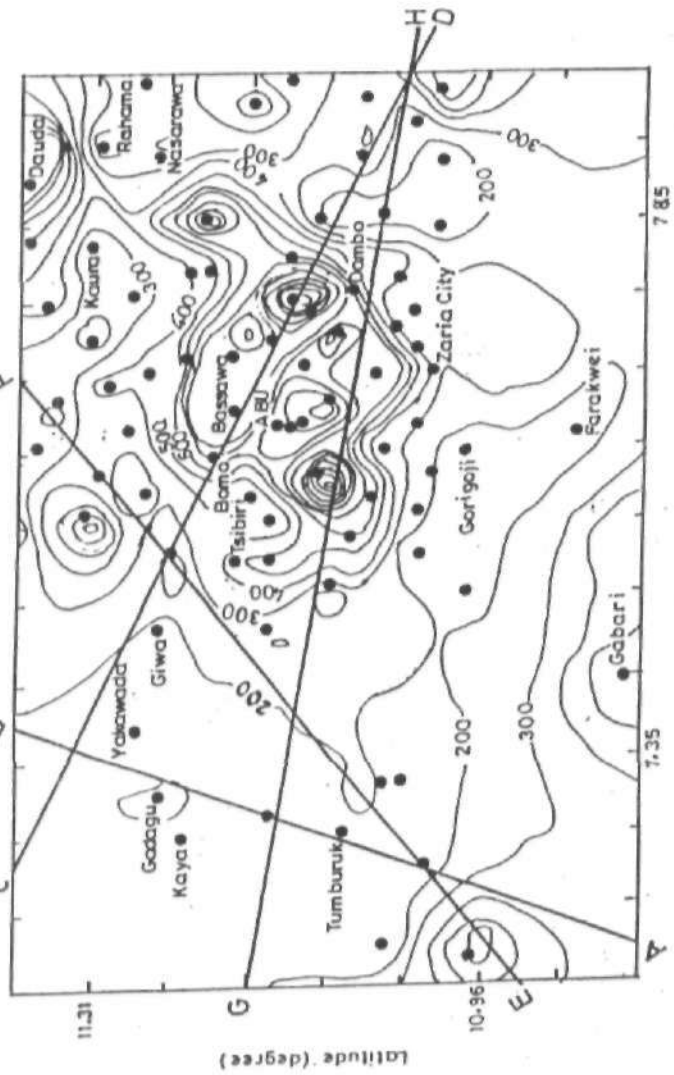


FIG-5-3h : ISORESISTIVITY CONTOUR MAP OF ZARIA AREA 40 METER DEPTH

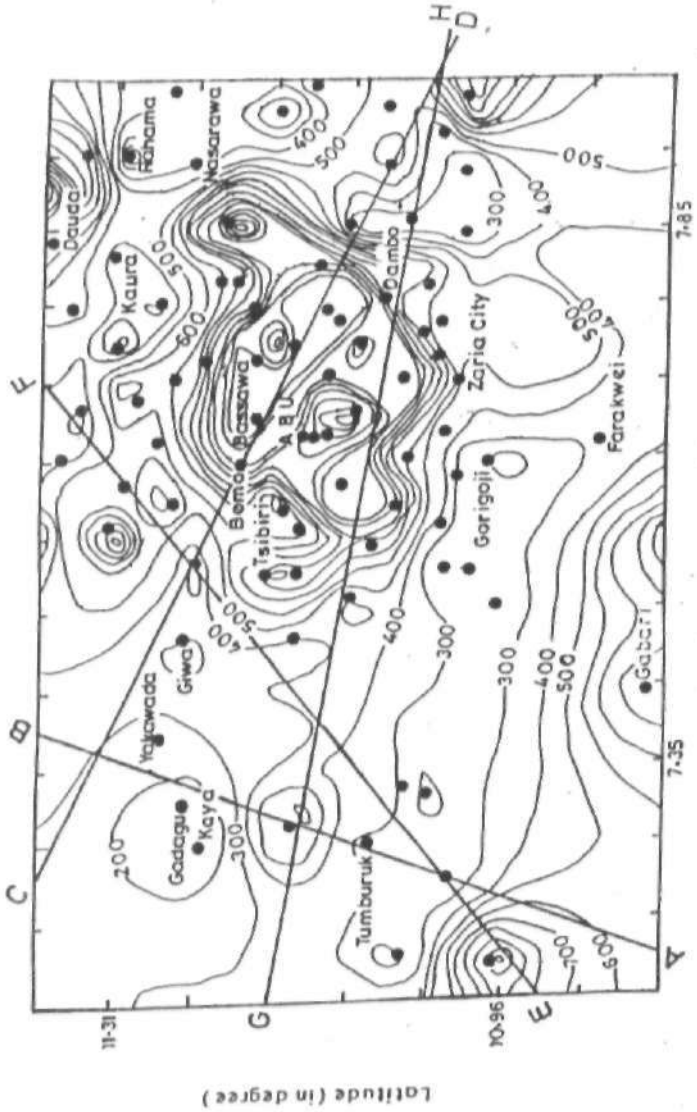


FIG-5.31: ISORESISTIVITY CONTOUR MAP OF ZARIA AREA AT 60 METER DEPTH

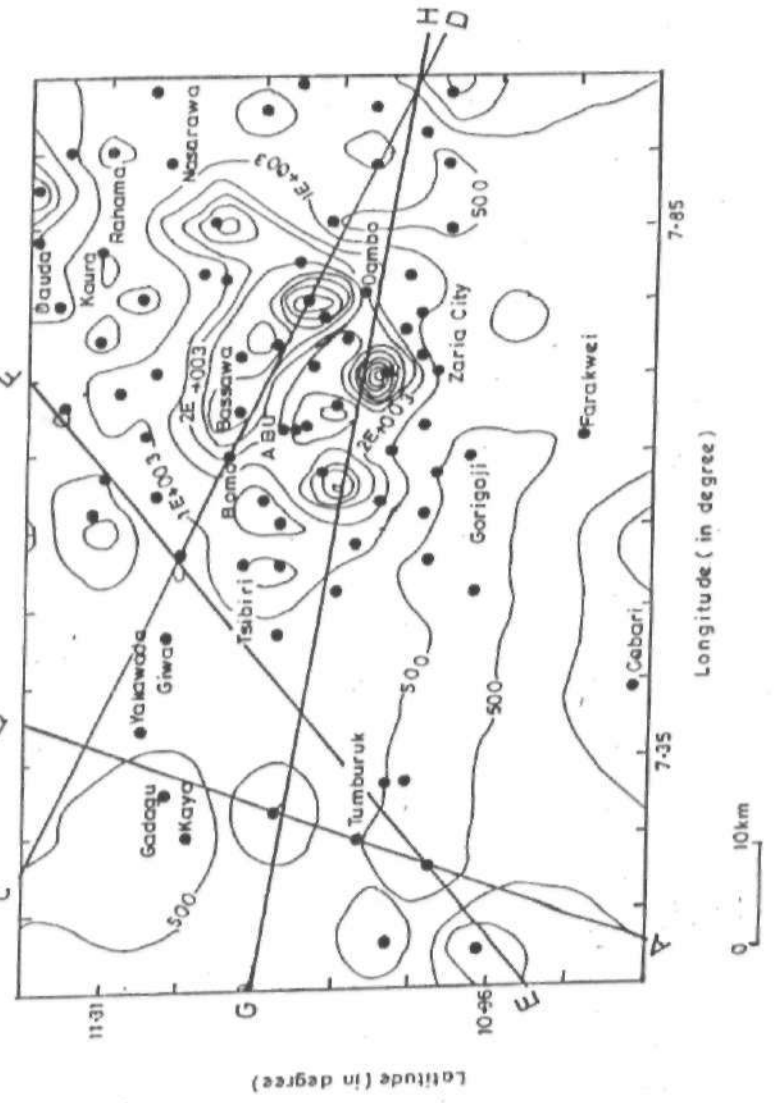


FIG. 53j: ISORESISTIVITY CONTOUR MAP OF ZARIA AREA AT 100 METER DEPTH

HUNKUYI 34 (FIELD DATA)

AB/2	App. Res.	AB/2	App. Res.
1.00	125.24	12.60	108.11
1.26	123.37	15.60	94.09
1.56	123.70	15.60	98.53
2.00	125.03	20.00	92.98
2.00	145.52	25.10	93.09
2.51	146.36	31.60	94.60
3.16	152.03	31.60	97.54
3.98	160.10	39.80	106.04
3.98	165.05	50.10	115.14
5.01	155.61	63.10	128.15
6.31	143.54	63.10	129.78
7.94	130.25	79.40	152.22
7.94	138.35	100.00	188.55
10.00	119.67	126.00	198.56
		156.00	227.17

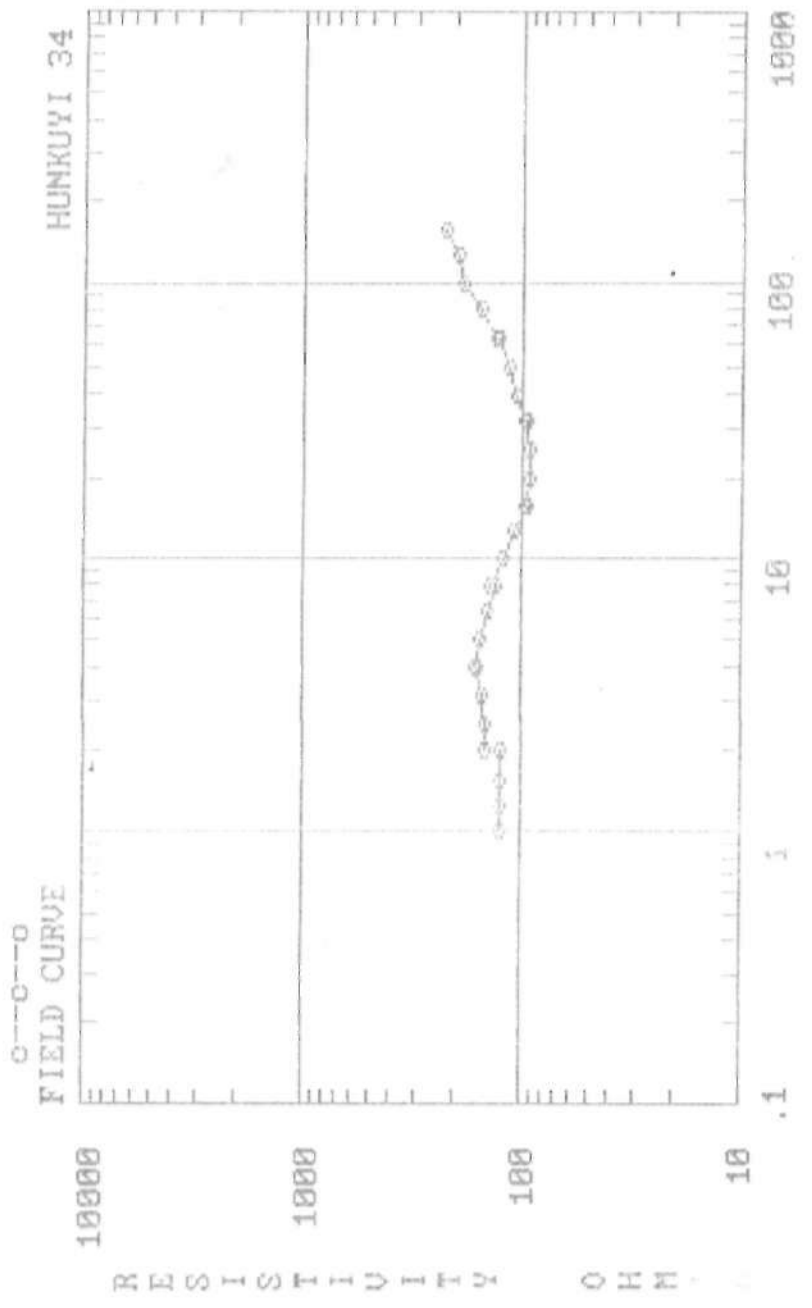


Fig. 5.4 Sudden Jump in VES Curve

5.3 Deriving The Geoelectric Sections

Resistivity values of earth materials derived in this work (Table 5.1) were arrived at using geologic controls such as lithologies observed in wells, boreholes (drill cores) and the knowledge of various types of formations found within the studied area and approximate ranges of electrical resistivity of rocks and solids from Keller and Frischknecht (1966). For example, the topsoil is mostly laterite and loam (borehole informations). The laterites, include the younger and older laterites (Tokaski, 1972) and contain some reddish to grey brown sands, silts and clay (Bala, personal communication). This laterised deposit form the topsoil in most of the survey area. In the stream channels of the Rivers Kubanni, Galma, and Saye and their tributaries alluvial deposits predominate. The alluvium consists of fine grey-brown sands, clay, red sand and gravels (McCurry, 1970).

In addition to the above information, geologic well-logs obtained from Kaduna State Water Board show that the topsoil is lateritic consisting of clayey silty and brownish material with an average thickness of 9 m over the entire survey area. The second layer is about 15 m thick and consists of fine sand and partly silty greyish material wherever they occur. These two layers generally overlie the weathered basement rocks which consists of fine to medium grained sand. Bellow the weathered basement are the fractured basement (wherever it occurs) and the fresh basement.

TABLE 5.1: RESISTIVITY VALUES FOR VARIOUS ROCKS AND SEDIMENTS

Rock Type	Resistivity Range (ohm-m)
Dry Sandy Soil	Greater than 250
Dry Soil	Greater than 300
Dry Clay	Greater than 150
Clay Saturated With Water	25 - 70
Loam	5 - 25
Laterite (fresh)	Greater than 500
Laterite (wet)	Less than 100
Sand and Gravel with Fresh Water	80 - 300
Basement Rock (fresh)	Greater than 1,000
Basement Rock (with fracture not connected)	500 - 1,000
Basement Rock (fractured with fresh water)	200 - 500
Weathered Basement Rock (Clayey)	30 - 80
Weathered Basement Rock (Gravely)	80 - 200

5.4 Qualitative Interpretation of VES at Borehole Locations

In view of the large area covered in this survey and the large number of VES measurements taken, the geology map of this area is used in comparing the VES of same geologic formation with representative sounding near at least three boreholes (with known lithologies) within the formation for proper correlation and interpretation of the resistivity sounding in terms of geologic cross-sections and resistivity/rock-type (formation) relation.

It should be noted that the discrimination between the different geoelectric layers is relatively easier for the n - layer models since small resistivity contrasts are easily distinguishable. This is more pronounced at shallow depths. However it is not possible through the borehole lithology log to distinguish these small contrasts due to possibly the increasing compactness with depth, saturation, coarseness or clay contents of individual formation. But despite this setback attempt has been made by the careful examination of the curves behaviour at the different depths taking into consideration that the resistivity values of each of the n-layer model is plotted at the mid-depth beneath the corresponding sounding location, hence the layer boundaries can be traced from the points of maxima and minima and points of inflection of the curves.

As mentioned earlier the boreholes are classified according to the formations in which they were drilled viz- metasediments, porphyritic Granite and Granite Gneiss.

5.4.1 Metasediments

a) ZA22 JAJI Borehole.

The geoelectric section was correlated with the geologic section using the resistivity-depth plot of the VES near the borehole and the borehole lithology log. Result of the sounding curve shows generally a four layer HA-type geoelectric structure.The first layer has a resistivity range of between 165-568 ohm-m. The relatively high resistivity value for this

layer could be attributed to loose topsoil. The first layer is underlain by a lower resistivity zone of 41-92 ohm-m. The third layer has a resistivity of 169 ohm-m and the last geoelectric layer has a resistivity of above 416 ohm-m.

Comparison of the resistivity results with the borehole lithology (fig. 5.5a) shows that the second and third layers which extends down to a depth of 51.65 m is composed of saturated medium to coarse sand and weathered material with high clay content. The last geoelectric layer at a depth of 51.65 m probably consists of fractured Basements in which the fractures are fairly connected in view of the relatively high resistivity. The borehole did not penetrate down to this depth.

(b) ZA 91 Karaukarau

Result of the sounding curve shows generally a four layer KH-type geoelectric with a good degree of agreement between the borehole lithology log boundaries and the geoelectric boundaries (fig. 5.5b). The first geoelectric layer has a resistivity range of 263-314 ohm-m underlain by a lower resistive zone of between 146 - 223 ohm-m. These two geoelectric layers can be grouped together to correspond to the first layer within the borehole, comparison of the thicknesses show a good agreement, 12 m for borehole and 11.13 m for geoelectric section. The Third geoelectric layer has a resistivity range of between 94 and 142 ohm-m and has a thickness of about 24 m, which corresponds to a sequence of

ZA 22 JAJI

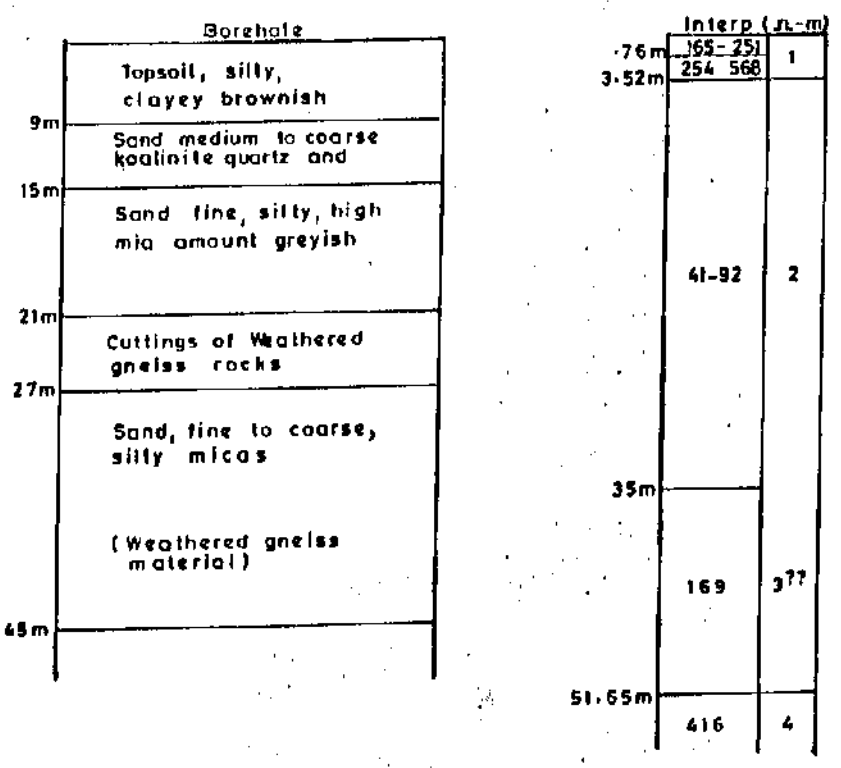


FIG.5.5a:JAJI BOREHOLE LITHOLOGY AND INTERPRETATION

ZA 91 Karankaran

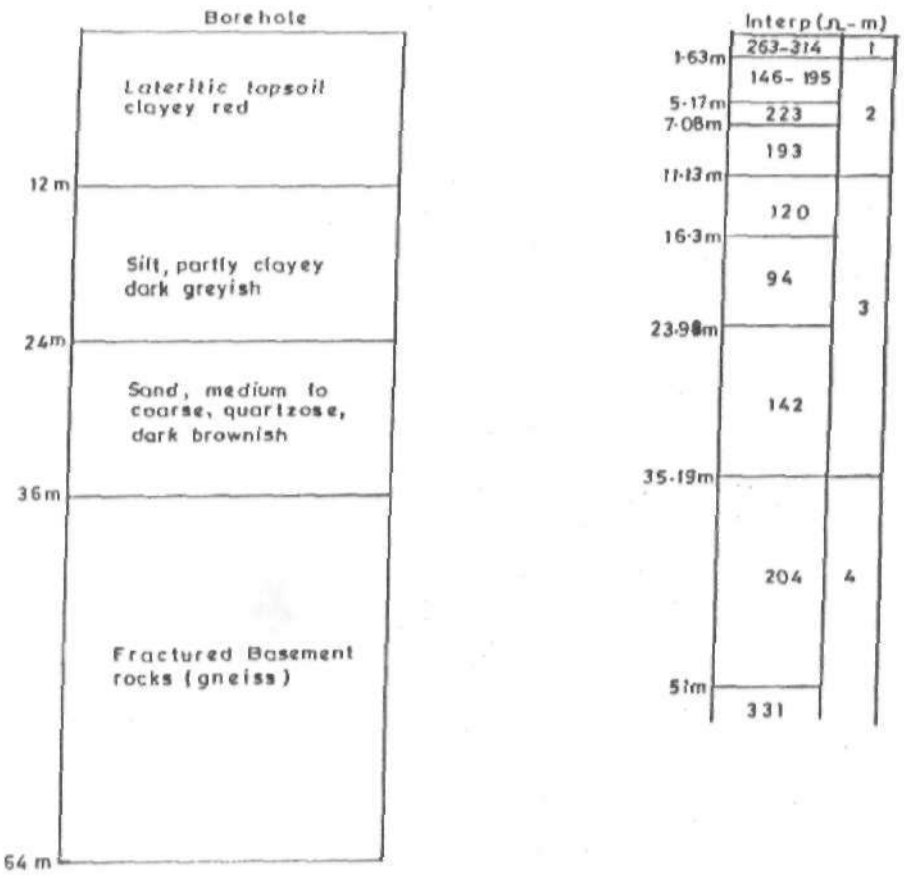


FIG.5.5b;KARANKARAN BOREHOLE LITHOLOGY AND INTERPRETATION

silt and medium to coarse sand within the borehole. The last geoelectric layer has a resistivity of above 204 ohm-m corresponding to fractured Basement within the borehole. In view of the low resistivity of this layer their is the likelihood that water could still be got within this fractured zone.

(c) Tsibiri ZA 99

The geoelectric section around Tsibiri borehole is primarily composed of a three layer H-type curve (fig. 5.5c). The first layer has a fairly high resistivity ranging from 221-562 ohm-m with a thickness of 6.82 m. This layer corresponds to lateritic topsoil within the borehole log which extends to a depth of 9 m. The second layer has resistivity ranging from 82-233 ohm-m this corresponds to a sequence of fine sand to medium quartzose, kaolinite and fractured gneiss. The third geoelectric layer is at a depth of 46 m which could be interpreted as fractured gneiss with resistivity of above 671 ohm-m, an indication of less saturation within this layer.

(d) Zundu ZA 94

Comparison between the geoelectric section and the borehole log for Zundu (fig. 5.5d) looks quite complicated, even the borehole lithology indicates a fractured basement between 12 m and 51 m depth. The geoelectric section indicates a four layer KH-type curve, the first layer resistivity ranges from 81-139 ohm-m with a thickness of about 3 m. The second

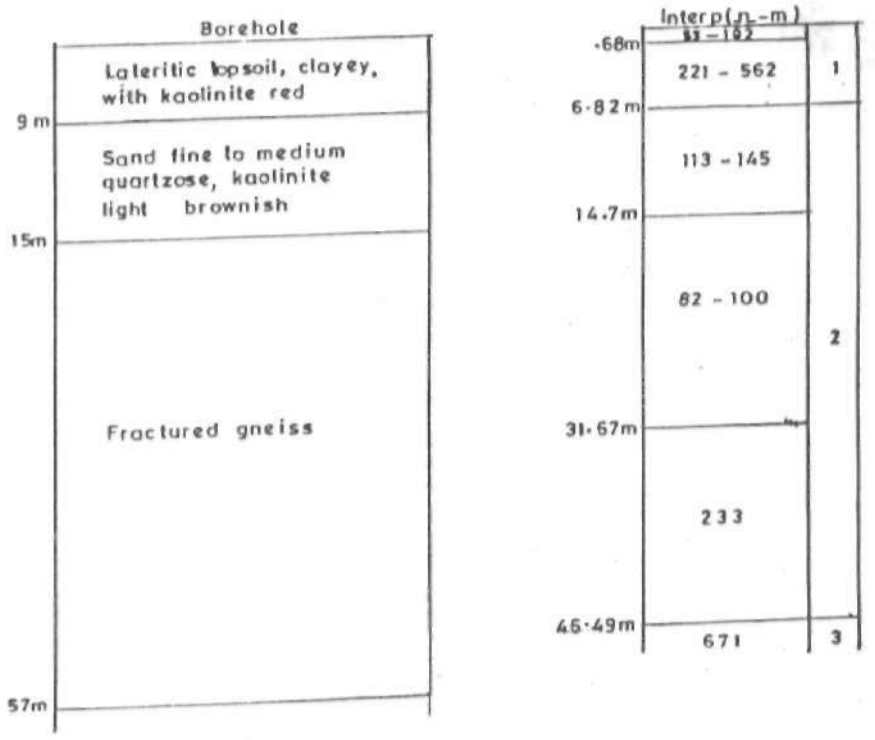


FIG.5.5c: TSIBIRI BOREHOLE LITHOLOGY AND INTERPRETATION

ZA 94 Zundu

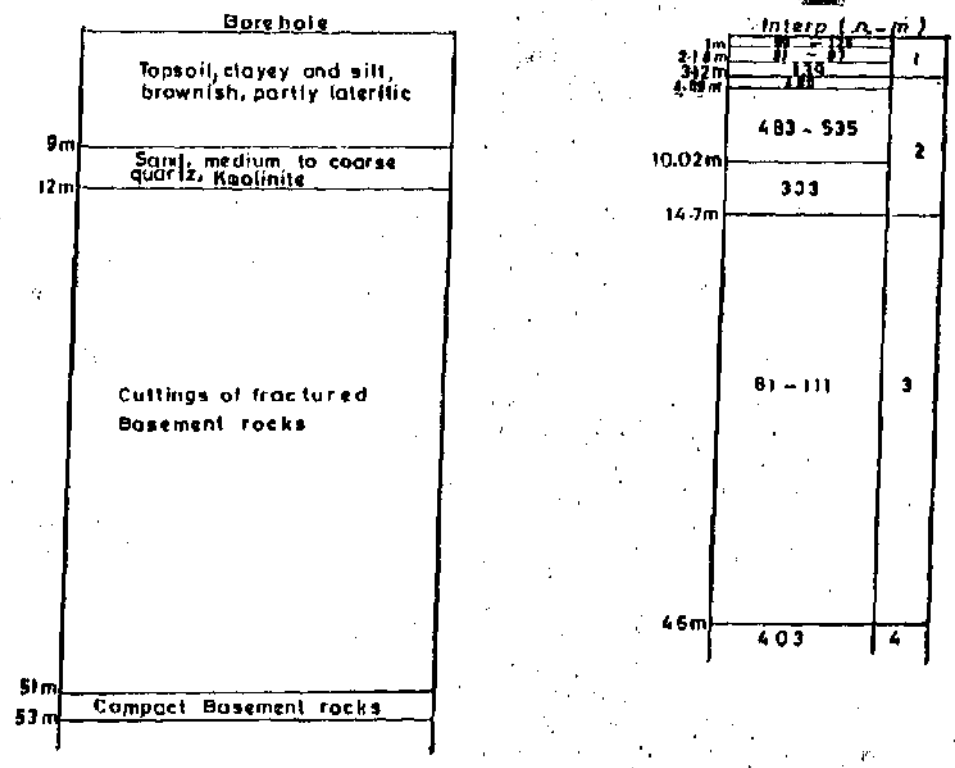


FIG.5.5d; ZUNDU BOREHOLE LITHOLOGY AND INTERPRETATION

layer has a thickness of 10 m with a resistivity ranging from 289 to 535 ohm-m. The third layer is a low resistive zone and has a thickness of about 30 m with resistivity range from 81-111 ohm-m. This is possibly due to high saturation within the weathered zone. The last geoelectric layer is at a depth of 46 m, with a resistivity of 403 ohm-m, and a comparison with the borehole within this depth indicates the layer to be fractured basement..

5.4.2 Porphyritic Granite

(a) Jema Kubanni

The geoelectric sounding around this borehole indicates generally a five resistivity layer HAH-type curve (fig. 5.5e). The first layer like in all other first layers is a thin (1.5 m) lateritic top, clayey soil and silty with a resistivity range of 116 to 139 ohm-m. The second layer has a lower resistivity range of 46 to 94 ohm-m extending to a depth of 21 m and a comparison of this with the borehole indicates a sequence of topsoil to fine sand, clayey and silty with a thickness of 18 m. The third geoelectric layer has a resistivity of 176 ohm-m with a thickness of 10 m corresponding to sand and fine to medium quartz and feldspars of the borehole. The fourth geoelectric layer has a relatively high resistivity of 380 ohm-m with a thickness of 15 m, there is no equivalent layer indicated on borehole log, but comparison of the depth to this layer with the borehole shows that the formation is possibly a transition from the weathered/fractured

ZA 112 Kubanni

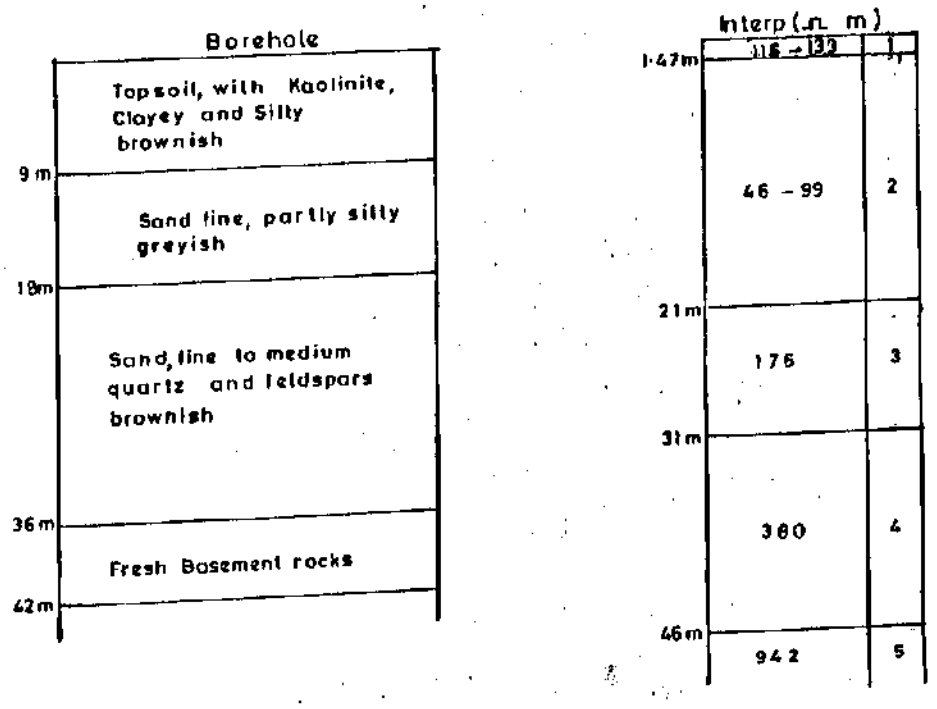


FIG.5.5e: KUBANNI BOREHOLE LITHOLOGY AND INTERPRETATION

basement to the fresh basement. The last geoelectric layer is encountered at a depth of 46 m with a resistivity of above 940 ohm-m corresponding to fresh Basement Rock.

(b) Farakwai ZA 29

Result of the sounding curve shows generally a 4-layer KH-type geoelectric structure (fig. 5.5f). The resistivity value for the first layer is not high ranging from 190 to 282 ohm-m. This could be attributed to the underflowage and drainage of water drawn from nearby stream. The layer is underlain by a resistive zone of between 168-667 ohm-m. The third layer has a resistivity range of 44 to 90 ohm-m. The fourth layer has a resistivity of above 107 ohm-m. Comparison of the resistivity results with the borehole lithology shows that the thin first and second geoelectric layers which extends from the surface to a depth of 11 m are composed of lateritic soil with clay. The third layer with a thickness of 24 m is made up of fine to medium sand highly weathered and porous, while the fourth layer is a continuation of weathered zone in the highly fractured basement rocks. The fresh Basement rock is not indicated in the geoelectric section.

(c) ZA 121 ABA

The sounding conducted close to this borehole shows generally a 4 layer HA type geoelectric structure (fig. 5.5g). The resistivity value for the first layer ranges from 109-209 ohm-m; this thin first layer is common to all the sounding

ZA 29 Farakwei

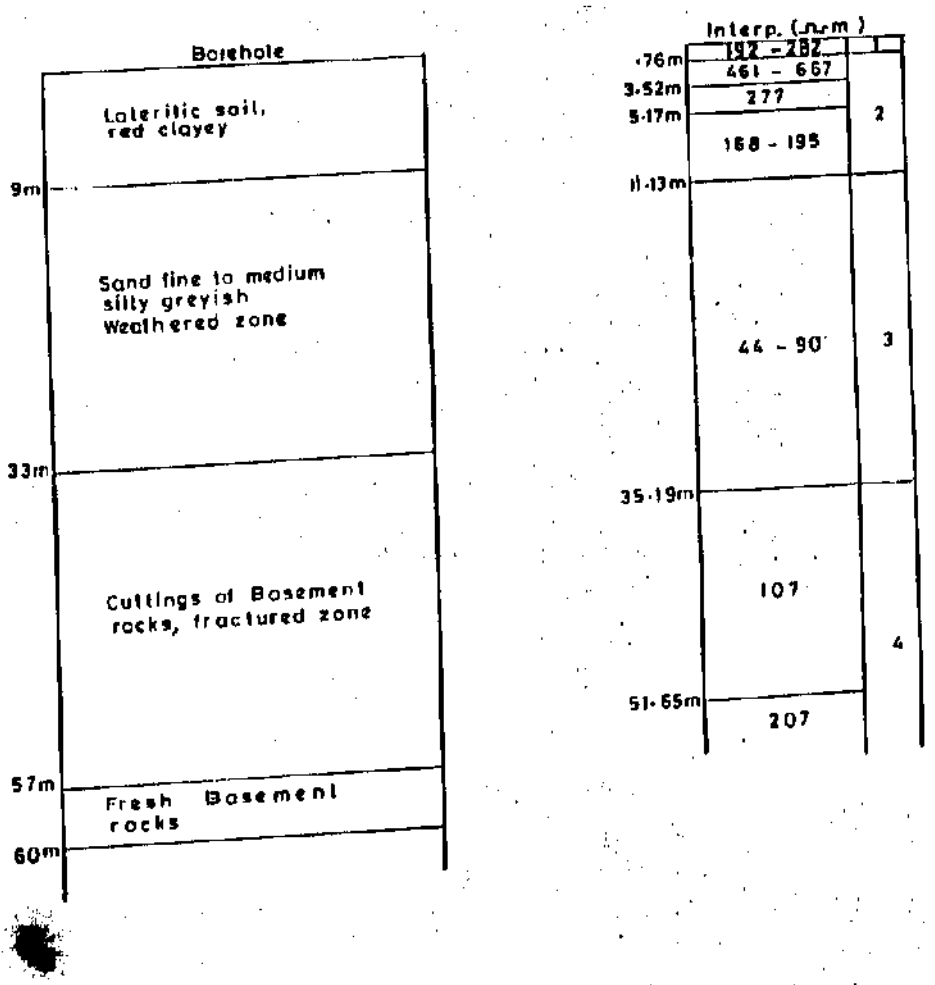


FIG. 5.51: FARAKWEI BOREHOLE LITHOLOGY AND INTERPRETATION

ZA 121 ABA

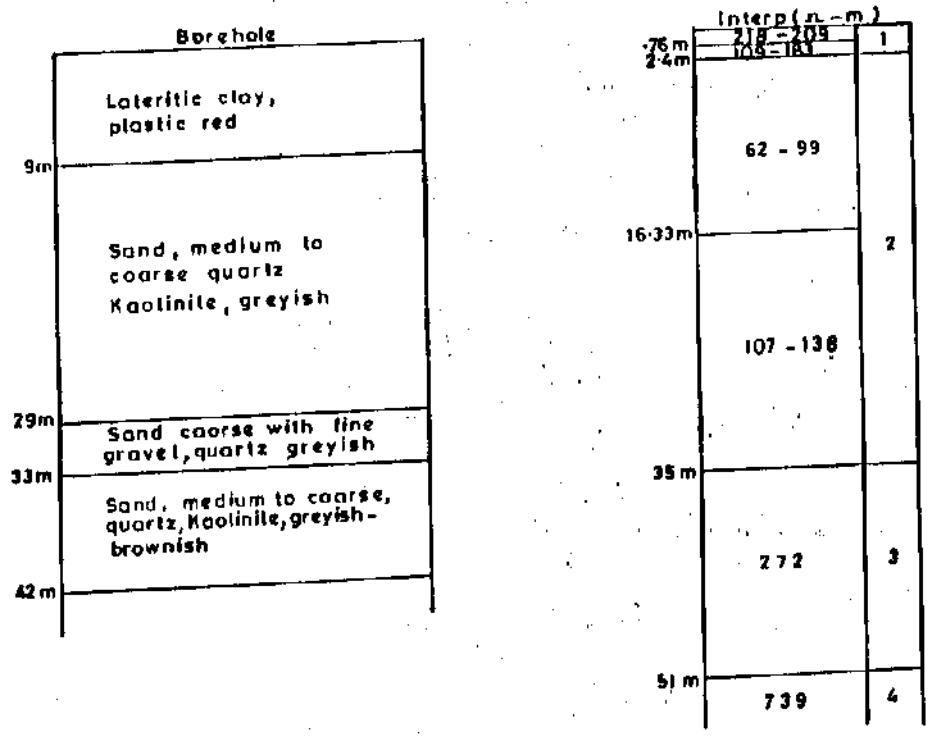


FIG.5.5g: ABA BOREHOLE LITHOLOGY AND INTERPRETATION

because of the small spacing values used within the initial sequence of the sounding. This layer is underlain by a lower resistivity range of between 62 to 138 ohm-m. The third layer has a resistivity of 272 ohm-m followed by basement with a resistivity of above 739 ohm-m.

Comparison with borehole indicates the first layer to be lateritic clay extending to a depth of 2.4 m. The second layer with a thickness of about 19 m is made up of medium to coarse sand with gravel, while the third layer is an indication of some weathered material but in a relatively more compact form. The last geoelectric layer at a depth of 51 m, is possibly the basement. The borehole, which is only 42 m deep, does not extend to the basement.

(d) Zabi Zaria ZA 106

Four major layers of KH-type geoelectric structure are indicated at this location (fig . 5.5h). The first layer with a resistivity range of 118 -175 ohm-m is the lateritic loose topsoil with high clay content. The second layer extends from 1.1 m to 7.58 m depth; it is composed of laterite and sand with resistivity range of 246-329 ohm-m. The third layer has a thickness of about 44 m with resistivity ranging from 154 to 191 ohm-m. This layer is composed of highly saturated weathered materials. The last geoelectric layer is at a depth of 51 m with a resistivity of 448 ohm-m, this fairly corresponds to fractured Basement rock in the borehole log at a depth of 45 m.

ZA 106 Zabi Zaria

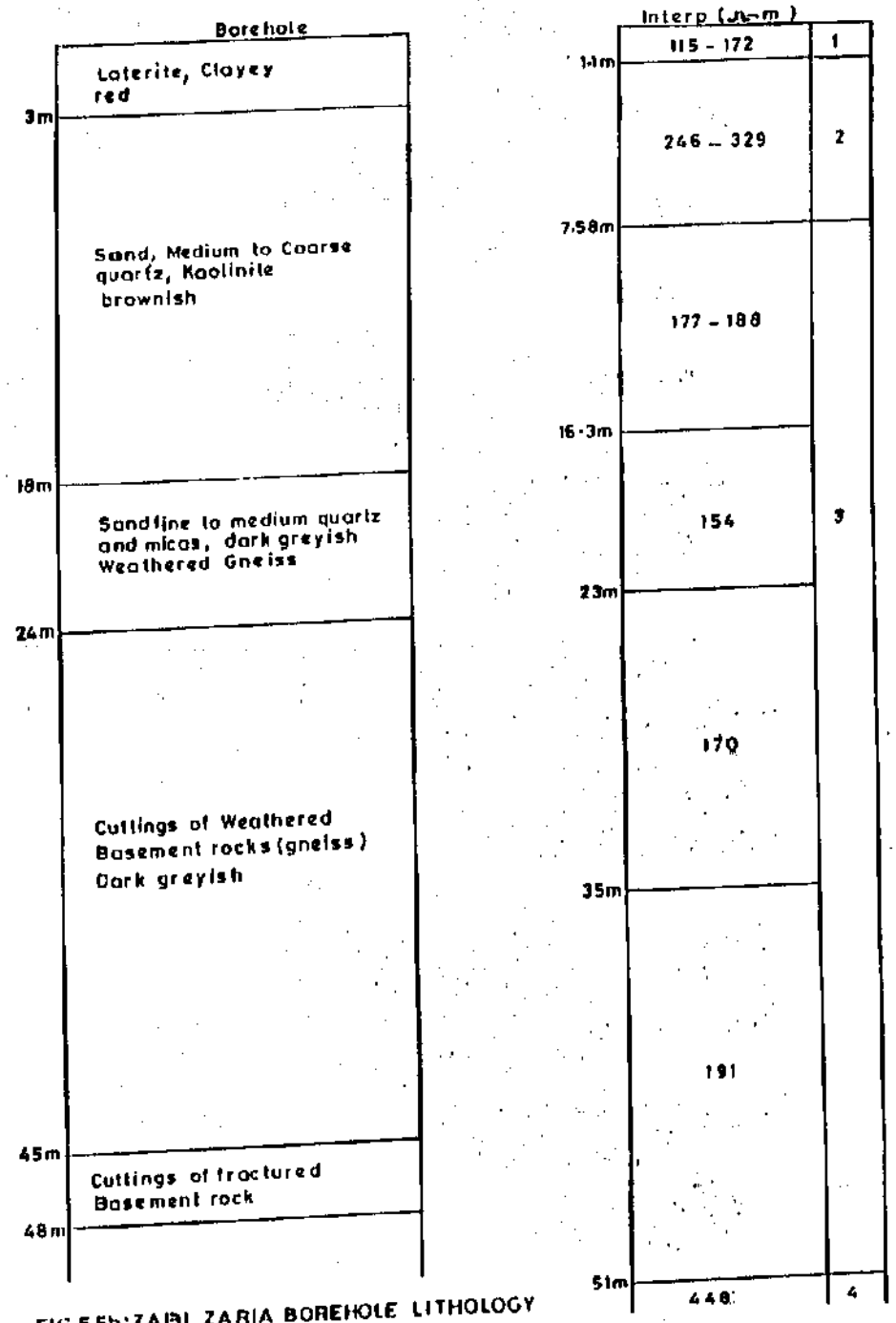


FIG.5.5h: ZABI ZARIA BOREHOLE LITHOLOGY AND INTERPRETATION

(e) Panhauya ZA 95

The sounding curve shows generally a three layer A-type geoelectric structure (fig. 5.5i). The first layer has low resistivity of between 58 to 209 ohm-m with a thickness of 21 m. The second layer has a resistivity range of between 351 and 421 ohm-m and the third layer has a resistivity of greater than 750 ohm-m. Comparison of this section with the borehole log indicates that the first layer is composed of medium to coarse sand with clay and quartz. The second layer with a thickness of 25 m corresponds to cuttings of Basement rocks while the geoelectric basement is at a depth of 46 m.

(f) Dumbi ZA 23

Results of the sounding curve shows generally a five layer geoelectric structure (fig. 5.5j). The resistivity value for the first layer ranges from 111-167 ohm-m. The resistivity of the second layer ranges from 92 to 154 ohm-m and that of the third layer is between 201 to 256 ohm-m. The fourth layer has a resistivity range of 332-444 ohm-m while the last geoelectric basement has a resistivity of greater than 592 ohm-m.

Comparison of this section with the borehole log shows that the first layer is composed of lateritic loose soil with a thickness of 3.5 m, underlain by medium to coarse sand with a thickness of about 6 m. The third layer has a thickness of about 12 m corresponding to cuttings of weathered Basement rocks. The fourth layer with a thickness of 28 m corresponds to

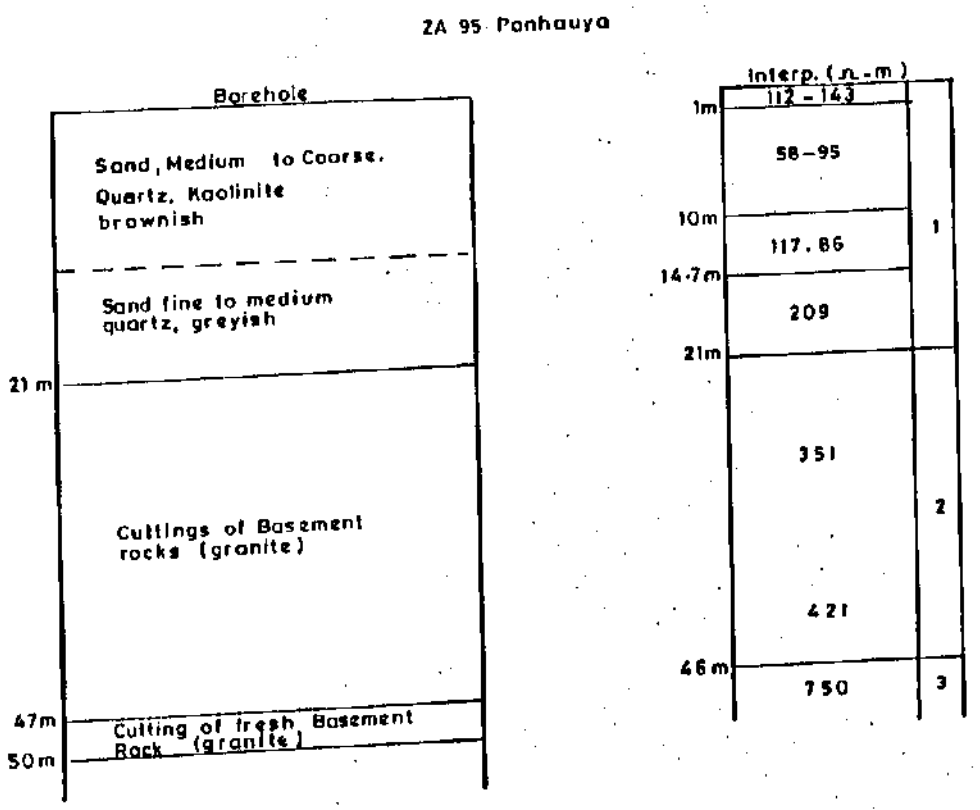


FIG.5.51: PANHAUYA BOREHOLE LITHOLOGY AND INTERPRETATION

ZA 23 Dumbi

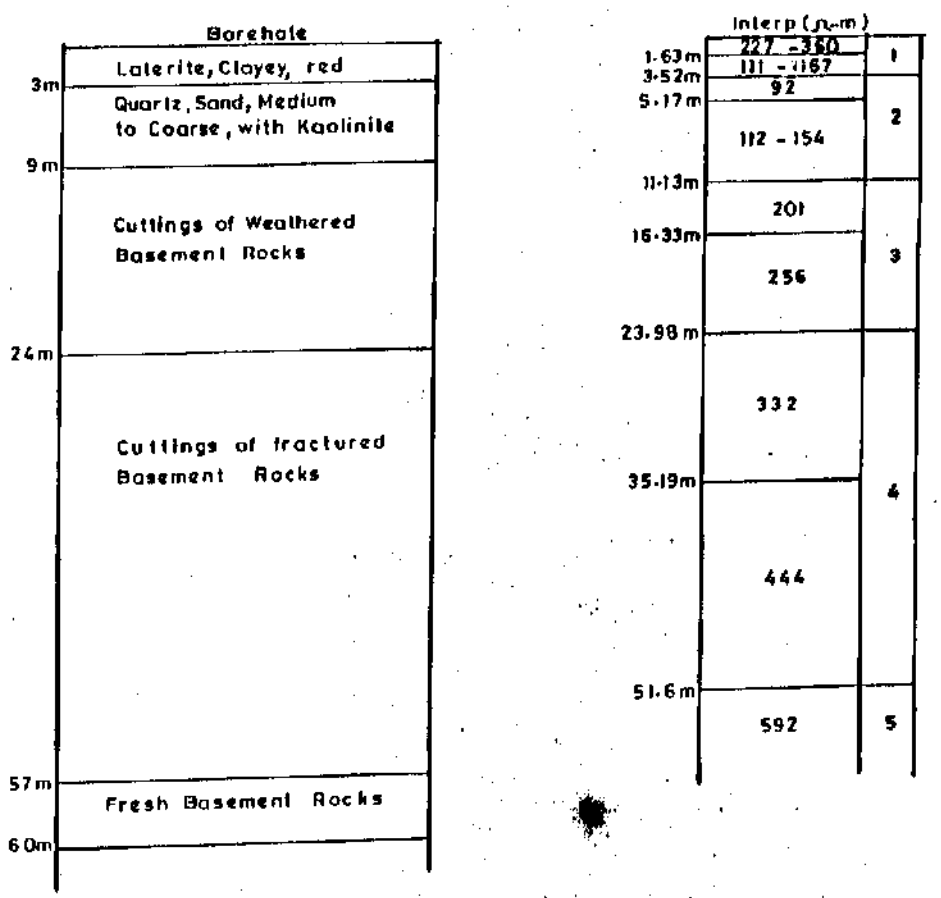


FIG.5.5j : DUMBI BOREHOLE LITHOLOGY AND INTERPRETATION

cuttings of fractured Basement rocks. This is followed by the high resistive geoelectric basement at a depth of 51.6 m.

5.4.3 Granite Gneiss

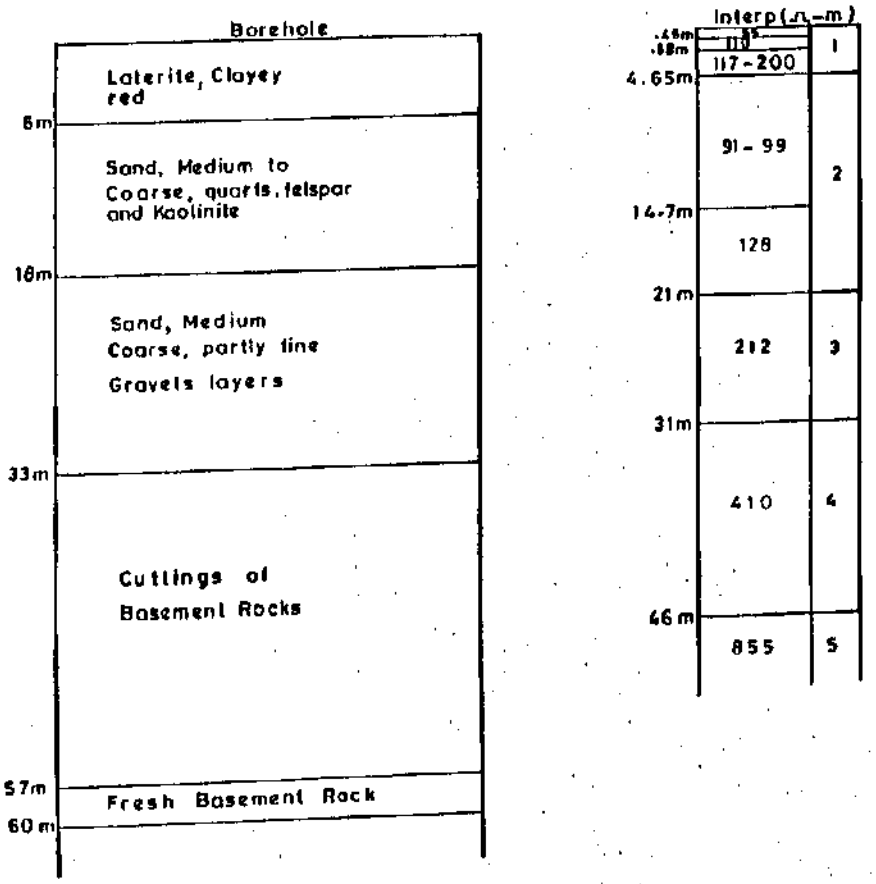
(a) Sakadadi ZA 108

The borehole log and the geoelectric sounding indicate generally 5 layer structure (fig. 5.5k). The first layer with a resistivity range of 55 to 200 ohm-m and a thickness of about 5 m corresponds to laterite and red clay; this is underlain by a low resistivity layer (91-126 m) of medium to coarse sand with quartz, feldspar and Kaolinite. The thickness is about 15 m. The third layer has a thickness of 10 m and it corresponds to a mixture of medium to coarse sand with partly fine gravel and has a resistivity of 212 ohm-m. The fourth layer with a resistivity of 410 ohm-m corresponds to cuttings of Basement rock and has a thickness of 15 m. The geoelectric basement is at a depth of 46 m with a resistivity of above 855 ohm-m. There is some disparity between this depth and that to fresh basement (57 m) of the borehole and this could be attributed to the transition between fractured basement and fresh basement which might have not been easily identified by the drillers.

(b) Bomo Gari ZA 110

Result of the sounding curve shows generally a five layer geoelectric structure (fig. 5.5l). The resistivity range of the first layer is between 55 and 204 ohm-m, this is underlain by a resistivity range of 134-146 ohm-m. The third layer has

ZA 108 Sakadadi



FIG·5.5k:SAKADADI BOREHOLE LITHOLOGY AND INTERPRETATION

ZA 110 Bomo Gari

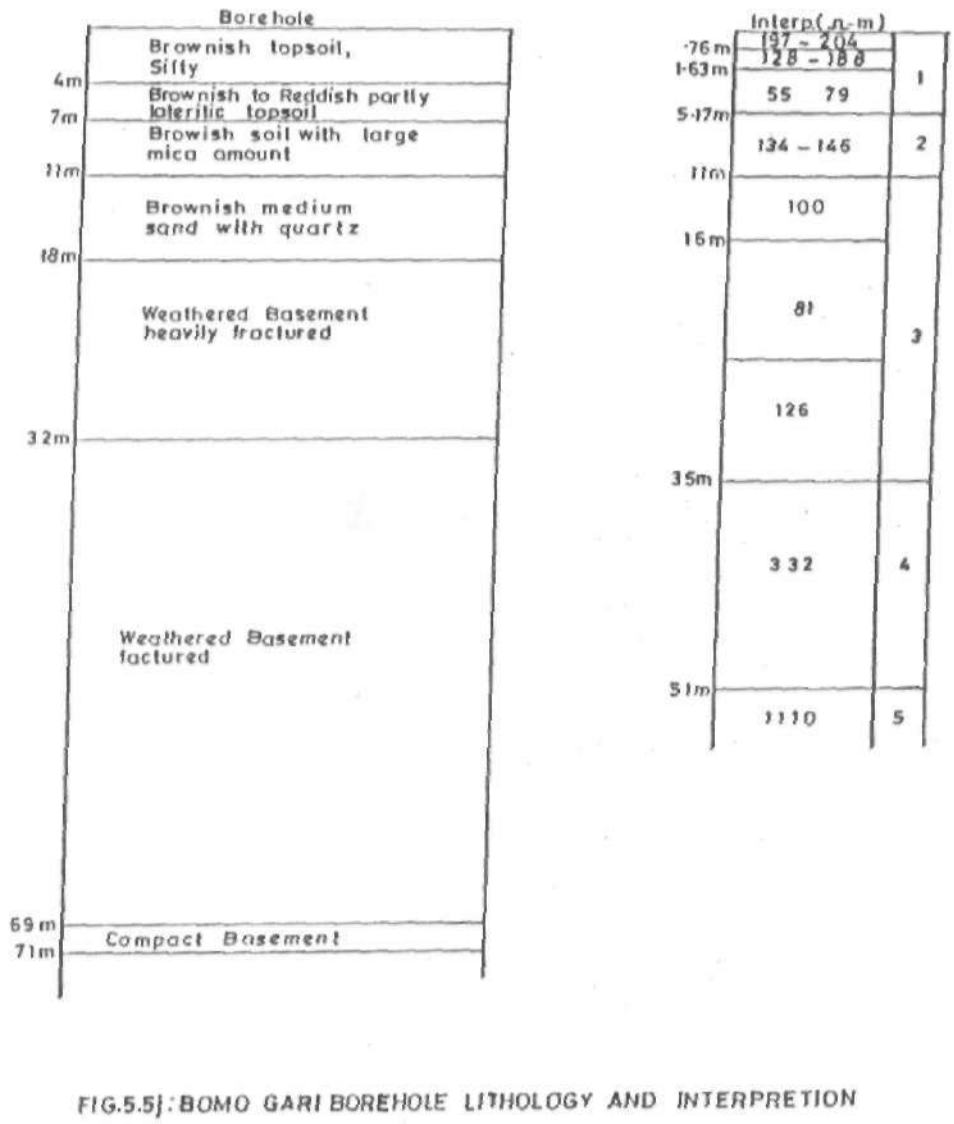


FIG.5.5J: BOMO GARI BOREHOLE LITHOLOGY AND INTERPRETION

resistivity between 100 and 126 ohm-m. Actually the second and third layer could be classified together in view of their resistivity values, but to show the correlation with the corresponding situation in the borehole log. The fourth layer has a resistivity of 332 ohm-m and the geoelectric basement has a resistivity of about 1110 ohm-m. Comparison of the resistivity results with the borehole lithology shows that the top layer is composed of lateritic topsoil, silty and brownish to reddish with a thickness of 5 m. The second layer is composed of brownish soil with a large concentration of mica; the thickness is about 6 m. This is underlain by weathered and heavily fractured basement extending to a depth of 35 m. The fourth layer is a continuation of weathered and fractured basement and has a thickness of about 16 m, this layer is underlain by the geoelectric basement at a depth of 51 m.

(c) Rahama Ik29

The result of this sounding indicates a 3 layer A-type geoelectric structure (fig. 5.5m). The first or top layer has a low resistivity, this could be attributed to the underflowage and drainage of water drawn from the nearby stream. The resistivity ranges from 30 to 87 ohm-m and is composed of clayey lateritic topsoil with some amount of fine silty sand and extends to a depth of 39 m. The second layer has a resistivity of 96 ohm-m with a thickness of 18 m it is composed of cuttings of heavily fractured basement rock and possibly with high clay content. The geoelectric basement is at a depth

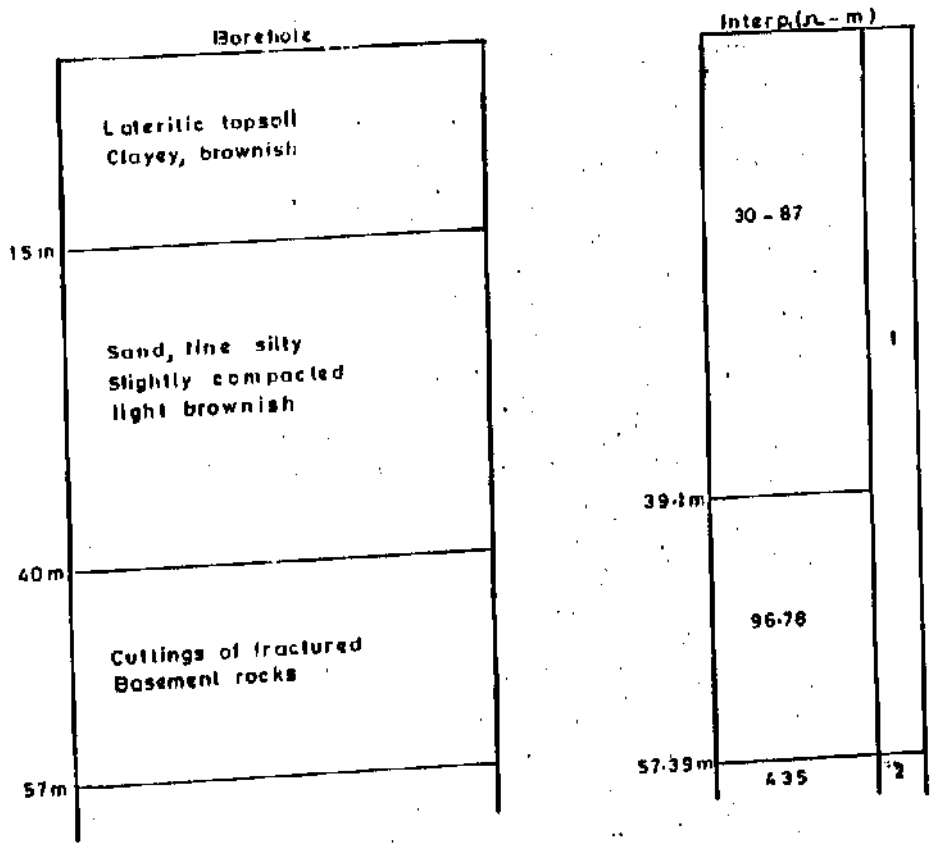


FIG.5.5m: RAHAMA BOREHOLE LITHOLOGY AND INTERPRETATION

slightly greater than 57 m with a resistivity of 435 ohm-m. The borehole does not extend beyond this level, but the resistivity value shows that the base of the borehole is within the range of fractured basement.

(d) Mahuta IK33

The geoelectric sounding curve indicates 3 major layers, H-type geoelectric structure (fig. 5.5n). The first layer has resistivities ranging from 125-156 ohm-m. The second layer has resistivity in the range of 71 to 191 ohm-m, and the geoelectric basement has a resistivity greater than 415 ohm-m. Comparison of the resistivity results with the borehole lithology shows that the first layer, which extends from the surface to a depth of 3.5 m, is composed of topsoil, coarse sized reddish laterite. The second layer, with a thickness of 32 m, is made up of weathered basement materials, while the last layer at a depth of 51 m is probably fractured basement, this layer is not penetrated by the borehole.

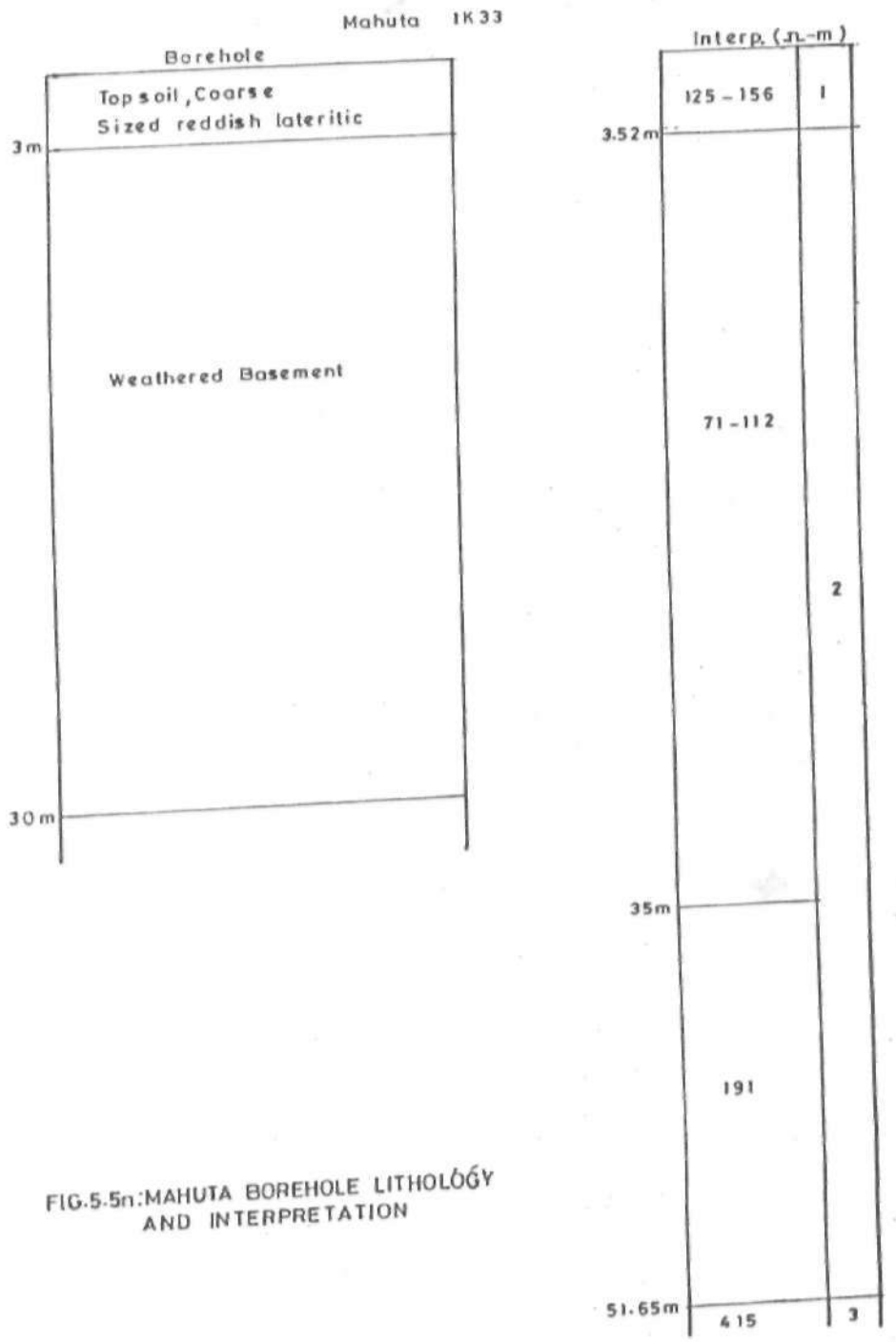


FIG.5.5n:MAHUTA BOREHOLE LITHOLOGY AND INTERPRETATION

5.5 Summary of VES Interpretation

The beginning of each geo-electric section was found to be influenced by the dry soil or laterite or fadama loam. The thicknesses of the layers also vary from location to location depending on the processes that have taken place and the type of parent rock. The top layers give resistivity values sometimes rising up to a few hundreds ohm-meters or as low as less than 100 ohm-m for fadama loams.

In general a typical succession of the curve is made of four layer pattern which are

(1) Superficial layer of dry soil, laterite, eolianite etc. This layer has resistivity of 200 to above 500 ohm-m and varies in thickness from 1 m to 20 m.

(2) Weathered Crystalline rock which is usually made up of varied material due to the weathering of the parent rock. They could contain mixed sands with varying degree of coarseness with clays. The thickness varies from 1 m to 60 m. But on the average the thickness is around 45 m and the resistivity is between 50 to 200 ohm-m. In cases where the structures are favourable this layer could serve as an aquifer.

(3) The fractured rock usually has high resistivity of 200 ohm-m to 500 ohm-m. Where the fractures/joints are connected and open, this layer can serve as a good aquifer.

(4) Solid bedrock: the resistivity here is very high; greater than 1000 ohm-m and sometimes running up to several thousands ohm-meters.

5.6 The Subsurface Resistivity Contour Section

The interpretation of the subsurface resistivity contour sections (fig. 5.3a-j) is carried out by careful examination of the contour behaviour at the different depths taking into consideration that the resistivity value of each of the n-hypothetical layers is plotted at the mid-thickness beneath the corresponding sounding location. Therefore, the layer boundaries can be traced from the contour gradients while the closed anomalies represent the width of the interpreted geoelectric layer. Using these criteria and the verification of lithologies from VES carried out close to boreholes, it was possible to construct the equivalent subsurface geologic sections (fig. 5.2a-d) from the contour sections.

The geologic interpretation reveals that the contour sections can successfully be used to draw much information about the subsurface lithology. In the shallower levels, the discrimination between the surface dry sandy/sandy soil/dry laterite and the moist sand was better and in addition the sections allow more precise delineation of the lithological sequence in the whole area. In the deeper levels, the aquifer zone is quite obvious by the extensive low resistivity values with the contours widely spaced. Moreover, the discrimination between the sandy/weathered basement aquifer and the fractured

crystalline rocks was obvious through the gradual increase in the resistivity values with increasing depth. The most interesting feature in the contour section is the occurrence of formation with high resistivity at depth which becomes more pronounced at relatively shallow depths around Zaria (figs. 5.3e, f & g). This correlates very well with the results of Olowu (1967) and Ajayi and Hassan (1989) who did some work within the Kubanni stream valley and A.B.U. main campus; both within the present survey area.

It is clear from the interpretation that the groundwater table level lies at between 1 and 20 m depth with an average depth of around 9 m which is quite comparable with the water table level deduced for boreholes within the area. The relatively low resistivity values in the saturated geologic layer are attributed to the preponderance of water bearing overburden materials with probably clay minerals, despite the fact that the survey was carried out during the peak of the dry season.

5.7 Maps Produced From Interpreted Data

In order to look at certain aspects of the area surveyed, some specialised maps were produced from the interpreted resistivity data for all the VES stations established. Such maps include the resistivity map of the surface layer, the depth to basement map, the resistivity map of the weathered basement, the coefficient of anisotropy map and so on. The

production of such maps and deductions made from them are discussed in detail below.

5.7.1 Resistivity Map of the Surface Layer

This map was produced by contouring the resistivity values obtained for the surface layer at all the VES points. The resulting map, using a contour interval of 100 ohm-m is shown in fig. 5.3a. The figure shows that the resistivity values of the topmost layer range from 30 ohm-m at the north eastern corner around VES 46 (Kaura), VES 47 (Taban Sani) and VES 63 (Rahama) to above 2000 ohm-m at VES 15 (Kanawa junction)and VES 58 (Awai). The surface layer at the north eastern corner was interpreted to be made up of clay, silt and sand (topsoil) while that of VES station 15 and 58 was seen to be made up of fresh laterite.

There are three major anomalous zones observed on this map (The resistivity map of the top layer). These anomalies are in the form of closure of contour lines around some VES stations. One of such anomalous areas is seen at the central part of the map, that is around VES 20 (Kakangi), 26 (Tsibiri), 25 (Biye), 28 (Angwan Tata) and 87 (Kwaba). This area is associated with low resistivity values which range between 35 and 200 ohm-m. The relatively low resistivity values at this point might be due to the fact that the topsoil at this area is more clayey and silty and there are preponderance of Fadamas at this zone.

Another anomalous area seen on the map is found around VES 58 (Awai). The resistivity range is very high (above 2000 ohm-m). This is interpreted to be loose sand/sandy materials which corresponds to local geology map.

The third anomalous area is seen around VES 15 (Kanawa Junction) and it trends approximately in the N-S direction. The resistivity values within this area is seen to be between 500 to 2000 ohm-m. This high resistivity range could be due to the very dry lateritic topsoil, it should be recalled that the survey was carried out during the peak of the dry season. Field evidence shows that the topsoil is dry loose laterite and probably contains some appreciable amount of ore minerals, thereby making them highly resistive.

5.7.2 Iso-Resistivity Contour Maps

Figures 5.3b -j are the iso-resistivity contour maps for depths corresponding to 5, 10, 15, 20, 25, 30, 40, 60 and 100 m respectively. These represent horizontal slicing of the area at these depths. They also suggest conductivity changes at about these depths.

The iso-resistivity contour map for depth of 5 m indicates a generally low resistivity zone broadening out through this horizon except towards the west edge of the map. A comparison of this horizon with that at the surface indicates a shift of the resistive structure from the southwest to the west. The resistivity ranges from less than 100 ohm-m to above 1,300 ohm-

m. The contour maps for 10 m and 15 m depths (figs. 5.3c and 5.3d respectively) follow almost similar pattern with that of figure 6.3b i.e. the map at 5 m depth, although the resistivities are slightly higher at 15 m depth. At 20 m depth almost all the entire survey area shows generally low resistivity values of between 100 and 300 ohm-m, this could be as a result of the fact that the whole area is probably composed of saturated weathered materials at this horizon. The maps at depths of 25 m, 30 m and 40 m (figs. 5.3d, 5.3e and 5.3f) show similar patterns with the central portion becoming more resistive, an indication of the possibility of the basement being encountered at these depths. The resistivity range varies from less than 100 to above 2,500 ohm-m at this central part. At depths of 60 m and 100 m the resistivity becomes increasingly higher with almost all the area exhibiting values of about 500 ohm-m and above. This is probably due to the presence of fresh laterite/unconnected fractured basement/fresh basement.

5.7.3 Depth to Water Table Contour

This map (fig. 5.6) was produced using depth to water table deduced from various VES points during the data interpretation. The purpose of the map is to observe the trend of the water table in the survey area. The figure suggests that the water table in the survey area is deepest around the western part where the depth is about 20 m at around VES 16 (Tumburuku). On the other hand, it was found to be shallowest

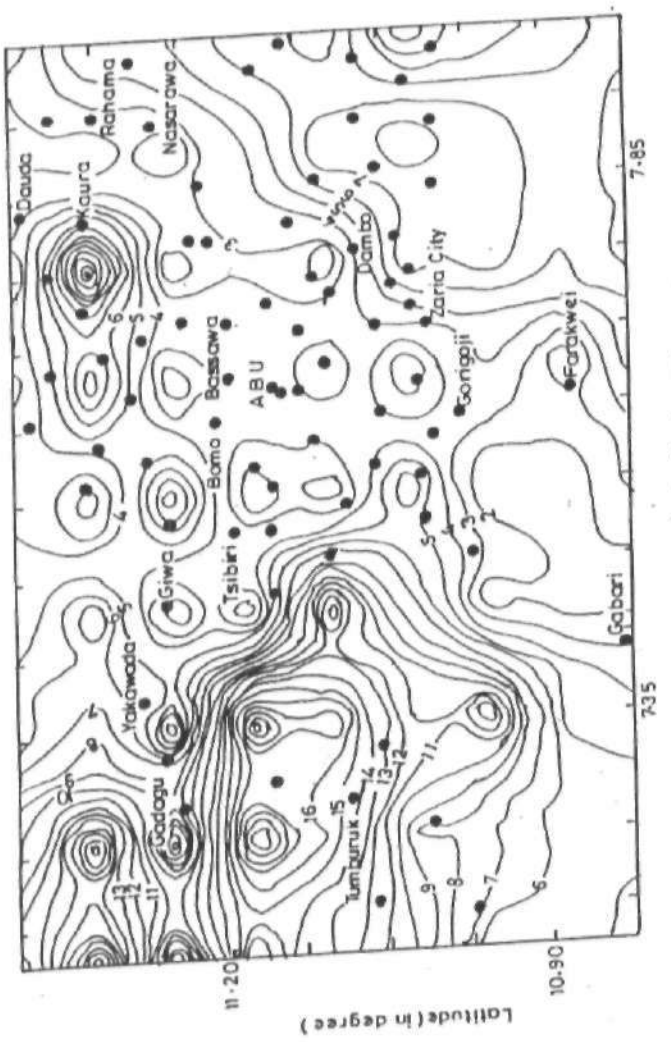


FIG.5.6:DEPTH TO WATER TABLE CONTOUR (M)

in the central part where it was less than 2 m deep. The average depth to the water table in the survey area, as determined from this work is about 9 m. As the measurements were taken in the months of January/February, the water level was most likely to be at its minimum level during the period. As such only discharge of water from the aquifer occurred as there was no rainfall. Therefore, it is expected that the water level would be at some considerable depth. During the rainy season, the underground water is expected to be more recharged than discharged resulting in the rise of water table. The map also suggests that the depth to water level is structurally controlled with the zone of deepest water table trending in the northwest direction. The structural trend of water table is most probably due to the fact that the weathered basement which is believed to be the main component of the aquifer is seen in the present work to be downwarped in the whole area surveyed.

5.7.4 Depth to Basement Map (Overburden thickness)

The depth to basement map was prepared from the interpreted depth to basement at each depth sounding point. The depth to the basement beneath each of the VES stations was plotted at the corresponding location on the base map and then contoured at an interval of 5 meters. This was done to enable a general view of the basement profile under the area as well as the variation in overburden thickness in the area to be known. Fig. 5.7 shows the resulting depth to basement contour of the area. The result of the contouring shows that the hard

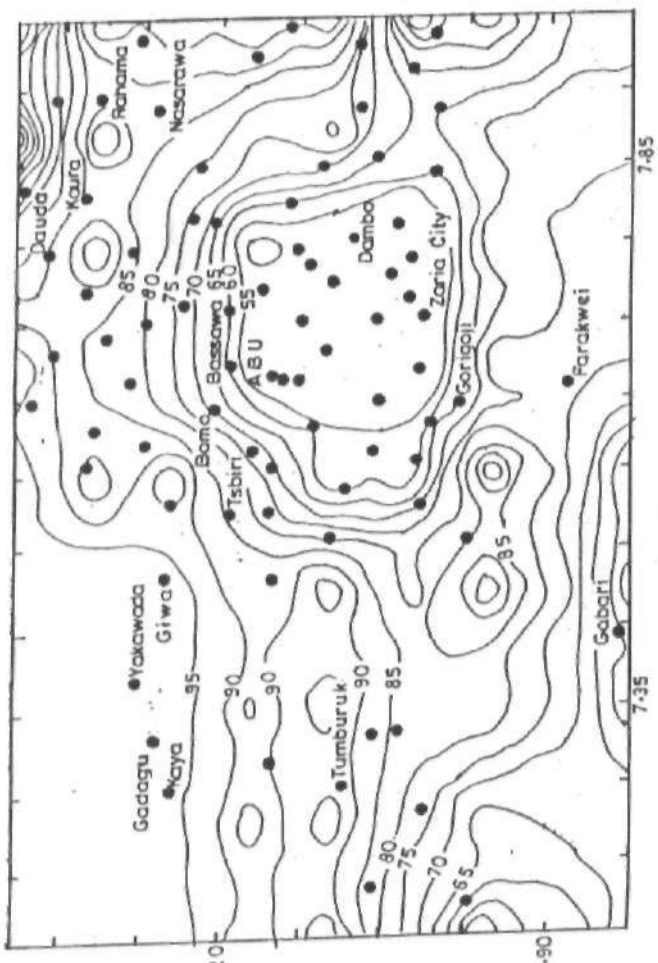


FIG-57:DEPTH CONTOUR TO FRACTURED INPERVIOUS BASEMENT(M)

rock is not of smooth and continuous surface, they exhibit undulating configuration. The depths to basement range generally from 28 m at the central part around Zaria township to above 90 m at the western part of the map.

The interpreted VES data suggest that the overburden, in most parts is made up of 2-4 different layers, composed of clays, silts and sand(topsoil), weathered basement, fresh laterite and weathered laterite. The present survey seems to agree with the possibility of shallow basement in the form of township as suggested by Messrs Preussag (1985). However the present work has established a good picture of the basement structure around Zaria and further extends the basement configuration to other previously unsurveyed areas.

5.7.4 Coefficient of Anisotropy Map

The overburden coefficient of Anisotropy (λ) was calculated for each VES station using the layer resistivities (ρ_i) and thicknesses (h_i) obtained from the VES interpretation results. The relevant equations as defined by Keller and Frischknecht (1966) and Zohdy et al. (1974) are of the form:-

$$\lambda = \sqrt{\frac{\rho_t}{\rho_l}} = \sqrt{\frac{\sum (h_l\ \rho_l) \sum \frac{h_l}{\rho_l}}{(\sum h_l)^2}}$$

where ρ_t is the transverse resistivity

ρ_l is the longitudinal resistivity

i the summation limits vary from 1 to n-1, where the nth layer represents the infinitely resistive bedrock.

The lambda values for the VES stations were plotted and contoured. The resulting overburden coefficient of anisotropy map (fig. 5.8) shows lambda values varying from 1.004 to 1.101. These values fall within the range obtained for areas underlain by metamorphic/igneous rocks in the southwestern Nigeria (Olorunfemi and Olorunniwo, 1985; Olorunfemi et al., 1990).

A comparison of the anisotropy map with the existing geology map, with emphasis on the areas where the basement rocks do not outcrop shows that the area is underlain by rocks with lambda values that are generally less than 1.1. The three rock types (metasediments, granites and gneiss) show significant overlap in lambda values that does not enable their differentiation. The relative low values of lambda can be explained in terms of its very low degree of, or non foliation.

5.7.5 Isopach Map of Aquifer Layer

The map (fig. 5.9) was produced from the thickness of the weathered (low resistivity) layer obtained during interpretation. The weathered layer thicknesses for all the VES stations were contoured at an interval of 5 m. This map was produced to see how the thickness of the weathered layer, considered to be the major component of the aquifer in the area varied from place to place within the area and also to see how variation affects the groundwater surface (water table) in the area. The weathered basement thickness map shows that the

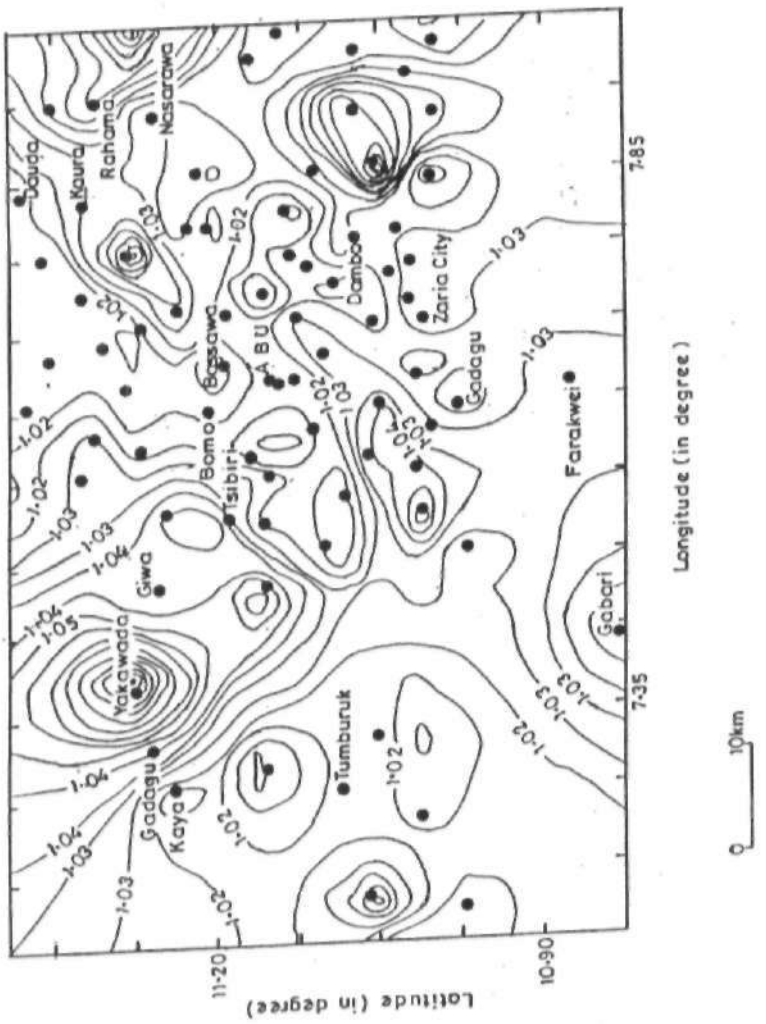


FIG. 5-8 : ANISOTROPY MAY OF ZARIA AREA

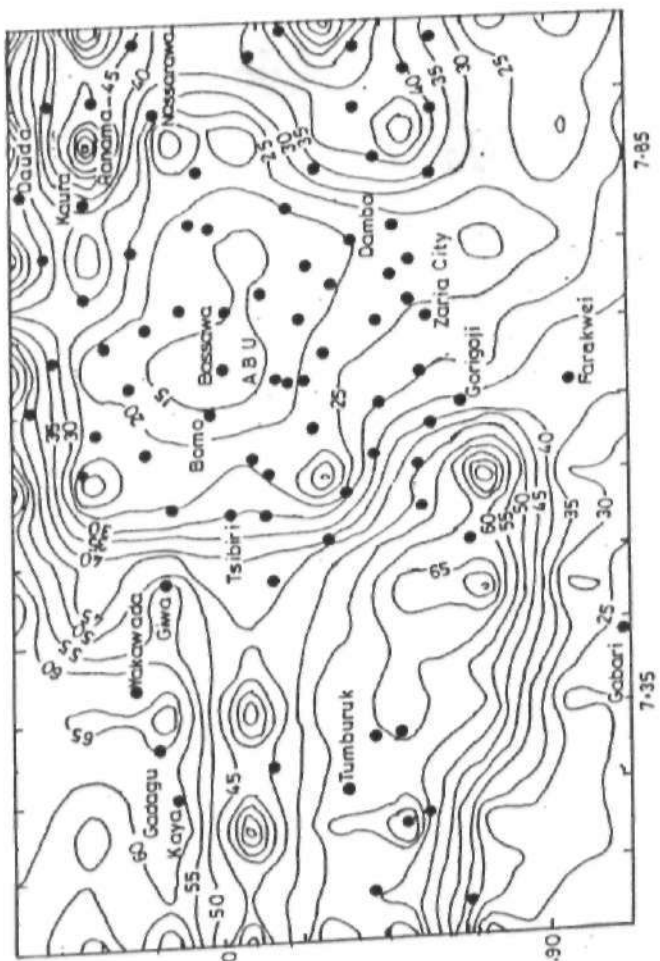


FIG-5.9:THICKNESS OF AQUIFER LAYER CONTOUR (M)

thickness varies from 15 m to 70 m with an average value of 30 m. A general examination of the map reveals that the shallow basements are mostly in the center, northeast and south east of the map. The low thickness values correlates with areas of shallow basement which could serve as watershed especially in the western, extreme northeast and eastern parts of the survey area. It suggests that areas of "outcrop" could serve as recharge points for the aquifer. However in other situation, it could serve as groundwater dams. The areas with large aquifer thickness correlates generally with areas with basement depressions. This seems to suggest that the geometry of the basement underlying the weathered basement most likely serve as a form of structural control on the flow of rivers within this area. Previous work has not been carried out at the western and northern part of this survey, but around the east and southeastern corner where Ajayi and Hassan (1990) and Adanu, (1987) carried out some resistivity works, which seem to confirm an average thickness of about 35 m for the aquifer thickness.

5.7.6 Subsurface Structural Trends

Applying a similar criterion as in section 5.1, It was possible to construct the equivalent subsurface geological sections (figs. 5.10a-j) from the contour sections along profiles. These represent vertical slicing of the subsurface down to a depth of 100 m. This was done to enable a general view of the geometry of the formations (layers) as well as the

variation in their thicknesses to be taken, hence the general structural trends can be known (it should be noted that there is some vertical exageration in the structural trend maps due to the relative shallowness of the basement compared to the total area of survey). In an area of this size with its complex geology, detailed and evenly spread information (data) will be required to make any meaningful interpretation and projections. But in this area, the boreholes are concentrated in certain sections due to the fact that the main purpose for the drilling is to meet the domestic water requirement of the rural people. There are therefore wide "windows" (gaps) which have to be interpolated through the use of information acquired from the VES measurements.

The result of the contouring of the depth to the 100 m depth shows that the formations (layers) are not of smooth and continuous surface. They exhibit an undulating configuration, with the bedrock getting deeper in areas of possibly fractures and faults. These fractures aid deep weathering as they serve as channels through which water infiltrates deep into the bedrock. The overburden is mostly made up of clays, silts and sands (topsoil), weathered basement and laterite.

These structural trend maps are preliminary maps, it could be considered as a first approach, because of the lack of sufficient data in the area. However with Geophysical information from 118 locations including 14 borehole informations in some of these locations, it is believed that

the maps give a general impression on how the various formation configurations are disposed towards each other. The maps also show the general trend of the subsurface structures which should be looked out for when prospecting for groundwater and other informations, such as structural foundation studies.

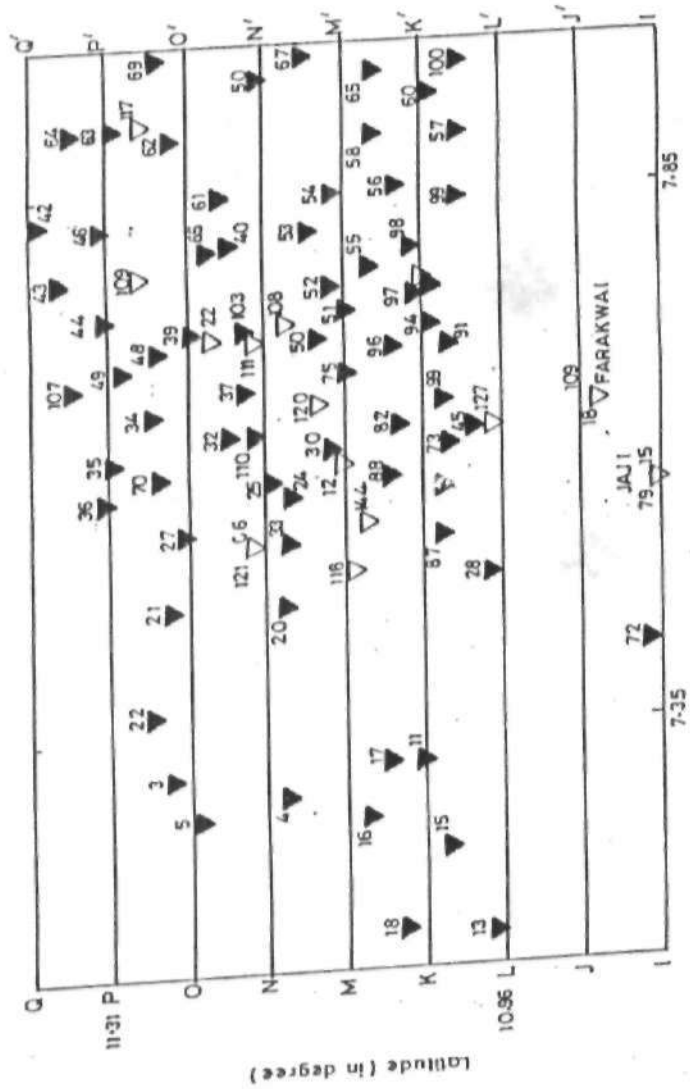


FIG.5.10:LOCATION OF PROFILES FOR THE STRUCTURAL TREND MAPS

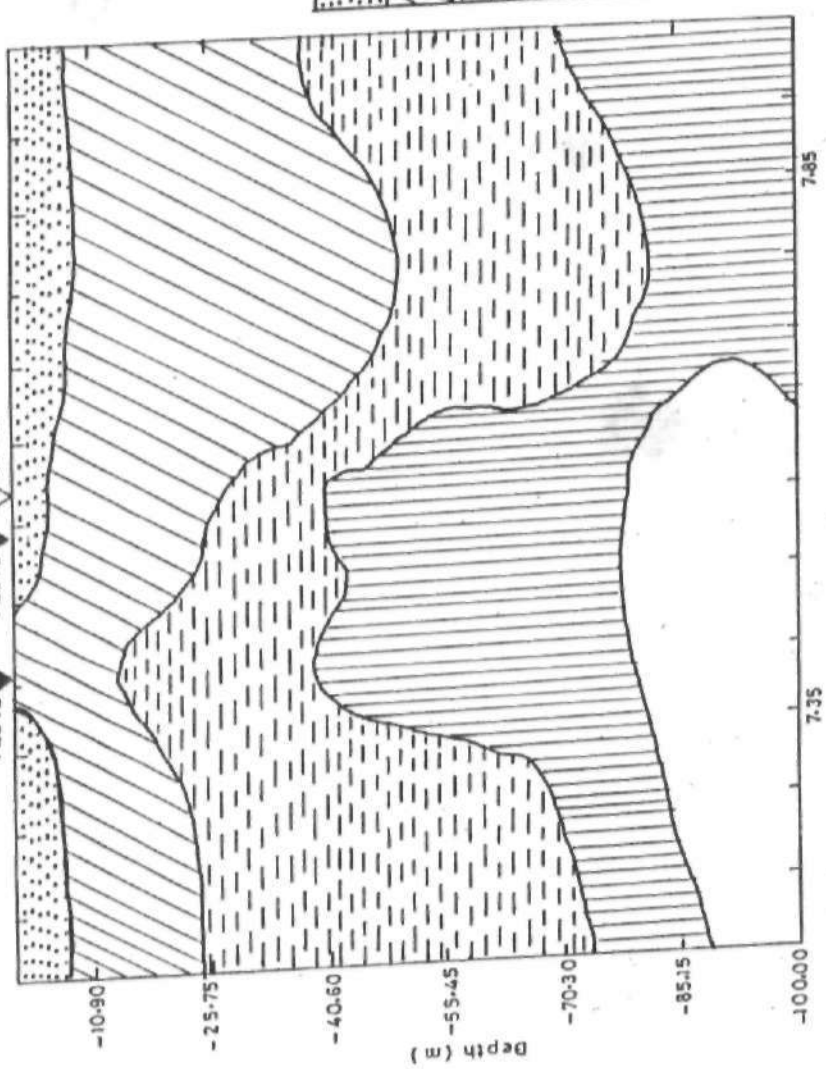


FIG-5-10a:SUBSURFACE GEOLOGIC SECTION EQUIVALENT TO RESISTIVITY CONTOUR SECTION ALONG II'

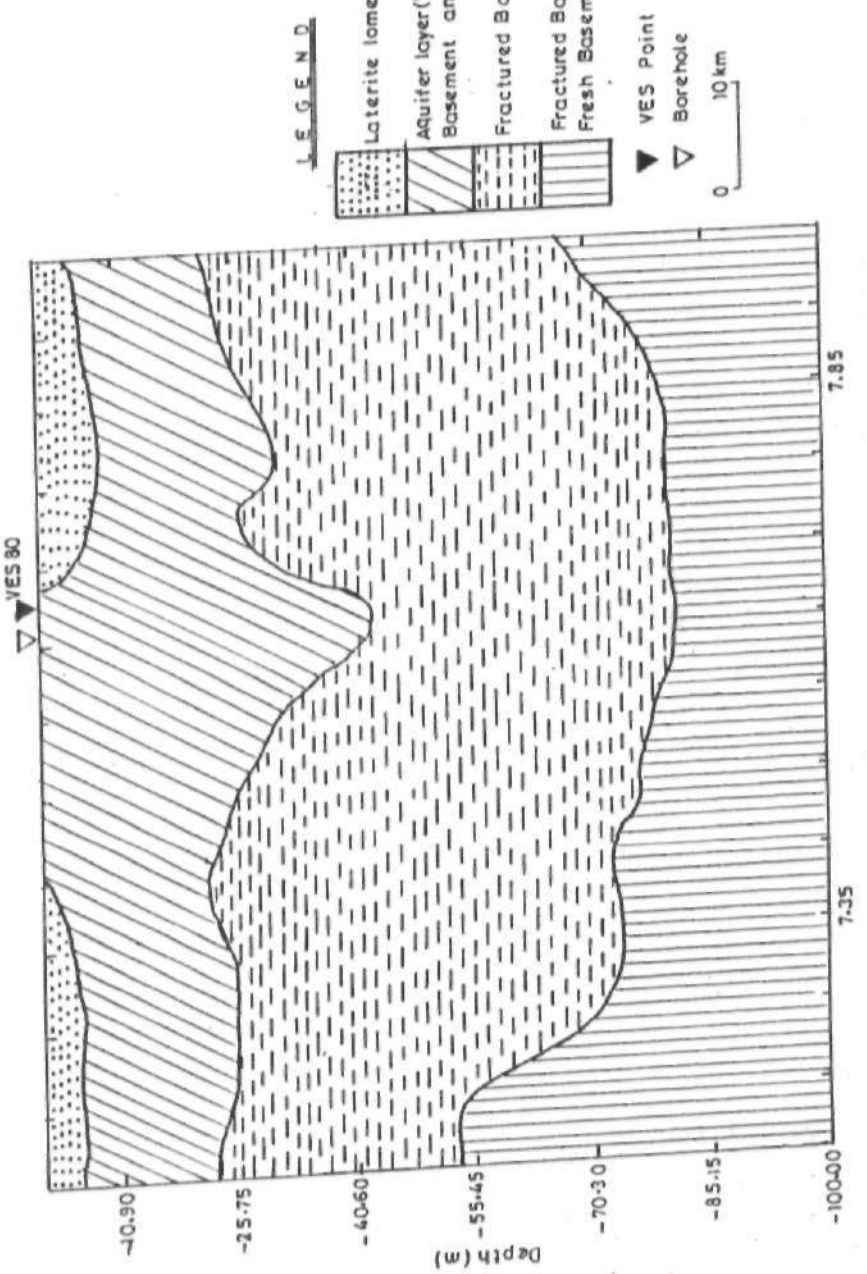


FIG 5.10:SUBSURFACE GEOLOGIC SECTION EQUIVALENT TO RESISTIVITY CONTOUR SECTION ALONG JJ'

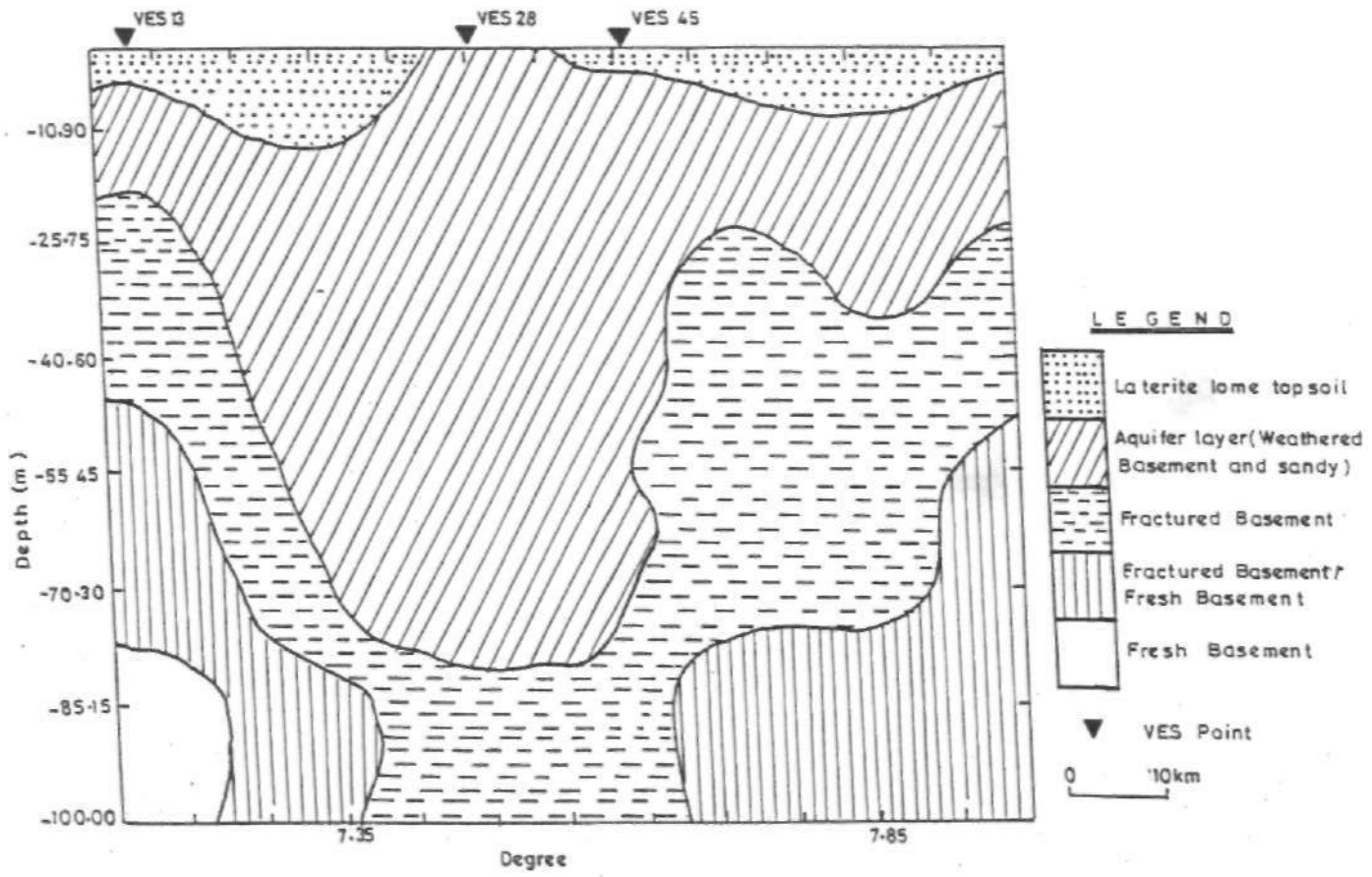


FIG.5-10c : SUBSURFACE GEOLOGIC SECTION EQUIVALENT TO RESISTIVITY CONTOUR SECTION ALONG K K'

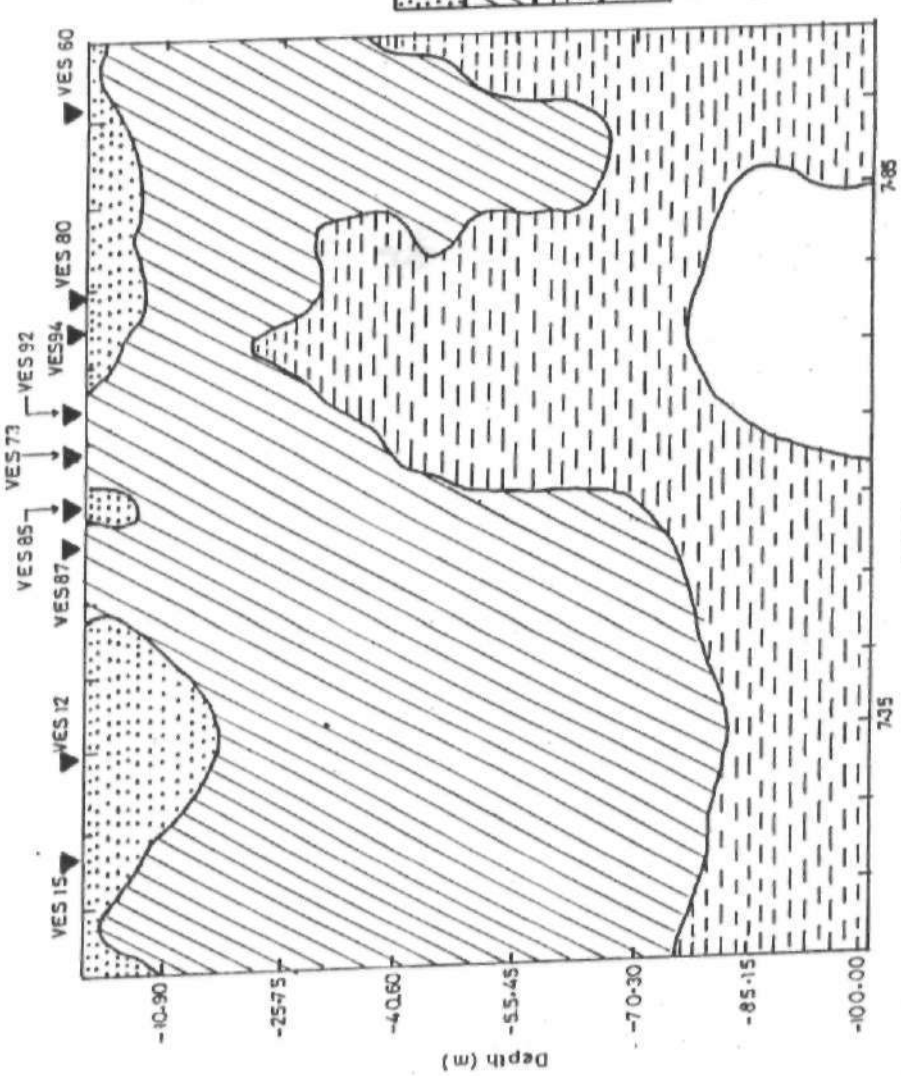


FIG.5.10d; SUBSURFACE GEOLOGIC SECTION EQUIVALENT TO RESISTIVITY CONTOUR SECTION ALONG LL'

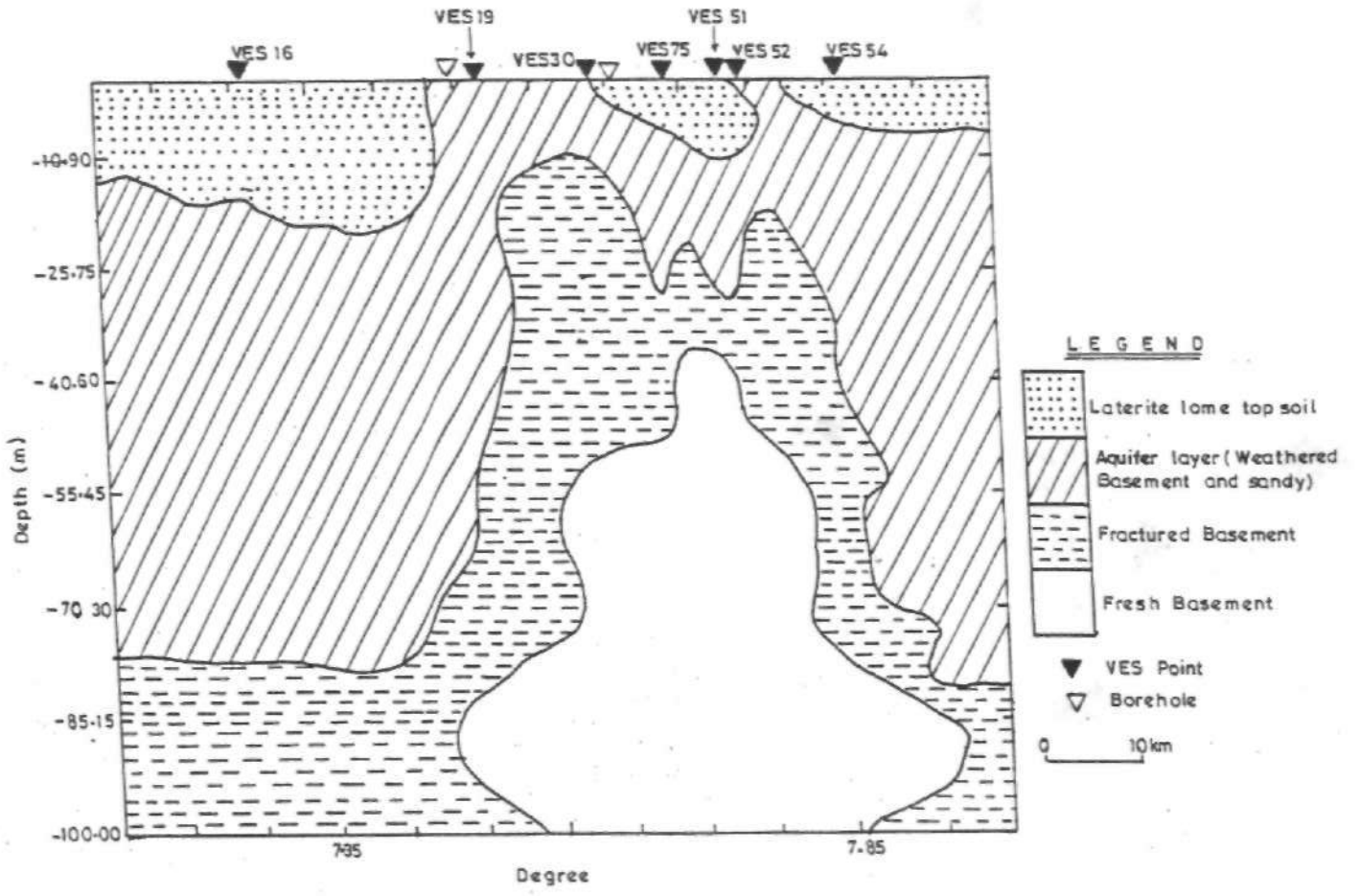


FIG.5-10c:SUBSURFACE GEOLOGIC SECTION EQUIVALENT TO RESISTIVITY CONTOUR SECTION ALONG MM'

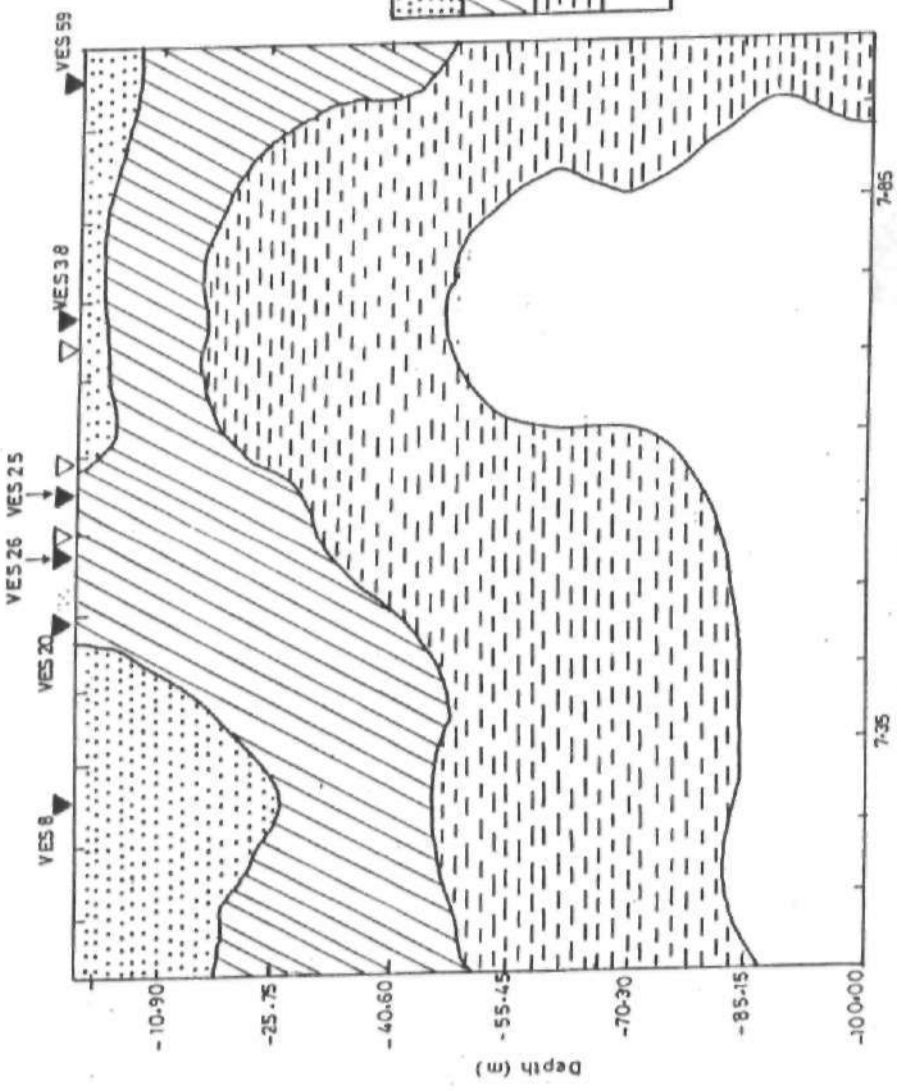


FIG-5.01:SUBSURFACE GEOLOGIC SECTION EQUIVALENT TO RESISTIVITY CONTOUR SECTION ALONG NN'

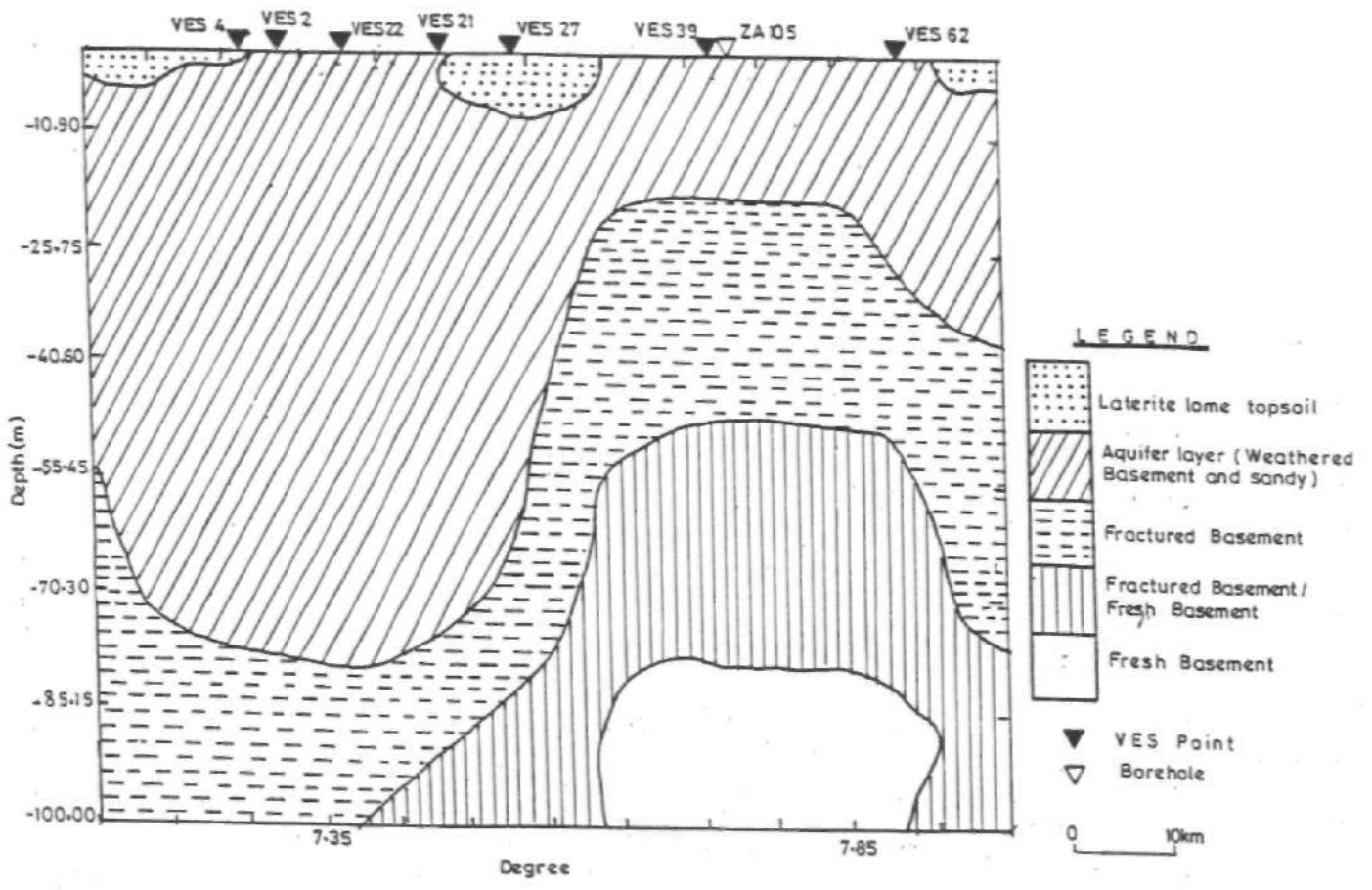


FIG-5-10g:SUBSURFACE GEOLOGI SECTION EQUIVALENT TO RESISTIVITY CONTOUR SECTION ALONG O O'

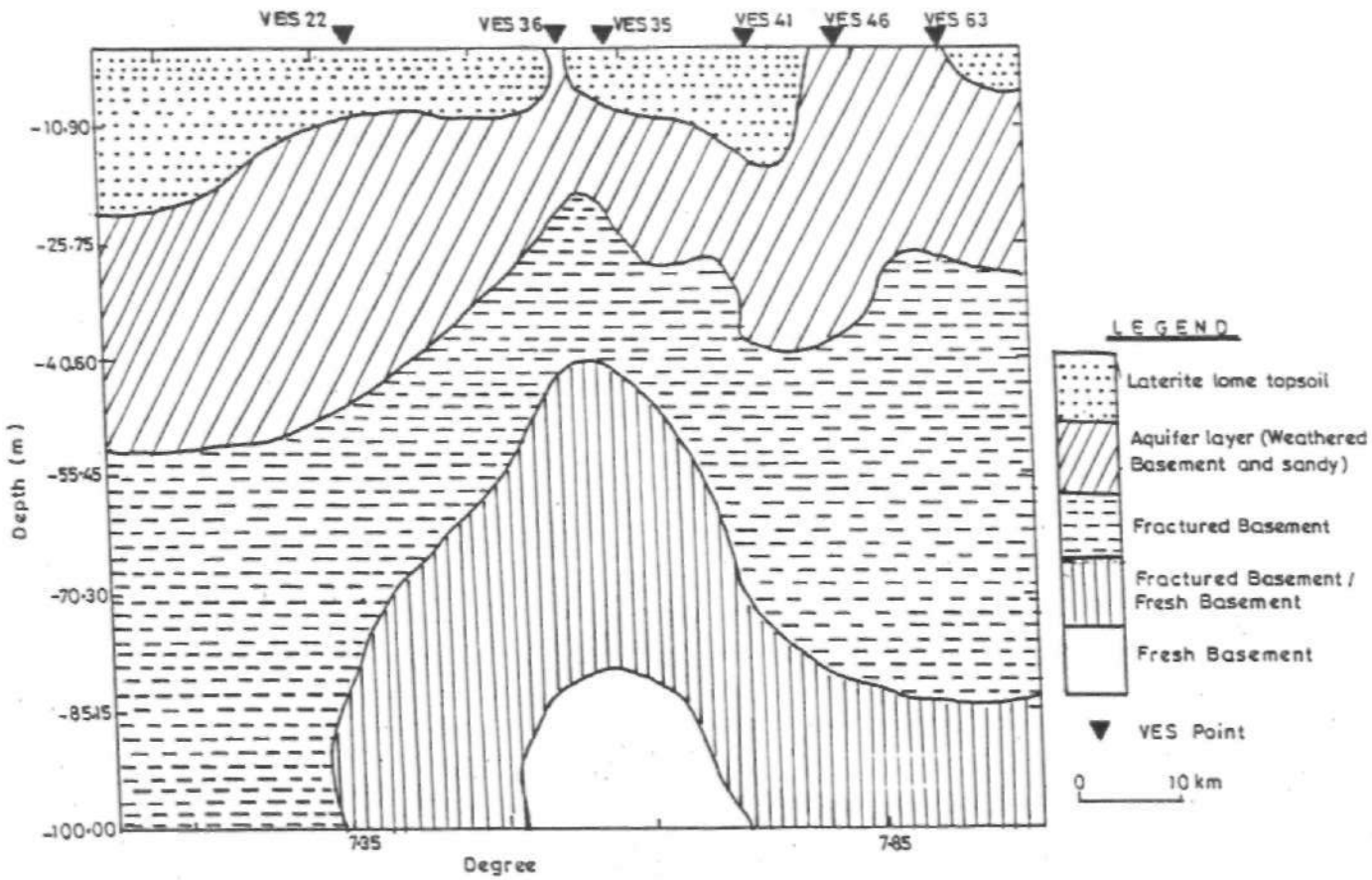


FIG-5-10h: SUBSURFACE GEOLOGIC SECTION EQUIVALENT TO RESISTIVITY CONTOUR SECTION ALONG PP'

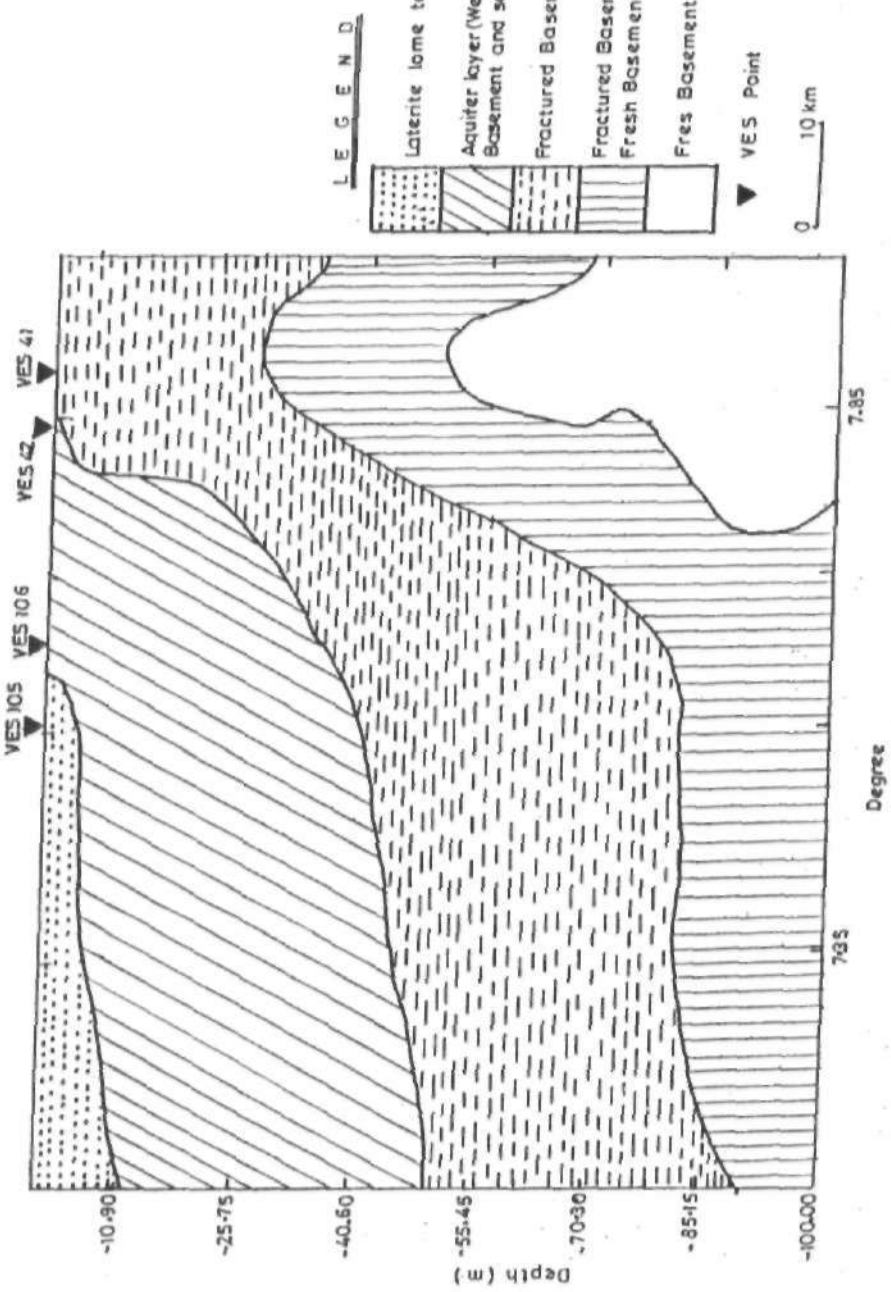


FIG.5.10j: SUBSURFACE GEOLOGIC SECTION EQUIVALENT TO RESISTIVITY CONTOUR SECTION ALONG Q Q'

CHAPTER SIX

6. GROUNDWATER PROSPECT AND MANAGEMENT

Although it has generally been assumed that groundwater is ever abundant and readily exploitable, experience has shown that special care and skill is needed for its exploration and exploitation. Even though a renewable resource, special effort is needed to determine the location(s) of development and the extent of the development in order not to exceed the critical limit that will result in over-exploitation and its grievous repercussions. There is therefore the need for the emergence of efficient and better methods for its exploration especially in these days of scarce resources.

6.1 Prospects and Exploration

The complex nature of the structures of the Basement aquifers, as shown in this study, has pointed out the need for more intensive and extensive work for the determination of the full potentials of the Basement Complex which according to Oyawoye (1964) covers about 50% of Nigeria.

When prospecting for groundwater, there is the need for both regional and local assessment. The intensity of the investigation will depend on the nature of the geological survey results most especially of the overlying overburden which has been shown to constitute the most promising structure hydrogeologically (Olowu, 1967). The structural trends and features need to be studied as these have been observed to have

strong influence on some of the high yielding boreholes in Zaria area.

In the past, borehole drilling was carried out relying on chance, luck and the experiences of drillers (wild catting). This has always resulted in very low success rate. The adoption of geophysical techniques in the prospecting for groundwater improved the success rate to about 72% with a similar increment in the yields rising up to 1.5 litres/second for borehole ZA106 (Danladi, 1985).

Geological mapping should normally be undertaken in the course of groundwater prospection followed by geophysical investigation. The Vertical Electrical Sounding (VES) is one of the most useful and fast methods applicable in the search for structures for groundwater occurrence. Its usefulness has been demonstrated in the Zaria area by its facilitating the mapping of the thickness of the overburden viz-a-viz the underlying basement configuration and the determination of areas for borehole location. The geophysical investigation has shown that the main promising structure is the basement overburden, further extensive detailed geophysical and hydrogeological information would be required on the actual fracture situation as it affects the groundwater in this area.

Prospecting in a new area for groundwater demands that there should be information with which the geophysical interpretation could be compared, however where there are no other informations full reliance can be placed on the

geophysical method of investigation. The most effective procedure is to carry out the study and drilling simultaneously. The VES measurements should normally be carried out at these borings in order to correlate the geoelectric section with the subsurface geology formation as indicated by the borehole lithology. Then the region of the validity of the logs of these borings can be extended by carrying out geophysical measurements as it is done in this survey.

In Zaria area, due to insufficient or lack of geophysical investigation, most of the boreholes drilled were found to be unproductive all the year round. Either they did not either fully penetrate the thickness of the overburden and the fracture zones or that the thickness of the aquifer in the locations of the boreholes are very small. Danladi (1981) reported the case of increase in yield of the borehole ZA105 when the depth was increased. This has positively demonstrated the usefulness of the geoelectrical measurements in the development of the Basement aquifers.

The application of Zohdy method in the determination of layer thicknesses and resistivities proved very useful in the determination of boundaries between the different layers when resistivity results were compared with borehole lithology logs, it demonstrates its usefulness in groundwater prospecting especially in an area of unpredictable structure like the Basement geology.

The exercise of groundwater development is both time and resource demanding. When the boreholes have been drilled, development and yield testing should naturally follow in order that other data and parameters could be obtained or determined for the aquifers. This will allow the study of the whole aquifer both locally and regionally through the study of transmissivities and hydraulic conductivities.

6.2 Groundwater Management

The potentials of the Basement Complex for groundwater supply is poor when compared with areas of sedimentary geology or when viewed in terms of supply of water for large urban settlements. But it is quite adequate for rural settlements and small holder irrigation agriculture. (MRT, 1979).

Groundwater in exploitable quantities adequate to supply villages and towns have been found in this study to be contained in (a) river alluvium which is irregularly distributed and is often with variable proportion of fine materials, (b) the weathered zone of the Basement Complex. This later source is the most extensive by virtue of the large occurrence of the overburden in the area. However, the fractured zone normally forms a poor aquifer (if fractures are not well connected) and yields are generally low or moderate (Danladi, 1981).

(a) River Alluvium

The potential of this source of groundwater has not been conclusively established by virtue of its occurrences in the smaller streams and in the reaches of the large rivers. The meander sections of the rivers probably contain the largest volumes of alluvium, though the proportion of fine material in the deposits may be large and the permeability could be low. The alluvium aquifers have been found to be assured of recharge during the rainy season when there is surface flow in the streams but extractions during the dry periods when there is considerable reduction in surface flow may rarely be sustained by the base flow. Therefore, these aquifers may not serve as source of all year round large supply. Areas of probable river alluvium aquifers in the survey area are around the Galma river, river Kubanni, river Shika, River Kangimi and Rafin Yashi flood plain. The specific capacity of boreholes located within some of these river valleys ranges from 1.2 to 14.3 $m.^3/d/m$ with an average of 4.5 $m^3/d/m$ (Danladi 1981).

Groundwater development within the river alluvium should be geared towards the determination of the alluvial extent and thickness. The defining of the extent, thickness and lithology of the saturated alluvium to the level demanded by the quantity of the water required will demand the use of geo-electrical method of prospecting, to define the lower boundary of the deposit and indicate the proportion of the clean sand. From the range of resistivity and thickness values obtained, such well field development could be planned.

The yield obtained in the boreholes in these aquifer types and their specific capacity and transmissivity show that these are potentially the most favourable areas to develop, especially during the period of dry season when some of the streams dry up.

(b) Weathered and Fractured Zone of the Basement Complex

The weathered and fractured zones of the Basement provides the most widespread source of groundwater in the area. This covers almost 90% of the area, leaving those areas where the fresh rock outcrops on the surface as hills, inselbergs and whale-backs.

The weathered zone ranges in thickness to a maximum of about 60 m. In general the zone is thickest beneath old drainage channels of subdued topography or fault zones where preferential weathering takes place as a result of infiltration of water.

The different types of parent rocks viz gneisses, granites and metasediments have differing aquifer potentials due to their different resistance to weathering and subsequent erosion and their lithological constitution. Their yield may vary depending on extent of the decomposition which could improve or limit the productivity. Highly weathered gneisses produce material containing a large proportion of Kaolinite or Clay (Danladi, 1981) and this is associated with low permeability.

The weathered zone of the Basement forms a complex of discontinuous aquifers with the low resistivity zone existing mostly in unconfined conditions (figs. 5.3a-j). Where laterites or clay bed occur overlying the aquifers, the condition could be confined or semi-confined. The water table is shallow, rarely exceeding 10 m below ground surface.

When properly sited using the geo-electrical methods and properly developed, the aquifers could supply large populations provided they are not single large settlements or towns.

Exploitable groundwater is contained in discontinuous aquifers and a regional approach to groundwater exploitation and development may not be applicable here. Each water supply development must be regarded as an individual problem so far as locating boreholes is concerned.

CHAPTER SEVEN

7. CONCLUSION AND RECOMMENDATIONS

7.1 General Statement

This thesis describes the geoelectric survey in the northern part of Kaduna State. The survey involved a total of 14 Schlumberger Vertical Electrical Soundings (VES) around boreholes and 104 VES locations within different geological formations and other fairly spaced locations within the survey area. The current electrode spacing was varied from 1 to 156 m.

The VES interpretation results are presented as geoelectric sections (figures 5.3b - j) and maps of the surface resistivity, aquifer thickness (isopach), depth to water table, basement depth (bedrock relief), coefficient of anisotropy, (figures 5.3a, 5.6, 5.7, 5.8, 5.9) and subsurface structural trends (figures 5.10a - j).

7.2 Limitations

There were quite a number of problems encountered in the field and limitations in the course of this survey.

(1) The topographic maps used as the base maps for this survey are old maps. They were published in 1963 and have not yet been updated as of the time of this work, as such, some of the villages located on the map are either presently non-existent or have changed their names. This made the locations of some of the stations difficult.

(2) Existing boreholes/wells were drilled on "wildcat" basis i.e. either at the market square or within the Village

Head's house, without regards to the hydrogeological conditions of these locations, hence in an attempt to conduct a VES at borehole locations for comparison purposes some electrode locations fell on or very close to tarred roads and built-up places, there is therefore the need to slightly alter the electrode positions to more convenient locations.

(3) The equipment requires that no measurements be carried out in the vicinity of high voltage sources such as high tension cables, transformers etc. The abundance of these types of high voltage electrical materials all over the survey area most especially within Zaria township prevented data collection at 19 of the earlier earmarked locations.

(4) Gullying and erosion made data collection at some stations a herculean task. This was so because the data collection at such points (locations) involved climbing or descending heights of about 3 - 6 m and wading through pools of water to get to points to stake the electrodes.

(5) Some of the boundaries of the borehole lithology do not correspond to geophysically interpreted layers. The reason could possibly have been due to lack of enough data to use as a guide during interpretation, since many of the work done in the survey area are not published in reputable journals, they could only be found in open files at government establishment as the case may be. Another reason could be that the recording of the depths by the drillers was faulty due to the use of the rotary (Danladi, 1985) method of drilling.

(6) In the application of Zohdy's method the assumption is that the incremental value during each sounding should be very small for homogeneity and isotropic conditions to hold for the different layers, this assumption is violated as the incremental value becomes large at higher decades, this therefore imposes some limitations in the use of Zohdy's method for very large current electrode spacings.

7.3 Conclusion

In spite of all the limitations enumerated above, several conclusions are arrived at.

The beginning of each geo-electric section was found to be influenced by the dry soil or laterite or fadama loam. The thicknesses of the layers also vary from location to location depending on the processes that have taken place and the type of parent rock. The top layers give resistivity values as large as a thousand ohm-meters for laterites and loose sands or as low as 100 ohm-m or less for fadama loams and clays.

In general a typical succession of the geoelectric section is made up of four layer pattern which are:

(1) Superficial (or top) layer made up of dry soil, laterite, eolianite etc. The resistivity of this layer could be as high as 1000 ohm-m and varies in thickness from 1 m to 20 m.

(2) Weathered Crystalline rock is usually made up of varied material due to the weathering of the parent rock. They could contain mixed sands with varying degree of coarseness with clays. The thickness varies from 1 m to 60 m, but on the average the thickness is around 45 m while the resistivity is between 50 to 200 ohm-m. Under favourable structural setting this layer could serve as an aquifer.

(3) The fractured rock usually has high resistivity which is greater than 500 ohm-m. Where the fractures/joints are connected and open, this layer could serve as a good aquifer.

(4) Solid bedrock: the resistivity here is very high; it is usually greater than 1000 ohm-m and sometimes running up to tens of thousands of ohm-meters.

The bedrock relief map (fig. 5.7) delineates a series of bedrock ridges (most especially around Zaria) and depressions within the survey area. The isopach map of the overburden (fig. 5.9) shows a relatively high thickness above 55 m within the depressions and relatively low values of less than 15 m on the ridges. The bedrock depressions being groundwater collecting centres are priority areas for groundwater development.

The use of the geoelectric method (VES) to determine the depth to the fresh bedrock has revealed a complex configuration

of the subsurface structure. The usefulness of the VES technique in the establishment of the boundaries between fresh rocks and the overburden, and between the various layers within the overburden has been demonstrated. The geophysical investigation has confirmed the limited lateral extent of the basement aquifers. The aquifers have been found to be heterogeneous in their occurrences in relation to their host rocks and they are of variable thickness. For example the results of this survey have shown that the aquifers are located within areas which are lithologically made up of weathered gneiss, weathered granite, river alluvia and sands in various degrees of coarseness. The VES curves have revealed that the overburden is mostly of the 4-layer types. The resistivity of the aquifers range from less than 100 ohm-m to about 500 ohm-m.

The complexities in the mode of occurrence and nature of the aquifers sometimes made the layer boundaries demarcation difficult. The use of the contour gradients brought out clearly the boundaries and facilitated the easy determination of the aquifer layers.

The groundwater occurs mostly in unconfined conditions, i.e. under water-table conditions, which were found to be dynamic in nature. Few locations occur under confined or semi-confined conditions. The fluctuations in the water table levels make the determination of the saturated zone rather difficult, as these vary with time of the year. It could be lower or higher depending whether it is rainy or dry season.

It has not been possible to determine the hydraulic conductivity and transmissibility of the boreholes due to non-availability of relevant data. However from the results of the VES the aquifers are of substantial thickness and many of them are located in areas where there are fewer streams and deep gullies, which means that the aquifer leakage in the area is minimal and highly confined. It follows therefore that boreholes sited in such areas with guaranteed recharge are very likely to have good yield.

An attempt has also been made towards lithological differentiation between the gneiss, granite and the metasediments using the parameters involving coefficient of electrical anisotropy (lambda) and the weathered layer resistivity. A comparison of the anisotropy map (fig. 5.8) with the existing geology map in areas where the basement rocks do not outcrop show that the area is underlain by rocks with coefficient of anisotropy values that are generally less than 1.1. The three rock types (metasediments, granites and gneiss) show significant overlap in coefficient of anisotropy values. This overlap does not enable their differentiation. The relative low values of coefficient of anisotropy can be explained in terms of their very low degree of, or non foliation.

The structural trend maps show the general trend of the subsurface structures which should be looked out for when prospecting for groundwater and other informations, such as

structural foundation studies. Hitherto, Zaria area has been considered to be a basement terrain, this implies that the thickness of overburden could be very small to make the construction of mighty structures like bridges, high rise buildings etc, almost impossible or expensive. However this study has shown that the depth to basement cold be as large as 90 m and the depth is fairly well distributed throughout the survey area. Bearing other constraints such as the strength of material in the subsurface, high rise buildings, bridges and other structures such as dams and underground rail system can be constructed in Zaria area without involving too heavy financial outlay which drilling through the rock will entail if the survey area were to be assumed to essentially of shallow basement terrain.

7.4 Recommendations

As in all methods of geophysics, the geoelectric method used here cannot single handedly give a complete and unique information about the parameters of interest within the survey area. For the full development of the groundwater resources and geotechnical knowledge in the survey area, there is need for further extensive geological and geophysical investigation using both photogeological interpretation, geoelectric (VES and profiling) and seismic refraction techniques. The use of these methods of investigation will permit the full exploitation of the aquifers and unambiguously delineate the different rock layers and structures.

On a final note the following specific suggestions are recommended.

(1) It is recommended that borehole location and design should take cognisance of the structures and thicknesses of various formations within the Zaria area and that the boreholes should be drilled deeper into the fractured zones of the rock. This will enable the full exploitation of the groundwater resources within the area.

(3) There is strong need for proper and continuous observation of the water levels. This will enhance the general study of the aquifer and the direction of flow of groundwater in the area. It will also allow checks on critical situations, such as over-exploitation of the aquifers.

(4) During drilling exercises, it is necessary to have piezometric wells for proper determination of aquifer parameters like hydraulic conductivity, transmissibility coefficient, coefficient of storage etc. The borehole test should be designed such that maximum and accurate data are obtained; for example, static water level, discharge rate, drawdown and rate of recovery.

(5) Boreholes should also be properly logged both geophysically and geologically. This will permit the checking and comparing with the interpretation of the VES investigation.

(6) Care should be exercised when exploiting boreholes to avoid contamination from surrounding pollutants which could be drawn in from long distance recharge due to excessive pumping.

(7) Studies on the determination of elasticity modulus should be carried out within the different formations most especially within the flood plains in Zaria area in order to know the amount of stress the subsurface material can withstand from surface structural constructions such as dams, bridges and so on, if put in place.

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APPENDIX I

VERTICAL ELECTRICAL SOUNDING LOCATIONS

LOCATION	LONGITUDE	LATITUDE	STATION NO.(VES)
ABU DRAMA VIL.	7.657620	11.143100	1
GADAGU EAST	7.320500	11.250000	2
GADAGU WEST	7.319500	11.250000	3
KAYA PRIM. SCH.	7.280000	11.230000	4
KAYA HEALTH C.	7.280800	11.230000	5
FATIKA GDSS	7.307000	11.153800	6
FATIKA MARKET	7.300000	11.155000	7
FATIKA SOUTH	7.304000	11.154000	8
DOGON DAWA WEST	7.140000	11.030000	9
DOGON DAWA EAST	7.147000	11.030000	10
KIDANDAN SOUTH	7.330000	11.030600	11
KIDANDAN NORTH	7.330000	11.030000	12
RUIKA EAST	7.170800	10.970000	13
RUIKA WEST	7.170000	10.970000	14
KANAWA JUNCTION	7.250000	11.010000	15
TUMBURUKU	7.280000	11.080000	16
GALADIMAWA	7.330000	11.050000	17
IYATAWA	7.180000	11.050000	18
KARAU KARAU	7.506340	11.097400	19
KAKANGI	7.470000	11.150000	20
GIWA GSS	7.470000	11.250000	21
YAKAWADA	7.380000	11.270000	22
ZUNDU	7.550000	11.080000	23
BIJIMI	7.569300	11.147600	24

LOCATION	LONGITUDE	LATITUDE	STATION NO. (VES)
BIYE	7.58870	11.164000	25
TSIBIRI	7.530000	11.180000	26
GUGA	7.539860	11.238200	27
ANGWAN TATA	7.500000	10.970000	28
TUDUN SARKI	7.656710	11.128200	29
PANHAUYA	7.611420	11.109600	30
BOMO	7.630440	11.201500	32
KWAKARA MANU	7.530000	11.150000	33
HUNKUYI	7.652630	11.273600	34
BAZANGA	7.612320	11.306200	35
DAN MAHAWAYI	7.577000	11.317500	36
BASSAWA BARKS.	7.673920	11.188400	37
ZABI ZARIA	7.737780	11.153100	38
GWANDA	7.725100	11.229200	39
LIKORO	7.799830	11.205600	40
MAKARFI	7.883170	11.375000	41
DAN GUZURI	7.834250	11.370500	42
ANGWAN DAUDA	7.774470	11.352400	43
KUDAN GDSS	7.740050	11.315200	44
GAURI GOJI	7.630000	10.980000	45
KAURA	7.824740	11.315200	46
TABAN SANI	7.779900	11.276300	47
GARU	7.711060	11.260900	48
UNGWAN MARKU	7.694750	11.297100	49
PALLADAN	7.714680	11.123200	50
KOGI	7.742760	11.093300	

LOCATION	LONGITUDE	LATITUDE	STATION NO.(VES)
KAKEYI	7.759970	11.113200	52
FARIN KASA	7.813420	11.133600	53
BAGALDI	7.849650	11.109600	54
DAMBO	7.782620	11.077900	55
YAKASAI	7.854630	11.052500	56
WANKA	7.903100	11.001800	57
AWAI	7.905810	11.070700	58
RICIFA	7.958350	11.168500	59
MAIGANA	7.939330	11.025400	60
SABON GARI DAJI	7.851460	11.213300	61
NASARAWA	7.908530	11.251400	62
RAHAMA	7.919400	11.304400	63
GIMI STATION	7.919400	11.342400	64
UNGWAN DANGASHI	7.800000	11.220000	65
GIMBA	7.961070	11.070700	66
MAGADA	7.984620	11.137700	67
KWASALLO	7.990060	11.191600	68
UNG. KANAKARGO	7.978280	11.266300	69
MADOBI EAST	7.596920	11.262700	70
MADOBI WEST	7.595970	11.262700	71
GABARI	7.420000	10.830000	72
KUFENA EAST	7.614130	11.007200	73
KUFENA WEST	7.617130	11.007200	74
TUDUN TUKUR	7.681620	11.099600	75
KUBANNI NORTH	7.655800	11.136800	76
KUBANNI SOUTH	7.655800	11.136400	78

LOCATION	LONGITUDE	LATITUDE	STATION NO. (VES)
JAJI BRKS	7.550000	10.880000	79
FARAKWAI EAST	7.650000	10.880000	80
FARAKWAI WEST	7.649050	10.880000	81
UNG. KANAWA (E)	7.633160	11.050700	82
UNG. MAKERA	7.633240	11.050700	83
UNG. SANI	7.576090	11.019000	85
KWABA	7.533520	11.015400	86
KWABA NORTH	7.536520	11.094000	87
UNGWAN KAFI	7.587870	11.058000	88
ABA EAST	7.762310	11.024500	89
ABA WEST	7.762240	11.024500	90
UNG. ZAKARA	7.708340	11.007200	91
PAN MADINA WEST	7.657580	11.018100	92
PAN MADINA EAST	7.657620	11.018100	93
UNG. SARKI KOGI	7.727820	11.024500	94
ZARIA CITY EAST	7.708340	11.055300	95
ZARIA CITY WEST	7.708290	11.055300	96
UNGWAN SARIKI	7.751820	11.039900	97
UNGWAN SARUBUTU	7.795300	11.035800	98
MARWA	7.842400	11.001800	99
KINGIBA NORTH	7.971940	11.001810	100
KINGIBA SOUTH	7.971940	11.001790	101
SAKADADI NORTH	7.725100	11.188400	102
SAKADADI SOUTH	7.725100	11.188330	103
DANJA HEALTH C.	7.563410	11.378600	104
DANJA MRKT.	7.563410	11.378600	105

LOCATION	LONGITUDE	LATITUDE	STATION NO. (VES)
DABAI	7.636780	11.366900	106
DAN MAI GAUTA	7.682070	11.344200	107

APPENDIX II

VALUES OF AB/2 AND MN USED FOR THE FIELD SURVEY

AB/2 (M)	MN (M)	AB/2 (M)	MN (M)
1.00	.40	25.12	6.40
1.26	.40	31.60	6.40
1.56	.40	31.60	12.80
2.00	.40	39.60	12.80
2.00	.80	50.00	12.60
2.51	.80	63.10	12.80
3.16	.80	63.10	25.60
3.98	1.60	79.40	25.60
5.01	1.60	100.00	25.60
6.31	1.60	126.00	25.60
7.94	1.60	156.00	25.60
7.94	3.20		
10.00	3.20		
12.6	3.20		
15.80	3.20		
15.80	6.40		
19.95	6.4		