DIRECT CURRENT RESISTIVITY AND SELF-POTENTIAL INVESTIGATIONS AT SHONGA (KWARA STATE, NIGERIA)

BY

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Dedicated to Buki, Kay and Tunji

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I have tried to acknowledge the consulted sources of information, either by direct or by general references. It is probable that credit to some who deserve it has been unintentionally omitted, since more than one source for such basic material exists, and original sources may be unknown to me. I regret any such omission.

ABSTRACT

Shonga, the study area is situated in the alluvium of the River Niger, in Kwara State, Nigeria, Between November 1980 and January 1981, twenty nine Vertical Electrical Sounding and four Horizontal Resistivity Profiling of a total length of 4.7 km using the Schlumberger and the Wenner electrode arrays respectively were undertaken in the study area. The aim was to map the aquifers and to determine the applicability of the dc resistivity methods in delineating the extent of iron contamination of the groundwater; since hydrochemical data indicates a high iron content (19 ppm), in the only borehole and a high chloride ion in some large diameter wells of the study area. In March, 1981 an SP survey with a total length of 3.7 Km that cut across the length of the study area was carried out for delineating the extent of high chloride content in the aquifer.

The electrical resistivity method has mapped the aquifers of the study area. However, qualitative and quantitative interpretations do not delineate the extent of iron contamination in the aquifers. Correlation with hydrochemical data from nearby wells has shown the high SP anomalies to represent the high chloride ion water - bearing aquifers of the study area.

The southern half of the study area has been identified as having fresh water aquifers; hence, future boreholes and wells are recommended to be sited in this region.

CHAPTER ONE

INTRODUCTION

Shonga, a town located on the southern bank and in the alluvium of River Niger in Edu Local Government of Kwara State has about 15,000 inhabitants. It is about 44 km N - E of Share. The study area lies between longitude $5^{\circ}7'$ and $5^{\circ}11'$, and latitude $9^{\circ}2'$ and $9^{\circ}8'$ (fig 1).

The inhabitants of Shonga rely on 15 large diameter wells for their drinking water (fig.2). Eight of these wells have a fairly high chloride ion concentration, which makes the water in the wells distasteful. Hence, the inhabitants use the water in these eight wells for laundry purposes only. The chloride concentration in the wells is monitored by means of direct water chemical analysis in a network of production wells. Normally, all the wells dry up during the dry season thus leaving the people with a single source of water: a highly polluted river.

A borehole was sunk and completed by the Kwara State Water Corporation in February, 1977, to alleviate the suffering of the people. The borehole recorded the highest groundwater yield in Kwara State: 136,000 litres per hour for a draw down of only 6.1 metres (KWWC/ENG/DRL6/472,vol 1). The high iron content, 19 ppm, of water in the borehole required treatment for the removal of the iron. The iron-

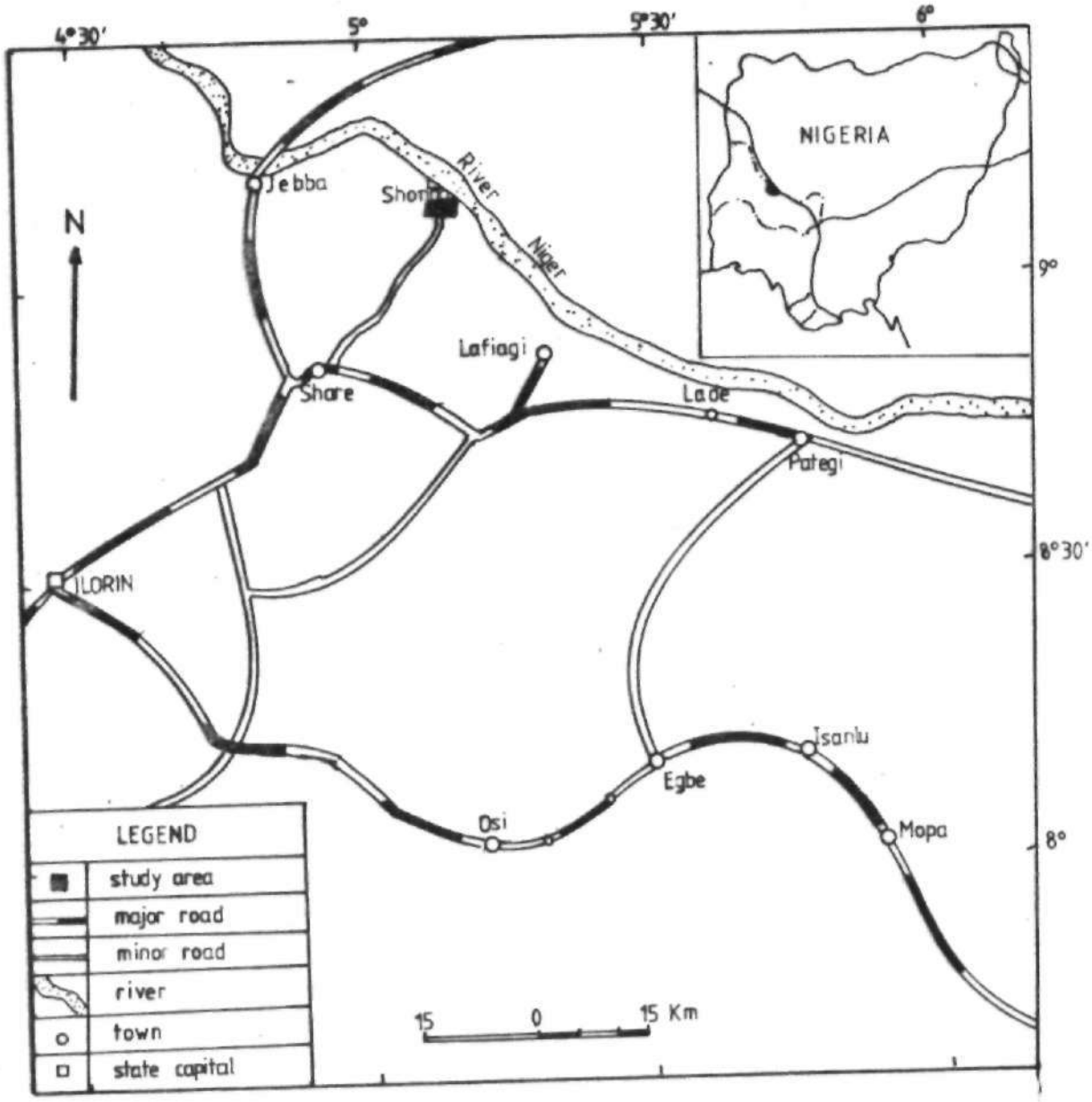


FIG 1: LOCATION OF THE STUDY AREA

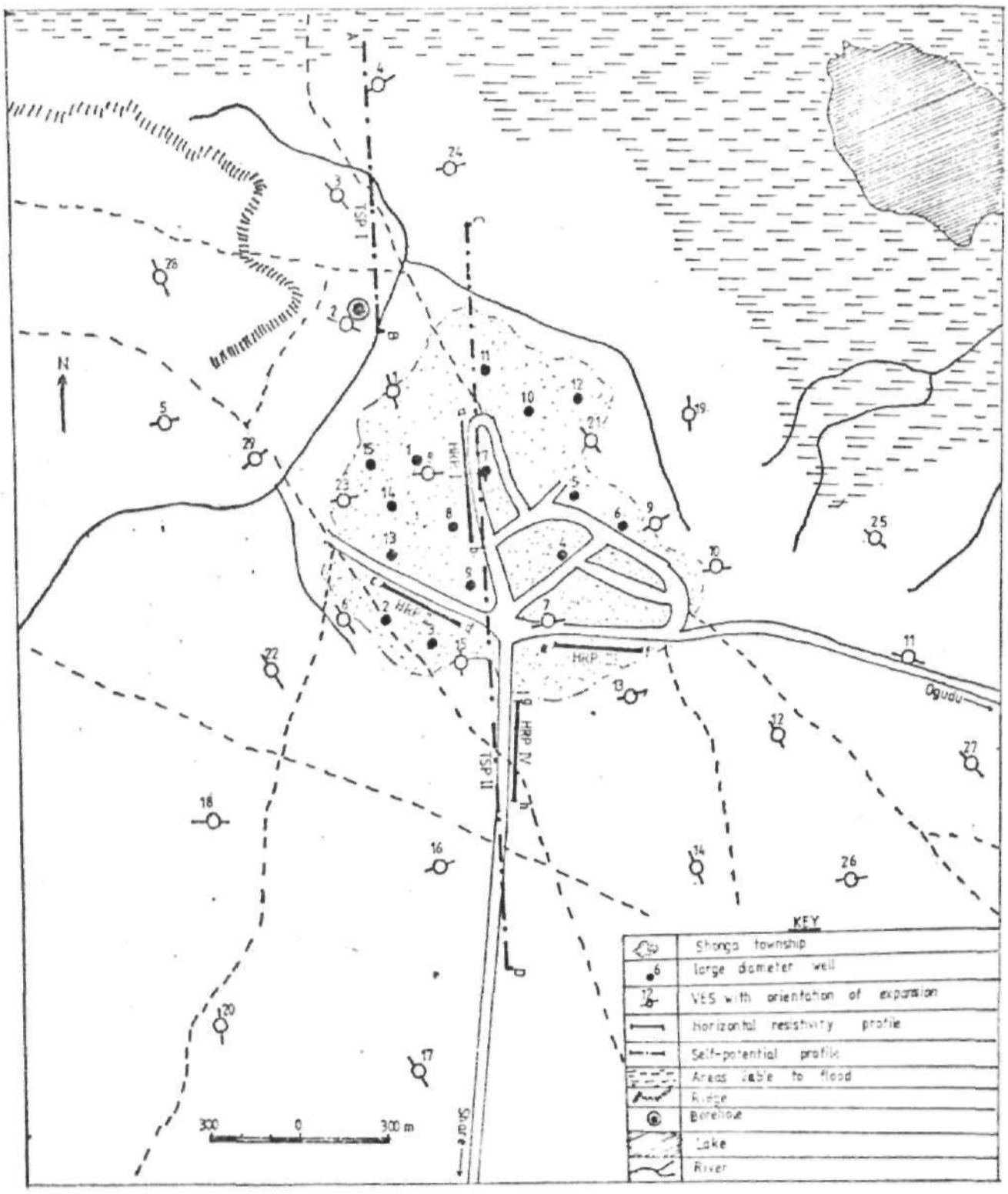


FIG 2: SHONGA AREA SHOWING THE LOCATIONS OF GEOPHYSICAL MEASUREMENTS AND WELLS.

removal plant had not been purchased at the time of this survey, hence the water cannot be utilized for human consumption.

The management of the Kwara State Water Corporation, Ilorin, felt that a geophysical investigation would delineate the aquifer. It was envisaged that iron contaminated and saline areas could be distinguised as well, so that future boreholes and hand dug wells would be sited in the freshwater zone of the study area. On the bases of these, the author was commissioned to carry out a groundwater investigation on the aquifers of Shonga.

In principle each of the four main methods of geophysical prospecting; the gravity, the magnetic, the seismic and the electrical methods, can furnish useful information on groundwater problems, when applied in areas in which the physical conditions are suitable. However, only the Electrical Resistivity and the Self-Potentials were used in the present work. Besides the availability of instrumentations other methods were not used for reasons discussed below.

Gravity Method

The gravity method is a rapid, inexpensive means of determining the gross configuration of an aquifer, providing density contrasts exist. It is useful in locating areas

of maximum aquifer thickness, in tracing the axis of a buried channel and in locating a buried bedrock high that may impede the flow of groundwater.

The success of the gravity method in defining the geometry of an aquifer in any area depends on the high density contrast between the unconsolidated fill and the bedrock. In areas where the contrast is lower, the definition of a narrow buried valley becomes more difficult.

No buried channels or similar structure were expected in this area, so the gravity method was not applied. However, if done, one would be advised to do density determinations e.g. by logging the existing wells.

Water in the interstices of a rock contributes to the total mass of the rock and if porosity is moderate or high, this effect is detectable with a gravity meter. If cores or cuttings had been taken when the hole was bored, a highly detailed, vertical profile of porosity could have been calculated. Neither the density log nor the cuttings were taken, hence the gravity method could not have been used successfully in the study area.

1.2. Magnetic Method:

The magnetic method of geophysical exploration involves measurement of the direction, gradient, or

intensity of the Earth's magnetic field and interpretation of variations in these quantities over the area of investigation.

Most sedimentary rocks are essentially non-magnetic and thus not amenable to direct study by magnetic methods. Igneous and metamorphic rocks generally contain a large proportion of magnetic minerals and are therefore more magnetic than sedimentary rocks but of less interest in groundwater investigations; however, determination of the configuration of the surface of a basement complex composed of igneous and metamorphic rock underlying water - bearing sediments is important in nearby groundwater studies.

The study area is in the sedimentary area of Kwara State; thus, the magnetic method of geophysical exploration was not attempted in the present work.

1.3. The Seismic Method:

Seismic method has, as its basis, the timing of artificially - generated pulses of elastic energy propagated through the ground and picked up by electromagnetic transducers operating as detectors. The geophysicist is interested in two parameters which affect the elapsed time of transmission of this pulse. They are the propagation velocity (or velocities) and the geometry of the propagation path.

The most common use of the seismic method in hydrogeology is in determination of the thickness of sediments which overlie essentially non water-bearing consolidated bedrock.

Seismic refraction measurement of semi-consolidated or unconsolidated clastic deposits reveal that compressional wave velocities increase abruptly at the water table. The velocity in saturated continental sediments generally is sufficiently higher than that in unsaturated sediments so that zone of saturation acts as a refractor.

If some of the velocity discontinuities in unconsolidated or semi-consolidated deposits represent stratigraphic breaks in the sedimentary section, seismic refraction method can be used under optimum conditions to unravel the gross stratigraphy of a deposit. If these breaks further represent significant hydrologic boundaries, such as those between water - producing formations and nonwater - producing formations, the seismic work may have special hydrogeologic interest.

Though the seismic method is used in groundwater investigation, it was not used in this investigation because of instrumental limitations. The author would have used either or both instruments available - the explosive and the hammer-seismic types. The explosive - source type would have been preferable. The hammer seismic is limited because it lacks the resolution and depth penetration required (about 15 m)

and secondly the looce sandy top soil of the study area would not allow an appreciable energy to be propagated through the ground.

1.4. Electromagnetic Method:

This method is a special type of electrical survey which makes use of a time - varying electromagnetic field as an energy source. When this primary field is imposed on Earth materials a flow of electrical current results. The current flow produces a secondary magnetic field that can be detected at or above the ground surface by measuring the voltage induced in a receiver.

The effective depth at which conductive bodies can be detected with electromagnetic methods is dependent upon both the frequency and spacing between the transmitter and the receiver loops. Thus, electromagnetic methos can be used in the same manner as resistivity measurements to obtain horizontal profiles and depth soundings.

If not because of non-availability of appropriate instrumentation it would be an interesting approach to the local problem of the study area.

1.5. Induced Polarization (IP) Method:

The use of induced electrical polarization method in ground-water exploration has been limited. The

method is widely used for orebodies.

Groundwater studies generally have been made with time-domain IP. The techniques of sounding and profiling, used in resistivity measurements, are also used in the IP method.

IP is related to ion exchange processes; with the salinity variation, in this area, it would have been a very useful method. Due to non-availability of instrumentation, the IP method was not used.

1.6. The Electrical Resistivity (ER) Method:

The Electrical Resistivity Method has been used mainly in the search for water-bearing formations, in stratigraphic correlation in oil fields and in prospecting for conductive ore bodies. Under favourable conditions this technique can be used to find depth of layers in the earth having anomalously high or low conductivities and to determine the depth and approximate thickness of the conductive zone. Among the parameters that characterize a body from the electrical point of view, resistivity alone is involved in direct current prospecting.

In November 1980 and January 1981, a surface resistivity survey was conducted using ABEM DC Terrameter. Twenty-nine vertical electrical soundings (VES) were undertaken with Schlumberger array and a

total distance of 3.4 Km was covered. Four horizontal resistivity trenching with a total distance of 1.16 Km was covered using the Wenner array (fig 2). The ER methods are discussed in detail in Chapter Three.

1.7. Self-Potential Method:

The Self-potential (SP) Method is the second geophysical method used in the study area. The SP methods involve measurement of electric potentials developed locally in the Earth by electro-chemical activity. The SP method of locating conductive bodies in the subsurface is unique among electrical methods in that no currents are artificially introduced into the ground, the conducting body itself acting as a battery which produces current detectable at the surface by means of a sensitive micro-ammeter.

With the SP method a total distance of 3.7 Km was covered cutting through the length of the study area (fig 2). The SP survey was carried out in early March, 1981.

CHAPTER TWO

HYDROGEOLOGY

2.1. GROUNDWATER AREAS IN KWARA STATE:

Three main groundwater areas are geologically identifiable in Kwara State (fig 3), as follows:

(a) The Basement Complex area: Archean crystalline rocks of Precambrian age called the Basement Complex underly about 70% of the total land area of Kwara State. The crystalline ancient rocks are composed mainly of gneisses, migmatites and granites. There are also occureence of quartzites and schists which assume local prominence in some places. The area is drained by numerous rivers all of which flow into River Niger. They include Rivers Mini and Osara in Lokoja - Okene area; Rivers Kampe, Oro, Oyi, Oshin, Awun (tributaries of Oyun and Asa) in the mid region and Rivers Moshi and Oli in Borgu area. Groundwater occurs under water-table conditions. Shallow groundwater tapped by hand-dug wells is widespread in this area.

(b) The Cretaceous Sediments Groundwater Area:

The outcrop of Nupe Sandstone follows the course of the Niger River. It covers a narrow strip of average width 20 Km south of River Niger

and stretching from Jebba to Lokoja. In most parts of Edu L.G.A. the formation is flat. In Kogi L.G.A., the sedimentary formations are represented by the Patti Formation and the Lokoja Sandstone which have characteristic mesas and flat-topped plateaux with laterite capping. There is a sedimentary formation, the Illo Formation which extends into the Northern extremity of Borgu from Sokoto State. The sedimentary formations yield dependable supplies of groundwater. Boreholes have average yields of 7,000 litres per hour. Groundwater occurs under water table and confined conditions.

(c) The River Alluvium Groundwater Area: The study area is in this division. River alluvium occurs along most water courses ranging in size from the thin discontinous sands occuring in the smallest streams to the thick alluvial deposits of the River Niger.

The river alluvium is the youngest of all the rocks in the whole geological spectrum. Results so far show that the alluvium of River Niger is by far the most significant both in terms of thickness of the sediment and the area over which the sediments are spread.

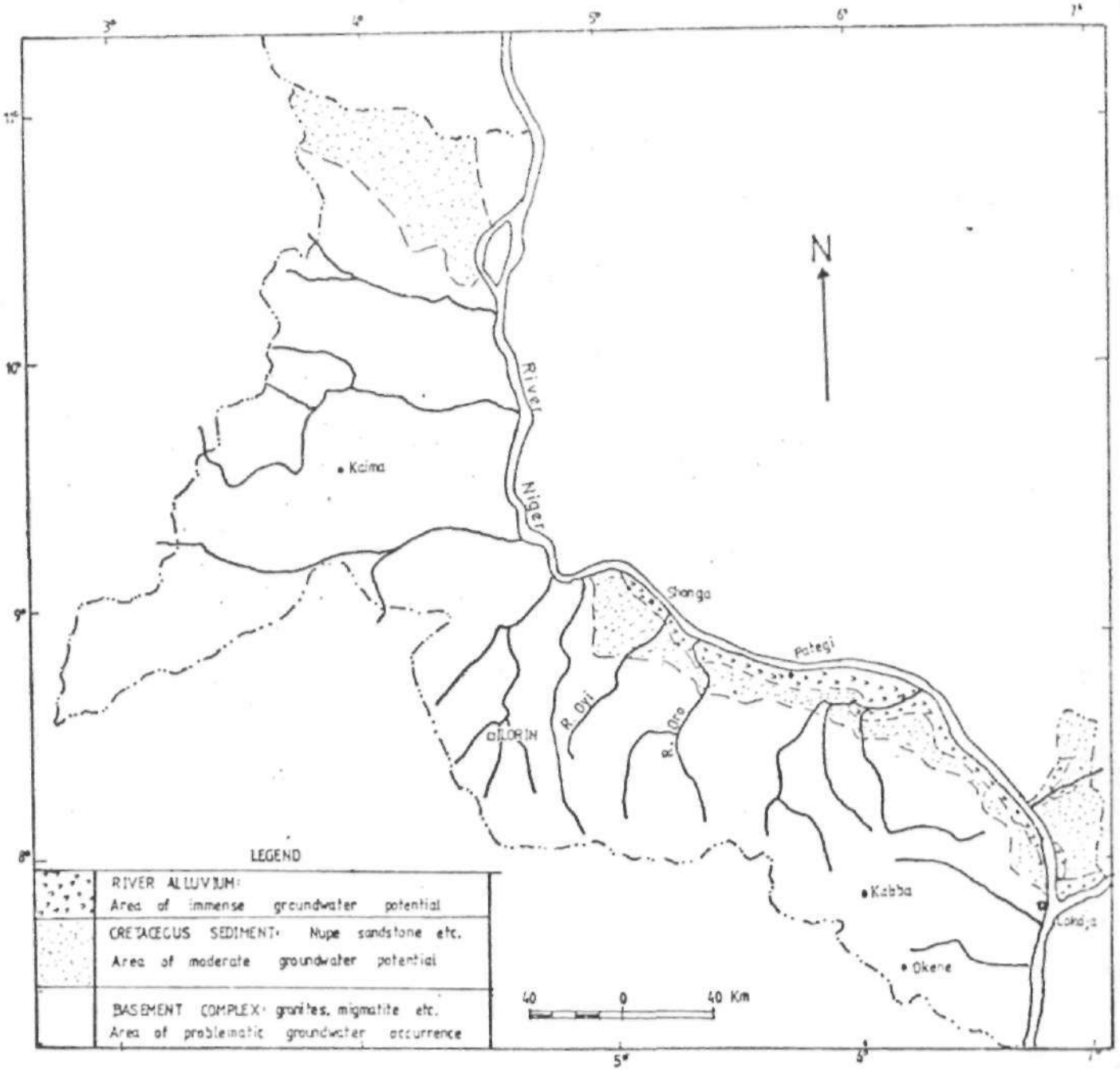


FIG 3: HYDROGEOLOGICAL MAP OF KWARA STATE

2.2. GEOLOGY OF THE STUDY AREA:

The geology of Shonga is known mainly from a series of borehole drilled in connection with gravel and water prostecting.

The borehole records indicate that the sediments composing river alluvium are very variable. The general lithology include unconsolidated gravel, coarse and fine sand, silt and clay overlying, the purple red to bluish green bound, very hard and dry Nupe Sandstone, Bedding is complex, lenses of coarse sand of varying thickness (1.5 - 7.0 m) and lateral extent alternate with less pervious materials or may be abruptly truncated by subsequent layers.

To the northwest of the study area, there is a highly compacted red to purplish sandstone ridge (fig. 2) with boulders of ferruginisad laterite. The sandstones are arkosic to quartzose, generally poorly sorted, with angular to sub-angular grains. Massive appearance is common, Thick to very thick flat-bedding (0.; 1.5 m) abd localized cross - stratification are also present.

Many of the coarser quartz grains commonly show smooth, flat surfaces giving the impression of vein quartz. Milky white and colourless quartz grains are

most common, with subsidiary pink, smoky and light chocolate - coloured grains. Feldspar grains are pink to beige and sometimes partly altered the quartz and feldspar grains are irregular, rod-like or roughly tabular.

2.3. GROUNDWATER POTENTIALITY OF THE STUDY AREA:

Groundwater in the alluvium is mainly replenished from the surface flow of streams. In the case of seasonal streams the quantity of water and the length of time that the water is retained in the alluvium after surface flow ceases is dependent on the porosity, permeability, thickness and the extent of the alluvium and the hydraulic gradient. In many streams water is retained in the alluvium throughout the year and these reserves may be large and constitute important source of groundwater. A disadvantage is that these shallow supplies are liable to pollution where waste disposal is not controlled.

Numerous streams and rivers (e.g. Rivers Kampe, Oro and Oyi) which traverse the basement complex and the Nupe Sandstone flow into the Niger system in the direction of dip of the sedimentary formation. Hence, many parts of the study area is subject to flooding during the wet seasons (fig 2).

TABLE I: WELL MEASUREMENT RESULTS AND CHEMICAL ANALYSES OF WATER SAMPLE AT SHONGA

Well No	Surface elevation (m)	Depth (m)	Water table (m)	PH	Cl^-	Conductivity (mho/m)
1	98.0	15.62	10.10	6.0	66.0	850
2	97.0	9.25	17.70	6.0	7.0	25
3	101.0	11.00	9.50	6.0	7.0	58
4	108.1	15.55	14.12	6.2	8.5	84
5	105.2	17.45	12.00	6.0	16.2	181
6	107.1	15.97	12.77	-	-	-
7	102.3	14.35	11.25	6.1	60.0	720
8	104.1	8.96	8.65	6.0	15.0	150
9.	109.0	9.72	9.10	-	-	-
10	100.0	14.59	10.26	6.8	53.0	750
11	95.8	13.56	9.60	6.0	56.0	600
12	97.0	16.19	10.22	7.0	32.0	650
13	94.2	11.50	7.43	6.0	18.0	178
14	93.0	10.09	8.20	-	-	-
15	91.0	8.25	7.13	7.0	7.0	680

In October, 1980 the author carried out a systematic measurement of the depth of all the hand-dug wells and depth of water table from the surface ground (Table I), in order to determine the quantity and direction of flow of the groundwater of the study area.

2.4. CHEMISTRY OF GROUNDWATER AT SHONGA:

The relatively slow movement of water percolating through the ground affords intimate and long contact of water with the minerals that make up the earth's crust. These minerals are soluble to a greater or lesser degree, so groundwater increases in mineral content as it moves along until a combined equilibrium or balance of the dissolved substances is reached.

Most groundwater contains no suspended matter and particularly no bacteria. It is usually clear and colourless. These characteristics contrast with those of surface waters, since surface waters are usually turbid and contain considerable quantities of bacteria. Groundwater, therefore, is normally of superior sanitary quality. Its temperature is relatively constant - another important factor in some cases.

Practically all water supplies contain some iron. The iron content is of considerable concern because

TABLE II: INTERNATIONAL STANDARDS OF DRINKING WATER (AFTER WHO, 1958)

	Permissible (ppm)	Excessive (ppm)	Shonga Wells(ppm)
Magnesium (Mg)	50.0	150.0	-
Calcium (Ca)	75.0	200.0	2.0-45.5
Iron (Fe)	0.3	1.0	19.0
Manganese (Mn)	0.1	0.5	-
Copper (Cu)	1.0	1.5	-
Zinc (Zn)	5.0	15.0	-
Fluoride (F)	0.5	1.5	-
Chloride (Cl)	200.0	600.0	7.0-66.0
Mitrate (NO_3)	50.0	100.0	-
Sulphate (SO_4)	200.0	400.0	-
Sulphate ($MgSO_4 + Na_2SO_4$)	500.0	1,000.0	2.3-15.7
Carbonates of Na + K(as $CaCO_3$	-	120.0	2.3-15.7
Total soluble solids	500.0	1,500.0	-
PH range	7.0-8.0	6.5 or 9.2	6.0- 7.0

small amounts seriously affect the water's usefulness for some domestic and industrial purposes. The standard of WHO (Table II), suggests the iron content of drinking water should not be greater than 0.3 ppm.

In the borehole sunk at Shonga by Kwara Water Corporation, the iron content in it is as high as 19 ppm. The iron occurs in the reduced state and quickly turns brown on standing. When the iron content of the water at the source, is excessive such as in the borehole at Shonga, treatment for removal is the ultimate solution.

The chloride content of the groundwater at Shonga requires special mention. The chloride ion concentration in some wells is as high as 60 ppm as against the background value of 7 ppm in some wells (TABLE I).

Water in the wells with high chloride concentration has a bad taste, hence, the inhabitants draw their drinking water from the wells of low chloride concentration. By the standard of WHO, water that contains less than 200 ppm of chloride is satisfactory for most purposes (Table II).

The relative concentration of hydrogen ions in water indicates whether the water will act like a weak acid, or if it will perform as an alkaline solution. At Shonga, the PH value of the water in the wells is variable (Table I). Most of the wells have a PH value less than 7, making the water in such wells to have acid taste.

CHAPTER THREE

ELECTRICAL RESISTIVITY SURVEY

3.1. General Principle

The electrical properties of most rocks in the upper part of the Earth's crust are dependent primarily upon the amount of water in the rock, the salinity of the water, and the distribution of the water in the rock. Saturated rocks have lower resistivities than unsaturated and dry rocks. The higher the porosity of the saturated rock, the lower its resistivity; and the higher the salinity of the saturating fluids, the lower the resistivity. The presence of clays and conductive minerals also reduces the resistivity of the rock.

Two properties are of primary concern in the application of electrical methods. (1) the ability of rocks to conduct an electric current, and (2) the polarization which occurs when an electrical current is passed through them.

The basis of the method is that when current is applied by conduction into the ground through electrodes, any subsurface variation in conductivity alters the current flow within the earth and this in turn affects the distribution of electric potential.

The degree to which the potential at the surface is affected depends upon the distribution and conductivities of the materials within the ground.

The usual practice with this method is to pass current into the ground by means of two electrodes and to measure the potehtial difference between a second pair placed in line between them. From the value of the potential difference, the current applied and also the electrode separation a quan tity termed the apparent resistivity can be calculated. In homogeneous ground this is the true ground resistivity but usually it represents a weighted average of the resistivities of all the formation through which the current passes. It is the variation of this apparent resistivity with change in electrode spacing and position that gives information about the variation in subsurface layering.

3.1. Basic Theory:

In making resistivity surveys a commulated direct current or very low frequency (< 1 ' $_Z$) introduced into the ground via two electrodes. The potential difference is measured between a second pair of electrodes. The electric potential V at any point P (fig.4), caused by a point electrode emitting an electric current I in an

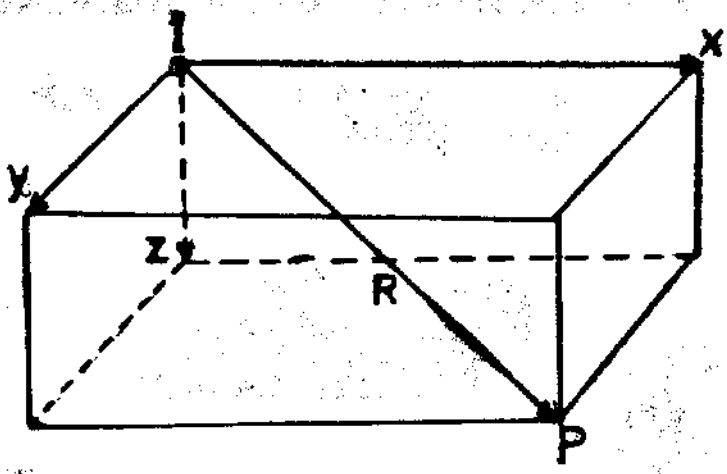


Fig 4: Diagram showing the relationship between a point source of current I (at origin of coordinates) in an isotropic medium of resistivity ρ and the potential V at any point P.

$$V = \frac{\rho I}{4\pi R}$$

where $R = \sqrt{x^2 + y^2 + z^2}$

when $z = 0$,

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

where AM = Distance between current electrode A and potential electrode M.

(After Zohdy, et al, 1974)

infinite homogeneous and isotropic medium of resistivity ρ is given by (Zohdy et al, 1974)

$$V = \frac{\rho I}{4\pi R} \qquad \text{.....(1)}$$

where $R = \sqrt{x^2 + y^2 + z^2}$

For a semi-infinite medium, which is the simplest Earth model, and with both current and potential point electrodes placed at the Earth surface (z = 0) equation (1) reduces to

$$V = \frac{\rho I}{2\pi\sqrt{x^2 + y^2}} = \frac{\rho I}{2\pi\, AM} \qquad \text{.....(2)}$$

where $\overline{AM}$ is the distance on the Earth surface between the positive current electrode A and the potential electrode M. When two current electrodes A and B and potential electrodes, M and N (fig.5) are used, the net potential difference is

$$\Delta V_{MN} = V_M - V_N \qquad \text{.....(3)}$$

from equation (3) we can express, the resistivity ρ by

$$\rho = \left\{ \frac{2\pi}{\frac{1}{AM} - \frac{1}{BM} - \frac{1}{NA} + \frac{1}{BN}} \right\} \frac{\Delta V}{I} \qquad \text{.....(4)}$$

Equation (4) is a fundamental equation in direct current electrical prospecting. The expression in parenthesis of equation (4) is called the geometric factor of the electrode arrangement and generally is designated by the letter K or G. Therefore

$$\rho = K \frac{\Delta V}{I} \qquad \text{.....(5)}$$

If the measurement of ρ is made over semi - infinite space of homogeneous and isotropic material, then the value of ρ computed from equation (5) will be the true resistivity of that material. However, if the medium is inhomogeneous and (or) anisotropic then the resistivity computed from equation (4) is called an apparent resistivity, ρ_a.

3.1.2. Electrode Configuration

The value of apparent resistivity ρ_a (eq.4) depends on four distance - variables AM, AN, BM, and BN. If ρ_a is made to depend on only one distance - variable the number of theoretical curves can be greatly reduced, Several electrode arrays have been invented to fulfil this goal. They include: the Wenner array , the Schlumberger array, the Dipole - Dipole array, and the Lee - partitioning array. Only the first two used by the author in this investigation are discussed below:

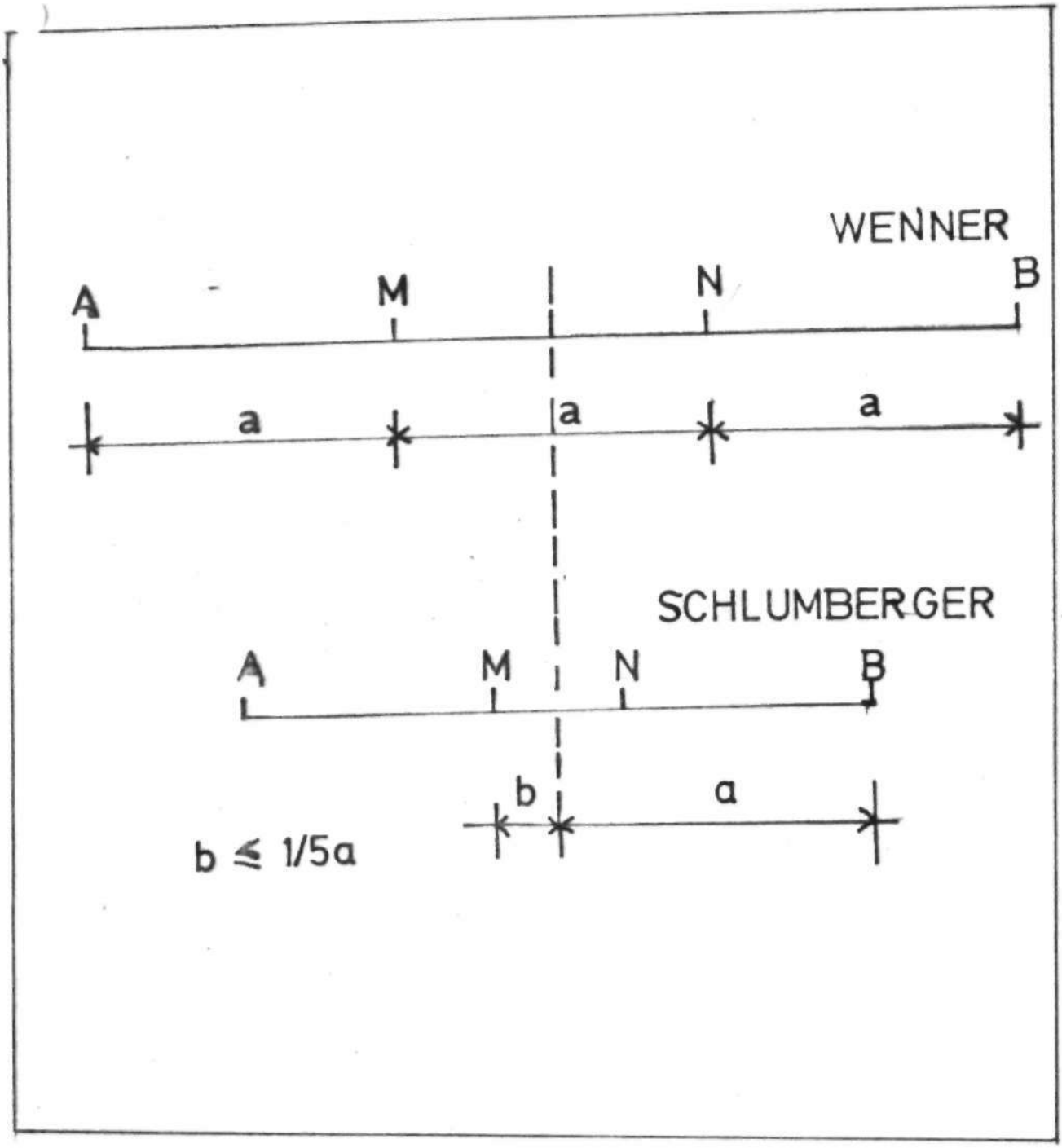


FIG 5: ELECTRODE CONFIGURATION FOR ELECTRICAL SOUNDING & PROFILING

(a) Wenner array:

The four electrodes A, M, N and B are placed at the surface of the ground along a straight line (fig.5) so that

$$AM = AN = BN = a$$

For the Wenner array, equation 4 reduces to

$$\rho_a = 2\pi a \frac{\Delta V}{I} \qquad \ldots\ldots\ldots\ldots(6)$$

(b) Schlumberger array:

This array is most widely used in electrical prospecting. Four electrodes are placed along a staked line on the Earth surface (fig.5) in the same order, AMNB, as in the Wenner array but with $AB < 5MN$

For Schlumberger array equation 4 can be written in the form:

$$\rho_a = \pi \frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN} \frac{\Delta V}{I} \qquad \ldots\ldots\ldots\ldots(7)$$

3.2. INSTRUMENTATION

The ABEM DC Terrameter was used for the electrical resisitivity investigation. The instrument is a battery - powered, deep pentration resisitivity meter with an output sufficient for a current electrode separation of 200 metres.

The DC Terrameter is made up of two units: the T-Box (transmitter) with detachable tray and the R-Box (receiver). Mechanically the T-Box and the R-Box are assembled in rugged aluminium boxes, that stand rough handling and give excellent protection to the electronic circuitry and instruments. All components are completely weather proofed and the casing is sealed against dust and damp.

The T-Box operating voltage is normally supplied from a clip-on battery tray, placed under the T-Box. The battery tray comprises ten 1.25 V series connected rechargeable NiCd cells and a battery charger. A standard 12 V car battery can be used for charging the cells and this can be done during operation of the T-Box.

Other important components of the Terrameter are the electrodes. On the transmitting side ordinary electrodes of galvanized iron were used. On the receiving side non-polarizable electrodes were used. The electrode comprises a durable, transparent plastic container around a copper conductor inserted in a stick of selected wood.

A drum cable set was used for the connection of the current electrodes to the T-Box. The drum cable set comprises four 1000 metre lengths of stranded, plastic-insulated single conductor with 0.5 mm^2 area on four drums with removable crank.

The block diagrams of the T-Box and the R-Box is in fig.6

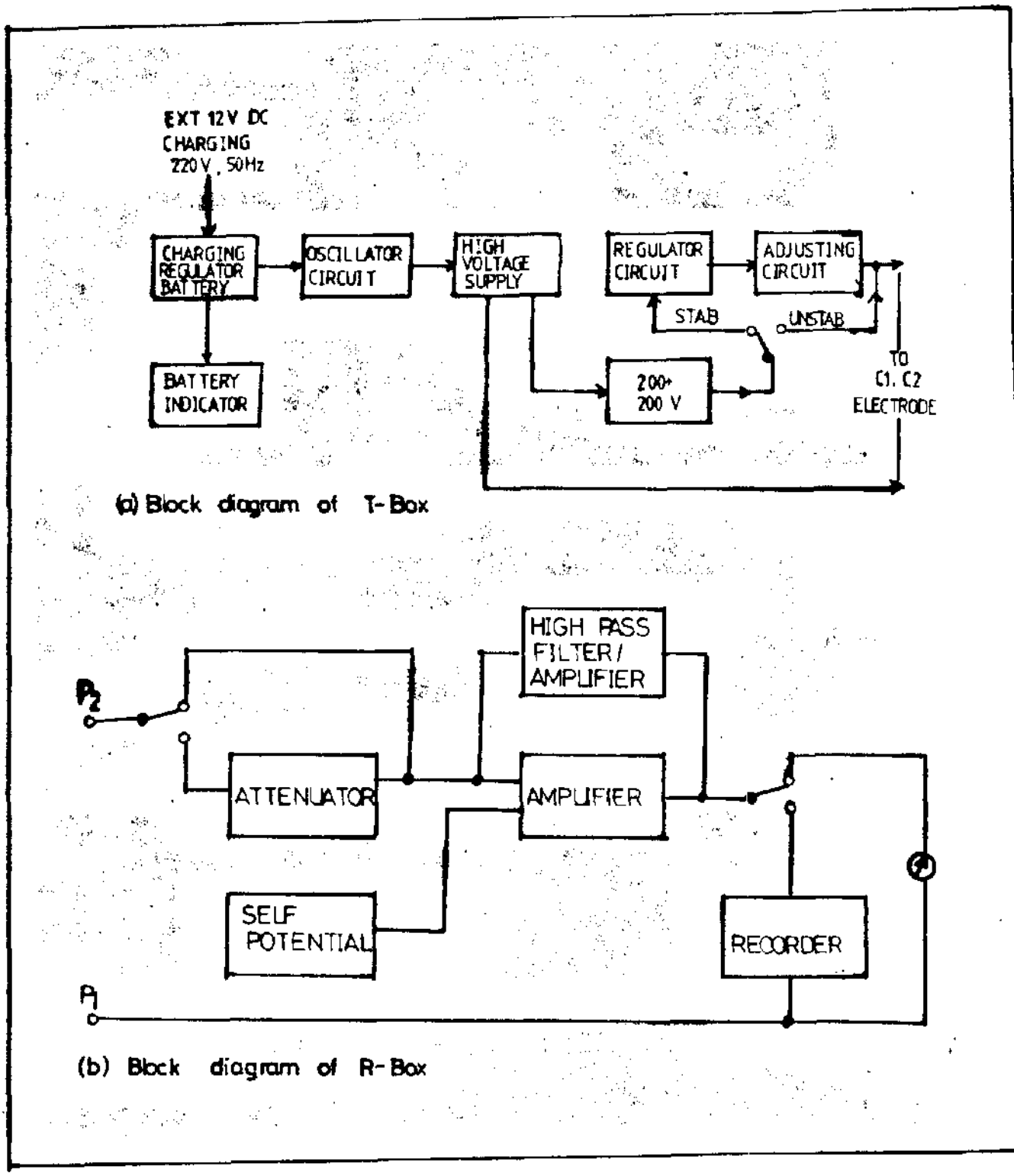


Fig 6: BLOCK DIAGRAMS OF T-BOX & R-BOX

3.3. FIELD PROCEDURE

The object of any geophysical survey is to obtain the information as quickly and as cheaply as possible and yet with sufficient accuracy. In this respect, prior to the geophysical investigation was begun, the author had access to some information from boreholes and hand dug wells. This provided information on the chemistry of the groundwater and the water table conditions of the study area. Also a knowledge of the geology of the area was invaluable.

A compass was used to get the direction of the traverse and ranging poles were driven into the ground at about 60m interval in order to get a straight traverse: The traverse was then cleared and wooden pegs were driven into the ground at intervals equal to the chosen electrode separation. The pegs were numbered so as to help in recovering the position of any interesting feature for further examination. Steel electrodes were driven into the ground at the position of the wooden pegs and connected to the DC Terrameter using connecting wires.

Due to the loose nature of the top soil as well as high surface resisitivities of the surface sandy soil (in most part of the survey area), high contact resistances existed at the current electrodes which had to

be watered with a salt water solution. Before taking any reading, the calibration of the instrument was often checked for consistency and adjustments made as necessary.

The electrical current that was introduced into the earth at the current electrodes was derived from DC equipment (fig 6); hence, measurement was made with two opposite directions of current flow.

The two field techniques used in this survey were the electrical sounding and the horizontal profiling.

(a) Electrical Sounding

The method of electrical sounding furnishes detailed information on the vertical succession of the various conducting zones and individual thicknesses and true resistivities. The technique is based upon the fact that the fraction of the electric current put into the ground, penetrating below any particular depth, increases with an increased separation of the current electrodes. The Schlumberger array was used in all the vertical electrical sounding in this work.

Twenty nine vertical electrical soundings (fig 2) were undertaken in November, 1980 and January, 1981, covering a total length of 2.4 Km. The current electrode separation varied between 200 m and 400 m, while the potential electrode spacing varied between 0.5 m and 20 m.

(b) Horizontal Profiling

In Horizontal profiling, a fixed electrode spacing of 20 m was chosen (on the basis of the measurement of the water table and depth of all the wells in the study area) and the whole electrode array was moved along a profile after each measurement was made.

In January 1981, four horizontal profilings were undertaken with a total length of 1.16 Km. The Wenner array with a constant electrode separation of 20 m and station interval of 10 m was used on all the horizontal resistivity profiles.

3.4. Height Determination

In March, 1981, the heights of all the profiles, sounding stations and well locations were determined using the Wallace and Tiernan altimeters, since topographical map of the area was not available. The height determinations were carried out inorder to find out the relationship between the apparent resistivity values and topography; and also for use in the drawing up of a map of the depth to the lowest resistivity layer.

The altimeters

Two Wallace and Tiernan atlimeters were used during the survey. The altimeters operate on the same general principle as aneoroid barometers, in which case the altimeter is a pressure sensitive device. The altimeters incorporate shock-resistant jewelled bearings which

are specially designed to eliminate backlash. Each scale division on the altimeter is equivalent to 10 ft (3.05 m).

Changes in atmospheric condition often affect the accuracy of the altimeter because its behaviour is pressure dependent. In the dry season, for example, the estimated accuracy if the instrument is read at the appropriate time of the day is 1.2 m; whereas in the wet season the accuracy may not be better than 2.5 m (Verheijen and Ajakaiye, 1978).

A central point of the study area was chosen as the base station for the levelling (fig 2). This base was occupied hourly and the levelling was done between 1730 hours and 1930 hours each day.

CHAPTER FOUR

SELF - POTENTIAL SURVEY

Self-potential methods involve measurement of electric potentials developed locally in the earth by electro - chemical activity, electrofiltration activity or both. The most common use of self-potential surveys has been in the search for ore bodies in contact with solutions of different compositions. The result of this contact is a potential difference and current flow which may be dectected at the ground surface. Of more interest to groundwater investigations are the potentials generated by water moving through a porous medium (streaming potentials). Measurements of these potentials have been used to locate leaks in reservoirs and canals (Ogilvy and others, 1969).

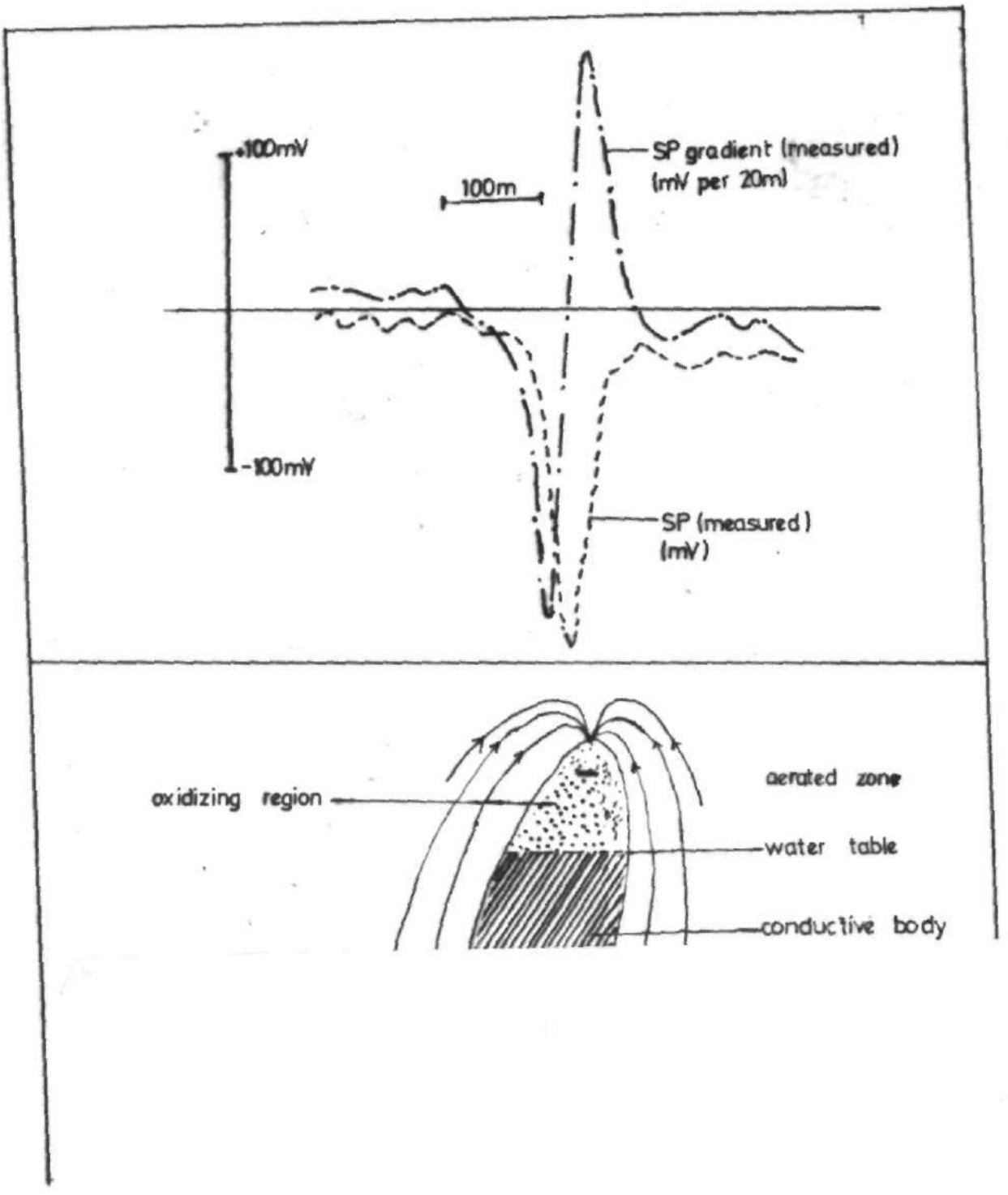
In the study area, the conductivity of water in the water-wells were high with ranges between 25 mho/m and 850 mho/m (Table I). In order to determine the cause of the high conductivity of the water in some of the wells and to delineate the high from the low conductive zones, a self - potential survey was carried out. A total distance of 3.7 km was covered by this method.

4.1 Origin of SP

Sato and Mooney (1960) expressed the view that self-potentials can not be due to oxidation of an orebody as such but the difference in the oxidation capacity of the waters near the upper and lower surface of an orebody, the electrical conduction in which takes place by electrons. With this proposal orebodies would be expected to show self-potentials under a wider variety of climatic and other conditions than those admitted by the oxidation theories.

In general, spontaneous polarization currents are set up by continuous veins of pyrite and pyrrhotite, the apex of which is near the surface. A minimum content of 5 to 10% of sulphides is required to make a deposit a conductor. Copper sulphides, chalcopyrite, chalcocite, and in pyrite masses improve the conductivity of the ore.

Spurious sources of potential are created by fluid streaming, bioelectric activity in vegetation, varying electrolytic concentration in ground water and other geochemical actions. These spurious sources often obscure effects of subsurface electrochemical action. For instance, it is often found that high ground is more negative than the low ground, indicating that the electric current tends to flow uphill. Telluric currents (natural earth currents of global extent flowing through the earth's crust) also result in


+100mV
-100mV
100m
SP gradient (measured)
(mV per 20m)
SP (measured)
(mV)
oxidizing region
aerated zone
water table
conductive body

potential differences which are sometimes difficult to separate from electrochemical potentials.

4.2. FIELD PROCEDURE:

Only the Receiver - Box (R.Box) of the ABEM DC Terrameter and two non-polarizable electrodes were used. The electrode comprises a durable, transparent plastic container around a copper conductor inserted in a stick of selected wood. When in use, the container was filled with saturated copper sulphate solution which trickles through the porous wood into the ground and thus provides excellent contact.

A drum cable set was used for the connection of the non-polarizable receiving electrode to the R - Box. The drum cable comprises 1000 m length of stranded, plastic insulated single conductor on a drum with removable crank.

Both the total potential and the gradient method were used in this SP survey. Along one traverse, TSP I (fig. 2), the total potential method covering a total length of 900 m was adopted. With this method one electrode was fixed at the base station while the other moves to successive stations with 20 m interval along the line. On the second traverse TSP II (fig 2), 2.5 Km

long, the gradient method was used i.e. both electrodes were moved while maintaining a fixed interval of 20 m between them. The leap - frog variation of the gradient method was adopted, in moving from station to station. The rear pot was carried beyond the forward pot to the new station and the polarities were reversed at successive stations in the process. In the leap-frog variation, cummulative errors inherent in some other methods are eliminated.

CHAPTER FIVE

RESULTS AND DISCUSSIONS

5.1 ELECTRICAL SOUNDINGS:

Resistivity curves were constructed for all the resistivity values measured by using half - the distance between the current electrodes as abscissa and the resistivity value as ordinate. Each curve was plotted on transparent bilogarithmic paper. Quantitative interpreation of the VES curves inorder to determine the thickness and the true resistivities of the individual layer in the ground was carried out by means of master curves for resistivity prospecting prepared by Rijkswaterstaat (1975). Most of the curves matched reasonably well.

By varying the parameters obtained from curve matching in a computer programme (Asten and Verheijen, 1978) theoretical models were obtained which gave the best fit with the field curves. Another computer programme (Verheijen, 1978) was used to compute measurement errors in the raw field data. This ranged from 3.0 - 11.67% for the resistivity values at the 29 sounding points interpreted. The sounding result is shown in Table III.

TABLE III: SOUNDING RESULTS

VES Stns.	Elevation of VES Stns.(m)	Apparent Resistivity (ohm-m)				Depth (m)			
		ρ_1	ρ_2	ρ_3	ρ_4	h_1	h_2	h_3	h_4
1	92.0	189	5.3	5000	-	1.95	3.3		-
2	75.2	424	132	5000	-	1.96	34.7		-
3	73.6	36.5	734.3	2.2	-	0.99	6.5		-
4	73.6	31	453.9	6.1	-	1.25	5.58		-
5	99.0	167.3	38.4	5000	-	3.01	61.6		-
6	97.2	428	84.3	330	-	0.85	18.3		-
7	108.1	529.6	38.2	724.6	-	1.35	14.7		-
8	98.0	310	20.6	0.8	-	1.6	25.6		-
9	100.4	1016	42.4	3680	-	2.9	24.1		-
10a	115.5	1659	67.1	10000	-	3.4	29.4		-
10b	115.5	2432	790	38.4	10000	1.2	4.16	16.2	-
11	109.0	4307	150.9	10000	-	1.03	6.3		-
12	95.0	1551	157.9	20000	-	1.3	15.8		-
13	108.2	1514	308	106000	-	1.7	18.6		-
14	109.0	551	226.9	15000	-	1.68	35.7		-
15	101.0	1472	87.8	9806	-	1.9	12.5		-
16	116.0	925.5	92.8	604	-	2.8	30.2		-
17	129.5	4939	978	252	10000	0.72	2.52	36.9	
18	119.0	1500	406		-	1.9	39.7		-

A distortion of the electrical sounding curve was observed on sounding station no 8. The distortion could be caused by lateral inhomogeneities in the ground, errors in measurements or equipment failure, current leakage from poorly insulated cables and by electrode spacing errors (Zohdy, 1968). The Schlumberger curve was rectified and smoothed accordingly by shifting the displaced segments of the curve downward to where it should be in relation to other segments of the curve.

Twenty four sounding curves except those at five locations No 3,4,8,23 and 24) are characterised by a high initial resistivity value ranging from 200 - 4000 ohm-m followed by a low resistivity value of 200 ohm-m average and finally by high resistivity values of 5000 - 150000 ohm-m, i.e. type H curve with $\rho_1 > \rho_2 < \rho_3$ (fig 8 and 9).

The field curves at stations 3,4 and 24 (fig 10) show a maximum ($\rho_1 < \rho_2 > \rho_3$) resistivity values of 500 ohm-m average juxtaposed between two low resistivity values. It is classified as type K. They are typical curves obtained near flood areas in the alluvium plain of River Niger. At these stations the top moistened alluvia is separated from a lower water bearing sandy layer by an impervious consolidated layer of claystone.

The field curves at stations 8 and 23 (fig 11) show a high initial apparent resistivity value of 300 ohm-m

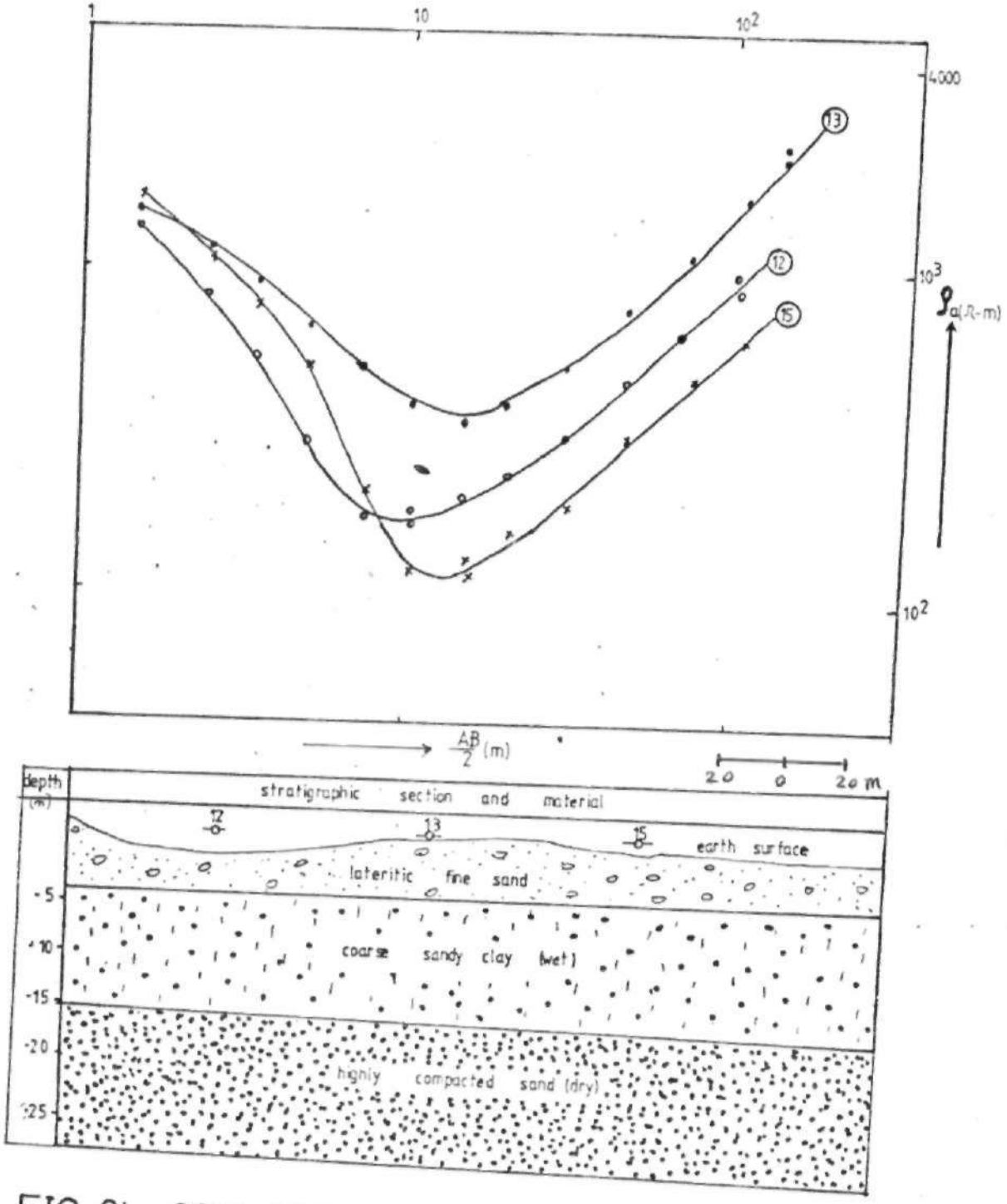


FIG 8: GEO-ELECTRICAL SOUNDING AND CROSS SECTION ALONG PROFILE AA'

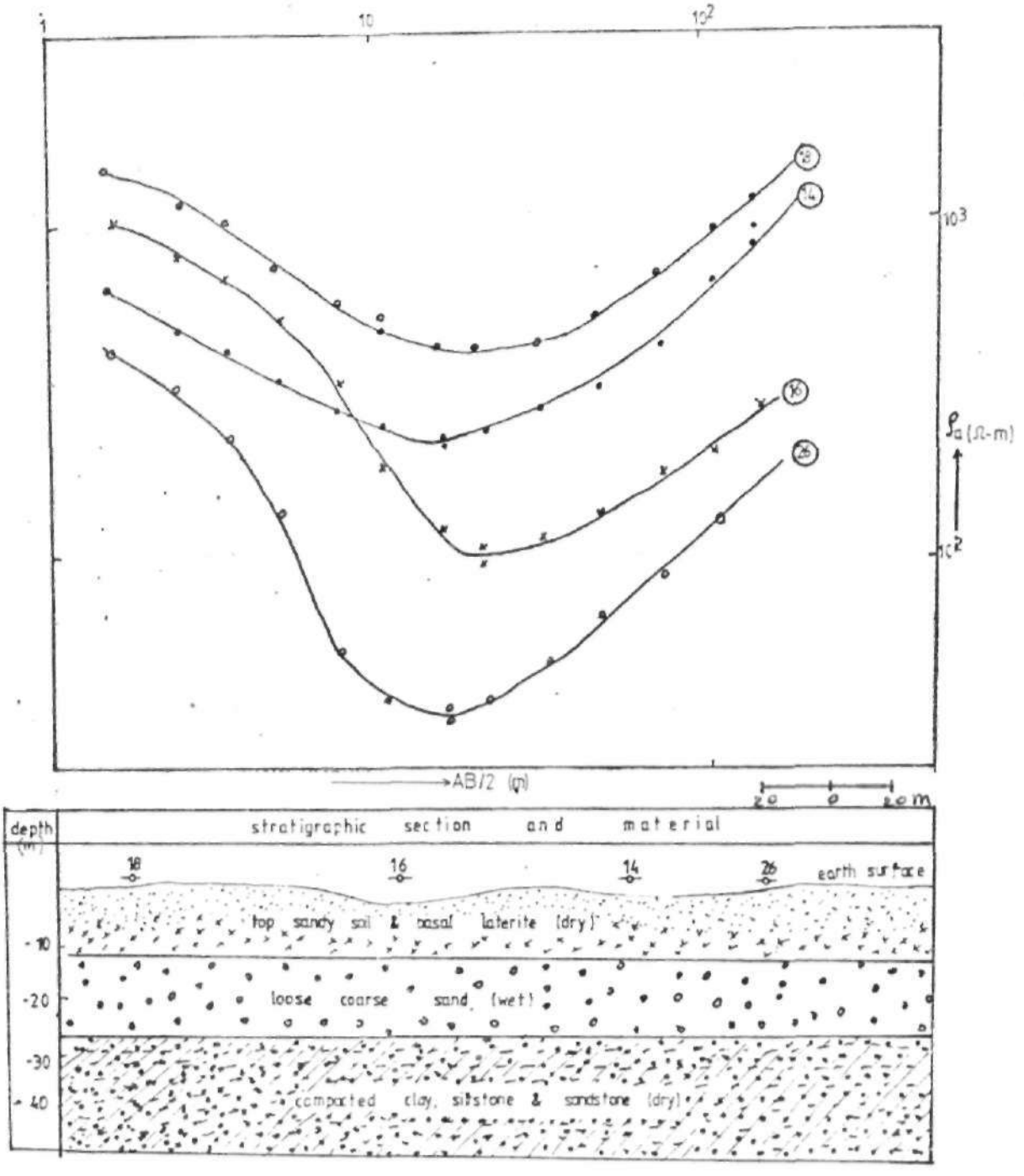


FIG 9: GEO-ELECTRICAL SOUNDING AND CROSS SECTION ALONG PROFILE BB'

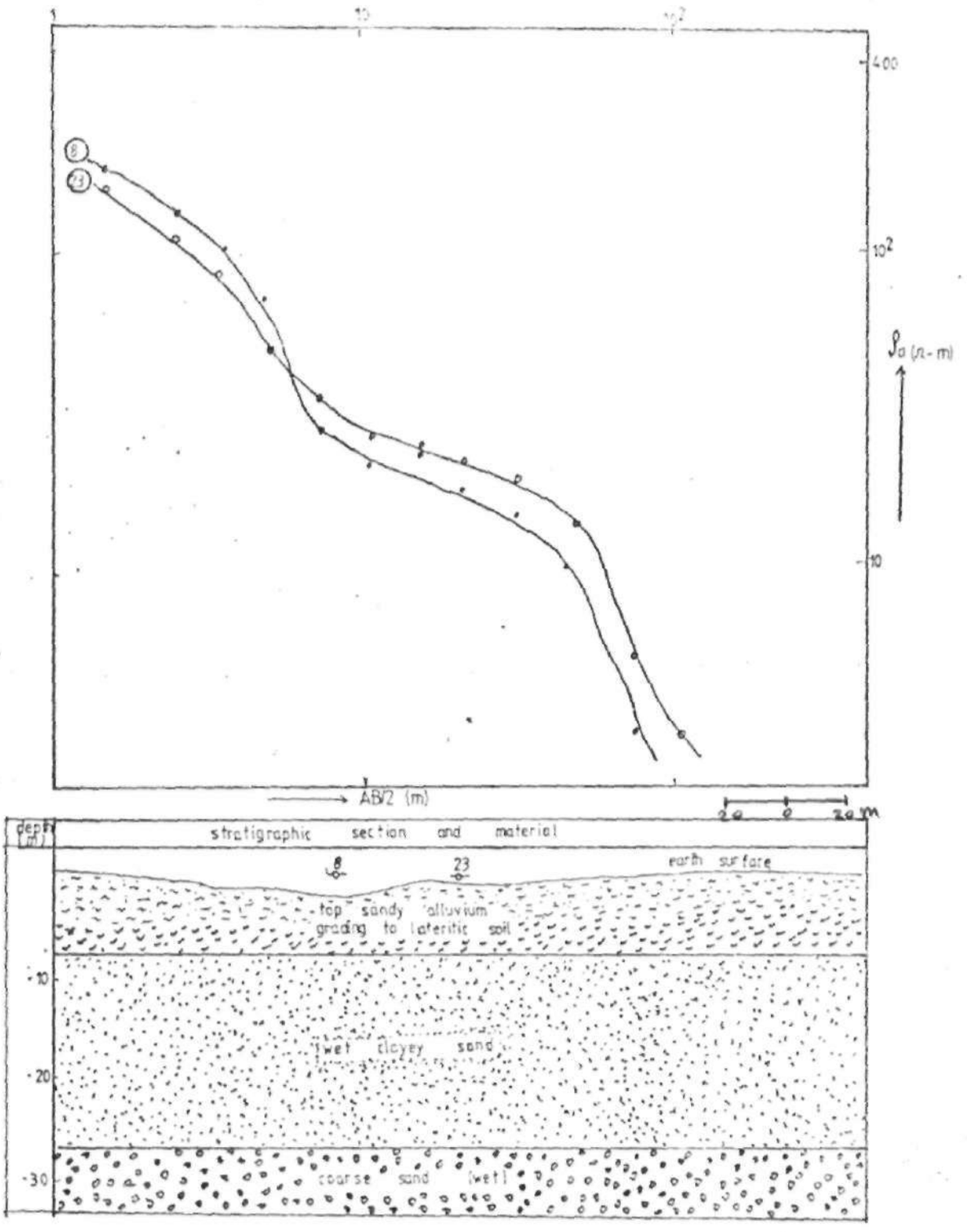


FIG 11: GEO-ELECTRICAL SOUNDING AND CROSS SECTION ALONG PROFILE DD'

average that decreases rapidly with electrode spacing i.e. $\rho_1 > \rho_2 > \rho_3$ and they are classified as type Q curve. These curves are found near the area with a higher chloride concentration in the groundwater.

Four interpreted profiles (fig 15) were drawn between adjacent stations in order to correlate the data between the stations. For example interpreted frofiles AA' and BB' (fig. 8 & 9) indicate an intermediate layer of low resistivity and appreciable depth emplaced between two layers of high resistivity values. The low resistivity stratum is most likely the water aquifer of the study area.

Profile CC' (fig 10) indicates a high resistivity layer separating a top wet alluvium from a water bearing coarse sandstone. The high resistivity layer is probably a dry sandy clay.

Profile DD' (fig 11) indicates a high resistivity layer overlying a very low resistivity layer. The apparent resistivity values in this zone are lower than other zones. This low value could be caused by the high chloride on concentration, as observed by hydrochemical data of the study area.

5.2. Borehole Correlation:

For control purposes an electrical sounding was carried out near the Kwara Water Corporation borehole

at Shonga (sounding No 2).

The curve for this sounding indicates a low resistivity layer emplaced between two high resistivity layers. The low resistivity layer with an apparent resistivity of 132 ohm-m being the aquifer. The first and the third layers have apparent resistivity values of 424 and 5000 ohm-m respectively. The first layer which extends from surface down to a depth of 1.96 m is composed of fine sand alluvial soil. The second layer is composed of wet coarse sand with clay intercalation, while the third layer represents a dry highly compacted sandstone - Nupe Sandstone.

The type section of the borehole is shown in fig 12 below. Records indicate that the borehole is a subartesan type with water level at 2 m below ground surface.

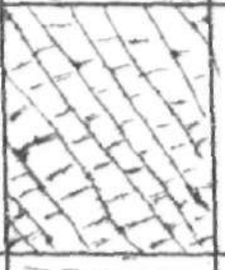
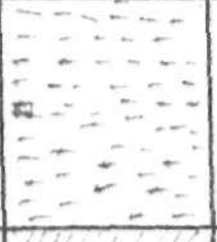
Depth (m)	Lithology	Description	Chemical Analysis
0–2		white sand, fine to medium grains	PH = 6.8 F^- = 0.18 mg/l Cl^- = 0.98 mg/l PO_4^{3} = 0.91 mg/l NH_4 = 1.04 mg/l Ca^{2+} = 2.85 mg/l Mg^{2+} = 12.16 mg/l Fe^{3+} = 19.0 mg/l $CaCO_3$ = 51.0 mg/l free CO_2 = 4.5 mg/l SiO_2 = 4.5 mg/l conductivity = 66.61 mho/cm
2–9		Wet coarse to very coarse white sand	
9–12		wet coarse to very coarse and pebbly sands	
21–38		W. coarse sand with sub-augular to well rounded gravel.	
38–below		Nupe Sandstone, purple red to bluish green clay bound and very hard	

Fig 12: Type Section and Chemical Analysis of the borehole at Shonga (KWWC/ENG/DRL 6/272)

The borehole information indicates a five layer medium (fig 12, above); with depth to the bedrock of 38.1 m as compared to 34.7 m, which is the best estimate derived from the resisitivity measurements. Assuming the borehole data to be more accurate, a measurement error of 11.6% (see section 5.1 above) computed for this sounding point will give a maximum bedrock depth estimate as 38.75 m which is comparable to that given by the borehole.

5.3. Horizonal Resistivity Profiles:

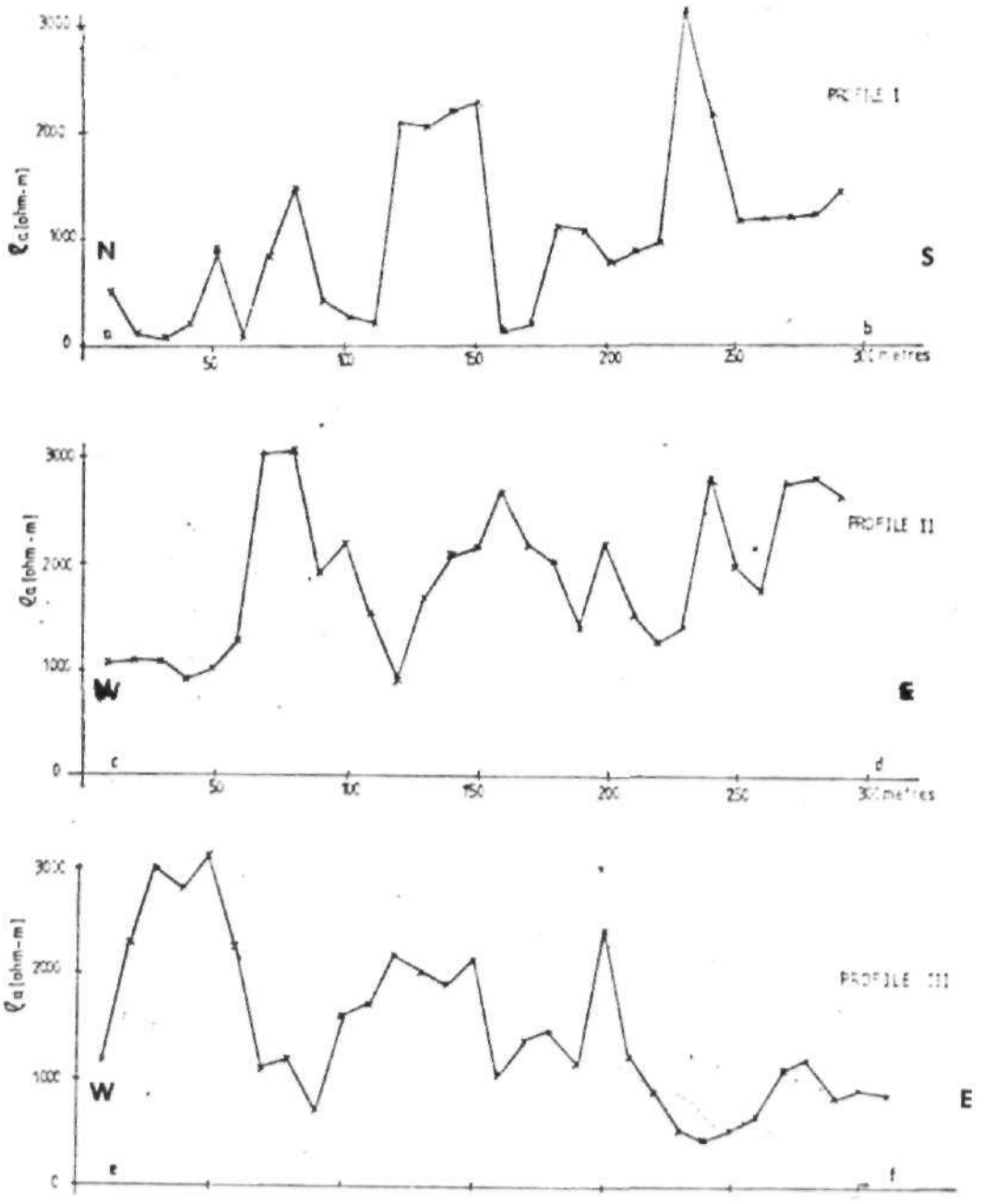
The apparent resistivity values calculated using the expression

$$\rho_a = 2\pi aR$$

is plotted at the geometric centre of the electrode array. The apparent resistivity is plotted on the ordinate and the electrode spacing on the abscissa of a normal graph paper.

The graphs of the apparent resistivity as a function of electrode spacing of the four profiles undertaken in this investigation are shown in fig 13. Profiles I and IV run from the northern portion to the southern portion of the study area, with a break of 600 m between them (fig.2).

On profile I, the low apparent resistivity values


PROFILE I
N
S
a
b
PROFILE II
W
E
c
d
PROFILE III
W
E
e
f
50
100
150
200
250
metres

of less than 60 ohm-m dominate about 110 m along the traverse except for the high values at about 50 m and 80 m from the North end of the traverse. The remaining section of the profile has an apparent resistivity value of 1000 ohm-m and above except for the low value of less than 100 ohm-m at distance 160 m to the end of the traverse. Profile IV shows a consistently high apparent resistivity of 2000 ohm-m and above, except at two stations where the apparent resistivity value falls to 1800 ohm-m.

Generally, Profiles I & IV show very low apparent resistivity values from the north in the alluvium of River Niger, increasing steadily towrads the south. The increasing values of apparent resistivity are thought to reflect the increasing freshness of formation water in the saturated aquifer. It is interesting to note that the northern portion of profile I, with very low apparent resistivity values correspond to the chloride ion - rich zone of the study area.

Horizontal resistivity profiles II & III run from West to East in the mid-region of the study area, with a break of about 600 m between them (fig.2). The apparent resistivity values vary between 500 and 2500 ohm-m, and there is no significant anomaly on the traverses.

From the results of the four horizontal profiles one could conclude that there is fresh water in the aquifer from the middle to the southern sections of the study area.

5.4. Self-Potential Profiles:

Precise quantitative interpretation of SP surveys is often carried out using formular similar to those used for interpretation of anomalies from magnetic poles. However, SP anomalies are greatly affected by local geological and topographic conditions which have to be allowed for. For instance it is often found that high ground is more negative than low ground which seems to indicate that electric currents tend to flow uphill. Hence, quantitative interpretation has not been very successful but qualitative interpreation of SP anomalies is fairly straightforward.

On self-potential gradient curves, a high positive and a high negative flanking a zero gradient indicate an anomalous zone, whereas on total potential curves a negative value indicates anomaly (fig 7).

The SP profiles (fig 14) indicate a high conductivity of the subsurface material in the north which decreases rapidly to the southern end of the traverse. Correlation with hydrochemical data from nearby wells has shown that the high SP values of

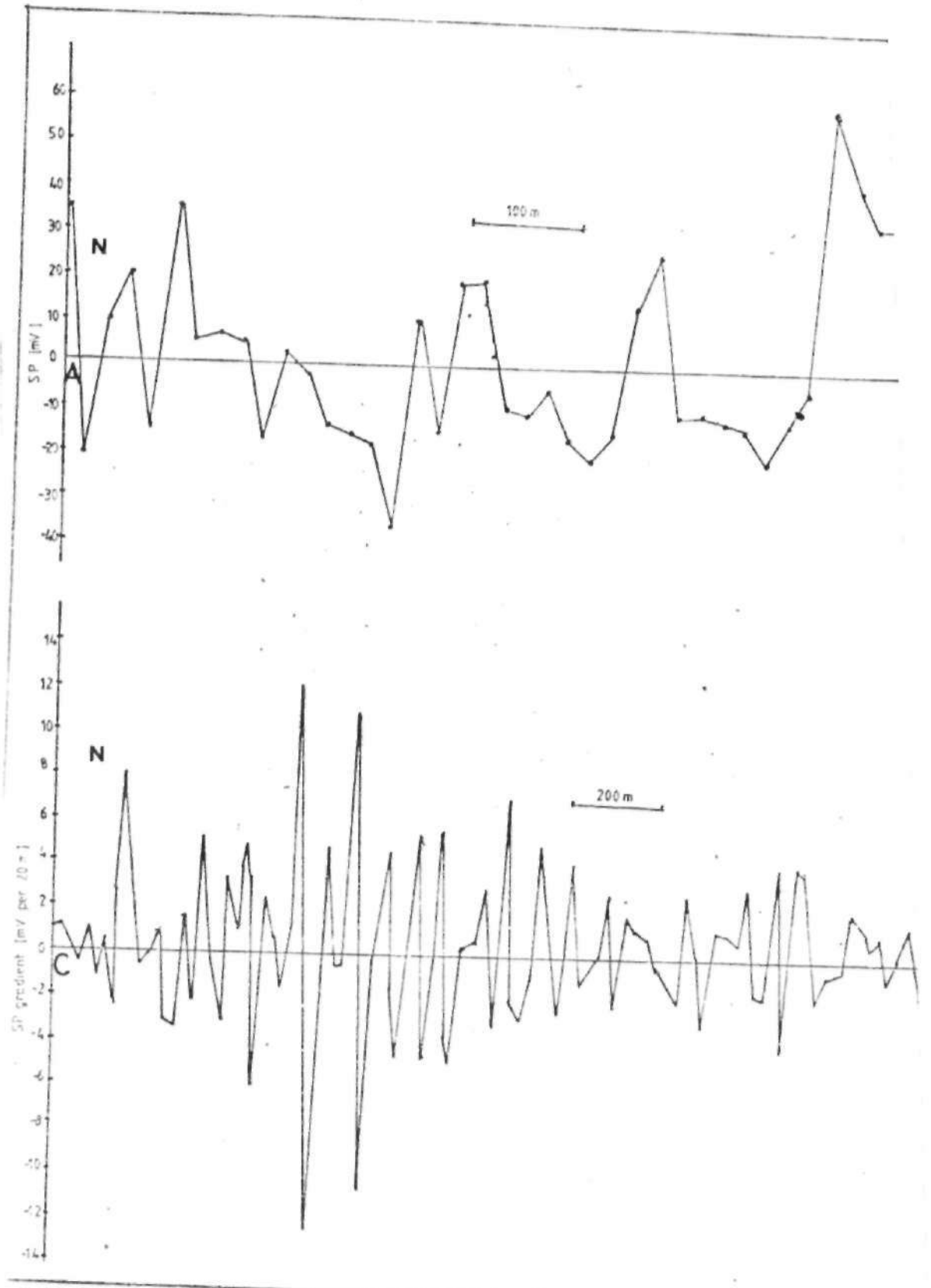


Fig 14: SELF-POTENTIAL PROFILES

± 14 m/V/20m, represent the water - bearing aquifer with high chloride content while the low values (± 2 mV per 20 m) represent the fresh water - bearing aquifers.

A thickening of the overburden towards the south may be responsible for the decreased self-potential, values observed from about the middle of Traverse II (TSPII, fig 14) to its end. However, the potential values of between ± 6.1 mVm^{-1} on this traverse may be due to a deeply buried conducting body.

5.5 Contour maps:

The map showing the resistivity of the "saturated" aquifer is shown in fig.15. It is observed that the 20 ohm-m contour line fringes the alluvial flood plain of the River Niger and the zone where the apparent resistivity is extremely low with values below 6.0 ohm-m. Except for the anomalous low of about 30.0 ohm-m to the East (which is thought to be due to clay intercaltion) a resistivity of 80 ohm-m and above is considered to indicate a fresh-water bearing aquifer, while lower values indicate chloride ion contaminated water bearing strata.

Fig. 16 shows a map of the depth to the lowest resistivity layer (aquifer). The top of this layer is deepest near the River Niger alluvial plain with an average value of 72 m and about 100 m above the Ordinance Datum in the extreme Northern end of the study area.

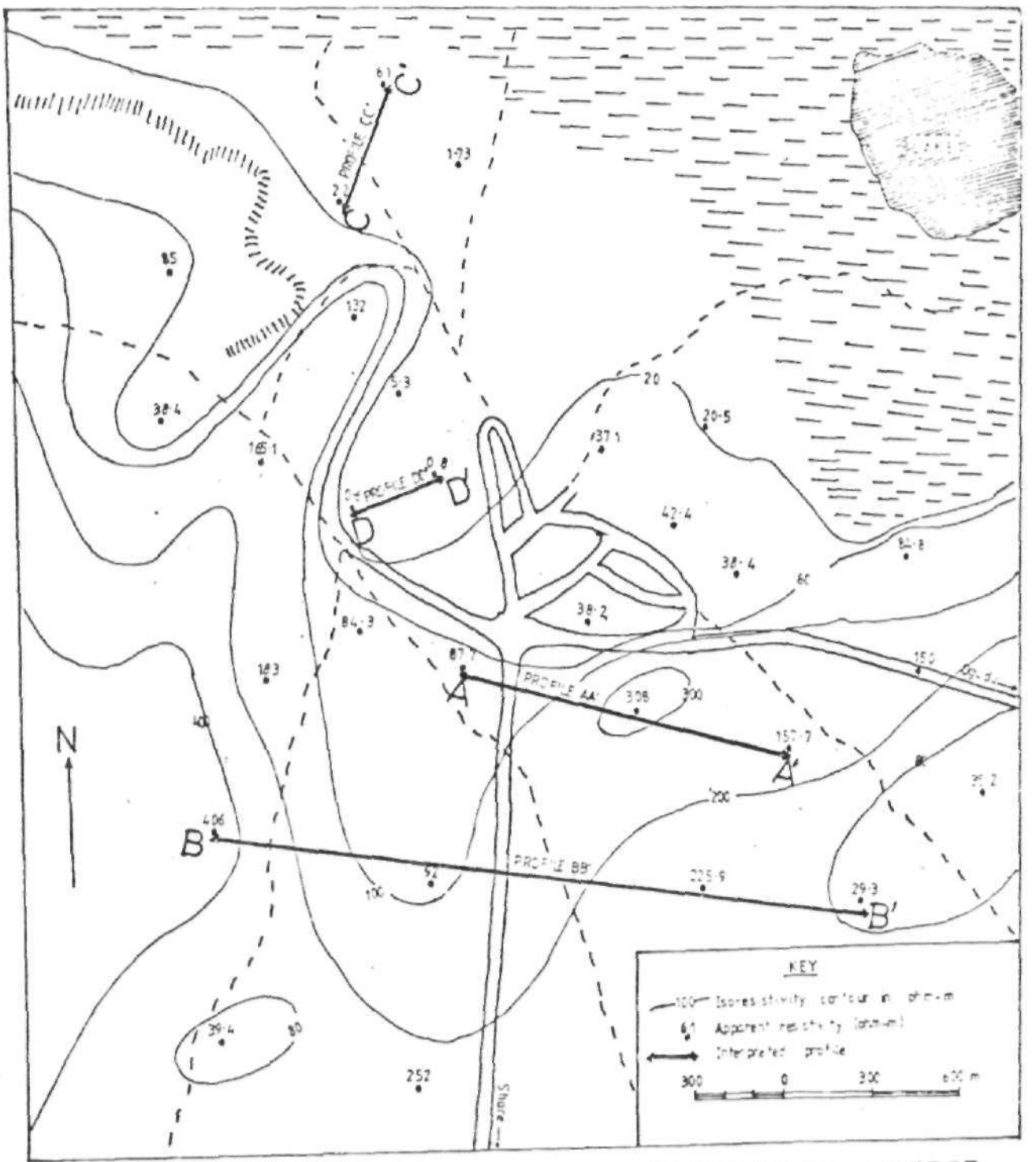


Fig 15: APPARENT RESISTIVITY MAP OF 'SATURATED' AQUIFER

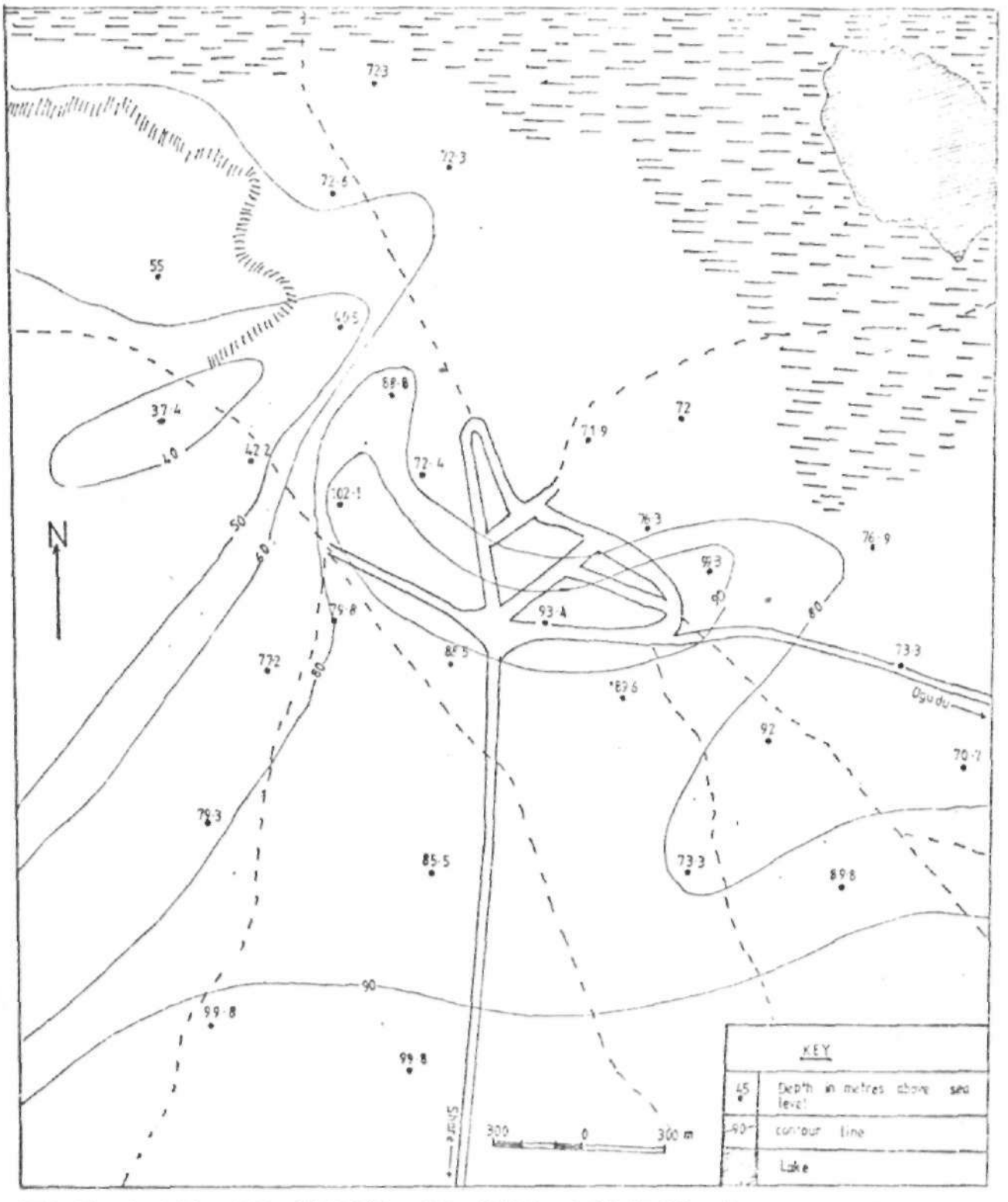


FIG 16: MAP OF DEPTH TO THE LOWEST RESISTIVITY LAYER

CHAPTER SIX

CONCLUSION

6.1 Summary of Results

From the results of the work described in this thesis and the results obtained from previous work in the entire Nupe Basin, it is obvious that valuable information pertaining to the presence of iron, the high chloride occurrence and the thickness of the aquifers at Shonga and environs has been obtained. The surface electrical resistivity method using direct current source has successfully mapped out the water bearing aquifers. The ER method indicates that 20 ohm-m contour line fringes the high conductive zone (fig.15) and that the sedimentary formations dip in the direction of the Niger system (fig.16).

The self-potential method, in particular has excellently delineated the high chloride ion aquifer at Shonga. The SP results indicate that the Northern half of the study area is anomalous, hence, confirming the hydrochemical data of the chloride ion contamination in the aquifers of this zone. The boundary between the contaminated and fresh water bearing aquifer is around VES station 10 in the East, through well no 4 and 13 in mid region of the study area (fig.2)

From the foregoing results and discussions it would appear that there is no geophysical evidence for delineating the iron contaminated zone in the sedimentary formations of the study area. The record of the borehole sunck by the Kwara Water Corporation indicate that the iron content in the borehole is as high as 19 ppm, and that this contamination was met at a depth of 38 metres, within the basal Nupe Sandstone; confirming the deposition of in situ ferruginous facies under oceanographic condition in the Nupe Basin (Adeleye, 1973).

6.2. Follow - up work:

A detailed seismic refraction investigation would be necessary inorder to have a better resolution of the depth of the aquifers in the study area. Also, a more detailed SP investigation would be necessary inorder to draw an SP anomaly map for the whole of the study area. It is envisaged that this would enable one to know the lateral extent of the chloride ion-rich aquifers of the study area.

In order to map the iron contaminated zones, it is suggested that a Geochemical survey be carried out in the study area. The geochemical survey should be a multimedia sampling programme including sampling of the stream sediments, soils and bedrocks. Special attention should be paid to ensure that only those streams whose

sources can be traced to specific geologic formation are sampled and that sampling is done at close intervals. It is hoped that this method would yield optimum results.

In addition, petrological analysis of the samples of the massive laterite and red purplish sandstone ridge near the borehole, may give a conclusive clue as to the cause and courses of the high iron content in the borehole.

6.3. Rcommendation:

On the basis of the available surface geophysical results and hydrochemical data, future hand-dug, large diameter wells are recommended to be sunk south of well No 14 and 13 especially around the Maternity & Dispensary centre (VES 6 & 15, fig.2) in the West through VES 7 to VES 10 (the Rest House, fig.2), in the East of the study area. Future borehole sites are strongly recommended to be located far away, at least 1.12 km South of the ridge at the NW of the study area and preferably South of the Shonga/Ogudu road, that is Southern half of the study area (fig.2). Further, the borehole should not be deeper than 60 m so as to avoid the basal ferruginised Nupe Sandstone of the study area. However, if a borehole is to be sunk North of this recommended zone, the borehole should not be deeper than 25 - 30 m.

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