# GEOELECTRIC INVESTIGATION FOR GROUNDWATER PROSPECTING IN KAZAURE LOCAL GOVERNMENT AREA OF JIGAWA STATE, NIGERIA.

A thesis submitted to the Postgraduate School, Ahmadu Bello University, in partial fulfillment of the requirements for the degree of Master of Science in Applied Geophysics.

BY

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February,1998.

# DECLARATION

This is to certify that:

(i) the work reported in this thesis was carried out by me, MOHAMMED SALEH, at the Geophysics section of the Department of Physics, Ahmadu Bello University, Zaria, Nigeria.

(ii) this thesis has not been submitted in any form to any institution, body, establishment or organization other than Ahmadu Bello University, Zaria, Nigeria, for the award of the degree of Master of Science.

(iii) all authors whose works are cited and referenced in this project report are duly acknowledged.



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# CERTIFICATION

The project thesis entitled GEOELECTRIC INVESTIGATION FOR GROUNDWATER PROSPECTING IN KAZAURE LOCAL GOVERNMENT AREA OF JIGAWA STATE , NIGERIA by MOHAMMED SALEH meets the regulations governing the award of the degree of Master of Science of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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# DEDICATION

This work is dedicated to my mother, Khadizah Saleh, who had been sparing her last kobo for the young yet to be author of the present work.

## ACKNOWLEDGEMENTS

I wish to express profound gratitude to my major Supervisor, Dr.P. O. Sule for his outstanding contributions to the successful conduct and completion of this study. Acknowledgement is gratefully extended to Prof. I. B. Osazuwa, the Co-supervisor for his keen interest, invaluable help and guidance.

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cannot be described by words. Bayero University provided the necessary financial assistance and formed part of the mostly acknowledged contributions.

# ABSTRACT

The present study deals with the geophysical part of a comprehensive groundwater exploration project being executed in Bodeyel, Karaftayi and Kazaure town by Water Resources and Engineering Construction Agency.

Eleven vertical geoelectric Schlumberger drillings (soundings) were conducted along the chosen profile of each area in order to study the layer parameters governing groundwater occurrences in the subsurface strata. The collected data have been reduced and analyzed automatically using an appropriate advanced computer software. In this respect, the geoelectric drilling data were subjected to inversion program of an n-layered model analysis. The results of the analysis are presented as subsurface layering and subsurface resistivity contour our sections

The geologic interpretation of the automatically interpreted data result was used in the construction of the subsurface equivalent geologic section of each profile. The geologic sections have revealed that the top and bottom layer have high resistivity values (1,000 to 7,000 *Qm)* while the middle layers have intermediate resistivity of less than 1,000 *Qm.* In addition, a close examination of the equivalent geologic sections indicates that there exists points

with complementary combination of layer parameters that favour highest Groundwater accumulation and storage. Such points have been selected and recommended as the best location of boreholes. These are BD06 (Bodeyel) , KT07 (Karaftayi) and KZ03 (Kazaure town).

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# CHAPTER ONE

## 1.1 INTRODUCTION

This work forms the geophysical part of the groundwater prospecting effort being carried out by Water Resources and Engineering Construction Agency in Kazaure Local Government Area of Jigawa State in order to alleviate the hardship being faced by the various communities in the area. The areas affected by the present development project are Bodeyel, Karaftayi and Kazaure town (Fig. 1.1).

Even though there were other methods that can equally or perhaps that could provide better results, some compelling reasons necessitated the use of direct current electrical method using Schlumberger configuration. Thirty three drillings (soundings) were made in all; eleven in each area.

The data collected was first reduced to apparent resistivity-electrode spacing and subsequently interpreted automatically using a basic computer program. The result obtained was re-interpreted by taking into consideration the geology of the areas and other related information like well-logs of nearby wells and past geophysical activities. The outcome of the latter interpretation gave the equivalent geologic maps of the study areas. One point on each of the maps was recommended for the sinking of a borehole.

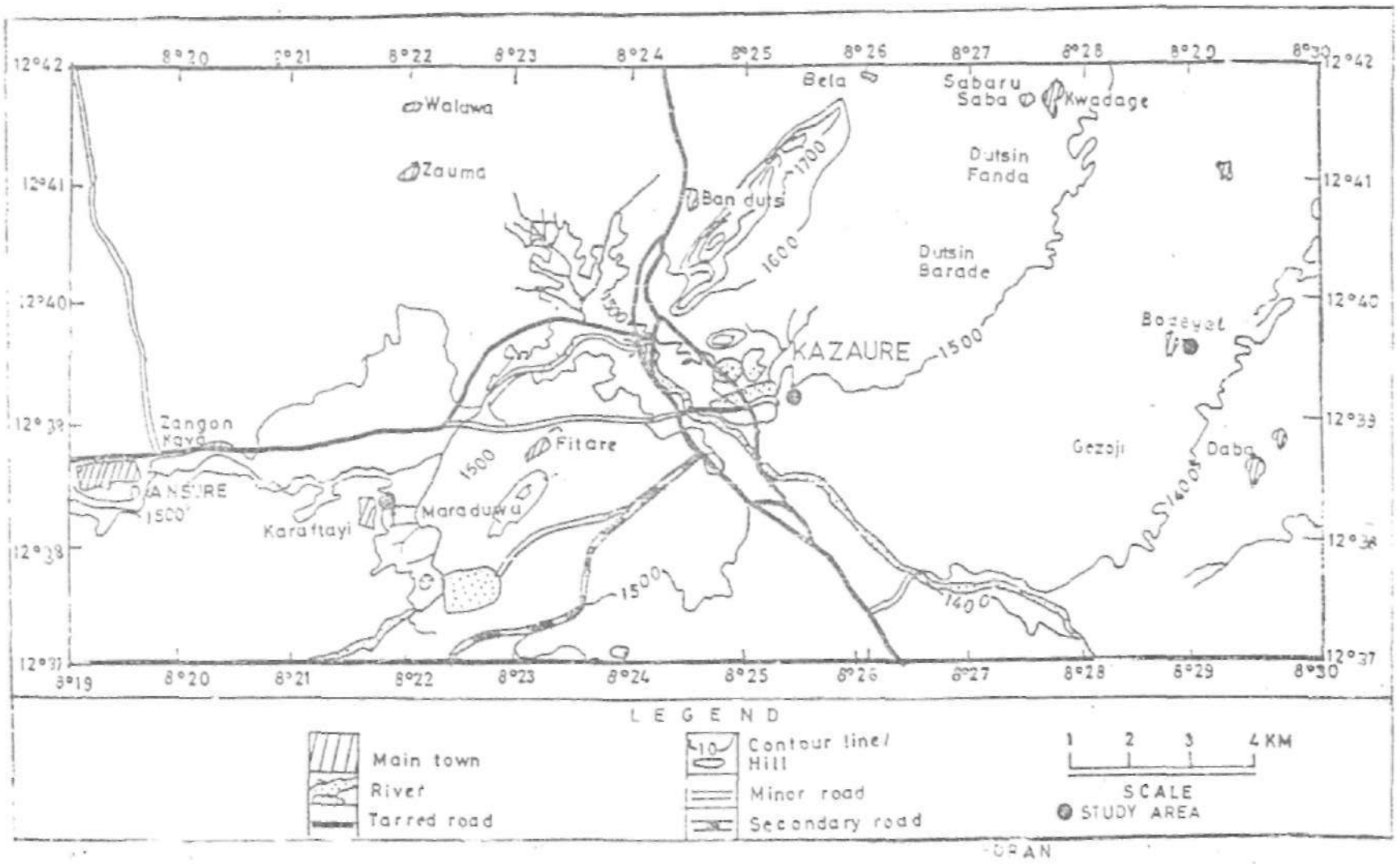



FIG.1.LOCATION AND TOPOGRAPHY OF THE STUDY AREAS.

## 1.2 Location of the Study Areas

The investigation areas, Bodeyel, Karaftayi and Kazaure town are in Kazaure local government area of Jigawa State. They are located in the South-east quadrant of the 1:50,000 Kazaure sheet number 35. Their respective approximate locations are as shown in Table 1.2. Kazaure local government area lies in the north-western end of Jigawa State and has only one main access road which is from Kano. The road proceeds through Danbatta and diverges at Kazaure. One end leads to Niger Republic while the other links up with Roni after passing through Dansure. Bodeyel and Karaftayi are positioned North-east and South-west of Kazaure town respectively (Fig. 1.1).

**Table.1.2:Location of the Study Areas**

| NAME | NORTH LATITUDE | EAST LONGITUDE |
|---|---|---|
| Bodeyel | $12^{O}$ 39' 50" | $8^{O}$ 29' 00" |
| Karaftayi | $12^{O}$ 38' 30" | $8^{O}$ 22' 00" |
| Kazaure town | $12^{O}$ 39' 00" | $8^{O}$ 25' 30" |

### 1.2.1 Distribution of the Geoelectric Drilling Points in Study Areas

The distribution of the drilling points in Bodeyel was as follows; BD01 was 423.0*m* from baobab tree and about 230.5*m* from gawo tree. A neem tree was directly south of BD05 and 46.5m away. The whole profile was about 0.5*m* from Bodeyel village with BD06 directly north of Malam Abdullahi's house which was the nearest house to the profile. A minor path leading

to Sabaru passed between BD07 and BD08 while BD09 and BD10 were 11.0*m* and 12.9*m* respectively south of a tamarind tree. The distribution of the various geoelectric drilling points in each of the study areas is given in figure 1.2.1(a-c).

In Karaftayi site, the profile was northeast of the village about 80.0m away. KT01 and KT02 were 112.0*m* and 120.4*m* respectively from a tamarind tree and KT07 was directly north of and 130.0*m* to a gawo tree, while KT09 was south of another gawo tree and 103.0*m* away. A cattle track passed in-between KT01 and KT06 while a path from Mara-dawa which is roughly 0.4*km* from KT11 passed through it.

For Kazaure site, the profile was on the southeastern side of the town and was about 300.0*m* away from the dispensary. KZ01 was 51.1*m*, 63.0*m*, and 240.0*m* from neem, baobab and dorawa trees respectively. KZ02 and KZ03, the closest geoelectric drilling points to the dispensary were 300.2*m* south of it. KZ05 was 120.0*m* from a neem tree, while KZ06 passed between a neem and tamarind tree and was 106.0*m* and 148.0*m* from them respectively. KZ07 was 160.4*m* away from a tamarind tree, while KZ08 and KZ09 were respectively 137.2*m* and 128.0*m* south of a neem tree. KZ10 was at the centre of a minor path coming from the main path to Bodeyel and lastly a gawo tree was 142.1*m* directly east of KZ11.

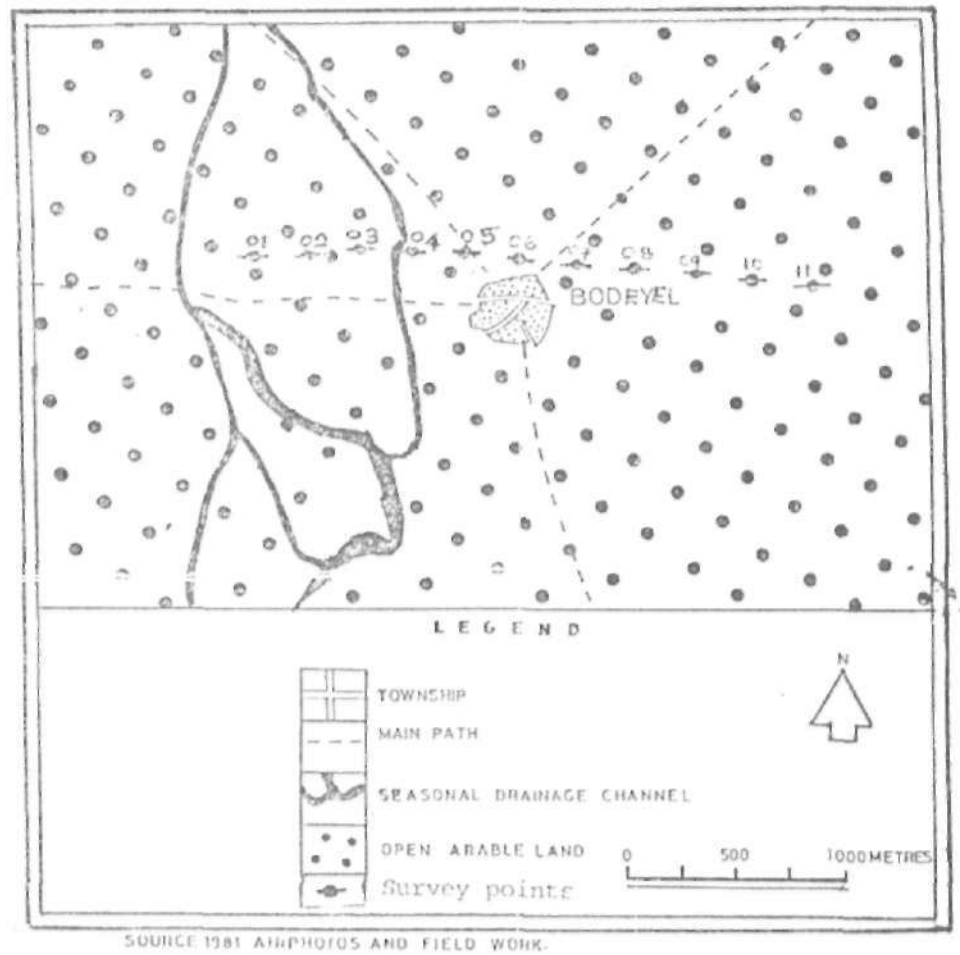



Fig. 1.2.1 (a) Distribution of the Geoelectric points in Bodeyel village.

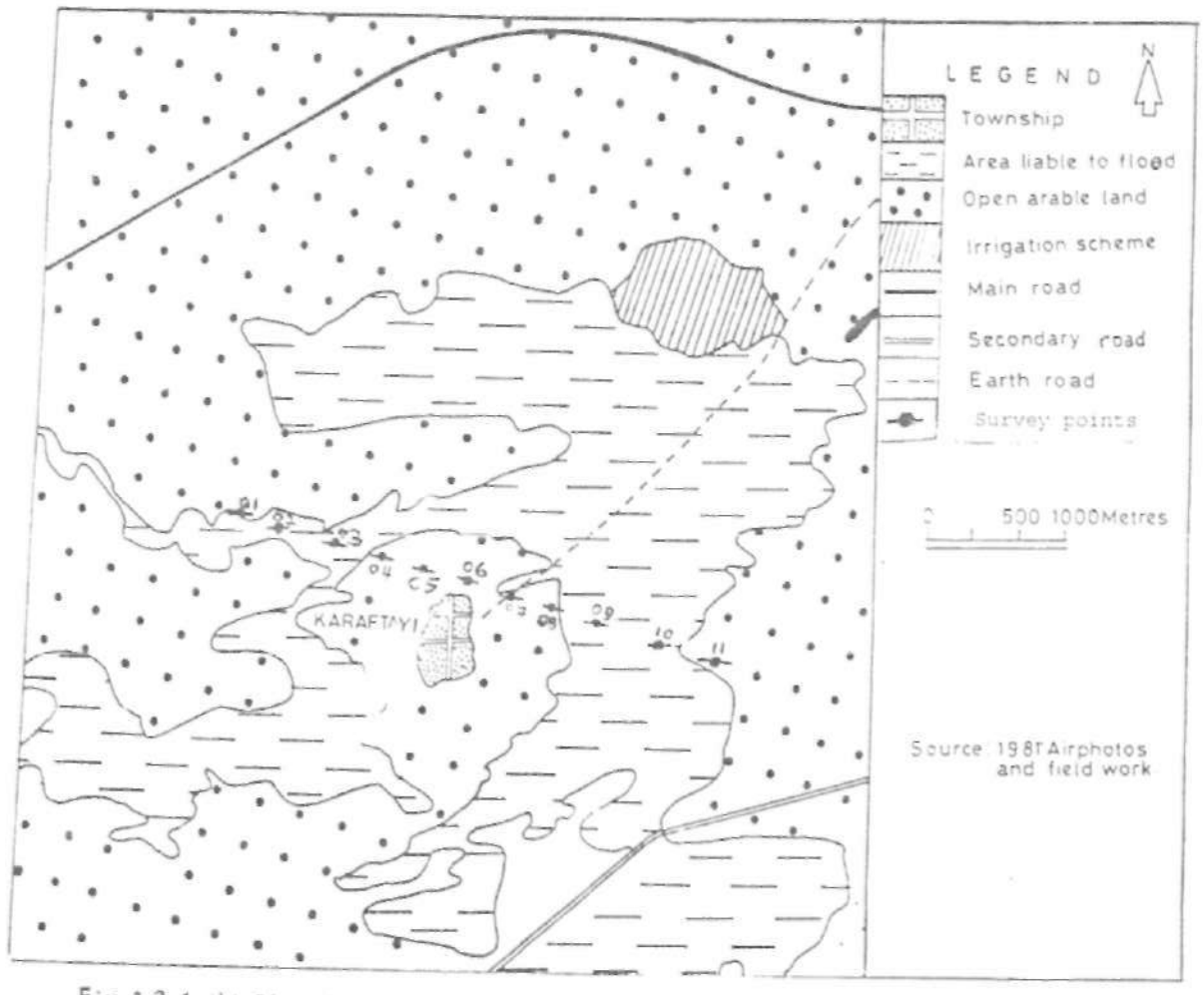



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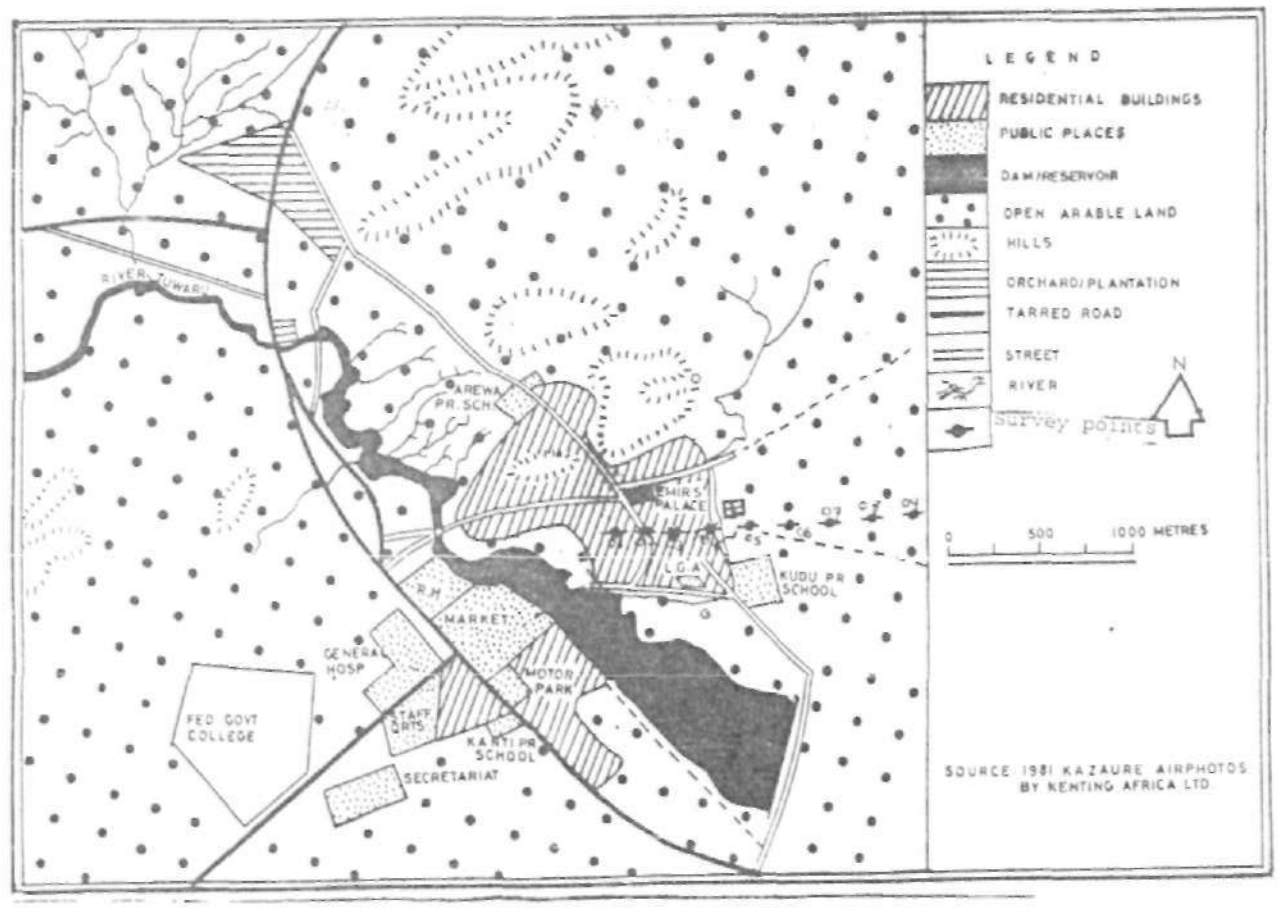



Fig. 1.2.1 (c) Distribution of the Geoelectric points in Kazaure town.

### 1.2.2 Climate, Vegetation and Land Use

The survey areas lie within the tropical Savannah zone of Nigeria. "The maximum monthly mean temperature in the areas occurs during the period March to May and it ranges from 31.11$^{O}$C to 35.00oC while the minimum monthly mean temperature is observed during the period December to January and ranges from 14.00$^{O}$C to 22.00$^{O}$C" (Iloeje, 1978). The mean annual rainfall is between 635*mm* and 762*mm* with a mean annual number of rainy days of approximately 40. Dry season begins in October and ends in June. The rainfall is not a reliable water source for domestic and industrial needs. The same applies to surface water which is localized to certain areas, many of them dry up during the dry season. Therefore, groundwater could be a viable alternative source of water supply in the areas. Its exploitation will complement both the surface water and rain water. The major surface water comes from Kazaure Dam and the Water treatment at Jakarande. Humidity is low from December to February and the weather is cool, dry and dusty whereas humidity is high during the rainy season.

The vegetation type found in these areas is Sudan Savannah and is made up of trees, shrubs and short grasses. The vegetation has been greatly obstructed by human activities. Such as expansion of settlements,

creation of forest reserves to check desert encroachment and construction of Dam.

Although crop cultivation is mostly done in the rainy season however, irrigation farming is carried out along some river banks during the dry season. The inhabitants of these areas are mostly subsistent farmers, producing crops like beans, guinea corn and millet.

### 1.2.3 Previous Studies in the Study Areas

There may have been many works in the study areas and nearby areas, but those that are available to the knowledge of the author are firstly, the E.M. resistivity survey by Hawker Sidney Water Engineering Limited (1986). In that work, the investigation points were randomly distributed and widely spaced. The range in spacing was not less than 1km in order to ensure total coverage of Kazaure local government area. Even though the survey lacked the necessary details, it had identified many areas of possible groundwater potentials. These among others are Bodeyel, Karaftayi and Kazaure town. The procedure relied on the conductivity values of an area for consideration as an anomalous (groundwater potential) zone. "For Karaftayi, the conductivity values were higher towards Mara-Dawa, about 50 milli-mhos per metre and decreasing towards the south, 6 to 8 milli-mhos per metre;therefore the site was the recommended anomaly

for future detail follow-up" (Randall, 1986). The same method was employed to identify the remaining areas.

The second work was compiled by Isa Mohammed in which hydraulic properties (characteristics) of the Basement Complex and the Chad Formation Aquifers obtained from borehole test pumping data were studied. These properties included aquifer transmissivity, coefficient of permeability and storativity. As explained in the work, boreholes in the Chad Formation had better water yielding ability due to higher transmissivity and coefficient of permeability. The author also recommend groundwater of Kazaure local government for most purposes. "The groundwater from hand-dug wells and boreholes is suitable for consumption, all agricultural purposes and some industrial purposes" (Mohammed, 1984).

Thirdly was a project for groundwater prospecting done by Nura Yusuf at Ajumawa village in Danbatta local government area, in which two methods of data acquisition were used namely, Electrical Resistivity and Seismic. Yusuf (1986) made use of an approximate method (curve matching technique) for interpreting the resistivity data. This method requires the use of a set of standard curves compiled by Compagnie Generale De Geophysique to obtain electrical parameters of each stratum of a geological strata. But many different

curves may agree to a particular matching (trial). This poses a great setback to the work.

And lastly is the resistivity investigation for groundwater in four villages in Roni local government area done by Ibrahim (1990) in which resistivity method was used during data collection. The method used in data interpretation was similar but more refined than that used by Yusuf (1986). In this case, the researcher initially made use of an approximation method to interprete the field data and obtained a layered model. The layer electrical parameters obtained from the model and the field data were fed into a computer for automatic interpretation. Hence this interpretation suffered the same handicap as the former. This problem was tackled in the present work, where the interpretation was effected in such a way that the transform (standard) curves were derived from the field data. Danbatta and Roni local government share common boundary and certain geological features with Kazaure local government area, where the present study areas are located (Fig. 1.2.3)

## 1.3 Aims and Objectives of the Present Work

This project deals with the geophysical part of a comprehensive groundwater exploration project being executed in Kazaure local government area. It serves as a detailed Survey done at the anomalous zones identified

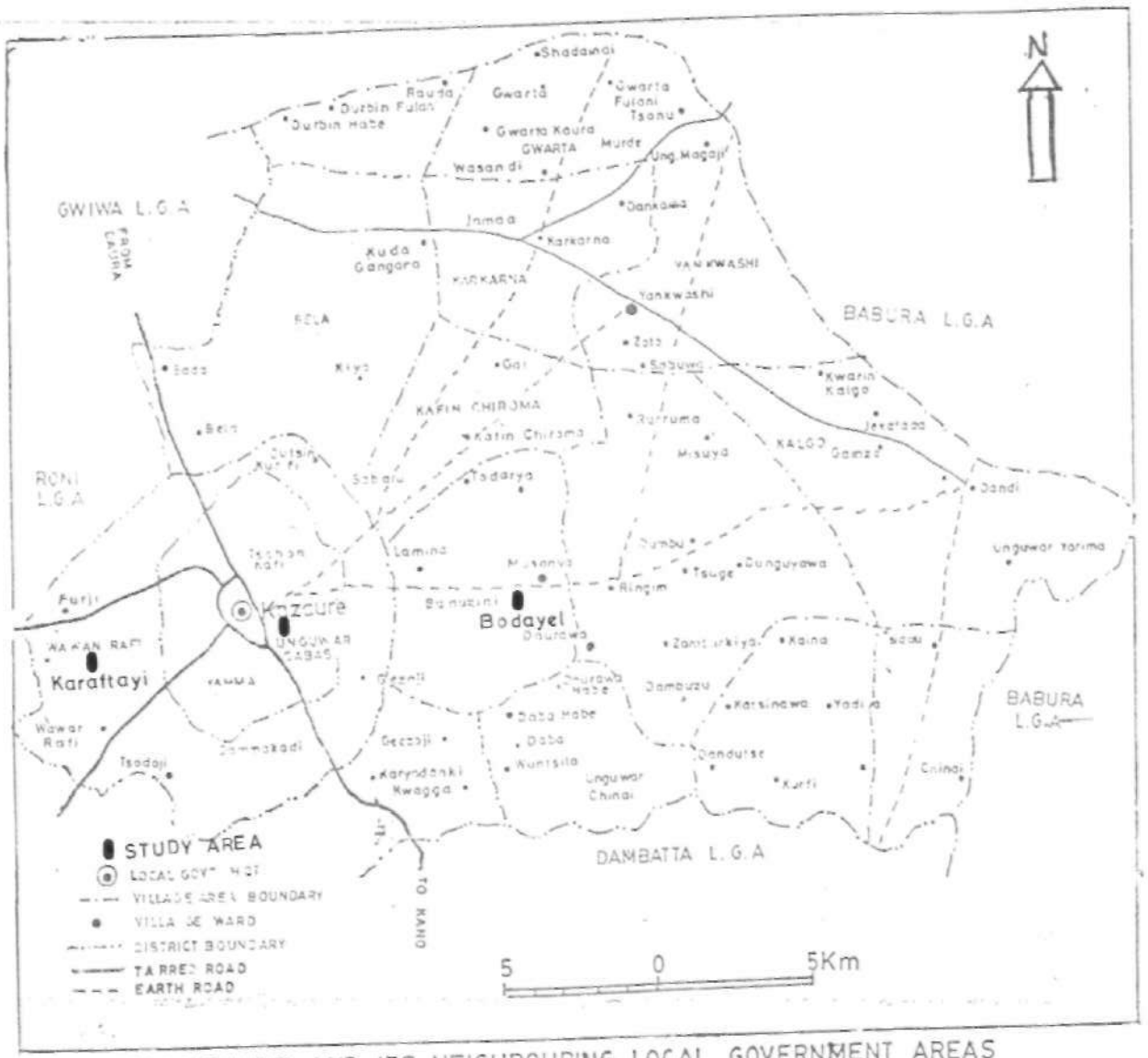



FIG. 1.2 KAZAURE AND ITS NEIGHBOURING LOCAL GOVERNMENT AREAS

during the Electromagnetic (EM) resistivity survey of Hawker Sidney water Engineering Limited(1986) with EM-31 and EM-34.

Hence the ultimate aim of this work is to locate points which will most likely provide sufficient and continuous supply of groundwater.This was achieved through careful and systematic analysis of the various electrical properties formations under the study areas so as to reduce the risk associated with wildcat method of borehole drilling and also to complement the other available water sources in the study areas.

## 1.4 Limitations of the Work

The study areas are in the semi-arid region, hence high resistive dry top layer has greatly limited the depth of penetration of the injected current, thereby reducing the depth of investigation.

Also non-availability of either seismic or E.M. equipment limited the scope of this work.

In addition, high cost of materials coupled with fuel scarcity brought a great setback to this project.

## 1.5 Nigerian Regional Geology and Rock Distribution

Nigeria is underlain by two major subdivisions of rocks namely, Basement Complex and Sedimentary Rocks, each occupying nearly equal area of the country. The Basement Complex Rocks are found in Western, Northern

and some part of eastern Nigeria, while the Sedimentary Rocks are found in the Coastal areas of eastern and western Nigeria, the Niger and Benue valleys and the Sokoto, Gongola and Chad Basins (Fig. 1.5(a)). The Basement Complex Rocks are mainly precambrian, whereas the Sedimentary Rocks date from Albian to Recent. The Nigerian Stratigraphic Succession of the Basement Complex is given in Table 1.5, while the stratigraphic succession of the Sedimentary Rocks consists of firstly arkosic grits and Conglomerate often forming the lower members of the oldest rocks, resting unconformably on the Basement complex; the poorly consolidated Sandstones resting above the more consolidated Sedimentary rocks.

The Basement Complex is composed of igneous and metamorphic crystalline rocks which store water only when weathered and/or fractured. The same applies to Sedimentary rocks which also can hold minute quantity of water though its storage capacity is as well greatly enhanced by weathering. The depth of weathering seems to relate to the nature of the rocks. Sedimentary rocks exhibit the deepest while Basement Complex rocks exhibit the thinnest weathering. "Mean depth of weathering all over the country is estimated at 80.2 metres. The average in the Basement Complex is 15.3 metres" (Oguntoyimbo et

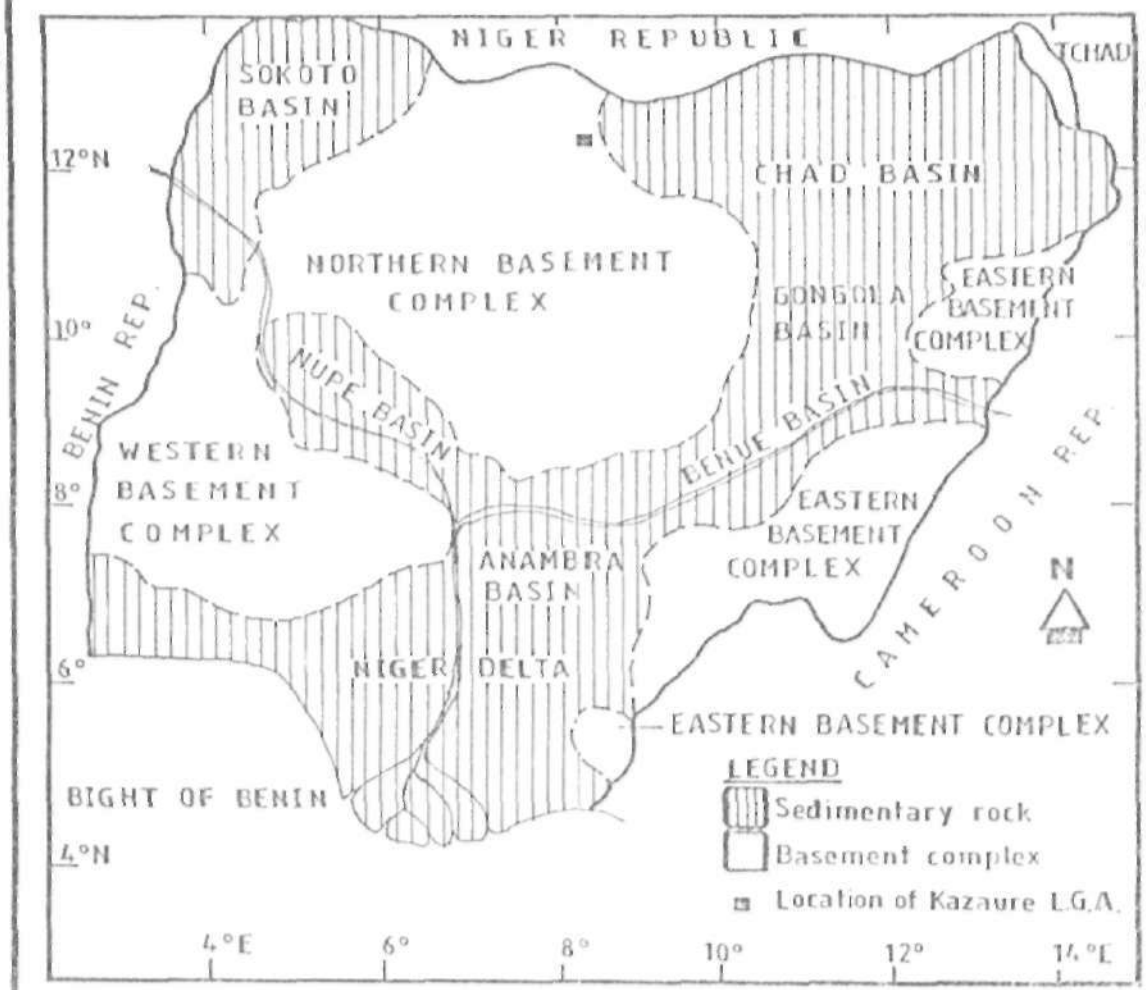



Fig. 1.5(a): Generalised geological map of Nigeria
(courtesy of G.S.N.)

al., 1983). Factors enhencing deep chemical weathering in Nigeria and elsewhere in the humid tropics include the following:

(i) availability of weatherable rocks;

(ii) climate, especially temperature and precipitation;

(iii) Vegetation;

(iv) low relief surfaces to minimize superficial erosion;

(v) crustal stability; and

(vi) availability of well drained sites.

**Table. 1.5: Stratigraphic Succession of the Nigerian Basement Complex (after McCurry, 1972)**

| PERIOD | LAYERING | COMPOSITION |
|---|---|---|
| Recent to tertiary | Superficial | Laterite, alluvial sand, silt and clay. |
| Cambrian to upper precambrian | Metasediment | Phyllite, semi-peltic schist, quartzite, hornfelsed schist, amphibolite. |
| Precambrian | Crystalline rock | Migmatite, complex feldspalthic quartzite, gneiss, migmatite, calcareous schist. |

The transition regions of Northern Nigeria provide favorable sites for deep chemical weathering, though studies on deep weathering in Nigeria have not been systematically carried out as data on this phenomenon have been obtained mainly from the following sources:

(i) geotechnical investigations at dam and other construction sites;

(ii) boreholes to supply water locally;

(iii) hand-dug wells;

(iv) boreholes related to mining;

(v) road cutting;

(vi) soil pits and auger holes and

(vii) geological and geophysical investigations. Therefore the result of present investigation provides an additional insight to the extent of deep weathering in these areas.

### 1.5.1 Geology of the Study Areas

The geology of the areas is that of a transition region i.e. a region separating the Basement Complex and Chad formation. This region trends NW-SE and is located towards the north-western end of Jigawa State (Fig. 1.5(b)).

The Basement Complex is part of the crystalline metamorphic rocks of the Nigerian Basement Complex. "Metamorphic rocks of the Nigerian Basement Complex are end-products of at least two major orogenic cycles" (Oyawoye, 1964). "The last of these two possibly extended from the late precambrian to lower paleozoic and was initiated by deposition of thick sands, meals and igneous materials on an eroded metamorphic Basement formed during the preceding cycle" (Mortimore, 1970). "Folding and low to medium-grade metamorphism of these accumulations also involve extensive remetamorphism and partial mobilization of the underlying basement, with the development of high grade gneiss, migmatites and older granites during the

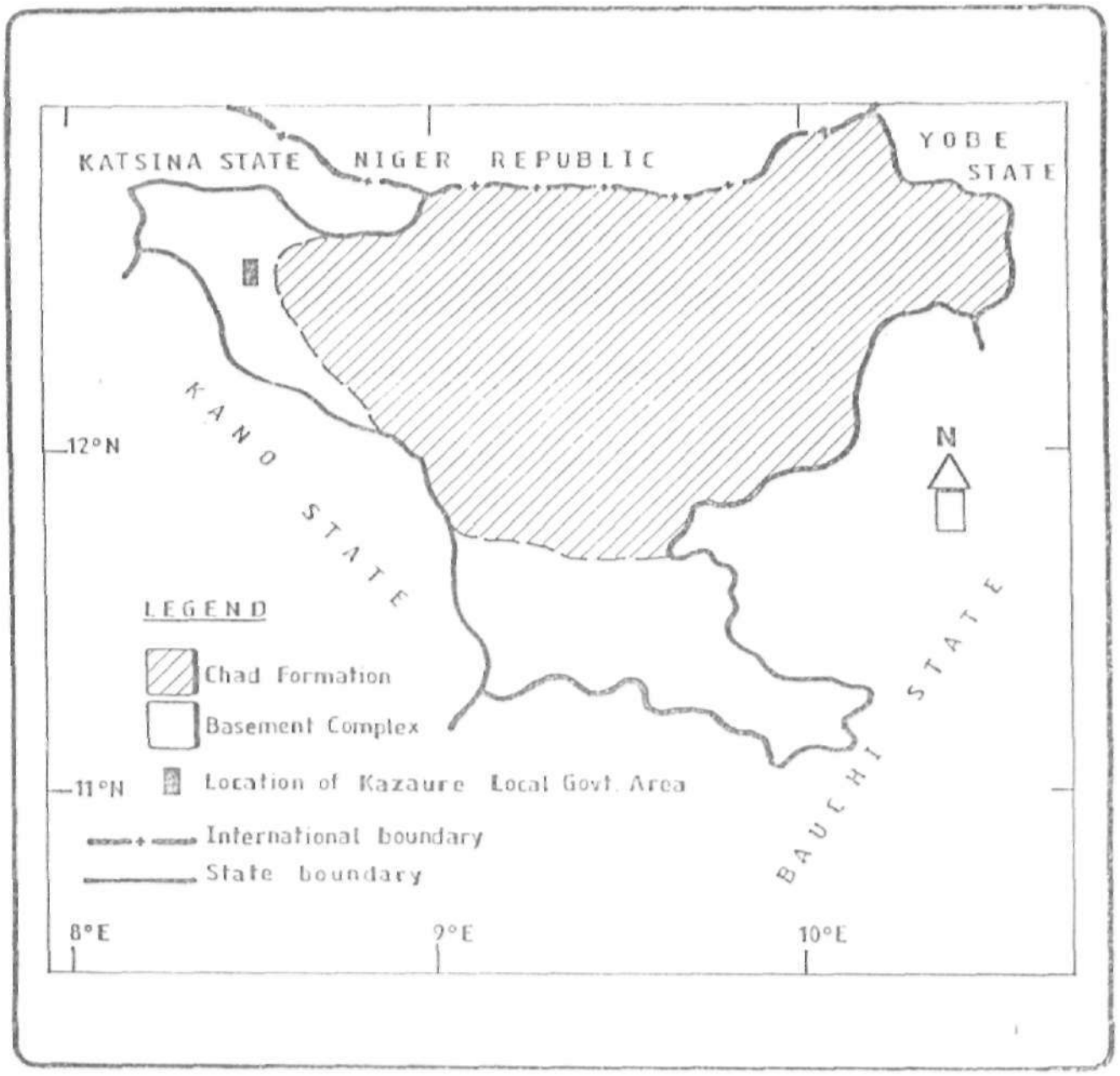



Fig. 1.5(b) Geological map of Jigawa state.
(Courtesy of GSN)

Pan-African orogenic cycle" (Garba, 1988). The Basement Complex occupies a small portion of the total area of Jigawa State.

The Chad formation is of lacustrine origin and was deposited by rivers flowing towards lake Chad on the Basement Complex during the Plio-Pleistocene. "The formation consists of clays, clayey sands, silts, sands and gravel which lie unconformably on the Basement Complex" (Mohammed, 1984). Small amount of Carbonaceous materials occur and the presence of diatomite has been reported. "The thickness of the Chad formation in Jigawa State does not exceed 152.4 metres" (Barber and Dupreez, 1955). The formation dips at a very low angle to the northeast, towards lake Chad. This formation lies Northeast of the Basement Complex and occupies a larger area of the State.

### 1.5.2 Hydrogeology of the Project Areas

Water is one of the basic needs of life. Because of high demand for water resulting from population explosion and other natural phenomena, there have been many groundwater development projects. Nearly everywhere in the world one can dig or drill a hole in the ground and at some depth encounter rock or soil that is saturated with water. This rock or soil saturated with water is known as an aquifer. The upper surface of this zone of saturation (aquifer) is known as groundwater table. "The surface topography is

reflected by the groundwater table, but with more gentle slopes and relief" (Riley, 1977), this is so for an unconfined aquifer. For a confined aquifer, the water is trapped between two impervious formations.

Since the areas are located in the transition zone from the Basement Complex to Chad formation their hydrogeology will reflect features of both regions.

"The Basement Complex consists of hard crystalline rocks which may be jointed, fractured and/or weathered, and are overlain by superficial deposits" (Mohammed,1984). Fresh crystalline rocks have low primary porosities and permeabilities. Higher values are obtained from jointed, fractured and/or weathered crystalline rocks, therefore it will be serving as an aquifer zone for the Basement Complex. The superficial deposits (like sand,gravel and loose sands) have high porosities and permeabilities but can only store significant volume of water when they are very thick.

The Chad formation is made up of Sedimentary rocks which are generally loose sediments. The formation constituents are clay,sands and gravel together with their mixed varieties. Clays generally have high porosities and permeabilities and are therefore the most significant aquifers. Generally, the Basement Complex is a poorer aquifer than the Chad Formation. The aquifer is unconfined or semi-confined

within the Basement Complex but it is confined in the Chad formation. When an aquifer is buried between two impervious formations or allcwed to interact with atmospheric pressure directly, it is said to be confined or unconfined aquifer respectively.

The drainage pattern of the areas is dandritic running towards Lake-Chad and shows two predominant flat relief namely 1500" and 1400" trending NW-SE direction.

# CHAPTER TWO

## THEORY AND INSTRUMENTATION

### 2.1 Introduction

This method probes the subsurface strata in order to determine their electrical resistivity as current propagates through them. In resistivity surveys, a well defined electrical signal current is injected into the ground through two current electrodes. "The resulting voltage change is measured between two potential electrodes generally placed between the current electrodes. The product of the geometrical factor and the ratio of potential difference and current gives apparent resistivity, $\rho_a$" (Miller, 1980).

"Apparent resistivity can be defined as the combination of potential difference, current and electrode geometrical factors which would equal true earth resistivity if the earth were uniform" (Mooney, 1980). Thus any observed variations from resistivity measurements must be interpretable as deviations from a uniform earth. Such deviations represent the geological target of resistivity exploration. These variations arise due to differences in conductivity which in turn alter the pattern of electric current flow in the ground and change the distribution of electrical potential. "The electrical conductivity of

any geological strata depends on the conductivity of the rock formation (and clay content, etc.), porosity, the water contained in the pore spaces, the salinity of the water, etc." (Grant and West, 1965).Thus determination of the electrical properties of the subsurface might reveal not only the geologic structure but also water bearing layers. Hence the suitability of the method in groundwater prospecting.

## 2.2 Theoretical Background of the Direct Current Resistivity Method

Consider a continuous current (direct current or low frequency a.c. source) flowing in an isotropic homogeneous medium. From Ohm's law

$$J = \sigma E \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$E = -\nabla U \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

From the principle of conservation of charge and Gauss' theorem,

$$\nabla J = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

leading to $\nabla^2 U = 0$ $\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$

Where J = current density

$\sigma$ = electrical conductivity

E = electrical potential gradient, and

U = scalar potential.

Equation (4) is Laplace's equation which in spherical coordinates $(r,\theta,\Phi)$, it is expanded as

$$\nabla^2 U = (1/r^2)\,\delta(r^2[\delta U/\delta r])/\delta r + [1/r^2\sin^2\theta](\delta^2 U/\delta\theta^2)$$

$$+ [1/r^2\sin\theta](\delta[\sin\theta(\delta U/\delta\theta)]/\delta\theta) = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

The solution of equation (5) depends on two boundary conditions. "Firstly, the potential is continuous across the boundary; secondly the normal component of current density must also be continuous" (Telford et al., 1976).

From symmetry of the system, the potential will be a function of r only, where r is the distance between the current and potential electrode. Under these conditions, equation (5) simplifies to:

$$\nabla^2 U = (1/r^2)(\, d[r^2 dU/dr]/dr) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

On integrating, equation (6) becomes

$$dU/dr = A/r^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

On integrating again and since potential tends to zero as r tends to infinity, equation (7) has solution as

$$U = -A/r \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

For a single current electrode at the surface of the ground, all the current flows through a hemispherical surface in the lower medium (the ground), thus the total current (I) crossing the surface is

$$I = 2\pi r^2 J = 2\pi r^2 \sigma E \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

But potential(U) is dependent only on r, then

$$E = -\nabla U = -dU/dr \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

From equation (7), (10) and (9),

$$A = -I\rho/2\pi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

Where $\rho = 1/\sigma$ =electrical resistivity of the medium (ground).

For current source i, equation (8) becomes

$$U_i = I_i\rho/2\pi r_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

For n current sources

$$U = \sum_{i=1}^{n} U_i = (\rho/2\pi)\sum_{i=1}^{n} (I_i/r_i) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (13)$$

Thus on rearranging the terms equation (13) becomes

$$\rho = (U/I)(2\pi r) = (U/I)K \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (14)$$

Where the parameter, K is known as configuration geometric factor and it has to do with electrode geometry. By measuring U and I and knowing the electrode configuration, resistivity ($\rho$) is obtained. Over homogeneous isotropic ground this resistivity will be constant for any current and electrode arrangement.

If the ground is inhomogeneous, however, and the spacing is varied, then resistivity will change. This will give different value for each measurement. The magnitude of $\rho$ is intimately involved with the arrangement of electrodes. The estimated quantity in this case is known as the apparent resistivity, $\rho_a$

Therefore equation (14) now becomes

$$\rho_a = (U/I)K \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (15)$$

A typical Schlumberger configuration is given in Fig.2.1.

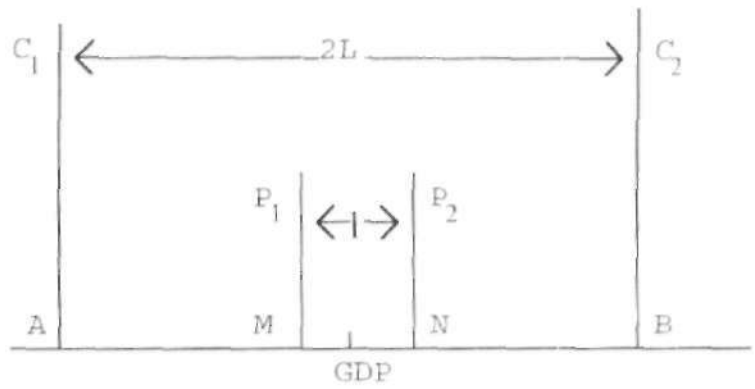



Fig.2.1: Schlumberger Configuration

Where $C_1$ and $C_2$ = Current electrodes;

$P_1$ and $P_2$ = Potential electrodes;

A and B = Current electrode positions;

M and N = Potential electrode positions;

L = half-current electrode spacing = AB/2

For Schlumberger array,

$$K = (\pi l)[(L/l)^2 - (1/4)] \quad \ldots\ldots\ldots\ldots\ldots\ldots (16)$$

Where $l$ = Potential electrode Spacing = MN

In geoelectric drilling technique using Schlumberger array, the potential electrodes remain fixed while the current electrodes are expanded symmetrically about the centre of the array "For larger values of current electrode spacing (2L) it may be necessary to increase the potential electrode spacing ($l$) in order to maintain measurable potential" (Telford et al., 1976). "A common guideline is that $l$ should be less than or equal to 2L/5" (Mooney, 1980).

## 2.3 Instrumentation

The instrument used in the data collection is ABEM Terrameter SAS 300. It is all-in-one portable instrument housed in a casing and has only five controls which are explained as follows;

(i) On/off switch which switches power pack current on/off.

(ii) 11-position transmitter current. This is used to select current from built-in transmitter (0.2*mA* to 20*mA* in 7 steps). Four extra high-power settings from 50*mA* to 500*mA* are available with optional booster transmitter control.

(iii) 9-position range selector switch. The resistivity ranges are 1$\Omega$, 100$\Omega$, 10k$\Omega$ and 1M$\Omega$, while the voltage ranges are 1v, 10v, 100v, 500v. The ninth range is a battery check which displays present actual battery voltage.

(iv) 4-position cycle switch. It selects single reading mode of 4, 16 or 64 averaged readings in automatic SAS mode, and

(v) measure (start) botton which initiates automatic check and select measurements (ATLAS Copco, 1980). All the controls and indicators (data display system) are grouped on the top panel of the system.

The power supply is a rechargeable pack of 10 Ni-Cd cells, normally 12.0v, contained in a clip-on battery tray. The current and potential electrode terminals are paired on either sides of the top panel of the

instrument. Terrameter generates the signal current (I), measures the resulting voltage (VU). When the measurement cycle is completed, it then displays the quotient (VU/I) digitally and a beeper signal would alert the operator.

In addition to the Terrameter, other accessories were used namely; (a) Metal electrodes, about 0.5m long which could be driven into the ground; (b) Light (and insulated) wires wound on portable reels; (c) connecting cables, measuring tape, pegs, buckets, hammer, crocodile clips and so on.

# CHAPTER THREE

## DATA ACQUISITION AND REDUCTION

### 3.1 Choice of Method And Electrode Spread

There are many geophysical methods, but those mostly employed for groundwater prospecting are namely seismic and electrical. Though seismic method provides greater resolution and more reliable result with less ambiguities but its operational cost and field requirements are enormous. Some factors made electrical method to be most frequently applied. These factors include:

1. Equipment is more readily available because it is less expensive;
2. Equipment is portable and thus easier to transport;
3. Equipment is easier to operate and
4. Field operation is comparably less expensive.

Electrical methods are classified into two according to the energy source as natural and artificial. The direct current resistvity method is an artificial energy source since the power is provided by an artificial source; Ni-Cd cells. Among all the electrical methods, this method has more advantages as follows:

(a) Flexibility - the field technique can be adjusted to suit either reconnaissance or detailed mapping and to provide depth discrimination.

(b) Relatively rapid though field time increases with target depth.

(c) Qualitative interpretation of data is straight forward.

(d) Equipment is light and portable.

(e) Controllable power Source.

Offsetting these are some limitations:

(1) Interpretations are ambiguous. Consequently, independent geophysical and geological controls are needed to discriminate between valid alternative interpretations of the resistivity data.

(2) Interpretation is limited to simple structural configurations. Any deviations from these simple situations may be impossible to interpret.

(3) Topography and the effect of near-surface resistivity variations can mask the effects of deeper variations.

(4) "The depth of penetration of the method is limited by the maximum electrical power that can be introduced into the ground and the practical difficulty of laying out long lengths of cable" (Keary and Brooks, 1984).

There are many electrode configurations as far as direct current geoelectric drilling is concerned. Wenner and Schlumberger are the most commonly applied. In this work Schlumberger spread was utilized due to the following reasons:

(1) Only two current electrodes were moved.

(2) effects of shallow resistivity variations was constant with fixed potential electrodes. Reasons given above support the use of Schlumberger direct current geoelectric drilling technique for data collection.

## 3.2 Geophysical Data Acquisition

Eleven points were selected along a profile running east-west over the suspected anomalous zone and perpendicular to the strike direction (north-south) in each of the study areas. The points were spaced 200m apart. Then gecelectric drilling was conducted about each point (geoelectric drilling point) using Schlumberger array (Fig. 2.1). Both current and potential electrcdes were connected to their respective terminals on the Terrameter top panel via wires wound on reels and connecting cables.

During field work, the current electrode spacing (L) was expanded at a logarithmic intervals (while maintaining the potential electrode spacing (*l*) fixed). Expanding L decreased the potential below the measuring capability of the Terrameter which necessitated expanding *l* ir order to obtain a measurable potential. The instrument then displayed the ratio of potential difference and injected current. Then sets of apparent resistivity ($\rho_a$) values were obtained using equations (15) and (16) for each

corresponding electrode spacings. The same values of electrode spacings (Table: 3.2) were used in data collection of the remaining poirts.

**Table. 3.2** Electrode Spacings Used in Taking the Field Data

| SERIAL NUMBER | AB/2 (m) | MN/2 (m) | K (m) |
|---|---|---|---|
| 1 | 1.50 | 0.50 | 6.28 |
| 2 | 2.00 | 0.50 | 11.78 |
| 3 | 3.00 | 0.50 | 27.45 |
| 4 | 4.00 | 0.50 | 63.00 |
| 5 | 6.00 | 0.50 | 112.01 |
| 6 | 7.00 | 0.50 | 153.14 |
| 7 | 8.00 | 0.50 | 200.28 |
| 8 | 10.00 | 0.50 | 313.41 |
| 9 | 10.00 | 2.00 | 75.42 |
| 10 | 12.00 | 2.00 | 209.95 |
| 11 | 14.00 | 2.00 | 150.80 |
| 12 | 15.00 | 2.00 | 173.63 |
| 13 | 17.00 | 2.00 | 223.87 |
| 14 | 20.00 | 2.00 | 311.14 |
| 15 | 25.00 | 2.00 | 487.73 |
| 16 | 30.00 | 2.00 | 703.45 |
| 17 | 35.00 | 2.00 | 983.97 |
| 18 | 40.00 | 2.00 | 1250.00 |
| 19 | 45.00 | 2.00 | 1586.61 |
| 20 | 45.00 | 10.00 | 302.30 |
| 21 | 60.00 | 10.00 | 549.49 |
| 22 | 70.00 | 10.00 | 752.66 |
| 23 | 100.00 | 10.00 | 1556.39 |
| 24 | 180.00 | 10.00 | 3518.39 |
| 25 | 200.00 | 10.00 | 6267.40 |

## 3.3 Precautions Taken During Field Work

Precautions taken during field work include firstly, insertion of considerable lengths of the electrodes into the soil to ensure good contact with the ground and also the wetting of the various

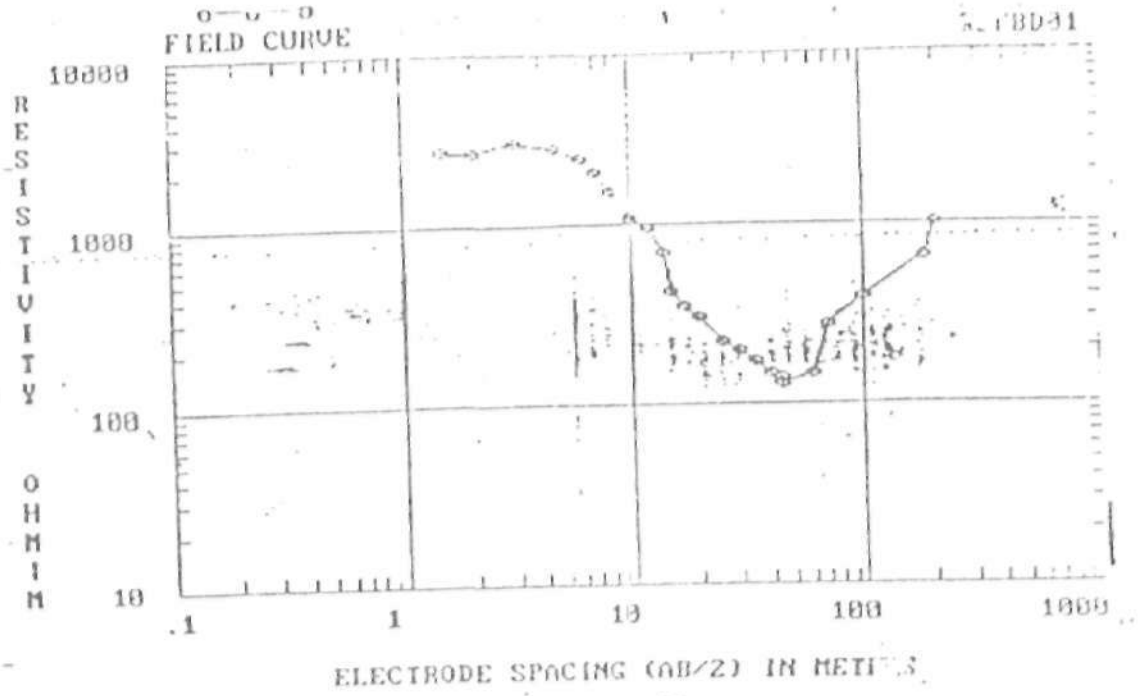
electrode positions with water. Secondly, the power supply was carefully monitored so as not to fall below 11.5V which otherwise the instrument would produce false and spurious readings.

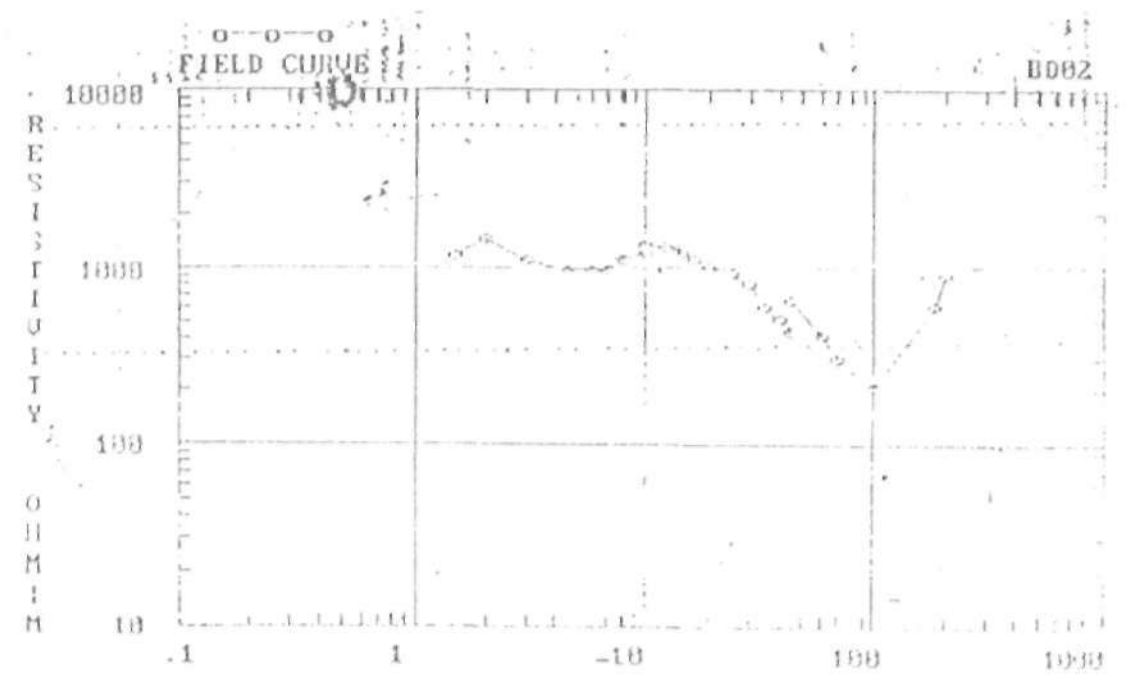
Thirdly, the profiles were taken in such away as to reduce the near surface effect caused by structures like metallic fence, buried pipes and electric cables and so on which will otherwise distort the current flow lines thereby increasing or decreasing the resistivity. The aftermath of this is the masking of the effect produced by the subsurface formations.

## 3.4 Data Reduction And Compilation

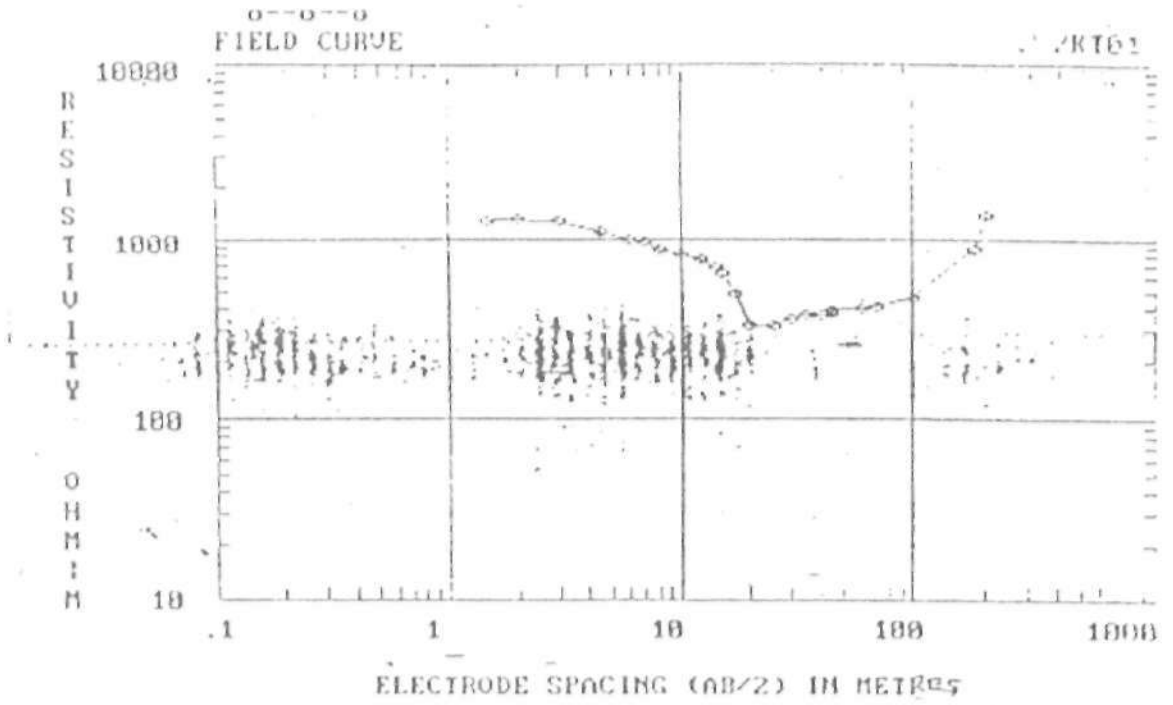
The data obtained were reduced using equations (15) and (16) to obtain the apparent resistivity. This is the weighted average of the resistivity (in ohm-metres) of all the formations through which the current has passed. The reduced field data were plotted in graph using a special software (Zohdy, 1975) that automatically plotted the values and produced apparent resistivity versus current electrode spacing curves (the field geoelectric drilling curves) on a bilogarithmic scale. Then these curves were processed and reduced to continuous smoothed curves. The continuous smoothed curves were then interpreted automatically. Typical examples of the automatically plotted field data curves for the first and second

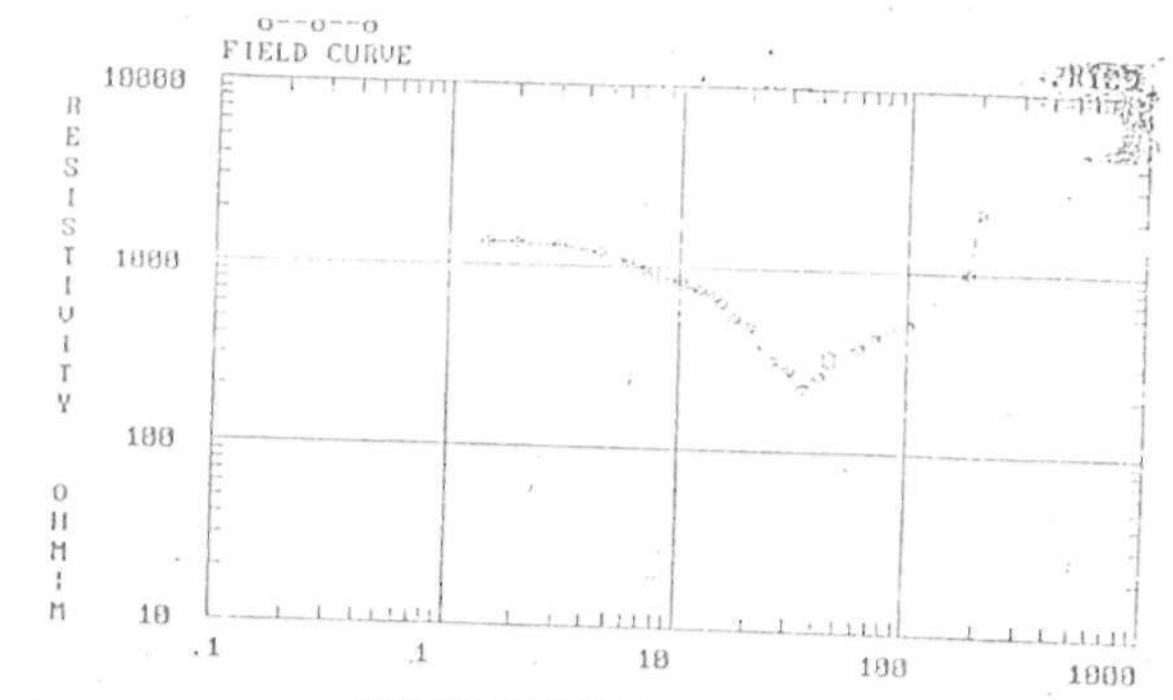
geoelectric drilling points of each area are displayed in figures 3.4(a-c).



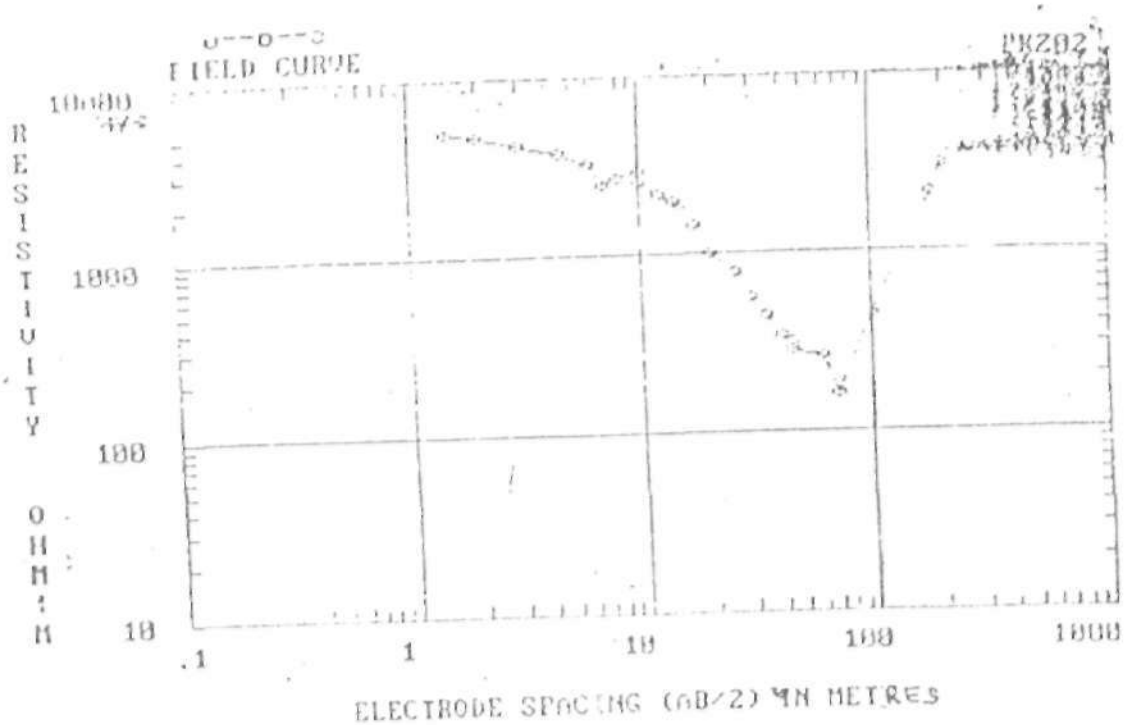



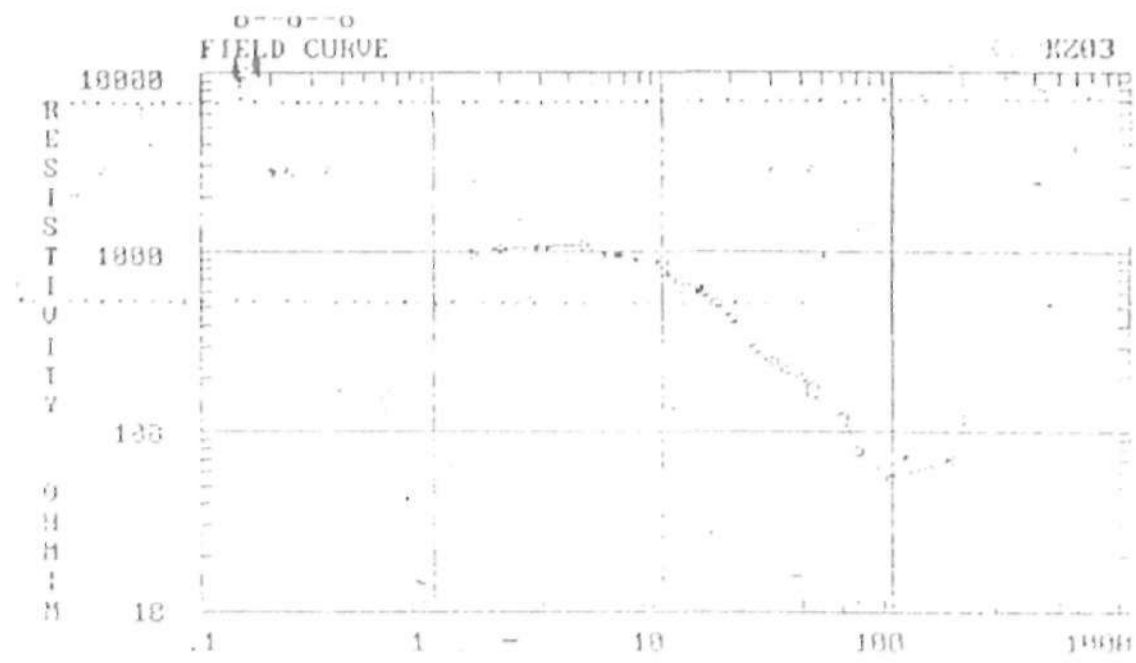

3.4(a) Typical Example of Bodeyel field Curves for two Geoelectric Drilling Points




3.4(b) .Karaftayi field Curves for the two Geoelectric Drilling Points




3.4(c) Kazaure town field Curvesfor the two Geoelectric Drilling Points

# CHAPTER FOUR

## INTERPRETATION

### 4.1 Introduction

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 made on the surface can yield useful information on the structure or composition of the buried formations. This is based on the fact that the resistivity of any two formations of different lithology and structure would be different from one another. Thus interpretation of resistivity data would give a meaningful guide for making a number of deductions regarding the stratification of the rock formations and the depth to basement rock. "This is so even though it is seldom that the rock formations exhibit a simple stratification in electrical properties" (Dobrin and Sarvit, 1988). Inspite of these difficulties, some solutions in nature can be approximated quite closely by a simple layering picture.

In places where there is an unconsolidated overburden of many formations over bedrock, it may be possible to compute the thicknesses of the various layers and depths of the various layers and the

bedrock below the surface. Such are parts of the procedure of the interpretation.

This interpretation involves two main steps namely, the automatic iterative interpretation and the geologic interpretation.

## 4.2 Automatic Iterative Interpretation

The method used for this interpretation is known as the Zohdy Method. "It allows the performance of automatic interpretation of the Schlumberger Sounding Curves using modified Dar Zarrouk function" (Zohdy, 1975), and it is based upon the similarity in shape existing in many cases between apparent resistivity and Dar Zarrouk Curves.

In the theory behind the Dar Zarrouk function reference is made to formations of parallel layers laterally homogeneous and unlimited. It is assumed that these layers are not anisotropic in the usual sense of physics (microanisotropy) and that no layer behaves as a whole as if it were anisotropic (microanisotropy), just because of the repeated alternation of fine beds of diverse facies.

A formation of the type in the preceding paragraph is considered to be made up of isotropic layers of thicknesses $h_1, h_2, h_3, \ldots\ldots\ldots\ldots\ldots$ with respective resistivities $\rho_1, \rho_2, \rho_3, \ldots\ldots\ldots\ldots\ldots$ which behaves as a whole as if it were anisotropic, a

phenomenon called the pseudoanisotropy. If, in this formation, a prism with a square base and sides of one unit length is cut, its electrical resistivity in the case of a current propagating perpendicular to the layers will be :

$$T = \sum_{i=1}^{n} h_i \rho_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.01)$$

where $T$ = transverse unit resistance. Similarly, if the current is parallel to the layers,

$$S = \sum_{i=1}^{n} h_i / \rho_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.02)$$

where $S$ is the longitudinal unit conductance, $T$ and $S$ are the Dar Zarrouk parameters.

To calculate from $T$ the resistivity $\rho_v$( as a whole of the block layers) measured in the direction normal to the layering;

$$\rho_V = T/H \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.03)$$

where $H = \sum_{i=1}^{n} h_i$ $\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.04)$

Similarly the average resistivity $\rho$ parallel to the layers will be;

$$\rho_p = H/S \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.05)$$

Therefore, the block of layers behaves as a whole like an anisotropic medium of resistivity $\rho_v$ and $\rho_p$, from

which the average square resistivity (pseudoresistivity) is deduced to be;

$$\rho_m = [\rho_v \rho_p]^{1/2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.06)$$

and the pseudoanisotropy;

$$\lambda = [\rho_v / \rho_p]^{1/2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.07)$$

In electrical prospecting, a layer of anisotropy $\lambda$ and thickness $H$ is indistinguishable from an isotropic layer of the same average resistivity and thickness $\lambda H$. Therefore, the block of isotropic layers considered is equivalent to a simple, but also isotropic layer of parameters;

$$\rho_m = [T/S]^{1/2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.08)$$

and

$$H_e = \lambda H = [T.S]^{1/2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (4.09)$$

where $H_e$ is the pseudodepth. "These two parameters are the coordinates of the Dar Zarrouk curve" (Orellana, 1963).

In the Zohdy method each interval between two consecutive sample points of the Dar Zarrouk curve is considered to represent a subsurface layer. For stratified earth model, these are defined as;

$$T_i = \sum_{i=1}^{n} h_i \rho_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.10)$$

$$S_i = \sum_{i=1}^{n} h_i / \rho_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.11)$$

then the parameters of each layer can then be determined from the following equations

$$h_i \rho_i = T_i - T_{i-1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.12)$$

and

$$h_i / \rho_i = S_i - S_{i-1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.13)$$

Zohdy (1974) replaces the Dar Zarrouk function by another function of the layer parameters which he calls the modified Dar Zarrouk function. This function is defined by the following equations:

$$\text{Pseudodepth} = h_i \{[T_i S_i] / h_i\}^{\alpha} \quad \ldots\ldots\ldots (4.14)$$

$$\text{Pseudoresistivity} = (h_i/S_i) \{[T_i S_i] / h_i\}^{\alpha} \quad \ldots\ldots (4.15)$$

where the superscript $\alpha$ takes any value from zero to one.

The method involves many iteration. This iterative method is fully automatic; it does not require any preliminary guess for the number of layers, their thicknesses or their resistivities. The procedure relies on the following assumptions:

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

ii) "The depths to the model layers are equal to the digitized electrode spacings which are equally spaced on a logarithmic intervals" (Koefoed, 1979).

iii) "The true resistivities of the model equal the apparent resistivities" (Zohdy, 1989).

The procedure involves two iterative processes. Firstly, depth determination iteration; and secondly, resistivity determination iteration. The former requires calculation of rms values for depth determination and then comparing the new rms percent with the previous one. If the new rms percent is less than the previous one, then the newly computed shallower depths will now be more inphase and closer in position with respect to the true depths. The iteration proceeds until the rms value is minimum. A minimum is detected when the root-mean-square percent increases as the depths are shifted too far to the left (are made too shallow). The root-mean-square percent (rms %) is computed from the equation

$$\text{rms}\% = \{ \Sigma_{j=1}^{N} [ ( \rho_{oj} - \rho_{cj} ) / \rho_{oj} ] / N \}^{1/2} \times 100 \quad \ldots (4.16)$$

where $\rho_{oj}$ = $j$th "observed" apparent resistivity, $\rho_{cj}$ = $j$th calculated apparent resistivity, and N = number of digitised apparent resistivity points (with $j$ =1 to N).

In order to arrive at the rms %, it is assumed that the digitized electrode spacings are equal to the depths and that the apparent resistivities are equal to the true resistivities at these depths. And the theoretical drilling curve for the multilayer model is computed by convolution.

After calculating the theoretical geoelectric drilling curve using shifted depths and apparent resistivities, then the amplitudes of these resistivities must be adjusted to obtain a better fit between observed and calculated curves. This adjustment was also done iteratively. At each digitized electrode spacing on the observed and calculated curves, if the computed apparent resistivity, at a certain spacing is less (or greater) than the corresponding observed apparent resistivity, the corresponding true resistivity of that layer should be increased (or decreased) so that the calculated apparent resistivity will rise (or fall) and approach an observed resistivity value. The amplitude of a layer is iteratively adjusted by using the following relationship;

$$\rho_{i,j}(j) = \rho_i(j) \times \rho_o(j)/\rho_{ci}(j) \quad \ldots\ldots\ldots\ldots\ldots\ldots (4.17)$$

where $i$ = number of iteration, $j$ = $j$th layer and $j$th spacing, $\rho_i(j)$ = $j$th layer resistivity at the $i$th iteration, $\rho_{ci}(j)$ = calculated apparent resistivity at the $j$th spacing for the $i$th iteration, and $\rho_o(j)$=observed apparent resistivity at the $j$th spacing.

The ratio of observed to calculated apparent resistivity is multiplied by the corresponding layer resistivity to adjust it to a higher or lower value. The new geoelectric drilling curve is calculated using the adjusted layer resistivities . And then new rms %

is computed and compared with the previously determined rms %. These processes are repeated until a match is found to the observed curve or until a slowness in further improvement in fit is detected and (or) the rms % increases instead of decreases.

The interpretation was effected by a special basic programme, developed and later modified by Zohdy (1975) using a filter (which transforms the resistivity into the apparent resistivity for a sampling distance of a sixth of a decade published by O'Neill (1975)) to obtain the equivalent n-layers model from the smoothed version of the field curve of each geoelectric drilling point. The output of the automatic iterative interpretation of each curve is apparent resistivity-depth graph on bilogarithmic scale (Appendix A ).

The smoothed curves are the calculated observed curves, while the curves designated with circles are digitized curve. And the histograms are the interpreted curves.

Moreover, both subsurface resistivity bar section of each geoelectric drilling point (Figs.4.3.1(a-c)) and subsurface contour section (Figs.4.2(a-c)) beneath the profile of each of the areas were constructed. The contour maps were constructed by plotting the resistivity values

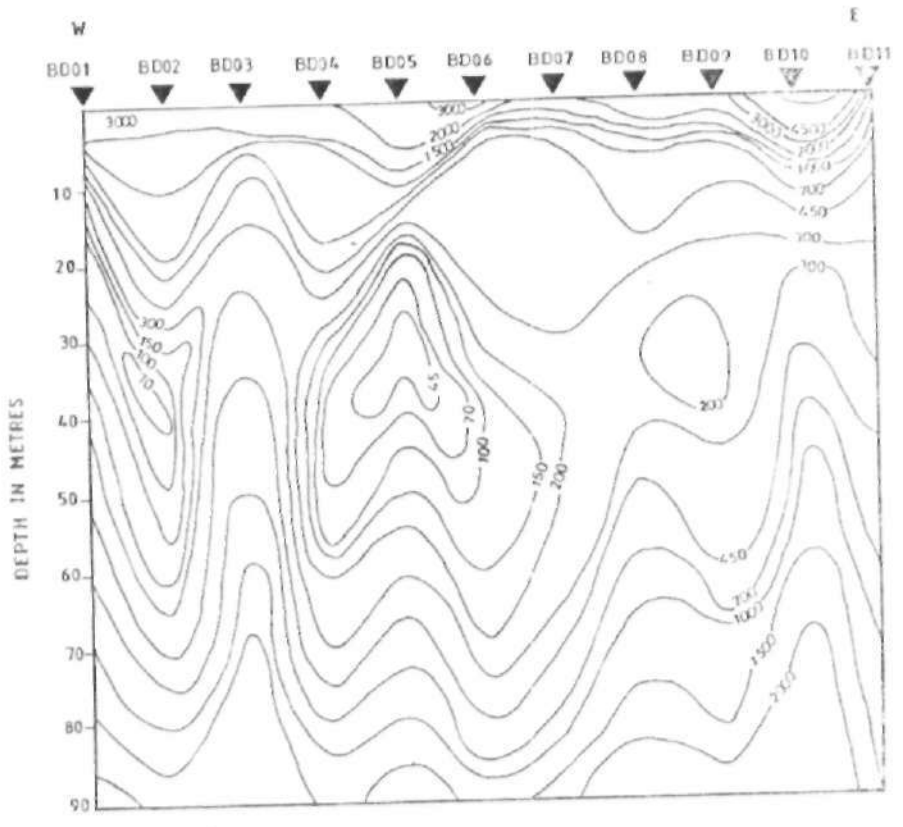



Fig. 4.2(a) Bodeyel subsurface resistivity contour section.

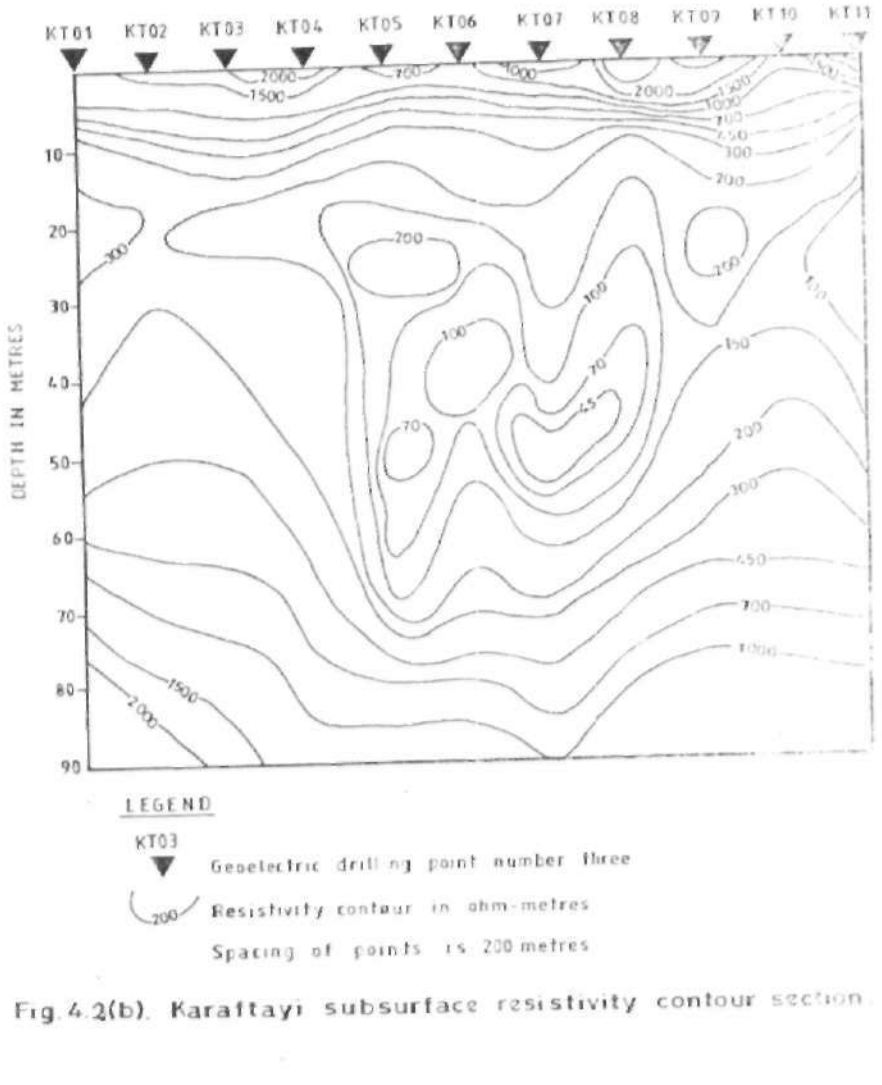



Fig. 4.2(b). Karaftayi subsurface resistivity contour section.

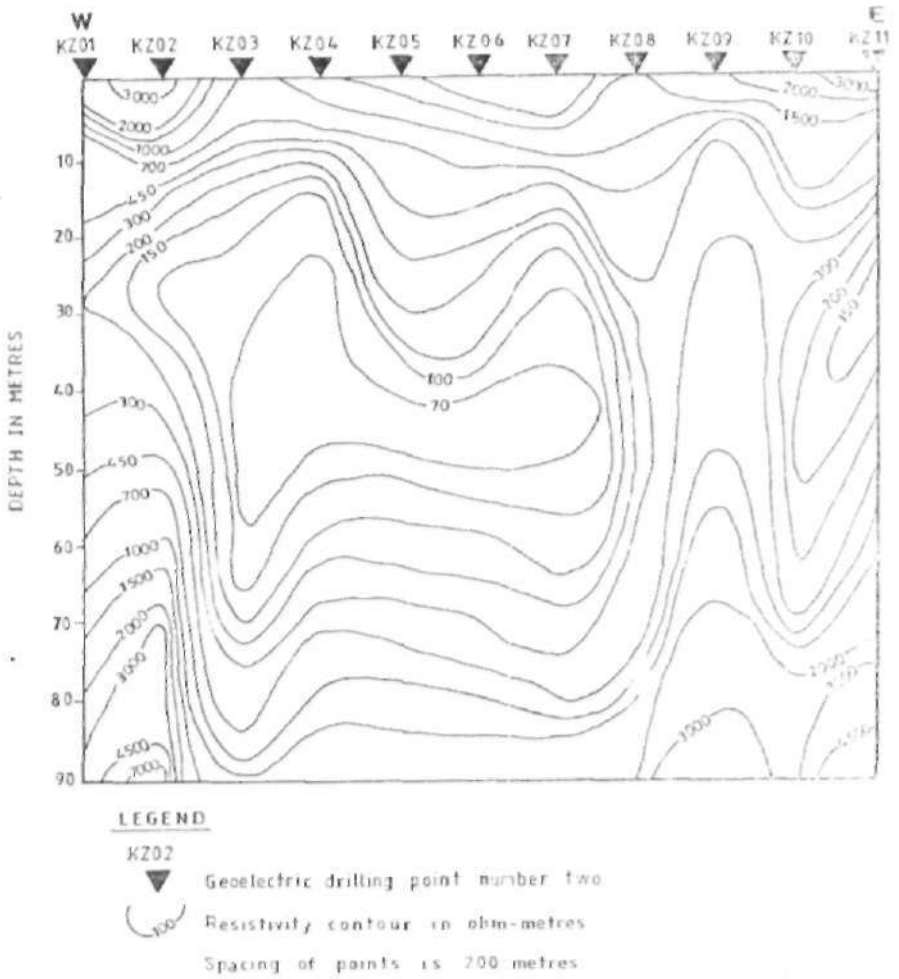



Fig. 4.2(c). Kazaure town subsurface resistivity contour section.

of each of the n-layer model of each geoelectric drilling at a point in mid-depth of this layer beneath geoelectric drilling point.

## 4.3 Geologic Interpretation

The interpretation of the geoelectric drilling was carried out using the subsurface resistivity contour and histogram curves (Figs. 4.2(a-c) and Appendix B). It must be pointed out, that the determination of resistivity solves the electric problem but not necessarily the geologic one (Parasnis, 1973). Thus layering models were carefully modified to agree with known geology and hydrology. These facts (Fig. 4.3 and Table 4.3(a)) were used to draw a new table of rock resistivity ranges (Table 4.3(b)) on which this interpretation was based. This is necessary because for most rocks, chemical composition is of such small importance as porosity and fracturing, that it is impracticable to try to place the different species on the constant and general conductivity scale.

In addition, some assumptions were made in the course of these interpretations because "if the contrast in properties are slight and/or spatial distribution of geological units is too complex, measurements cannot be interpreted geologically" (Walton, 1970). Thus it is assumed that the layers are horizontal and isotropic; and the surface of the earth

is taken to be the zero depth as recommended by Rorman (1963).

**Table. 4.3(a): Ranges of Resistivity Values for Various Rocks in Kano State(Okwueze, 1978, Yusuf, 1986 and Ibrahim, 1990)**

| ROCK TYPE | RESISTIVITY RANGES (Ωm) |
|---|---|
| Loamy soil | 5 - 65 |
| Clay saturated with water | 25 - 95 |
| Dry clay soil | 150 |
| Dray sand soil | 250 |
| Dry sand and gravel | 900 |
| Sand and gravel saturated with water | 80 - 300 |
| Laterite | 180 - 240 |
| Crystalline rock fracture with fresh water | 200 - 800 |
| Crystalline rock with fracture not connected | 800 - 1000 |
| Weathered crystalline rock, clayey | 30 - 80 |
| weathered cystalline rock, gravelly | 80 - 200 |
| Fresh crystalline rock | 1000 |

The subsurface layering resistivity ranges used in the interpretation is fixed by considering;

( i ) the geologic well logs obtained from the nearby areas (Fig. 4.3), which composes up of four subsurface strata namely sandy soil as the top layer covering laterite layer, weathered and fractured crystalline layer with clay and (or) sand appearing beneath the laterite layer and then the bottom layer which is the fresh basement complex.

( ii ) the resistivity of the various rock type in table 4.3(b) to fix the resistivity ranges of each of the substratum.

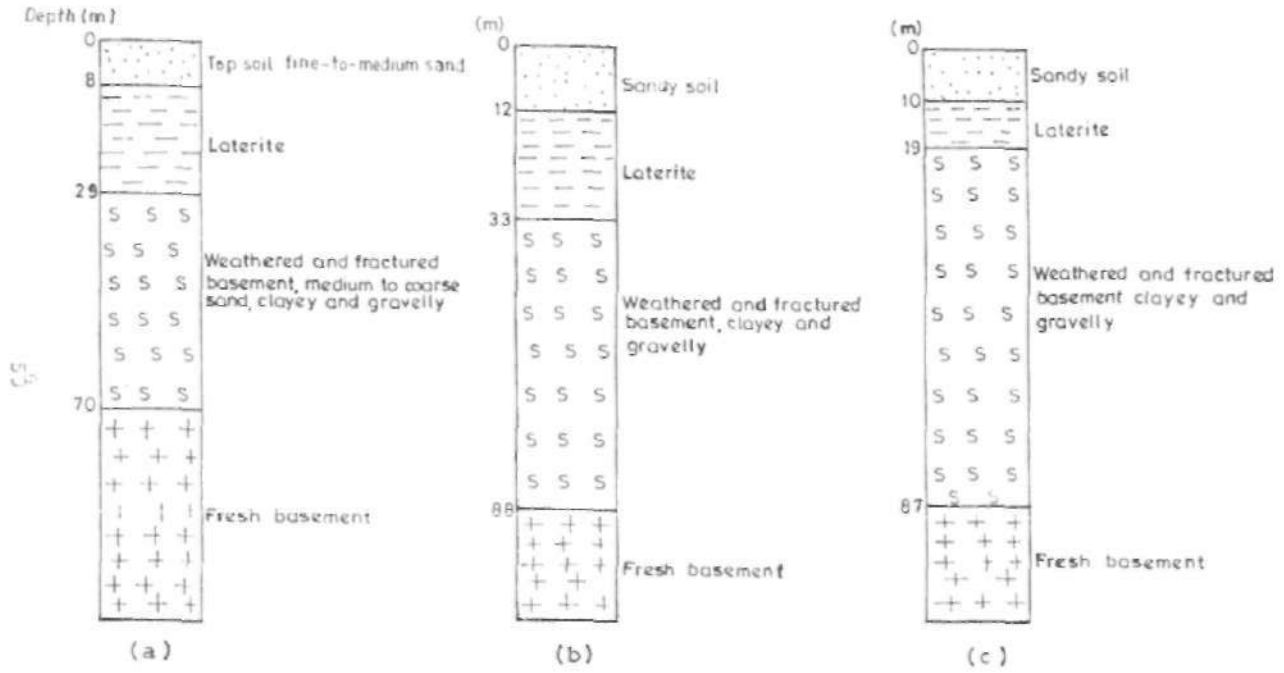



FIG. 4.3. GEOLOGICAL WELL LOGS OBTAINED IN (a) DANSURE BY WRECA (b) MARADAWA (RANDALL, 1986) AND (c) SABARU (RANDALL, 1986)

**Table. 4.3(b): Resistivity Values Used to Derive the Geologic Section in the Present Interpretation**

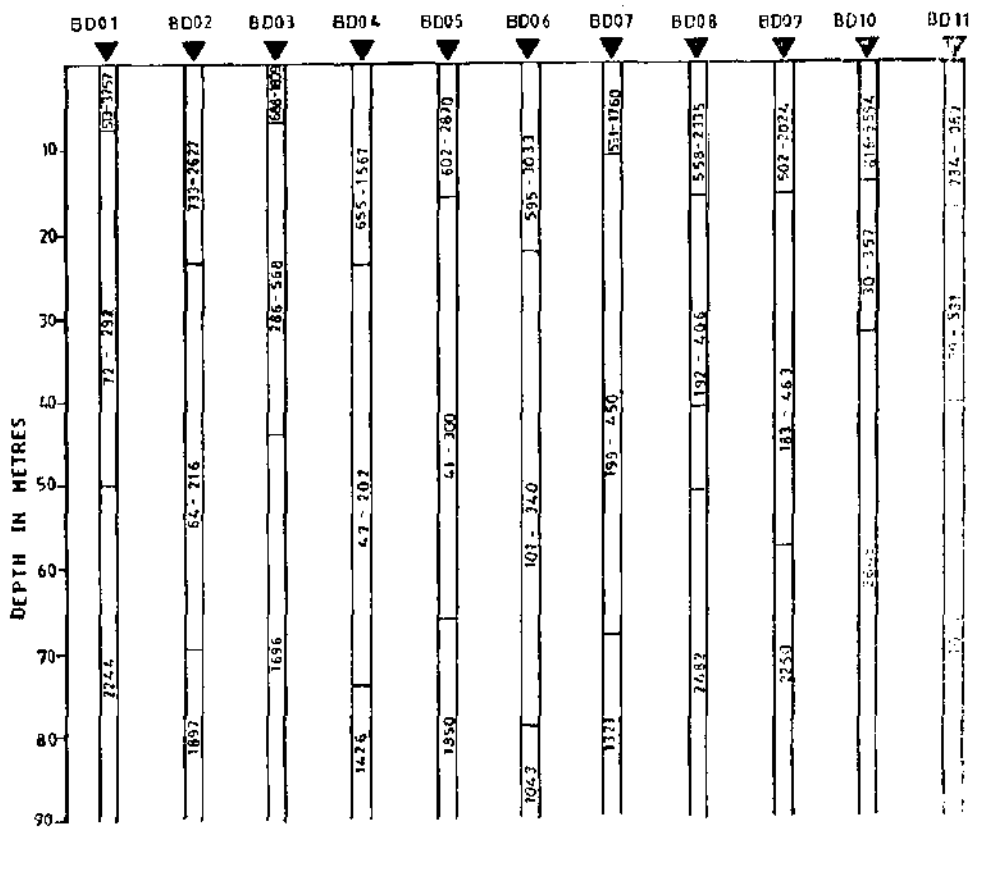
| ROCK TYPE | RESISTIVITY RANGES (Ωm) |
|---|---|
| Dry sand | 700 - 7000 |
| Dray sand and gravel | 700 - 1000 |
| Weathered layer | 200 - 750 |
| Fresh laterite | 1000 - 4800 |
| Weathered crystalline rock (clayey and/or gravelly | 30 - 300 |
| Weathered crystalline rock | 100 - 480 |
| Crystalline rock with fracture not connected | 800 - 1000 |
| Fresh crystalline (Basement) rock | 1000 |

### 4.3.1 The Subsurface Bar Section

The subsurface layering models obtained in the interpretation of the different individual geoelectric drilling points were represented as resistivity bars (Figs.4.3.1(a-c)) beneath its location to form the subsurface layering section. An equivalent geoelectric section which includes the previous interpretations will not show clearly the valuable information as explained by Zohdy (1989).However, to provide a clear picture, the interpretations were concentrated on the subsurface contour sections (Figs. 4.2(a-c)).

### 4.3.2 The Subsurface Resistivity Contour Section

The interpretation of the subsurface resistivity contour sections (Figs. 4.2(a-c)) was carried out by the cautious examination of the contour behaviour at the



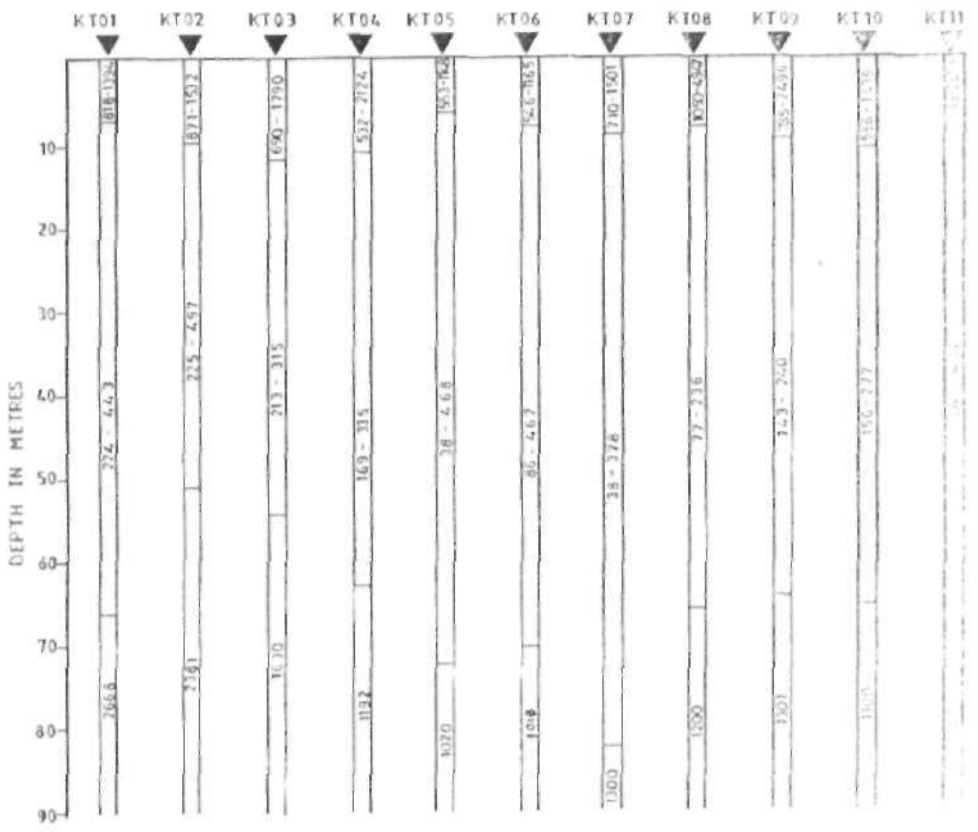

LEGEND

BD01 ▼ Geoelectric drilling point number one

21-300 Resistivity value in $\Omega m$

Spacing of points is 200 metres

Fig. 4.3.1(a): Bodeyel subsurface resistivity bar section (layering section).




LEGEND

KT02 ▼ Geoelectric drilling point number two

224-443 Resistivity value in Ωm

Spacing of points is 200 metres

Fig 4.3.1(b): Karaftayı subsurface resistivity bar section (layering section)

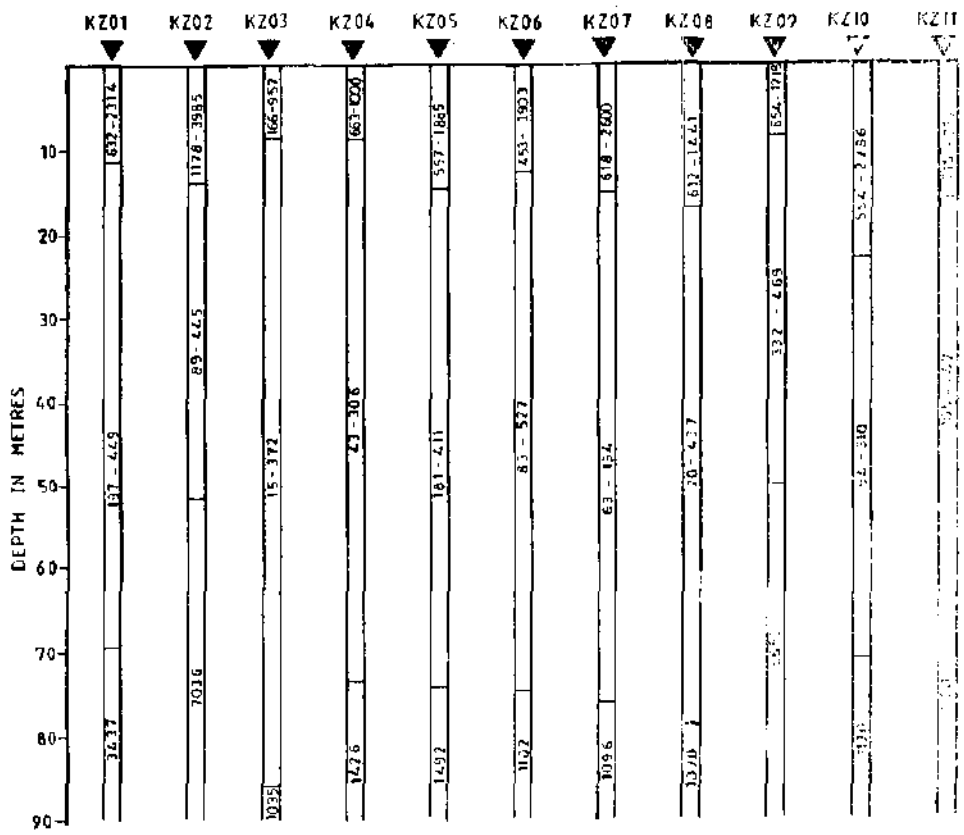



Fig. 4-3.1(c): Kazaure town subsurface resistivity bar section ( layering section ).

different depths taking into consideration that the resistivity value of each of the layered model was plotted at mid-depth beneath the corresponding geoelectric drilling point. Therefore, the layering boundaries were traced from the contour gradients, while the chosen anomalies represented the width of the interpreted geoelectric layer. The criteria made it possible to construct the equivalent subsurface geologic sections of each area.

## 4.4 Derived Subsurface Geologic Sections

### 4.4.1 The Bodeyel Equivalent Geologic Section

The geologic section of Bodeyel (Fig 4.4(a)) shows no exposed laterite layer. The top layer has a high resistivity value in the range of 1,500 to 7,000$\Omega m$, and thickness ranging from 0.5$m$ (BD11) to 9.3$m$ (BD10).

The second layer has resistivity of 300 to 1,000$\Omega m$. The layer extends down to a maximum depth of 30.0$m$ (BD07).

The third layer with resistivity ranging from 45$\Omega m$ to about 100$\Omega m$ has a maximum depth of 86.0$m$ (corresponding thickness of 64.0$m$) at BD06. But the layer is thickest at BD05 (65.0$m$).

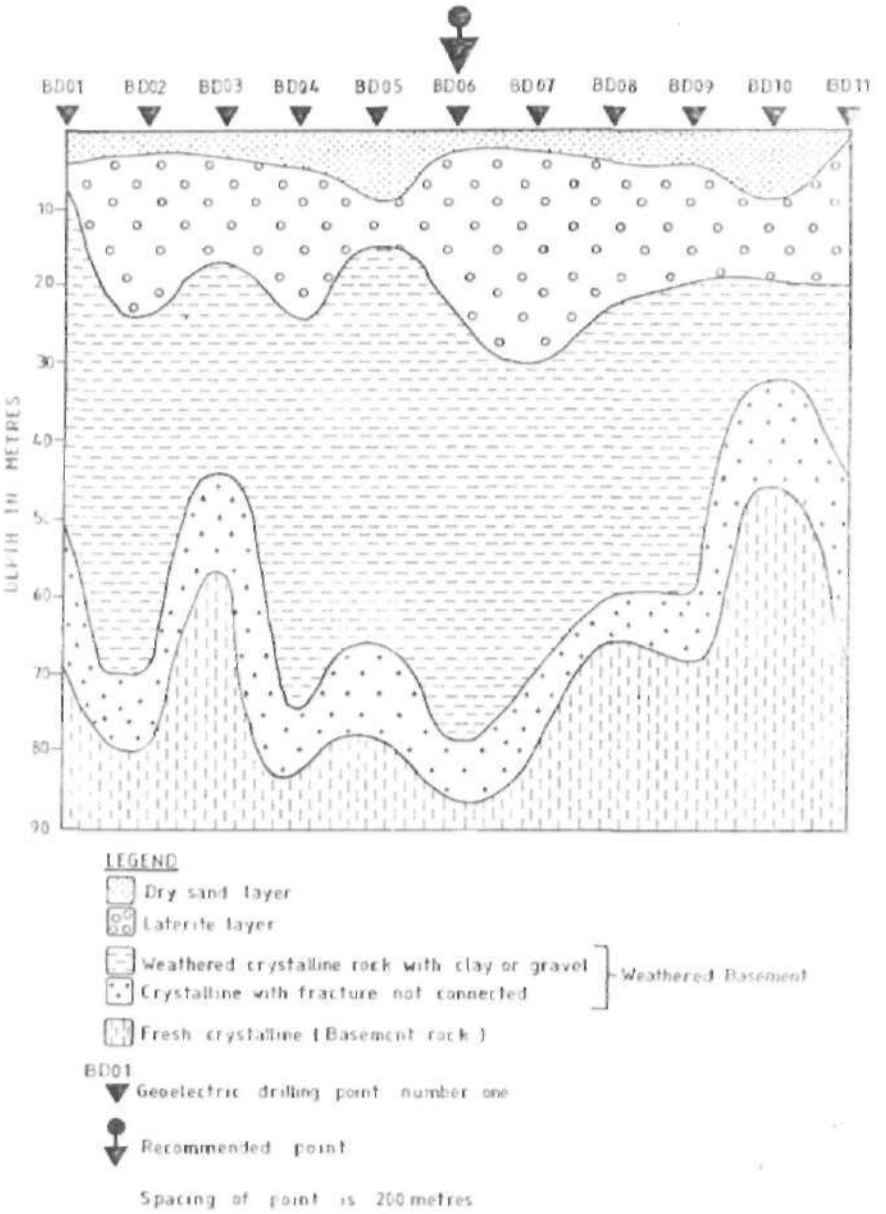



Fig 4.4(a) Subsurface geologic equivalent section to Bodeyel village resistivity contour section

Fresh basement, the last layer which has resistivity in the range of 1,000 to 2,668 $\Omega m$ continues downward.

### 4.4.2 The Karaftayi Equivalent Geologic Section

Figure 4.4(b) exhibits both the four and the three subsurface stratigraphic succession. Laterite appears at KT01, KT05, KT06 and KT10.

The sandy layer has resistivity in the range of 1,000 to 3,000 $\Omega m$ and a maximum depth of 6.0$m$. The laterite layer reaches up to a depth of 13.5$m$ (KT03). Maximum thickness of laterite is 12.5$m$ (KT03) and the range of its resistivity values is from 300 to 700 $\Omega m$.

Weathered and fractured basement (45 $\Omega m$ to about 1,000 $\Omega m$) has the deepest point (86.5$m$) located at KT07 which also corresponds to the thickest region of the layer. The last layer, the fresh basement as usual, has very high resistivity value in the range of 1,000 to 2,668 $\Omega m$.

### 4.4.3 Kazaure Town Equivalent Geologic Section

In the geologic section (Fig. 4.4(c)) of Kazaure town, laterite is only exposed at KZ03, thus all the other points exhibit four layer stratigraphy.

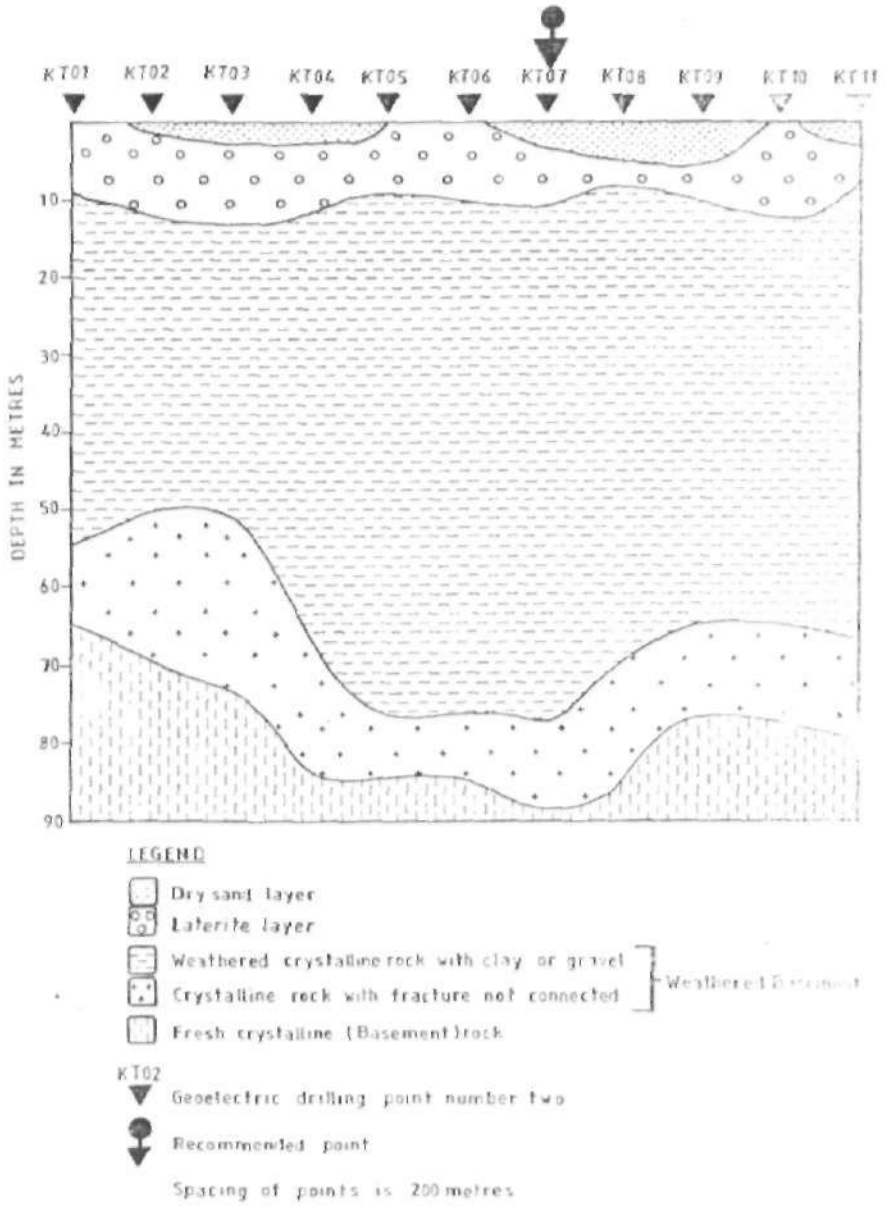



Fig 4.4(b) Subsurface geologic equivalent section to Karaftayi village resistivity contour section.

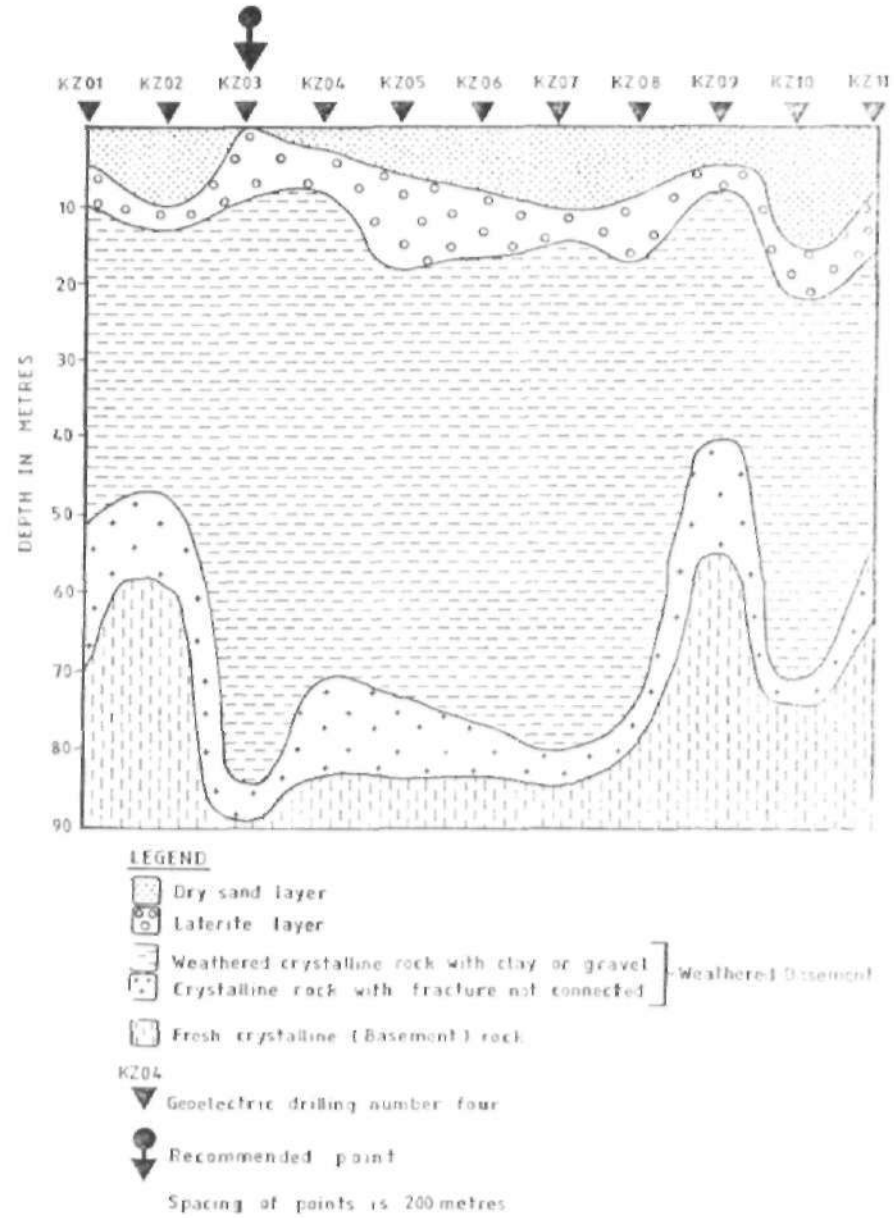



Fig. 4.4(c). Subsurface geologic equivalent section to Kazaure town resistivity contour section.

The sand layer (1,000 - 4,500 Ωm) extends to a maximum depth of 15.0m (KZ10). Underlying the sand layer is the laterite layer (450 - 1,000 Ωm) which undulates, narrows and widens, reaching a depth of 22.0m at KZ10 and with a maximum thickness of 12.5m at KZ05.

The weathered and fractured basement layer with resistivity from 700 to 1,000 Ωm, extends up to a depth of 88.5m under KZ03, which also corresponds to the thickest portion (62.0m) of this layer. Following this layer, the high resistive fresh basement (1,000 to 7,000 Ωm) continues down.

### 4.4.4 Summary of the Derived Subsurface Geologic Sections

It is clear from the interpretation of the geologic sections (Fig.4.4) that the study areas are underlain by four or at certain points by three layers. The layers vary in thickness, depth and resistivity. For four layer locations, the top soil is composed of sandy soil, next layer is laterite which is followed successively by the weathered and fractured layer separating the above two layers from the lowest, the fresh basement. At certain places laterite is exposed, this is associated with three layer locations.

The weathered and fractured layer is composed of both sand and gravel. Walton(1970) has tabulated the

representative permeability, porosity and specific yield ranges for some selected rocks. This explains why this layer can be assumed to constitute a formation which yields water in sufficient quantity to be regarded as a source of water supply. In addition to these ranges, the thickness and depth of weathering affect its storage capacity. The thickest and correspondingly the deepest exhibit highest yield. Therefore, more emphasis was placed on the relationship of these two parameters in deciding the best lacation.

## 4.5 Geologic Stratigraphic Controls

The well-logs (Fig.4.3) show that the subsurface structure can be classified into four substrata, viz.; the sand layer, the laterite layer, the weathered and fractured basement layer and the fresh basement layer.

The geologic well-log obtained at Dansure (Fig.4.3(a)) shows that sand has a thickness of 8.0*m* followed by laterite layer up to a depth of 29.0*m*. This is underlain by weathered and fractured basement.

Similarly the well-logs at Maradawa (Fig.4.3(b)) and Sabaru (Fig.4.3(c)) have top Soil of loose, dry, fine to medium sand grains. The thickness of the layers in the two locations are 12.0*m* and 10.0*m* respectively. These layers are underlain by laterite (reaching a respective depth of 31.0*m* and 19.0*m*).

Fresh basement was encountered at a depth of 88.0*m* and 87.0*m* with weathered and fractured basement layer at the two locations occurring at depths 33.0*m* and 19.0*m* respectively and its respective thicknesses at the two locations are 55.0*m* and 68.0*m*.

Dansure and Maradawa are located roughly 3.0*km* from Karaftayi which is also about 5.0 km from Kazaure town. Therefore the well-logs Figure 4.3.were considered to have stratigraphic control over the subsurface geology of the areas concerned. The well-log obtained from Sabaru is as well employed to serve partly as stratigraphic control over stratigraphy of Bodeyel.

# CHAPTER FIVE

## CONCLUSION AND RECOMMENDATIONS

### 5.1 Introduction

The comprehensive picture of the subsurface geologic layers in conjunction with the contour sections of the study areas as presented in the previous chapter provides some remarkable information that will be used with some information derived from the resistivity bar sections to study in detail the lithologic variations and the subsurface structural setting of the areas. Such study will provide information on the best points for locating boreholes.

### 5.2 Aquifer Thickness Under the Study Areas

"An aquifer is a saturated bed or formation or group of formations which serves as a source of underground water supply" (Walton, 1970). Though sand and laterite can store water, the water always occupies position of lowest hydraulic gradient, the weathered and fractured layer as explained by De Wiest (1969). Therefore water will occupy location with maximum weathering depth.

A large number of dense rocks have porosities of less than 2 percent and permeabilities ranging from 10 to 20 darcy. Granite, quartzite and gabbro are a few of the common dense rocks which are abundant in the outermost crust of the earth. Such rocks in their

unmodified state will not yield water to wells nor will they store significant amount of water in their limited pore spaces. But Weathering and fracturing of these rocks will increase the overall permeabilities to many orders of magnitude. "Weathering will increase rock porosity from initial values generally less than 5% to final values of between 30 and 60%" (Stewart, 1964). "Fracturing alone however, does not generally increase overall rock porosities by more than 2 to 5 %" (De Wiest, 1969).

This relation between weathering and fracturing to porosity and permeability, coupled with hydraulic gradient suggests, that the most effective aquifer region is the weathered and fractured layer. Since the bottom rocks (Basement rocks) have low permeabilities and porosities, the groundwater would accumulate within the weathered basement.

Therefore, the thickness of the aquifer under the various points was obtained by subtracting the thickness of the beds overlying the weathered basement from the depth of the fresh basement from the surface. Numerical values of the depth to the fresh basement and the thicknesses of the subsurface strata at each geoelectric drilling point in each of the study areas are shown in Tables 5.2(a-d).

## 5.3 Recommended Borehole Locations

Obviously, the analysis and interpretation of the geophysical data in correlation with geology and previous hydrogeophysical works have provided valuable information, which is used for making the choice of points for sinking boreholes. Groundwater move through pores as separate thin parallel streams. This type of flow movement is called laminar flow. The rate of movement and accumulation of groundwater depends on the permeability of rocks and hydraulic gradient. Darcy (1969) gave a relationship between the flow velocity, permeability and hydraulic gradient for a laminar flow. The relationship is expressed by the formula;

$$I' = \phi(h/l) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.3.1)$$

where $I'$ is the flow velocity; $\phi$ is a constant denoting the permeability of a given rock; $h$ is the relative height of water level at one point above the water level at another; $l$ is the distance between the points; the ratio $(h/l)$ is the hydraulic gradient. This indicates that water always occupies position of lowest pressure (hydraulic) gradient. Thus the recommended points were arrived at by noting that water will always occupy region with maximum weathering depth from the surface which is the location with lowest hydraulic gradient. Thus in view of the previously discussed sections. The following

points were considered as the best positions to locate boreholes in the study areas.

**Table 5.2(a): Depth to Fresh Basement at various geoelectric Drilling Point in Bodeyel, Karaftayi and Kazaure town**

| BODEYEL | | KARAFTAYI | | KAZAURE TOWN | |
|---|---|---|---|---|---|
| POINT | DEPTH (m) | POINT | DEPTH (m) | POINT | DEPTH (m) |
| BD01 | 68.5 | KT01 | 65.0 | KZ01 | 71.5 |
| BD02 | 80.0 | KT02 | 70.0 | KZ02 | 58.5 |
| BD03 | 56.5 | KT03 | 73.5 | KZ03 | 89.0 |
| BD04 | 84.5 | KT04 | 83.5 | KZ04 | 83.0 |
| BD05 | 79.0 | KT05 | 85.0 | KZ05 | 83.5 |
| BD06 | 86.5 | KT06 | 85.0 | KZ06 | 83.5 |
| BD07 | 82.0 | KT07 | 88.5 | KZ07 | 85.0 |
| BD08 | 86.0 | KT08 | 85.0 | KZ08 | 80.0 |
| BD09 | 68.0 | KT09 | 76.0 | KZ09 | 55.0 |
| BD10 | 45.5 | KT10 | 78.0 | KZ10 | 73.5 |
| BD11 | 71.0 | KT11 | 79.0 | KZ11 | 62.0 |

**Table 5.2(b): Thicknesses of the Subsurface Strata in Bodeyel village under each of the Geoelectric Drilling Points**

| BODEYEL VILLAGE SITE | | | | |
|---|---|---|---|---|
| POINT | DRY SAND (m) | LATERITE (m) | WEATHERED CRYSTALLINE ROCK WITH CLAY/SAND (m) | WEATHERED CRYSTALLINE WITH FRACTURE NOT CONNECTED (m) |
| BD01 | 4.00 | 4.00 | 46.00 | 18.30 |
| BD02 | 3.00 | 22.00 | 55.00 | 10.00 |
| BD03 | 3.50 | 13.00 | 28.00 | 11.50 |
| BD04 | 4.50 | 20.00 | 50.00 | 10.00 |
| BD05 | 9.00 | 7.00 | 50.00 | 13.00 |
| BD06 | 3.00 | 21.00 | 55.50 | 7.00 |
| BD07 | 2.00 | 28.00 | 40.50 | 11.50 |
| BD08 | 4.00 | 18.50 | 37.00 | 0.50 |
| BD09 | 4.00 | 15.00 | 41.00 | 8.00 |
| BD10 | 9.00 | 10.50 | 13.00 | 13.50 |
| BD11 | 1.00 | 19.00 | 25.00 | 26.00 |

**Table 5.2(c): Thicknesses of the Subsurface Strata in Karaftayi village under each of the Geoelectric Drilling Points**

| KARATAYI VILLAGE SITE | | | | |
|---|---|---|---|---|
| POINT | DRY SAND (m) | LATERITE (m) | WEATHERED CRYSTALLINE ROCK WITH CLAY/SAND (m) | WEATHERED CRYSTALLINE WITH FRACTURE NOT CONNECTED (m) |
| KT01 | 0.00 | 8.50 | 46.00 | 10.00 |
| KT02 | 1.00 | 9.50 | 39.50 | 20.00 |
| KT03 | 2.50 | 11.00 | 38.00 | 22.00 |
| KT04 | 3.00 | 8.50 | 55.00 | 18.00 |
| KT05 | 0.00 | 8.50 | 68.00 | 8.50 |
| KT06 | 0.00 | 9.00 | 67.00 | 9.00 |
| KT07 | 3.50 | 8.00 | 66.00 | 11.00 |
| KT08 | 5.50 | 3.00 | 61.00 | 15.50 |
| KT09 | 6.00 | 4.50 | 54.00 | 11.50 |
| KT10 | 0.00 | 12.50 | 52.50 | 13.00 |
| KT11 | 4.50 | 1.50 | 60.50 | 12.50 |

**Table 5.2(d): Thicknesses of the Subsurface Strata in Kazaure town under each of the Geoelectric Drilling Points**

| KAZAURE TOWN SITE | | | | |
|---|---|---|---|---|
| POINT | DRY SAND (m) | LATERITE (m) | WEATHERED CRYSTALLINE ROCK WITH CLAY/SAND (m) | WEATHERED CRYSTALLINE WITH FRACTURE NOT CONNECTED (m) |
| KZ01 | 5.00 | 5.00 | 41.00 | 20.50 |
| KZ02 | 9.00 | 4.00 | 34.00 | 11.50 |
| KZ03 | 0.00 | 8.50 | 79.50 | 5.00 |
| KZ04 | 2.50 | 5.00 | 63.50 | 18.00 |
| KZ05 | 5.00 | 12.50 | 55.50 | 10.50 |
| KZ06 | 7.50 | 9.00 | 60.50 | 7.50 |
| KZ07 | 10.00 | 4.50 | 65.50 | 15.00 |
| KZ08 | 7.50 | 9.50 | 57.00 | 6.00 |
| KZ09 | 5.00 | 3.00 | 32.00 | 15.00 |
| KZ10 | 15.00 | 7.00 | 48.00 | 13.50 |
| KZ11 | 7.50 | 7.50 | 45.00 | 12.00 |

(1) **Bodeyel Village Borehole Location:** Figure 4.4(a) shows the equivalent geologic section of Bodeyel. The point BD06 is recommended as the best point for drilling a borehole. A close examination of the section reveals that BD06 is the point with maximum weathered layer thickness and maximum depth to fresh basement.

(2) **Karaftayi Village Borehole Location:** In Figure 4.4(b), the point KT07 corresponds to the location with maximum aquifer thickness and fresh basement depth, thus representing the point with the lowest hydraulic gradient, and is recommended for drilling a borehole.

(3) **Kazaure town borehole location:** It is clear from Figure 4.4(c) that the point with the thickest aquifer and deepest depth to fresh basement is KZ03. Thus it is recommended for siting a borehole.

## 5.4 Conclusion

The result of the present work shows that the subsurface stratigraphic succession of the study areas can be broadly classified into two; the four layer stratigraphic succession in which sand tops the remaining subsurface layers and the three layer case in which laterite appears at the surface. Resistivity distribution in the areas indicates that the top and bottom layer have high resistivity values (1,000 to

7,000Ωm) while the middle layers have intermediate resistivity values (less than 1,000Ωm).Points with suitable combination of layer parameters for groundwater accumulation and storage are recommended as the best locations for boreholes as follows; BD06 (Bodeyel), KT07(Karaftayi) and KZ03 (Kazaure town).

Even though this investigation is not purposely meant for subsurface weathering study and cannot stand to be a general representative of the Kazaure local government area, it will provide an approximate thickness for the weathered layer in the study areas and beyond.

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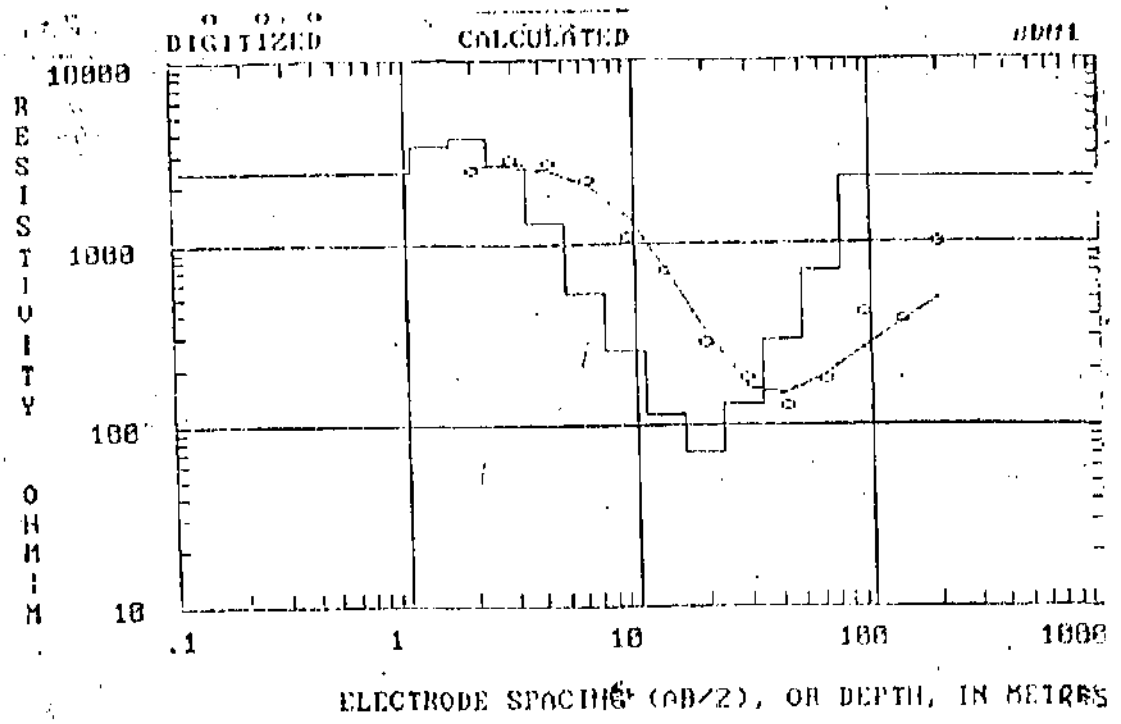
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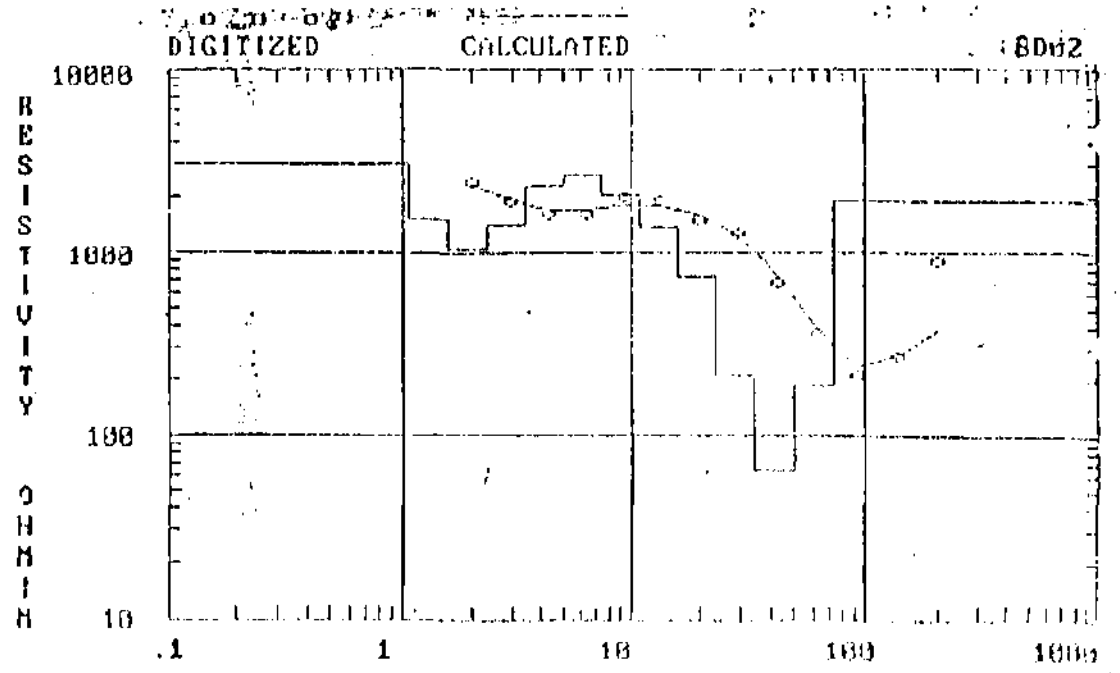
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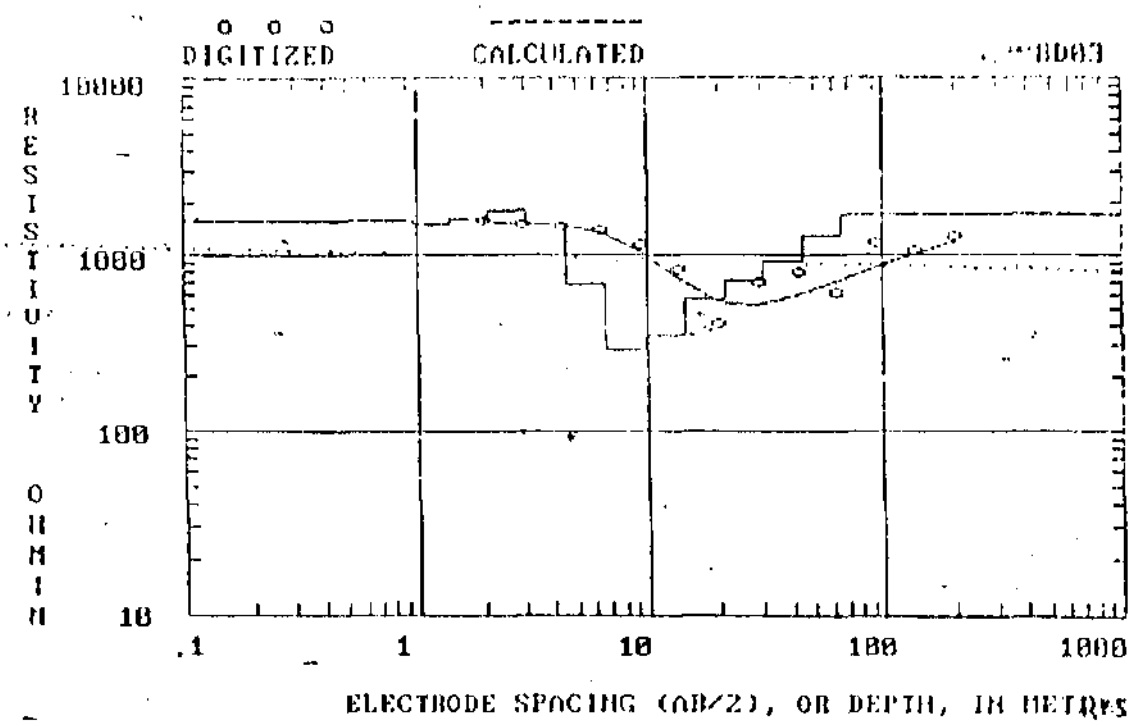
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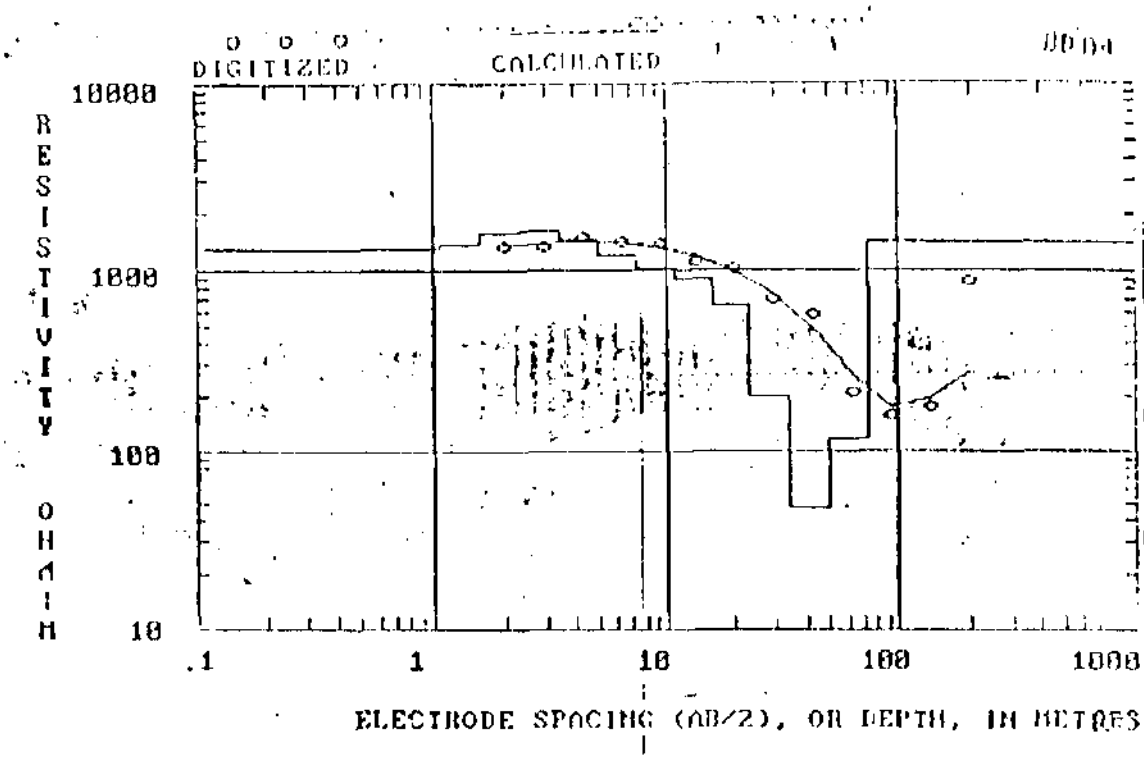
# APPENDIX A

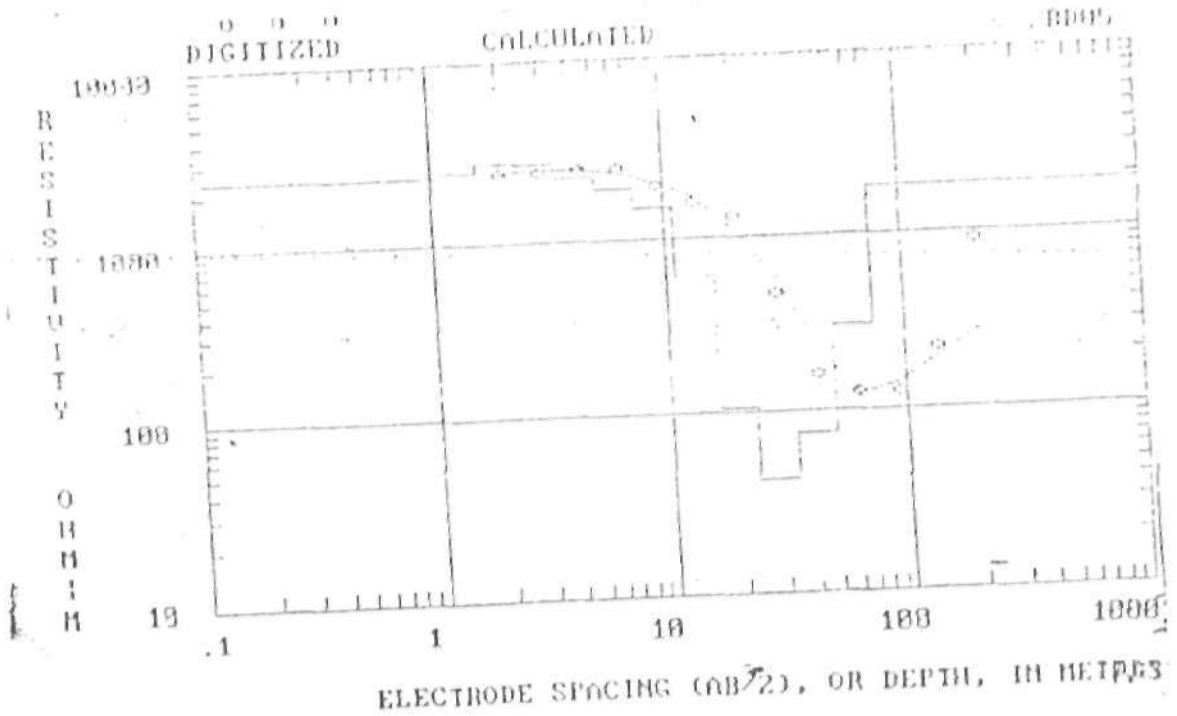
AUTOMATICALLY INTERPRETED FIELD CURVES FOR BODEYEL ,
KARAFTAYI AND KAZAURE TOWN.

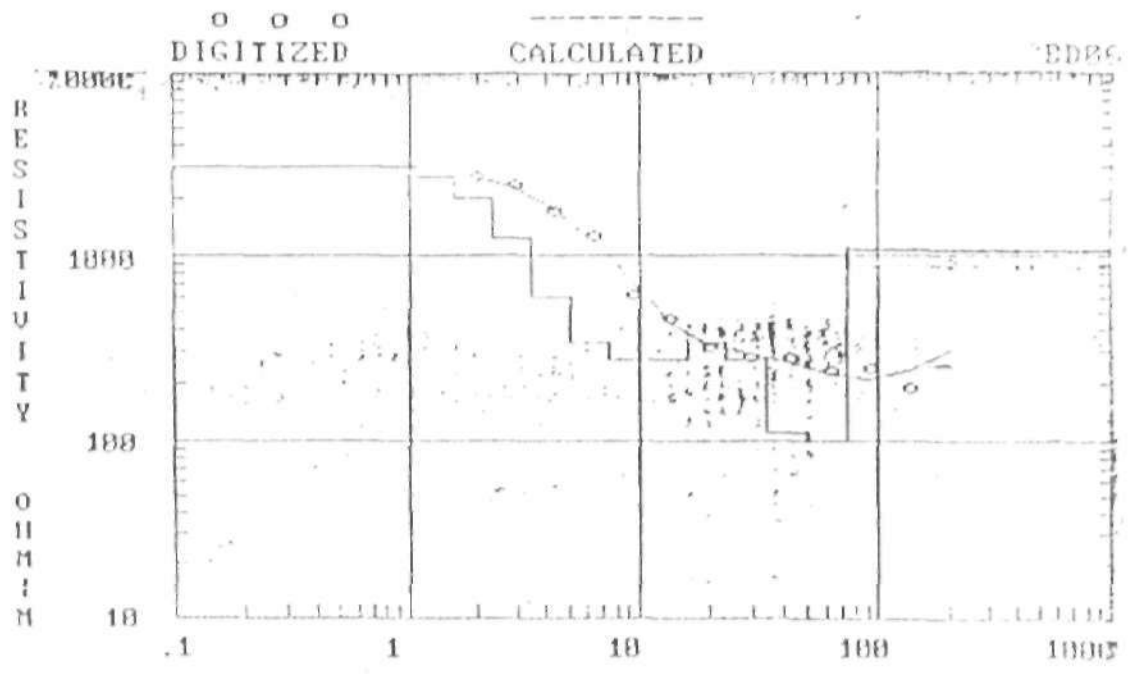

DIGITIZED
CALCULATED
BD01
RESISTIVITY OHMIM
10000
1000
100
10
.1
1
10
100
1000
ELECTRODE SPACING (AB/2), OR DEPTH, IN METRES

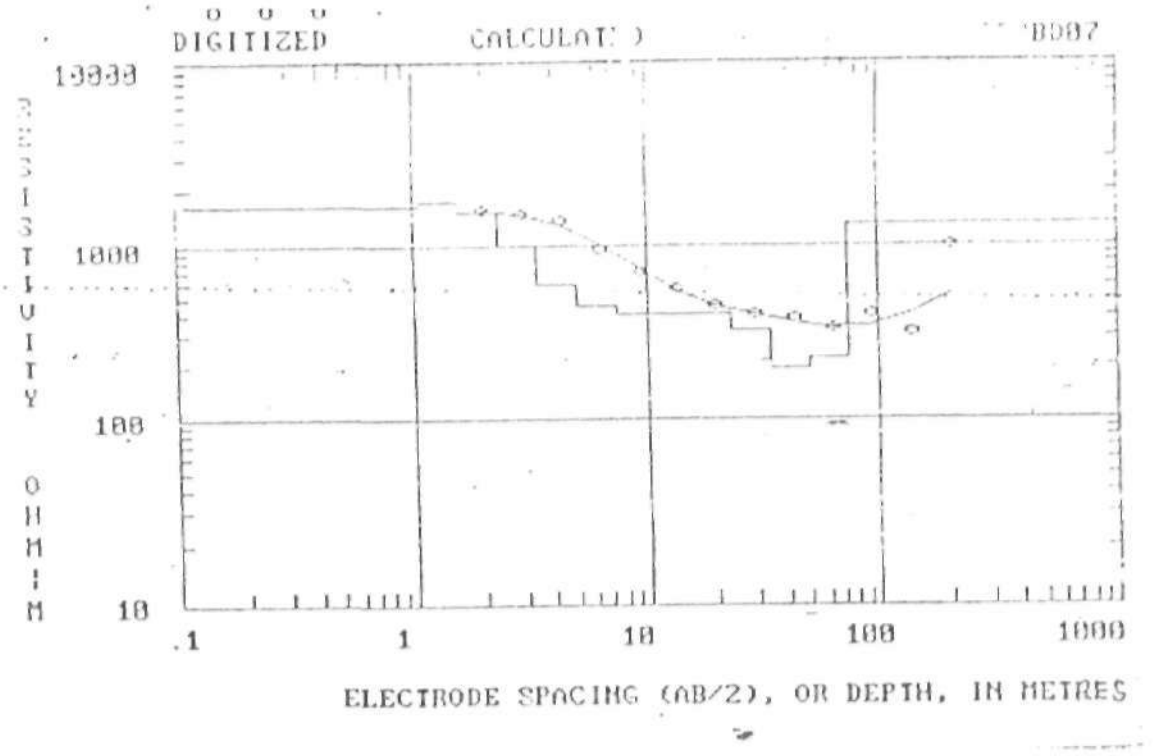

DIGITIZED
CALCULATED
BD02
RESISTIVITY OHMIM
10000
1000
100
10
.1
1
10
100
1000
ELECTRODE SPACING (AB/2), OR DEPTH, IN METRES

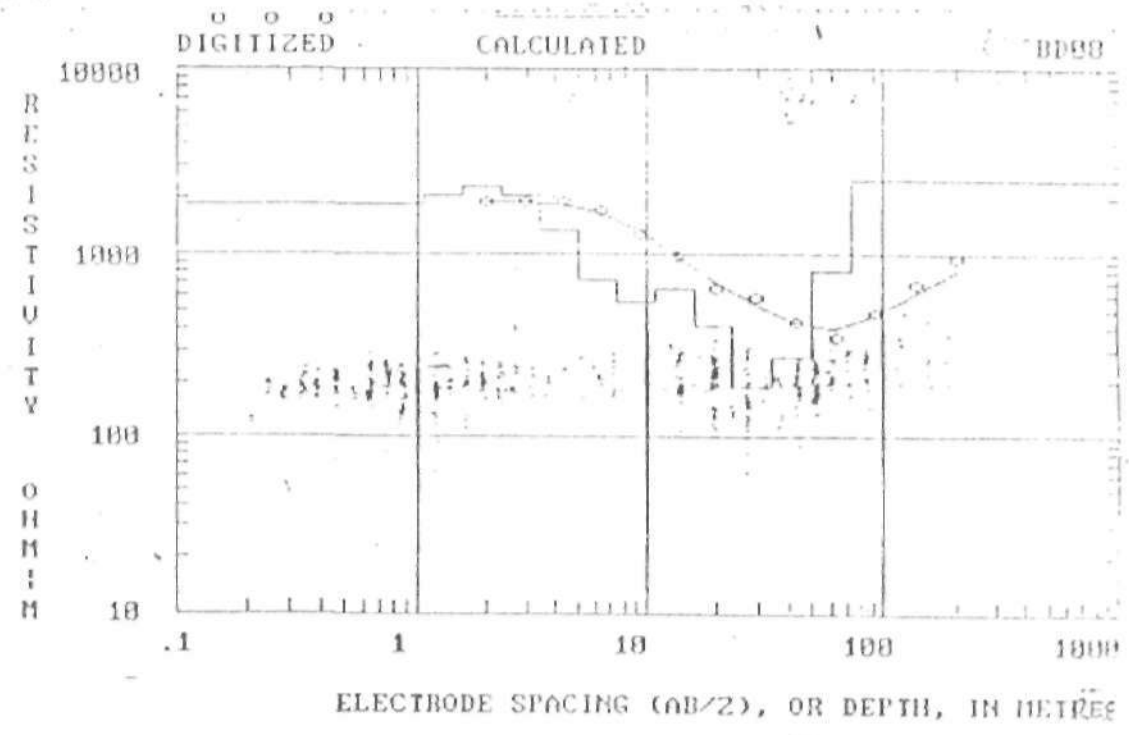

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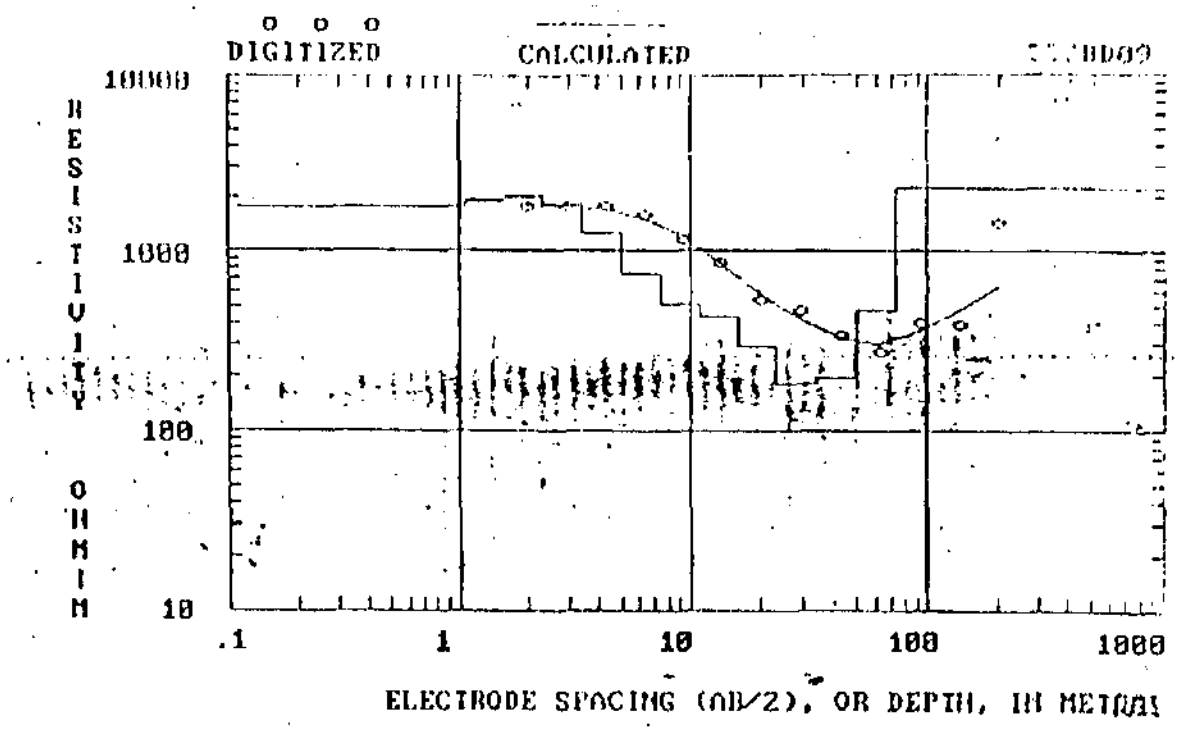

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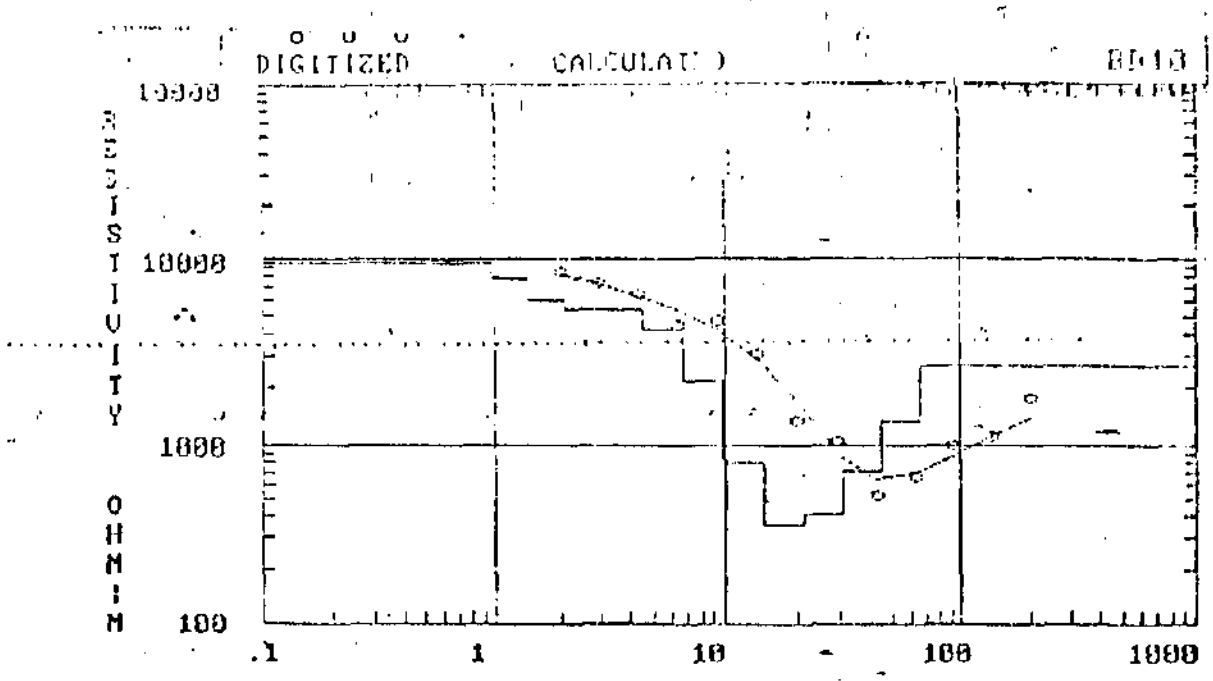

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ELECTRODE SPACING (AB/2), OR DEPTH, IN METRES

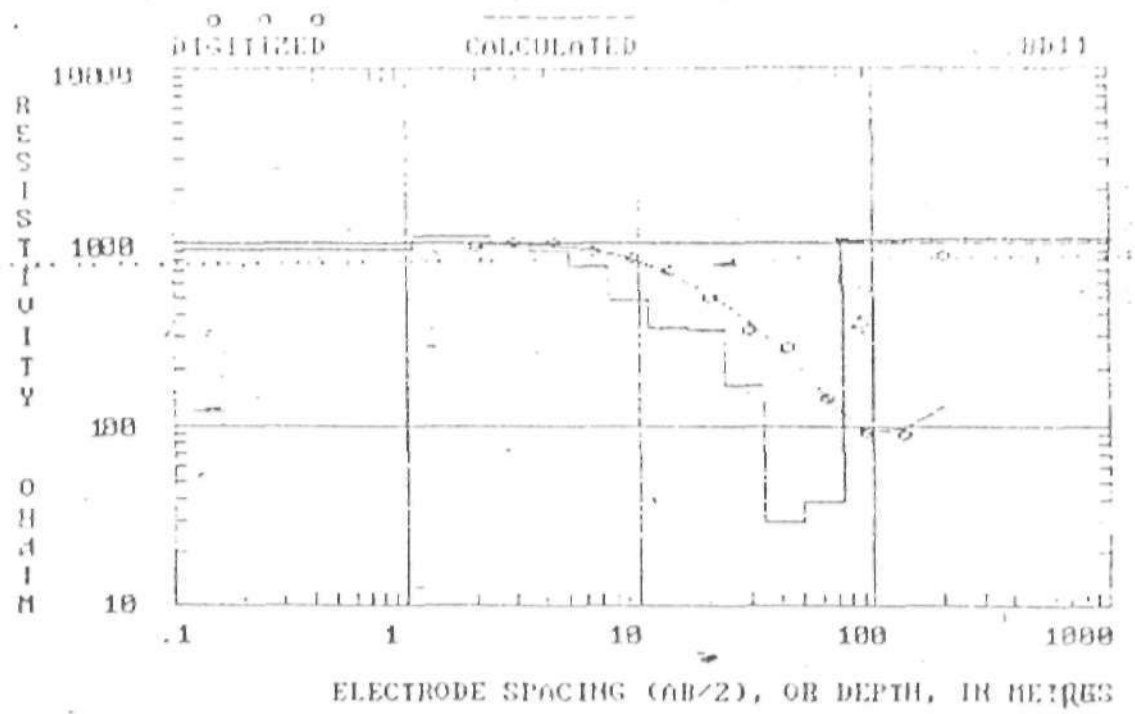

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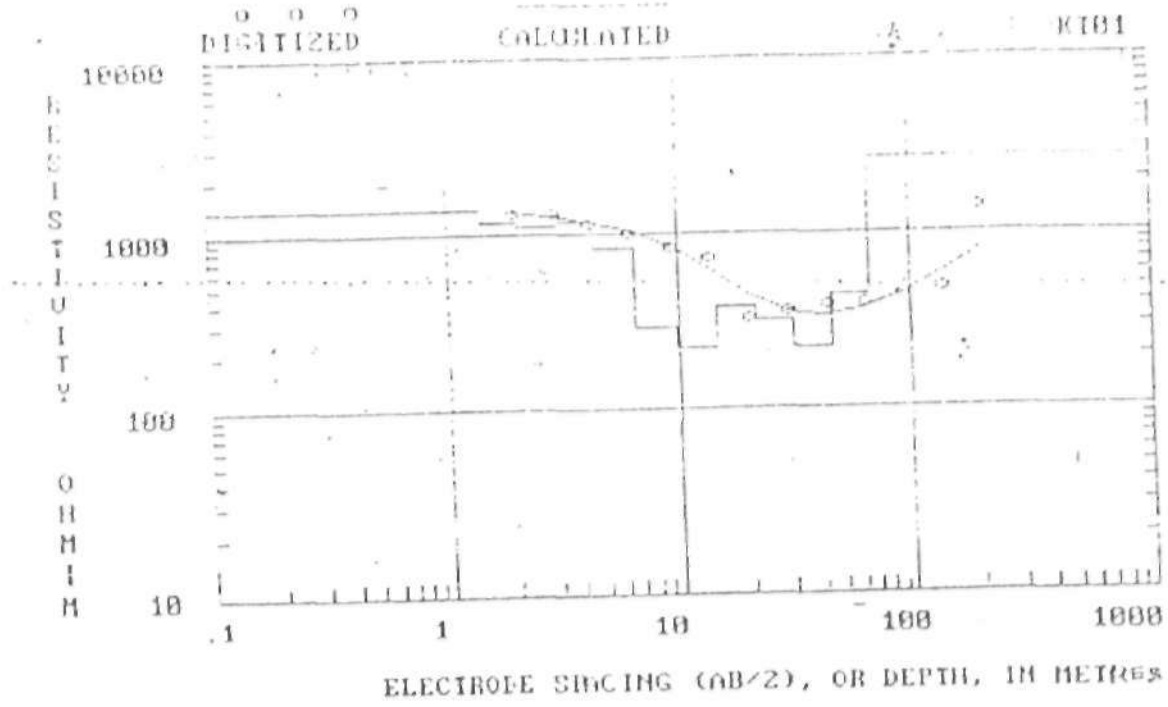

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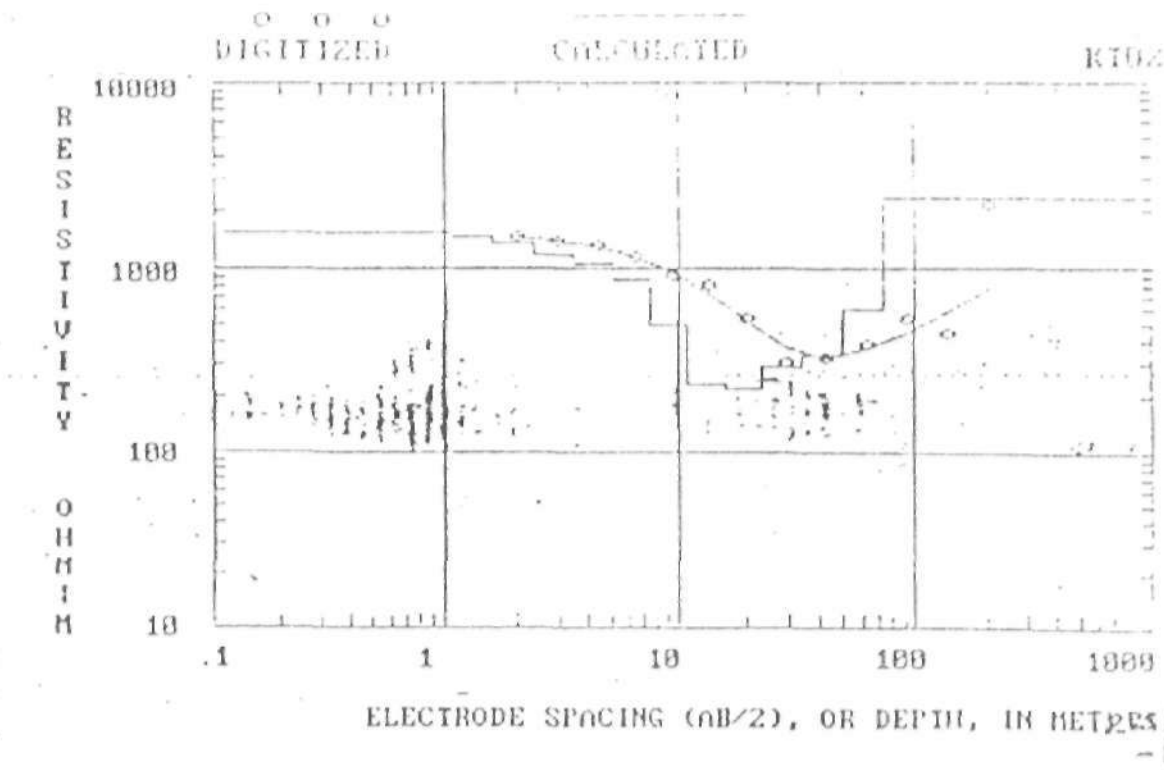

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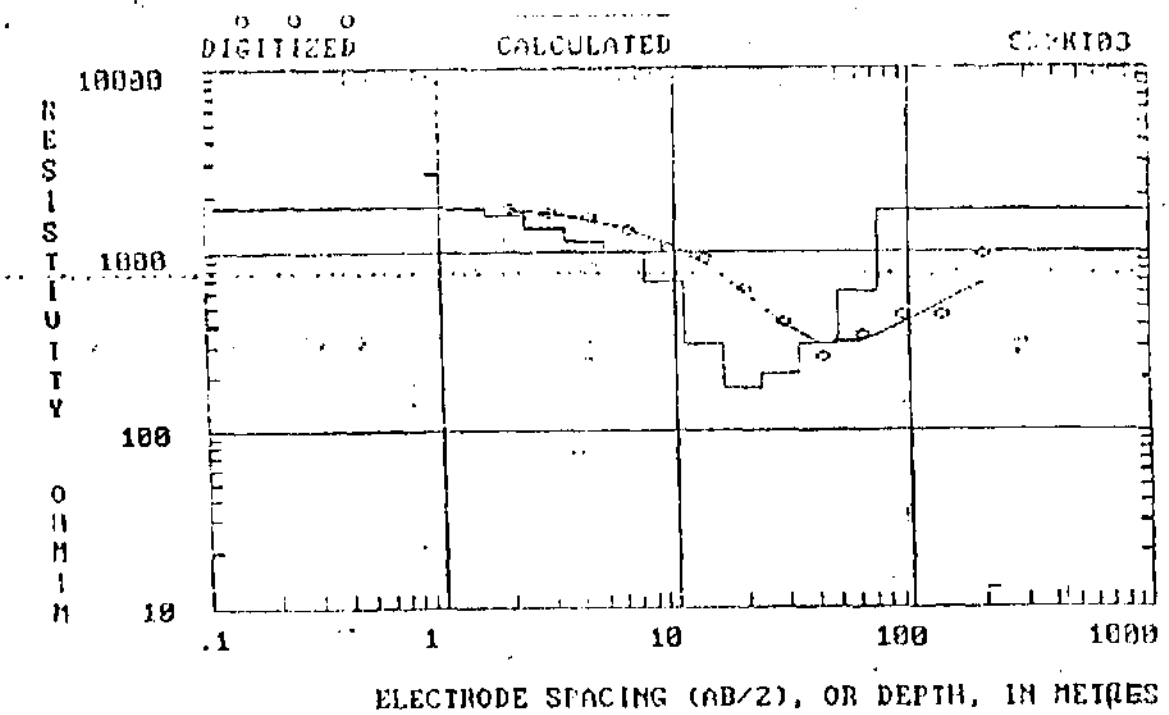

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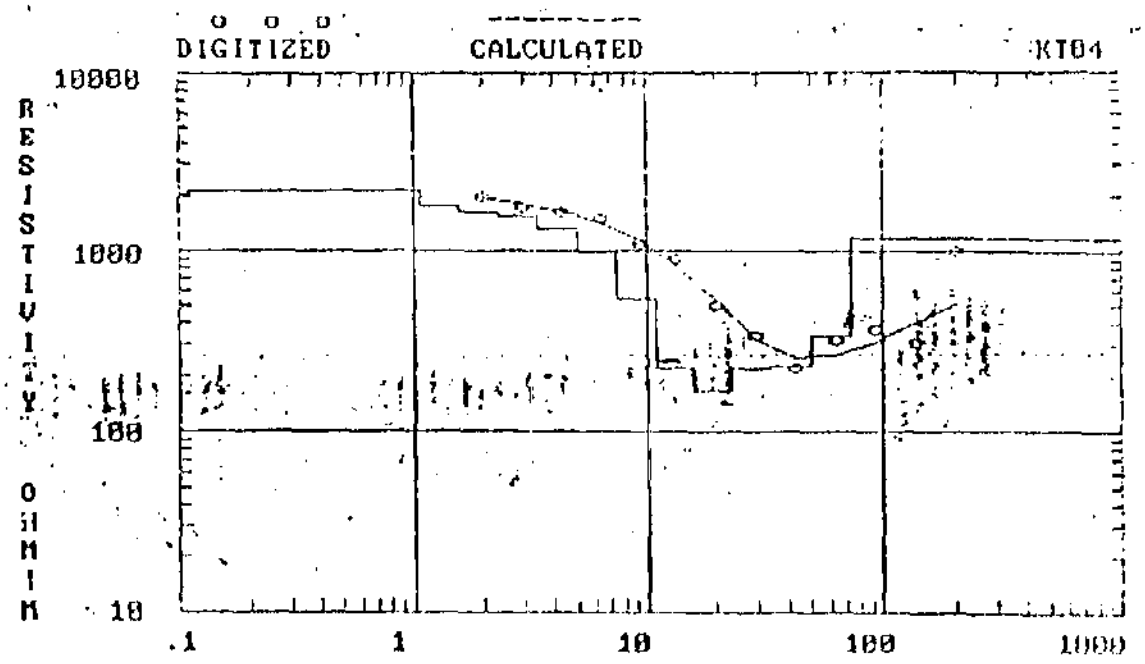

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ELECTRODE SPACING (AB/2), OR DEPTH, IN METRES

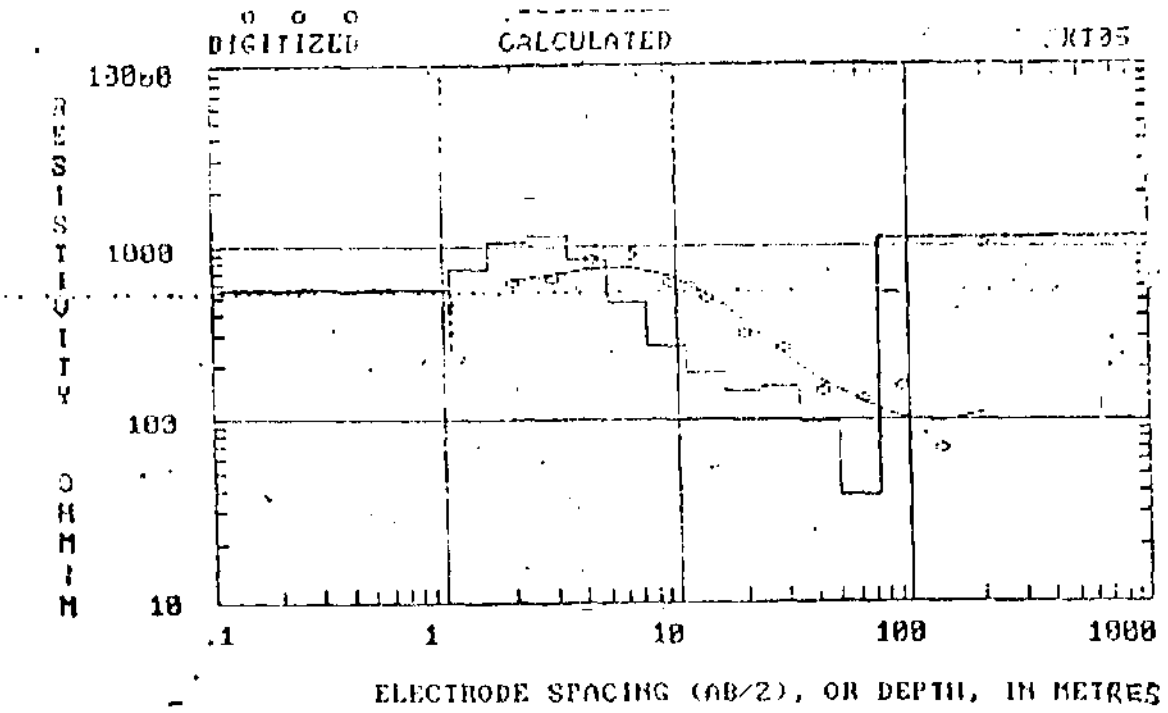

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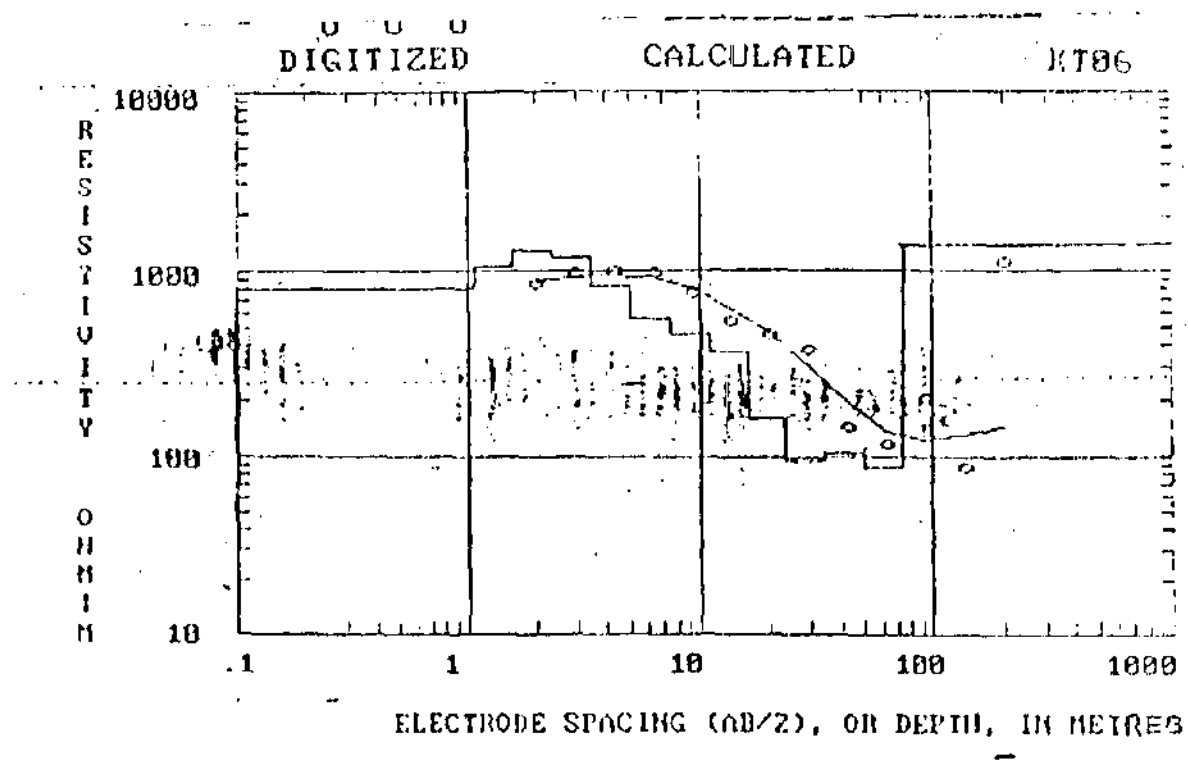

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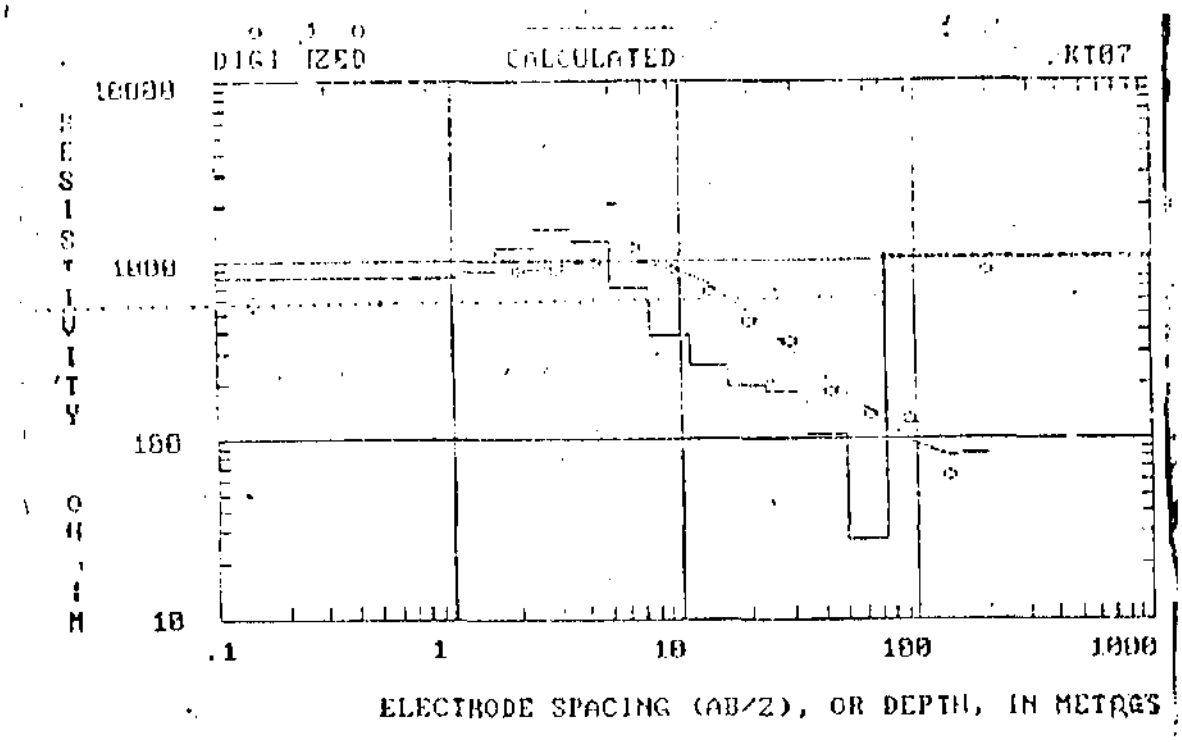

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CALCULATED
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ELECTRODE SPACING (AB/2), OR DEPTH, IN METRES

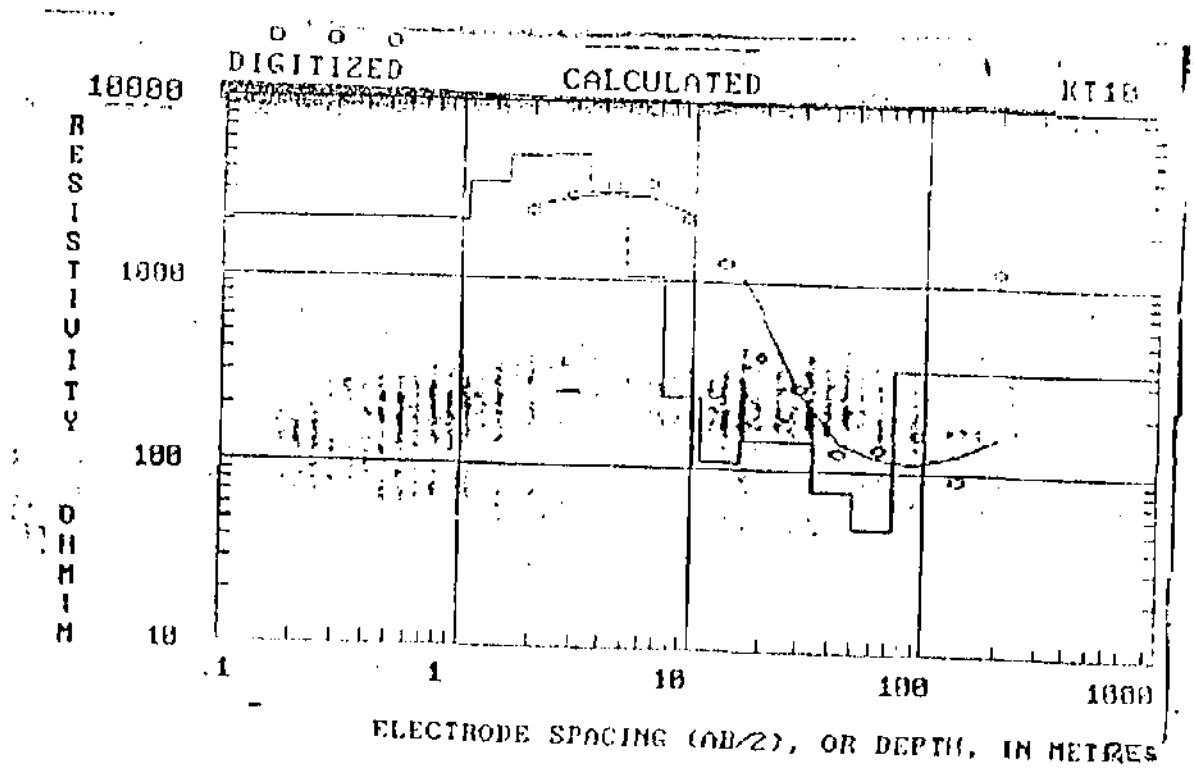

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ELECTRODE SPACING (AB/2), OR DEPTH, IN METRES

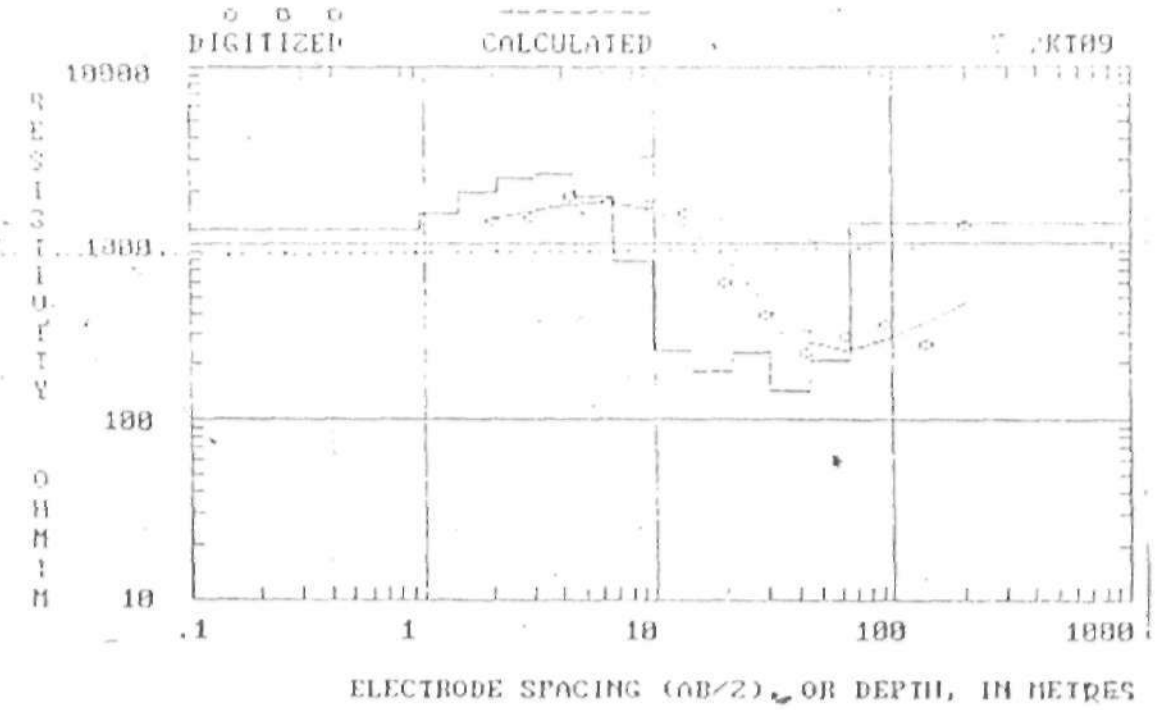

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ELECTRODE SPACING (AB/2), OR DEPTH, IN METRES

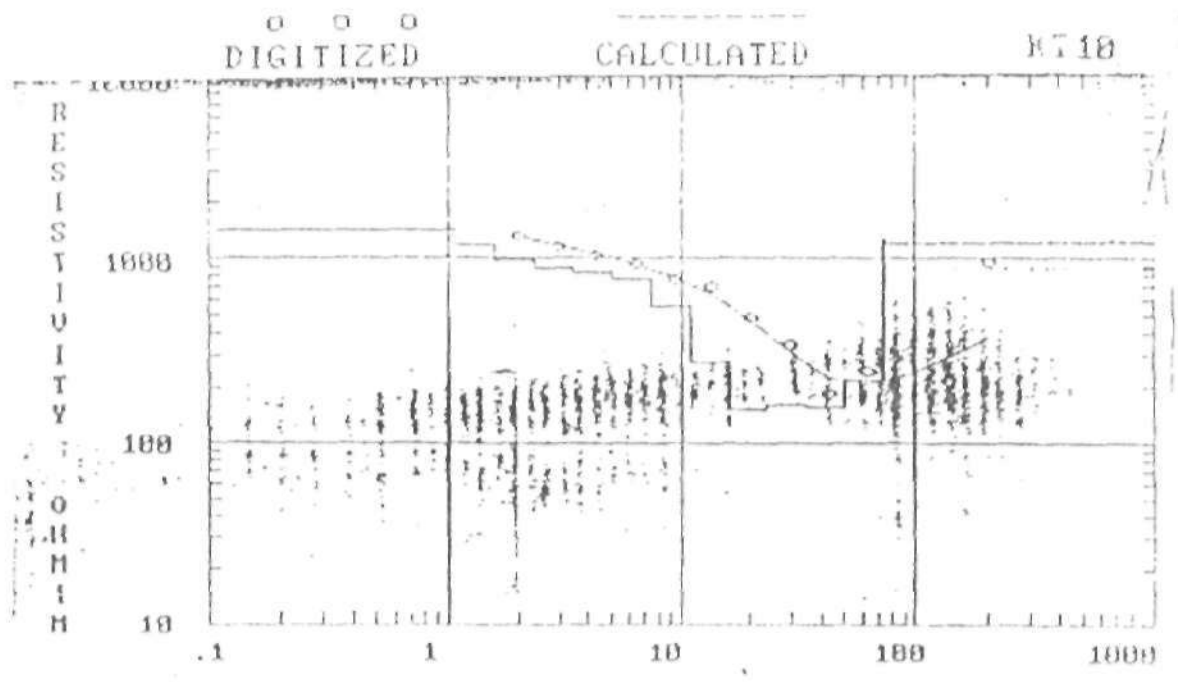

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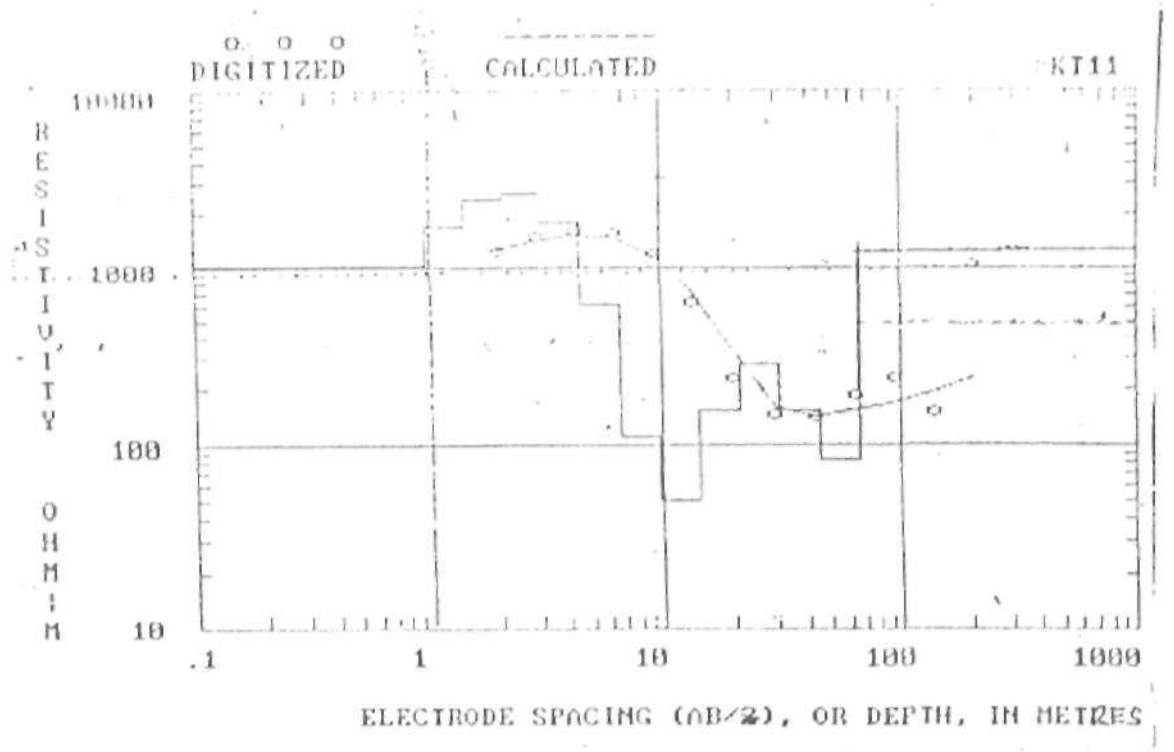

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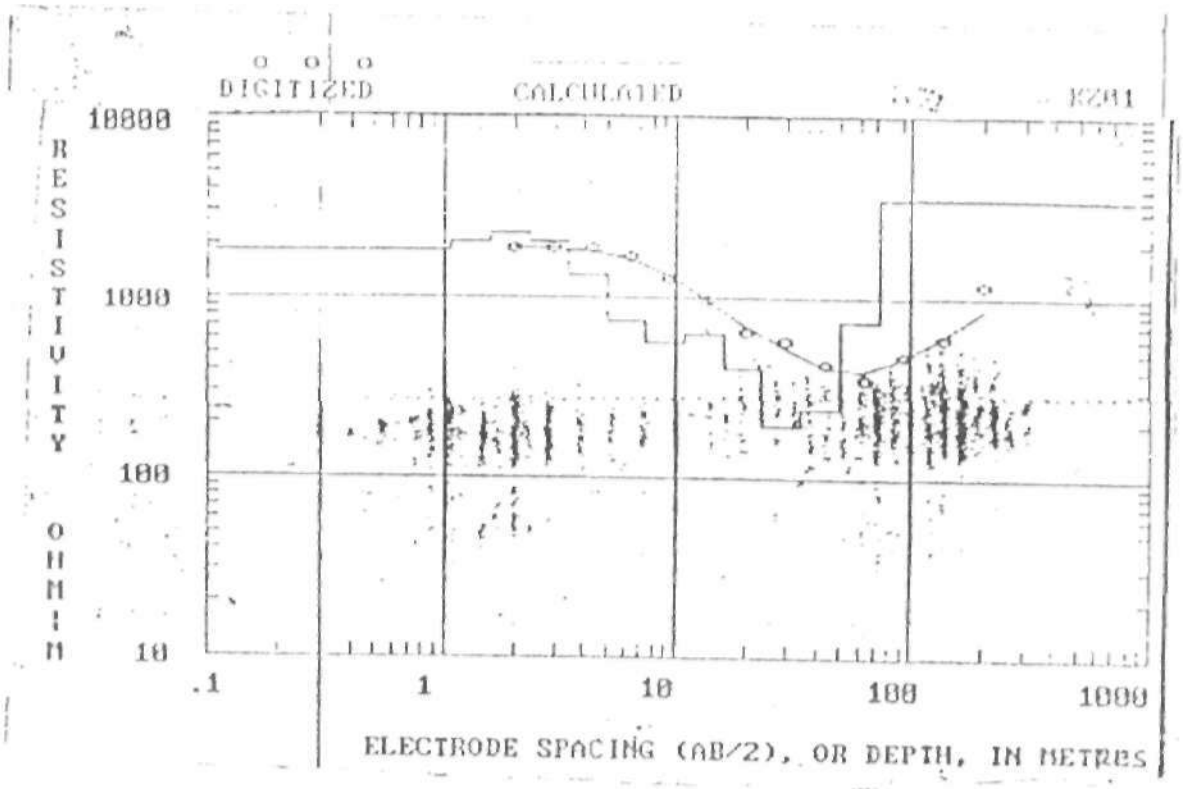

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ELECTRODE SPACING (AB/2), OR DEPTH, IN METRES

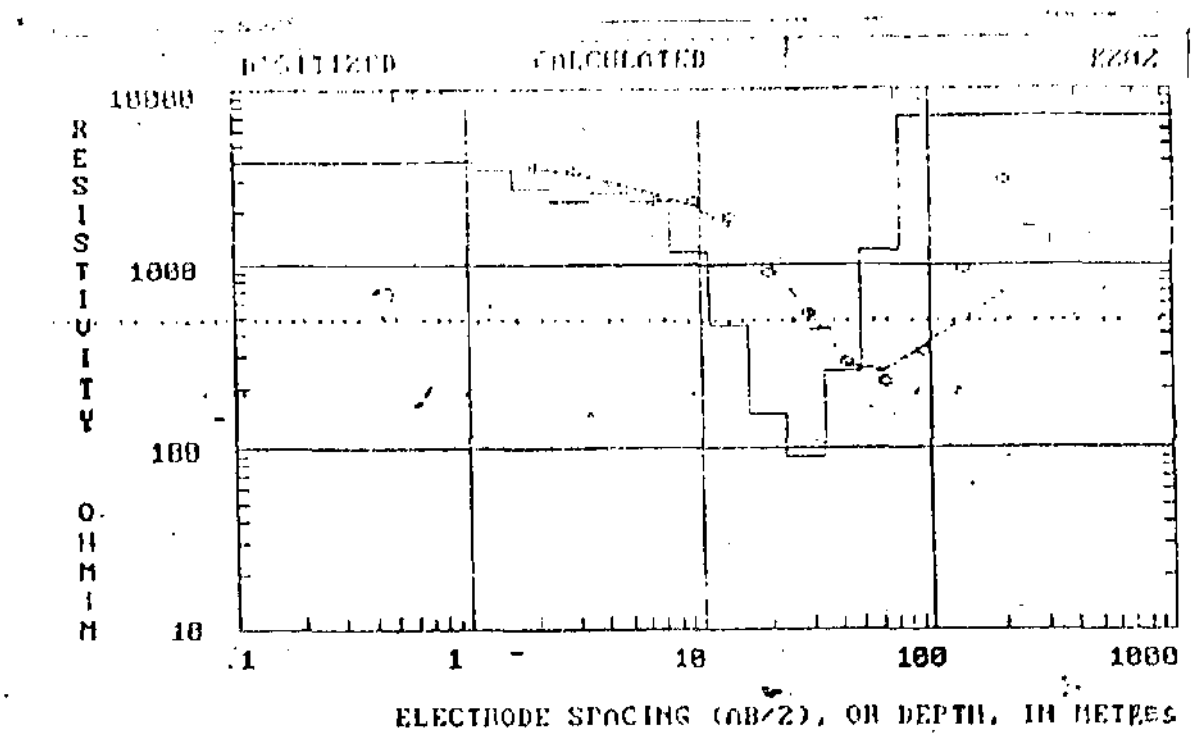

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ELECTRODE SPACING (AB/2), OR DEPTH, IN METRES

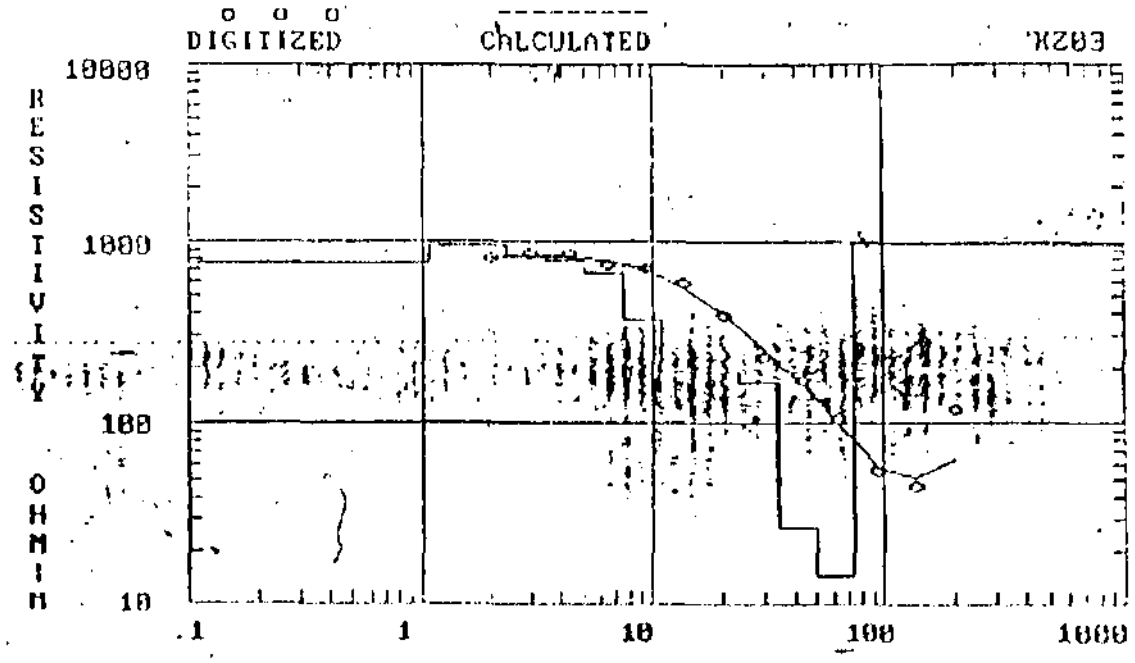

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RESISTIVITY OHMIM
ELECTRODE SPACING (AB/2), OR DEPTH, IN METRES

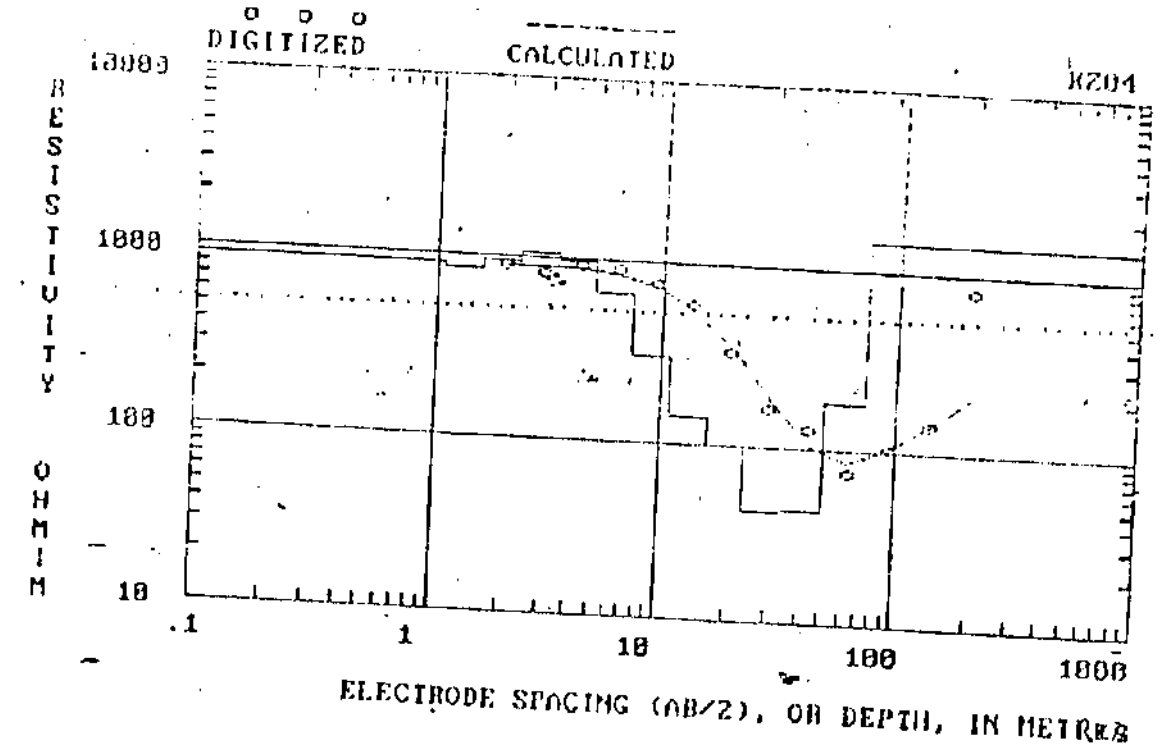

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RESISTIVITY OHMIM
ELECTRODE SPACING (AB/2), OR DEPTH, IN METRES

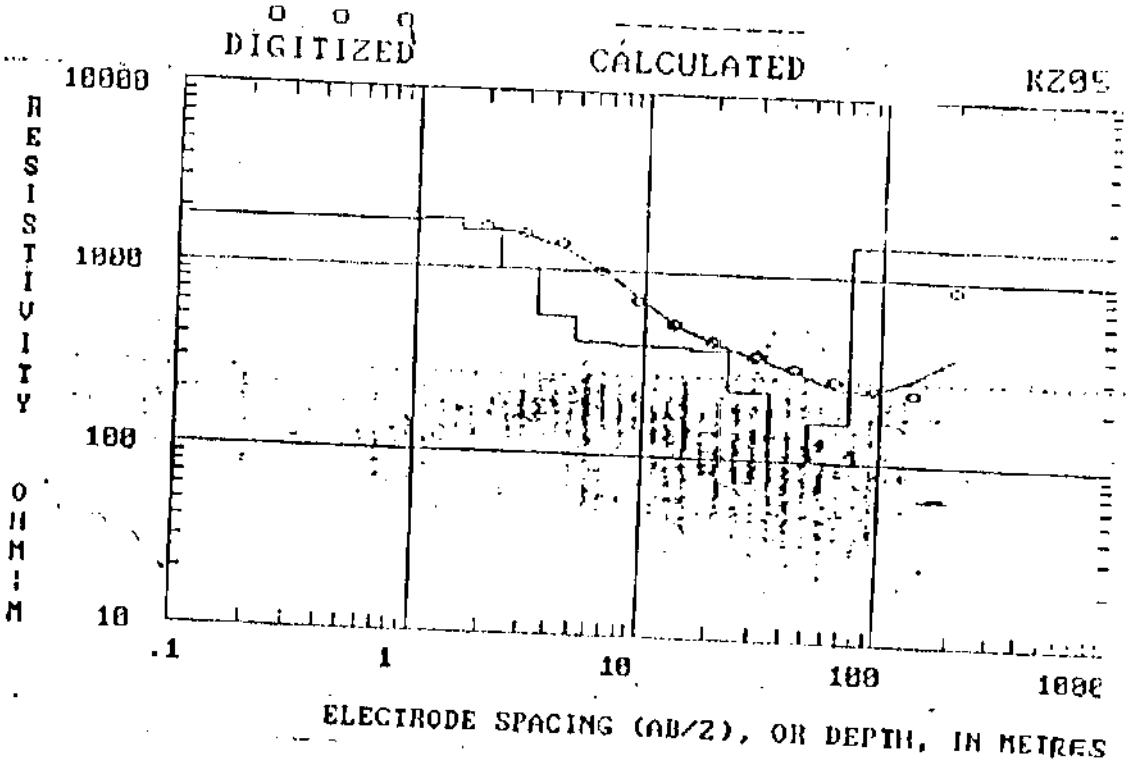

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ELECTRODE SPACING (AB/2), OR DEPTH, IN METRES

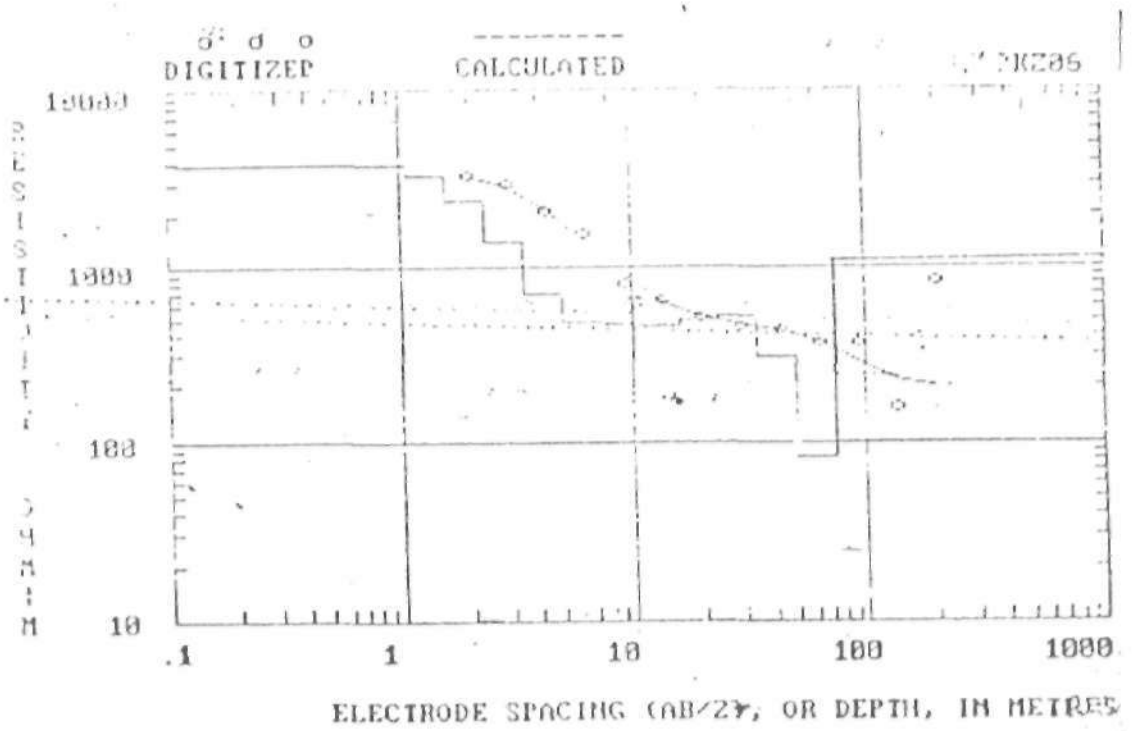

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ELECTRODE SPACING (AB/2), OR DEPTH, IN METRES

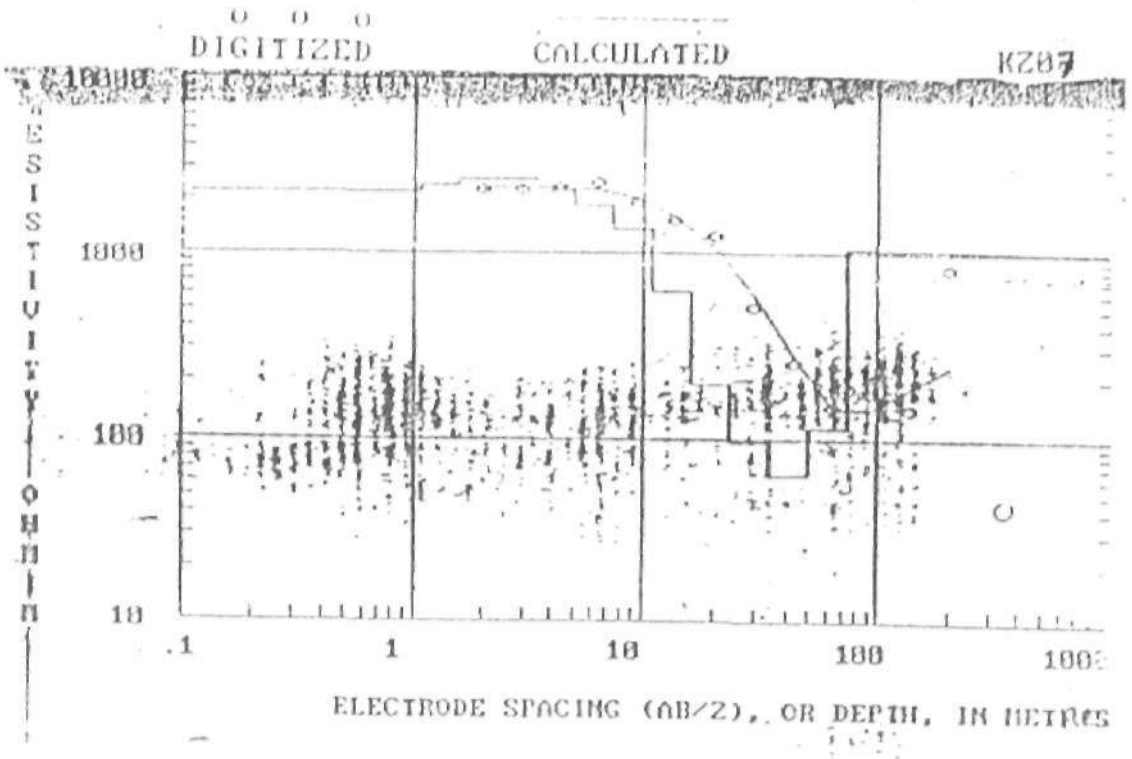

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RESISTIVITY OHMIN
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ELECTRODE SPACING (AB/2), OR DEPTH, IN METRES

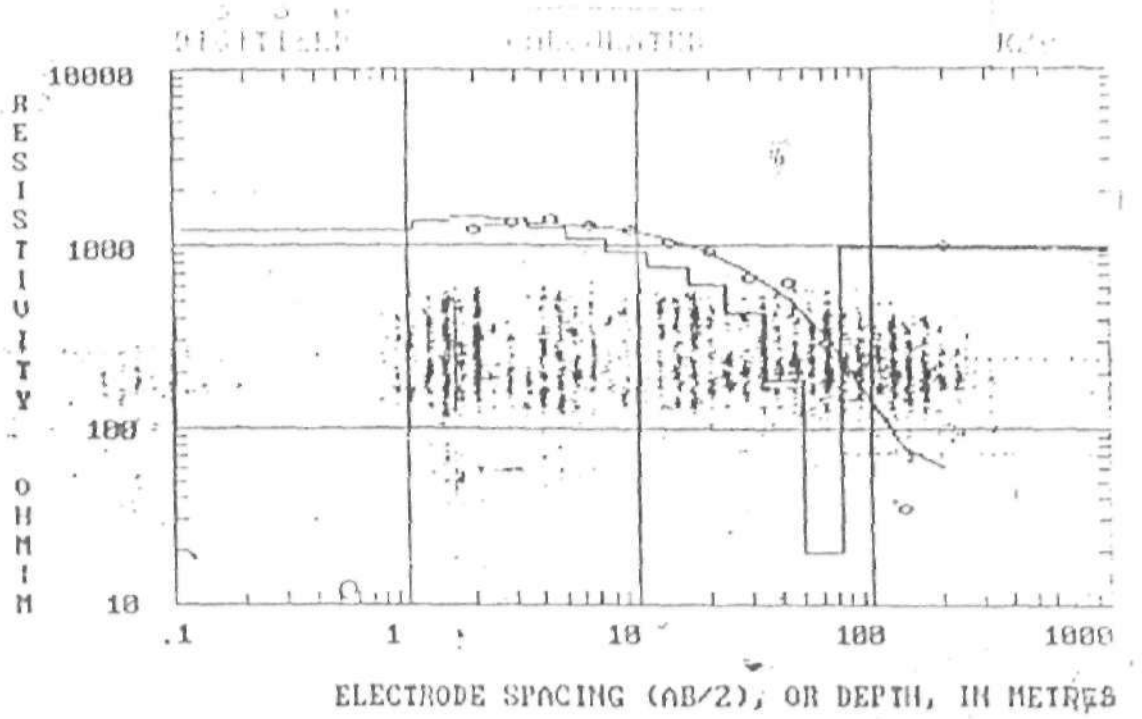

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RESISTIVITY OHMIN
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ELECTRODE SPACING (AB/2), OR DEPTH, IN METRES

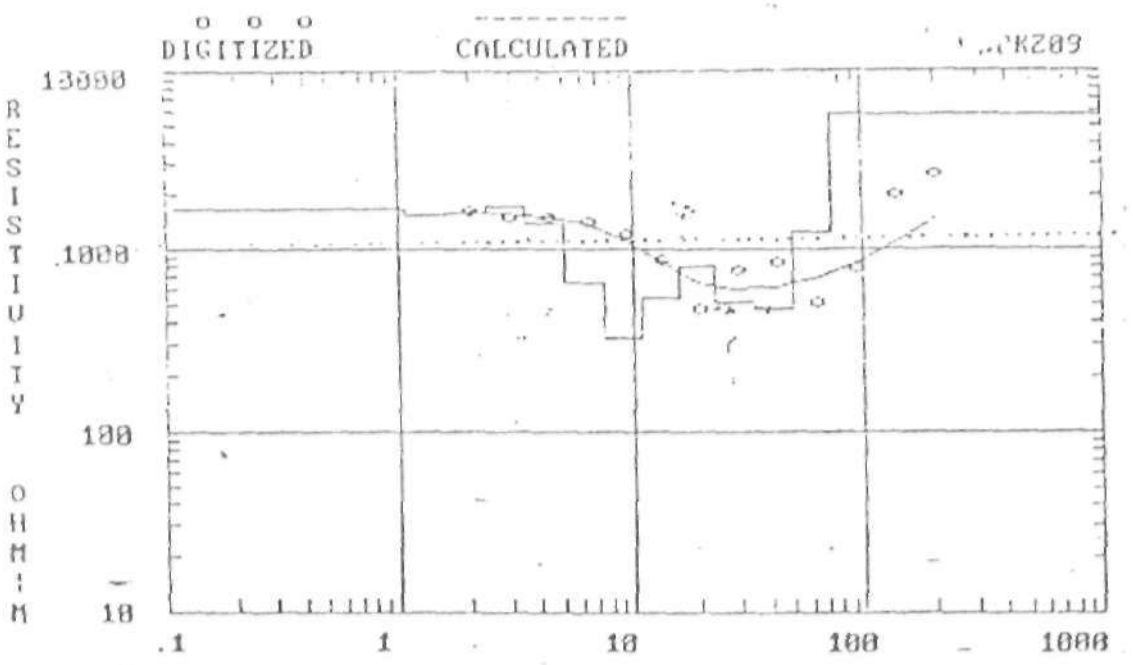

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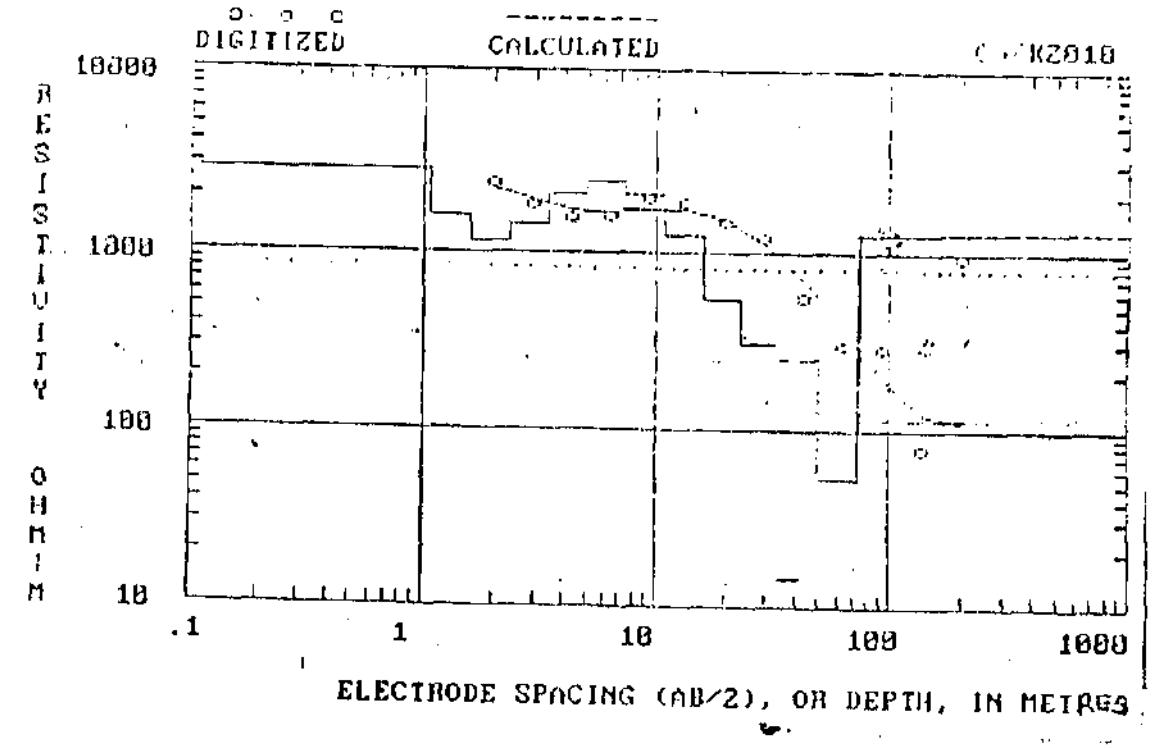

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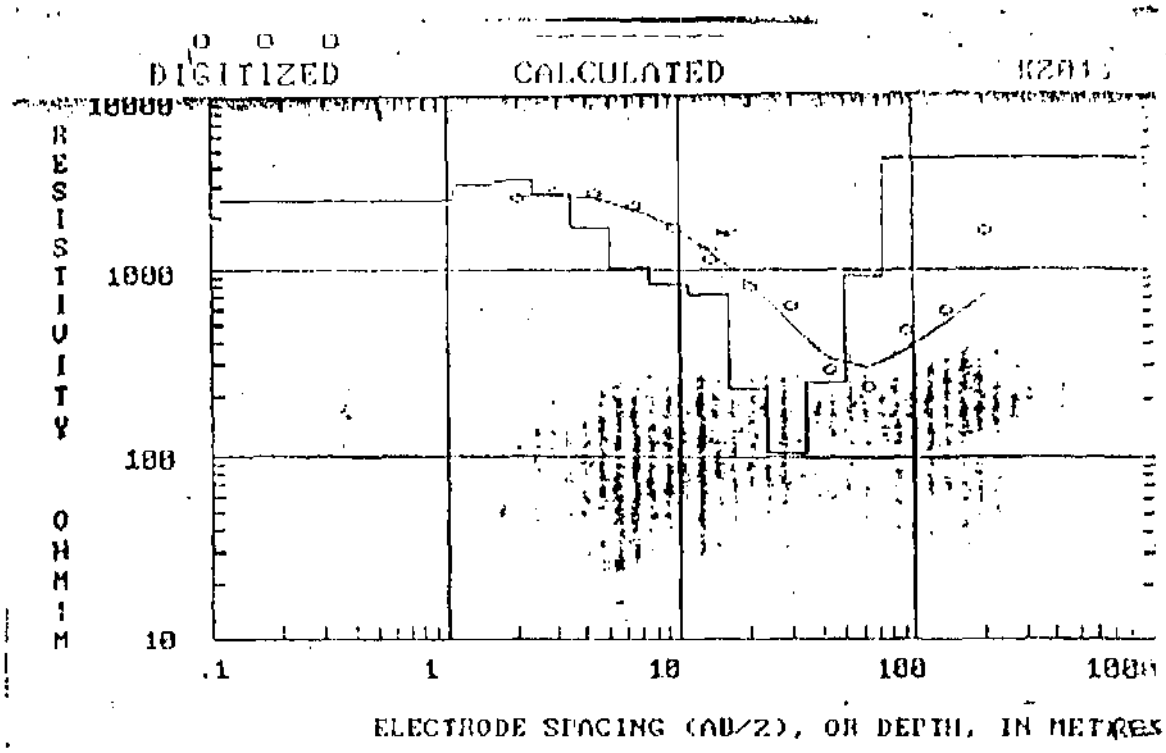

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ELECTRODE SPACING (AB/2), OR DEPTH, IN METRES


DIGITIZED
CALCULATED
KZ07
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10
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100
ELECTRODE SPACING (AB/2), OR DEPTH, IN METRES


DIGITIZED
CALCULATED
RESISTIVITY OHMIM
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ELECTRODE SPACING (AB/2), OR DEPTH, IN METRES

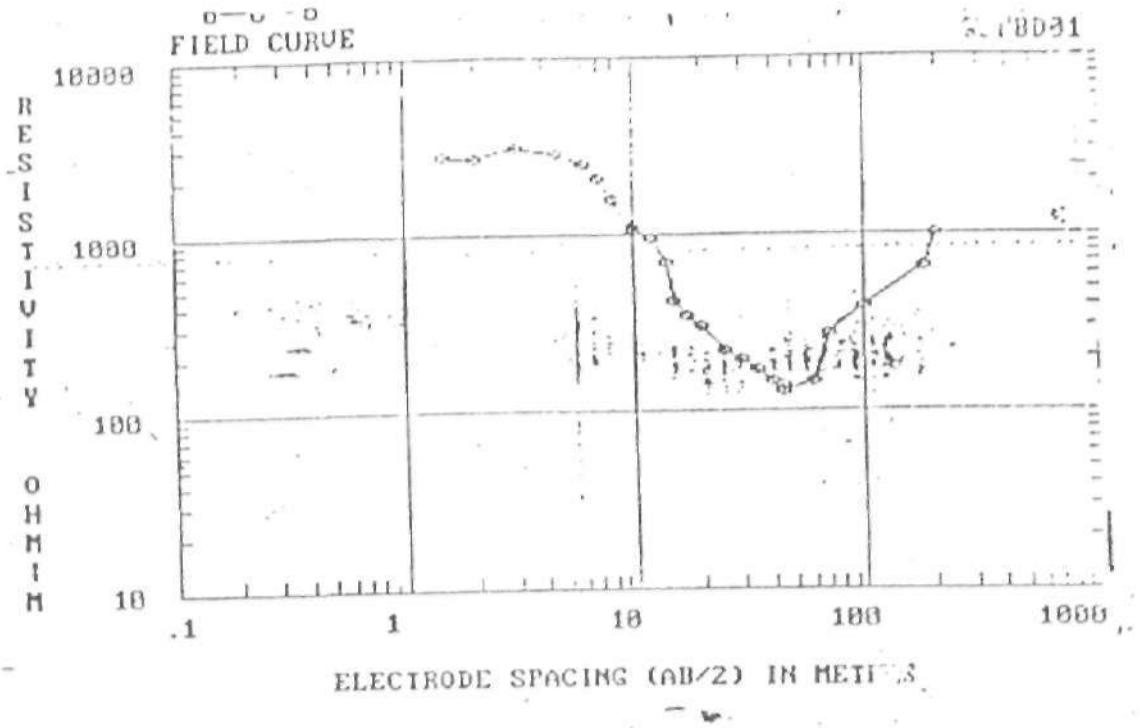

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ELECTRODE SPACING (AB/2), OR DEPTH, IN METRES

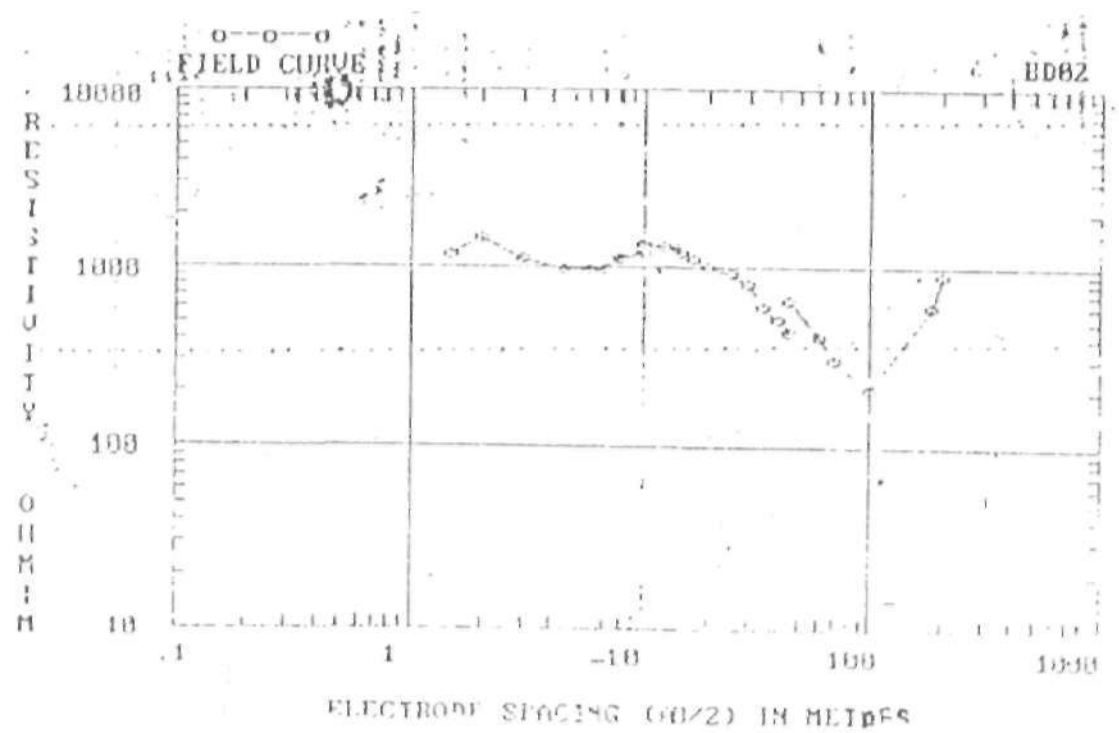

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RESISTIVITY OHM-M
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ELECTRODE SPACING (AB/2), OR DEPTH, IN METRES

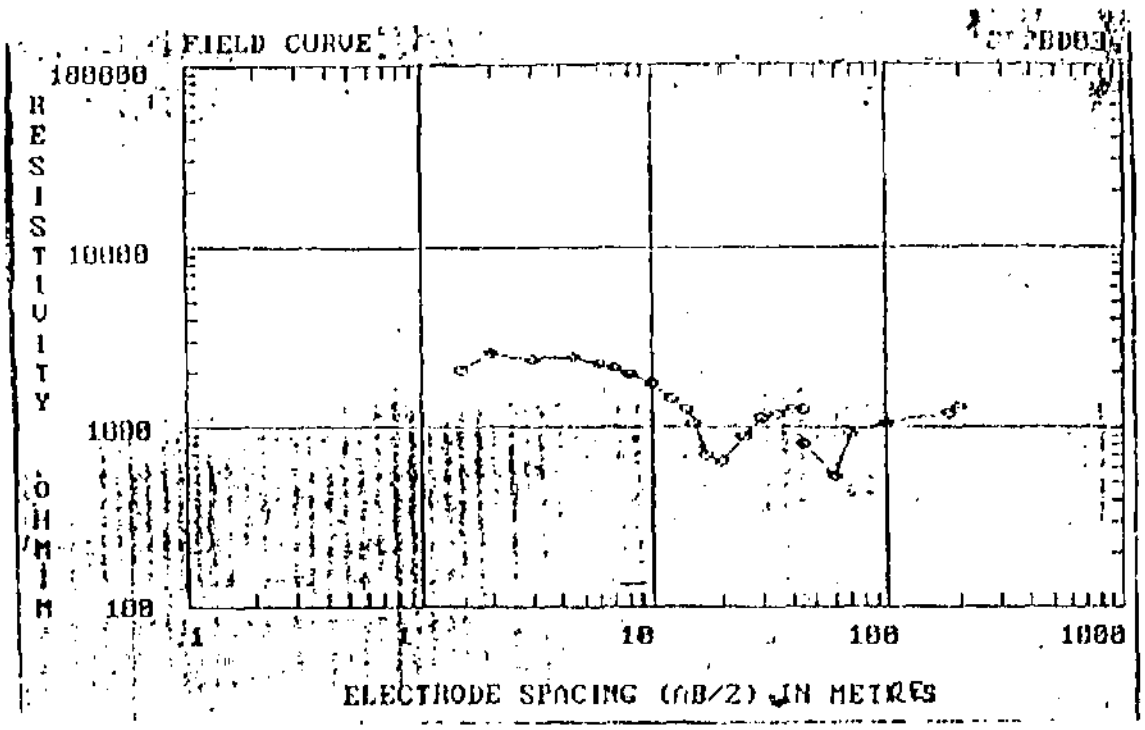

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RESISTIVITY OHM-M
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ELECTRODE SPACING (AB/2), OR DEPTH, IN METRES

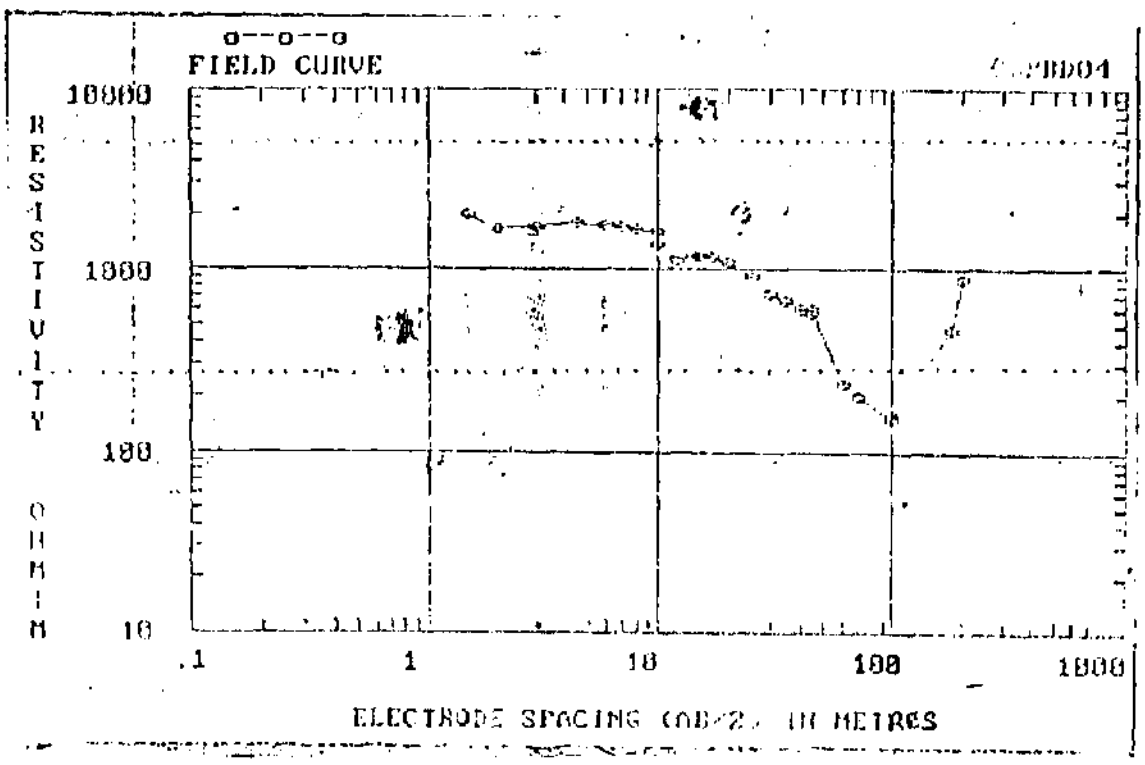
# APPENDIX B

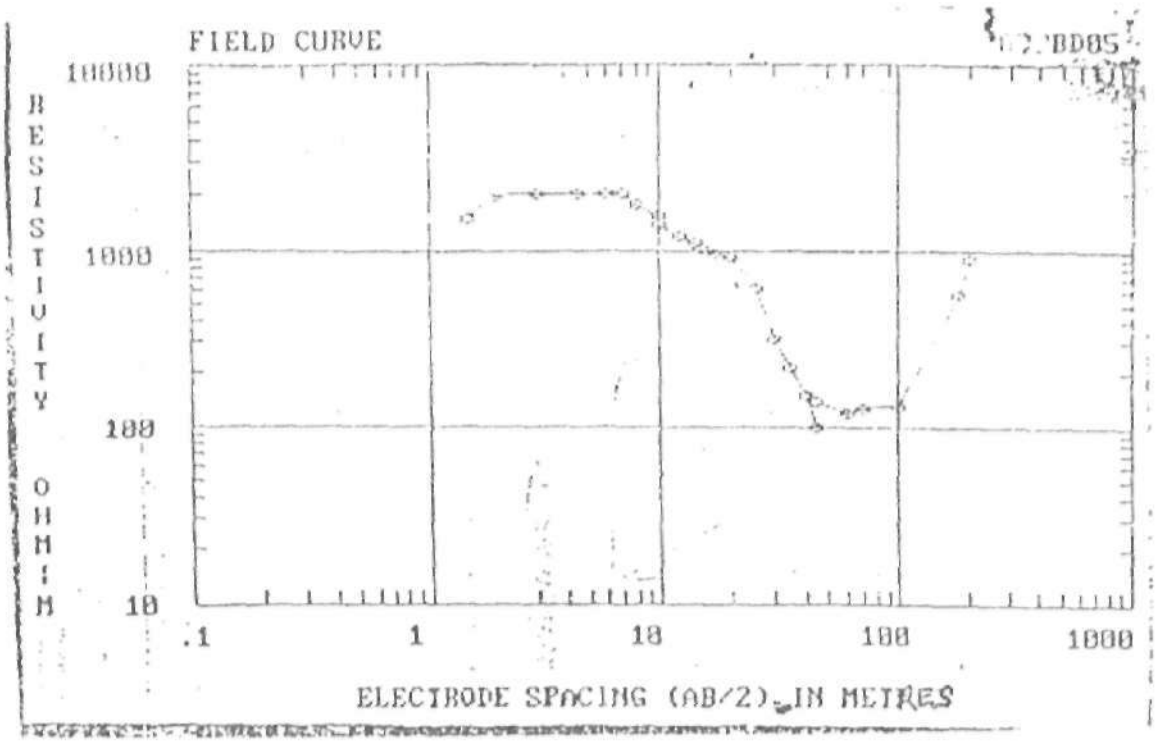
AUTOMATICALLY PLOTTED FIELD CURVES PRIOR TO
INTERPRETATION FOR BODEYEL, KARAFTAYI AND KAZAURE TOWN.

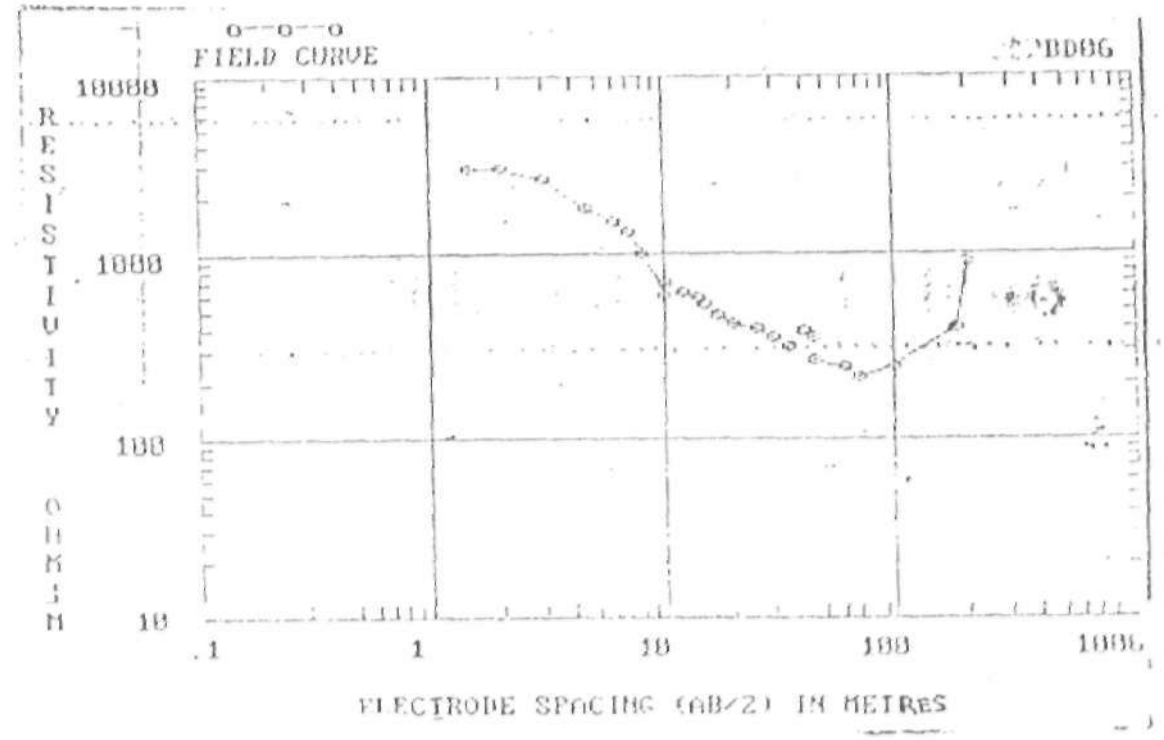

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RESISTIVITY OHMIM
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ELECTRODE SPACING (AB/2) IN METERS

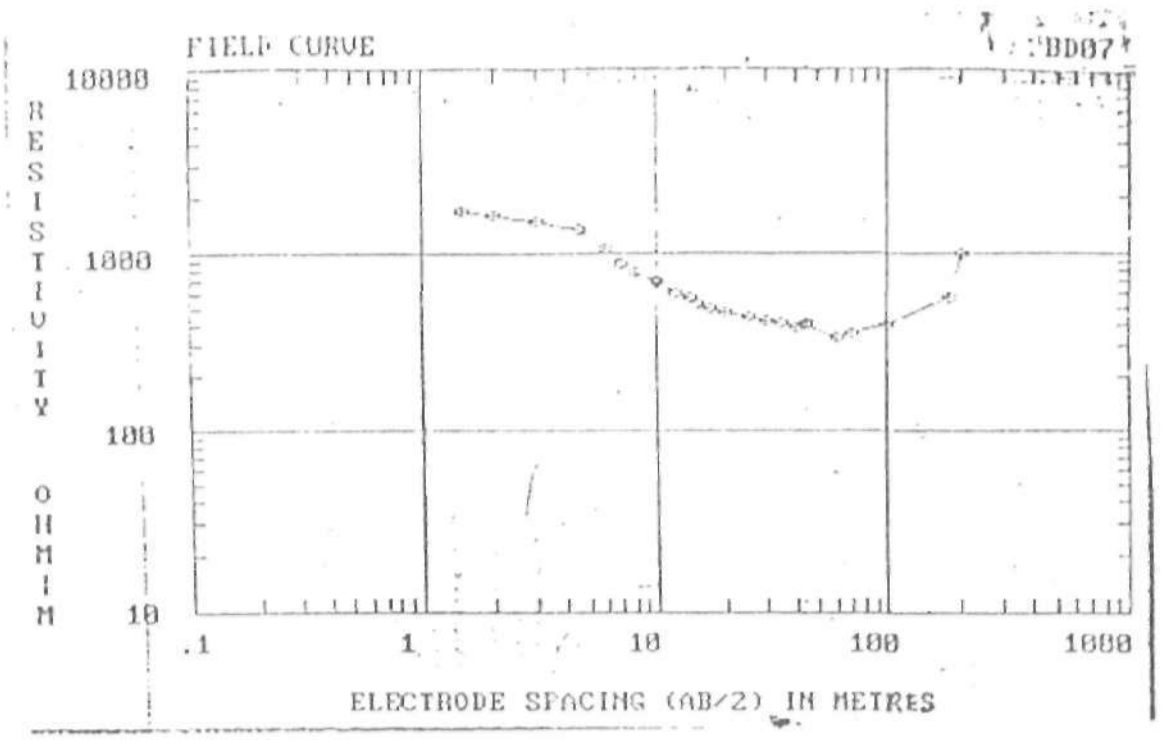

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ELECTRODE SPACING (AB/2) IN METERS

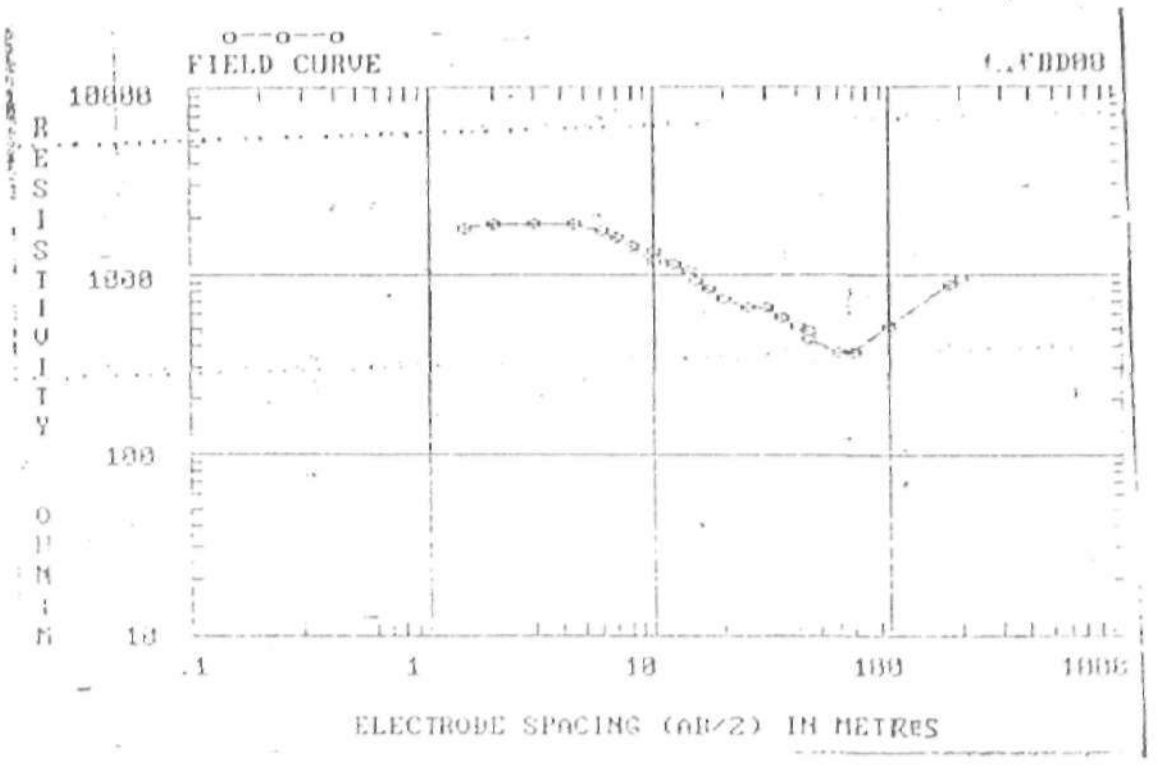

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RESISTIVITY OHMM
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1000
ELECTRODE SPACING (AB/2) IN METRES

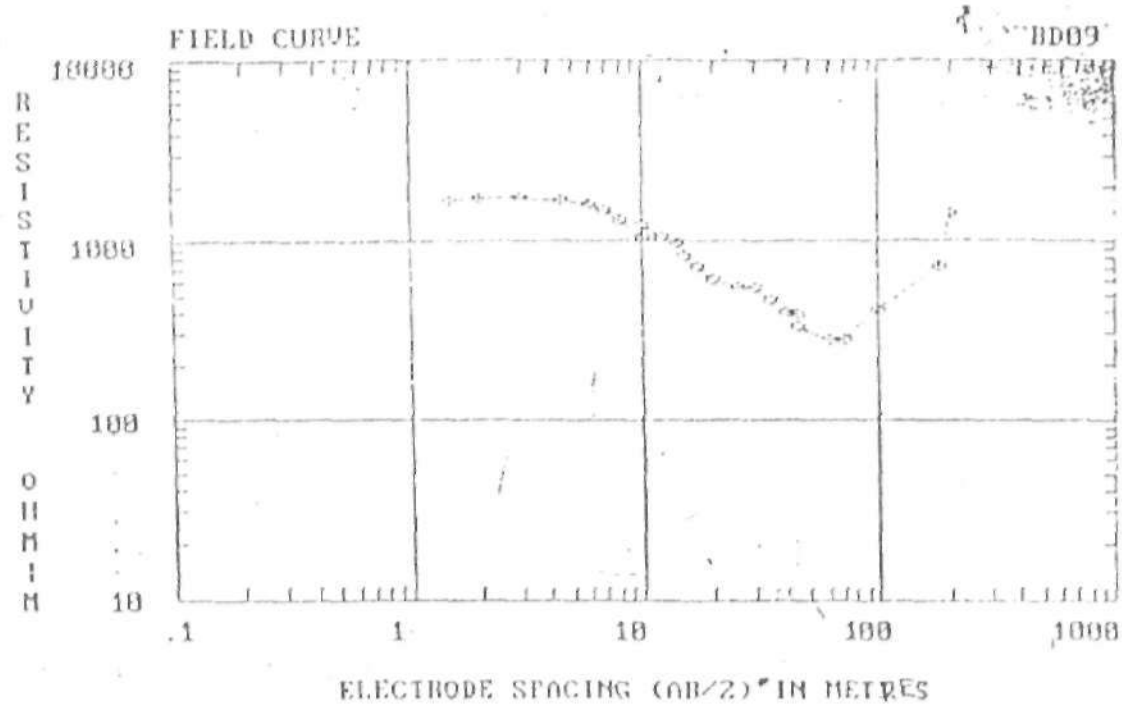

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RESISTIVITY OHMM
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1000
ELECTRODE SPACING (AB/2) IN METRES

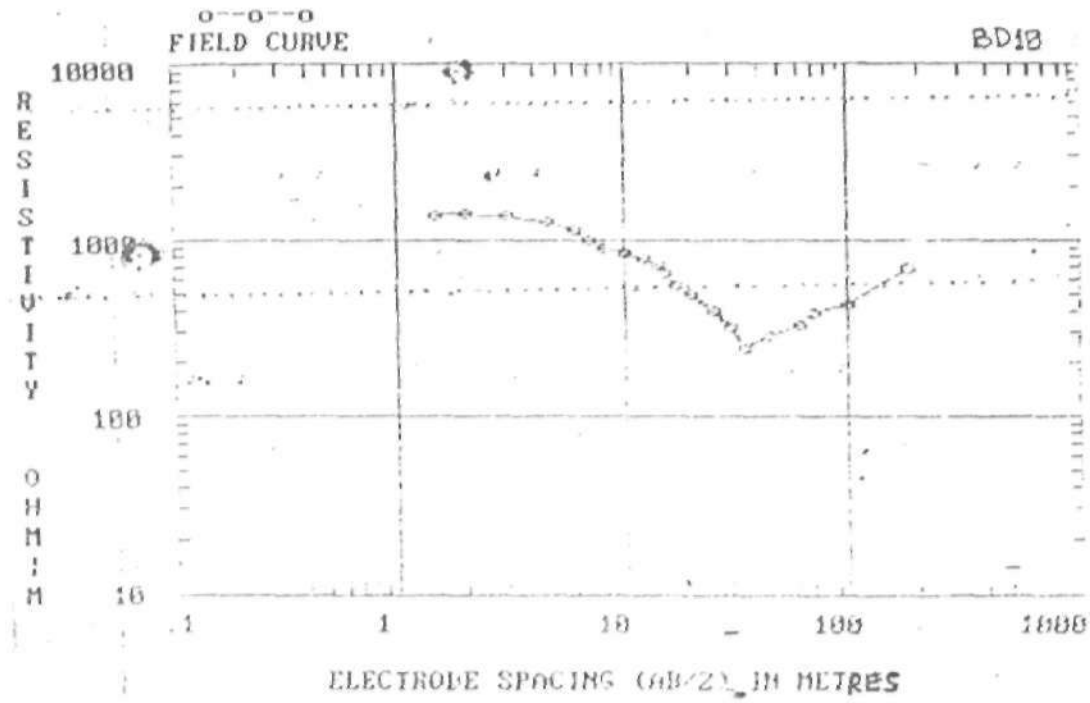

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RESISTIVITY OHMS M
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ELECTRODE SPACING (AB/2) IN METRES

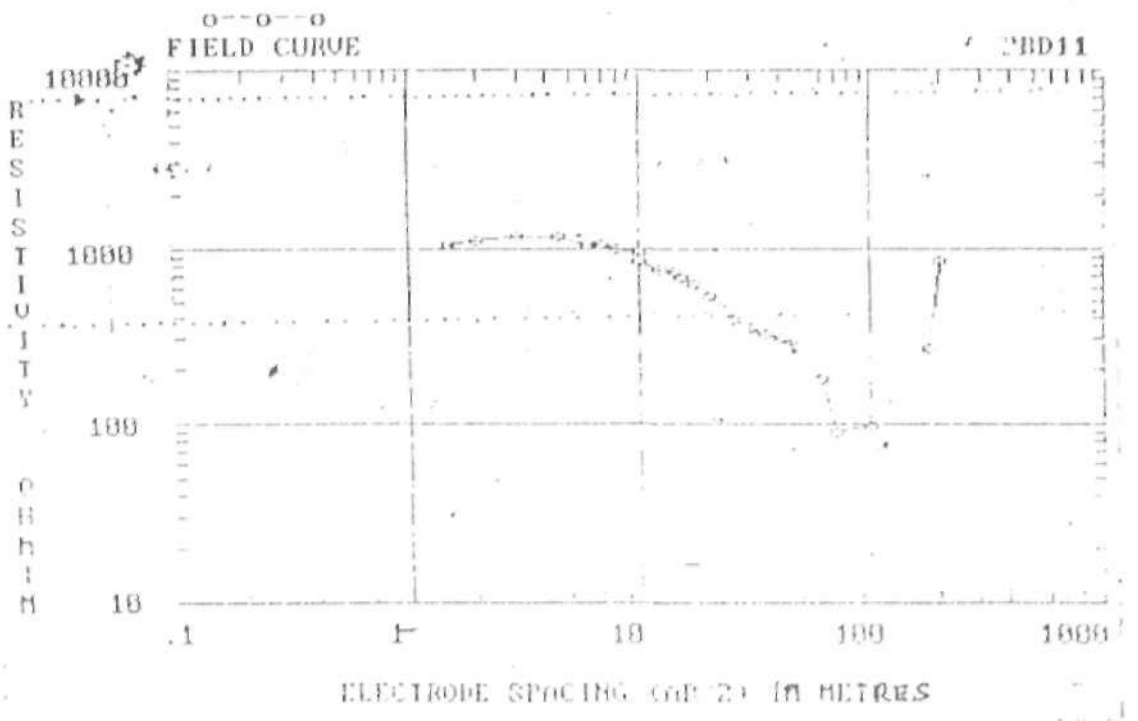

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RESISTIVITY OHMS M
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ELECTRODE SPACING (AB/2) IN METRES

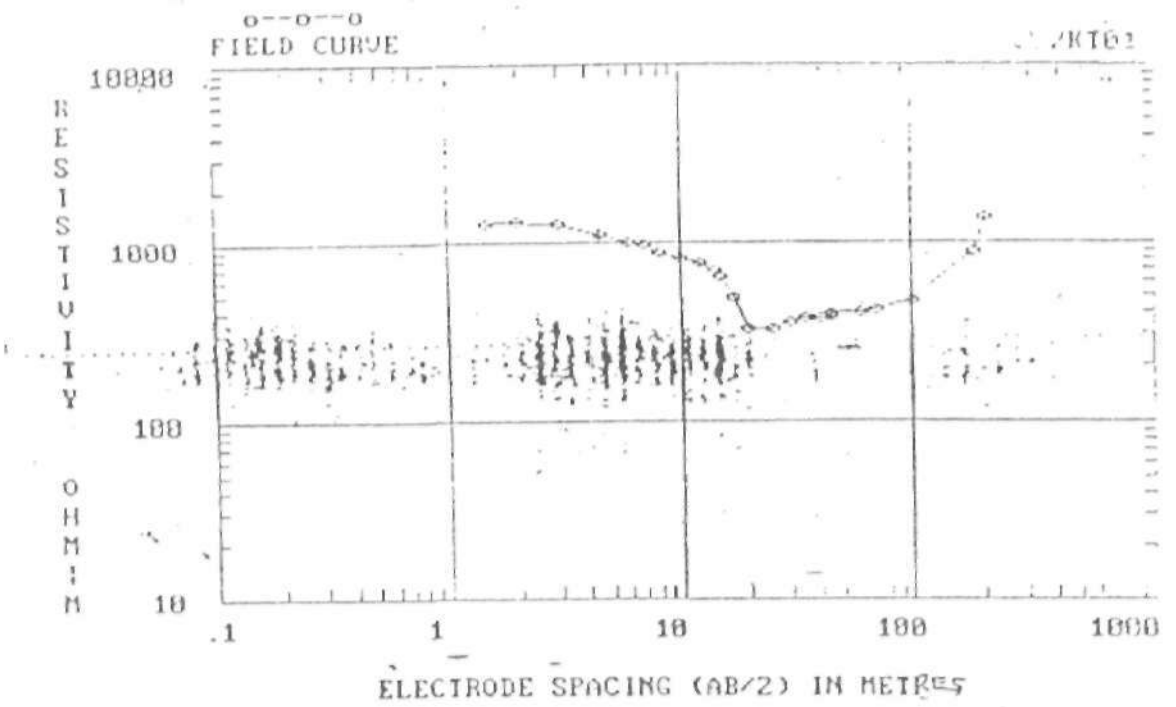

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RESISTIVITY OHMIM
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1000
ELECTRODE SPACING (AB/2) IN METRES

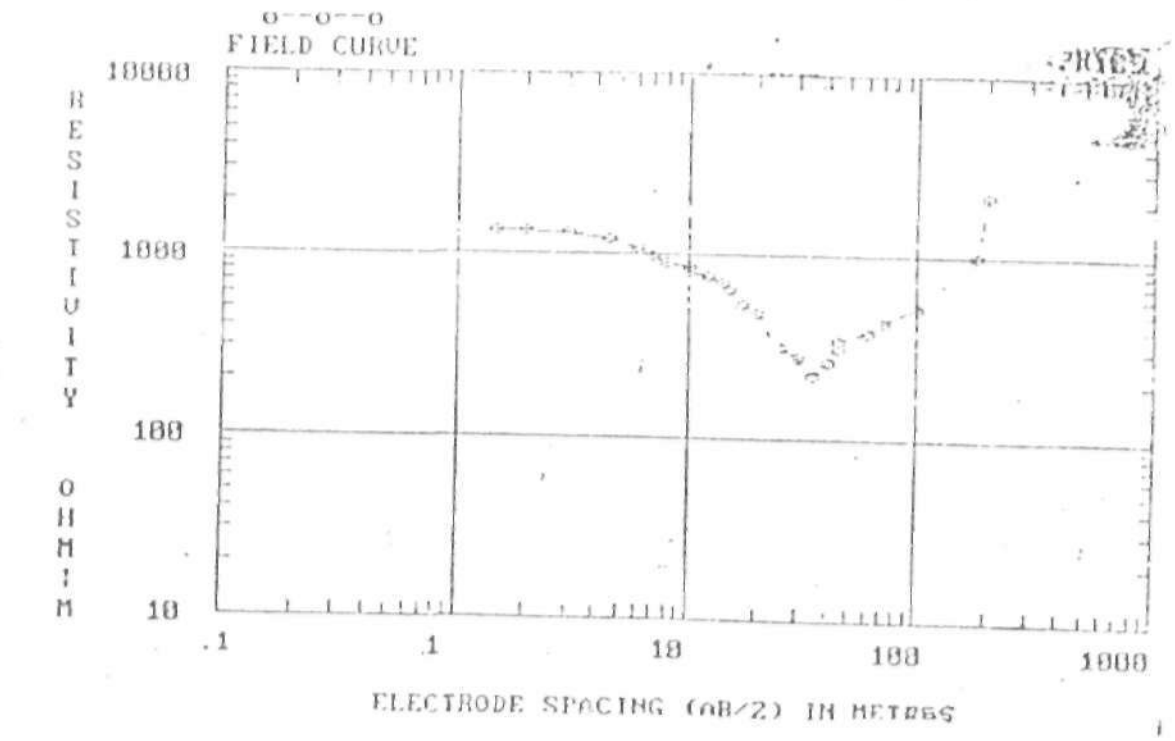

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RESISTIVITY OHMIM
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ELECTRODE SPACING (AB/2) IN METRES

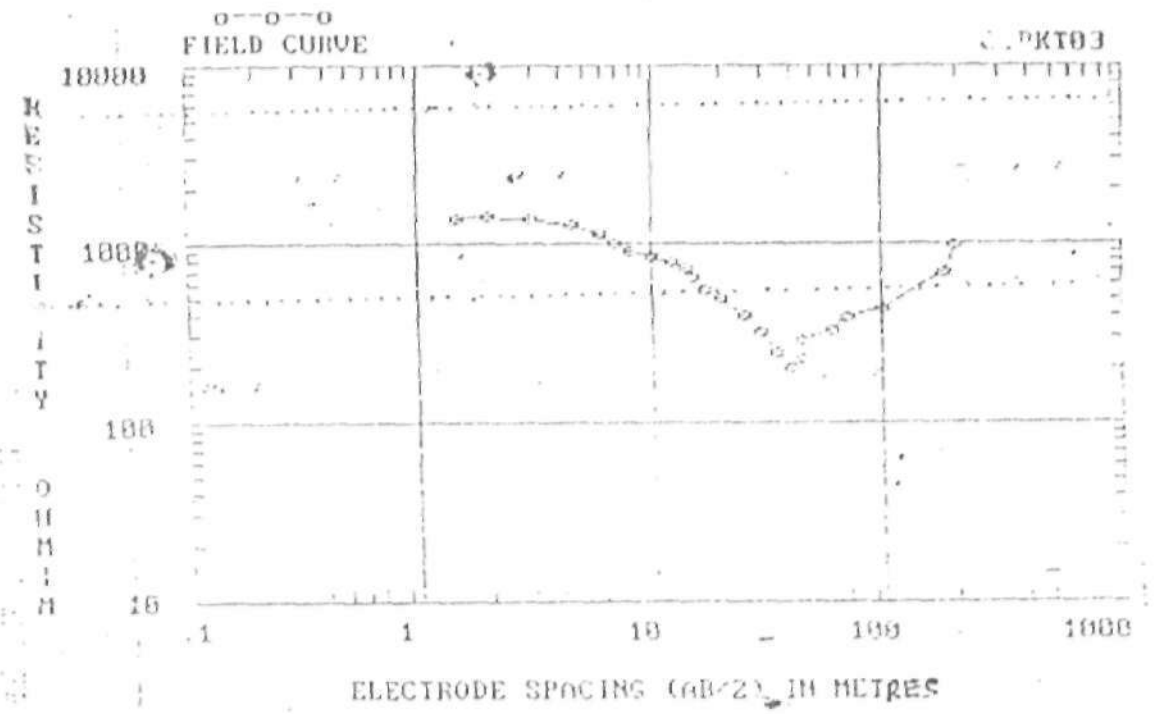

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ELECTRODE SPACING (AB/2) IN METRES

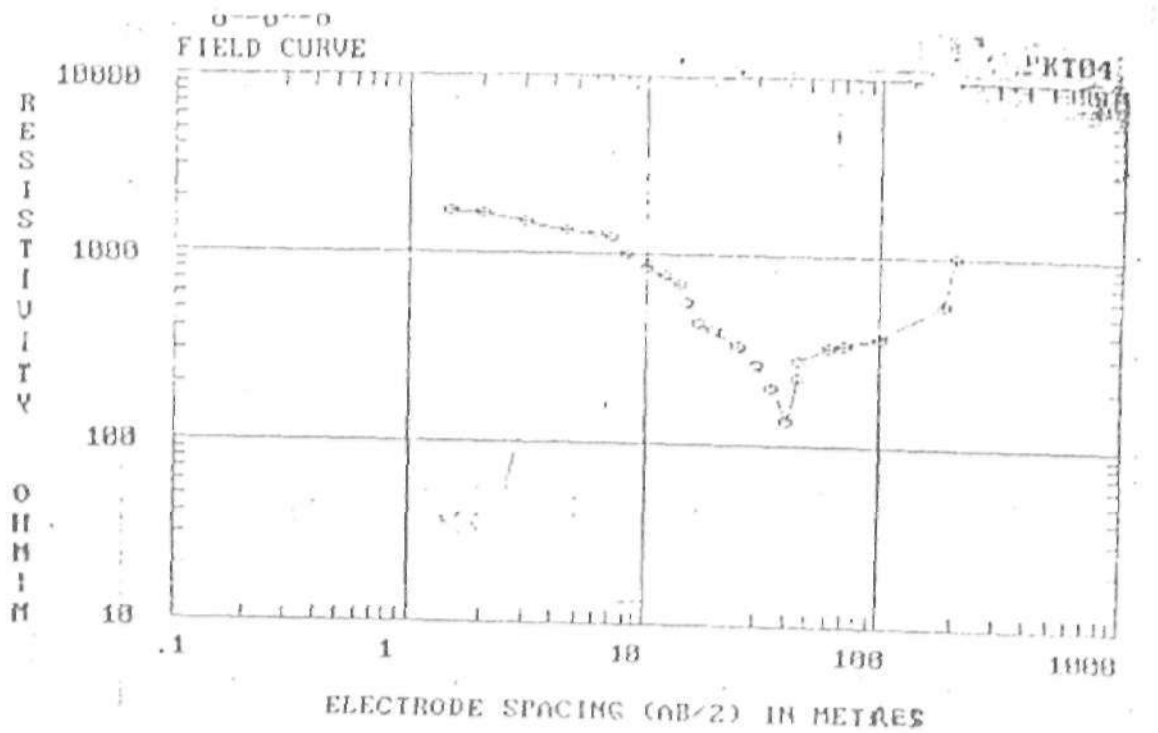

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RESISTIVITY OHMIM
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100
1000
ELECTRODE SPACING (AB/2) IN METRES

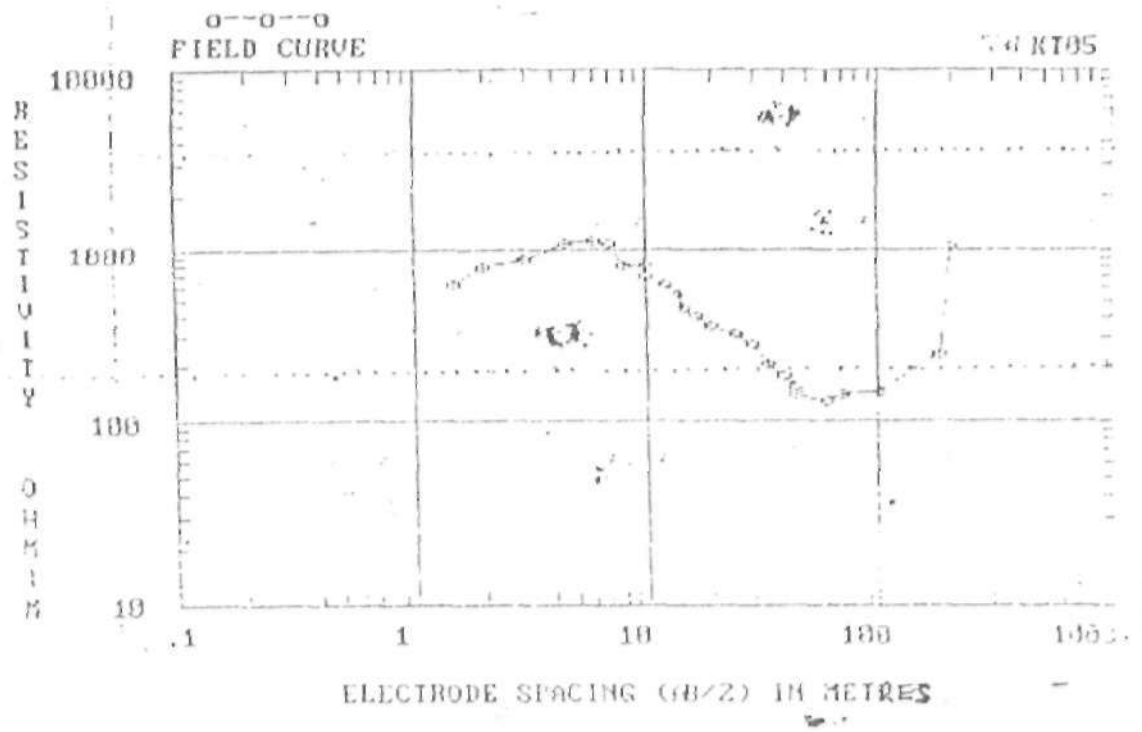

o--o--o
FIELD CURVE
BD11
10000
1000
100
10
RESISTIVITY
OHMM
.1
1
10
100
1000
ELECTRODE SPACING (AB/2) IN METRES

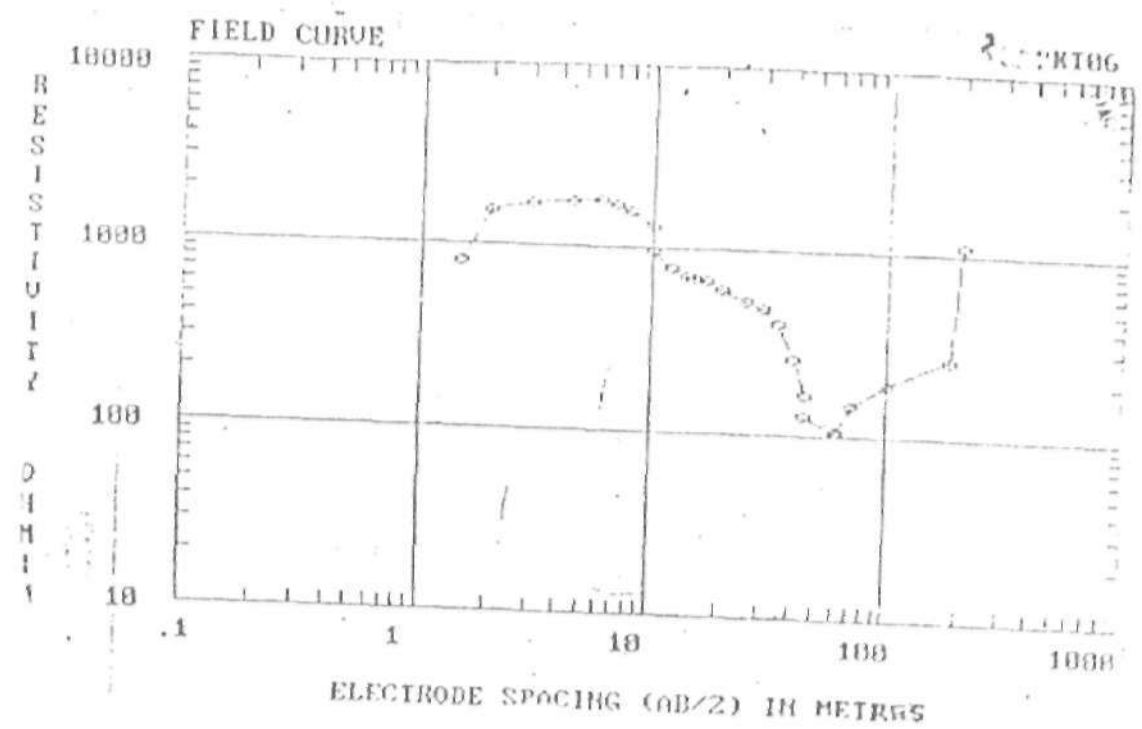

o--o--o
FIELD CURVE
10000
1000
100
10
RESISTIVITY OHMIM
.1
1
10
100
1000
ELECTRODE SPACING (AB/2) IN METRES

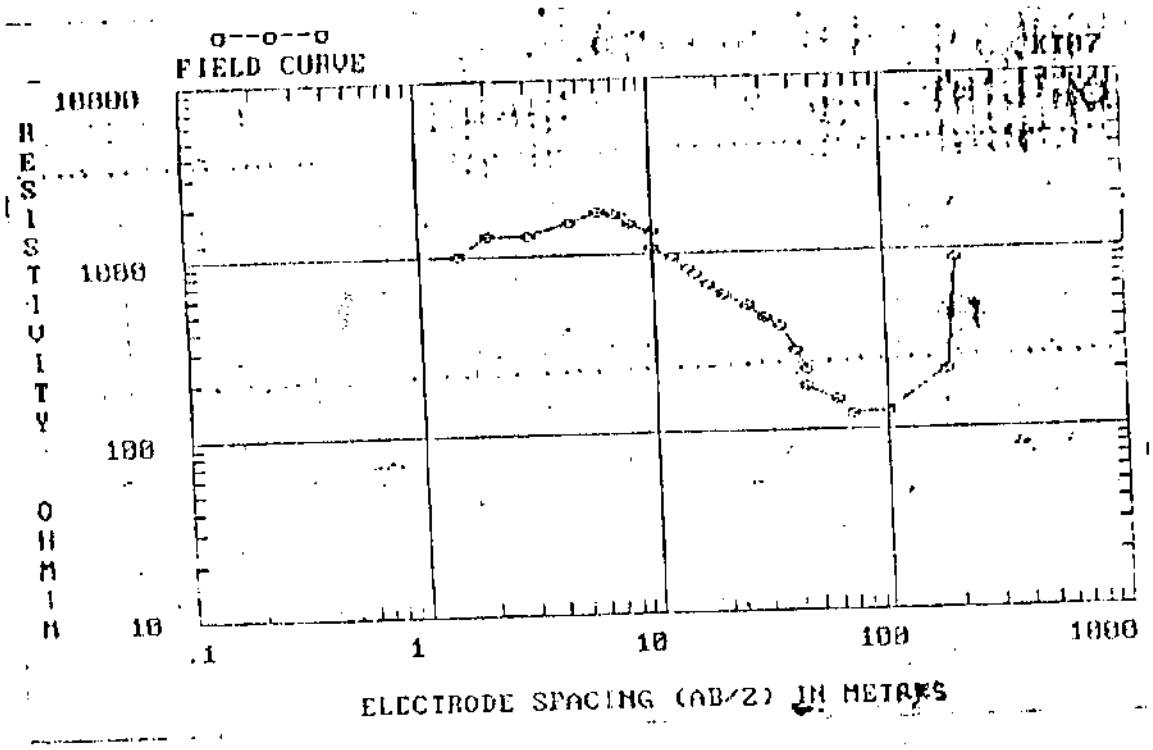

o--o--o
FIELD CURVE
10000
1000
100
10
RESISTIVITY OHMIM
.1
1
10
100
1000
ELECTRODE SPACING (AB/2) IN METRES

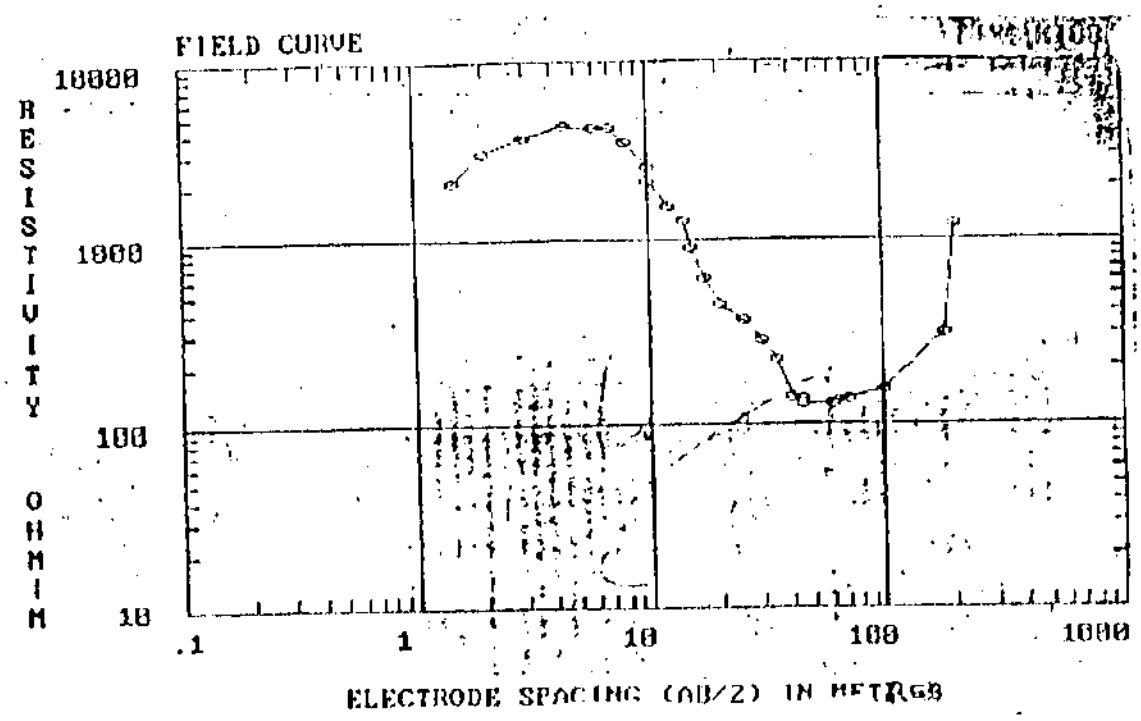

o--o--o
FIELD CURVE
PKT03
10000
1000
100
10
RESISTIVITY OHMIM
.1
1
10
100
1000
ELECTRODE SPACING (AB/2) IN METRES

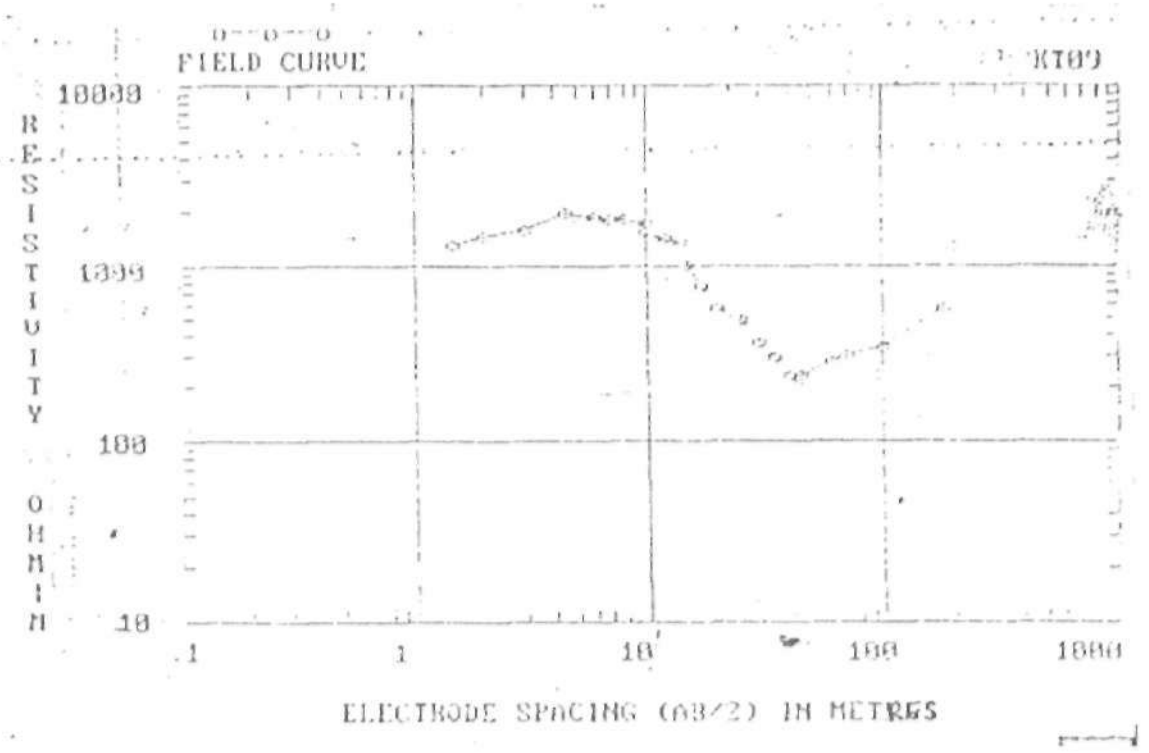

o--o--o
FIELD CURVE
PKT04
10000
1000
100
10
RESISTIVITY OHMIM
.1
1
10
100
1000
ELECTRODE SPACING (AB/2) IN METRES

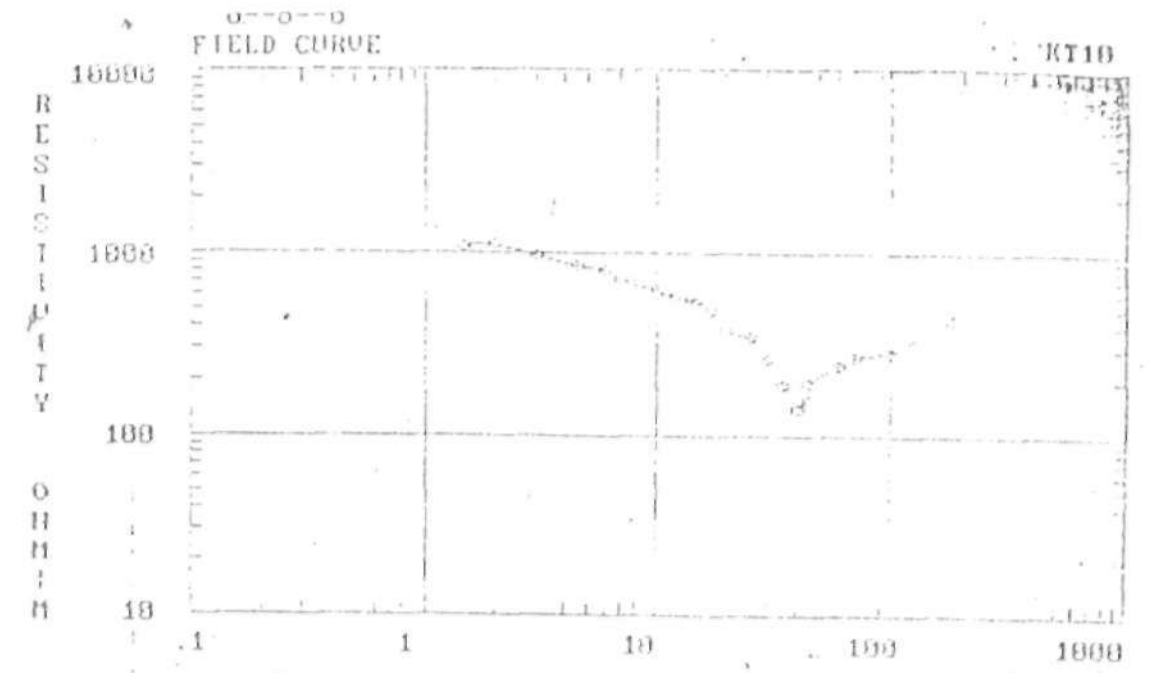

o--o--o
FIELD CURVE
KT05
10000
1000
100
10
RESISTIVITY OHMS
.1
1
10
100
ELECTRODE SPACING (AB/2) IN METRES

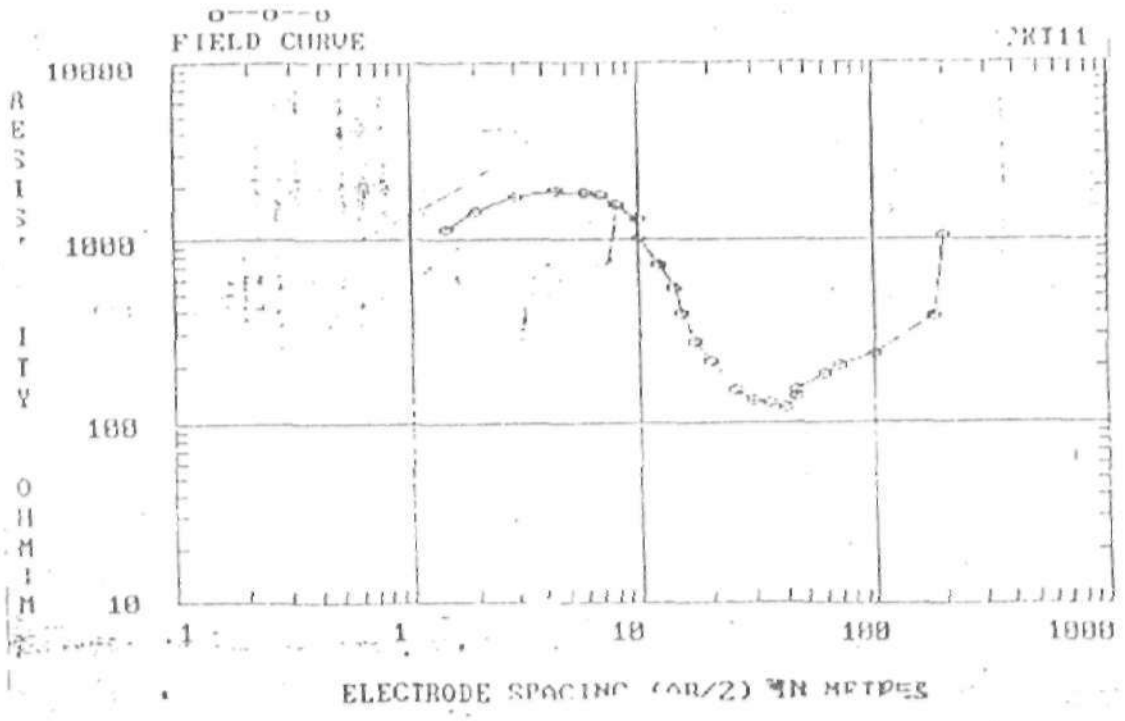

FIELD CURVE
KT06
10000
1000
100
10
RESISTIVITY OHMS
.1
1
10
100
1000
ELECTRODE SPACING (AB/2) IN METRES

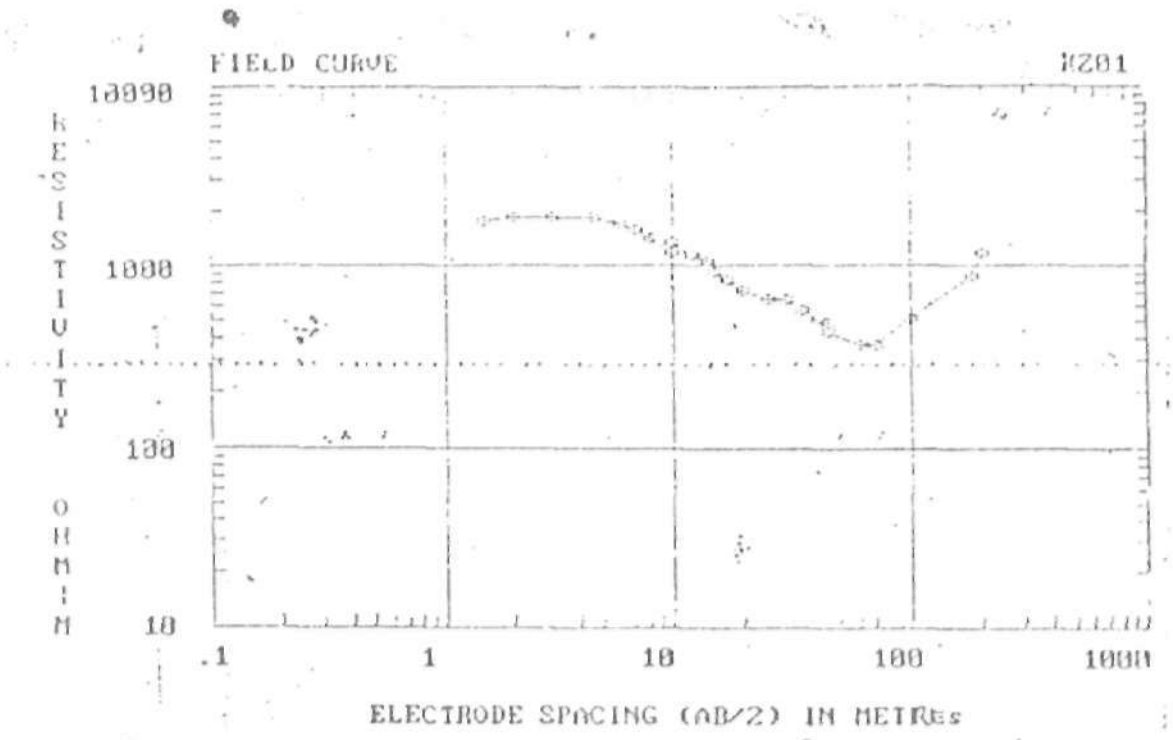

o--o--o
FIELD CURVE
10000
1000
100
10
RESISTIVITY OHMIN
.1
1
10
100
1000
ELECTRODE SPACING (AB/2) IN METRES

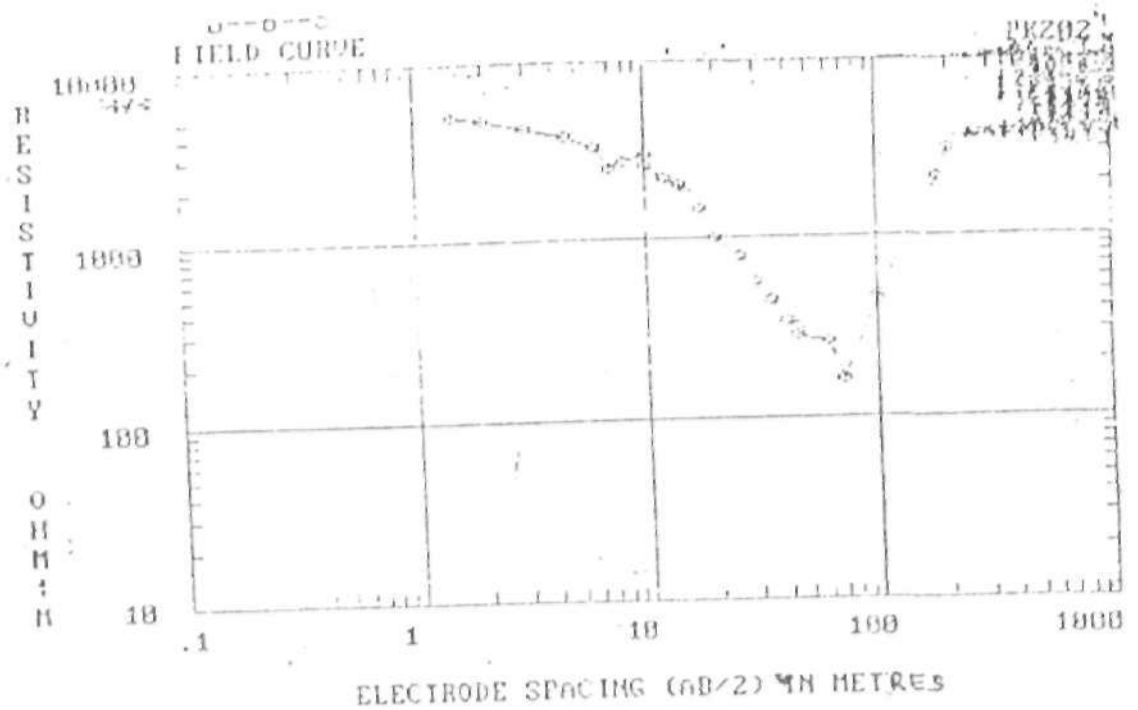

FIELD CURVE
10000
1000
100
10
RESISTIVITY OHMIN
.1
1
10
100
1000
ELECTRODE SPACING (AB/2) IN METRES

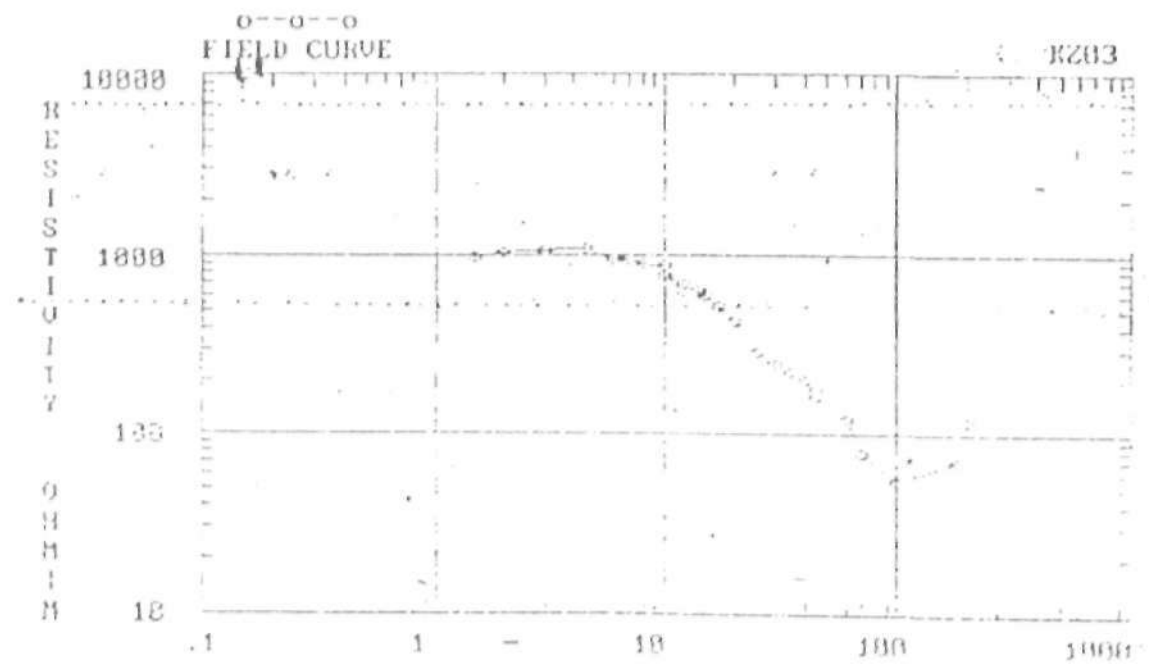

FIELD CURVE
KT09
10000
1000
100
10
RESISTIVITY OHMM
.1
1
10
100
1000
ELECTRODE SPACING (AB/2) IN METRES

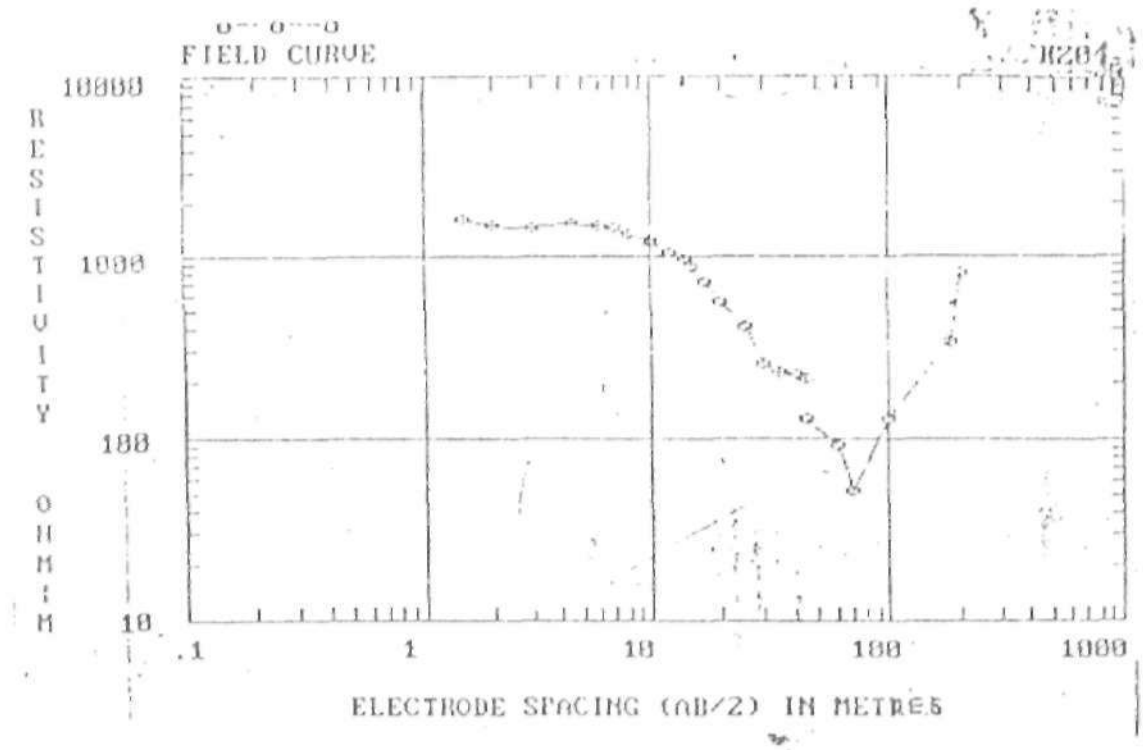

FIELD CURVE
KT10
10000
1000
100
10
RESISTIVITY OHMM
.1
1
10
100
1000
ELECTRODE SPACING (AB/2) IN METRES

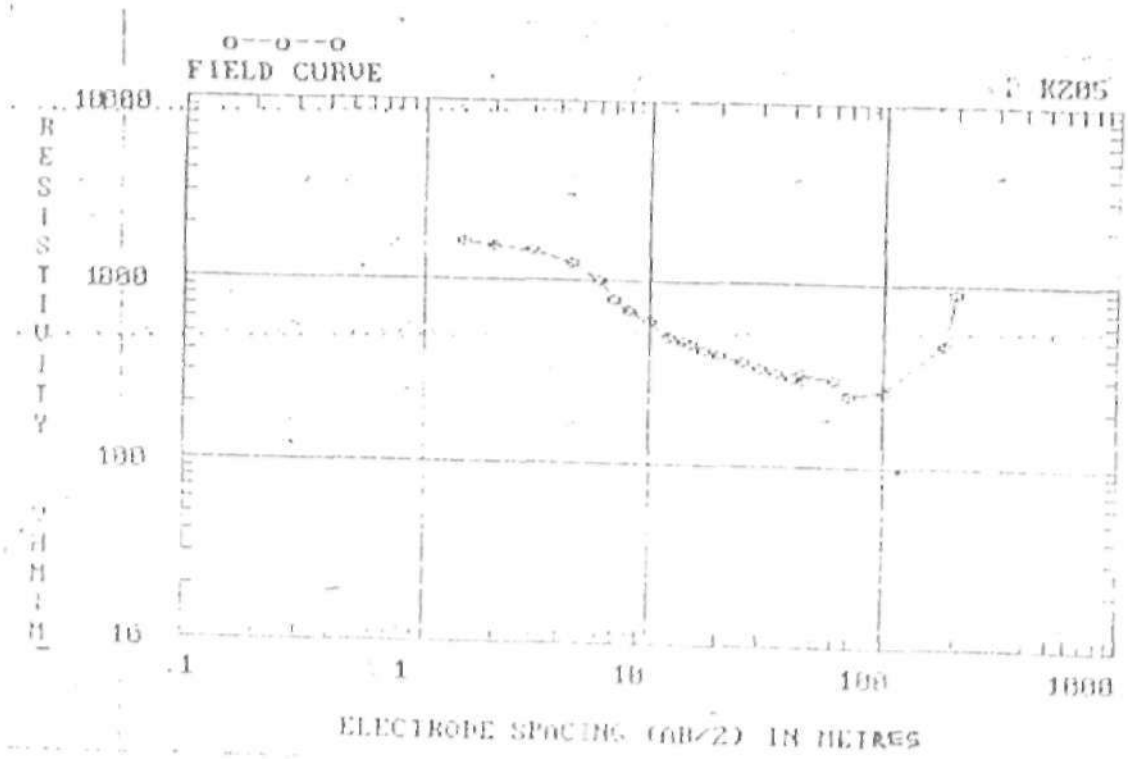

FIELD CURVE
10000
1000
100
10
RESISTIVITY OHMIM
.1
1
10
100
1000
ELECTRODE SPACING (AB/2) IN METRES

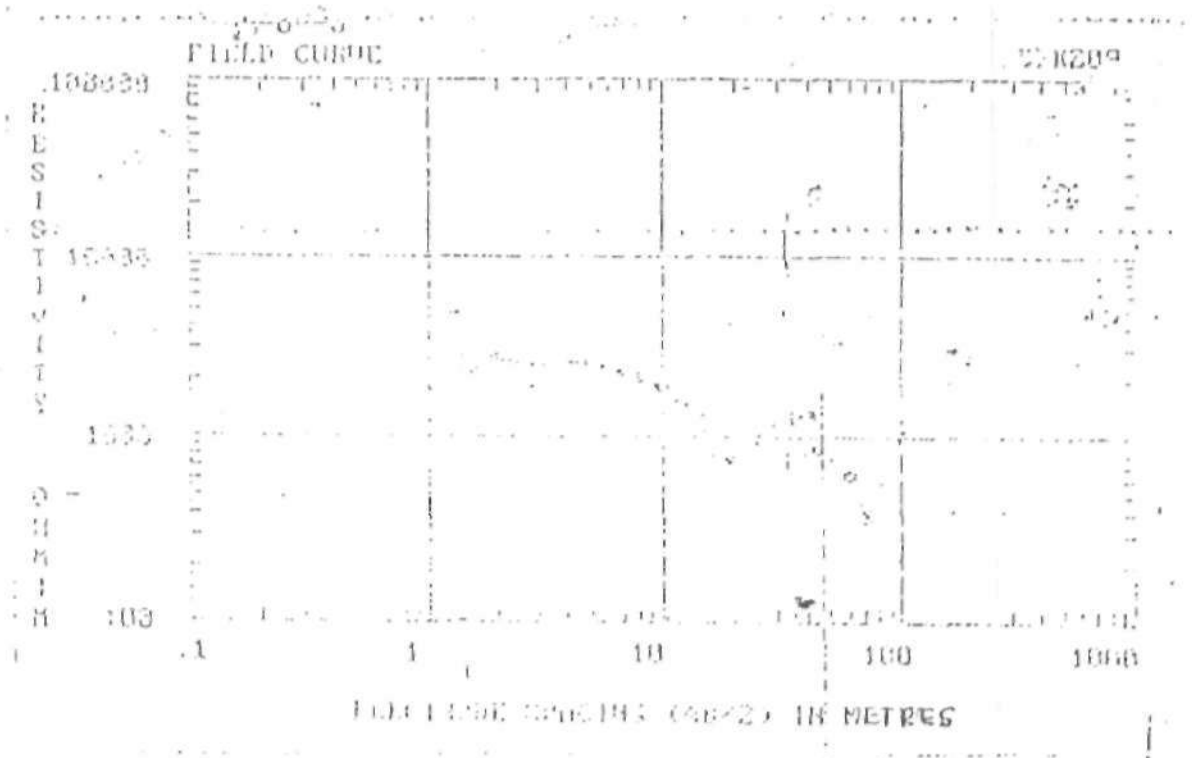

FIELD CURVE
10000
1000
100
10
RESISTIVITY OHMIM
.1
1
10
100
1000
ELECTRODE SPACING (AB/2) IN METRES

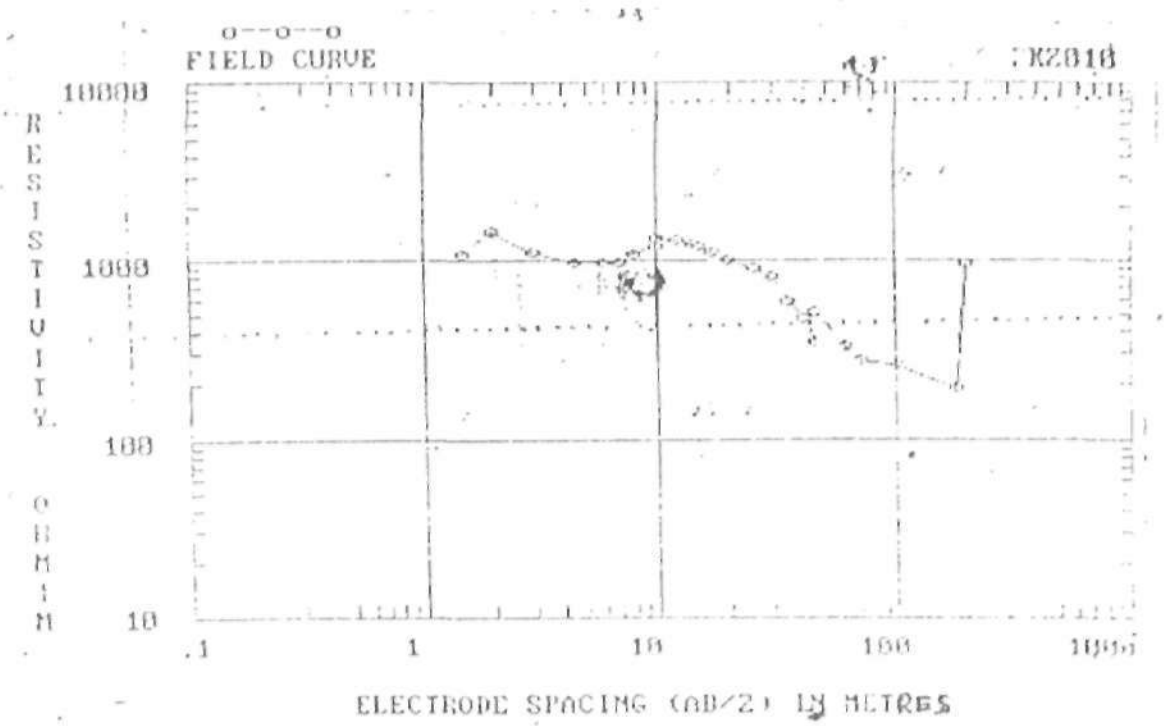

o--o--o
FIELD CURVE
PKZ02
10000
1000
100
10
RESISTIVITY
OHM-M
.1
1
10
100
1000
ELECTRODE SPACING (AB/2) IN METRES

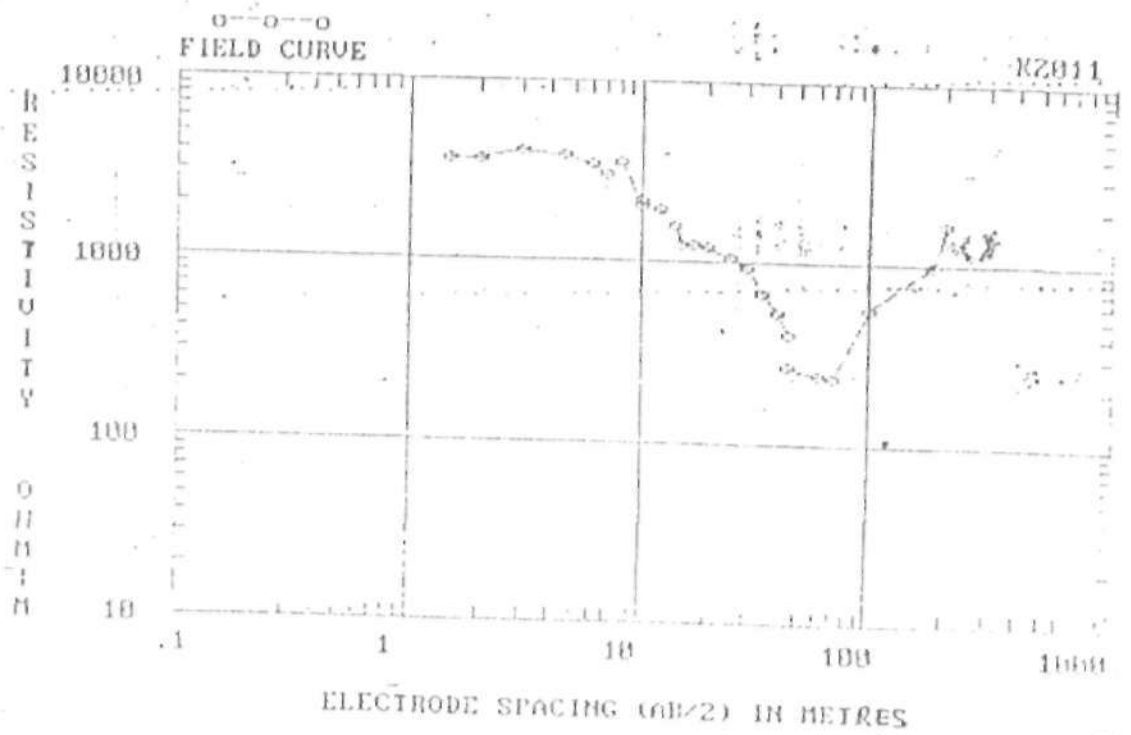

o--o--o
FIELD CURVE
KZ03
10000
1000
100
10
RESISTIVITY
OHM-M
.1
1
10
100
1000
ELECTRODE SPACING (AB/2) IN METRES


o--o--o
FIELD CURVE
KZ04
10000
1000
100
10
RESISTIVITY OHMIM
.1
1
10
100
1000
ELECTRODE SPACING (AB/2) IN METRES


o--o--o
FIELD CURVE
KZ05
10000
1000
100
10
RESISTIVITY OHMIM
.1
1
10
100
1000
ELECTRODE SPACING (AB/2) IN METRES


FIELD CURVE
RESISTIVITY OHMIM
10000
1000
100
10
.1
1
10
100
1000
ELECTRODE SPACING (AB/2) IN METRES


o--o--o
FIELD CURVE
KZ010
RESISTIVITY OHM M
10000
1000
100
10
.1
1
10
100
1000
ELECTRODE SPACING (AB/2) IN METRES


o--o--o
FIELD CURVE
KZ011
RESISTIVITY OHM M
10000
1000
100
10
.1
1
10
100
1000
ELECTRODE SPACING (AB/2) IN METRES