THE APPLICATION OF ELECTRICAL RESITIVITY METHOD IN THE INVESTIGATION OF KUFENA STONE AGE ARCHAEOLOGICAL SITE, ZARIA-NIGERIA

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DECLARATION

I declare that the thesis entitled 'The Application of Electrical Resistivity Method in the Investigation of Kufena Stone Age Archaeological Site Zaria, Kaduna State, and North Western Nigeria' has been carried out by me in the department of Physics. The information derived from literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at this or any other institution.

_____ _____ _____

Name of Student Signature Date

CERTIFICATION

This thesis entitled "THE APPLICATION OF ELECTRICAL RESISTIVITY METHOD IN THE INVESTIGATION OF KUFENA STONE AGE ARCHAEOLOGICAL SITE, ZARIA KADUNA STATE, NORTH-WEST NIGERIA" by Adamu Abubakar meets the regulations governing the award of the degree of master of science of Ahmadu Bello University, Zaria, and is approved for its contribution to the knowledge and literary presentation.

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DEDICATION

In loving memory of my dear Grandmother late HAJIYA AISHATU UWA. May her soul continue to rest in perfect peace with Almighty Allah, Ameen.

ABSTRACT

Geophysical investigation of Schlumberger Vertical Electrical Sounding (VES) data and a Horizontal Electrical Profiling (EP) with a Wenner electrode array were carried out in archaeological Kufena Stone Age site Zaria, Zaria Local Government Area of Kaduna state. The aim of the work was to conduct and electrical resistivity measurement and electrical profiling methods in order to delineate the archaeological features in the study area. The study was conducted having an objective of the geophysical assessment to bring out the important subsurface geophysical information useful in the location of anomalous areas of interest in Kufena Stone Age site Zaria and characterized the anomalies obtained so as to suggest to archeologists on where and at what depth they should excavate. VES data were entered to the computer and curves were plotted using IP12win Interpretation Software. EP data were processed using Microsoft Excel and Golden Software Surfer V.12. The survey area is dominated by mainly four layers namely: Topsoil basement, overburden basement, weathered/fractured basement and fresh basement. The VES results have revealed that the artifacts of archaeological material remain lie within the overburden basement of the predominantly four layered geoelectric structure. VES points $1a_1$ - $1a_8$, $2a_1$ - $2a_8$ and $3a_3$ - $3a_6$. Along the three profiles were clearly show the overburden depth where the archaeological materials are located, ranging from 1.4 - 5.5 m. Similarly the electrical resistivity profiling results with a depth of 3 m and 5 m show high resistivity anomalous spot location ranging from 30-190 ohm which is also suitable for an archaeological excavation of material remains in the area of study.

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CHAPTER ONE: Introduction

1.1 General Overview

The application of geophysical methods changed the starting point of scientific approaches towards archaeological investigation in the 20th century. Traditional methods used in archaeology gave limited or sometimes no information on unexcavated subsurface archaeological features. The application of geophysics to archaeology dates back to the early 1950s Leucci and Giorgi, (2012). The rapidly evolving technology over the past 20 years has made the geophysical approach a reliable investigative tool, both before and during excavation. Geophysical prospecting allows the physical parameters of the subsoil to be mapped in large-scale surveys. In specific cases, it has provided useful information on the depth and shape of buried structures of anthropogenic origin and has helped in detection of individual artifacts (Tsokas *et al.*, 2009). An effective use of geophysics can improve the reliability, reduce the invasiveness and, in many cases, lower the overall costs of archaeological investigations (Hargrave *et al*., 2002). Geophysical survey in Archaeology continues to flourish as of 2006, with estimated component of at least 23.4% of all evaluations arising from planning applications (Radulescu *et al.,* 2006). The techniques are also finding an increasing role in the presentation and interpretation of archaeological sites, in contribution to archeological and forensic research, and in helping to satisfy the demand for media coverage of archaeological subjects. Geophysical methods applied to archaeological problems are increasingly being recognized as a valuable tool for characterizing subsurface cultural deposits prior to excavation (John, 2009). Archaeological geophysics encompasses an assortment of non-invasive methods for the analysis and delineation of subsurface archaeological deposits. The non invasive nature of geophysical methods is

attractive to the modern archaeologists, tasked with managing the balance between conducting field of research and implementing a site conservation Management Plan (Hargrave et al., 2002).

Surface geophysical methods allow subsurface features to be located, mapped and characterized by making measurements at the surface that respond to a physical, electrical or chemical property. The non-invasive measurements can be effectively used to provide reconnaissance for detailed geologic information, guide sub-surface sampling and excavation, and provide continuous monitoring. Subsurface geophysical methods provide data at a variety of scales, from the regional geological setting to site-specific geotechnical forensics. (Technos, 2004). Archaeology is the scientific study of past human culture and behaviour, from the origin of human to the present, through the examination of material remains of previous human societies (Fagan, 2009). These remains include the fossils (preserved bones) of humans, food remains, the ruins of buildings, and human artifacts – items such as stone tools, pottery and jewelry from their studies, archaeologists attempt to reconstruct past ways of life. A place where there are clustering of the archaeological features is called an archaeological site.

Archaeologists mostly concern themselves with retrieving such features that are of archaeological interest primarily through field survey, excavation and proper documentation of the archaeological findings. Binford (1972) described the main task of archaeology as seeking origins and tracing the history of culture. Therefore archaeological researches can result to reconstruction of the history of the prehistoric civilizations. The findings are made mostly through careful excavations of concealed features. Such practice are of diverse scales varying from as small as excavating a clay pot (or even potsherds) in a 50cm x 50cm pit to as large as tracing an outline of a prehistoric human community currently under soil cover, perhaps as a result of past natural disaster.

1.2 Location of the Study Area

The study area which is Kufena archaeological Stone Age site in Zaria, is about 5 km along Zaria-Birnin-Gwari federal road on a Plateau of about 656.56 m above sea level (See Figure 1.1). The Survey area lies between Latitude 7°39' 7.79"N and 7°39'7.67"N and Longitude 11°05'23.72"E and 11°05'7.14"E with a total Area of 500 m^2. It also lies within the basement Complex of North-Western Nigeria.

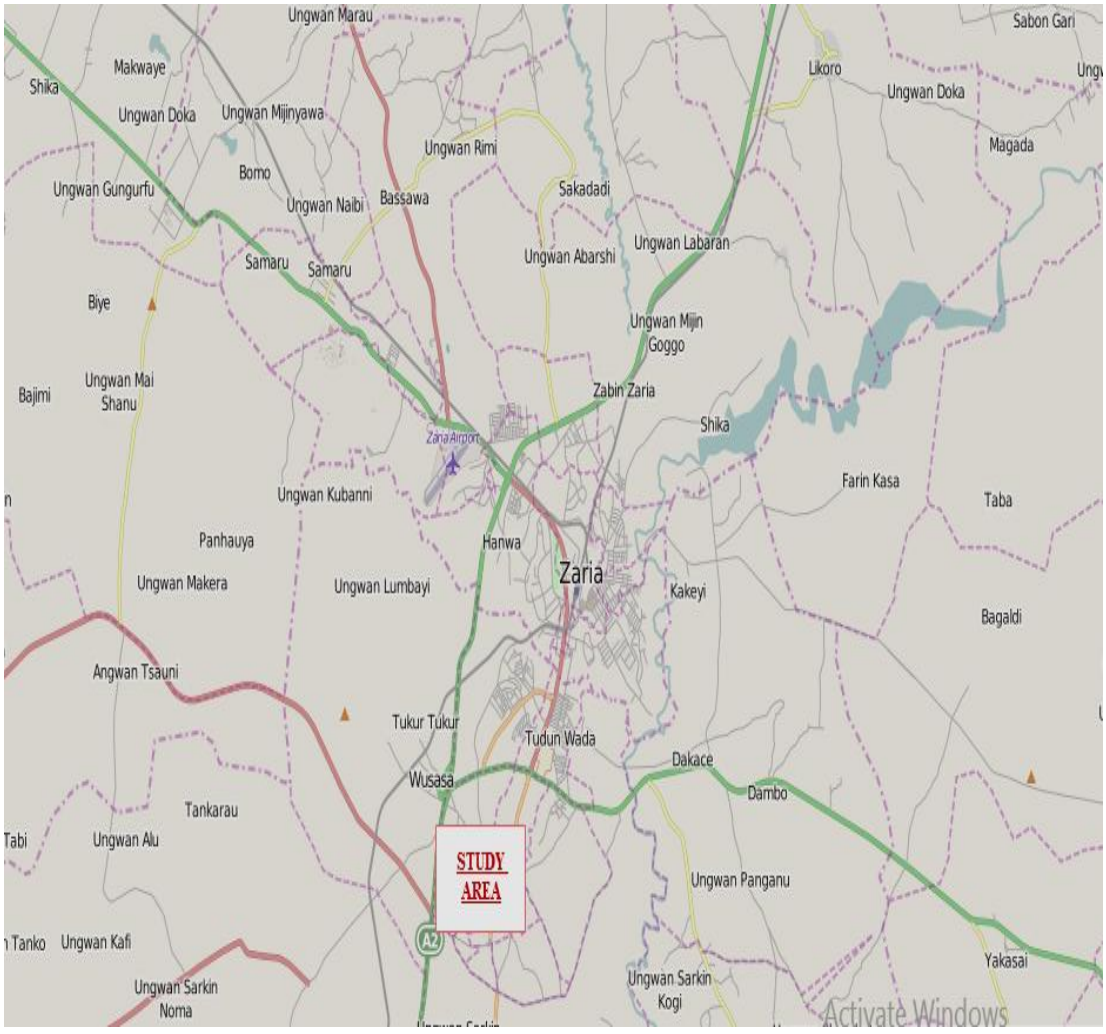


Figure 2.1: Map showing the road network from ABU Samaru to the Study Area (Courtsy Google Map)

1.3 Geology of the Study Area

The rocks in the study area are mostly Precambrian in age. These have been subjected to several deformity, the last being the Pan- African orogeny (Mc Curry, 1975). This thermo tectonic event has virtually obliterated the imprints but left it is own structural landmarks, which includes folding, fracturing, shearing, granitic emplacement and granitization.

Rahaman (1976) recognized three (3) petrological units within the basement complex of Nigeria namely;

1. The Migmatites Gneiss Complex
2. Para-Schist and Meta Igneous sediments
3. Minor dyke-like bodies

1.3.1 Migmatites – the Gneissic Complex

These rocks are the main lithology in the investigated area around Kufena, large tracts of the area are underlined by poorly exposed weathered gneiss with subordinate migmatites. The gneisses characteristically underlay the low-lying areas, petrographically the gneisses found around Kufena are available in composition and texture, they range from biotite and hornblende-bearing and the textures ranging from banded to augen varieties (Garba, 1988).

1.3.2 Para-schist and Meta Igneous Sediments

The Meta igneous sediments occur as minor xenoliths within the hilly granitoids referred to as the older Granites. These rocks represents remnant of formally widespread rock type that is now only preserved in an area west of Zaria. These rocks are mostly politic schist with minor carbonaceous schist. The varieties of schist include: muscovite schist and feldspathic schist.

1.3.3 Minor Dyke-like Bodies

Several pegmatites and quartz were observed at several localities around Kufena area example at Kuregu, Pantaki and Uguwan Sarki, which shows spatial affinities with the granite bodies, these minor bodies include: Micro granite dykes, Pegmatites and Quartz veins

Microgranite Dykes: The Microgranite is the most abundant of the minor rock types and varies considerably in width and outcrop length. Some can be as long as 50 – 100m and vary from about 0.5 – 5m in width. They are found to often be infilling longititudunal fractures. Model analyses of some of these rocks elsewhere by McCurry (1973) and Olatunji (1979) show the Microgranite to be made up of 38 – 40.5%, Kafeldspar, 26 -27% plagioclase, 28.5 – 31.5% quarts and 4 – 6% biotite and others.

Pegmatites: The pegmatites are next in abundance among the minor rock formations and are both concordant and discordant to regional structure. They occur in different textural variants of the granites around Kufena especially at Unguwar Sarki, as well as within the Microgranite dykes. The pegmatites generally outcrop for about 5 – 20m along strike and vary in width from less than 10cm to about 1m, with dip angles ranging $45^0 – 90^0$.

Quartz Veins: The quartz veins are the last and smallest group of the minor formations in the district. They occur as small veins and vein lets (from less than 1cm in biotite granite to about 10cm in the Microgranite dykes). They are often short in strike length hardly exceeding few metres. The quartz veins are generally the glassy variety, but varying shades of smoky, amethystine and milky colouration may be present in the same vein.

1.3.4 Structural Geology of the study area

Two types of structures are discernible in the Zaria region (a) folding and cleavage; and (b) fractures, faults and joints.

Folding and cleavage the following structural elements belong to this group includes foliation, lineation, minor folds and major folds.

Foliation a tectonic foliation, which forms a well-developed schistosity in the metasediments in defined by parallel alignment of platy and tabular minerals such as mica, amphibolites and microcline mega crysts, and also by compositional banding (in gneiss).

Lineation is very important structure in the gneisses, especially where they occur as lenses within the metasedimentary rocks. This lineation, especially of hornblende and feldspar can become so penetrative in many places that at tends to obscure the foliation.

Minor folds" Minor folds are found in the metasediments, where the folding is predominantly isoclinals, with N-S fold axes plunging at low angle, and medium to sleep west dipping curvilinear axial planes. The foliation in the limbs of folds is parallel to the fold axial planes in tightly folded structures, and an axial plane foliations seldom developed.

Folds Non-cylindrical, slightly overturned isoclinals folds are found within most of the areas occupied by gneisses and metasedimentary belt to the west and north east of Zaria.

1.3.5 Fractures, Faults and joints

All the rocks in this region appear to have been fracture and faulted subsequent to orogenesis. The associated structural features are visible as trend on a photograph, and control drainers are visible as trends on air photographs, and control drainage and topography in the area (Olatunji, 1979).

Joints and fractures: Two prominent joint sets are found in the area one is approximately N-S, frequently in filled with quartz veins in he granites, suggesting an early origin, the other trends $90^0 – 120^0$ and frequently shows small central displacements (McCurry, 1973; Olatunji, 1979).

Faults: In the northern eastern part of the study area fault zone trending NE-SW has displaced a laterite and Microgranite. Displacement is in order of 10cm, which also caused a swing in structural trends of the dyke by drag on either side of the fault.

The Pan –African orogeny is the second orogeny characterized by a total migmatization, mobilization, and intrusion of granite.

Granitic rocks emplaced during orogeny are collectively referred to as the older granites (Rahaman, 1976). These granitic rocks are believed to be analectic bodies formed by the mobilization of pre –existing basement older granites strongly to non porphyroblast and variably foliated forms groups of inselberg. Foliations where present is defined by generally regional alignment of tabular microcline porphyroblast up to 2 cm long and biotitic. Flake local deviations are common and in some exposure the porphyroblast are randomly oriented the geology map of the study area is shown in Figure 1.2.

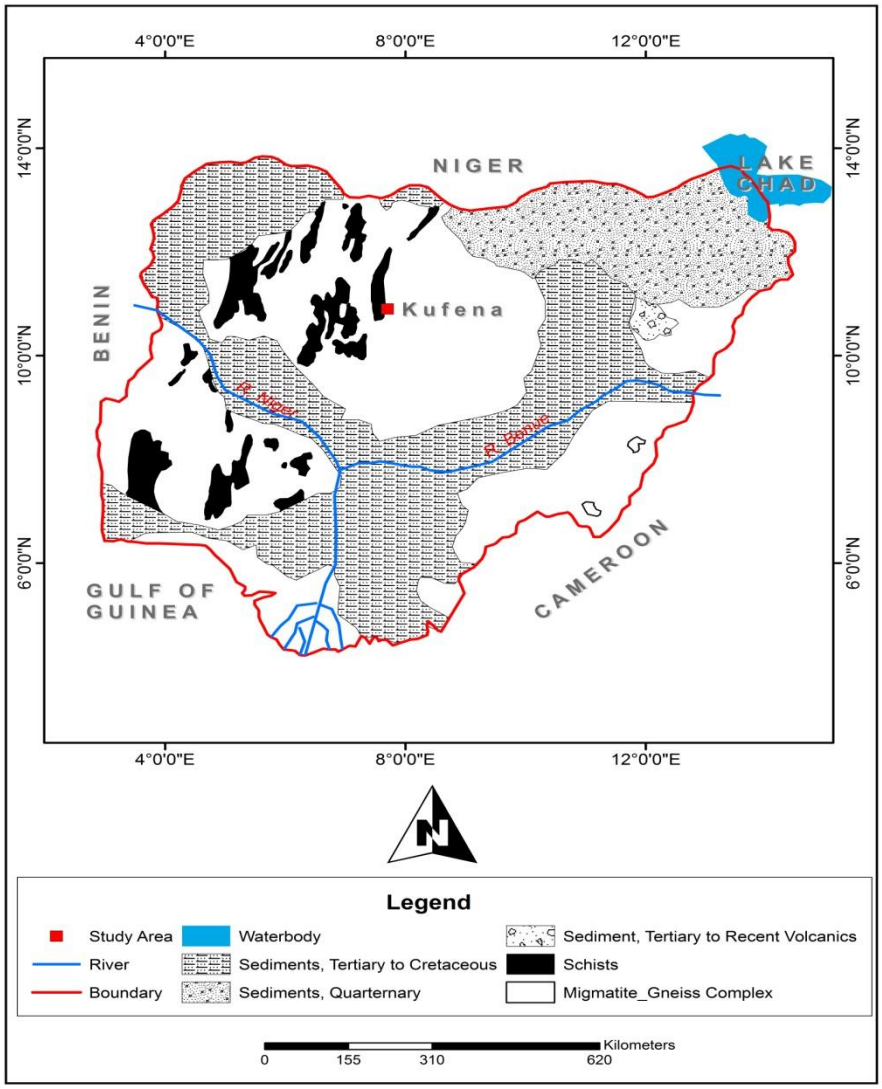


Figure1. 2 Simplified Geological map of Nigeria showing the study area (adopted from Mc Curry, 1973)

1.3.3 Rock Types of the Study Area

The study area which lies to the north western part of Zaria city is composed of Precambrian rocks of the Gneiss –Migmatites complex intruded by the Pan- African older granites. Rocks unit observed in the area includes from the oldest to the youngest older granites. This rock type is the most common in the study area occupying the whole area. It out crops as dome Inselberg, Low whalebacks Inselberg, and also as lying out crops called ruwares (Lawal, 2000). In hand specimen, orthoclase, biotite and quartz are observed. The rocks are typical of older granites described elsewhere in all sections of the study area are the "porphyroblastic biotite granite.

1.3.4 Economic Geology of the Study Area

Building material in the area include crushed stones from the oldest granites, non porphyroblastic varieties being preferred for crushing. Superficial deposits, mainly of older alluvium, are extensively dug and made locally into bricks for house building.

Porphyroblastic older granites could make ornamental stone, and is available in large quantities. Dark green and pink amphibolites might also have potentials as decorative materials, but quantities so far found are not readily accessible for pottery manufacture appears to be confined to rather small pockets. Kaolinitic clays of variable quantity are obtained from deeply lateritic.

1.4 Statement of Research Problem

There was a report on the analysis of features in Kufena Stone age site excavation in Zaria, Kufena area is rich in clay, quartz and laterite deposits all of which could have been used

in the past for manufacturing utilitarian objects such as pottery, figurines as well as stone artifacts but have abandoned it (Lawan, 1987).

1.5 Justification of Research

Lawan (1987) found after excavation that the Zaria Stone Age archeological site in Kufena area has rich deposits of clay, quartz and laterite. But the excavation was done on a wild cat basis and no Geophysical survey was carried out before the excavation. Hence the destruction of the ground in some part of the survey area. There is therefore the need to carry out Electrical Resistivity Surveying in the area so as to advice the archaeologist where and at what depth they should excavate. The idea of using geophysical measurements for detection of archeological remains covered with soil is based on the fact that there is often a significant difference in physical properties between the remains and the surrounding soil. Therefore, a rapid scientific and non-destructive technique is needed to delineate any buried archaeological remains in the area in order to rescue them from being lost.

1.6 Aim and Objectives of this Study

The Aim of this present research is to conduct an electrical resistivity method in order to delineate the archaeological features of Kufena Stone Age Site Zaria. The specific objectives of the study are:

i. To carry out Electrical resistivity measurements in order to bring out the various layers of the subsurface in the Kufena Stone Age site Zaria.
ii. To map out the data collected in the site so as to locate anomalous areas of interest.
iii. To characterize the anomalies obtained in (ii) above so as to suggest to archaeologists on where and at what depth they should excavate.

CHAPTER TWO

LITERATURE REVIEW

2.1 REVIEW OF RELATED WORK

Clark (1975) carried out a Geophysical investigation with Archaeological prospecting methods at Svanesund, Orust, Sweden. He revealed the possibility of using electrical resistivity methods to detect anomalous areas of archaeological interest and large stones or accumulations of stones which may be hearth without removing the vegetation cover. At a Stone Age Site on the Island of Orust in Western Sweden with rather faint archaeological remains all hearths were detected by the resistivity method. Owing to unfavorable geological conditions, the magnetic method was less successful on this site.

Sutton (1976) carried out a survey in Pantaki site Kufena Zaria where he discovered potsherds, ground stone tool and figurina dominated the surface collections made from the flattish area between the great domes of the Inselberg. In addition to the above collections, he located and described stone circles, rock hollows and the two caves on the Inselberg. In furtherance of the work, Sutton excavated two sites on the Kufena Inselberg. The first site was a cutting through the old wall of Kufena and its ditch at the Southern side, in order to test its dimension, style and the materials used in the walling system. This cutting was extended inwards to examine evidence of occupation in the narrow area between the walls line and the foot of the rock screen (that is the climbable small loose stones which slide down when trodden on). From the age assigned to the wall dissection, Sutton was able to prove archaeologically that Kufena wall belong to an earlier "Pre Amina" phase dating between 11^{th} – 13^{th} centuries, A.D. The second site was an occupation site consisting of a series of reasonably well preserved stone circles at the Northern end known as the Pantaki site. In fact pottery dominated the finds recovered from there.

Bala (1978) had excavation on the same Pantaki site. He excavated three pits with the following intentions. Firstly to test for settlement evidence on the hill and then determine the degree of the peoples activities, Secondly, to know whether there are any changes in the pottery sequence (by comparing pottery from the various layers with an attempt to analyze them together with the pots made by present day villages living around the hills), and finally to know the age of the settlement. Excavation from these pits revealed pottery as the commonest find and from the pottery collections made. However, Bala (1978) speculation that the site has two distinct periods, had been disputed by Sutton (1976) who also conducted excavation in a cleave lying immediately to the north of Pantaki settlement. He has also indicated the difficulty in determining the age of this site since no enough carbon samples were collected from either his excavation or Bala's own. Bala (1978) however believed that from preliminary observations of the pottery, the site on the Hill pre-dates the one at the base with a wall surrounding it.

Lawan (1987) carried out a report analysis of finds and features of Kufena '87 Excavation in Zaria Area, Kaduna State Nigeria. He found after excavation that the Zaria Stone Age Archaeological Site in Kufena Area has rich deposits of clay, quartz, laterite, all of which could have been used in the past for manufacturing utilitarian objects such as pottery, figurines as well as stone artifacts.

Hugo *et al.,* (2006) were carried out a detail geophysical investigation using the micro-resistivity method. Their survey carried out inside of verzea church comprised dipole-dipole, gradient and pole-pole arrays. The dipole-dipole and gradient data were inverted using 2D and 3D approach. Excavation works, carried out in accordance with the results of geoelectrical investigation successfully found a 2.7 x 0.8 x 1.7 tomb, here several human bones have been collected.

Radulescu *et al.,* (2006) carried out geophysical electrical methods (geoelectrical) at the saint Nicholas church in Densus (Hunedoara county). Their result provided an image of the apparent resistivity distribution for depths between 0 and 2m. These investigations ended with the identification of possible high resistivity zone, which may indicate the presence of archaeological sites.

Tsokas *et al.,* (2009) carried out a detailed Geoelectrical Resistivity Method at the archaeological site of Occhiola (Sicily, Italy) a medieval village, on the North Western part of a hill named "Terravecchia" at 491m above sea level. Geoelectrical methods were used to obtain a map of the subsurface, to find evidence of buried structures, more precisely voids (related to the presence of crypts and/or tombs) and to delimit these structures.

2.2 Archaeology

The scientific study of past human culture and behaviour, from the origins of human to the present. Archaeology study past human behaviuor through the examination of materials remains of previous human societies. These remains include the fossils (preserved bones) of humans, food remains, the ruins of buildings, and human artifacts- items such as tool, pottery, and jewelry (Peace, 1986). From their studies, archaeologists attempt to reconstruct past way of life.

2.2.1 The Scope of Archaeological Study

Archaeological study covers an extremely long span of time and a great variety of subjects. The earliest subjects of archaeological study date from the origins of humanity. This includes fossil remains believed to be of human ancestors who lived 3.5 million to 4.5 million years ago. The earliest archaeological sites include those at Hadar, Ethiopia, Olduvai and Laetoli, Tanzania; East Turkana, Kenya; and elsewhere in East Africa (Baker, 1961).

2.2.2 Research site in archaeology

Within the scope and scientific characteristics of archaeology- which enable an ancient location to qualify to be an archaeological site; Kufena Zaria is extremely qualified to be an archaeological site from (Peace, 1985). This is because archaeological site are places where human habitation or other activities took place where artifacts, features and ecofacts are all found. Kufena Stone Age site has been substantially investigated over the years and it is one of the richest archaeological sites in the Zaria region alongside Turunku. These sites have attracted a lot of archaeological works resulting to the discovery of much materials evidence which indicate that Turunku is the original home land of the 22nd Habe ruler of Zazzau (Bakwa Turunku) who ruled before the conquest of the Hausa land in 1804 (Hogben and Kirk-Green, 1966).

2.3 Pottery

Pottery is an omnibus word, which is used to describe any kind of ceramic ware, but it's application is generally more limited. The exact day of the origin of pottery is not really known, but it is believed that pottery making developed when man stopped the wearing nomadic life of hunting and gathering and started living a settled life. It is appearance and development marked an important stage in the progress of man. Though the origin of pottery can not be ascertained, there are, however, various explanations given in an attempt to find its origin. One such explanations is found in the encyclopedia of Art which states "that the discovery of pottery is by accident than decision". As the prehistoric man walked through the rain soaked mud, he noticed his foot prints. He later observed that his impression on the mud had hardened and changed colour through the combine efforts of the wind, sun and the fire he had made (Shillington, 1966).

Pottery is one of the most ancient arts of mankind. The oldest sculptures found in Nigeria, indeed in the whole of black Africa were terracotta from the Nok cultures in the Zaria province of Nigeria (Hore, 1970).

Baker (1961) believes that the origin of pottery can be traced, to 4000Bc in Egypt, where the earliest known examples were turns used for holding the ashes of the dead. On the other hand, Clark, (1975) suggests that the first evidence of pottery appeared from Zagos area of the Mediterranean basin, dating back to 6000Bc.

2.3.1 Role of Pottery in the Study of Nigerian History

Pottery, one of the oldest surviving crafts, has been practiced from pre-historic period to the present. Given the vast quantity, which survives, and with several collections in various museums, the world over and the ever increasing volume being unearthed by carefully controlled excavations, pottery has a significant role to play in the study of ancient Nigerian.

According to Fatunsi (1989), “from excavations, historical record can be derived not only from the potsherds that litter archaeological sites, but also from the continuing practice of the craft, associated as it is with traditional beliefs, festivals and other activities”. Pottery forms have effectively served as canvas which potters have used to record historical events, expressed ideas and observations from their environments. Pottery forms served so much as such veritable tablets for potters to communicate, that the Greeks were so mindful of what glaze they used on their pottery forms to avoid running and destroying their surface embellishments. They were so mindful that they worked in partnership with the painters.

2.3.2 Pottery Classification

The study of pottery is it in traditional contemporary society or as found in archaeological context is of prime importance particularly to archeologist. Pottery is an important artifact in archeological study because of its universality since early farming period. It can be vitally important in the establishment of cultural sequence, the definition of regional groupings and for throwing light on the complexities of commercial production and trade. It is used in the reconstruction of past life, ways of people, and could be used to establish chronological sequence and absolute dating in different archaeological deposits.

In pottery classification, two attributes, such as neck and necklace are used to classify pottery wares into two broad categories, pots and bowls. Each group is further classified into sub types. However, ethnographic studies have shown that both the potter's and the users of pots classify their pottery wares based on the intended functions of the wares. And in some cases the potter intended functions, may be at variance with those of the pottery users. Also one pot can serve more than one function at different times within it is like span, pottery helps in no small measures to reconstruct history of a people through the wealth of information in the several archaeological excavations.

2.4 The Clay

Nature has endowed man with clay from creation. Clay deposits are found along existing or old river banks. Clay is a type of earth material formed through the decomposition of rocks by weathering agents, such as snow, rain, wind, sun and so on. Clay is defined as a fine-grained earthy material that develops plasticity when wet, and loses its chemical combination when fired. (Hodges, 1964). The ancient Egyptian potters had at their disposal two basically different types

of clay. The most abundant and frequently used was the alluvial Nile situ clay available throughout Egypt on the bank of Nile, and in the cultivated area, which boarder the river.

According to Ogunsina, (1992) many clay deposits are still in their primary state (in-situ) at Iwo, Abeokuta, Zaria, Jos and Igbeti, marble field. Clay which is the major materials in pottery, is relatively cheap and a wonderful material to handle. One can make a variety of useful and decorative items with it such jewelry, teapots, drain pipes. It can be found in many colours determined by impurities in it, and can itself be coloured with enrobes and glazes.

2.4.1 The Geological Origins of Clay

Speight and Toki (1999) "the earth surface was formed from melted rock that cooled and solidified. Over millions years, the weathering action of alternating freezing and thawing, along with the grinding of glaciers, the pounding of rain, the buffering of wind, the flow of rushing streams, and probing of tree roots, slowly breaks down the earth's crust into boulders, then into stones, then pebbles and finally into small particles that make different types of clay".

2.4.2 Clay Components

Feldspar, the most abundant mineral on the earth's surface is an essential component of granitic rocks, and is the basis of clay made up primarily of the oxides silica and alumina, it combines with such alkaline as potassium, and some so-called impurities, as iron. It is this feldspathic origin of clay that makes it possible to fire objects of clay to a dense and permanent hardness.

2.4.3 Types of Clay

Ceramists refer to the particular types of clay, they use as clay bodies. The clay bodies used may consists of clay as it was found in it's natural state, but the term clay body usually refers to a

combination of materials that a potter sculptor, or supplier formulated for a specific purposes. Basically, there are two types of clay, primary clays and secondary clays (Ogunsina, 1992). Primary clays are usually clays, which have not moved out from their original location, and are found to settle at the place of their formation. After the parent rock has been broken down completely, the smaller pieces, which resulted from this action, become what are known as primary or residual clays. This class of clays is commonly found in great quantities in China, hence the name China clay. These are purest form of clay and usually come in while or grayish colours (Ogunsina, 1992). Secondary clays, also called sedimentary or transported clays, they are clays that have been move from the site of their formation and away from the parent rock and deposited in to their new or secondary location by the action of running water, ice, or wind. These clays are distinguished from primary clays by having finer particles (Ogunsina, 1992).

2.4.4 Characteristics of Clays

Clay's plastically, when damp, is mainly due to the fineness of its particles, flat-shape of the platelet, which cling together due to action of later between them. In addition, the organic materials that become mixed with the clay in its journey from rock to riverbed play their part in making it malleable (Peace, 1986).

Vitrification is another property of clay that means it is permanently hard and rock-like after it has been fired. According to Steinzor (1986), "during firing, fluxes such as feldspathic minerals being to melt together with the pure clay particles, and other minerals present, and a glassy bond is formed". As this fusion occurs, the particles draw closer together and fired shrinkage takes place the clay now becomes hard as a result of developing Vitrification.

2.5 GEOPHYSICAL EXPLORATION IN ARCHAEOLOGICAL WORK

A geophysical survey of an archaeological work is successful if it can identify and characterize buried archaeological features, but many factors beside archaeology contribute to variation in the data. Geophysical measurements unfortunately have some degree of "noise" associated with them. Noise in geophysical data includes anything that is not representative of what lies on or beneath the surface. Examples of noise are data spikes extremely high or low, often solitary readings usually surrounded by valid measurements) and other random or periodic error related to instrument operation (Hargrave *et al*., 2002).

CHAPTER THREE

MATERIALS AND METHODOLOGY

3.1 Introduction

In this research study an archaeological geophysical investigation method involving the Schlumberger Vertical Electrical Sounding (VES) and the Wenner Horizontal Electrical Profiling were carried out in archaeological Stone Age site along Birnin Gwari trunk A, Federal road Kaduna state covering a total area of 500 m^2. The Schlumberger electrodes configuration was used in carrying out the vertical electrical soundings at a separation of 3 metres. A profile with a total of 16 VES stations was established on each of the line 1, 2 & 3. Data collected from the Vertical Electrical Soundings were processed using IP12win (a software for interpreting Vertical Electrical Sounding) and the results was used to bring out the various layers of the subsurface in the Kufena stone age site. The horizontal electrical profiling was carried out along line 1 and 2 and line 2 and 3 the data collected from the horizontal electrical profiling were processed using the surfer 12 (a software for interpreting Horizontal Electrical Profiling) and the result was used to locate the anomalous areas of interest.

3.2 RESISTIVITY METHOD

The electrical properties of earth materials, consolidated and unconsolidated, vary widely. Various types of unconsolidated materials differ significantly in voids and contained fluids; a consolidated rock, for example sandstone and granite, likewise differ in porosity and fluid content. Their differences affect the conductivity or its reciprocal resistivity. These contrasts between consolidated and unconsolidated materials arc: usually of a higher order than

differences within the two groups; hence electrical exploration for depths of unconsolidated material is generally successful in engineering site investigations.

The general basis of the electric methods of geophysical prospecting is the detection of the surface effects produced by the flow of electrical current inside the earth (Telford *et al.*, 1976). In archaeological investigations geophysics, have been the most widely employed of the electrical subsurface exploration methods

3.2.1 Resistivity of Rocks and Minerals

The resistivity of a material is defined as numerically the resistance in ohms between the opposite faces of a uniform unit cube of the materials. For a conducting cylinder of resistance R, length l, and cross sectional area A, the resistivity is given by

$$\rho = \frac{RA}{l} \quad \text{..... 3.1}$$

Electrical resistivity is a physical property of rocks and minerals that shows the greatest variation. Rocks and minerals are considered to be good, intermediate, or poor conductors respectively within the following ranges;

i. Minerals and rocks of resistivity 10^{-8} to about $1\,\Omega m$ (mostly metals, graphite, the sulfides etc.)
ii. Minerals and rocks of resistivity 1 to $10^{7}\Omega m$ (mostly oxides, ores and porous rocks containing water)
iii. Minerals and rocks of resistivity above $10^{7}\Omega m$ (silicates, carbonates nitrates etc.)

The large contrast in resistivity between ore bodies and their host rocks (table 3.1) is exploited in the electrical resistivity prospecting especially for minerals that occur as good conductors.

Table 3.1 Resistivities of Common Rocks/Materials and Selected Ore Minerals (source: delta Mine Center, DMTC, Alaska, 2006)

Common Rocks/Materials	**Resistivity** (Ωm)	**Ore Minerals**	**Resistivity** (Ωm)
Clay	1-100	Pyrrholite	0.001-0.01
Graphitic Schist	10-500	Galena	0.001-100
Topsoil	50-100	Cassiterite	0.001-10,000
Gravel	100-600	Chalcopyrite	0.005-0.1
Weathered Bedrock	100-1000	Pyrite	0.01-100
Gabbro	100-500,000	Magnetite	0.01-1000
Sandstone	200-8000	Hematite	0.01-1000000
Granite	200-100000	Sphalerite	1000-1000000
Basalt	200-100000		
Limestone	500-10,000		
Slate	500-500,000		
Quartzite	500-800000		
Greenstone	500-200000		

3.3 FACTORS AFFECTING ELECTRICAL RESISTIVITY OF EARTH MATERIALS

The electrical resistivity of rocks and minerals are extremely variable property and depend on a number of factors. Bulk resistivity from the surface to more than 15 km depth in a normal crust are controlled by aqueous electrolytic conduction by way of pores, fractures, faults and sheer zones (Telford *et al.*, 1976). The resistivity of crystalline rock formations such as granulites, granites, and diorites in situ are largely dependent upon the water in the fissures and fractures, similarly, the porosity, degree of saturation and the nature of pore-electrolyte govern

the resistivity of rocks like sandstone and limestone. A slight increase in resistivity with depth is the result of decreasing pore, fracture, and fault and shear-zone porosity due to increased litho static load (Telford *et al.,* 1976).

3.3.1 Water Salinity

Conduction in near-surface rocks is electrolytic, taking place in connected pore spaces, along grain boundaries, in fractures, faults and shear zones but negligibly through the silicate frame work. The ions which conduct the current result from the dissociation of salts, such dissociation occurring when salts are dissolved in water. Since each ion is able to carry only a definite quantity of charge, it follows that the more ions that are available in a solution, the greater will be the charge that can be carried. Hence, the solutions with larger number of ions will have higher conductivity. In general, for a given, porosity, a rock which contains saline water within its pores will have greater conductivity when the salinity of the water is high than when it is low. Resistivity decreases with increase in salinity (Telford *et al.,* 1976).

3.3.2 Porosity of Rock

Porosity can be defined as the ratio of the percentage of the volume of void space to the total volume of the rock. Porosity arises from the fact that the particles do not occupy all the possible space. It provides a direct measure of the total void space available for the storage of fluids (Clark, 1960).

Resistivity and porosity in sedimentary rocks can be related by the general form of Archie's law, which for rocks devoid of clay is written as

$$f = \frac{\rho_r}{\rho_s} = \alpha\phi^{-m} \quad \text{.....3.2}$$

Where f is the formation resistivity factor, $\rho_r$is the resistivity of the rock, ρ_s is the resistivity of the solution in the pores of the rock, ϕ is porosity, while α and m are constants peculiar to the rock type. The constant 'm' is usually referred to as the coefficient of saturation. The most common minerals forming the soils and rocks have very high resistivity in a dry condition, and the resistivity of soils and rocks is therefore normally a function of the amount and quality of water in pore spaces and fractures. The degree of connection between the cavities is also important.

3.3.3 Effects of Temperature

An increase in temperature lowers the viscosity of water, with the result that ions in the water becomes more mobile. The increased mobility of the ions results in an observed resistivity decrease with increase in temperature according to the formula (Keller and Frischknecht, 1966)

$$\rho_r = \frac{\rho_{18^o}}{1+\alpha(t-18^o)} \quad \text{.....3.3}$$

Where ρ_r is the resistivity at this temperature t, ρ_{18^o} is the resistivity at 18^oC, α is the temperature coefficient of resistivity $(about\ 0.025/^oC)$for most electrolytes) and t is the ambient temperature.

3.3.4 Effects of Rock Texture and Porosity

The texture of a rock dictates its resistivity in the following ways

i. A well sorted sandstone has large void spaces and hence exhibits low resistivity if there is water in the pore space.
ii. Poorly-sorted sandstone will have a much lower porosity and hence will exhibit higher resistivity.

iii. Dissolution along fractures in a limestone will enhance porosity and hence lower resistivity.

iv. Precipitation of some minerals in any rock will lower the porosity and hence increase resistivity.

v. Basal has much unconnected or dead-end pore spaces and hence low permeability, so that even basalt of high porosity may exhibit high resistivity (Telford *et al.,* 1976).

3.3.5 Effects of Geological Processes

In general, geological processes reduce the resistivity of a rock but there are exceptions. Weathering and hydrothermal alteration of granite significantly lowers its resistivity. Dissolution, faulting and shearing usually increase porosity and fluid permeability, and hence lower resistivity (Telford *et al.,* 1976). Precipitation of calcium carbonate and silica reduces porosity and hence reduce fluid permeability and increase resistivity. Indurations by compaction or metamorphism will reduce porosity and permeability and hence increase resistivity. Salt water intrusion provides more ions for conduction and therefore reduces resistivity.

3.4 THE THEORY OF THE RESISTIVITY METHODS

The basis of the resistivity method is that when a current is driven into the earth any variation of the surface resistivity will alter the current flow which will in turn affect the distribution of electrical potentials (Telford *et al.,* 1976).

In the resistivity method, artificially-generated electric currents are introduced into the ground and the resulting potential differences are measured at the surface. Deviations from the pattern of potential difference expected from homogeneous ground provide information on the form and electrical properties of the subsurface in homogeneities.

Generally, the theory of the resistivity method derived from Ohm's law which provides the relationship between the magnitudes of the electric field, E and current density, j and it states that;

$$j = \sigma E \quad \text{.....3.4}$$

Where $\sigma = conductivity$

Since'

$$\sigma = \frac{1}{\rho} \quad \text{.....3.5}$$

Where ρ is the resistivity, then

$$j = \frac{E}{\rho} \quad \text{..... 3.6}$$

The above definitions assumes zero frequency.

For an isotropic medium, the conductivity will be a scalar quantity so that $j$and E will be in the same direction. E is the gradient of a scalar potential, V in volts. Thus we have

$$E = -\nabla V \quad \text{.....3.7}$$

Hence from equations (3.4) above, we have

$$j = -\sigma \nabla V \quad \text{.....3.8}$$

Taking the divergence of the current density we have

$$\nabla \cdot j = -\nabla \cdot (\sigma \nabla V) = 0 \quad \text{.....3.9}$$

And since σ is a constant equation (3.9) reduces to

$$\nabla^2 V = 0 \quad \text{.....3.10}$$

This is the Laplace's equation, i.e. the potential is harmonic for equation (3.10) to hold two boundary conditions must be satisfied (Telford *et al.*, 1976).

(1) The potential must be continuous across the boundary

(2) The normal component of j must be continuous

3.4.1 Single Point Current Electrodes at Earths Surface

Consider a point current electrode C_1 at the surface of the homogenous isotropic medium and the air above has zero conductivity and the second nature current electrode C_2 is at great distance (See Figure 3.1). Equation (3.10) above is then applicable because of symmetry (the potential will be a function of **r** only, where **r** is the distance from the First electrode). The Laplace's equation in spherical coordinates simplifies to

$$\nabla^2 V = \frac{d^2 v}{dr^2} + \left(\frac{2}{r}\right)\frac{dv}{dr} = 0 \quad \text{.....3.11}$$

Multiplying by r^2 and integrating, we get

$$\frac{dv}{dr} = \frac{A}{r^2} \quad \text{.....3.12}$$

Integrating again, we have

$$V = -\frac{A}{r} + B \quad \text{.....3.13}$$

Where A and B are constants. From the above equation V = 0 when $r \rightarrow \infty$, we get B = 0. In addition, all the current flows through a hemispherical surface in the lower medium, thus the total current crossing the hemisphere is given by

$$I = 2\pi r^2 J = -2\pi r^2 \sigma \frac{dv}{dr} = -2\pi\sigma A \quad \text{.....3.14}$$

Hence,

$$A = -\frac{I\rho}{2\pi r} \quad \text{.....3.15}$$

And from Equation (3.13) we have

$$V = \frac{I\rho}{2\pi r} \quad \text{.....3.16}$$

Or

$$\rho = \frac{2\pi rV}{I} \quad \text{.....3.17}$$

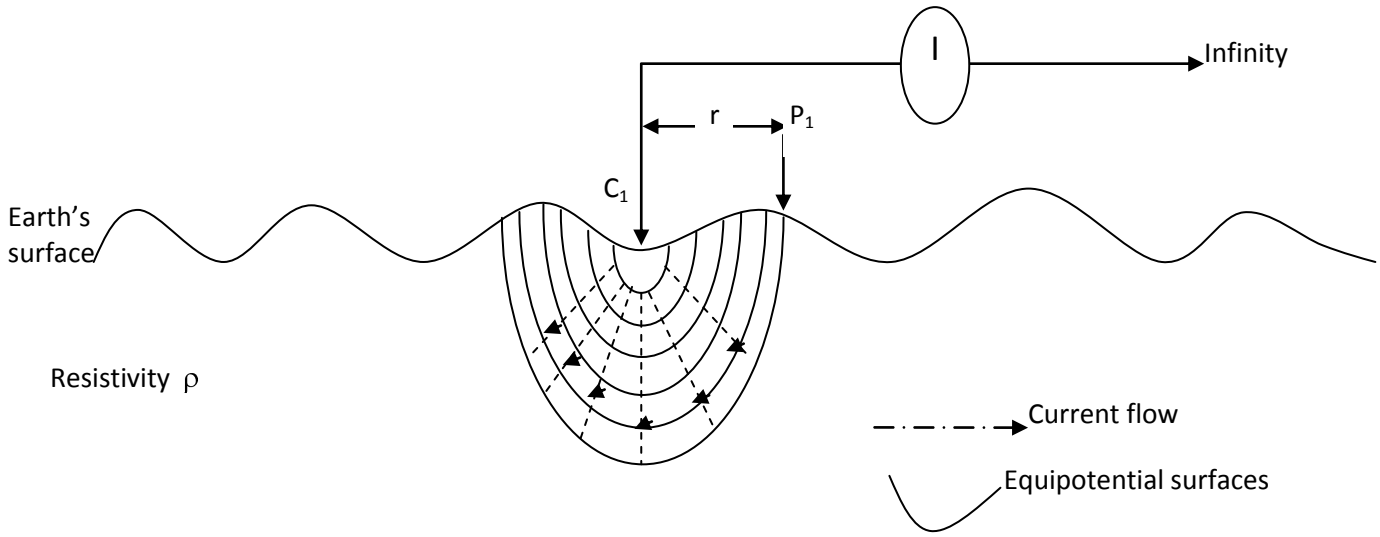


Figure 3.1: ***A point current electrode on the earth's surface (and the second electrode at infinity)***

3.4.2 Two Point Current Electrodes at Earth's Surface

Consider two point current electrodes in which the distance between them is finite figure (3.2). The potential at any new surface point will be affected by both current electrodes and hence the potential due to C_1 at P_1 is

$$V_1 = -\frac{A}{r_1} \quad \text{.....3.18}$$

And the potential due to C_2 at $P_1$is

$$V_2 = -\frac{A}{r_2} \quad \text{.....3.19}$$

Where $A_1 = -A_2 = A$ thus, we have

$$V_1 + V_2 = \frac{I\rho}{2\pi}\left(\frac{1}{r_1} - \frac{1}{r_2}\right) \quad \text{.....3.20}$$

Introducing the second potential electrode at P_2 the potential difference between the two potential electrodes is given by

$$\Delta V = \frac{I\rho}{2\pi}\left\{\left(\frac{1}{r_1} - \frac{1}{r_2}\right) - \left(\frac{1}{r_3} - \frac{1}{r_4}\right)\right\} \quad \text{.....3.21}$$

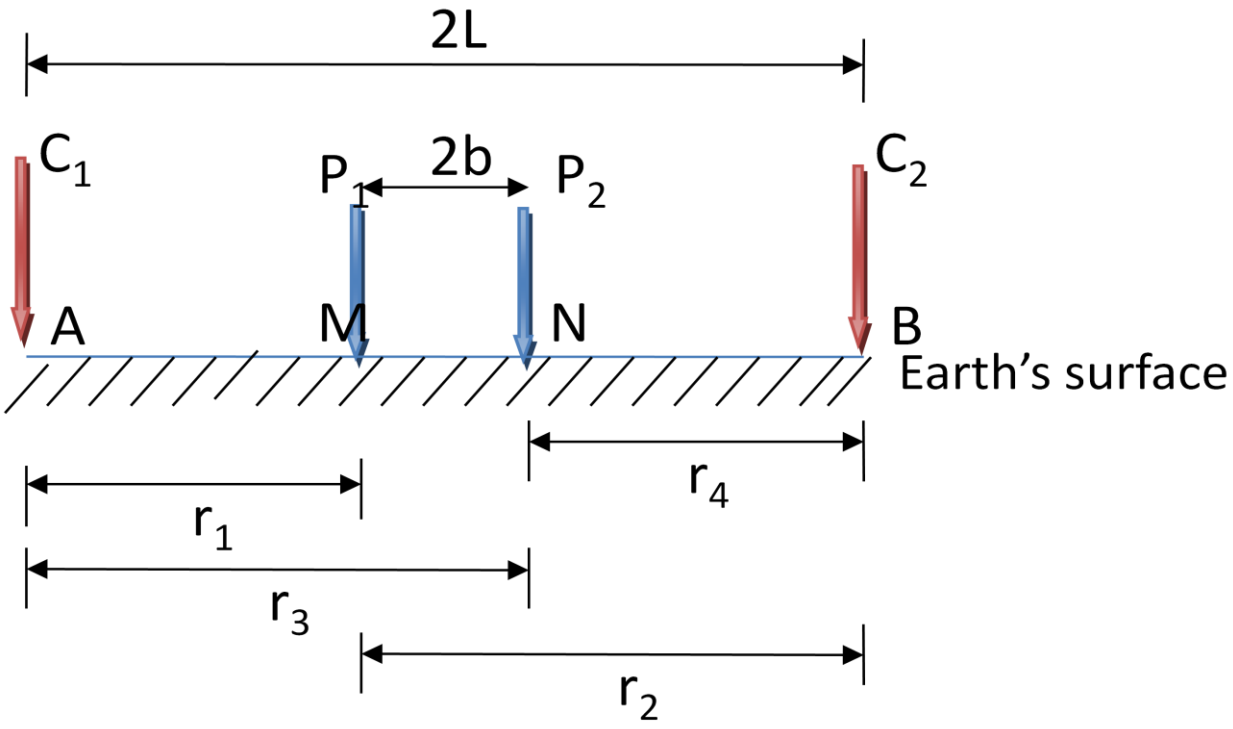


Figure 3.2: ***Two point current electrode on the earth's surface***

Where, C1 is the Current electrode at point A, C_2 is the Current electrode at point B, P_1 is the Potential electrode at point M, and P2 is the Potential electrode at point N

Equation (3.21) gives the potential difference between the two potential electrodes. The electrode layout is referred to as the general four electrode configuration over a homogenous isotropic earth, a variation of which is normally used in electric resistivity measurements.

3.4.3 Apparent Resistivity

From equation (3.21), the resistivity ρ is given by

$$\rho = \frac{2\pi\Delta V}{I}\frac{1}{\left\{\left(\frac{1}{r_1}-\frac{1}{r_2}\right)-\left(\frac{1}{r_3}-\frac{1}{r_4}\right)\right\}} = \left(\frac{\Delta V}{I}\right)K \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.22$$

Where the parameter K, has to do with the electrode geometry. Wherever these measurements are made over a real heterogeneous earth, as distinguished from the fictitious homogenous half space, the symbol ρ is replaced by ρa. This measured resistivity is called the *apparent resistivity* since the measured resistivity is usually a composite of the resistivity of several layers.

3.5 ELECTRODE LAYOUT

The electrical resistivity method uses a series of electrodes nailed to the ground about six centimeters deep along a straight profiles or 3-D grid. The distance between the electrodes depends on the desired depth of investigation and the target to be imaged. The farther apart the electrodes the "deeper" the electricity goes into the earth, at the expense of resolution; this is because the fraction of a total current that flow at depth varies with the current-electrode separation. Usually the depth of penetration is about one-third of the current electrode spacing. The most commonly used configuration activates four electrodes at a time, two for passing current into the ground and two for measuring the potential difference; these are the Wenner, the Schlumberger and the dipole-dipole electrode layout.

3.5.1 Schlumberger Electrodes Configuration

In this array, the current electrodes are spaced much further apart than the potential electrodes (See Figure 3.4). The electric field is measured approximately. Thus from equation (3.22) the apparent resistivity is given as

$$\rho_a = \pi\left(\frac{l^2}{2b} - \frac{b}{2}\right)\frac{\Delta V}{I} \quad \text{.....3.23}$$

Where l is the distance of the current electrode from the Sounding, point and b is the potential electrode distance from the sounding point. sounding, the potential electrodes are fixed while the current electrode separation is increased symmetrically about the Centre of the spread, Schlumberger soundings are carried out under the constraint potential electrode spacing (MN) is small compared to the current electrode spacing (AB) i.e MN < AB/2.

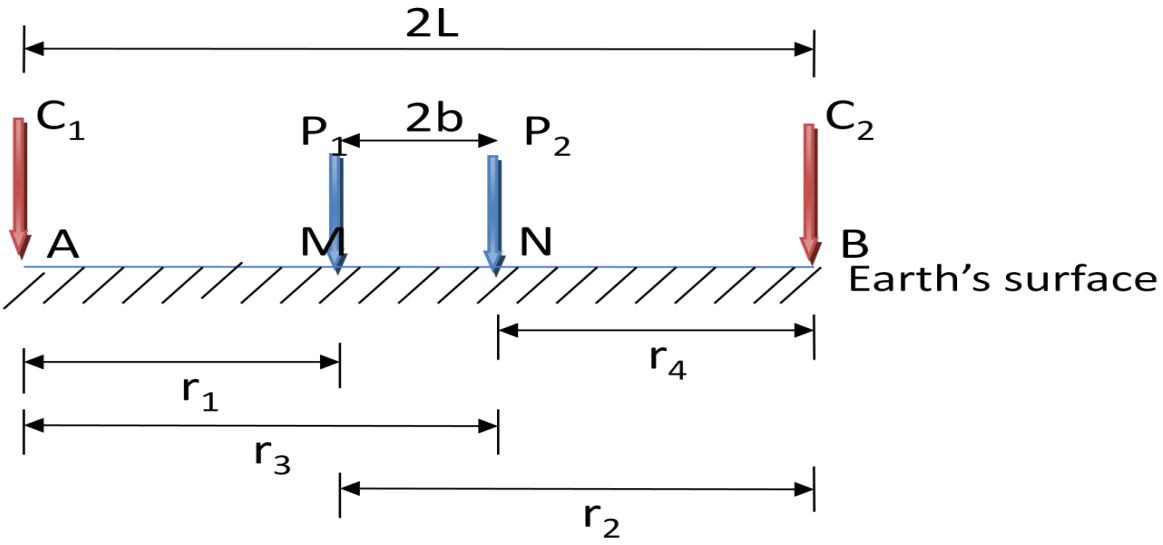


Figure 3.4: ***The Schlumberger array (A and B are current electrodes while M and N are potential electrodes).***

Where, C_1 is the Current electrode at point A, C_2 is the Current electrode at point B , P_1 is the Potential electrode at point M , P_2 is the Potential electrode at point N

In this research the Schlumberger electrode configuration was used to carry out the vertical electrical soundings because of the following reasons:

(i) The effect of Local and shallow in homogeneities near the electrodes is constant for all measurements since the potential electrodes are kept fixed.

(ii) Schlumberger array is faster in field operations since only the current electrodes must be moved between all readings while the potential electrodes are moved only occasionally It is therefore more effective since the array saves time and manpower.

(iii) The relative error resulting from the electrode effect is same for all measurements and this can be handled easily.

3.5.2 The Wenner Electrode Configuration

The Wenner electrode Geometry is illustrated in figure 3.5. Spacing between all electrodes is equal and conventionally denoted by letter 'a' in conducting the horizontal electrical profiling with this configuration all electrodes are moved along a straight line or between the selected profiles after every reading such that the spacing between electrodes remains equal and takes on certain preselected values (Bowen, 1986). The general equation for the apparent resistivity in this configuration is given by

$$\rho_a = 2\pi a \frac{DV}{I} \quad \text{.....3.24}$$

The major advantages of the configuration are;

(i) The larger potential electrode spacing places less demand on the instrument sensitivity.

(ii) The simplicity of the apparent resistivity equation (3.21) when the electrodes are equally spaced (equation 3.22).

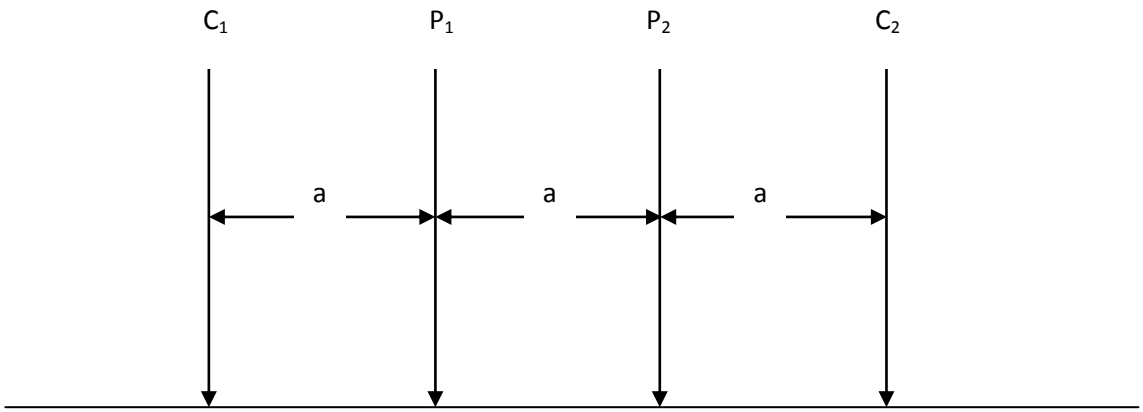


Figure 3.5: ***The Wenner Electrode Configuration***

3.5.3 Field Equipment

The instrumentation used for this survey consist of the **OHMEGA** Ohm Terrameter **E0506**, four steal electrodes, field hammers, measuring tape and reels of wire. The **OHMEGA** Ohm Terrameter **E0506** measures the resistance and displays on its screen board depending on its magnitude, it may be in kilo ohms, ohm or milliohms. The **OHMEGA** Ohm Terrameter contain three basic sub-units; a microprocessesor for monitoring, control and computation; an electrically isolated transmitter for the supply of defined regulated signal current. It can operate at frequency as low as 4 cycles per second; this property makes it suitable for greater depth of investigation. It is portable. It carries out signal averaging by taking consecutive readings automatically and displaying the average result. This makes it possible for the Terrameter to extract the signal from any of noise. See plate I, II, III, IV, V & VI.

Plate I: OHMEGA ohm Accessories E0506

Plate II: OHMEGA Ohm Terrameter

Plate III: Survey layout Area I

Plate IV: Survey layout Area II

Plate V: Survey layout Area III

Plate VI: Survey layout Area IV

3.6 FIELD PROCEDURES AND DATA COLLECTION

There are two procedures for carrying out the resistivity field survey depending on whether one is interested in resistivity variations with depth or with lateral extent, and these are the vertical electric sounding and the horizontal electrical profiling.

3.6.1 The Vertical Electrical Sounding

Using the Schlumberger configurations, the potential electrodes remain fixed while the current-electrode spacing expands symmetrically about the center of spread. As the current electrodes spacing increased progressively, it may become necessary to increase the potential electrodes spacing in order to obtain a measurable potential. This method is useful in determining depth of overburden, structure and resistivity of flat-laying sedimentary beds and possibly of the basement (Telford *et al., 1976).*

3.6.2 Horizontal Electrical Profiling

The Wenner electrode configuration was used to carry out the horizontal electrical profiling in other to determine the lateral variations of resistivity along the profile. The current and potential electrodes are maintained at a fixed separation and progressively moved along a profile. This method is widely employed to locate faults or shear zones and to detect localized bodies of anomalous conductivity. It is also used in archaeological surveys to determine variations in bedrock depth and can also indicate the presence of potentially unstable ground conditions (Kearey *et al.,* 2002).

3.6.4 Data Collection

The resistivity of the subsurface varies vertically with depth and laterally with distance. Both of these variations give useful information about the sub-surface structures. It is therefore necessary to look at these variations. In this case study the vertical electrical sounding and the horizontal electrical profiling were carried out to investigate the resistivity vertically and laterally respectively.

a. Vertical Electrical Sounding Data Collection

In this study, Vertical Electrical Sounding (VES) method was employed and VES survey was carried out in forty eight (48) locations within the area (See Fig. 3.6) using schlumberger electrode configuration. For resistivity sounding using schlumberger array, the current electrodes are usually spaced much farther apart as compared to the potential electrodes. Although, a number of electrode arrangements for current electrodes (A, B) and potential electrodes (M, N) have suggested for this purpose, the symmetrical schlumberger arrangement for the VES survey was thus used. In symmetrical arrangement, the points A,M,N,B are usually taken on a straight line such that point M and N will be symmetrically placed about the centre 'O' of the spread (See Fig. 3.7). Here the separation between two current electrodes A and B is 2L, and the separation between the two potential electrodes is 2l. For schlumberger array, the relation between drop (DV), current flow (I), apparent resistivity (ρ_a) and the distance between current electrodes and apparent resistivity can be given by $\rho_a = k(^{\Delta v}/_{I})$, in case of schlumberger sounding the above mathematical relation is used, however, in the actual sounding survey the separation between the current electrodes AB (2L) is always taken five times greater than the separation between the potential electrodes MN (2l) (Shemang, 1990). A maximum current electrodes spacing (AB) of 200metres was used with the aim of probing a depth of at least ¼ of AB (Gholam and Nad, 2005).

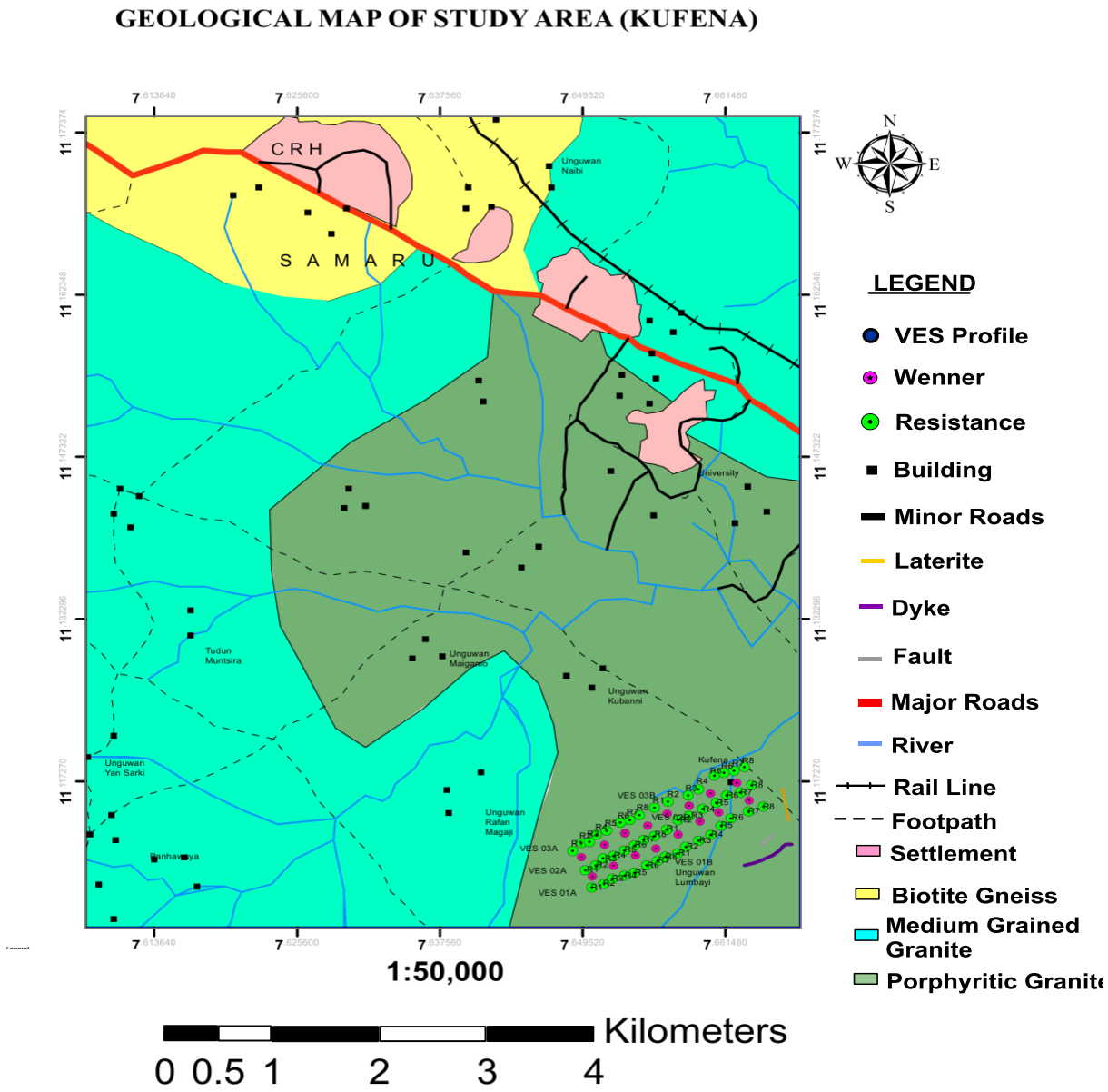


Figure 3.6: The Geology of the Study Area and its Profile positions on which the VES Station lie

The arrangements of the current and potential electrodes were in such a way as to maintain a straight line. These electrodes were connected to the Terrameter. The Terrameter was switched "ON" and current was introduced artificially into the earth through the pair of electrode C_1 and C_2 and the resulting potential difference due to the current were measured through the other pair of electrode P_1 and P_2. Any subsurface variation in resistivity or conductivity alters the current flow, which in turn affects the distribution of electric potential at the surface, thereafter the Terrameter was switched "OFF". The field procedure consists of expanding current electrodes (C_1 and C_2) while holding potential electrode's distance (P_1 and P_2) fixed. This process yields a rapidly decreasing potential difference across P_1 andP_2, which ultimately exceeds the measuring capabilities of the instrument. At this point, a new value for potential distance was established (Keller and Frischknecht, 1966; Osemeikhian and Asokhia 1994). This systematic movement of the current and potential electrode continued until the survey was completed. A current variation in the ranged of 0.2-1.0A, found suitable in basement terrain was used during the measurement (Bowen, 1986).

The numerical values of the geometric factors for each pair of the current electrode spacing were determined so that the apparent resistivity was calculated on the field easily.

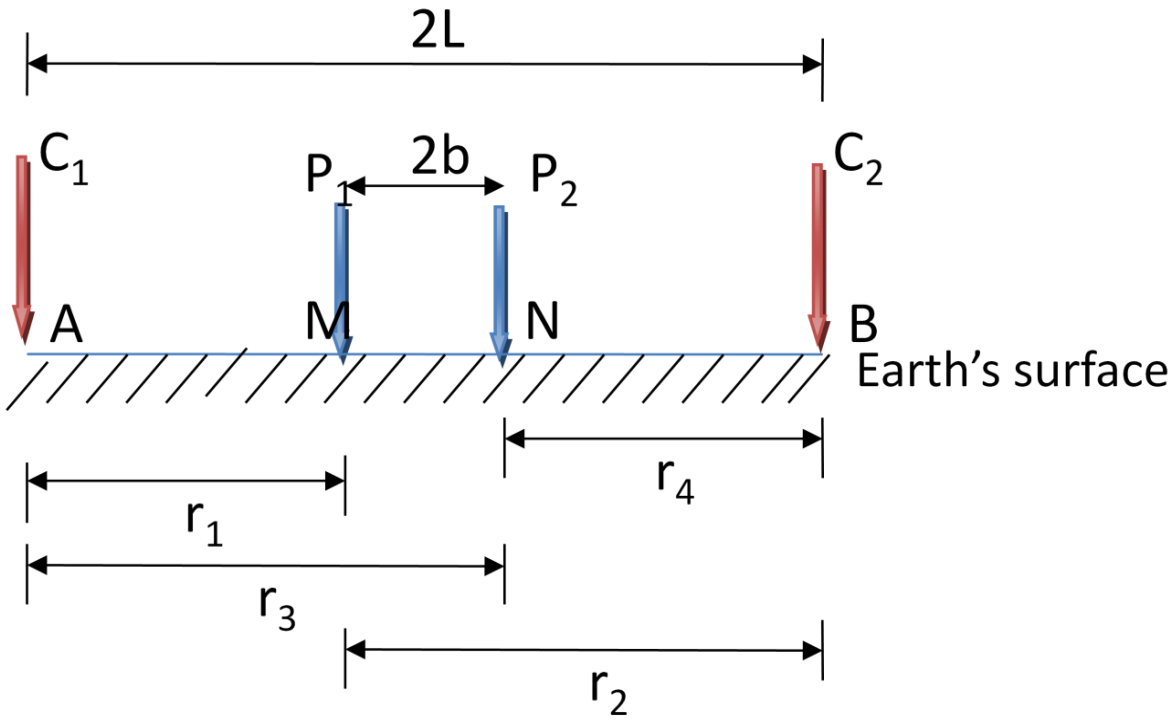


Figure 3.7: The Schlumberger arrangement of the current and potential electrodes as used in the field.

Where, C_1 is the Current electrode at point A , C_2 is the Current electrode at point B , P_1 is the Potential electrode at point M , P_2 is the Potential electrode at point N

(b) The horizontal electrical profiling data collection

In this case the survey was carried out along the six profiles on the same VES profiles. The electrodes spacing remained constant and moved along a profile of 160 meters. The Wenner configuration was used using electrode spacing ‘a’ of 2 metres. This is because, in general most archaeological work does not extend beyond the depth of 5 metres only on exceptional case where serious excavation of earth material has to be done.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 INTRODUCTION

The interpretation of geophysical data involves expressing the information obtained from the surface measurement into geological section/form, from which both qualitative and quantitative deductions can be made. Generally, due to the advance in modern computers, software's are readily available for such interpretations and hence percentage of ambiguity is greatly reduced.

4.2 LIMITATIONS OF THE INTERPRETATION

Quantitative interpretations of geophysical data generally have some limitations. This present work is no exception. The observed limitations are highlighted below;

(i) Presence of non-horizontal layer boundaries; the computed resistivity curves are based on the assumption that the sub-surface layers are horizontal. In reality this may not be the case. Thus, the assumption generally will introduce some measure of error into the interpretation.

(ii) Lateral variation in resistivity of the layers; the various geoelectric layers encountered were assumed to be electrically homogenous. Lateral variation in resistivity within a geoelectric layer exist (Keller and Frischknecht, 1966). This is a possible source of error as the interpretation of the soundings took into cognizance of homogeneity in lateral variation in resistivity of the various layers.

4.3 INTERPRETATION OF RESISTIVITY DATA

An inclusive quantitative of apparent resistivity data is often difficult because of the wide variations in resistivity possessed by geological materials and the difficulty in developing

theoretical expressions for apparent resistivity's of all but the simplest geometries (Bhattacharya, 1992). There are so many methods of interpreting apparent data, these are the empirical methods which included Moore Cumulative Resistivity Method (Mooney, 1966) and the Barnes layer Method (Barnes, 1952), Analysis Methods; this involved the curve matching, the computer-based etc.

The computer-based approach is suggested by Zohdy (1965), recently, due to the advancement in modern technology, different computer programmers have been designed to ease the ambiguity in the interpretation of apparent resistivity data. However, because of the problem of equivalence and suppression and because of the many factors that affect curve details, a thorough knowledge of resistivity principles and as much experience as, possible must go hand-in-hand with computer-derived solutions for field measurements (Bhattacharya, 1992). In this research *IP12Win* is used in Vertical electrical sounding interpretation while *SURFER 12* is used for the horizontal electrical profiling interpretation.

4.3.1 IP12Win Overview

IP12Win is designed for the electrical sounding and/or induced polarization data obtained with any of a variety of the most popular arrays used in the electrical prospecting (Bobachev *et al.,* 2001). Special attention is paid to the user-friendly interactive interpretation. Due to handy controls, the interpretation is able to choose from a set of equivalent solutions, the one best fitting both geophysical data (i.e. providing the least fitting error) and geological data (i.e. geologically data (i.e. geological sensible resistivity cross-section).

The main important menu in the IP12Wiin software included:

- **File:** This contain controls for opening a new VES point, adding a file, exporting a file, printing curves, reopening existing file etc.

- **Edit:** This contained controls for sounding a file, discarding the latest change of a model, restoring the model sounding point, Dar-Zarrock analysis, synthetic curve analysis etc.
- **Point:** This contained controls for inversion, profile inversion, new model generation etc.
- **Section:** This contained controls for zooming in and out, more depth resolution, resistivity section etc.
- **Tool:** This contained controls for statistical analysis, equivalence and conductance viewing.

The software has the capabilities of data management, curve interpretation and result management. The main interaction features of the software are the data entering, data correction and data alteration.

Entering data: IP12Win internal utility for creating data file is run by choosing the file. New VES point menu item, or by clicking the make new VES point button on the toolbar. The new VES point window will appear. The left part of the window is a table of a field data, each line represents spacing. The columns of the table are current electrode spacing (AB/2 column), potential electrode spacing (MN), apparent chargeability (SP), voltage (U), current (I), Coefficient (K), and apparent resistivity (R_O_a). Current electrode spacing and potential electrode spacing must be typed into the corresponding cells of the table. To enter the voltage and current (in the case where the instrument do not measure the resistivity directly) click the input U and I button of the window, and then type the values in the corresponding cells of the table. To enter the voltage and current (in the case where the instrument don not measure the resistivity directly) click the input U and I button of the window, and then type the values in the corresponding cells. The tray type used must be selected from the Array droop-down list of the window. After all the data are entered click “OK” button of the window in figure 4.1

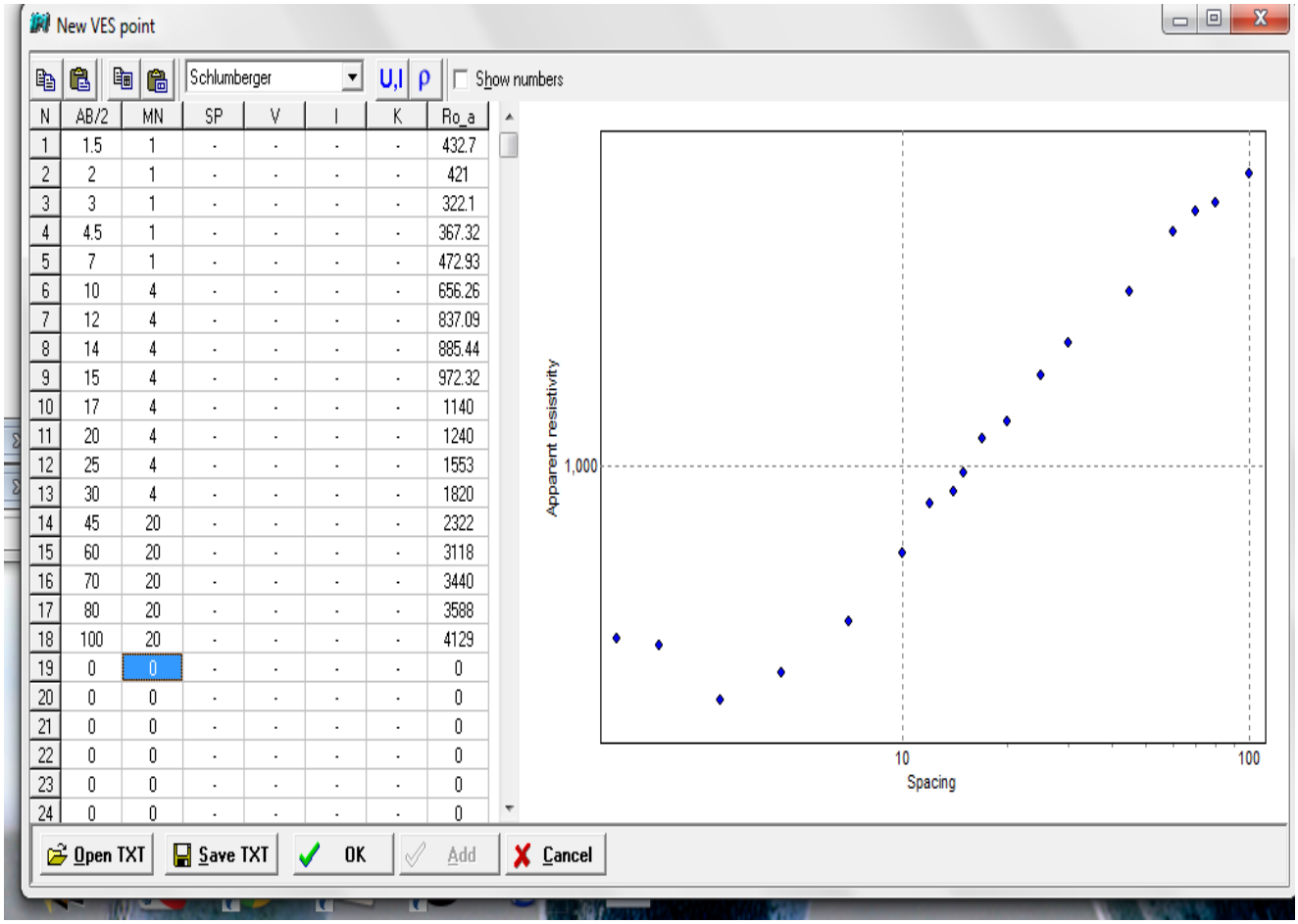


Figure 4.1: A simple window for data input

Data correction and alteration: After clicking OK button of the window, a new window appeared displaying the field curve, synthetic curve field model and a table for the field model. The curve is plotted on a logarithmic scale for both axes. This window allowed for data correction and alteration. This is however possible based on the interpreter skills and knowledge of the theory of resistivity (See Fig. 4.2). After this is carried out the result obtained can be saved, copy as bitmap or print out directly.

4.3.2 Vertical Electrical Sounding Interpretation

The value of the apparent resistivity at each sounding point was calculated from the resistance values obtained in the field (table 4.1) and presented as sounding curves using *IP12win*. Four curve types have been identified within the study area. These are H, HKH, KH, and HA (figure 4.4) with the KH as the predominant curve type (See Fig. 4.3).

The results of the interpreted VES curves along the six profiles are shown in the appendices A, B, C, D, E and F. The numbers of layers vary between two and five layers.

Table 4.1 a typical resistivity data for station 1a4 (Azimuth NW – SE, Alt:-2.36)

AB/2(m)	MN/2(m)	RES(ohm)	K factor (m)	Apparent Resistively (ohm – m)
1.5	0.5	63.09	6.30	397.50
2	0.5	29.16	11.80	344.03
3	0.5	10.96	27.50	301.20
4.5	0.5	6.05	63.62	385.20
7	0.5	3.33	153.15	509.71
10	0.5	3.60	194.40	700.70
12	2.0	8.52	109.96	821.56
14	2.0	6.33	150.8 0	936.59
15	2.0	6.45	173.57	954.29
17	2.0	5.91	223.84	1119.00
20	2.0	5.43	311.02	1324.00
25	2.0	3.75	487.73	1689.00
30	2.0	3.76	703.72	1829.00
45	2.0	2.80	944.84	2647.00
60	10.0	5.92	549.73	3252.00
70	10.0	4.65	753.98	3505.00
80	10.0	4.04	989.60	3996.00
100	10.0	3.10	1555.09	4819.00

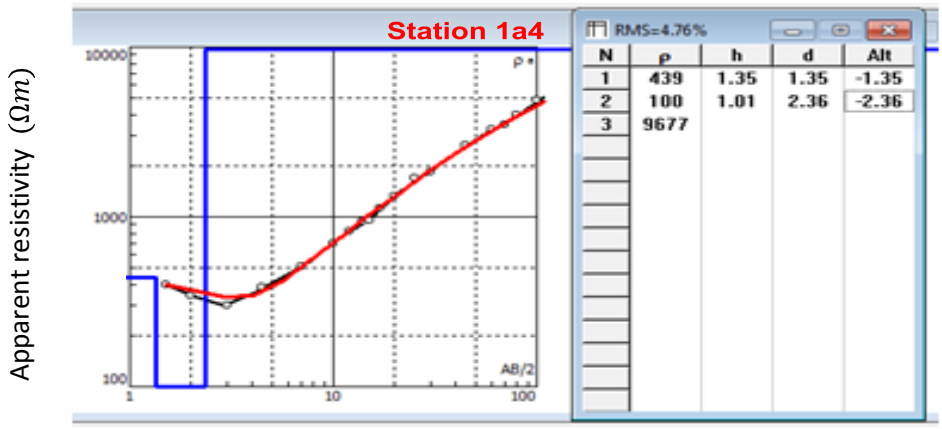
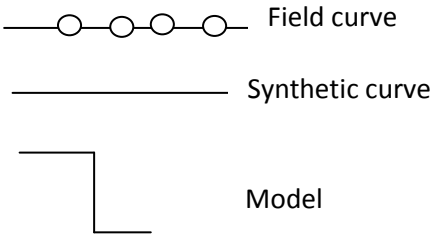


Figure 4.2a Curve Type H



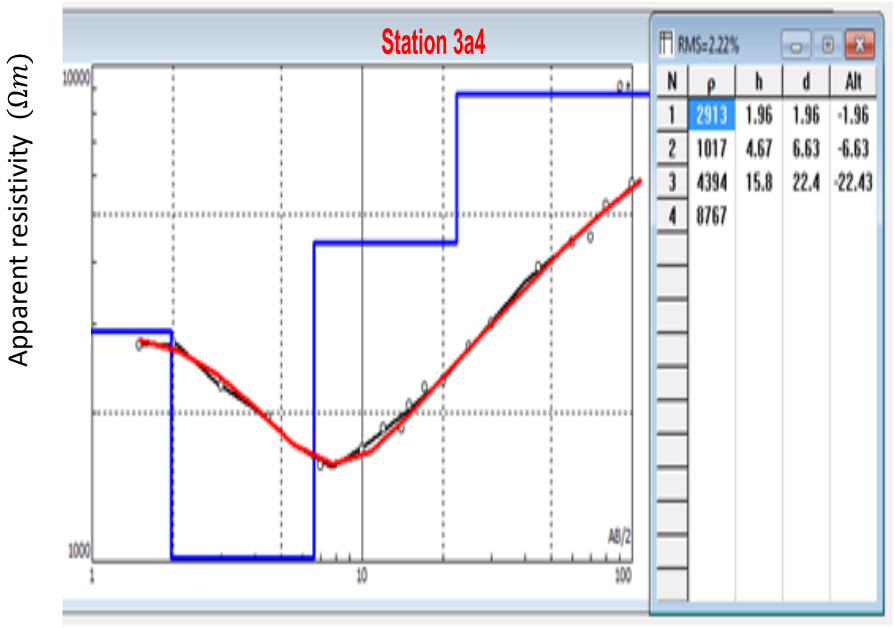
ρ – layer resistivity in Ohm-metre

h – layer thickness in metres

d – depth to interface in metres

N – layer number

Figure 4.2 Examples of resistivity sounding curve types obtained from the study area and their model interpretation

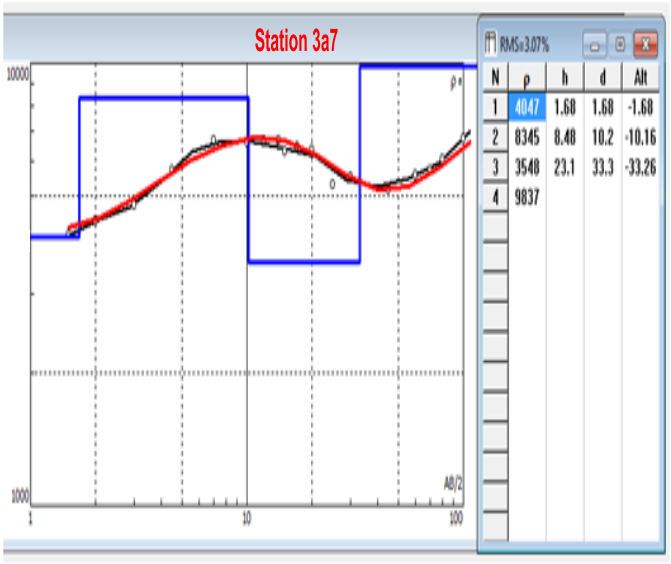


Apparent resistivity (Ωm)

Electrode Spacing AB/2(m)

Figure 4.2b Curve Type HKH

Apparent resistivity (Ωm)



Electrode Spacing AB/2(m)

Figure 4.2c Curve Type KH

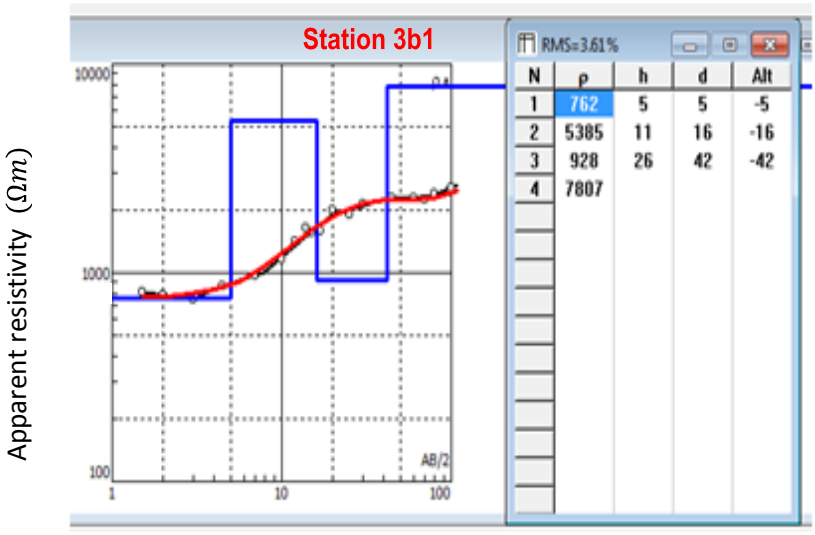


Figure 4.2d Curve Type HA

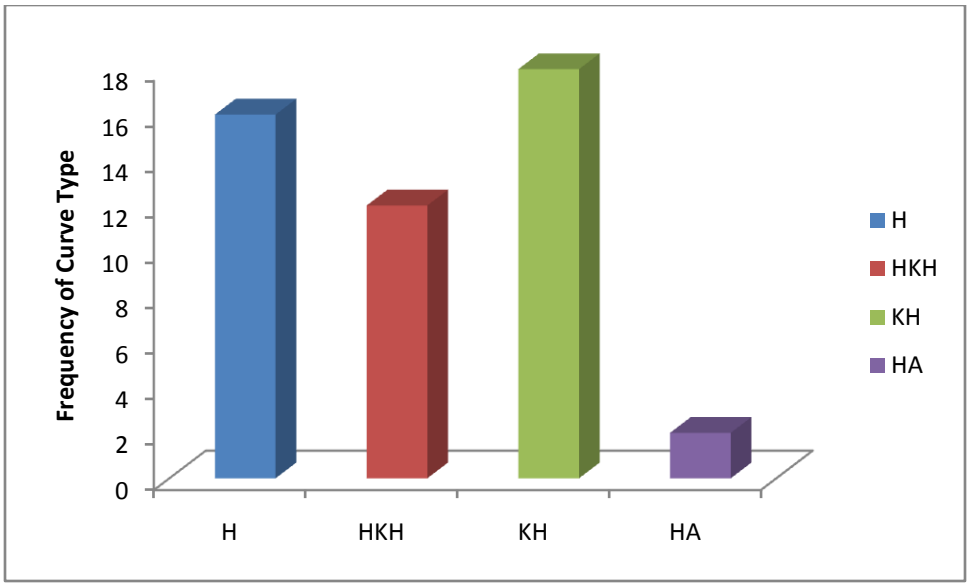


Figure 4.3: Histogram of resistivity sounding curve types obtained from the study area

4.3.3 Geoelectric Sections of the study area

The VES interpretation results were used to prepare 2 – D geoelectric sections along the six profiles 1A, 1B, 2A, 2B and 3A, 3B, (See Figure 4.4, 4.5, 4.6, 4.7, 4.8, and 4.9). The geoelectric section for each of the profiles is plotted for clarity. The geoelectric sections delineate a maximum of three geoelectric subsurface layers comprising the top soil layer, overburden basement, weathered to fractured basement.

The top soil layer has resistivity values ranging from 62 – 452 Ωm. These indicate that the resistivity of the top layer varies from place to place across the entire profile. The main factor that controls the resistivity of this layer is the moisture content within the formation. The second layer resistivity varies between 86.2 - 952 Ωm, this indicates that it is the overburden basement and is also composed of sandy lateritic soil with the resistivity values ranging from 86.2 - 952 Ωm. This basement layer is therefore the appropriate section where most archaeological remains can be found. Those overburden depth areas was on geoelectric plot profile 1A, 1B, 2A, 3A and 3B are found to range from 1.8 – 5.5 m.

The third layer is the weathered to fractured basement, this layer likely undergone the weathering process due to the presence of fracture within the basement its resistivity value range from 125-950 Ωm at a depth of 5.8 – 10 m.

Figure 4.4, 4.5, 4.6, 4.7, 4.8 & 4.9 shows the geoelectric sections plot

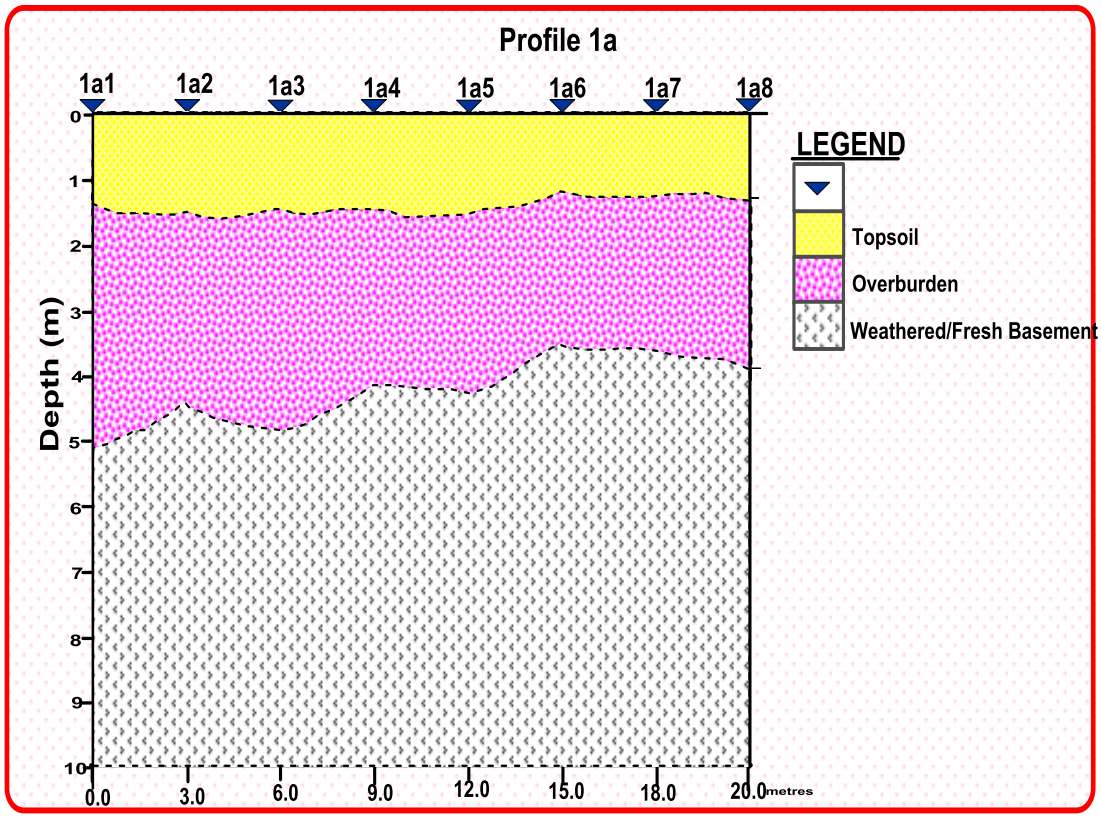


Figure 4.4: Geoelectric section along profile 1A

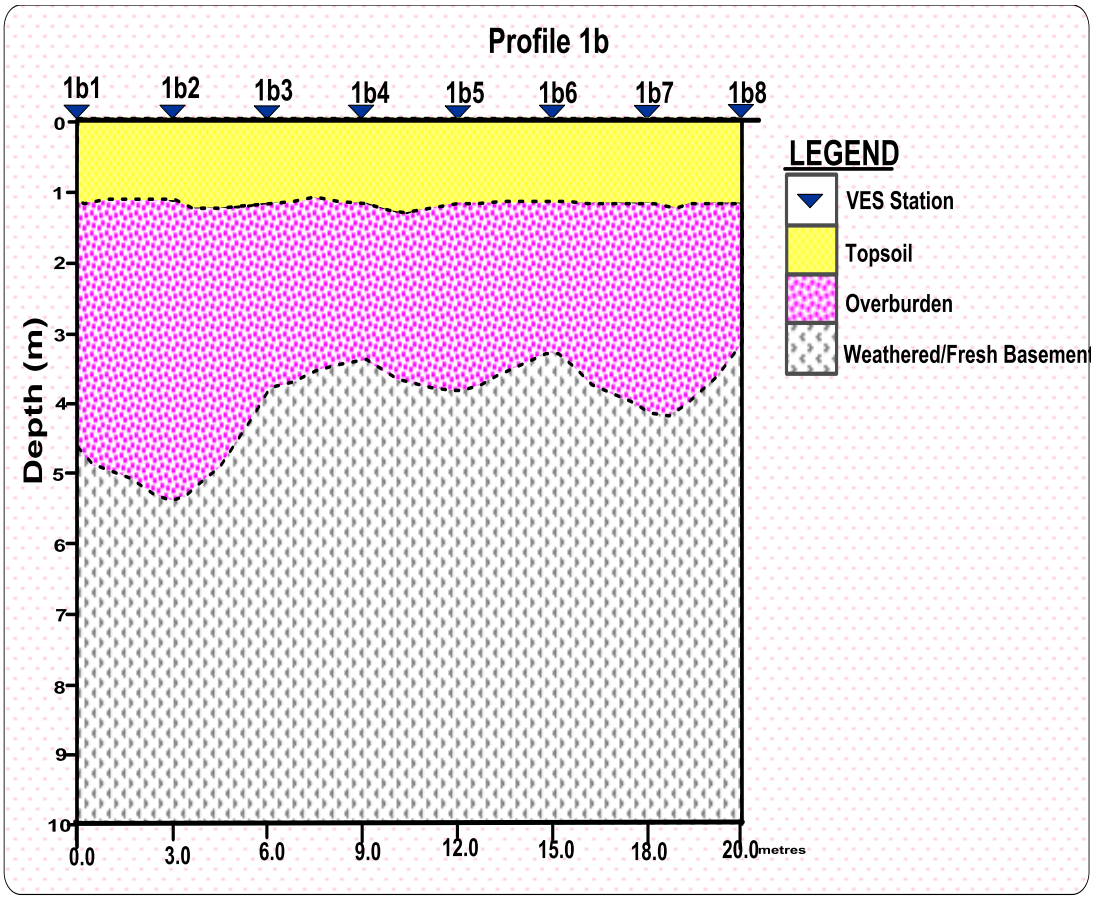


Figure 4.5: Geoelectric section along profile 1B

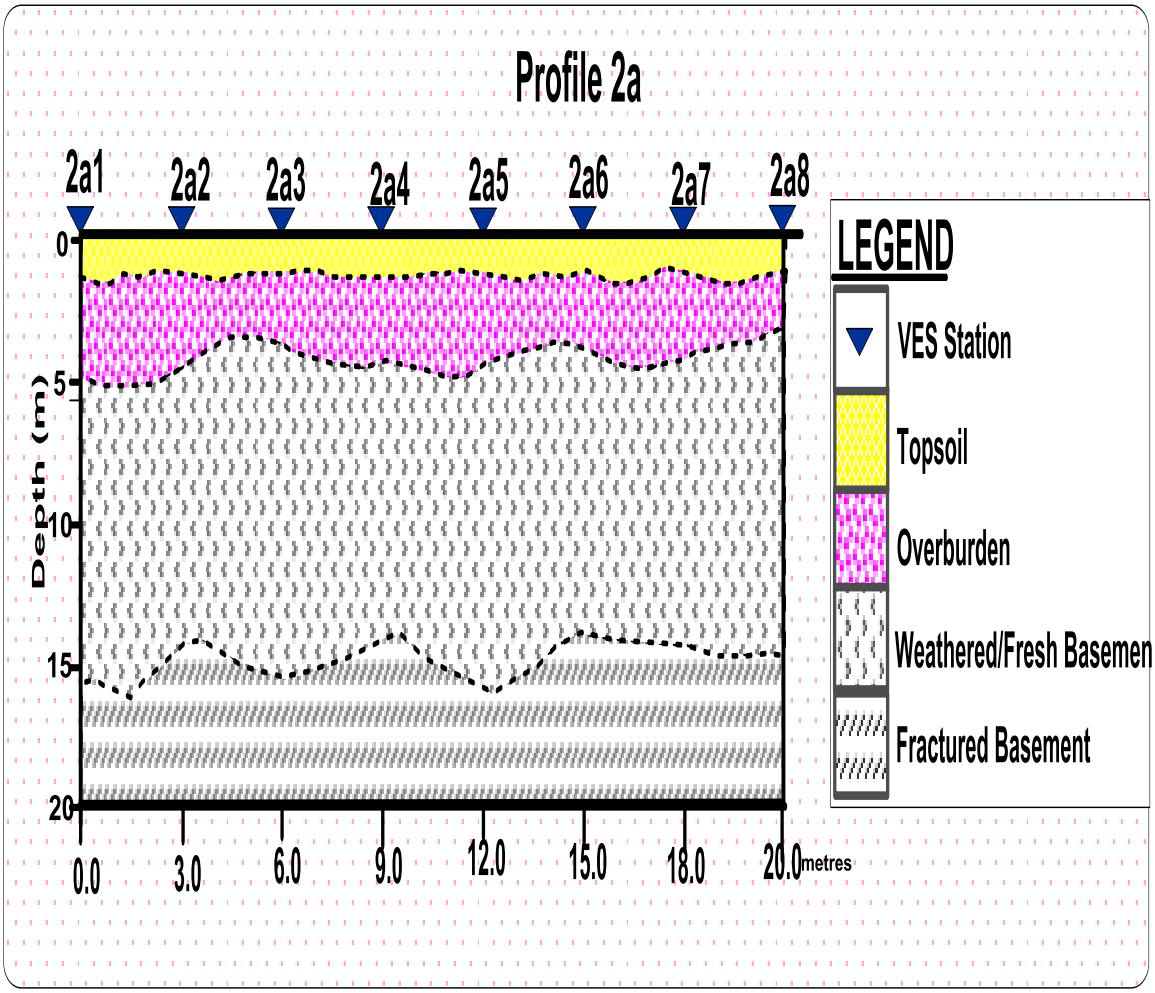


Figure 4.6: Geoelectric section along profile 2A

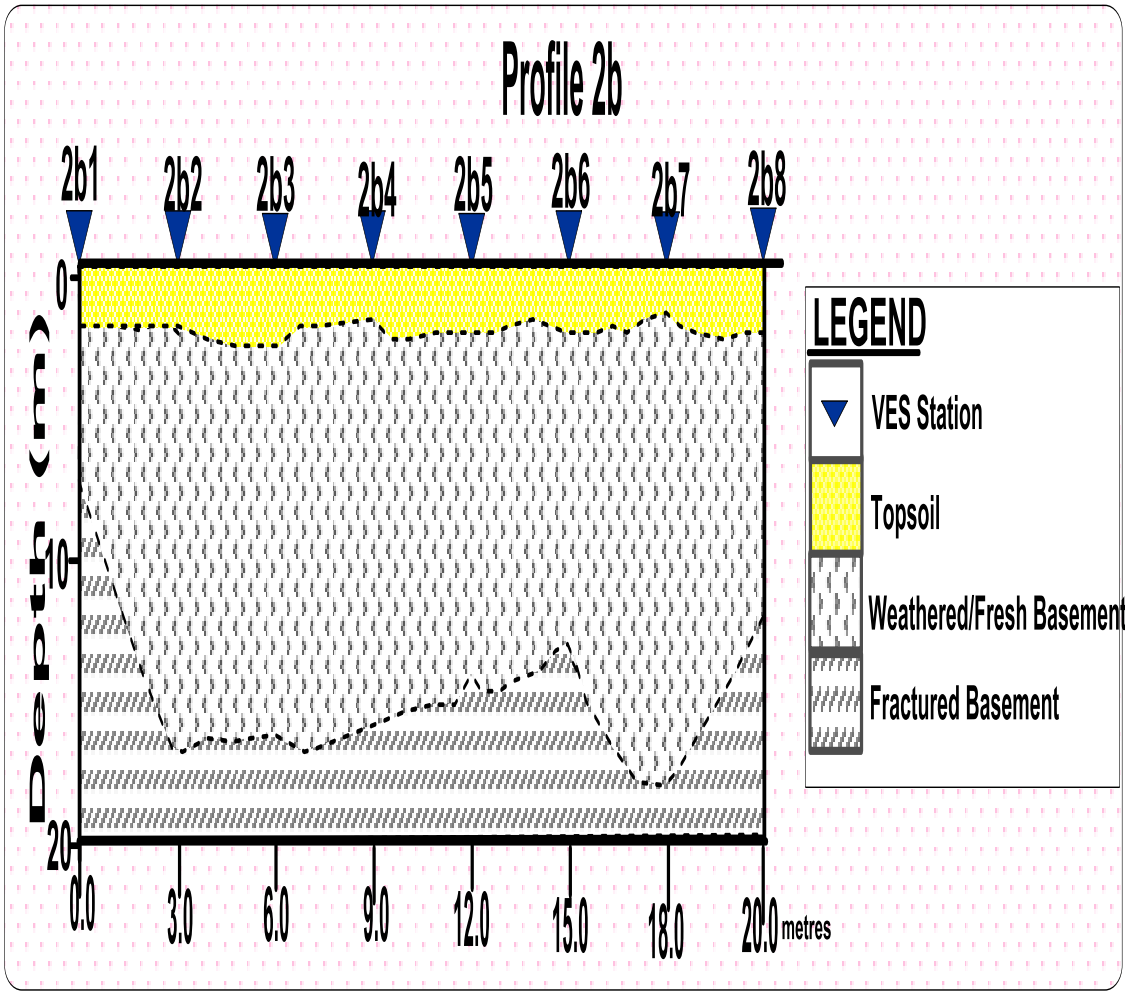


Figure 4.7: Geoelectric section along profile 2B

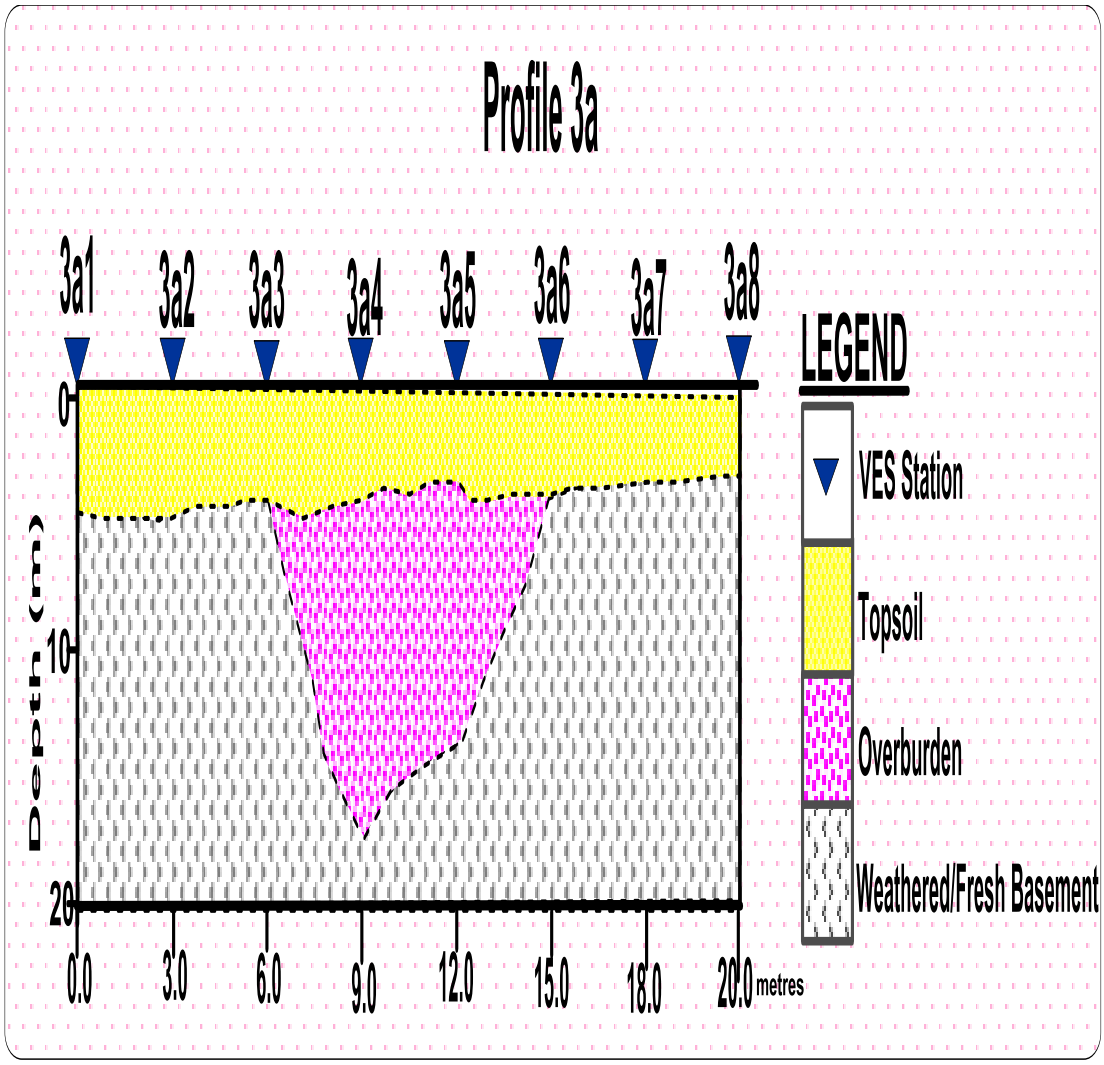


Figure 4.8: Geoelectric section along profile 3A

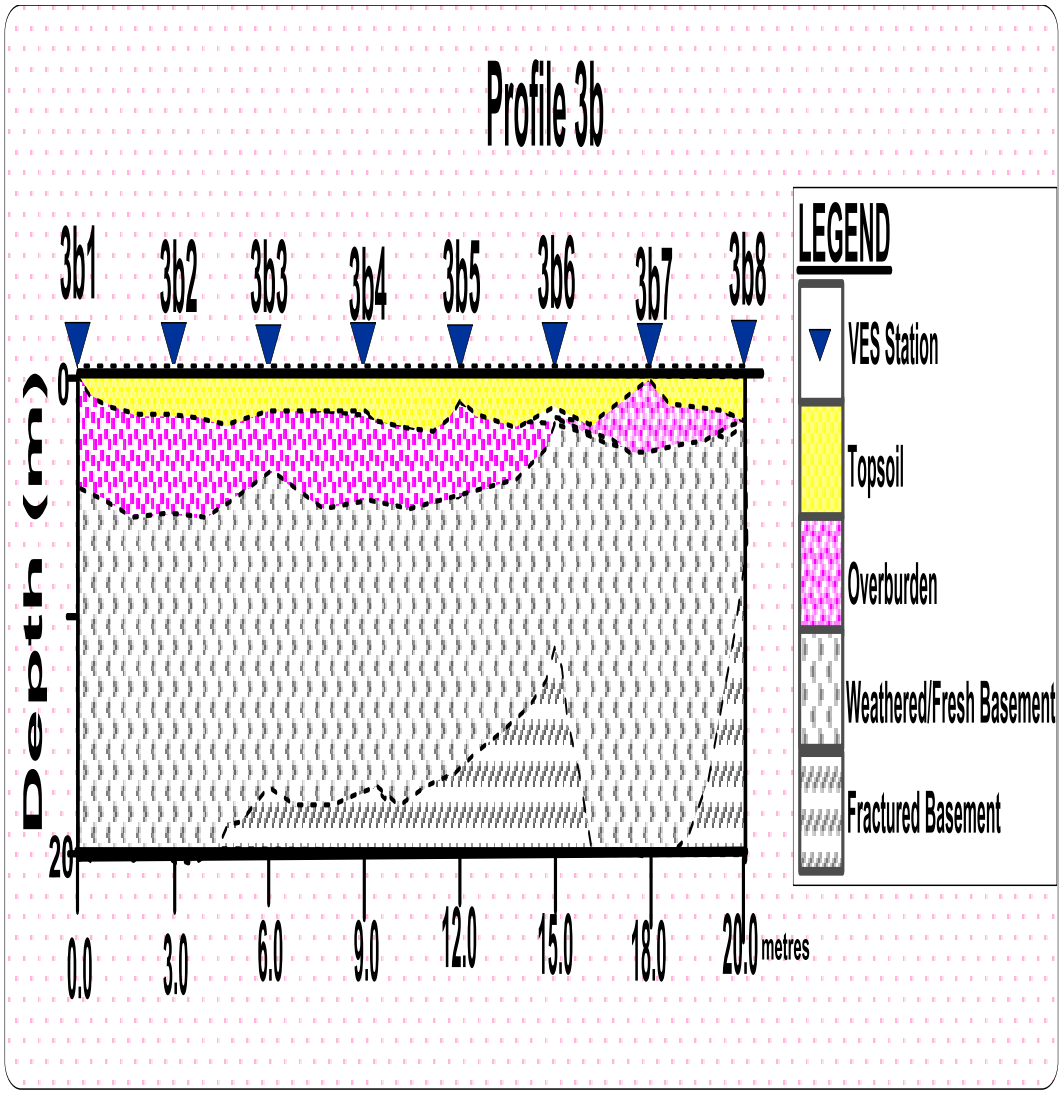


Figure 4.9: Geoelectric section along profile 3B

Table 4.2 Typical Resistivity values of rock materials (after Aboh, 2006)

No. Rock types	Resistivity range (ohm – m)
1. Top soil	1 – 100
2. Sand and gravel	100 – 180
3. Lateritic soil	200 – 500
4. Weathered laterite	500 – 100
5. Weathered basement	20 – 800
6. Fractured basement	135 – 950
7. Fresh basement	> 1000

Table 4.3 Resistivity values adopted for this work

No. Rock types	Resistivity range (ohm – m)
1. Top soil	1 – 120
2. Overburden basement	98 – 456
3. Weathered to fractured basement	125- 950

Table 4.3 thickness of the overburden, depth to the fractured basement and depth to the fresh basement.

Depth to basement	Probable Zone
Top soil basement	1.2m-1.8m
Overburden Basement	3.2 – 5.2m
Weathered to fractured basement	10.4m-20m

Table 4.4 Resistivity values of different layers and their description obtained from the study area through this research.

Layers	**Resistivity values (Ωm)**	**Description**
Surface layer	66 - 456	Top soil consists of saturated clay materials, and indicates high moisture content. Top soil consist of laterite and sand materials
Second layer	673-1450	Overburden basement which is most likely to find an archeological remains when excavating.
Third layer	496-5640	The third layer is the weathered to fractured basement, this layer likely undergone the weathering process due to the presence of fracture within the basement its resistivity value range from 125-950 Ωm.

4.3.4 Basement Topography of the study area

The 3D Model identify the various position of the VES station and the expected depth of penetration of each of the VES points, which shows the subsurface basement of the area better than 2D Model. It also gives the idea of overburden depth based on archaeological purposes. The areas that shows the valley in the basement implies that the overburden is thick and the areas that show the hill in the basement implies that the overburden is thin. Therefore in terms of archaeology the valley areas are more likely to have an artifact when excavated, and the suitable depth of the areas location range from 3.2 m to 5.2 m (See Fig. 4.10).

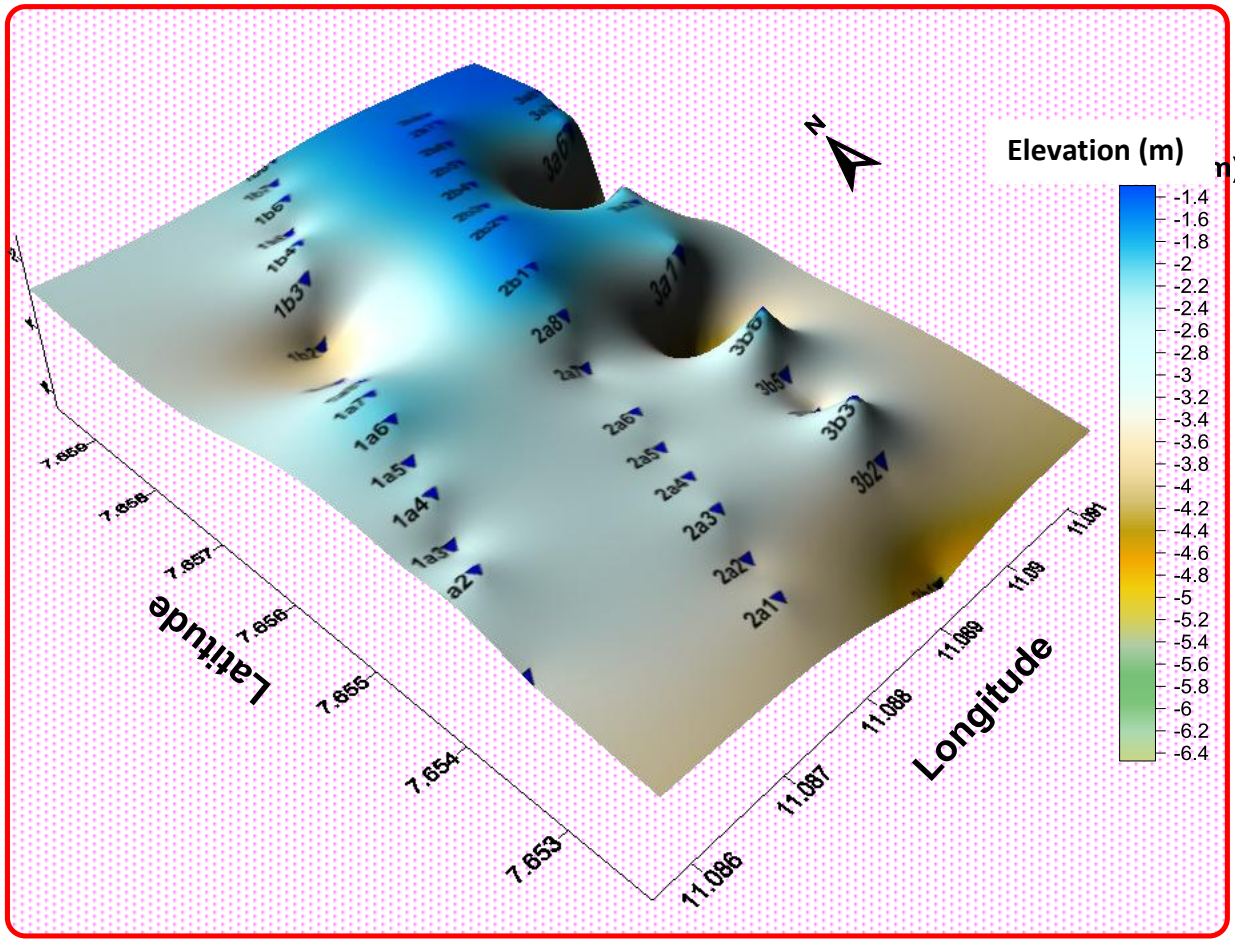


Figure 4.10: the Basement topography of the study area 3D-Model

4.3.5 The Horizontal Electrical Profiling interpretation

Electrical resistivity Profiling (EP) survey was conducted in the survey area along the six profile lines with sampling intervals of 1m each for the depth of 2m, 3m, 4m and 5m along NE-SW direction. (See Fig. 4.11, 4.12, 4.13, and 4.14 shows the plots with corresponding geological sections.

The distance between the electrodes was at 2m and 4m the results of this investigation are presented on a map (See Fig. 4.11 & 4.12).

From the map it is evident that the north – western part of the investigated area contains small spot anomalies location. The chances of finding remains were therefore have considered a smaller amount favorable, and the resistivity values found to range from 140 to 190 Ωm which correspond to the standard resistivity value of the clay after (Aboh, 2006). This indicates that there is no much chances of probable zone of interest in finding archaeological remains.

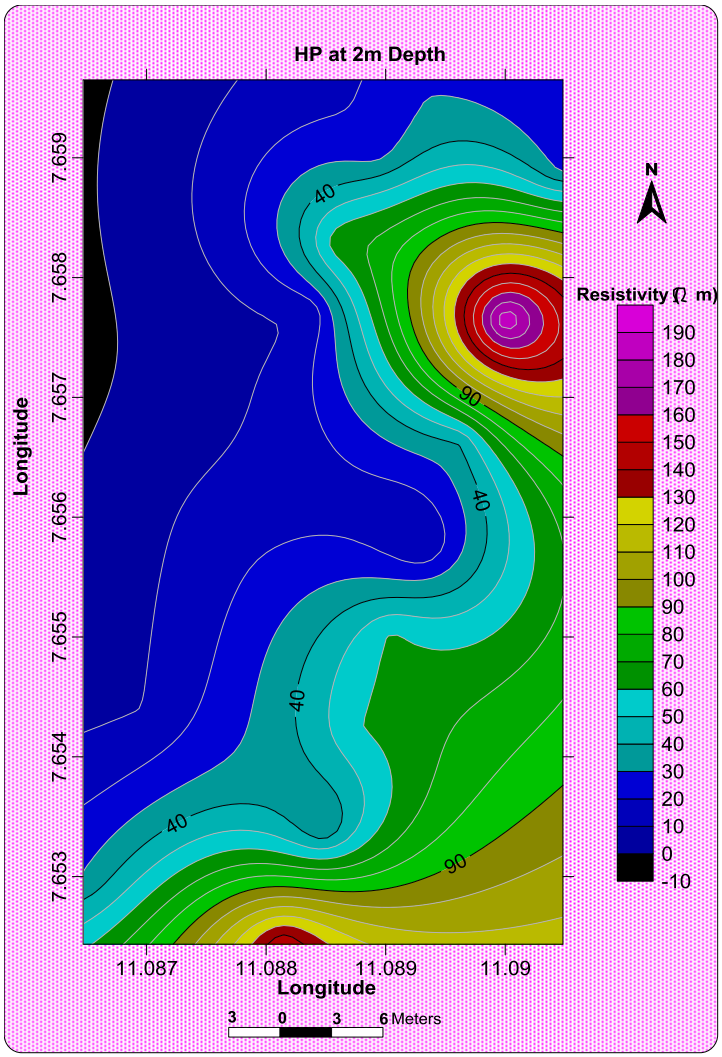


Figure 4.11: Map of horizontal profiling at 2m depth

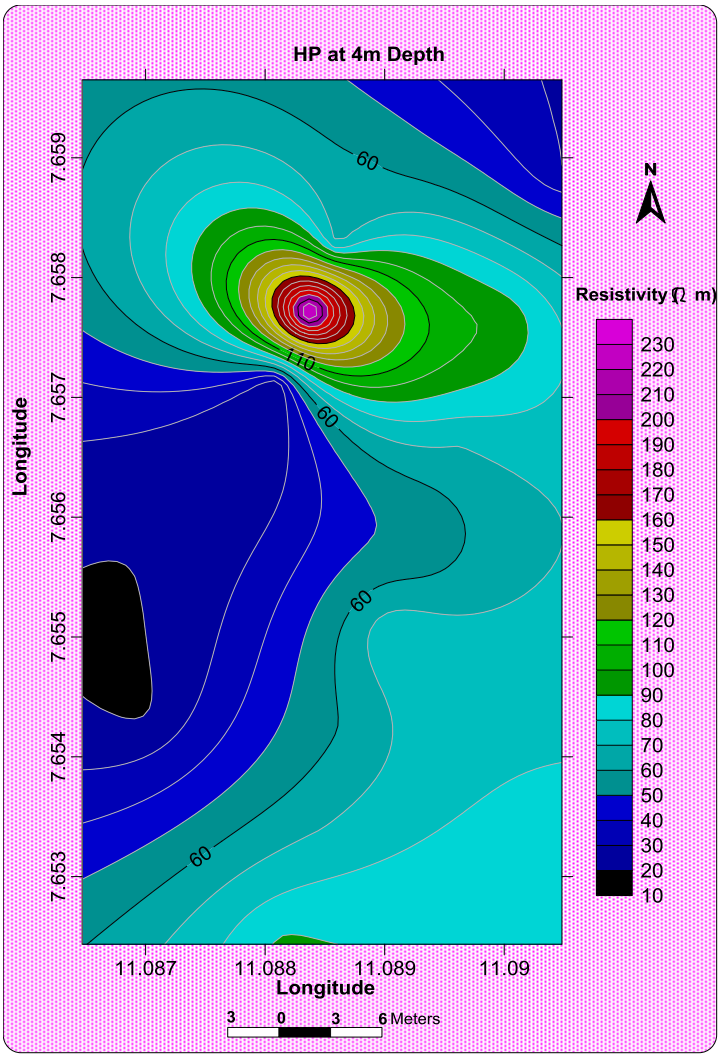


Figure 4.12: Map of horizontal profiling at 4m depth

To obtain more detailed information on the anomalous areas of interest, a resistivity survey with a Wenner configuration at a depth of 3 m and 5 m along profile 2 and 3 as in Fig.3.6 The results from this survey are shown on a map which resistivity values range from 120 to 260 Ωm (See Fig. 4.13 & 4.14).

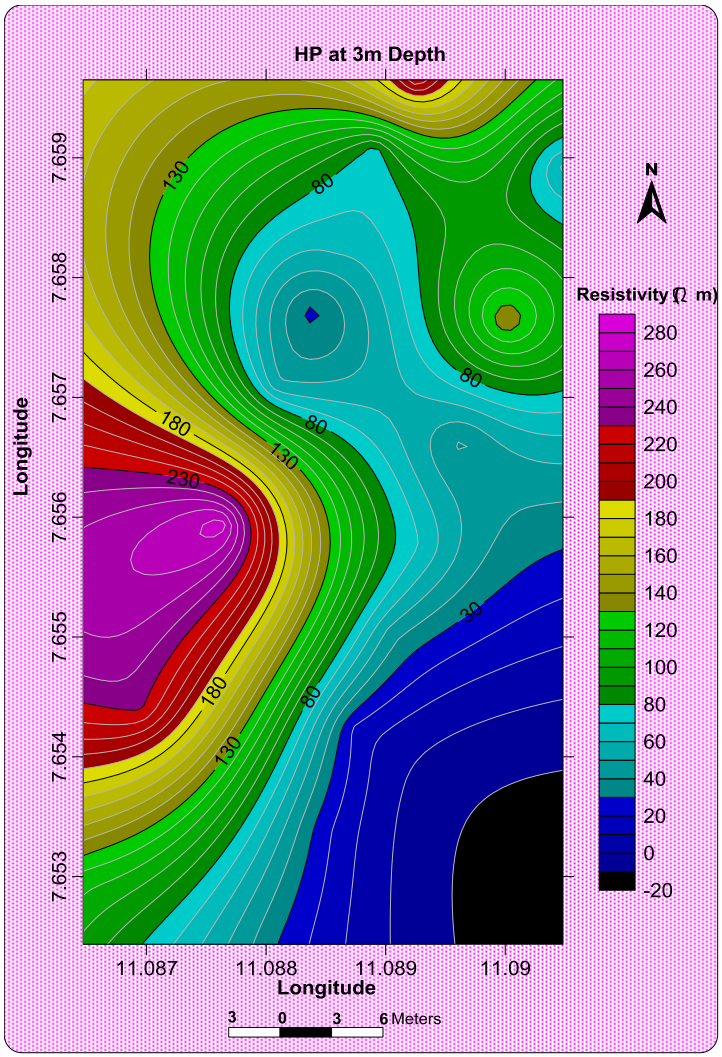


Figure 4.13: Map of horizontal electrical profiling at 3m depth.

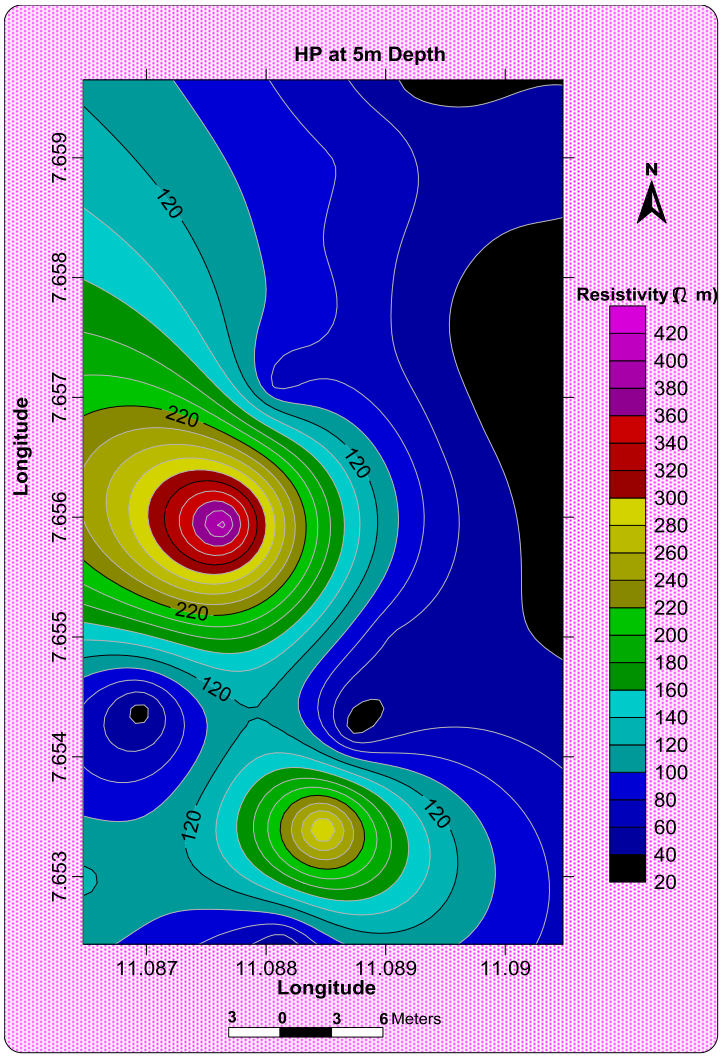


Figure 4.14: Map of horizontal electrical profiling at 5m depth

In comparison, the anomalous pattern obtained for the 3 m and 5 m depth in horizontal electrical profiling resistivity survey are the best because of high resistivity anomalous location which correspond to the resistivity values of 80 to 340 Ωm of the standard resistivity value of a clay and laterite after (Aboh, 2006). Therefore, these resistivity location areas suggest that there is most likely to find an artifact of archaeological remains of anomalous point of interest. In terms of 2 m and 4 m depth when compared, they show low resistivity areas in terms of anomalies pattern, this indicate that there is no much chances in finding artifacts of archaeological remains of probable zones of interest owing to unfavorable condition.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Discussion

The discussion on this research finding will be based on subsurface geophysical evaluation of the study area. This later happens to be the most important discussion aspect as this research focuses on archaeological geophysics.

5.1.1 Discussion of the Subsurface Geophysical Evaluation of the Study Area

From the geophysical survey carried out within the study area, a maximum of three subsurface layers have been delineated. The VES soundings also indicate that resistivity of the layer vary as low as 20Ωm to as large as 950 Ωm.

The geoelectrical sections have revealed the various resistivity values of the layers delineated. The derivation of the geoelectric sections carried out was by correlating the characteristics resistivity values of the various earth materials found within the study area. The geoelectric sections suggest that the first layer was the top soil where the presence of artifact was not found on that layer. The second layer was the overburden basement which most archeological remains are suspected and the depth found to range from 3.2 m – 5.2 m.

The third layer is the weathered to fractured basement, this layer likely undergone the weathering process due to the presence of fracture within the basement its resistivity values range from 125-800 Ωm.

5.2 Conclusion

This research to a large extent has been able to delineate some geoelectric features/factors responsible for archaeological geophysical studies observed in Kufena stone age site Zaria Kaduna state north central Nigeria. From the findings in the research, the geo-electric sections of the six profiles brought out the subsurface layers in the Kufena Stone Age site, to the top soil basement, overburden basement, weathered to fractured basement. The 3D Model of the basement topography gives the idea of overburden depth which was found to range from 3.2 to 5.2 m. This range is found to be suitable in finding artifact of most archaeological remains when excavated. The results of the interpretation of the field survey of horizontal electrical profiling revealed only the presence of anomalous location at depth 2m, 3m, 4m and 5m. This research attempts to identify the archaeological structures of Kufena Stone Age, site using electrical resistivity method. The results from the survey may be used to detect similar structures for future research.

5.3 Recommendations

As a fundamental and important subsurface investigation tool, geophysical investigations should be applied in any archaeological investigation in order to delineate the archaeological features in the study area. This will help to identify the anomalous areas of interest resistivity before excavation.

Also, based on the findings of this research, it is recommended that the horizontal profiling resistivity mapping using the surfer 12 software be adopted in helping the archaeologist to quickly identify the prospective archaeological zones of interest for conducting specifics site investigation and reasonably thus, considerably scaling down extent of this research.

5.2.1 Contribution to Knowledge

The following contributions have been achieved through this research;

1. The archaeological areas have been revealed showing the location of the anomalous areas of interest in resistivity.
2. Areas with archaeological prospects within the study area have been revealed and categorized as the location of high anomaly on the horizontal profiling map.
3. The VES profiles (tactically located across the basement – cretaceous sedimentary boundary) proves the suitability of the boundary to locating productive boreholes in the high potential zones of the study area.
4. A typical example of the basement topography within the study area has been provided
5. The potential of the application of horizontal profiling contouring resistivity of the anomalous areas of interest in archaeological prospecting has been further highlighted for archaeo resources consultants to maximize.

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APPENDIX A:

Resistivity Sounding Curves Along The Profile 1A & 1B Derived From The Application of IPI2win Software

Field curve

Synthetic curve

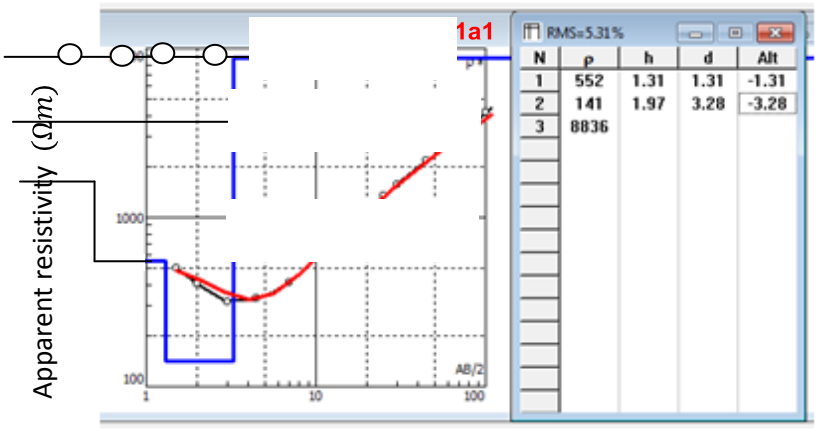
Model

$\boldsymbol{\rho}$ – layer resistivity in Ohm-metre

h – layer thickness in metres

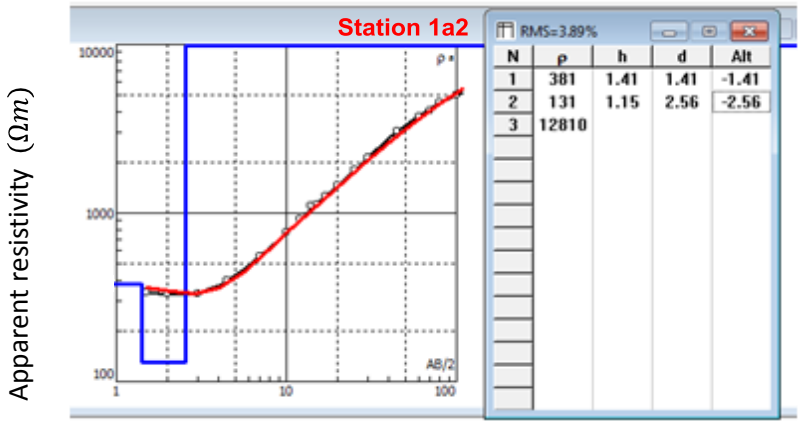
d – depth to interface in metres

N – layer number



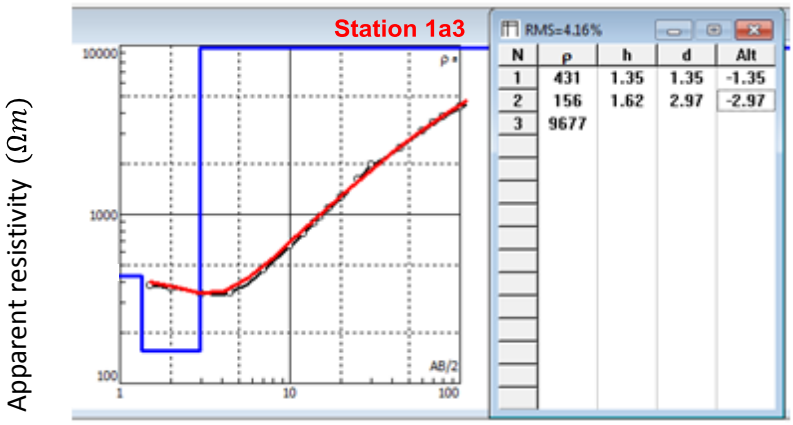
Electrode spacing AB/2(m)

STATION 1A1: CURVE TYPE H



Electrode spacing AB/2(m)

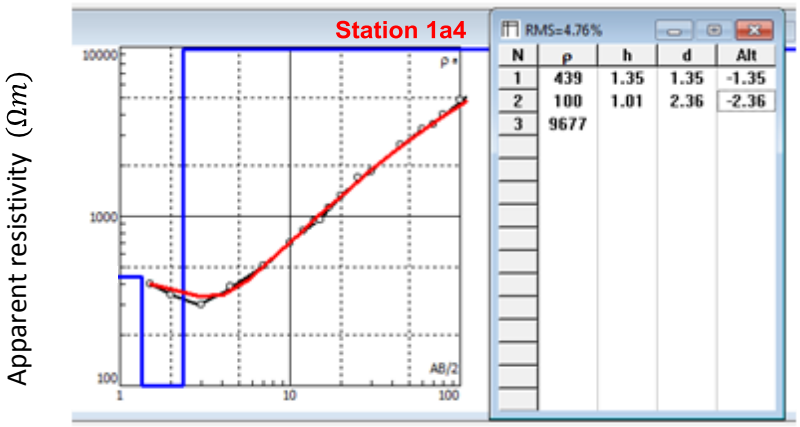
STATION 1A2: CURVE TYPE H



Apparent resistivity (Ωm)

Electrode spacing AB/2(m)

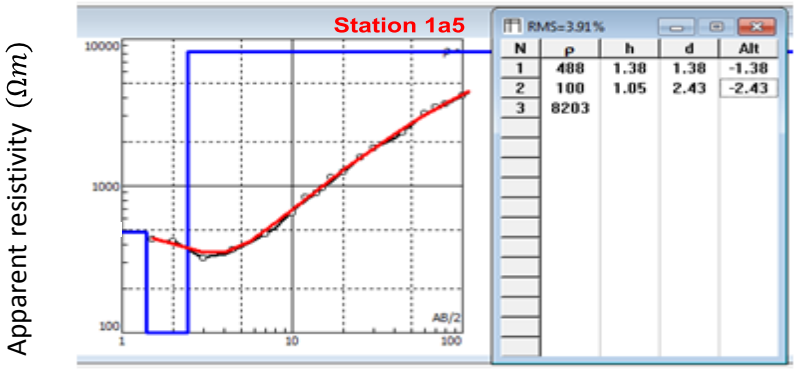
STATION 1A3: CURVE TYPE H



Apparent resistivity (Ωm)

Electrode spacing AB/2(m)

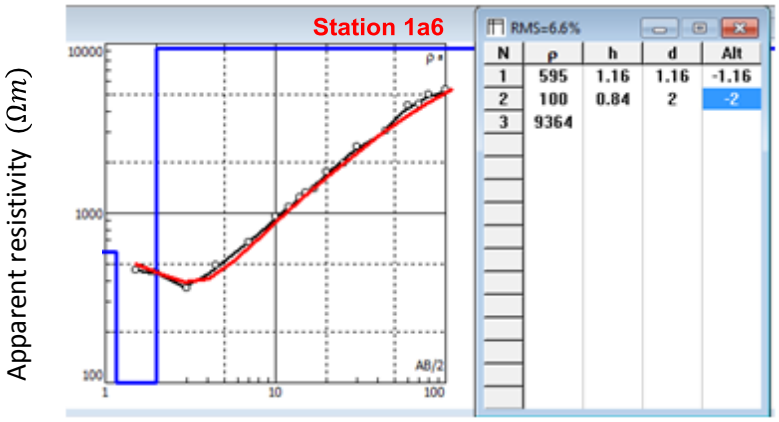
STATION 1A4: CURVE TYPE H



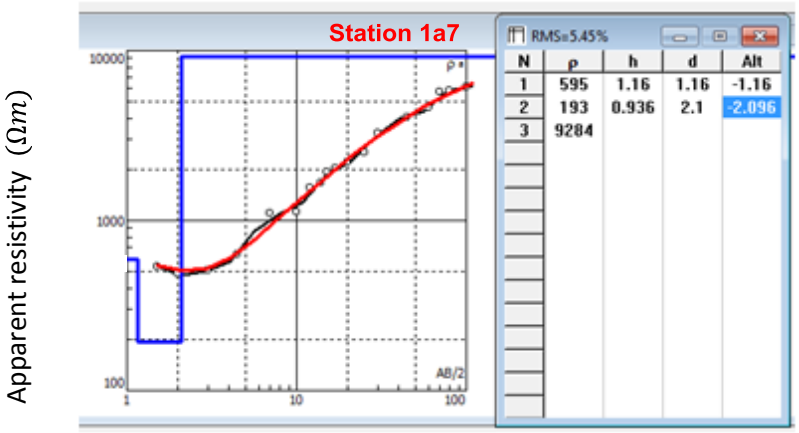
Apparent resistivity (Ωm)

Electrode spacing AB/2(m)

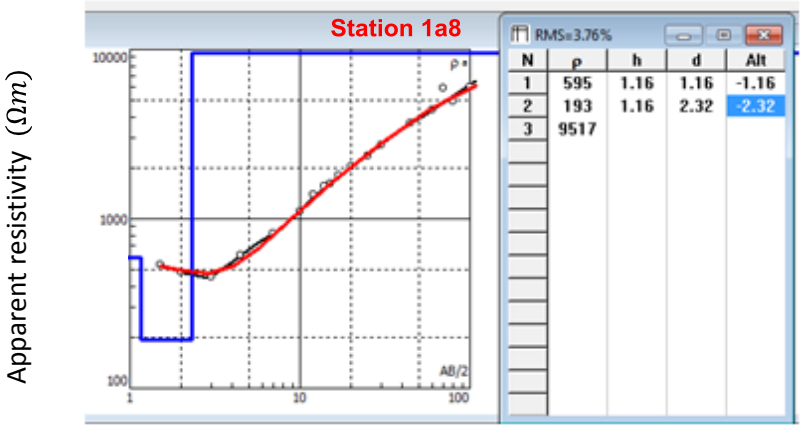
STATION 1A5: CURVE TYPE H



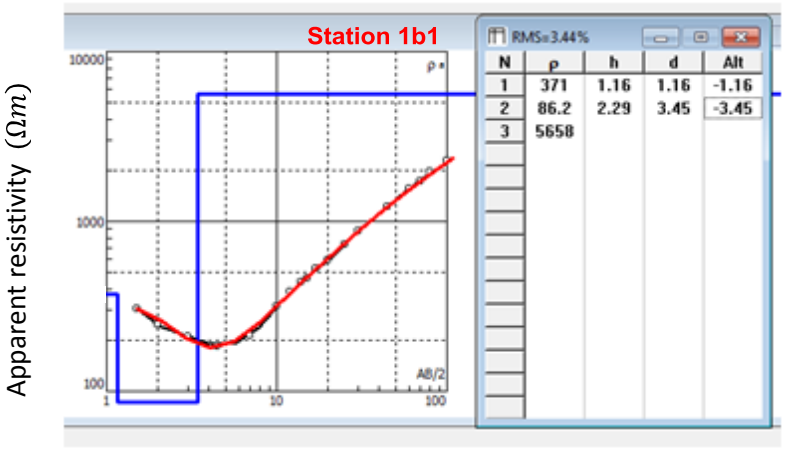
STATION 1A6: CURVE TYPE H



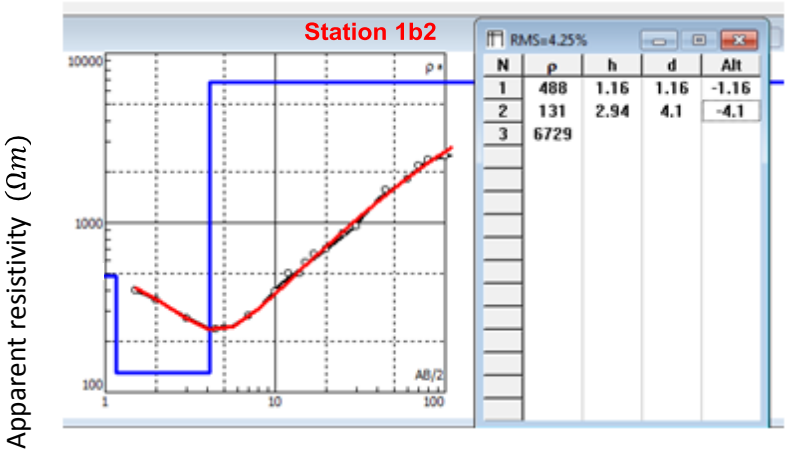
STATION 1A7: CURVE TYPE H



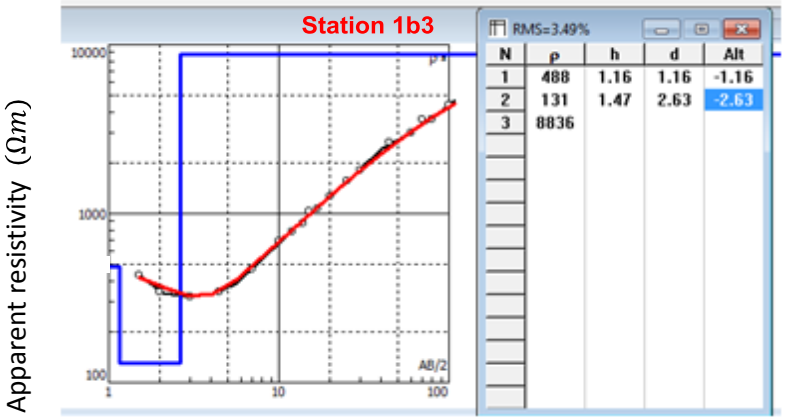
STATION 1A8: CURVE TYPE H



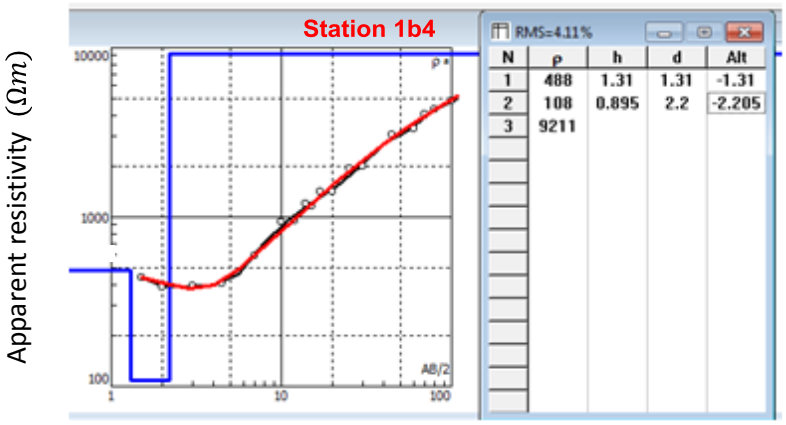
STATION 1B1: CURVE TYPE H



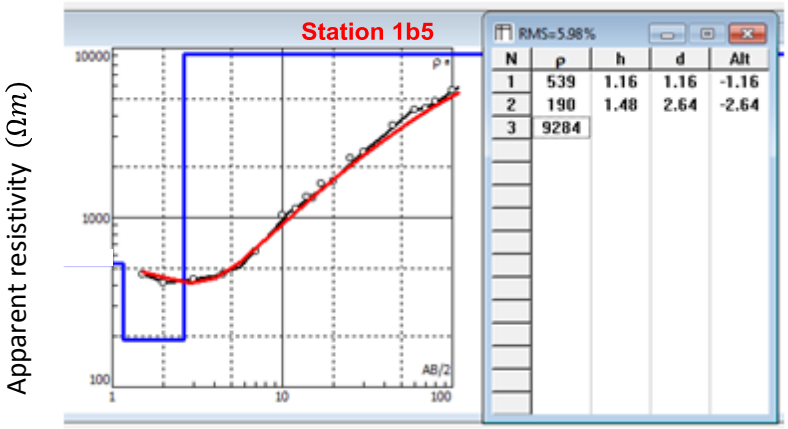
STATION 1B2: CURVE TYPE H



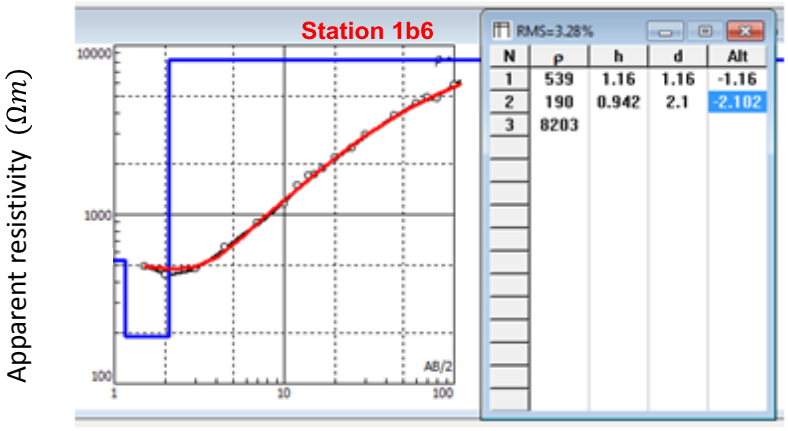
STATION 1B3: CURVE TYPE H



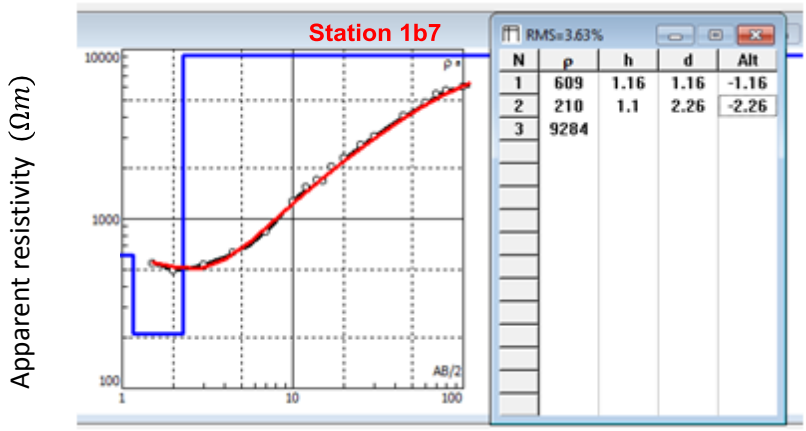
STATION 1B4: CURVE TYPE H



STATION 1B5: CURVE TYPE H

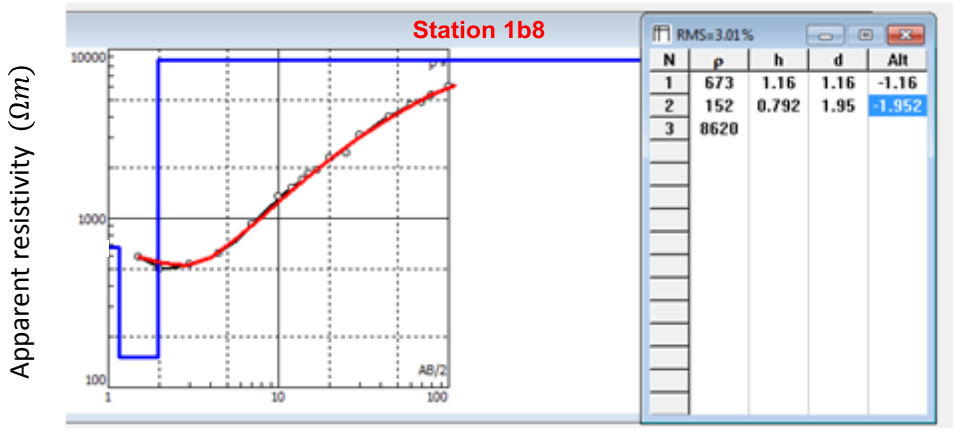


STATION 1B6: CURVE TYPE H



Electrode spacing AB/2(m)

STATION 1B7: CURVE TYPE H



Electrode spacing AB/2(m)

STATION 1B8: CURVE TYPE H

APPENDIX B:

Resistivity Sounding Curves along Profile 2A & 2B Derived From The Application of IPI2win Software

Field curve

Synthetic curve

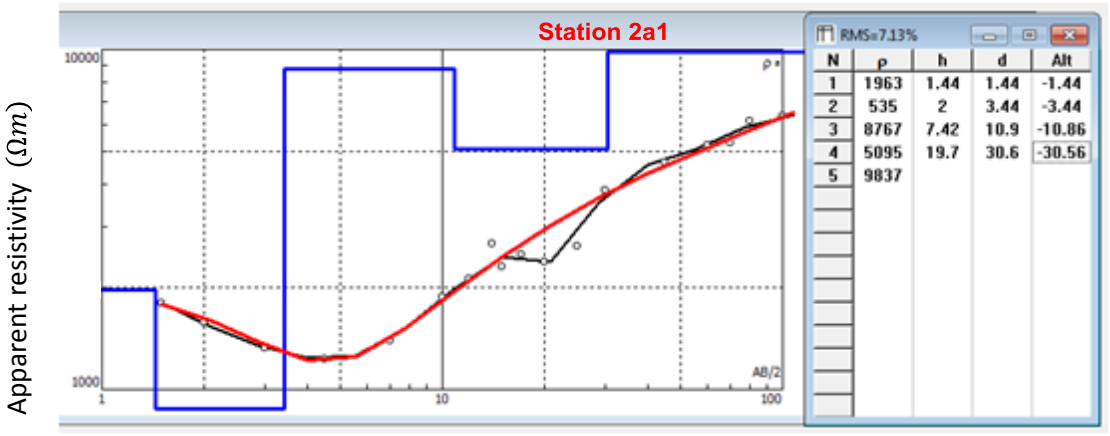
Model

$\boldsymbol{\rho}$ – layer resistivity in Ohm-metre

h – layer thickness in metres

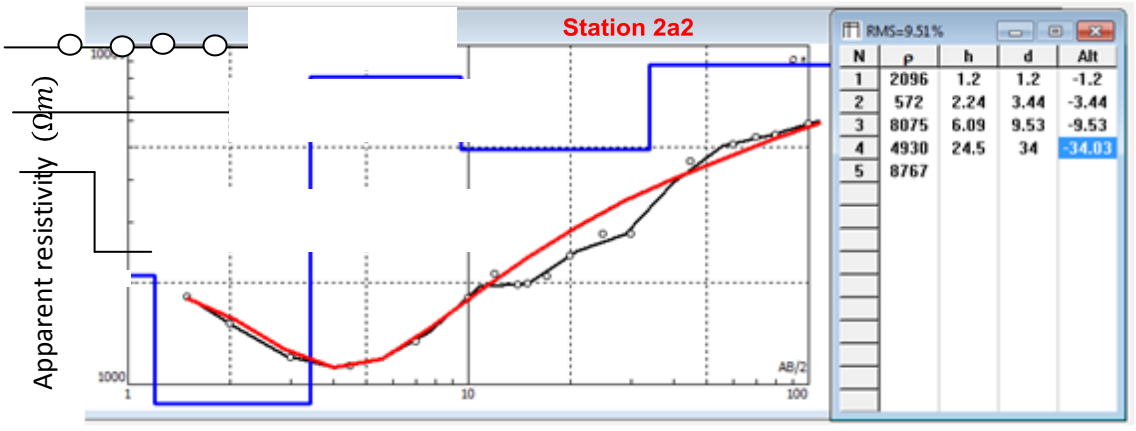
d – depth to interface in metres

N – layer number



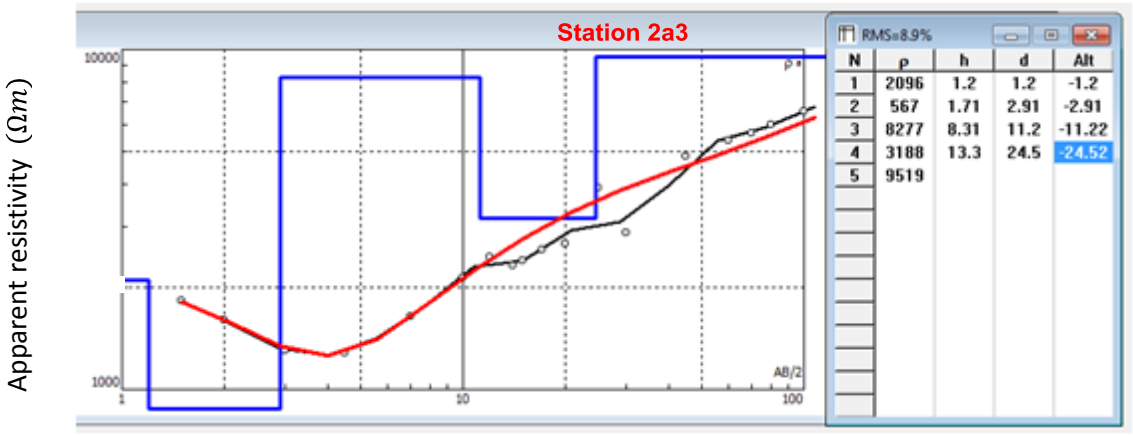
Electrode spacing AB/2(m)

STATION 2A1: CURVE TYPE HKH



Electrode spacing AB/2(m)

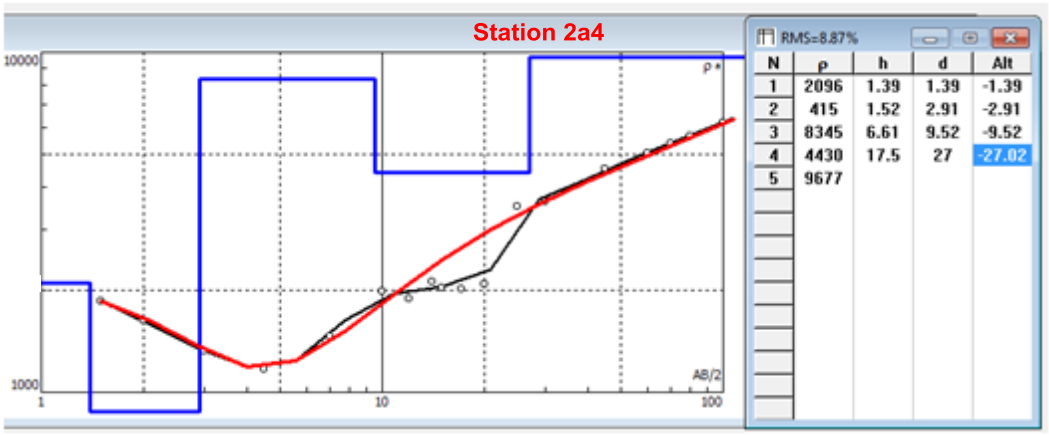
STATION 2A2: CURVE TYPE HKH



Apparent resistivity (Ωm)

Electrode spacing AB/2(m)

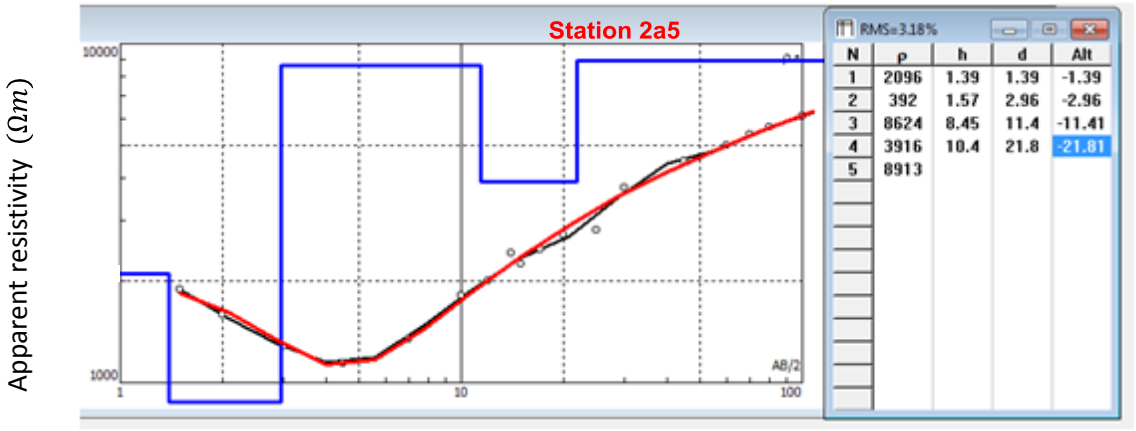
STATION 2A3: CURVE TYPE HKH



Apparent resistivity (Ωm)

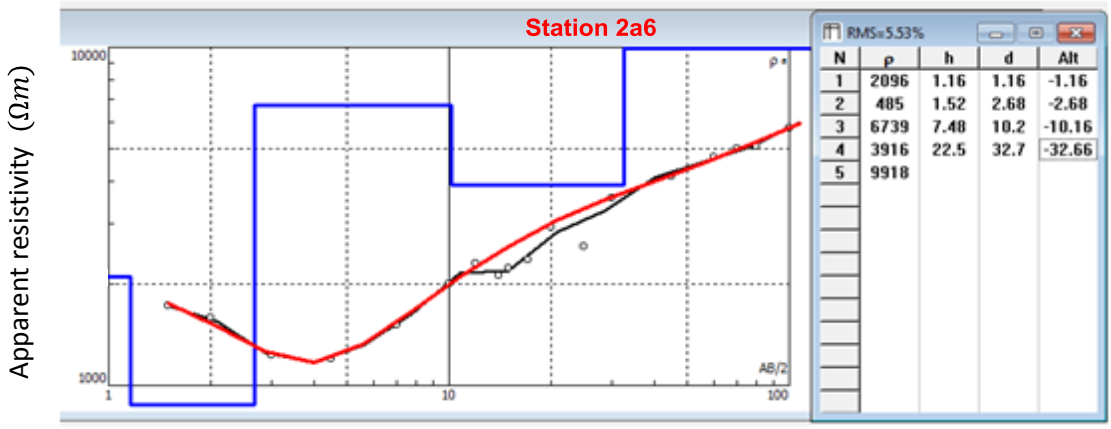
Electrode spacing AB/2(m)

STATION 2A4: CURVE TYPE HKH



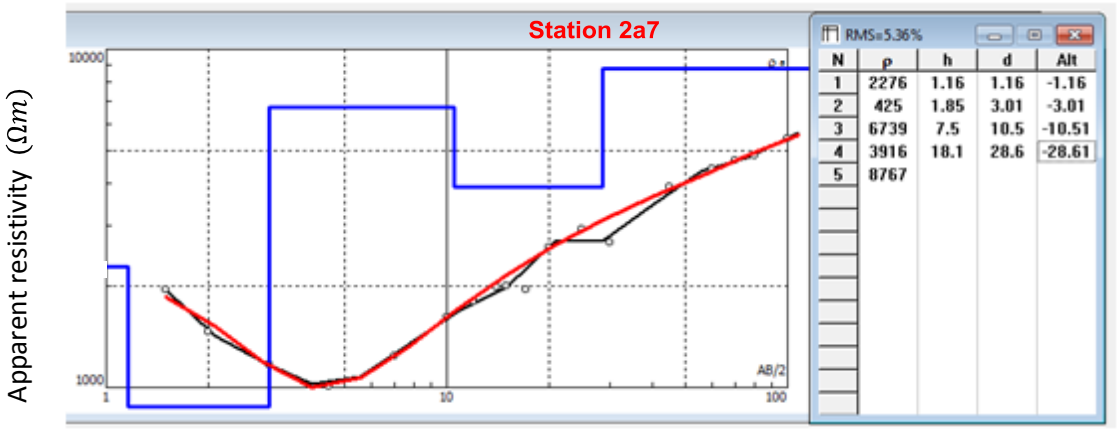
Electrode spacing AB/2(m)

STATION 2A5: CURVE TYPE HKH



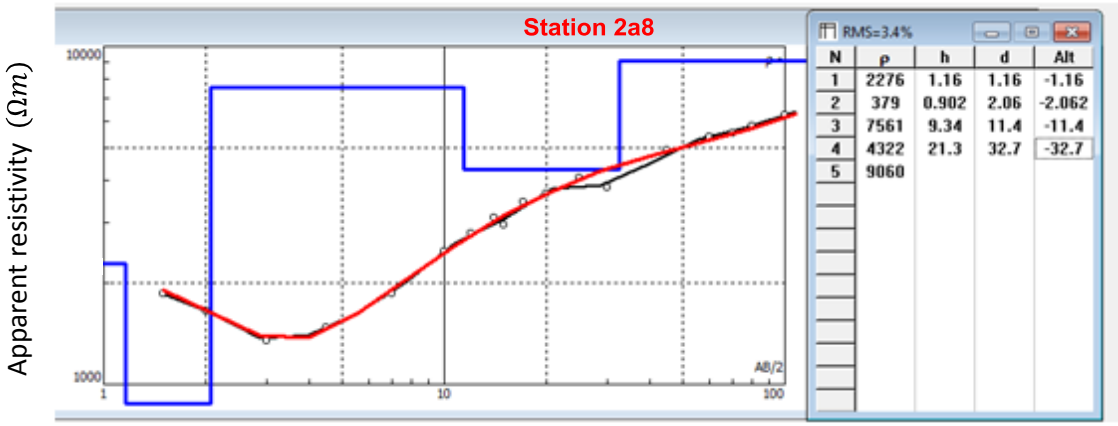
Electrode spacing AB/2(m)

STATION 2A6: CURVE TYPE HKH



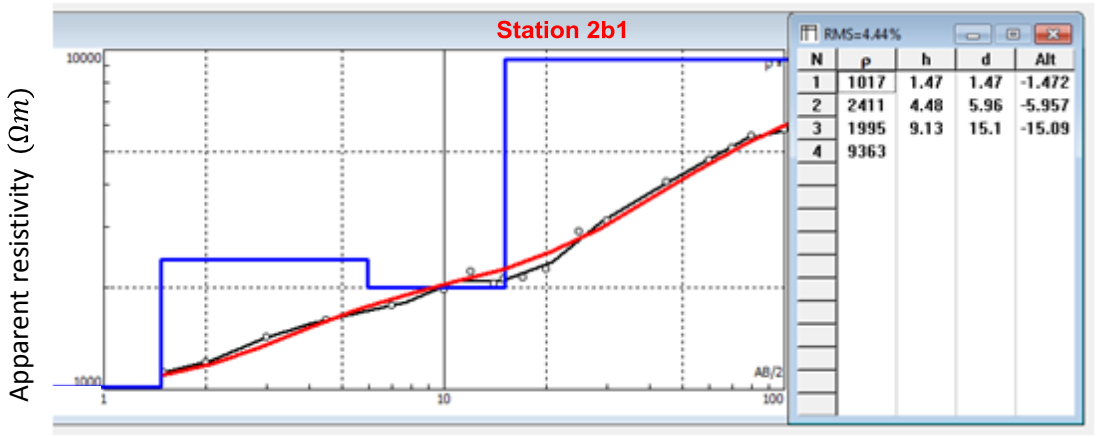
Electrode spacing AB/2(m)

STATION 2A7: CURVE TYPE HKH



Electrode spacing AB/2(m)

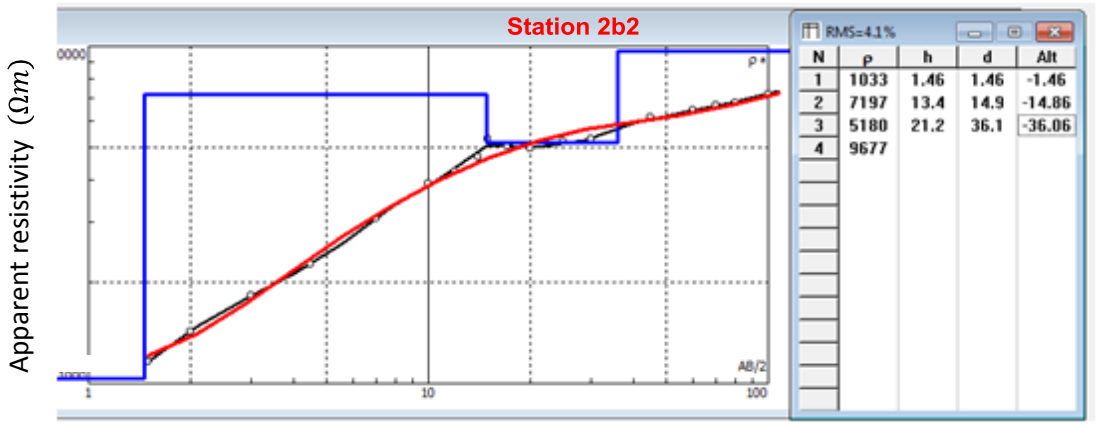
STATION 2A8: CURVE TYPE HKH



N	ρ	h	d	Alt
1	1017	1.47	1.47	-1.472
2	2411	4.48	5.96	-5.957
3	1995	9.13	15.1	-15.09
4	9363			

Electrode spacing AB/2(m)

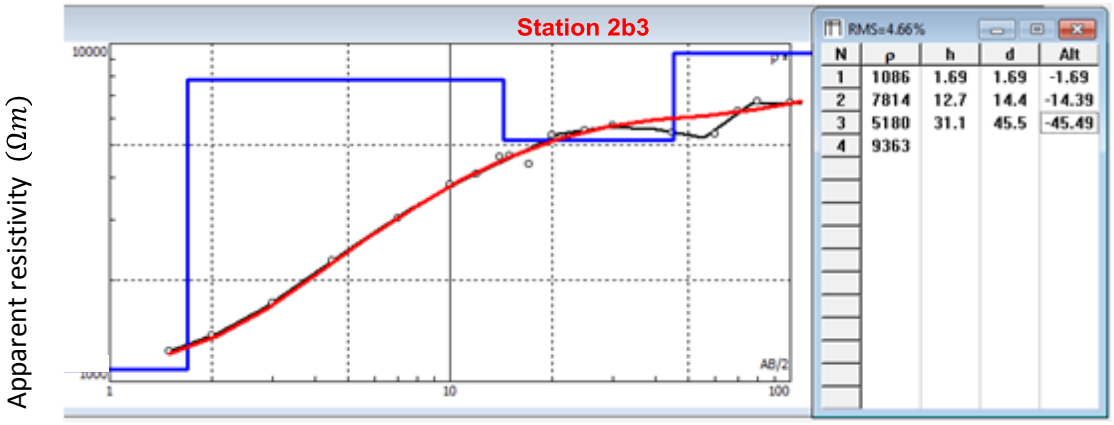
STATION 2B1: CURVE TYPE HKH



N	ρ	h	d	Alt
1	1033	1.46	1.46	-1.46
2	7197	13.4	14.9	-14.86
3	5180	21.2	36.1	-36.06
4	9677			

Electrode spacing AB/2(m)

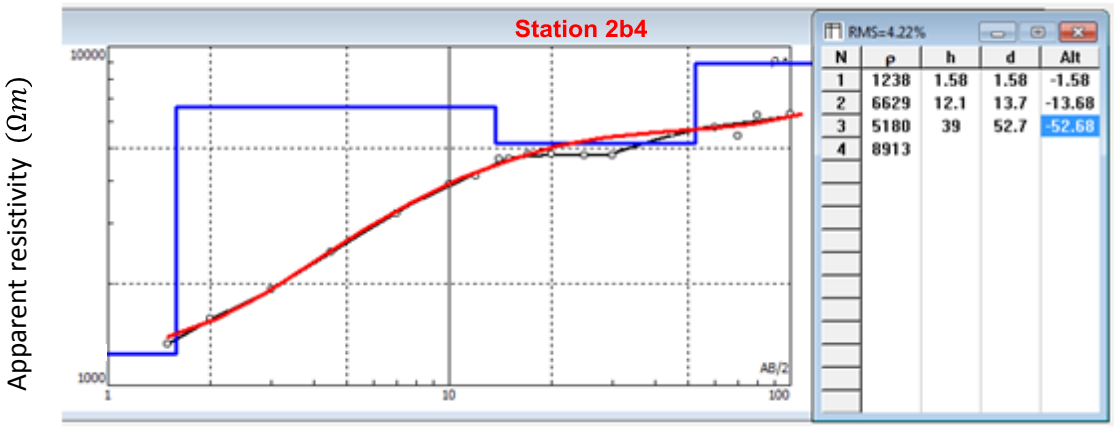
STATION 2B2: CURVE TYPE KH



Apparent resistivity (Ωm)

Electrode spacing AB/2(m)

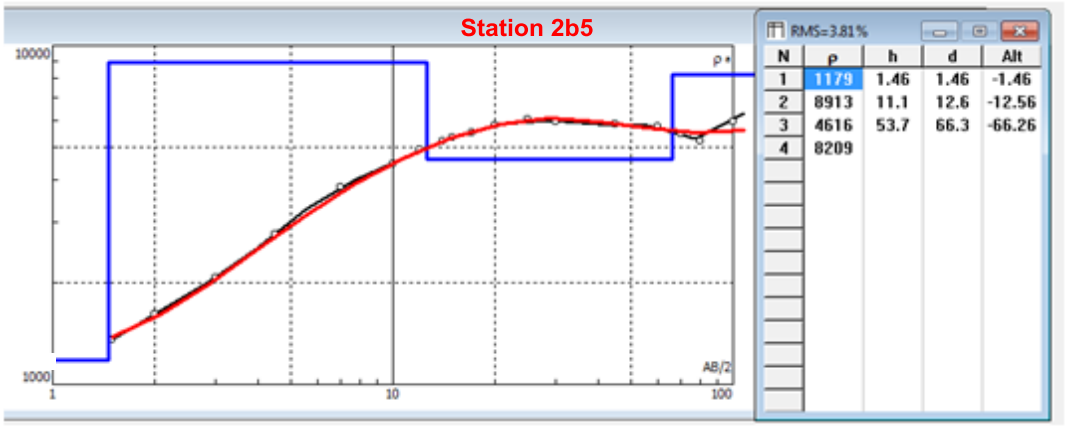
STATION 2B3: CURVE TYPE KH



Apparent resistivity (Ωm)

Electrode spacing AB/2(m)

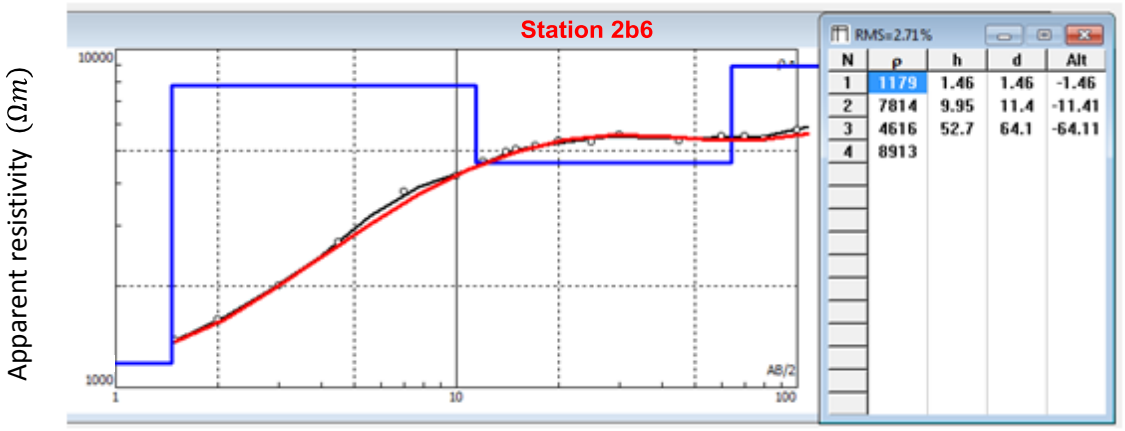
STATION 2B4: CURVE TYPE KH



Apparent resistivity (Ωm)

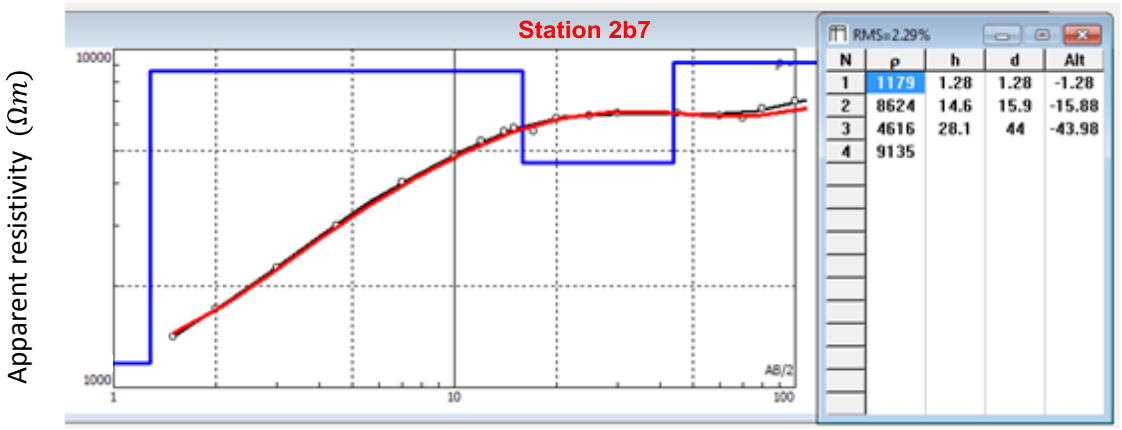
Electrode spacing AB/2(m)

STATION 2B5: CURVE TYPE KH



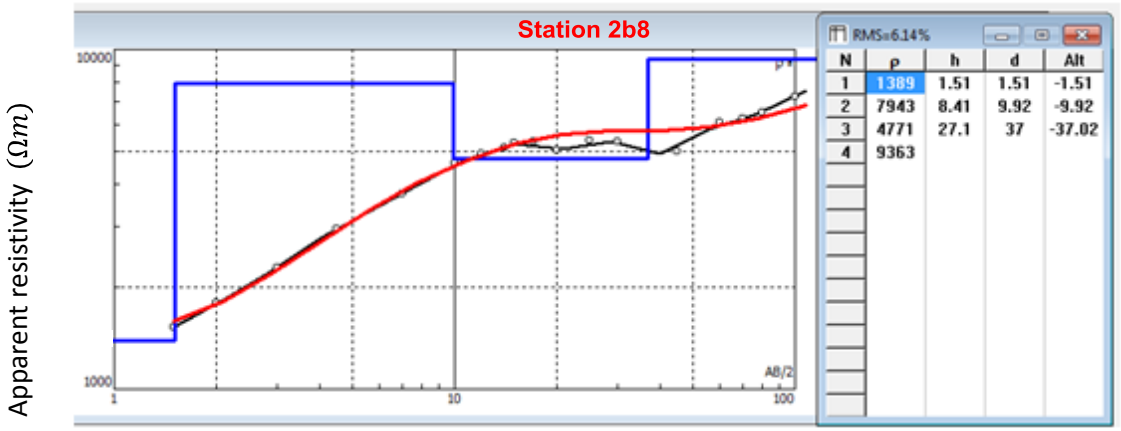
Electrode spacing AB/2(m)

STATION 2B6: CURVE TYPE KH



Electrode spacing AB/2(m)

STATION 2B7: CURVE TYPE KH

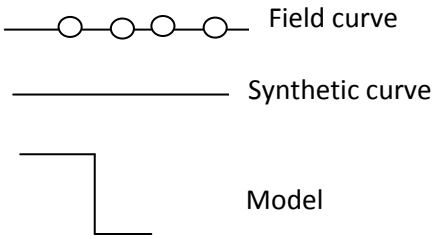


Electrode spacing AB/2(m)

STATION 2B8: CURVE TYPE KH

APPENDIX C:

Resistivity Sounding Curve Along Profile 3A & 3B Derived From The Application of IPI2win Software

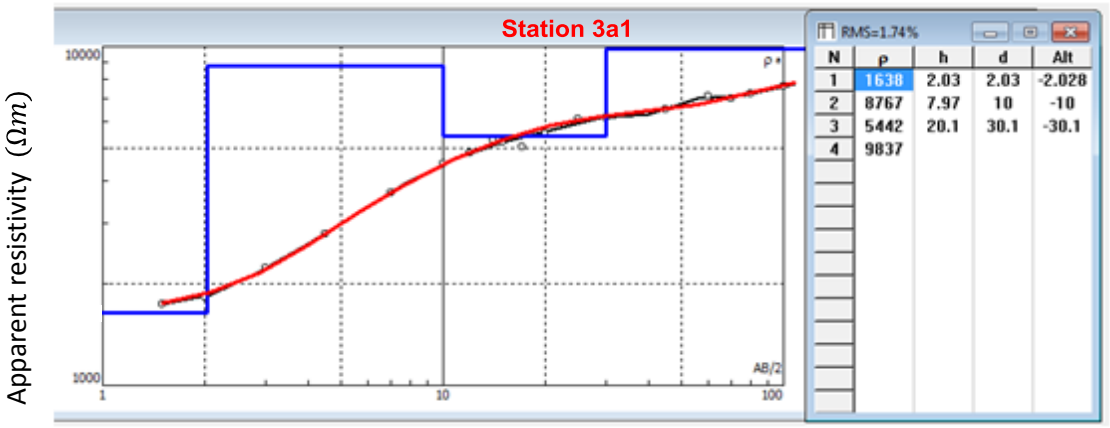


ρ – layer resistivity in Ohm-metre

h – layer thickness in metres

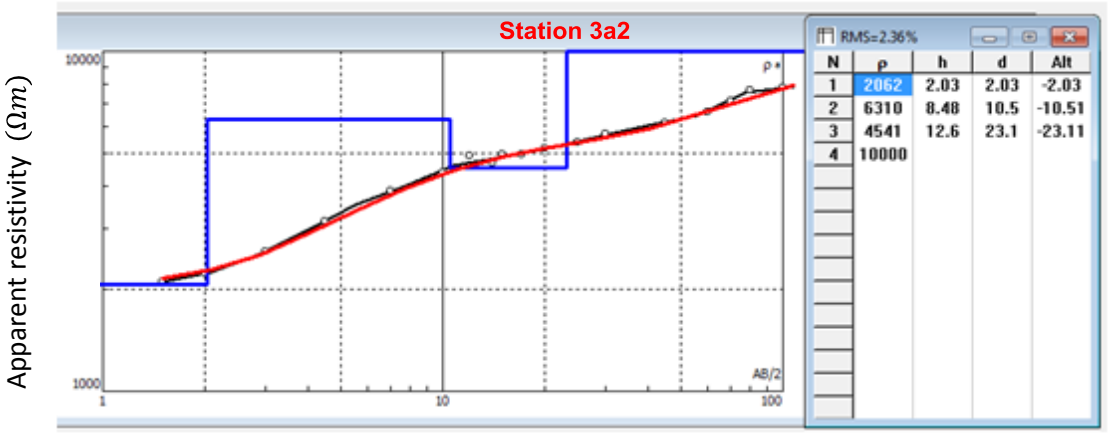
d – depth to interface in metres

N – layer number



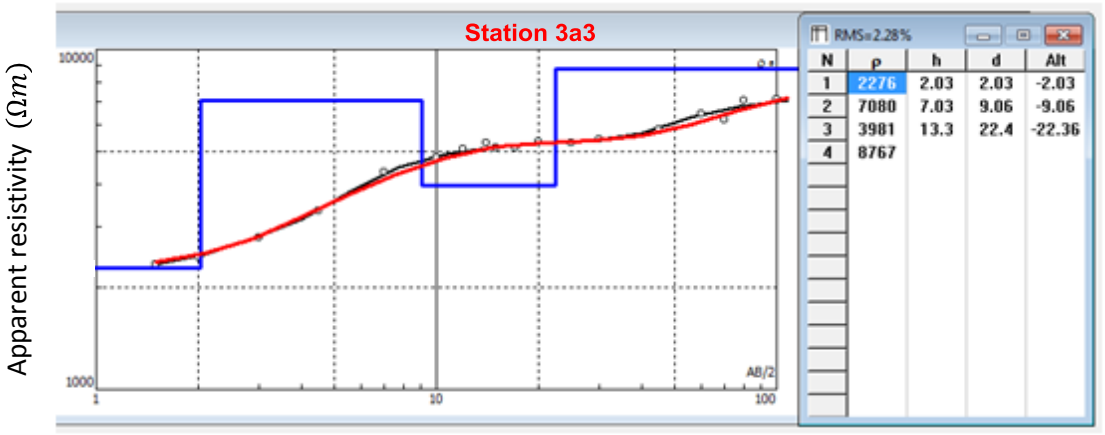
Electrode spacing AB/2(m)

STATION 3A1: CURVE TYPE KH



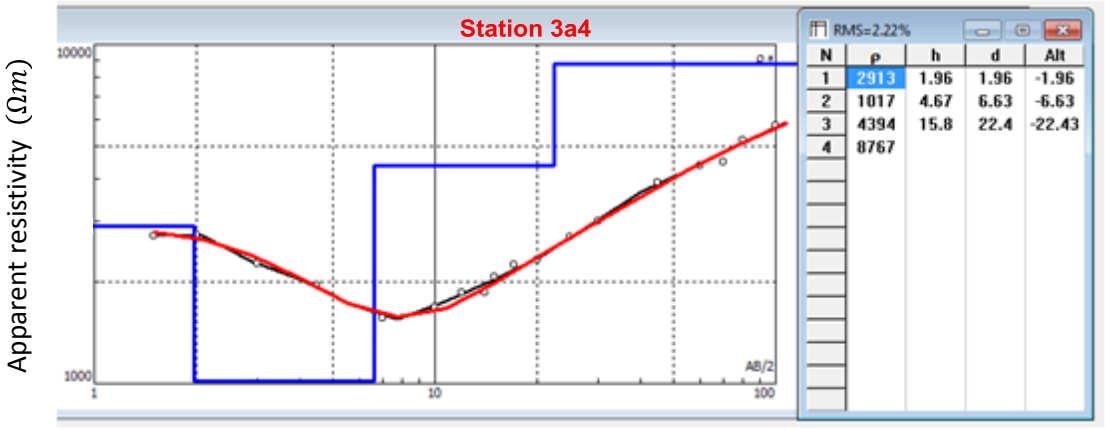
Electrode spacing AB/2(m)

STATION 3A2: CURVE TYPE KH



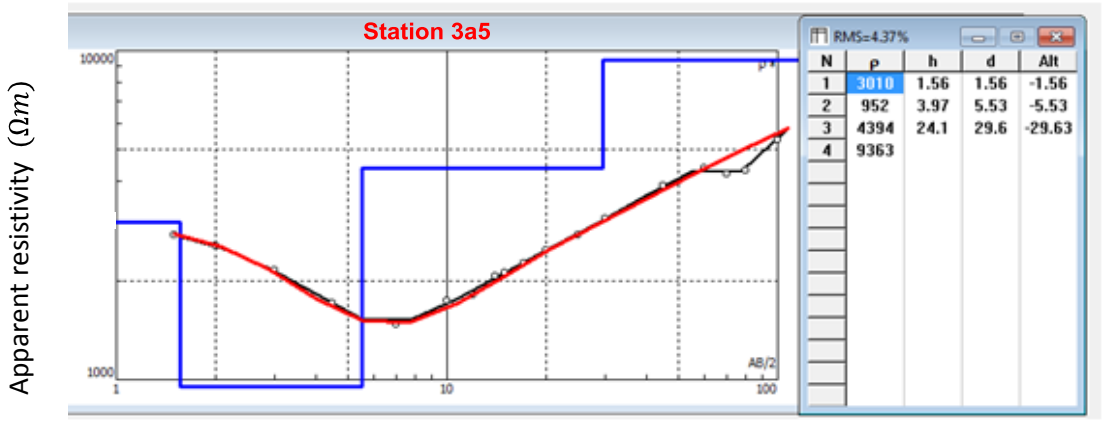
Electrode spacing AB/2(m)

STATION 3A3: CURVE TYPE KH



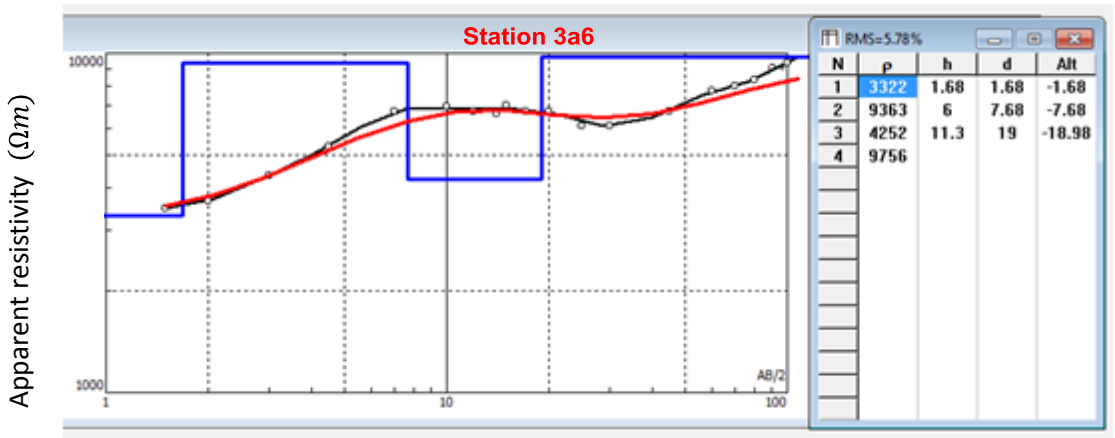
Electrode spacing AB/2(m)

STATION 3A4: CURVE TYPE KH



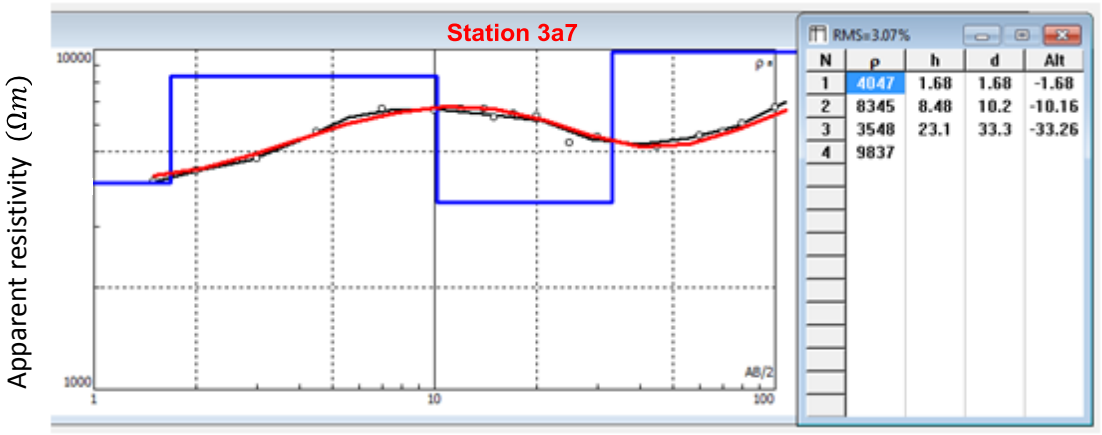
Electrode spacing AB/2(m)

STATION 3A5: CURVE TYPE KH



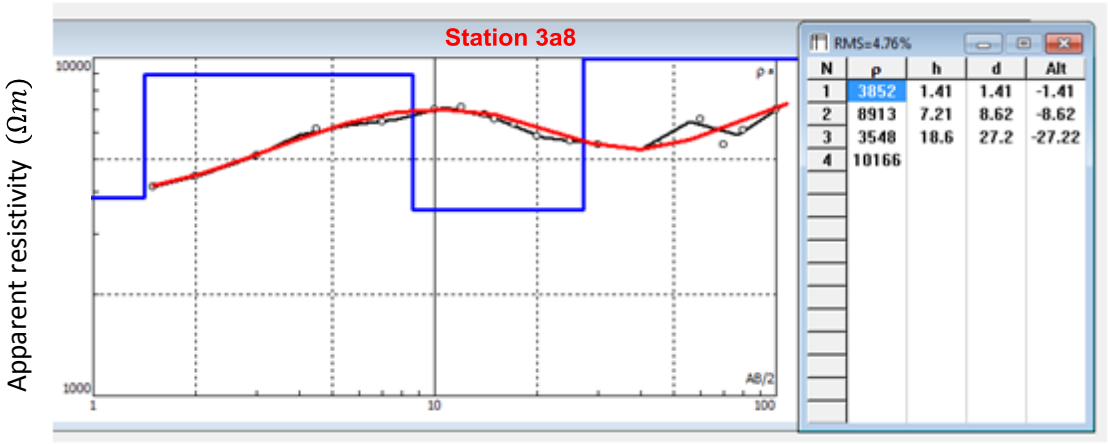
Electrode spacing AB/2(m)

STATION 3A6: CURVE TYPE KH



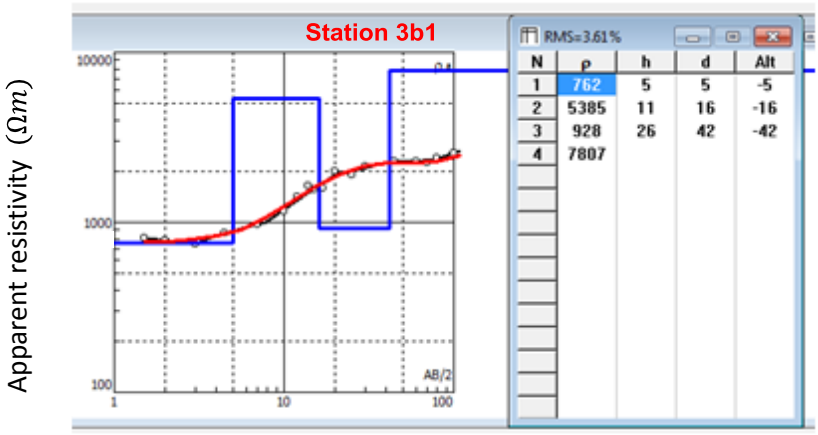
Electrode spacing AB/2(m)

STATION 3A7: CURVE TYPE KH



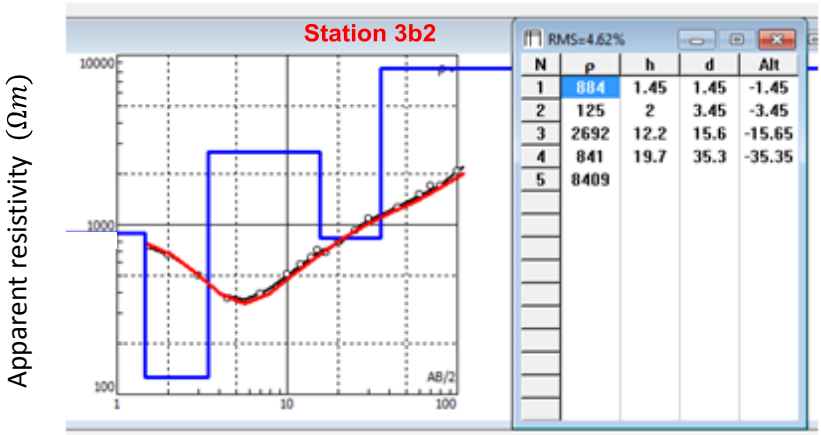
Electrode spacing AB/2(m)

STATION 3A8: CURVE TYPE KH



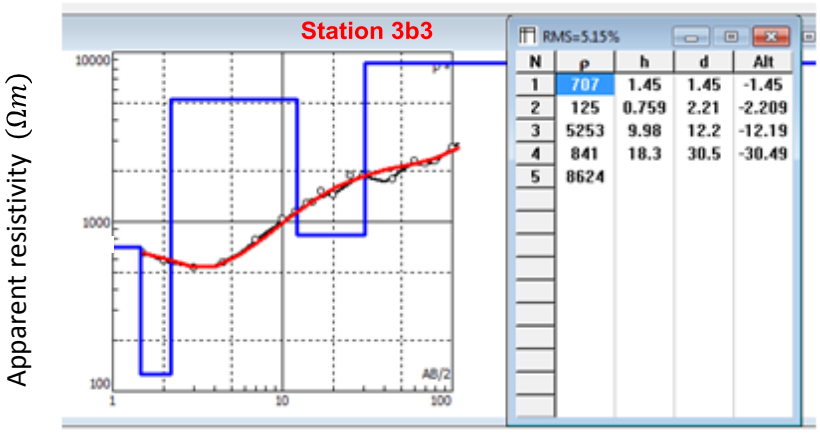
Electrode spacing AB/2(m)

STATION 3B1: CURVE TYPE HA



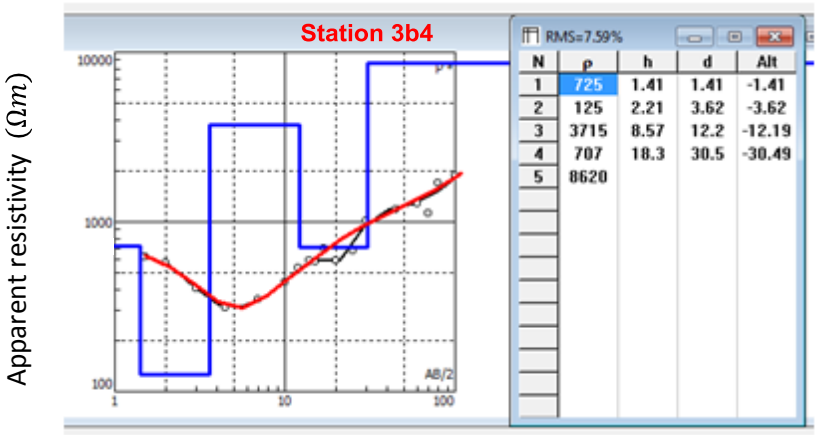
Electrode spacing AB/2(m)

STATION 3B2: CURVE TYPE KH



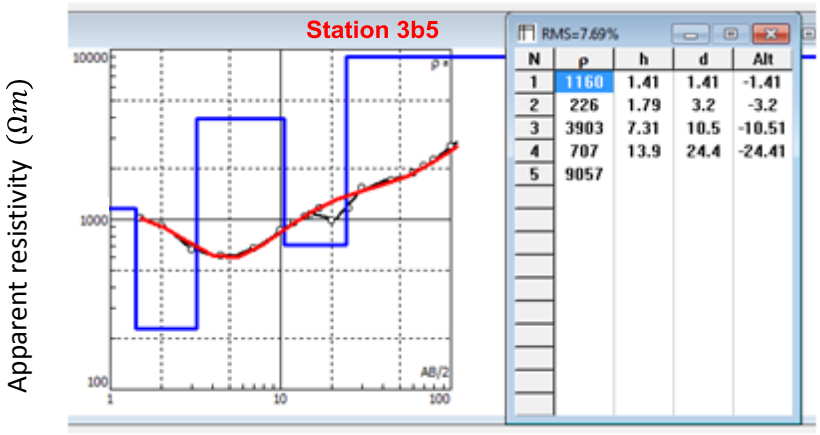
Electrode spacing AB/2(m)

STATION 3B3: CURVE TYPE KH



Electrode spacing AB/2(m)

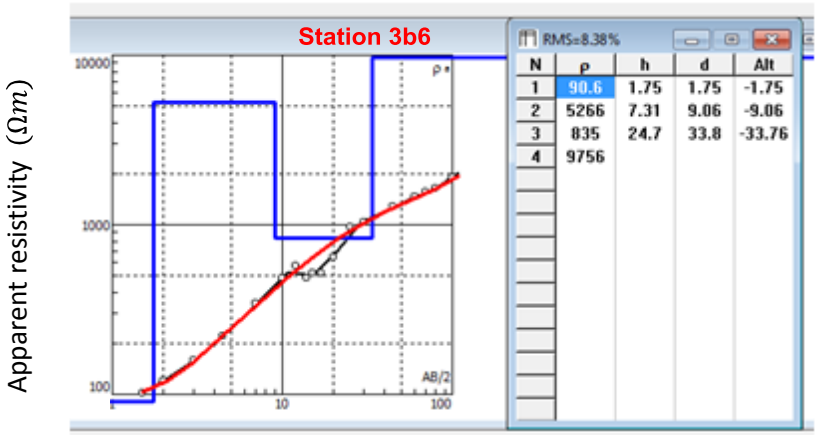
STATION 3B4: CURVE TYPE KH



Apparent resistivity (Ωm)

Electrode spacing AB/2(m)

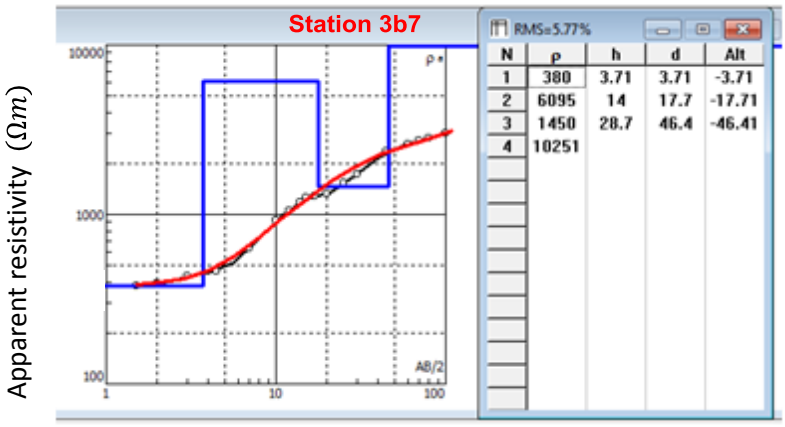
STATION 3B5: CURVE TYPE KH



Apparent resistivity (Ωm)

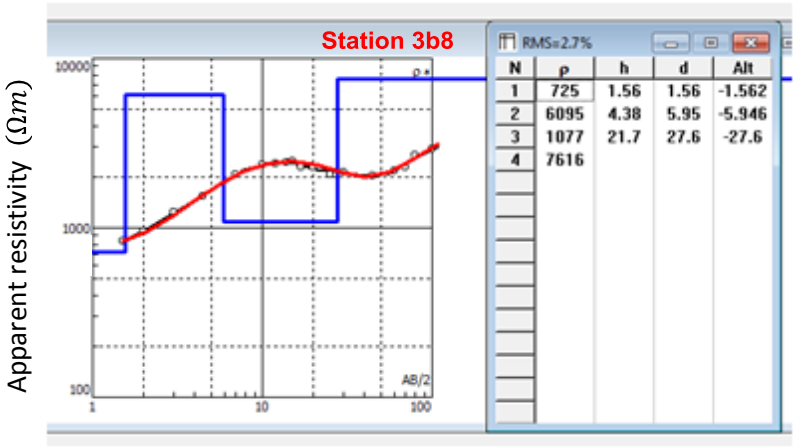
Electrode spacing AB/2(m)

STATION 3B6: CURVE TYPE KH



Electrode spacing AB/2(m)

STATION 3B7: CURVE TYPE KH



Electrode spacing AB/2(m)

STATION 3B8: CURVE TYPE HA