

**TWO-DIMENSIONAL GEO-ELECTRICAL
IMAGING SURVEY FOR SHALLOW SITE
INVESTIGATION AT UWELU EGOR L.G A, EDO
STATE, NIGERIA.**

BY

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DEDICATION

This Project is dedicated to God Almighty for his love, guidance, protection, and also to my parents Mr and Mrs Igbinosa.

CERTIFICATION

I hereby certify that this project was carried out under my supervision by
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I also appreciate my friends who helped during the course of my study.

ABSTRACT

A geoelectrical imaging survey was conducted at Uwelu and its environs in Egor Local Government Area of Edo State, Nigeria, for Shallow site investigation in order to determine the applicability of 2-D resistivity imaging in studying the subsurface, which in turn determines how feasible the area would be in terms of erection of structures that will stand the test of time. The area is underlain mainly with low resistivity materials with minor intrusion high resistivity materials like gravel, limestone basalt and slate. Geophysical survey was carried out using 2-D electrical resistivity imaging technique. The Wenner Alpha configuration was employed. Field data were obtained for ten electrical imaging lines, at Uwelu market area in Egor Local Government Area, subjected to inversion, in order to remove geometrical effects from the pseudo-section and produce an image of true depth and true formation resistivity. The 2-D electrical investigation at the survey site showed that the soil lithology compartment will be a good site for big building and other construction works even for shallow site works.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND TO STUDY

The knowledge of the subsurface geology and the characterization of the spatial distribution of subsurface physical properties are necessary for effective environmental monitoring, protection and remediation in polluted areas, as well as for infrastructure development purposes. These will, in addition, assist policy makers and environmental managers to take quality decisions required to preserve and sustain a healthy environment for mankind and the ecosystems in general, and to effectively and safely manage our natural resources. (Ahzegbobor, 2010)

Geophysical techniques can provide more dense information with high temporal and spatial resolutions, including 2-D and 3-D images of the subsurface. Most geophysical techniques are non-invasive and can therefore preserve the subsurface local equilibrium. The methods are comparatively cost-effective and field data are acquired much faster than point sampling.

Geophysical investigations of the subsurface involve taking measurements at or near the earth's surface that are influenced by the subsurface distributions of physical properties such as density, elasticity, magnetic susceptibility, electrical

conductivity, spontaneous polarization, magnetic permeability, dielectric permittivity, thermal conductivity and radioactivity. These physical properties are influenced by the subsurface lithology, porosity, structure and degree of pore connectivity, and water saturation. All geophysical methods depend on the contrasts in one of or a combination of these physical properties which are usually associated with rocks and minerals in the subsurface. The goal of any geophysical investigation is to determine more accurately the location and nature of these subsurface rocks and minerals.

The choice of a particular geophysical method depends mainly on the objective of the investigation relative to the sensitivity of the method, the resolution desired, the site conditions, time required for the survey, and the funds and computational resources available. Different geophysical techniques as well as available hydrogeological and geological data are often integrated to obtain a better understanding of the subsurface media at different scales and resolutions (Meju, 2000; Pedersen et al., 2005).

The study of weathering profile, its vertical variation, spatial distribution, textural characteristics of the constituent materials are essential step towards a better understanding of shallow site investigation in complex areas. Due to the heterogeneous nature of the subsurface, the geology of the subsurface needs to be investigated in considerable details. to locate a successful site for construction. (Le

Grand, 1962; Asseez, 1972). This knowledge has led to the application of geophysical methods mostly Electrical resistivity imaging in site investigation. Due to the limitations of the conventional resistivity sounding and profiling, electrical resistivity imaging (2-D) was used in this study for mapping the subsurface layers at Uniben in Ovia North-East Local Government Area, Edo State, Nigeria because it is capable of yielding adequate information on subsurface rock types and distribution.

1.2 AIM OF STUDY

The aim of this research work is to determine if the study area is good for shallow site work.

1.3 OBJECTIVES OF STUDY

The objectives are to:

- i. Determine the nature of the topography of the land form.
- ii. Determine the lithology and texture of the parent rock.
- iii. Determine if the site is a shallow site for engineering purpose.

1.4 LOCATION OF STUDY AREA

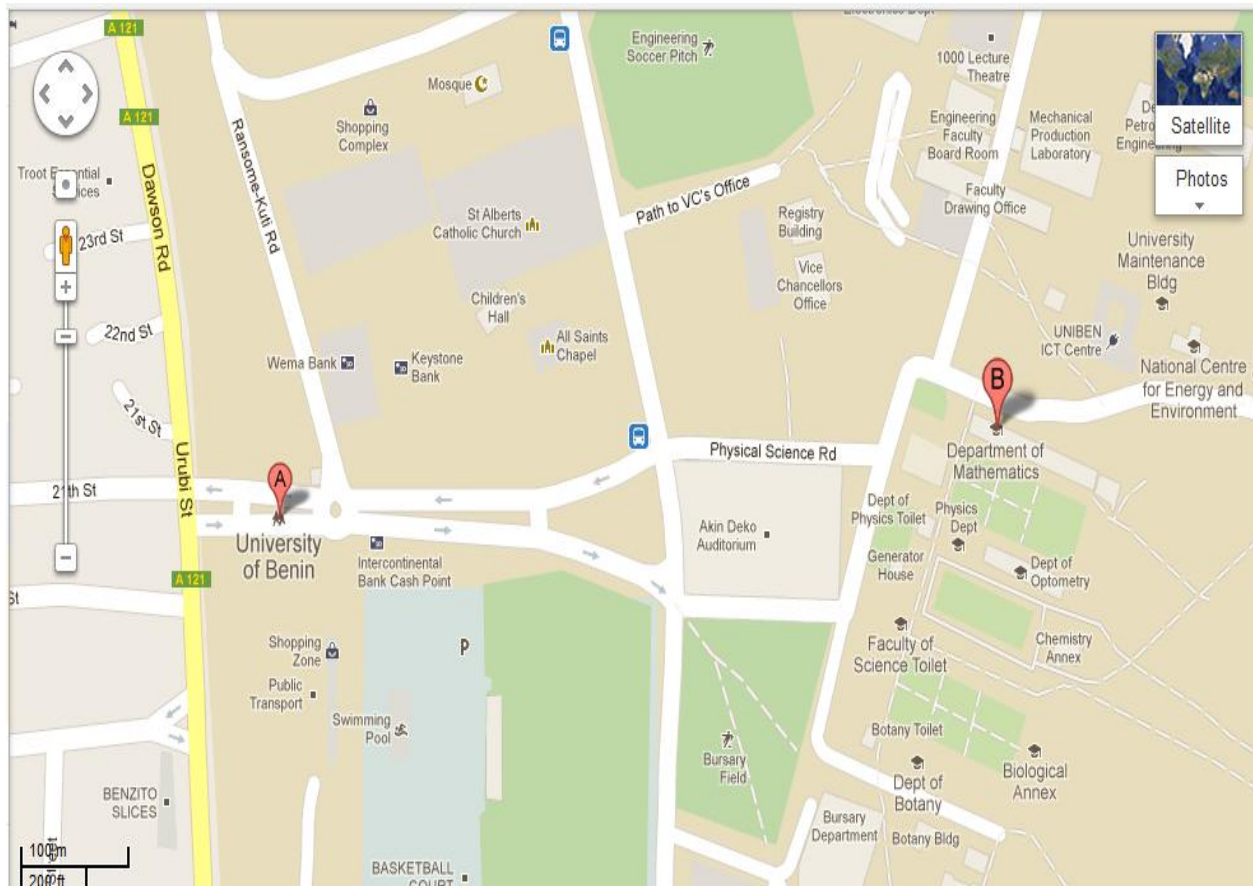


Figure 1.1: A picture of the study area. (Source: Google – Earth)

1.5 GEOLOGY OF THE STUDY LOCATION

Geology of the study area is described in the geology of Niger delta. Niger delta is one of the ten major sedimentary basins of Nigeria. The others are Abakaliki basin, Anambra Basin, Benue trough, Bida basin, Bornu-Chad basin,

Dahomey basin, Gongola basin, Sokoto basin and Yola basement complex. These are Western end of the Cameroun volcanic zone, Northern Nigeria massif and the eastern end of West African massif. The basins and basement complex are shown in figure 1.2 The Niger Delta complex basin is situated on the Gulf of Guinea on the west coast of Central Africa. It built out into the Atlantic ocean at the mouth of the Niger-Benue river system during the tertiary (Doust and Omatsola 1990). The maximum sediment thickness is at the central part of the delta within the greater Ughelli megastructure. The thickness is about 12 kilometers.

The formation of Niger delta basin and others started with the break of the central African-south American part of the Gondwana super continent. This took place in the Mesozoic. It is along a series of rift zones of different orientations that met in a triple junction on the present gulf of Guinea. Two of the arms, which followed the south eastern and south western coasts of Nigeria developed into collapsed continental margins of south.

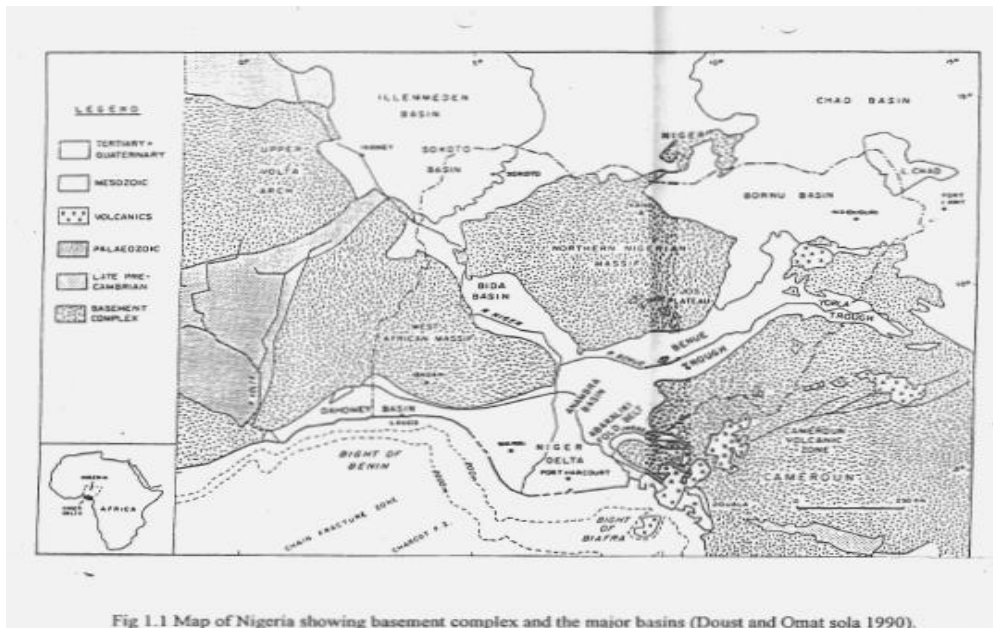


Fig 1.2 Map of Nigeria Showing the basement complex and the Major Basins (Doust and Omatsola 1990)

The first sediments of the cretaceous to tertiary cycle accumulated during the rift-fill phase. Thick successions of marine and marginal marine clastics and carbonates were deposited in a series of transgressive and regressive phases. On complete separation of the continent, the sea transgressed inland to Benue trough which is the third arm due to subsidence of the continental basement.

The present Niger delta basin is built on the collapsed continental margins of the south Atlantic. The core of the delta is located over the site of the triple junction. The bulk of sediment supply from the north and east is through the Niger-Benue river in the tertiary. The Benue and Cross rivers supplied substantial amount of volcanic detritus from Cameroun volcanic zone since the Miocene . The Niger delta has prograded into gulf of Guinea at a steady rate. This is due to drainage area, basement subsidence, and eustatic sea level changes. Presently the Niger delta is typically wave and tidal dominated. It appears to be constructive at the centre and destructive at the flanks (Nedeco 1959) where it is sandy.

The lower plain consists mainly of distributary channels of rivers surrounded by fresh water swamps. The destructive part of the delta are salt water mangrove swamps with greater tidal influence. Long shore currents carry sediments off the area form sandy beaches, beach bridges and offshore bars along coast flanks (Burke 1972). The marginal areas of the delta suffer encroachment due to lack of sediment supply. The submarine portion of the delta consists of shallow shelf which gradually merges into a long continental slope. The upper part of the slope is marked by a zone of faulted sediments, clay walls and diapirs known as distal belt. This is the outermost portion of the developed part of the delta. The trend of development of the Niger delta is a major factor in the stratigraphy and structure of the region.

1.6 STRATIGRAPHY

Since the inception of the Cenozoic delta in the Paleocene/Lower Eocene, the history has been one of a major regression with a gradual southward offlap of thin, quite extensive lenses of sediments formed as result of deposition occurring simultaneously under full terrestrial (fluvial) conditions with the interplay between terrestrial and marine influence (i.e. paralic) and under fully marine conditions (Frankl & Cordry 1967). Thus the sequence observed laterally (i.e. starting with coarse sandy deposits and ending with marine clays) is also observed vertically in the Niger delta. In a cross-section, a time stratigraphic unit of such

deltaic sediment is characteristically S-shaped or sigmoidal (Merki, 1972). The formations are therefore strongly diachronous, their ages becoming progressively younger in a downdip direction and ranging from Paleocene to Recent. Thus the established tertiary sequence in the Niger delta demonstrates a tripartite lithostratigraphic succession (Fig.3) from marine prodeltaic shale (Akata Formation) through a sand/shale paralic unit (Agbada Formation) to continental sands (Benin Formation). The strata compose and estimated 8535 m of the section at the approximate depocentre in the central part of the delta (Short and Stauble, 1967). The characteristic features of these formations are outlined below:

1.6.1 Akata Formation

It is characterized by a uniform shale development. The formation is a marine sedimentary sequence laid down in front of an advancing delta. These prodeltaic shales are medium to dark grey, fairly hard or at places soft, gumbo-like and sandy or silty in several places, the shales of this formation were found to be undercompacted, and therefore mobile, and may contain lenses of abnormally high-pressure siltstone or fine-grained sandstone (Allen, 1965; Reyment, 1965; Short & Stauble, 1967 and Oomkens, 1974). The upper boundary of the formation has been structurally deformed, while diapirism and high-pressure zones developed in it, on a large scale. Generally, the Akata Formation contains rich foraminiferal fauna. Planktic foraminifera may constitute more than 50% of the microfauna. The

benthonic foraminiferal assemblages indicate that the shale was deposited on a shallow marine shelf and slope. The Akata Formation is considered to be the main source rock in the Niger delta (Evamy et al, 1978; Bustin 1988 and Schlumberger, 1985). The known age of the Akata Formation is Eocene to Recent (Asseez, 1976; Doust and Omatsola 1990). The shale is continuous in the subsurface with its probable outcrop equivalent the Paleocene/Eocene Imo Formation. The complex movements of the Niger delta sediments are controlled by the adjustments of the shale either by the downward movements in response to the pressure impacted by the overlying sediments or lateral motion of the shale on the continental slope or its upward diapiric motion. These movements are believed to have assisted in the formation of the growth faults and roll over structures, which are common features of the main Niger delta basin. Its thickness is unknown because most wells drilled in the Niger delta did not encounter the base of the Akata Formation, except for the northern part of the delta where the formation has been drilled into the Cretaceous.

1.6.2 Agbada Formation:

This sequence of strata forms the hydrocarbon prospective sequence in the Niger delta. The formation is characterized by alternating sandstones and shales of the delta front, distributary channel, and deltaic plain origin. Weber (1971) showed that the alternating sequence of sandstones and shales of the Agbada Formation is of cyclic sequences of marine and fluvial deposits. The sand content ranges from

50 to 75%. The sandstones are medium to fine grained, fairly clean locally calcareous, and shelly. They consist dominantly of quartz and potash feldspar with subordinate and illite. The shales are dark to grey, fairly consolidated and silty with local glauconite. They consist dominantly of kaolinite (average value 73%) with small amount of mixed layers of illite and montmorillonite. The formation has a maximum thickness of 3940 meters at the central part and thins northwards and towards the North western and Eastern flanks of the delta. Although, the thickest known section is about 3480 meters, the maximum thickness may well be much greater (Short and Stauble 1967). Generally, the boundary between the sand and shales is sharp. Where the sands grade into shales, shell fragments, glauconites, limonite coatings are common. The shales are denser at the base than higher up in the column because of compaction. They become silty and sandy towards the Benin Formation while shaliness increases downwards and laterally into the Akata Formation.

The Agbada shales contain microfauna that are best developed at the base of individual shale units. The depth of the fossil assemblage ranges from littoral estuarine to marsh types of fauna developed at a water depth of approximately 100 meters. The slightly consolidated sand has a calcareous matrix, but most of the sand is unconsolidated. The coarse and poorly sorted sand indicates a fluvial origin while the well-sorted sand represents beach or coastal barrier deposits. The

mature Eocene to Miocene shales interbedded within the deltaic sands in the lower part of the paralic sequence is considered to be a major source rock. (Nwachukwu & Chukwura, 1986; Knox & Omatsola 1989; Shannon & Naylor 1989; Doust & Omatsola 1990 and Reijers 1996). The Agbada Formation is held to contain most of the reservoir rocks of the Niger delta. The porosity is of excellent quality (ranging between 28 and 32%) while permeability is in the darcies. Reservoir quality is closely dependent on the depositional environment.

The Agbada Formation is less carbonaceous and more marine than overlying Benin Formation there is also an increase in microfauna with depth. This could be an indication of increasing rate of sedimentation and changes in salinity and temperature of the delta front. The age of the Agbada Formation varies from Eocene to Recent.

1.6.3 Benin Formation:

This is the uppermost unit of the Niger delta complex. The formation can be easily distinguished based on its high sand percentage (70 - 100%). The sand is dominantly massive highly porous and freshwater bearing with locally interbedded shale beds, which are considered to be of braided stream origin. The sands are poorly sorted, ranging from fine to coarse – grained and occasionally pebbly and they contain abundant wood, fragments, which become lignitic with depth. Composition, structure and grain size show deposition in a probably upper deltaic

environment. The thickness is variable and may be more than (1990m) in Warri – Degema area. Most companies exploring for oil in the Niger delta, arbitrarily define the base of the Benin Formation by the deepest fresh - water – bearing sandstone that exhibits high resistivity. Short & Stauble (1967), however, defined the base of the Benin Formation by the first marine foraminifera within shale, as the formation is non-marine in origin. Avbovbo (1978) partly agrees with Short & Stauble (op cit) but also demonstrated that the base of the fresh water in the delta sediments extends into the Agbada Formation and thus not coincident with the base of the Benin Formation. The Benin Formation is deposited across the entire Niger delta. It is a continental deposit and consists of various structures such as natural levees channel fills, ox-bow fills etc. these structures indicate a variability of the shallow water depositional medium (Short & Stauble, 1967). It becomes progressively younger from North towards the South.

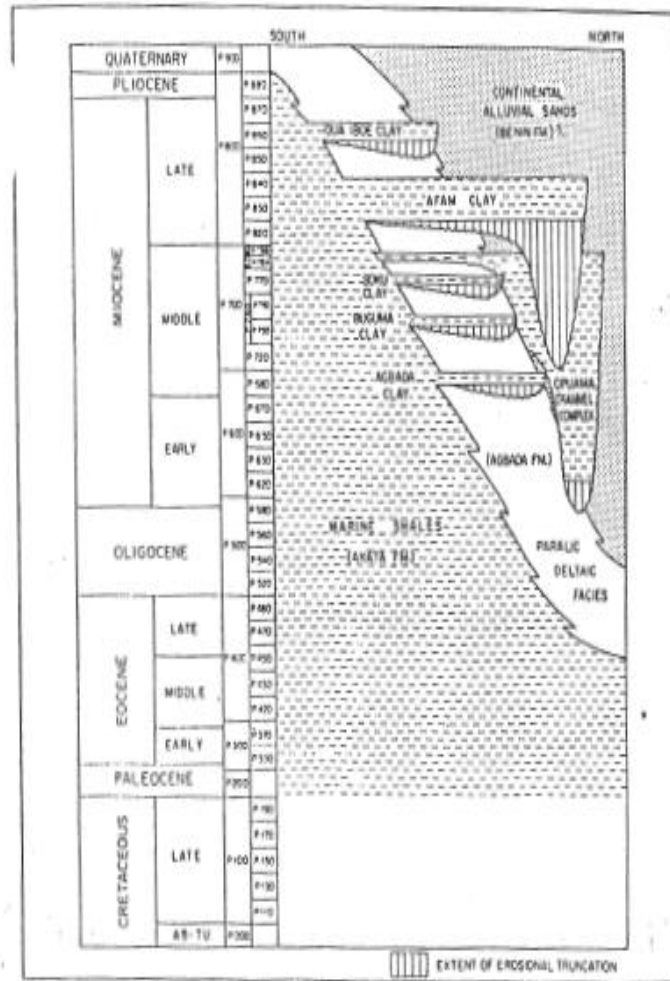


Figure 1.3 The tripartite sequence of major lithofacies units of the Niger

The Akata formation is composed of shales, silts and clays is at the base of the delta sequence. It contains a few streaks of sand. The sand is turbiditic in origin

and were deposited in the holomarine environments. The shale ranges from paleocene to Holocene in age. They crop out offshore in diapirs along continental slope and onshore in the northeast of the delta (Imo shale). The top of this formation is the economic Basement for oil. The deeper formation contains gas dissolved in oil field waters under high pressure. The onshore is rich in benthonic foraminefera. Sand and silt beds break the uniform shale.

The Agbada formation is the hydrocarbon prospective sequence. It consists of sand, silts and clays in various proportions representing offlap units. They were deposited in delta fronts, delta topset and fluvio-deltaic environments. The alternation of fine and coarse clastics provide multiple reservoir seal couplets. This is present in all the sedimentary units. The age ranges from Eocene to pleistocene. The sand consists of lignite streaks and limonite. The thickness of Agbada formation is about 3000m. In this formation pre-Miocene reservoir rocks are deposited as continuous sand, point bars and channel sand. Miocene and younger rocks were deposited as barrier bars. The Agbada formation lies between Akata and Benin formation (weber and Dakoru 1975).

The Benin formation is the uppermost unit. It is made up of massive fresh water bearing sand and gravel. The sand was deposited in alluvial environment. The Benin formation sand is thinner in the coastal swamp and in the offshore

deposits. Its maximum thickness is about 2000m. Little oil is found in this formation (Short and Stauble 1967, Avbovbo 1978).

One characteristic which distinguishes these formations is the sand to shale ratio. The top of Agbada formation is the base of fresh water inversion while the base of Agbada formation is the onset of hard over pressured zone. This marks the top of Akata formation which continues to the basement rock.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 BASIC RESISTIVITY THEORY

The purpose of electrical surveys is to determine the subsurface resistivity distribution by making measurements on the ground surface. From these measurements, the true resistivity of the subsurface can be estimated. The ground resistivity is related to various geological parameters such as the mineral and fluid content, porosity and degree of water saturation in the rock. (Loke, 2001).

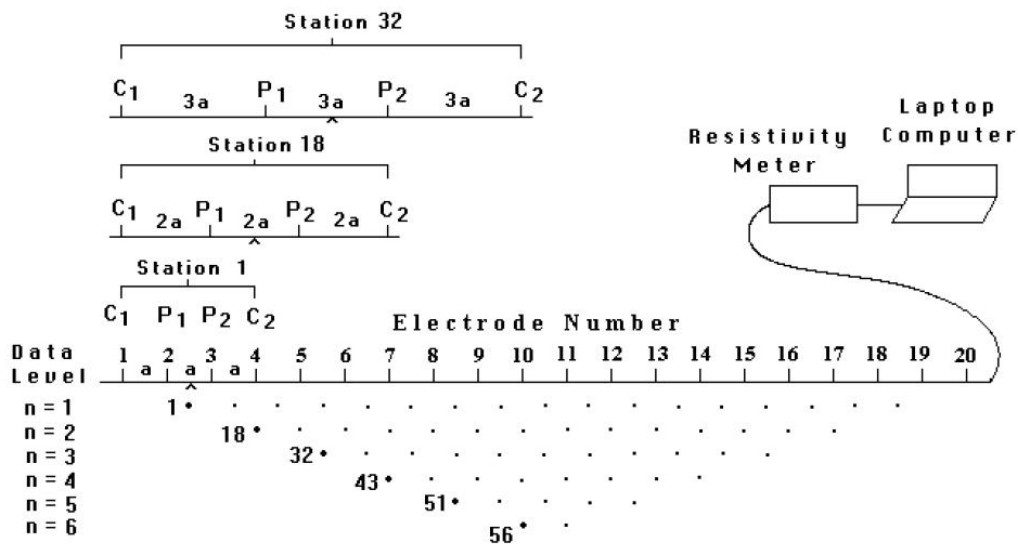
2.2 2-D ELECTRICAL SURVEYS – DATA ACQUISITION, PRESENTATION AND ARRAYS

A more accurate model of the subsurface is a two-dimensional (2-D) model where the resistivity changes in the vertical direction, as well as in the horizontal direction along the survey line. 2-D surveys are the most practical economic compromise between obtaining very accurate results and keeping the survey costs down (Dahlin et al., 1999). Typical 1-D resistivity sounding surveys usually involve about 10 to 20 readings, while 2-D imaging surveys involve about 100 to 1000 measurements.

Two-dimensional electrical imaging/tomography surveys are usually carried out using a large number of electrodes, 25 or more, connected to a multi-core cable (Loke and Barker, 1996). At present, field techniques and equipment to carry out

2-D resistivity surveys are fairly well developed. The necessary field equipment is commercially available from a number of international companies.

To obtain a good 2-D picture of the subsurface, the coverage of the measurements must be 2-D as well.



Sequence of measurements to build up a pseudosection

Figure 2.1. The arrangement of electrodes for a 2-D electrical survey and the sequence of measurements used to build up a pseudosection.

The first step is to make all the possible measurements with the Wenner array with an electrode spacing of “1a”. For the first measurement, electrodes number 1, 2, 3 and 4 are used. Notice that electrode 1 is used as the first current electrode C1, electrode 2 as the first potential electrode P1, electrode 3 as the second potential electrode P2 and electrode 4 as the second current electrode C2.

For the second measurement, electrodes number 2, 3, 4 and 5 are used for C1, P1, P2 and C2 respectively. This is repeated down the line of electrodes until electrodes 17, 18, 19 and 20 are used for the last measurement with “1a” spacing. After completing the sequence of measurements with “1a” spacing, the next sequence of measurements with “2a” electrode spacing is made. First electrodes 1, 3, 5 and 7 are used for the first measurement. The electrodes are chosen so that the spacing between adjacent electrodes is “2a”. For the second measurement, electrodes 2, 4, 6 and 8 are used. The same process is repeated for measurements with “3a”, “4a”, “5a” and “6a” spacings. To get the best results, the measurements in a field survey should be carried out in a systematic manner so that, as far as possible, all the possible measurements are made. This will affect the quality of the interpretation model obtained from the inversion of the apparent resistivity measurements (Dahlin and Loke 1998).

2.3 APPARENT RESISTIVITY AND GEOMETRIC FACTOR

Usually, the potential difference between two points is measured. The injecting (current) electrodes could be used, in theory, to measure the potential difference. But the influence of the resistances between the subsurface and current electrodes is not precisely known (Cheng et al., 1990). Thus, two potential electrodes are

$$\Delta\Phi = \frac{I\rho}{2\pi} \left(\frac{1}{C_1P_1} - \frac{1}{C_1P_2} - \frac{1}{C_2P_1} + \frac{1}{C_2P_2} \right).$$

dedicated to detect the response signal. If P1 and P2 are the potential electrodes (Figure 2.2), the potential difference between P1 and P2 is

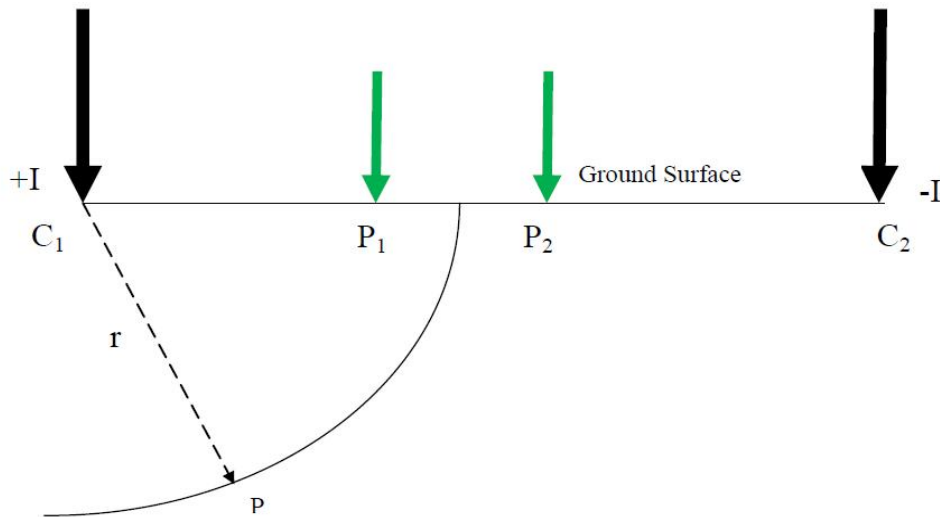


Fig: 2.2 Arrangement of electrodes showing the potential difference between P1 and P2

This equation gives the potential that would be observed over a homogeneous half-space with a typical four electrode configuration. The subsurface is commonly heterogeneous so that the resistivity observed is apparent, that is the resistivity of a homogeneous subsurface medium that would give the

same resistivity value for the same electrode configuration. Apparent resistivity can be seen as a weighted average of the resistivities of the subsurface volume under the four electrodes. The apparent resistivity depends on the configuration of the electrodes and is determined by the injected current and voltage values.

The flow of electric current in subsurface materials at shallow depths is mainly by electronic and electrolytic conduction. Electrolytic conduction is the dominant mechanism in environmental and engineering investigations because most common soil and rock forming mineral grains are insulators in dry state. The conduction of electricity in these mineral grains is through the interstitial water (or other fluids) in the pores and fissures of the rocks. Groundwater that fills the pore spaces of rocks is a natural electrolyte with a considerable number of ions present to increase its conductivity (Sharma, 1997). Thus, the amount of water and properties of the groundwater largely determine the resistivity of subsurface materials.

Weathering and fracturing depend on the lithology and texture of the parent rock and the extent of the weathered overburden and the presence of joints and fractures in the underlying bedrock (Acworth, 1987). Deep weathering has proved to be the most important single factor in geological environments (Le Grand, 1962; Asseez, 1972) especially in the humid tropics by providing an overburden of relatively more porous and more permeable materials from the rocks. There is

ample evidence that there is a considerable weathering depth in The development of thick clay in basement complex terrain leads to failure in constructions. Other prevailing environmental factors such as topography, vegetation and climate favour engineering construction. The study of weathering profile, its vertical variation, spatial distribution, textural characteristics of the constituent materials are essential step towards a better understanding of shallow site investigation in basement complex areas. To locate a successful site for construction in Precambrian basement terrain is problematic due to the heterogeneous nature of the subsurface and so the geology of the sobesurface needs to be investigated in considerable details.

2.4 ELECTRODE CONFIGURATION OF 2-D IMAGING

There are different electrode arrangements with different applications used in electrical resistivity imaging survey. The most commonly known are Wenner (α , β and γ), Dipole- Dipole, Pole-Dipole, pole-pole and Wenner-Schlumberger arrays. The basic resistivity measuring technique is just similar to the conventional principles. Basically, four electrodes are required; two for current injection and two electrodes for potential measurement. Each array has their own advantages and drawbacks in data acquisition and processing works. But one might has better sensitivity and resolution power for vertical as well as lateral structural variations than the other. For instance, Wenner array in multi-electrode mode has good

resolution power for horizontal structure having vertical variations but weak for horizontally variable geological structures.

Note that as the electrode spacing increases, the number of measurements decreases. The type of array used also matters the number of measurements to be obtained. The Wenner array gives the smallest number of possible measurements compared to the other common arrays used in 2-D surveys. The survey procedures followed in the pole-pole array are similar to that used for the Wenner array, whereas, survey procedures of dipole-dipole, Wenner-Schlumberger and pole-dipole arrays are slightly different. Wenner-Schlumberger array which is the emphasis of this paper will be discussed more.

Wenner-Schlumberger array

Among the multi-electrodes arrays, the Wenner-Schlumberger array has better resolution and high sensitivity for vertical and horizontal geological variations. The Wenner-Schlumberger array is a technique where different combinations of an electrode spacing 'a' and a factor 'n' can be used. The factor 'n' is the ratio of the distance between the C1-P1 (or P2-C2) electrodes to the spacing between the P1-P2 potential pair. It has value 1 for the first sequence of measurement and 2 for the next, and so on. Wenner-Schlumberger is a recent hybrid from the Wenner and Schlumberger arrays for better 2-D imaging survey. The conventional Schlumberger array is one of the most commonly used array for

resistivity sounding surveys. On the other hand, Wenner array is the successful procedure for profiling survey. The spacing between adjacent electrodes is 'a'. The first sequence of measurements is carried out, this array, with electrode spacing of '1a'. In this sequence of measurement, the first measurement is made with electrodes 1, 2, 3 and 4. In this case, electrodes 1 and 4 are used as the current electrode C1 and C2 respectively, and electrode 2 and 3 act as the potential electrode P1 and P2 respectively. For the second measurement, electrodes number 2, 3, 4 and 5 are used for C1, P1, P2 and C2 respectively. This is repeated down the line of electrodes until the last set of electrodes, 69, 70, 71 and 72, are used for the last measurement with '1a' spacing. For instance, a system of measurement with 72 electrodes will have 72, 3, 69 possible measurements with '1a' spacing. This configuration has just the classical Wenner array. The next sequence of measurements is made by choosing spacing a current electrode and a potential electrode to be '2a' and the spacing between two potential electrodes is set to be 'a' (may be a fractional number) to get Schlumberger depth of investigation. In this case 'n' factor have a value 2. First measurement is made using electrodes 1, 3, 4 and 6, and then the second measurement uses electrodes 2, 4, 5 and 7 for C1, P1, P2 and C2 respectively for each. But normally only one either of the two trends is taken. This process is repeated down the line until electrodes 67, 69, 70 and 72 are used for the last measurement with spacing '2a'. The same process is repeated for

measurements with '3a', '4a', '5a', '6a' and soon. To understand more, a good figurative illustration of Wenner-Schlumberger electrode configuration is presented in the Figure 2.3 below.

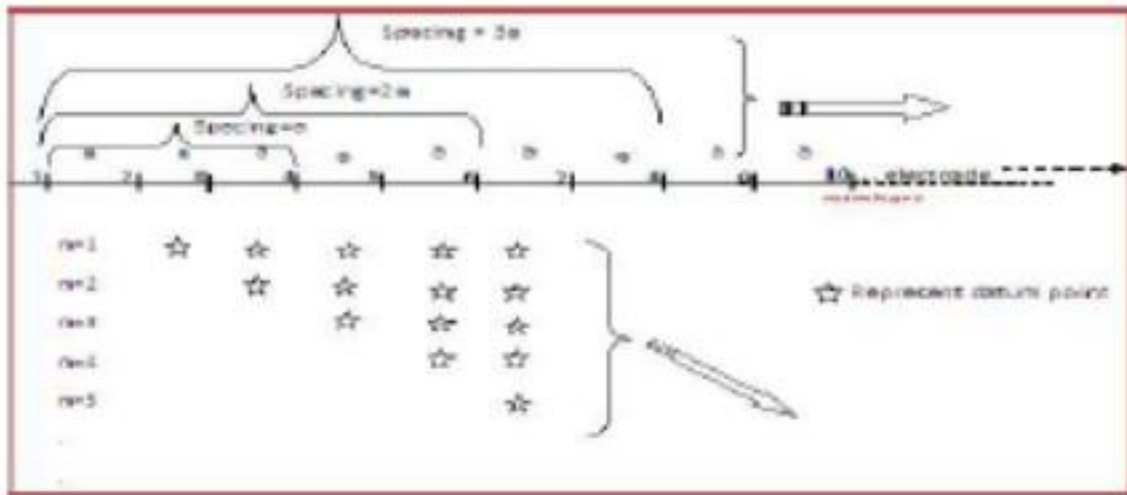


Figure 2.3 The Wenner- Schlumberger 2-D imaging array procedure

Wenner-Schlumberger array is quite sensitive to both horizontal and vertical structures and is better applicable for areas where both types of geological structures are expected. The signal strength for this array is smaller than that for the Wenner array, but it is higher than the dipole-dipole array. The median depth of investigation (z) for the Wenner-Schlumberger array is moderately deeper than the dipole-dipole and Wenner arrays (Loke, 2000)

2.5 VARIATION OF ELECTRICAL RESISTIVITY AS A FUNCTION OF SOIL PROPERTIES.

The purpose of electrical resistivity surveys is to determine the resistivity distribution of the surrounding soil volume. Artificially generated electric currents are supplied to the soil and the resulting potential differences are measured. Potential difference patterns provide information on the form of subsurface heterogeneities and of their electrical properties. The greater the electrical contrast between the soil matrix and heterogeneity, the easier is the detection Loke M.H 2009. The resistivity measurements are normally made by injecting current into the ground through two current electrodes A and B (or C1 and C2) at the external positions , and measuring the resulting voltage difference at two potential electrodes M and N (or P1 and P2) in between.

$$\rho_a = k \left(\frac{V}{I} \right) \dots\dots\dots 2.1$$

$$\rho_a = kR \dots\dots\dots 2.2$$

The apparent resistivity is the bulk average resistivity of all soils and rocks influencing the flow of current, I is the current, V is the voltage and k is the geometric factor which depends on the arrangement of the four electrodes (Milsom J, 2003). There are many arrays used for resistivity imaging where each array has advantages and disadvantages depending on the nature of the study area. The most

common arrays in Resistivity Imaging are Wenner, dipole-dipole and Wenner-Schlumberger (Samouelian et al., 2006) (Loke, 2009). Choosing the right array for the resistivity surveys is important for two reasons, the first one is in each array there are advantages and disadvantages compared with the other arrays, and the second reason is the geological image created by means of (RI) for the same structure will be different for each array. Choosing the right array depends on the target survey, sensitivity of the resistivity meter, electric background noise and the subsurface structure. Moreover, choosing the array requires some considerations such as the depth of the image, vertical and horizontal change in the subsurface, the length of the image and the signal strength.

The Wenner electrode configuration is an array in which the four electrodes are arranged in line with equal electrode spacing. If the survey is in a noisy area and a good vertical resolution is required with a limited survey the Wenner array will be the best option (Loke, 2009). While the other commonly used array is Wenner-Schlumberger array which is hybrid between Wenner and Schlumberger arrays (Pazdirek and Blaha, 2011) arising out of a relatively recent work with electrical image surveys. If there is uncertainty whether both reasonably good horizontal and vertical resolution are required, the Wenner-Schlumberger array with overlapping data levels is the best option. This array is moderately sensitive to both horizontal and vertical structures (Anthony, 2006).

The electrical resistivity is a function of a number of soil properties, including the nature of the solid constituents (particle size distribution, mineralogy), arrangement of voids (porosity, pore size distribution and connectivity), degree of water saturation (water content), electrical resistivity of the fluid (solute concentration) and temperature. The porosity is the major control of resistivity of rocks, and that resistivity generally increases as porosity decreases. Porosity and cementation, on the other hand, are related. It then means that electrical resistivity could be used to determine the degree of cementation to better characterize the subsurface soil for engineering structures (Ayolabi et al., 2009).

The air medium is an insulator (i.e. infinitively resistive), the water solution resistivity is a function of the ionic concentration, and the resistivity of the solid grains is related to the electrical charges density at the surface of the constituents. These parameters affect the electrical resistivity, but in different ways and to different extents. Electrical resistivity experiments have been performed to establish relationships between the electrical resistivity and each of these soil characteristics (Samouelian et al., 2006).

The most common minerals forming 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. Consequently, the

resistivity of a type of soil or rock may vary widely. The resistivity of the pore water is determined by the concentration of ions in solution, the type of ions and the temperature.

Mineral	Formula	Resistivity (Ωm)	
		Range	Average
Bismuthinite	Bi_2S_3	18-570	
Covellite	CuS	$3 \times 10^{-7} - 8 \times 10^{-5}$	2×10^{-5}
Chalcocite	Cu_2S	$3 \times 10^{-5} - 0.6$	10^{-4}
Chalcopyrite	CuFeS_2	$1.2 \times 10^{-5} - 0.3$	4×10^{-3}
Bornite	Cu_5FeS_4	$2.5 \times 10^{-5} - 0.5$	3×10^{-3}
Pyrite	FeS_2	$2.9 \times 10^{-5} - 1.5$	3×10^{-1}
Pyrrhotite	$\text{Fe}_{7-9}\text{S}_m$	$6.5 \times 10^{-6} - 5 \times 10^{-2}$	10^{-4}
Cinnabar	HgS		2×10^7
Molybdenite	MoS_2	$10^{-3} - 10^6$	10
Galena	PbS	$3 \times 10^{-5} - 3 \times 10^2$	2×10^{-3}
Millerite	NiS		3×10^{-7}
Stannite	$\text{Cu}_3\text{FeSnS}_2$	$10^{-3} - 6 \times 10^3$	
Stibnite	Sb_2S_3	$10^5 - 10^{12}$	5×10^6
Sphalerite	ZnS	$1.5 - 10^7$	10^2
Cobaltite	CoAsS	$3.5 \times 10^{-4} - 10^{-1}$	
Arsenopyrite	FeAsS	$2 \times 10^{-5} - 15$	10^{-3}
Niccolite	NiAs	$10^{-7} - 2 \times 10^{-3}$	2×10^{-5}
Bauxite	$\text{Al}_2\text{O}_3 \cdot n\text{H}_2\text{O}$	$2 \times 10^2 - 6 \times 10^3$	
Cuprite	Cu_2O	$10^{-3} - 300$	30
Chromite	FeCr_2O_4	$1 - 10^6$	
Specularite	Fe_2O_3		6×10^{-3}
Hematite	Fe_2O_3	$3.5 \times 10^{-3} - 10^7$	
Limonite	$2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$	$10^3 - 10^7$	
Magnetite	Fe_3O_4	$5 \times 10^{-5} - 5.7 \times 10^3$	
Ilmenite	FeTiO_3	$10^{-3} - 50$	
Wolframite	Fe, Mn, WO_4	$10 - 10^5$	
Pyrolusite	MnO_2	$5 \times 10^{-3} - 10$	
Quartz	SiO_2	$4 \times 10^{10} - 2 \times 10^{14}$	
Cassiterite	SnO_2	$4 \times 10^{-4} - 10^4$	0.2
Rutile	TiO_2	30-1000	500
Uraninite (pitchblende)	UO_2	1-200	
Anhydrite	CaSO_4		10^9
Calcite	CaCO_3		2×10^{12}
Fluorite	CaF_2		8×10^{13}
Siderite	$\text{Fe}_2(\text{CO}_3)_3$		70
Rock salt	NaCl	$30 - 10^{13}$	
Sylvite	KCl	$10^{11} - 10^{12}$	
Diamond	C	$10 - 10^{14}$	
Serpentine		$2 \times 10^2 - 3 \times 10^3$	
Hornblende		$2 \times 10^2 - 10^6$	
Mica		$9 \times 10^2 - 10^{14}$	
Biotite		$2 \times 10^2 - 10^6$	
Bitum. coal		$0.6 - 10^5$	
Anthracite		$10^{-3} - 2 \times 10^5$	
Lignite		9-200	
Fire clay			30
Meteoric waters		$30 - 10^3$	
Surface waters (ign. rocks)		$0.1 - 3 \times 10^3$	
Surface waters (sediments)		10-100	
Soil waters			100
Natural waters (ign. rocks)		0.5-150	9
Natural waters (sediments)		1-100	3
Sea water			0.2
Saline waters, 3%			0.15
Saline waters, 20%			0.05

Table 2.1 Resistivity of some materials (Source: Applied Geophysics by W.M. Telford, L.P. Geldart, R.M. Sheriff, 2004)

CHAPTER THREE

3.0 THEORY AND METHODOLOGY

3.1 FIELD SURVEY METHOD - INSTRUMENTATION AND MEASUREMENT PROCEDURE

Two-dimensional electrical imaging/tomography surveys are usually carried out using a large number of electrodes, 25 or more, connected to a multi-core cable (Griffiths and Barker, 1993). A laptop microcomputer together with an electronic switching unit is used to automatically select the relevant four electrodes for each measurement (Figure 3.1). At present, field techniques and equipment to carry out 2-D resistivity surveys are fairly well developed. The necessary field equipment is commercially available from a number of international companies. Some institutions have even constructed “home-made” manually operated switching units at a nominal cost by using a seismic cable as the multi-core cable. *Figure 3.0* shows the typical setup for a 2-D survey with a number of electrodes along a straight line attached to a multi-core cable. Normally a constant spacing between adjacent electrodes is used.

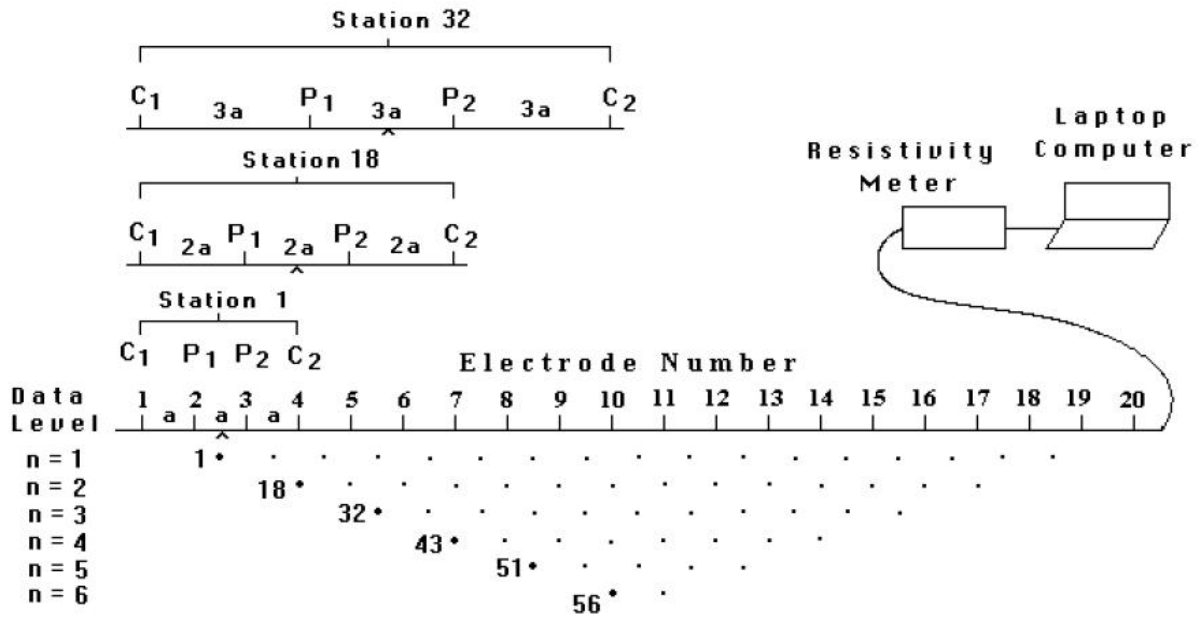


Figure 3.1: The arrangement of electrodes for a 2-D electrical survey using Wenner array and the sequence of measurements used to build up a pseudosection.

The multi-core cable is attached to an electronic switching unit that is connected to a laptop computer. The sequence of measurements to take, the type of array to use and other survey parameters (such as the current to use) is normally entered into a text file which can be read by a computer program in a laptop computer. Different resistivity meters use different formats for the control file, so one will need to refer to the manual for ones system. After reading the control file, the computer program then automatically selects the appropriate electrodes for each measurement. Some field systems have an in-built microprocessor system so that a laptop computer is not needed. This could be a significant advantage for surveys in very rugged terrain.

In a typical survey, most of the fieldwork is in laying out the cable and electrodes. After that, the measurements are taken automatically and stored in the computer. Most of the survey time is spent waiting for the resistivity meter to complete the set of measurements. To obtain a good 2-D picture of the subsurface, the coverage of the measurements must be 2-D as well.

Figure 3.1 shows a possible sequence of measurements for the Wenner electrode array for a system with 20 electrodes. In this example, the spacing between adjacent electrodes is “a”. The first step is to make all the possible measurements with the Wenner array with electrode spacing of “1a”. For the first measurement, electrodes number 1, 2, 3 and 4 are used. Electrode 1 is used as the first current electrode C_1 , electrode 2 as the first potential electrode P_1 , electrode 3 as the second potential electrode P_2 and electrode 4 as the second current electrode C_2 . For the second measurement, electrodes number 2, 3, 4 and 5 are used for C_1 , P_1 , P_2 and C_2 respectively. This is repeated down the line of electrodes until electrodes 17, 18, 19 and 20 are used for the last measurement with “1a” spacing. For a system with 20 electrodes, there are 17 i.e. $(20 - 3)$ possible measurements with “1a” spacing for the Wenner array.

After completing the sequence of measurements with “1a” spacing, the next sequence of measurements with “2a” electrode spacing is made. First electrodes 1, 3, 5 and 7 are used for the first measurement. The electrodes are chosen so that the

spacing between adjacent electrodes is “2a”. For the second measurement, electrodes 2, 4, 6 and 8 are used. This process is repeated down the line until electrodes 14, 16, 18 and 20 are used for the last measurement with spacing “2a”. For a system with 20 electrodes, there are 14 ($20 - 2 \times 3$) possible measurements with “2a” spacing. The same process is repeated for measurements with “3a”, “4a”, “5a” and “6a” spacings. To get the best results, the measurements in a field survey should be carried out in a systematic manner so that, as far as possible, all the possible measurements are made. This will affect the quality of the interpretation model obtained from the inversion of the apparent resistivity measurements (Dahlin and Loke, 1998).

As the electrode spacing increases, the number of measurements decreases. The number of measurements that can be obtained for each electrode spacing, for a given number of electrodes along the survey line, depends on the type of array used. The Wenner array gives the smallest number of possible measurements compared to the other common arrays that are used in 2-D surveys. The survey procedure with the pole-pole array is similar to that used for the Wenner array. For a system with 20 electrodes, firstly 19 of measurements with a spacing of “1a” are made, followed by 18 measurements with “2a” spacing, followed by 17 measurements with “3a” spacing, and so on.

For the dipole-dipole, Wenner-Schlumberger and pole-dipole arrays, the survey procedure is slightly different. As an example, for the dipole-dipole array, the measurement usually starts with a spacing of “1a” between the C₁-C₂ (and also the P₁-P₂) electrodes. The first sequence of measurements is made with a value of 1 for the “n” factor (which is the ratio of the distance between the C₁-P₁ electrodes to the C₁-C₂ dipole length), followed by “n” equals to 2 while keeping the C₁-C₂ dipole pair spacing fixed at “1a”. When “n” is equals to 2, the distance of the C₁ electrode from the P₁ electrode is twice the C₁-C₂ dipole length. For subsequent measurements, the “n” spacing factor is usually increased to a maximum value of about 6, after which accurate measurements of the potential are difficult due to very low potential values. To increase the depth of investigation, the spacing between the C₁-C₂ dipole pair is increased to “2a”, and another series of measurements with different values of “n” is made. If necessary, this can be repeated with larger values of the spacing of the C₁-C₂ (and P₁-P₂) dipole pairs.

A similar survey technique can be used for the Wenner- Schlumberger and pole-dipole arrays where different combinations of the “a” spacing and “n” factor can be used.

3.2 Classification of Electrical Resistivity Measuring Instruments (Terrameters)

The instrument type can be divided into two broad categories: static and dynamic systems. Most instruments are of the static type where many electrodes are connected to a multielectrode cable and planted into the ground during the survey. A typical static system is the Abem Lund system. One common configuration is a split spread type of cable connection to the switching unit at the center to reduce the individual cable length and weight. The weight of a cable roll is directly proportional to the number of nodes and the spacing between the nodes. A common spacing used for most engineering and environmental surveys is 5 meters. Most systems come with a minimum of 28 nodes, with some system having up to 128 nodes or more. The Lund system is a little unusual in that there are 4 individual cables. Most systems use a 2 cables arrangement. The static systems can be further divided into two sub-categories depending on the arrangement for the switching of the electrodes. Most of the systems house the switches in a single unit and uses a cable with many individual wires connected to each node. Typical examples are the Abem Lund and Campus Geopulse systems. Another arrangement is to have a small switching unit at each electrode and a cable with the minimum number of wires. One early example is the Campus MRT system (Griffiths and Turnbull, 1985). A more recent example is the PASI system.

There have been two new and interesting developments in the resistivity meter systems. One is the addition of I.P. capability. The second is multi-channel measuring systems. In such a system, a number of potential measurements can be simultaneously made for a single pair of current electrodes. This could significantly reduce the survey time. With certain array configurations, a single 2-D survey line could involve thousands of measurements. The major part of the survey time is waiting for a single channel instrument to complete the measurements that could take more than several hours.

Static systems use a large number of nodes to get a wide data coverage. In contrast, dynamic systems use a small number of nodes but move the entire system to obtain a wide coverage. An example of such a system is that designed by Aarhus University in Denmark (Sorenson 1996). It uses a 100 meters cable with nine heavy cylindrical electrodes pulled by a small vehicle. Two of the electrodes are used as current electrodes, while six of them are used for the potential measurements and one is used as a ground electrode. This system relies on the current being injected into the ground by direct contact, so it can only be used in open ground, such as farmlands. A Wenner-Schlumberger type of arrangement is used but with non-integer “n” values for some of the measurements. Another mobile system that does not require direct contact with the ground but uses capacitive coupling to induce the flow of current in the ground is the Geometrics

Ohm Mapper system where a cable with 4 to 6 electrodes attached to a measuring unit is pulled by a single operator. This system can be used in areas that are paved, such as roads and city areas. Since the capacitive coupling type does not require direct ground contact, it can be used in many areas where normal resistivity surveying systems cannot be used (for example in built-up areas). It however has the problem of a more limited depth of penetration due to the limited amount of current that can be induced into the ground compared to direct contact systems. An underwater environment provides an almost ideal situation for a direct contact type of mobile system since there is no problem in obtaining good electrode contact. For an underwater mobile surveying system where a cable with a number of nodes is pulled along the river/lake/sea bottom by a boat, two of the nodes are used as current electrodes, while the rest are used as potential electrodes. If this system is coupled with a multi-channel resistivity meter, the survey can be carried out very rapidly. Shallow seismic reflection surveys are frequently used in rivers/lakes/marine environments for engineering site surveys. A mobile resistivity survey might be a useful addition in some situations, such as in seismically opaque areas. In theory, both surveys can be carried out simultaneously to reduce costs.

3.3 Pseudosection data plotting method

To plot the data from a 2-D imaging survey, the pseudosection contouring method is normally used. In this case, the horizontal location of the point is placed at the mid-point of the set of electrodes used to make that measurement. The vertical location of the plotting point is placed at a distance that is proportional to the separation between the electrodes.

Another method is to place the vertical position of the plotting point at the median depth of investigation (Edwards, 1977), or pseudo depth, of the electrode array used. This pseudo depth value is based on the sensitivity values or Frechet derivative for a homogeneous half space. The pseudosection plot obtained by contouring the apparent resistivity values is a convenient means to display the data.

The pseudosection gives a very approximate picture of the true subsurface resistivity distribution. However the pseudosection gives a distorted picture of the subsurface because the shapes of the contours depend on the type of array used as well as the true subsurface resistivity. The pseudosection is useful as a means to present the measured apparent resistivity values in a pictorial form, and as an initial guide for further quantitative interpretation. One common mistake made is to try to use the pseudosection as a final picture of the true subsurface resistivity. Different arrays used to map the same region can give rise to very different contour

shapes in the pseudosection plot. It is worthy of note that the pole-pole array gives the widest horizontal coverage, while the coverage obtained by the Wenner array decreases much more rapidly with increasing electrode spacing. One useful practical application of the pseudosection plot is for picking out bad apparent resistivity measurements. Such bad measurements usually stand out as points with unusually high or low values.

3.4 HIGH-RESOLUTION ELECTRICAL SURVEYS WITH OVERLAPPING DATA LEVELS

In seismic reflection surveys, the common depth point method is frequently used to improve the quality of the signals from subsurface reflectors. A similar technique can be used to improve the data quality for resistivity/IP surveys, particularly in noisy areas. This is by using overlapping data levels with different combinations of “a” and “n” values for the Wenner-Schlumberger, dipole-dipole and pole-dipole arrays.

To simplify matters, let us consider the case for the Wenner-Schlumberger array with an inter-electrode spacing of 1 meter along the survey line. A high-resolution Wenner-Schlumberger survey will start with the “a” spacing (which is the distance between the P_1 - P_2 potential dipole) equals to 1 meter and repeat the measurements with “n” values of 1, 2, 3 and 4. Next the “a” spacing is increased to

2 meter, and measurements with “n” equals to 1, 2, 3 and 4 are made. This process is repeated for all possible values of the “a” spacing. To be on the safe side, the data set should contain all the possible data points for the Wenner array. The number of data points produced by such a survey is more than twice that obtained with a normal Wenner array survey. Thus the price of better horizontal data coverage and resolution is an increase in the field survey time.

A Wenner array with “a” equals to 2 meters will have a total array length of 6 meters. In comparison with the Wenner array, the Wenner-Schlumberger array will have a slightly smaller (approximately the same) depth of investigation. While the depth of investigation of the two arrangements are similar, the section of the subsurface mapped by the two arrays will be slightly different due to the different sensitivity patterns. So the two measurements will give slightly different information about the subsurface. If measurements obtained from three different values of “a” are used, the data set will have measurements with three different pseudo depths. This results in a pseudosection with overlapping data levels.

A similar “high-resolution” survey technique can also be used with the dipole-dipole and pole-dipole arrays by combining measurements with different “a” and “n” values to give overlapping data levels. In particular, this technique might be useful for the dipole-dipole array since the signal strength decreases rapidly with increasing “n” values. A typical high resolution dipole-dipole survey might use the

following arrangement; start with a dipole of "1a" and "n" values of 1, 2, 3, 4, 5; followed by a dipole of "2a" and "n" values of 1, 2, 3, 4, 5; and if necessary another series of measurements with a dipole of "3a" and "n" values of 1, 2, 3, 4, 5. Measurements with the higher "n" values of over 4 would have higher noise levels. However, by having such redundant measurements using the overlapping data levels, the effect of the more noisy data points will be reduced. This arrangement has been widely used for IP surveys with the dipole-dipole array (Edwards 1977).

In theory, it should be possible to combine measurements made with different arrays to take advantage of the different properties of the various arrays. Although this is not a common practice, it could conceivably give useful results in some situations.

3.5 OTHER EQUIPMENT USED FOR THE FIELD WORK

Measuring Tape: This is used to measure the length of spread of both the potential and current electrodes. It is calibrated in centimeter, meter and feet. In cases where the length of the spread is exhausted and there are still distances to be measured, measured distances on the ground can be marked and the remainder of the distance, measured.

Electrodes: These are metallic conductors used in field work because of their high conductivity. One end of the metal is pointed; this is to ease its penetration into the ground.

Current and Potential Electrode Cables: These are made of electrical cables which are wound around insulators which can be rolled. On the field, one end of the cable is reeled out and used to make contact with the electrodes. Current is sent from an electrical power source, through the cable, to the current electrodes which then transmit this current into the earth. The cable is also used to connect both the current and potential electrodes to the terrameter.

Terrameter: This is a computerized system which is at the heart of the entire field operation. There are numerous, and these have been discussed analytically in the preceding section (section 3.2).

Hammer: This is used to hit the electrodes into the earth for greater penetration in areas of highly compacted soil structure.

Battery: This is used to power the terrameter. It is also the source of the current which is sent into the earth, from which the potential difference across the potential electrodes is measured.

Cutlass: This is used in rough terrain. It is used to clear off weeds, grasses and all unwanted obstruction along the walk-way or on points disturbing the placement of electrodes.

Geographical Positioning System (GPS): This is used to obtain knowledge of geographical location (longitude and latitude) of the survey area. It is very important, in that it tells us the elevation of the surface layer with respect to the sea level. This is needed for accurate analysis of the position of subsurface anomalies.

Below is a picture of some of the basic instruments used.



Figure 3.2 Pictures of instruments used for the field work

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION OF RESULT

4.1 RESULT

4.1.1 2-D Wenner Array Electrical Resistivity Field Record – Trasverse one

Date: 30-10-2014 Instrument: Terrameter SAS 1000 Location: Uwelu

Long: 005°06'20.6''

Lat: 05°39'24.7''

Elevation: 108.4

Geometric Factor, $K = 2\pi a$

Electrode location at a=10m, n= 1,k=62.84				
Electrode locations				
C1(m)	P1(m)	P2(m)	C2(m)	ρ (Ω m)
0	10	20	30	1589.852
10	20	30	40	1778.372
20	30	40	50	1753.236
30	40	50	60	1816.076
40	50	60	70	1646.408
50	60	70	80	1759.52
60	70	80	90	1382.48
70	80	90	100	1552.148
80	90	100	110	1087.132
90	100	110	120	1244.232
100	110	120	130	1338.492
110	120	130	140	1263.084
120	130	140	150	1363.628
130	140	150	160	1376.196

140	150	160	170	1206.528
150	160	170	180	1281.936
160	170	180	190	1200.244
170	180	190	200	1112.268
180	190	200	210	948.884
190	200	210	220	1112.268
200	210	220	230	961.452
210	220	230	240	942.6
220	230	240	250	1036.86
230	240	250	260	980.304
240	250	260	270	948.884
250	260	270	280	942.6
260	270	280	290	999.156
270	280	290	300	942.6
280	290	300	310	1131.12
290	300	310	320	1080.848

Electrode location at $a=10m, n=2, k=125.68$				
Electrode locations				
C1(m)	P1(m)	P2(m)	C2(m)	ρ (Ωm)
0	20	40	60	1985.744
10	30	50	70	1922.904
20	40	60	80	1797.224
30	50	70	90	1847.496
40	60	80	100	1897.768
50	70	90	110	2061.152
60	80	100	120	2048.584
70	90	110	130	2249.672
80	100	120	140	1822.36
90	110	130	150	1772.088
100	120	140	160	1709.248
110	130	150	170	1583.568
120	140	160	180	1596.136
130	150	170	190	1734.384
140	160	180	200	1571
150	170	190	210	1369.912
160	180	200	220	1470.456
170	190	210	230	1470.456
180	200	220	240	1156.256
190	210	230	250	1193.96
200	220	240	260	1294.504

Electrode location at a=10m, n= 3, k=188.52				
Electrode locations				
C1(m)	P1(m)	P2(m)	C2(m)	ρ (Ω m)
0	30	60	90	2281.092
10	40	70	100	2356.5
20	50	80	110	2337.648
30	60	90	120	2356.5
40	70	100	130	2149.128
50	80	110	140	2054.868
60	90	120	150	1979.46
70	100	130	160	2186.832
80	110	140	170	2243.388
90	120	150	180	2224.536
100	130	160	190	2036.016
110	140	170	200	2036.016
120	150	180	210	2036.016
130	160	190	220	2054.868
140	170	200	230	1922.904
150	180	210	240	1885.2
160	190	220	250	1658.976
170	200	230	260	1602.42
180	210	240	270	1470.456
190	220	250	280	1413.9
200	230	260	290	1413.9

210	230	250	270	1244.232
220	240	260	280	1219.096
230	250	270	290	1168.824
240	260	280	300	1168.824
250	270	290	310	1960.608
260	280	300	320	2036.016

210	240	270	300	1413.9
220	250	280	310	1357.344
230	260	290	320	1338.492

Electrode location at a=10m, n= 4, k=251.36				
Electrode locations				
C1(m)	P1(m)	P2(m)	C2(m)	ρ (Ω m)
0	40	80	120	2764.96
10	50	90	130	2790.096
20	60	100	140	2513.6
30	70	110	150	2387.92
40	80	120	160	2463.328
50	90	130	170	2337.648
60	100	140	180	2463.328
70	110	150	190	2513.6
80	120	160	200	2463.328
90	130	170	210	2513.6
100	140	180	220	2387.92
110	150	190	230	2362.784
120	160	200	240	2312.512
130	170	210	250	2186.832
140	180	220	260	2010.88
150	190	230	270	1759.52

160	200	240	280	1734.384
170	210	250	290	1608.704
180	220	260	300	1533.296
190	230	270	310	1533.296
200	240	280	320	1457.888

Electrode location at $a=10\text{m}$, $n= 5$, $k=314.2$				
Electrode locations				
C1(m)	P1(m)	P2(m)	C2(m)	ρ (Ωm)
0	50	100	150	2859.22
10	60	110	160	2733.54
20	70	120	170	2670.7
30	80	130	180	2607.86
40	90	140	190	2545.02
50	100	150	200	2702.12
60	110	160	210	2702.12
70	120	170	220	2733.54
80	130	180	230	2733.54
90	140	190	240	2733.54
100	150	200	250	2702.12

110	160	210	260	2702.12
120	170	220	270	2450.76
130	180	230	280	2482.18
140	190	240	290	2262.24
150	200	250	300	2042.3
160	210	260	310	2042.3
170	220	270	320	1539.58

Electrode location at $a=10\text{m}$, $n= 6$, $k=377.04$				
Electrode locations				
C1(m)	P1(m)	P2(m)	C2(m)	ρ (Ωm)
0	60	120	180	2526.168
10	70	130	190	2488.464
20	80	140	200	2488.464
30	90	150	210	2563.872
40	100	160	220	2488.464
50	110	170	230	2601.576
60	120	180	240	2714.688
70	130	190	250	2752.392
80	140	200	260	2714.688
90	150	210	270	2639.28
100	160	220	280	2639.28
110	170	230	290	2413.056
120	180	240	300	2149.128
130	190	250	310	1998.312
140	200	260	320	1847.496

Electrode location at $a=10\text{m}$, $n= 7$, $k=439.88$				
Electrode locations				
C1(m)	P1(m)	P2(m)	C2(m)	ρ (Ωm)
0	70	140	210	2639.28
10	80	150	220	2727.256
20	90	160	230	2595.292
30	100	170	240	2639.28
40	110	180	250	2815.232
50	120	190	260	2815.232

60	130	200	270	2771.244
70	140	210	280	2683.268
80	150	220	290	2595.292
90	160	230	300	2507.316
100	170	240	310	2551.304
110	180	250	320	2507.316

Electrode location at $a=10\text{m}$, $n= 8$, $k=502.72$				
Electrode locations				
C1(m)	P1(m)	P2(m)	C2(m)	ρ (Ωm)
0	80	160	240	2865.504
10	90	170	250	2915.776
20	100	180	260	2966.048
30	110	190	270	3167.136
40	120	200	280	3116.864
50	130	210	290	3066.592
60	140	220	300	3116.864
70	150	230	310	2865.504
80	160	240	320	2915.776

Electrode location at $a=10\text{m}$, $n= 9$, $k=565.56$				
Electrode locations				
C1(m)	P1(m)	P2(m)	C2(m)	ρ (Ωm)
0	90	180	270	3110.58
10	100	190	280	3336.804
20	110	200	290	2149.128
30	120	210	300	3223.692
40	130	220	310	3167.136
50	140	230	320	3110.58

Electrode location at $a=10\text{m}$, $n= 10$, $k=628.4$				
Electrode locations				
C1(m)	P1(m)	P2(m)	C2(m)	ρ (Ωm)
0	100	200	300	3330.52
10	110	210	310	3581.88
20	120	220	320	3393.36

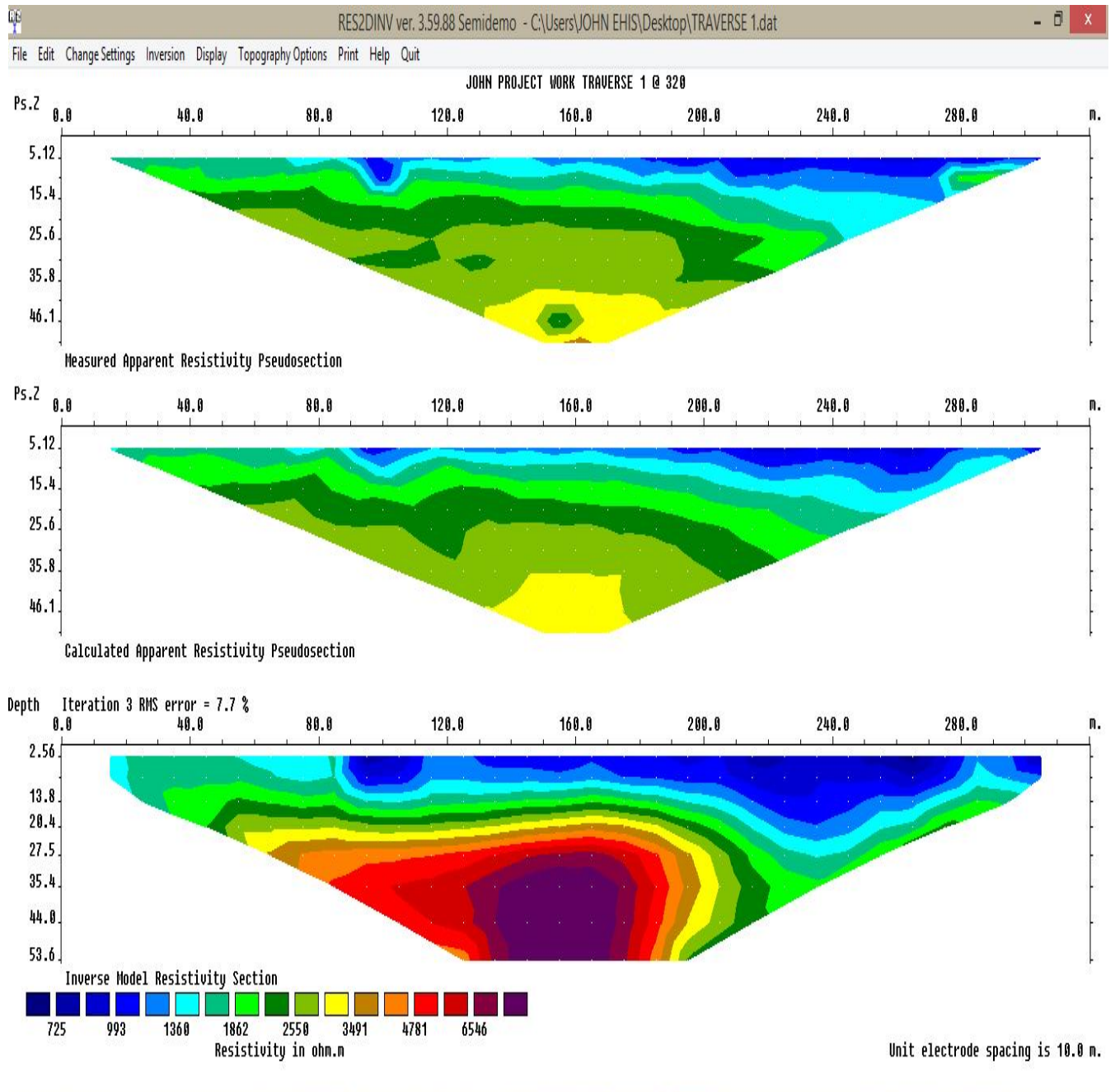


FIGURE 4.1: INTERPRETED 2-D SECTION FOR TRAVERSE ONE

4.2 INTERPRETATION AND DISCUSSION OF RESULT.

Table 4.1: Resistivity Values of Some Common Rocks, Minerals and Chemicals.
(Keller and Frischknecht, 1966)

Material	Resistivity ($\Omega \cdot m$)	Conductivity(Siemen/m)
Igneous and Metamorphic Rocks		
Granite	$5 \times 10^3 - 10^6$	$10^{-6} - 2 \times 10^{-4}$
Basalt	$10^3 - 10^6$	$10^{-6} - 10^{-3}$
Slate	$6 \times 10^2 - 4 \times 10^7$	$2.5 \times 10^{-8} - 1.7 \times 10^{-3}$
Marble	$10^2 - 2.5 \times 10^8$	$4 \times 10^{-9} - 10^{-2}$
Quartzite	$10^2 - 2 \times 10^8$	$5 \times 10^{-9} - 10^{-2}$
Sedimentary Rocks		
Sandstone	$8 - 4 \times 10^3$	$2.5 \times 10^{-4} - 0.125$
Shale	$20 - 2 \times 10^3$	$5 \times 10^{-4} - 0.05$
Limestone	$50 - 4 \times 10^2$	$2.5 \times 10^{-3} - 0.02$
Soils and waters		
Clay	1 – 100	0.01 – 1
Alluvium	10 – 800	$1.25 \times 10^{-3} - 0.1$
Groundwater (fresh)	10 – 100	0.01 -0.1
Sea water	0.2	5

Chemicals		
Iron	9.074×10^{-8}	1.102×10^7
0.01 M Potassium chloride	0.708	1.413
0.01 M Sodium chloride	0.843	1.185
0.01 M acetic acid	6.13	0.163
Xylene	6.998×10^{16}	1.429×10^{-17}

Table 4.2: Lithological Interpretation of the 2-D Data inversion

Resistivity(Ωm)	Inferred Rock Type	Standard Resistivity ($\Omega\cdot\text{m}$) values for rocks.
3000-6988	Basalt	$10^3 - 10^6$
600-6988	Slate	$6 \times 10^2 - 4 \times 10^7$
3233-6988	Sandstone	$8 - 4 \times 10^3$
3233-6988	Granite	$5 \times 10^3 - 10^6$
420-2000	Alluvium (soil)	10 – 800
2000-6988	Quartz	$10^2 - 2 \times 10^8$
2000-6988	Marble	$10^2 - 2.5 \times 10^8$
420-5000	Shale	$20 - 2 \times 10^3$

The already recorded apparent resistivity data from the electrical resistivity survey were interpreted using RES2DINV software to produce true resistivity images shown in figure 4.1.

Figure 4.1 reveals eight distinct layers ranging from alluvium through shale, marble, quartzite, basalt, slate, and sandstone to granite with apparent resistivity values ranging from 756 Ωm to 6545 Ωm . The materials extend to about 54.6m below the surface towards the end of the profile. We observed an increase in the coarse nature of the rock materials which is reflected in the increase in resistivity of the rock types as we go deeper in the profile.

Basalt is a common igneous rock, formed from the rapid cooling of basaltic lava exposed at or very near the surface of a planet or moon. By definition, basalt is an aphanitic igneous rock with less than 20% quartz and less than 10% feldspar by volume and where at least 65% of the feldspar is in the form of plagioclase. Basalt features a glassy matrix interspersed with minerals. Basalt is defined by its mineral content and texture, and physical descriptions without mineralogical context may be unreliable in some circumstances. Basalt is usually grey to black in colour, but rapidly weathers to brown or rust-red due to oxidation of its mafic (iron rich) minerals into rust. Although usually characterized as “dark”, basaltic rocks exhibit a wide range of shading due to regional chemical processes. Due to weathering or high concentrations of plagioclase, some basalt is quite light

coloured, superficially resembling rhyolite to untrained eyes. Basalt has fine-grained mineral texture due to the molten rock cooling too quickly for large mineral crystal to grow, although it is often porphyritic, containing the larger crystal formed prior to the extrusion that brought the lava to the surface, embedded in finer-grained matrix.

Slate is a fine-grained, foliated metamorphic rock that is created by the alteration of shale or mudstone by low-grade regional metamorphism. It is popular for a wide variety of uses such as roofing, flooring and flagging because of its durability and attractive appearance.

Slate is composed mainly of clay minerals or micas depending upon the degree of metamorphism to which it has been subjected. The original clay minerals in shale alter to mica with increasing levels of heat and pressure. Slate can also contain abundant quartz and small amounts of feldspar, calcite, pyrite, hematite and other minerals. Shale and mud stones in the sedimentary basin are compressed by horizontal forces with minor heating. These forces and heat modify the clay minerals in the shale and mudstone. Foliation develops at right angles to the compressive forces of the convergent plate boundary to yield a vertical foliation that usually crosses the bedding planes that existed in the shale. Most slates are gray in colour and range in a continuum of shades from light to dark gray. It could

also be green, red, black, purple and brown depending on the amount and type of iron and organic material that are present in the rock.

The formation of sandstone involves two principal stages. First, a layer or layers of sand accumulates as the result of sedimentation, either from water (as in a stream, lake, or sea) or from air (as in a desert). Typically, sedimentation occurs by the sand settling out from suspension; i.e., ceasing to be rolled or bounced along the bottom of a body of water or ground surface (e.g., in a desert). Finally, once it has accumulated, the sand becomes sandstone when it is compacted by pressure of overlying deposits and cemented by the precipitation of minerals within the pore spaces between sand grains. Sandstone is a clastic sedimentary rock composed mainly of sand-sized minerals or rock grains. Most sandstone is composed of quartz and/or feldspar because these are the most common minerals in the Earth's crust. Fine-grained aquifers, such as sandstones, are more apt to filter out pollutants from the surface than are rocks with cracks and crevices, such as limestone or other rocks fractured by seismic activities.

Granite often occurs as relatively small, less than 100 km stock masses (stocks) and in batholiths that are often associated with organic mountain ranges. Small dikes of granitic composition called aplites are often associated with the margins of granitic intrusions. Granitic rock is widely distributed throughout the continental

crust and is the most abundant basement rock that underlies the relatively thin sedimentary veneer of the continents.

From the above discussion, it can be stated that 2-D electrical resistivity analysis of conventional site investigation has led to a far better understanding of the site than could have been achieved using traditional site investigation methods alone. The 2-D electrical investigation in uwelu environs shows that the soil lithology and compartment will be a good site for big building and other construction works even for shallow site works.

CHAPTER FIVE

5.0 CONCLUSION

Site investigation using 2-D electrical resistivity imaging is an essential step to be taken before the erection of any structure for minimum damage because a balanced interaction of soil and structure is the hall-mark of a successful design of foundation. Based on the findings, the weathering pattern at Uwelu and its environs is uniform and the basement is uniformly thick. Hence its ability to withstand heavy structure is sure. The imaging result indicates that the use of 2-D electrical imaging will be more beneficial in site investigation than carrying out spatial sounding because it gives detail information about the subsurface.

5.1 RECOMMENDATIONS

1. I recommend that before any big structural building can be carried out in any site, a proper 2-D resistivity survey should be carried out in such location to investigate the lithology, soil type, nature of the rock and minerals and also, to know the pictorial view of the sub-surface of such location.
2. I recommend that more than one array should be used, time and cost permitting, before proper inference can be made with regards subsurface earth resistivity.

3. More work should be done to enhance the efficiency of 2-D Electrical Resistivity Interpretation software so that sharp contrasts in resistivity can be recorded.

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