GEOPHYSICAL INVESTIGATION OF ROAD FAILURE USING ELECTRICAL RESISTIVITY IMAGING METHOD, A CASE STUDY OF UHIELE – OPOJI ROAD EDO STATE

BY

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AN MSC THESIS SUBMITTED TO THE DEPARTMENT OF GEOLOGY, FACULTY OF PHYSICAL SCIENCES, UNIVERSITY OF NIGERIA, NSUKKA, IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF MASTER OF SCIENCE (M.SC) DEGREE IN GEOLOGY

SUPERVISOR: DR. MAMAH L. I.

DECEMBER, 2013

CERTIFICATION

This is to certify that Ebhohimen, Victor Osemudiamen, a postgraduate student of the Department of Geology, University of Nigeria, Nsukka, with registration number PG/MSC/09/51515 has satisfactorily completed the requirement for research work for the award of Master of Science (MSC) in Geology. This work has not been submitted in part or full for any other Diploma or Degree in this or any other University.

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EXTERNAL EXAMINER

APPROVAL PAGE

This thesis has been read and approved for the award of the degree of Master of Science (MSC) in the Department of Geology, University of Nigeria Nsukka.

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DEDICATION

To GOD Almighty for His love and grace over my educational pursuit and live goals. To my daddy, ELDER ABRAHAM EBHOHIMEN OMOHIMEN and family who set the standard I strive to reach.

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The completion of this of this Master thesis would not have been possible without the help and assistance given to me by a number of persons. Therefore I would like to express my deepest and sincere gratitude to the following people; my Supervisor, Dr. Mamah L.I. for his patience, guidance, encouragement and immerse contributions throughout this project.

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The creator of heaven and earth, for the wonderful life and blessings that continuously come my way, I say thank you LORD.

ABSTRACT

A shallow geophysical investigation for road surface failure using 2D electrical resistivity imaging profiling was conducted to produce an approximate model of the subsurface resistivity. This study was done with the aim of revealing the horizontal and vertical geological discontinuities using electrical resistivity, an intrinsic property of all materials. Probable zones of untimely failure along the road are then investigated by variation in resistivity. Four traverses were established on the road with one parallel to the road segment. The Electrical Resistivity Imaging (ERI) Profiling involving the Wenner array 2D Imaging was adopted for the resistivity survey. The Pseudosection results revealed that the road structure is founded on a near homogeneous substratum indicating that the road is situated on a better geology than those from previous studies done in this geologic environment. The apparent resistivity values for all the profiles ranged from 273.94 Ým ï 3566.7 Ým for profile I; 1561.2 Ým ï 4062.4 Ým for profile II; 714.36 Ým ï 3856.4 Ým for profile III and 700.06 Ým ï 3994.65 Ým for profile IV. Apparent Resistivity values of Area Studied ranged from 273.94Ým to 4062.4Ým with an average of 2168.17Ým which characteristically placed the studied area in a sedimentary basin with the presence of clay- sandstone intercalation. The low apparent resistivity values between 273.93 Ým to 979.64 Ým were obtained alternately with high apparent resistivity values along all the profiles investigated and were also obtained where there were major cracks, accentuated by water ingress. Geotechnically, it was inferred that highly resistive soils, usually at most times correlate with competent zones and the low resistive zones correlate to the incompetent soils. The engineering properties of soils using Weaverôs rippability rating chart (seismic velocity and hardness) of soils, showed that the low resistive soils were incompetent for engineering structures like road pavement etc. The causes of road pavement failure on the studied road was found to be majorly as a result of a combination of clayey topsoil/sub grade soils, water-logged sands due to ingress with characteristically low resistivity values and thin pavement thereby unable to withstand pressure exerted on the road.

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CHAPTER ONE

1.0 INTRODUCTION

The incessant incidence of pavement failure of road structure is becoming alarming and has become a common phenomenon in many parts of Nigeria. These failures have been attributed to a number of factors such as inadequate information about the soil and the incompetence of these subsurface geologic materials. Failures are not limited to any particular geologic setting. Failures have been recorded on crystalline, basement, complex rocks and sedimentary formations.

The state of Nigerian roads had remained poor for a number of reasons. The number one problem is poor quality roads, resulting from faulty designs, lack of gutters and very thin coatings that are easily washed away by floods and hardly withstand heavy traffic. Secondly, funding of road maintenance has been grossly inadequate. From 1999 to 2002 in retrospect, less than 10 per cent of the funding request made by the Federal Ministry of Works and Housing (FMW&H, 2002) for road maintenance was appropriated by the Federal Government of Nigeria (CBN, 2002). Even at this, only about 53.5 per cent of the appropriation was released. These were the collections from tollgates across the country ï N569.29 million, N742.72 million and N779.84 million in 2000, 2001 and 2002 respectively (FMW&H, 2002, CBN, 2002). For each year, tollgates collections alone were much higher than the total funds released for road maintenance. Third is the excessive use of the road network, given the undeveloped state of waterways and the poor state of the railways, which are alternative transport modes. In particular, the railways serve the purpose of transporting bulky goods, which are not good for road haulage. Fourth, information from the Chief Highway Engineers in Nigeria showed that there is no articulated programme for road maintenance. (Federal Ministry of Works and

Housing, 2002; CBN. 2002). Road maintenance decisions are taken at the headquarters and are in most cases influenced by politics and not necessarily on the actual maintenance needs. For this reason most of the roads have been neglected.

1.1 ROAD DEVELOPMENT IN NIGERIA

The Government of Nigeria is committed to improve road network within the country and this venture is laudable since to a great extent, it will enhance her economic development. Recent years have seen a major development in the infrastructure of this area, including several new roads linking the towns and villages. The road network is currently estimated at about 194,000 kilometers, with the Federal Government being responsible for about 17 percent, State Governments 16 percent and local Governments 67 percent (FMW&H). This has led to a situation, whereby for a variety of reasons, roads were constructed in areas with a history of surface and subsurface geological degradation. In spite of various rehabilitation efforts, several segments of our highways fail perpetually soon after commissioning. Such rehabilitation has become an annual ritual and a big financial burden on various tiers of Government (Adiat et al. 2009). This has resulted in the need for reparations and the use of remedial measures to ensure the usability of the transportation network (Hadjigeorgiou, 2006).

As more roads are envisaged in the near future, it is necessary to learn from past failures so as to avoid repeated problems in the future, resulting in a waste of the limited economic resources (Onita, 1985). Some huge amount of money allocated towards rehabilitating and maintenance of roads throughout the country which were over laid with asphaltic concrete in order to increase their strength could have been reduced if adequate geological and geophysical advice were sought prior to the construction of these roads. It is a problem that every right thinking person should be concerned about, since the large sum of money spent on road repairs could have been injected into other vital sector of the economy (Aigbedion, 2007).

If this must be achieved, sufficient technological, geophysical and environmental data on the causes of road failures must be provided for both, in the maintenance of these roads and the construction of other roads on similar soils. The need for pre-foundation studies has therefore become very imperative so as to prevent loss of valuable lives and properties that always accompany such failure. Foundation studies usually provide subsurface information that normally assists civil engineers and geologists in the design of foundations of civil engineering structures (Akintorinwa and Adeusi, 2009).

1.2 DEFINITION OF ROAD PAVEMENT FAILURES

Road pavement failure can be defined as a discontinuity in a road network resulting from cracks, potholes, bulges and depression. A road network is supposed to be a continuous stretch of asphalt layer for a smooth ride. Visible cracks, potholes and depressions generally regarded as road failure may punctuate such smooth ride (Rahaman 1976, Aigbedion 2007). Flexible highway (i.e. good and well developed interconnectivity of roads) aids easy and smoothôs vehicular movement, and have been very useful for transportation of people, goods and services from one point to another, especially in developing countries where other means of transportation such as rail, underground tube, air, and water transportation systems have remained largely undeveloped. However, bad portions of road, many of which result from poor construction or being founded on incompetent sub-grade and sub-base materials had been found to do more harm than good. They have been responsible for many fatal accidents, wearing down of vehicles and waste of valuable time during traffic jams (Osinowo, 2011). The various types of road failure identified in the study area (see plate 1, plate 2), include failure of the black top surfacing, pitting or minor dent, shear or massive failure (pot-holes) extending through the pavement, and occasionally to the subgrade etc. (Plate 1) (Osinowo, 2011).

PLATE 1: (A) Failed section of Opoji old road along Opoji ï Irrua road (B) Pavement surface removal after rehabilitation along Uhiele ï Opoji road (C) Zoomed section showing very thin coating of the pavement surface (D) Longitudinal view of Uhiele ï Opoji road with very thin surface coating.

1.3 INSTABILITY OF UNDERGROUND

Recent studies in the area show that the physically obvious road failures witnessed in almost all roads in this terrain are not only as a result of factors like drainage and quality of materials used for construction alone, but also as a result of instability in the underground geology as well as sub standard materials used in pavement construction (Aigbedion 2007).

1.4 MINERALOGY OF SUBBASE

Geological factors are rarely considered as precipitators of road failure even though the highway pavement is founded on the geology. (Momoh et al., 2008, Ozegin et al., 2011). Some sections of major roads failed because their soil properties were not thoroughly investigated at the initial state. In fact, little or no consideration was given to the effect of clay mineralogy and the associated engineering soil behaviour, as highway foundation materials. The bearing capacity of rocks in relation to traffic is one the essential parameters to be reckoned with, in road construction projects. Some major Nigerian highways are known to fail shortly after construction and well before their design ages.

PLATE 2: Major Highways failing before their design age within the state. (A) A Federal highway route in the country (B) and (C) Roads collapsing due to lack of proper drainage system within the state in Benin metropolis (D) Benin ï Ore road (2010) (Wednesday, 13 July 2011, Nigerian Compass)

1.5 LACK OF ADEQUATE GEOPHYSICAL SURVEY

The factors responsible for road failures are traceable to lack of adequate geophysical survey before commencement. Such preliminary studies are capable of delineating structures such as unconsolidated soil formations with varying resistivity and conductivity (Sikdar, et al, 1999; Praveen, and Ankit, 2010). They can also detect naturally occurring underground water channels which may expedite weathering and surface deformation. A number of important engineering problems which include dams, reservoirs, huge and heavy constructions that can cause road failure have been identified in which geophysical methods find extensive application (Aigbedion, 2007), since geophysics offers a unique window into the earth as a means of detecting subsurface conditions in which its relevance lies in the concrete and cost effective benefits it delivers.

Several factors are considered during investigation for road failures, which include geological, geomorphological, geotechnical, road usage, construction practices, and maintenance (Adegoke, et al, 1980; Ajayi, 1987, Adiat et al. 2009). Field observations and laboratory experiments carried out by Adegoke, et al, (1980), Mesida (1981), and Ajayi (1987), Adiat et al. (2009), showed that road failures are not primarily due to usage or design construction problems alone but can equally arise from inadequate knowledge of the characteristics and behavior of residual soils on which the roads are built and non-recognition of the influence of geology and geomorphology during the design and construction phases.

1.6 INTEGRITY OF GEOPHYSICAL SURVEY

For the past two decades, geophysics has proved quite relevant in road and site investigations and several of these engineering and geological problems have been successfully solved by geophysical methods (Nelson and Haigh, 1990, Adiat et al. 2009). The integrity of near surface geophysical investigation methods to complement geotechnical studies in some foundation engineering problems cannot be overemphasized (Osinowo et al. 2011).

The non recognition of this fact has led to loss of integrity of many highway routes and other engineering structures across the country as observed by (Olorunfemi et al., 2000 a, b, Ozegin et al., 2011). This research therefore tries to use Electrical Resistivity Imaging surveying method to study the causes of consistent failure of Uhiele-Opoji road. It involves a longitudinal probe of the failed, fairly stable, and stable portion of the road as well as perpendicular probe using a two dimensional (2D) imaging profile, in order to characterize the near surface geologic materials that constitute the sub-grade, sub-base and the foundation upon which the pavement was founded.

1.7 SAND AND SANDSTONES AS ROAD BUILDING MATERIALS

Soil is formed by the process of óWeatheringô of rocks, that is, disintegration and decomposition of rocks and minerals, at or near the earthôs surface through the actions of natural or mechanical and chemical agents into smaller and smaller grains. Sand is an important economic resource. The uses of sand are many. In some purposes, sand is used an abrasive to clean a skillet or mess kit. Other uses require a particular kind and quality of sand (Broswell, 1989). Sands are sources of silica for making sodium silicate, for manufacturing carborundum, for silica brick, for the manufacture of both common and optical glass. Sand is an ingredient in plaster, in concrete, in addition to clay to reduce shrinkage and cracking in brick manufacture and then is mixed with asphalt to make road dressing. It is used in foundries as moulding and parting sand, and it is used as an abrasive sand paper and sand blast. Sands are exploited for rare minerals and rare elements, which they contain. Some are gold bearing, others contains gem, platinum uranium etc. Sandstones are used for building, stone construction as flagstone and if crushed as road fill, road metal and railroad ballast. There are three basic types of sand materials used for construction of roads: gravel, sand, and fines (listed in order from largest to smallest particle size). Gravel and sand particles, coarse material, are readily distinguishable to the naked eye. Fines (silts and clays) are generally comprised of particles too small for the eye to see. Each soil material has specific properties that make it useful for different aspects of road building. Coarse material provides strength and has large voids between the particles that provide good drainage. Fines fill the voids between the coarse material particles holding them together, and on the road surface, decrease infiltration of water into the road. An ideal road bed should have two layers; a base layer that provides strength and is free draining and a surface layer that is strong and dense, shedding rainfall and preventing it from infiltrating into the bed. When selecting road bed material, it is important to have a range of different sizes of gravel and sand so that the particles ñlockò together. This is called well-graded. If they are all the same in size, they are more apt to move around, causing a rut.

1.8 ROADBED CLAY

Clays are very small-grained hydrous aluminosilicate with the phyllosilicate structure. Clays are classified as hydrosilicate, which means that they are formed from the chemical decomposition of pre-existing silicate minerals. Most clays result from the product of weathering and sedimentation, but they are also formed by hydrothermal activities. Clays can occur as part of a soil structure or as independent layers and lenses. They are also commonly found in glacial till, where glacial action has ground the rocks and boulders into fine particles. Clay particle sizes range from 0.002 mm to 0.001 mm diameter for quartz, feldspar, mica, iron, and aluminum oxides. The finer parts (less than 0.001 mm in diameter) are colloidal and consist mainly of layer silicates with smaller amounts of iron and aluminum oxides. Two basic parameters can be used to estimate the clay content of soils and other geologic layers. These are electrical conductivity and membrane polarization.

The resistivity of soils and rocks vary from 1 ï 30,000 ohm-m. Thus, the appropriate geophysical methods are conductivity measurements (or resistivity) and Induced Polarization, measuring the membrane for some clays and shaleśs to over 1,000 ohm-m for limestone, intrusive rocks such as granites, and some metamorphic rocks. However, in sedimentary soils and rocks, where resistivity generally ranges from 10 to 1000 ohm-m, resistivity is also significantly influenced by the porosity and salinity of the water in the pore space. In order to estimate clay content, the resistivity/conductivity of the layer/zone of interest has first to be determined. Then a relationship is needed to convert the conductivity to clay content. However, as mentioned previously, conductivity is strongly influenced by porosity and the salinity of the pore water, thus making the conversion from conductivity to clay content tenuous. It is possible that the Induced Polarization method may be more successful since it is less influenced by the resistivity of the material. However, the method needs more research before production surveys are undertaken.

Clays can swell as well as have low shear strength. Swelling is usually caused by moisture within the clay. Fine grained material such as clay can hold a significant amount of water. Moisture can be acquired from surface runoff or can be drawn from material beneath them because of the small pore size in clays and the resulting strong capillary forces. Shear strength of clays are significantly influenced by moisture content, decreasing with increased moisture. Furthermore, clays with high swelling potentials are susceptible to extreme volume changes as moisture content changes. The economical importance is that roads constructed over areas of soft clay will result in poorly performing pavement systems and often result in a sub-grade failure.

Sub-grade failure may be visibly observed as pavement deformations over problem areas. Cation Exchange Capacities of some common clay types are presented in Table below.

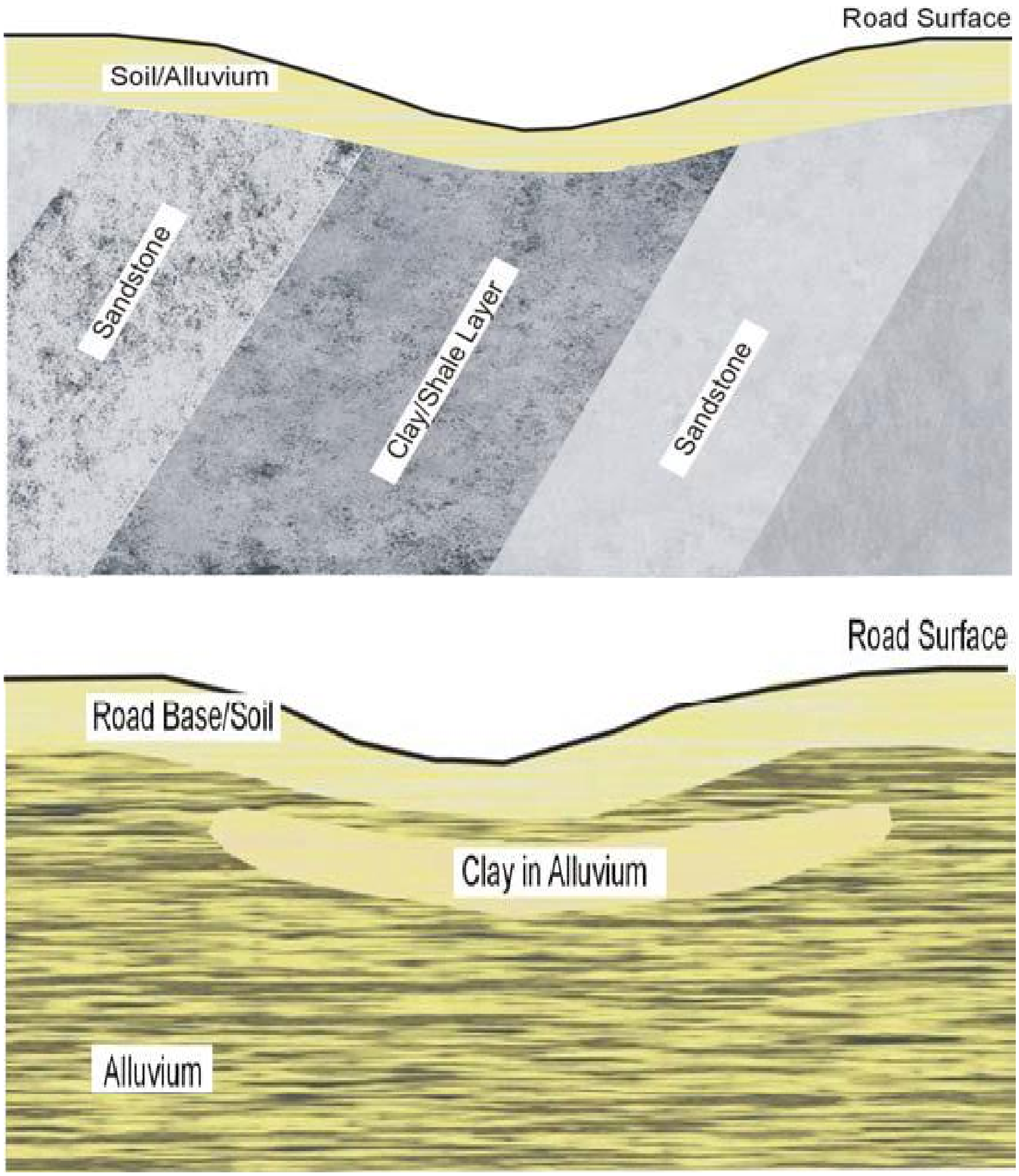

PLATE 3: Volume changes of clay beneath road pavement

TABLE 1: CATION EXCHANGE CAPACITIES (CEC) OF COMMON CLAY TYPES.

Clay type	Cation Exchange Capacity
Kaolinite	3 -15
Chlorite	10 -40
Illite	10 -40
Montmorillonite	80 -150
Vermiculite	100 -150

It was observed that majority of roads have failed because clay was used as construction materials (Aigbedion 2007). Also, studies have shown that the area contain near surface low resistivity geologic materials which are highly favourable to road failures (Ozegin et al. 2011). These zones are structurally weak, as a result of fractures, favorably disposed to groundwater seepage and accumulation, thus making them low resistivity zones, with great potential for pavement failure (Osueni, 2009).

1.9 DRAINAGE

Drainage system is another important factor that is responsible for road or pavement failure in Nigeria. Surface drainage is collection of rain water from the surface of the road to side drains or to lower sides in open terrain. This is possible if the road have sufficient cross slope about 2%, and free from depressions, potholes and cracks otherwise water will enter into the road structure. Subsurface drainage is the collection of that water that has entered into the road structure. This internal drainage function of a road pavement is usually performed by the GSB (Granular Sub Base, consisting gravel and sand mixed in defined proportion) layer. This layer itself must be drained in some way in order to keep the water-table low, to prevent the moisture content of the subgrade from increasing through capillary action, and hence decreasing the subgrade strength. Strength of soils decreases with increase in moisture content.

To keep the moisture content low, proper drainage of subgrade and sealing of the crust (to stop ingress of water) is a must. Also the road pavement itself must be constructed so that it will drain in the event of a failure of the integrity of the surfacing layers, i.e. if water is able to enter the road pavement there must be a path for it to exit. Once water has entered a road pavement, water damage is initially caused by hydraulic pressure, i.e. vehicles passing over the road pavement pass on considerable sudden pressure on the water present in the road pavement, this pressure forces the water further into the road structure and breaks it up. This process can be very rapid once it begins. Sooner or later the water will descend to the subgrade layer below the road pavement and weaken this layer thus lowering the strength of the subgrade, and complex failure of the road will begin. Road pavements have failed for various reasons due to poor drainage, caused either by:-

a) Inadequate drainage provision in the original road pavement design,
b) Lack of maintenance of the drainage so that it no longer functions in a correct manner.
c) Rise in water table thus weakening the road pavement,
d) Failure of the impervious nature of the surface course such as thin layers of premix carpet without proper sealing coat, cracks and potholes and undulations causing pooling, thus allowing the passage of surface water in to the road pavement matrix.

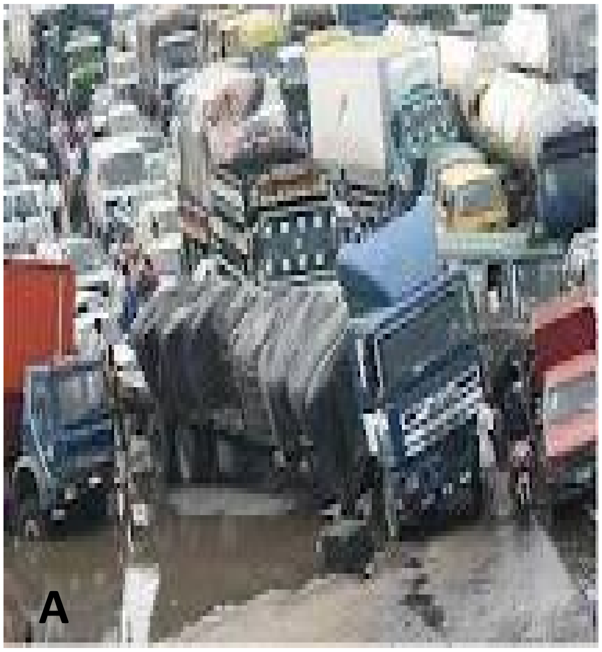

PLATE 4: Roads with Poor Drainage Systems along Nigerian highways.

(A) Benin ï Ore road congested with traffic due to bad sections of the road

(B) Road flooded due to poor drainage system along the road in Benin metropolis.

1.11 STUDY AREA DESCRIPTION

1.11.1 LOCATION

The road investigated, exists within Ekpoma and Irrua towns in Esan West and Central respectively in Edo state. The road serves as a link between the University town of Ekpoma and the major high way leading to the Eastern part of Nigeria. The old road linking Irrua and Opoji joins the Ekpoma ï Uhiele road at Ugbegun leading to the Eastern part of the country. At the time of study, these roads are undergoing some major cracks, potholes, rippling and depressions which will in turn lead to a major road failure.

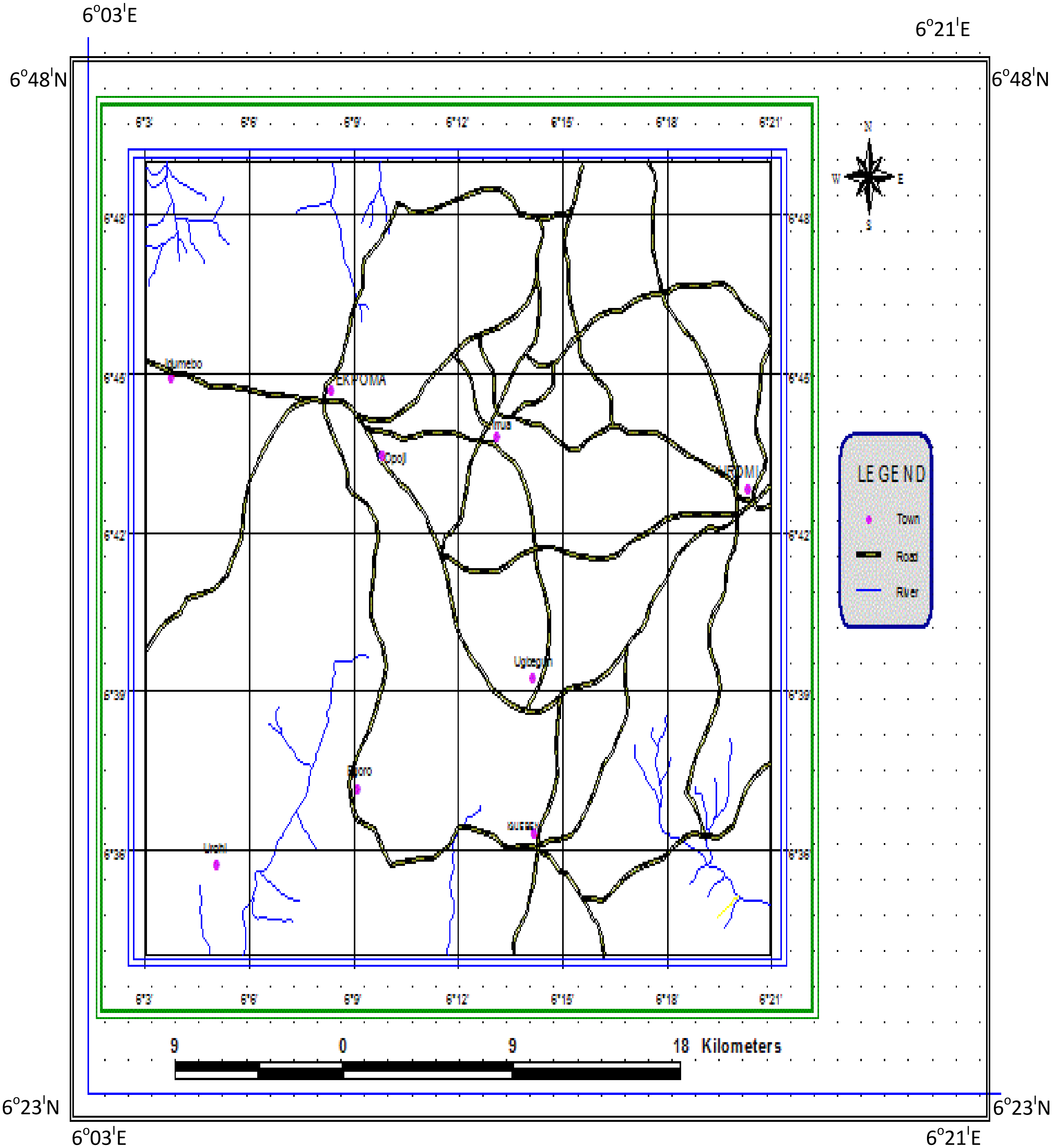

FIGURE 1: ACCESSIBILITY MAP OF STUDY AREA

1.11.2 PHYSIOGRAPHY AND CLIMATE

The study area, which is Uhiele ï Opoji main road in the central part of Edo state, south-south Nigeria, is situated on a gently undulating terrain with elevation between 296m and 335m above the main sea level on latitude 6^0 41′N, longitude 6^0 10′E (Uhiele), latitude 6^0 42′N, longitude 6^0 11′E (Opoji), and latitude 6^0 43′N, longitude 6^0 17′E (Irrua). The areas lie in a region where typical characteristics of the tropical rain forest are displayed; multitude of evergreen trees, climbing plants, parasitic plants that live on other plants and creepers. Two main seasons exist in the area, the dry season which lasts from November to March and the rainy season which begins in April and ends in October with a short period of reduced rains in August commonly referred to as ñAugust breakò. Temperature in the dry season ranges from 20°C to 38°C, and results in high evapotranspiration, while during the rainy season temperature ranges from 16°C to 28°C, with generally lower evapotranspiration. It has a mean annual rainfall of about 1400mm and the annual mean temperature is between 25^0C and 30^0C. These climatic conditions are responsible for the development of thick lateritic soils in the area, due to transportation and sedimentation of soil particles resulting from weathering.

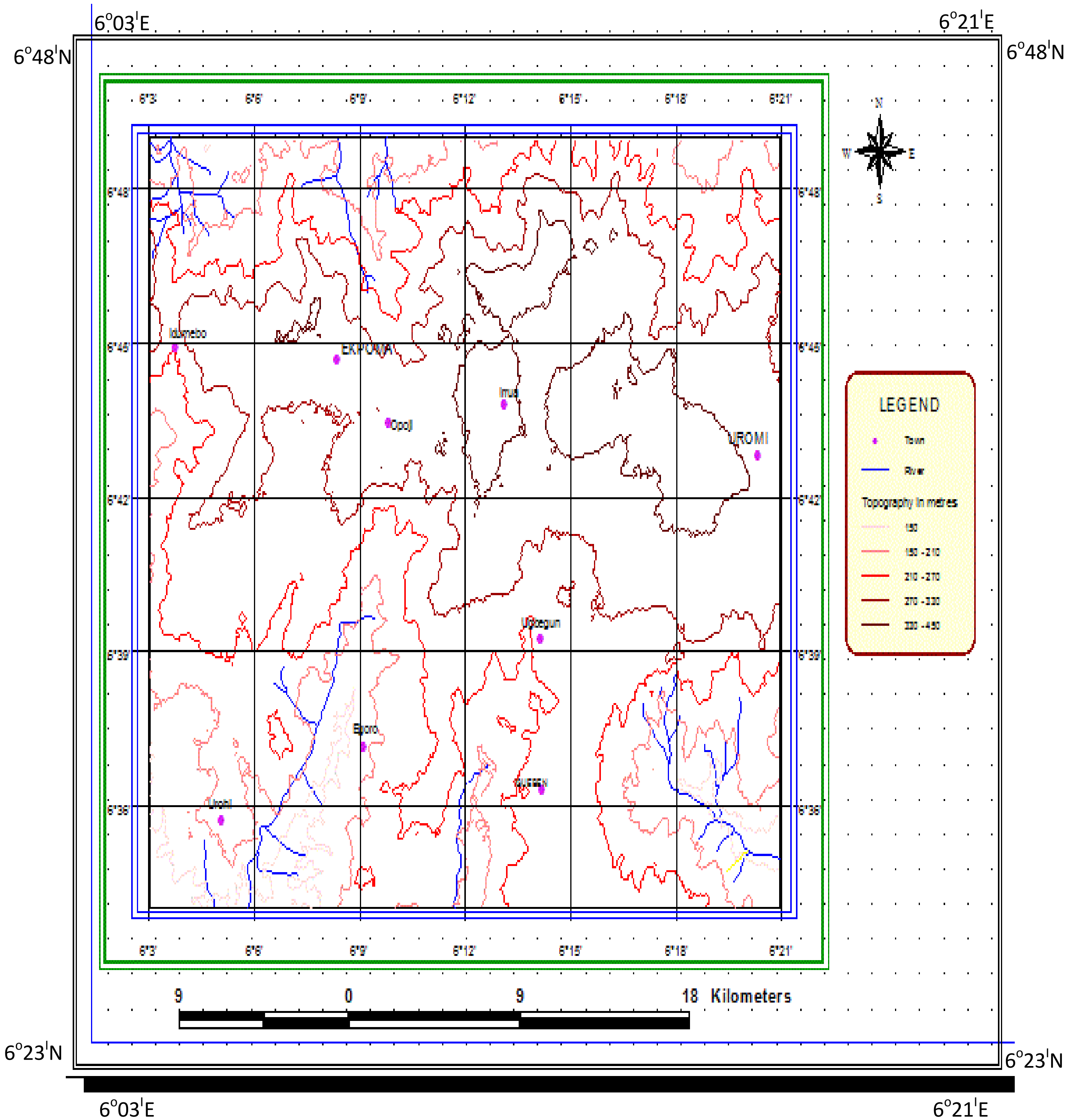

FIGURE 2: TOPOGRAPHICAL MAP OF STUDY AREA

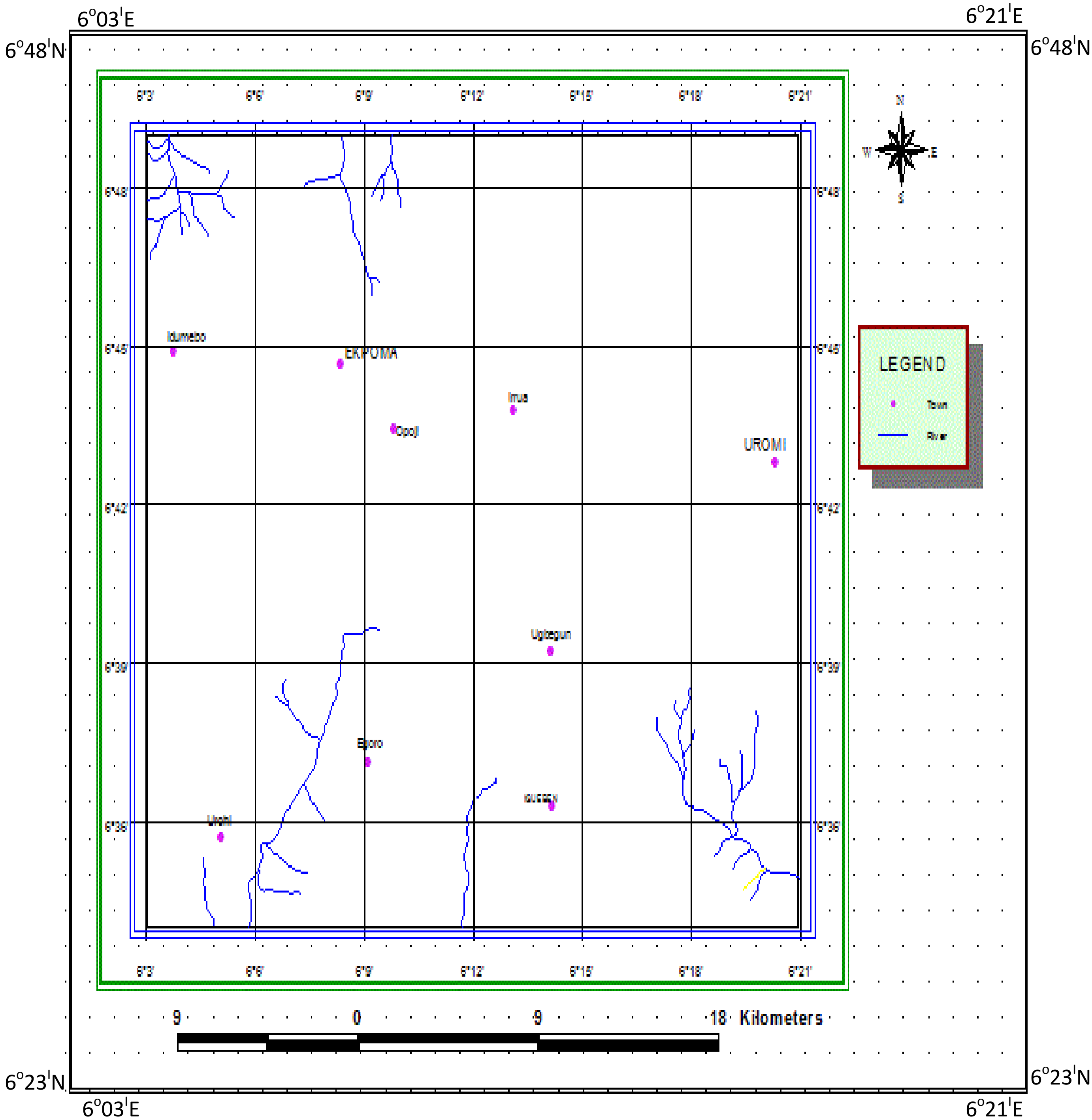

FIGURE 3: DRAINAGE MAP OF STUDY AREA

1.12 GEOLOGY OF STUDY AREA

The Niger Delta in Southern Nigeria has been prograding outward to the Atlantic Ocean since late Cretaceous times and is in-filled with Tertiary and Quaternary sediments which decrease in age progressively southwards. The deposit comprise (figure 4) from north-east to south-west, the Imo shale. A unit of Paleocene to Eocene (lower Tertiary) is the blue gray shale with thin sandstones and limestone. The Eocene to Oligocene is the Ameki Formation, comprising clays, sandstones and limestone. Oligocene to Miocene clays, comprises sands and grits with occasional lignite (carbonaceous deposits) of the Ogwashi-Asaba Formation. The Miocene to Pilocene, Benin Formation is composed of coasted-plain sands and pebbly sands with clay lenses and lignite. These sediments were deposited in a variety of environments from marine, through deltaic, estuarine and coastal swamp to lagoon and fluvial. In all, the sediments pile reaches a thickness of around 12,000m (Osueni 2009).

The study area is geologically characterized by deposits, laid during the Tertiary and Cretaceous periods on the South Western extension of the Niger Delta Basin, (Reyment, 1965). The various formations in the geology of Edo State are the Benin, Bende Ameki, Ogwashi-Asaba, Imo, Nsukka Formation and the various Quaternary Deposits. In this study the entire investigated area is underlain by sedimentary rocks of the Niger Delta Basin of southern Nigeria, (Precambrian basement complex of southern Nigeria) with about 90% of sandstone and shale intercalation. It has coarse grained to locally fine grained in some area, poorly sorted, sub-angular to well rounded, which bears lignite streaks and fragments (Figure 5) (Kogbe, 1976). The type of granite mostly found in the area of study is gneiss consisting of feldspar, mica and quartz as dominant minerals. Its origin and evolution have been discussed by several workers including Hospers (1965), Burke et al. (1972) and Nwachukwu (1972). The origin is believed to be linked to a series of tectonic activities that occurred in the south Atlantic region during the late Cretaceous times (Murat, 1972). The Sediments penetrated by the Gbakebo ñBò well located at Okitipupa Ridge on the western flank of Niger Delta form part of the late Cretaceous and Tertiary sequences of the southern Nigerian Basin (Kogbe, 1976). Deposition of sediments in the Niger Delta Basin began in the Tertiary and continued into post Tertiary times. The Niger Delta sediments include Benin, Agbada and Akata Formations and they range in age from Eocene to Recent (Short and Stauble, 1967; Asseez, 1976). The Agbada Formation is a down-dip continuation of Eocene-Miocene Ameki and Ogwashi-Asaba Formations, while the Akata Formation is a down-dip continuation of Paleocene- Imo Formation (Frankland Cordy, 1967). The geology of the study area is characterized by deposits laid during the Tertiary and Cretaceous periods. The area is underlain by sedimentary rocks constituting part of the formation which is made up of over 90% massive, porous, coarse sand with clay/shale inter-beds having high ground water retention capacity. Soil particles vary from coarse grained to fine grained is some areas, poorly sorted, sub-angular to well rounded particles with lignite fragments.

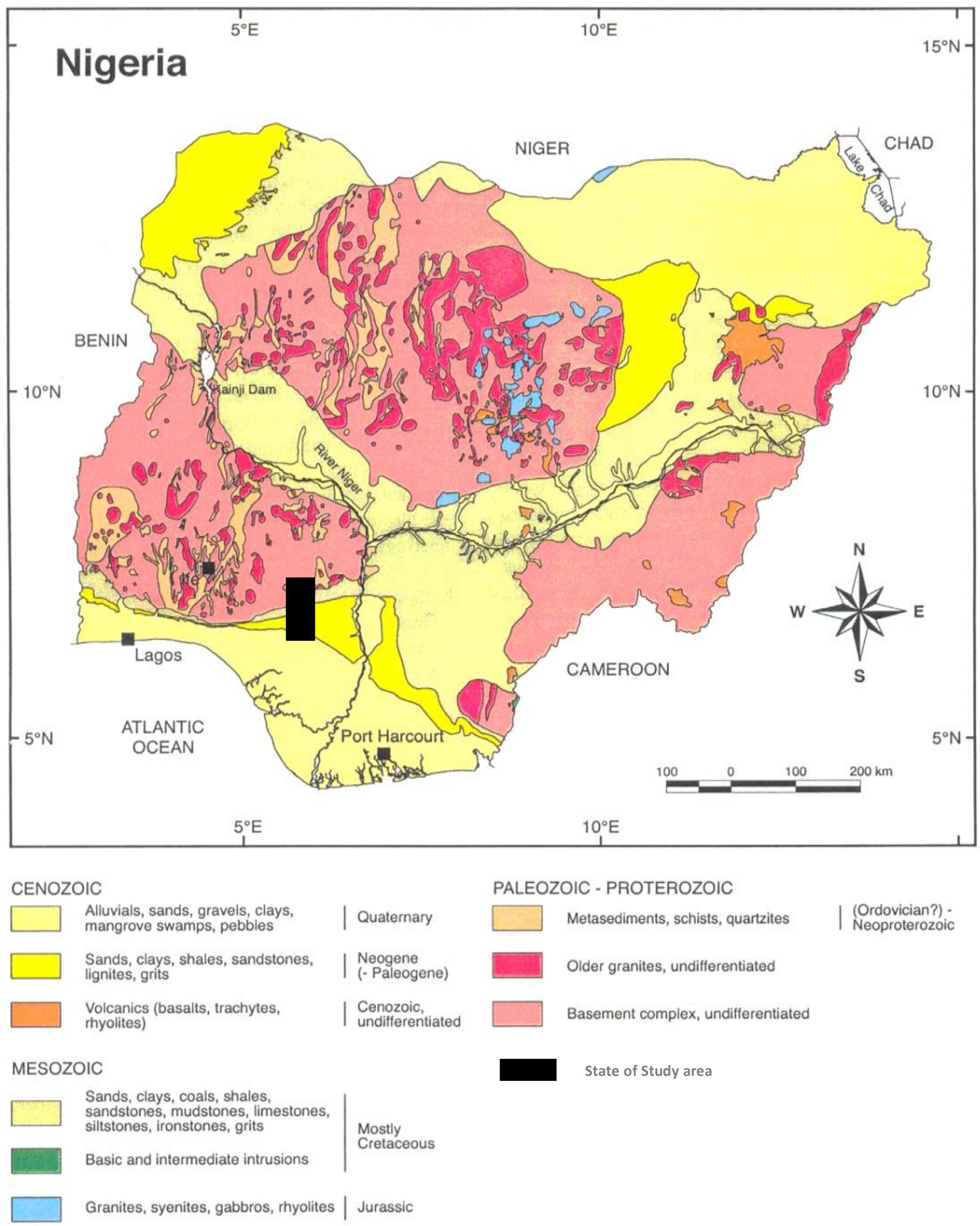

FIGURE 4: GEOLOGICAL MAP OF NIGERIA SHOWING THE STATE OF STUDY AREA.

Agwae, (2011)

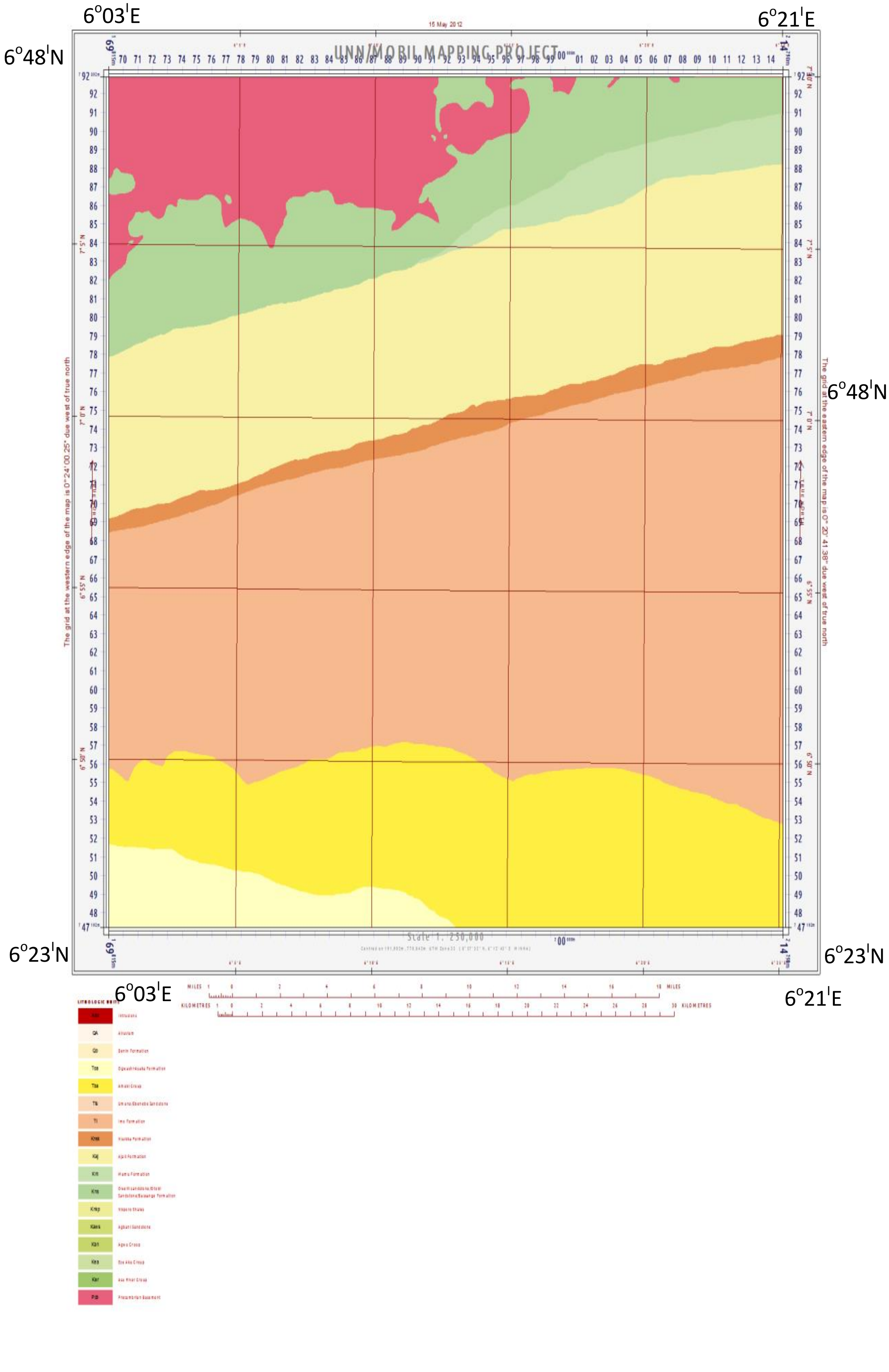
6°03'E
6°21'E
6°48'N
6°23'N
6°03'E
6°21'E
6°48'N
6°23'N
15 May 2012
UNN/MOBIL MAPPING PROJECT
The grid at the western edge of the map is 0°24'00.25" due west of true north
The grid at the eastern edge of the map is 0° 20' 41.38" due west of true north
Scale 1: 250,000
MILES
KILOMETRES
LITHOLOGIC UNITS
Intrusions
Alluvium
Benin Formation
Amaki Group
Imo Formation
Nsukka Formation
Ajali Formation
Mamu Formation
Precambrian Basement

FIGURE 5: ENLARGED GEOLOGICAL MAP OF STUDY AREA (An extract from the geological map of Nigeria, Department of Geology). The geological map of the study area shows part of the Precambrian basement complex of Southern Nigeria (pink) prograding through Mamu Formation (light green), Ajali Formation (off green), Nsukka Formation (brown), Umanu Formation (whitish brown), Ameki Formation (yellow), and Ogwashukwu Formation (whitish yellow) advancing downwards as a result of accumulation of sediments. The study area formation falls within the Ameki and Ogwashukwu formations.

1.13 STATEMENT OF THE PROBLEM

The roads to be investigated serve as a link between the University town of Ekpoma and the major high way leading to the Eastern part of Nigeria. The occupation of the people living in this part of the town is predominantly farming. The failures of these roads have generated a lot of problems of which a few are listed below;

i. Farm produce from these communities hardly get to the outside market as a result of bad road network.
ii. Commercial road users have totally neglected these roads due to major failure of some parts of the roads. They make use of more distant routes at the expense of the passengers.
iii. Criminals have taken a great deal of advantage of these failed portions to perpetrate their unwholesome acts by waylaying people when they slow down.

1.14 PURPOSE OF STUDY

This project work is prompted by lack of data on the geotechnical and geological properties of the subsoil in the study area. The objective of this project is to appreciate geophysical investigation in identifying weak and competent (that is, conductive and resistive) zones. Geologic factors such as bedrock, subsurface features, like faults, fractures, depressions and joints that are responsible for these incessant road failures even after rehabilitation. This study expects to correlate geophysical results with geotechnical standards to ascertain the causes of road failures within the project site. The result will aid road construction and maintenance on similar soils by engineers, planners, designers and contractors in the future.

This practice is common in developed countries where roads are constructed with detailed information from geophysical investigation of the construction site. This ensures design stability, economical construction, maintenance free roads. Such geophysical investigations provide full details of the area topography, lithological characteristics of the soil or rock and groundwater conditions in that particular construction site. The roads investigated in this study have protracted failure characteristics such as potholes, cracks, depressions and water percolated channels. These failure potentials become incessant despite inadequate previous rehabilitation programs.

CHAPTER TWO

2.0 GEOPHYSICAL METHODS

Geophysical methods provide information about the physical properties of the earthôs subsurface. There are two general types of method: the active, which measures the subsurface response to electromagnetic, electrical and seismic energy; and a passive, one which measures the earth's ambient magnetic, electrical, and gravitational fields. Information provided by these methods can be applied to sites with undesired or buried objects, to determine other geologic and hydrogeologic conditions, of the subsurface. Geophysical methods can also be subdivided into either surface or borehole methods. Geophysical methods have been used for nearly 70 years, although predominantly in the exploration for natural resources. Oil, gas and mineral exploration demanded better technologies to locate and define highly needed natural resources before and during World War II. Since the 1950s, the use of geophysics in the natural resource exploration industry has increased to the point that it is used as the first level effort on every project. Drilling and other physical means of defining the geologic setting, composition, and depth of interest are used after imaging the subsurface. The use of geophysics among construction companies and transportation agencies varies widely depending on the knowledge of the individuals and the combined experiences of the agencies. Over the past decade there has been an increased effort on the part of the engineering geophysical community to provide technologies that aid the design and construction needs of transportation projects.

In the most generalized sense, geophysics is the application of physical principles to define geology and study geomaterials; for example, soil or rock (Greenhouse and Pehme, 2001; National Cooperative Highway Research Program, NCHRP, 2006). We designate the study of the earth using physical measurements at the surface as geophysics. Geology involves the study of the earth by direct observations on [soils and] rocks, either from surface exposure or boreholes, and the deduction of its structure, composition, or history by analysis of such observations. Geophysics, on the other hand, involves the study of those parts of the earth hidden from direct view by measuring their physical properties with appropriate instruments, usually on the surface. It also includes interpretation of the measurements to obtain useful information on the structure and composition of the concealed zones (Dobrin 1976).

Whether active method or passive method geophysics affords the opportunity to cost-effectively sample large volumes of the subsurface using such principles as seismic or electromagnetic (EM) wave transmission, electrical current flow, magnetic and gravity potential fields. The science is technical in its application, and is quantitative in its measurement, yet it provides only the qualitative information about geomaterial properties needed by engineers. For example, it does not directly measure density, moisture content, or stiffness, but provides a relationship between a measured value (e.g., seismic velocity) and the physical parameter that governs it (e.g., density). It is the complement of using a broad view of the subsurface imaged from a geophysical investigation and data directly obtained from drilling that creates the value and benefit of this technology. Those responsible for design and construction on sites that pose significant risk to society require the most advanced technologies to better characterize the distribution of physical properties in the subsurface. The purpose of using geophysics, as defined for this study, is to identify and characterize physical properties of subsurface geomaterials in a manner that benefits highway projects and transportation programs. These benefits can be associated with reduced project costs, better and broader subsurface characterization, increased speed of acquisition, and utilizing a noninvasive approach to evaluate subsurface conditions.

Over the past 10 years the increased need to reduce risk for the design and construction of engineered structures has dictated better instrumentation and data processing software, as well as added educational opportunities, to effectively make geophysical technologies available. Environmental and Engineering Geophysical Society [EEGS], and its members have worked to educate end-users on the correct application of geophysics.

The passive geophysical method also called non-contacting techniques such as ground conductivity, magnetometry, and gravity surveying. They are important in profiling, electrical resistivity traversing and sounding. Here the objective is to determine the boundaries between the different beds of soil or rock, in order either to correlate among boreholes or to infill between them. Techniques used for subsurface investigation include electrical resistivity, depth sounding methods and geophysical borehole logging. Sectioning is carried out to provide cross-sections of the ground, generally to give details of beds and layers. It is potentially useful when there are marked contrasts in the properties of the ground (as between the stiffness and strength of clay and rock), and the investigation is targeted at finding the position of a geometrically complex interface, or when there is a need to find hard inclusions or cavities. In addition, as with vertical profiling, these techniques can allow extrapolation of borehole data to areas of the site which have not been the subject of borehole investigation. Examples of such techniques are seismic tomography, ground probing radar, and seismic reflection. One of the major needs of any ground investigation is the classification of the subsoil into groups with similar geotechnical characteristics. Geophysical techniques are not generally of great use in this respect, except in limited circumstances. An example occurs where there is a need to distinguish between cohesive and non-cohesive soils. Provided that the salinity of the groundwater is low, it is normally possible to distinguish between these two groups of materials using either electrical resistivity or ground conductivity.

Finally, almost all geotechnical ground investigations aim to determine stiffness, strength, and other parameters in order to allow design calculations to be carried out. Traditionally, geotechnical engineers felt that the determination of geotechnical parameters from geophysical tests was impossible. The acceptance, within the last decade or so, that the small strain stiffness relevant to the design of civil engineering and building works may, in many circumstances be quite similar to the very small strain stiffness that can be determined from seismic and resistivity contrast methods has led to a worldwide reawakening of interest in this type of method. This section provides an overview to some common geophysical methods that are used during investigation of road failures and subsurface investigations generally.

Geophysical methods such as the Electrical Resistivity (ER), Seismic Refraction, Electromagnetic (EM), Magnetic and Ground Penetrating Radar are used singly or in combinations for engineering site investigation. The applications of such geophysical investigation were a determination of depth to bedrock, structural mapping and evaluation of subsoil competence.

2.1 THE PRINCIPLE OF ELCETROMAGNETIC METHOD

Electromagnetic method is one of the geophysical methods commonly used in foundation investigation and environmental studies (Olorunfemi & Mesida, 1987; Sharma, 1997; Osinowo et al 2011). The principle is based on induction of a secondary magnetic field (Hs) in the subsurface conductor of conductivity (ů) due to effect of an artificially generated primary field (Hp). Electromagnetic measurements are usually presented as the mutual impedance ratio Z/Zo or charge in the impedance over a conductor which has ability to provide clear information about the subsurface conductivity and structure. Electromagnetic (EM) methods, also referred to as electromagnetic induction methods, are some of the most diverse and useful geophysical techniques. Although they are commonly subject to cultural interferences, they can:

I. Locate buried objects (metal and non-metal);

II. Obtain geologic and hydrogeologic information; and

III. On rare occasions, delineate residual and floating product.

Electromagnetic methods refer to the measurement of subsurface conductivities by low frequency electromagnetic induction. A transmitter coil radiates an electromagnetic field which induces eddy currents in the subsurface. The eddy currents, in turn, induce a secondary electromagnetic field. The secondary field is then intercepted by a receiver coil. The voltage measured in the receiver coil is related to the subsurface conductivity. These conductivity readings can then be related to subsurface conditions. The conductivity of geologic materials is highly dependent upon the water content and the concentration of dissolved electrolytes. Clays and silts typically exhibit higher conductivity values because they contain a relatively large number of ions. Sands and gravels typically have fewer free ions in a saturated environment and, therefore, have lower conductivities. Metal objects, such as steel, display very high conductivity measurements which provide an indication of their presence. Passing alternating current through long wires or coils normally generates the primary or source fields used in electromagnetic prospecting. For simple geometric configurations, the resultant fields can be calculated exactly for points in the surrounding region, although this is not generally possible. Furthermore, it is essential to know the primary field at the receiver, or at least to eliminate its effect because it is always present, along with secondary fields due to currents induced in the subsurface. Consequently, one must measure the disturbing field in the presence of the original primary field. The EM receiver and transmitter coils can be configured in many different ways, depending on the objectives of the survey. One common configuration for shallow environmental investigations utilizes transmitter and receiver coils that are attached to the ends of a rigid fiberglass rod at a fixed distance (*i.e.*, fixed-coil separation). The equipment is then moved across the area of investigation.

2.1.1 THEORETICAL CONSIDERATIONS

As the name implies, Electromagnetic method makes use of a response of the ground to the propagation of electromagnetic fields which are composed of an alternating electric intensity and magnetizing force. There is a close analogy between the transmitter, receiver and buried conductor in the electromagnetic field situation, and a trio of electric circuits coupled by electromagnetic induction. The electromagnetic ground method was developed in regions where the detection of conductive base metal deposits was facilitated by their large contrast with the resistive host rock and generally thin overburden. Practically, all electromagnetic equipment transmits and receives continuously, one frequency at a time. Such a continuous wave system is said to be operating in the frequency domain (FDEM), (Telford et al., 2004). Almost all electromagnetic fields equipments include a portable power source. However, limited use, have also been made of radio transmission stations in the frequency range of about 10 KHz to 100 KHz and recently in the very low frequency range 5 to 25 KHz. One other field method that can be reasonably applied with electromagnetic method, is the AFMAG (audio-frequency magnetic fields), which makes use of atmospheric energy resulting from worldwide thunder storm.

An advantage of the inductive coupling is that it permits the use of electromagnetic systems in aircrafts. Airborne electromagnetic method, usually in combination with aeromagnetic equipments, has been widely used in mineral exploration reconnaissance and recent surveys.

2.1.2 LIMITATIONS OF ELECTROMAGNETIC METHOD

The limitations of Electromagnetic methods are primarily a result of the interferences, typically caused when this method is applied within 5 to 20 feet of power lines, buried metal objects (including rebar), radio transmitters, fences, vehicles, or buildings. In addition, its success depends upon subsurface conductivity contrasts. However, mapping more subtle targets, such as fine versus coarse material or contamination, is less predictable. Consequently, pilot studies can be conducted to determine if an adequate conductivity contrast exists for the objective of the study.

2.1.3 VERY LOW FREQUENCY (VLF) – ELECTROMAGNETIC METHOD

VLF-EM method of geophysics utilize Very Low Frequency radio communication signals to determine electrical properties of near-surface soils and shallow bedrock (Mcneill and Labson, 1992). The technique is especially useful for mapping steeply dipping structures such as faults, fracture zones and areas of mineralization. In the reconnaissance mode, VLF profiles can be run quickly and inexpensively to identify anomalous areas which may require further investigation; either with more detailed geophysical measurements and/or drilling and sampling.

VLF can detect long conductors such as electric cables, pipelines, and certain bedrock fractures. The reception is best in the morning, but adequate all day. In order for the VLF method to be effective in detecting underground geologic structures, the structure must have:

1) The direction of its long axis within 30 degrees relative to a line tangent to the concentric rings that "ripple" from the transmitter (to initiate induction);
2) Minimum dimensions of approximately 50 meters in length, 10 meters in depth, and about one meter in thickness;
3) A dip angle not less than 30 degrees from horizontal; and

4) Higher electrical conductivity than the surrounding material.

The receiver for detecting VLF signals measures a tilt and quadrature component by means of two mutually perpendicular coils wound on ferrite cores. The coil whose axis is normally vertical is held in a horizontal position and rotated in azimuth to find a minimum. This direction is in line with the transmitter station and is usually well defined (Telford, 2004). The same coil is first held vertically and tilted about a horizontal axis parallel to the direction of propagation. The second coil is rigidly mounted at right angles to the first. Its signal is shifted in phase by 90^0 and, connected in series with the vertical coil through which signal is fed into the receiver. The amplitude of this signal is adjustable on the quadrature dial, which reads percent plus or minus. A clinometer on the instrument allows tilt angle measurement. By tilt and quadrature adjustments, a good minimum is obtained. (Telford, 2004). VLF is an effective reconnaissance geophysical tool for mapping geoelectric features. It may be used wherever an electrical conductivity contrast is present between geological units. This may include:

ÅFault mapping,

ÅGroundwater investigations,

ÅOverburden mapping,

ÅContaminant mapping,

ÅMineral exploration

Electrically conductive features include fault zones, and zones of mineralization which tend to be more conductive than the surrounding bedrock or host rock. Other conductive geologic units include moist, clayey, or fine grained soils which tend to be more conductive than dry, sandy or course grained soils. Hence, these geologic objectives are reasonable ñtargetsò and can be mapped using electrical or electromagnetic methods. Depth of investigation is controlled by the electrical ñskin depthò of the local geology. It varies from 40-60 meters in highly resistive soils to 4-5 meters in conductive soils. VLF instruments are ñback packò portable and operated by one person. Productivity depends on the terrain and vegetation, but generally several kilometers of line may be covered in a good day. Unlike terrain conductivity, the depth of VLF penetration is not a function of coil spacing, but rather the resistivity of the materials surveyed. Depth of penetration of VLF signals is directly proportional to (varies by approximately four times the square root of) the material's resistivity. For example, VLF signals propagating through granite (a highly resistive material) can penetrate to depths greater than 300 meters. However, a material such as salt water may limit depth of penetration to one to five meters.

2.1.4 VLF – EM APPLICATION

VLF ï EM techniques measure the perturbations in a plain-wave radio signal (15-30 KHz) emanating from the source (Mcneill and Labson, 1992). The primary field (the transmitted radio signal) causes eddy currents to be induced in conductive geologic units or structures. Faradayôs principle of electromagnetic induction tell us that any oscillating magnetic field (e.g., the radio wave) will produce an electric field and hence an electric current in a conductive media. Those eddy currents in turn create a secondary magnetic field which is measured by the VLF receiver. The secondary or perturbed field may be phase shifted and oriented in a different direction than the primary field depending on the shape or geometry of the conductor, the orientation of the conductor, and the conductivity contrast with the surrounding material (e.g., the host rock). The instrument measures both the primary and secondary fields together. All VLF instruments measure two components of the magnetic field or equivalently the ñtilt angleò and ellipticity of the field. Some instruments also measure the third magnetic component and/or the electric field. The electrical field is measured by inserting two probes in the ground, spaced about 5 meters apart, and measuring the potential difference at the transmitter frequency. The electric field provides additional information about the overburden thickness and conductivity. The VLF receiver measures the current density due to the primary (transmitted) and secondary (induced) magnetic fields. From these measurements, structures such as water-saturated fracture zones, metallic ore bodies, mineralized zones, and long conductors such as electric cables or pipelines may be detected. The ability to detect water-filled bedrock fracture zones makes this type of survey method useful for bedrock water supply development and for site investigations that involve bedrock contamination (Mcneill and Labson, 1992).

2.1.5 VLF – ADVANTAGE

The advantages of VLF-EM method are lightweight and inexpensive equipment design, speed of field operation, ease in equipment handling, and low overall operation cost (Paterson and Ronka, 1971). VLF-EM method has proved to be an effective exploration tool for quick mapping of the resistivity, phase and other VLF-EM parameters such as the real and imaginary components of the vertical magnetic field which contain valuable diagnostic information and tilt angle of the near surface features using only 5m of electric dipole. This method can delineate contrast in conductivity at depth and is used in the search for contrast, faults, mineralized bodies, overburden, fractures, and voids for a variety of other purposes, including the location of utility lines and sitting of water wells. In a VLF investigation, the magnetic field components of the transmitted signal are measured, although the electrical field components can also be measured as required.

2.1.6 VLF – DISADVANTAGE

The VLF survey operator has no control over power source - VLF transmitters are sometimes turned off for maintenance. Even when the transmitters are operating, the orientation (both strike and dip) of the object surveyed to the power source (which the operator also has no control over) will affect the success of the survey. VLF data interpretation is difficult - VLF data does not provide data that can be directly related to subsurface conductivity. Interpretation is more subjective and therefore relies heavily on operator experience.

2.1.7 VLF – LIMITATIONS

VLF is used primarily as a reconnaissance tool to identify anomalous areas for further investigation, either with other geophysical methods or drilling. Weaknesses of the method include:

- VLF measurements are sensitive to ñcultural interferenceò from pipelines, utilities, fences, and other linear, conductive objects.
- Interpretation is generally qualitative in nature; quantitative modeling requires a high data density and a well constrained model.
- Topographic effects can bias the data, are difficult to remove, and are model dependent.
- VLF transmitters are subject to outages for scheduled or unscheduled maintenance.
- Unfavorable ionospheric conditions may compromise the quality of the data.
- Susceptibility to surface anthropogenic interferences is extremely reduced in areas that contain shallow material of high conductivity.

2.2 ELECTRICAL SURVEYING METHODS

Electrical surveying involves many methods. Some make use of fields within the Earth while others require the introduction of artificially generated currents into the ground. Examples include

I. Resistivity Method

II. Induced Polarization Method

III. Self Potential (spontaneous polarization) Method

The resistivity method is used in the study of horizontal and vertical discontinuities in the electrical properties of the ground, and also in the detection of three-dimensional bodies of anomalous electrical conductivity. It is routinely used in engineering and hydrogeological investigations to investigate the shallow subsurface geology. The induced polarization method makes use of the capacitive action of the subsurface to locate zones where conductive minerals are disseminated within their host rocks. The self-potential method makes use of natural currents flowing in the ground that are generated by electrochemical processes to locate shallow bodies of anomalous conductivity. Electrical methods utilize direct currents or low frequency alternating currents to investigate the electrical properties of the subsurface, in contrast to the electromagnetic methods discussed above that use alternating electromagnetic fields of higher frequency to this end.

2.2.1 RESISTIVITY METHOD

Electrical Resistivity is an intrinsic property of all materials. The method uses artificially-generated electric currents, introduced into the ground and the resulting potential differences are measured at the surface. Deviations from the expected pattern of potential differences from homogeneous ground provide information on the form and electrical properties of subsurface inhomogeneities. When subsurface inhomogeneities exist, however, the resistivity will vary with the relative positions of the electrodes. Any computed value is then known as the apparent resistivity (ρ_a) and will be a function of the form of the inhomogeneity. In homogeneous ground the depth of current penetration increases as the separation of the current electrodes is increased.

Two main types of procedure are employed in resistivity surveys.

2.2.1.1 VERTICAL ELECTRICAL SOUNDING (VES)

Vertical electrical sounding (VES) also known as œelectrical drillingô or œexpanding probeö, is used mainly in the study of horizontal or near-horizontal interfaces. The current and potential electrodes are maintained at the same relative spacing and the whole spread is progressively expanded about a fixed central point. Consequently, readings are taken as the current reaches progressively greater depths. The technique is extensively used in geotechnical surveys to determine overburden thickness and also in hydrogeology to define horizontal zones of porous strata. Vertical electric sounding (VES) employs collinear arrays designed to output a 1-D vertical apparent resistivity versus depth model of the subsurface at a specific observation point. The induced current passes through progressively deeper layers at greater electrode spacing. The potential difference measurements are directly proportional to the changes in the deeper subsurface. Apparent resistivity values calculated from measured potential differences can be interpreted in terms of overburden thickness, water table depth, and the depths and thicknesses of subsurface strata. The two most common arrays used for Electrical surveying are the Wenner array and the Schlumberger array (Cardimona, 1990).

For the purpose of this study, it is the conventional practice in VES interpretation to make the assumption that layers are horizontal and isotropic. Deviations from these assumptions result in errors in the final interpretation (Kearey and Brooks, 2002).

2.2.1.2 CONSTANT SEPARATION TRAVERSING (CST)

Constant Separation Traversing (CST) known as Electrical Resistivity (ER) profiling, uses collinear arrays to determine lateral resistivity variations in the shallow subsurface at a more or less fixed depth of investigation. The current and potential electrodes are moved along a profile with constant spacing between electrodes (Cardimona, 1990). It is also the use of an electrical prospecting arrangement with fixed spacing of electrodes by moving the system progressively along profiles, detecting changes in resistivity of the earth as one move along the profile. Hence, it measures lateral variation of apparent resistivity. This method is employed in mineral prospecting to locate faults or shear zones and to detect localized bodies of anomalous conductivity. It is also used in geotechnical surveys to determine more importantly the presence of steep discontinuities. Results from a series of CST traverses with fixed electrode spacing can be employed in the production of resistivity pseudosections. The two most common types used for CST are the dipole-dipole and pole-dipole arrays.

2.2.2 INDUCED POLARIZATION

The passage of current through a rock as a result of an externally imposed voltage is accomplished mainly by electrolytic flow in the pore fluid. Most of the rock forming minerals have a net negative charge on their outer surfaces in contact with the pore fluid and attract positive ions onto this surface. In prospecting for metallic ores, interest is obviously in the electrode polarization (overvoltage) effect. Membrane polarization, however, is indistinguishable from this effect during IP measurements. Membrane polarization consequently reduces the effectiveness of IP surveys and causes geological ‗noise‘. Chargeability is measured over a specific time interval shortly after the polarizing current is cut off. A common method of presenting IP measurements is the pseudosection, in which readings are plotted so as to reflect the depth of penetration. VES resistivity data can also be presented in this way with the plotted depth proportional to the current electrode separation. Pseudosections give only a crude representation of the IP response distribution at depth. Quantitative interpretation is considerably more complex than for the resistivity method. The IP response has been computed analytically for simple features such as spheres, ellipsoids, dykes, vertical contacts and horizontal layers, enabling indirect interpretation (numerical modeling) techniques to be used. Much IP interpretation is, however, only qualitative. Simple parameters of the anomalies, such as sharpness, symmetry, amplitude and spatial distribution may be used to estimate the location, lateral extent, dip and depth of the anomalous zone (Kearey and Brooks, 2002).

2.2.3 SELF POTENTIAL (SP) METHOD

The self-potential (or spontaneous polarization) method is based on the surface measurement of natural potential differences resulting from electrochemical reactions in the subsurface. Typical SP anomalies may have amplitude of several hundred millivolts with respect to barren ground. They invariably exhibit a central negative anomaly and are stable over long periods of time. They are usually associated with deposits of metallic sulphides (Corry 1985, Kearey and Brooks, 2002), magnetite or graphite. SP anomaly interpretation is similar to magnetic interpretation because dipole fields are involved in both cases. It is thus possible to calculate the potential distributions around polarized bodies (Kearey and Brooks, 2002) by making assumptions about the distribution of charge over their surfaces. Most interpretation, however, is qualitative. The anomalous body is assumed to occur directly over the anomaly minimum, although it may be displaced downhill in areas of steep topography. The depth of the anomaly can be estimated by the anomaly half width. The symmetry or asymmetry of the anomaly provides information on the attitude of the body, the steep slope and positive tail of the anomaly lying on the down dip side. The type of overburden can have a pronounced effect on the presence or absence of SP anomalies. Sand has little effect but a Clay cover can mask the SP anomaly of an underlying body. The SP method is only of minor importance in exploration. This is because quantitative interpretation is difficult and the depth of penetration is limited to about

30m. It is, however, a rapid and cheap method requiring only simple field equipment. Consequently, it can be useful in rapid ground reconnaissance.

Electrical surveying, also referred to as galvanic electrical methods, is useful, generally for determining shallow, deep geologic and hydrogeologic conditions. By measuring the electrical resistance to a direct current applied at the surface, this geophysical method can be used to;

I. Locate fracture zones, faults, karst, and other preferred groundwater/contaminant pathways;
II. Locate clay lenses and sand channels;
III. Locate perched water zones and depth to groundwater; and
IV. Occasionally, locate large quantities of residual and floating product.

2.2.4 THEORETICAL CONSIDERATIONS

Resistivity techniques are based on the response of the earth to the flow of electrical current. In these methods, an electrical current is passed through the ground and two potential electrodes allow us to record the resultant potential difference between them, giving us a way to measure the electrical impedance of the subsurface material. The apparent resistivity is then a function of the measured impedance (ratio of potential to current) and the geometry of the electrode array. Depending upon the survey geometry, the apparent resistivity data are plotted as 1-D soundings, 1-D profiles, or in 2-D cross-sections in order to look for anomalous regions. In the shallow subsurface, the presence of water controls much of the conductivity variation. Measurement of resistivity (inverse of conductivity) is, in general, a measure of water saturation and connectivity of pore space. This is because water has a low resistivity and electric current will follow the path of least resistance. Increasing saturation, increasing salinity of the underground water, increasing porosity of rock (water-filled voids) and increasing number of fractures (water-filled) all tend to decrease measured resistivity. Increasing compaction of soils or rock units will expel water and effectively increase resistivity. Air, with naturally high resistivity, results in the opposite response compared to water when filling voids. Whereas the presence of water will reduce resistivity, the presence of air in voids should increase subsurface resistivity. Resistivity measurements are associated with varying depths depending on the separation of the current and potential electrodes in the survey, and can be interpreted in terms of a lithologic and/or geohydrologic model of the subsurface. Data are termed *"apparent"* resistivity because the resistivity values measured are actually averages over the total current path length but are plotted at one depth point for each potential electrode pair. Two dimensional images of the subsurface apparent resistivity variation are called *pseudosections*. Data plotted in cross-section is a simplistic representation of actual, complex current flow paths, Telford et al., (1976), Ward (1990), Burger (1992), Kearey and Brooks (2002).

2.2.5 OHM'S LAW

The electrical resistivity method is based on the transmission of an electric current through the subsurface materials and measurement of the materialôs resistance to the flow of the current. Direct Current (DC) or a low frequency alternating current from a transmitter is introduced into the subsurface materials. The potential difference is measured and the resistivity of the material is then calculated. Using Ohmsô Law, which is a relationship between the resistance (R), the potential difference (V), and the current (I) exists:

$$R = \frac{V}{I} ---------------------------------- (1)$$

where V = potential difference (volts),

I = direct current (amps), and

R = resistance (ohms)

This relationship holds for earth materials as well as simple circuits. Resistance, however, is not a material constant. Instead, resistivity is an intrinsic property of the medium describing the resistance of the medium to the flow of electric current. Resistivity is defined as a unit change in resistance scaled by the ratio of a unit cross-sectional area and a unit length of the material through which the current is passing. (ɟ = ŭA ŭR/ŭL). Resistivity is measured in ohm-m or ohm-ft, and is the reciprocal of the conductivity of the material.

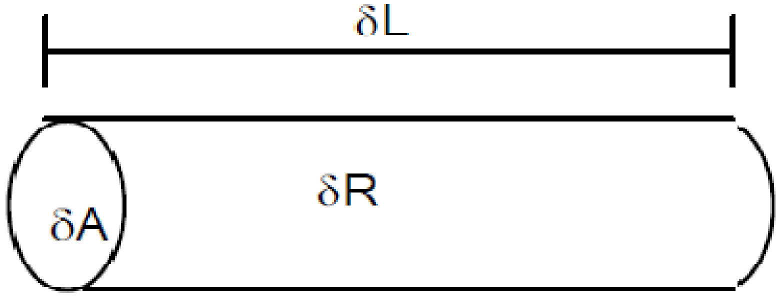

FIGURE 6: RESISTIVITY is Defined based on the Change in RESISTANCE ŭR for a given Change in LENGTH ŭL and Cross-Sectional AREA ŭA of a material.

Apparent Resistivity (ɟ) is similar to resistance (R), but such resistivity also involves a geometric factor (K).

ρ_a = 2´ $k\,\Delta V/I$ --------------------- (2)

In performing a standard earth resistivity survey, four electrode stakes are inserted into the ground, two electrodes (current electrodes) are connected to a battery and a direct current is applied. The remaining two electrodes (potential electrodes) are used to measure the potential difference or voltage drop. The configuration of the electrodes determines the geometric factor (K) in equation (2). Different electrode configurations result in different geometric factors (K). By knowing the amount of current (I, amps) introduced into the earth, the spacing of the electrodes (a) and the configurations of the four electrodes (the geometric factor K, meters), and measuring the resulting potential difference in volts (V), the apparent resistivity (ȷ) can be calculated.

2.2.6 POISSON'S EQUATION

The recordings we make in resistivity methods are surface measurements of the potential field distribution due to the current passing through the ground. This potential is a solution to Poissonôs equation, ^{2}P = 0, where ^{2} is a second derivative operator and P is the potential. For the potential P at a distance ñrò from the current source I on the surface of the earth (an infinite half space below), the solution is given by P = Iȷ/2´r. In reality, a single electrode cannot pass current through a half-space because two electrodes are required to complete the electrical circuit. Also, we do not measure potential, but measure the potential difference between two electrodes. The solution to Poissonôs equation for each pair of current and pair of potential electrodes would give a general form for a measured potential difference with electrodes placed anywhere on the surface. In practice, however, the current and potential electrodes are arranged most often in a linear or collinear pattern.

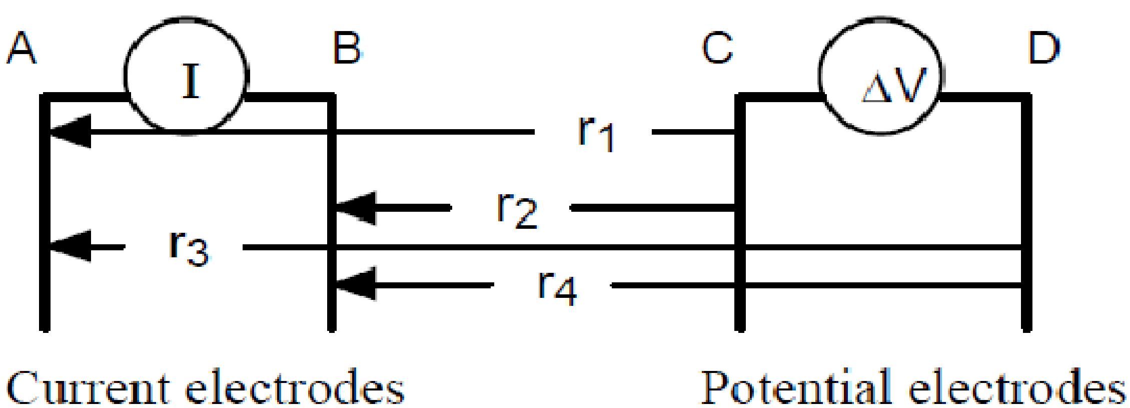

FIGURE 7: Geoelectric Survey with Current and Potential electrodes.

The resulting equation for the measured potential (voltage) difference is

$$\Delta V = \frac{I\rho}{2\pi}\left[\left(\frac{1}{r_1}-\frac{1}{r_2}\right)-\left(\frac{1}{r_3}-\frac{1}{r_4}\right)\right]$$ -- (3)

By solving the above equation for (ɟ), we can determine the resistivity of the subsurface region. We derive the above equation assuming a homogeneous and isotropic half-space. Because the earth is neither homogeneous nor isotropic, a measured voltage difference yields a resistivity value that is an average over the path length the current follows. Thus, we can determine only apparent resistivity, given by (Cardimona, 1990).

$$\rho_a = \frac{2\pi\Delta V}{1}\left[\frac{1}{\left(\frac{1}{r_1}-\frac{1}{r_2}\right)-\left(\frac{1}{r_3}-\frac{1}{r_4}\right)}\right] = \frac{\Delta V}{1}G(k)$$ -------------------------------- (4)

G(k) is a geometric factor and is dependent upon the spatial arrangement of electrodes for specific arrays.

ΔV is a change in potential difference

ρ_a is the apparent resistivity

r_1, r_2, r_3, r_4 are the distances of the four electrodes respectively.

2.2.7 OPERATING PRINCIPLE

A variety of electrode configurations or arrays (*e.g.*, Wenner, Schlumberger, dipole-dipole) can be used depending on the application and the resolution desired. Typically, an electrical current is applied to the ground through a pair of electrodes. A second pair of electrodes is then used to measure the resulting voltage. The greater the distances between the electrode pair, the greater the depth of investigation. Because various subsurface materials have different resistivity values, measurements at the surface can be used to determine the vertical and lateral variation of underlying materials. As with Electromagnetic methods, success depends upon subsurface resistivity contrasts.

2.2.8 WENNER ARRAY METHOD

In the Wenner array configuration, potential electrodes are nested within the current electrodes with a common lateral distance between adjacent electrodes called the electrode *a*-spacing. For sounding measurements, the electrodes in a Wenner array are expanded about a center point by equally incrementing the *a*-spacing. The current therefore progressively passes into deeper layers, with the nominal depth of investigation being equal to the a-spacing. This procedure provides apparent resistivity values that are dependent upon vertical conductivity variations of the subsurface. The geometric factor for the Wenner array is G(k) = 2*a.* This simplicity of algebraic form as well as in-field set-up is part of this arrayĝs appeal. The Wenner array generally provides for high signal-to-noise ratios, good resolution of horizontal layers, and good depth sensitivity. (Ward, 1990; Cardimona, 1990).

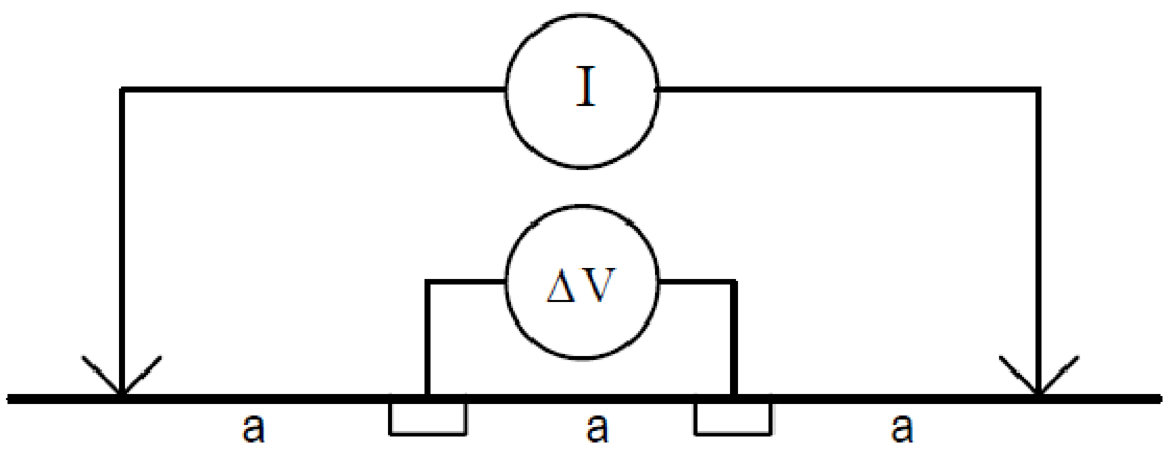

FIGURE 8: Wenner array: Depth of sounding controlled by distance ñaò, or a-spacing.

The classical methods of geoelectrical resistivity surveys have undergone significant changes in the last three decades. The traditional horizontal layering technique are rapidly being replaced with two-dimensional (2D) and three-dimensional (3D) models of data acquisition especially in complex and heterogeneous subsurface media. Field techniques have advanced from measurements made at separate and independent points to automated measuring systems with multi-electrode array along the profiles. Data acquisition was more or less carried out manually till the 1980s, and this was labour intensive and slow, and the quality of the resistivity data poorer. A range of fast automated multi-electrode and multi-channel data acquisition systems now exist that allows flexibility in the acquisition of geoelectrical resistivity data (Barker, 1981; Stummer and Maurer, 2001; Auken et al., 2006, Aizebeokhai, 2010).

Traditionally, electrical resistivity surveying was limited to either delineating the variation of apparent resistivity over a surface or compiling quasi-2D sections from a rather limited numbers of vertical electrical soundings (VES). The use of multi-electrode/multi-channel systems for data acquisition in geoelectrical resistivity surveys has led to a dramatic increase in field productivity as well as increased quality and reliability of subsurface resistivity information obtained. Initially, multi-electrode systems with manual switching (Barker, 1981, Aizebeokhai, 2010) were used before the emergence of computer-controlled multi-electrode/multi-channel systems with automatic measurements and data quality control, which has tremendous impact on the quality of the data and the speed with which they are collected. Intelligent multi-electrode with built-in-preamplifiers, analog-to-digital converters, and digital transmission lines can now be effectively used for data acquisition.

2.2.9 ELECTRIC PROFILING OR AREAL MAPPING

Profiling and areal mapping are recording techniques for mapping lateral variations in resistivity at approximately constant depths. This is achieved by moving a fixed-length array along traverses or across an areal grid. Variations in apparent resistivity highlight anomalous areas. The Wenner array is especially well suited for profiling and areal mapping due to the equidistant spacing between electrodes. Often, a few VES data sets are recorded prior to a profiling or mapping campaign to estimate the necessary electrode spacing (Zhody et al., 1973). Beside the well-established Wenner arrangement, the gradient array might, in some situations, be a good choice for profiling or mapping, because only two electrodes have to be moved (Furness, 1993, Peter 2003).

2.2.10 ADVANTAGE

Although resistivity is subject to interferences from the same objects as electromagnetism, it is less affected by them. Electrical resistivity method use electric current generated with electrodes into the ground but the electromagnetic method which involve the use of lower frequency radio waves are electromagnetically induced in the ground. Electrical resistivity method cause different current patterns in the ground and do not measure the same subsurface properties as electromagnetic methods. In addition, if the location of metal pipes and utilities is known for example, electrode arrays can often be arranged to minimize interferences. Furthermore, resistivity resolution is comparable to, and sometimes better than electromagnetic method (Geophysics guide, 1993).

2.2.11 LIMITATIONS

Electrical resistivity, however, has a number of limitations. The following is a list of the most significant issues that should be considered when selecting this method:

I. Electrodes must be in direct contact with soil; if concrete or asphalt is present, holes must be drilled for inserting the electrodes and then refilled when the survey is complete.

II. For deep investigations, electrode arrays can be quite long. The distance between outside electrodes must be 4 to 5 times the depth of investigation.

III. Measurements may be limited by either highly conductive or highly resistive surface soils.

If shallow clays and extremely shallow groundwater are present, most of the current may concentrate at the surface. Although the condition is very rare, the presence of thick, dry, gravelly material (or massive dry material) at the surface may prevent the current from entering the ground.

2.2.12 ELECTRICAL RESISTIVITY IMAGING

The use of Electrical Resistivity Imaging to address a wide variety of hydrological, environmental and geotechnical issues is increasingly popular. The use of vertical electrical sounding is grossly inadequate to map such complex and multi-scale geology. Two dimensional (2D) electrical resistivity imaging, in which the subsurface is assumed to vary vertically down and laterally along the profile but constant in the perpendicular direction, has been used to investigate areas with moderately complex geology (Griffiths and Barker, 1993; Dahlin and Loke, 1998; Olayinka and Yaramanci, 1999; Amidu and Olayinka, 2006; Aizebeokhai et al., 2010). Electrical resistivity imaging (ERI) has become an important engineering and environmental site investigation tool reasons being that, there is a broad range of resistivity values (Reynolds, 1997) which allows for potential discrimination between various geological materials. Resistivity images are created by inverting tens or hundreds to thousands of individual resistivity measurements (Loke and Barker, 1996; Bentley and Mehran 2004) to produce an approximate model of the subsurface resistivity.

2.3 FACTORS RESPONSIBLE FOR RESISTIVITY OF SOIL OR ROCK

These factors include the following

(1) Porosity,

(2) Degree of water saturation,

(3) Concentration of dissolved salts,

(4) Degree of fracturing,

(5) Percentage fracture filled with water.

(Loke, 2000).

2.4 TYPICAL RESISTIVITY VALUES FOR DIFFERENT TYPES OF SUBSURFACE MATERIALS

Granite	$5x10^{3}$ ï 10^{6}	
Basalt	10^{3} - 10^{6}	
Slate	$6x10^{2}$ ï $4x10^{7}$	Igneous and Metamorphic Rocks
Marble	10^{2} ï $2.5x10^{8}$	
Quartzite	10^{2} ï $2x10^{8}$	
Sandstone	8 ï $4x10^{3}$	
Shale	20 -210^{3}	Sedimentary Rocks
Limestone	50 ï $4x10^{2}$	
Clay	1 ï 100	
Aluminum	10 ï 800	Soils and Waters
Groundwater (fresh)	10 ï 100	
Sea water	0.2	

Igneous and Metamorphic Rocks	- high resistivity values and greatly dependent on the factors above.
Sedimentary Rocks	- lower resistivity values since they are more pore and have higher water content.
Wet Soils and Groundwater	- even lower resistivity values.

(Loke, 2000).

The objective of this study is to find out how anomalous zone in the subsurface can be correlated with typical resistivity values of soils above using electrical resistivity imaging techniques. The electrical resistivity data were obtained using the ABEM SAS (signal averaging system) 1000 Terrameter. The Wenner Electrode Configuration method which is very suitable for shallow depth investigation of the subsurface was employed with a view of detecting lateral variation of apparent resistivity within the study area. It is important to understand that Electrical Resistivity, though a fundamental property of earth materials, it varies with rock or sediment type, porosity and the quality and quantity of water.

Electricity can be conducted in the earth electrolytically by interstitial fluids (usually water) and electronically by certain materials, such as clay minerals, by cation exchange. As a result, poorer quality ground water (that is water with higher concentrations of dissolved solids) or sediments with higher clay content are usually more conductive (Zohdy et al., 1974, Alile et al., 2011). Resistivity is expressed in ohm-meters, and is an estimate of the earth resistivity calculated using the relationship between resistivity, an electric field, and current density (ohmȏs law), and the geometry constant, spacing of the current and potential electrodes. Where the earth is not homogeneous and isotropic, this estimate is called the apparent resistivity, which is an average of the true resistivity in the measured section of the earth.

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

In this research work, the Wenner array in electrical resistivity survey was adopted. The basic field equipment for this study is the ABEM Terrameter SAS 1000 which displays apparent resistivity values digitally as computed from ohmôs law. It is powered by a 12 Volt (V) Direct Current (DC) power source. Other accessories to the Terrameter include the four metal electrodes, cables for current and potential electrodes, harmers (four), measuring tapes, writing pads. In field configuration, the four electrodes are positioned symmetrically along a straight line, the current electrodes on the outside and the potential electrodes on the inside. Both the current and potential electrode positions are aligned using constant electrode ñaò spacing. To change the depth range of the measurements, the current electrodes and the potential electrodes are displaced outward together. During the field work, the ABEM Terrameter SAS 1000 (Self Averaging System) performs automatic recording of both voltage and current, stacks the results, computes the resistance in real time and digitally displays it (Dobrin and King, 1976; Alile et al., 2011). The Terrameter was configured in a mode that it displays apparent resistivity and induced polarization data automatically at the same time.

3.1 DATA PRESENTATION

3.1.1 COLLECTION PROCEDURES

1. **Establishment of Profiles:** Three profiles/traverses, with two parallel/longitudinal and the last being perpendicular/transverse to the road segment were established and had a length of 250m each for convenience of space due to vehicular movement. Traverse I and Traverse II were established along parts of the road (Figure 9) that showed major cracks and rippling of the pavement and a fairly stable part respectively while Traverse III was

established midway of Traverse I. The profiles were located between the geographical grid of latitudes 6^0 41ǫ57.7ǫǫN and 6^0 41ǫ50.05ò N, and longitudes 6^0 10ǫ47.06ǫǫE and 6^0 10ǫ 44.06ǫǫ E for Profile line I, Latitudes 6^0 41ǫ 55.09ǫǫ N and 6^0 42ǫ 00.02ǫǫ N and longitudes 6^0 10ǫ48.02ǫǫE and 6^0 10ǫ41.07ǫǫE for Profile line II and Latitudes 6^0 42ô 00.01ò and 6^0 42ô 03.05ò and longitudes 6^0 10ô 41.03ò and 6^0 10ô 34.04ò for Profile line III.

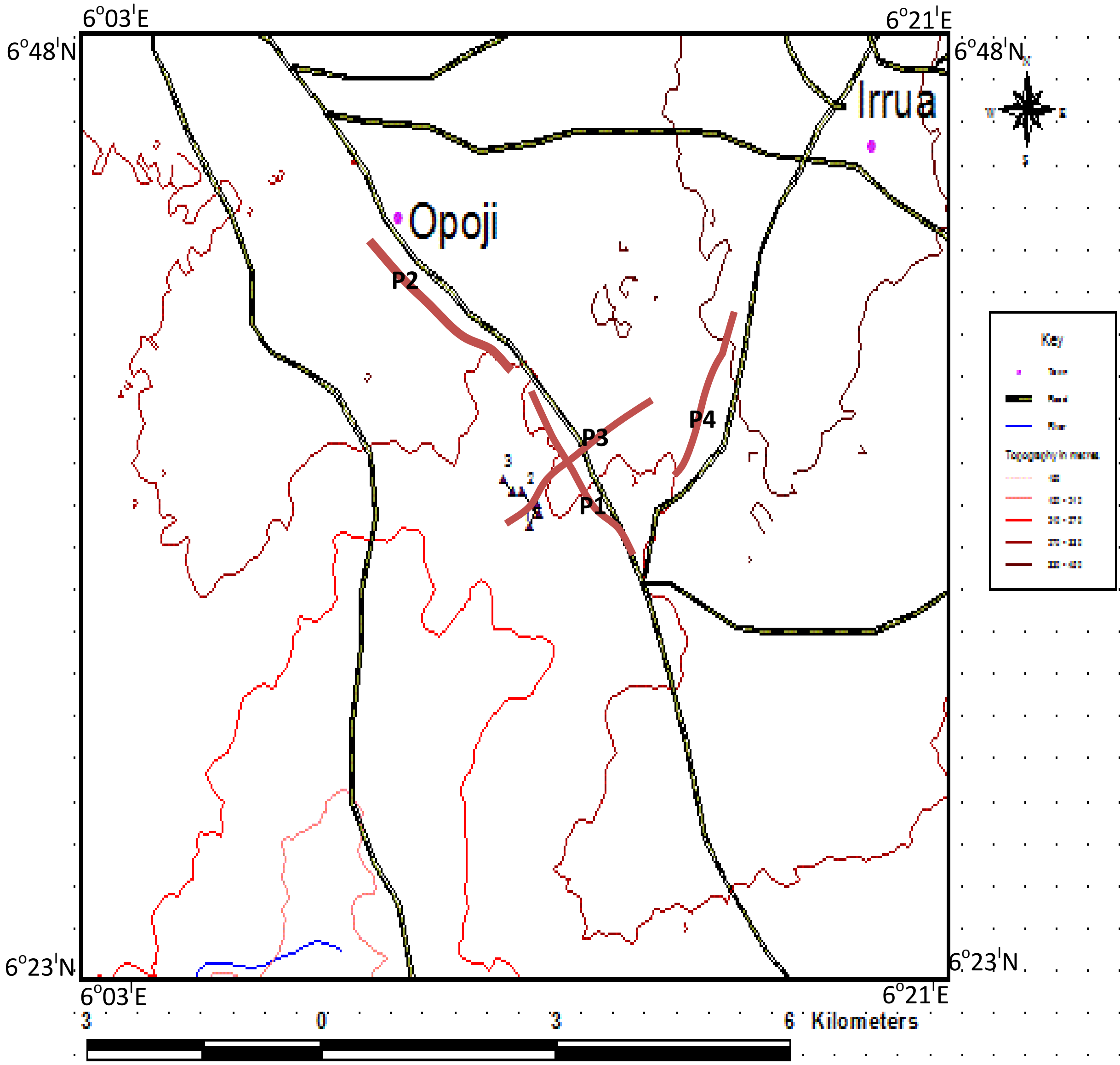

FIGURE 9: PROFILE ORIENTATION ALONG ROAD SEGMENT

3.1.2 DATA ACQUISITION

Acquiring field data is usually time consuming and labour intensive, as it involves the movement of the four electrodes from one point to another for each data point to be measured. A minimum of one person was required to handle each of the electrodes with its connecting cable and an additional person who handled the recording equipment, thus making a five-man data collection crew for this survey. The electrode spread (Wenner array configuration) for data collection along the four profiles surveyed, used different electrode spacing of 10m, 20m, 30m and 40m respectively. A total length of 250m, 250m, 250m and 600m was surveyed for profile I, II, III and IV respectively. One major precaution taken for using the Wenner array method was the provision of high signal-to-noise, good resolution of horizontal layers and good depth sensitivity of the method (Ward, 1990; Cardimona, 1990). The equipment (Terrameter) is portable, light weight and relatively cost effective when compared with other geophysical data acquisition systems. A conventional setup of the earth resistivity meter basically consists of the following: a constant current source, commonly a battery pack connected to a commutated DC circuit to change polarity of the current source; an ammeter which measures the injecting current; a very sensitive voltmeter that measures the response signal (which in this case were in built); four metal stake electrodes, usually stainless steel and non-polarizing which ensures low impedance characteristic; and four cable reels used in connecting the electrodes to the current source and hammers used in pushing the electrode into the earth. The tables below show the apparent resistivity and induced polarization values produced by the Terrameter during the survey.

TABLE 2: APPARENT RESISTIVITY DATA FOR PROFILE 1

S/N	MID POINT ELECTRODE SPACING	ñaò SPACING	APPARENT RESISTIVITY	INDUCED POLARIZATION
1	15	10	1513.5	1.24
2	25	10	1622.4	1.28
3	35	10	1384.5	4.11
4	45	10	1879.7	1.54
5	55	10	1729.4	4.15
6	65	10	1508.6	1.46
7	75	10	1673.7	1.12
8	85	10	979.88	0.99
9	95	10	798.76	1.35
10	105	10	1053.6	1.2
11	115	10	979.64	1.88
12	125	10	978.8	1.78
13	135	10	901.88	1.17
14	145	10	893.63	1.61
15	155	10	863.94	2.63
16	165	10	1071.7	1.78
17	175	10	1259.5	2.78
18	185	10	1430.5	1.07
19	195	10	1535.1	1.96
20	205	10	1941.8	1.88
21	215	10	2273.6	1.98
22	225	10	2167.4	2.07
23	235	10	2335.3	2.42
24	30	20	887.48	-211
25	40	20	1781.3	-178
26	50	20	1488.3	-142
27	60	20	1088.4	-126
28	70	20	835.43	-241
29	80	20	853.3	30.1
30	90	20	501.88	-109
31	100	20	273.94	-169
32	110	20	300.75	-68
33	120	20	1622.3	1.78
34	130	20	1476.9	1.74
35	140	20	1485.7	2.16
36	150	20	1439.1	1.75
37	160	20	1670.1	1.9
38	170	20	2098.2	1.92
39	180	20	2371.3	1.68

40	190	20	2377.6	1.53
41	200	20	2769.4	2.1
42	210	20	3187.3	2.56
43	220	20	3293.2	1.8
44	45	30	1304.7	209
45	55	30	2523	610
46	65	30	915.84	-168
47	75	30	654.48	-124
48	85	30	657.04	-61.4
49	95	30	599.3	-88.2
50	105	30	443.12	60
51	115	30	310.04	-595
52	125	30	426.07	-779
53	135	30	515.1	-406
54	145	30	570.3	-164
55	155	30	1009.6	-242
56	165	30	1173.6	-154
57	175	30	346.49	-1640
58	185	30	613.34	-763
59	195	30	692.14	-997
60	205	30	421.43	113
61	60	40	2042	1.15
62	70	40	3566.7	1.62
63	80	40	3080.3	1.52
64	90	40	2952.1	1.73
65	100	40	2559.5	1.48
66	110	40	2820	1.08
67	120	40	3190.8	1.22
68	130	40	3115.4	1.06
69	140	40	3025.3	1.7
70	150	40	2526.8	-71.3
71	160	40	1899	-25.9
72	170	40	1382.7	-143
73	180	40	1238.7	-136
74	190	40	412.79	-251

TABLE 3: APPARENT RESISTIVITY DATA FOR PROFILE II

S/N	MID POINT ELECTRODE SPACING	ñaò SPACING	APPARENT RESISTIVITY	INDUCED POLARIZATION
1	15	10	1704.6	1.25
2	25	10	1696.1	1.71
3	35	10	1634.8	1.62
4	45	10	1843	1.82
5	55	10	1561.2	3.64
6	65	10	1566.8	1.05
7	75	10	1806.5	2.68
8	85	10	1882.6	2.7
9	95	10	2183.5	1.21
10	105	10	2169.1	1.96
11	115	10	1699	1.89
12	125	10	1896.9	1.68
13	135	10	1888.7	0.71
14	145	10	1723	1.87
15	155	10	1941.3	2.1
16	165	10	1779.8	15.4
17	175	10	2091.5	2.4
18	185	10	2212.4	1.41
19	195	10	2011.7	10.3
20	205	10	1815.3	5.41
21	215	10	1826.2	5.37
22	225	10	1568.2	-23.8
23	235	10	1669.1	4.69
24	30	20	2164.8	1.55
25	40	20	2368.3	2.84
26	50	20	2396.9	3.16
27	60	20	2246.4	2.53
28	70	20	2228.2	2
29	80	20	2437.2	1.9
30	90	20	2795	11
31	100	20	3034.2	1.35
32	110	20	2399.3	1.25
33	120	20	2406.2	1.93
34	130	20	2775.3	9.11
35	140	20	2765.2	2.32
36	150	20	2482	2.58
37	160	20	2559	1.88
38	170	20	2665.8	1.18
39	180	20	2758.5	30.2
40	190	20	2766.7	8.85

41	200	20	2435.7	1.24
42	210	20	2133.6	1.38
43	220	20	1614.7	37.6
44	45	30	2953.8	1.71
45	55	30	2761.4	2.04
46	65	30	2657.7	2.43
47	75	30	2868.9	2.04
48	85	30	3260.6	1.26
49	95	30	3534.4	0.87
50	105	30	3259.3	1.11
51	115	30	3042.5	0.47
52	125	30	2938.2	1.29
53	135	30	3017.5	1.77
54	145	30	3057.1	1.12
55	155	30	2944.4	0.67
56	165	30	3039.1	7.02
57	175	30	3305.8	8
58	185	30	3529.8	1.58
59	195	30	3236.3	1.96
60	205	30	2729.7	5.58
61	60	40	3213.1	1.79
62	70	40	3214.6	1.84
63	80	40	3567.8	2.3
64	90	40	3927.3	2.21
65	100	40	3837.9	1.12
66	110	40	3832.7	2
67	120	40	3581.2	2.15
68	130	40	3160.7	-3.2
69	140	40	3151.4	1.97
70	150	40	3093.9	21.6
71	160	40	3454.8	0.91
72	170	40	4062.4	1.69
73	180	40	4048.6	-3.89
74	190	40	3815	4.74

TABLE 4: APPARENT RESISTIVITY DATA FOR PROFILE III

S/N	MID POINT ELECTRODE SPACING	ñaò SPACING	APPARENT RESISTIVITY	INDUCED POLARIZATION
1	15	10	1198.1	1.24
2	25	10	1058.5	1.72
3	35	10	883.94	1.49
4	45	10	943.54	7.26
5	55	10	1180.4	1.09
6	65	10	971.72	14
7	75	10	1047.5	-1.97
8	85	10	1153.9	1.28
9	95	10	1027.2	0.82
10	105	10	1105.1	0.63
11	115	10	1135.8	1.18
12	125	10	1266.9	1.32
13	135	10	1421.2	1.48
14	145	10	1357.7	2.09
15	155	10	1687.7	1.18
16	165	10	1538.4	1.81
17	175	10	1251.6	1.56
18	185	10	957.07	1.18
19	195	10	935.97	1.31
20	205	10	802.35	1.46
21	215	10	853.72	1.29
22	225	10	714.36	1.54
23	235	10	781.81	1.1
24	30	20	1211.2	6.92
25	40	20	1336.5	1.9
26	50	20	1742.6	1.93
27	60	20	1730	4
28	70	20	1495.2	0.67
29	80	20	1672.2	6.51
30	90	20	1701.1	-0.97
31	100	20	1681	0.96
32	110	20	1828.9	1.21
33	120	20	2042.4	-1.01
34	130	20	1868.5	1.94
35	140	20	1641.5	1.12
36	150	20	2012.6	1.66
37	160	20	2511.7	1.69
38	170	20	2134.2	0.98
39	180	20	1608.6	1.68
40	190	20	1484.1	1.44

41	200	20	1521.9	1.6
42	210	20	1462.3	1.84
43	220	20	1547.1	1
44	45	30	2025.1	6.99
45	55	30	2327	2.17
46	65	30	2388.5	1.72
47	75	30	2151.5	4.79
48	85	30	2167	1.01
49	95	30	2264.6	1.84
50	105	30	2532.8	-9.12
51	115	30	2369.2	1.84
52	125	30	2189.9	-3.84
53	135	30	2073.9	1.59
54	145	30	2420	1.82
55	155	30	2744.9	0.99
56	165	30	3455.2	1.42
57	175	30	3856.4	1.5
58	185	30	3270.2	1.86
59	195	30	2570.5	1.53
60	205	30	2018.7	1.73
61	60	40	2814.2	1.4
62	70	40	3061.2	1.83
63	80	40	2948.1	1.64
64	90	40	2945.9	1.47
65	100	40	2780.1	1.56
66	110	40	2606.7	1.37
67	120	40	2606.7	-4.4
68	130	40	2599.7	1.7
69	140	40	2888.6	0.86
70	150	40	3193.9	2.02
71	160	40	3181.8	1.4
72	170	40	3141.6	1.46
73	180	40	2801.3	1.41
74	190	40	2281.7	1.34

TABLE 5: APPARENT RESISTIVITY DATA FOR OPOJI OLD ROAD PROFILE.

S/N	MID POINT ELECTRODE SPACING	ñaò SPACING	APPARENT RESISTIVITY
1	15	10	763.62
2	25	10	792.04
3	35	10	774.18
4	45	10	724.23
5	55	10	804.61
6	65	10	793.05
7	75	10	700.06
8	85	10	727.41
9	95	10	767.91
10	105	10	732.13
11	115	10	777.95
12	125	10	856.12
13	135	10	812.45
14	145	10	839.14
15	155	10	855.23
16	165	10	861.78
17	175	10	833.99
18	185	10	854.23
19	195	10	871.26
20	205	10	891.41
21	215	10	860
22	225	10	821
23	235	10	893.74
24	245	10	901.74
25	255	10	892.17
26	265	10	853.63
27	275	10	841.96
28	285	10	834.81
29	295	10	756.42
30	305	10	791.35
31	315	10	761.91
32	325	10	788.56
33	335	10	736.42
34	345	10	800.12
35	355	10	861.45
36	365	10	812.56
37	375	10	857..23
38	385	10	905.42
39	395	10	916.74
40	405	10	928

41	415	10	933.81
42	425	10	911.9
43	435	10	923.54
44	445	10	987.01
45	455	10	922.9
46	465	10	946.32
47	475	10	914.46
48	485	10	979.53
49	495	10	936.53
50	505	10	845.54
51	515	10	853.45
52	525	10	795.98
53	535	10	874.31
54	545	10	893.15
55	555	10	987.66
56	565	10	986.42
57	575	10	974.47
58	585	10	999.72
59	30	20	987.23
60	40	20	878.52
61	50	20	1005.87
62	60	20	1104.88
63	70	20	976.65
64	80	20	945.74
65	90	20	1015.78
66	100	20	1130
67	110	20	982.65
68	120	20	985.75
69	130	20	989.47
70	140	20	789.789
71	150	20	858.74
72	160	20	866.13
73	170	20	866.78
74	180	20	987.96
75	190	20	989.65
76	200	20	978.79
77	210	20	1156.7
78	220	20	1258.21
79	230	20	1154.78
80	240	20	1535.5
81	250	20	1215.47
82	260	20	1254.89
83	270	20	1524.78
84	280	20	1452.54
85	290	20	1346.98

86	300	20	1513.54
87	310	20	1614.80
88	320	20	1784.65
89	330	20	1465.65
90	340	20	1352.87
91	350	20	1533.72
92	360	20	1566.84
93	370	20	1461.46
94	380	20	1344
95	390	20	1525.48
96	400	20	1585.75
97	410	20	1555.74
98	420	20	1855.42
99	430	20	1954.10
100	440	20	1856.23
101	450	20	1453.00
102	460	20	1995.54
103	470	20	1654.78
104	480	20	1643.45
105	490	20	1436.45
106	500	20	1365.96
107	510	20	1635.53
108	520	20	1436.35
109	530	20	1364.8
110	540	20	1346.68
111	550	20	1364.45
112	560	20	1536.78
113	570	20	1365.46
114	45	30	1647.45
115	55	30	1343.18
116	65	30	1842.87
117	75	30	1568.45
118	85	30	1542.88
119	95	30	1717.75
120	105	30	1327.57
121	115	30	1678.65
122	125	30	1372.21
123	135	30	1698.88
124	145	30	2403.52
125	155	30	2045.12
126	165	30	2245.78
127	175	30	2541.63
128	185	30	2466.85
129	195	30	1345.56
130	205	30	1995.87

131	215	30	1789.65
132	225	30	1965.76
133	235	30	1969.54
134	245	30	2255.97
135	255	30	3351.55
136	265	30	2553.365
137	275	30	2585.65
138	285	30	2676.65
139	295	30	2555.68
140	305	30	2583.03
141	315	30	2587.52
142	325	30	2252.58
143	335	30	2545.52
144	345	30	2552.69
145	355	30	2786.98
146	365	30	2874.98
147	375	30	3984.59
148	385	30	3438.48
149	395	30	2557.75
150	405	30	2524.68
151	415	30	1288.58
152	425	30	2876.85
153	435	30	3864.14
154	445	30	2558.89
155	455	30	2787.47
156	465	30	2755.74
157	475	30	3583.25
158	485	30	3688.12
159	495	30	2454.42
160	505	30	2545.78
161	515	30	3554.75
162	525	30	3252.15
163	535	30	2455.42
164	545	30	1951.45
165	555	30	2684.96
166	60	40	2545.42
167	70	40	2535.68
168	80	40	2873.58
169	90	40	3224.45
170	100	40	2876.45
171	110	40	2456.98
172	120	40	2558.79
173	130	40	2465.45
174	140	40	2345.25
175	150	40	2520.12

176	160	40	3143.54
177	170	40	1231.54
178	180	40	3325.552
179	190	40	2325.63
180	200	40	2535.34
181	210	40	2522.54
182	220	40	3123.51
183	230	40	3456.45
184	240	40	2575.45
185	250	40	3536.25
186	260	40	2545.53
187	270	40	1587.62
188	280	40	3545.45
189	290	40	2725.46
190	300	40	2555.45
191	310	40	3254.54
192	320	40	3534.45
193	330	40	3541.23
194	340	40	3497.79
195	350	40	3354.26
196	360	40	3485.54
197	370	40	3894.96
198	380	40	3354.11
199	390	40	3355.56
200	400	40	3658.88
201	410	40	3952.36
202	420	40	3879.27
203	430	40	3544.69
204	440	40	3151.21
205	450	40	3041.45
206	460	40	3001.78
204	470	40	3874.95
208	480	40	3994.65
209	490	40	3985.42
210	500	40	3253.49
211	510	40	3655.55
212	520	40	3982.98
213	530	40	3789.20
214	540	40	3568.09

3.2 INTERPRETATION AND DISCUSSIONS

3.2.1 2D ELECTRICAL RESISTIVITY IMAGING (ERI) METHOD

The data were collected in order to automatically generate a two dimensional (2-D) resistivity model for the subsurface which can be referred to as Electrical Image. These values obtained were used for the qualitative interpretation of the profiles. Tables 2, 3 and 4 are data collected along Uhiele road while Table 5 shows data collected along Opoji ï Uhiele old road. Only one profile was established during the survey on Opoji old road. The essence of the data collected from this profile was to understand the subsurface geology in the study area. Values were automatically generated from the Terrameter during the survey.

Two dimensional (2D) electrical imaging surveys are widely used to map areas of moderately complex geology where conventional resistivity surveys and profiling may be inadequate. The results from such surveys are usually plotted in the form of a pseudosection which gives an approximate picture of the subsurface geology. Traditionally, the direct-current (DC) electrical survey is used to determine the subsurface resistivity distribution by measuring the electrical potential difference between a pair of potential electrodes (M and N) on the ground surface with a current applied through a pair of current electrodes (A and B) (Keller and Frischknecht, 1966; Telford et al., 1990). The apparent resistivity ȷ a in ohmï meter (q ï m) is then computed from Ohm's law: ȷ a = 2´ nqpv; where n is distance in meters between the electrodes; qpv is the measured potential difference in millivolts (mV).

Recent developments in DC technology allows for automatic measurements, by switching the current and potential electrodes between a series of equally spaced electrodes laid out along a profile (Yang et al., 2002; Hauck et al., 2003; Chien-chih Chen et al., 2010). This allows a dense sampling of subsurface resistivity variation at shallow depth within a short amount of time .This type of electric survey aims to investigate the lateral variation in electrical properties which are mainly related to the other physical and structural parameters of the soil for limited depth along the profile extension. Profiling was conducted using Wenner array which is used for its advantages in such type of surveys. This array is characterized by its sensitivity for vertical variation in the subsurface resistivity below the center of the array. However, it is less sensitive to lateral changes in the subsurface resistivity. The median depth of investigation of this array is approximately 0.5 times the .a. spacing used (Loke, 2000). Also, the Wenner array has the strongest signal strength; therefore, it is the most appropriate array for DC-resistivity survey in the area under investigation

A common way to present apparent resistivity data is to plot the recorded values beneath the array midpoints at depths equal to a specified fraction (usually 1/3 or 1/2) of the array spacing. Contouring of the resistivity values reflects variations in apparent resistivity along the surveying line. Since the depths are not true depths, such a plot is called pseudosection (Hallof, 1957). Even though true depth information cannot be directly inferred from pseudosections, they are valuable tools for qualitative analyses and quality control (Dahlin, 1993, 1996; Peter, 2003). The apparent resistivity distribution of the subsurface structure was then inverted using the commercial RES2DINV® software to estimate the true resistivity structure. This produces a subsurface map of the ñapparentò resistivity distribution (pseudosection). The algorithm uses a 2D smoothness constrained, least-squares inversion with a Jacobian matrix calculation for the first iteration and then employs a quasi-Newtonian technique to reduce numerical calculations (Loke and Barker, 1996a). The inversion is stopped once the difference of the root mean square (RMS) error between the current and previous iterations is less than 0.1%. The inverted data produce the 2D resistivity distribution map, which is then used for extracting information about the contact between sediment and bedrock.

Surfer ® 10 which is a grid-based graphics program was also used to produce pseudo sections of apparent resistivity. Thus there is a correlation of two pseudosections of same profile. 3D maps of the subsurface were also produced by the Surfer program to display the apparent resistivity, to obtain a better resistivity image of the subsurface in the study area.

The Figures, 10 ï 20 below shows the pseudosection plots profiles I, II, III, IV of Tables 2, 3, 4 and 5 as well as contour and 3D maps of Tables 2, 3 and 4 respectively.

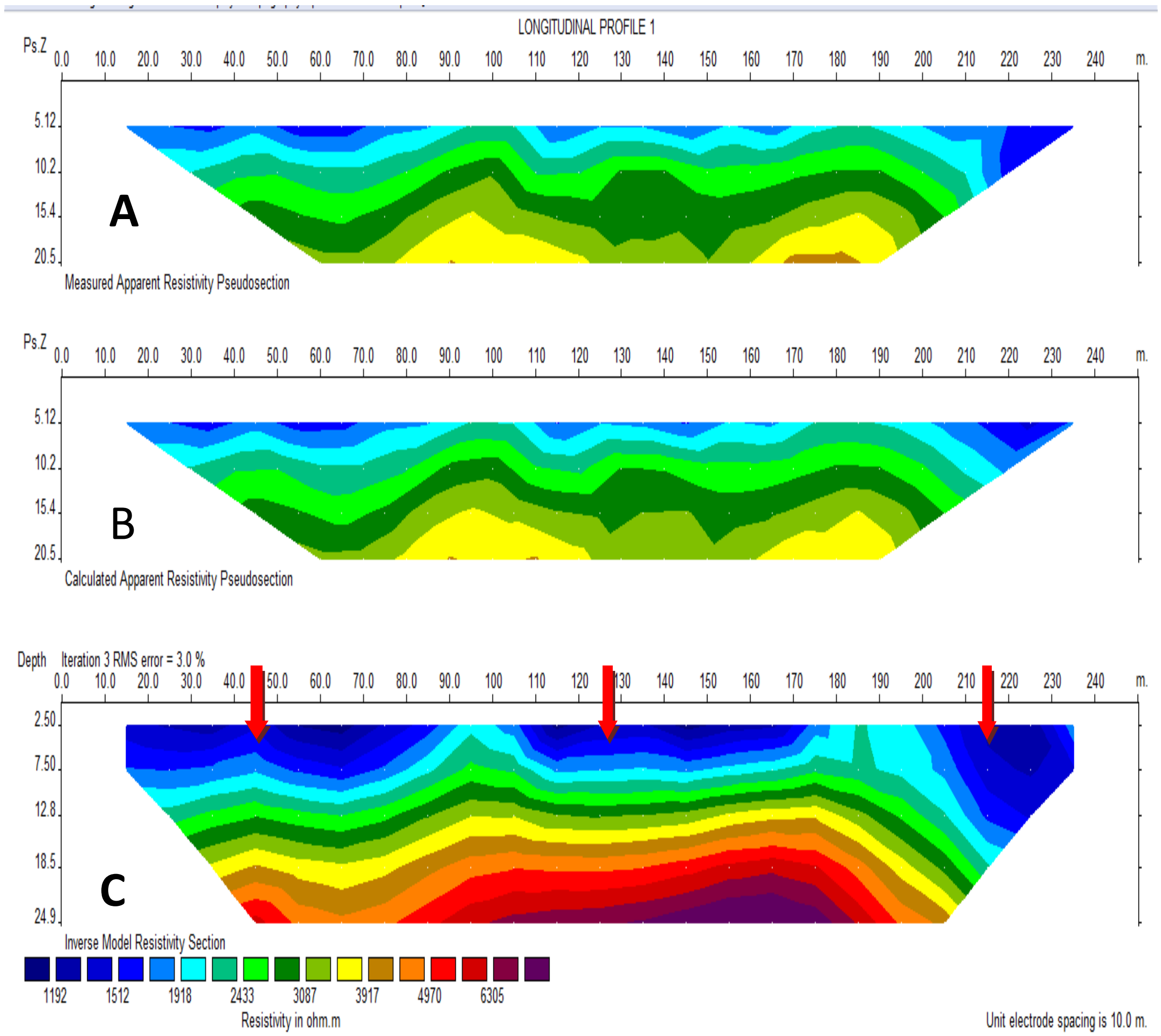

FIGURE 10: Pseudosection plot of Apparent Resistivity Data showing the stratified layers for the first profile along Uhiele ï Opoji road at kilometer 12 to Ekpoma main town. The arrows depict regions with very low resistivity values represented by blue colour.

The pseudo sections above show coloured layering of

(a) Measured and interpreted apparent resistivity values of the profile

(b) Calculated apparent resistivity values of layers of profile

(c) Computer interpreted iterated inverse model resistivity section of the profile

PLATE 5: This picture plate is showing the part of the road where profile I was taken (Uhiele ï Opoji road, linking Ekpoma town to the East part of the country).

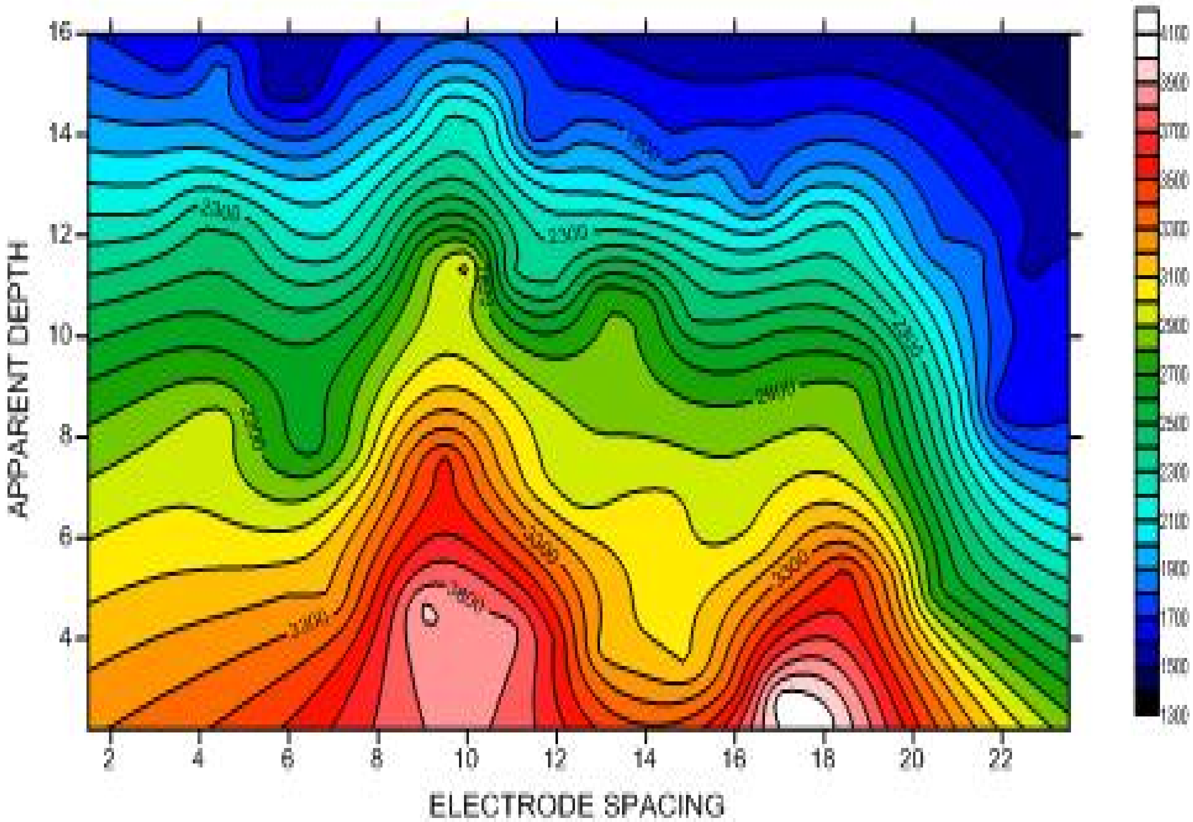

FIGURE 11: Geoelectric Isoresistivity Contour of first longitudinal profile of road segment. A plot of electrode spacing versus apparent depth. The contour lines show the apparent resistivity of layers similar to figure 10 (B)

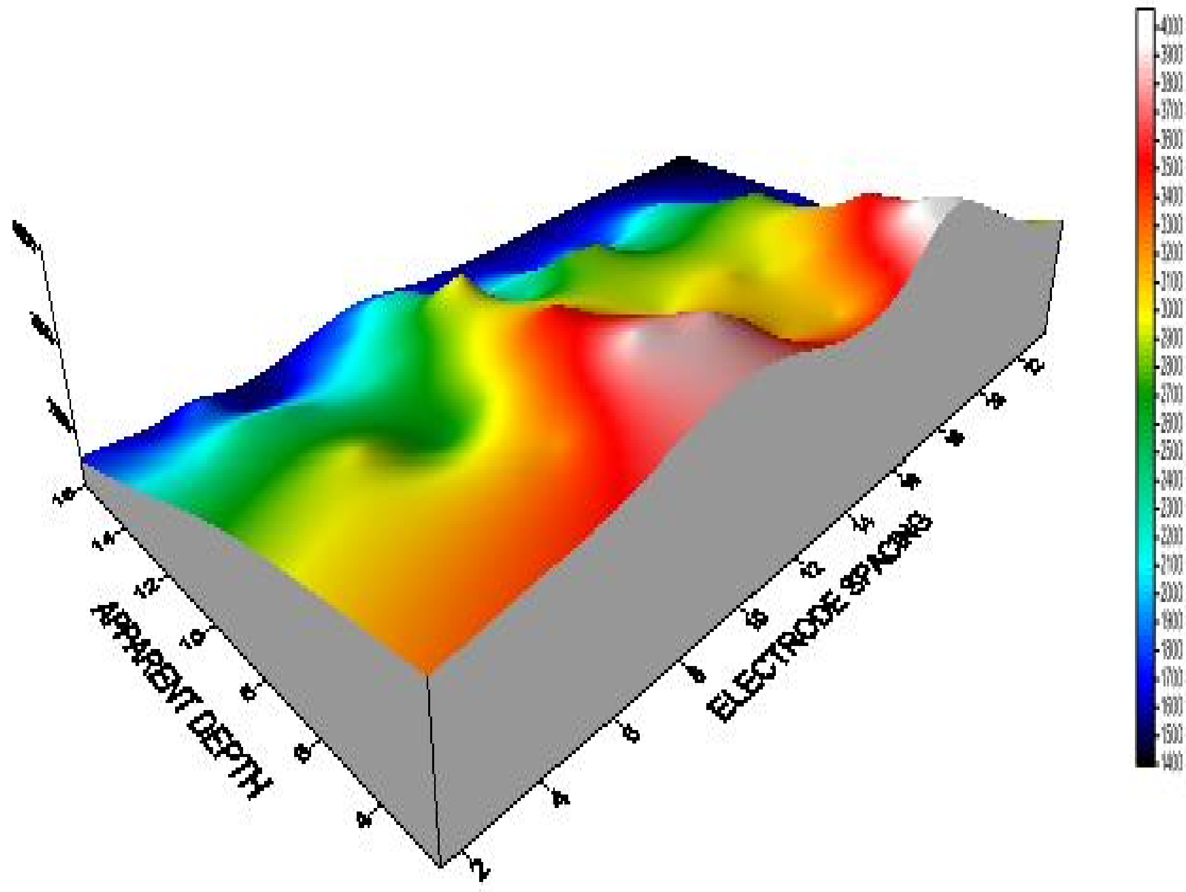

FIGURE 12: 3D map of the first longitudinal profile, showing an enhancement of resistivity ridge mid way through the profile

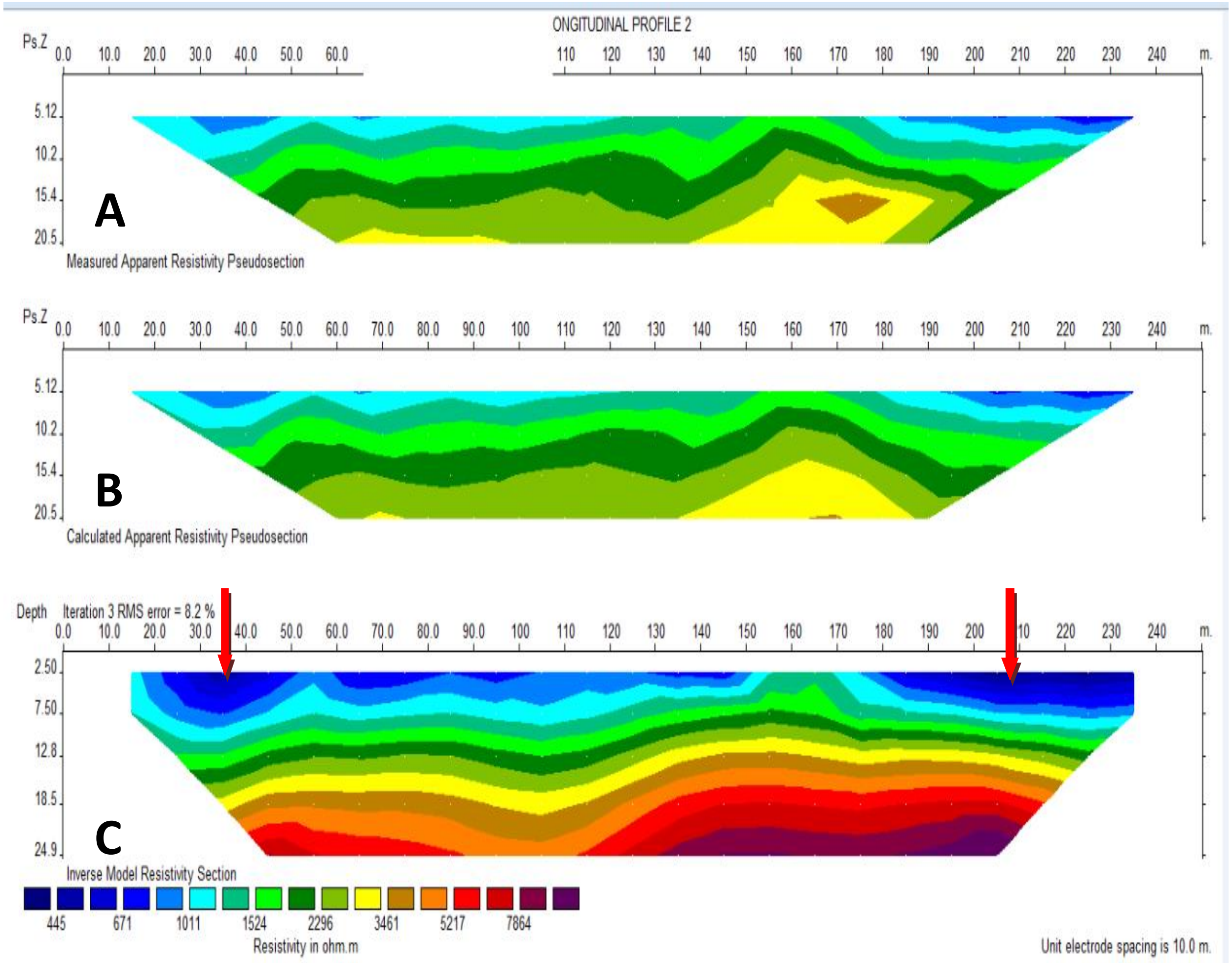

FIGURE 13: Pseudosection plot of Apparent Resistivity Data showing the stratified layers for the second longitudinal profile of the road section along Uhiele ï Opoji road at kilometer 11 to Ekpoma main town. The arrows depict regions with very low resistivity values represented by blue colour.

The pseudosections above show coloured layering of

(a) Measured apparent resistivity values of the profile
(b) Calculated apparent resistivity values of the profile
(c) Computer interpreted iterated inverse model resistivity section of the profile

PLATE 6: This picture plate is showing the part of the road where profile II was taken (upper end of Uhiele ï Opoji road, linking Ekpoma town to the East part of the country).

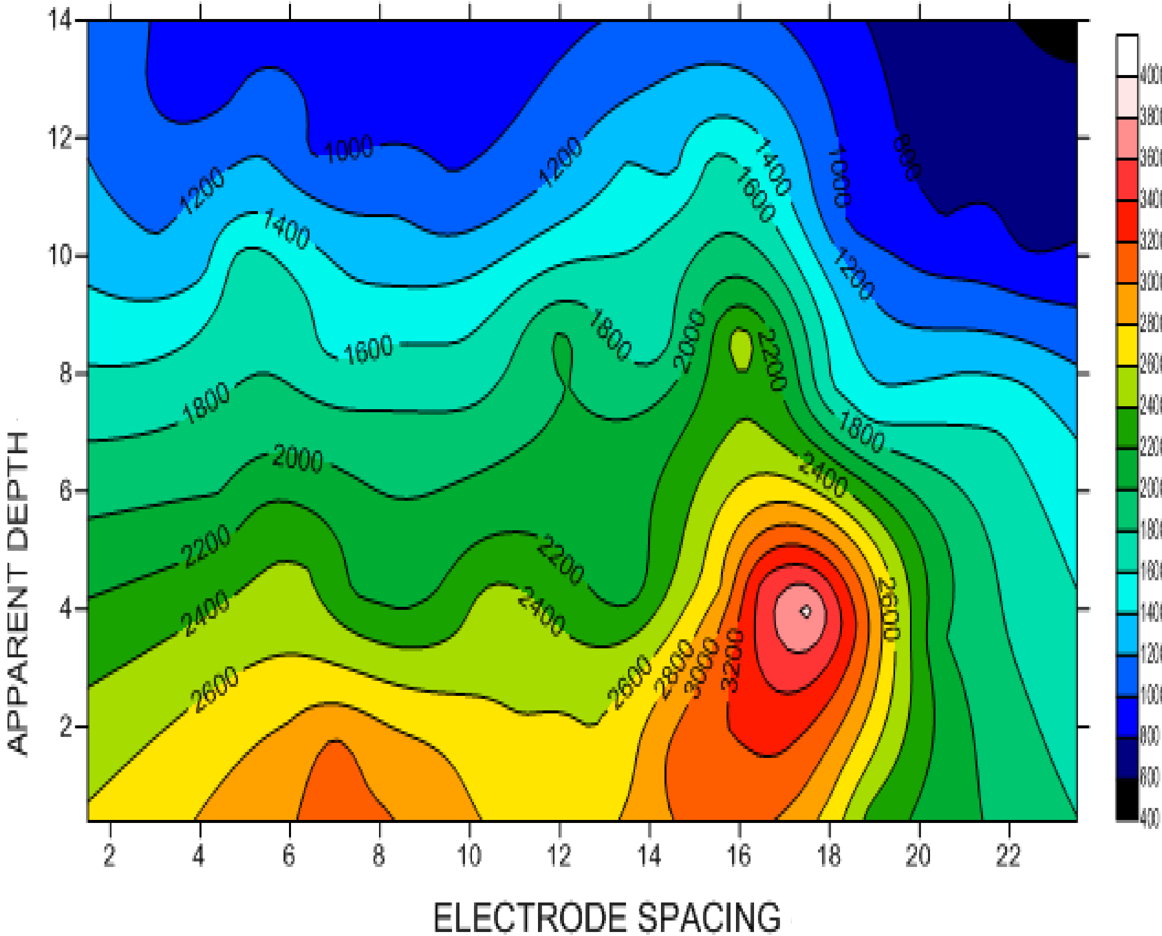

FIGURE 14: Geoelectric Isoresistivity Contour of second longitudinal profile of road segment. A plot of electrode spacing versus apparent depth. The contour lines show the apparent resistivity of layers similar to figure 13 (B).

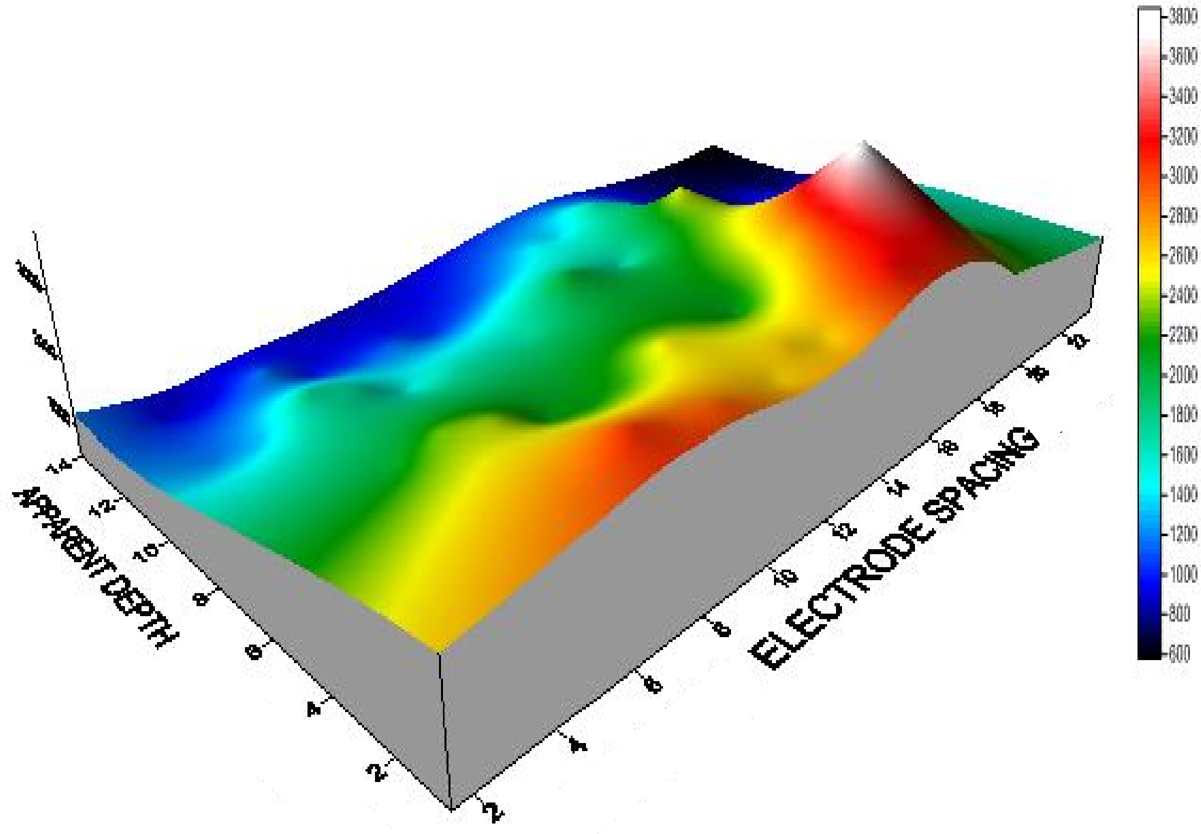

FIGURE 15: 3D maps of Traverse II showing high resistivity ridge with adjacent low resistivity zone.

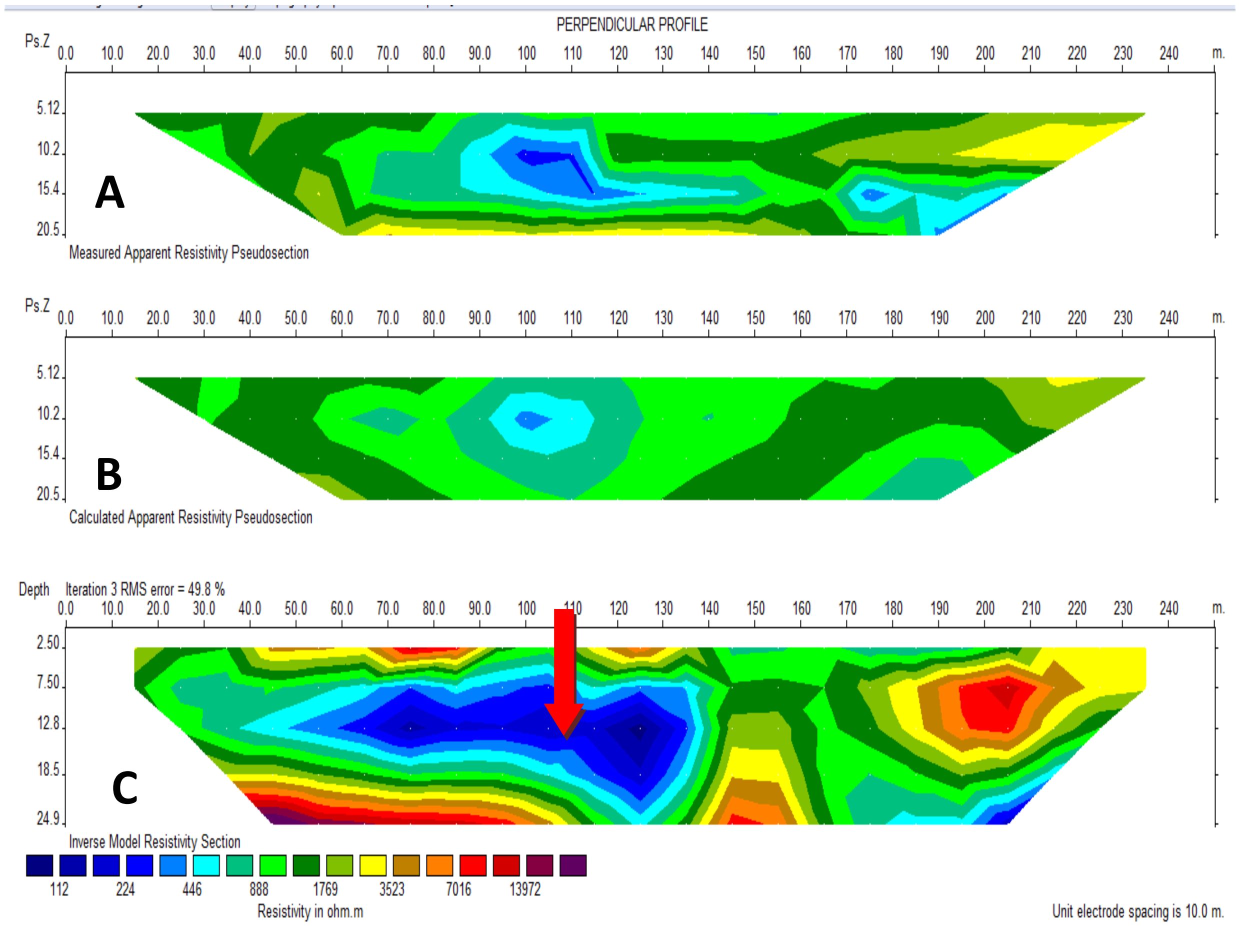

FIGURE 16: Pseudosection plot of Apparent Resistivity Data showing the stratified layers for the transverse profile of the road section along Uhiele ï Opoji road at kilometer 12 to Ekpoma main town. The arrows depict regions with very low resistivity values represented by blue colour.

The pseudosections above show coloured layering of

(a) Measured apparent resistivity values of the profile

(b) Calculated apparent resistivity values of the profile

(c) Computer interpreted iterated inverse model resistivity section of the profile

PLATE 7: This picture shows the part of the road were the transverse/perpendicular profile was taken with thin surface coating.

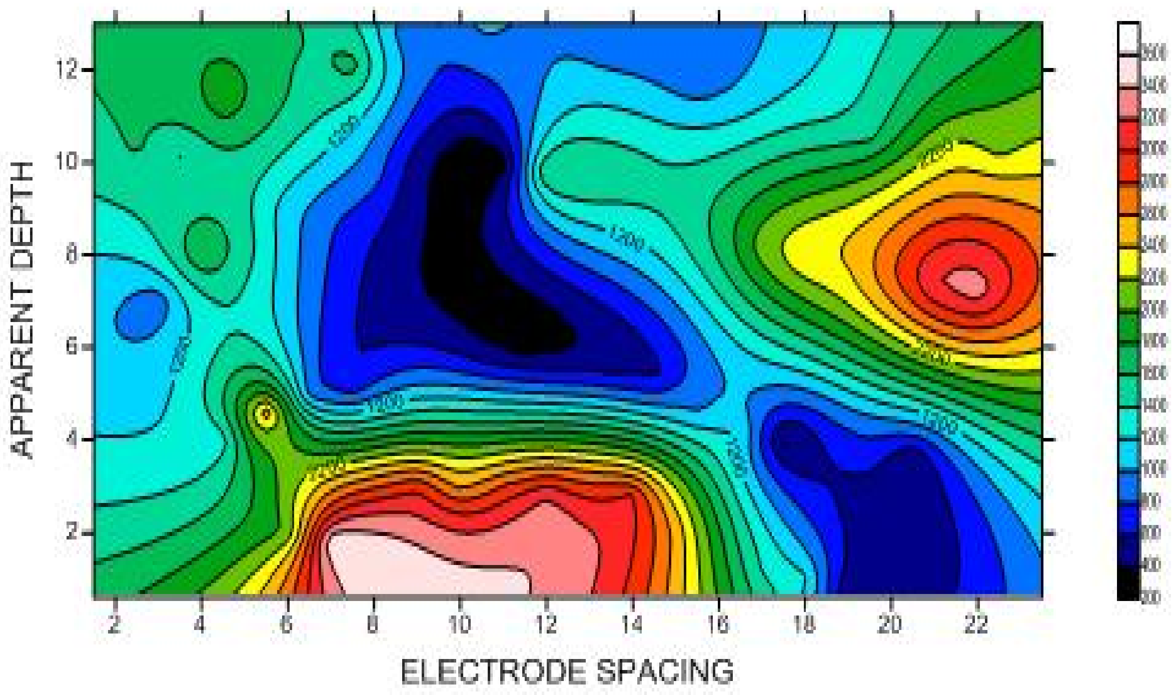

FIGURE 17: Geoelectric Isoresistivity Contour of Transverse profile of road segment. A plot of electrode spacing versus apparent depth. The contour lines show the apparent resistivity range of the area of subsurface surveyed.

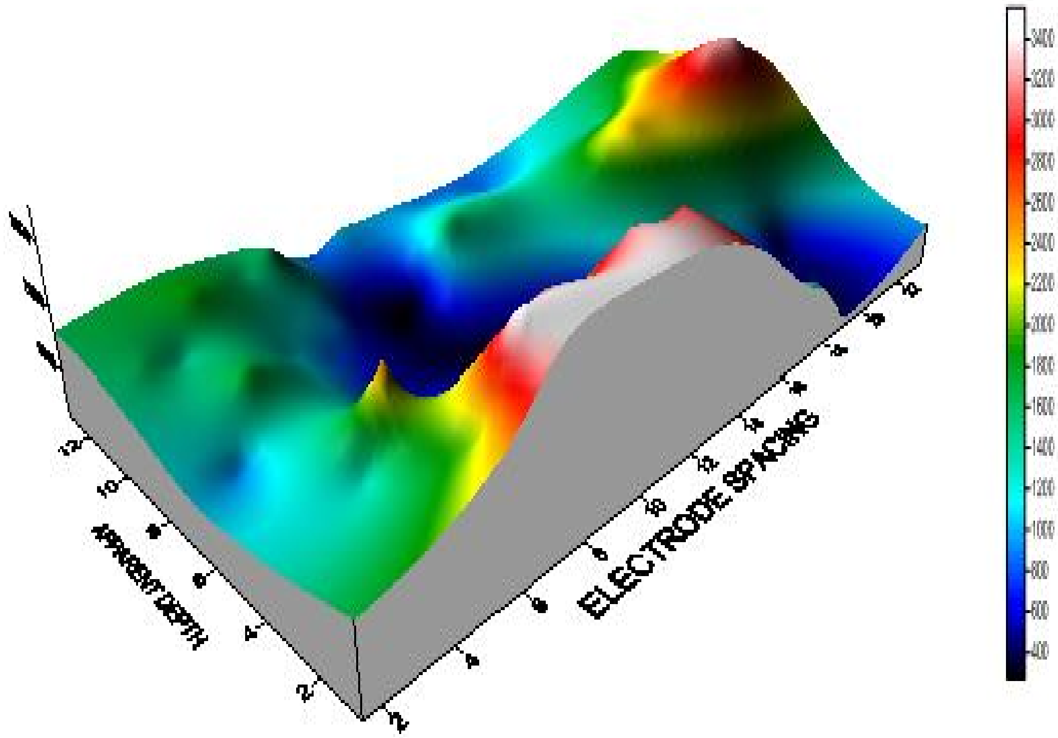

FIGURE 18: 3D map of the Transverse profile; showing a channel of low resistivity. From the surface, this agrees more with Figure 16 (B)

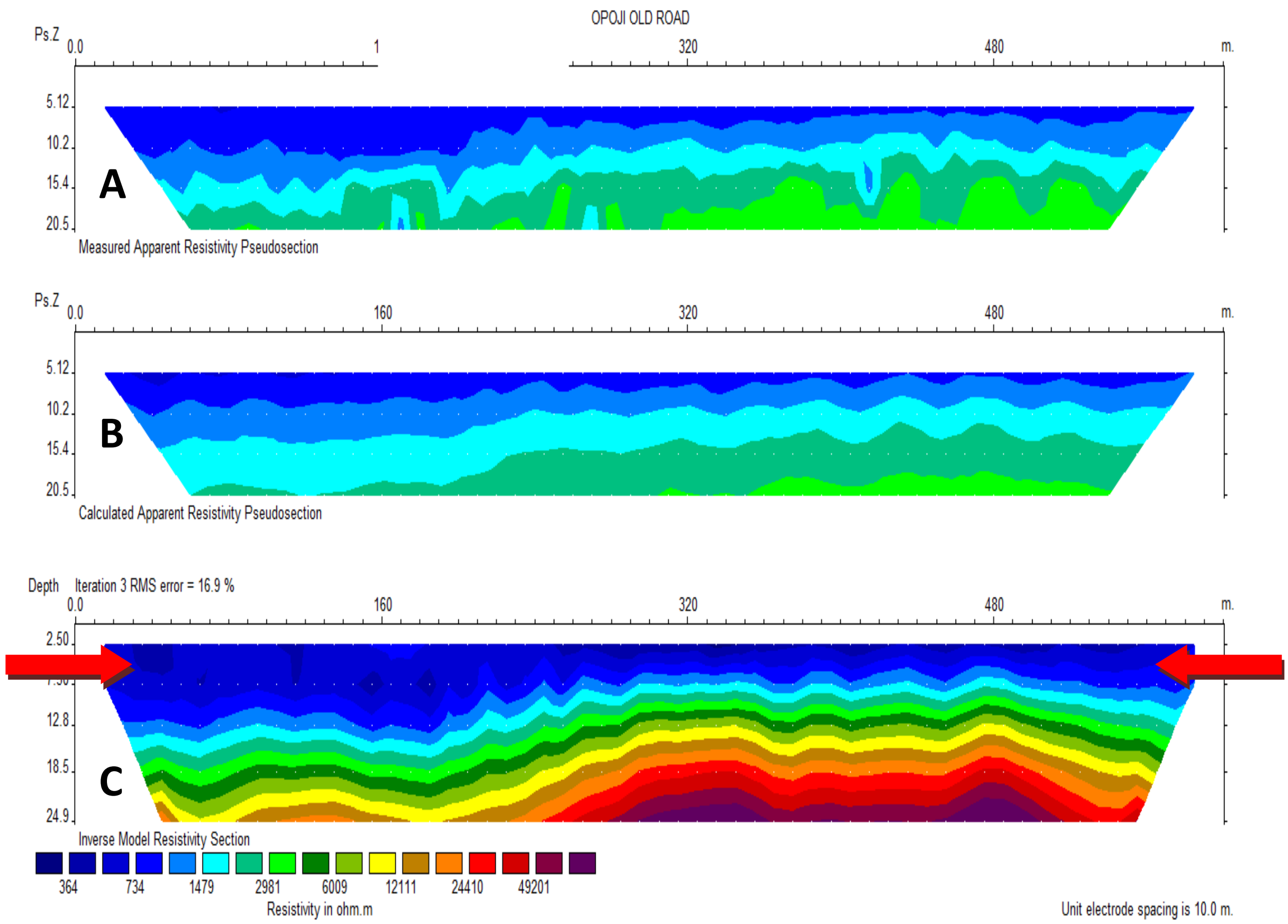

FIGURE 19: Pseudosection plot of Apparent Resistivity Data showing the stratified layers for the Opoji old road profile at kilometer 14 to Ekpoma main town. The arrows depict regions with very low resistivity values represented by blue colour.

The pseudosections above show coloured layering of

(a) Measured apparent resistivity values of the profile
(b) Calculated apparent resistivity values of the profile
(c) Computer interpreted iterated inverse model resistivity section of the profile

PLATE 8: This picture is showing the part of the Opoji old road where the profile was taken.

3.3 DISCUSSION

Careful examination of the resistivity pseudosection curves was employed to set the appropriate resistivity range that corresponds to the lithological variations beneath these profiles. The colours on tables 6, 7, 8 and 9 respectively is a pseudo match of the inverted resistivity section in Figure 10 C, Figure 13 C, Figure 16 C and Figure 19 C. Here Blue represent very poor rocks, Green represent poor rocks, Yellow represent fair rocks, Red represent good rocks and Purple represent very good rocks.

Along the first profile (Table 6), shows 4 layers; the apparent resistivity at 5m depth ranges between 798.76 ohm-m to 2335.3 ohm-m. Increasing depth to 10m, the range was between 273.94 ohm-m to 3293.2 ohm-m. With depth increased to 15m, the resistivity range was 310.04 ohm-m to 2523 ohm-m. When the depth was increased to 20m, the resistivity range was 412.79 ohm-m to 3566.7 ohm-m.

Along the second profile (Table 7), shows 4 layers; the different electrode spacing (10m, 20m, 30m, and 40m) showed different resistivity ranges. The apparent resistivity values at shallow depth of 5m range between 1561.2 ohm-m to 2214.4 ohm-m. With increasing depth to 10m, this range changes between 1614.7 ohm-m to 3034.2 ohm-m. With the depth increased to 15m, the resistivity range was 2657.7 ohm-m to 3534.4 ohm-m. With the depth increased to 20m, the resistivity range becomes 3151.4 ohm-m to 4062.4 ohm-m. There is an indication that variations in resistivity values are controlled by thickness of formation down to the basement.

Along the third profile (Table 8), shows 4 layers; perpendicular to the road section, the apparent resistivity at 5m depth ranges between 714.36 ohm-m to 1687.7 ohm-m. Increasing depth to 10m, the range was between 1211.2 ohm-m to 2511.7 ohm-m. With depth increased to

15m, the resistivity range was 2018.7 ohm-m to 3856.4 ohm-m. When the depth was increased to 20m, the resistivity range was 2281.7 ohm-m to 3193.9 ohm-m.

Profile IV (Table 9), shows 4 layers; was established along Opoji old road which is about 500m away from the first road in other to check the continuity of the subsurface geology in this terrain. The apparent resistivity at 5m depth ranges between 700.06 ohm-m to 999.72 ohm-m. Increasing depth to 10m, the range was between 789.78 ohm-m to 1995.54 ohm-m. With depth increased to 15m, the resistivity range was 1288.55 ohm-m to 3984.59 ohm-m. When the depth was increased to 20m, the resistivity range was 1231.54 ohm-m to 3994.65 ohm-m.

Table 6: The ranges of layer resistivity and lithology variations across the geoelectric sections using inverted resistivity section for Profile I

Depth (m)	Layer	Least Value (q ï m)	Maximum Value (q ï m)	Inferred Lithology
2.50 ï 7.50	1	798.76	2335.3	Shales/clay
7.50 ï 12.8	2	273.94	3293.2	Shales/clays
12.8 ï 18.5	3	310.04	2523	Shales/clay
18.5 ï 24.9	4	412.79	3566.7	Shales/clay

Table 7: The ranges of layer resistivity and lithologic variations across the geoelectric sections using inverted resistivity section for Profile II

Depth	Layer	Least Value (q ï m)	Maximum Value(q ï m)	Inferred Lithology
2.50 ï 7.50	1	1561.2	2214.4	Shales
7.50 ï 12.8	2	1614.7	3034.2	Shales
12.8 ï 18.5	3	2657.7	3534.4	Shales
18.5 ï 24.9	4	3151.4	4062.4	sandstones

Table 8: The ranges of layer resistivity and lithologic variations across the geoelectric sections using inverted resistivity section for Profile III

Depth	Layer	Least Value (q ï m)	Maximum Value(q ï m)	Inferred Lithology
2.50 ï 7.50	1	714.36	1687.7	Shales/clay
7.50 ï 12.8	2	1211.2	2511.7	Shales
12.8 ï 18.5	3	2018.7	3856.4	Shales
18.5 ï 24.9	4	2281.7	3193.9	shales

Table 9: The ranges of layer resistivity and lithologic variations across the geoelectric sections using inverted resistivity section for Profile IV

Depth	Layer	Least Value (q ï m)	Maximum Value(q ï m)	Inferred Lithology
2.50 ï 7.50	1	700.06	999.72	Clays
7.50 ï 12.8	2	789.78	1995.54	Clays
12.8 ï 18.5	3	1288.55	3984.59	Shales
18.5 ï 24.9	4	1231.54	3994.65	shales

The apparent resistivity values for all the profiles ranged from 273.94Ým to 4062.4Ým, with; 273.94 ohm-m to 3566.7 ohm-m for profile I; 1561.2 ohm-m to 4062.4 ohm-m for profile II; 714.36 ohm-m to 3856.4 ohm-m for profile III and 700.06 ohm-m to 3994.65 ohm-m for profile IV. The average range of apparent resistivity values of the entire study is 2168.17ohm-m. These range of values characteristically placed the studied area in a sedimentary basin. At an approximate depth of about 5-8 meters in all the longitudinal profiles, the measured resistivity, calculated resistivity and inverted resistivity pseudosection plots as shown in Figures 10, 13, 16, and 19, indicate a relatively low resistivity (high conductivity) profile as a result of increased porosity. The interpretation is that such low resistivity may be the result of electrolyte percolation into the subsurface. Also the high permeability in this area occurs from factors which are evident in the area such as lack of drainage system, undulating topography of terrain, poor construction materials etc. It is seen that in all the inverse resistivity model profiles investigated, low resistivity values with alternating moderately high values at 90m to 105m and 170m to 200m on profile I, 150m to 175m on profile II and also at points outside the road section on the perpendicular profile (Figure 16) from 0m to 35m and 140m to 250m. Profile IV showed very low values all through the entire length. The low resistivity values were recorded to an approximate depth of 8m in all the road sections. The least resistivity value recorded was 273.93 ohm-m and also to a range of 979.64 ohm-m which were obtained in the permeable zones of the road sections where the major cross cuttings occurred. The soaked subgrade materials, because of the cracks on the pavement surface, swells as water enters the portions with clay/silts beneath.

The high apparent resistivity values depict competent geologic materials (green, red and purple colour contours on the pseudosections) such as sand or clayey sand formation. Very low resistivity suggests clay or water saturated sands (blue colour contours), often less competent to support the stability of heavy and always busy traffic on the surface of the road pavement. The electrical resistivity contrasts existing between geoelectric layers in the area enabled the delineation of lithologic units, occurring at varying depths. Resistivity ranges and the presumed layer lithology of the various profiles are presented in the tables above. Resistivity in the range of 1-100 Ohm-m suggests clays while those in the range of 50 ï 150 Ohm-m suggest lateritic clay (Reynolds, 1997, Falaye, 2011). It is observed that the subsurface in the study area showed higher resistivity values as a result of sand filling during road construction with different types of materials like gravels, palm kernel shafts etc. The resistivity distribution of the geologic materials over the entire study area shows an alternating sequence in all the profiles (wet lateritic clays). The portion showing high resistivity values suggests areas with reliable degrees of competence of the near surface geologic materials in that zone. As earlier stated the study area is located in the sedimentary basin with all features of the soil types clearly outlined. The distribution of apparent resistivity values at different depth suggested that competent soils (Ó 1000Ým) underlie the site.

Okeke et al., 2011, and investigations from various studies showed that boreholes drilled in the study area all have an aquifer depth both for confined and unconfined aquifers greater than 120 meters. The least average aquifer resistivity obtained from VES investigations in Ekpoma and its environs is 107.70Ým (Ezomo and Ifedili, 2004). Therefore the resistivity values obtained were arbitrarily not influenced by underground water level even though the investigation was carried out during the wet (rainy) season. To this end, a recommendation has been made to the fact that adequate geological and geophysical investigation be conducted prior to drilling of any water borehole in the area (Okeke et al., 2011) to reduce the incidence of abortive boreholes which can attest to the fact that underground water is not a factor that can result to surface failure in this terrain. The subsurface geological section of the study area consists of clay and sandstone intercalation which covers the basement rocks. The thickness varies according to the variation in depth of the basement surface. This depth of basement is mainly controlled by the structural elements affecting the area during their formation. On this note, the low resistivity values are attributed to the moisture content especially near surface wet clays. Shallow basement rocks will lead to decrease in resistivity measurement.

3.4 CORRELATION BETWEEN GEOPHYSICAL DATA AND CONVENTIONAL ENGINEERING PROPERTIES OF SOILS

Among the emerging trends of field investigation methods used for analyses in Civil Engineering practices, Vertical Electric Sounding (VES) and Electrical Profiling (ER) methods are finding a wide acceptance due to the versatility of these methods as also the comparable results obtained through these methods and the other conventional field methods like Cone Penetration Tests (CPT) and Standard Penetration Tests (SPT) etc. As Vertical Electric Sounding method for geotechnical site investigations is becoming popular, an attempt was made in this study using Electrical Profiling (ER) method to correlate the data obtained, with that of conventional engineering properties of soils like stiffness and permeability etc, (Soupios, 2007).

Studies have shown that geophysical results usually correlate well with geotechnical results (Faleye and Omosuyi, 2011). High values of geotechnical analysis such as Cone Penetration Tests (CPT) and Standard Penetration Tests (SPT) have been shown to agree with high resistivity values from geophysical surveys of the same area where there is not much differential in soil liquid/fluid content. Areas with high liquid and plastic limits (Atterbergôs limit) correlate with low resistivity zones, apparently suggesting high groundwater saturation or permeable zone. The low resistivity values obtained from this study represented parts of the road that have failed which agrees with the geotechnical inference made above affirming that incompetence of the road sections is detectable through resistivity investigation. The most widely used static and dynamic penetration test are the Cone Penetration Test CPT (for soft soils) and the Standard Penetration Test SPT (for relatively hard soils) (Baldi et al., 1995, Akintorinwa and Adesoji, 2009). For CPT, a cone at the end of a series of rods is pushed into the ground at a constant rate, and measurements are made of the resistance to the penetration. This is known as ñcone resistanceò which is the total force acting on the cone divided by the projected area of the cone. The cone resistance is a direct indicator of the strength of the soil at a given depth. Cost, efficiency, speed, simplicity, reliability, and the ability to provide near continuous information on the soil properties with depth are the important reasons for the increasing popularity of CPT. The primary significance of CPT comes from the fact that it represents a miniature driven pile or foundation in soil; hence, the pile bearing capacity (pressure between a foundation and the soil which will produce shear failure in the soil) can be directly estimated from cone resistance. Thus, CPT provides valuable constraints for all settlement and stability calculations. CPT (cone resistance) responds to soil changes within five to ten times the cone diameter (standard = 35.6 mm) above and below the cone. It is of interest to know that though CPT provides valuable information as to the strength of the soil, the information is restricted to the CPT location (Eslaamizaad et al., 1998 Akintorinwa et al., 2009). CPTs are commonly performed tens or hundreds of meters apart. Soil models based on lateral interpolation of CPT data collected at a few locations at a given site obviously contain large uncertainties, increasing the risk in engineering design (Akintorinwa and Adesoji, 2009).

In resistivity instrumentation normally, the field data is obtained in the form of apparent resistivity values. The interpretation of electrical profiling data basically involves converting /

transforming apparent electrical resistivity values recorded at different current penetration depths (electrode separations, a) into true resistivity and thicknesses of various subsurface strata through which the electric current passes. The true electrical resistivity (ɟ) is a fundamental property of the material, which is independent of volume and remains constant for the isotropic and homogeneous material. For an-isotropic, non-homogeneous and stratified/layered subsurface materials, the resistivity does not remain constant throughout the depth of such deposit (Rajiv, 2011). The effective resistivity value measured for layered deposit is referred as mean or apparent resistivity (ɟ A). The apparent resistivity is a function of true resistivity and thickness of various subsurface strata through which current flows. Interpretations for diverse information can be obtained from this data, provided a thorough knowledge of the local geologic conditions and stratigraphic setup is known to the investigator. Whether true or apparent resistivity values for qualitative interpretation of the data, the apparent resistivity values have been found to be adequate e.g. distinction between soil (different stratifications) and bed rock position or even for distinguishing different major soil strata within the soil formation can also be distinguished. Thickness of backfill over the natural ground surface can be determined along with the profile of such backfill over the natural ground surface. Similarly, weathered rock zones sandwiched between the soil overburden and the bed rock, in the case of soil formed in-situ as undisturbed residual soils is also accurately possible to be determined.

Through the intensive resistivity survey in different areas and in different geologic & meteorological conditions, it has been found that different geomaterials invariably always identify themselves by certain numerical values obtained as Apparent Resistivity Values. This identity *"range of resistivity values associated with earth materials"* have been assigned to such geomaterials so as to have a proper understanding of the behaviour under in-situ conditions and thus to have a correlation with results of other conventional methods (Rajiv, 2011).

Table 10: RESISTIVITY VALUES FOR SEVERAL TYPES OF SOILS AND WATER

Types of soil or Water	Typical Resistivity Ým	Usual Limit Ým
Sea Water	2	0.1 to 10
Clay	40	8 to 70
Ground well & spring water	50	10 to 150
Clay and sand mixtures	100	4 to 300
Shale, slates, sandstone etc	120	10 to 100
Peat, loam & mud	150	5 to 250
Lake and brook water	250	100 to 400
Sand	2000	200 to 3000
Moraine gravel	3000	40 to 10000
Ridge gravel	15000	3000 to 30000
Solid granite	25000	10000 o 50000
Ice	100000	10000 to 100000

Table 11: VARIATIONS IN SOIL RESISTIVITY WITH MOISTURE CONTENT

TYPICAL RESISTIVITY (Ým)

Moisture % by weight	Clay mixed with sand	Silica Based sand
0	10 000 000	-
2.5	1 500	3 000 000
5	430	50 000
10	185	2 100
15	105	630
20	63	290
30	42	-

Tables 10 and 11 above, give various resistivity values of soil types from different geological environment. With this type of understanding and then, satisfactory information regarding the type of foundation which can be provided to any structure being planned on such terrains, the foundation depth and competence can also be decided depending upon the details of the structure. The resistivity values obtained showed a correlation with the values of clay mixed with sand for the incompetent zones and sand for the competent zones. An important factor often considered in foundation design is water table and water table fluctuation (Bowles, 1984; Coduto, 1998, Falaye, 2011). As stated earlier, underground water is not a factor that can enhance surface failure in this terrain (Okeke et al., 2011). Consequently, this correlation between apparent resistivity values of subsurface materials and the resistivity variation of the engineering properties proves that Electrical Resistivity Imaging is an interesting tool to estimate the competence of subsurface materials on which engineering structures are constructed.

3.5 RESISTIVITY OF RIPPABLE SOILS

Weak soils which are referred to as rippable soils are those found at the incompetent zones in the study area. An assessment using seismic velocity from conventional charts was used as a rating system of quantifying rippability. Effort was made to correlate the electrical resistivity with known seismic velocity of soil types. In much of the attempts to reconcile electrical resistivity and seismic velocity, the common trend is that resistivity and velocity are both functions of porosity (Rudman et al., 1975, Meju et al., 2003) and also the unifying assumption in nonï invasive experiments. An interesting observation is that the resistivity (ɉ in Ým) and seismic (*P*-wave) velocity (*Vp* in m/s) distributions seem to be related in the form

$$\mathbf{Log_{10}\,\rho = m\,Log_{10}}\,\boldsymbol{Vp} + \mathbf{c} \quad \text{---------------------} \quad (3.1)\ \text{(Meju et al., 2003)}$$

Where the constants m, and c have values of 3.88 and -11 respectively for deep consolidated rocks (> 3m deep). An inverse relation appears to hold for the unconsolidated soil/drift deposits (ie., top 3m) where m = -3.88 and c = 13 (Rudman et al., 1975, Meju et al., 2003). Laboratory measurements (Mazac et al., 1988, Meju et al., 2003) on cores suggest that resistivity increases with decreasing saturated permeability. It is also known that *Vp* increases with degree of grain packing in unconsolidated materials while *Vp* increases as the natural logarithm of permeability in consolidated materials (Marion et al., 1992, Meju et al., 2003). It is thus practical that the fracture or saturated permeability decreases with depth, with a corresponding rise in both resistivity and velocity.

The 2D psuedosection images in figures 11, 14 and 17 above suggests the presence of co-relatable trends in the near surface resistivity; and velocity and is interpreted as lending support to a hypothesis that porosity or fracture permeability may be a key factor in understanding electrical ï seismic relations in both consolidated and unconsolidated subsurface. The seismic velocity of a rock formation is related to characteristics of the rock mass which include rock hardness and strength, degree of weathering and discontinuities. Usually the velocity is just one of several parameters used in the assessment of rippability. The rippability of a rock formation is favoured by the following factors:

- Open fractures, faults and other planes of weakness of any kind
- Weathering
- Brittleness and crystalline nature
- High degree of stratification or lamination
- Large grain size
- Low compressive strength

Weaver (1975) presented a comprehensive rippability rating chart, Table 12 below; in which the *P*-wave velocity value and the relevant geological factors could be entered and assigned appropriate weightings. The total weighted index (results from apparent resistivity values substituted into equation 3.1 above) was found to correlate very well with actual rippability shown below.

Table 12: RIPPABILITY RATING CHART

Rock Class	I	II	III	IV	V
Description	**Very Good Rock**	**Good Rock**	**Fair rock**	**Poor Rock**	**Very Poor Rock**
Seismic Velocity (m/s)	>2150	2150 ï 1850	1850 ï 1500	1500 ï 1200	1200 ï 450
Rating	26	24	20	12	5
Rock Hardness	Extremely Hard Rock	Very Hard Rock	Hard Rock	Soft Rock	Very Soft Rock
Rating	10	5	2	1	0
Rock Weathering	Unweathered	Slightly Weathered	Weathered	Highly Weathered	Completely Weathered
Rating	9	7	5	3	1
Joint Spacing (mm)	>3000	3000 ï 1000	1000 ï 300	300 ï 50	<50
Rating	30	25	20	10	5
Resistivity	>3000	3000 ï 1500	1500 ï 700	700 ï 300	<300
Rating	>4.0	3.5	3.0	2.5	<2.0

The last row of the chart shows the range of apparent resistivity values of this particular study. An average value of resistivity from each column was used to obtain an approximated rating value (i.e, logarithm of apparent resistivity) of the soil types compared along side with seismic velocity values. From the apparent resistivity values, an average value for all incompetent zones (400Ωm) was taken. A seismic velocity value of 700m/s (average value for fair rocks/soils to very poor rocks/soil) was used. An effort was made by substituting the average resistivity value and the seismic velocity value for poor soils into the equation (3.1) above. The values obtained showed a good correlation. The apparent resistivity value 400Ým (for very weak zones ñblue colourò figures 11, 14 and 17) gave a ñratingò of 2.6 and an average seismic velocity value, 700m/s gave 1.96 for unconsolidated soils. The range of values given for both types of soils indicated that these parts of the study area can be grouped as fair rocks/soils in terms of hardness under rippability rating.

3.6 EFFECT OF CLAY ON RESISTIVITY

The apparent ambiguity, called low resistivity, produced by the implementation of the different geophysical methodologies indicated that the above-mentioned detected geophysical anomaly (clay outcrop) could be resolved in the context of the time the survey was conducted. As mentioned earlier in this study, the ERI measurements were carried out during the rainy season. This in compliance with various studies drove this experimental work to examine the temporal stability of the results and their relative independence of environmental conditions, by taking into account that the near-surface geological structure was studied. In order to associate the measured resistivity values with the effect of clay on resistivity and the influence of water, it is useful to refer to the general climatic trends that exist in the study area. Specifically, the climatological conditions in Edo State during rainy season are very wet with high precipitation rate. Thus, during this period subsurface clay remains much more humid through ingress of surface water. Contextually, the detected anomaly is expected to exhibit much lower resistivity compared to the surrounding geology. However, the clay, due to its low plasticity, granularity and porosity, is only slowly moistened compared to the surrounding soil types and thus appears highly conductive. Therefore the Low Resistivity behaviour of the clay and the surrounding rocks is in agreement with the measured resistivities and the literature (Butler and Knight 1998, Soupios, 2007).

CHAPTER FOUR

4.1 CONCLUSION

Stability of natural and engineered structures such as buildings, roads, dams, bridges etc, is the most vital aspect of geotechnical engineering. Geophysical methods (geoelectrical, ground penetrating radar, seismic refraction, etc) have become increasingly applied in engineering site characterization, because it is rapid and an implied cost-effective method. Among these methods, geoelectrical survey is a very attractive tool for delineating subsurface properties without soil disturbance. Several attempts have been made by many researchers to explore the phenomenon of electrical resistivity in soils and its relationship with other soil properties; such as water content, thermal resistivity, salinity, CEC, hydraulic conductivity, ground water distributions etc. Few studies have been carried out to correlate electrical resistivity and geotechnical parameters of soil such as moisture content, plasticity index, grain size etc (Fahad et. al., 2012). The conclusions derived from this study are far reaching. It readily provides resistivity to evaluate subsurface lithology geotechnically.

Resistivity surveys give a picture of the subsurface resistivity distribution. To convert the resistivity picture into a geological picture, some knowledge of typical resistivity values for different types of subsurface materials is important. Igneous and metamorphic rocks characteristically have high resistivity values. The resistivity values of these rocks are greatly dependent on the degree of fracturing, and the percentage of the fractures filled with ground water. Sedimentary rocks, which usually are more porous and have higher water content, normally have lower resistivity values. Wet soils and fresh ground water have even lower resistivity values. Clayey soil normally has a lower resistivity value than sandy soil. This is because the resistivity of a particular rock or soil sample depends on a number of factors such as the porosity, the degree of water saturation and the concentration of dissolved salts. The resistivity of ground water varies from 10 to 100 ohm meter (Ým), depending on the concentration of dissolved salts. This makes the resistivity method an ideal technique for mapping the saline and fresh water interface in coastal areas. Resistivity values have a much larger range compared to other physical quantities mapped by other geophysical methods. The resistivity of rocks and soils in a survey area can vary by several orders of magnitude. In comparison, density values used by gravity surveys usually change by less than a factor of 2, and seismic velocities usually do not change by more than a factor of 10. This makes the resistivity and other electrical or electromagnetic based methods very versatile geophysical techniques.

From the above study of the terrain and instrumentation it is clear that geophysical data if carefully obtained, processed and interpreted in the light of the terrain characteristics, it is possible to generate numerical values, as the case may be, without using the conventional field equipments and the laboratory support needed by such equipments. It is evidently clear that where cost is a factor, the terrain can be characterized for the engineering behaviour of the materials present. Therefore, the geophysical approach involving the Electrical Resistivity Imaging (ERI) methods (Wenner Array) have proven to be very useful as a method to investigate the cause of incessant road failure along Uhiele ï Opoji road in Edo state. Results from the geophysical survey identified the most probable causes of failures on the road pavement to include:

1. Differential settlement caused by clayey nature of the top soil underlying the road pavement. Clay by nature is porous and not permeable as a result of poor connectivity of its pores, has elastic properties, retain water without releasing it thus making it swell and

consequently a high tendency to deform at the exertion of pressure creating zones that are structurally weak as observed on the roads.

2. Poor subgrade materials as well as very thin asphalt coating of the surface resulted in major cracks, because it was unable to withstand heavy traffic plying this particular road.
3. Poor (none) drainage pattern for runoff at the two sides of the road pavement thereby leading to its ponding as observed on these two roads.
4. Near surface features which include undulating topography and lithological contacts or joints beneath the road pavement which act as zones of weakness that enhance the accumulation and percolation of water leading to pavement failure.

In addition, the physically obvious road failure witnessed along the profiles, are not generally as a result of the instability in the underground geology alone as revealed by studies carried out already in this locality, but rather factors like drainage and quality of materials used for the construction of the road. It was observed in this study that majority of the roads in this area and almost throughout the country, failed because the road were constructed over a considerable amount of clay as well as subgrade materials. Thin pavement coating seen virtually in all roads which can hardly resist the pressure of heavy and prolonged traffic is another factor responsible for road failure. This implies that responses to the underlying materials to imposed stresses are a dominant factor responsible for failures. For durability of Nigeria roads, such factors which result to failure of roads should be adequately checked and remedied.

4.2 CONCLUSIONS FROM GEOPHYSICAL STUDY INCLUDE

The results obtained at the end of the geophysical study;

- Was first to re-validate geophysical investigations of road failures done in times past in this geologic environment.
- To appreciate the use of geophysics as an effective and constructive method in engineering and geotechnical investigations.
- Have helped to identify some of the major causes of road failure in the basement/sedimentary complex.
- Have provided information on determination of the zones of competence and weakness along Uhiele ï Opoji Road. The resistivity values of the incompetent zones ranged from 272.93Ým to 979.64Ým and the competent zones was assumed to be greater than 1000Ým for this study.
- That underground water with average aquifer resistivity of 107.70Ým, and an average depth of 120m was exclusively not a factor that enhanced the failure of the road pavement surface
- Will provide information on mapping the bedrock using electrical images to delineate structural features such as faults, fractures, and joints etc when and where they are available.
- That Electrical Resistivity Survey is an attractive tool for delineating subsurface properties without soil disturbance.
- Will help all tiers of government in decision making towards maintenance and further construction of affected roads

4.3 RECOMMENDATIONS

The survey has facilitated a better understanding of the causes of road failure and the characterization of a segment of the Uhiele ï Opoji road. In other to forestall future occurrences of road pavement failures in this study area and other similar sites, it is recommended that;

i. Detailed geophysical investigation should be carried out on any proposed site for road construction and/or rehabilitation before embarking on the project in order to ensure long term stability and integrity of the pavement.

ii. For the purpose of the rehabilitation work that has been done on Uhiele ï Opoji road and yet still undergoing serious deformations, the clay deposits (laterite) as well as highly weathered geologic materials existing beneath the pavement and the parts of the roads sand filled with clay, should be excavated and replaced with more competent materials before laying the asphalt.

iii. There could be a need for excavation of the subsurface materials, the topsoil at depth of three to five meters especially areas were surface water have accumulated along these sections of the road and replaced with competent road-fill materials excavated to be used as road embankment.

iv. Methods like Vertical Electrical Sounding (VES), Seismic etc., can also be used to probe beyond the shallow level of the near earth surface in order to enhance a better resolution of the geoelectric sequence of the underlying earth materials in terms of delineating the various lithological units constituting the subsurface geology and the exact location and depth to aquifer zones.

v. Suitable drainage channels should be constructed with a view to resolving the problems of flooding and washing away of the pavement.

It is therefore believed that if these recommendations are strictly adhered to within and outside the area of study, road transportation in Nigeria would not only improve considerably but transform from a much deteriorated state and nightmare (which is currently the case) to a smooth and pleasant ride for all.

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