

**DETERMINATION OF SANDSTONE DEPOSIT [USING 2-
DIMENSIONAL ELECTRICAL RESISTIVITY METHOD] IN
COLLEGE OF EDUCATION, ABUDU, ORHIONWON, EDO
STATE, NIGERIA.**

BY

EMMANUEL KUDYO

(PSC1607982)

**DEPARTMENT OF PHYSICS
FACULTY OF PHYSICAL SCIENCES
UNIVERSITY OF BENIN
BENIN CITY.**

JULY, 2021.

**THE USE OF WENNER ARRAY TO DETERMINE SANDSTONE
DEPOSIT IN COLLEGE OF EDUCATION, ABUDU,
ORHIONWON, EDO STATE, NIGERIA.**

BY

EMMANUEL KUDYO

(PSC1607982)

**A PROJECT SUBMITTED TO THE DEPARTMENT OF
PHYSICS, FACULTY OF PHYSICAL SCIENCES, IN PARTIAL
FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD
OF THE DEGREE OF BACHELOR OF SCIENCE (B.Sc) OF THE
UNIVERSITY OF BENIN,
BENIN CITY, EDO STATE, NIGERIA**

JULY, 2021.

CERTIFICATION

I certify that this work was carried out by EMMANUEL KUDYO in the Department of Physics, Faculty of physical sciences, University of Benin, Benin city, Edo state, Nigeria under my supervision.

.....

PROF. O.M. ALILE(Ph.D)

(Project Supervisor)

.....

DATE

.....

PROF. O.M. ALILE (Ph.D)

(H.O.D Physics)

.....

DATE

.....

EXTERNAL EXAMINER

.....

DATE

DEDICATION

This project is dedicated to God Almighty, the One in whom I live and move and have my being. The One who keeps making a way for me. The One who have always been there for me from the beginning of my program till this time. I am eternally grateful. And to my late Dad, Surv. Yona D. Kudyo, my hero, I love you.

ACKNOWLEDGEMENT

I hereby express my sincere and profound gratitude to my family, relatives and friends for seeing me through from the inception of my academic journey to this point.

Special thanks to my project supervisor PROF. O.M. ALILE(Ph.D) for his concern and contributions, mental assistance, encouragement and understanding, thank you sir. Sincere and heartfelt gratitude to Dr John Airen for his support and encouragement, all through this work. Also, Dr. Ebomwonyi, thank you for being a great course adviser, Dr. Ben Iyorzor, thank you for being a father to everybody who has come across you, God bless you sir.

am greatly indebted to my family, especially my mum Mrs Grace Kudyo, my siblings, Natuwa Mariam Kudyo, Dr. Deborah Kudyo, Comfort Kudyo for standing by me at all time. My spiritual Father and Mother, Pastor G. and Pastor(Mrs) J. U Osobase for standing in the gap for me in prayers and for supporting me all the way. My Aunt, Mrs Oghenefegor Dittimi, thank you so much. Special thanks to friends that made my Uniben experience worthwhile. Eyitemi Urhobocho, you are the best anybody could ever have as a friend and a brother. Thank you for been there, Omoriyekewen Benjamin, Nelson Pedro, Lucius Aghoghowvia, Orihaki Queen, Ayomide Olusegun, Emmanuel Eboi, Greg Osaro, God'swill Oselu, Emmanuel Awele, my very own Emem Charles and many others, God bless you all.

ABSTRACT

The purpose of this study is to analyze sandstone deposit using 2-Dimensional Electrical resistivity tomography survey investigation of the subsurface and getting detailed structures, properties, deposited volume and it's economic importance, using the study area as a case study.

Two dimensional Electrical Resistivity Tomography (ERT) survey each of 200m in length was laid in College of Education, Abudu, Edo State to locate and delineate sandstone deposits present at igarra. Wenner-alpha array configuration was employed to acquire field data for the various transverses which were generated in parallel and perpendicular directions using dipole-dipole electrode configuration with electrode spacing of 10m. The 2D data were collated and inverted using a computer software known as RES2DINV to obtain true resistivity images of 2D model for each line, which has various options that could be altered to obtain models that correlate with the known geology of the study area. Pasi-Earth Resistivity meter was used to measure the apparent resistivity in order to obtain a 2-D image of the subsurface for each line. These geophysical survey area were observed to be composed of sandstone, clay, limestone, shale, with resistivity values ranging between 259 m Ω to 2160 m Ω for the unit electrode spacing adopted during the period in the survey areas. The data gotten has depth ranging from 2.50m to 40m beneath earth surface and width of 200m.

The first transverse has resistivity values between 20 Ω m to 1000 Ω m indicating various subsurface minerals having resistivity within that range, these indicate the presence of sedimentary rocks formation, a large percentage of shale was discovered alongside clay, sandstone and limestone in mall proportions.

The second, third and Fourth transverses have resistivity range of 25.2 Ω m to 40,000 Ω m, 20 Ω m to 3000 Ω m, 40.5 Ω m to 600 Ω m respectively, indicating the presence of marble, quartzite, sandstone, shale, limestone, clay, granite, Groundwater(freshwater) and basalt. The physical properties of sandstone, shale, limestone, granite, clay agree with some of the outcrop minerals found in the study area. It was observed that sandstone content is evenly distributed within the area of study.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND STUDY OF SUBSURFACE ROCKS AND MINERAL AVAILABILITY

Sandstones are an important group of sedimentary rocks. Supposed good estimate of the percentage of sedimentary rocks that would be classified as sandstones is about 25%.

Subsurface rocks in general are naturally made up of different minerals which are inherently insulators. Petrology, the study of rocks is concerned with the identification of the individual minerals found in a rock, their textures, abundance in nature and grain size. This information is a fundamental aspect to the understanding of the origin of a rock and its classification. Rocks can be classified into three major groups; igneous, sedimentary and metamorphic rocks (Cornelius and Cornelius, 1999). These rocks have distinct properties that gives required information on the formation of subsurface minerals, these major group of rocks are further explained as thus;

1.2 IGNEOUS ROCKS

Igneous rock makes up approximately 95% of the upper 10 miles (16 km) of the earth's crust, but their great abundance is hidden on the earth's surface by a relatively thin but widespread layer of sedimentary and metamorphic rocks. Igneous rocks have crystallized from a silicate melt known as magma (Cornelius and Cornelius, 1999). Igneous rocks are formed from the solidification of magma, which is a hot (600 to 1,300 °C, or 1,100 to 2,400 °F) molten or partially molten rock material. Earth is composed predominantly of a large mass of igneous rock

with a very thin veneer of weathered material—namely, sedimentary rock. Whereas sedimentary rocks are produced by processes operating mainly at Earth's surface by the disintegration of mostly older igneous rocks, igneous—and metamorphic—rocks are formed by internal processes that cannot be directly observed and that necessitate the use of physical-chemical arguments to deduce their origins. Because of the high temperatures within Earth, the principles of chemical equilibrium are applicable to the study of igneous and metamorphic rocks, with the latter being restricted to those rocks formed without the direct involvement of magma. Magma is thought to be generated within the plastic asthenosphere (the layer of partially molten rock underlying Earth's crust) at a depth below about 60 kilometres (40 miles). Because magma is less dense than the surrounding solid rocks, it rises toward the surface. It may settle within the crust or erupt at the surface from a volcano as a lava flow. Rocks formed from the cooling and solidification of magma deep within the crust are distinct from those erupted at the surface mainly owing to the differences in physical and chemical conditions prevalent in the two environments. Within Earth's deep crust the temperatures and pressures are much higher than at its surface; consequently, the hot magma cools slowly and crystallizes completely, leaving no trace of the liquid magma. The slow cooling promotes the growth of minerals large enough to be identified visually without the aid of a microscope (called phaneritic, from the Greek *phaneros*, meaning "visible"). On the other hand, magma erupted at the surface is chilled so quickly that the individual minerals have little or no chance to grow. As a result, the rock is either composed of minerals that can be seen only with the aid of a microscope (called aphanitic, from the Greek *aphanēs*, meaning "invisible") or contains no minerals at all (in the latter case, the rock is composed of glass, which is a highly viscous liquid). This results in two main categories of Igneous rocks which are: (i) plutonic intrusive igneous rocks that solidified deep within the crust

and (ii) volcanic, or extrusive, igneous rocks formed at Earth's surface. Some intrusive rocks, known as subvolcanic, were not formed at great depth but were instead injected near the surface where lower temperatures result in a more rapid cooling process; these tend to be aphanitic and are referred to as hypabyssal intrusive rocks.

Generally, the intrusive rocks have cross-cutting contacts with the country rocks that they have invaded, and in many cases the country rocks show evidence of having been baked and thermally metamorphosed at these contacts. The exposed intrusive rocks are found in a variety of sizes, from small veinlike injections to massive dome-shaped batholiths, which extend for more than 100 square kilometres (40 square miles) and make up the cores of the great mountain ranges. As magma cools there is generally a definite order of crystallization of the various mineral constituents. When this takes place at considerable depths, the rocks are referred to as Extrusive and Intrusive rocks which are explained respectively

Extrusive rocks occur in two forms:

- (i) as lava flows that flood the land surface much like a river and,
- (ii) as fragmented pieces of magma of various sizes (pyroclastic materials), which often are blown through the atmosphere and blanket Earth's surface upon settling.

1.2.1 COMPOSITION AND CHEMICAL COMPONENTS OF IGNEOUS ROCKS

The great majority of the igneous rocks are composed of silicate minerals (meaning that the basic building blocks for the magmas that formed them are made of silicon [Si] and oxygen [O]), but minor occurrences of carbonate-rich igneous rocks are found as well. Indeed, in 1960 a sodium carbonate (Na_2CO_3) lava with only 0.05 weight percent silica (SiCO_3) was erupted from a volcano

in northern Tanzania, Africa. Because of the limited occurrence of such carbonate-rich igneous rocks, however, the following discussion will consider the chemistry of silicate rocks only. The major oxides of the rocks generally correlate well with their silica content: those rocks with low silica content are enriched in magnesium oxide (MgO) and iron oxides (FeO, Fe₂O₃, and Fe₃O₄) and are depleted in soda (Na₂O) and potash (K₂O); those with a large amount of silica are depleted in magnesium oxide and iron oxides but are enriched in soda and potash. Both calcium oxide (CaO) and alumina (Al₂O₃) are depleted in the rocks that have a silica content of less than about 45 weight percent, but, above 45 percent, calcium oxide can be as high as 10 percent; this amount decreases gradually as the silica increases. Alumina in rocks that contain more than 45% silica is generally above or approximately 14%, with the greatest abundance occurring at an intermediate silica content of about 56%. Because of the importance of silica content, it has become common practice to use this feature of igneous rocks as a basis for subdividing them into the following groups: silicic or felsic (or acid, an old and discredited but unfortunately entrenched term), rocks having more than 66 percent silica; intermediate, rocks with 55% to 66% silica; and subsilicic, rocks containing less than 55% silica. The latter may be further divided into two groups: mafic, rocks with 45 to 55% silica and ultramafic, those containing less than 50%. The subsilicic rocks, enriched as they are in iron (Fe) and magnesium (Mg), are termed femic (from ferrous iron and magnesium), whereas the silicic rocks are referred to as sialic (from silica and aluminum, with which they are enriched) or salic (from silica and aluminum). The terms mafic (from magnesium and ferrous iron) and felsic (feldspar and silica) are used interchangeably with femic and sialic.

The silica content also reflects the mineral composition of the rocks. As the magma cools and begins to crystallize, silica is taken from the magma to be

combined with the other cationic oxides to form the silicate minerals. For example, one mole of SiO_2 is combined with one mole of MgO to make the magnesium-rich pyroxene, MgSiO_3 (enstatite): $\text{SiO}_2 + \text{MgO} \rightarrow \text{MgSiO}_3$. Two moles of SiO_2 are needed to be combined with one mole each of CaO and Al_2O_3 make the calcium-rich plagioclase, $\text{CaAl}_2\text{Si}_2\text{O}_8$ (anorthite).



Fig 1.1 Image of an Igneous rock, Andesite (geology.com)

1.3 SEDIMENTARY ROCKS

Sedimentary rocks are produced by the weathering of preexisting rocks and the subsequent transportation and deposition of the weathering products. Weathering refers to the various processes of physical disintegration and chemical decomposition that occur when rocks at the Earth's surface are exposed to the atmosphere (mainly in the form of rainfall) and the hydrosphere. These processes produce soil, unconsolidated rock detritus, and components dissolved in groundwater and runoff. Erosion is the process by which

weathering products are transported away from the weathering site, either as solid material or as dissolved components, eventually to be deposited as sediment. Any unconsolidated deposit of solid weathered material constitutes sediment. It can form as the result of deposition of grains from moving bodies of water or wind, from the melting of glacial ice, and from the downslope slumping (sliding) of rock and soil masses in response to gravity, as well as by precipitation of the dissolved products of weathering under the conditions of low temperature and pressure that prevail at or near the surface of the Earth.

1.3.1 COMPOSITION OF SEDIMENTARY ROCKS

Sedimentary rocks are the lithified equivalents of sediments. They typically are produced by cementing, compacting, and otherwise solidifying preexisting unconsolidated sediments. Some varieties of sedimentary rock, however, are precipitated directly into their solid sedimentary form and exhibit no intervening existence as sediment. Organic reefs and bedded evaporites are examples of such rocks. Because the processes of physical (mechanical) weathering and chemical weathering are significantly different, they generate markedly distinct products and two fundamentally different kinds of sediment and sedimentary rock:

- (i) terrigenous clastic sedimentary rocks and,
- (ii) allochemical and orthochemical sedimentary rocks.

Geologic materials cycle through various forms. Sediments composed of weathered rock lithify to form sedimentary rock, which then becomes metamorphic rock under the pressure of Earth's crust. When tectonic forces thrust sedimentary and metamorphic rocks into the hot mantle, they may melt and be ejected as magma, which cools to form igneous, or magmatic rock.

Clastic terrigenous sedimentary rocks consist of rock and mineral grains, or clasts, of varying size, ranging from clay-, silt-, and sand- up to pebble-, cobble-, and boulder-size materials. These clasts are transported by gravity, mudflows, running water, glaciers, and wind and eventually are deposited in various settings (e.g., in desert dunes, on alluvial fans, across continental shelves, and in river deltas). Because the agents of transportation commonly sort out discrete particles by clast size, terrigenous clastic sedimentary rocks are further subdivided on the basis of average clast diameter. Coarse pebbles, cobbles, and boulder-size gravels lithify to form conglomerate and breccia; sand becomes sandstone; and silt and clay form siltstone, claystone, mudrock, and shale. Chemical sedimentary rocks form by chemical and organic reprecipitation of the dissolved products of chemical weathering that are removed from the weathering site. Allochemical sedimentary rocks, such as many limestones and cherts, consist of solid precipitated nondetrital fragments (allochems) that undergo a brief history of transport and abrasion prior to deposition as nonterrigenous clasts. Examples are calcareous or siliceous shell fragments and oöids, which are concentrically layered spherical grains of calcium carbonate. Orthochemical sedimentary rocks, on the other hand, consist of dissolved constituents that are directly precipitated as solid sedimentary rock and thus do not undergo transportation. Orthochemical sedimentary rocks include some limestones, bedded evaporite deposits of halite, gypsum, and anhydrite, and banded iron formations.

1.3.2 ECONOMIC IMPORTANCE OF SEDIMENTARY ROCKS

Finally, it is appropriate to underscore the economic importance of sedimentary rocks. For example, they contain essentially the world's entire store of oil and natural gas, coal, phosphates, salt deposits, groundwater, and other natural resources.

Sedimentary petrology is the study of their occurrence, composition, texture, and other overall characteristics, while sedimentology emphasizes the processes by which sediments are transported and deposited. Sedimentary petrography involves the classification and study of sedimentary rocks using the petrographic microscope. Stratigraphy covers all aspects of sedimentary rocks, particularly from the perspective of their age and regional relationships as well as the correlation of sedimentary rocks in one region with sedimentary rock sequences elsewhere. Sedimentary rocks cover approximately 80% of the earth's land surface, but their total contribution to the upper 10 miles (16 km) of the earth's crust is estimated to be only about 5%. As such the sedimentary sequences represent only a veneer over a crust, consisting mainly of igneous and metamorphic rocks (Cornelius and Cornelius, 1999).



Fig 1.2 Image of a sedimentary rock, Breccia (geology.com)

1.4 METAMORPHIC ROCKS

The word metamorphism is taken from the Greek for “change of form”; metamorphic rocks are derived from igneous or sedimentary rocks that have altered their form (recrystallized) as a result of changes in their physical environment. Metamorphism comprises changes both in mineralogy and in the fabric of the original rock. In general, these alterations are brought about either by the intrusion of hot magma into cooler surrounding rocks (contact metamorphism) or by large-scale tectonic movements of Earth’s lithospheric plates that alter the pressure-temperature conditions of the rocks (regional metamorphism; see also plate tectonics). Minerals within the original rock, or protolith, respond to the changing conditions by reacting with one another to produce a new mineral assemblage that is thermodynamically stable under the new pressure-temperature conditions. These reactions occur in the solid state but may be facilitated by the presence of a fluid phase lining the grain boundaries of the minerals. In contrast to the formation of igneous rocks, metamorphic rocks do not crystallize from a silicate melt, although high-temperature metamorphism can lead to partial melting of the host rock.

1.4.1 FORMATION OF METAMORPHIC ROCKS

Geologic materials cycle through various forms. Sediments composed of weathered rock lithify to form sedimentary rock, which then becomes metamorphic rock under the pressure of Earth's crust. Because most of Earth’s mantle is solid, metamorphic processes may also occur there. Mantle rocks are seldom observed at the surface because they are too dense to rise, but occasionally a glimpse is presented by their inclusion in volcanic materials. Such rocks may represent samples from a depth of a few hundred kilometers, where pressures of about 100 kilobars (3 million inches of mercury) may be operative. Experiments at high pressure have shown that few of the common

minerals that occur at the surface will survive at depth within the mantle without changing to new, high-density phases, in which atoms are packed more closely together. Thus, the common form of SiO_2 , quartz, with a density of 2.65 grams per cubic cm (1.53 ounces per cubic inch), transforms to a new phase, stishovite, with a density of 4.29 grams per cubic centimeter (2.48 ounces per cubic inch). Such changes are of critical significance in the geophysical interpretation of Earth's interior.

In general, temperatures increase with depth within Earth along curves referred to as geotherms. The specific shape of the geotherm beneath any location on Earth is a function of its corresponding local tectonic regime. Metamorphism can occur either when a rock moves from one position to another along a single geotherm or when the geotherm itself changes form. The former can take place when a rock is buried or uplifted at a rate that permits it to maintain thermal equilibrium with its surroundings. This type of metamorphism occurs beneath slowly subsiding sedimentary basins and also in the descending oceanic plate in some subduction zones. The latter process occurs either when hot magma intrudes and alters the thermal state of a stationary rock or when the rock is rapidly transported by tectonic processes (e.g., thrust faulting or large-scale folding) into a new depth-temperature regime in, for example, areas of collision between two continents. Regardless of which process occurs, the result is that a collection of minerals that are thermodynamically stable at the initial conditions are placed under a new set of conditions at which they may or may not be stable. If they are no longer in equilibrium with one another under the new conditions, the minerals will react in such a way as to approach a new equilibrium state. This may involve a complete change in mineral assemblage or simply a shift in the compositions of the preexisting mineral phases. The resultant mineral assemblage will reflect the chemical composition of the

original rock and the new pressure-temperature conditions to which the rock was subjected. Examples of metamorphic rocks are Slate, Marble, Schist, Gneiss etc.



Fig 1.3. Image of a metamorphic rock, Amphibolite (geology.com)

1.5 SANDSTONE

Sandstones are siliciclastic sedimentary rocks that consist mainly of sand-size grains (clast diameters from 2 to 1/16 millimetre) either bonded together by interstitial chemical cement or lithified into a cohesive rock by the compaction of the sand-size framework component together with any interstitial primary (detrital) and secondary (authigenic) finer-grained matrix component. They grade, on the one hand, into the coarser-grained siliciclastic conglomerates and breccias described above, and, on the other hand, into siltstones and the various finer-grained mudrocks described below. Like their coarser analogues—namely, conglomerates and breccias—sand-size (also called arenaceous) sedimentary rocks are not exclusively generated by the physical disintegration

of preexisting rocks. Varieties of limestone that contain abundant sand-size allochems like oöids and fossil fragments are, in at least a textural sense, types of sandstones, although they are not terrigenous siliciclastic rocks. Such rocks, called micrites when lithified or carbonate sands when unconsolidated, are more properly discussed as limestones. Also, pyroclastic sandstones or tuffs formed by lithifying explosively produced volcanic ash deposits can be excluded from this discussion because their origin is unrelated to weathering.

Sandstones are significant for a variety of reasons. Volumetrically they constitute between 10 and 20% of the Earth's sedimentary rock record. They are resistant to erosion and therefore greatly influence the landscape. When they are folded, they create the backbone of mountain ranges like the Appalachians of eastern North America, the Carpathians of east-central Europe, the Pennines of northern England, and the Apennine Range of Italy; when flat-lying, they form broad plains and plateaus like the Colorado and Allegheny plateaus.

1.5.1 ECONOMIC IMPORTANCE OF SANDSTONE

Sandstones are economically important as major reservoirs for both petroleum and water, as building materials, and as valuable sources of metallic ores. Most significantly, they are the single most useful sedimentary rock type for deciphering Earth history. Sandstone mineralogy is the best indicator of sedimentary provenance: the nature of a sedimentary rock source area, its composition, relief, and location. Sandstone textures and sedimentary structures also are reliable indexes of the transportational agents and depositional setting.

1.5.2 SANDSTONE COMPONENTS AND COLOUR

There are three basic components of sandstones:

- (1) detrital grains, mainly transported, sand-size minerals such as quartz and feldspar,
- (2) detrital matrix of clay or mud, which is absent in “clean” sandstones, and
- (3) cement that is chemically precipitated in crystalline form from solution and that serves to fill up original pore spaces.

The colour of a sandstone depends on its detrital grains and bonding material. An abundance of potassium feldspar often gives a pink colour; this is true of many feldspathic arenites, which are feldspar-rich sandstones. Fine-grained, dark-coloured rock fragments, such as pieces of slate, chert, or andesite, however, give a salt-and-pepper appearance to a sandstone. Iron oxide cement imparts tones of yellow, orange, brown, or red, whereas calcite cement imparts a gray colour. A sandstone consisting almost wholly of quartz grains cemented by quartz may be glassy and white. A chloritic clay matrix results in a greenish black colour and extreme hardness; such rocks are wackes.

1.5.3 FORMATION OF SANDSTONES

The formation of Sandstones involves two fundamentally important stages.

- a layer or mostly layers of sand accumulated as a result of sedimentation either from water body or from air (as in desert). Typically, sedimentation occurs by the sand settling out from suspension , that is, ceasing to be rebounded along the bottom of a body of water or desert air. Finally once it has accumulated, the sand becomes sandstone when it is compacted by the

pressure of overlying deposits and cemented by the precipitation of minerals within the pore spaces between sand and grains.

- cementing materials; they include silica and calcium carbonate which are often derived either from dissolution or from alteration of other sand after it was buried. The environment where it is deposited is crucial in determining the characteristics of the resulting sandstone, which in finer detail, include its grain size, sorting and composition and in more general form include the rock geometry and sedimentary structures.

Sandstones occur in strata of all geologic ages. The formation of Sandstones involves two fundamentally important stages. Firstly, a layer or mostly layers of sand accumulated as a result of sedimentation either from water body or from air (as in desert). Typically, sedimentation occurs by the sand settling out from suspension , that is, ceasing to be rebounded along the bottom of a body of water or desert air. Finally once it has accumulated, the sand becomes sandstone when it is compacted by the pressure of overlying deposits and cemented by the precipitation of minerals within the pore spaces between sand and grains.

The most common cementing materials are silica and calcium carbonate which are often derived either from dissolution or from alteration of other sand after it was buried. The environment where it is deposited is crucial in determining the characteristics of the resulting sandstone, which in finer detail, include its grain size, sorting and composition and in more general form include the rock geometry and sedimentary structures.

1.5.4 BEDDING STRUCTURE OF SANDSTONE

One of the most fruitful methods of deciphering the environment of deposition and direction of transport of ancient sandstones is detailed field study of the sedimentary structures. Bedding in sandstones, expressed by layers of clays, micas, heavy minerals, pebbles, or fossils, may be tens of feet thick, but it can range downward to paper-thin laminations. Flagstone breaks in smooth, even layers a few centimeters thick and is used in paving. Thin, nearly horizontal lamination is characteristic of many ancient beach sandstones. Bedding surfaces of sandstones may be marked by ripples (almost always of subaqueous origin), by tracks and trails of organisms, and by elongated grains that are oriented by current flow (fossils, plant fragments, or even elongated sand grains). Sand-grain orientation tends to parallel direction of the current; river-channel trends in fluvial sediments, wave-backwash direction in beach sands, and wind direction in eolian sediments are examples of such orientation.

A great variety of markings, such as flutes and scour and fill grooves, can be found on the undersides of some sandstone beds. These markings are caused by swift currents during deposition; they are particularly abundant in sandstones deposited by turbidity currents. Within the major beds, cross-bedding is common. This structure is developed by the migration of small ripples, sand waves, tidal-channel large-scale ripples, or dunes and consists of sets of beds that are inclined to the main horizontal bedding planes. Almost all sedimentary environments produce characteristic types of cross-beds; as one example, the lee faces of sand dunes (side not facing the wind) may bear cross-beds as much as 33 meters (108 feet) high and dipping 35°.

Some sandstones contain series of graded beds. The grains at the base of a graded bed are coarse and gradually become finer upward, at which point there

is a sharp change to the coarse basal layer of the overlying bed. Among the many mechanisms that can cause these changes in grain size are turbidity currents, but in general they can be caused by any cyclically repeated waning current. After the sand is deposited, it may slide down slope or subside into soft underlying clays. This shifting gives rise to contorted or slumped bedding on a scale of centimeters to tens of meters. Generally these are characteristic of unstable areas of rapid deposition. Local cementation may result in concretions of calcite, pyrite, barite, and other minerals. These can range from sand crystals or barite roses to spheroidal or discoidal concretions tens of meters across.

1.5.5 TEXTURE OF SANDSTONE

The texture of a sandstone is the sum of such attributes as the clay matrix, the size and sorting of the detrital grains, and the roundness of these particles. To evaluate this property, a scale of textural maturity that involved four textural stages was devised in 1951. These stages are described as follows. Immature sandstones contain a clay matrix, and the sand-size grains are usually angular and poorly sorted. This means that a wide range of sand sizes is present. Such sandstones are characteristic of environments in which sediment is dumped and is not thereafter worked upon by waves or currents. These environments include stagnant areas of sluggish currents such as lagoons or bay bottoms or undisturbed seafloor below the zone of wave or current action. Immature sands also form where sediments are rapidly deposited in subaerial environments, such as river floodplains, swamps, alluvial fans, or glacial margins. Sub-mature sandstones are created by the removal of the clay matrix by current action. The sand grains are, however, still poorly sorted in these rocks. Sub-mature sandstones are common as river-channel sands, tidal-channel sands, and shallow submarine sands swept by unidirectional currents. Mature

sandstones are clay-free, and the sand grains are subangular, but they are well sorted—that is, of nearly uniform particle size. Typically, these sandstones form in environments of current reversal and continual washing, such as beaches. Supermature sandstones are those that are clay-free and well sorted and, in addition, in which the grains are well rounded. These sandstones probably formed primarily as desert dunes, where intense eolian abrasion over a very long period of time may wear sand grains to nearly spherical shapes.



Fig 1.4. Image of Sandstone (geology.com)

AIM AND OBJECTIVES OF THE STUDY

The aim of this study is to use Geophysical Methods to delineate the presence of mineral deposits at College of Education, Abudu, Edo State. The objectives are to:

- i. Acquire 2D resistivity data in parallel and perpendicular directions of the survey location

- ii. Invert the data set to produce 2D images of the subsurface using RES2DINV software
- iii. Use Electrical Resistivity Survey to investigate the presence of surface and near surface conductivity and resistivity for sandstone formation
- iv. Proffer adequate information on the availability and evaluate the strength of sandstone and different subsurface soil layers in the study area for economic use

1.7 GEOGRAPHICAL LOCATION AND AREA

The study area lies within longitude 6.02822 and 006°01'41.59"E and latitude 6.295859 and 006°17'45.09"N of the Equator in Edo State region. The study area was accessible by roads (major and minor) and footpaths. The study area is overlain by materials with range between loose sandy to very coarse sand. Edo state is situated in the South-Southern part of Nigeria, it is an important sedimentary basin in Nigeria due to her closeness to the oil fields within the Niger-Delta area of the Country.



Fig 1.5 Geological map of Abudu and neighbouring towns.

1.8 CLIMATE AND VEGETATION

The climatic condition of Abudu and its environs fall within the warm-horrid tropical climate region where the wet and dry seasons are noticed prominently in the area. The rainy season last for about seven months (May to October) and the dry season last for about five months (November to April). Rainfall is moderate between the months of March and May and heaviest between June and September with average rainfall between 1000 mm and 1500 mm and temperature as high as 36.7°C especially within the hottest period of February to April. The study area lies within the Guinea Savannah vegetation belt

characterized by short trees and tall grasses. The vegetation here is prominently made up of sparsely distributed trees, herbs, shrubs, and grasses. The trees (mango and orange) help check the activities of erosion. Trees in this area are mostly concentrated along fracture zones within the plutonic bodies and on the Quartzite ridges where adequate soil cover has resulted and there is adequate groundwater retention. The vegetation in this area is mostly secondary i.e. the natural vegetation is being altered and such agricultural crops such as Maize, Yam, Cocoa, Cassava, Pineapple, Cashew, Mango, and Sugar cane are grown.

1.9 SETTLEMENT AND LAND-USE

The major occupation of the inhabitants of Abudu and its environs is mainly subsistence farming and the major crops produced are yams, cassava and pineapples, others are maize and cocoa. Most of these farming activities are carried out in the valleys which in most cases have loamy soils and also within a region that has a high water table. The process of bush burning is followed by hunting of bush animals by the indigenes. Some of the farmers produce palm oil in small quantities from the palm trees.

The economy of Orhionwon cuts across Agriculture which serves as the major means of employment for about 83.5% of the working class population. About 8.8% are Traders while about 4.3% are Educationists which indicates a low level of Education in the area and 4.0% Health care providers.

The climatic condition of Abudu and its environs fall within the warm-horrid tropical climate region where the wet and dry seasons are noticed prominently in the area. The vegetation in this area is mostly secondary i.e. the natural vegetation is being altered and such agricultural crops such as Maize, Yam, Cocoa, Cassava, Pineapple, Cashew, Mango, and Sugar cane are grown.

1.10 WEATHERING AND EROSION

The study area and most part of South-southern Nigeria are currently being devastated by soil and gully erosion at alarming rates and magnitudes. Several workers have attributed the prevalence of gully erosion to climatic and anthropogenic factors (Ofomata, 1973). (Nwajide, 1980), recognized biologic and hydro geotechnical characteristics of the gully areas as important factors in the gullying process. The high incidence of gullying and land sliding result from the susceptibility of the sandy units to erosion under the influence of meteoric and anthropogenic factors.

CHAPTER TWO

LITERATURE REVIEW

2.1 ELECTRICAL RESISTIVITY METHOD

Electrical Resistivity Tomography (ERT) is a geophysical technique for imaging subsurface structures from electrical measurements made at the surface of the ground. It is currently the most frequently used geo-electrical method (Dahlin 1996, Loke 2010). It is broadly used in geomorphology (Schrott and Sass 2008) engineering (Daily and Ramirez 2000), archeology (Cararelli 2002, Moscicki 2008) and environmental studies (Dahlin et al. 2006, Amidu and Dunbar 2008, Georgaki et al. 2008, Sechman et al. 2013). As with all other resistivity methods, ERT employs an artificial source of electric current (DC or low frequency AC), which is introduced into the ground through point metallic stakes (electrodes). The purpose of electrical resistivity surveys is to determine the subsurface resistivity distribution. High density ERT is receiving much attention for near surface geophysical prospecting (Zhou, 2007; Zhou et al, 2001, 2002, 2004; Kemma et. Al. 2002) Application either use the earth's resistivity to characterize site and understand the subsurface geologic structures and lithology (Shima, 1992, 1995; Susuki and Ohnishi, 1995) or utilize the temporal variation of the earth's resistivity to investigate underlying physical and chemical processes (Zhou et al., 2001, 2002, 2004). Usually only the earth's resistivity or electrical potential data are available, so a successful application of ERT requires a reliable inversion algorithm that can convert the measured data to spatial distribution of resistivity (Zhou, 2007). Geophysical inversion seeks to find a model that gives a response that is similar to the actual measured values. The model has a set of model parameters that are physical quantities to be estimated from the observed data. The model response is the synthetic data that can be calculated from the mathematical relationship

defining the model for a given set of model parameters. All inversion methods essentially try to determine a model for the subsurface whose response agrees with the measured data subject to certain restrictions.

Dipole-Dipole array is widely used in resistivity/induced polarization(I.P) surveys because of the low electromagnetic (EM) coupling between the current and potential circuits. The choice of a particular method is governed by the nature of the terrain and cost (Alile, 2008). Electrical and electromagnetic (EM) methods have been important in the field of Applied Geophysics for about a century, particularly for shallow and near-surface investigations. The use of geoelectrical resistivity surveys for investigating subsurface layered media has its origin in 1912 due to the work of Conrad Schlumberger who conducted the first geoelectrical resistivity experiment in the fields of Normandy; and about 1915, a similar idea was developed by Frank Wenner in the United State of American (USA) (Kunetz, 1966). Ever since, geoelectrical resistivity surveying has greatly improved, and has become an important and useful tool in hydrogeological studies, mineral prospecting and mining, as well as in environmental and engineering applications (e.g. Griffiths et al., 1990; Griffiths and Barker, 1993; Dahlin and Loke, 1998; Olayinka, 1999; Olayinka and Yaramanci, 1999; Amidu and Olayinka, 2006; Aizebeokhai et al., 2010).The classical methods of geoelectrical resistivity surveys have undergone significant changes in the last three decades.

The use of electrical resistivity measurements has been a favorite tool of geophysics for over 200 years because of the wide range of resistivity values found in nature. Resistivity in various geologic settings can be found ranging from less than 1 ohm-meter-meter for ore bodies to over 10,000 ohm-meters for Precambrian gneiss. This represents a grater dynamic range for this technique than most of the commonly used methods (Hoover et al, 1999). Mineral exploration in Nigeria dates

back to the geological expeditions by the colonial masters in the early part of the 20th century (Ajakaiye, 1985; Chuku, 1988). It has resulted in revenue accruing earnings and economic development. In the southern part of Nigeria, especially the Northern part of Edo State, solid mineral exploitation is an everyday activity that is currently going on, but, on a ‘wild cat’ basis. The mining industry in Edo State is of great potential which has the capacity to contribute to local and foreign exchange earnings as well as the attraction of foreign direct investment thereby boosting the country’s economy (Ndinwa and Ohwona, 2014; Dogara and Aloa, 2017)

Electrical resistivity is a fundamental property that characterizes a material almost as completely as does its density (Chaker 1981). It is a physical property of the material of the conductor, which expresses its ability to oppose flow of charge (Lowrie 1997).

$$R = \rho \cdot L/A$$

Where;

ρ = resistivity (Ωm),

L = length (m) equaling the distance between the electrodes

A = cross-sectional area (m^2) equaling the area of the electrode

$$\rho = RA/L$$

As previously stated, electrical conductivity is the reciprocal of electrical resistivity and the rearrangement of the next two equations explains this relationship. Taking the reciprocal of the above equation obtained. This equation shows that the inverse of resistance is directly proportional to the cross-sectional area and inversely proportional to the length of the path.

$$1/R = 1/\rho \cdot A/L$$

Where,

$1/R = \text{Conductance } (\mu\text{S}),$

By substituting the inverse of resistivity for a variable denoted as electrical conductivity and rearranging the equation above, electrical conductivity is defined as thus,

$$EC = 1/R \cdot L/A$$

Where,

EC = Electrical conductivity ($\mu\text{S/m}$).

2.1.1 The Theory of Electrical Resistivity Methods

Electrical resistivity method measures both vertical and horizontal variation of resistivity (Parasnis, 1986). This is achieved based on the assumption that the surface is to be homogeneous and isotropic (Abdullahi and Udensi, 2008). From Ohm's law, the current I and the potential V in a metal conductor at constant temperature are related as follows:

$$V = IR \quad \dots\dots\dots(2.1)$$

Where R is the constant of proportionality known as resistance, measured in ohms. The resistance R , of a conductor is related to its length L and cross sectional area A , by

$$R = \rho L / A \quad \dots\dots\dots(2.2)$$

Where ρ is the resistivity, and it is a property of the material considered. From equation (1) and (2),

$$V = I\rho L / A \quad \dots\dots\dots(2.3)$$

Using the configuration in the works of Dogara and Aloa (2017), the surface area will be $2\pi L^2$, where L is the radius of the sphere. Thus,

$$V = I\rho / 2\pi L \dots\dots\dots(2.4)$$

and

$$\Delta V = I\rho / 2\pi [(1/r^1 - 1/r^2) - (1/r^3 - 1/r^4)] \dots\dots\dots (2.5)$$

$$\Rightarrow \rho = 2\pi\Delta V / I [1/(1/r^1 - 1/r^2) - (1/r^3 - 1/r^4)] \dots\dots\dots(2.6)$$

Apparent resistivity in ohm-metre:

$$K = 2\pi [1/(1/r^1 - 1/r^2) - (1/r^3 - 1/r^4)] \dots\dots\dots(2.7)$$

K is called the geometric factor whose value depends on the type of electrode array used.

For Schlumberger array, MN = 2b and AB /2 = L, then,

$$K = \pi (L^2/ 2b - b/2)$$

For the Wenner array;

$$r1 =r4 = 2b$$

Therefore, K = πb

In this survey, the two electrical resistivity methods were used to study both the lateral and vertical variation of resistivity with respect to subsurface formation.

2.1.2 Field design and survey procedure

Near-surface sources usually treated as noise in traditional geophysical exploration surveys are often the targets of interest in hydrological, environmental and engineering investigations. The subsurface geology is usually complex, subtle and multi-scale such that spatial variations can change rapidly both laterally along the survey profiles and vertically with depths. Thus, a closely spaced grid of observation points is required for the accurate characterization, high spatial resolution and

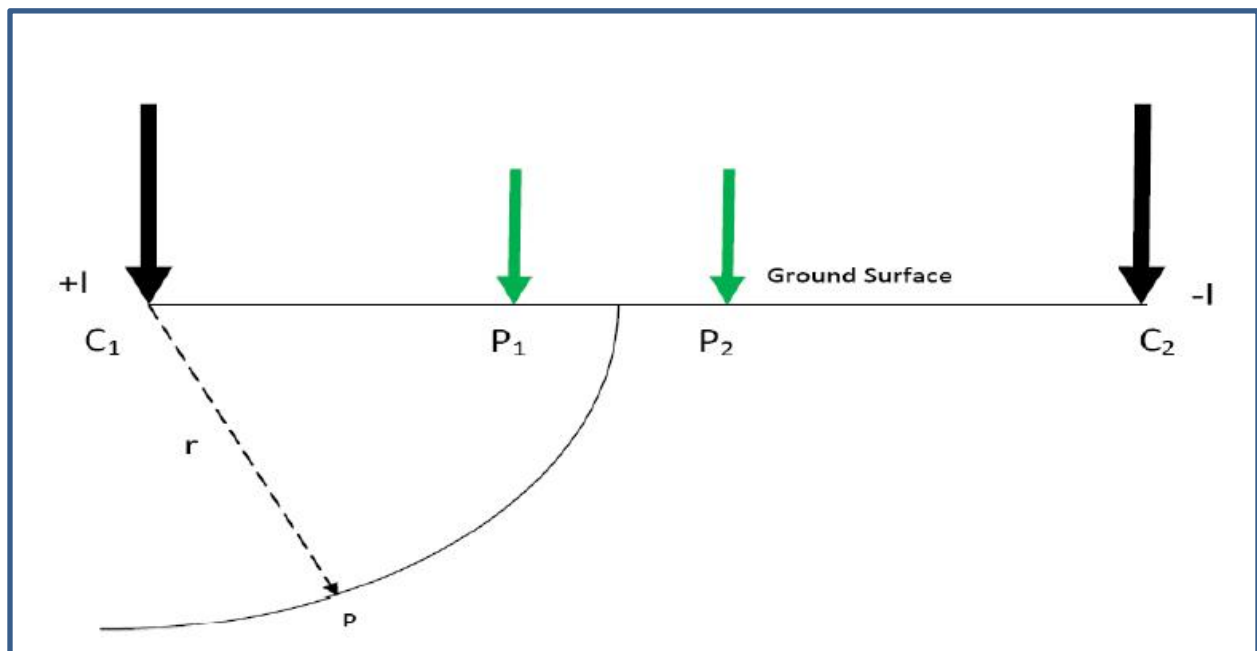


Fig 2.1 Potential distribution due to a current source in a homogeneous half-space.

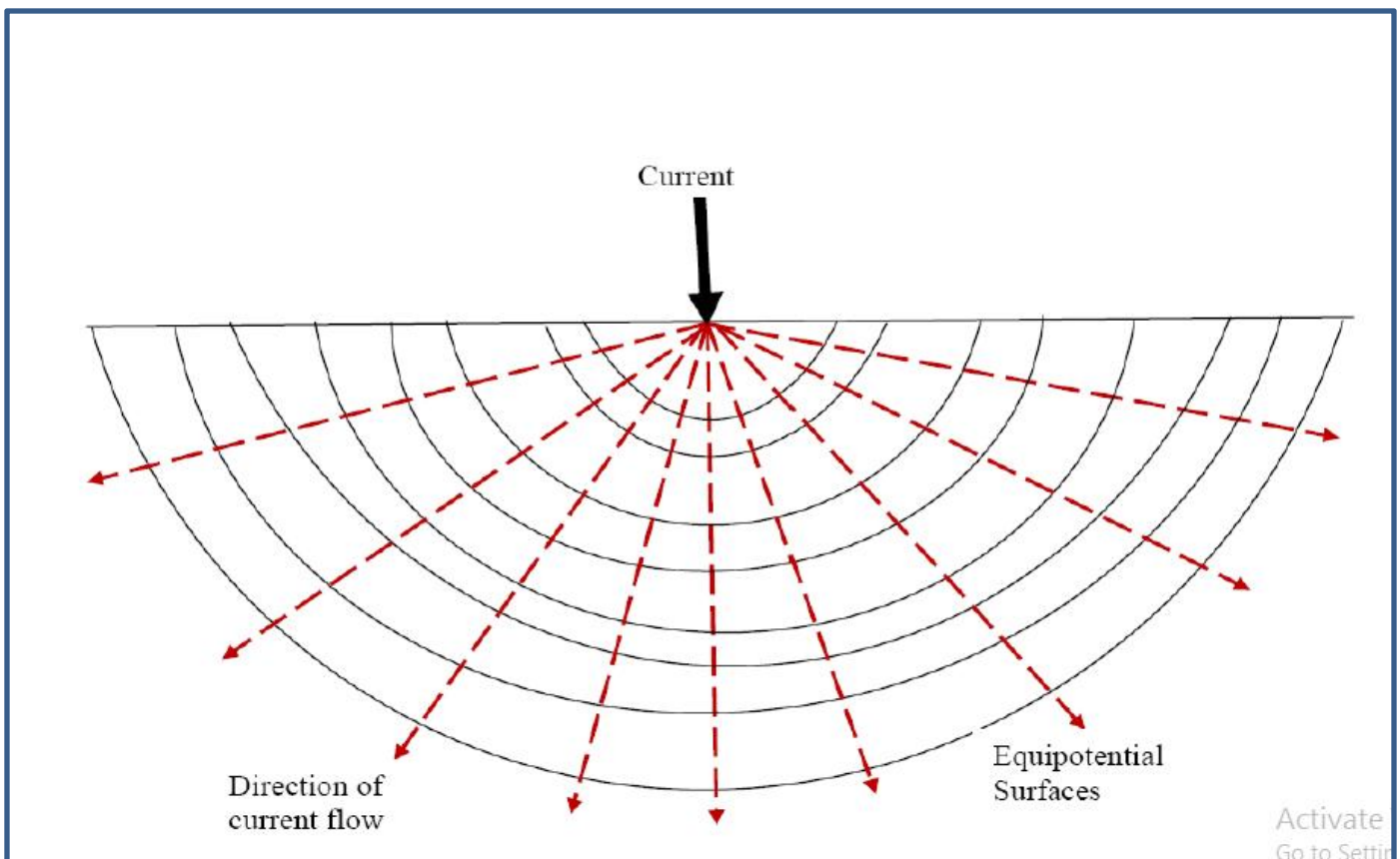


Fig 2.2 Current from a point source and the resulting equipotential distributions.

good target definition of such highly heterogeneous subsurface. Survey design must take into account the capabilities of the data acquisition system, heterogeneity of the subsurface electrical conductivity and the required resolution. Other factors to be considered are the areal extent of the site to be investigated, the cost of the survey and the time required to complete the survey.

2.1.3 Electrode configurations

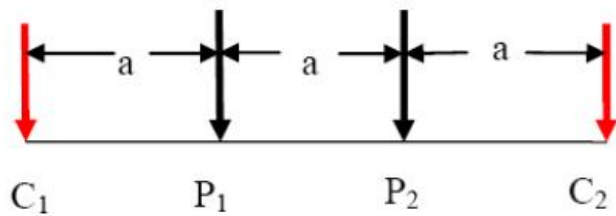
Four electrodes are generally placed at arbitrary locations however, a number of electrode configurations have been used in recording resistivity field data, each suitable for a particular geological situation. The conventional arrays most commonly used include Wenner (alpha), Schlumberger, dipole-dipole, pole-pole and pole-dipole arrays. The apparent resistivity values observed by the different array types over the same structure can be very different. The choice of a particular array depends on a number of factors, which include the geological structures to be

delineated, heterogeneities of the subsurface, sensitivity of the resistivity meter, the background noise level and electromagnetic coupling. Other factors to be considered are the sensitivity of the array to vertical and lateral variations in the resistivity of the subsurface, its depth of investigation, and the horizontal data coverage and signal strength of the array. The conventional Wenner (alpha) and Schlumberger arrays are relatively sensitive to vertical variations in the subsurface resistivity below the centre of the array but less sensitive to horizontal variations in the subsurface resistivity. The arrays have moderate depths of investigation and generally strong signal strength which is inversely proportional to the geometric factor used in calculating the apparent resistivity values. The major limitation of these arrays is the relatively poor horizontal coverage with increased electrode spacing. Wenner array is preferred for surveys in a noisy site because of its high signal strength; however, the array is less sensitive to 3D structures (Dahlin and Loke, 1997).

The dipole-dipole array is the most sensitive to resistivity variations below the electrodes in each dipole pair and is very sensitive to horizontal variations but relatively insensitive to vertical variations in the subsurface resistivities. Thus, it is the most preferred array for mapping vertical structures like dykes and cavities. Dipole-dipole array is, however, very poor in mapping horizontal structures such as sills, sedimentary or horizontal layers. In addition, it is the most sensitive array to 3D structure among the common arrays (Dahlin and Loke, 1997). The depth of investigation of the array depends on both the current electrode spacing, a and the distance between the two dipoles; and is generally shallower than that of Wenner array. However, dipole dipole array has better horizontal data coverage than Wenner array. The major disadvantage of this array is the decrease in signal strength with increasing distance between the dipole pair.

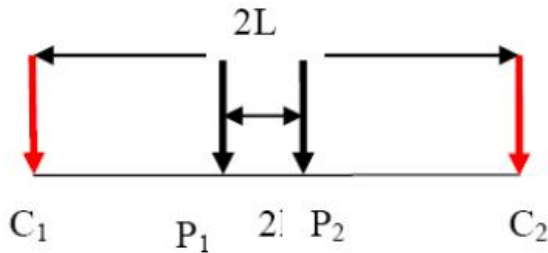
The pole-dipole array is an asymmetrical array with asymmetrical apparent resistivity anomalies in the pseudosections over a symmetrical structure, which could influence the inversion model. It has relatively good horizontal coverage and higher signal strength compared with dipole-dipole array. It is much less sensitive to telluric noise than the pole-pole array. Repeating measurements with the electrodes arranged in the reverse order can eliminate the asymmetrical effect. The combined measurements of the forward and reverse pole-dipole array would remove any bias in the model due to asymmetry. However, this will increase the survey time as the number of data points to be measured will be doubled. The signal strength of the pole-dipole array is lower than that of Wenner and Schlumberger arrays, and is very sensitive to vertical structures. The pole-pole array consists of one current and one potential electrode with the second current and potential electrodes at infinite distances. Finding suitable locations for these electrodes so as to satisfy this theoretical requirement is often difficult. In addition to this limitation, the pole-pole array is highly susceptible to large amount of telluric noise capable of degrading the quality of the observed data. However, the pole-pole array has the widest horizontal coverage and the deepest depth of investigation but the poorest resolution. The resolution of the pole-pole array is very poor as subsurface structures tend to be smeared out in the inversion model (Dahlin and Loke, 1997). If the electrode spacing is small and good horizontal coverage is desired, the pole-pole array is a reasonable choice. Apart from these conventional arrays, many nonconventional electrode configurations have been studied (Stummer et al., 2004; Wilkinson et al., 2006). For ‘n’ equally spaced collinear electrodes, there exist a number of non-reciprocal four-point electrode configurations (Noel and Xu, 1991) given by:

$$n_d = \frac{1}{8}n(n-1)(n-2)(n-3)$$



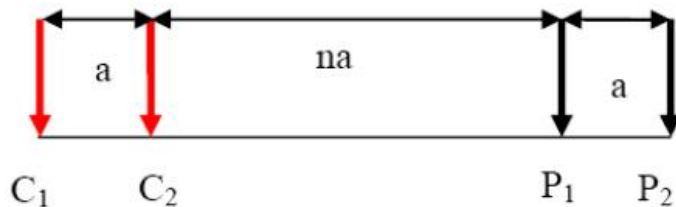
$$G = 2\pi a$$

(a) Conventional Wenner (Wenner-alpha) array



$$G = \frac{\pi L^2}{2l}$$

(b) Schlumberger array



$$G = \pi n(n+1)(n+2)a$$

(c) Dipole-dipole array

Act
Go to

Fig 2.3 Conventional electrode configurations commonly used in geoelectrical resistivity surveys with their corresponding geometric factors.

These measurements set include every possible conventional and non-conventional electrode arrays. Measurements with this set of electrode configurations results in comprehensive data sets which would contain all resistivity subsurface information that the n-electrodes system is capable of gathering. However, a large portion of these configurations have large geometric factors capable of reducing the stability of the inversion of the observed data sets. Stummer et al. (2004) assessed the imaging potential of the data sets acquired with modern multi-electrode resistivity systems using synthetic and field examples. They showed that comprehensive data sets recorded with large numbers of four-

point electrode configurations provides significantly more information than those with standard electrode arrays. However, the recording of comprehensive data sets requires too many measurements and is therefore not cost effective in routine geoelectrical resistivity surveys. An optimization procedure that utilizes a goodness function that ranks the sensitivities of all electrode configurations can be used to define suite of electrode configurations that yields images comparable in quality to those obtained from comprehensive data sets (Wilkinson et al., 2006; Furman et al., 2007; Hennig et al., 2008).

The goodness function includes weighting terms which counterbalance the high sensitivities of the model relative to deeper parts and minimize the influence of well resolved regions of the model based on the experimental design procedure. Measurements are initially made on coarse arrays, with subsequent electrode configurations optimised according to the result of previous measurements. Data generated with electrode configurations that yields large amounts of new information according to their high sensitivities and depth of influence are incorporated into the successively increasing optimal data sets. Fast online inversion schemes are required to update the model estimates between measurements and to find the optimal array configurations (Maurer et al., 2000; Stummer et al., 2004; Auken et al., 2006).

2.1.4 Data acquisition instruments

Geoelectrical resistivity field data are acquired using earth resistivity meter commonly referred to as Terrameter. The equipment 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; four metal stake electrodes, usually stainless steel and four cable reels used in connecting the electrodes to the current source and voltmeter. A low frequency AC signal may be used as current source instead of a commutated DC source (Christensen, 1989).

The internal impedance of the ammeter, connected in series with the current source, should be low so as to minimize its effect on measuring circuit. Similarly, the voltmeter connected in parallel with the ammeter should have high input impedance so as to suppress any effect arising from the ammeter. In general, the current source and both meters are usually housed in a single box. This process is usually time consuming and labour intensive, as it involve the movement of the four electrodes from one point to another for each data point to be measured. A minimum of one person is required to handle each of the electrodes with its connecting cable and an additional person is needed to handle the recording equipment, thus making a minimum of five-man data collection crew in a typical survey. The development of multi-electrode data acquisition systems has greatly improved the speed and reduced the cost of acquiring field data. With multi electrode systems, two or three persons can conveniently carry out field surveys especially in 2D and 3D resistivity imaging where large volumes of data are required. The automated multi-electrode systems offer efficient means of acquiring field data in arbitrary four-point electrode configurations, thus allowing flexibility in the choice of electrode configuration(s) in a given survey.

The automated systems generally consist of a resistivity instrument, a relay unit (electrode selector), a portable computer, electrode cables, various connectors and electrodes (Griffiths et al., 1990). Two or more components of the multi-electrode systems may be housed in the same box, making the systems more compact and portable. Some multi-electrode systems employ intelligent switches with built-in-

amplifiers (Stummer and Maurer, 2001; Stummer et al., 2004) at each electrode take-out instead of a central switching unit. Other features of the multi-electrode systems that enhanced productivity and quality of data acquired are analog-to-digital converters and digital transmission lines.

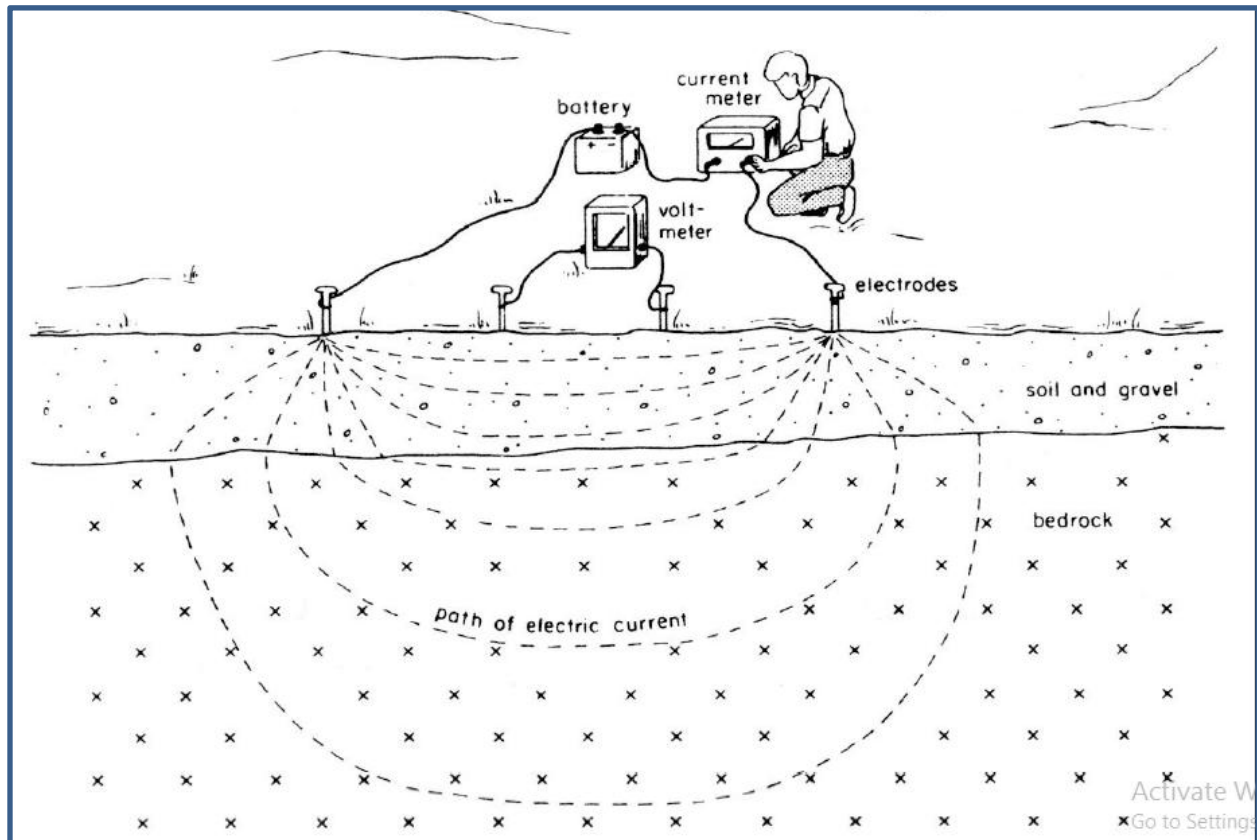


Fig 2.3 A conventional set-up of the earth resistivity meter geoelectrical resistivity field observations (after Robinson and Coruh, 1988).

The automated multi-electrode systems are either single channel or multi-channel. The multi-channel systems consist of multi-channel transmitters and receivers that enable them to simultaneously carry out series of measurements. For any N -channel multi-electrode systems, N numbers of data can be recorded simultaneously thereby increasing the data acquisition speed by a factor of N . A number of multi-electrode systems are commercially available for shallow investigations.

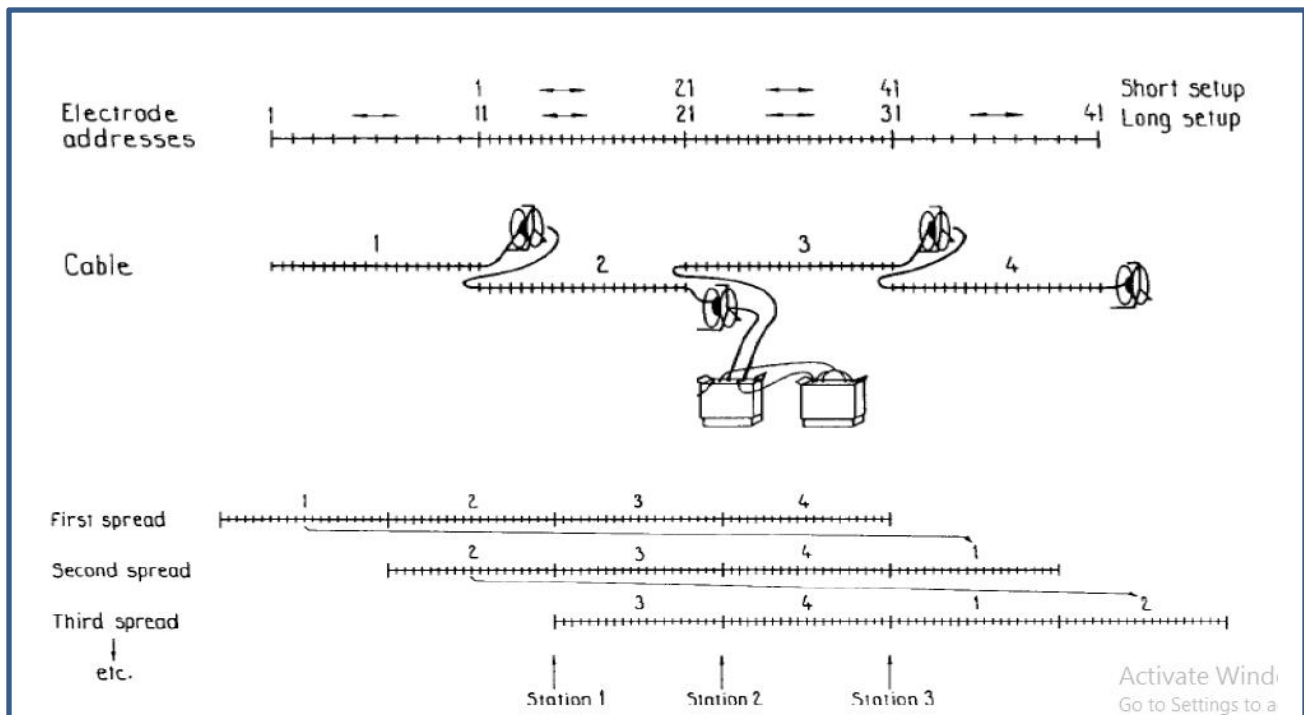


Fig 2.4 Schematic layout of automatic data acquisition system using four electrode cables, indicating the roll-along technique

2.1.5 Two-dimensional (2D) and three-dimensional (3D) Geoelectrical resistivity surveying

Two-dimensional (2D) geoelectrical resistivity imaging can be achieved by integrating the techniques of vertical electrical sounding with that of electrical profiling. It involves apparent resistivity measurements from electrodes placed along a line using a range of different electrode separations and midpoints. The procedure is repeated for as many combinations of current and potential electrode positions as defined by the survey configuration. 2D resistivity imaging can be seen as continuous vertical electrical sounding (CVES) in which a number of VES conducted in a grid are merged together or as a combination of successive profiles with increasing electrode spacing.

Two-dimensional (2D) resistivity surveys are usually carried out using large numbers of electrodes connected to multi-core cables. For a system with limited

number of electrodes, the area covered by the survey can be extended along the survey line using the roll-along technique (Dahlin and Bernstone, 1997).

This can be achieved by moving the cables past one end of the line by several units of electrode spacing, after completing a sequence of measurements. A number of arrays have been used in recording 2D geoelectrical resistivity field data, each suitable for a particular geological situation. The conventional arrays most commonly used include Wenner, dipole-dipole, pole-pole and pole-dipole. Most of the pioneering works in 2D geoelectrical resistivity surveys were carried out using Wenner array (e.g. Griffiths and Turnbull, 1985; Griffiths et al., 1990; Oldenburg and Li, 1999; Olayinka and Yaramanci, 2000).

The resistivity of the 2D model is assumed to vary both vertically and laterally along the survey line but constant in the direction perpendicular to the survey line. The observed apparent resistivity values are commonly presented in pictorial form using pseudosection contouring which gives an approximate picture of the subsurface resistivity distribution. The shape of the contours depends on the type of array used in the investigation as well as the distribution of the true subsurface resistivity. The pseudosection plot serves as a useful guide for detailed quantitative interpretation. Poor apparent resistivity measurements can easily be identified from the pseudosection plot. The pseudo-depth values are based on the sensitivity values or the Fréchet derivatives for a homogeneous half-space. All geological structures and spatial distribution of subsurface petrophysical properties are inherently three dimensional in nature. The three-dimensional effects of subsurface structures are more pronounced in environmental and engineering investigations where the geology is highly heterogeneous and subtle. Model images resulting from 2D resistivity surveys often contain spurious features due to 3D effects and violation of the 2D assumption. This usually leads to

misinterpretation of the observed anomalies in terms of magnitude and location (Bentley and Gharibi, 2004).

Hence, a 3D survey with a 3D interpretation model in which the resistivity is allowed to vary in all directions should, in theory, give the most accurate and reliable results especially in subtle heterogeneous subsurface.

What constitute a 3D data set that would yield significant 3D subsurface information for geoelectrical resistivity imaging is not clearly understood. Ideally, the measurements of apparent resistivity values that would constitute a complete 3D data set should be made in all possible directions. The techniques for conducting 3D electrical resistivity surveys have been presented by Loke and Barker (1996).

The use of pole-pole (Li and Idenburg, 1994; Loke and Barker, 1996; Park, 1998) and pole-dipole (Chambers et al., 1999; Ogilvy et al., 1999) arrays in 3D electrical resistivity surveys have been reported. Square and rectangular grids of electrodes with constant electrode spacing in both x- and y-directions in which each electrode is in turn used as current electrode and the potential measured at all other electrode positions were commonly used.

For n number of electrodes in a grid, the maximum number of independent data points (a complete 3D dataset) that can be measured (Xu and Noel, 1993) is given by:

$$d_{\max} = n(n-1)/2$$

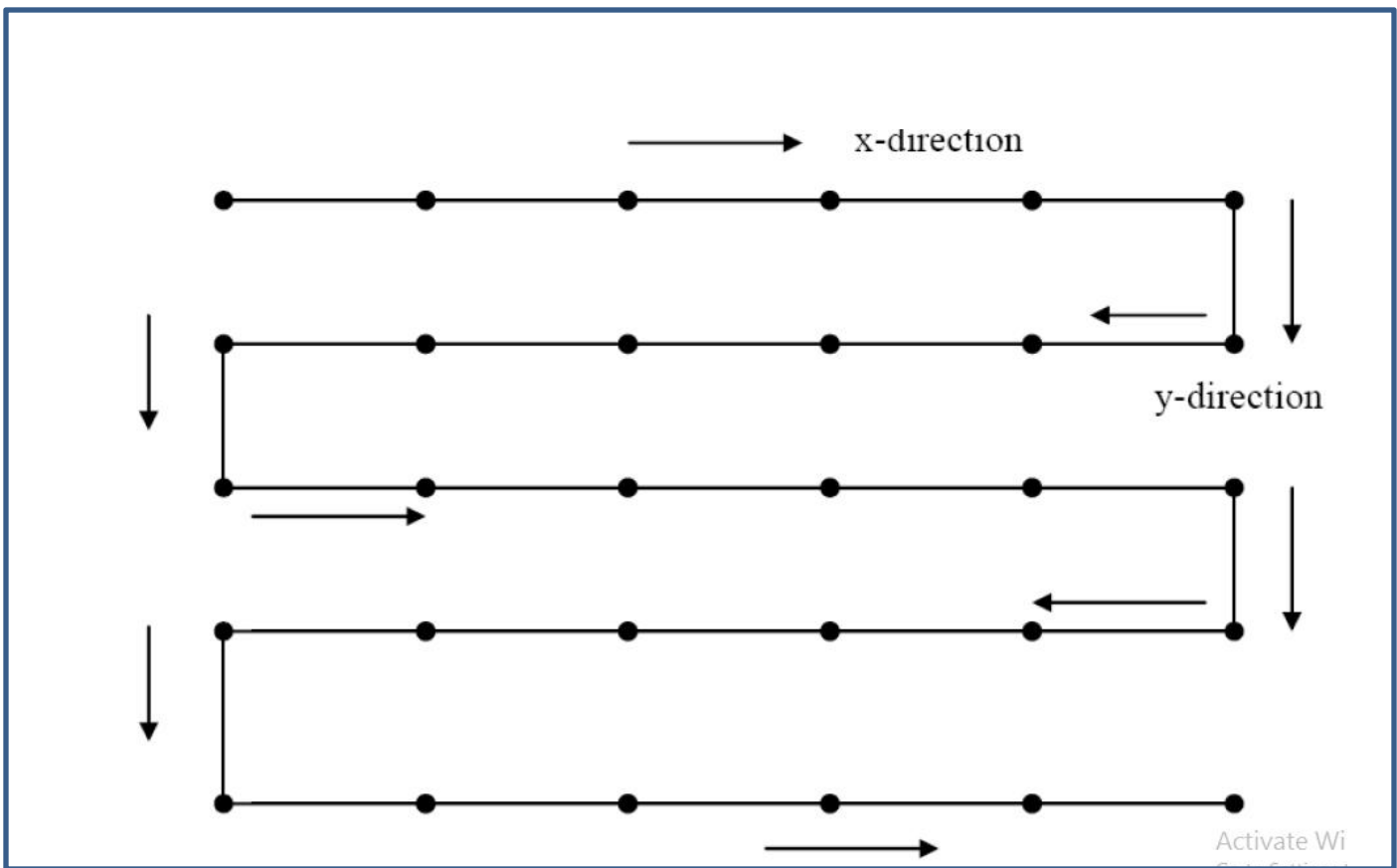


Fig 2.5 The arrangement of electrodes for a 6 by 5 grid in a 3D resistivity survey.

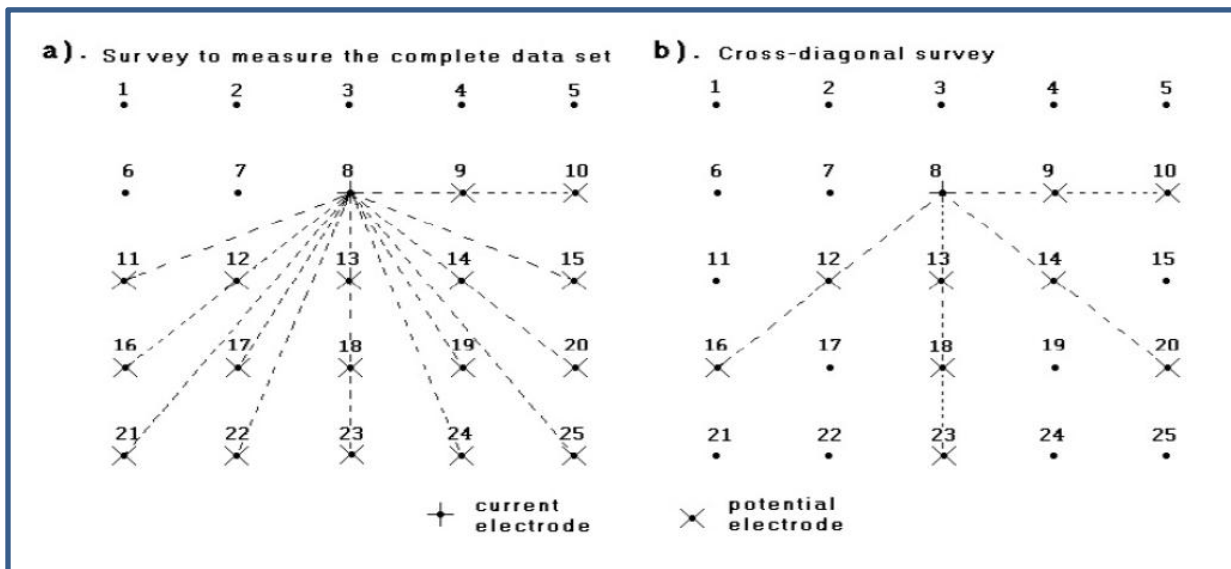


Fig 2.6 Two possible measurement sequences for a 3D geoelectrical resistivity survey with potential electrodes corresponding to a single current electrode in (a) a complete data set survey and (b) cross-diagonal survey.

2.2 METHODS OF GEOPHYSICAL EXPLORATION

Geophysical exploration is an important process that is employed to determine geological structures that gives detailed result of the Earth's subsurface possibly bounded by a distribution of physical properties which are naturally three dimensional, subsurface rocks are generally made up of a variety of minerals buried within the Earth. In geo-electrical resistivity surveys, electrodes are arranged in parallel and perpendicular way in 2D configuration while 3D configurations are arranged in square and rectangular grid with constant electrode spacing (O.M Alile et al., 2017). These minerals from rocks (lithology) include clay, Limestone, shale and sandstones embedded in sedimentary rocks. Sandstone is a composition of sedimentary rock consisting of sheets of sand, mineral particles and binding matrix deposited one atop in water environments and desert formations, they have a resistivity of $8 - 4 \times 10^3 \text{m}\Omega$ and conductivity of $2.5 \times 10^{-4} - 0.125 \text{m}\Omega$. Sandstones are very porous, letting water penetrate through it easily, they are of different colour formation which ranges from red to purple, pink and others and are usually called brownstones when they exist inherently in these form, appearing in a variety of surface textures and earth-toned colours.

Sandstones are clastic in origin (as opposed to organic i.e, chalk and coal) or chemical in form of gypsum and jasper. They are formed from cemented grains that may either be fragments of a pre-existing rock or moni-minerallic crystals. The cements binding these grains together are typically calcite, clays and silica in nature. Sandstones in grain sizes are within the ranges of 0.0625mm to 2mm(0.0025-0.08 inches). Clays and other related sediments are really not visible to the naked eye which includes shales and siltstones in most cases called argillaceous sediments.

2.2.1 Magnetic methods

Certain types of ore, especially magnetite, limonite and pyrrhotite bearing sulphide deposits, produce distortions in the earth's magnetic field which can be used to locate such ores. Besides this direct application, the magnetic methods of prospecting can also be used for tracing ore-bearing formations and geologic features like faults, contact zones, intrusions etc.

This method exploits small variations in magnetic mineralogy (magnetic iron and iron-titanium oxide minerals, including magnetite, titanomagnetite and some iron sulphide minerals, including grignite among rocks). Measurements are made fluxgate proton-precession, over Hauser, and optical absorption magnetometers. In most cases, total magnetic field data and vector measurements are made in some instances. Magnetic rocks contain various combinations of induced and remanent magnetization that perturb the earth's primary field (Reynolds, 1990). The magnitudes of both induced and remanent magnetization depend on the quantity, composition, and size of magnetic-mineral grains. Magnetic anomalies may be related to primary igneous or sedimentary processes that establish the magnetic mineralogy or they may be related to secondary alteration that either introduces or removes magnetic minerals. In mineral exploration and its geo-environmental considerations, the secondary effects in rocks that host ore deposits associated with hydrothermal systems are important and magnetic surveys may outline zones of fossil hydrothermal.

Variation of magnetic field over the earth surface is shown by isomagnetic charts. That is, maps on which lines are drawn through points of same values of magnetic elements. Contours of equal intensity in X, Y, Z, H or F are called

Isodynamics. Contours of equal declination are called Isogenics. Contours of equal inclination are called Isoclinics.

Units: C.G.S system, 1 Oe (Oersted or Gauss)

M.K.S system = Tesla (10^{-4} Oe).

For geophysical works, common unit of field intensity is the gamma, where,

1 gamma (γ)= 10^{-5} Oe.

The total magnetic field of the earth is normally 0.5Oe

2.2.2 Gravity methods

The gravitational method is seldom employed in ore prospecting for reconnaissance purposes. It is employed on the contrary as an auxiliary method, usually on well defined specific target area, for "screening" the geophysical indications obtained by other methods (Parasnis, 1975). This method is widely used in mineral exploration but not commonly used for site specific investigations. A combination of electromagnetic and microgravity to design a strategic approach to mapping karstic features are commonly needed. Other common applications are the detection of void within the subsurface where the small changes in the earth's gravitational attraction caused by such contrasts in density can be recorded with modern instrumentation.

Electromagnetic indications on isolated thin sulphide veins or on graphite zones and on zones of weak impregnation are often as strong as the indications due to massive ore bodies. Gravity anomalies are sometimes of help in deciding between the various alternatives. This is because the gravity indication above a massive body will be strong while those above an isolated thin vein or above graphite zones will be almost nonexistent.

2.2.3 Electrical methods

Electrical methods comprise of multiplicity of separate techniques that employ differing instruments and procedures, have variable exploration depth and lateral resolution, and are known by a large lexicon of names and acronyms describing techniques and their variants. Electrical methods can be described in five classes (i) direct current resistivity, (ii) mise a' la masse (iii) induced polarization, and (iv) self potential. In spite of all the variants, measurements fundamentally are of the earth's electrical impedance or relate to changes in impedance. Electrical methods have broad application to mineral and geoenvironmental problems. They may be used to identify leachate plume, mineral structures and lithologies.

The basic principle behind electrical methods is the injection of current into the ground using a pair of electrodes. This current causes a potential difference in the ground which is measured by a separate pair of electrodes. The voltage measured can then, using the parameters of the survey, be converted into an apparent resistivity value. The value can provide a range of information regarding the materials being tested. Different types of soil compositions have different resistivity. A number of different electrode configurations can be employed for electrical surveys include;

- Vertical electrical soundings (VES) for grounding studies
- 2-D and 3-D Electrical Resistivity Tomography (ERT)
- 2-D dipole-dipole gradient maps (in the horizontal plane) of resistivity and induced polarization

This method of prospecting makes basic use of a very tangible range of techniques such as resistivity, induced – polarization, electromagnetic self

potential, telluric – current methods. Each of these methods is based on some different electrical properties or characteristics of materials in the earth’s subsurface. Electrical Resistivity method is designed to yield information on formations or bodies having anomalous electric conductivity.

Induced–polarization method is employed in the exploration of disseminated ore of bodies such as sulfides. Telluric current methods use natural earth currents and anomalies in the passage of such currents through earth’s materials. Self-Potential method is used to detect the presence of certain minerals which react with electrolytes in the earth in such a way to generate electrochemical potentials.

2.3 RELATIONSHIP BETWEEN GEOLOGY AND RESISTIVITY

Variations in the resistivity of subsurface materials are mostly a function of lithology. Information about resistivity variations within the subsurface can be associated with different materials. Some resistivity values are given in the table below

Earth Material	Resistivity, Average or Range (Ohm-m)	Earth Material	Resistivity, Average or Range (Ohm-m)
Granite	10^2-10^6	Sandstone	$1-10^8$
Diorite	10^4-10^5	Limestone	$50-10^7$
Gabbro	10^3-10^6	Dolomite	10^2-10^4
Andesite	10^2-10^4	Sand	$1-10^3$
Basalt	$10-10^7$	Clay	$1-10^2$
Peridotite	10^2-10^3	Brackish water	0.3-1
Air	~ 0	Seawater	0.2

Table 2.1 Resistivity of common Earth’s materials (Robinson, 1988)

From the table, it can be noted that most materials are characterized by resistivity values that vary by several orders of magnitude. For example, limestone has resistivity values ranging from 50 ohm-m to 10^7 ohm-m. Most

minerals are considered to be insulators or resistive conductors. So in the majority of rocks, electrical current flow is accomplished by passage of ions in pore fluids (electrolytic conduction). The conductivity, which is the inverse of resistivity, is mostly affected by porosity, saturation, salinity, lithology, clay content and to some degree by temperature. Accordingly, materials with constant mineralogical composition can possess different resistivity values, depending on all the above mentioned parameters.

2.4 OHM'S LAW AND RESISTIVITY

In 1872, George Simon Ohm derived empirical relationship between the resistance (R) of a resistor in a simple series circuit, the current passing through the resistor (I), and the corresponding change in potential (ΔV) :

$$V = I R$$

A simple series circuit that consists of a battery connected to a resistor by a wire demonstrates this relationship. By using Ohm's Law, the value of resistance (R) can easily be calculated by plugging values of voltage (ΔV) and current (I) in the equation. The last two values are given because they can be measured. The electrical resistivity tomography concept is based on this relationship with the assumption that the resistor in the circuit is the Earth. There is another relationship that defines resistance (R) as a function of geometry of a resistor and the resistivity of the cylindrical-shaped body:

$$R = \rho L / A$$

This equation shows that the magnitude of resistance is affected by the length (L) and the cross-sectional area (A) of the cylindrical-shaped body through which electrical current flows (resistor). A factor that defines the ease with which electrical current flows through the media is known as resistivity (ρ).

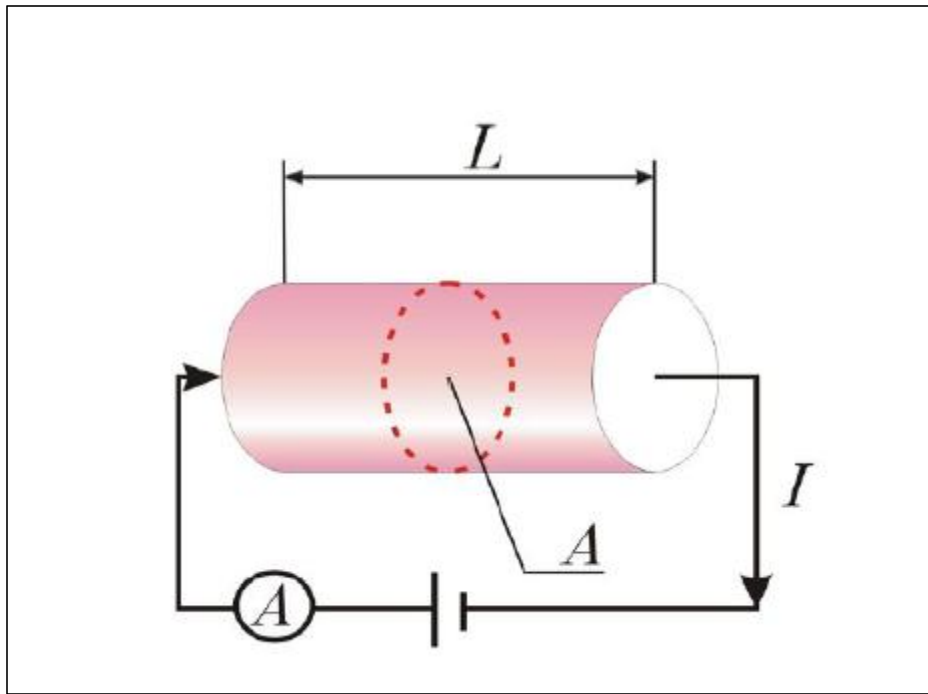


Fig 2.7 Electric circuit for illustration of Ohm's Law

2.5 DIRECT CURRENT RESISTIVITY METHOD

The electric anomalies of subsurface conductors depend upon the electric resistivity contrast between the conductors and the host rocks. It is therefore desirable to have an idea of the resistivity of rocks and ores within a survey area. It's unit is the ohm metre (Ωm).

The electrical resistivity of rocks and minerals is an extremely variable property and depends on a number of factors. The resistivity of crystalline rock formations such as granite, granulite, diorite and others is largely dependent upon the water in the fissures and fractures. Similarly, the porosity, the degree of saturation and the nature of pore electrolytes govern the resistivity of rocks like sandstones, limestone, etc. generally speaking, hard rocks are bad conductors of electricity, but zones of crushed and badly fractured rocks may sometime have resistivity as low as those of certain ores.

Ores and minerals can be divided into two classes, the good conductors and the bad conductors. Generally, minerals having a metallic luster and these ores

are good conductors. The resistivity of ore deposited of course, upon the amount of conducting minerals in them, the mode in which these minerals are distributed etc. thus, massive ores of pyrite, magnetite etc, have low resistivity while impregnation ores have a high resistivity.

Crystalline bedrock may sometimes be impregnated by conducting minerals like magnetite and graphite and therefore acquire considerably lower resistivity than would otherwise be the case. Thus granulites rock when unimpregnated, has resistivity of the order of 20,000-50,000 Ωm but moderate impregnation of conducting minerals brings its resistivity down to 3000-5000 Ωm in many areas.

2.6 ELECTRICAL PROPERTIES OF ROCKS AND MINERALS

Several electrical properties namely potentials, conductivity or resistivity and dielectric constant of rocks and minerals are significant in electrical surveying methods. But electrical resistivity being the parameter of interest in this study is what would be discussed. The electrical properties of rocks and minerals in the upper part of the earth's crust depend primarily on the porosity, permeability, degree of water saturation and clay content. An increase in porosity typically leads to increase in water content and permeability, which reduces the electrical resistivity of the subsurface materials. The presence of clay minerals in a water-bearing rock formation will increase the conductivity of the formation through ion-exchange process. These minerals bind water molecules and ions, and thereby facilitate electrical conduction in the rock formations. Clay particles coating the surfaces of the larger mineral particles may have a dominating effect on the bulk resistivity of a predominantly coarse grained rock forming mineral by creating surface conduction (Ward, 1990).

Other geologic factors that can significantly influence subsurface electrical properties include rock texture, groundwater salinity, concentration of dissolved

salts and temperature of pore water and the properties of the contaminants (Loke, 2004). An increase in temperature generally enhances the mobility of ions, which results in the decrease of resistivity values (Keller and Frischknecht, 1966). The variation of temperature in the subsurface is generally small, thus its influence on resistivity in the subsurface is usually negligible. However, in special cases such as the determination of resistivity distributions in permafrost regions, the influence of temperature on resistivity can be significant.

The flow of electric current in subsurface materials at shallow depths is mainly by electronic and electrolytic conductions. Electrolytic conduction is the dominant mechanism in environmental and engineering investigations because most common soil and rock forming mineral grains are insulators in dry state. The conduction of electricity in these mineral grains is through the interstitial water or other fluids in the pores and fissures of the rocks. Groundwater that fills the pore spaces of rocks is a natural electrolyte with a considerable number of ions present to increase its conductivity (Sharma, 1997). Thus, the amount of water and properties of the groundwater largely determine the resistivity of subsurface materials. However, if the pore spaces are not connected, as in basalt, there would be no closed paths for the conduction of electric current through the rock. This would result in low permeability and high resistivity in the rock mass.

2.7 THEORETICAL DETERMINATION OF RESISTIVITY

The estimation of the apparent resistivity of the earth is relatively simple if several assumptions are made. The first assumption is that a model-Earth is uniform and homogeneous, thus it possesses constant resistivity throughout the entire earth.

The second assumption is that the Earth is a hemispherical resistor in a simple circuit consisting of a battery and two electrodes (the source and the sink

electrodes) pounded into the ground. The battery generates direct electrical current that enters the Earth at the source electrode connected to the positive portal of the battery. The current exists at the sink electrode coupled to the negative portal of the battery.

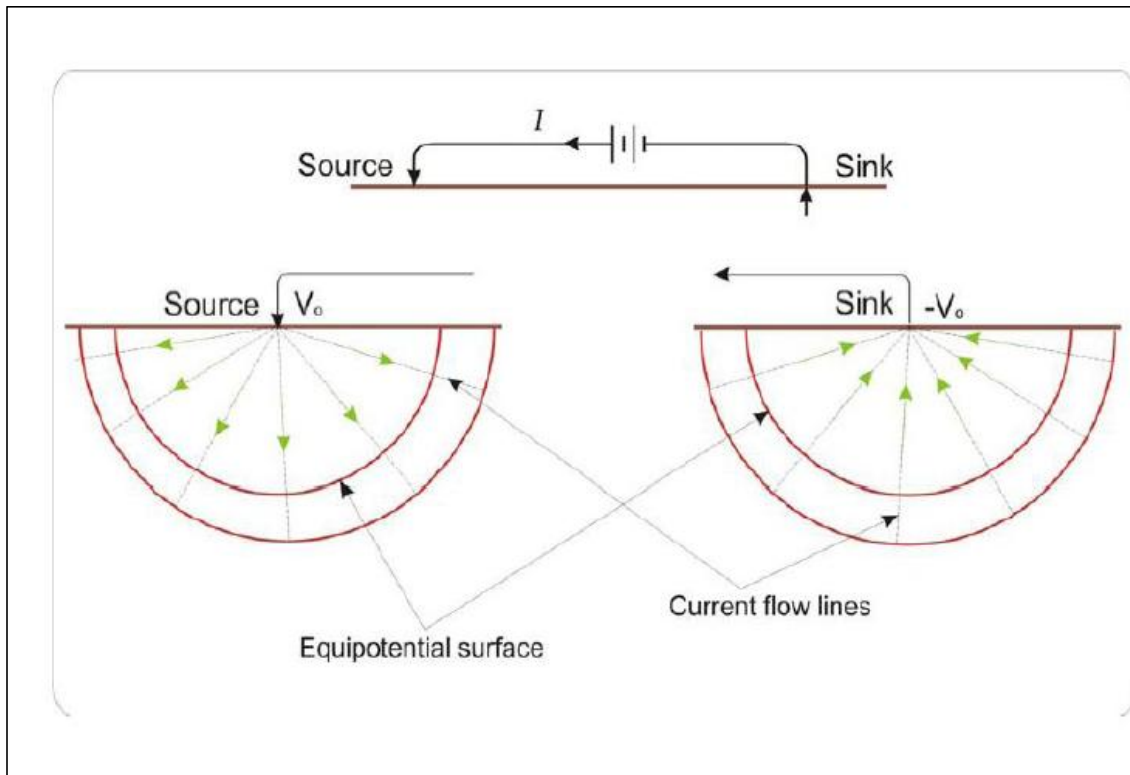


Fig 2.8 Current lines radiating from the source and converging on the sink electrodes (Edwin S. Robinson, 1989)

When the current is introduced to the ground, it is compelled to move outward from the source electrode. Due to the assumption that the earth is homogeneous, the current spreads outward in all directions from the electrode, and at each moment of time, the current front will move through a hemispherical zone. The area of such a hemispherical zone can be found from the relationship

$$A = 2\pi d^2 \dots\dots\dots(2.8)$$

Where d is the distance from the source electrode to the point on the hemispherical surface defined by, By substituting equation into equation we can obtain an expression that defines the resistance of the media at a point separated from the source by distance d :

$$R = \rho / 2\pi d^2 \dots\dots\dots(2.9)$$

The potential difference resulting from the flow of current through the hemispherical resistor can be found from combining Ohm's law expressed equation 2,

$$V = \rho \pi = V_0 - V_d, \dots\dots\dots(2.10)$$

V_0 is a potential at the source electrode and V_d is a potential at the surface of the hemisphere with radius d .

This equation demonstrates that for any point located at the hemispherical surface with radius d , the potential between this point and the source electrode is the same. Such a hemisphere is a surface of constant potential and is called an equipotential surface. In other words, the potential difference between a source and any point on the equipotential surface has the same numerical value.

When the two electrodes are at a finite distance from each other, the potential at any point M separated by distance d_1 from the source electrode, and distance d_2 from the sink electrode, can be found as the sum of the potential contributions from source and sink electrodes for point M in figure

$$I\rho/2\pi [1/d_1 - 1/d_2] . \dots\dots\dots(2.11)$$

This equation can be employed to calculate the potential point by point throughout the earth. By plotting these points and connecting those that are equal, the equipotential surfaces can be obtained from figure

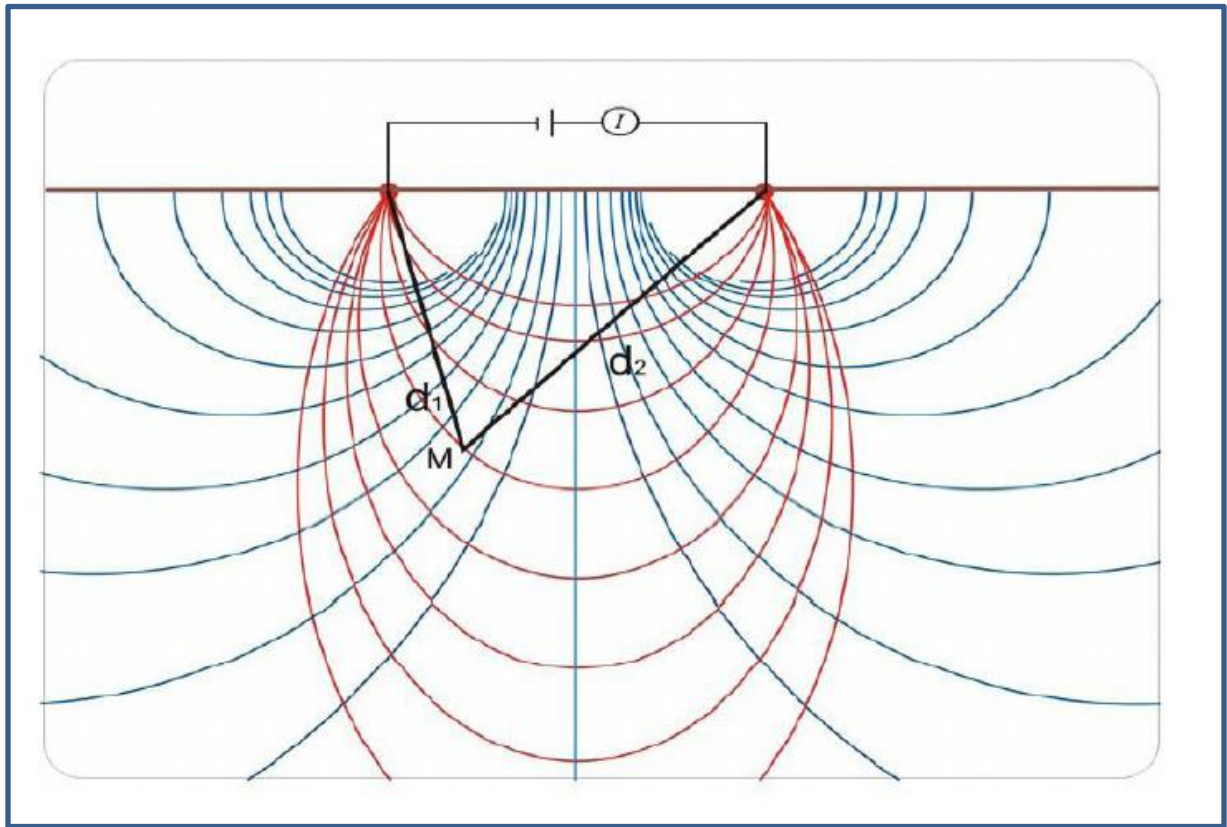


Fig 2.9 Current lines and equipotential surfaces in a medium of uniform resistivity(Edwin S. Robinson, 1989)

Current flow direction is shown by red lines and equipotential surfaces are indicated by blue lines. The assumption that the media through which the current is compelled to flow is homogeneous provides for a constant value of resistivity irrespective of where the voltmeter electrodes are placed. Taking into account the geometry of the electrodes' configuration, as illustrated in Figure , the electric potential at point M can be deduced from the equation:

$$V_M = I\rho/2\pi [1/d_1 - 1/d_2] \dots \dots \dots (2.12)$$

$$V_N = I\rho/2\pi [1/d_3 - 1/d_4] \dots \dots \dots (2.13)$$

Therefore, the potential gradient between these two points, V_{MN} , is

$$VMN = VM - VN = I\rho/2\pi [1/d_1 - 1/d_2 - 1/d_3 + 1/d_4] \quad (2.14)$$

in practice, subsurface materials possess different physical characteristics, and the assumption that resistivity is the same everywhere is not true. Thus, resistivity values that are measured in the field are average resistivity values between two equipotential surfaces, and are known as apparent resistivity values ρ_a .

It can be expressed as:

$$\rho_a = K * VMN / I \quad \dots\dots\dots (2.15)$$

Where K is the geometric factor that depends on the electrode array configuration.

$$K = 2\pi / [1/d_1 - 1/d_2 - 1/d_3 + 1/d_4] \dots\dots\dots (2.16)$$

2.8 ELECTRICAL RESISTIVITY ARRAY CONFIGURATION

For modern electrical resistivity tomography surveys, multi-electrode systems are preferred. The greater the number of electrodes permanently attached to multi-core cable, the higher the investigation capabilities, and less time is spent in the field. Use of multi electrode system allows combination of vertical sounding and horizontal profiling data to be collected simultaneously. Also it allows the generation of a two-dimensional model of resistivity distribution (Lateral and Vertical).

For 2-D imaging using a modern multi-electrode system, the spacing between electrodes stays fixed for the entire survey. Measurements are taken sequentially using different sets of four electrodes controlled by switching device. The depth of investigation is a function of the array type, the length of array and the physical parameters of material underlying the area of interest,

and typically ranges from one-third to one-fifth of the length of the entire array (Robinson et al., 1988).

2.9 2-D RESISTIVITY ARRAYS

Some of the more common electrode configurations such as Wenner array, Schlumberger array, and Dipole-dipole array are briefly discussed below. The geometry of an electrode array depends on the target depth, the time allowable for data acquisition, and the required spatial resolution. When a multi-electrode system is used, the spacing between all electrodes remains the same, while the distance between current and potential electrodes depends on electrode configuration. This distance is controlled automatically by resistivity meter. Most electrical resistivity tomography surveying is done with one of the electrode geometries illustrated in Figure 5.5.

For the 2-D Wenner Array (Figure 5.5), current and potential electrodes are separated by equal distance ‘a’ such that,

$$AM = MN = NB = a \quad \dots\dots\dots (2.17)$$

All the electrodes are arranged along a continuous line, also known as survey line or traverse. The geometric factor for Wenner Array can be expressed as,

$$KW = 2 * \pi * a \quad \dots\dots\dots (2.18)$$

2.10 EQUIPMENT USED FOR ERT

Electrical resistivity tomography (ERT) involves introduction of electrical current into the subsurface by means of electrodes attached to the ground. All required measurements are by resistivity meter. For this project, a multi-channel portable memory Earth resistivity PASI-EARTH Meter manufactured by

Advanced Geosciences, Inc. The Pasi-Earth Meter was powered by a 12-volt battery. For larger scale projects, two batteries can be used.

For this project, twenty electrodes were connected to the insulated low resistance multi-core cable. Each electrode is tied to a metal stake pounded on the ground using a rubber - band, this allows electric current to flow from the electrode to the ground or subsurface. The electrodes are connected to the switching unit which also connects the Terameter. Dipole - dipole array configuration was used. In dipole - dipole array configuration, as shown in Figure below attached to a multi-core cable in a straight line.

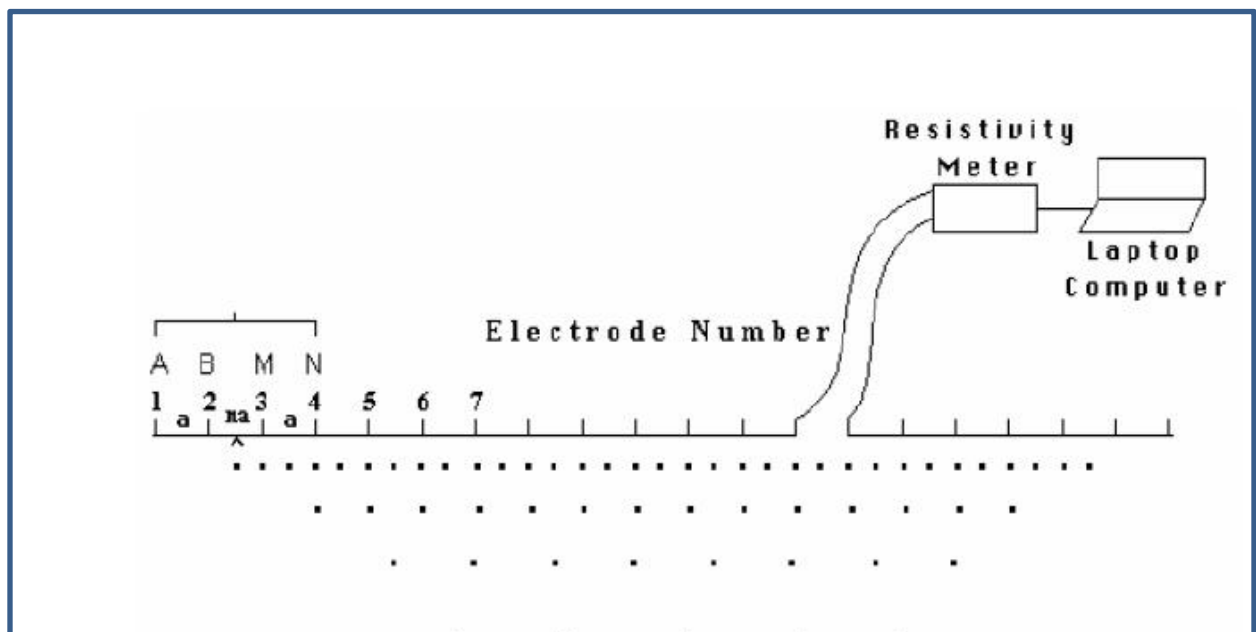


Fig 2.10 Electrical resistivity dipole-dipole array configuration used in the field.

The cable is connected to the switching unit hardwired into the SuperSting resistivity meter. The unit controls the selection of the current (A&B) and potential (M&N) electrodes for each measurement. The Pasi- Earth resistivity meter is connected to a laptop computer where the data is stored.

2.11 ELECTRICAL RESISTIVITY TOMOGRAPHY DATA PROCESSING

The resistivity data sets collected in the field were converted into resistivity models for interpretation of subsurface conditions using the RES2DINV software.

ERT(Electrical Resistivity Tomography) data was processed using the following steps;

- Inspection of the resistivity data sets for presence of unreasonably high and low (negative) resistivity values called “ bad data points” (Loke, 2004).
- Removal of “bad data points”.
- Compilation of a resistivity model/ERT resistivity profile that displays horizontal and vertical resistivity distribution.

Before processing, the data acquired had to be inspected for presence of “bad data points” (Loke, 2004). “Bad data points” mean resistivities of unrealistically high or low (negative) values. “Bad data points” can be caused by several factors, such as failure during survey of equipment used, for example electrode malfunction. Also, very poor electrode - ground contact can result to “bad data points”. In addition, when a metal stake attached to an electrode is driven into an ice lens, resistivity measurements are affected

Ice acts as an insulator, and affects resistivity measurements. This is a problem for surveys done in winter. Inspection of “bad data points” is done by viewing a profile plot.

The “bad data points” appear as stand out points. All “bad data points” are marked as red plus signs. The RES2DINV software offers an option that allows for removal of such points manually by simply clicking on them. After the

resistivity data sets acquired in the field were inspected and all unrealistic values removed, the RES2DINV software used an inversion algorithm to convert the measured resistivity model/ERT resistivity profiles to a geologic model which reflect lateral and vertical resistivity distribution. The software creates a resistivity model/resistivity profile that has the same resistivity distribution as the actual resistivity distribution below the corresponding traverse. To increase the quality of the calculated model, the Root Mean Square (RMS) method is used, (Loke, 2004).

In this method, the smaller the RMS value, the better the calculated model correlates with real resistivity distribution. In this project, an RMS value of 50% was used.

To create a resistivity model, the RES2DINV subdivides the subsurface into a finite number of rectangular pixels. Each pixel is assigned a resistivity value which represents the resistivity of different materials encompassed within that discrete pixel; therefore some lateral and vertical smoothing takes place (Anderson, 2006).

The size of the pixels is affected by the spacing between the adjacent electrodes. Horizontal dimension of a pixel is equal to lateral distance between adjacent electrodes, and at shallow depth, the vertical dimension is approximately equal to 20% of the spacing between two adjacent electrodes. With increasing depth of investigation, the vertical dimension of pixels gradually increases up to 100% of the distance between adjacent electrodes (Anderson et al., 2006).

When a Dipole-dipole array is used, the maximum depth of investigation is approximately 20%-25% of the array length but this is affected by subsurface

condition such as the top layer of the ground being very dry. For this project, the depth of investigation was about 3m.

The ERT resistivity profiles generated are later interpreted by picking the inverse model resistivity sections. The unit electrode spacing was 10m each.

CHAPTER THREE

THEORY AND METHODOLOGY

3.1 INTRODUCTION

2-D Resistivity tomography involves the deployment of an array of co-linear, equidistant electrodes on the surface of the ground for data collection. The survey technique involves measuring a series of constant electrode separation with the electrode separation being increased with each successive measurement. The unit electrode spacing determines the length of the profile, depth of investigation and resolution. (Thomas, 2002).

3.2 EQUIPMENT/INSTRUMENT DESCRIPTION

- 21 steel electrodes
- Pasi Earth Resistivity Meter/Terrameter
- Hammers
- Cables
- Battery
- G.P.S
- PVS Measuring tape

3.2.1 INSTRUMENTS

I. Metal Electrodes: These are stainless steel with high tensile strength, they are metallic conductors used in fieldwork because of their high conductivity. One end of the metal is pointed; this is to ease its penetration into the ground.

II. Pasi Earth Resistivity Meter: This is a computerized system which is at the heart of the entire field operation'

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

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

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

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

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

measured, measured distances on the ground can be marked and the remainder of the distance measured

3.3 FIELD SURVEY METHOD

Two dimensional electrical imaging surveys are usually carried out using a large number of electrodes, about 25 or more, connected to a multi-core cable (Griffiths and Barker, 1993). A laptop microcomputer together with an electronic switching unit is used to automatically select the relevant four electrodes for each measurement. At present, field techniques and equipment is commercially available from a number of international companies. Some institutions have even constructed “home-made” manually operated switching units at a nominal cost by using a seismic cable as the multi core cable.

The multi core cable is attached to an electronic switching unit that is connected to a laptop computer. The sequence of measurements to take, the type of array to use and other survey parameter (such as the current to use) is normally entered into a text file which can be read by a computer program. Different resistivity meters use different format for the control file, so one will need to refer to the system manual. After reading the control file, the computer program then automatically select the appropriate electrodes for each measurement. Some field systems have an inbuilt microprocessor system so that a laptop computer is not needed.

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

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

After completing the sequence of measurements with “1a” spacing, the next sequence of measurements with “2a” electrode spacing is made. First electrodes 1,3,5 and 7 are used for the first measurements. The electrodes are chosen so that the spacing between adjacent electrodes is “2a”. for the second measurement, electrodes 2,4,6,and 8 are used. This process is repeated down the line until electrodes 14,16,18 and 20 are used for the last measurement with “2a” spacing, the same process is repeated for measurements with “3a”, “4a”, “5a” and “6a” spacings. To get the best results, the measurements in a field survey should be carried out in a systematic manner so that all the possible measurements are made. This will affect the quality of the interpretation model obtained from the inversion of the apparent resistivity measurements (Dahlin and Loke, 1998).

As the electrode spacing increases, the number of measurements decreases. The number of measurements that can be obtained for each electrode spacing, for a given number of electrodes along the survey line, depends on the type of array used. The Wenner array gives the smallest number of possible measurements compared to the other common arrays that are used in 2-D surveys. The survey

procedure with the pole-pole array is similar to that used for the Wenner array. For a system with 20 electrodes, firstly 19 of measurements with a spacing of “1a” are made, followed by 18 measurements with “2a” spacing, followed by 17 measurements with 3a spacing, and so on.



Figure 3.1 image of instruments used for field work

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 RESULT

Field data obtained from the instrument readings at each survey lines was recorded in a data sheet. The geometrical factor for each sequence of measurement was computed using the geometric factor ‘K’ = $2\pi a$

Where “a” is the inter-electrode spacing, this was then used to multiply the resistance values read from the instrument to obtain the apparent resistivity.

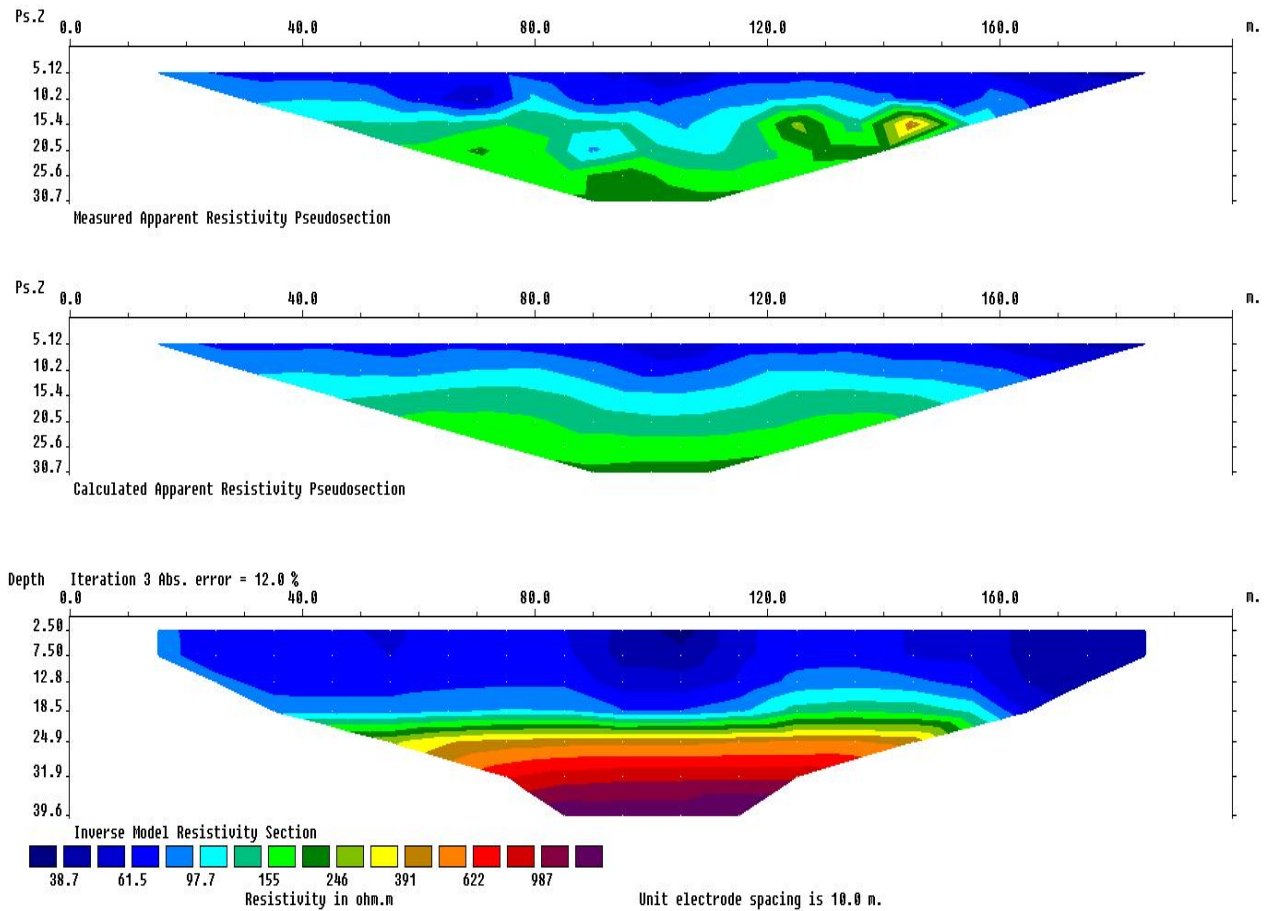
Table 4.1.1 2-D Wenner Alpha Electrical Resistivity Field Report (Transverse one)

ARRAY TYPE	Wenner Array	Date	
INSTRUMENT USED	PASI Earth Resistivity Meter	State	EDO State
LOCATION	College of Education	L.G.A	Orhionwon
TRANSVERSE	One		

COLLEGE OF EDUCATION, ABUDU					
Wenner traverse 1 Long 06°05'42.5" Lat 07°17'34.8" Elev 305.6m					
Traverse 1 a = 10m					
C1	P1	P2	C2	R(Ω)	$\rho(\Omega m)$
0	10	20	30	0.514	32.29976
10	20	30	40	0.871	54.73364
20	30	40	50	0.789	49.58076
30	40	50	60	1.3	81.692
40	50	60	70	1.3	81.692
50	60	70	80	1.7	106.828
60	70	80	90	1.6	100.544
70	80	90	100	1.5	94.26
80	90	100	110	1.2	75.408
90	100	110	120	1.2	75.408
100	110	120	130	1.2	75.408
110	120	130	140	0.699	43.92516
120	130	140	150	0.715	44.9306
130	140	150	160	0.75	47.13
140	150	160	170	0.677	42.54268
150	160	170	180	0.753	47.31852
160	170	180	190	0.955	60.0122
170	180	190	200	1.1	69.124
Traverse 1 a = 20m					
C1	P1	P2	C2	R(Ω)	$\rho(\Omega m)$
0	20	40	60	0.648	81.44064
10	30	50	70	0.853	107.205
20	40	60	80	1.1	138.248
30	50	70	90	1.2	150.816
40	60	80	100	0.869	109.2159
50	70	90	110	0.479	60.20072
60	80	100	120	0.954	119.8987
70	90	110	130	1	125.68
80	100	120	140	0.683	85.83944
90	110	130	150	0.56	70.3808
100	120	140	160	0.535	67.2388
110	130	150	170	0.439	55.17352
120	140	160	180	0.473	59.44664
130	150	170	190	0.631	79.30408
140	160	180	200	0.651	81.81768
Traverse 1 a = 30m					

C1	P1	P2	C2	R(Ω)	$\rho(\Omega\text{m})$
0	30	60	90	0.789	148.742
10	40	70	100	1	188.520
20	50	80	110	1.1	207.372
30	60	90	120	0.921	173.627
40	70	100	130	1.1	207.372
50	80	110	140	0.869	163.824
60	90	120	150	0.841	158.545
70	100	130	160	0.858	161.750
80	110	140	170	0.602	113.489
90	120	150	180	0.518	97.653
100	130	160	190	0.515	97.088
110	140	170	200	0.404	76.162
Traverse 1 a = 40m					
C1	P1	P2	C2	R(Ω)	$\rho(\Omega\text{m})$
0	40	80	120	0.889	223.459
10	50	90	130	0.859	215.9182
20	60	100	140	0.819	205.8638
30	70	110	150	0.73	183.4928
40	80	120	160	0.722	181.4819
50	90	130	170	0.672	168.9139
60	100	140	180	0.889	223.459
70	110	150	190	0.515	129.4504
80	120	160	200	0.571	143.5266
Traverse 1 a = 50m					
C1	P1	P2	C2	R(Ω)	$\rho(\Omega\text{m})$
0	50	100	150	0.934	293.4628
10	60	110	160	0.903	283.7226
20	70	120	170	0.639	200.7738
30	80	130	180	0.636	199.8312
40	90	140	190	0.61	191.662
50	100	150	200	0.588	184.7496
Traverse 1 a = 60m					
C1	P1	P2	C2	R(Ω)	$\rho(\Omega\text{m})$
0	60	120	180	0.799	301.255
10	70	130	190	0.689	259.7806
20	80	140	200	0.629	237.1582
Wenner traverse 1 Long 06°05'44.8" Lat 07°17'28.7" Elev 305.5m					

4.1.2 INVERSION OF TRANSVERSE ONE



In transverse one, we have about 8 distinct layers of different colours ranging from a resistivity of $38.7\Omega\text{m}$ - $987\Omega\text{m}$, which indicates very valuable deposits with a depth of about 39.6m. The various layers and inferred minerals as compared with the standard resistivity table shows some buried valuable minerals in the table below.

Sandstone	8 - 4x10 ³	2.5x10 ⁻⁴ - 0.125
Shale	20 - 2x10 ³	5x10 ⁻⁴ - 0.05
Limestone	50 - 4x10 ²	2.5x10 ⁻³ - 0.02
Soils and waters		
Clay	1 - 100	0.01 - 1
Alluvium	10 - 800	1.25 x10 ⁻³ - 0.1
Groundwater (fresh)	10 - 100	0.01 - 0.1

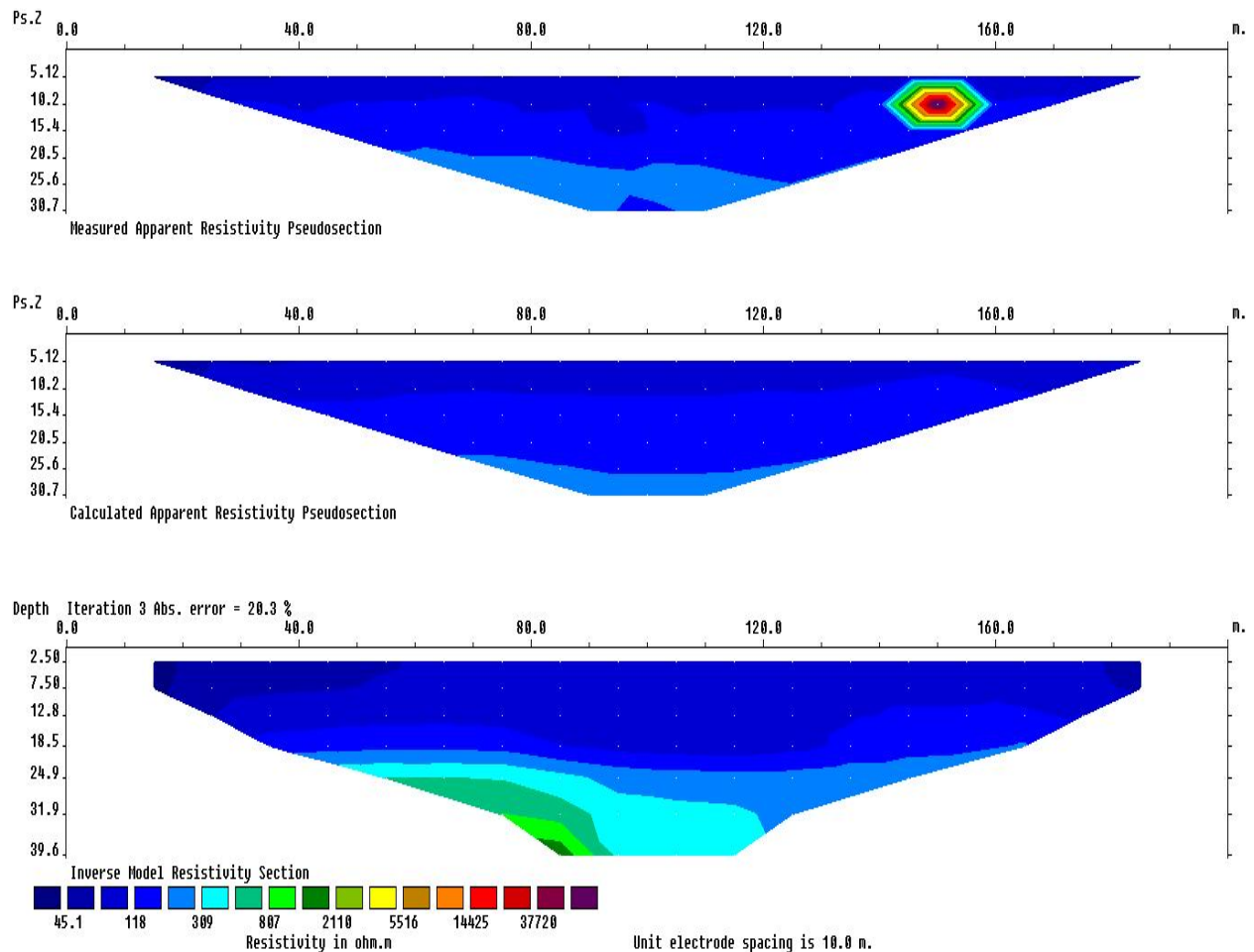
4.1.3

COLLEGE OF EDUCATION, ABUDU					
Wenner traverse 2 Long 06°05'49.3" Lat 07°17'32.3" Elev 304.6m					
Traverse 2 a = 10m					
C1	P1	P2	C2	R(Ω)	ρ(Ωm)
0	10	20	30	1.4	87.976
10	20	30	40	1.2	75.408
20	30	40	50	1.1	69.124
30	40	50	60	1.1	69.124
40	50	60	70	1	62.84
50	60	70	80	1.2	75.408
60	70	80	90	1.2	75.408
70	80	90	100	1	62.84
80	90	100	110	0.962	60.45208
90	100	110	120	0.759	47.69556
100	110	120	130	1.1	69.124
110	120	130	140	1.1	69.124
120	130	140	150	0.998	62.71432
130	140	150	160	1	62.84
140	150	160	170	0.998	62.71432
150	160	170	180	0.809	50.83756
160	170	180	190	0.75	47.13
170	180	190	200	0.709	44.55356
Traverse 2 a = 20m					
C1	P1	P2	C2	R(Ω)	ρ(Ωm)
0	20	40	60	0.741	93.12888
10	30	50	70	0.771	96.89928
20	40	60	80	0.751	94.38568

30	50	70	90	0.556	69.87808
40	60	80	100	0.385	48.3868
50	70	90	110	0.815	102.4292
60	80	100	120	0.509	63.97112
70	90	110	130	0.573	72.01464
80	100	120	140	0.673	84.58264
90	110	130	150	0.729	91.62072
100	120	140	160	0.813	102.1778
110	130	150	170	0.654	82.19472
120	140	160	180	0.488	61.33184
130	150	170	190	0.694	87.22192
140	160	180	200	0.507	63.71976
Traverse 2 a = 30m					
C1	P1	P2	C2	R(Ω)	$\rho(\Omega m)$
0	30	60	90	0.67	126.308
10	40	70	100	0.667	125.743
20	50	80	110	0.703	132.530
30	60	90	120	0.812	153.078
40	70	100	130	0.734	138.374
50	80	110	140	0.684	128.948
60	90	120	150	0.494	93.129
70	100	130	160	0.646	121.784
80	110	140	170	1.4	263.928
90	120	150	180	0.716	134.980
100	130	160	190	2.4	452.448
110	140	170	200	0.608	114.620
Traverse 2 a = 40m					
C1	P1	P2	C2	R(Ω)	$\rho(\Omega m)$
0	40	80	120	0.653	164.1381
10	50	90	130	0.804	202.0934
20	60	100	140	0.684	171.9302
30	70	110	150	0.368	92.50048
40	80	120	160	0.53	133.2208
50	90	130	170	0.46	115.6256
60	100	140	180	0.581	146.0402
70	110	150	190	0.846	212.6506
80	120	160	200	0.826	207.6234
Traverse 2 a = 50m					
C1	P1	P2	C2	R(Ω)	$\rho(\Omega m)$
0	50	100	150	0.542	170.2964
10	60	110	160	0.557	175.0094
20	70	120	170	0.734	230.6228

30	80	130	180	0.54	169.668
40	90	140	190	0.528	165.8976
50	100	150	200	0.55	172.81
Traverse 2 a = 60m					
C1	P1	P2	C2	R(Ω)	$\rho(\Omega\text{m})$
0	60	120	180	0.538	202.8475
10	70	130	190	0.638	240.5515
20	80	140	200	0.56	211.1424
Wenner traverse 2 Long 06°05'43.2" Lat 07°17'30.7" Elev 305.3m					

4.1.4 Transverse two



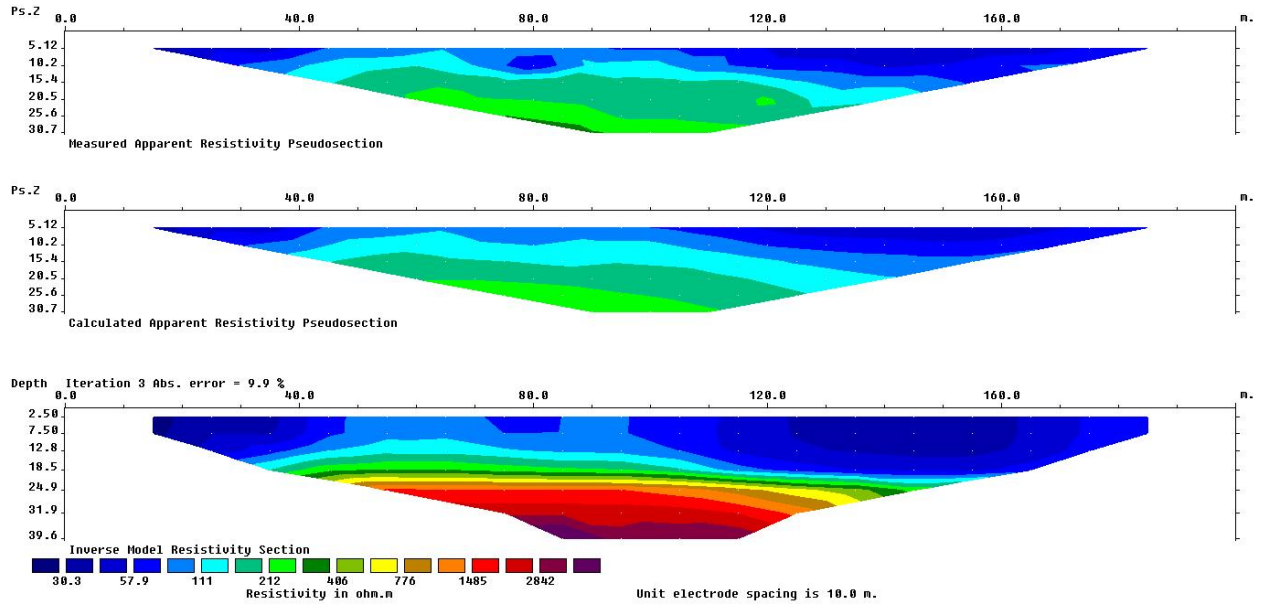
In transverse two, we have about 6 distinct layers of different colours ranging from a resistivity of 45.1 Ωm - 37728 Ωm , which indicates very valuable deposits with a

depth of about 39.6m. The various layers and inferred minerals as compared with the standard resistivity table shows some buried valuable minerals which includes Limestone, Marble, Magnetite(Fe_3O_4).

COLLEGE OF EDUCATION, ABUDU					
Wenner traverse 3 Long 06°05'58.6" Lat 07°17'36.7" Elev 298.6m					
Traverse 3 a = 10m					
C1	P1	P2	C2	R(Ω)	$\rho(\Omega m)$
0	10	20	30	1.3	81.692
10	20	30	40	1.9	119.396
20	30	40	50	1.7	106.828
30	40	50	60	1.5	94.26
40	50	60	70	1.6	100.544
50	60	70	80	1.3	81.692
60	70	80	90	1.1	69.124
70	80	90	100	1.1	69.124
80	90	100	110	1.3	81.692
90	100	110	120	1.2	75.408
100	110	120	130	1.3	81.692
110	120	130	140	1.4	87.976
120	130	140	150	1.3	81.692
130	140	150	160	1.5	94.26
140	150	160	170	1.5	94.26
150	160	170	180	1.5	94.26
160	170	180	190	1.4	87.976
170	180	190	200	1.3	81.692
Traverse 3 a = 20m					
C1	P1	P2	C2	R(Ω)	$\rho(\Omega m)$
0	20	40	60	0.986	123.9205
10	30	50	70	0.959	120.5271
20	40	60	80	1.1	138.248
30	50	70	90	1.1	138.248
40	60	80	100	1	125.68
50	70	90	110	0.931	117.0081
60	80	100	120	0.856	107.5821
70	90	110	130	0.785	98.6588
80	100	120	140	0.805	101.1724
90	110	130	150	0.937	117.7622

100	120	140	160	0.886	111.3525
110	130	150	170	0.805	101.1724
120	140	160	180	0.939	118.0135
130	150	170	190	1.1	138.248
140	160	180	200	1	125.68
Traverse 3 a = 30m					
C1	P1	P2	C2	R(Ω)	$\rho(\Omega\text{m})$
0	30	60	90	0.974	183.618
10	40	70	100	0.821	154.7749
20	50	80	110	0.862	162.5042
30	60	90	120	0.61	114.9972
40	70	100	130	0.663	124.9888
50	80	110	140	0.863	162.6928
60	90	120	150	0.91	171.5532
70	100	130	160	0.811	152.8897
80	110	140	170	0.85	160.242
90	120	150	180	0.813	153.2668
100	130	160	190	0.862	162.5042
110	140	170	200	0.931	175.5121
Traverse 3 a = 40m					
C1	P1	P2	C2	R(Ω)	$\rho(\Omega\text{m})$
0	40	80	120	0.936	235.273
10	50	90	130	0.756	190.0282
20	60	100	140	0.765	192.2904
30	70	110	150	0.625	157.1
40	80	120	160	0.715	179.7224
50	90	130	170	0.608	152.8269
60	100	140	180	0.688	172.9357
70	110	150	190	0.709	178.2142
80	120	160	200	0.887	222.9563
Traverse 3 a = 50m					
C1	P1	P2	C2	R(Ω)	$\rho(\Omega\text{m})$
0	50	100	150	1	314.2
10	60	110	160	0.74	232.508
20	70	120	170	0.642	201.7164
30	80	130	180	0.798	250.7316
40	90	140	190	0.71	223.082
50	100	150	200	0.937	294.4054
Traverse 3 a = 60m					
C1	P1	P2	C2	R(Ω)	$\rho(\Omega\text{m})$
0	60	120	180	0.417	157.2257
10	70	130	190	0.309	116.5054

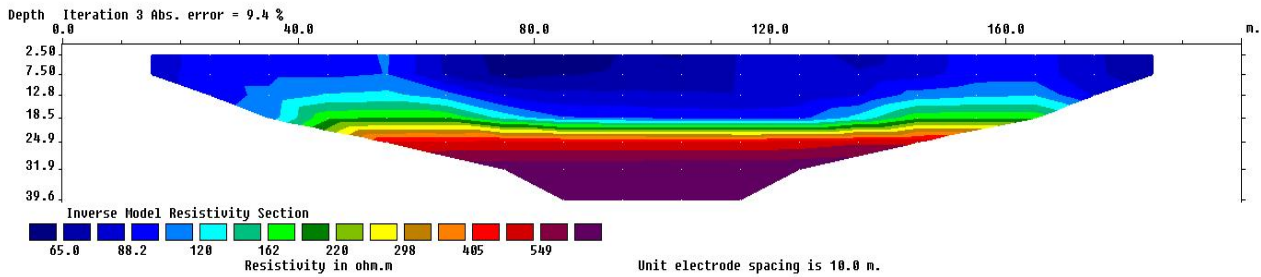
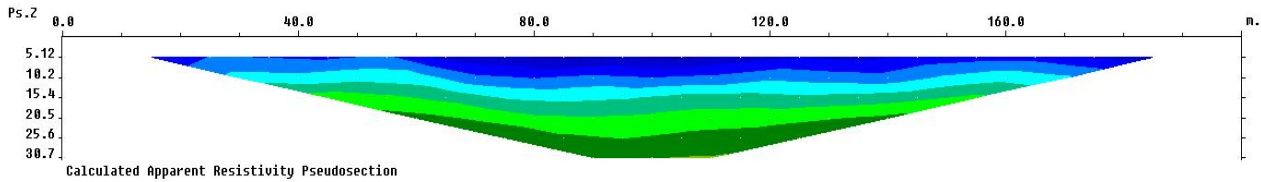
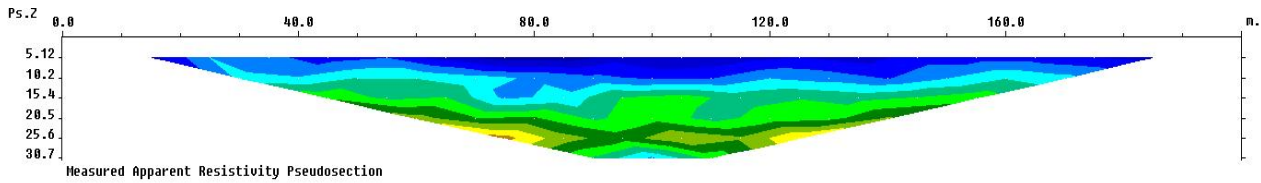
20	80	140	200	0.45	169.668
Wenner traverse 3 Long 06°05'52.6" Lat 07°17'33.6" Elev 295.7m					



COLLEGE OF EDUCATION, ABUDU					
Wenner traverse 4 Long 06°05'50.2" Lat 07°17'36.7" Elev 292.1m					
Traverse 4 a = 10m					
C1	P1	P2	C2	R(Ω)	$\rho(\Omega\text{m})$
0	10	20	30	0.639	40.15476
10	20	30	40	1.1	69.124
20	30	40	50	1.1	69.124
30	40	50	60	1.4	87.976
40	50	60	70	1.3	81.692
50	60	70	80	1.2	75.408
60	70	80	90	1.1	69.124
70	80	90	100	1.4	87.976
80	90	100	110	1.1	69.124
90	100	110	120	1.4	87.976
100	110	120	130	1.6	100.544
110	120	130	140	1.8	113.112
120	130	140	150	1.6	100.544
130	140	150	160	1.5	94.26
140	150	160	170	1.6	100.544

150	160	170	180	1.2	75.408
160	170	180	190	1.1	69.124
170	180	190	200	1.3	81.692
Traverse 4 a = 20m					
C1	P1	P2	C2	R(Ω)	$\rho(\Omega\text{m})$
0	20	40	60	1	125.68
10	30	50	70	0.899	112.9863
20	40	60	80	0.968	121.6582
30	50	70	90	0.988	124.1718
40	60	80	100	1.1	138.248
50	70	90	110	0.865	108.7132
60	80	100	120	0.896	112.6093
70	90	110	130	0.962	120.9042
80	100	120	140	0.862	108.3362
90	110	130	150	0.886	111.3525
100	120	140	160	0.898	112.8606
110	130	150	170	1.1	138.248
120	140	160	180	998	125428.6
130	150	170	190	1	125.68
140	160	180	200	1.1	138.248
Traverse 4 a = 30m					
C1	P1	P2	C2	R(Ω)	$\rho(\Omega\text{m})$
0	30	60	90	0.689	129.890
10	40	70	100	0.666	125.554
20	50	80	110	0.798	150.439
30	60	90	120	0.751	141.579
40	70	100	130	0.742	139.882
50	80	110	140	0.558	105.194
60	90	120	150	0.688	129.702
70	100	130	160	0.741	139.693
80	110	140	170	0.751	141.579
90	120	150	180	0.668	125.931
100	130	160	190	0.748	141.013
110	140	170	200	0.768	144.783
Traverse 4 a = 40m					
C1	P1	P2	C2	R(Ω)	$\rho(\Omega\text{m})$
0	40	80	120	0.862	216.6723
10	50	90	130	0.766	192.5418
20	60	100	140	0.766	192.5418
30	70	110	150	0.728	182.9901
40	80	120	160	0.711	178.717
50	90	130	170	0.686	172.433

60	100	140	180	0.581	146.0402
70	110	150	190	0.701	176.2034
80	120	160	200	0.762	191.5363
Traverse 4 a = 50m					
C1	P1	P2	C2	R(Ω)	$\rho(\Omega\text{m})$
0	50	100	150	0.748	235.0216
10	60	110	160	0.668	209.8856
20	70	120	170	0.648	203.6016
30	80	130	180	0.771	242.2482
40	90	140	190	0.687	215.8554
50	100	150	200	0.611	191.9762
Traverse 4 a = 60m					
C1	P1	P2	C2	R(Ω)	$\rho(\Omega\text{m})$
0	60	120	180	0.558	210.3883
10	70	130	190	0.452	170.4221
20	80	140	200	0.568	214.1587
Wenner traverse 4 Long 06°05' 56.4" Lat 07°17' 38.7" Elev 302.2m					



CHAPTER FIVE

5.1 RECOMMENDATIONS AND CONCLUSIONS

5.2 CONCLUSION

The Wenner Array methods were employed in this work and have revealed the possible location of sandstone in Abudu, Orhionwon, Edo State, Nigeria. From the survey carried out, it was observed that the Wenner Alpha array has seventeen (17) layers with resistivity ranging from about $30\Omega\text{m}$ to $37728\Omega\text{m}$ and depth ranging from 2.50m to about 40m. From this results it can be inferred that Limestone, Sandstone, Shale and Granite can be found in this area.

The Use of Electrical Resistivity Survey to investigate the presence of near surface conductivity and resistivity of sandstone formation was possible by acquiring 2D resistivity data in parallel and perpendicular directions of the survey location and Inverting the data set to produce 2D images of the subsurface using RES2DINV software was useful in analyzing the presence of sandstone deposit. The applied methods was used to proffer adequate information on the availability and evaluate the strength of sandstone and different subsurface soil layers in the study area for economic importance.

5.2 RECOMMENDATIONS

1. More researches on 2-D geo-electrical resistivity imaging should be carried out in other locations within the same local government area to ascertain other types of minerals and aggregates that can be found in the environment and also to compare with what has already been determined,

2. For cases where the Wenner Array appears to be the best option but still appears insufficient and unreliable, the offset-Wenner array should be used,
3. Gravity survey and other Geophysical methods can be combined with the already used procedures to delineate more minerals and ore bodies existing in the survey location.

5.3 CONTRIBUTION TO KNOWLEDGE

1. This research has shown that there's a reasonable amount of sandstone deposit spread along the surface of the study area
2. The use of Geo electrical resistivity survey is helpful in determining subsurface materials in the earth,
3. Using ERT (electrical resistivity tomography) shows the presence of mineral deposit in reasonable amount in the study area, these minerals include Sandstone, Limestone, Clay, Shale e.t.c

REFERENCES

Alile, O. M. (2008): Application of electrical sounding method to decipher the existing subsurface stratification and groundwater occurrence status in a location in Edo North Nigeria; *international journal of physical sciences vol 3. (10) PP 245-249*

Alile, O.M., Enoma, N., Ojo, K.O., Osuoji, O.U. (2016): Two dimensional Electrical Resistivity surveying for mineral deposit in Eguare, Igueben L.G.A south-south, Nigeria. *Journal of scientific Research in Applied Sciences. 68,p.67-81.*

Aigbogun C.O. and Osarenren U.O. (2012): Geo-electric estimation of acquifer parameters in the southern oart of Edo State, Nigeria.

Griffiths , D.H. and Barker, R.D. (1993): Two Dimensional Resistivity Imaging and Modeling in areas of Complex Geology. *Journal of Applied Geophysics, 29, p. 211-226*

Loke, M.H. (2014): Tutorial 2-D and 3-D electrical imaging surveys p/28-40

Parasnis, D.S (1975): Mining Geophysics Methods in Geochemistry and Geophysics. *Elsevier Scientific Publishing Company Amsterdam, Oxford, New York*

Reynolds, J.M., (1998) : An Introduction to Applied and Environmental Geophysics. John Wiley and Sons ltd., London UK. Second Edition. 423