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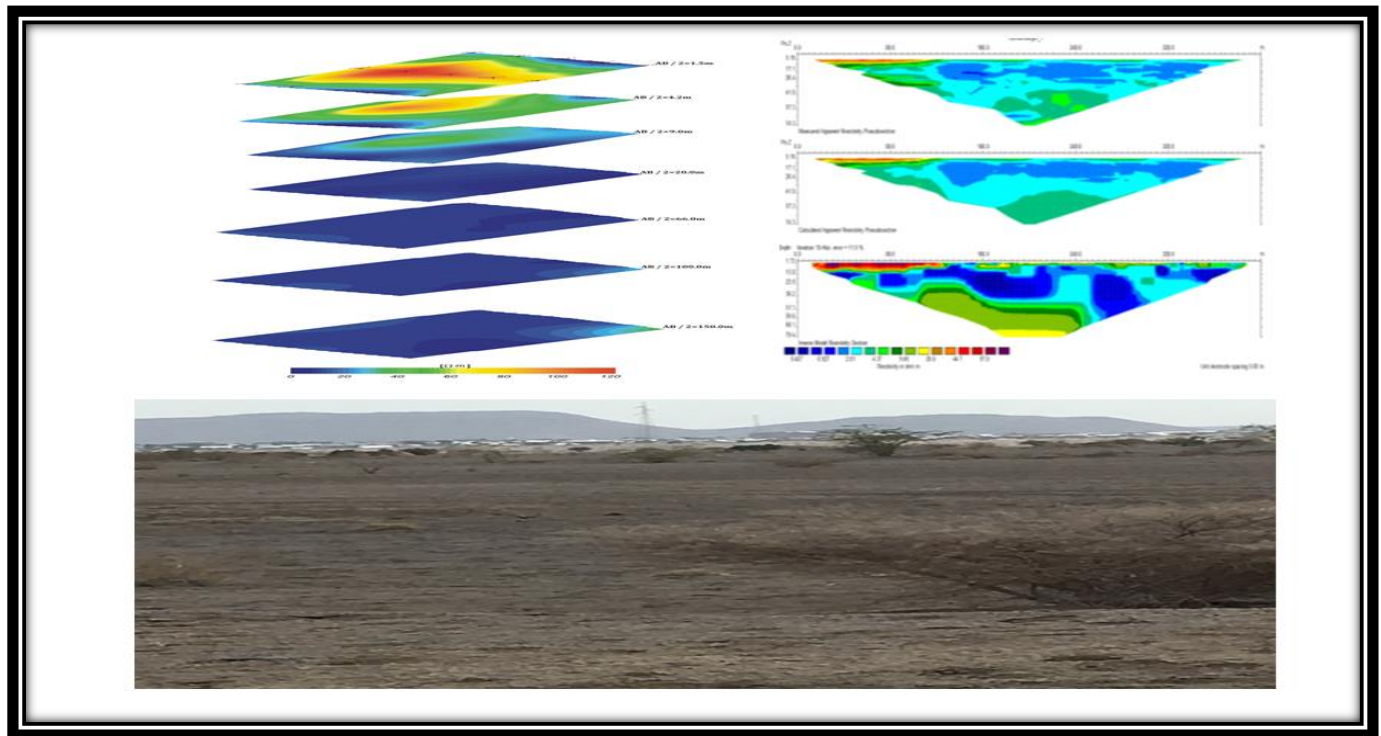
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**COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCES  
SCHOOL OF EARTH SCIENCES**

**Application of Electrical Resistivity Techniques in Building Foundation  
Assessment at Ududaytu area in the Tandaho Graben of Afar, North Eastern  
Ethiopia**



**A Thesis Submitted to the School of Earth Sciences of Addis Ababa University  
in Partial Fulfillment of the Requirements for the Degree of Master of Science  
in Applied Geophysics**

**Yayso Issa**

**July, 2020**

**ADDIS ABABA UNIVERSITY**  
**COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCES**  
**SCHOOL OF EARTH SCIENCES**

**Application of Electrical Resistivity Techniques in Building Foundation Assessment at Ududaytu area in the Tandaho Graben of Afar, North Eastern Ethiopia**

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## Declaration

I hereby declare that the thesis prepared by Yayso Issa entitled: **“Application of Electrical Resistivity Techniques in Building Foundation Assessment at Ududaytu area in the Tandaho Graben of Afar, North Eastern Ethiopia”** is my original work conducted under the supervision of Dr.Shimeles Fisseha and has not presented to any university or institution for the award of any degree or diploma program and all sources of materials used for the thesis are duly acknowledged.

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## **Abstract**

A geophysical survey involving the electrical resistivity method utilizing the Vertical Electrical Sounding (VES) and Electrical Resistivity Imaging Techniques were conducted around Ududaytu area in the Tandaho graben of Afar, North eastern Ethiopia with the aim to characterize the suitability of the Ududaytu area for building foundation to support engineering structures. A total of 16 VES stations and four Electrical Resistivity Imaging profiles were conducted. The VES stations were measured using Schlumberger Configuration with AB/2 varying from 150 m to 220 m. Whereas Electrical Resistivity Imaging profiles were acquired using Wenner-Schlumberger configuration with electrode spacing of 5m.

Four to five main geoelectric sequences were delineated within the study area; these include the topsoil, the upper clay, fine to coarse sand and the bottom clayey sandy /clayey silty layer. A major NNW - SSE discontinuity (fracture zone) was identified. Therefore, this study has showed the usefulness of geophysical methods to delineate the lateral and vertical variations of the subsurface layers and its implication in engineering structures.

From geotechnical point of view, the geoelectrical results has shown that the study area is underlain thick sequence of sediments that are not competent enough to bear loads from heavy engineering structures. The study area being within tectonically active region, with peak ground acceleration (PGA,  $g > 0.3$ ), erecting multistory structures over such relatively weak formation require proper engineering measures during the design and construction stage. Specially, since the amplification potential of such soft formations in the site-soils, could be ominously larger, the design should address the entire relevant factor towards proper mitigation.

**Key words:** Electrical Methods, Vertical Electrical Sounding, Electrical Resistivity Imaging, Building Foundation

## **Acknowledgement**

First of all, I would like to extend my heartfelt gratitude to my advisor Dr.Shimeles Fisseha for providing sufficient reading materials, close follow-up during the field work, constructive comments and sound suggestion throughout the research work. I don't have words to express his support and fatherly advice not only in the subject matter but also for my future career endeavor. My especial thanks go to Addis Ababa University, and Afar Design and Supervision Works Enterprise for funding this research project.

I also indebted to Ato Tibebe Mengesha (Freelance geophysicist) for his fatherly approach, encouragement, crucial comments and providing conducive environment to discuss about various practical aspects of the geophysical methods in general and electrical resistivity method in particular. I also thanks to my colleague Mr.Tsegay Berhe for his support and motivation during the field work.

Last not least, I would like express my gratitude to my family for generous support and motivation. In addition to that, I thank all who were motivating and encouraging me to accomplish my MSc. study and carry out this research project in a Successful manner.

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## Acronym

a.m.s.l	above mean sea level
CSA	Central Statistical Agency
E	East
ERI	Electrical Resistivity Imaging
GPS	Global Positioning System
Km	Kilometer
l/s	liter/second
m	meter
N	North
NW	Northwest
SE	Southeast
UTM	Universal Transversal Mercator
VES	Vertical Electrical Sounding
$\Omega$ -m	ohm-meter
1D	One Dimensional
2D	Two Dimensional

## Chapter One

### 1. Introduction

#### 1.1 Background

A building is an assemblage that is firmly attached to the ground and may have a variety of sizes, shapes, and functions. Building types may range from simple shacks to multistory, high-rise towers. Buildings can be classified based on occupancy and use. These includes; Assembly Buildings, Business Buildings, Educational Buildings, Factory and Industrial Buildings, High Hazard Buildings, Institutional Buildings, Mercantile Buildings, Residential Buildings, Storage Buildings, and Utility and Miscellaneous Buildings according to International Building Code (2001).

A foundation is an integral part of a building that sustains the weight of the building to the ground underneath. The main use of building foundation is to: distribution of loads, minimize stress against soil movement, provide stability against sliding & overturning and prevent differential settlement. Foundations can generally be shallow or deep. Most importantly, foundation design has to done in such a way that the structural loads are transmitted to the subsoil safely, economically and without any detrimental movement during the construction period and throughout the anticipated life of the building. However, to ensure proper design and successful construction, it is important to investigate the subsurface and obtain crucial geotechnical and engineering parameters of the specific site.

Geophysical investigations are now playing increasingly important role in urban planning development. In the last decade, the involvement of geophysics in civil and environmental engineering has become a cost effective approach for mapping and monitoring physical parameters of subsurface rocks and soils. Geophysical methods a wide range of applications ranging from foundation study to the inspection of dams and tunnels for mitigation purposes, (e.g., Burger, 1992; Milsom, J., 2009)

Geophysical methods in geotechnical investigations are applicable to map soil properties, subsurface inhomogeneity, cavities, ancient relics, generally, any buried structures or bodies that have different physical properties from their geological surroundings (Sirles, 2006 as cited in Yonatan Garkebo, 2011).These methods are used to provide site specific information about the

subsurface properties, depth to bedrock, location and distribution subterranean fluids, location and orientation of fractures. There are a number of geophysical methods which can be used for foundation study like Seismic Method, Electrical Resistivity Magnetic Method, Gravity Method and Ground Penetrating Radar. With lithological logging of the boreholes in the study area, geophysical parameters give adequate insight. The main objectives of this thesis project is to implement integration of geophysical techniques for mapping the subsurface in engineering site assessment at Ududaytu plain, located between Logia and Samara town in Afar regional state. The specific land plot is intended for construction residential building blocks.

The original plan was to employ three techniques: Seismic Refraction, Magnetic and Electrical Resistivity methods. However, due several logistic and technical problems, it has not been possible to conduct the seismic refraction and magnetic investigations. But, the project is adequately mapped using electrical resistivity survey via Vertical Electrical Sounding (VES) and 2D Electrical Resistivity Imaging/ Resistivity tomography (ERT).

## 1.2 Description of the study area

### 1.2.1 Location and accessibility of the study area

The study area, Ududaytu plain is located in Tandaho Graben between Logia and Samara town, Afar Regional State, North Eastern Ethiopia. It can be accessed by the main asphalt road of Addis Ababa-Djibouti and at around 500km from Addis Ababa. The study area is geographically bounded between latitudes 1292000 N to 1304000 N and longitudes 710000 E to 725000 E as shown in figure 1.1. The area can be described as flat.

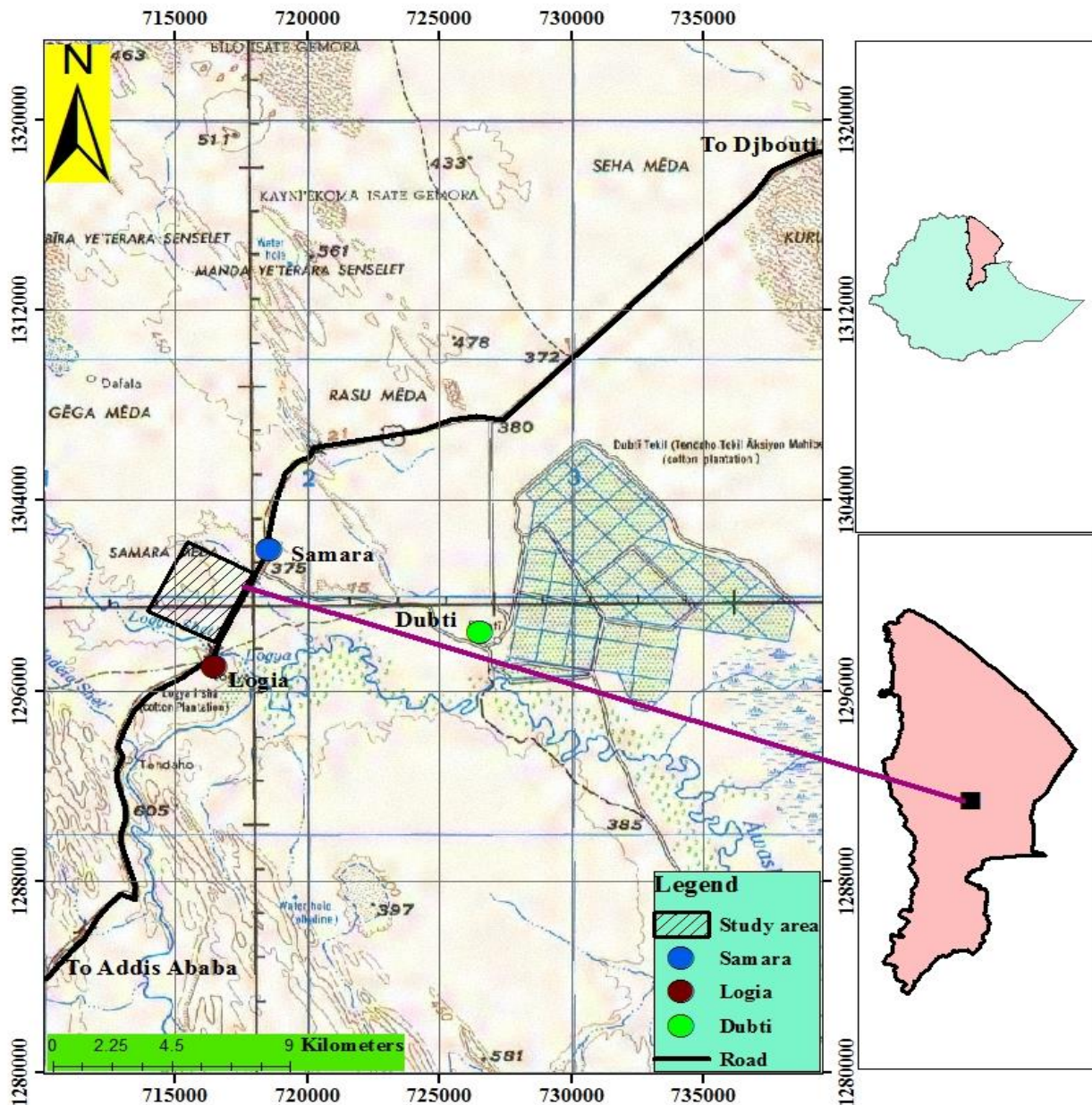


Figure 1.1 Location Map of the Study area

### 1.2.2 Physiography and Drainage Pattern of the study area

The project area is situated within the rift valley and it is formed by the volcanic activities, erosion and deposition processes.



*Plates 1.1 Partial view of the Study area*

The study area is generally characterized by the two major types of land forms such as flat plain (with an average elevation of 380m a.m.s.l), surrounded by volcanic ridges as shown in the figure 1.2. The study area is mainly drained by Logia River and the drainage of the area is characterized by dendritic pattern.

### 1.2.3 Climate of the study area

Afar is characterized by an arid and semi-arid climate with low and erratic rainfall. Rainfall is bi-modal throughout the region with a mean annual rainfall below 500 mm in the semi- arid western escarpments decreasing to 150 mm in the arid zones to the east. The study area is lying in subtropical climate classified as semi-arid and arid climate zones. Where evaporation exceeds precipitation and has higher temperature with low and unreliable rainfall that sometimes results in long periods of drought. The mean maximum temperature is 36.2<sup>0</sup>c with a minimum of 19.80<sup>0</sup>c (Ethiopian mapping agency, 1981).

### **1.3 Statement of the Problem**

Afar region is the most seismically and volcanically active part of the East Africa Rift System. The most notable recent earthquake activities that occurred not far from the location of the study area are the 1969 and 1989 earthquake sequences at Sardo and Dobi graben, respectively, (Ayele,1995). If multifaceted development activity is to be planned in the area, it is highly recommended that should be implemented in an environmentally friendly manner and requires close follow-up of the background activity with state-of the- art geophysical and geological studies (Ayele et al., 2015).

Driven by the increasing population of Samara-Logia town and growing demand for site development, the Afar National Regional State is planning to use Ududaytu area for construction of different types of building infrastructures. The current study is motivated by the aforementioned recommendations that adverts cautions on loss of life and properties. Therefore, in order to ensure a long term performance and stability of building foundation, proper geotechnical assessment of the proposed site is imperative. The use of integrated geophysical techniques for such detail subsurface investigation has been proved advantageous.

### **1.4 Objectives**

#### **1.4.1 General Objective**

The primary objective of the thesis project is to study the application of Electrical Resistivity Techniques in engineering site characterization. The project is implemented at the Ududaytu area through applying VES and Electrical Resistivity imaging for mapping the subsurface material in engineering sites assessment.

#### **1.4.2 Specific objectives**

The objectives of the study are:

- Examining the variations in the diagnostic physical parameters (electrical resistivity) of lithological layers constituting the geological sections beneath the pre-selected points and profiles.
- Delineating zones of peculiar physical responses (anomalies) which may indicate presence of any possible geological structures (faults, fractures or any weak zones) that pose post- construction hazards.
- Studying the Groundwater condition of the project site.

### 1.5 Methodology

The thesis project was planned to be implemented in the following sequences.

**Pre-field work (Desk study):** at this stage previous works and literatures with direct relevance for the present study were collected and reviewed in the office. The literature review was focused on published journals, previous reports maps and section on the geological, hydrogeological and geophysical works in the study and the surrounding area.

**Field work:** at this stage the actual field survey was done and primary data was collected. This comprises:

- Geological and hydrogeological observation. During the field work the major geological and hydrogeological features of the project area, identified at the pre-field stage, were verified and the additional observations were also made.
- Geophysical data acquisition: the actual data used in the present study was acquired using Vertical Electrical Sounding and 2D-Electrical Resistivity Imaging.

**Post-field work:** The main undertaking accomplished at this stage includes;

- Reduction and processing the geophysical data.
- Preparation of charts maps and sections
- Analysis and interpretation the geophysical survey result,
- Compilation of the final manuscript, the Thesis.

### 1.6 Significance of the Study

The study area is found in Tandaho graben which is tectonically active. Hence, the design and construction of major engineering structure in the region require proper understanding of the subsurface geological and geotechnical settings. So, this study will have significant contribution to the decision making process on the design and construction details of the envisaged housing project. Moreover, the project avails opportunity for the candidate to impart practical knowledge on the planning and execution of geophysical campaign for engineering site assessment.

### 1.7 Limitation and shortcomings

As stated in section 1.1 and referred on the title, the aim was to integrate three geophysical techniques namely, seismic refraction, magnetic and electrical resistivity methods in two field campaigns. During the first field trip, the electrical resistivity survey was successfully done. However, due to unexpected instrument failure, the magnetic survey could not be done as planned. All the efforts to fix the magnetometer went futile. The second field campaign, which

was intended for Seismic refraction and possibly magnetic survey, could not be implemented following because of the COVID 19 pandemic. As a result, the geophysical data is limited to Vertical Electrical Sounding (VES) and 2D Electrical Resistivity Imaging/ Resistivity tomography (ERT).

### **1.8 Review of Previous Work**

Many Geological and Geophysical investigations have been conducted on Afar depression since Afar Region is an area of active extensional tectonics and volcanism, where the Red Sea, the Gulf of Aden and the Ethiopian Rift Systems Converge. Because of these, the area has drawn the interests of several geoscientists. The different works which have been carried out in Afar depression in general and in the Tandaho Graben in particular are summarized below.

**I.** According to Yohannes Lemmal et al. (2010) Regional and Semi-detailed geophysical studies have been carried out in the Afar Depression and Tandaho geothermal field, with the aim to investigate the deep structures and to delineate possible geothermal reservoir. The methods include Magneto-telluric (MT) (e.g. Berktold, 1975); Vertical Electrical Sounding (VES), Magnetics and Gravity survey (e.g. Aquater, 1980) among others. In 1971 MT survey was carried out in the Afar region to investigate the deep electrical resistivity distribution (Berktold, 1975). The survey included measurement of the electric field in 36 temporary stations along three profiles for a total length of 900 km. Results indicate that in the Afar Depression and the marginal parts of the Western plateau, the resistivity is decreasing from 200-500 Ohm-m in the uppermost kilometers to 10-50 Ohm-m at a depth of about 15 km (Berktold, 1975).

**II.** Temporary broadband seismic networks deployed from 2007 to 2011 around the Afar triple junction of the East African Rift System provide insights into seismicity patterns of the actively deforming crust around the 1.86 km<sup>3</sup> impounded lake system behind the Tandaho dam. The observed seismicity correlates well with the active magmatic centers around central Afar. The area around the dam site is characterized by a network of intersecting NNE- and NW-trending faults. Seismicity clusters observed in the specified time interval indicate that both fault sets are active and are potential sources of seismogenic hazards around the study area (Atalay et al., 2015).

**III.** Regional Gravity Survey in Afar and Surrounding Plateaus: Between 1992 and 2004 the Geological Survey of Ethiopia has carried out regional gravity surveys in Afar depression and adjacent plateaus. The principal objective of the survey was to produce the Bouguer gravity and

its derivative maps of the studied region at 1:500,000 scale. Accordingly, data were collected at 5km interval along accessible roads, using the Lacoste and Romberg gravimeter. All types of data reductions were applied, including terrain correction. The survey result revealed density variations related to crust-upper mantle structures, major tectonic disturbed zones (faults) with NW-SE orientation dominating in northern and NE-SW trend in southern Afar that stretched towards central Afar. Besides, the data clearly indicated that the crustal thickness of the northwestern plateau is greater than that of the southeastern plateau and the Afar depression. Accordingly, the estimated thickness of the NW plateau is about 40km, whereas that of the depression less than 25km. It is particularly thin along the peripheries of the depression, the NW escarpment and parallel to the depression axis.

**IV. Geological Survey of Ethiopia Geothermal Resource Exploration and Evaluation Directorate:** Detailed geophysical survey has been conducted in the Tandaho and surrounding area geothermal fields. The techniques/methods employed include Schlumberger resistivity traversing for  $AB/2=500m$  and  $1000m$ , Head on resistivity profiling and gravity. Tacheometric method was used in determining the locations and altitudes of most of the geophysical survey points. In both cases, the influence of the two regionally dominant structures, NW and NE ones are the major factors controlling the flow of hot geothermal fluids from depth to near surface.

**V. Logia Town Water Supply Project-Feasibility Study and Design, by Water Works**

**Design and Supervision Enterprise:** The aim of the study was to discuss options and make recommendations relating to the water supply system up to the year 2026. The study and design considers two design phases the duration of which consists 10 years (2007-2016) for the first phase, and another 10 years (2017-2026) for the second phase. Population projection has been made using growth rates established by CSA for urban population projection at country level.

The strategy assumed in this document considers use of groundwater resource as a first alternative. This is because there are four existing boreholes that could satisfy the demands of the town till the end of the stipulated design period. The required maximum water demand at the end of the design year was estimated to be 20.78l/s. However, the total yield from the existing four boreholes was 22.5l/s. Hence, the existing boreholes were sufficient to satisfy the demand till the end of the design period.

**VI. Water Supply Borehole Siting in Seven Selected area of the Afar Region:** Geophysical survey was conducted in seven selected areas of the Afar National Regional State for water supply borehole siting. The surveys were done from May 2, 1999 to August 4, 1999 as part of a contract agreement reached between the Ethiopian Institute of Geological Surveys (EIGS) and the Water Resources Bureau of the Afar National Regional State for water supply well siting for 50 towns and villages. Geophysical methods (VES and Magnetics) were used for borehole site selection and a total of 51 resistivity soundings and 9.56 line-km magnetic profiling were conducted in the selected areas. In five areas, drilling is recommended on geophysically identified locations assumed to have favorable conditions for groundwater development. Most of the well sites are recommended on low resistivity zones, where deep weathering and/or fracturing are presumed to have taken place.

### **1.9 Structure of the Thesis**

This thesis is organized in six chapters. The first chapter is introduction which deals with the background, site description, and statement of the problem, objectives, methodology, significance and limitation of the study. The second chapter is about geology, hydrogeology and seismic setting of the study area. The third chapter discuss about theoretical background of the geophysical methods employed. The fourth chapter covers data acquisition, processing and presentation. The fifth chapter addresses the result, discussion and interpretation, and the last chapter which is chapter sixth contains conclusions and recommendations.

## Chapter Two

### 2. Geology, Hydrogeology and Seismic Setting

#### 2.1 Geologic and Tectonic Setting

The Afar Depression is part of the East African Rift system, which is part of Afro Arabian Rift System. This system extends from southern Africa, through the East African Rift System, Afar Depression, Red Sea, Dead Sea, through the Jordan Valley and terminates in Syria (Ebinger, 2005). The Afar Depression, a diffuse triple junction where the Gulf of Aden, the Red Sea and the MER radiate, covers an area of ~250,000 km<sup>2</sup> and is encircled by steeply inclined fault escarpments, which close at the Alid graben north of Dallol Depression (Barberi, et al., 1972). The depression is bordered on the west by the Ethiopian escarpment, on the east and northeast by the Danakil Microplate, and on the south by the Somalian Plateau. The elevation drops radically from the rift bounding Ethiopian plateau that stands well above 3500 meters above sea level to the lowest point in northern Afar Depression (Dallol Depression) at ~146 meters below sea level. As tectonically defined, Afar is clearly distinguished from the Ethiopian Rift. The uniquely depressed region of the area is thus called “the Afar Triangle or Depression”. This area is a place where the process of continental break-up is ongoing as the Nubian and Somalia Plates slowly separate. Of the very few places in the worldwide where the process of continental break-up is ongoing, and Afar is unique to study the active processes of continental break-up associated with mantle plumes and for its accessible to land-based geology (Megersa and Getaneh, 2006).

The Regional Geologic outline of Afar area is unique because of its location at the Junction of three major rifts; the Main Ethiopian rift, the Red Sea rift and the Gulf of Aden rift. It is a place where the process of continental break-up is ongoing (birth of oceanic spreading) (Megersa and Getaneh, 2006). The geology of the Afar Depression and its margins is of great interest because it may represent the complete sequence of rocks spanning from the Late Proterozoic to the present. The Afar Depression is not only a site of volcanism; it is also an excellent site of depositional environment. The geological formations of the Afar Depression and its marginal areas and surrounding plateaus can be divided into four broad divisions: Pre-rift complexes; Syn-rift igneous rocks; Pliocene–Pleistocene volcanic rocks; and Quaternary volcanic and sedimentary rocks. Rifting in Afar began during lower Miocene on a continental arch where important basaltic activity was probably in progress. The Afar Depression is believed to have reached to its

present geological setting during the Pleistocene period, with the determination of axial ridge. Intense tensional tectonics affects the entire depression, thus, forming a complex mosaic of horsts and grabens that are still active and contain localized sedimentary basins. From west to east, these are the Tandaho Graben, the Dobi Graben, the Gaggade Graben and the Assal Graben (Bonini *et al.*, 2005).

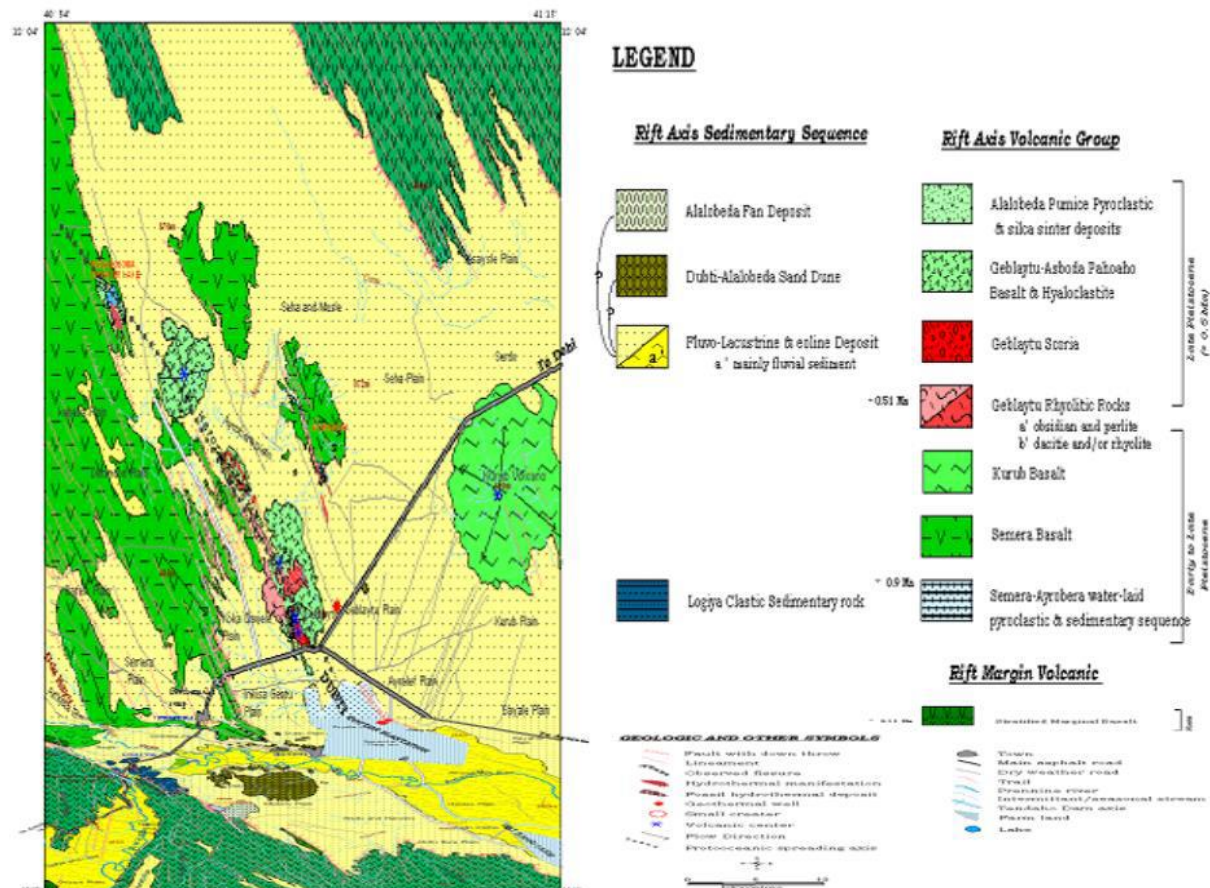


Figure 2.1 Geological map of Tandaho Graben (After Megersa and Getaneh, 2006)

The Tandaho Graben is the largest rift basin in the central Afar (Acocella *et al.*, 2008 as cited in Yonas Teshome, 2015). It is typically 50 km in width and extends a few hundred kilometers in the NW-SE direction. The Tandaho graben is bounded by Logya fault to the west and Gamare fault to the East. In the Tandaho region NW and NNE trending faults predominate (UNDP, 1973 as cited in Lemma *et al.*, 2010). The borders of the Tandaho rift are constituted by the Afar Stratoid Series and the rift is filled with lacustrine and alluvial deposits and with post stratoid basalt flows. This filling is topped by recent volcanoes, including the historically active Kurub and Damal Ale. The relief from flanks to basin bottom is a few hundred meters however the

sediment thickness exceeds 1600m in places and could be much thicker based on data from the Tandaho Geothermal Project (Aqater, 1996). Accordingly the stratigraphies under the graben floor are grouped into:

1. Upper unit: thick sedimentary sequence consisting of fine to medium grained sandstone, siltstone and clay probably intercalated by basaltic lava sheets; and
2. Lower unit: basaltic lava flows of the Afar stratoid series.

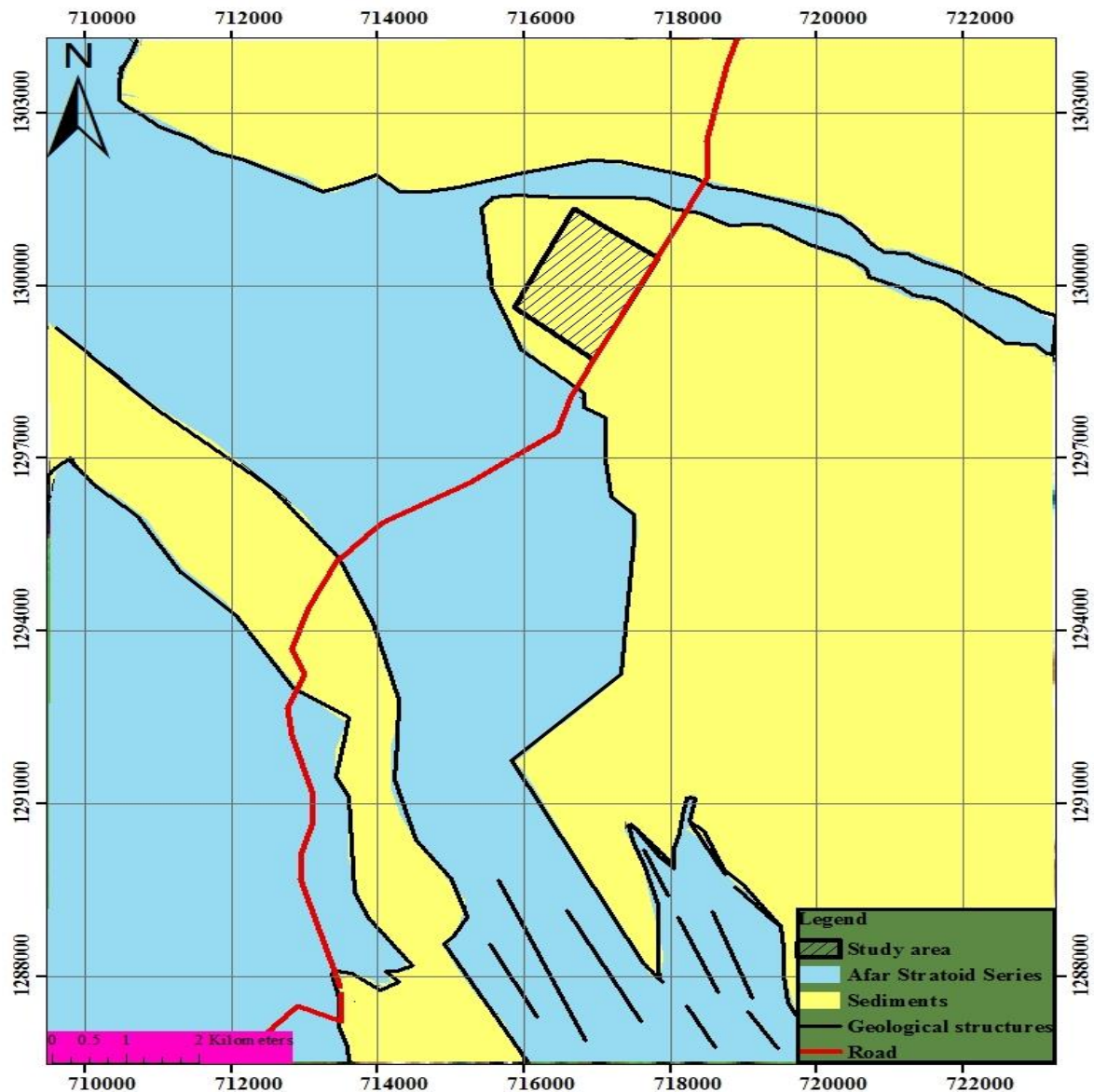


Figure 2.2 Geological map of the Study area modified from UNSCO, 2014



*Plates 2.1 Alluvial deposit (left) and Basalt Exposure (right).*

## **2.2 Hydrogeological Condition**

According to Asfaw Aymeku (2017), the general Hydrogeological condition of the Afar region based on the observation from well drilling logs of different boreholes drilled in different geological environments of the region the major water bearing geologic units in the area can be categorized into two main groups as extensive and unconsolidated Alluvial aquifers (including the Alluvial fans) of Sand and Gravel at shallow to deep level, and the deep fractured aquifers of Basalts , Scoracious basalts and sometimes with highly fractured Ignimbrites and trachytes. The unconsolidated Alluvial aquifers in the region occupy the wide Alluvial plains of the region like Teru, Awra, Gulina, Ewa, Chifra, Worenso-Mille, Middle Awash, Tandaho, Alidege, Erebt and Bahri plains as well as marginal structural Grabens like Abaala, Ayshet , Borkena and Robit Grabens. The narrow structural Grabens in central Afar including the Dobi, Guma, Hanle, Manda-Inakir grabens are filled by thin layers of these aquifers at shallow depth overlaying the deep fractured aquifers below the Alluvial. Recharge source for the deep regional fractured aquifers is the groundwater flow from marginal highlands precipitation in the western and eastern plateau areas of the rift. However recharge source for shallow fractured stratoid basalt aquifers in many of narrow structural grabens are limited to the nearby highlands and volcanic centers. Therefore understanding the local meteorological condition is very important. In addition to the hydraulic properties of the subsurface formations, the groundwater flow regime is also controlled by the complex structural and tectonic features.

The groundwater flow system in the region can be grouped into two main groundwater basins depending on the flow direction controlled and drained by two different surface water bodies (Lakes) in and outside the region where the groundwater is discharging. Accordingly the deep groundwater from north western and northern rift margins and areas including some parts of Awra, Gloina, Teru Kori and Bidu groundwater is controlled by Lake Afdera and on the other hand the groundwater regime in Central, west, eastern, north eastern and southern part of the Afar region (dominantly groundwater of the Awash basin) is controlled by the Lake Asal which is the lowest lake surface (156m below sea level) in Africa located at Djibouti boarder. These also include the groundwater in the north eastern part like the Tanadaho graben (Aysaita, Dubti and Logiya areas) Gega, Seha and Sardo plain, Elidear and Bure areas.

### **2.3 Seismicity**

Earthquake is shaking or trembling caused by the sudden release of energy from rocks and usually associated with faulting or breaking of rocks. Earthquake intensity depends on site condition, source effect and travel Path effect.

Distinguished by explicit tectonic, geologic and seismic features, Ethiopia is divided into three major source zones named as; “the Afar Depression, the Escarpment and the Ethiopian Rift System” (Mammo, 2005). On the other hand, the Ethiopia Building Code Standard (1995), the divides the country into five zones seismic risks depending on the known distribution of earthquakes. These zones are no damaging zone (0 zones), less damaging zones (zone 1 and 2) and zones of major damaging (zone 3 and 4) as shown in figure 2.3. This map is based on the amplitudes of the ground acceleration to be expected during 100 years return period which depends on the seismic zones as shown in the table 2.1 below.

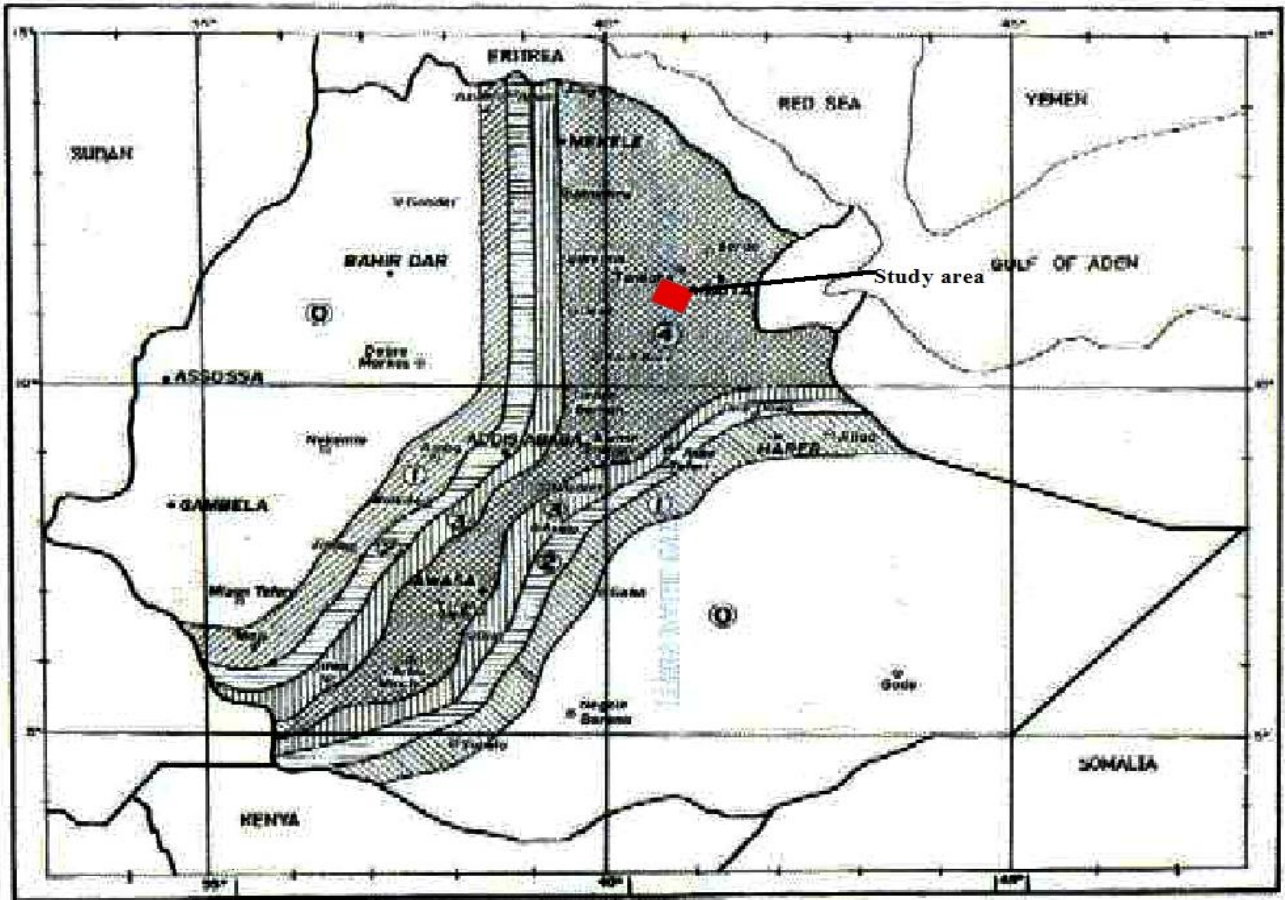


Figure 2.3 Seismic hazard map of Ethiopia for 100-year return period as per EBCS 8: 1995.

Table 2.1 Ground Acceleration Ratio

Zone	4	3	2	1
Ao	0.1	0.07	0.05	0.003

Accordingly, the study area is found in Afar depression seismic source zone and it also lies at seismic zone 4 of Ethiopia Building Code Standard which is a major damaging zone with ground acceleration of 0.10. This shows that the study area and its surrounding are at seismically active area. Therefore, considering the thick alluvial deposit, and complex and intensive geological structures, which are able to magnify the amplitude of earthquakes in the site. As a result, the foundation design should incorporate all necessary conditions to withstand any seismic hazard the study area.

## Chapter Three

### 3. Electrical Methods

#### 3.1 Preamble

Electric prospecting involves the detection of surface effects produced by electric current flow in the ground. Using electrical methods, one may measure potentials, currents, and electromagnetic fields that occur naturally or are introduced artificially in the earth. Measurements can be made in a variety of ways to determine a variety of results. Basically, however, it is the enormous variation in electrical conductivity found in different rocks and minerals that makes these techniques possible (Telford et al., 1990).

There are many varieties of electrical method. They are often classified by the type of energy source involved that is, natural or artificial. Some make use of fields within the Earth while others require the introduction of artificially-generated currents into the ground. Electrical methods utilize direct currents or low frequency alternating currents to investigate the electrical properties of the subsurface.

Electrical and EM methods include self-potential (SP), Telluric currents (TC) and Magnetotellurics (MT), DC Resistivity/Induced Polarization (Res/IP) Method - Equipotential Line (EPL) Method - Potential Drop ratio (PDR) Method, and Mise -a-la-masse Method of prospecting.

Electrical methods have been used for many decades in hydrogeological, geothermal exploration mining and geotechnical investigations (Griffiths and King, 1965). More recently, they have been extensively used for environmental studies (Reynolds, 2011)

#### 3.2 Direct Current (DC) Resistivity Methods

##### 3.2.1 Introduction

Electrical resistivity methods were developed in the early 1900s but have become very much more widely used since the 1970s, due to the availability of computers to process and analyze the data (Koefoed, 1979). These techniques are used extensively in the search for suitable groundwater sources; in engineering survey to locate subsurface cavities, faults and fissures; in archaeology for mapping the areal extent of remnants of buried foundation of the ancient buildings, amongst many applications (Reynolds, 1997).

### 3.2.2 Basic Principles

DC Electrical resistivity surveys are based on the response of the subsurface materials to the flow of artificially generated electrical current introduced into the ground by means of a pair of electrodes. The resulting potential differences, measured at the surface across another pair of electrodes provide a means to determine the resistivity that governs the relation between the current density and the gradient of the electrical potential (Telford et al., 1990; Lowrie 1977). With few exceptions, most common rock-forming minerals are electrically insulators. Conduction of electricity in rocks and soils is therefore via electrolytes within the pore space which implies the resistivity in the subsurface is largely dependent upon the amount of pore water present, its conductivity, and the manner of its distribution within the material (Guyod, 1964). Hence, the electrical resistivity contrasts existing between lithological sequences in the subsurface is used in the delineation of distinct geoelectric layers which can ultimately be used to understand their physical and mechanical characteristics, such as compositions, moisture /fluid contents as well as degrees of weathering and fracturing.

The practical use of electrical resistivity measurements in studying groundwater potential is related to the fact that the variation in electric resistivity of a rock formation depends on the nature of rock material (density, porosity, pore size and shape), and by and large, the interstitial water content, its quality as well as temperature. This enables delineating the subsurface geological unit may be subdivided into different geoelectrical units according to the different percentage of fluid content/humidity within it (Parasnis, 1997).

In resistivity measurements, highest resistivity is associated with igneous rocks. Sedimentary rocks tend to be most conductive due to their high fluid content. Metamorphic rocks have intermediate resistivity. Granites and quartzite have high resistivity ranges; sandstone and shale have intermediate resistivity ranges (Bernard, 2003). The resistivity therefore in a particular geological environment has an influence on the aquifer resistivity. Numerical values of resistivity for various types of rocks are outlined (Table 3.1).

Table 3.1 Resistivity's of different rocks types (Loke, 1999)

Rock types	Resistivity ( $\Omega$ -m)
Metamorphic/Igneous rocks	5 x10 <sup>3</sup> - 10 <sup>6</sup>
Slate	6x10 <sup>2</sup> – 4 x 10 <sup>7</sup>
Gneisses	8-10x10 <sup>3</sup>
Marble	1x10 <sup>6</sup> – 1 x 10 <sup>7</sup>
Quartzite	1x10 <sup>6</sup> - 1 x 10 <sup>8</sup>
Basalt	5x10 <sup>3</sup> – 1x10 <sup>5</sup>
Andesite	5x10 <sup>3</sup> – 1x10 <sup>5</sup>
Sedimentary Rocks	
Sandstone:	1x10 <sup>5</sup> – 1x10 <sup>6</sup>
· Saturated with fresh water	3x10 <sup>1</sup> – 2x10 <sup>2</sup>
· Saturated with saline water	1-10
Clay:	1x10 <sup>3</sup> –1x10 <sup>5</sup>
· Saturated with fresh water	1x10 – 1x10 <sup>2</sup>
· Saturated with saline water	1-10
Gypsum	1x10 <sup>5</sup> – 1x10 <sup>7</sup>
Shale	20 -2 x 10 <sup>3</sup>
Limestone	50 - 4 x 10 <sup>2</sup>
Unconsolidated (colluvial and alluvial)	Varies based on their parent rock

### 3.2.3 Instrumentation and measurement principles in DC Resistivity

Resistivity survey instruments are designed to measure the resistance of the ground, that is, the ratio ( $\square V/I$ ), to a very high accuracy. They must be capable of reading to the very low levels of resistance commonly encountered in resistivity surveying. Apparent resistivity values are computed from the resistance measurements using the formula relevant to the electrode configuration in use.

Most resistivity meters employ low-frequency alternating current rather than direct current, for two main reasons. Firstly, if direct current were employed there would eventually be a build-up of anions around the negative electrode and cations around the positive electrode; that is, electrolytic polarization would occur, and this would inhibit the arrival of further ions at the electrodes. Periodic reversal of the current prevents such an accumulation of ions and thus overcomes electrolytic polarization. Secondly, the use of alternating current overcomes the effects of telluric currents which are natural electric currents in the ground that flow parallel to the Earth's surface and cause regional potential gradients. The use of alternating current nullifies their effects since at each current reversal the telluric currents alternately increase or decrease the measured potential difference by equal amounts. Summing the results over several cycles thus removes telluric effects.

The frequency of the alternating current used in resistivity surveying depends upon the required depth of penetration. For penetration of the order of 10m, a frequency of 100 Hz is suitable, and this is decreased to less than 10 Hz for depths of investigation of about 100m. For very deep ground penetration direct currents must be used, and more complex measures adopted to overcome electrolytic polarization and telluric current effects. Many modern instruments make use of a square wave current input to overcome the polarization.

Resistivity meters are designed to measure potential differences when no current is flowing. Such a null method is used to overcome the effects of contact resistance of the electrodes with the ground. The potential between the potential electrodes is balanced by the potential tapped from a variable resistance. No current then flows in the resistivity circuit so that contact resistance will not register, and the variable resistance reading represents the true resistance of the ground (equal to the ratio  $\frac{V}{I}$  in the relevant equations).

Previous generations of resistivity meters required the nulling of a displayed voltage by manual manipulation of a resistor bank. Modern instruments have microprocessor-controlled electronic circuitry which accomplishes this operation internally and, moreover, performs checks on the circuitry before display of the result.

Resistivity surveying for shallow penetration can be made more efficient by the use of spike electrodes which are mounted on small wheels and towed along a profile by the operator. Improvements in instrument technology have also led to the development of electrodes in the

form of antennae which are capacitively coupled to the ground (Panissod *et al.* 1998), so that there is no need for spike electrodes to be placed in the ground and a CST may be accomplished by an operator towing the array at a walking pace by foot or vehicle. Measurements can be taken automatically and are no longer restricted to areas where electrodes can be inserted, such as road metal, ice, permafrost, etc. Such a system allows the collection, by a single operator, of 500% more data in the same time as a conventional instrument with a crew of two. However, the limitations of the physical dimensions of such equipment considerably restrict penetration.

### **3.2.4 Electrode Layouts and Field Procedure**

In the electrical resistivity surveying work, an electric current is introduced into the ground by means of two current electrodes (C1 & C2) and the potential difference between two potential electrodes (p1 & p2) is measured as shown in Figure 3.3. Direct measurement of the potential drop or apparent resistance in Ohms is preferable than the observed current and voltage. Finally, the apparent resistance value is converted to apparent resistivity by use of a geometric factor that depends on the particular electrode configuration used in the particular survey (Bell, 2007).

An enormous number of electrode spreads have been used in resistivity at various times; not more than a half dozen have survived to any extent. In principle it is not necessary to use a collinear array. Practically, however, the electrodes are almost always in line; otherwise interpretation of results becomes difficult and the field work is complicated.

One drawback in resistivity work is the practical difficulty of moving stakes with great lengths of wire attached, a slow and expensive task in relation to magnetics, EM, and some other electrical survey methods. Thus it is an advantage to use electrode spreads that may require only one or two electrodes to be moved, and these at close spacing where possible (Telford,1990).

The most common of these arrangements are the Wenner, Schlumberger and the Dipole-Dipole, but there are several other variations.

#### **a) Wenner array**

In this layout the current and potential electrodes are uniformly spaced in a line. For depth exploration using the Wenner array, the electrodes are expanded about a fixed center, increasing the spacing in steps. For lateral extent variation, the spacing remains constant and all four electrodes are moved along the line and shifted to another profile.

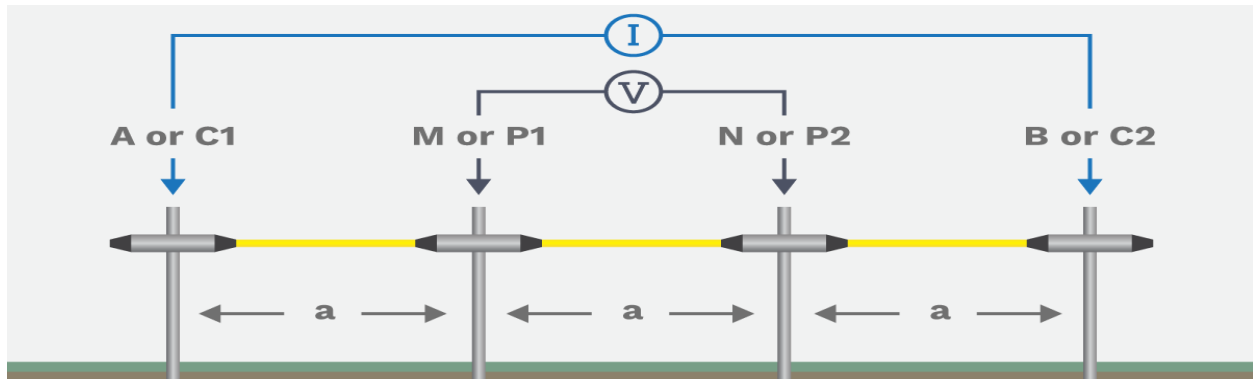


Figure 3.1 <https://www.agiusa.com/Wenner-array>

**b) Schlumberger array**

In this configuration, the electrodes are symmetrically placed about a point at the center of the array. It is used commonly to study the resistivity variation in depth.

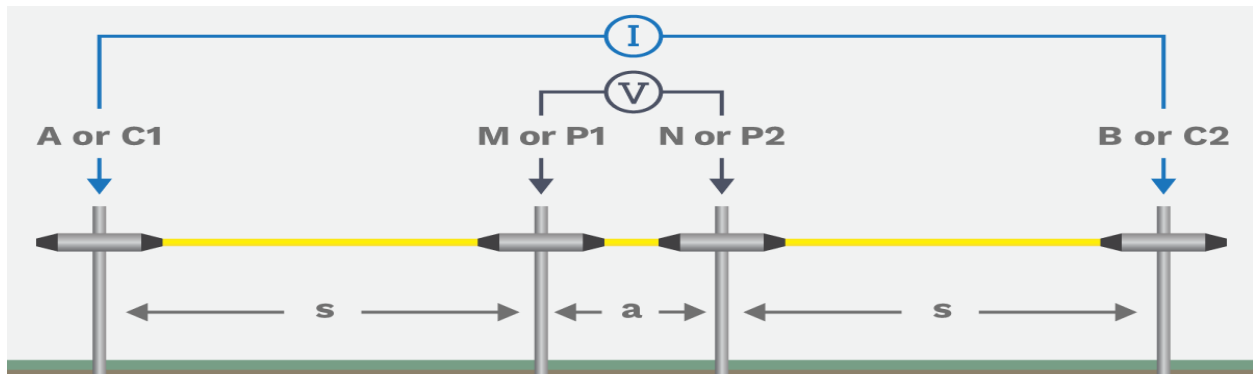


Figure 3.2 <https://www.agiusa.com/schlumberger-array>

**c) Dipole- Dipole array**

For this array type, the distance between the current dipole and the potential dipole is increased in discrete steps in order to increase the depth of penetration. Dipole-dipole array includes six different configurations but for the present study axial array were utilized.

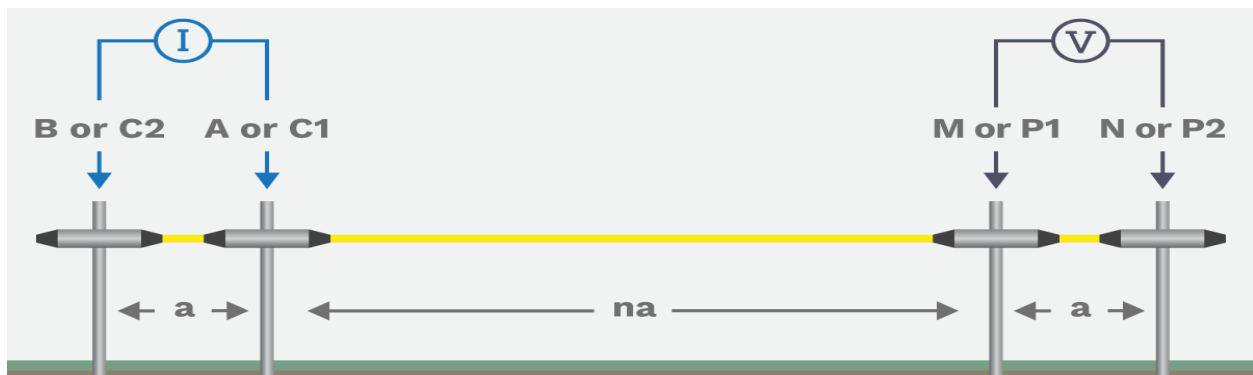


Figure 3.3 <https://www.agiusa.com/Dipole-Dipole-array>

### **3.2.5. Measurement modalities**

Two common procedures are well known in resistivity surveying work. The particular procedure to be used depends on whether one is interested in resistivity variations with depth or with lateral extent as well as in both directions. In order to acquire data different electrode configurations are available. The selection depends on the study objectives and site access conditions.

#### **3.2.5.1. Vertical Electrical Sounding (VES)**

This procedure is 1D surveying applied for detection of subsurface resistivity variations in depth. It uses a fixed center with an increasing spreads symmetrically. In the symmetrical four electrodes configurations, deeper current penetration can be achieved by successively increasing the separation between the outer and current-injecting. The procedure is especially utilized to study the vertical resistivity variations.

#### **3.2.5.2. Horizontal profiling**

1D profiling survey is mainly applied for investigation of the subsurface lateral lithological and/or structural variations. In contrary to the resistivity sounding, the electrodes are fixed in length but systematically displace along the survey line.

#### **3.2.5.3. 2D Imaging**

The greatest drawback of the VES survey is that it only considers vertical variation in the subsurface resistivity and to fill this gap, a two-dimensional (2-D) model is introduced. 2-D model show resistivity change in the vertical direction as well as in the horizontal direction along the survey line. It is more accurate and reliable model of the subsurface. In this case, it is assumed that resistivity is constant in the direction that is perpendicular to the survey line. Nowadays, 2-D surveys are the most practical and cost effective means of obtaining accurate results of the subsurface resistivity contrast compared to 3D survey. 1-D resistivity sounding surveys usually involve limited readings, while 2-D imaging surveys involve about hundreds to thousands of measurements. In many geological conditions, the use of 2-D electrical imaging surveys can provide useful results that are complementary to the information obtained by other geophysical surveys (*Loke, 1999*).

## Chapter Four

### 4. Data Acquisition, Processing and Presentation

#### 4.1 Introduction

In the current project Electrical Resistivity survey measurement, which is comprised of a Vertical Electrical Soundings and Electrical Resistivity Imaging, was done along selected traverse lines within the study area. The aim is to map the subsurface layer stratification, determine the thickness of the overburden soil and the depth extent to the top of a potential foundation rock and reveal any concealed geologic structures, which may impose post construction hazards. The data were acquired and analyzed to get the relevant information for the subsurface foundation condition for the proposed building site.

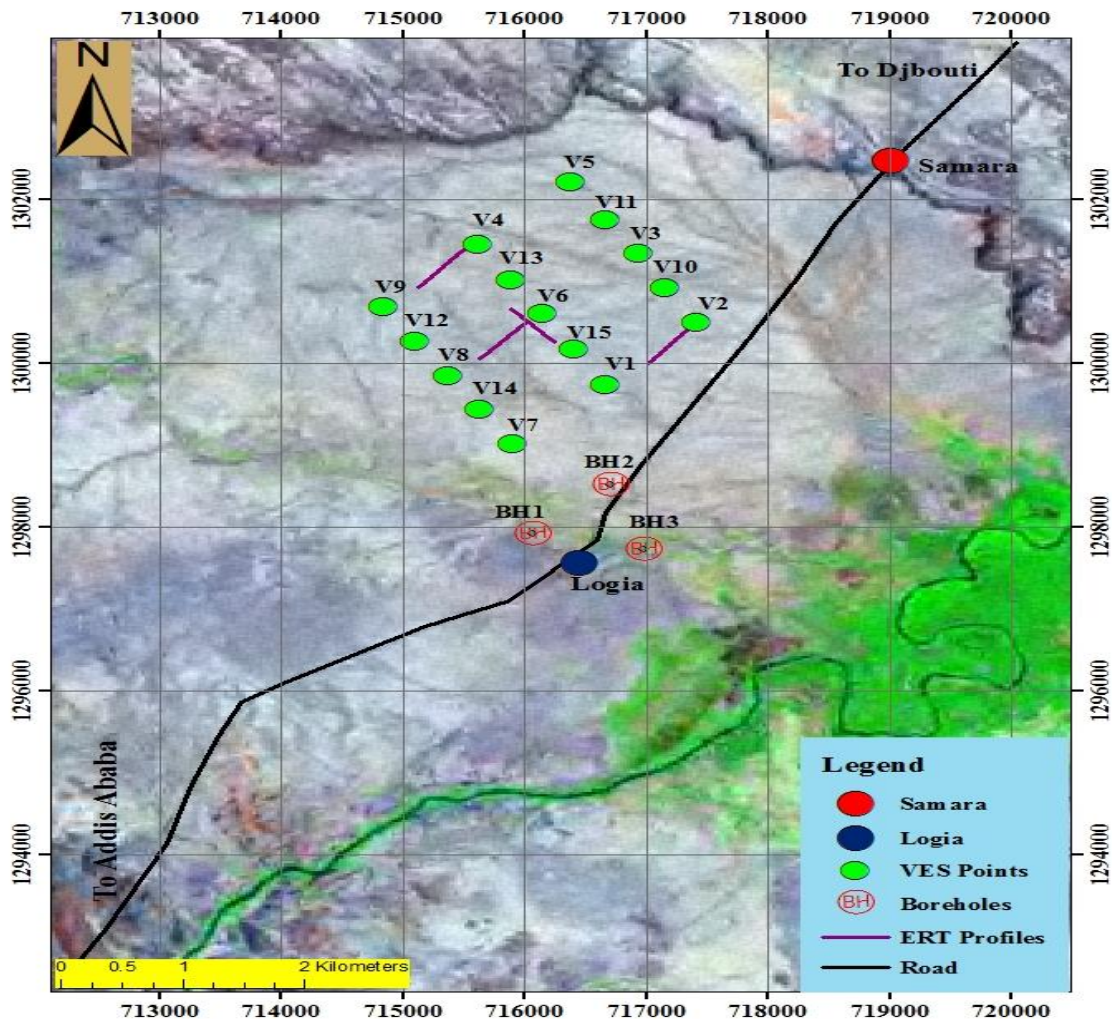


Figure 4.1 Field layout of the Vertical Electrical Sounding points and ERT lines.

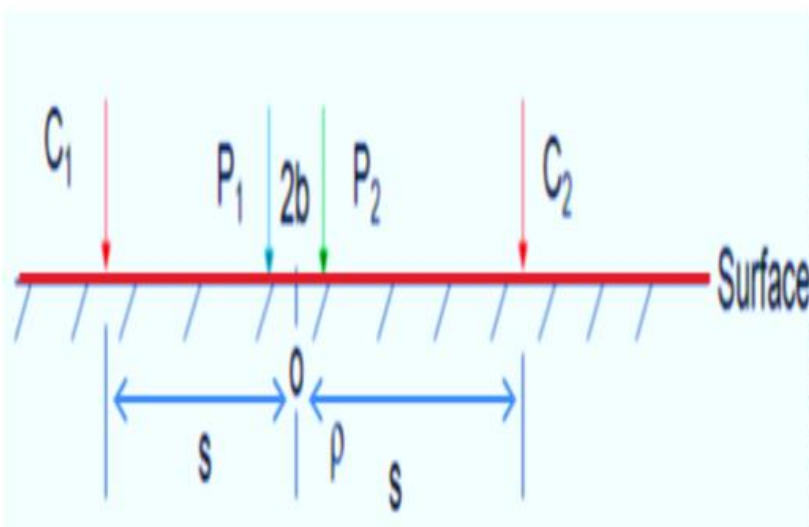
## 4.2. Electrical Resistivity survey

### 4.2.1. Instrumentation, Field procedure and Data summary

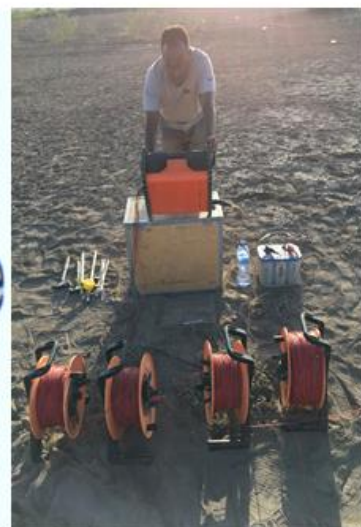
#### 4.2.1.1. Vertical Electrical Sounding (VES)

Vertical Electrical Sounding Survey was conducted using the instrument called ABEM LS Terrameter with four electrodes arranged in a Schlumberger electrode configuration. This technique was implemented by injecting electrical current (I) into the ground by means of two current electrodes and measuring the resulting potential difference ( $\Delta V$ ) by another pair of potential electrodes placed close to the center of the array by systematically expanding the separation between the current electrodes and maintaining the center of array fixed for a number of successive measurements. The maximum current electrode separation,  $(AB/2) = 150\text{m}$ , was chosen based on the depth of interest. At  $AB/2=20$  and  $30\text{m}$  repeated readings were taken at two different potential electrode positions  $(MN/2)$  in order to examine the data quality and also assess any possible effect of heterogeneity of the underlying ground mass.

a)



b)



*Plates 4.1 a) The steps in the Schlumberger arrays. Explanation of indexes:  $C_1$ ,  $C_2$ —current electrodes;  $P_1$ ,  $P_2$ —potential electrodes; b) Photo of the VES system in the field.*

A total of sixteen vertical electrical sounding survey stations were measured to understand the subsurface conditions of the site, figure 6. Among the VES station, fifteen of them were placed

along five profile lines whereas one VES measurement was carried out in the vicinity of the borehole so as to correlate with lithological logging of the borehole.

For each set of measurement, the readings (along with the current and potential electrode separations) were carefully recorded on data sheet and simultaneously stored in the instruments' internal memories. Moreover, the exact position of Each VES point was annotated using hand held GPS in UTM coordinates (37N, Adindan-Datum), see Appendix-2. Concurrent plotting of the data on the field and studying the tendency of the curves was used to decide on the adequacy of the current electrode spacing and monitoring the data quality.

#### 4.2.1.2. Electrical Resistivity Imaging (ERI)

The instrument ABEM LS Terrameter, utilizes 72 electrodes which are connected to the multi core cables at every 5m spacing. In this study, the Wenner–Schlumberger configuration (Plate 4.2a), has been utilized. This arrangement provides deeper penetration, reliable stability and better resolution to detect both horizontal and vertical subsurface features (Dahlin and Zhou, 2004).

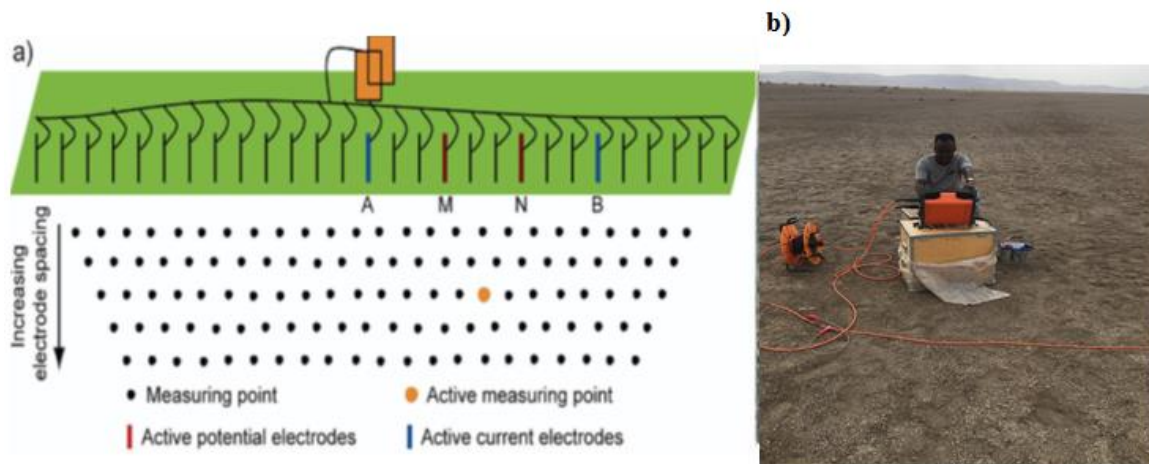


Plate 4.2 a) The steps in the Wenner-Schlumberger arrays for deeper penetration. Explanation of indexes: A, B—current electrodes; M, N—potential electrodes; b) Photo of the ERT system in the field.

The configuration is based on fixed spacing between potential electrodes while, the spacing between current electrodes is logarithmically increased for number of dipole lengths. Then the spacing between potential electrodes is increased in order to obtain more deep penetration. The unit electrode spacing was 5 m along most of the acquired profiles. The total length of each

profile in such cases reaches 360m. The GPS locations (X, Y) of the starting and end points of the traverse lines are given in App-1.

ERT survey was done along four profile lines, of which three parallel profiles are in NE-SW orientation while one perpendicular profile is t orientated NW-SE (Figure 6).

### 4.2.3 Data Processing and Presentation

#### 4.2.3.1 Vertical Electrical Sounding

A comprehensive analysis of conventional DC resistivity data sets commences from a broad qualitative appraisal of the subsurface electrical behavior beneath each survey area. Because, the knowledge on the directional variations in the electrical resistivity at the subsurface shades additional light towards a better understanding of the geological framework of the area under investigation. A software package used for processing resistivity (modelling/inverting) sounding data in terms of layered earth models is WinRESIST (Vander Velpen, 2004). Starting from a user provided initial model, the program utilizes a ridge-regression inversion and fits the field data to a suitable subsurface model through an iterative process in a least square sense.

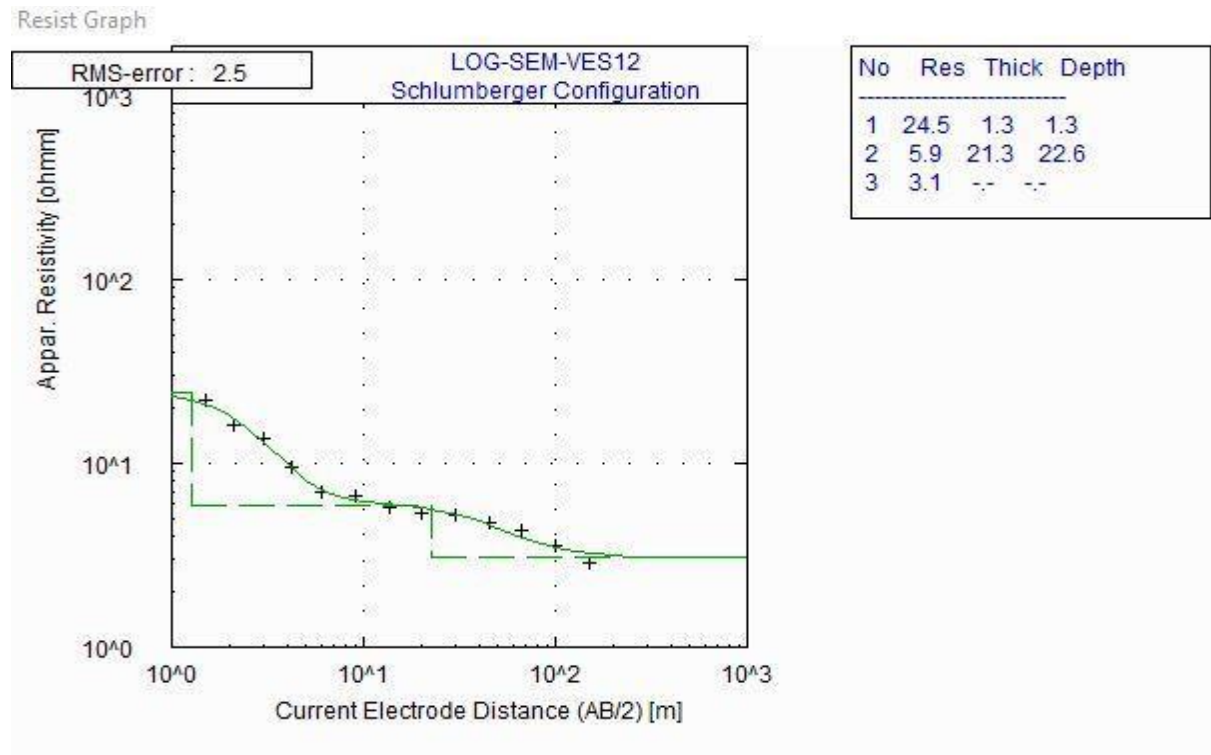


Figure 4.2 A typical graphic output from WinResist package showing the final model (layer) parameters, the measured apparent resistivity data, the calculated response curve and the misfit as a Root Mean Square – RMS-error. 4.2.3.2 Electrical Resistivity Imaging survey.

#### 4.2.3.2. Electrical Resistivity Tomography

The electrical resistivity tomography data was appraised using a 2D processing software, RES2DINV (Loke, 2002), a package that determines a two dimensional (2D) resistivity model of the subsurface automatically from a set of the measured electrical imaging data. The arrangement of the rectangular blocks which constitutes the model is consisted of a certain number of whose is roughly tangled to the dispersal of the data points in the pseudo-section. Roughly guided by the scattering of the input data points, the program automatically generates the size and arrangements of the constituent blocks; and for the given electrode array, the depth to the bottommost row is fixed to be equal to the equivalent depth of investigation for the data point at the maximum outer electrode separation (Edwards 1977). The program optimizes the nonlinear inversion based on the smoothness constrained method (deGroot-Hedlin and Constable 1990, Loke and Barker 1996). The program reduces the discrepancy between the measured and calculated apparent resistivity values by iteratively adjusting the resistivity of the model blocks. The misfit is quantified as a root-mean squared (RMS) error. Upon achieving acceptable misfit and/or the RMS error changing insignificantly, the user can opt to display the result graphically. Figure 9 shows the output obtained after 15 iteration on the data from the current project.

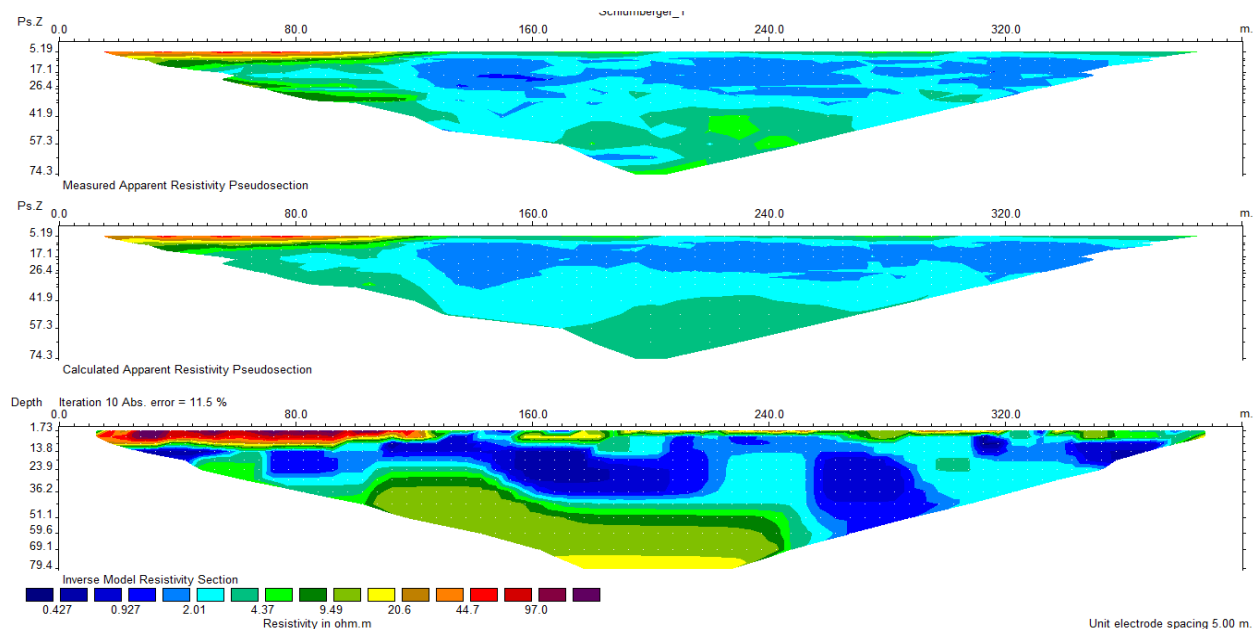


Figure 4.3 Inversion output from RES2DINV package showing the pseudosection plots of the measured (top), calculated (middle) apparent resistivity data; and the final block model section (bottom) of from Ududaytu survey site.

## Chapter Five

### 5. Results, Discussion and Interpretation

#### 5.1 Introduction

In this chapter the results obtained from the processing and analysis of the geoelectric data collected from the project site are presented and discussed. The Vertical Electrical Sounding data is first presented in the form of apparent resistivity stacked sliced-plan maps. This facilitates studying directional variations in the electrical resistivity and shades additional light towards a better understanding of the geological framework of the project area. Moreover, notable contrast in formation resistivity responses within narrow transition zone may also be used to obtain indications on possible local structural features.

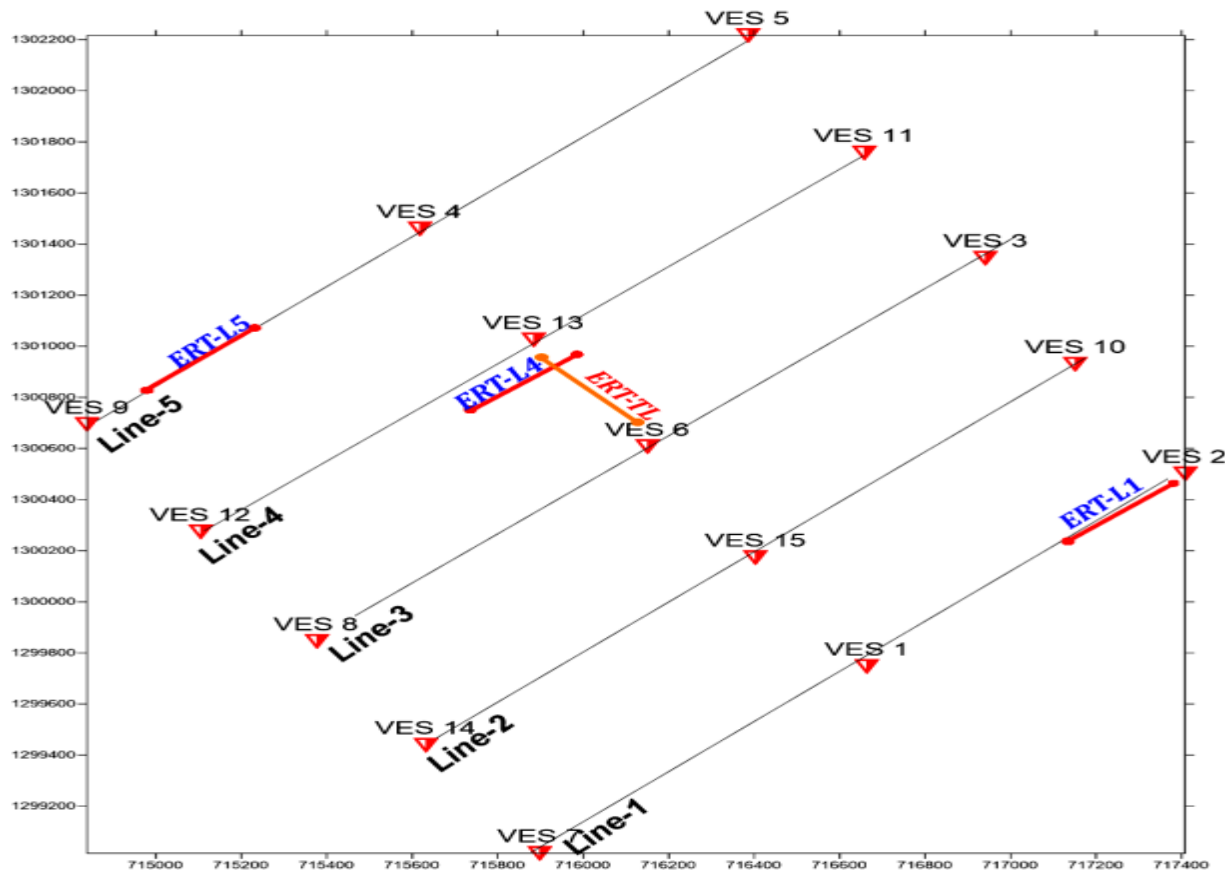


Figure 5.1 Profiles along VES points and ERT lines.

Then, pseudo-depth sections prepared using data from aligned VES points along traverse lines (figure 5.5) are used to assess the local resistivity trends on a vertical section along a specific orientation. Subsequently, each sounding data set were modeled/inverted to extract the model parameters (resistivity and thickness/depth) beneath the sounding points which are ultimately

used to construct the true Resistivity-Depth sections for the final quantitative appraisal. The 2D, ERT sections are also presented and discussed.

Finally, geological log data from nearby boreholes are integrated to provide adequate information about the subsurface properties to characterize the geotechnical features of the Ududaytu construction site.

### 5.2. Apparent Resistivity plan (depth-slice) maps

As specified in section 5.2, the appraisal of VES data customarily commences by examining the broad geoelectric pictures of the subsurface from the sliced pseudo-depth sections (plan map) of the particular target area.

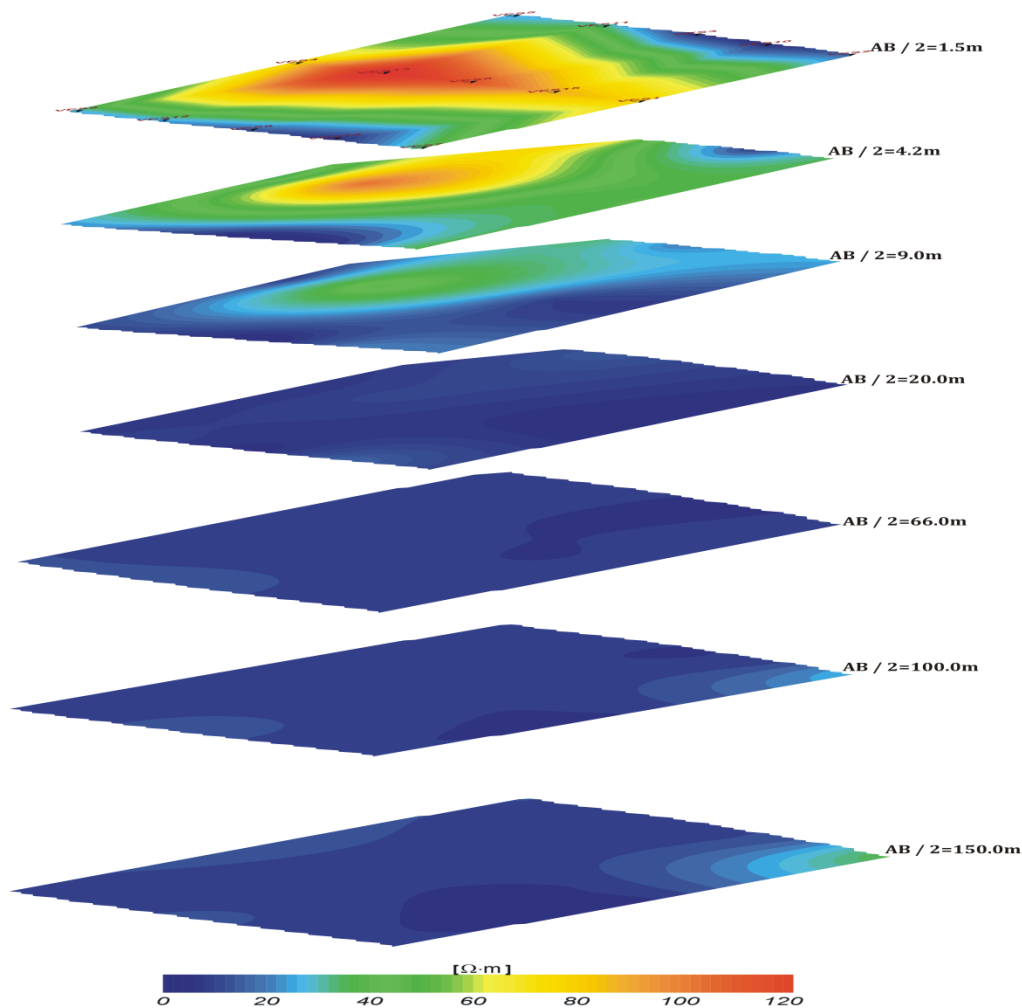


Figure 5.2 The stacked apparent resistivity depth-sliced plan map of the Ududaytu survey grid

Figure 5.2 displays the stacked apparent resistivity depth-sliced plan map of the Ududaytu survey grid for the subsurface. The relatively higher apparent resistivity responses ( $>65 \Omega \cdot m$ ) recorded from the ground surface down to a pseudo-depth- $AB/2 = 6.0m$  indicate that the top soils is seemingly dry and resistive. However, the apparent resistivity values, recorded from the pseudo-depth of  $AB/2 = 9.0m$  down to a pseudo-depth,  $AB/2=150m$ , are extremely low ( $<10 \Omega \cdot m$ ). Such very conductive response may indicate that the area is underlain by thick, clay rich sediments, possibly wet.

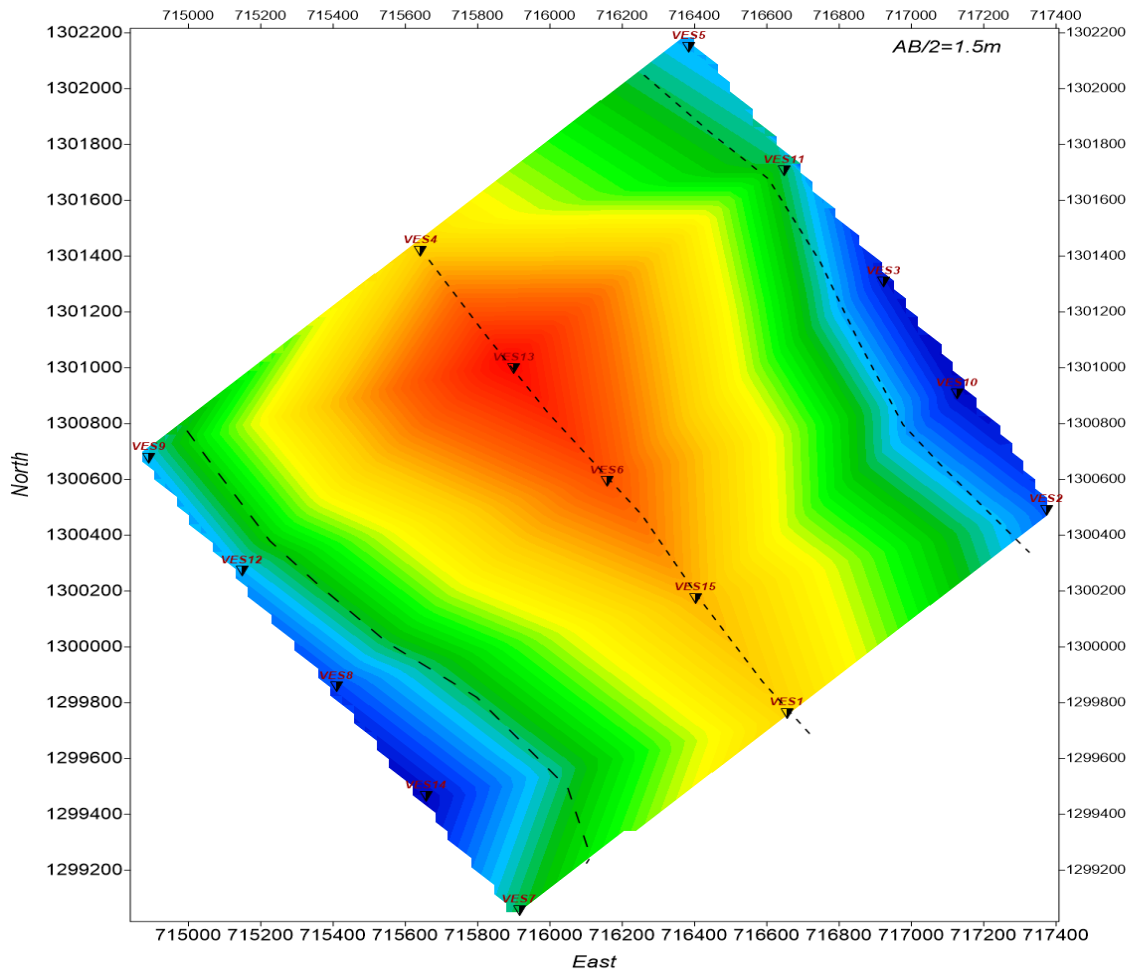


Figure 5.3 The apparent resistivity depth-sliced plan map at  $AB/2=1.5m$ , Ududaytu survey grid

For further observation, the sliced plan map at  $AB/2=1.5m$  is presented at larger scale on figure 5.3. The broad resistive horizon at the central portion on the shallow sliced section ( $AB/2=1.5m$ ) fades out both to the east and western flanks of the survey grid. Based on the fast transition in electrical response (apparent resistivity contour value), zones of discontinuity (probably fractures/faults) are anticipated and traced as broken black lines on figure 5.3.

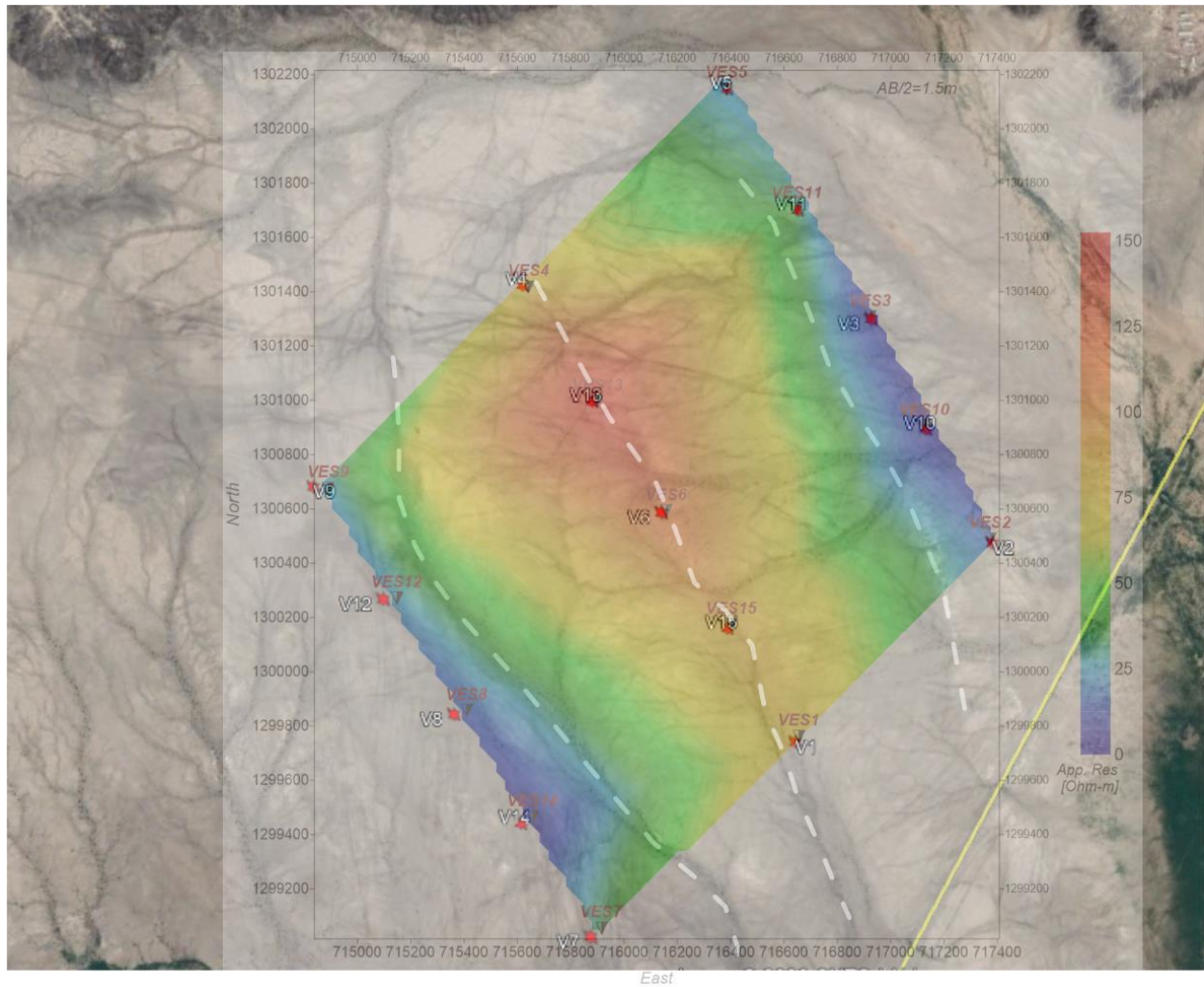


Figure 5.4 The apparent resistivity depth-sliced plan map at  $AB/2=1.5m$  Ududaytu survey grid superimposed on high resolution Google map of the region.

The juxtaposition of the apparent resistivity plan map at a pseudo-depth level,  $AB/2=1.5m$ , on a high resolution Google image of the Ududaytu survey grid and the surrounding region is portrayed on figure 5.4. It can readily be seen that the quasi-linear features on the ground almost coincides with the traces that designate the discontinuities in geoelectric behavior. Since such ground features often appear as surface signatures geologic structures, the observed coincidence confirms the existence of the speculated fissure (fractures/faults).

### 5.3. Apparent Resistivity Pseudo-sections

The fifteen VES points were distributed over the survey grid in five traverse lines. Figure 5.5 exhibits the apparent resistivity-pseudo depth section along the five profiles.

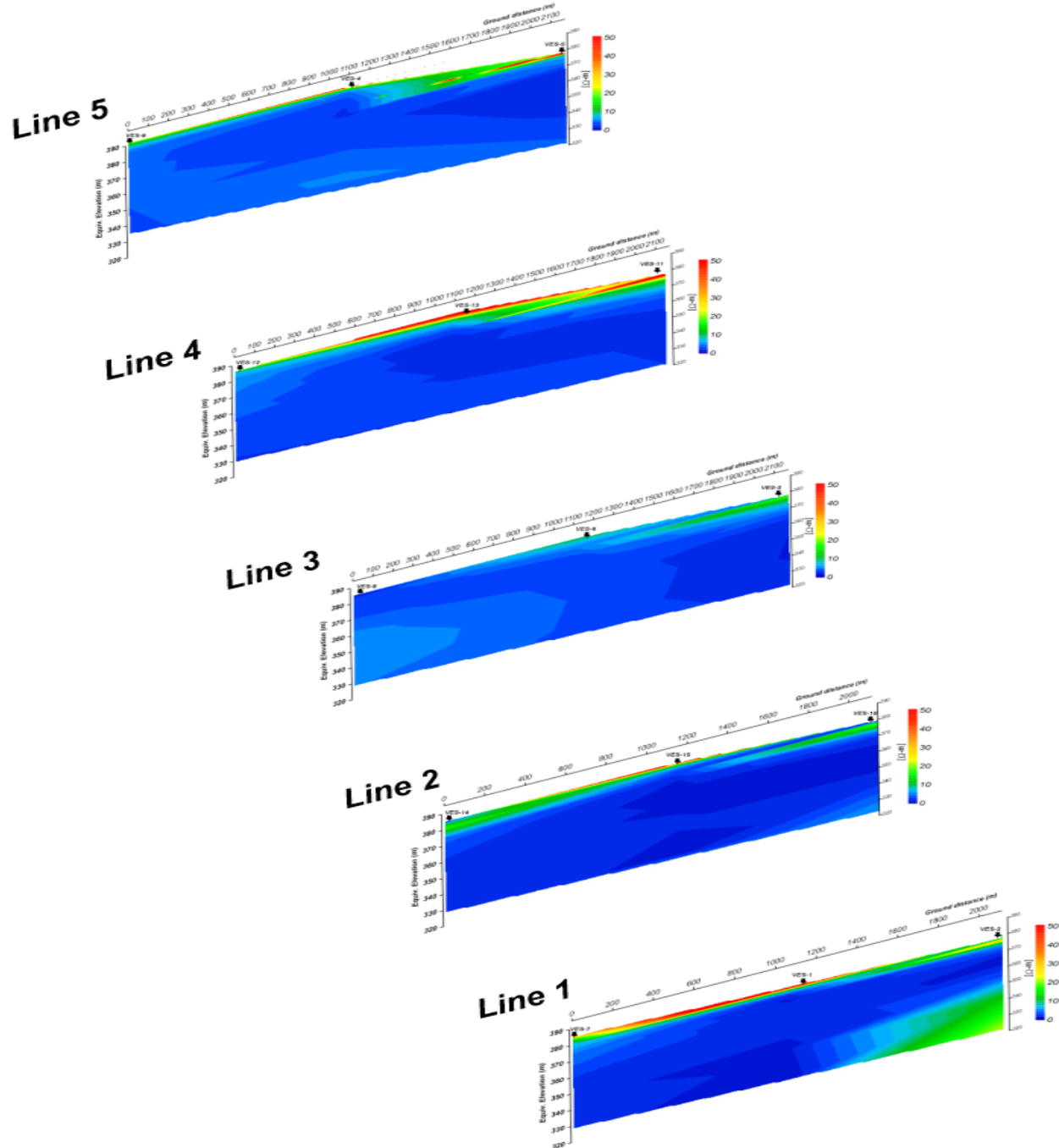


Figure 5.5 The apparent resistivity-pseudo depth section along the five profiles.

The line to line variation in subsurface geoelectrical behavior of the study area, in the SE – NW direction, is presented in the form of stacked apparent resistivity-pseudo depth section along the five profiles, on figure 5.5. With 1km average separation between the sounding points, the length of the traverse line along all the five profile, presented on figure 5.5 is about 2Km. Since, the overall range in the measured apparent resistivity is practically narrow, the variation in subsurface geoelectrical, along the general strike direction NW appears quite smooth.

Apart from the sharp contrast observed at shallow portions across all the five pseudo-depth sections, the variation in the measured apparent resistivity within the boarder ground section beneath the study area is quite small, less than  $10 \Omega \cdot m$ .

In order to demonstrate the directional variation, the pseudo-depth section plot from the southwestern line, Line 1 is shown on figure 5.6.

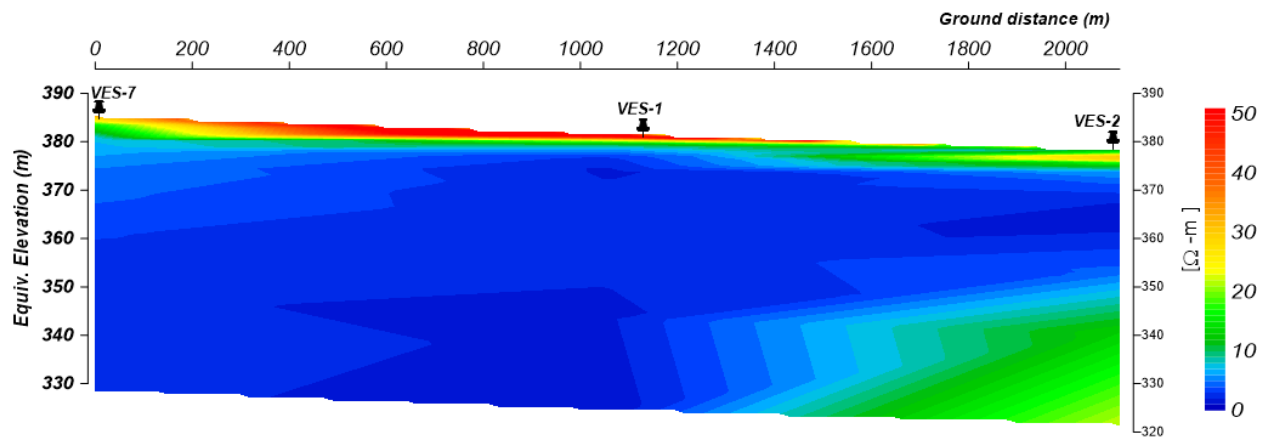


Figure 5.6 The apparent resistivity-pseudo depth section along the Line1.

This section has relatively contrasting feature both in lateral and vertical directions. Depth wise, the peculiarly high resistivity horizon on ground surface terminates shallow. Then the electrical resistivity in the vast portion drops considerably, below  $10 \Omega \cdot m$ .

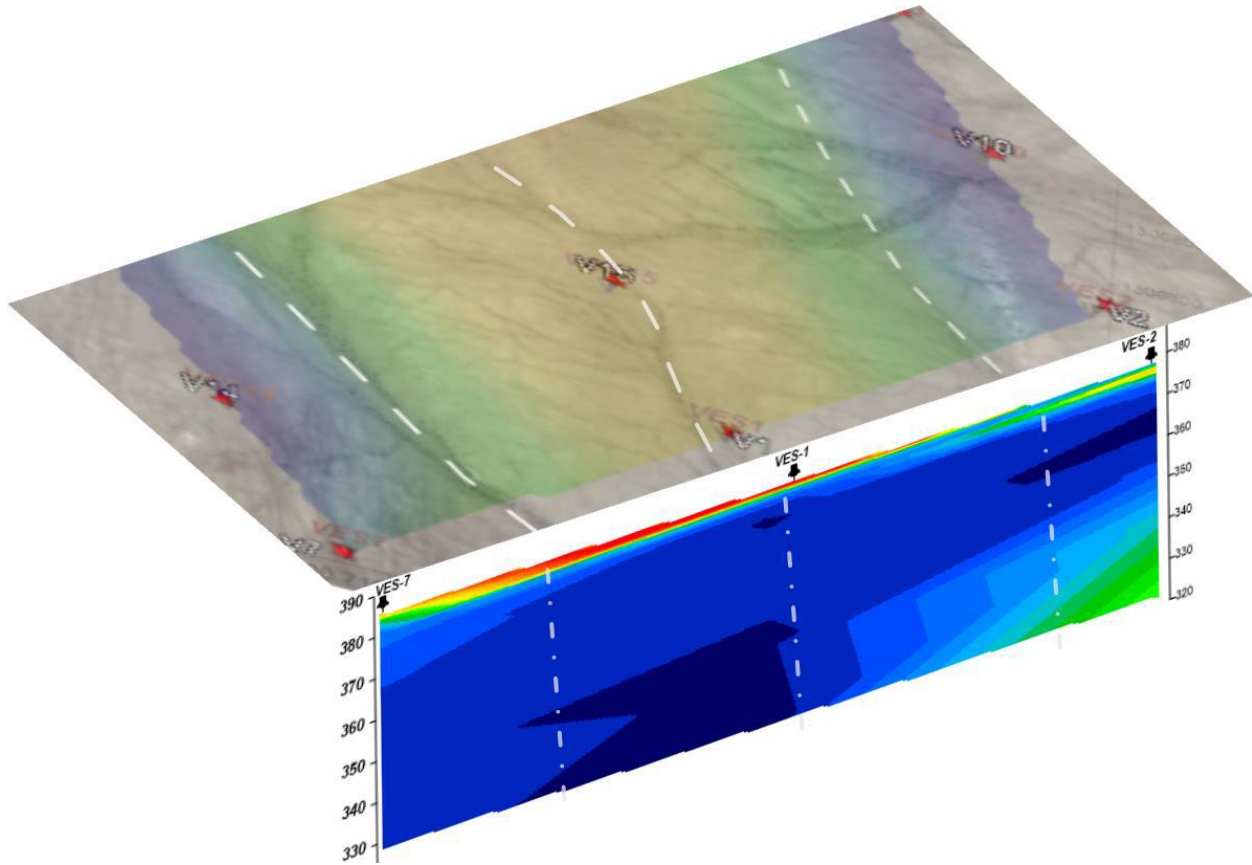


Figure 5.7 The apparent resistivity-pseudo depth section along the Line1 with traces of structures.

Laterally, though in a quite narrow range, there appears some variation indicating the effect of the NW-SE oriented features, figure 5.7.

The Apparent resistivity pseudo section and the fracture trace plot from Line 4 are presented on figure 5.8 and 5.9, respectively.

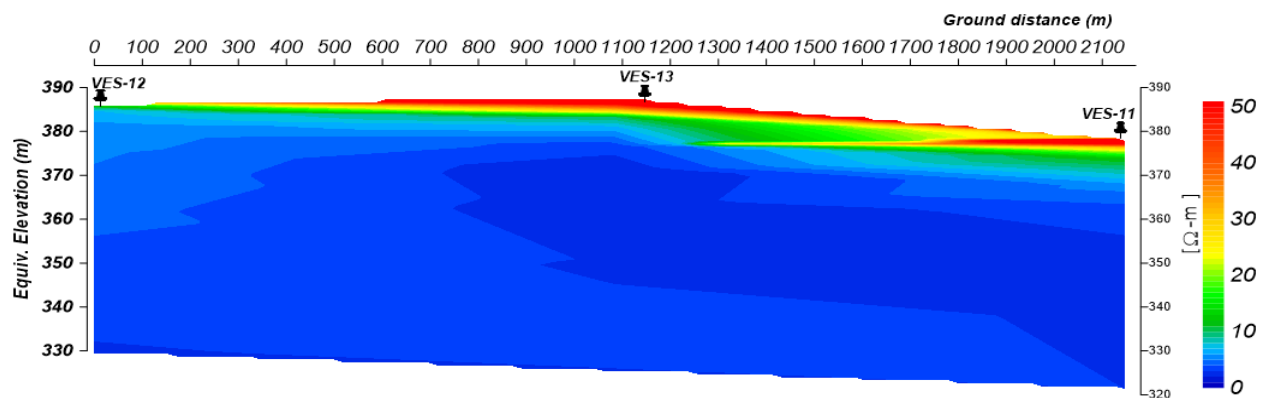
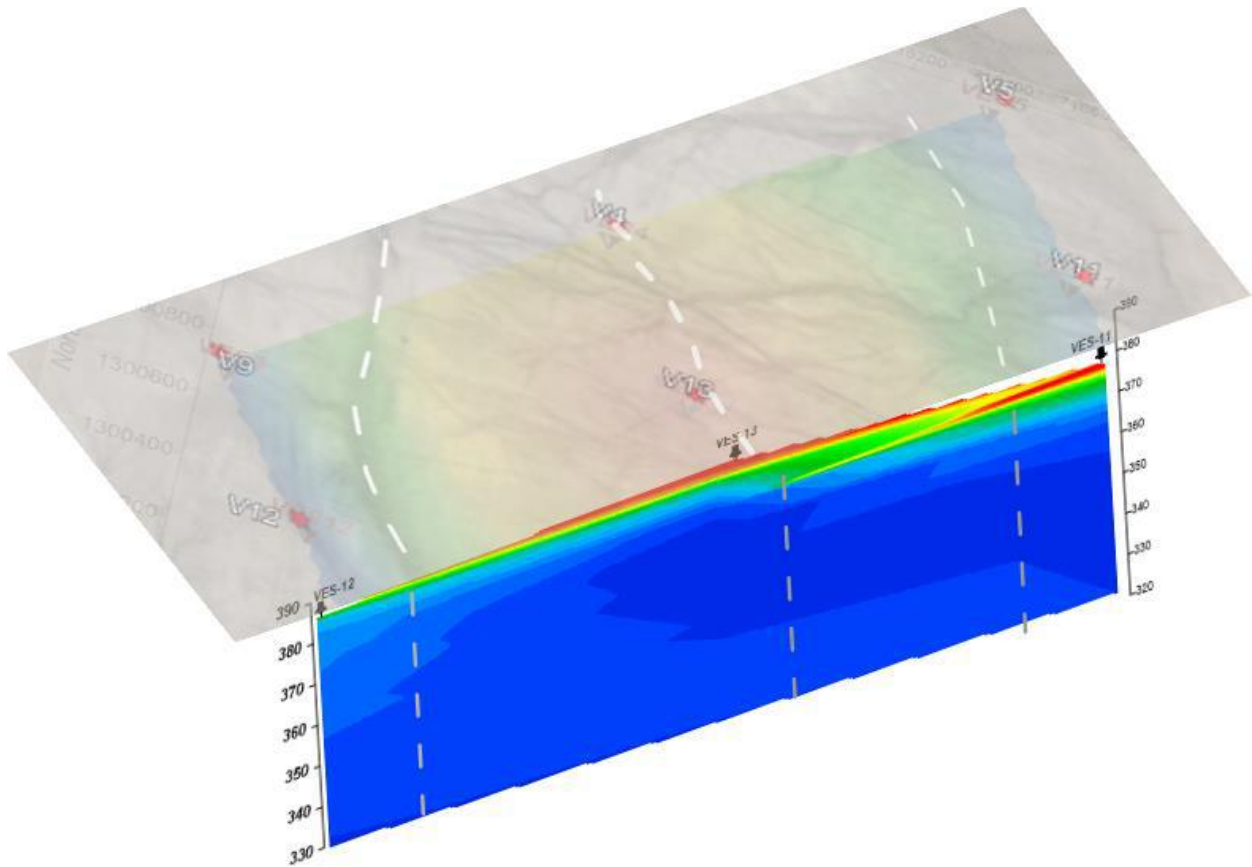


Figure 5.8 The apparent resistivity-pseudo depth section along the Line4.

This section has also relatively contrasting feature both in lateral and vertical directions. Depth wise, the peculiarly high resistivity horizon on ground surface terminates shallow. Then the electrical resistivity in the vast portion drops considerably, below 10  $\Omega\cdot\text{m}$ .



*Figure 5.9 The apparent resistivity-pseudo depth section along the Line4 with traces of structures.*

Figure 5.9 displays variation of resistivity though in a quite narrow range laterally, there appears some variation indicating the effect of the NW-SE oriented features.

### 5.4. Quantitate appraisal - Geoelectric Section.

The final depth section (figure 5.11, figure 5.12, figure 5.13) resulted from a 1D modelling and inversion of the apparent resistivity data is comprised of four to five geoelectric layers.

**Correlation b/n formation Resistivity (VES 17) and Lithological log data of Logia Well #2/08**

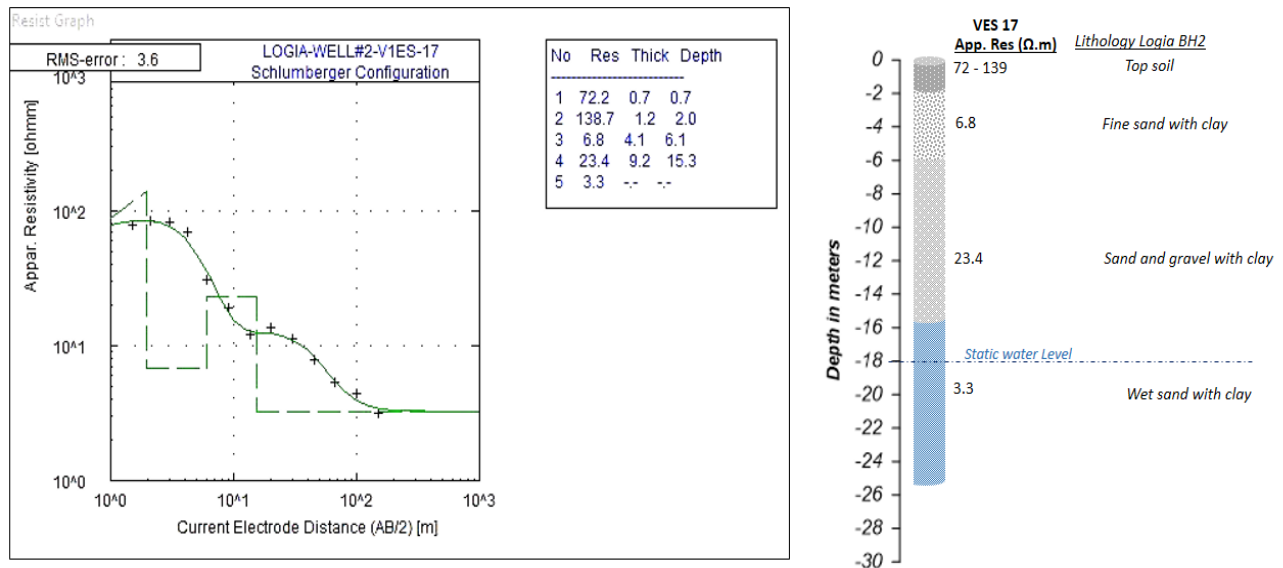


Figure 5.10 Lithology correlations between Logia#2-08 and VES-17.

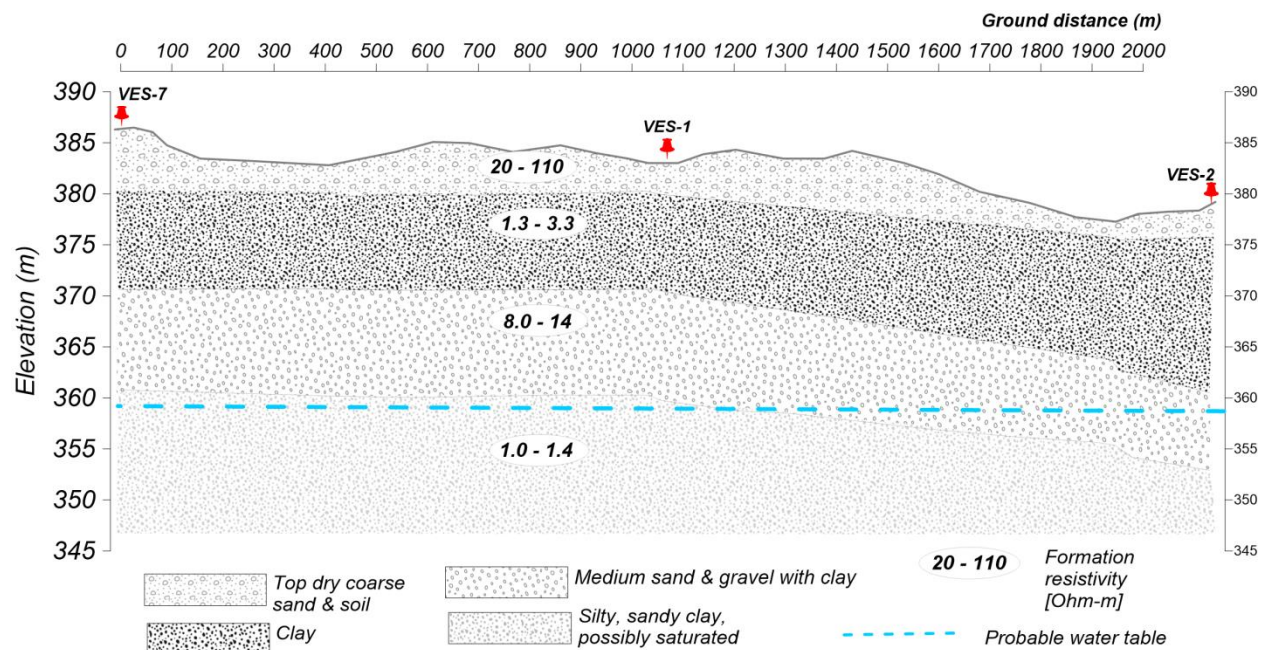


Figure 5.11 Geoelectric section along Line-1.

The lithological attribution for the subsurface geoelectric layer (Figure 5.10) is made by correlating the available log data from an existing borehole Logia #2-08 and a parametric sounding (VES-17) done within few meters from the bore hole. The correlation is then used to construct a three geoelectric section. Two of them are along line 1 and line four respectively. Whereas the third geoelectric section is transversal to them. The first Geoelectric section connects VES-7, -1 and -2 (Line-1), which is about a kilometer north of the bore hole. The second geoelectric section connects VES-12,-13, and -11(Line-4).While the third geoelectric section connects VES-4,-13,-6,-15, and -1(transversal).

The geoelectric section along line-1, figure 5.11, has relatively a simple feature and portraits three to four geoelectric layers. The top layer, with uneven thickness (3 – 5m), delineates the soil cover which is comprised of sandy and gravelly. The overall range of the electrical resistivity, 20.0 to 110.0  $\Omega\cdot m$ , is indicative of relatively dry mass. The second layer is characterized by resistivity value (1.3 – 3.3  $\Omega\cdot m$ ) and prevails all along the survey line ranging in thickness from 10 to 20m. According to the lithological log illustrated on figure 5.10, this conductive second layer is attributed to a clay bed. The third layer is demarcated by an slightly elevated range of resistivity, (8.0 – 12.0  $\Omega\cdot m$ ) which could be, according to log description of Logia#2-08, a signature from a horizon composed of the medium size sand and gravel with clay. At an average depth of about 30m, the drop in formation resistivity range (<1.5  $\Omega\cdot m$ ), marks the top of the fourth layer which, according to the borehole data, a saturated bed of sand, silt and clay. Despite its uniformity in formation resistivity, the fourth layer exhibited a depth variation at the eastern side of the grid, below VES 2.

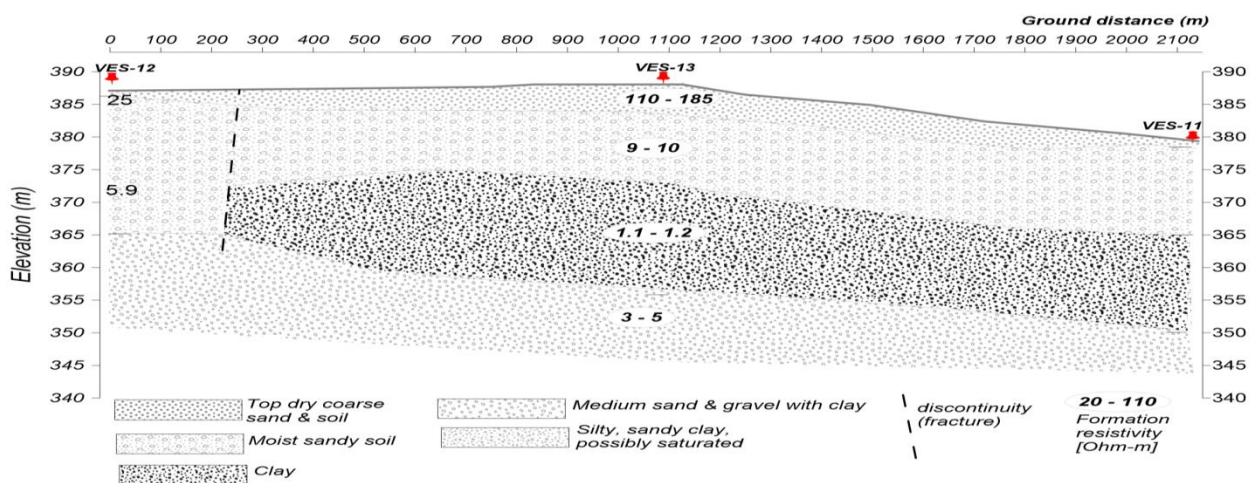


Figure 5.12 Geoelectric section along Line-4.

The geoelectric section along line-4, figure 5.12, reflects four geoelectric layers. The top layer is characterized with very narrow thickness, delineates the soil cover which is comprised of sandy and gravely. The overall range of the electrical resistivity, 110.0 – 185  $\Omega\cdot m$ , is indicative of relatively dry mass. The second layer is characterized by resistivity value (9.0 – 10.0  $\Omega\cdot m$ ) and prevails all along the survey line ranging in thickness from 25 to 30m. According to the lithological log illustrated on figure 18, this layer is attributed to fine sand. The third layer is characterized by a low range of resistivity, (1.1– 1.2  $\Omega\cdot m$ ) which could be, according to log description of Logia#2-08, a signature from a horizon composed of the clay formation. At an average depth of about 30m, the increment information resistivity range (3.0 – 5.0  $\Omega\cdot m$ ), marks the top of the fourth layer which, according to the borehole data, a saturated bed of sand, silt and clay.

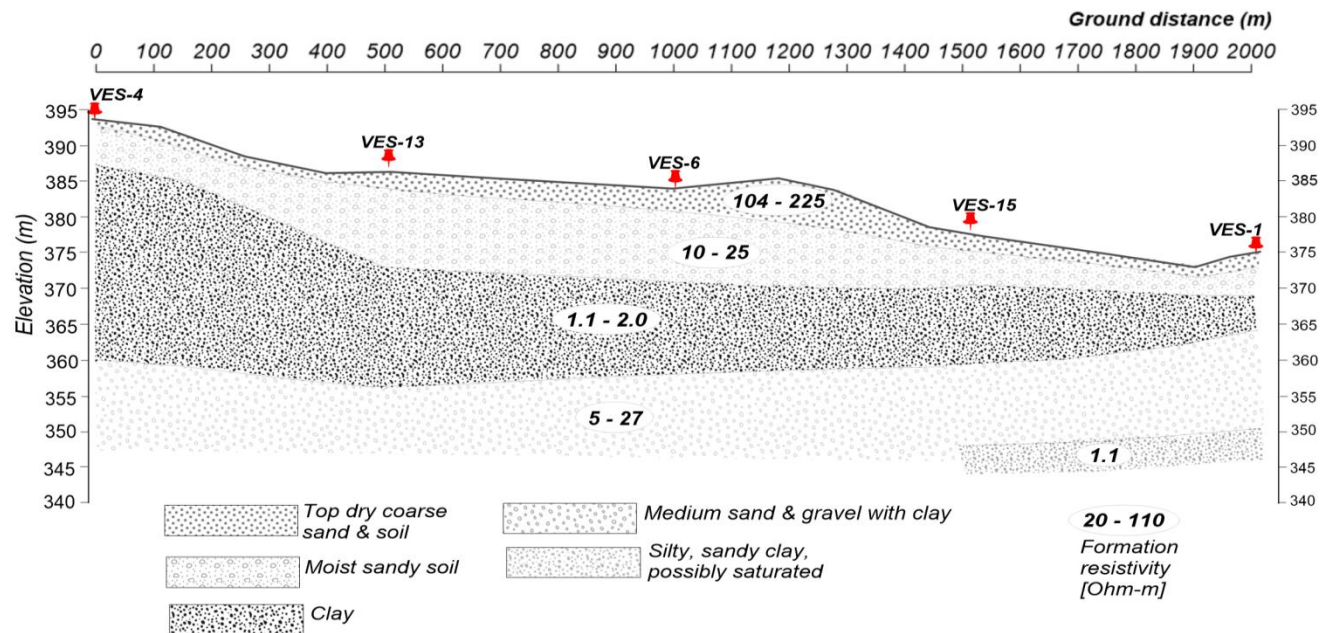


Figure 5.13 Transversal Geoelectric section

The transversal geoelectric section, figure 5.13 portraits five geoelectric layers. The top layer, which is very thin, delineates the soil cover which is comprised of sandy and gravely. It has an overall range of the electrical resistivity, 104.0 to 225.0  $\Omega\cdot m$ , is indicative of relatively dry mass. The second layer is characterized by resistivity value (10.0 – 25  $\Omega\cdot m$ ) and gets thicker at the center; this layer is attributed to fine and coarse sand. The third layer is demarcated by a low range of resistivity, (1.1-2.0  $\Omega\cdot m$ ) having a thickness ranging from 35 to 5m which could be, according to log description of Logia#2-08, a signature from a horizon composed of clay

formation. The fourth layer has a resistivity value (5.0- 27  $\Omega\cdot\text{m}$ ) and it is correlated with clay sand formation. The bottom layer marks the top of the fifth layer having a resistivity value of 1.1  $\Omega\cdot\text{m}$  which, according to the borehole data, a bed of clay.

Despite its uniformity in formation resistivity, the fourth layer exhibited a depth variation at the eastern side of the grid, below VES 2.

### 5.5. 2D model sections

A total of four electrical resistivity imaging profiles were conducted in the study area. Three of the profiles are oriented nearly NE-SW while the other one profile line is perpendicular to the former profiles as shown in the figure 5.1. All the four profiles are acquired with full sequences having 2215 data points and covering a horizontal distance of about 400m.

Figure 5.14 portrays the result of the 2D inversion of the resistivity data from the ERT survey along Line 1. The imaging survey line runs over the last 400m of the VES-traverse line 1, on the eastern edge of the grid.

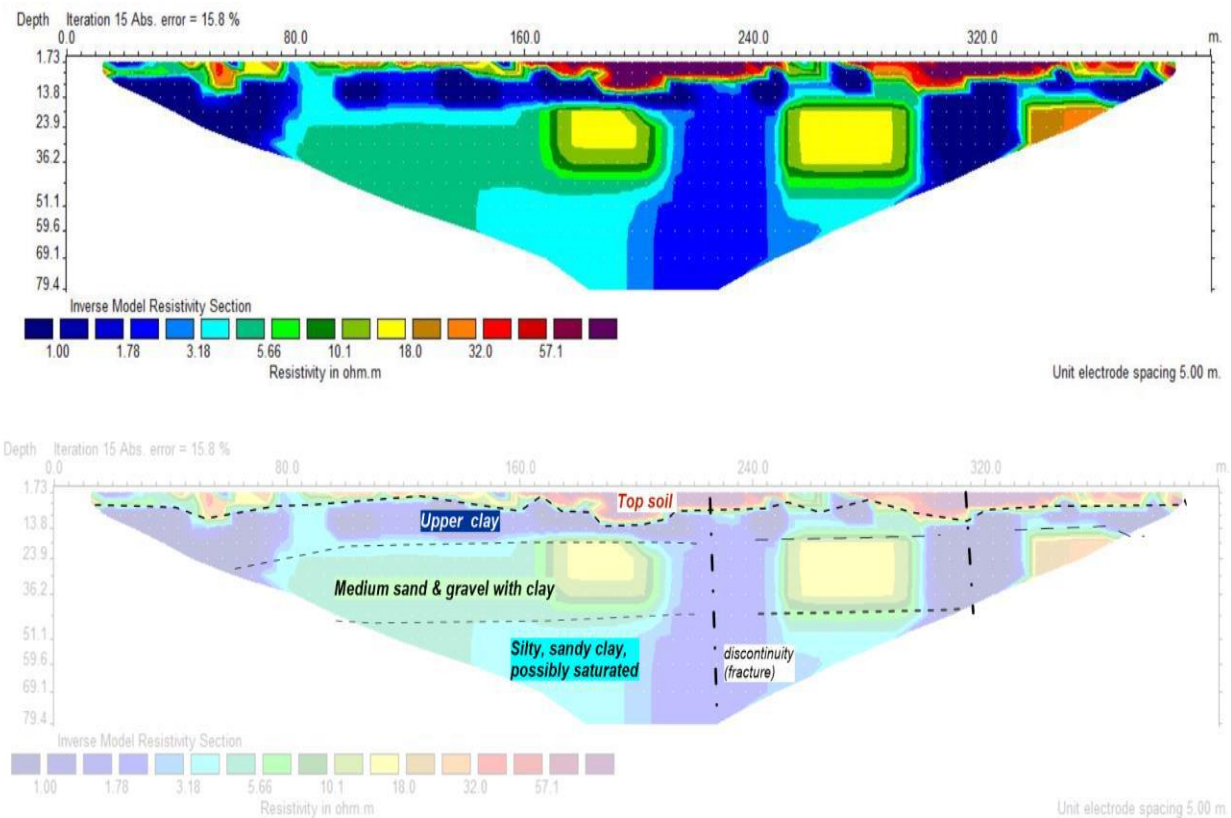


Figure 5.14 The 2D resistivity model along the eastern end of Line 1, (top) and the layer attribution in analogy to the parametric sounding (bottom).

The 2D geo-electrical picture shows that the shallow ground is characterized by relatively moderate variations in electrical resistivity both in vertical and lateral directions. Close to the surface, slight rise in resistivity ( $>60 \Omega \cdot m$ ) is the dominant feature. This underlain a layer by a conductive ( $<2.0 \Omega \cdot m$ ) horizon. At the intermediate depth level, the subsurface resistivity shows increment ( $10 - 18 \Omega \cdot m$ ). At the bottom of the section, the resistivity again drops below  $2.0 \Omega \cdot m$ . As illustrated on the bottom panel of figure 5.14, the result obtained from the 2D mapping is compatible with the results of the 1D inversion of VES data, of course, reveals more details.

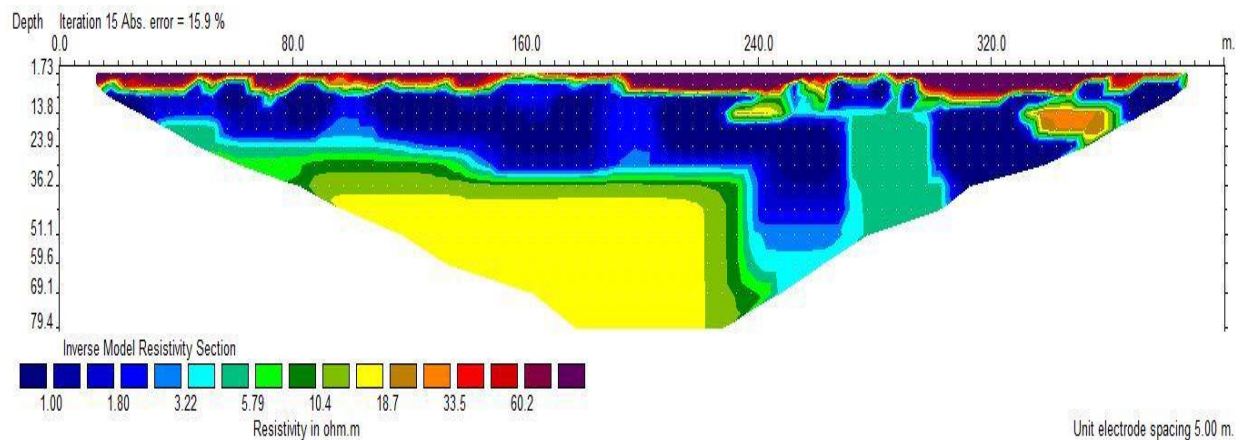


Figure 5.15 The 2D resistivity model along the central region of Line 4.

Further to the northwest, the second and third 2D model section plot is shown on figure 5.15 and figure 5.16, respectively. The models resulted from the two WSW – ENE imaging lines (Line4 and Line 5), is located in the central part and northwest edge of the survey area.

Both these sections indicate that the slightly resistive sand/gravel layer appears to be thicker towards the northwestern flank of the grid. In both cases, the higher resistivity block goes deeper than observed on the conventional sounding 1D section.

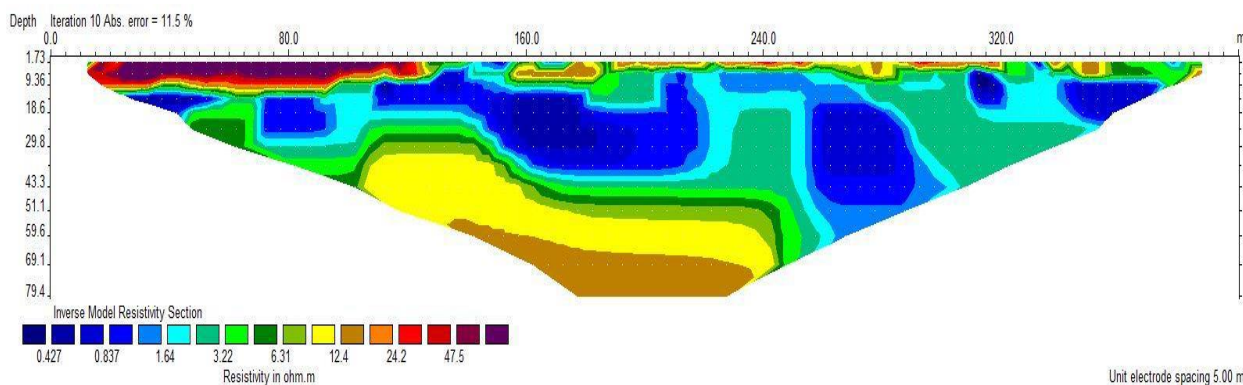
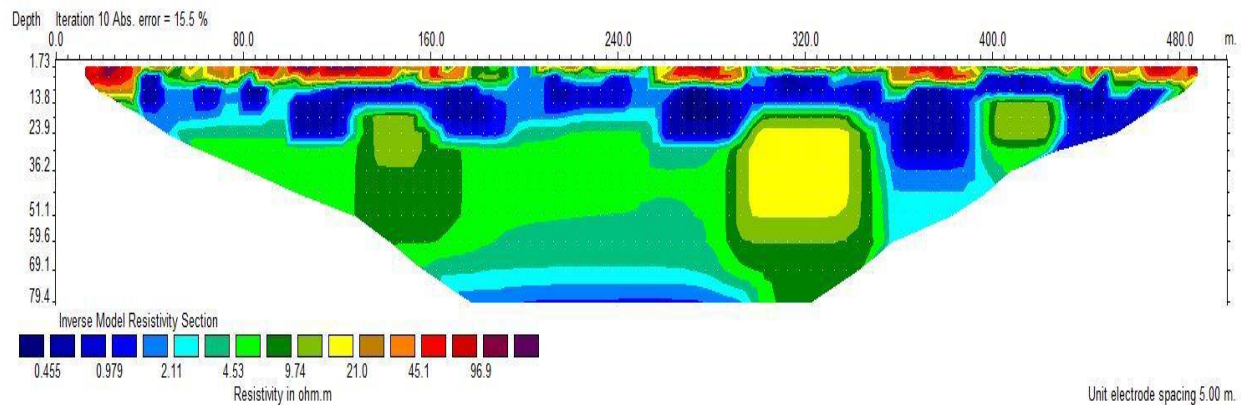


Figure 5.16 The 2D resistivity model along the western end of Line 5.

The other interesting feature on the 2D model section of figure 5.15 & 5.16 is the relative lateral contrasts in formation resistivity probably indicating that the signatures of the aforementioned weak zones at depth.

The last 2D model section of figure 5.17 depicts the subsurface resistivity variation along the base line, i.e., in NW – SE direction, which is orthogonal to the other 2D profiles.



*Figure 5.17 The 2D resistivity model a transversal (NW-SE) direction mapping the north central part of the grid.*

The subsurface geoelectric picture along this transversal line appears smoother than the other orthogonal lines may be suggesting the structures are dominantly in the NW direction.

## 5.6. Discussions

Worku (2011) has highlighted the dire need for revising the Ethiopian seismic code and giving emphasis on the significantly larger amplification potential of site soils in large ground acceleration regions. Figure 24 shows recently the regional seismic hazard map for Ethiopia and the neighboring region, (Ayele, 2017; Worku 2011). The study area is situated in high risk seismic zone where the PGA reaches 0.2g or more.

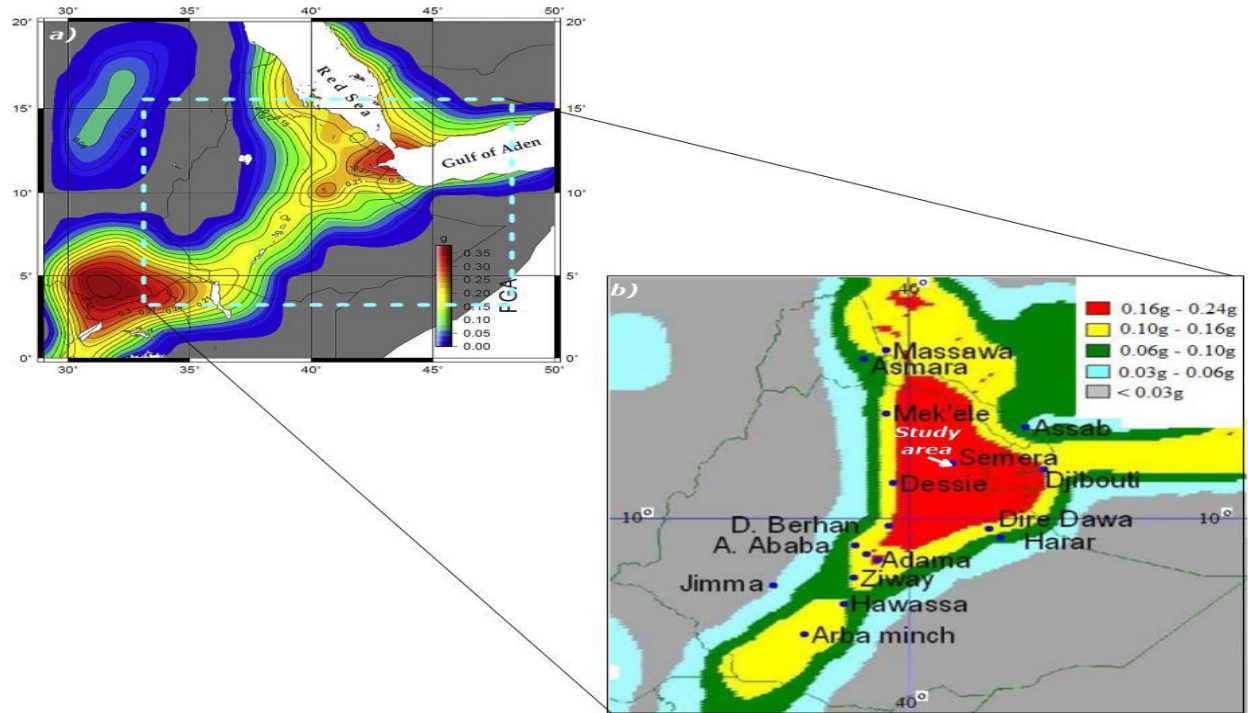


Figure 5.18 a) Regional seismic hazard map for Ethiopia and the neighboring region (based on Horizontal Peak Ground Acceleration, adopted from Ayele, 2017) and b) the seismic hazard map Ethiopia (adopted from Worku, 2011.)

In light of the main objectives of the study, the electrical resistivity survey has shown that the site under investigation is underlain by vast low resistivity horizons which, according to the lithologic log data from the nearby borehole have been attributed to clay rich gravel sand and silt. It has also been shown that local ground water table is shallow (20 -30).

These findings are quite important. Because, located in such seismically active region, loose saturated sedimentary deposits are prone to liquefaction and settlements during strong ground motion, (Seed, B. 1979). Moreover, the dynamic response such thick sediment to strong motion is also of grave important for stability of structures.

## Chapter Six

### 6. Conclusion and Recommendation

#### 6.1 Conclusions

A geophysical investigation involving the electrical resistivity methods was carried out for building foundation assessment at a study area, Ududaytu plain in Tandaho graben of Afar, north eastern Ethiopia. The survey was conducted using the Vertical Electrical Sounding (VES) and continuous Electrical resistivity (2D) Imaging techniques. The results of geophysical investigations obtained are correlated with lithological logging of the boreholes existing in the area. The major findings of the geoelectrical survey are summarized in the sections below.

- 1) The geoelectrical survey enabled to establish the major subsurface lithologic stratification of the potential construction site Ududaytu plain in Tandaho graben. Moreover, the survey identified a potential zone of saturation and revealed likely weak zones. Accordingly: the top dry soil cover (20.0 to 110.0  $\Omega\cdot\text{m}$ ) shows thickness variation ranging from few tens of centimeters to 6m. This is underlain by 14 -20 m thick, conductive 1.0 to 3.0  $\Omega\cdot\text{m}$  clay layer. The third layer, which is attributed to medium size sand and gravel with clay has been delineated at an average depth of 20m with a resistivity ranging 8.0 – 12.0  $\Omega\cdot\text{m}$  and average thickness of around 16m. In the fourth layer, the formation resistivity drops drastically to about 1.0  $\Omega\cdot\text{m}$ , demarcating a saturated bed of sand, silt and clay.
- 2) From the geoelectrical indication and correlation with a borehole log data, the probable water table in the study area is labeled to be at a depth of about 25m.
- 3) Based on the lateral variation in electrical resistivity the shallow subsurface, the likely locations of geologic weak zones (fractures/faults) have been identified and validated with surface morphologic imprint.

Summing up all the above findings, it is imperative to conclude that:

- The envisaged construction site is underlain by thick sediments with shallow level of saturation.
- The adverse impact of the identified geological weak zones on engineering structures also extra down side.
- This is especially critical due to the fact that the study area is situated within high risk seismic zone where the PGA reaches 0.2g or more.

The other important observation is that though, not exhaustive, geoelectrical investigations can impart vital input on the geotechnical characteristics of a geologic media.

## **6.2 Recommendation**

Based on the main findings and conclusions drawn above, the following specific recommendations are given:

1) To conduct a geotechnical drilling and perform a wide variety of laboratory tests on soils, and other units to measure a multiple properties the subsurface. This may include but may not be limited to:

- Atterberg limits
- Direct shear test
- Expansion Index test
- Hydraulic conductivity tests
- Oedometer test
- Particle-size analysis

2) To study the dynamic response of the sediments to strong motion.

3) To prevent percolation of surface runoff to soil and thereby protect the base of the structures from cracking and settlement, proper drainage should be constructed to maintain the moisture content in the underlying materials.

4) Proper consideration of seismicity of the study area is important in the design of the foundations and superstructures due to the proximity of the study area to the most notable recent earthquake activities that occurred at Sardo and Dobi graben in 1969 and 1989 earthquake sequences respectively.

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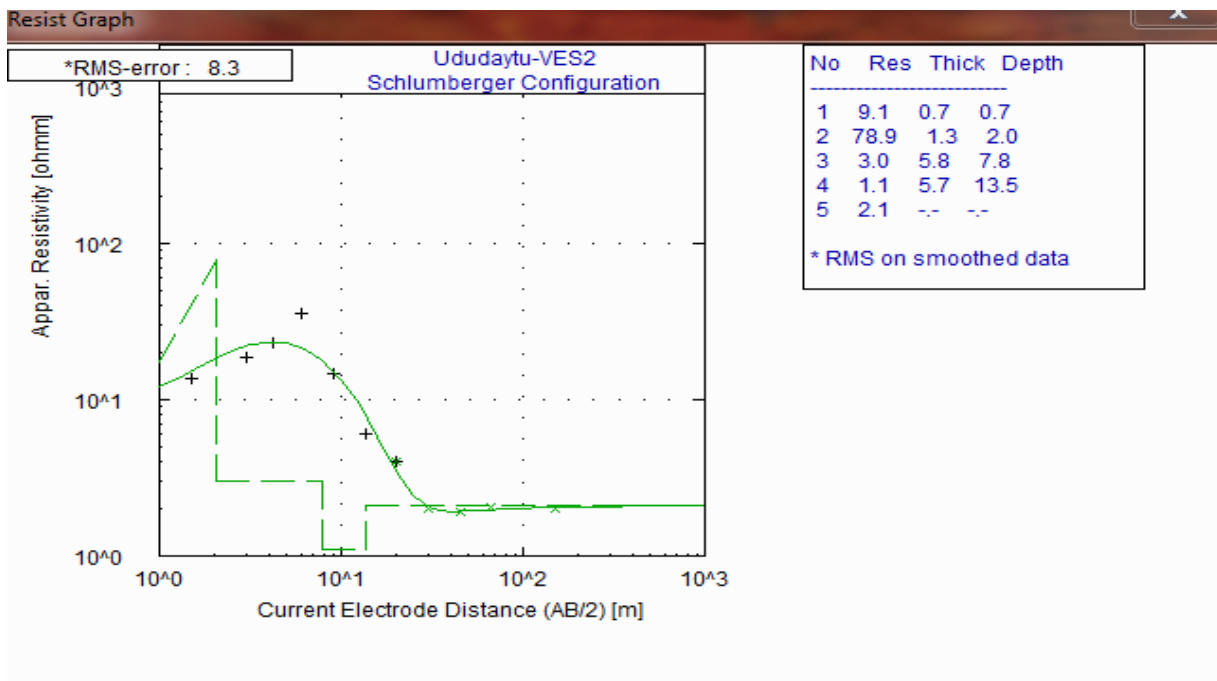
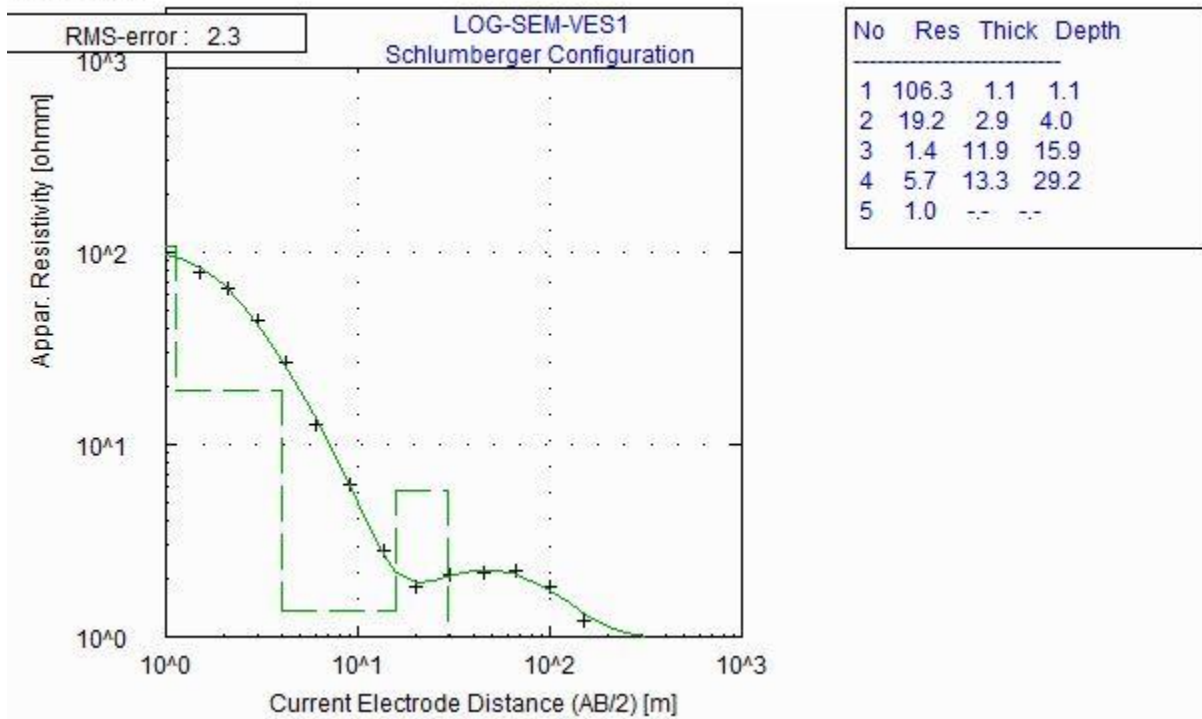
## Appendices

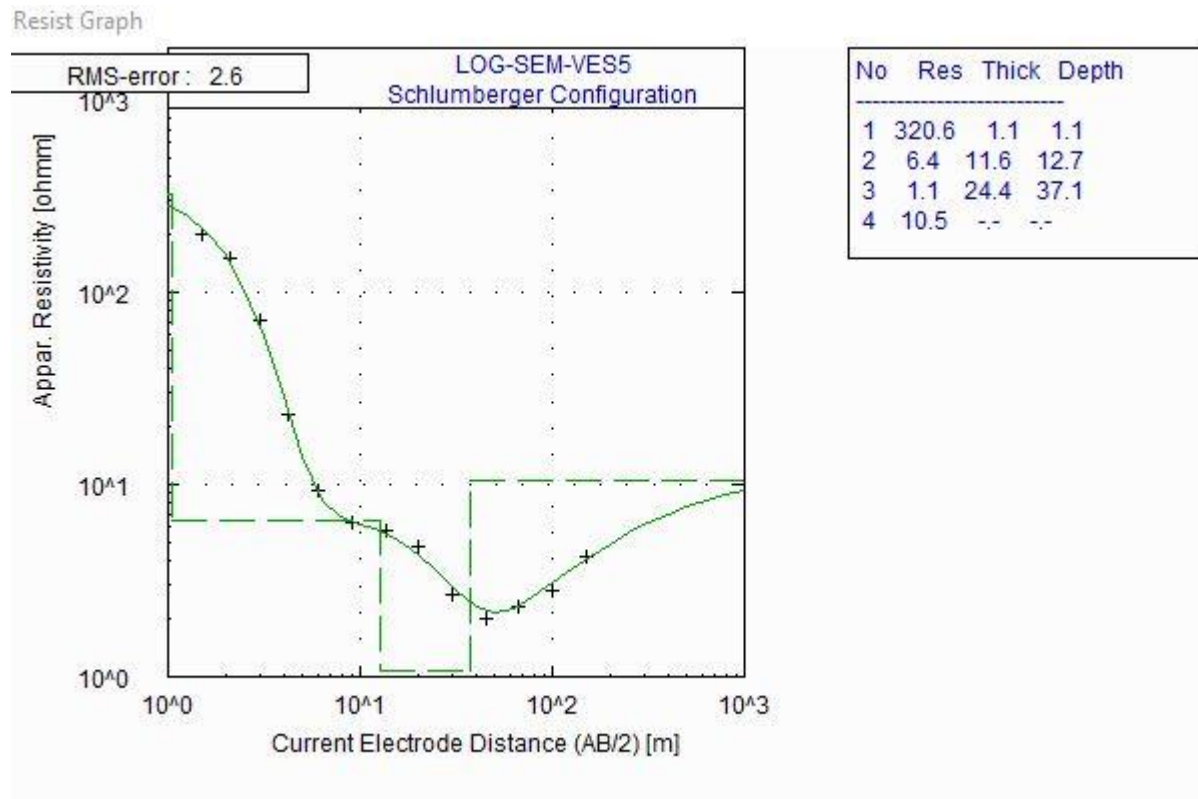
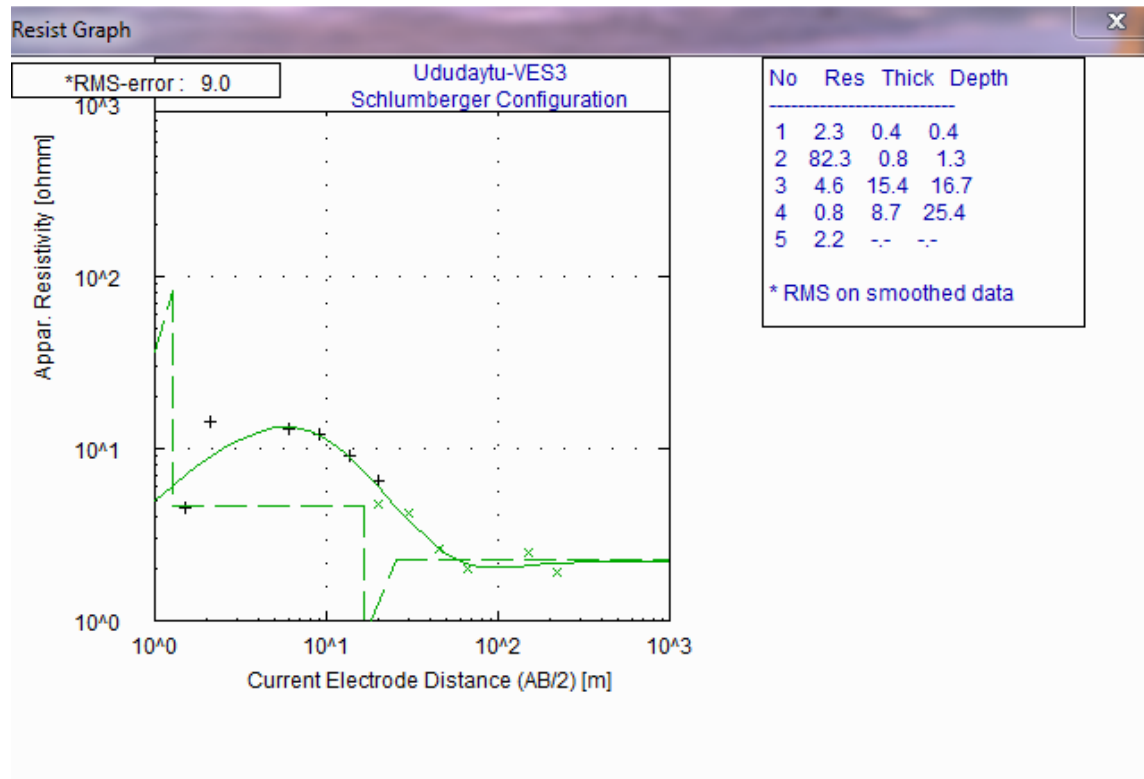
### Appendix 1 Location of Logia Well #2/08

LITHOLOGICAL LOG DATA			
WELL ID: Logia Well#2			
GPS Location (UTM, ADINDAN): 716702E,1298511N, 390 a.m.s.l			
DEPTH RANGE (m)		THICKNESS, (m)	Lithological Description
From	To		
0	2		Top soil
2	10		Fine to coarse sand
10	16		Clay
16	24		Fine to medium gravel
24	34		Sand with clay
34	42		Silty clay
42	50		Silty sand
50	54		Silty clay
54	64		Clay
64	90		Sticky black clay
90	100		Gravel
100	120		Clay

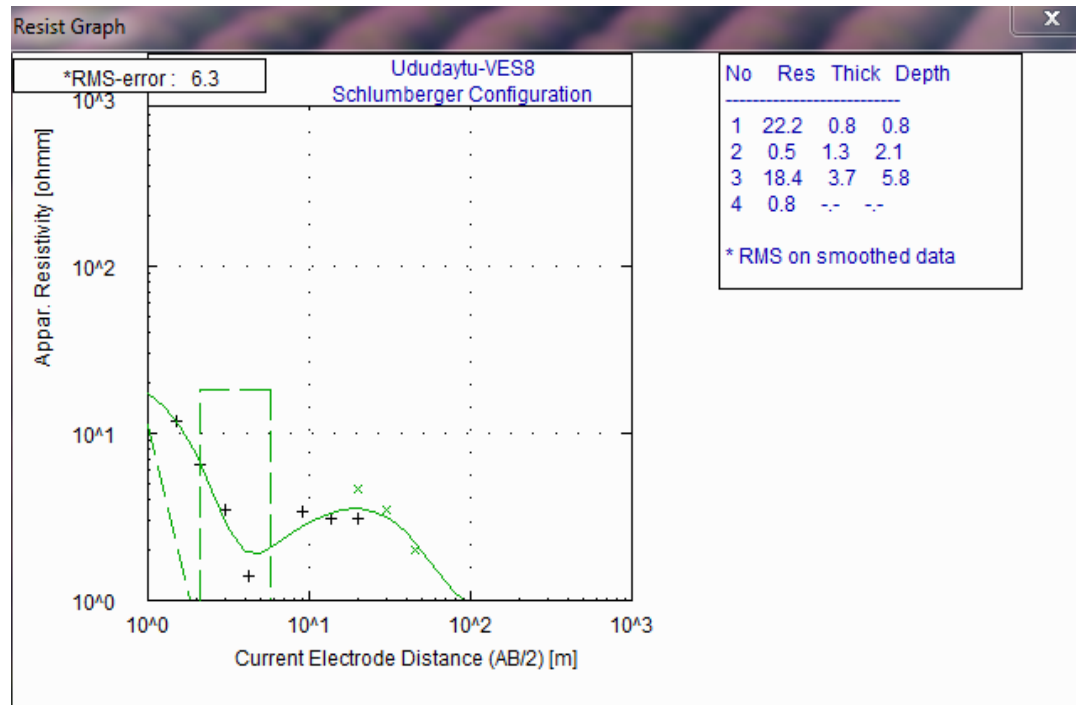
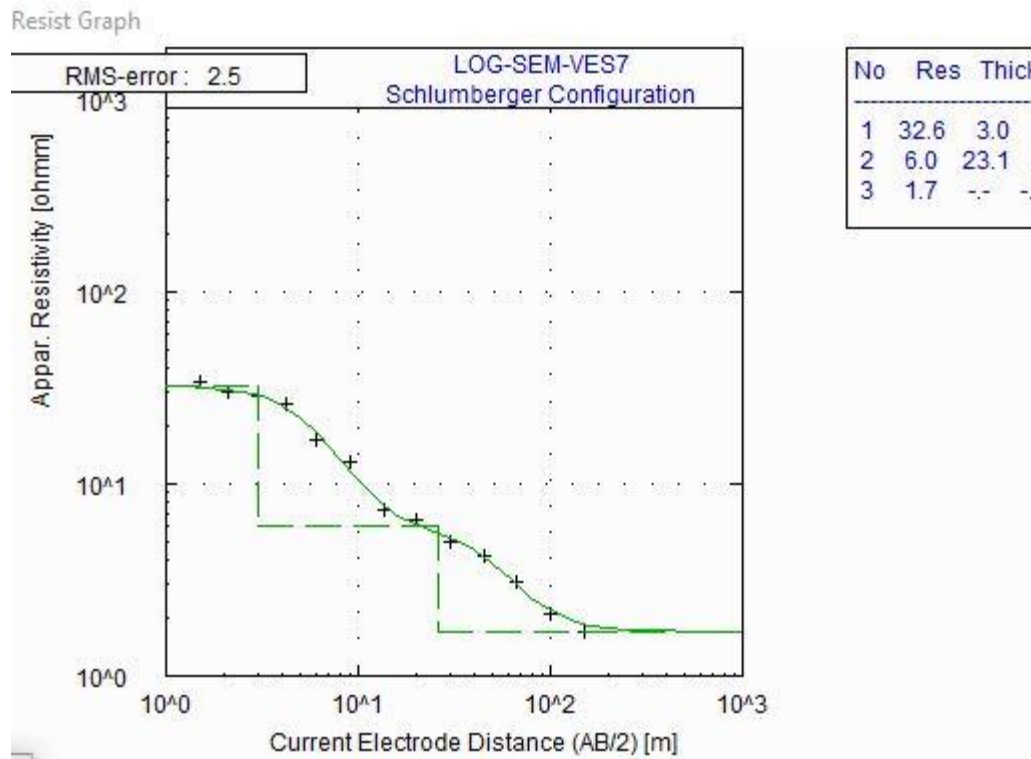
Appendix 2 Samples of Resistivity Sounding Curves

Resist Graph

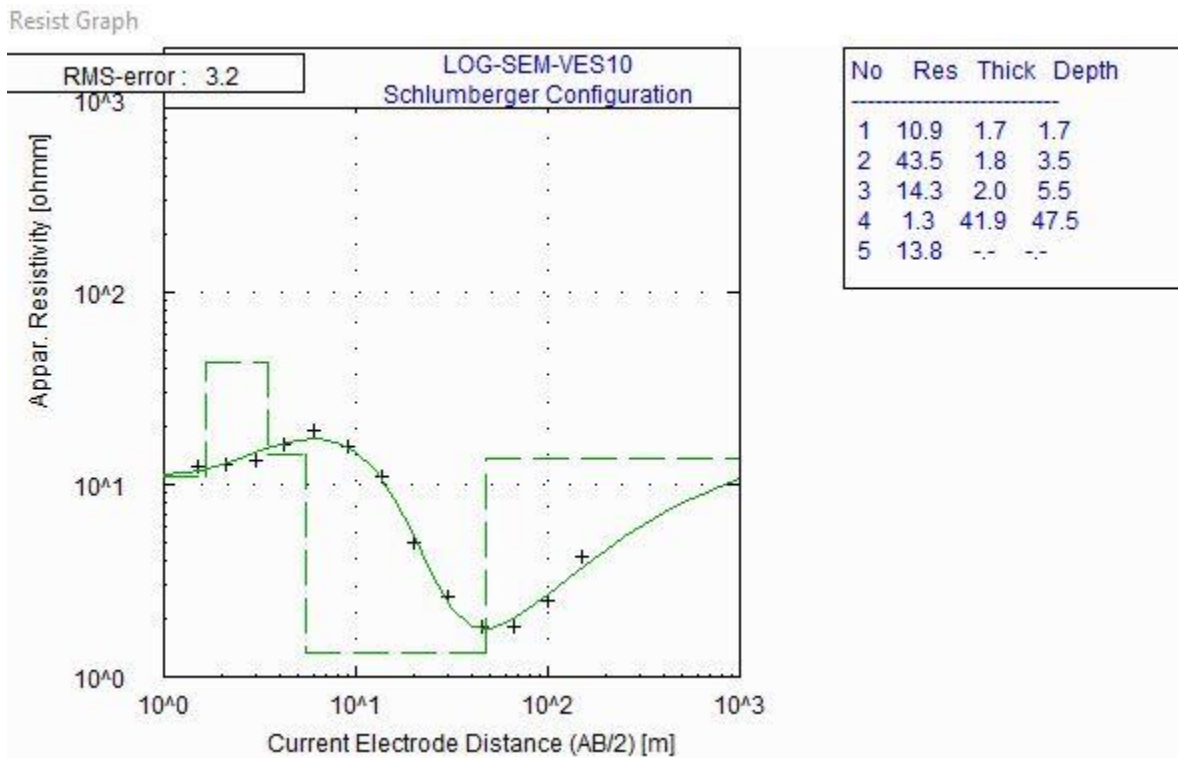
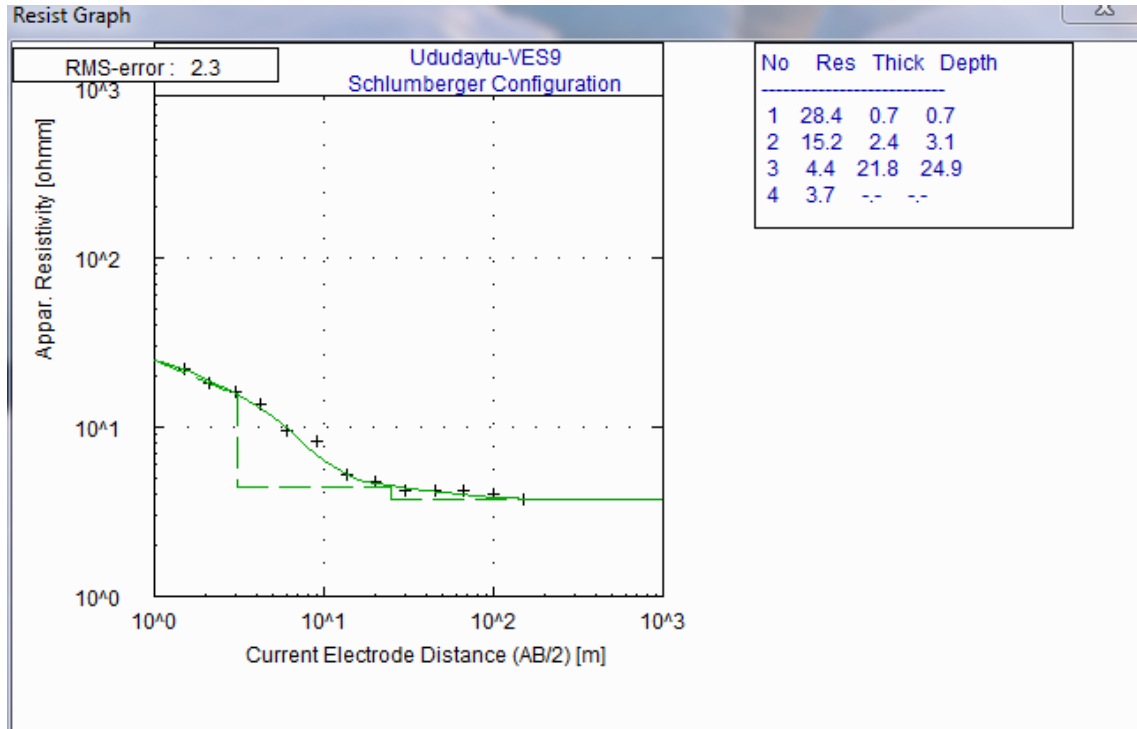




Application of Electrical Resistivity Techniques in Building Foundation Assessment at Ududaytu area in the Tandaho Graben of Afar, North Eastern Ethiopia

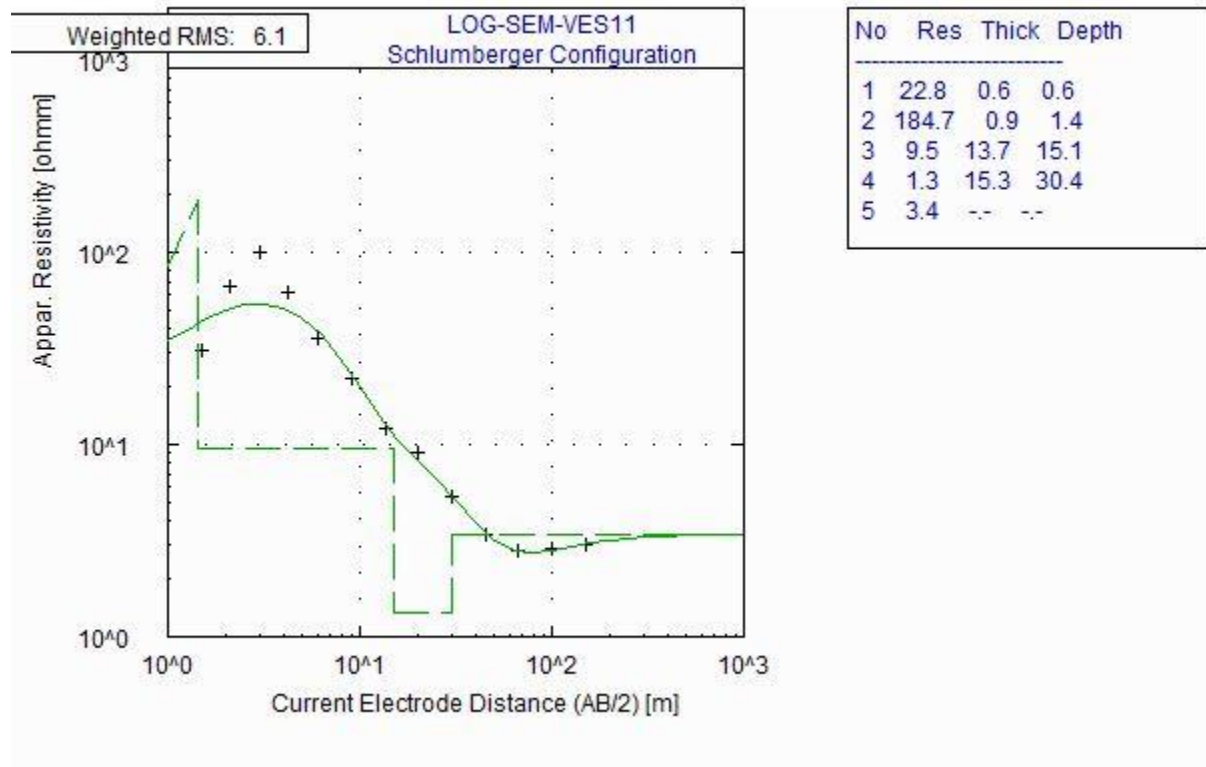


Application of Electrical Resistivity Techniques in Building Foundation Assessment at Ududaytu area in the Tandaho Graben of Afar, North Eastern Ethiopia

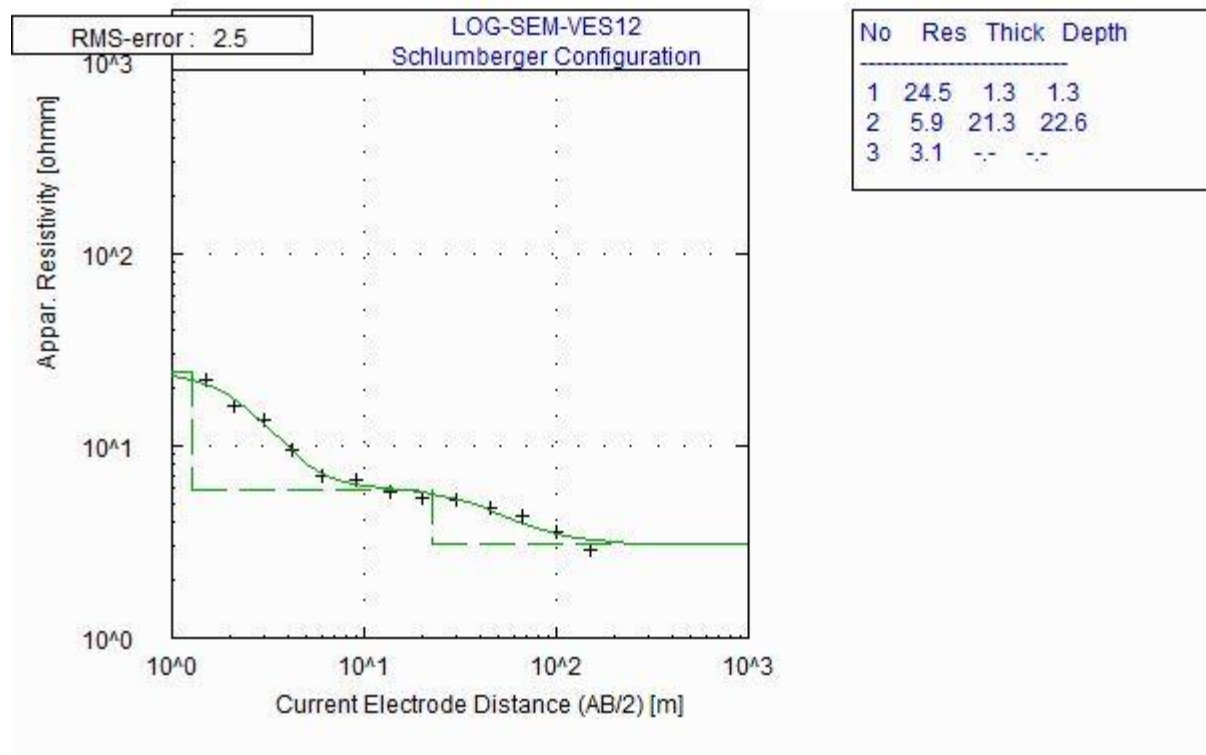


Application of Electrical Resistivity Techniques in Building Foundation Assessment at Ududaytu area in the Tandaho Graben of Afar, North Eastern Ethiopia

Resist Graph

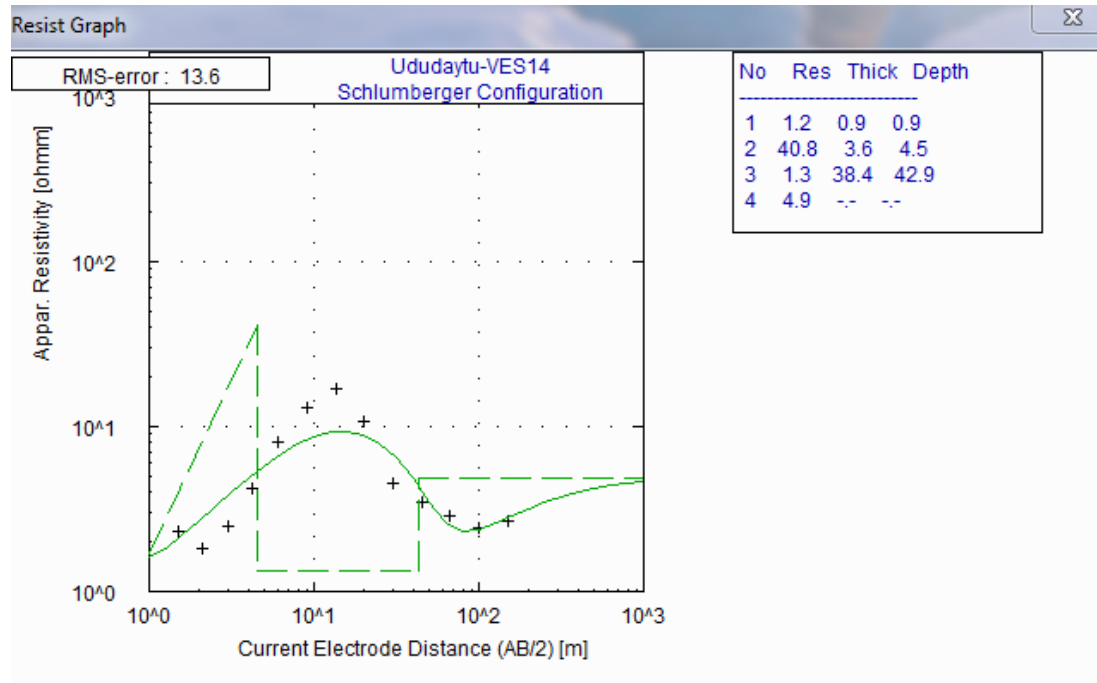
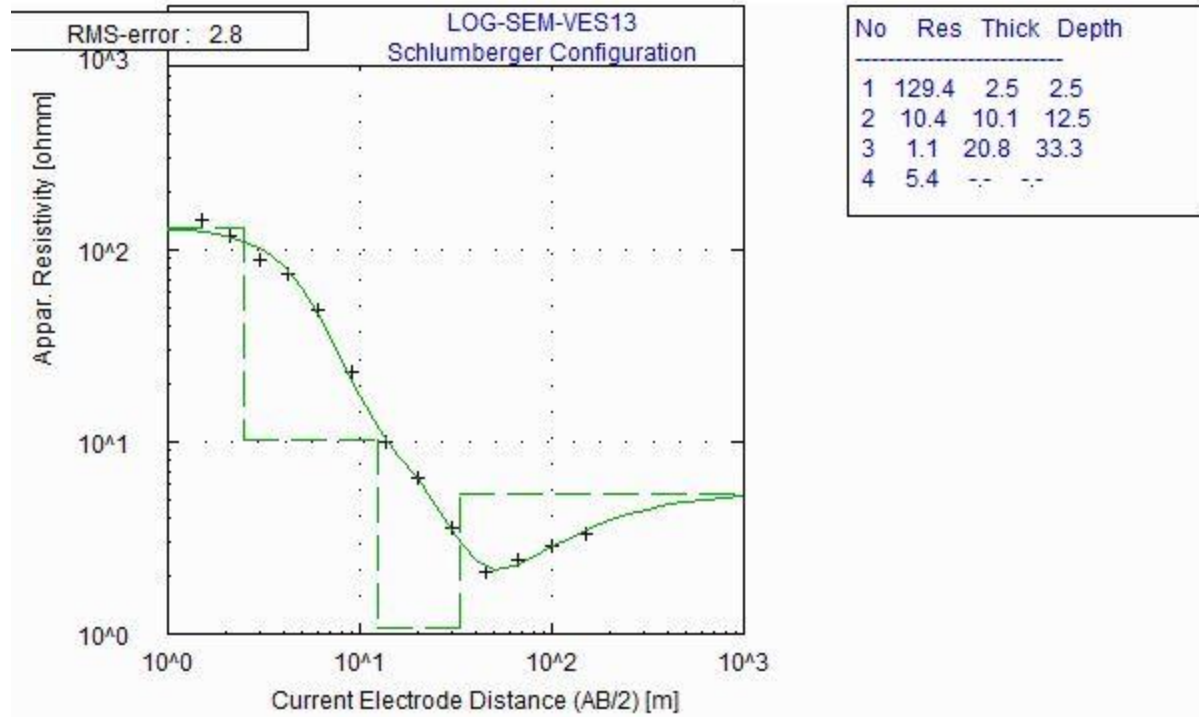


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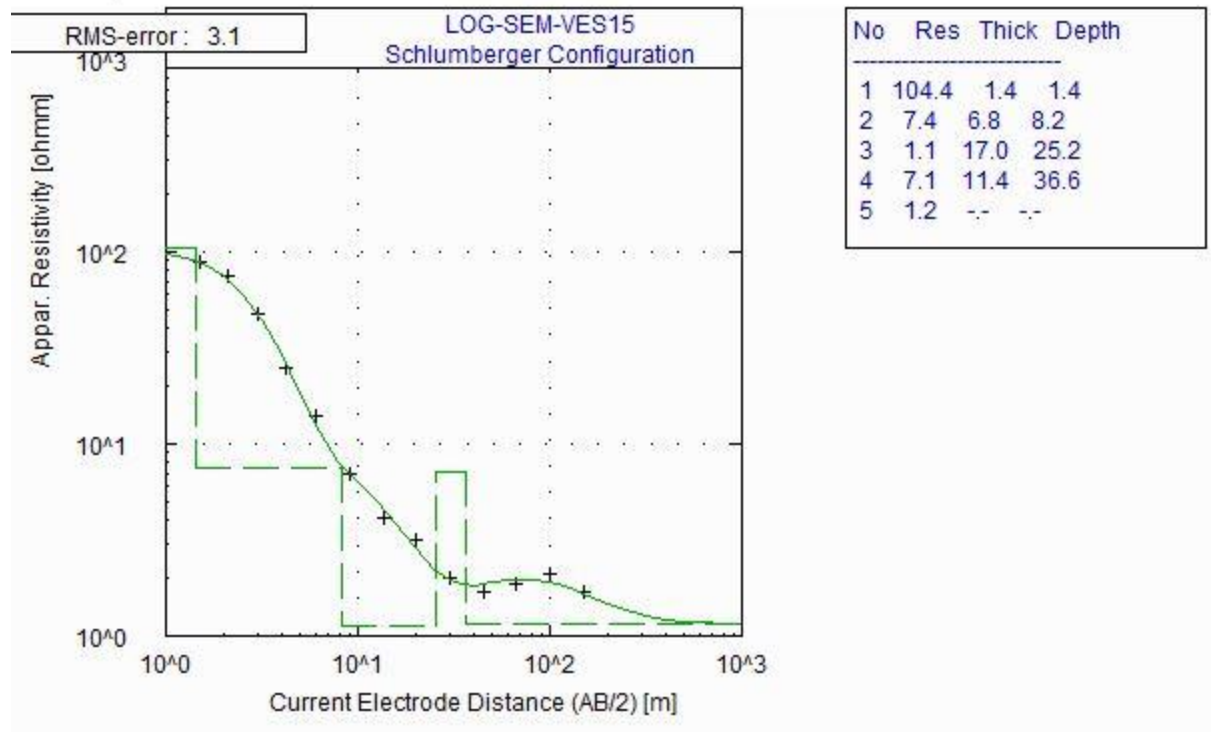


Application of Electrical Resistivity Techniques in Building Foundation Assessment at Ududaytu area in the Tandaho Graben of Afar, North Eastern Ethiopia

Resist Graph



Resist Graph



Resist Graph

