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**QUALITATIVE AND QUANTITATIVE APPRAISAL OF THE
CLAY DEPOSITS IN ERUSU-AKOKO AREA OF ONDO STATE,
SOUTHWESTERN NIGERIA**

BY

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**A THESIS SUBMITTED TO THE DEPARTMENT OF GEOSCIENCES, FACULTY OF
SCIENCE, UNIVERSITY OF LAGOS, IN PARTIAL FULFILLMENT OF THE RE-
QUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE (M.Sc.) DEGREE IN
HYDROGEOLOGY AND ENGINEERING GEOLOGY**

JUNE, 2023

CERTIFICATION

I hereby certify that this project was carried out by ERINFOLAMI, TUNDE GIDEON, with Matriculation Number: 189078040 of the Department of Geosciences, Faculty of Science, University of Lagos, Lagos state, Nigeria.

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DEDICATION

This project work is dedicated to Almighty God for His protection and provision, As well to all Nigerians students who pass through thick and thin.

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ACKNOWLEDGEMENT

I thank God Almighty for His unquantifiable grace and opportunity giving to me to be able to start and complete this Master Programme in sound and good healthy.

My gratitude also extends to my amiable Supervisor Dr. MoroofOloruntola whose kind and through supervision brought out the best in me.

I would also use this medium to appreciate my doting and caring parents Mr. and Mrs. C.A Erinfolami for their support both financially and physically in course of my education in this great citadel of learning.

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ABSTRACT

Qualitative and quantitative evaluations of clay deposits in Erusu-Akoko in Ondo-State, South-western, Nigeria, were executed with a view to determining its quantity and possible utilities.

Sixty (60) Vertical Electrical Sounding (VES) distributed on a 250 m by 250 m grid map were adopted for the resource quantification. The Vertical Electrical Sounding method was combined with the kriging based contour map to estimate the volume of the clay deposits in the study area. Four representative bulk samples were collected and subjected to geotechnical analysis which include; grain size analysis test, bulk density test, unconfined compressive strength test, modulus of rupture test, permeability test, compaction test and mineralogy test.

The result of the geotechnical analysis showed that the liquid limit ranged from 48.30 – 52.30 % with a mean value of 50.10 % and its plasticity index limit ranged from 26.0 – 31.9 with a main value of 20.30 % which is an indication of intermediate plasticity. The plastic limit ranged from 26.0 – 31.90 % with a mean value of 29.4 % which implies that the clay can withstand volumetric shrinkage on heating and exhibit a low to medium swelling potential when wet. The amount of fine fractions about 60.41 – 75.32 %, clay sized fractions about 10 – 22 %, average compressive strength 230 kpa, average bulk density 2.03 g/cm^3 , average porosity 27.4 %, average compaction 1.92 %, permeability coefficient $1.7 \times 10^{-5} \text{ cm/s}$, average firing temperature 1350°C and average modulus rupture 1100°C showed that the clay possesses properties of a good liner for landfill, pottery, refractory materials and firebricks. The geophysical analysis results revealed that the horizon beneath the clay horizon is the bedrock with apparent resistivity value of $1.30 \text{ } \Omega\text{m}$ to $145 \text{ } \Omega\text{m}$ for the clay horizon which has a thickness of 0.7 – 9.8 m. However, the computed experimental variogram revealed a range of influence of 450 m, a sill of 4 m and a nugget of 5 m. These values were incorporated into the constructed Gaussian model to estimate the volume of the clay deposit in the study area as 92698.2 m^3 and the reserve (tonnage) as 2437962.66 metric tons.

The study showed that the clay deposits in the study area can be used for the production of ceramic, pottery, firebricks, blast furnace for metals and refractories.

Keywords: Clay deposit, Tonnage, Geotechnical Assessments, Geostatistical Analysis and Variogram.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the study

The basement complex of Nigeria has been subjected to more than two phases of deformations (polyphase) and weathering, which has led to the generation of many sediments of which clay and clay minerals are among. Hence, the occurrence and importance of clay and clay minerals have been recognized since stone age and time immemorial. In recent time, clay has found wide application in areas such as ceramics, pharmaceutical and building construction industry (Oloruntola *et al.* 2010).

Some studies have shown that some clays in Nigeria are good for brick making based on their natural water content, natural swelling potentials and cold crushing strengths (Aniyi and Adewara, 1986; Hassan and Adewara, 1993). Other studies have found clays in some other parts of Nigeria useful for furnace construction as a result of their high thermal shock resistance, refractoriness values, cold crushing strength and bulk density (Abolarin *et al.*, 2004; Omowumi, 2001; Adediran *et al.*, 1989). Oloruntola *et al.*, (2010) evaluated the physical, refractoriness and firing properties of Falafonmu, Igaran, Idofe, Oke-Okoko clay and determined their suitability for ceramic production, fire bricks production and glass furnace for metals. In spite of this recognized suitability of the clay in this area for different utilities, the information about the clay reserve still remain unknown.

However, to positively address the major economic and social problems of Nigeria such as unemployment, social unrest and over-dependency on foreign goods to mention a few, it becomes imperative and of paramount importance to diversify the major source for the nation income from crude oil and gas (Suberu *et al.*, 2015; Uzonwanne, 2015). It is also essential to effectively use the available local mineral resources such as clay sand as a result of their contribution to the nation's wealth base and aid socio economic development and sustainability

of the country industrialization, most especially small and medium scale industries where the major local needs for production and fabrication of ceramics (wall and tiles, table wares and electric porcelain).

The resource quantification involved the use of vertical electrical sounding [VES] to determine the thickness at several points and geostatistical methods for volume and tonnage estimation. Geostatistics applies a local neighborhood search to develop a local fitting model. The values obtained at nearly samples points are used to produce the value at the unknown points using a linear combination of weight (Samanta *et al.*, 2004a).

Nevertheless, the need for local sourcing of clay for production of needed refractory materials in Nigeria has been suggested by Etukudoh *et al.*, (2016). The suggestions aroused the interests of Nigerian researchers in characterizing and investigating the suitability of many clay deposits across the country for various engineering applications to address the implications of refractory importation on the country's economy.

However, the focus of this work is to investigate the occurrence of clay deposits around Erusu-Akoko and its environs as well as evaluate its possible applications.

1.2. Aim

The main aim of this project work is to quantitatively and qualitatively assess the clay deposits in Erusu-Akoko, Ondo State, Nigeria.

1.3 Objectives of the Study

The objectives of the study include to;

1. undertake a detailed geological mapping of the area
2. investigate the occurrence of clay deposits around Erusu-Akoko for different utilities.
3. determine the various geotechnical properties of Erusu-Akoko clay for Engineering or constructional purposes.

4. estimate the thickness, volume and tonnage of the clay deposits in the study area.
5. produce a detail geological map of the study area.

1.4 Description of the Study Area

1.4.1 Location and Areal Extent

The study area is located in the North part of AkokoWest local government area (L.G.A.) of Ondo state, Southwestern, Nigeria, (Figure 1.1) and lies between Latitude $7^{\circ} 30'N$ and $7^{\circ} 35'N$ and Longitude $5^{\circ} 45'E$ and $5^{\circ} 50'E$ occurring in the northern part of Owo, Northwestern sheet (225) of the Federal Survey of Nigeria (1978).The area measures about 60 square kilometers.

1.4.2 Accessibility

The study area is accessible with Erusu-Akoko being dissected by a tarred road linking the area with main Imo-Arigidi -Erusu-Akoko road to the west (Figure 1.1).The road has been upgraded and serves as a link to Ibaramu from Arigidi. The bifurcated road serves as a major transit road for heavy duty vehicles travelling to and from the northern part of the country.

1.4.3 Vegetation and Climate

The vegetation of the study area is typical of tropical rainforest. The area is covered by thick evergreen forest with the exception of some places where settlement and farming have resulted in the removal of the original forest cover and has dense savannah. Different variations of vegetation occur in the area and the plant grown in the area include both annual crops such as cassava, maize and perennial crops such as kola nut, cocoa, palm tree etc. The climate of the study area is hot, humid, and tropical. The wet season covers the period of April to October while the dry season covers period of November to March.

1.4.4 Topography

The study area is of moderate relief with a few high lands at the southwestern part of the study area. There is presence of a prominent ridge in the south-eastern part of the study area and northwestern area and low land in the southern part. The area is moderately to highly undulating with an average elevation of about 362 m.

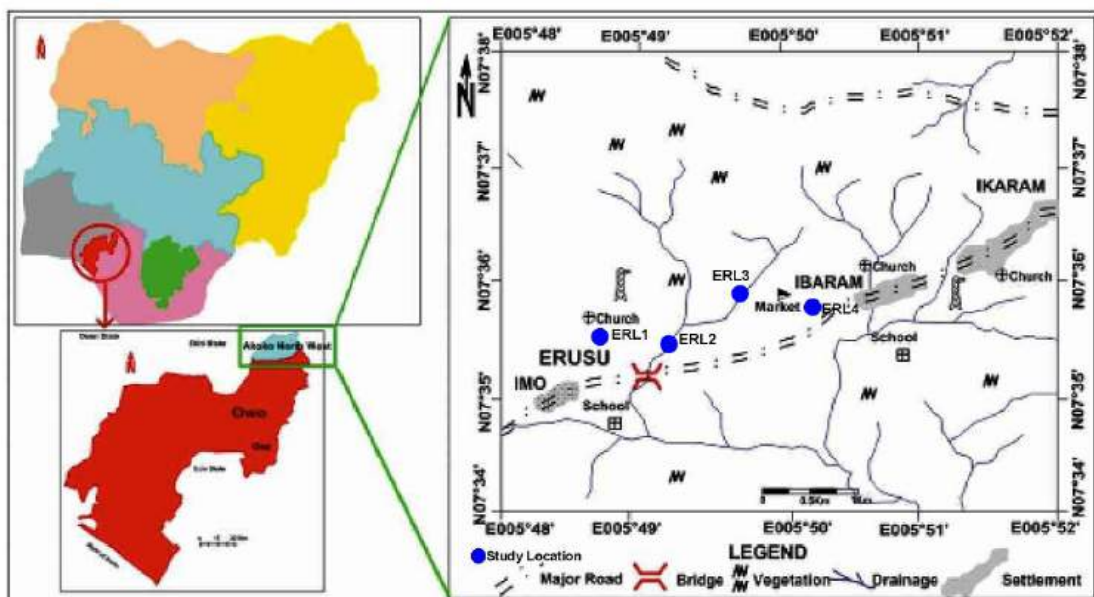


Figure 1.1: Location map of the study area (Insight is map of Nigeria and Ondo State).

1.5 Scope

This research is focused on the region between latitude $7^{\circ} 30'N$ and $7^{\circ} 35'N$ and longitude $5^{\circ} 45'E$ and $5^{\circ} 50'E$, covering, an area of approximately 266 km. The study entails detailed geological mapping, geotechnical, geostatistical and geophysical analysis. The geological mapping involves measurements of some structural features such as strike and dips, trends of joints, collection of fresh soil samples determination of field relationship and determination of engineering properties of the soil. Sixty (60) VES stations were acquired for the geophysical study in the area

and geo- referenced with an accurate global positioning system (GPS) recording devices current electrode separation (AB). The geotechnical and geostatistical analysis were also used to support the geophysical analysis.

1.6 Drainage

The area is mainly drained by River Auga and other streams which are seasonal. The river dominates the drainage system of the study area and it is mainly dendritic (figure 1.1).

1.7 Problem Definition and Justification

The composition of the Nigeria basement complex differs from place to place and thus, the basement complex of Southwestern, Nigeria. However, the scale of variation is not the same since, the study area lies in the basement complex of Southwestern, Nigeria, this study seek to discern the clay deposits in Erusu-Akoko, with a view to ascertain its suitability for various utilities. Ademila and Adebajo (2017), has established the suitability of the clay deposits for ceramic and pottery (Figure 1.3) and brick making (Figure 1.4), however, nothing has been done on the resource quantification of the reserve in place of the study clay deposits. In spite of this gap in knowledge, this study seek to use the two applied geological methods (geophysical and geostatistical method) to estimate this unknown volume of clay deposits in place.

The hypotheses to be tested include;

1. Whether the clay deposits in the study area are suitable for constructional, engineering and industrial purposes?
2. Whether Erusu-Akoko clays is large enough to be exploited industrially and commercially .

1.8 Literature Review

The lithological variations of the basement complex of Nigeria have been summarized by Turner (1964) and they include; migmatite -gneiss -quartzite complex, slightly migmatized to unmigmatized paraschists, gabbroic and dioritic rocks, charnokites and older granite suite.

Adeleye (1971), identified clay in the middle Niger basin and Dessauvage (1972) classified this clay deposits as Nupe group. According to Adeleye (1972) the stratigraphic succession of the Nupe sand stone involved the overlying of the basements complex directly by coarse conglomerate, clay stone and mixture of boulders of sedimentary origin. The stratigraphic units were in turn overlain by sandstones; subsidiary clay stones silt stones and conglomerates.

Ademila and Adebajo (2017) furtherly stressed that rocks in Erusu-Akoko have been subjected to varying degrees of weathering which has led to the formation of clay deposits and that claimed that clays are found in nature as a rock or soil, which may be transformed to soil-like within a time interval of less than 1-70 years.

Ajibade *et al.*, (1979) claimed that clay has found wide application such as ceramic, pharmaceutical and building construction industries and most of the clay deposits are yet to be assessed quantitatively and qualitatively. It has been reported that clays as one of the major Nigeria, mineral deposits cover and estimated proven of billions of tons, and are found in all other the states of the country.

Ajisafe *et al.*, (2016) argued that clay deposits are found in Nigeria in most of the sedimentary basins (Imo shales, Eze-Aku shales etc) while alluvia deposit is peculiar all around the country, residual clay deposit is found above various basement rocks especially gneissic and lateritic soil.

Aniyi and Adewara (1986) emphasized that the geology of many places where clay deposits occur have been studied very little, effort have been made to assess these deposits in order to determine their utilities. These clay deposits have found uses in the construction of furnaces, kiln, reactors and other high temperature vessels depending on the refractory properties of the

clay .in spite of these, studies that have been conducted in Erusu-Akoko clay deposits are suitable for brick making because of the presence of quartz in significant amounts which gives strength and durability to bricks (Figure 1.3 and Figure 1.4).

Ademila and Adebajo (2017) critically assessed the industrial potentials of the clay deposits in Eruru Akoko based on their geotechnical and geochemical characteristics and suggested that they are suitable for the production of refractory bricks and ceramics. Oloruntola *et al.*, (2010) showed that the occurrence and importance of clay have been recognized since ancient times, when it has been used for primitive applications like pottery (figure 1.3), construction of mud houses, bricks and further explained that clay can be used traditionally either in the raw state or at best made into simple sun dried bricks for construction of houses. Manassero *et al.*, (1996) stipulated that clay rich soils are used for constructing soil liners, because of their low hydraulic conductivity and their ability to attenuate inorganic contaminants.

Mosuro *et al.*, (2019) quantified the clay deposits in Iganran, Imope, Idoofe, Apari and Falafunmu in southwestern Nigeria, using the two applied geological methods namely; geophysical and geostatistical method and found that the two methods are efficient and cost effective in reserve estimation of the clay deposit. Although geostatistics is claimed to be the best in resource estimation (Rossi and Deutsch 1989) and that it has a limitation since it is unable to effectively tackle the clear definition of geological controls of structurally controlled deposits (Sinclair and Deraisine, 1974; Doming *et al.*, 2004). Due to this, in the research of Doming *et al.*, (1999a) the authors stated that in estimating the resources in narrow veins, classical or geostatistical method could be used; however, classical techniques are often used due to the difficulty, in applying geostatistical method (Roy, 2000).

Kriging as an advance method of geostatistics was named after Dr. D.G Kriging 1951 who first applied the method to estimate the reserve of rand gold deposits in South Africa in 1951. He developed an experimental method for determining a true ore grade distribution from

distributions based on sampled ore grade in the 1950's and this method was later developed by Metheron in 1963.

However, traditional method for ore tonnage and average grade estimation in a single ore deposit can be roughly classified as either geometric or geostatistical (Roy, 2000). Evaluations can be made on either a global or a regional basis much of the original work in this problem was carried out by Metheron (1962). He argued that Ore-grade and tonnage obey long-normal distribution.



Figure 1.2: photograph of clay bricks



Figure 1.3: Photograph of potteries made from the study clay.

CHAPTER TWO

2.0 GEOLOGICAL SETTING

2.1 Regional Geology

The Nigeria Basement is situated in the pre-drift mobile belt defined by Kennedy, (1969) as east of the west African and San Luis cratons and northwest of the Congo cratons (Figure 2.1). The area composed of rocks which have suffered metamorphism the late Proterozoic –early Phanerozoic Pan-African Orogeny (600+150 ma). This Pan-African mobile belt is divided into two main regions;

- a. The Frontal Region-Which is situated at the eastern margin of the West African Craton and has passed through a phase geosynclines prior to the Pan-African event, and
- b. The inter region: This has been affected only by deformation and the thermal reactivation during the Pan-African orogeny without extensive sedimentation. The Nigeria complex lies in this region.

The western half of Nigeria (NW and SW), which form the object of this synthesis, is generally referred to as the Schist belts to distinguish it from the area east of longitude 8° which is largely granitic with much lower development of metasediments. The rocks of the Nigeria basement complex make up almost half of the total 923,768 km² surface area of Nigeria. The basement complex outcrops are distributed in three main areas they are;

- (i) A triangular area in the Southwestern Nigeria where the rock continue westwards into the neighborhood Benin Republic (Rahaman, 2006).

Earlier workers such Oyawoye (1965) and Cooray (1974) subdivided the rocks of the basement into three major groups;

- a. The Older met sediments, consisting of Calc-silicate rocks arkosic quartzite and high grade schist which are present as lensoid relicts in regional gneisses or as paleosomes of the migmatites.
- b. The gneisses, migmatites and
- c. The Older granites

Cooray (1974), added the following significant information

- a. A conclusion that the older granites and related Charnockitic rocks are intensive rather than metasomatic origin.
- b. Subdivision of Older granites and granodiorites on the basis of emplacement relative to deformation into the following groups; Syntectonic microcline-megacrysts, partly foliated granites and granodiorites with cross-cutting contacts and occasional thermal aureoles (McCurry and Wright 1971; Jones and Hockey, 1964).
- c. A mainly north-south to northeast-southwest structural grains
- d. A Polyphase metamorphism; and that

The basement bears the imprint of at least three plutonic events during the Eburnean, Kibarian and Pan-African orogenic episodes (Grant, 1972).

The work of Oyawoye (1965) and Cooray (1974) among others, Rahaman and Ocan (1978) classified the rocks of the basement complex into six major groups. They are;

- i. Migmatite-Gneiss-Quartzite complex;
- ii. Slightly migmatized to unmigmatized paraschists and
- iii. Gabbroic and Dioritic rocks;
- iv. Older granite suite.
- v. Younger granite suites
- vi. Charnockitic rocks.

Based on the geochronology and age determination, the basement complex of Nigeria is classified into four age groups namely;

- Liberian (>2500ma)
- Eburnean ($\geq 7200 < 1800$)
- Liberian (1100+200ma); and
- Pan-African (600+_150ma)

Different types of migmatites result from the varying relationship between these components,

2.2 Metasedimentary and Metavolcanic Rocks

They are generally called the schist belts and occupy north-south trending synformal troughs and are better in folded into the MGC and are better developed in the western half of the country. They are largely sediment - dominated and important lithologies are pelites, semi-pelites and quartzites. Some belts host metamorphosed chemical sediment like marbles and banded iron formation (BIF), while mafic to ultramafic rocks now present as amphibolites and ultramafites occur in the others.

The geochemistry of the rocks of the schist belts confirm the sedimentary nature of most of them but the geochemistry of the mafic to ultramafic rocks within them has led to controversy. Some workers believe that the metavolcano-sedimentary sequences in the belts are Archean in age (>2600ma). Grant (1978), Holt (1982), and Turner (1983) however on the basis of structural and lithological association suggested some of the belts to be Kibarian age (1100+_200ma) and Older. They believed others to be Pan-African (550+100ma) in age. Ajibade *et al.*, (1979) disagreed with the structural evidence and proposed a Pan-African age for all the schist belts. Rahaman *et al.* (1988), argued on the basis of available Geochronological data that, an Archean age for the schist belts is preclude.

There are also controversy on whether the belts represent different depositional centers or relicts of a single supracrustal cover. The geodynamic setting of the schist belts is also controversial with some workers like Olade and Elueze (1979) favoring ensialic largely the processes in the evolution of the Schist belts while Rahaman (1981), and Egbuniwe (1982) have stressed the importance of ensimatic processes in the evolution of the belts.

2.2.1 The Pan-African Granitoids (Older Granites)

"Older granites "as a term was first introduced by Falconer,(1911).He distinguished the Pan-African granitoids from the Jurassic high level an orogenicvolcanic, hyperbyssal, peralkaline" younger granites" of the Jos Plateau Region (Rahaman *et al.*, 1988).The term Pan-African granitoids include biotite and biotite muscovite granites, Syenites, charnockites, diorites, Monzonites, Sepertinites and anorthosites.

In many places the coarser grained biotite hornblende granites have concordant foliation with the host rock MGC or Schist.NeoProterozoic (~600ma) U-Pb. Rb-Sr,K-Ar ages have been reported from these granitoids (Van Breeman *et al.*, (1977). The U-pb dates on Zircon s confirm Pan-African age emplacement for the Charnockitic rocks which were formally thought to be Kibarian or even Archean in age. Rahaman (1988) distinguished the following types of the Charnockitic rocks on the basis of their structures.

- i. Gneissic Charnockitic rocks that possess a planar penetrative fabric
- ii. Foliated charnokites which show a magmatic foliation due to the platy parallelism of feldspar megacryst and the concentration of mafic minerals into discreet plains; and
- iii. Coarse grained massive, non-foliated, often porphyritic Charnockitic rocks

2.3 Acid and Basic Dykes

The undeformed acid and basic dykes are to post-- tectonics Pan-African. They crosscut the three main units described above and include;

- a. Felsic dykes that are associated with pan-African granitoids such as muscovite, tourmaline and beryl bearing pegmatites, micro granites, Aplites and Syenites.
- b. Basic dykes that are generally regarded as the less common basaltic, dolerite and Lamprophiric dykes. The ages of the felsic dykes has been put between 580-535ma from Rb-Sr studies on the whole rocks by Van Breeman *et al.*, (1977) while the basic dykes have a much younger suggested age of 500ma, 478 ± 19ma (Grant, 1978).

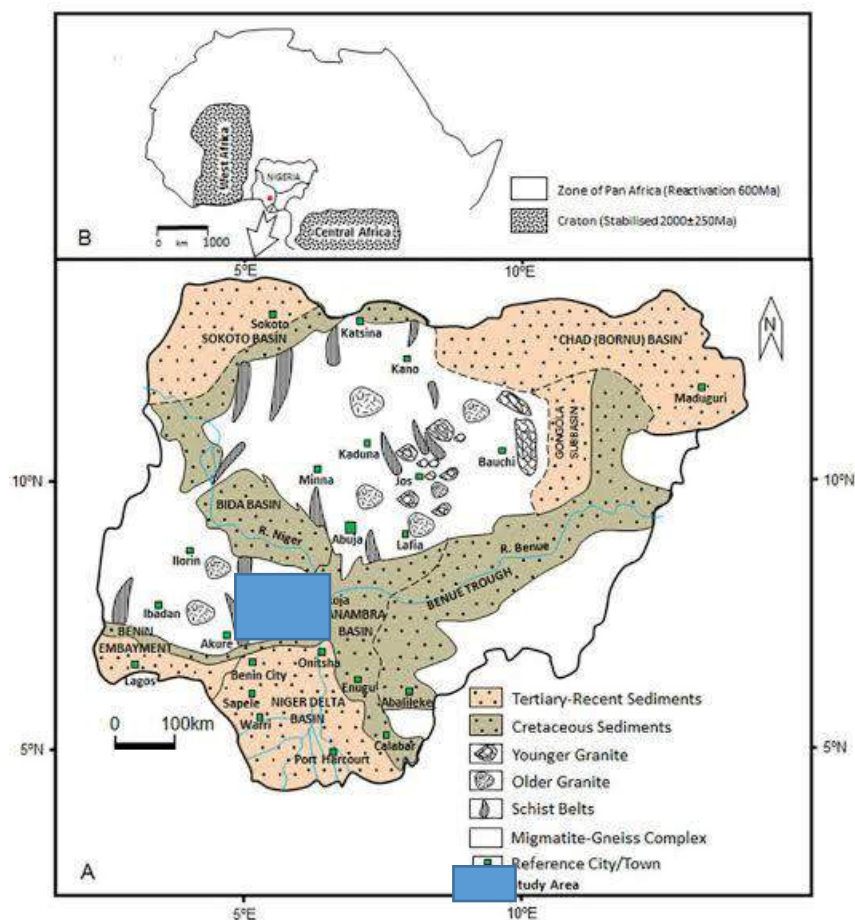


Figure 2.1: Showing the geological map of Nigeria modified by Ajibade *et al.* (1979)

2.4 Local Geology

Erusu- Akoko area comprises mainly of gneisses in association with porphyritic older granites, charnokite, pegmatite, aplite, granites, vein quartz and amphibolitic intrusions (figure 2.2). The gneisses in the area occur as grey gneiss and quartzo-feldspathic gneiss respectively, granodiorite to tonaltic quartz-dioritic in composition. The grey gneiss occurs within the granite gneiss. It is dark grey to dark green in colour and medium coarse grained with well- developed thin mineralogical bands. The light-colored bands are quartzo-feldspathic while the dark coloured bands are rich in ferro- magnesian mineral. The grey gneiss contains intrusions of pegmatite and quartzo-feldspathic veins and is regarded as the oldest rock in the area.

There are five major types of rocks encountered in the mapped area (figure 2.2). These rocks are:

2.4.1 Granite

This occurs as ridges and flat lying exposures in the area being medium-coarsed texturally. They have a vague outlines, uniform appearances and contain smaller crystals of large feldspars than the enclosing rocks (granite gneiss and augen gneiss). A general north- south alignment of biotite plates pervade the whole body of the granites. Erusu Akoko granites intrude the gneissic rocks and the charnokite with evidence of contact metamorphism around the contact separating them. The feldspar alignment is weaker along the margin than in the centre, (Ajibade *et al.*, 1979). At its margin there is a crowding of poorly formed pinkish crystals of feldspar about 1.5-2cm long, without any obvious alignment (Raman *et al.*, 1988).

The porphyritic granites are non-foliated because of the simple fact that the feldspar megacrysts are arranged haphazardly within the ground mass of the rock (figure 2.4).

2.4.2 Granite Gneiss

They formed the rugged topography observed in the northwestern part of the area, they are approximately trending N-S and border the metasediments, both to the west and eastern part of the

area. They have a granoblastic texture and are medium grained with grain diameter of about 1-2 mm. The granite gneiss ranges from dark biotite-rich melanocratic varieties to light Leucocratic varieties. Mineralogical banding occurs with the light bands being rich in quartz and potassium feldspar ranging in thickness from 0.35cm – 2.7cm. The characteristic property of the rock is in the preferred alignment of the phenocrysts which show elongation in the Northwest-Southwestern direction. The rock is intruded by. Granite and contact aureole is developed around the contact of the intrusion.

2.4.3 Grey Gneiss

These gneisses (figure 2.2) are wide spread in the area constituting about 60% of the rock types found in the study area, and have been intruded by the Pan-African granitoids (granite, charnokite, pegmatite and aplites). They occur as massive rugged rocks and rolling plains assuming batholithic dimensions and forming impressive outcrops which tower few hundred metres, above the surrounding low lanes and showing different types of geological structures such as folds, faults, foliation and joints.

These structures suggest that the area has been subjected to at least two phases of deformation. (John, 1960).

2.4.4 Augen Gneiss

This is a metamorphic rock dominantly found around Erusu-Akoko area trending from the northwest to southwest of Erusu Area (figure 2.2). This is also a portion of the banded gneiss is Migmatite gneiss in the area. The intensity of metamorphism of the outcrop leads to the alteration of the mafic and felsic minerals in the rock. Also, the texture of the outcrop is medium-grained. Structures mapped include foliation, lineation dykes, folds, joints and cracks.

2.4.5 Charnokites

The Charnockitic rocks in the study area is very massive and outcropped as circular hills which ranges between 5m and 10m. The charnokite has been subjected to massive deformations both structurally and mode of formation as large numbers of boulders are found around the outcrop. In terms of colouration, Erusu-Akoko, charnokites are dark green in colouration and medium to coarse grained in texture. Generally, the outcrop is trending in N-S direction with limited accessibility. It is similar in composition to those described by Oyawoye (1972) and Rahaman (1976, 1978)

The outstanding features of the coarse-grained Erusu-Akoko charnokites is generally the even texture and homogenous with mineral aggregate, mainly K-feldspar and biotite.

2.4.6 Other Rock Types

Vein quartz is another type of neosome found in the study area. They occurred as veins, varying in thickness from a few millimeters to about 10 cm. They show great variety of irregularities in their forms and are seen in places to thin out. Widen or thin in their course in this area. Flakes of muscovite and at times biotite may be found associated with quartz veins (figure 2.4)

Quartzo-feldspathic rocks: They occur as concordant and semi- concordant veins.





Figure 2.3: showing a typical fold observed in the study area



**Figure 2.4: Showing a pronounced quartz veins running across the porphyritic granite
observed in the study area**



Figure 2.5: Showing foliation observed on the outcrop of granite.

2.5 Metamorphism

Metamorphic imprints on the rocks of the Nigeria basement complex are reflected in the mineral assemblages associated with penetrative fabrics of the Pre-Pan-African rocks and to a lesser extent in the Granitoids. Wide spread occurrence of chlorite, biotite, staurolite, sillimanite and sometimes kyanite in rocks of Erusu-Akoko area point to a medium pressure and medium temperature (Barrovian-Michigan) type of metamorphism. The association of cordierite-athophyllite-andalusite ,indicate a medium pressure high temperatures types of metamorphism. The grade of metamorphism is believed to have attained granulite faciesalthough, granite gneiss of Erusu-Akoko, lack index minerals. Studies in the area confirmed granulite facies condition in the study area rocks.

Nevertheless, the deformation and metamorphism of the basement complex of Nigeria is largely plurifacial in history (Rahaman ,1979 and Ajibade *et al.*, 1979).

2.6 Structural Geology

The various phases of deformations the area has suffered has led to the development of structures like folds, faults, foliations, lineations and joints among others.

- i. Folds: These are wavelike structures that occur when an originally planar geological surface, is subjected to compressive stress. Both minor and major folds are observed in Erusu-Akoko area. Symmetrical folds, asymmetrical folds, recumbent folds and ptygmatic folds are among the major fold types (Figure 2.3) that were encountered in the study area.

Minor folds: These are shown on the outcrops of granite gneisses and are overturned largely to the east over most of the southwestern region, plunges are to the north and are rarely exceed 25° , although in some areas steeper plunges have been encountered.

Recumbent folds: These are folds that the axial plane dips at an angle less than 10° and the two limbs are nearly horizontal or horizontal. These observed on the outcrop of the granite gneiss and augen gneiss in the study area.

Symmetrical folds: These are folds in which one limb of a fold is mirror image of other, and the axial surface is plane of symmetry.

Asymmetrical folds: usually have limbs of unequal length and an enveloping surface which is not perpendicular to the axial plane (see Appendix A).

- ii) Foliation: This is refers to as any microscopically penetrative parallel alignment of plane fabric elements in a rock usually metamorphic. It is a fundamental characteristic of regionally metamorphosed rocks. Foliation is expressed by mineralogical banding (figure 2.5). The lithological banding has led to granite gneiss encountered in the study area. The dominant trend of the foliation in Erusu-Akoko area is Nw-SE and the foliation in general

is parallel to the limbs of the major folds. Superimposed and transpose foliation are the foliation types that are observed in the study area.

- iii) Joints: They are fractures on the rocks along which no displacement has occurred. They vary in orientation with some being parallel to the strike of the host rocks while others occurred oblique to the strike (see Appendix A). The joints in the rocks of this area are of tectonic in origin and they resulted from the deformations of the rocks. it is common in the granite and granite gneiss of the study area.
- iv) Lineation: This defined a sub- parallel to parallel alignment of elongated fabric elements in a rock body, commonly penetrative at the outcrop in hand specimen or microscopic scale. The types of lineation observed in the study area are bedding cleavage lineation, boukdins and mullions.
- v) Shear zones: These are narrow sub parallel sided zones of strong coaxial fractures, the zones are being characterized by sigmoidal drags and fractures.
- vi) Faults: These are fractures along which blocks of rocks has been displaced relative to each other. These planar discontinuities originate by tectonic forces acting regionally. Strike faults and normal faults are the major faults observed in the study area,
Normal fault: This is the fault in which the hanging wall has moved relatively to the footwall.
Strike fault: is a fault which runs parallel to the strike of the rocks.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Field Description of Samples

The field work was carried out between the Month of August and September; 2020. it involved mainly the collection of samples from different outcrops in various part of Erusu-Akoko, Ondo state, Nigeria. Ten different representative samples were collected using hammer and these specimens are kept in the rock bag and taking to the laboratory for petrographic analysis.

3.2 Geotechnical Analysis

For a detailed qualitative assessment of the clay samples in the study area, four representative samples were collected with GPS referencing in order to ascertain their exact points of collections. The four samples were collected at the depth of 2-3m using a digger, cutlass and spade (figure 3.1)

The collected samples were packed in polythene bags and each bag labeled for easy recognition. The collected samples were taken to the laboratory for different geotechnical analysis. The four soil samples were subjected to physical properties test, moulding and firing parameters in order to determine their suitability for different industrial utilities. The samples were prepared for testing by crushing using a jaw crusher, followed by gently grinding the samples to avoid destruction of the structure of the minerals. Samples were air-dried for two weeks immediately after removing samples for the determination of moisture contents to facilitate the sieving process in the laboratory for geotechnical investigation and clay mineralogical analysis.

The qualitative characterization of the clay deposits in Erusu-Akoko, was carried by subjecting the collected samples to geotechnical analysis in two standard laboratories in Nigeria. The

Atterberg limit test, Natural moisture content test, Plasticity index test, clay content, Ph and bleaching test, sieve analysis test, permeability test and compression test were the different geotechnical tests conducted on the four samples and this was carried out at Civil Engineering soil laboratory, Federal University of technology, Minna, Niger state, Nigeria. While the linear shrinkage test, apparent porosity test, specific gravity test, modulus of rupture test, California bearing ratio test, unconfined compressive strength test, firing test and compaction test were conducted in Federal Institute of Engineering Laboratory, Oshodi in Lagos State, Nigeria. The laboratory analyses were carried out in accordance to British standard methods of test for soils for Civil Engineering purposes. (B.S 1377: part2:1990).

The collected soil samples were subjected to the following geotechnical tests;

1. Apparent porosity
2. Modulus of rupture
2. Natural moisture content
3. Atterberg limit test (liquid, limit, plastic limits, shrinkage limit, and plastic index).
4. Specific gravity.
5. Percentage of clay contents
6. PH and bleaching test
7. Particle size distribution test
8. Compaction
9. California bearing ratio (CBR)
10. Firing test
11. Permeability
12. Unconfined compressive strength
13. Thermal shock resistance (TSR)
14. Hydraulic conductivity



Figure3.1: Showing student collecting clay sample for laboratory analysis.

3.3 Geophysical Techniques

3.3.1 Field Method and Data Acquisition

The geophysical ground survey was carried out in the study area using Vertical electrical sounding techniques (figure 3.2) of Electrical resistivity survey method.

Sixty (60) VES stations in a grided form (figure 3.3) were acquired using GPS to georeference accurately the probed locations in the study area (Table 1). Other equipment such as Pacimeter, electrodes, measuring tapes, electric cables, and cutlass were also deployed and used in course of geophysical survey of the study area. This geophysical survey was conducted using a maximum electrode spacing of 100 m and four personnel were on ground to carry out the survey which lasted for seven days.

The electrode array utilized for this survey is the Schlumberger array (figure 3.2) and the observed apparent resistivity data were presented as depth sounding curves (Appendix) in which the apparent resistivities were plotted against half electrode spacing ($AB/2$) along the Abscissa. The results of the iteration obtained from curve matching technique were then used to carry out the interpretation and analysis through the application of a computer software known as WINRESIST. This in turn reduced the over iterated depth obtained in the study area in course of the geophysical survey work.

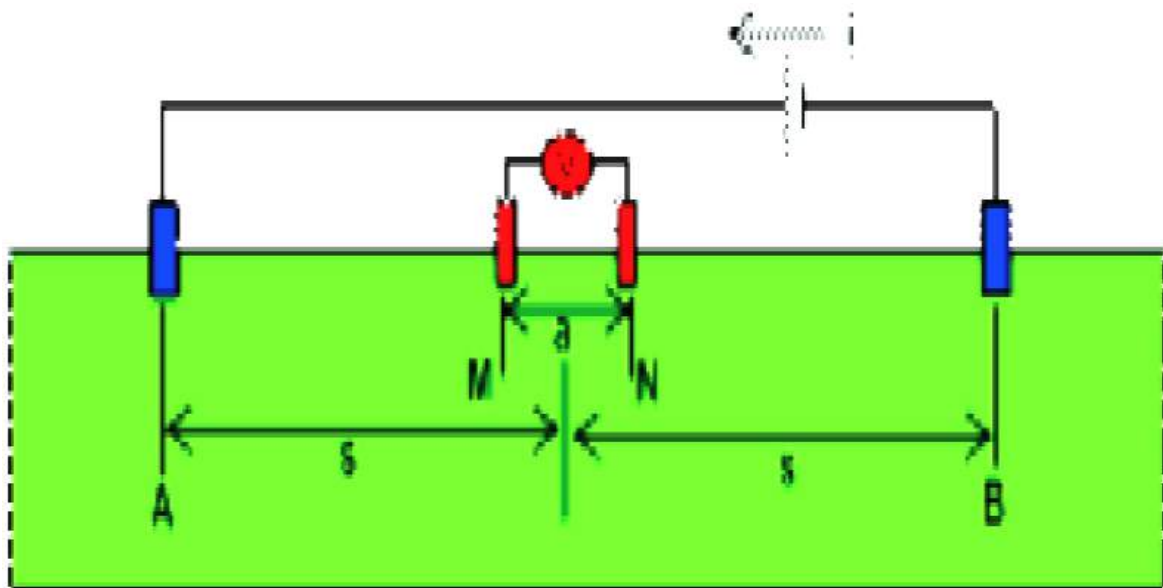


Figure 3.2: A sketch diagram of schlunger array.



Figure 3.3: Showing students carrying out vertical electrical sounding (VES) in the study area

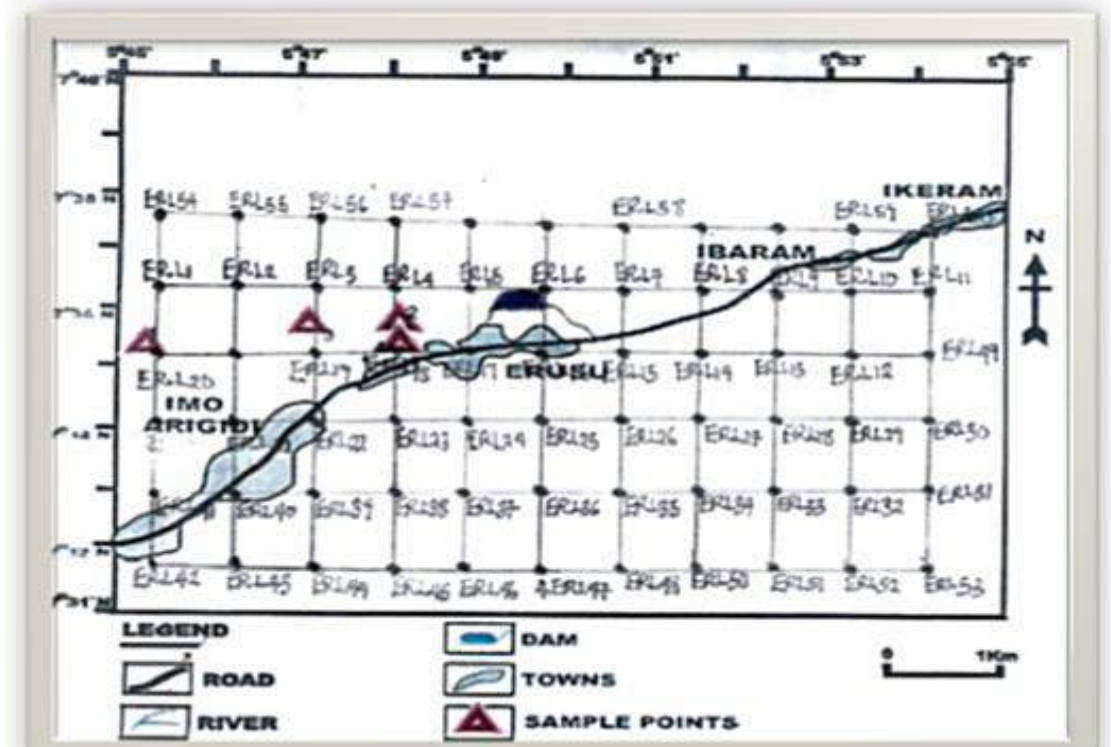


Figure 3:4: Map of the study area showing 50 grid points' square grids and 60 VES points

3.4 Geostatistical Analysis

Geostatistics began in the early 1960's by Matheron and Krige for mineral resource quantification. The concept of geostatistics is a combination of various sciences such as geology, statistics and probability theory (Kapageridis, 1999).

3.4.1. The Kriging Methods of geostatistics

The Kriging method is an advanced geostatistical procedure that generates an estimated surface from a scattered set of points with Z-values. Unlike other interpolation methods, this Kriging tools effectively involves an interactive investigation of the spatial behavior of the phenomenon

represented by true values before selection of the best estimation method for generating the output surface.

The Kriging geostatistical method was used to estimate the volume of the deposits in place. Since Kriging assumes that the distance direction between sample points (figure 3.4) reflects a spatial correlation that can be used to explain variation in the surface.

Kriging was used to fits a mathematical method (functioned to specified radius, in the study area to determine the output value for each location. As Kriging is a multi-stop process, the following steps was carried out in the course of the analysis.

1. Explanatory statistical analysis of the data
2. Variogram modeling
3. Creation of the surface and
4. Exploration of a variance surface

The method was employed in this research work because there was a spatially correlated distance directional bins in the data obtained in the field of study.

The general formula for this Kriging method of geostatistics is formed as weighted sum of data and this is expressed mathematically as stated below.

$$Z \hat{\Sigma}_{(s_0)} = \sum_{i=1}^N \gamma_i z(s_i) \dots \dots \dots (1)$$

Where:

$Z(s_i)$: the measured value at the i th location

(s_0) = An unknown weight for the measured value at the i th location

S_0 = the prediction location

N = the number of measured value

The unknown values were successfully predicted in course of the research work as a result of deployment of Kriging method of geostatistical method. The data obtained in this field was used

twice, to firstly estimate the spatial auto correlation of the data and secondly predicted the unknown values.

The spatial modeling of the structure of the measured points, began with a graph of the empirical semivariogram, computed with the following equation for all pairs of locations separated by distance.

The general formula for computing semivariogram is given as semivariogram ($\hat{\gamma}(h)$)

$$\hat{\gamma}(h) = 0.5 \times \frac{\sum_{i,j} (z_i - z_j)^2}{2n} \dots\dots\dots (2)$$

The above stated formula was used to calculate the difference squared between the values of the period locations. Below are the sampled points in the study area, all the pairs of points in the study area was plotted and the value of which the semivariogram model attained range (the value on the y-axis was estimated as the Sill. A partial Sill is the Sill-minus the nugget.

The nugget effect can be attributed to measured errors or spatial sources of variation at distances smaller than the sampling sources of variation at distances smaller than the sampling interval (or both) .

Finally, the Gaussian model was applied to estimate the volume of the clay deposits in the study area (Erusu-Akoko) because there were spatial auto correlation decreases exponentially with increasing distance. Once each pair of locations was plotted after being binned, a model (Gaussian model) was fitted through them, range, Sill and nugget were used to describe these models.

$$Y(h) = A_0 + w [1 - \exp(-h/r)^2]$$

$$\text{Where } \gamma(h) = 1, h > 0, \gamma(h) = 0, h = 0$$

A_0 is nugget effect caused by possible errors of measurement $A_0 + w$ is Sill, which is the variance of the field less than discontinuity, a is range, or the correlation distance, and is in practice the maximum distance for which observations are correlated.

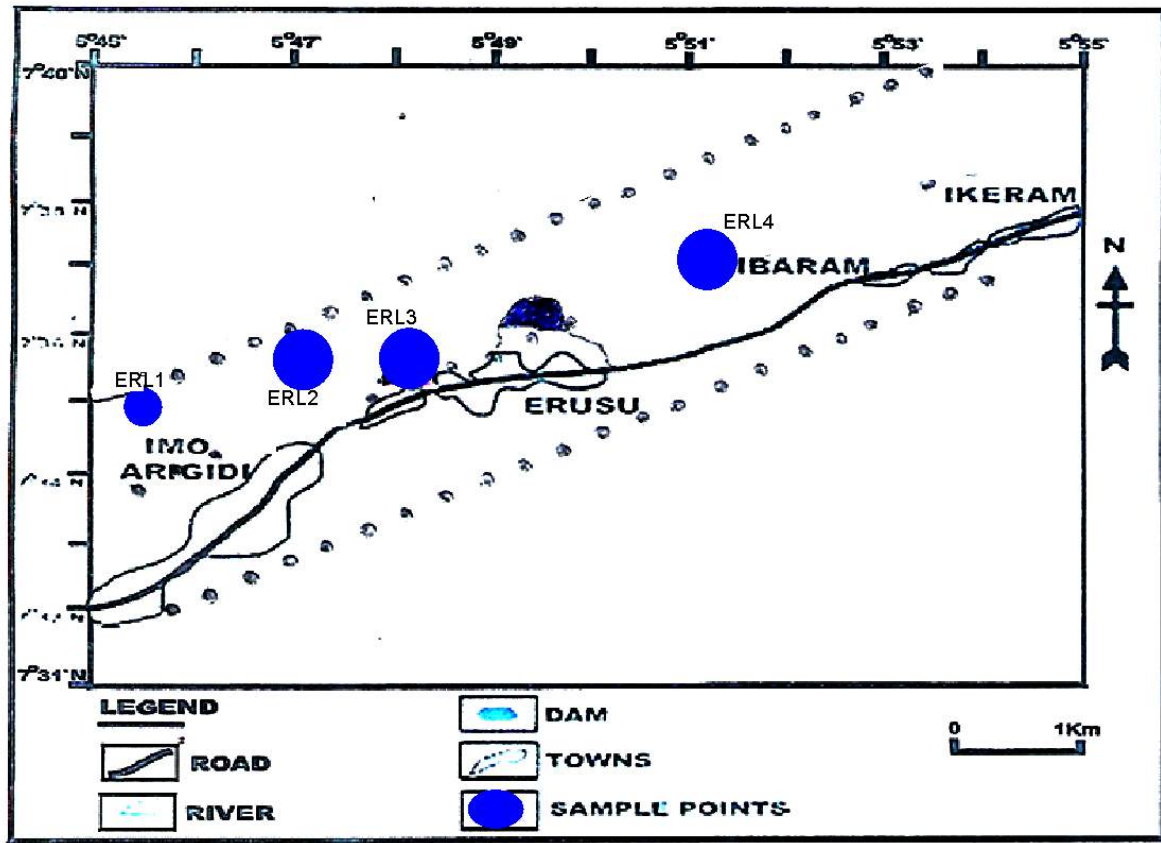


Figure 3.5: Showing unbiased sampling point for Geostatistical analysis in Erusu- Akoko

3.4.2 Estimating the gross tonnage of the clay deposit in the study area.

The gross tonnage of the clay deposits in the study area is estimated using the formula propounded by Metheron (1962) to determine the tonnage of Ore deposits with grades above a specified value.

This formula is expressed mathematically as Gross tonnage (metric tons), = Average gravity x volume of the deposit.

Average volume of the study clay as estimated using Kriging method of geostatistics and electrical resistivity method of geophysics was used to multiply the average specific gravity of the collected four samples from the study area (ERL₁, ERL₂, ERL₃ and ERL₄). The unit of the calculated tonnage of the clay deposits is in metric tons.

CHAPTER FOUR

PRESENTATION, INTERPRETATION, AND DISCUSSION OF RESULTS

4.1 Presentation of Results

The results of the three analysis performed on different samples collected from Erusu-Akoko area, are presented below;

4.1.1 Natural Moisture Content

Table 1 and Figure 4.1 presented the results of the Natural moisture contents of Erusu-Akoko clay deposits. The moisture content for ERL1, ERL2, ERL3 and ERL4 is 13.10 % for ERL1, 13.50 % for ERL2, 22.90 % for ERL3 and 29.50 % for ERL4. The natural moisture content is important in understanding the engineering proportions of soil for construction and industrial use.

The moisture content is a functions of ratio and specific gravities of the clay samples. The high moisture content obtained confirms to the generally accepted high porosity and low permeability properties of clay (Omowumi, 2001). The modified classification of plasticity chart and plotted for the clay sample presented in figure 4.1 and figure 4.2 showed that the soil samples fall above the “A” line within the region of CL [which is inorganic clays of intermediate plasticity, (Texas department of transportation, 1997) stated that soils with liquid limit value less than 35% are grouped as low plasticity while those with values between 35 and 50 are classified as intermediate plasticity] as such the moisture content value of the study clay deposits confirm to the accepted standard by Texas department of transportation (1999) since the range of the moisture contents in the study area falls between 13.10 % - 29.50 % and the average moisture natural contents of the sample is 17.20 % which confirm to the accepted high porosity and low mouldability character is of a clayey materials with a range value of > 30 % for soil good for engineering purposes such as landfills, brick making and construction as stipulated by Omowumi (2001).

Table 1: Some Engineering properties of the clays, (value of natural moisture contents MC), liquid limit (LL), Plastic Limit (PL), Plasticity Index (PI), linear shrinkage (LS) and specific gravity (S.G) of the clay sample.

LOCA- TION	Average % of Particles				Atterberg Limits			Average %		%	PH	% Lost on	(%)	SG
	Gravel	Clay	Silt	Sand	Liquid	Plastic	Plastic					Ignition	Linear	
		(>2m m)	10.063- 2mm)	10.002- 0.063mm)	>0.02 mm	Liquid Limit (%)	Plasticity (%)	Plasticity Index (%)	Moisture	Clay Control				
ERL 1	A	3.3	69.5	16.2	17.1	52.2	21.5	30.7	13.1	73.21	5.24	11.8	8.9	2.71
ERL 2	B	4.4	70.00	12.0	15.2	50.4	18.3	31.9	13.5	70.32	5.32	15.3	8.5	2.39
ERL 3	C	4.9	70.0	18.1	8.0	48.4	22.1	26.3	22.9	69.41	5.61	15.0	8.7	2.70
ERL4	D	4.2	68.7	19.1	10.0	48.3	22.3	26.0	29.5	75.32	4.96	12.05	8.9	2.75

4.1.2 Atterberg Limit

Table 1 contains the summary of the values of the consistency limits while Figure 4.1 shows the Casagrande chart classification of the soil. The plasticity index varies from 26.0 to 31.90 %. The results of the liquid limits is presented in Table 1 as ERL1 has 52.20 %, ERL2 has 50.40 %, ERL3 has 48.40 % and ERL4 has 48.30 %. According to engineering specifications, the liquid limit value less than 30% shows low plasticity between 35 % and 50 % (Rowe *et al.*, 1985).

The range of values of the plastic limits is shown in Table1 as (18.3-22.30 %). This fall within the range of value of intermediate plasticity and compressibility as such plotting in the inorganic clay group of the Casagrande chart. With the plasticity range of (18.30-22.30 %), it is confirmed that the four clay samples from the study area are suitable for ceramic production as presented by Grimshaw (1971) who proposed a range between 10 and 60 % for clay used for ceramic production. The plasticity chart in figure 4.2 and 4.1 shows that the soils belong to the inorganic clay of intermediate plasticity. Three types of clay minerals were confirmed from the plotted modified plasticity chart (montmorillonite, illite and kaolinite). The plots on the charts showed that Kaolin is the predominant clay mineral with 40 % followed by the other two minerals (illite and montmorillonite) with each having 30 % figure 4.3 (Bain,1971).

The range of the plasticity index for the four soil samples is between 26.0% and 31.90% with ERL2 having the highest plasticity index of 31.90% while the ERL4 has the least plasticity index of 26.0%. liquid limit of less than 90 % was recommended for landfill barrier soils by Declan and Paul (2003).

The plot of the plasticity index against the liquid limit on the Casagrande chart (1948) shows that the four samples (ERL1, ERL2, ERL3 and ERL4) plotted within the inorganic clays of medium or intermediate plasticity.

With reference to the soil classification by Bain (1971) Erusu-Akoko clay deposits is considered as a kaolinitic clay deposit. These clays are good materials for landfill liners as they all meet the

engineering requirements of (P.I.>7%) condition.

The results of the liquid limit were more than 20 % but less than 90 %. The result findings of the study clay deposits conform to that of (Benson *et al.*, 1994; Kabir and Taha, 2004) and therefore, the soil in the study area can be recommended as landfill barrier soils.

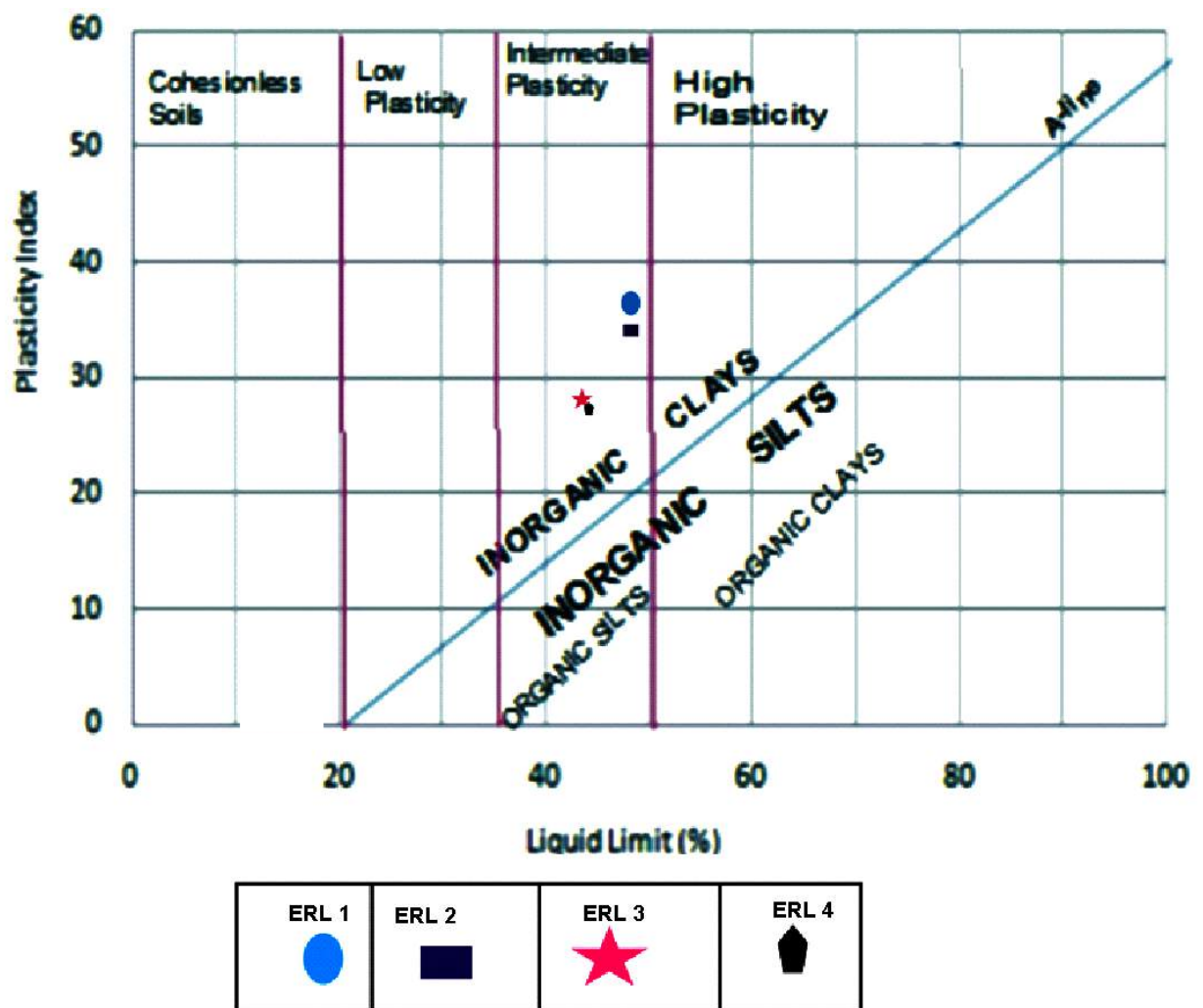


Figure 4.1: Plasticity curve after Casagrande (1978)

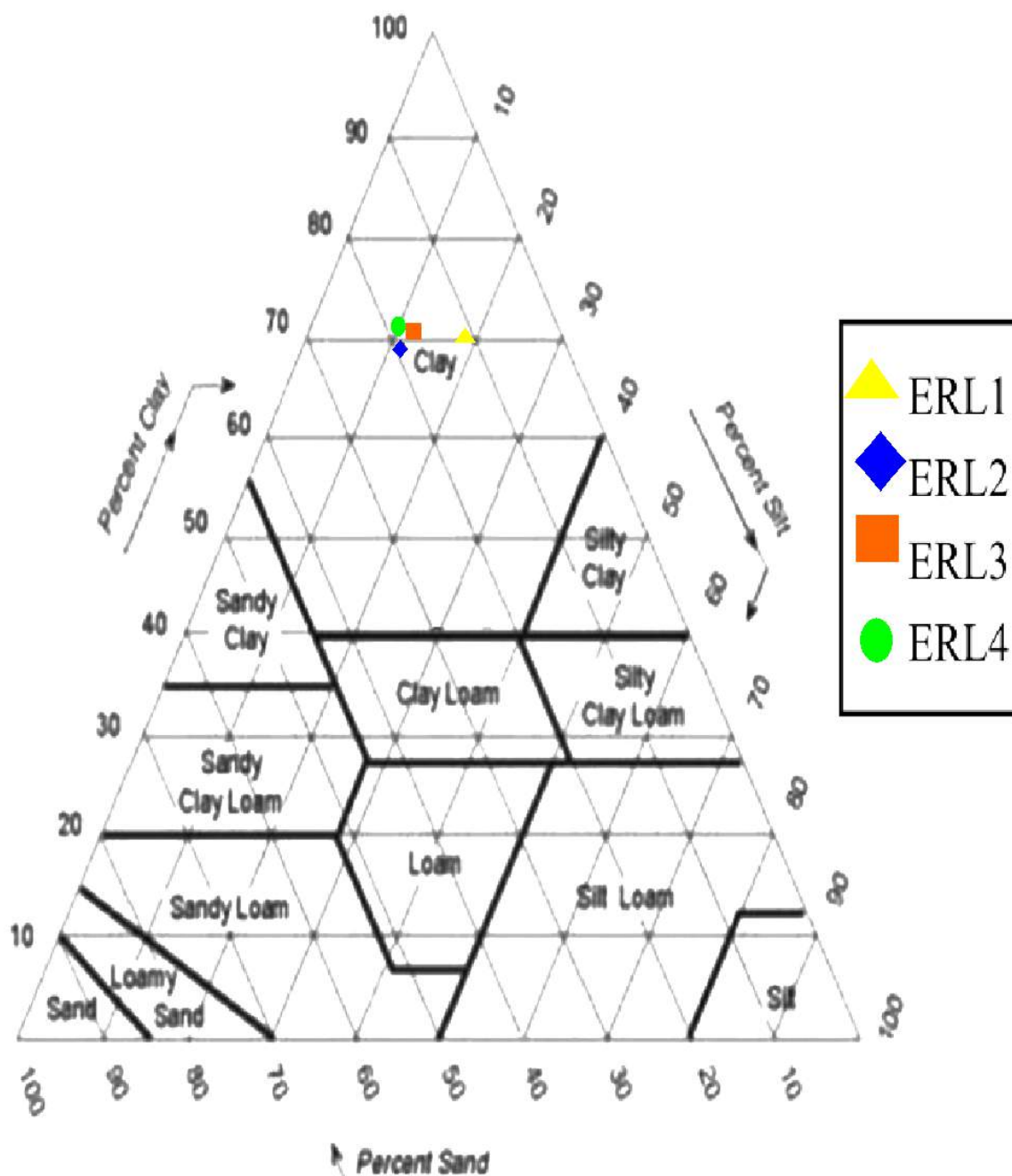


Figure 4.2: Textural classification of clay samples (After Bain, 1971).

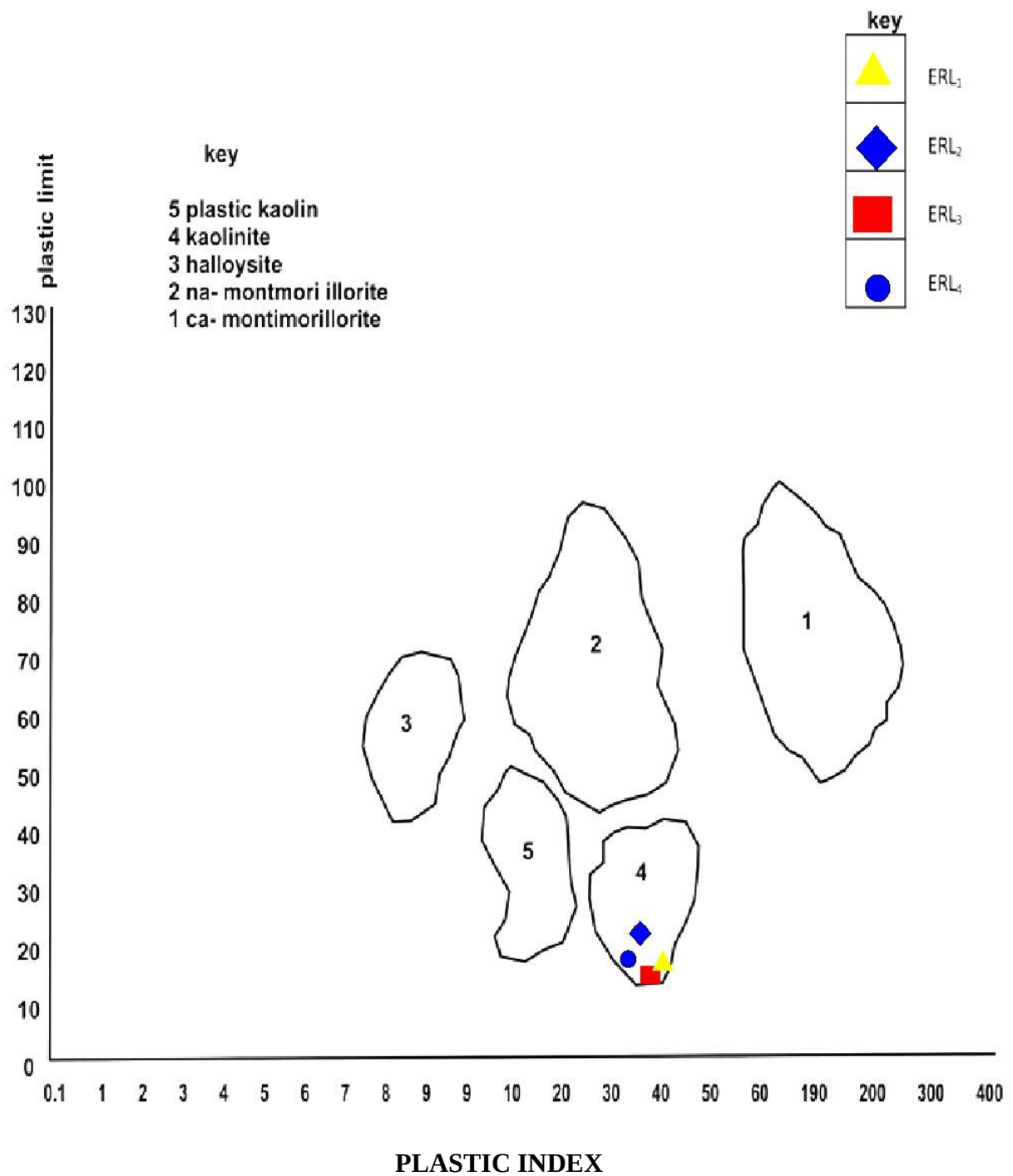


Figure 4.3: Showing classification identification of chart using plastic limit and plastic index as parameter (After Bain, 1971).

4.1.3 Linear Shrinkage and Apparent Porosity

Figure 4.5 and Table 3 present the linear shrinkage and apparent porosity results of the clay bricks from ERL1, ERL2, ERL3 and ERL4 respectively. It is observed that there is a slightly decreased in the linear shrinkages as the firing temperature increased from 900°C to 1200°C. This decrease agrees with a decrease in apparent porosities of the samples. As the firing temperature increases, the moisture (figure 4.4 and table 2) within the bricks changes into vapour and diffuse out of the brick, thereby creating vacant sites within the clay. Clay particles then migrate to occupy the vacant sites. This results in the shrinkage of the clay molecules and collapse of the voids within the brick. At the point of intersection of clay grains, necking occur leading to the fusion of the clay grains. This is termed grain consolidation which leads to the formation of the bonds which increased density (Figure 4.7) of the bricks due to reduced porosities within the volume of the bricks. It was also found that the linear shrinkage was proportional to the plastic index and clay content of the soils and inversely proportional to the shrinkage limit value (Omowumi, 2001). It is also worth noting that soil shrinkage will result in cracks in the soil. The cracks make the soil more permeable to water and may damage geotechnical structures (Stirs, 1954) as such soil with shrinkage value greater than 10 % should not be used for engineering constructions. Such as brick making, dam construction and pottery (Stir, 1954). Since all the shrinkage limits of the study clay deposits are below 10⁰C, the study clay deposits are good for engineering construction such as landfill liners, brick making and pottery.

Table 2: showing percentage of fire linear shrinkage with temperature

S/N	900°C	1000°C	1100°C	1200°C
ERL1	5.0	7.0	8.0	8.5
ERL2	7.0	8.0	8.5	9.5
ERL3	4.0	6.0	7.0	7.5
ERL4	6.0	7.0	7.5	8.0

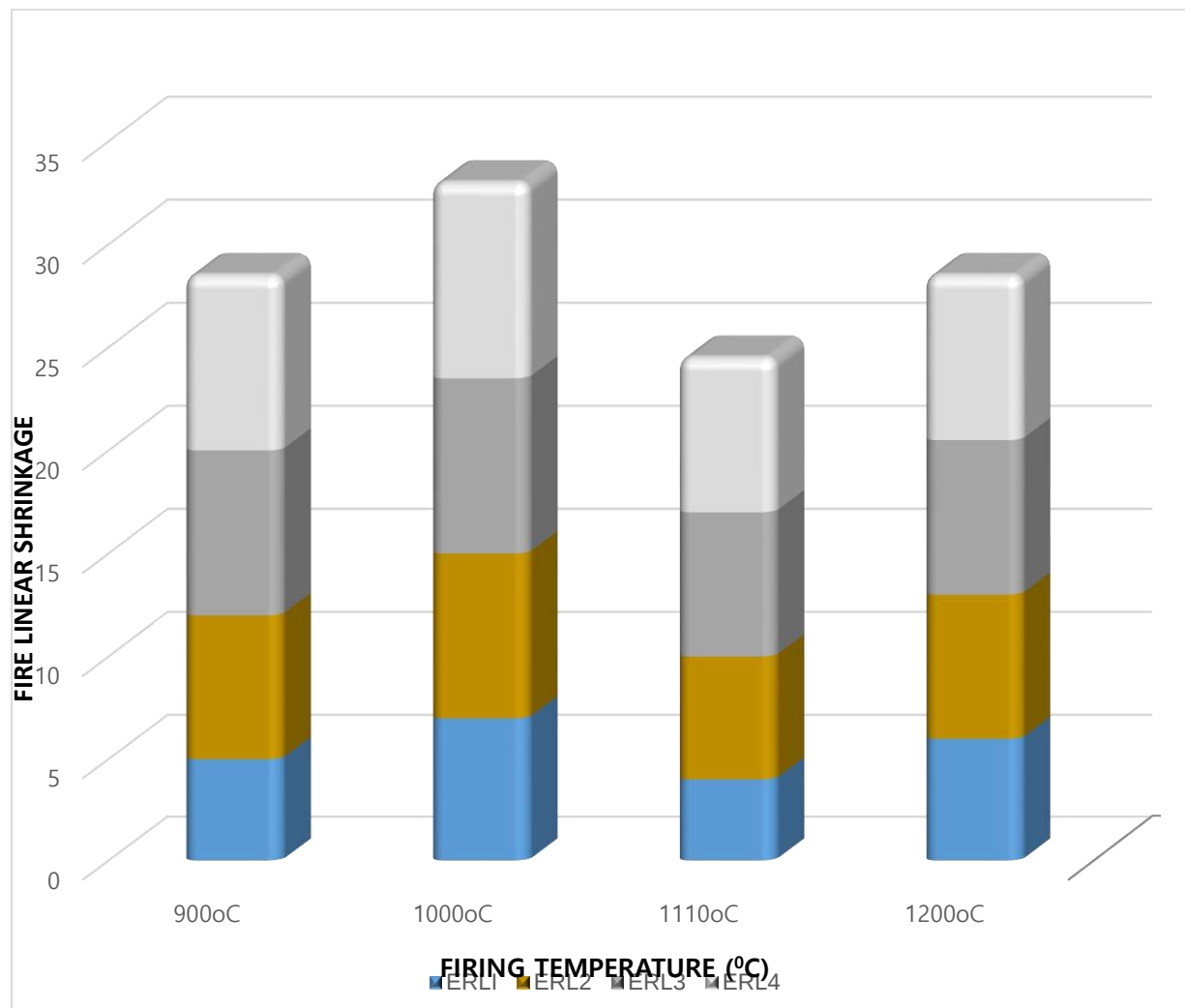


Figure 4.4: Showing percentage of fire linear shrinkage with temperature

4.1.4 Specific Gravity

Table 1 shows the specific gravity of the four samples (ERL1, ERL2, ERL3 and ERL 4) collected from the study area. The specific gravity enables appropriate design of the equipment which are beneficiary to the removal of the non-clay fractions. The specific gravity of the four samples fall within the range of 2.39-2.75. Sample ERL1 has 2.71, ER l2 has 2.39 with the minimum value, ERL 3 has 2.70 and ER l4 has the maximum value with 2.75.

Roy and Dass (2012) stipulated that the increase in specific gravity lead to an increase in the shear strength of the sub-grade materials which is used in constructional work such as road construction. Since the specific gravity of the four soil samples fall within the standardized engineering range of 2.73 was specified by Roy (2012), hence, the four clay samples collected from the study area can be used for constructional works such as road construction and liners in Sanitary landfill (Omowumi, 2001).

4.1.5 Water Absorption

The water absorption capacity reduces as the particles shrink together and hence, porosity decreases. Figure 4.5 and Table 4, shows that the water absorption decreases with apparent porosity. The average percentage of the water absorption capacity of the fired disc (figure 4.5) at 900°C, 1000°C, 1100°C and 1200°C range from 13.39-16.0 %, 9.95-14.67 %, 7.75-12.38 % and 5.36-10.42 % respectively. This reveals that consistency decrease with increase in temperature. Since the water absorption properties of the collected clay samples directly depend on the specific gravity of the soil therefore, the four clay samples are good for brick making and ceramic works (Aniyi and Adewara, 1986).

Table3:Showing percentage of water absorption of the clay with temperature

S/N	900°C	1000°C	1100°C	1200°C
ERL1	16.0	14.67	12.38	10.42
ERL2	14.64	13.36	12.21	7.85
ERL3	13.89	11.29	11.40	6.45
ERL4	11.29	9.95	7.75	5.36

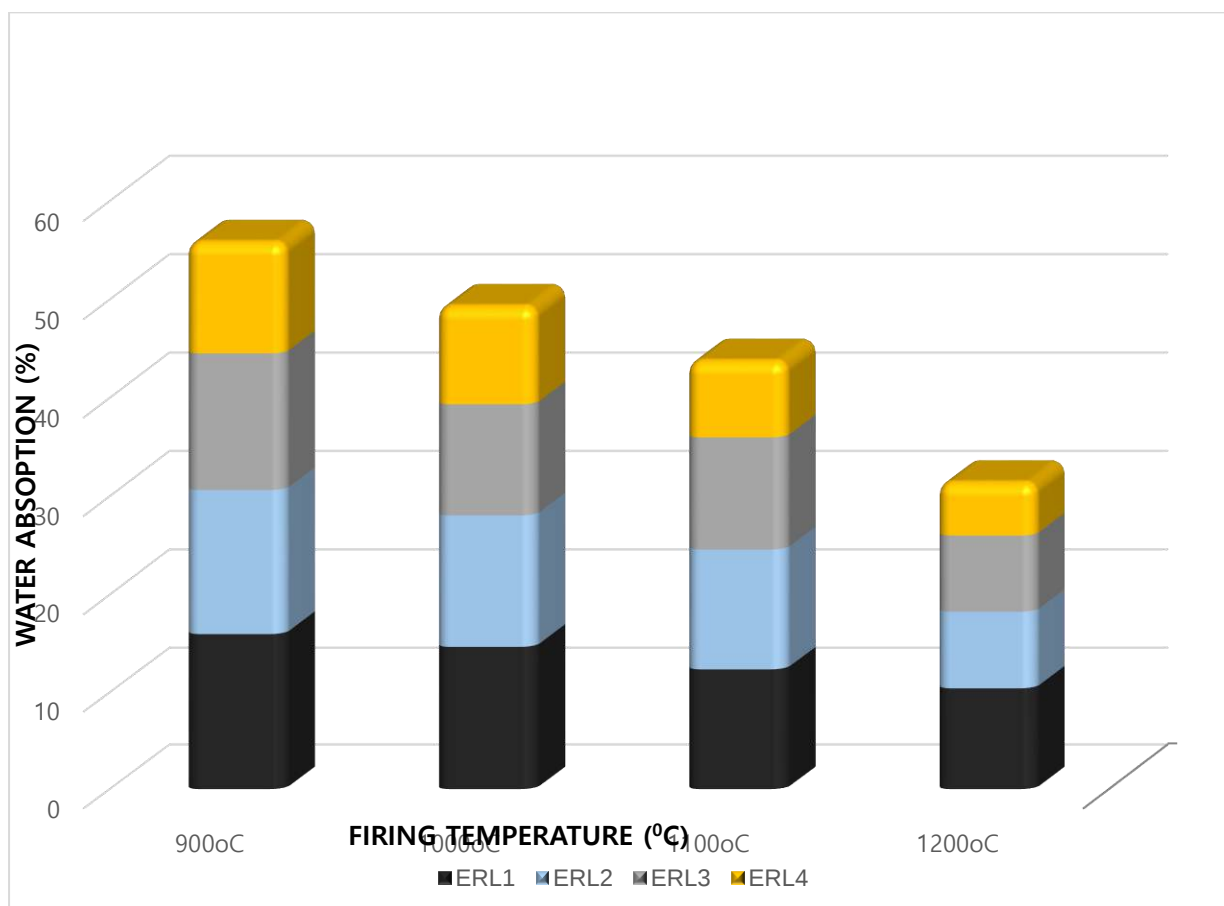


Figure 4.5: Showing water absorption of the clay with temperature

4.1.6 Modulus of Rupture (PSI)

Figure 4.7 and Table 5, shows the modulus of rupture obtained from the samples collected from the study area. The modulus of rupture of the clay sample at 900°C, 1000°C, 1100°C and 1200°C ranges from (219.6-364 PSI for ERL1), (352.94-430.10 PSI for ERL2), (480.71-580.64 PSI for ERL3) and (732.30-840.06 PSI for ERL4) respectively. It can be seen in Figure 4.7 that the modulus of rupture of the four clay samples collected from the study area increased with increased in temperature. The liquid increased in amount and upon cooling, solidifies to form glass at a temperature above 1000oc and thereby acting as a cementing materials holding the masses together. Clew *et al.*, (1969) propounded a range of 200-700 PSI for a clayey material to be used as refractories and for blast furnaces. Since the values obtained conformed to this specification, hence, the four soil from Erusu-Akoko can be used as raw materials for blast furnace and as refractories (Hassan *et al.*, 1993).

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Table 4: Showing percentage of modulus of rupture (PSI)

S/N	900°C	1000°C	1100°C	1200°C
ERL1	364.00	423.54	480.91	800.62
ERL2	340.20	430.10	500.40	840.06
ERL3	219.60	391.30	482.29	732.30
ERL4	325.62	352.94	580.64	800.21

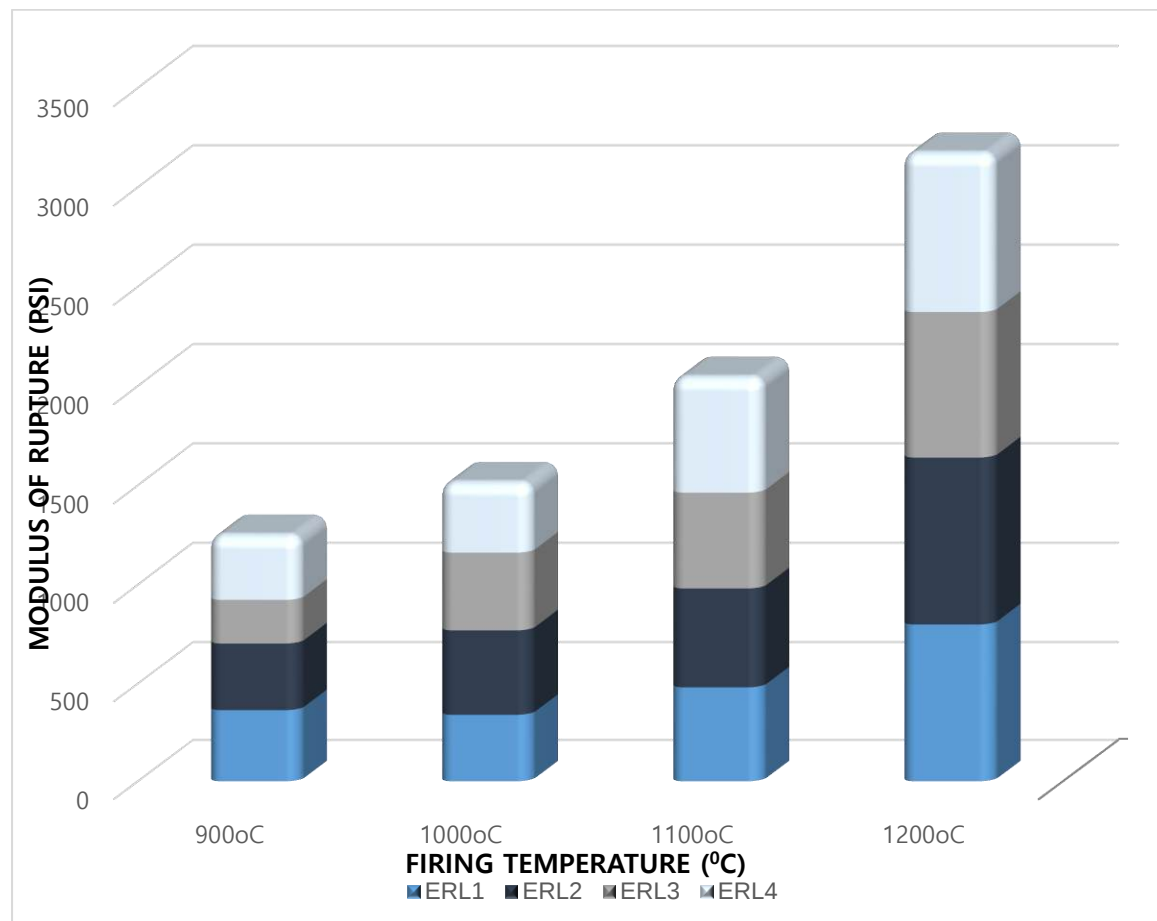


Figure4.6: Showing modulus of rupture with firing temperature

4.1.7 Clay Content

The clay contents observed in the sample collected from the study area that has the least amount of clay particles portrayed the highest percentage of clay particles table 1. This clay content value fall between 69.41 and 75.32 %. Interestingly, the Erusu-Akoko (ERL₄) sample that has the least amount of clay size particles has the highest percentage of clay (Table 1). However the percentage is less than 88.25 % which is the amounts of fines % of clay and silt size particles. Implicitly, this revealed that some of the clay size particles are silts. The appreciable clay content in the samples rather than silts favours easy mouldability and high plasticity (Aniyi and Adewara, 1986).

4.1.8 Porosity and Bulk Density

Figure 4.6 and Table 6, displayed the porosities and bulk densities of the fired bricks produced from clay obtained from Erusu-Akoko (ERL₁, ERL₂, ERL₃ and ERL₄). It is observed that the Porosities vary with the bulk densities. Clay bricks from site ERL₁ has percentage Porosities ranging from 32.02 to 40.36 %, ERL₂ has 18.32 to 30.34 %, ERL₃ has 28.94 to 40.46 % and that from ERL₄ has a Porosities range from 27.30 to 32.64 %. Their respective average bulk densities vary from 1.38 g/cm³ to 2.93 g/cm³. The porosity value of the brick samples from ERL₁, ERL₂, ERL₃ and ERL₄ are in line with recommended standard range (10 to 40.50 %) for fired clay refractory by Hassan *et al.*, (2015). In addition, the bulk densities fall approximately within the range of 1.2-2.4 g/cm³ for dense fire bricks (Apeh *et al.*, 2011)

Table 5: Showing percentage of bulk density of the clay with increasing firing temperature

S/N	900°C	1000°C	1100°C	1200°C
ERL1	1.38	1.50	2.67	2.75
ERL2	1.42	1.60	2.53	2.67
ERL3	1.40	1.80	2.00	2.84
ERL4	1.60	1.72	1.90	2.93

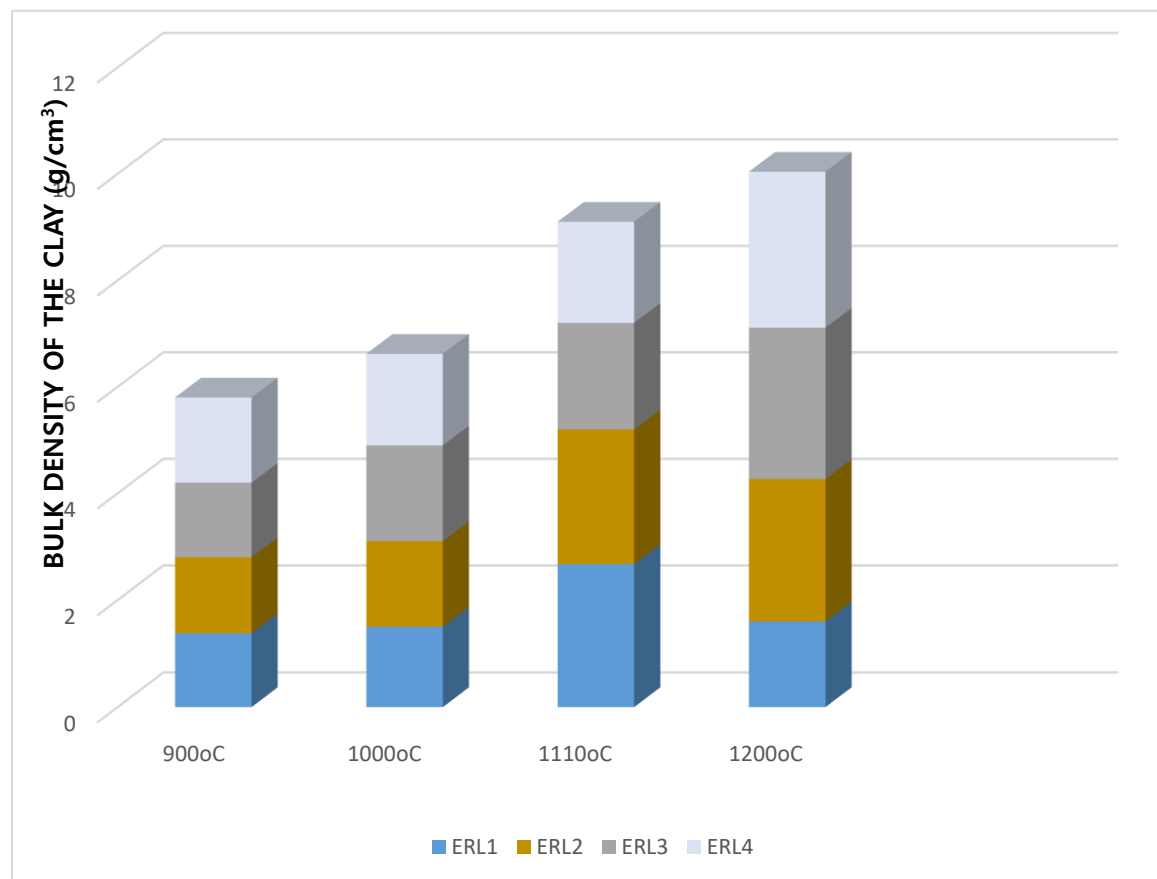


Figure 4. 7: Showing the bulk density of the clay with increasing fire temperature.

4.1.9 Particle Size Distribution

The grading curves for the soil samples in the study area are presented in Figure 4.8 while Table 7 shows the different particle sizes obtained from the four samples (ERL1, ERL2, ERL3 and ERL4). The generally high amounts of fine fractions (about 69.50 %-70.0 %) are typical of fine grained soil. The value of the clay particle observed in each of the samples is given as ERL1 (69.5%) of the clay materials, ERL2 (70.0 %), ERL3 (70.0 %) and ERL4 (68.70 %) while the percentage of sand in the samples is given as ERL1 (16.20 %), ERL2 (12.00%), ERL3 (18.10%) and ERL4 (19.10 %). The percentage of silt in the samples is given as (ERL1 (3.3 %), ERL2 (4.4%), ERL3 (4.7 %) and ERL4 (4.2 %)). The gravel percentage of the clay samples are relatively low with ERL1 having (2.2 %), ERL2 has (1.18 %), ERL3 has (2.15 %) and ERL4 has (1.43%). Rowel *et. al.*, (1999) stipulated amount of fines of at least 30% for good liners for landfills. The amount of silty size fraction (about 12 % to 18 %) are not too different from the minimum stipulated value of 15%. These values are relatively high and good for their mouldability and plasticity (Omowumi, 2001). It is established that the four clay samples collected from the study area are well-graded and poorly sorted. According to the Unified Classification System (USCS), only soil samples plotted within percentage of silt and clay at (60% and 5%) are usually described as well-graded clayey sand or gravel. According to engineering specification, any soil with 15.35% sand, will display high clay content, low silt and low sand content, will possess low permeability which is an important property required for the construction of sanitary landfill liner (Rowe *et al.*, 1999).

Table 6 showing the percentage of grain size analysis

Sample	Percentage passing (%)										
	Sieve size (mm)										
	5.00	3.250	2.360	2.00	1.80	0.85	0.600	0.45	0.300	0.150	0.075
ERL 1	99.13	97.68	96.00	95.30	90.21	86.19	80.62	80.47	7.70	60.77	50.79
ERL 2	99.83	99.50	97.62	97.09	94.00	91.34	86.39	70.03	61.92	50.39	40.62
ERL3	97.30	98.0	96.10	95.70	92.00	87.29	83.61	60.27	56.89	48.07	39.63
ERL 4	96.96	97.52	97.50	94.10	90.21	94.09	91.20	82.60	81.57	70.00	55.01

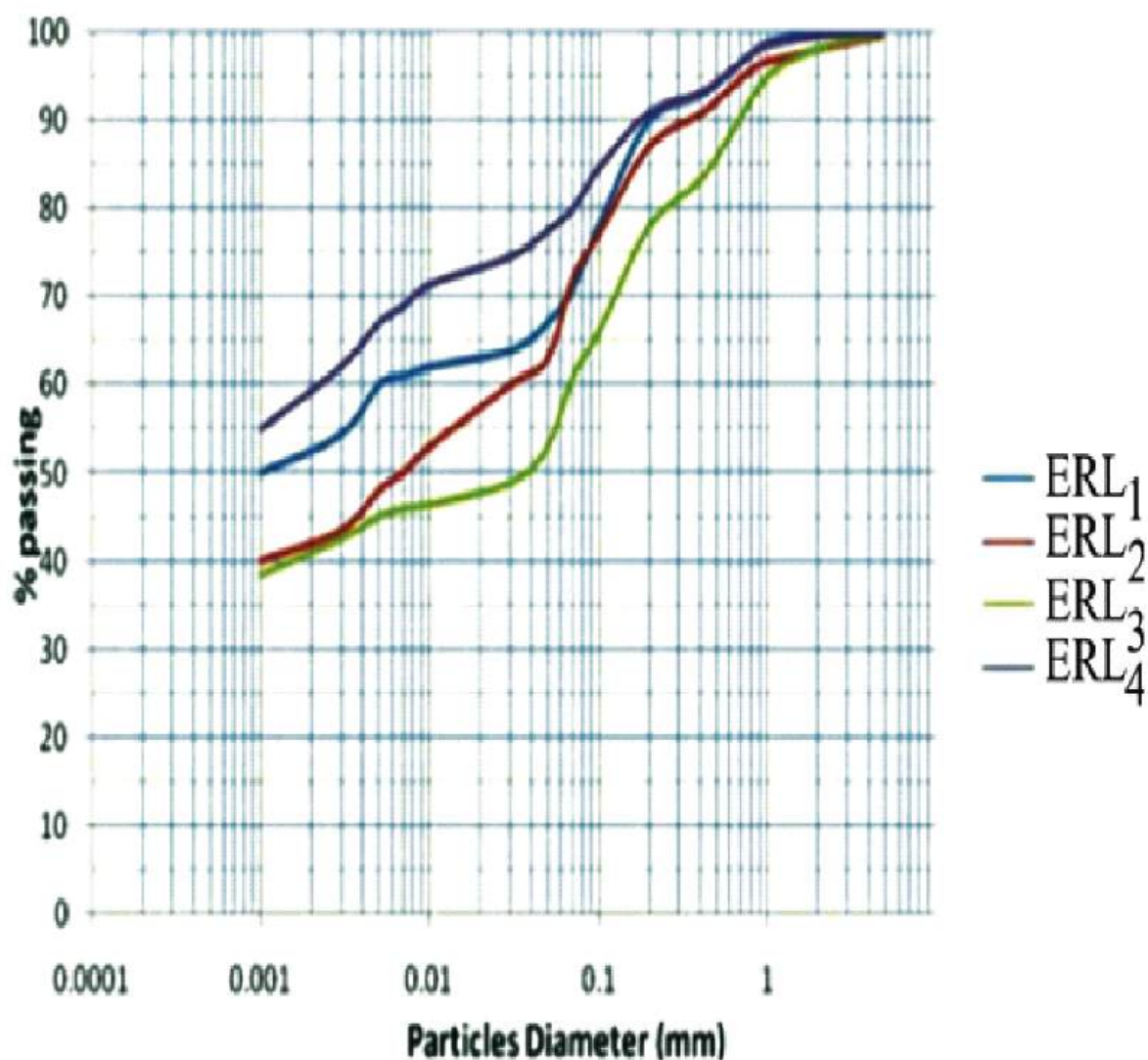


Figure 4.8: Showing the grading curve of the samples

4.1.10 California Bearing Ratio

Table 7 shows California bearing ratio for the soaked values in Erusu-Akoko as ERL1 having 24%, ERL2 having 13.0%, ERL3 having 33.0% and ERL4 having 20.0% respectively. In the same vein, the values for the California Bearing ratio for the unsoaked values are as follows; ERL1 has 50%, ERL2 has 48%, ERL3 has 47% and ERL4 has 35% respectively. The analyzed samples from the study area have the required 40 % unsoaked and 15% soaked CBR values recommended for highway sub-based and sub-grade soils by Federal Ministry of Works and Housing, specification for roads and bridges. The study clay deposits showed decrees in CBR value after soaking. The soaked CBR meets minimum required CBR standard of 15 % for sub-base courses and the road sub-base, there is a reduction in strength as a result soaking of the compacted clay samples (Hassan *et al.*, 2015). Based on this, the study sub can be classified as having good CBR and can be used a sub-grade and sub-fill materials as well as foundation liner materials as stated by Omowumi (2001).

Table7: Showing unsoaked and soaked CBR

N/S	UNSOAKED CBR			SOAKED CBR		
SAMPLE NO	BEARING VALUE AT 2.5 MM(os)	BEARING VALUE AT 2.5MM (%)	ACCEPTED CBR BY Hassan et al. (1993).	BEARING VALUE AT 2.5MM (%)	BEARING VALUE AT 2.5MM (%)	ACCEPTED CBR (%)
ERL1	50	45	60	24	21	24
ERL2	43	43	53	13	16	16
ERL3	47	46	57	23	19	23
ERL4	35	38	43	20	17	18

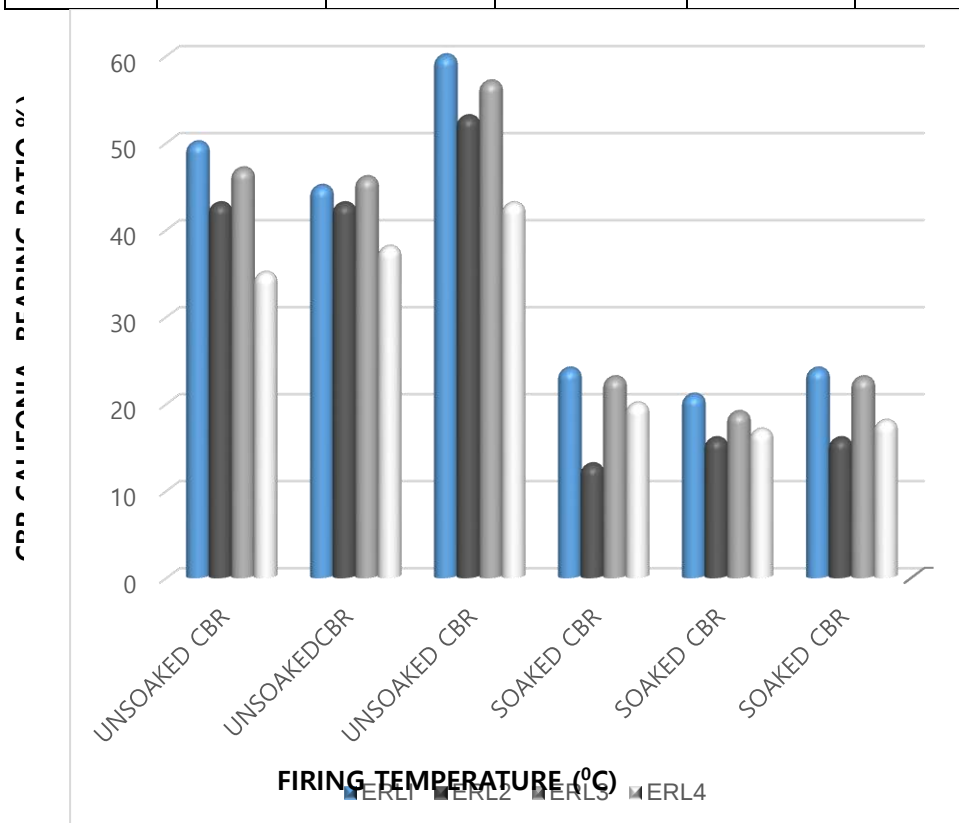


Figure 4.9: Showing CBR of soaked and unsoaked value in the study.

4.1.11 Unconfined Compressive Strength

Figure 4.10 and table 8 show the result of unconfined compressive strength test (UCS). The shear strength was determined by the peak pressure from the unconfined compressive strength (UCS) test after all the samples were cured. The cold crushing strength of the collected clay samples from the four locations in the study area ERL1 (432 kg/cm³), ERL2 (493 kg/cm³), ERL3 (500 kg/cm³ and ERL4 452 kg/cm³ respectively. However, the UCS of the bricks obtained at 1200°C for ERL1, ERL2, ERL3 and ERL4 are 360 kpa, 130 kpa, 120kpa and 110 kpa for the incured UCS while 420 kpa, 373kpa, 400 kpa and 410 kpa for the cure UCS respectively. The high UCS recorded for the four clay bricks could be due to the high percentage of fine fractions filling void spaces and the interlocking of the coarse clay materials hence, reducing the compressibility, porosity and deformation and thus increasing the shear strength of the clay deposits. The UCS of the study clay samples conformed to the stipulated range of 100 kpa for strength at peak and soil used as liners for landfill (Hassan *et al.*, 2015). Since the cold crushing strength is a useful indicator of any soil to be used as a refractories and the cold crushing strength of the study clay samples conformed to the stipulated range of 100 kpa proposed by Omowumi (2001) for any soil to be used as a refractory as such the clay deposit can be used as refractory and constructional works such as dam embankment, and liners and landfills and brick making as they pour within the range of 100 kpa to 110 kpa which is the minimum standard of soil used for constructional purposes (Hassan , 2015).

Table 8 : Showing unconfined compressive strength of the clay.

	UNCOFINED COMPRESSIVE STRENGTH	
SAMPLE NO	UNCURED (Kpa)	CURED (kpa)
ERL1	360	420
ERL2	130	373
ERL3	120	400
ERL4	110	410

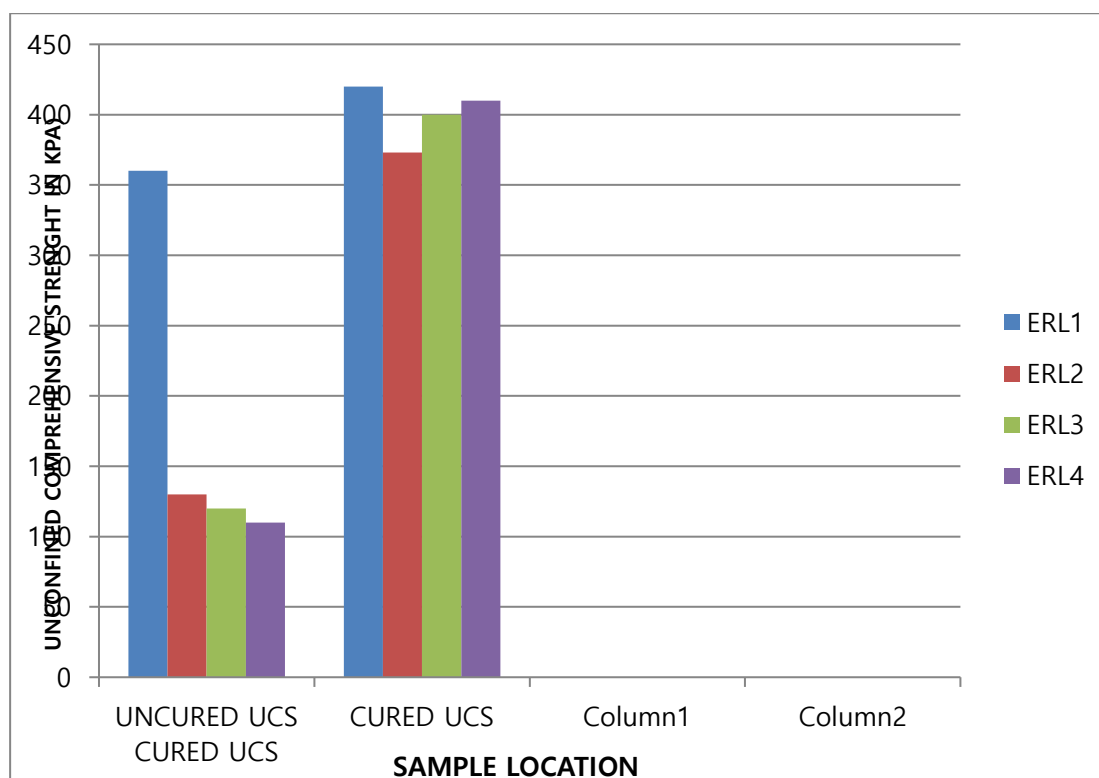


Figure 4.10: Showing cured and uncured compressive strength

4.1.12 Firing Test and Thermal Shock Resistance (TSR)

Figure 4.11 shows that the firing temperatures of the four bricks collected from the study area (ERL1, ERL2, ERL3 and ERL4). The temperature range is between 1250⁰c and 1500⁰c. This temperature is an indication of moderate refractoriness because the normal range for a fire clay brick is 1580 %-1750 % as recommended by engineering specification Aniyi and Adewara, (1986). These high values of refractoriness could be as a result of presence of silica content of a very high percentage. Therefore, the four clay samples will be suitable to be used to processing materials since the melting points do not exceed 1500⁰c. The presence of ferric oxide may either discolour or enhance the beauty of the fired product depending on whether a yellow or red material is desired. The presence of ferric oxide (Fe₂O₃) imparted a reddish- brown colour on the discs at a temperature of 950-1450 ⁰C as shown in Figure 4.11. The presence of Ferric oxide in the four clay samples collected from the study area further justify the existence of high reddish- colouration being observed in the Four samples after firing. in view of this, the four soil samples are suitable for dwindling of contaminants in engineering landfills, as indicated in Table6, sample ERL1, ERL2, ERL3 and ERL4 can be classified as Clayey soil. The four samples are within the stipulated standard range of previous work Abolarin *et al.*, (2004). As such Sample ERL1, ERL2, ERL3 and ERL4 can be used as landfill liners.

Showing Colour change of clay samples before (erl1, erl2, erl3, erl4) after firing, (ERL1, ERL2, ERL3, ERL4)

The results of the thermal shock test (table 9) conducted in the four clay samples collected from the study area indicated that the samples could withstand study changes in the temperature since the sample survived plus 29 cycles without any cracks by standard, fire clays are expected to survived 20-30 cycles (Rowe *et al.*, 1995; Omowumi 2001; Chester, 1993). However, Hassan (1990) classified TSR excellent (>30 cycles), good (25-30 cycles), fair (12 to 20 cycles, acceptable (10 – 15 cycles) and very poor (< 10 cycles) by this classification the clay samples

thermal resistance shock values were therefore within the “good class” range as such the clay deposit are suitable for the production of fire breaks for thermal application.

Table 9: Showing Thermal Resistance Shock (TRS)

N/S	LOCATION	TSR (CYCLE)
1	ERL1	35
2	ERL2	40
3	ERL3	38
4	ERL4	42



Figure 4.11: Colour change of clay samples before (erl1, erl2, erl3, erl4) after firing, (ERL1, ERL2, ERL3, ERL4)

4.1.13 Permeability and Hydraulic Conductivity

The amount, distribution and movement of water have an important role in the proportion and behavior of soil. Data from field permeability test are needed in the design of various engineering works, such as cut off wall design of earth dams, to ascertain pumping capacity. The range of

value of the study clay deposits permeability are ERL1 0.000017 cm/s, ERL2 0.000015 cm/s, ERL3 0.00017cm/s and ERL4 0.0000015 cm/s (table 11) (Allen, 2008), stipulated a range of 0.00000160 0.00000001 for geology materials soil to be used as barrier soil in landfill soil can used as a barrier soils equal or less than 1×10^{-7} cm/s meets the criteria for landfills liners (Adediran *et al.*, 1989), as such the study clay deposits are good for landfill liners since the permeability of the collected samples are greater than 1×10^{-7} cm/s.

Table 9 shows the hydraulic conductivity of the four clay samples collected from the study area. The hydraulic conductivities of the four clays are ERL1, ERL2, ERL3 and ERL4 (Respectively) (table 10).

The low hydraulic conductivity value of the study clay deposits could be attributed to its high clay and silt size contents, between the course particles, thus, causing a reduction in the sizes controlling the follow and also, causing a reduction in the hydraulic conductivities of the four clay samples. Since the hydraulic conductivity of the four clay samples confirm to the required standard of 10^{-7} cm/s less stipulated for clay base liner materials (Ghana Landfills Guideline 2002) as such the four samples can serve as a liner in landfill.

Table 10: Hydraulic conductivity of the soils

Sample No	Effective size (D10) (cm)	Effective Size (D30) (cm)	Effective size (D60) (cm)	K (cm/sec)	Soil type
ERL 1	0.0007	0.03	0.19	1.7×10^{-5}	Clay
ERL 2	0.0008	0.01	0.290	1.5×10^{-5}	Clay
ERL 3	0.0009	0.05	0.212	1.7×10^{-5}	Clay
ERL4	0.0009	0.06	0.213	1.7×10^{-5}	Clay

Table 11: Permeability standard in relation to soil types

SOIL TYPE	K (CM/SEC)	(FT/MM)
Clean gravel	1.0 – 100	2.0 – 200
Coarse sand	1.0 – 0.01	2.0 – 002
Fine sand	0.01- 0.001	0.01 – 0.002
Silty	0.001 – 0000	0.002 – 0.00002
Clay	Less than 0.000001	Less than 0.000002

4.1.14 Compaction

According to AASHTO classification of the soils, all the soil samples have excellent to good ratings of A-1-a to A-2-7 compaction type. The values of Maximum Dry Density (MDD) for samples ERL₁, ERL₂, ERL₃ and ERL₄ are 1.99 kg/m³, 1.89 kg/m³, 1.94 kg/m³ and 1.97 kg/m³ respectively as shown in Table 11. The corresponding Optimum Moisture Content (OMC) of samples ERL₁, ERL₂, ERL₃ and ERL₄ are 11.8 %, 15.3 %, 13.0 % and 12.05 % respectively. The geotechnical properties of the soils are enhanced generally by elevated level of compaction of the soil, thereby achieving the preferred degree of relative compaction required to meet particular properties of soil (Omowumi, 2001). MDD greater than 1.45g/cm³ for basement rocks derived soils according to Kabiret.al., (2004), can be used for landfill liners, therefore all the four soil samples with MDD (figure 10) greater than 1.7g/cm³ meets compaction test prerequisite making them suitable for liners in landfills. Also (Madalor, 2006) recommended a minimum MDD of 1650 kg/m³ or bungalow bricks, indicating that the examined clays are suitable for good brick making materials.

Table 12: Summary of the compaction (ASHTO) Type of compaction

Location	Optimum moisture content (%)	Maximum dry density (kg/m ³)
ERL 1	11.8	1.998
ERL 2	15.3	1.898
ERL 3	13.0	1.942
ERL4	12.05	1.9661

4.2 Extraction of Clay Thickness From Geophysics

4.2.1 Data Presentation and Interpretation

The field data collected from the study area was interpreted quantitatively and qualitatively. The quantitative results of this study area presented as depth sounding curves, bar chart, tables (Table 13) and geo-electric sections. Table 14 shows the summary of results obtained from the resistivity data in the study area while the pictorial statistical analysis of the result is presented in figures, curve types identified in the study area were H, HA, HK, KH, QH, QK, AKH, HKH, HKH, QKH, QHA and KHA (table 13).

Table 13: showing percentage of curve types in the study area

CURVE TYPE	FREQUENCY	PERCENTAGE (%)
H	4	6.7
Q	1	1.7
HA	7	11.7
HK	4	6.7
KH	7	11.7
QH	29	48.1
QK	1	1.7
AKH	2	3.3
HKA	3	5
QHA	1	1.7
KHA	1	1.7

Table 14: Showing Clay Resistivity and thickness obtained from the Vertical Electrical Sounding (VES)

S/ VES N	STATION	RESISTIVITY (ohm-M)	THICKNESS (M)	INFERRED LATITUDE LITHOLOGY		LONG- TITUDE
1.	ER1	611.5	11.3	Lateritic Clay	7°36'30.10"	5°45'56.42"
2.	ER2	693.8	7.6	Lateritic Clay	7°36'3.18"	5°46'57.32"
3.	ER3	661.5	7.8	Lateritic Clay	07°3'30.18"	5°47'40.36"
4.	ER4	407.3	10.0	Lateritic Clay	07°3'30.22"	5°48'10.32"
5.	ER5	452.2	4.6	Lateritic Clay	7°36'30.62"	5°49'20.48"
6.	ER6	-	-	-	7°36'30.30"	5°49'59.71"
7.	ER7	-	-	-	7°36'30.11"	5°15'30.34"
8.	ER8	39.3	7.2	Clay	7°36'30.41"	5°51'59.42"
9.	ER9	23.1	9.8	Clay	7°36'30.26"	5°52'10.34"
10.	ER10	15.3	9.9	Clay	7°36'30.14"	5°53'40.42"
11.	ER11	31.6	6.3	Clay	7°36'30.42"	5°53'10.62"
12.	ER12	29.7	9.9	Clay	7°36'20.44"	5°53'40.48"
13.	ER13	20.65	19.0	Clay	7°35'20.22"	5°52'30.42"
14.	ER14	26.0	6.2	Clay	7°35'20.26"	5°50'30.23"
15.	ER15	44.75	9.0	Clay	7°38'20.29"	5°50'30.24"
16.	ER16	24.0	10.9	Clay	7°35'20.21"	5°48'35.4"
17.	ER17	16.8	9.3	Clay	7°35'20.21"	5°47'35.1"
18.	ER18	14.8	7.5	Clay	7°35'20.62"	5°47'5.11"
19.	ER19	11.9	16.3	Clay	7°35'20.20"	5°47'15.00"
20.	ER20	11.4	6.1	Clay	7°35'20.00"	5°45'30.00"
21.	ER21	18.2	9.5	Clay	7°34'10.00"	5°46'20.00"
22.	ER22	18.9	7.8	Clay	7°34'10.00"	5°47'30.00"
23.	ER23	9.4	4.1	Clay	7°34'10.00"	5°48'10.00"
24.	ER24	12.0	11.4	Clay	7°34'10.00"	5°49'10.00"
25.	ER25	13.9	10.2	Clay	7°34'10.00"	5°50'60.41"
26.	ER26	10.8	16.5	Clay	7°34'10.18"	5°30'55.28"
27.	ER27	12.4	6.7	Clay	7°34'10.11"	5°54'30.01"
28.	ER28	112	8.3	Sandy Clay	7°34'10.11"	5°52'30.10"
29.	ER29	12.0	9.8	Clay	7°34'10.24"	5°53'4.11"
30.	ER30	12.7	9.8	Clay	7°34'10.31"	5°54'30.01"
31.	ER31	46.5	2.5	Clay	7°33'00.32"	5°54'30.11"
32.	ER32	18.2	14.2	Clay	7°33'00.88"	5°53'20.06"
33.	ER33	53.2	4.9	Clay	7°33'00.17"	5°52'30.15"
34.	ER34	26.5	9.5	Clay	7°33'00.22"	5°51'35.08"
35.	ER35	147	5.3	Sandy Clay	7°33'00.12"	5°50'38.41"
36.	ER36	16.4	11.9	Clay	7°33'00.22"	5°49'44.30"
37.	ER37	12.3	20.1	Clay	7°33'58.51"	5°48'46.96"
38.	ER38	12.4	9.9	Clay	7°34'59.20"	5°49'47.50"
39.	ER39	12.2	12.3	Clay	7°33'00.00"	5°46'20.00"
40.	ER40	17.7	11.8	Clay	7°33'00.00"	5°45'20.00"
41.	ER41	62.5	3.6	Clay	7°31'55.00"	5°45'30.00"

42.	ER42	130.7	3.1	Sandy Clay	7 ⁰ .31'55.00"	5 ⁰ .46'20.00"
43.	ER43	42.5	3.8	Clay	7 ⁰ .31'56.00"	5 ⁰ .46'20.00"
44.	ER44	13.8	9.2	Clay	7 ⁰ .31'55.00"	5 ⁰ .47'30.00"
45.	ER45	14.1	14.1	Clay	7 ⁰ .31'55.00"	5 ⁰ .46'10.00"
46.	ER46	11.4	12.9	Clay	7 ⁰ .31'55.00"	5 ⁰ .49'10.00"
47.	ER47	44.6	3.5	Clay	7 ⁰ .31'55.00"	5 ⁰ .49'55.00"
48.	ER48	30.4	18.1	Clay	7 ⁰ .31'55.00"	5 ⁰ .49'55.00"
49.	ER49	29.3	16.9	Clay	7 ⁰ .31'55.00"	5 ⁰ .54'10.00"
50.	ER50	60.5	19.0	Clay	7 ⁰ .31'55.00"	5 ⁰ .51'45.00"
51.	ER51.	38.2	8.0	Clay	7 ⁰ .31'55.00"	5 ⁰ .50'30.00"
52.	ER52	22.4	12.2	Clay	7 ⁰ .31'55.00"	5 ⁰ .53'10.00"
53.	ER53	45.9	3.0	Clay	7 ⁰ .31'55.00"	5 ⁰ .54'20.00"
54.	ER54	49.8	2.4	Clay	7 ⁰ .31'20.00"	5 ⁰ .45'20.00"
55.	ER55	12.6	10.2	Clay	7 ⁰ .31'20.00"	5 ⁰ .46'30.00"
56.	ER56	11.0	20.4	Clay	7 ⁰ .31'20.00"	5 ⁰ .47'30.00"
57.	ER57	18.3	19.1	Clay	7 ⁰ .31'20.00"	5 ⁰ .48'10.00"
58.	ER58	14.5	11.4	Clay	7 ⁰ .31'20.00"	5 ⁰ .50'50.00"
59.	ER59	14.2	13.8	Clay	7 ⁰ .31'20.00"	5 ⁰ .53'35.00"

4.2.1.1 Sounding curves

In the study area, 11 curve types were identified, these are H, Q, HA, HK, KH, QH, QK, AKH, HKA, QHA and KHA. The different dominant curve types found in the study area. Figure 4.12A and table13 show the occurrences of different curve types found in the study area are shown in figure 4.12A (a-k), while the remaining curve types are in appendix B. where type curve QH has highest percentage (48.1%) occurrence (figure 4.12B and table 13) shows the occurrences of different curve type of the study area, where type curve QH has highest percentage (48.1%) occurrence, followed by HA and KH curves type has (11.7%) while H, Q, HK, QK, AKH, HKH, QHA, KHA type curve have 6.7%, 1.7%, 6.7%, 1.7%, 3.3%, 5%, 1.7%, 1.7% respectively. The typical curve types as shown in figure 4.12A (a-k) indicated that the presence of HA, QH, KH curve types suggest the presence of a homogeneous unit.

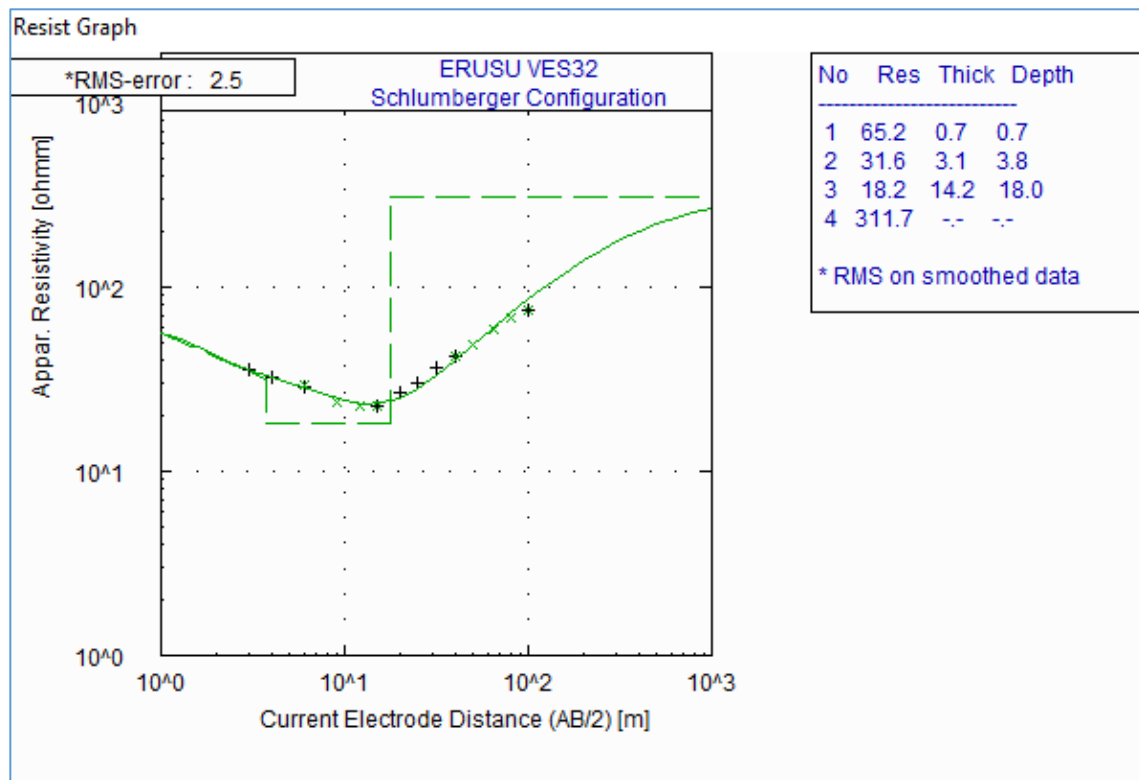


Figure 4.12A (a): showing QH curve type in the study area.

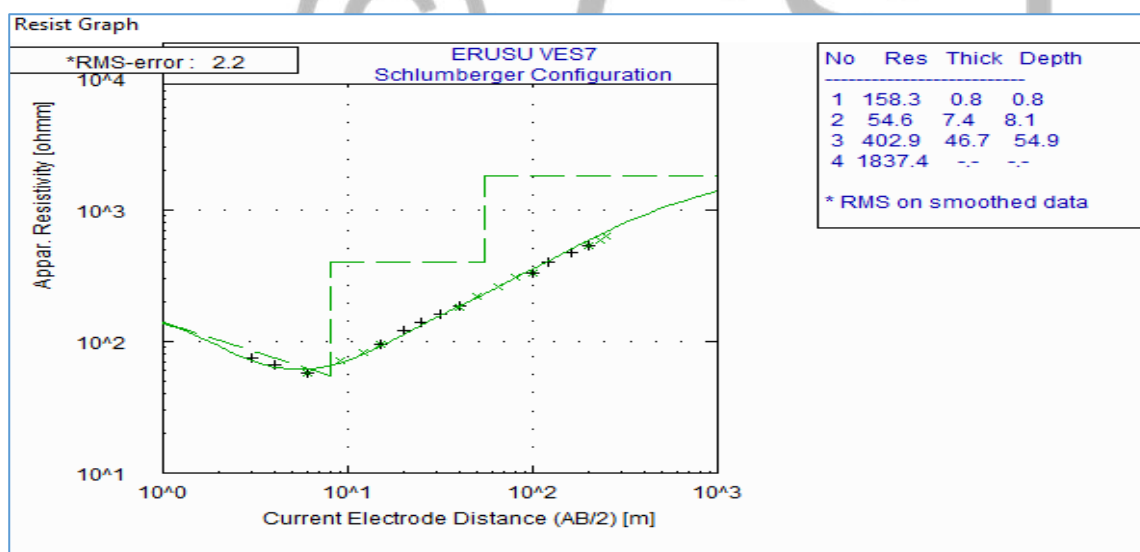


Figure 4.12A(b): showing HA curve type in the study area.

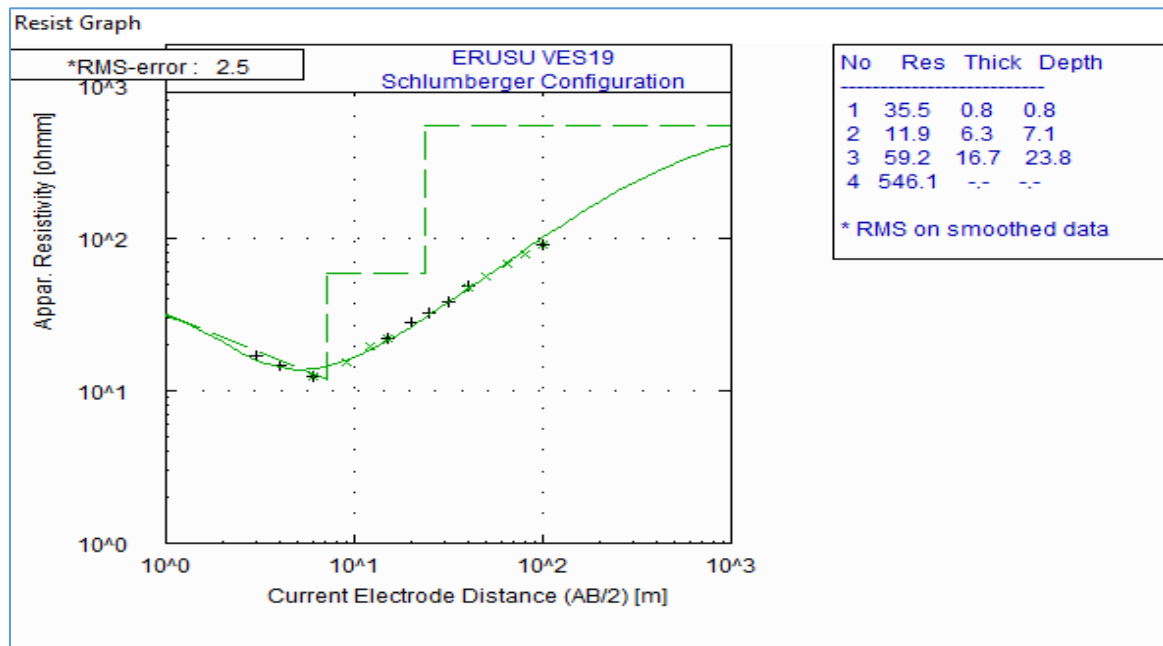


Figure 4.12A(c): showing HK curve type in the study area.

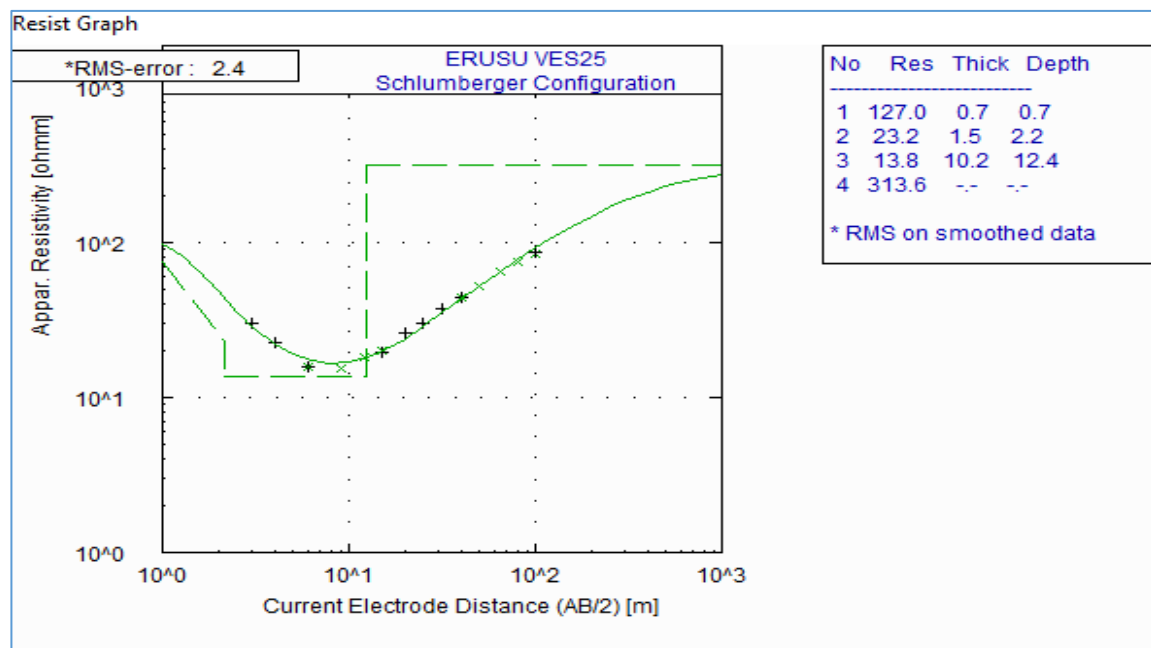


Figure 4.12A (d) : showing KH curve type in the study area.

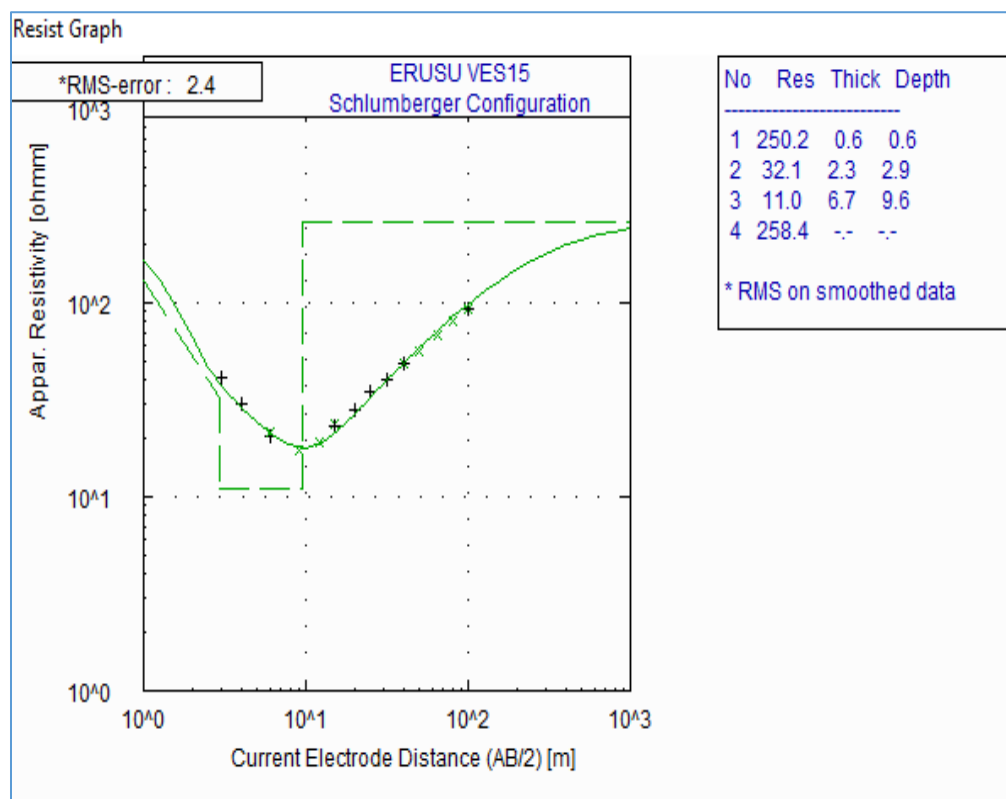


Figure 4.12A (e) : showing QK curve type in the study area.

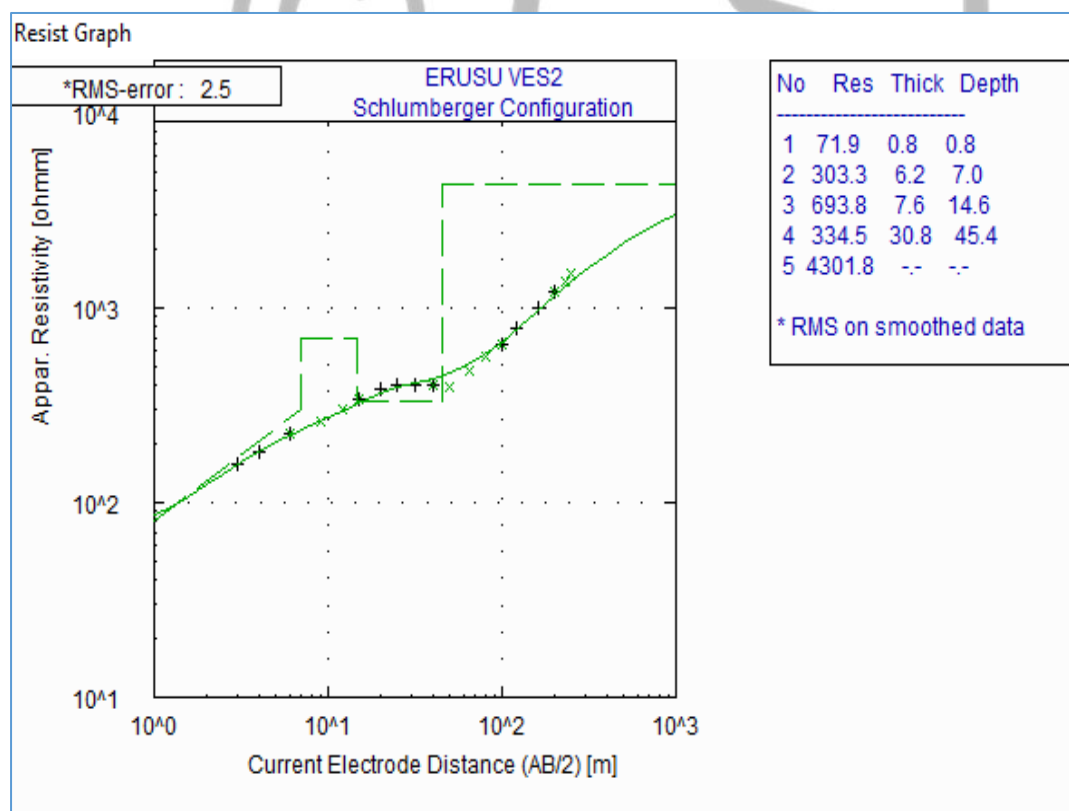


Figure 4.12A (f) : showing AKH curve type in the study area.

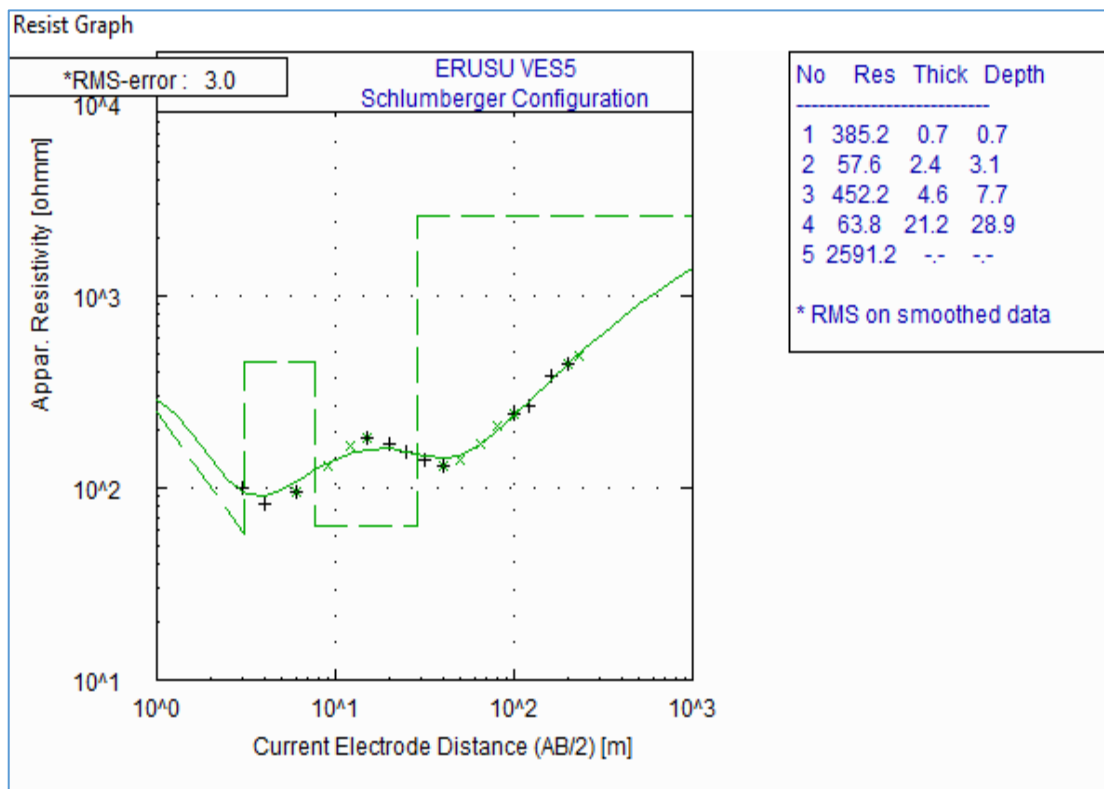


Figure 4.12A (g) : showing HKH curve type in the study area.

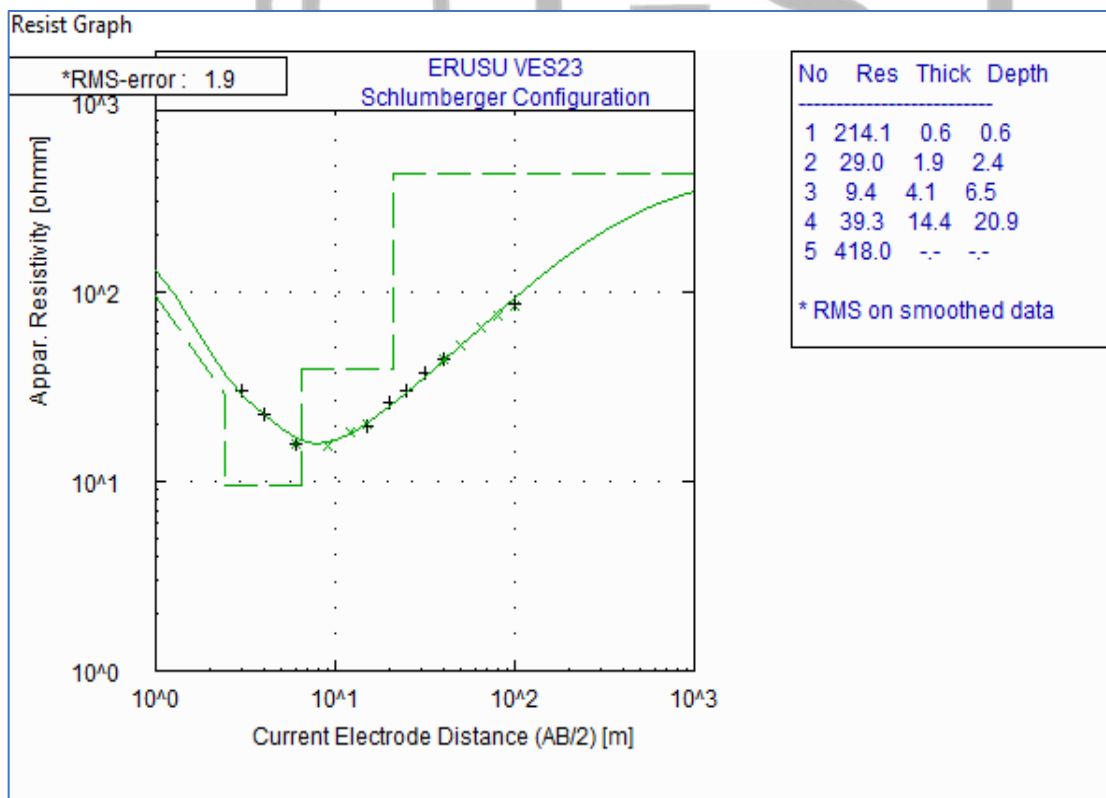


Figure 4.12A (h) : showing QHA curve type in the study area.

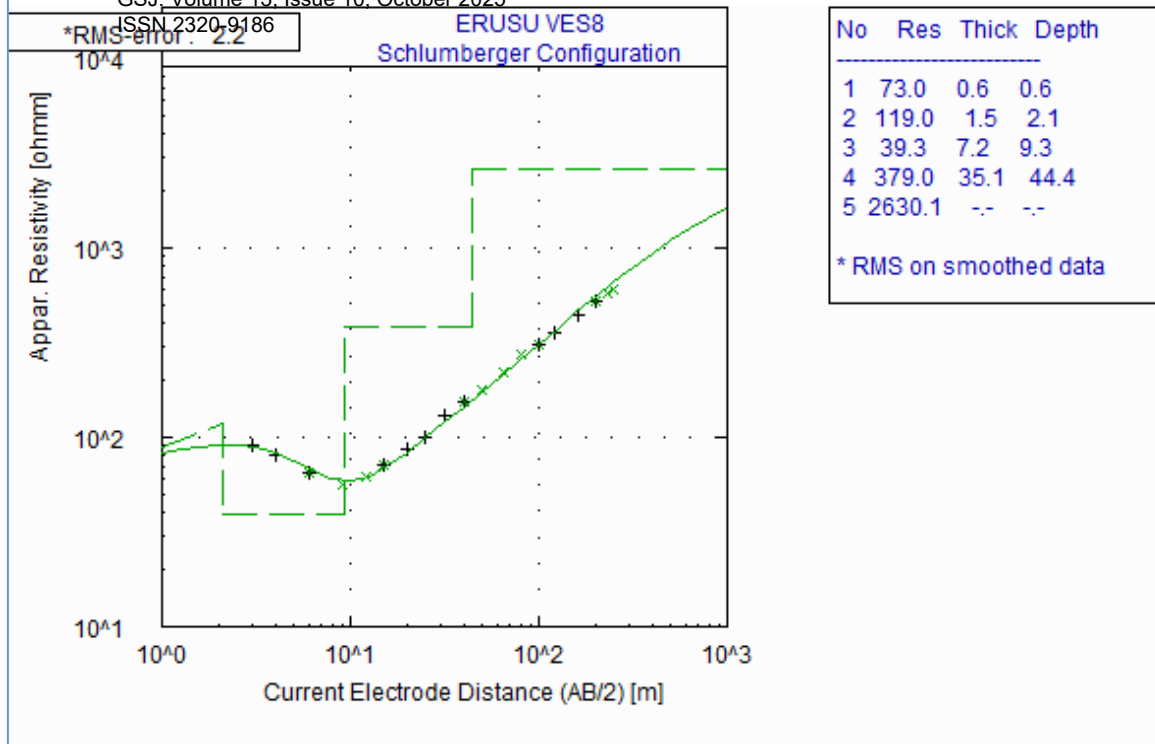


Figure 4.12A (i) : showing KHA curve type in the study area.

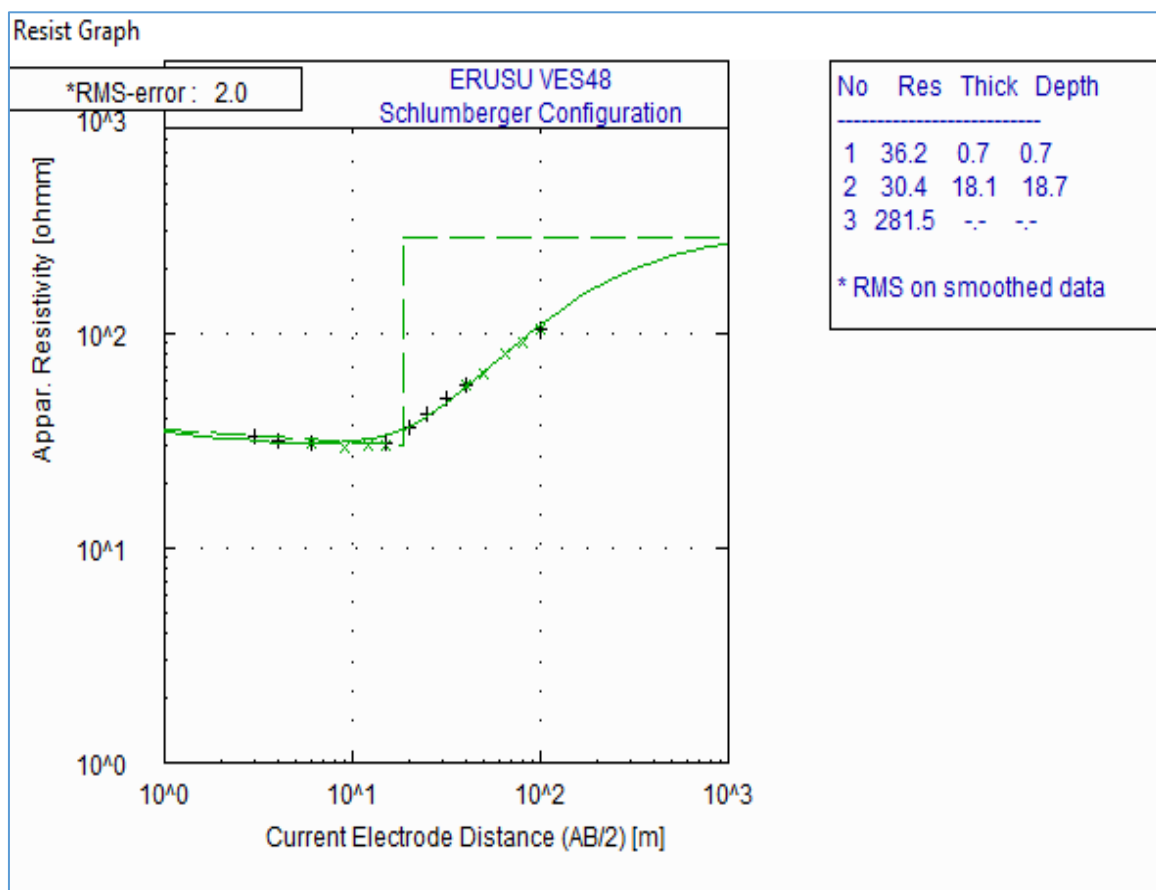


Figure 4.12A (j) : showing Q curve type in the study area.

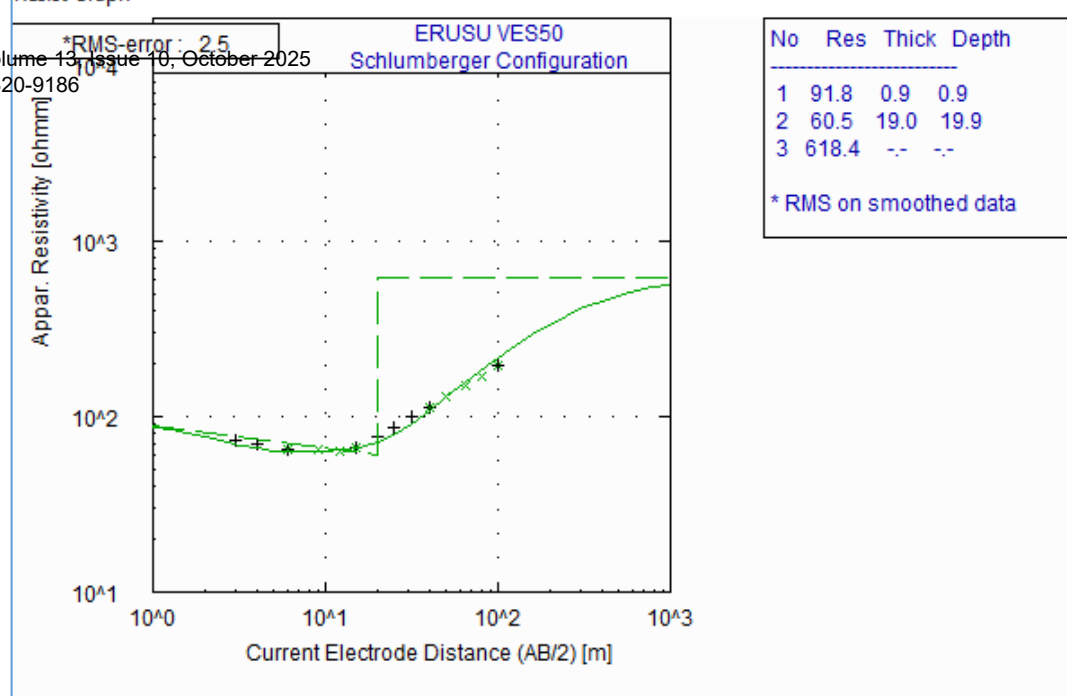


Figure 4.12A (k) : showing H curve type in the study area.

Figure 4.12A: showing representative of different curve types in the study area

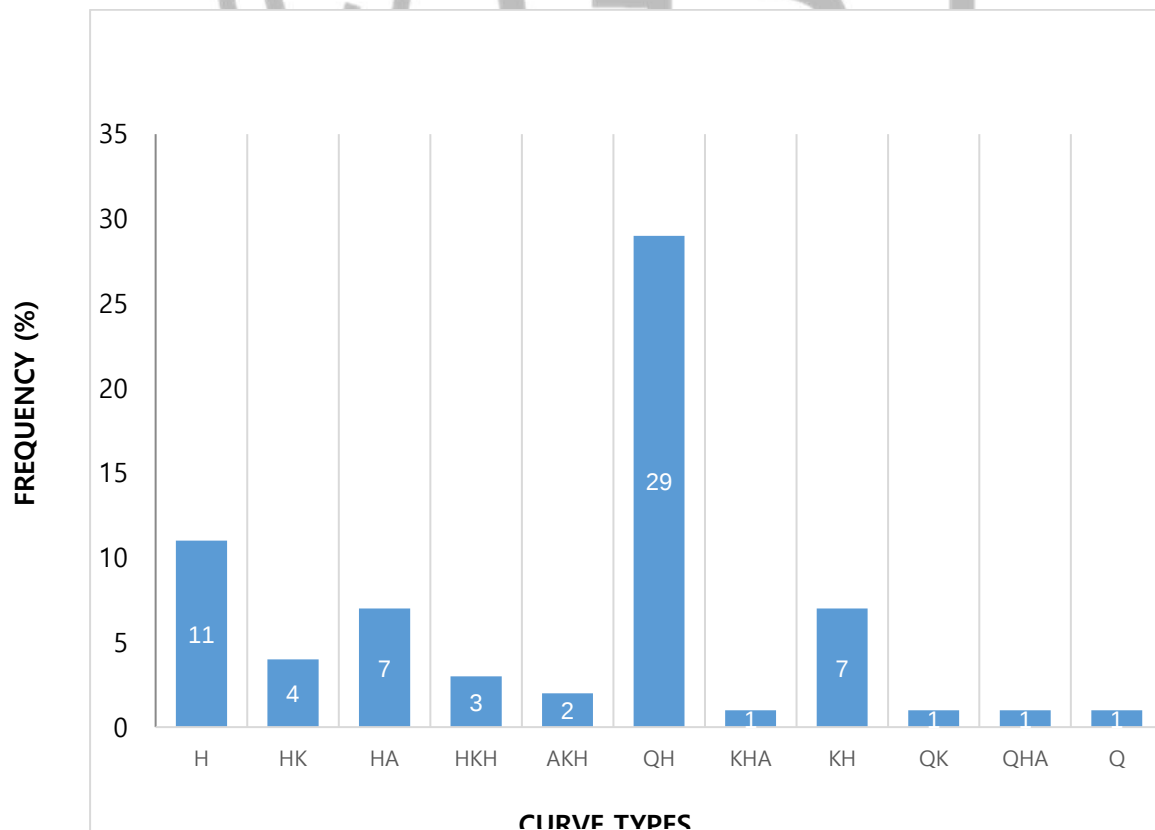


Figure 4.12B: showing a bar chart containing the percentage of curve types in the study area

4.2.1.2 Geo-Electric Section

Figure 4.13a to 4.13d contains four geo-electric sections drawn along transverses 1,2,3,4 trending in the directions of NE –SW, W-E, N-S, E-W respectively while geo-electric sections of VES 1-60 are all in appendix C . These sections defined variations in resistivity and thickness values of layers within the depth penetrated in the study area (Erusu-Akoko) at each probed VES station. Loke (2000) described lithologies with resistivity values between 1-100 Ω m as clay. Horizons with such resistivity values were inferred as clay while those with resistivity values slightly above 100 Ω m that are found above the basements were inferred as being slightly sandy but predominantly of clay.

. The geo-electric section along the transverse (NE-SW) in figure 4.13a, shows four distinct layers namely; clay soil, lateritic clay, fractured basement and basement. The clay soil has thickness vary from about 0.7 m to 12.5 m while its resistivity values vary from 150 to 1150 ohm-m. The second layer is lateritic clay with resistivity value ranging from 200 ohm-m to 150 ohm-m and thickness ranging from about 5 m to 15 m. The third layer is the fractured basement with the layer resistivity value vary from 312 ohm-m to 616.6 m, while the thickness varying from 32 m to 83 m. The fourth layer is the basement bedrock with resistivity values of 1097 ohm-m and above. The geo-electric section along transverse (N-S) in the figure 4.13c shows four layer geo-electric layers, just like the first two layers above. The first layer, which is the clayey soil, varies in thickness from about 0.7m to 1.4m while its resistivity values range from 190-620 ohm-m. The second layer is lateritic clay with resistivity values ranging from 2.9 ohm-m to 1089 ohm-m. The thickness of the lateritic clay varies between 2.9 m and 16 m. The third layer is the fractured basement with resistivity values varying from 20.5 to 146 ohm-m and thicknesses of 18.5 m and 96.3 m. The fourth layer is the basement bedrock with 13630 ohm-m to infinity respectively.

The geo-electric section along transverse E-W in figure 4.13d shows four geo-electric section layers, the clayey layer which is relatively thin has thickness ranging from 2.5 m to 16.5 m while the resistivity value range from 9.42 ohm-m to 6939 ohm-m. The low resistivity values obtained within the layer indicates that the topsoil is composed majorly of clayey soil. The second layer has thickness ranging from 1.9 m and 7.5 m and resistivity values from 28 ohm-m to 110 ohm-m. This layer predominantly composed of clayey soil. The third layer is a weathered /fractured layer with thickness ranging from 8.6m to 47.5 m and resistivity values ranging from 312 ohm-m to 616 ohm-m. This contains weathered and fractured rocks and the basement resistivity value range between 648 ohm-m and 1097.0 ohm-m. The bedrock also from depth to bedrock within the area range between 6.6 m and 48.9 m.



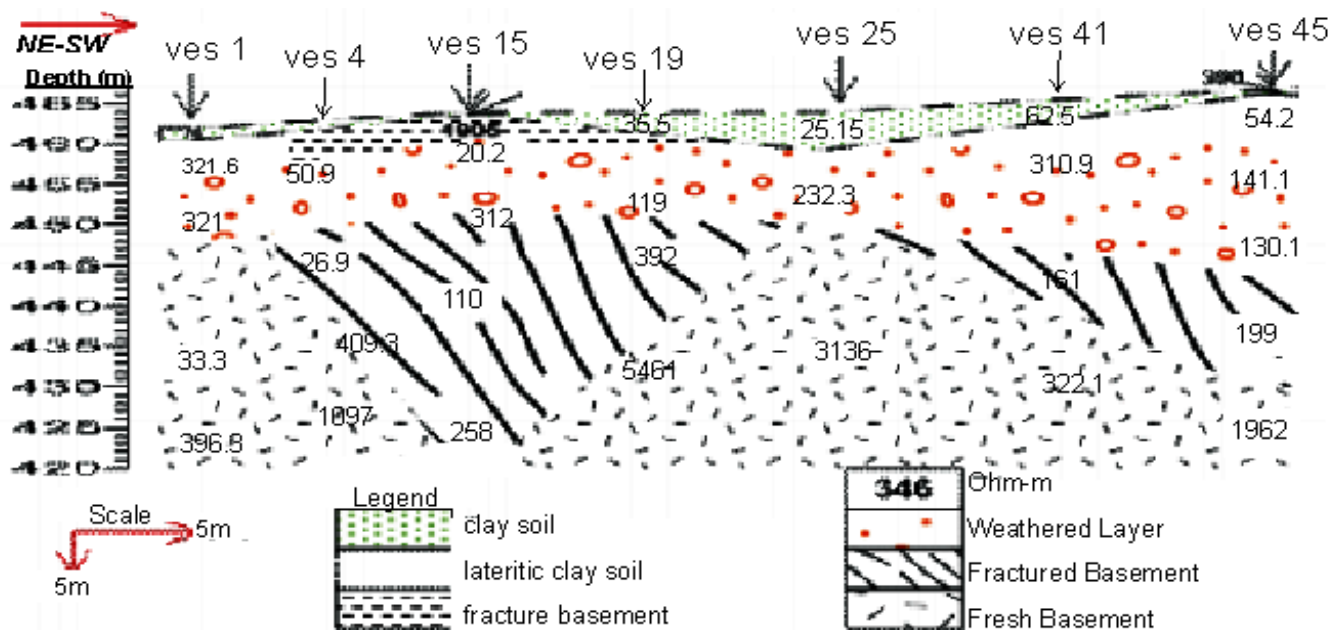


Figure 4.3a: Geo-electric section through VES points 1, 4, 15, 19, 25, 41, and 45

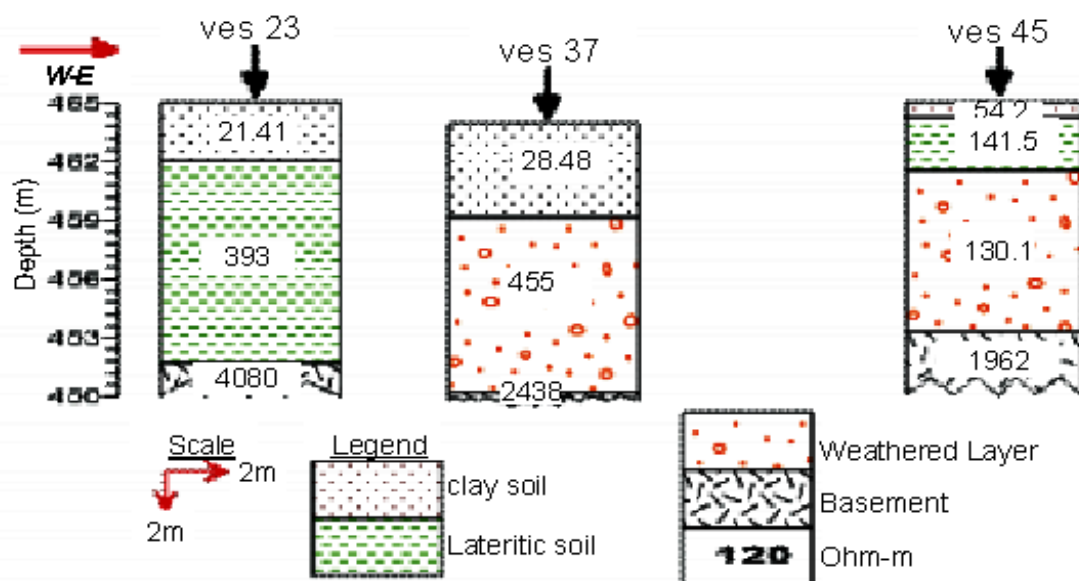


Figure 4.1.3b Geo-electric section through VES points 23, 37 and 45

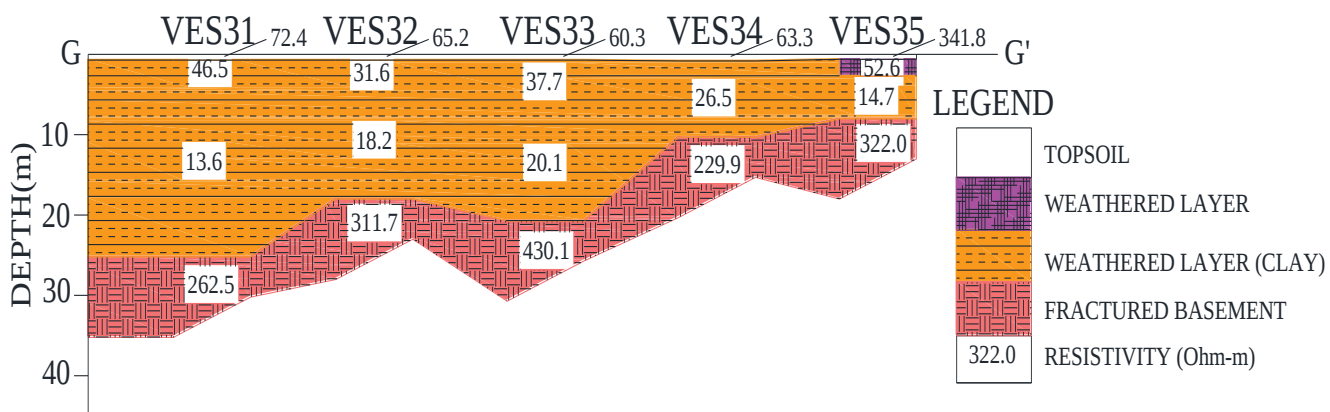


Figure 4.13c: Geo-Electric Section along transverse E-W

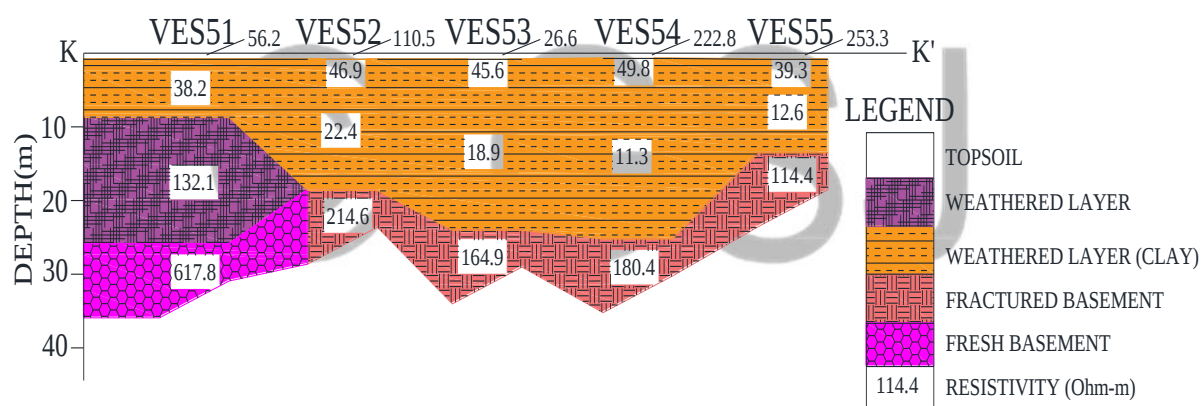


Figure 4.13d: Geo-Electric Section along transverse E-W

4.3 Estimating The Area, Volume, And Tonnage of the Clay Deposits in the Study Area.

4.3.1 Calculation of Variogram against lag time.

Ordinary Kriging is the basis of geostatistics used to make optimal predictions under the assumption that the process is second order stationery as well as distributed with normal and that observed values are realization of a stationary stochastic processes of fairly simple structures. Kriging model is the weighted linear combination of observations with white noise processes. This optimal predictor will be accepted by minimizing mean squared prediction error. The observed values are first used to estimate the unknown parameters of the process and to compute empirical semivariogram. These observed value parameters and semi-Variogram are used to produce the best linear unbiased predictor of the unobserved points Metheron *et al.*, (1963).

The general formula for both interpolators is formed as a weight sum of the data and it is expressed mathematically as

$$Z \hat{\Sigma}_{(s_0)} = \sum_{i=1}^N \gamma_i z(s_i) \dots \dots \dots (1)$$

Where:

$Z(s_i)$: the measured value at the i .th location

(s_0) = An unknown weight for the measured value at the i .th location

S_0 = the prediction location

N = the number of measured values

In spatial modeling of the structure of the measured points, it is usually advisable to begin with a graph of the empirical semivariogram, computed parameter by distance h .

The general formula for computing semivariogram is given as semivariogram ($\hat{\gamma}(h)$)

$$\hat{\gamma}(h) = 0.5 \times \frac{\sum_{i,j} (z_i - z_j)^2}{2} \dots \dots \dots (2)$$

This formula involves calculating the difference square between the values of the parcel locations. In view of this, the above mathematical formula was used to create Table 12, which was used to plot the semi Variogram graph, the value at which the semivariogram in model intercepts the y-axis is the nugget. The nugget effect was due to measurement errors. It was estimated to be 5m from the graph.

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Table 12: Showing Variogram against semi Variogram (lag distance (m)

AVERAGE VARIOGRAM		75	10	15	20	25	35	40	45	53	59	52	43	47	39	48	43	47	39	48	43	49	507.5
VARIOGRAM	VALUE i	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0	60.0	65.0	70.0	75.0	80.0	85.0	90.0	95.0	100.0	105.0	110.0
	value	10.0	20.0	35.0	45.0	55.0	65.0	75.0	85.0	95.0	105.0	115.0	125.0	135.0	145.0	155.0	165.0	175.0	185.0	195.0	205.0	215.0	225.0
(VALUE i-VALUE j	5.0	10.0	15.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0	60.0	65.0	70.0	75.0	80.0	85.0	90.0	95.0	100.0	105.0	110.0	115.0	115.0
(VALUE i-VALUE j) ²	25.0	100.0	225.0	625.0	900.0	1225.0	1600.0	2025.0	2500.0	3025.0	3600.0	4225.0	4900.0	5625.0	6400.0	7225.0	8100.0	9025.0	10000.0	11025.0	12100.0	13225.0	
(VALUE i-1/2 VALUE j) ²	12.5	50.0	112.5	312.5	550.0	612.5	800.0	1012.5	1250.0	1512.5	1800.0	2112.5	2450.0	2812.5	3200.0	3612.5	4050.0	4512.5	5000.0	5512.5	6050.0	6612.5	
LAG DISTANCE (M)	285	300	305	31.0	311	290	285	230	312	312	270	450	500	630	700	730	860	900	990	1000	1100	1150	1570

4.3.2. Plot of experimental Variogram against lag distance

The empirical semivariogram is a graph of the averaged semi Variogram values on the y-axis and the distance (or lag) on the x-axis (figure 4.14). This is constructed using a software called Sulfur 8 and it is used to fit a model parameters such as Sill, Nugget effect and Range.

Figure 4.13 shows a non-zero intercept (nugget) is the distance the 0 variance on y-axis and the Variogram model intercept with the x-axis. (this is estimated from the Omni-Directional Variogram as 5 m). partial sill is the vertical distance between the nugget and the part of the curve that level off. If the Variogram approaches zero on the y-axis, then the nugget is 5 and the partial sill is simply referred to as the sill and it is estimated from the semi Variogram as 40 m). The difference along the x-axis where the curve level off is referred to as the range and it is estimated from the above semivariogram as 450 m). However, at an infinity small separation distance, the Variogram often exhibits a nugget effects, which is a value greater than 0 and this was estimated as 5 m from Omni-directional experimental Variogram (figure 4.14).

These parameter values were in turn put into the Gaussian model to estimate the total volume of the clay deposit in place, in the study area (Erusu Akoko).

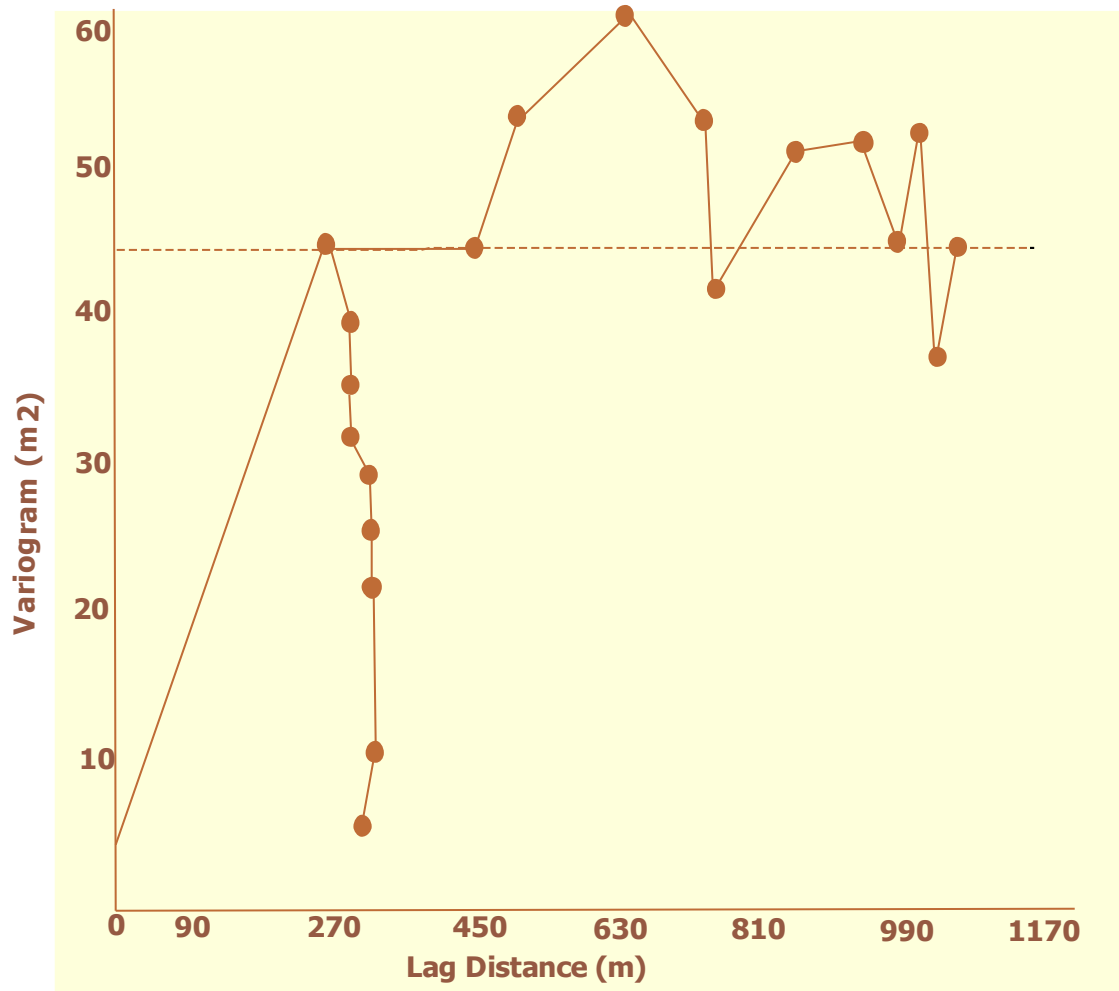


Fig 4.14: Showing Omni-Directional Experimental with Gaussian Model

Table 13: Model parameters of the Variogram

Variogram	Clay structure
Model	Gaussian
Range (m)	450
Sill (m ²)	40
Nugget effect (m ²)	5.0

4.3.3 Fitting constructed model

The goal of Variogram model is to apply the model that best fits the sample experimental Variogram. This requires picking the proper model, then tweaking the partial sill, range and nugget parameters.

From the analysis of the empirical semivariogram graph, the theoretical model suitable to represent the visited spatial variability is done by determining the lag as defined by Gaussian model.

This formulated model was used to determine the optimal volume of the reserve in place for the interpolation after estimating the semivariogram model, structural analysis and interpolation for the observed points in the study area.

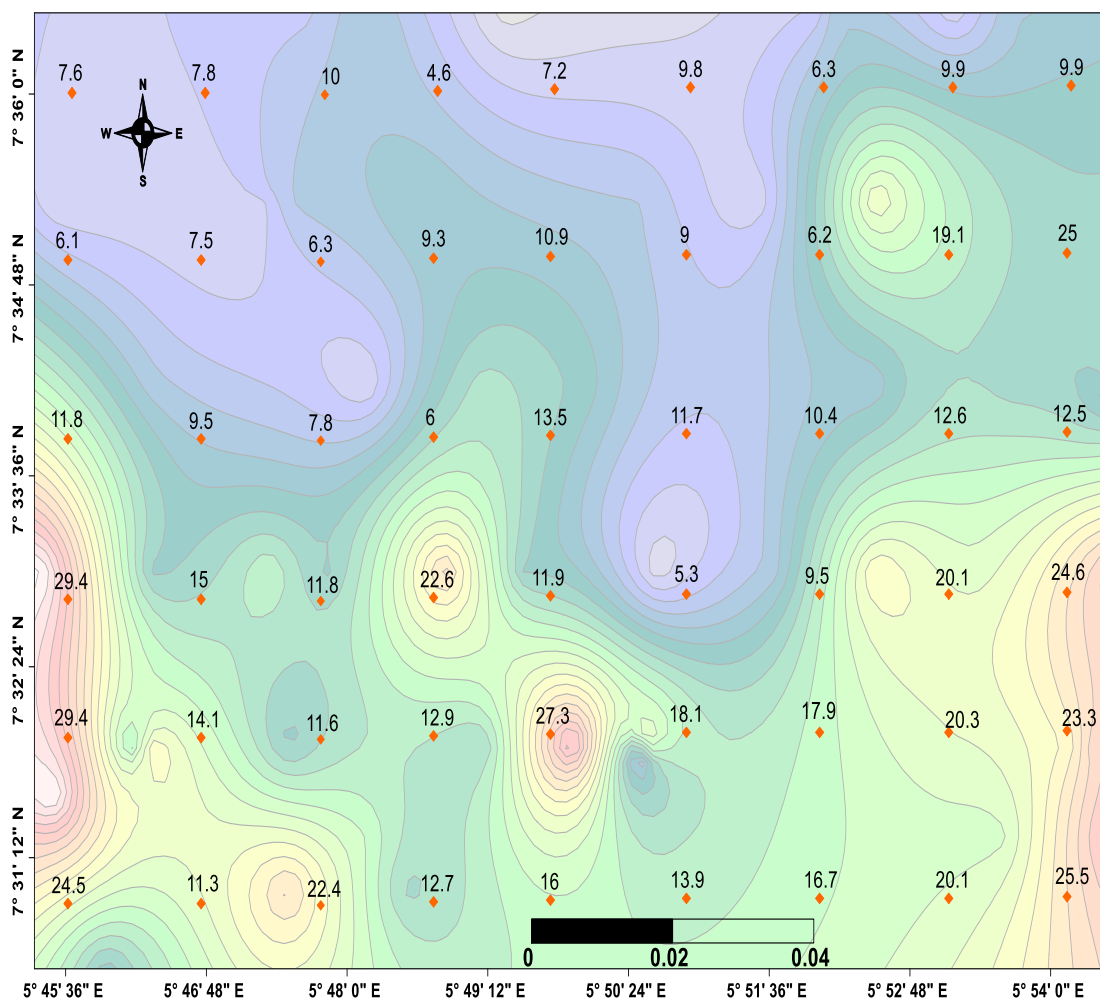
The general formula for Gaussian model is given as

$$\hat{\gamma}(h) = A_0 \hat{\gamma}(h) + w [(1 - \exp(-h/a))^2]$$

Where $h=1$ for $h > 0$, $\hat{\gamma}(h) = 0$ for $h=0$

4.3.4 Kriging Based Contour Map

The Kriging base contour map was combined with the Vertical electrical sounding (VES) techniques of the geophysical method to estimate the average thickness of the 60 square grids. The values of the semivariogram parameters such as (Sills, Nugget effects and range) were used as input for the Kriging base contour map(Figure 4.15) using Golden software sulfur 8. The thickness of the clay deposits was determined using the two geological methods (geophysical and geostatistical) in the study area and it is estimated as 9.8m. The volume (m^3) of the clay deposits in the study area was estimated as the product of the clay thickness (m) calculated from the mean of the values of the contour line and that of the VES and area (m^2) extent as estimated using the Gaussian model formula.



Figur4.15: Showing Kriging based contour map of the study area .

The semivariogram adopted in this research work is the Gaussian semivariogram model. The Gaussian model formula was used to estimate the volume of clay deposits in the study area.

$$\hat{\gamma}(h) = A_0 + w [1 - \exp(-h/a)^2]$$

Where $\hat{\gamma}(h)=1$ for $h > 0$, $\hat{\gamma}(h) = 0$ for $h=0$

A_0 is nugget effect caused by possible errors of measurement and this is equivalent to 7m
 h is the number unbiased sampling points from the study area and this is equivalent to 44 sampling points.

A_0+w is the Sill (which is the variance of the field less than the discontinuity). This is equal to 40m as estimated from the semivariogram graph. W is the partial Sill, which is Sill minus nuggets. This is equal to $45-5=40m$

$\hat{\gamma}(h)$ = area of the clay deposits in the study area, where 100,000 is the conversion factor.
 W is the partial Sill and a is the range(the correlation distance, and is in practice the maximum distance for which observation are correlated). This is equal to $450= m$

Hence:

$$\hat{\gamma}(h) = A_0 + w [1 - \exp(-h/a)^2] (100,000)$$

Where $\hat{\gamma}(h)=1$ for $h > 0$,

$$\hat{\gamma}(h) = A_0 + w [1 - \exp(-h/a)^2] (100,000)$$

$$\hat{\gamma}(h) = A_0 + w [1 - \exp(-h/a)^2] (100,000)$$

$$\hat{\gamma}(h) = 5.0 + 40 [1 - \exp(-44/450)^2] (100,000)$$

$$\hat{\gamma}(h) = 5.0 + 40 [1 - \exp(-0.09778)^2] (100,000)$$

$$\hat{\gamma}(h) = 5 + 40 [1 - \exp(-0.0095607111)] (100,000)$$

$$\hat{\gamma}(h) = 5 + 45 [1.00001418 - 1] (0.000189118) (100,000)$$

$$\hat{\gamma}(h) = 50[(0.00189118)] (100,000)$$

$$\hat{\gamma}(h) = 1891.8 \times 50$$

$$\hat{\gamma}(h) = 94590.00$$

$$\bar{d}(h) = 94590.00$$

Hence, average area of the clay deposited in the study area as estimated using the (geostatistical method) through Kriging is 94590.00 m^2 .

The volume of the clay deposit = average thickness of the clay deposit (m) x the area of the clay deposits (m^2).

$$\text{Volume of the clay deposits in place in } \text{m}^3 = 94590.00 \text{ m}^2 \times 9.8 \text{ m.}$$

$$= 926982 \text{ m}^3$$

Therefore the estimated clay deposits using Kriging method of geostatistics is 926982.00 m^3 .

4.3.5 Estimating the gross tonnage of the clay deposits

The gross tonnage of the clay deposit in the study area is calculated using the formula of Metheron (1963).

This formula is expressed mathematically as

$$G.T. = K_1 V$$

Where

G.T. is the gross tonnage in metric tons

K_1 = is the specific gravity of the samples collected from the study area.

V = is the volume in m^3 as estimated using both Kriging method of geostatistics and electrical resistivity method of geophysics.

$$\text{Average volume (V) of the study clay deposits} = 926982.0 \text{ m}^3$$

$$\text{Average specific gravity of the collected clay samples from the study are (ERL1, ERL2, ERL3, ERL4)} = 2.71 + 2.39 + 2.70 + 2.72 = 10.53$$

The average specific gravity (K_1) = Total specific gravity

$$\frac{4}{4}$$

$$\therefore K_1 = 10.52$$

$$\frac{4}{4}$$

$$K_1 = 2.63$$

Hence,

$$G.T = K_1 V$$

$$G.T = 926982.0 \times 2.63$$

$$G.T = 2437,962.66 \text{ metric tons}$$

∴ The tonnage of the study clay deposits is 2437962.66 metric tons

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CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Conclusively, based on the field relationship, physical inspection, results of the geotechnical analysis, geophysical survey and, geostatistical investigation of the clay deposits carried out in the study area, it can be shown that the clay deposits in Erusu-Akoko can be utilized in the manufacture of ceramics, refractory materials, moulding, bricks production, as a liners in landfills and pottery. If stabilized with lateritic soil of good quality, Erusu clay deposits can also be used for production of both sun-cured and burnt bricks of adequate strength for building construction. The reserve (tonnage in metric tons) of the clay deposits in the area under investigation is estimated to be approximately 2437,962.66 metric tons. While the average volume of the deposit is estimated to be about 926982.0 cubic meters and the thickness range 9.8 meters to 12.0 meters, hence, surface mining techniques could be used since the estimated clay deposit reserve (tonnage) in the study area conform to the minimum requirements of average tonnage (23,000.00 metric tons) stipulated by Metheron (1963).

Finally, the clay deposits in Erusu-Akoko, Ondo State, Southwestern, Nigeria, is large enough for both industrial and commercial exploitation with a total estimated reserve (tonnage) of 2437962.66 metric tons.

5.2 Recommendation

Since different sets of criteria are important to the production of any specific blind for a raw material in industry e.g. in ceramic production, hence, it is therefore imperative, to call for the study of the effect of additive to improve the industrial suitability of these clay deposits. In view of this, I therefore recommend, that Erusu-Akoko clay deposits should be stabilized with additives to improve their industrial suitability. Based on the aforementioned, I hereby recommend a more detail engineering work should be carried out on the Erusu-Akoko, Amo, and Imo Arigidi where

large concentration could be located; as well as more detail hydro-geological studies should be conducted to confirm the reason behind the Erusu Akoko, failed Earth dam sited within the clay deposits.

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APPENDIX A



Plate1: showing student conducting electrical resistivity geophysical technique in the study area.



Plate 2: student conducting unbiased sampling during geostatistical field work in the study area.



Plate 3: student on an outcrop of Granite during geological field mapping



Plate 3: student on an outcrop of Granite during geological field mapping

APPENDIX B

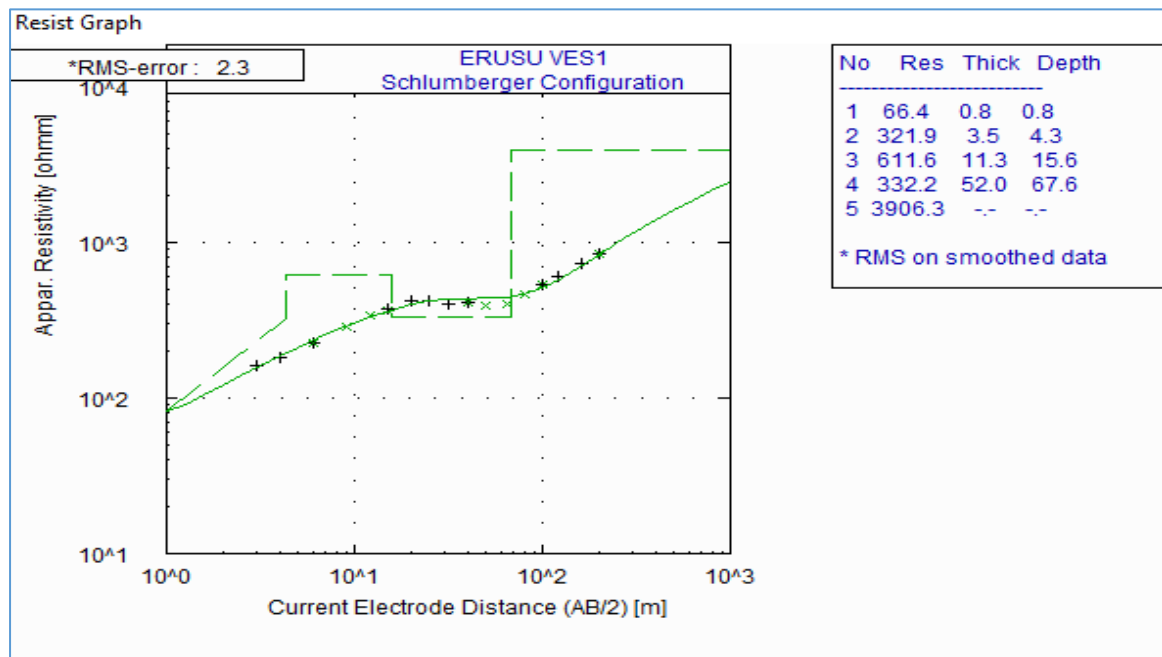


Plate 5: Showing curve sounding of VES point 1

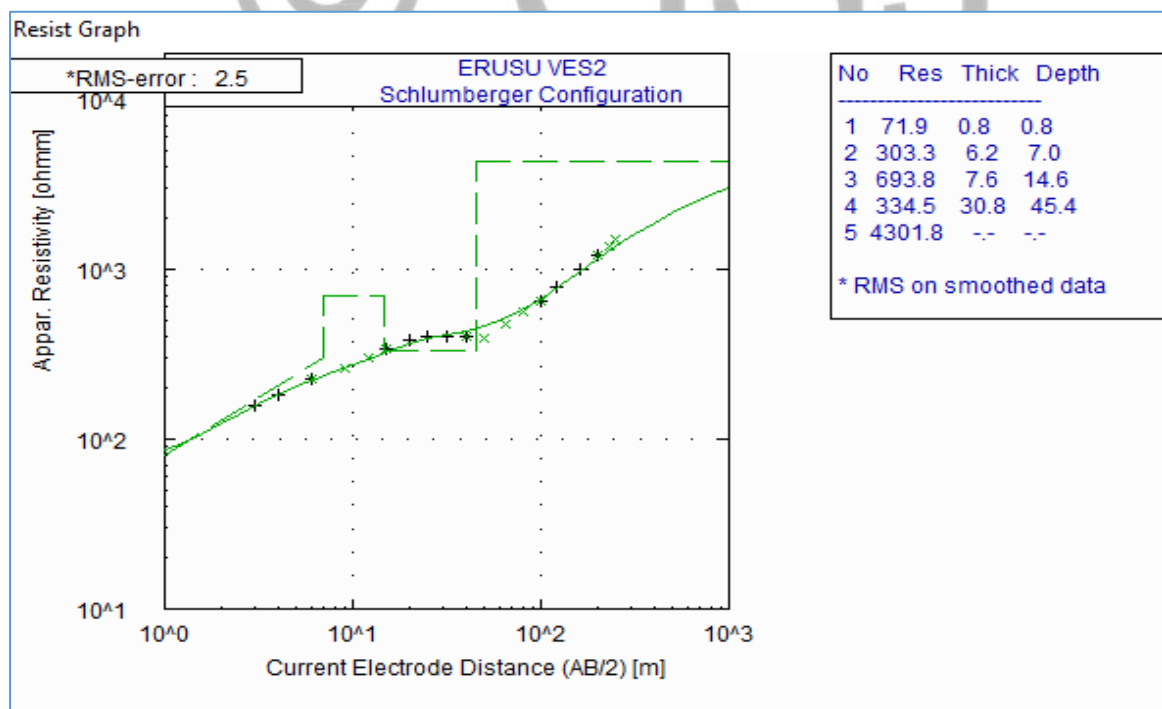


Plate 6: showing sounding curve of VES point 2

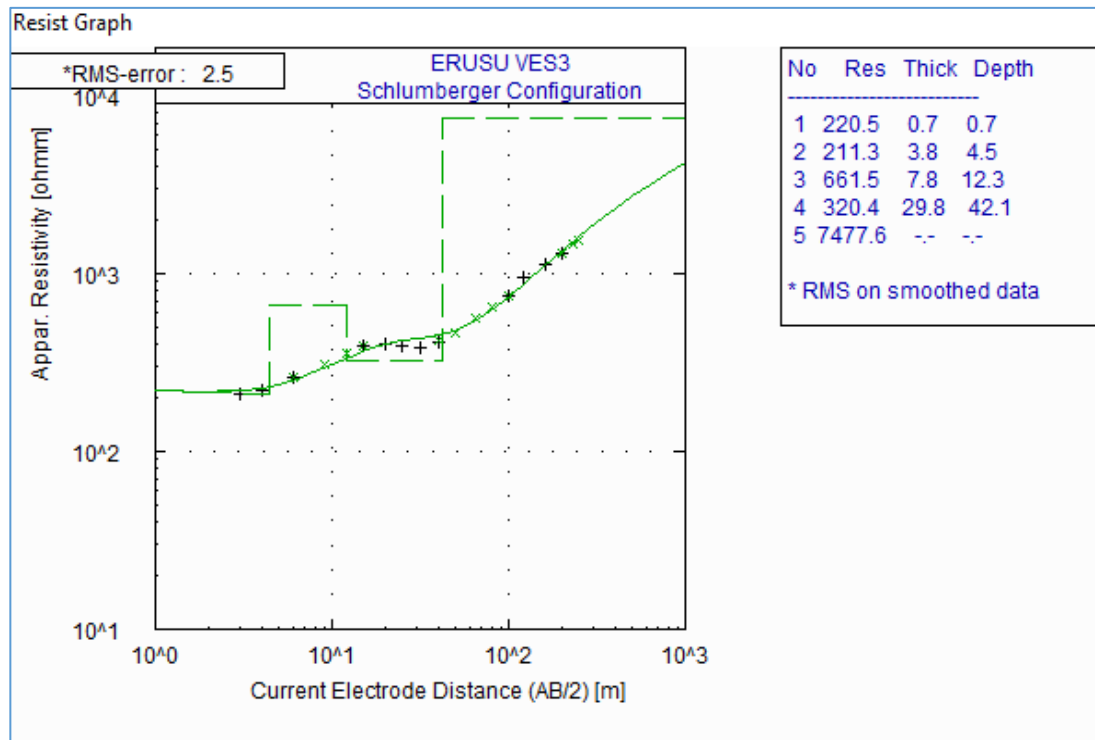


Plate 7: showing sounding curve of VES point 3

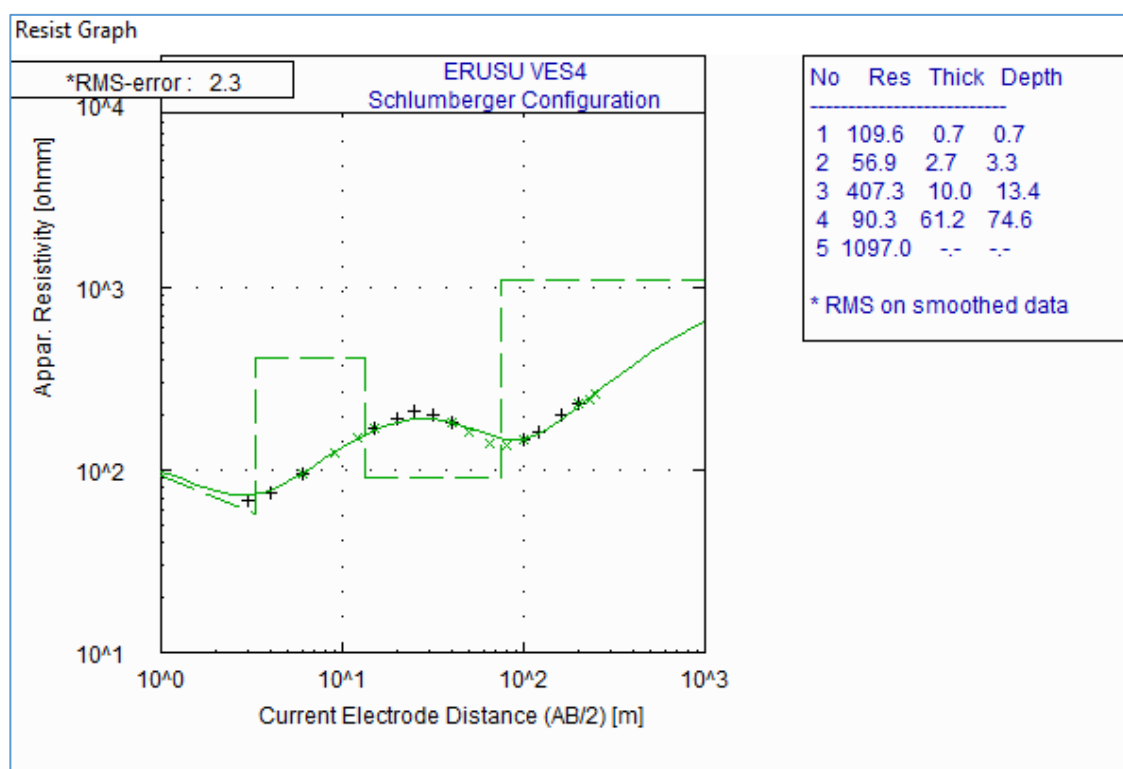


Plate 8: showing sounding curve of VES point 4

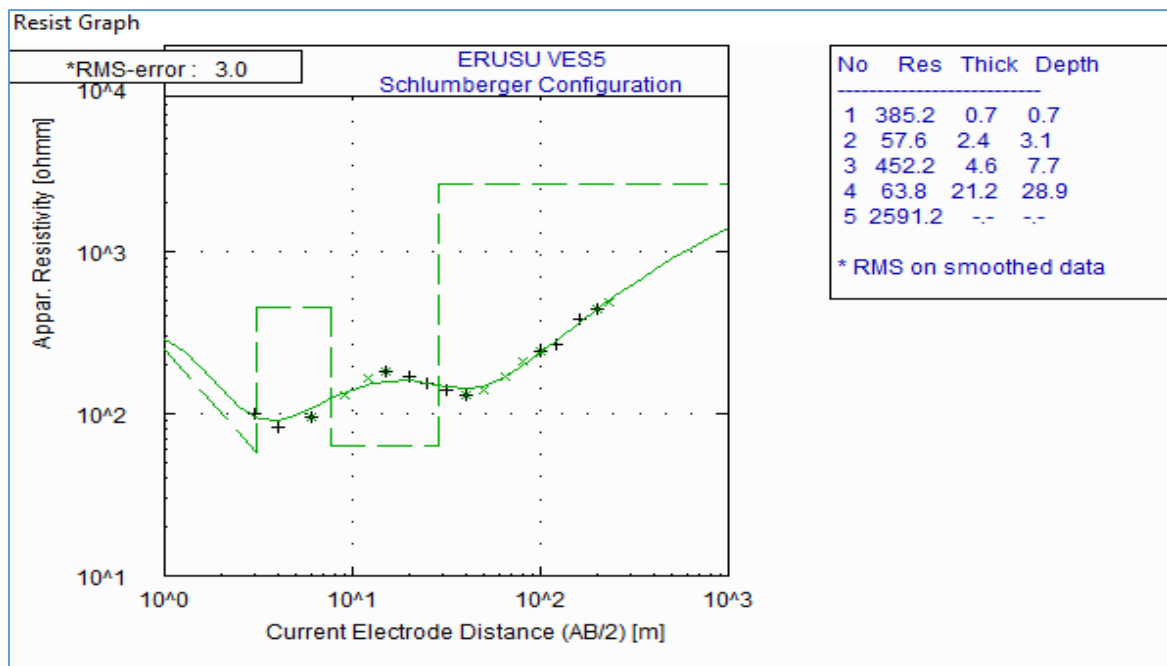


Plate 9: showing sounding curve of VES point 5

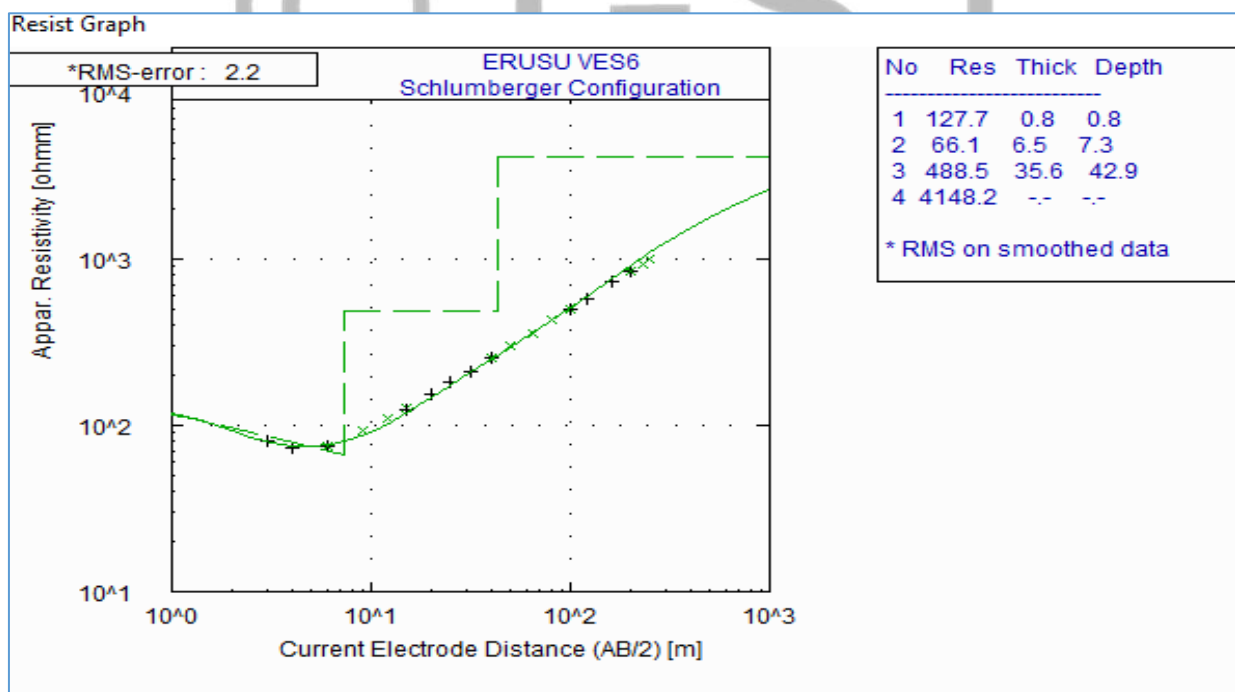


Plate 10: showing sounding curve of VES point 6

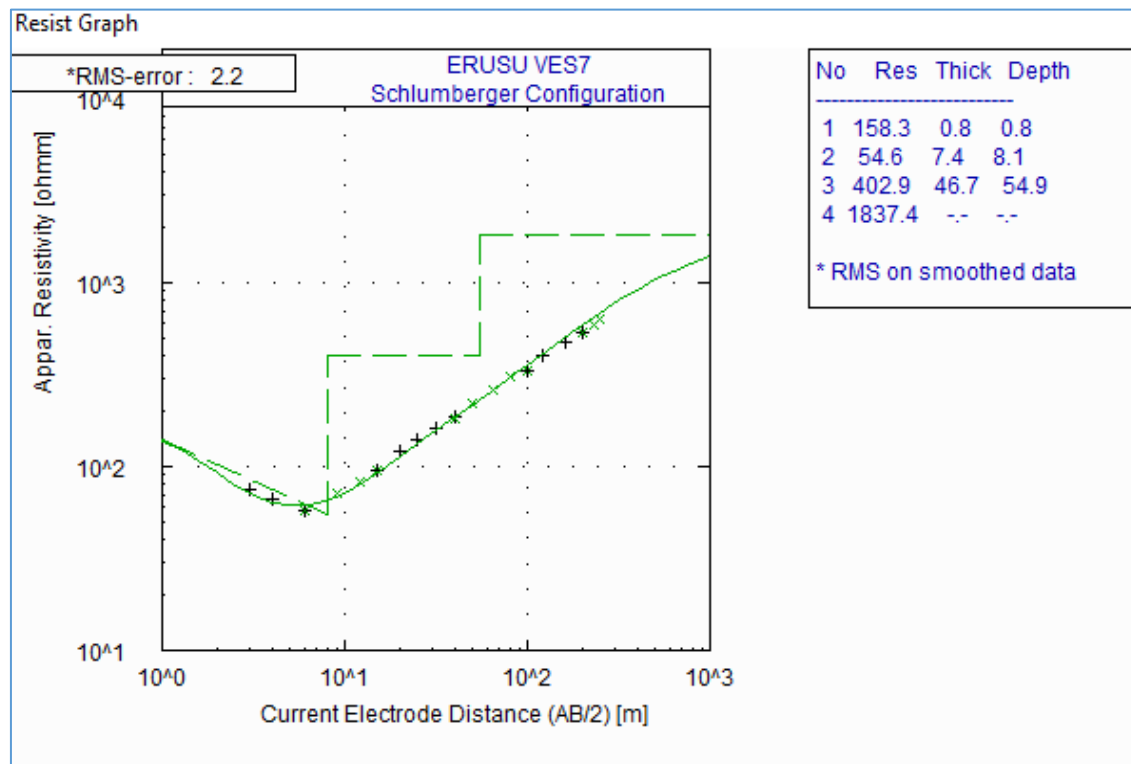


Plate 11: showing sounding curve of VES point 7

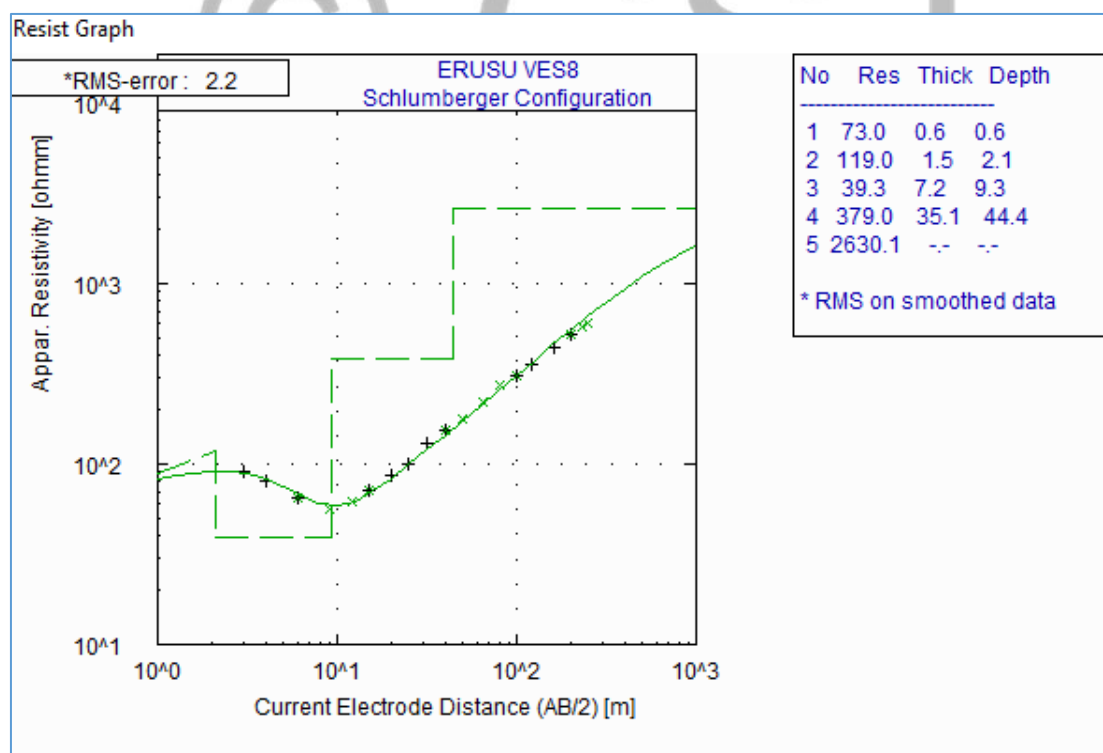


Plate 12: showing sounding curve of VES point 8

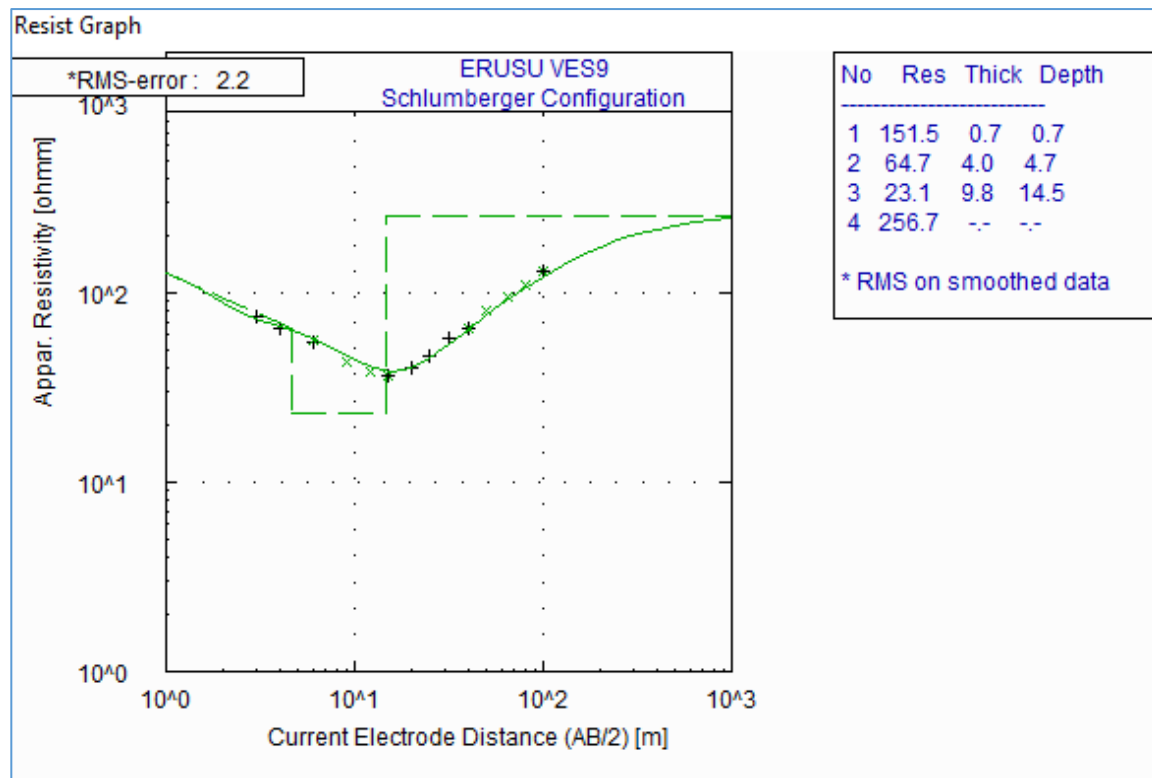


Plate 13: showing sounding curve of VES point 9

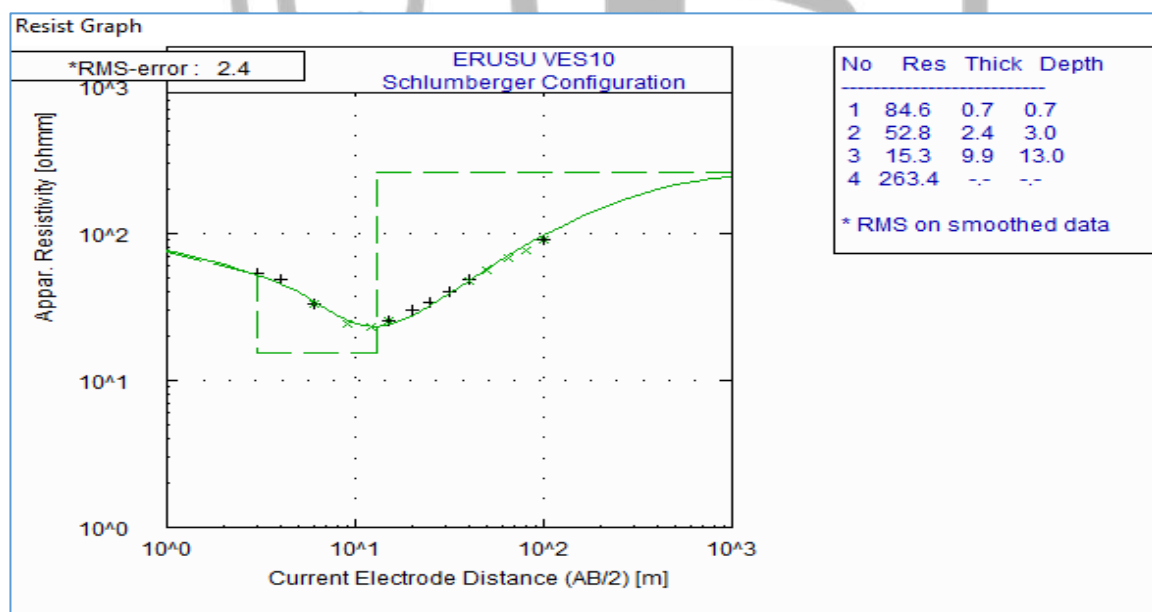


Plate 14: showing sounding curve of VES point 10

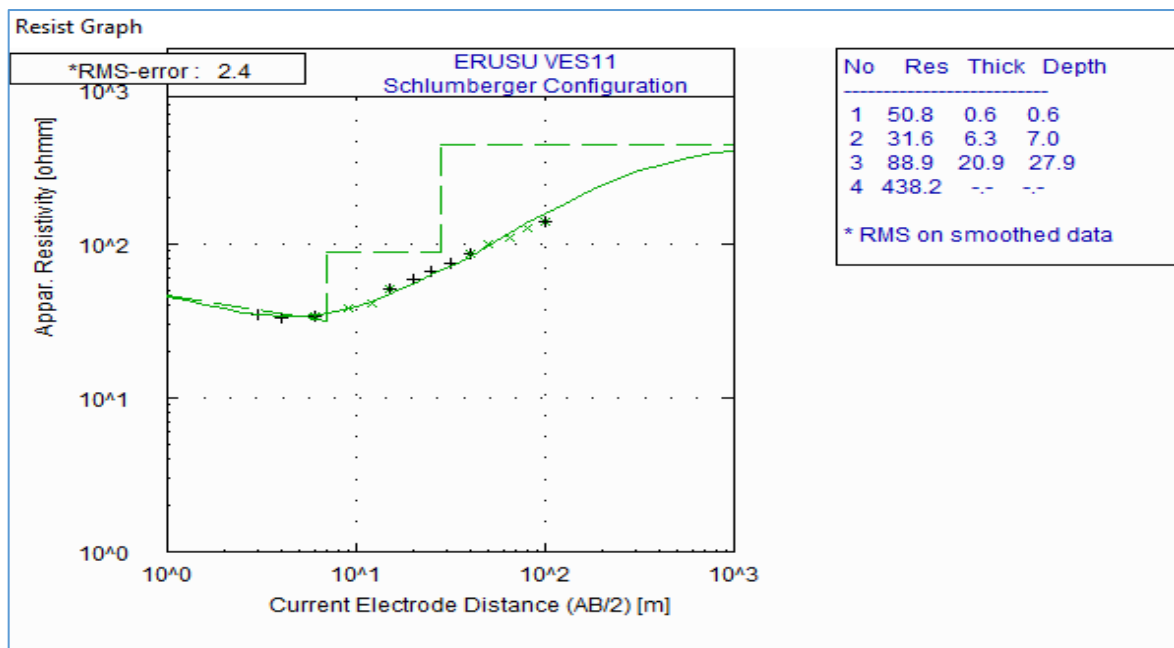


Plate 15: showing sounding curve of VES point 13

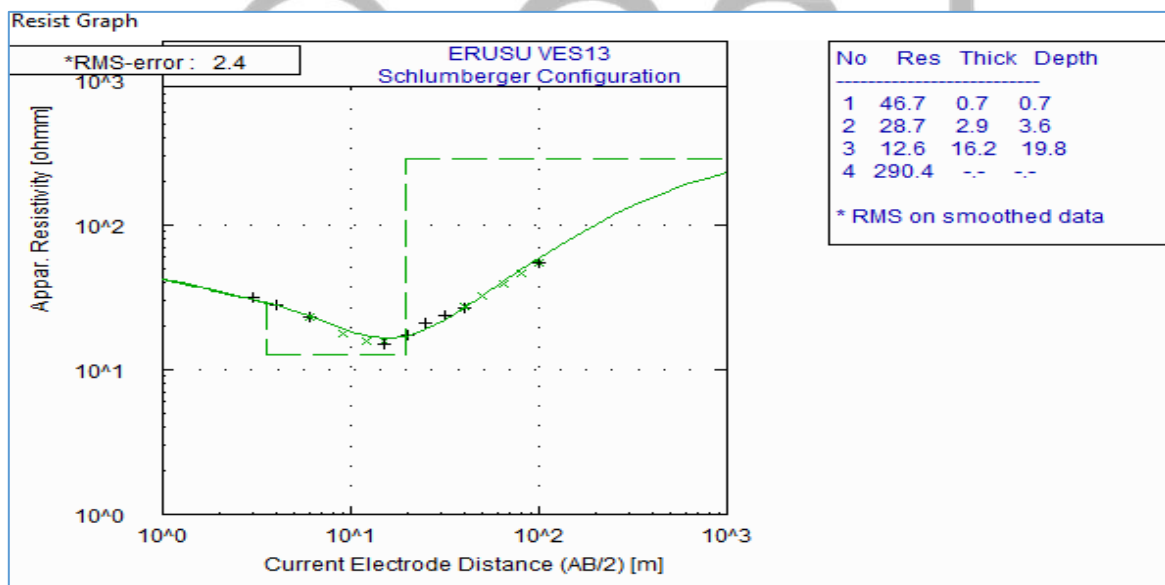


Plate 16: showing sounding curve of VES point 13

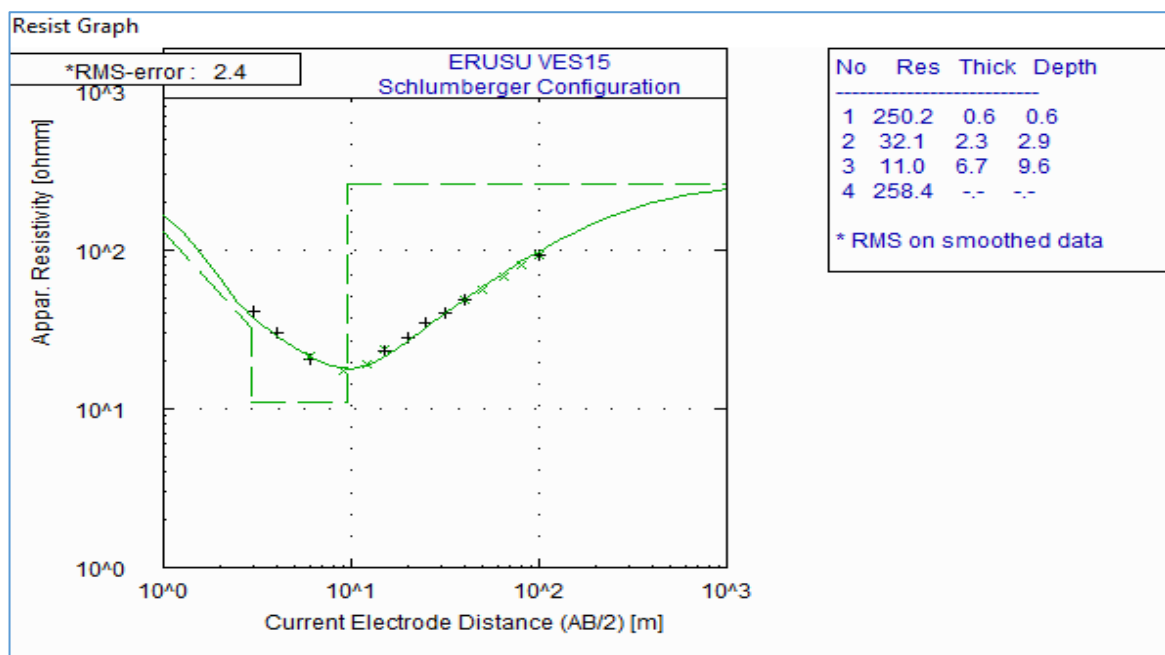


Plate 17: showing sounding curve of VES point 15

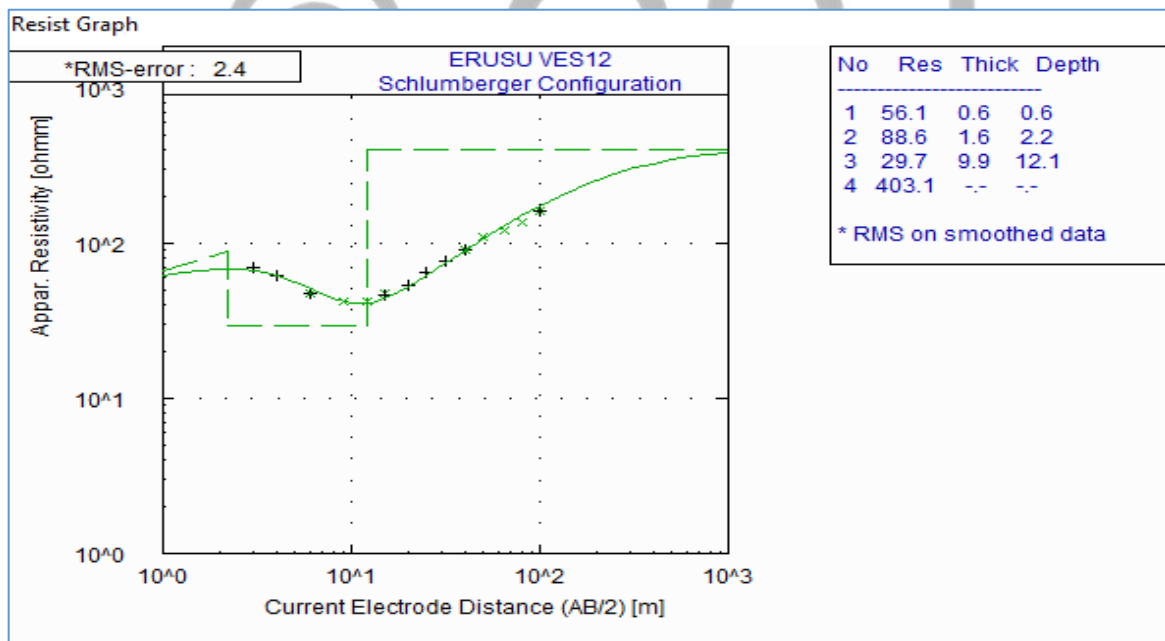


Plate 18: showing sounding curve of VES point 12

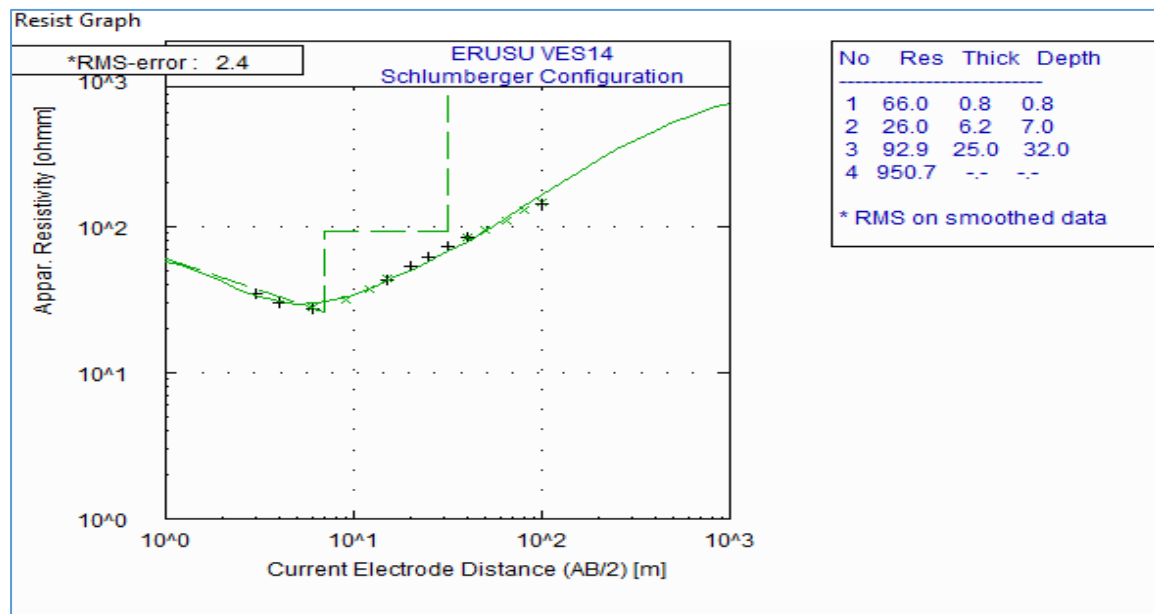


Plate 19: showing sounding curve of VES point 14

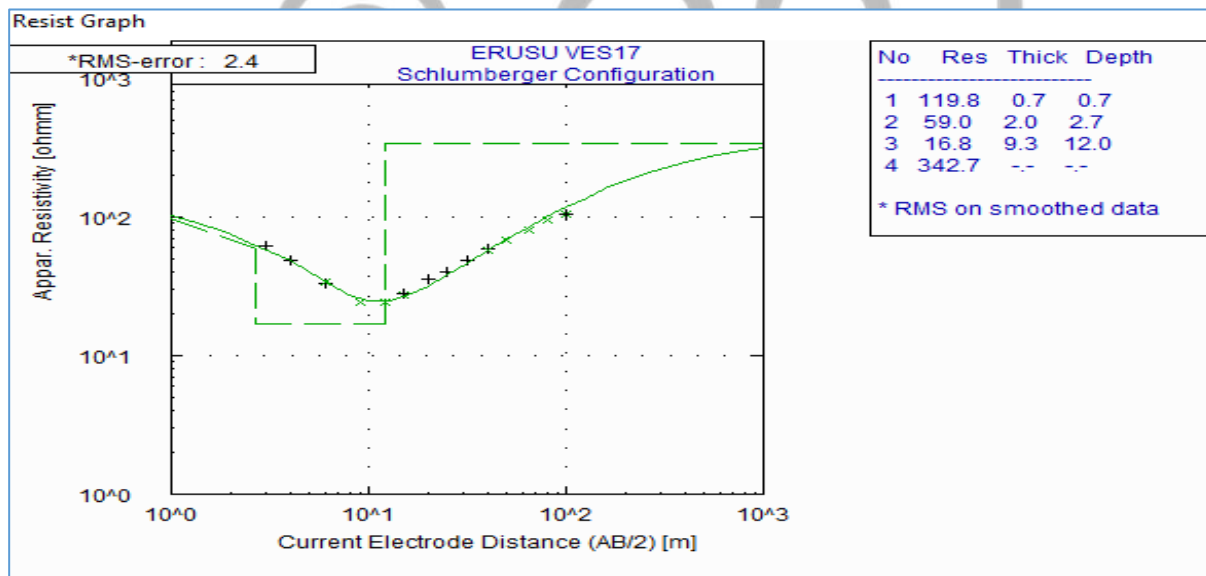


Plate 20: showing sounding curve of VES point 17

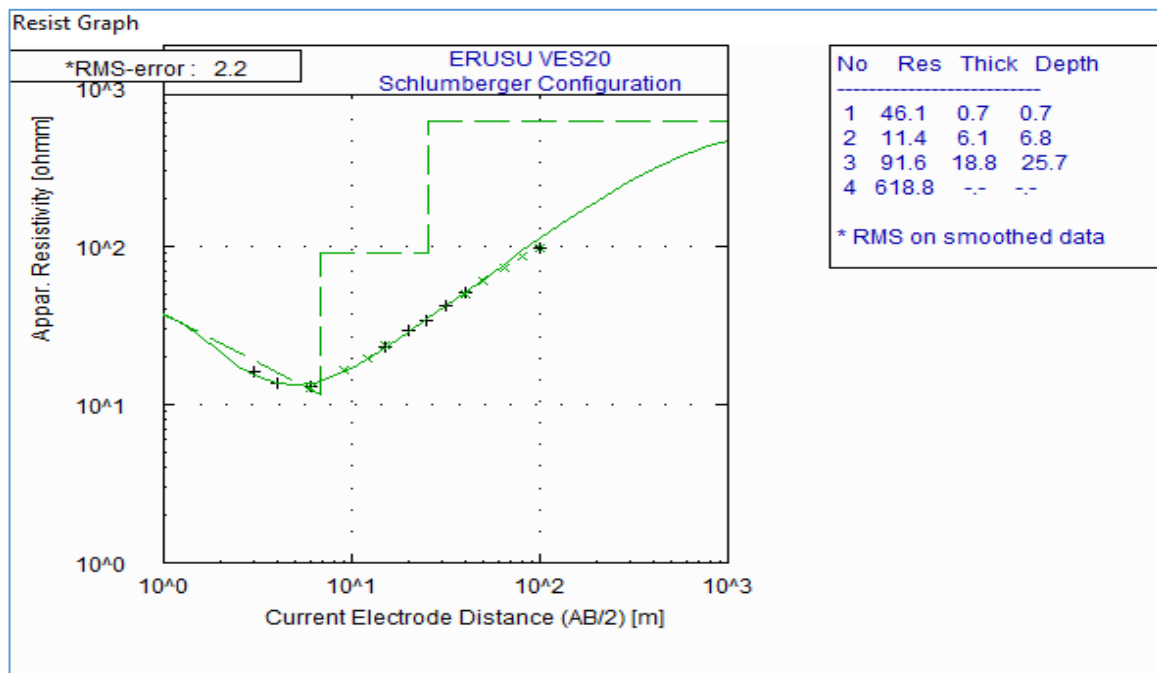


Plate21: showing sounding curve of VES point 20

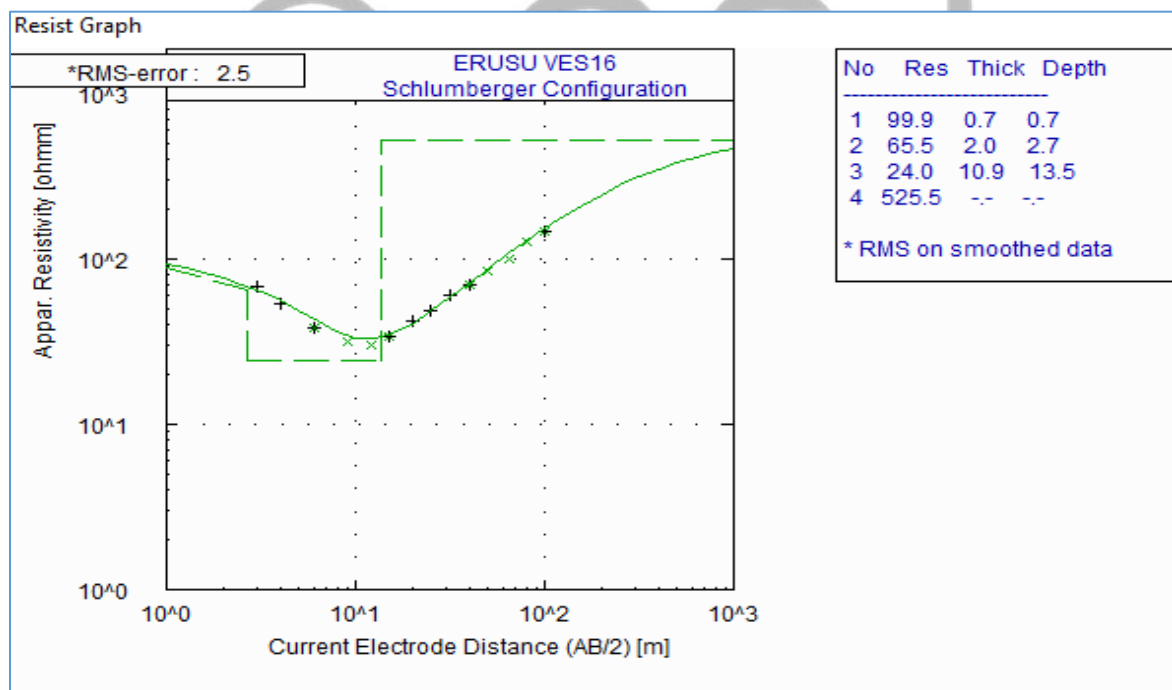


Plate 22: showing sounding curve of VES point 16.

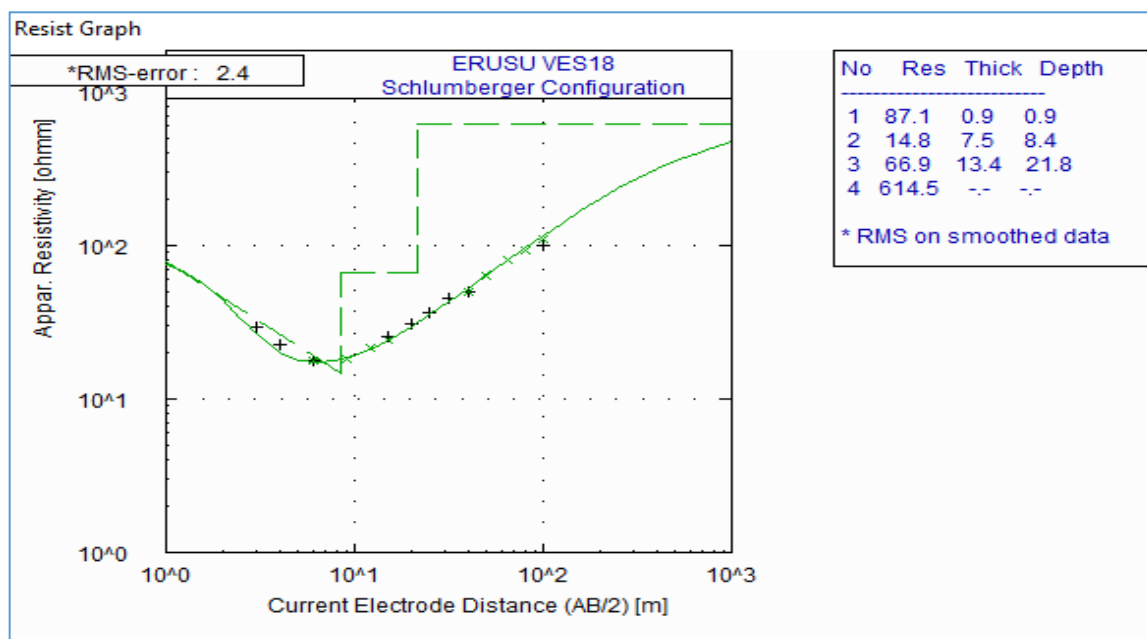


Plate 23: showing sounding curve of VES point 18

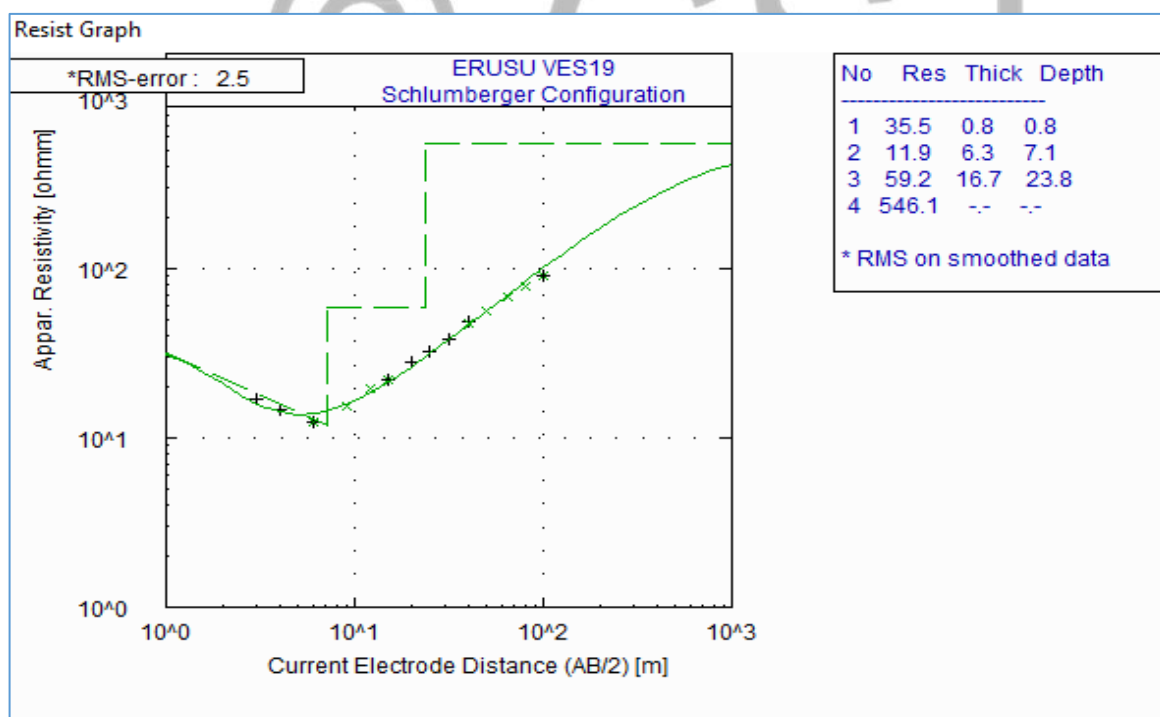


Plate 24: showing sounding curve of VES point 21

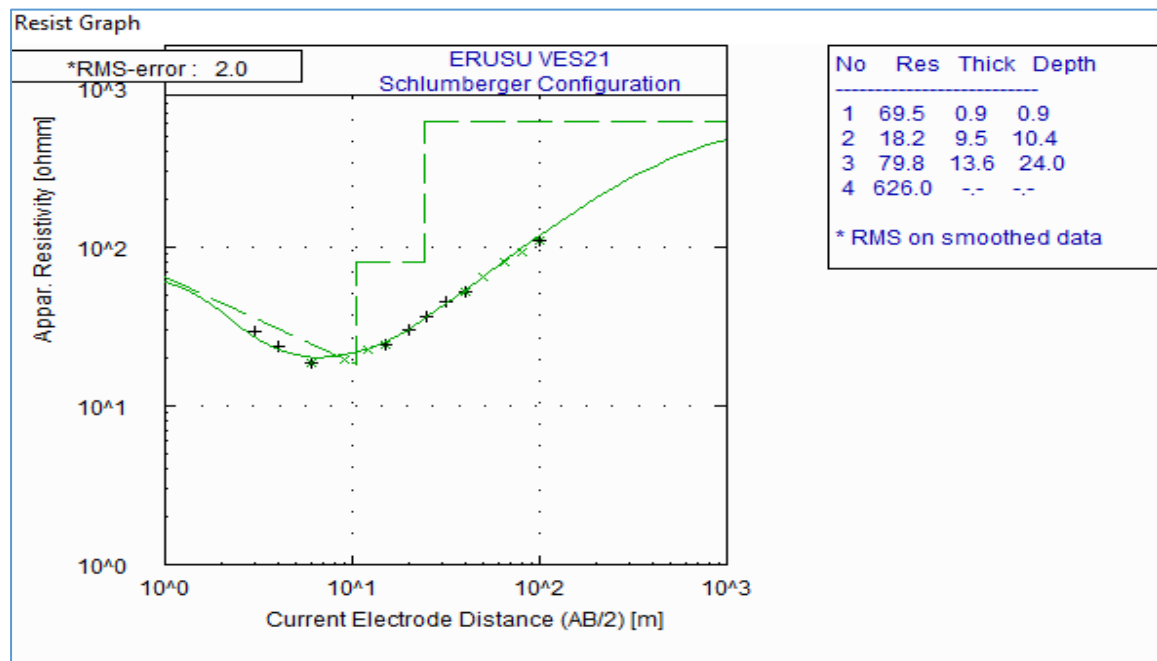


Plate 25: showing sounding curve of VES point 21

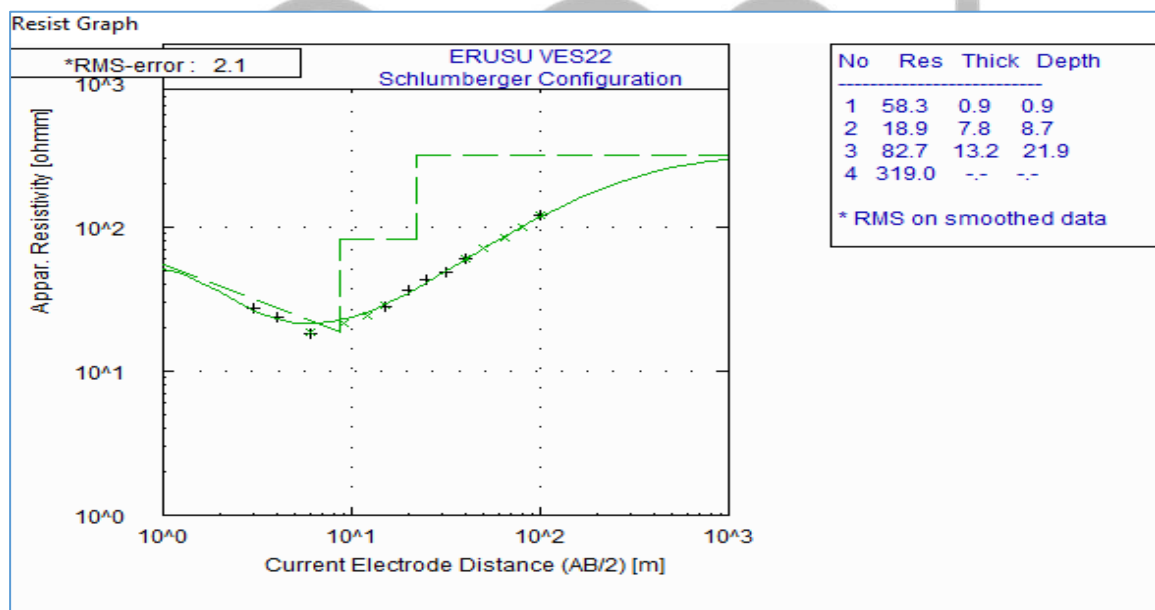


Plate 26: showing sounding curve of VES point 22

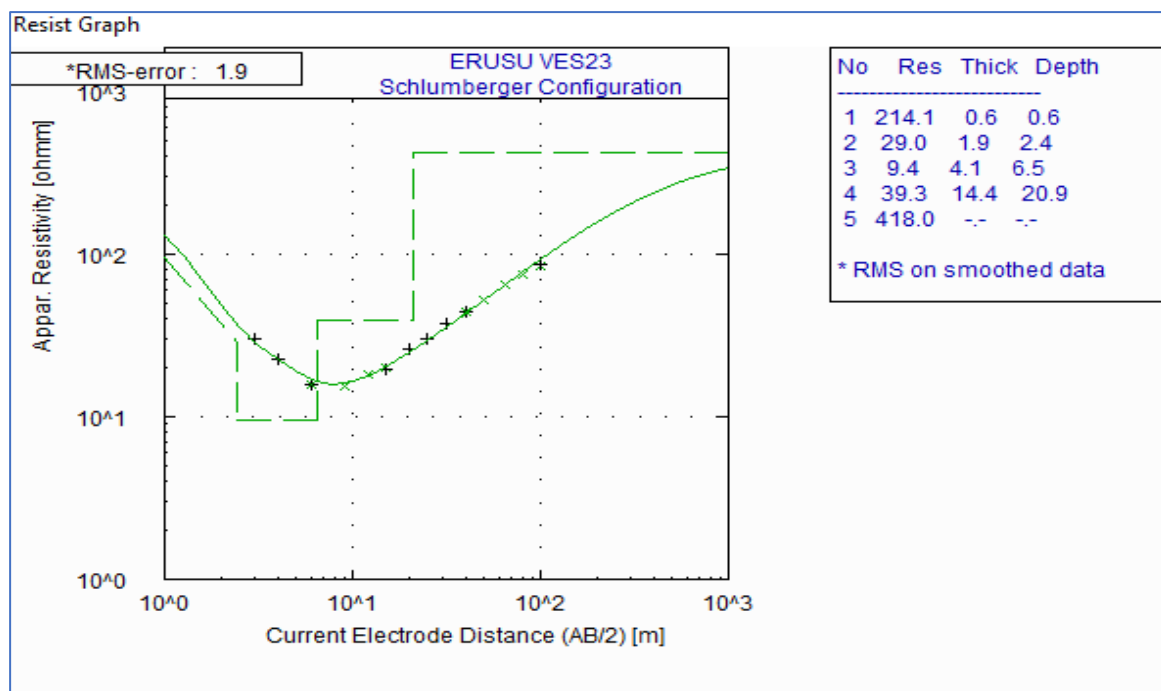


Plate 27: showing sounding curve of VES point 23

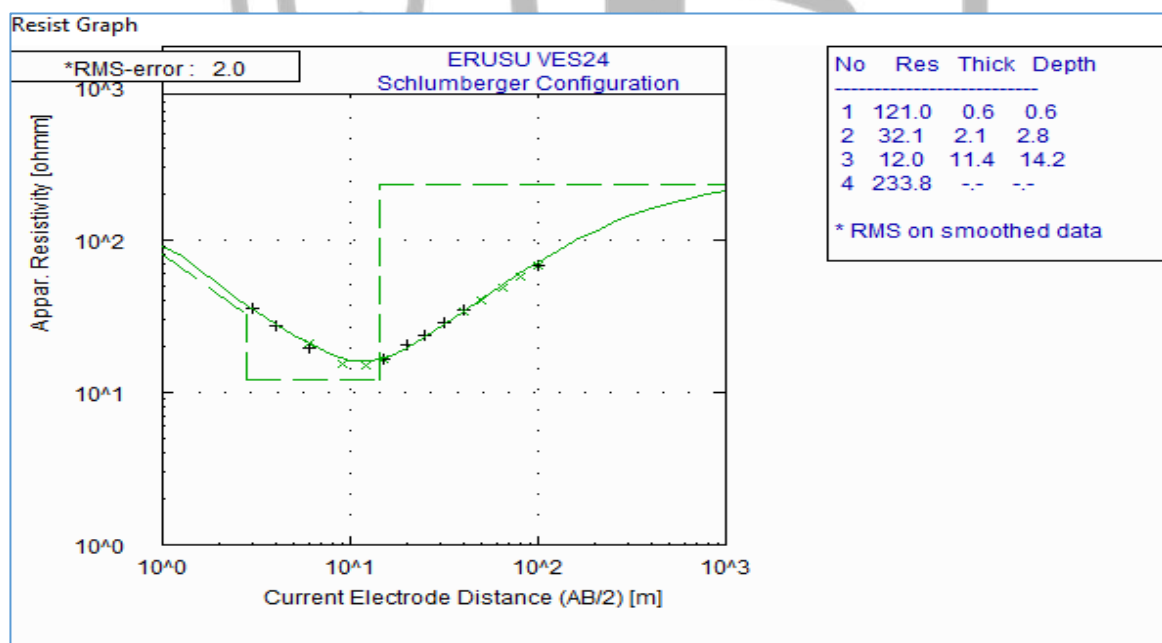


Plate 28: showing sounding curve of VES point 24

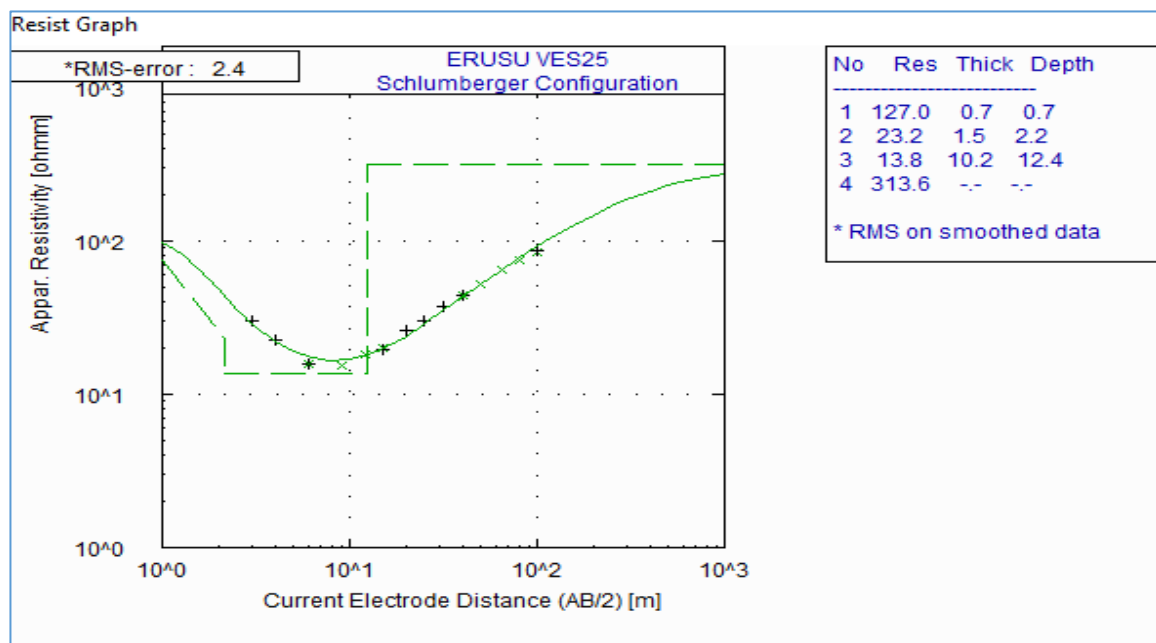


Plate 29: showing sounding curve of VES point 25

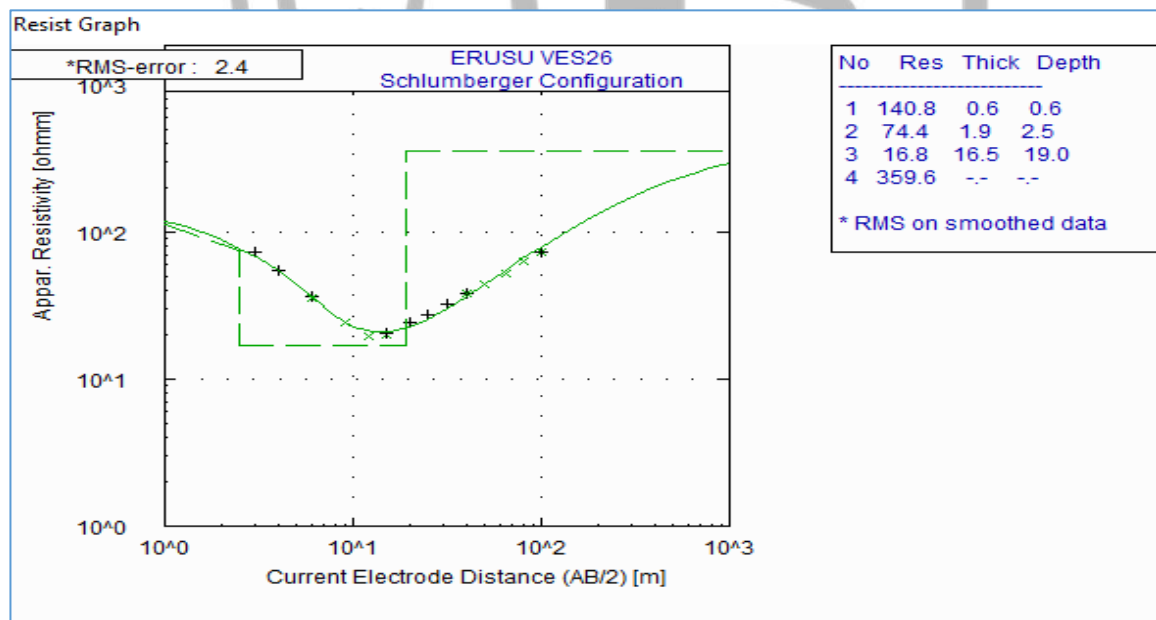


Plate 30: showing sounding curve of VES point 26

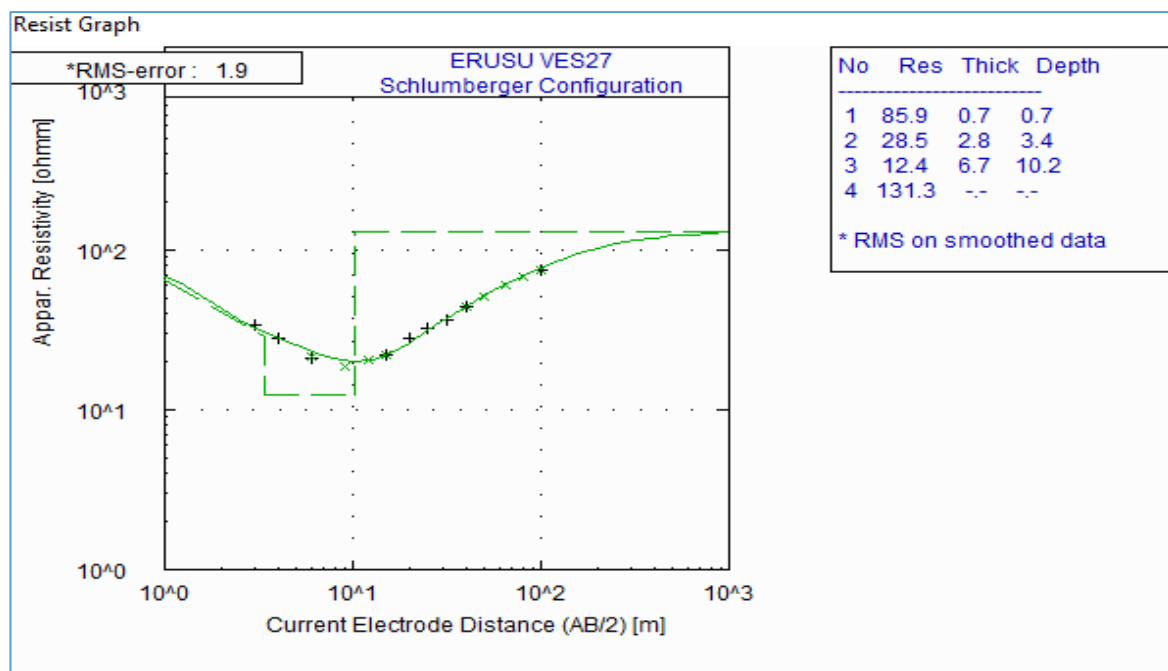


Plate 31: showing sounding curve of VES point 27

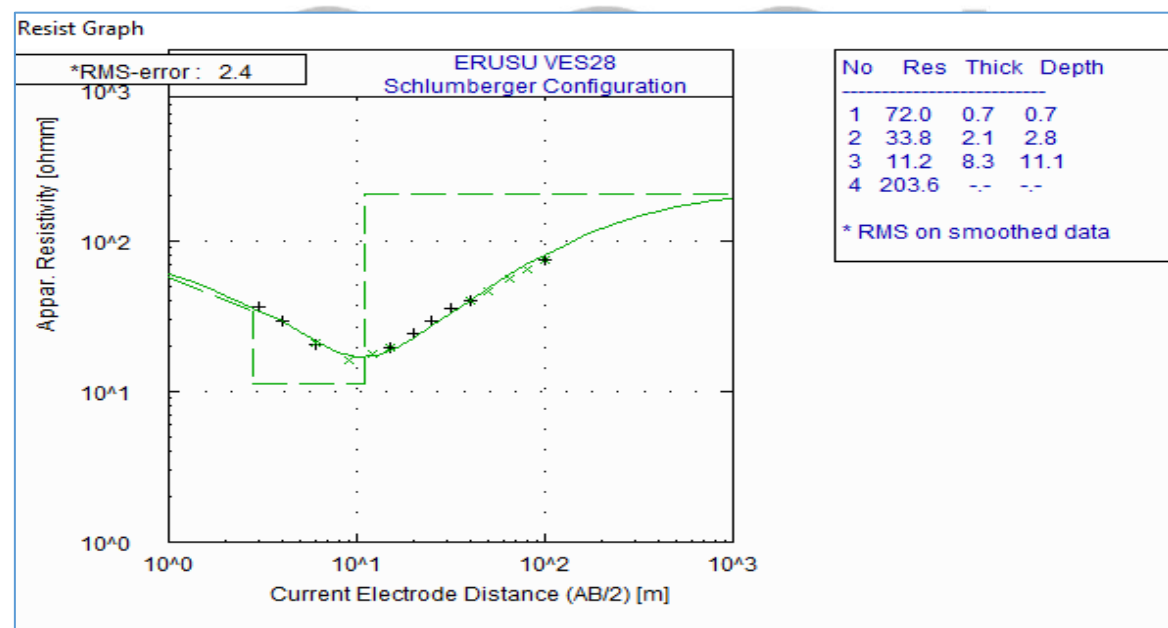


Plate 31: showing sounding curve of VES point 28

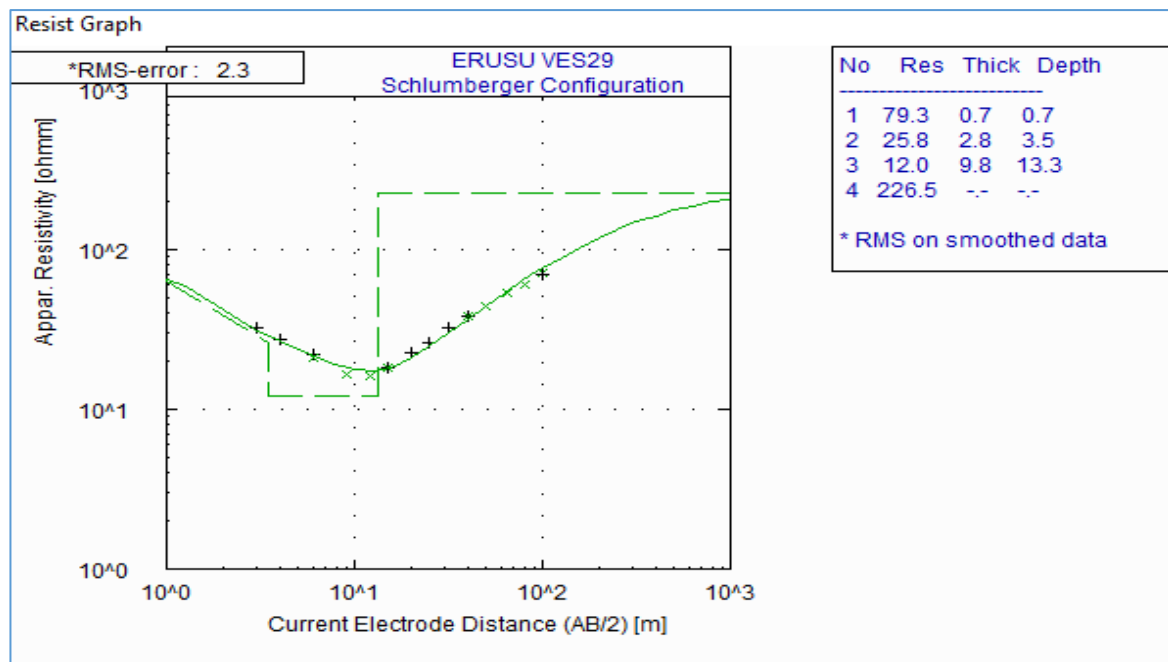


Plate 32: showing sounding curve of VES point 29

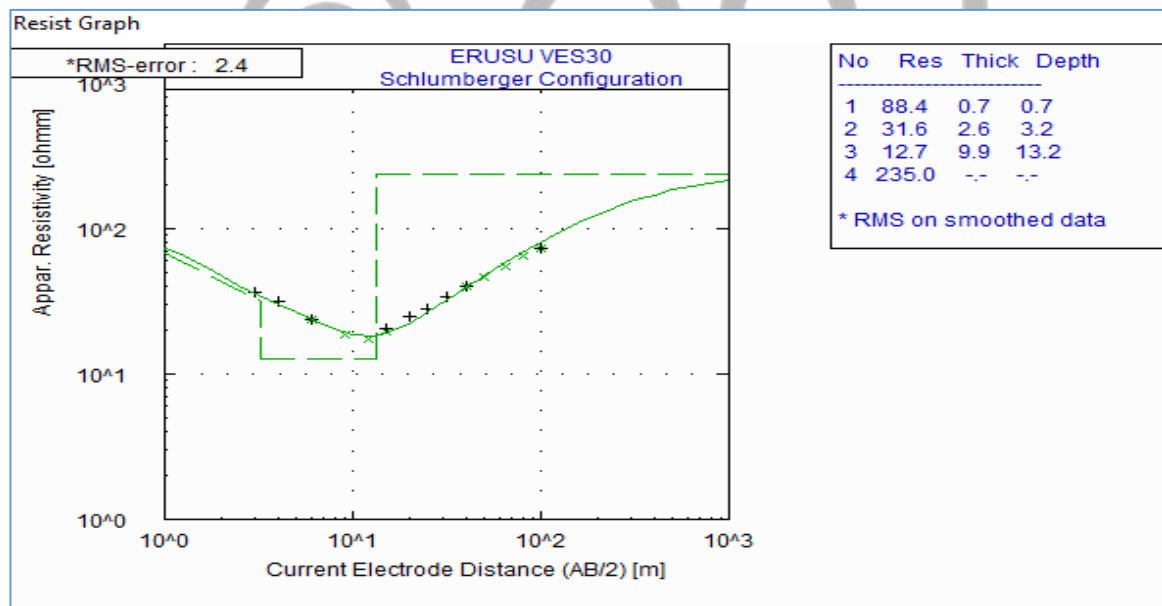


Plate 33: showing sounding curve of VES point 30

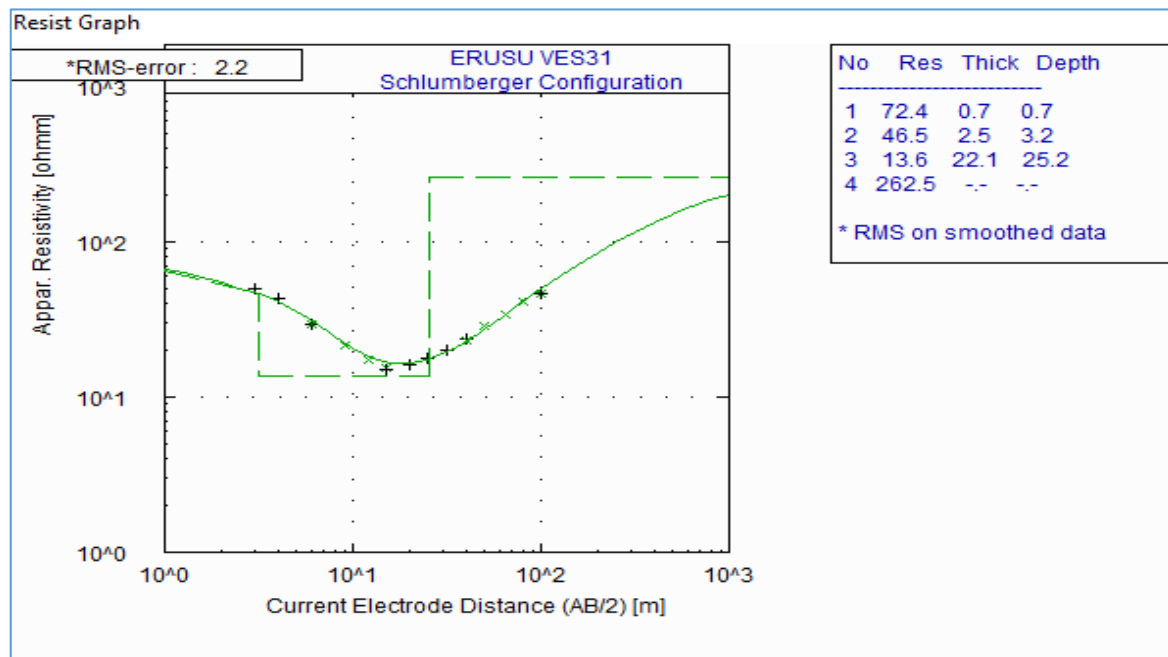


Plate 34: showing sounding curve of VES point 31

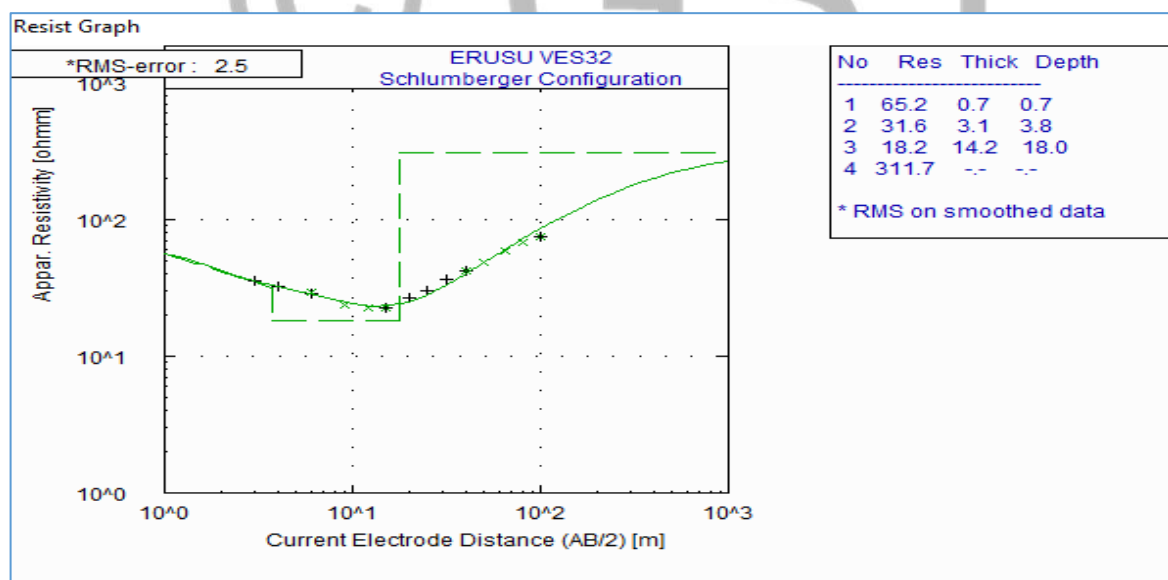


Plate 35: showing sounding curve of VES point 32

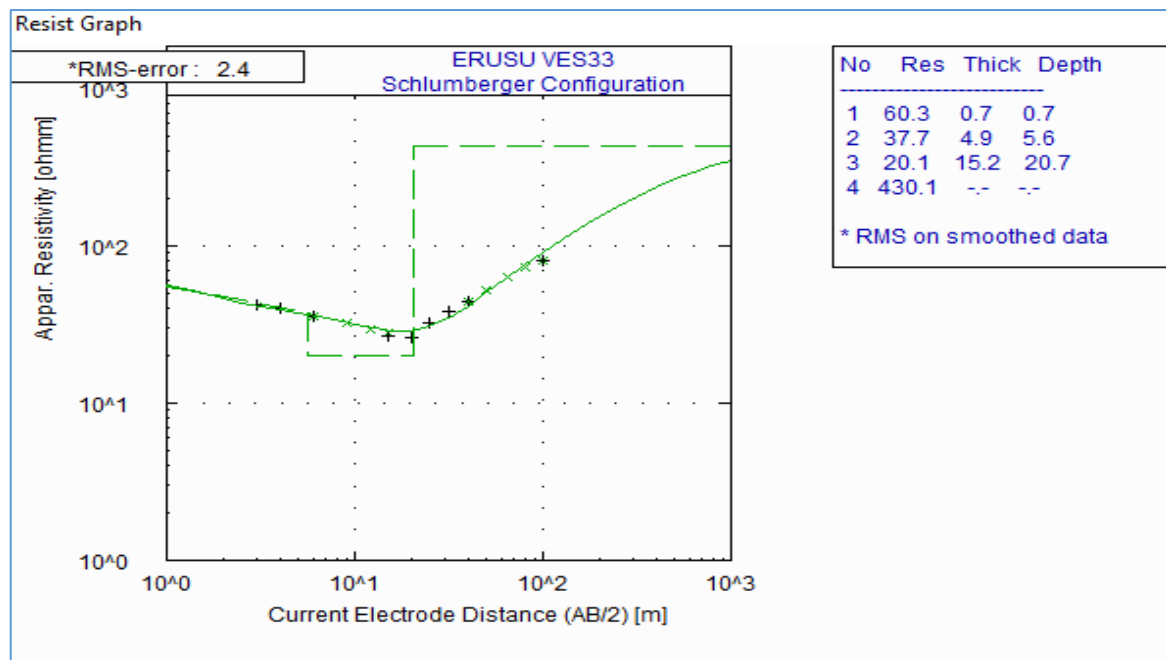


Plate 36: showing sounding curve of VES point 33

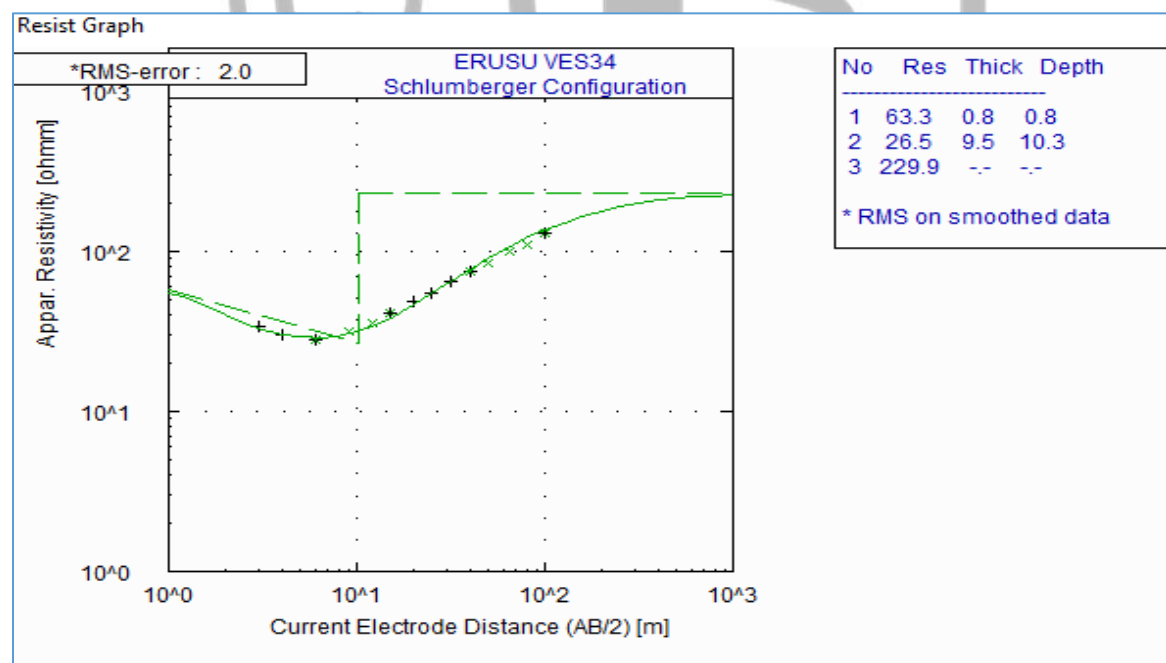


Plate 37: showing sounding curve of VES point 34

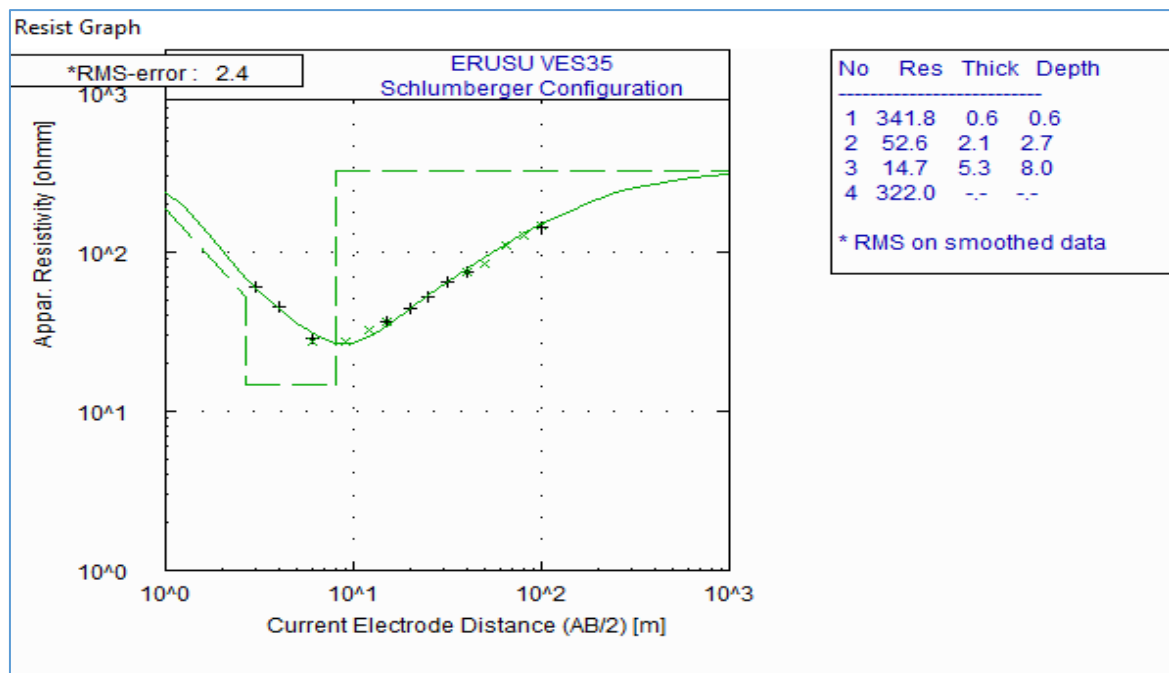


Plate 38: showing sounding curve of VES point 35

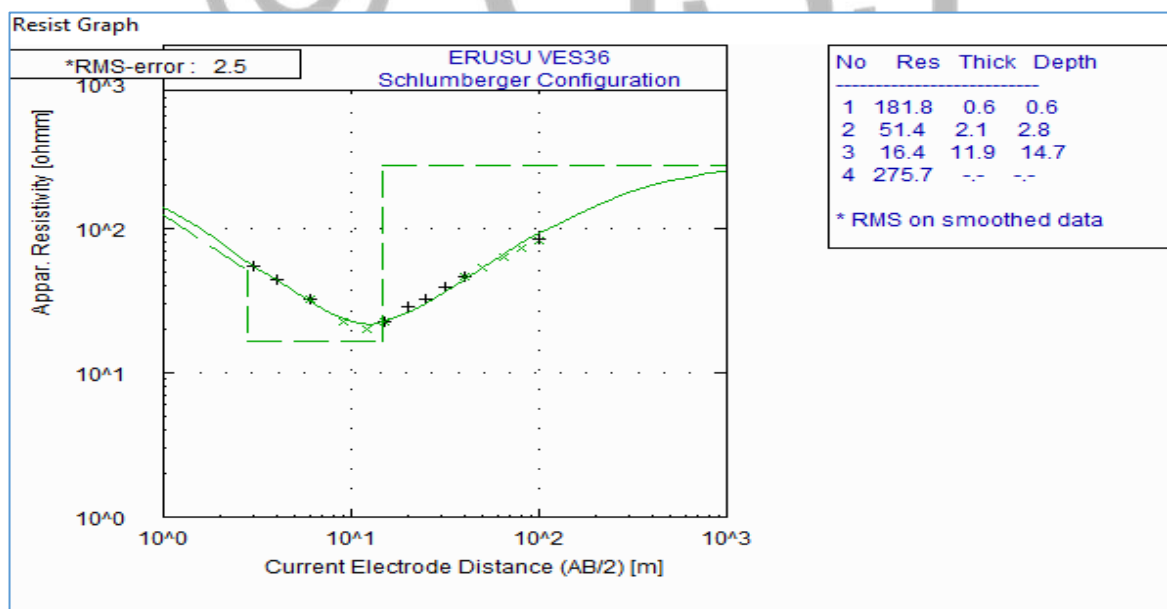


Plate 39: showing sounding curve of VES point 36

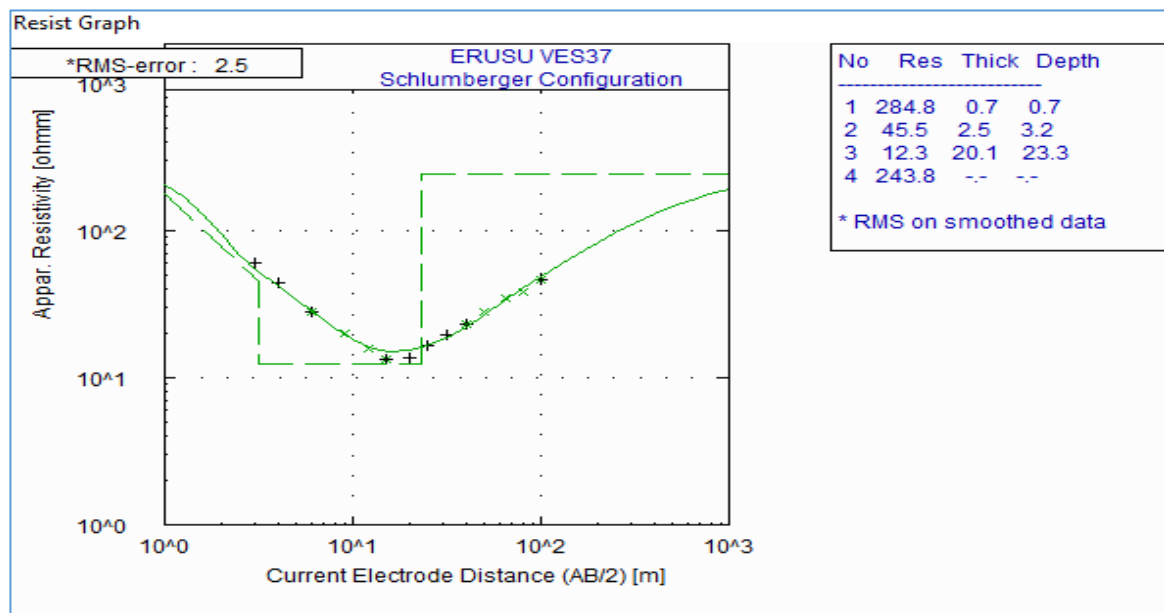


Plate 40:showing sounding curve of VES point 37

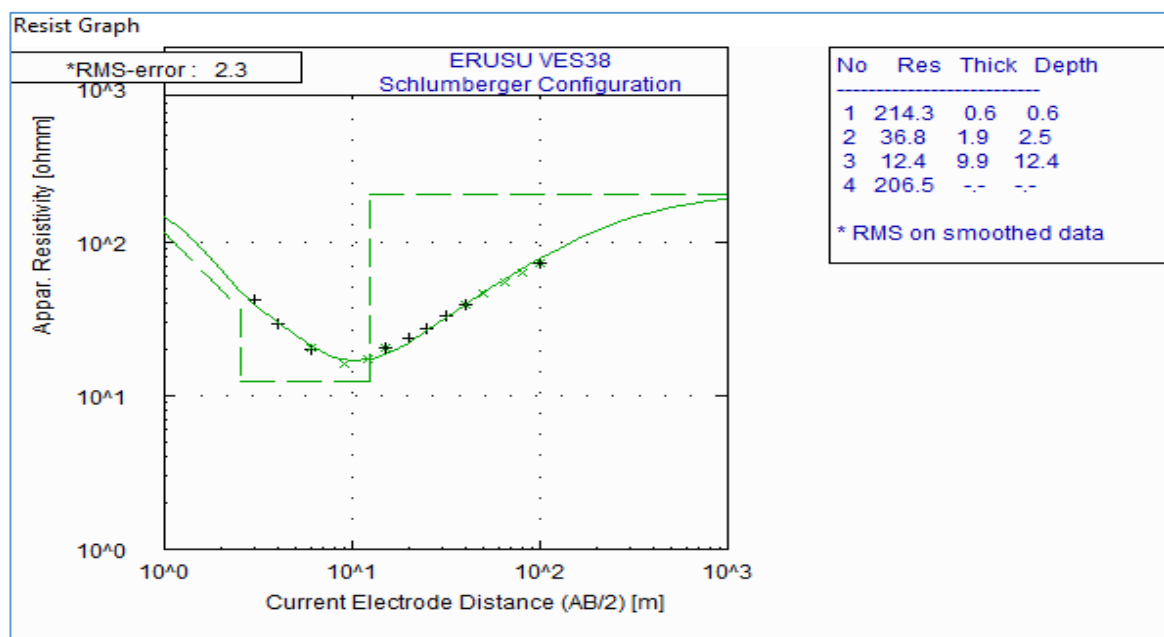


Plate 41:showing sounding curve of VES point 38

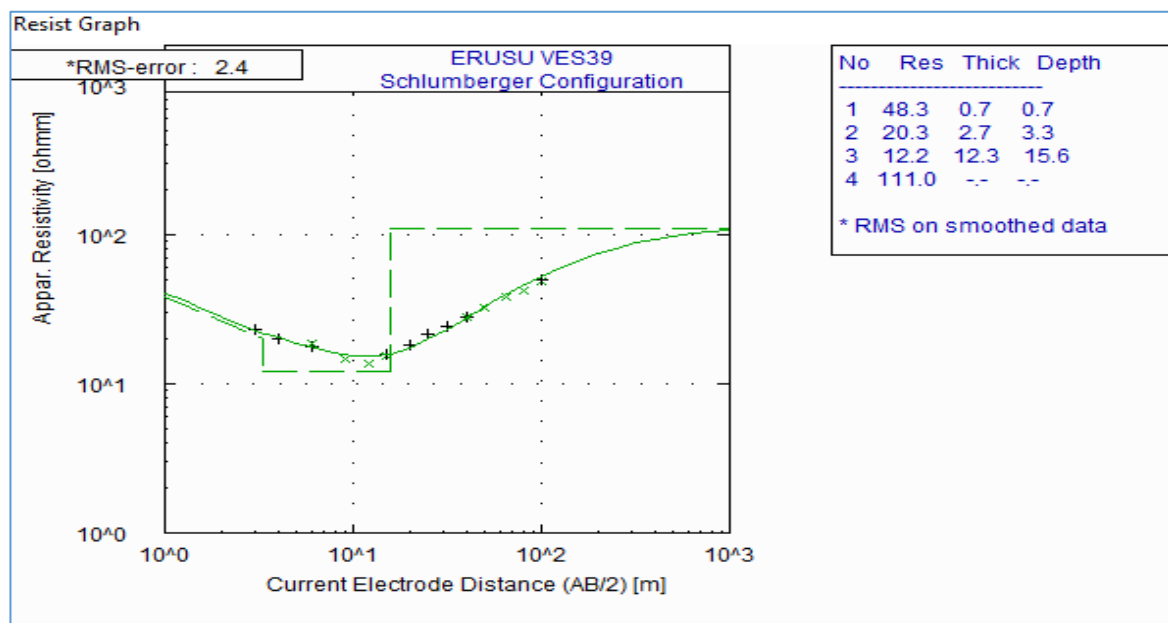


Plate 42: showing sounding curve of VES point 39

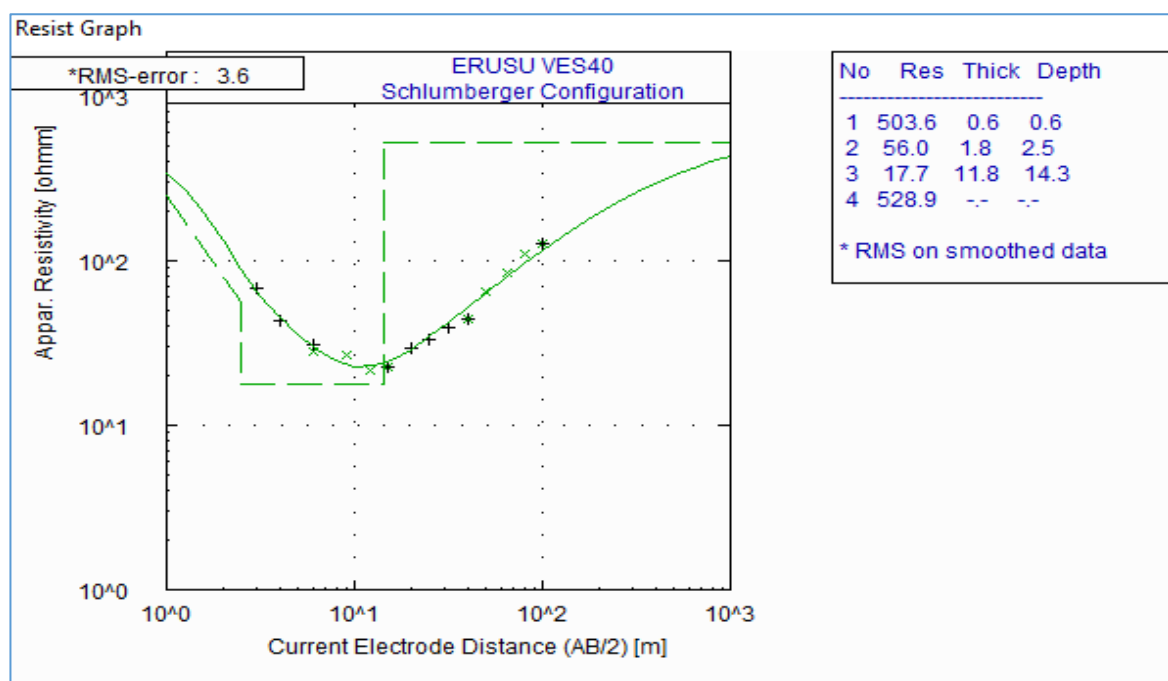


Plate 43: showing sounding curve of VES point 40

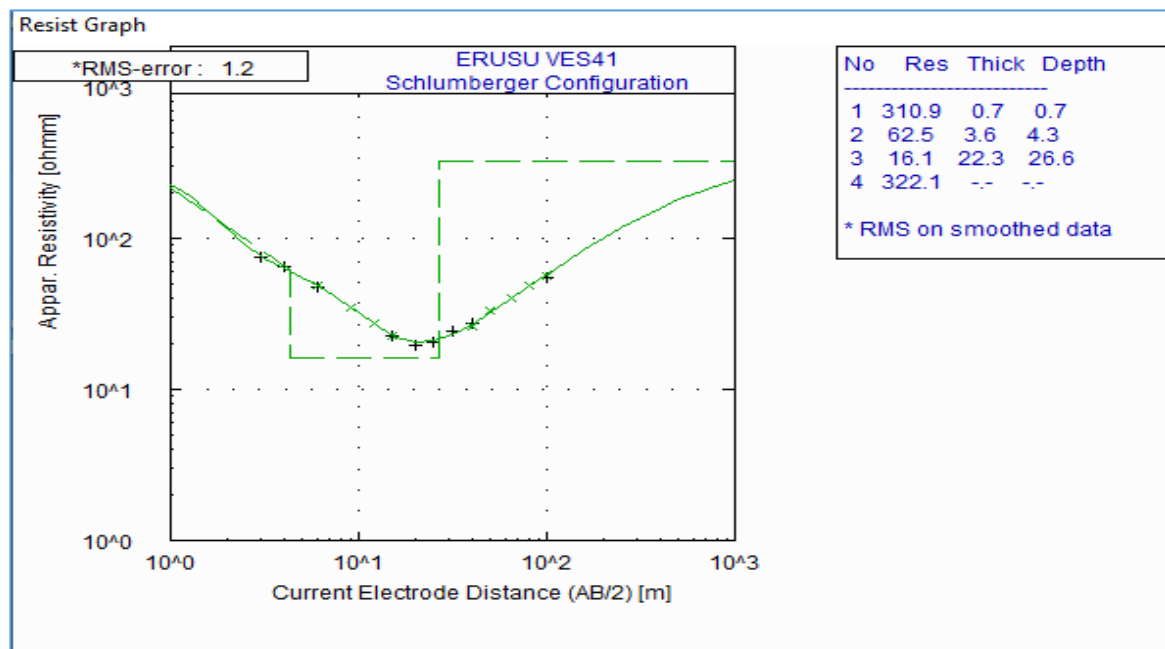


Plate 44:showing sounding curve of VES point 41

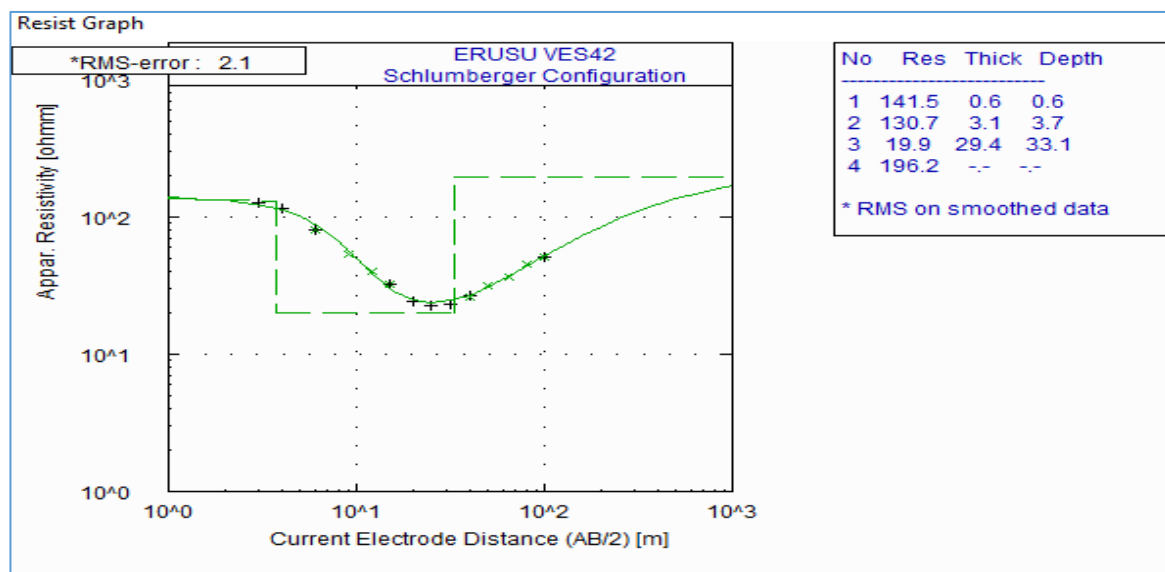


Plate 45:showing sounding curve of VES point 42

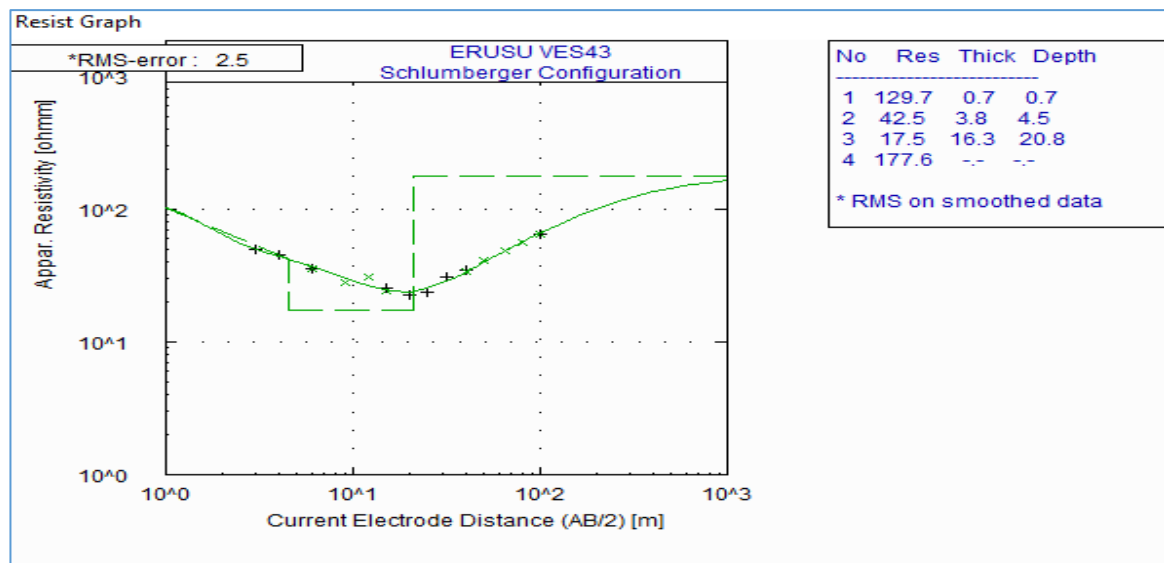


Plate 46: showing sounding curve of VES point 43

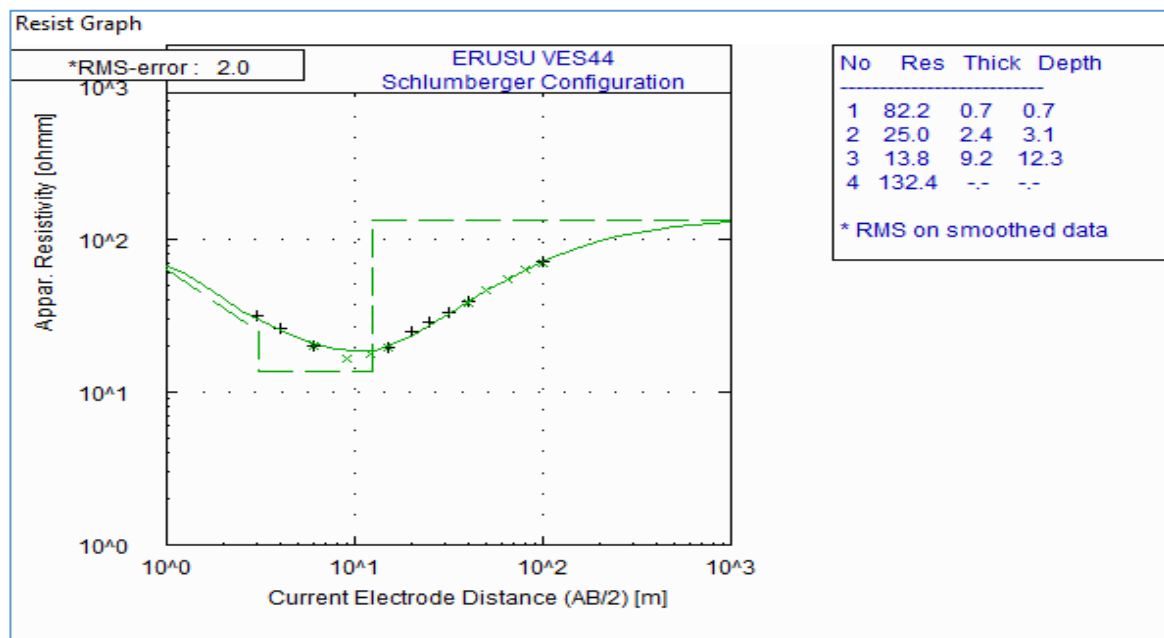


Plate 47: showing sounding curve of VES point 44

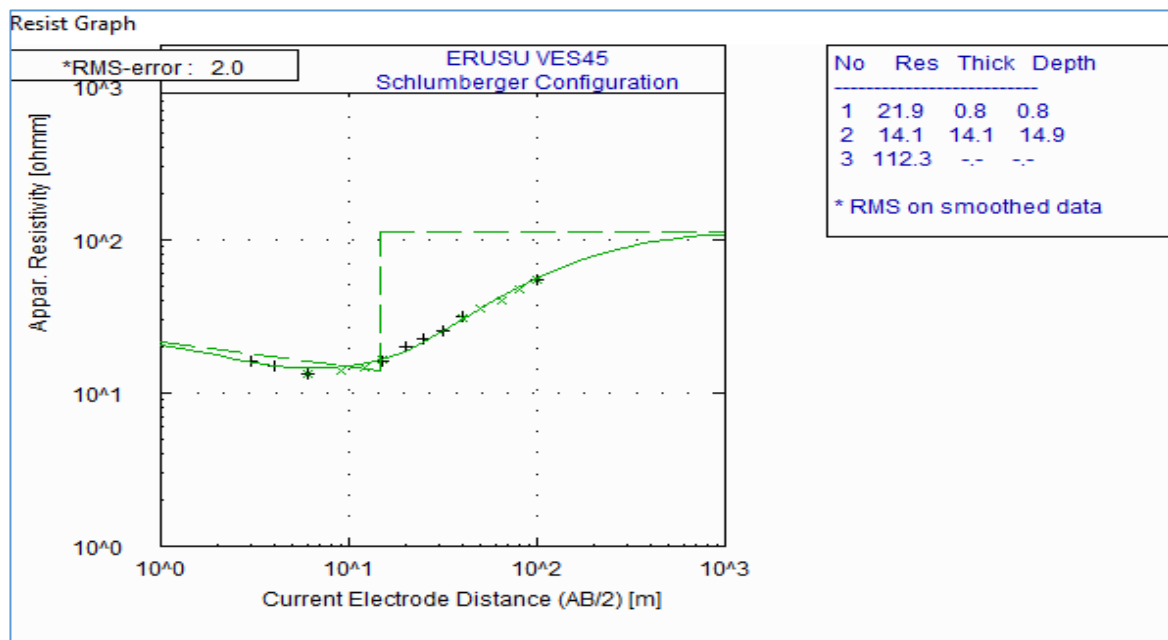


Plate 48: showing sounding curve of VES point 45

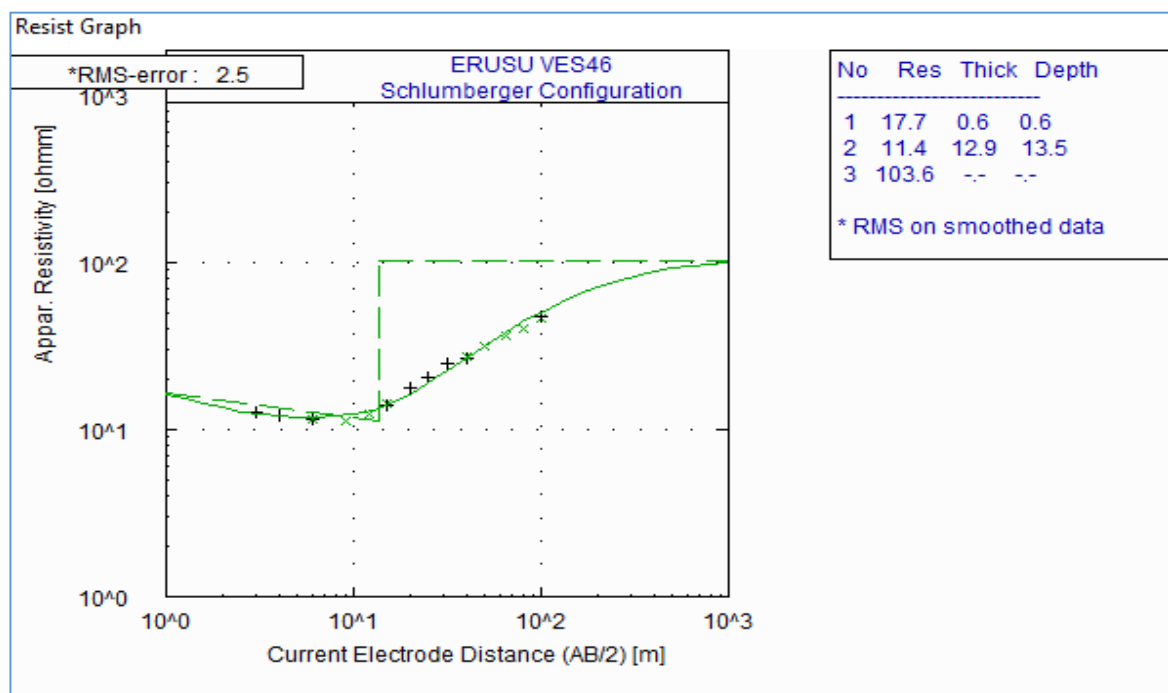


Plate 49: showing sounding curve of VES point 46

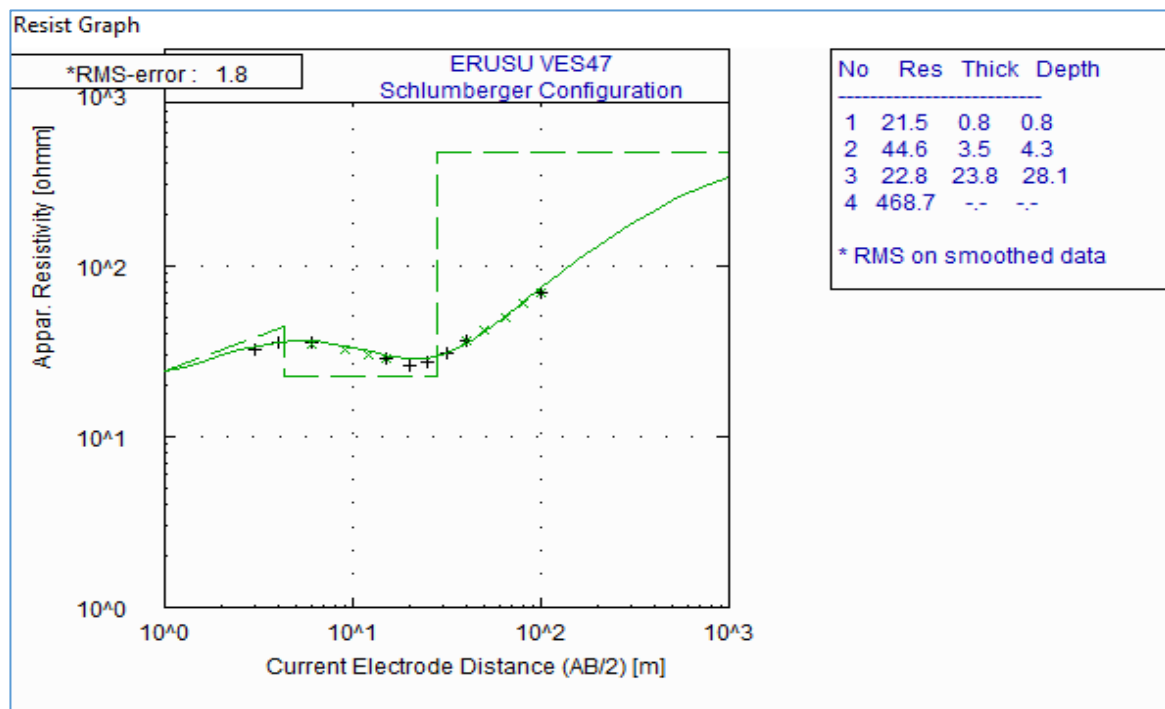


Plate 50: showing sounding curve of VES point 47

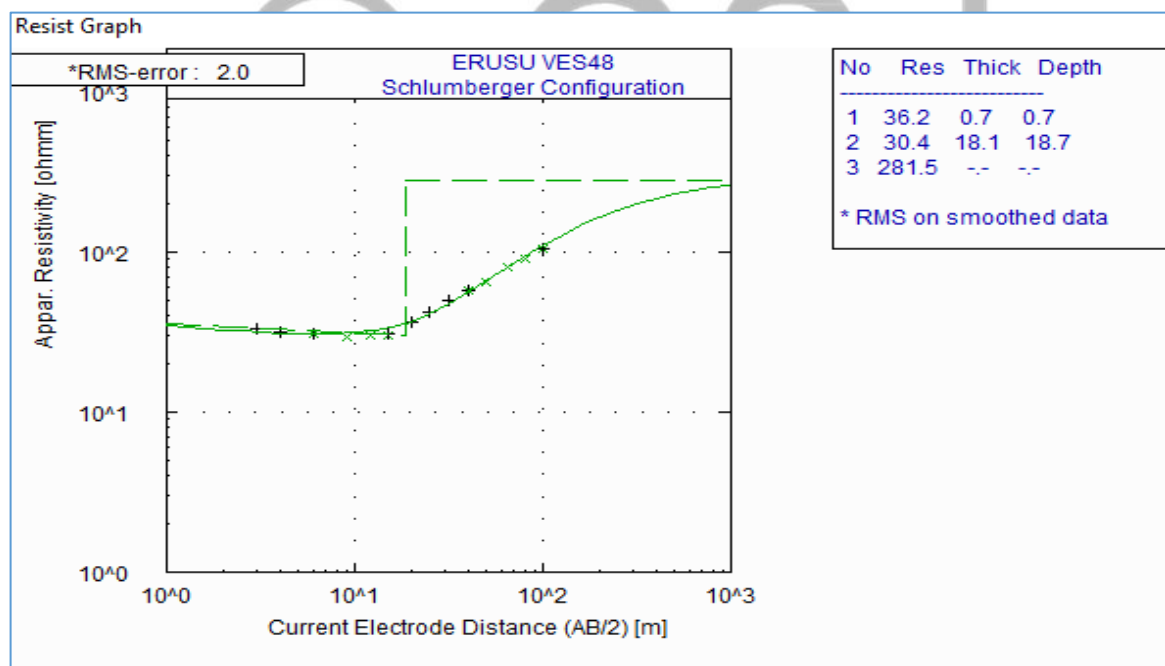


Plate 51: showing sounding curve of VES point 48

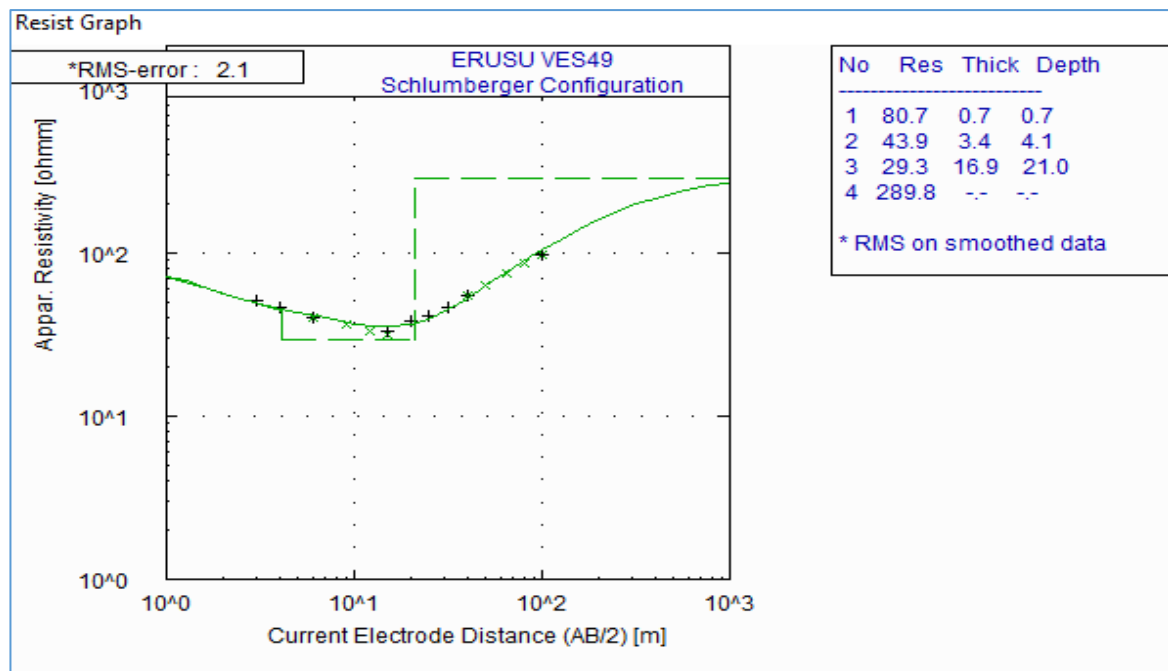


Plate 52: showing sounding curve of VES point 49

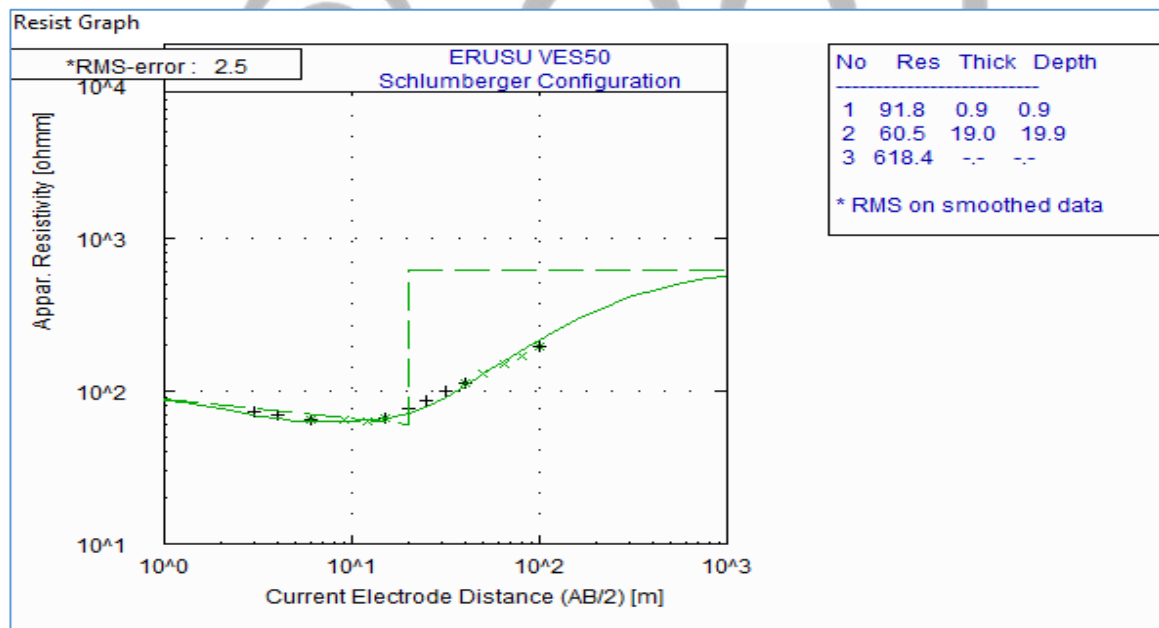


Plate 53: showing sounding curve of VES point 50

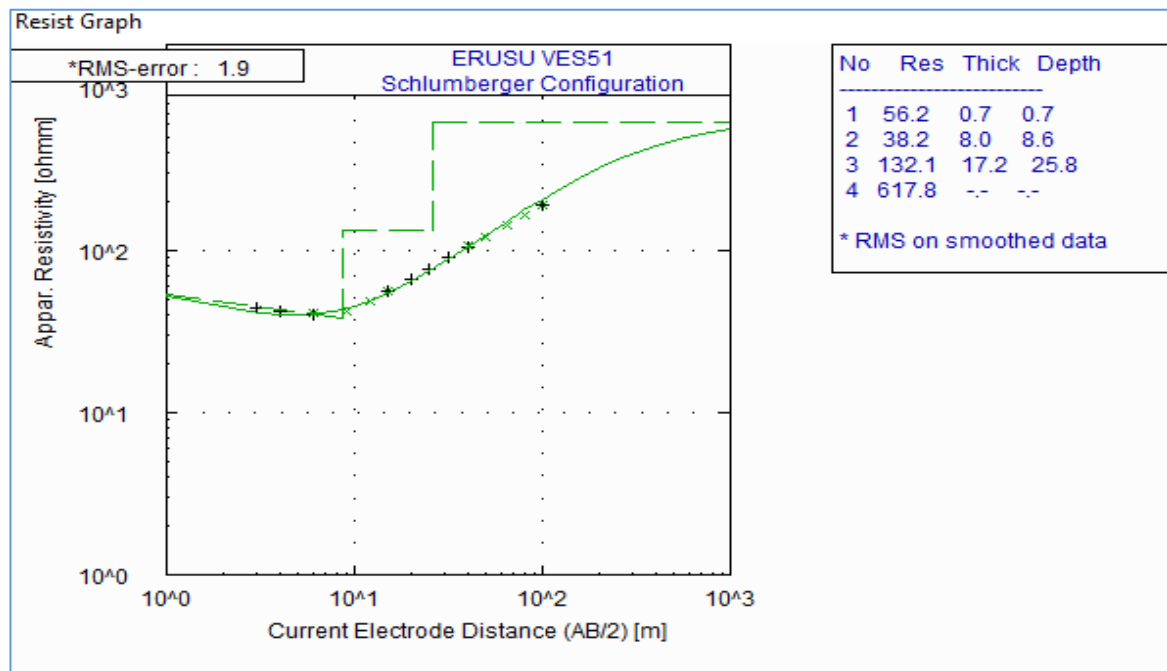


Plate 54: showing sounding curve of VES point 51

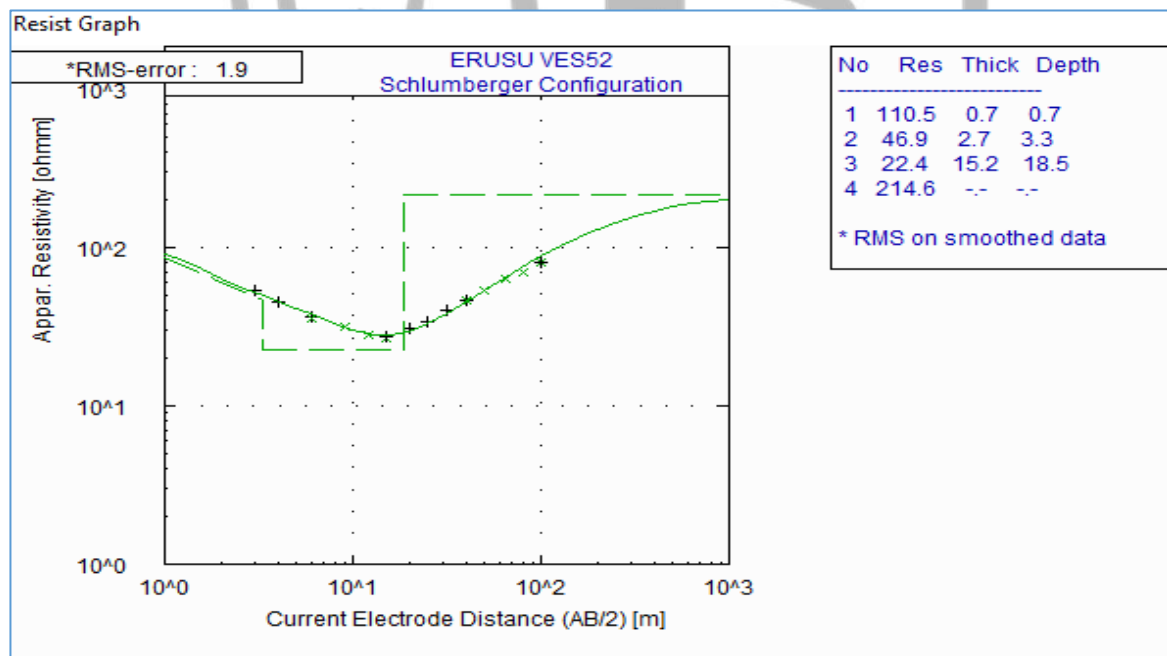


Plate 55: showing sounding curve of VES point 52

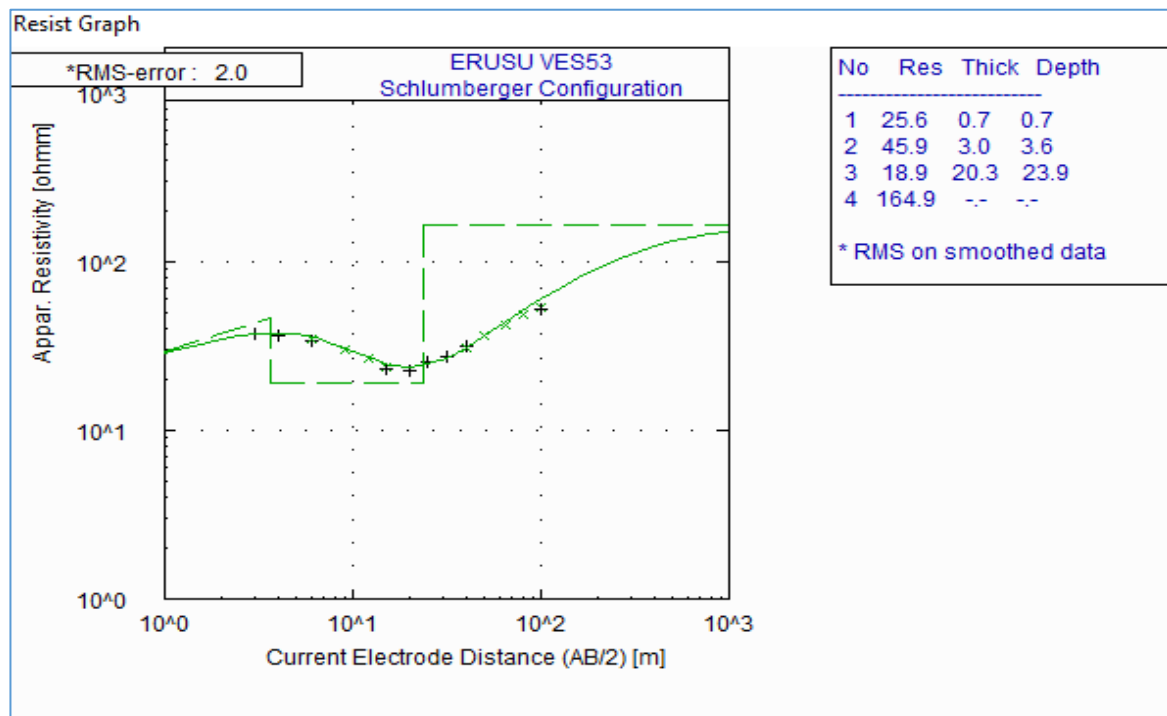


Plate 56: showing sounding curve of VES point 53

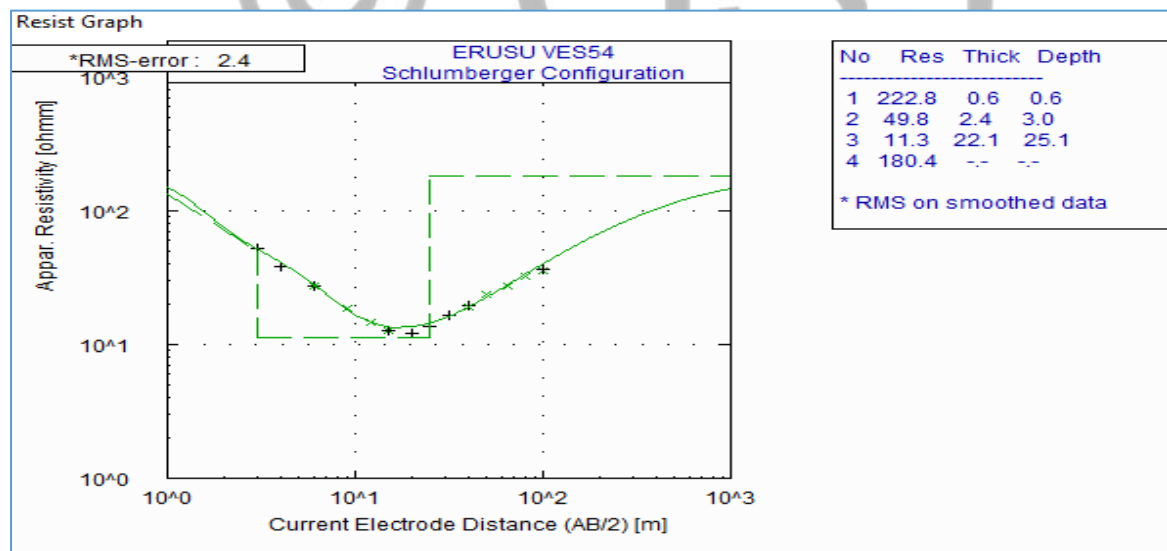


Plate 57: showing sounding curve of VES point 54

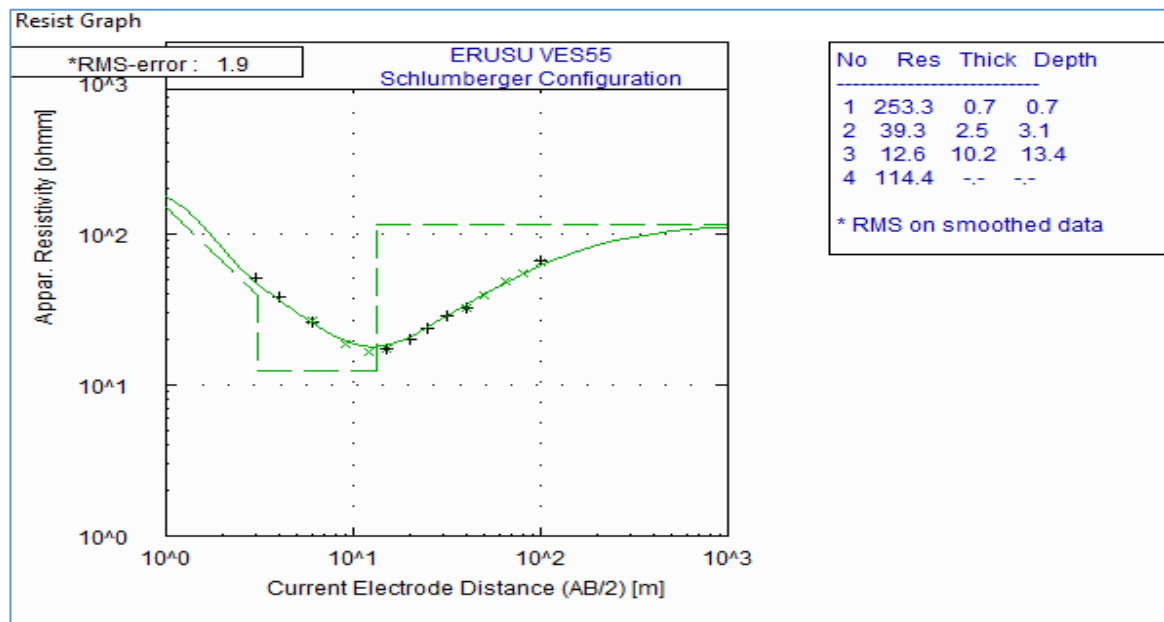


Plate 58: showing sounding curve of VES point 55

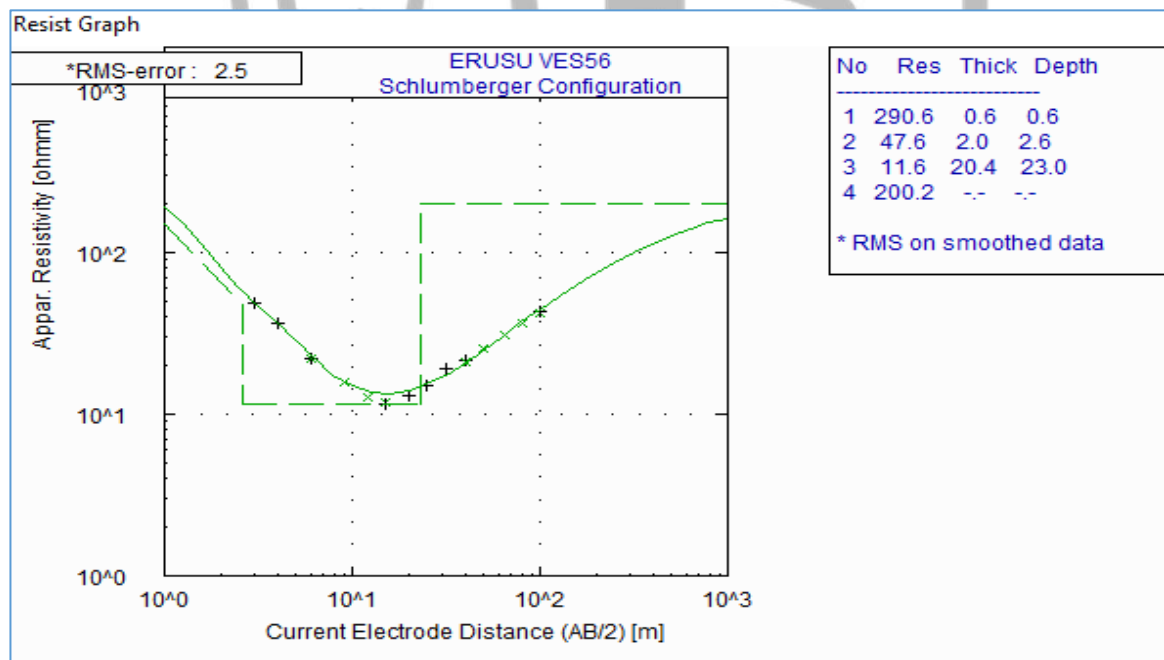


Plate 59: showing sounding curve of VES point 56

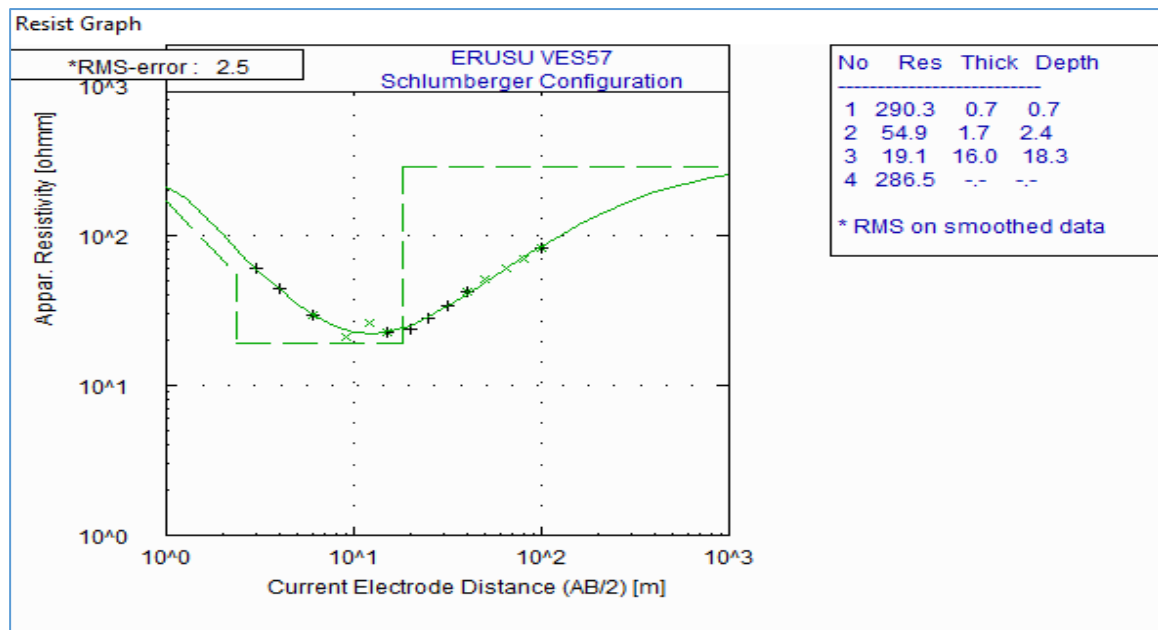


Plate 60: showing sounding curve of VES point 57

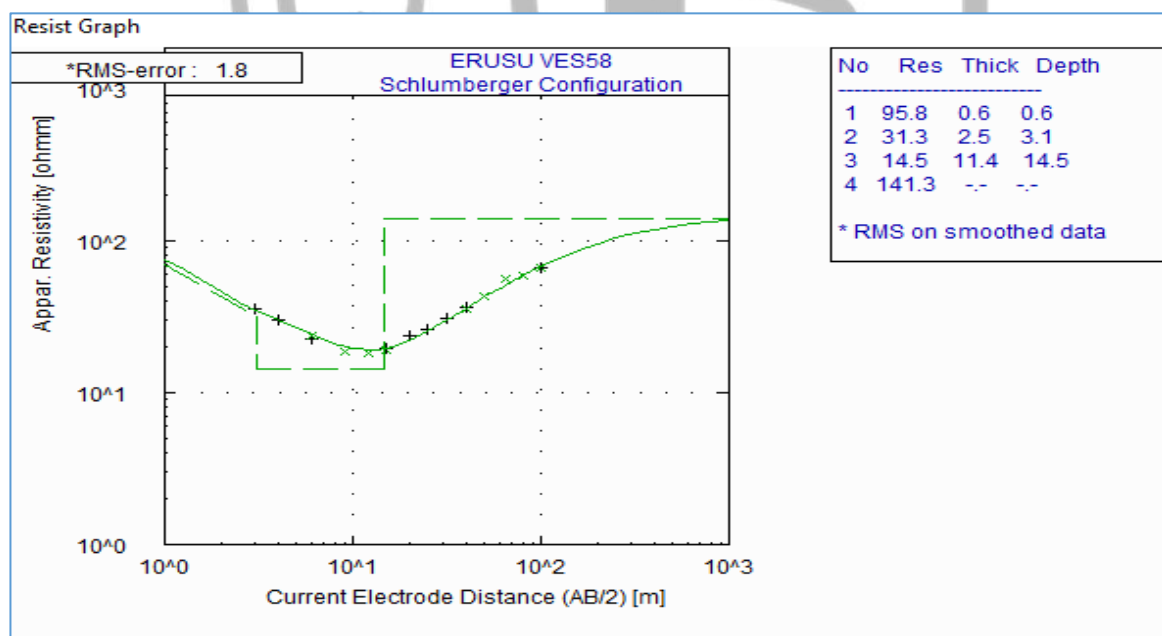


Plate 61: showing sounding curve of VES point 58

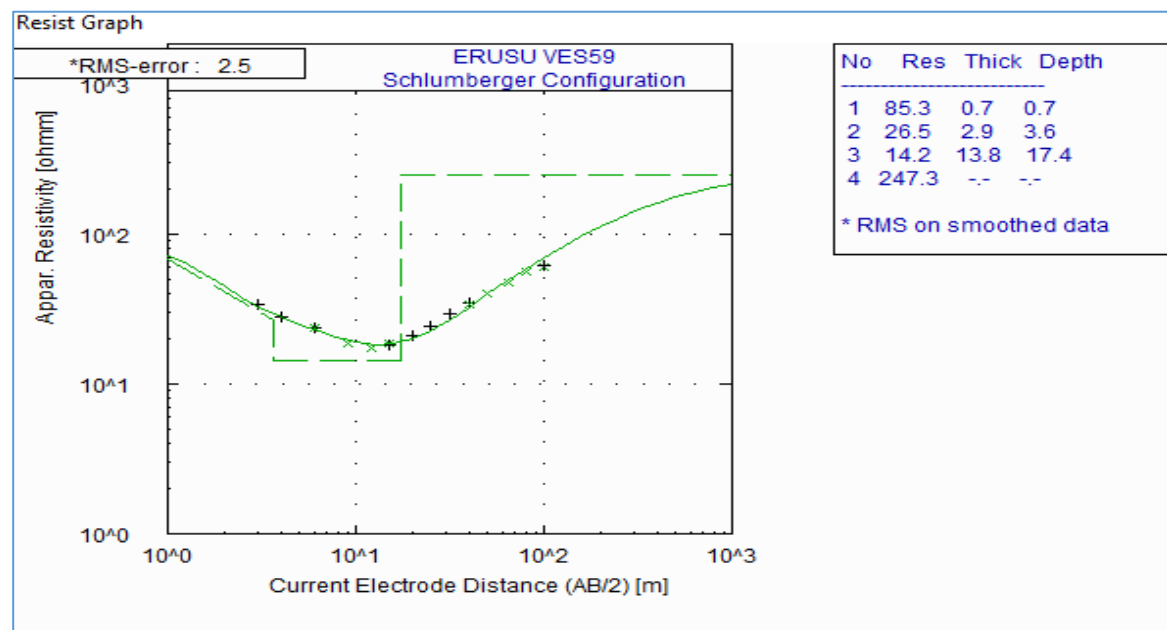


Plate 62: showing sounding curve of VES point 59

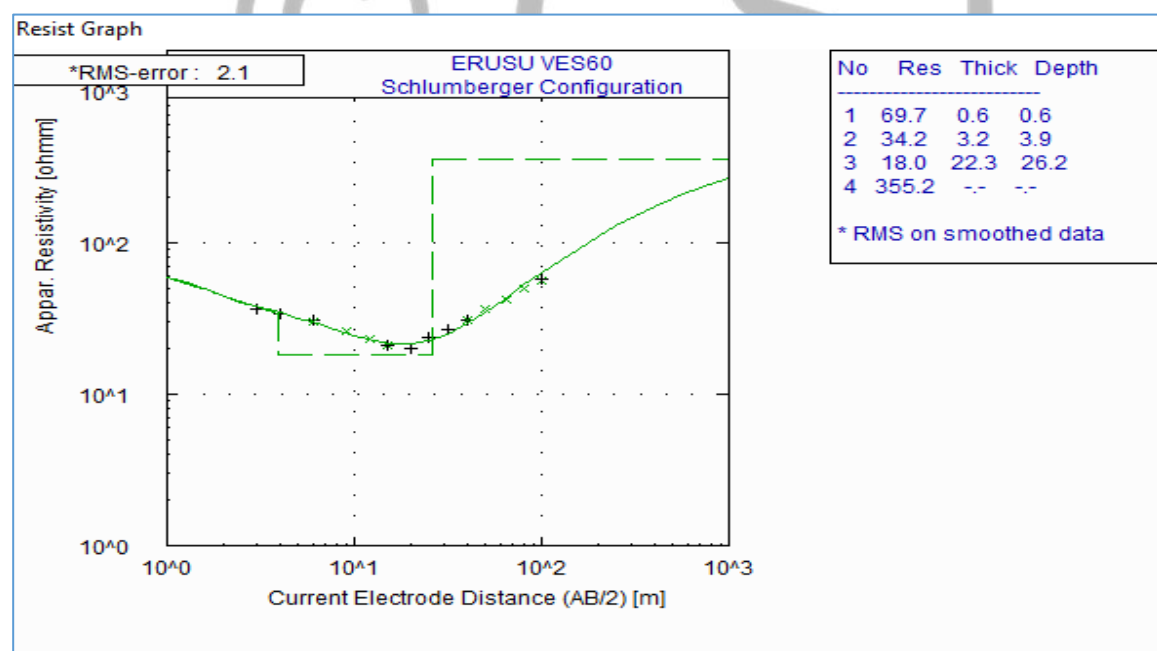


Plate 63: showing sounding curve of VES point 60

ELECTRICAL SOUNDING CURVES OF VES 21-60

APPENDIX C

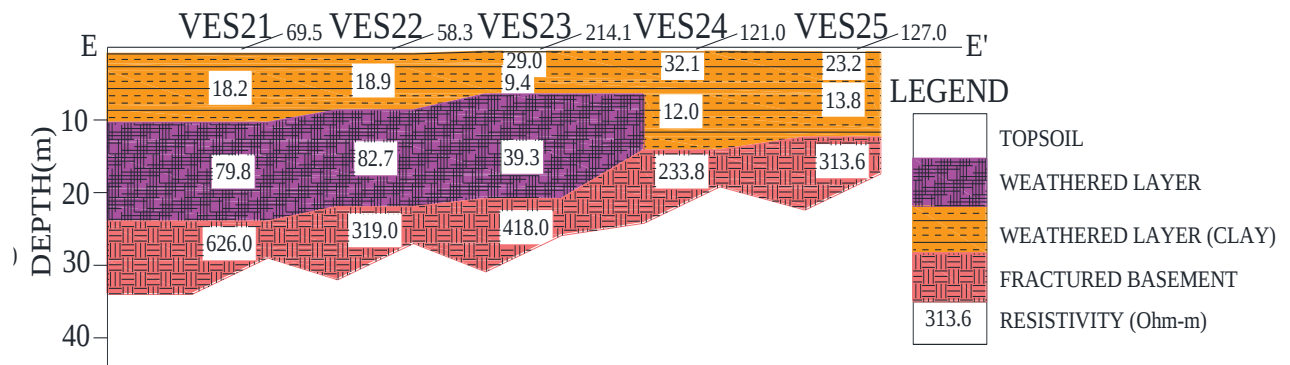


Plate 64: showing Geo-electric section of VES 21-25

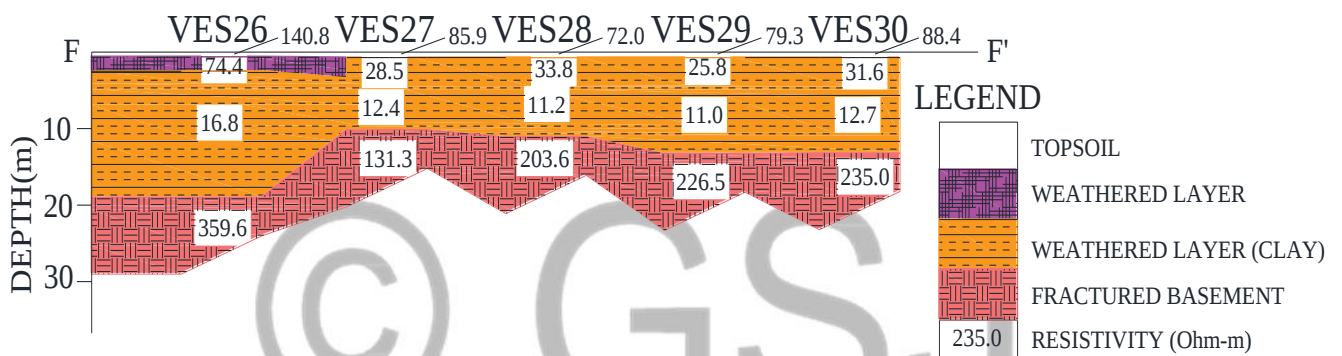


Plate 65: showing Geo-electric section of VES 26-30

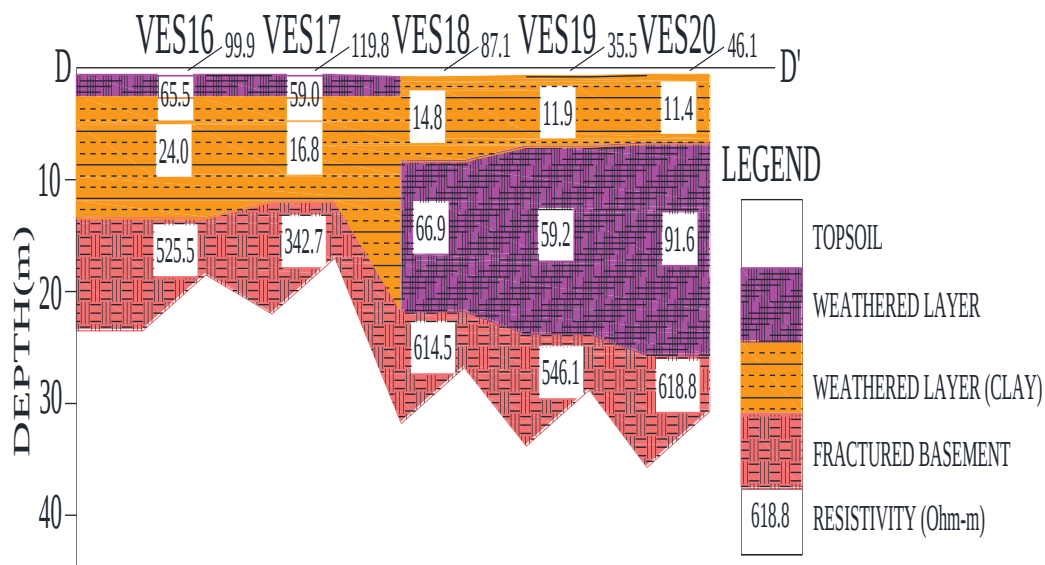


Plate 66: showing Geo-electric section of VES 6-7

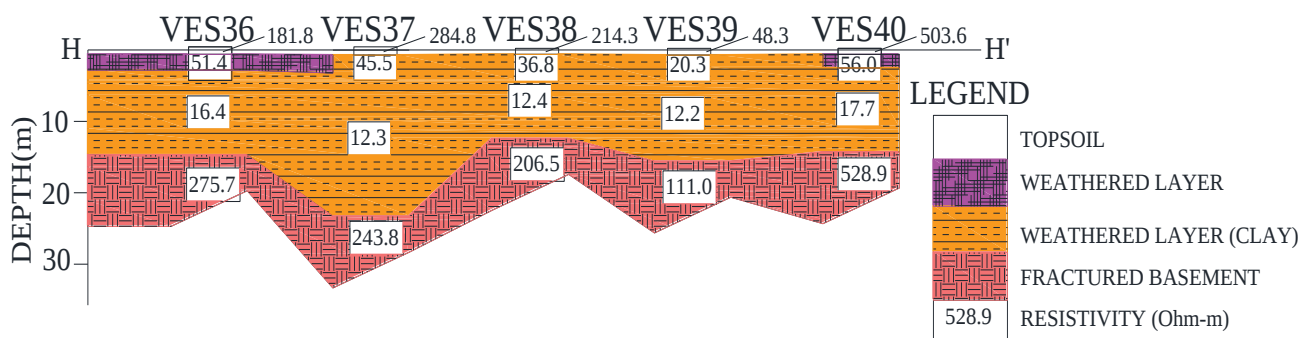


Plate 67: showing Geo-electric section of VES 36-40

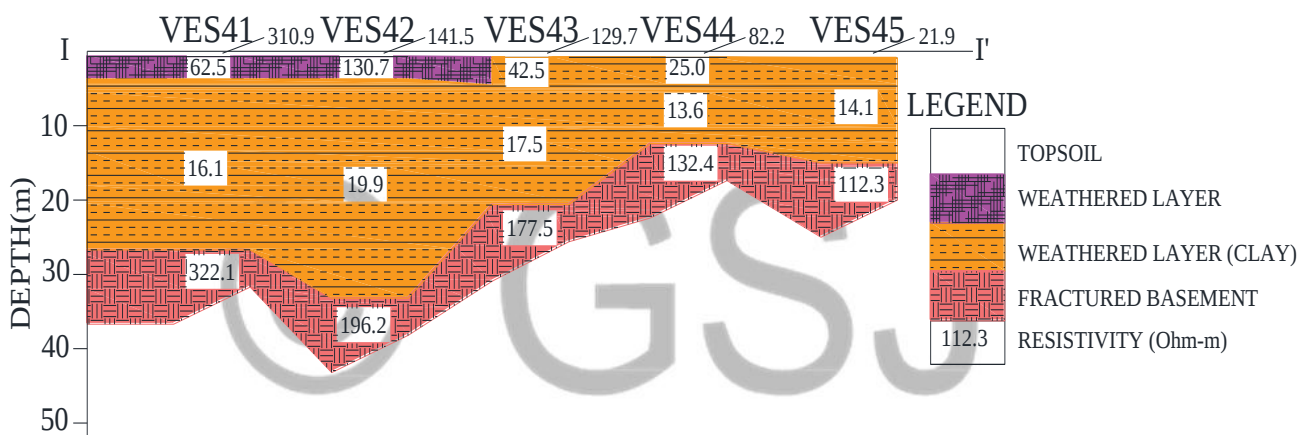


Plate 68: showing Geo-electric section of VES 41-55

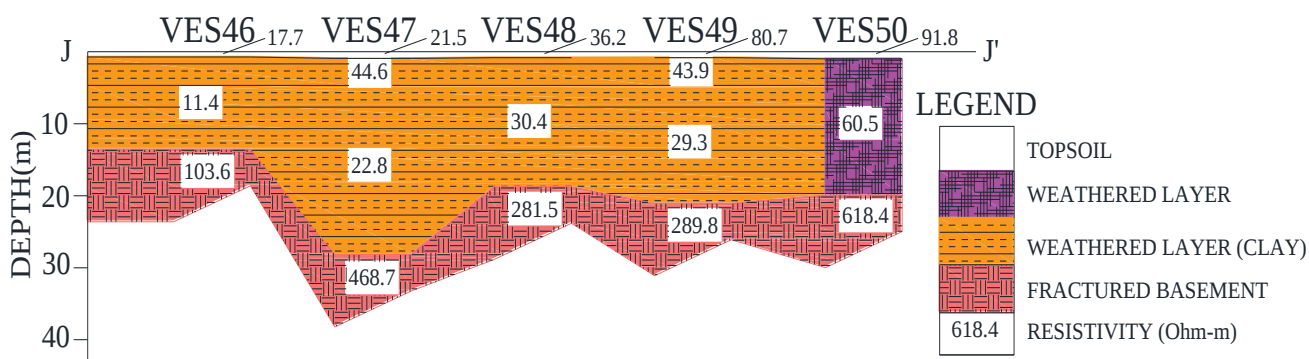


Plate 69: showing Geo-electric section of VES 46-50

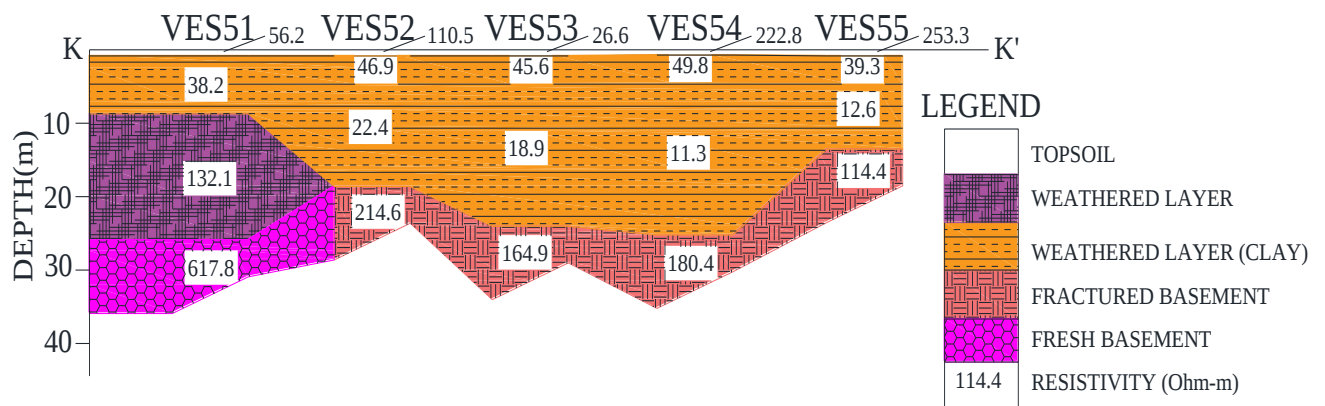


Plate 70: showing Geo-electric section of VES 51-55

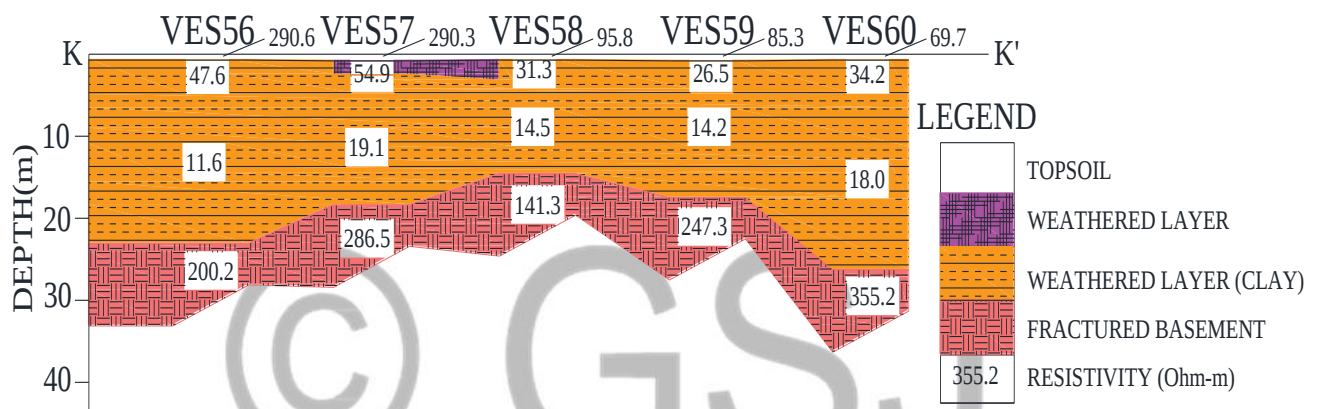


Plate 71: showing Geo-electric section of VES 55-60.

APPENDIX D

PICTURES OF ERUSU AKOKO EARTH DAM



Plate 72: showing reservoir serving the failed earth dam in the study area.



Plate 73: showing irrigation system attached to the failed earth dam.