COMPARISON OF 1D AND 2D RESISTIVITY INSTRUMENTS TO IDENTIFY THE DC SHIFT FOR POSSIBLE CORRECTION

By

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DECLARATION

The work described in this thesis was practically carried out by me at the Geological Survey & Mines Bureau, under the supervision of Prof.I.K. Perera and Mr. Nalin de Siva. And the report described on this thesis has not been submitted to any other university or another degree.

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AFFECTIONATELY DEDICATED TO

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ABSTRACT

Resistivity technique is one of the commonly practiced geophysical methods in Sri Lanka to delineate subsurface geology and find water in the near surface. Over the years 1D resistivity application become one of the major geophysical applications of GSMB to accomplish many subsurface explorations. With the limited applications and cumbersome maneuvers of the 1D system, 2D versions of the same become more advantageous over the former system. The 2D system is generally known as Resistivity Imaging. However, the user has a limited control over the 2D method as the data inversion is almost automatic. In order to utilize two systems alternatively there should be a common agreeable platform that enhances the confident level of two systems. With this objective is in focus, the following criteria has been adopted to compare and contrast the two systems in order to recognize their differences if any.

A stretch of 50m, undisturbed and flat ground with possible vertical resistivity variation has been selected as survey site. One-D system, ABEM 800 SAS, was deployed in the field during two working days and data were collected according to Schlumberger Array, Vertical Electrical Sounding (VES), with station interval of 4m. The collected data, apparent resistivity values, were arranged to a xyz file and a pseudo apparent resistivity section has been synthesized with data interpolation methods. The 2D system, AGI Advanced System, has been deployed along the same stretch overlapping the 1D survey and 2D data were collected with 2m electrode spacing in the same array type. With the aid of 2D inversion software, a system that built-in to the AGI 2D System, raw data were converted into true resistivity values. One-D resistivity data, which acquired along the line at 15 VES locations, were converted into true resistivity values in RESIST 1D inversion software. Both true resistivity values were plotted on the 2D inverted results for comparison.

The results reveal that there are shifts when comparing both the resistivity and depth values of two systems. The shift can be identified; hence, possible corrective measure will be introduced with further analysis. However the 2D system is more accurate as we get the low RMS value than the 1D system. In 2D system the depth control and penetration depths are limited compared to 1D system.

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ABBREVIATIONS

1 D	One Dimensional
2 D	Two Dimensional
DC	Direct Current
EM	Electro Magnetic
3 D	Three Dimensional

SYMBOLS

ρ	Resistivity
Ω	Ohm
m	meter

CHAPTER 1

INTRODUCTION

1.1 Company Profile

Geological Survey and Mines Bureau (GSMB) is the proud successor to a series of geo-scientific departments which spans nearly a century, starting as the Mineral Survey of Ceylon (MSC) in 1903 headed by Ananda Coomaraswamy. Throughout the history, these departments had an exceptional record of discovering, promoting and acquiring data on the country's mineral resources, to which all currently operating mineral-based industries owe their existence.

The establishment of the Bureau as the lead agency in mineral development underscores the Government's commitment to promoting mineral-based industries. Minerals, by providing substitutes for expensive imports; commodities for the building and construction industry and the raw materials for export industries, create employment and generate income for the country. The Bureau is also responsible for maintaining the national geo-science database, and ensuring that this information is made available to the public.

The Vision of the GSMB is to be the premier national geoscience agency that generates and disseminates geoscientific information and regulates mining and processing of Sri Lanka's mineral resources in the most sustainable manner.

The mission of the GSMB is to provide geoscientific information, advice and services to the policy makers and the community and to promote and manage the mineral resources of the country for economic development while ensuring environmental sustainability. It regulates exploration, extraction, value addition, transportation and trading of minerals.

The functions of the GSMB are:

- To undertake systematic geological mapping of Sri Lanka and preparation of geological maps.

- To identify and assess the mineral resources of Sri Lanka.
- To evaluate the commercial viability of mining for processing and export of such minerals.
- To regulate exploration and mining for minerals and processing, trading and export of such minerals by issuing licenses.
- To undertake geological investigations, seismic activity monitoring, geological research and provide geological consultancy services.
- To advise the Minister on measures to be adopted for the promotion of the extraction and production of minerals on a commercial basis.

For the project a site was selected to test the two instruments and fieldwork has been conducted in swift successions with an assumption that the ground conditions remains constant while the test of apparatus. Few working days were allotted for fieldwork and the study was conducted according to a procedure that is outlined in methodology.

A stretch of 100m in Belantota, Dehiwala area has been selected for this study. The selected narrow strip is almost a flat natural ground next to a channel. This location has been proposed due to vertical contrast of resistivity due to low water-table.

Figure 1.1: Selected stretch of land for fieldwork. Both 1D and 2D systems were deployed in the same stretch for data collection. 1D survey was conducted with 4m station spacing (details are given below) and the same stretch has been imaged with AGI 2d system at electrode spacing 2m with total of 28 electrodes.

1.2 Objectives

1.2.1 General Objective

Compare and contrast 2D and 1D resistivity application to model the subsurface with an emphasis to the instrumental drift. As an extension, the response of different sub-surface formations for two instruments will be assessed.

1.2.2 Specific Objective

Find out and fix possible parameters to obtain similar results in both techniques; identify the common plat form for similar results.

CHAPTER 2

LITERATURE SURVEY

2.1 DC - Resistivity Surveys

Geophysical surveys can be classified into one of two types: Active and Passive. Passive geophysical surveys incorporate measurements of naturally occurring fields or properties of the earth. Gravity and magnetic surveys are considered as passive methods, as in these two cases, the naturally occurring fields are the gravitational and magnetic fields.

In conducting active geophysical surveys, on the other hand, a signal is injected into the earth and then measures how the earth responds to this signal. These signals could take a variety of forms such as an electrical current. DC Resistivity method is one of the good examples for active methods. In EM and seismic surveys it is required to inject signals into the ground to make measurements.

2.1.1 Electrical Methods Overview

Bridging our subdivision of geophysical techniques into passive and active methods are the electrical and electromagnetic methods. Taken as a whole, the electrical and electromagnetic methods represent the largest class of all geophysical methods; some passively monitor natural signals while others employ active sources.

In addition to their great variety, this group of geophysical techniques represents some of the oldest means of exploring the Earth's interior. Natural electrical currents in the Earth, referred to as telluric currents, were used to identify the earth's structure.

Electrical methods employ a variety of measurements of the effects of electrical current flow within the Earth. The phenomena that can be measured include current flow, electrical potential (voltages), and electromagnetic fields. A summary of the more well known electrical methods is given below.

(a)DC Resistivity - This is an active method that employs measurements of electrical potential associated with subsurface electrical current flow generated by a DC, or slowly varying AC, source. Factors that affect the measured potential, and thus can be mapped using this method, include the presence and quality of pore fluids and clays.

(b)Induced Polarization (IP) - This is an active method that is commonly done in conjunction with DC Resistivity. It employs measurements of the transient (short-term) variations in potential as the current is initially applied or removed from the ground. It has been observed that when a current is applied to the ground, the ground behaves much like a capacitor, storing some of the applied current as a charge that is dissipated upon removal of the current. In this process, both capacitive and electrochemical effects are responsible. IP is commonly used to detect concentrations of clay and electrically conductive metallic mineral grains.

(c)Self Potential (SP) - This is a passive method that employs measurements of naturally occurring electrical potentials commonly associated with the weathering of sulfide ore bodies. Measurable electrical potentials have also been observed in association with ground-water flow and certain biologic processes. The only equipment needed for conducting an SP survey is a high-impedance voltmeter and some means of making good electrical contact with the ground.

(d)Electromagnetic (EM) - This is an active method that employs measurements of a time-varying magnetic field generated by induction through current flow within the earth. In this technique, a time-varying magnetic field is generated at the surface of the earth that produces a time-varying electrical current in the earth through induction. A receiver is deployed that compares the magnetic field produced by the current-flow in the earth to that generated at the source. EM is used for locating conductive base-metal deposits, for locating buried pipes and cables, for the detection of unexploded ordnance, and for near-surface geophysical mapping.

(e)Magneto Telluric (MT) - This is a passive method that employs measurements of naturally occurring electrical currents, or telluric currents, generated by magnetic induction of electrical currents in the ionosphere. This method can be used to determine electrical properties of materials at relatively great depths (down to and including the mantle) inside the Earth. In this technique, a time variation in electrical potential is measured at a base station and at survey stations. Differences in the recorded signal are used to estimate subsurface distribution of electrical resistivity.

2.1.2 Why Resistivity, and NOT Resistance

The problem with using resistance as a measurement is that it depends not only on the material from which the wire is made, but also the geometry of the wire. If we were to increase the length of wire, for example, the measured resistance would increase. Also, if we were to decrease the diameter of the wire, the measured resistance would increase. We want to define a property that describes a material's ability to transmit electrical current that is independent of the geometrical factors.

The geometrically-independent quantity that is used is called resistivity and is usually indicated by the Greek symbol ρ.

In the case of a wire, resistivity is defined as the resistance in the wire, times the cross-sectional area of the wire, divided by the length of the wire. The units associated with resistivity are thus, Ω m (ohm - meters).

Resistivity is a fundamental parameter of the material making up the wire that describes how easily the wire can transmit an electrical current. High values of resistivity imply that the material making up the wire is very resistant to the flow of electricity. Low values of resistivity imply that the material making up the wire transmits electrical current very easily.

Although some native metals and graphite conduct electricity, most rock-forming minerals are electrical insulators. Measured resistivities in Earth materials are primarily controlled by the movement of charged ions in pore fluids. Although water itself is not a good conductor of electricity, ground water generally contains dissolved compounds that greatly enhance its ability to conduct electricity. Hence, porosity and fluid saturation tend to dominate electrical resistivity measurements. In addition to pores, fractures within crystalline rock can lead to low resistivities if they are filled with fluids.

2.1.3 DC-Resistivity.

DC resistivity is an active survey method where the current injects to the subsurface and measures the response of the earth. The physical property that the measurements are based on is earth resistivity.

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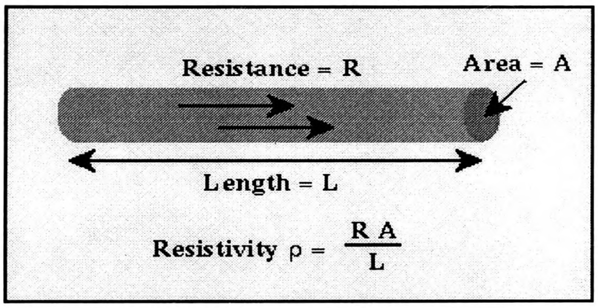

The property that describes a material's ability to transmit electrical current that is independent of the geometrical factors is called resistivity (ρ)

In the case of a wire, resistivity is defined as the resistance in the wire, times the cross-sectional area of the wire, divided by the length of the wire. The units associated with resistivity are thus, Ω m (ohm - meters).

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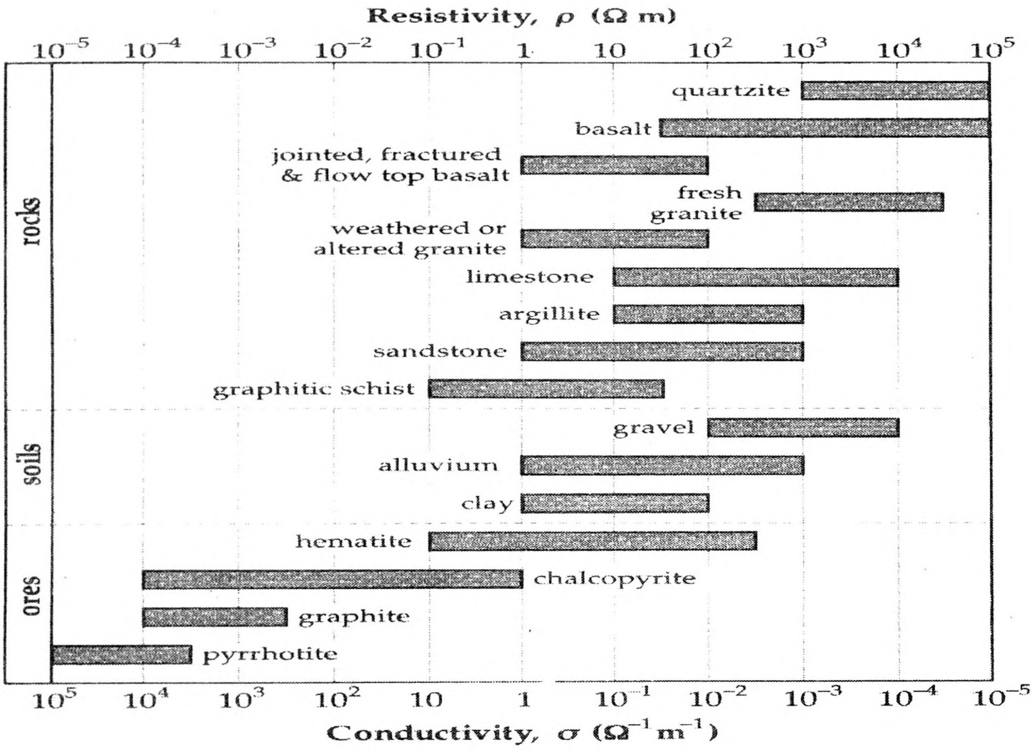
2.1.4 Resistivity of Earth Materials

Although some native metals and graphite conduct electricity, most rock-forming minerals are electrical insulators. The movement of charged ions in pore fluids primarily controls measured resistivities in Earth materials. Although water itself is not a good conductor of electricity, But groundwater generally contains dissolved compounds that greatly enhance its ability to conduct electricity. Hence, porosity and fluid saturation tend to dominate electrical resistivity measurements. For instance a fractured rock with water bearing zones display a low resistivity values though the same type of fresh rock is highly resistive.



There is a large range of resistivities, not only between varying rocks and minerals but also within rocks of the same type. This range of resistivities, as described above, is primarily a function of fluid content. Thus, a common target for electrical surveys is the identification of fluid saturated zones. For example, resistivity methods are commonly used in engineering and environmental studies for the identification of the water table. The method is extensively used to determine groundwater resources in fractured zones.

2.2 Measurements of Resistivity

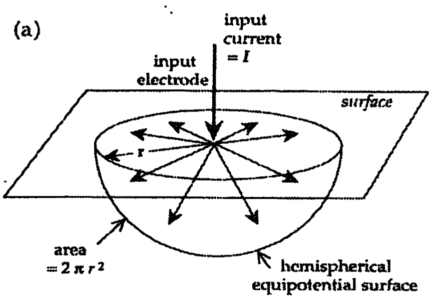
2.2.1 Current Densities and Equal potentials

To describe the nature of electrical current flow in media occupying a volume, we must move beyond our simple notions of current and voltage gained from our experience with wires, resistors, and batteries. In the Earth, or any three-dimensional body, electrical current is not constrained to flow along a single path as it does in a wire.

2.2.2 Electrode Systems

(a) Point Electrode

Once a current is inject to the ground through an electrode the current spread through the medium can be explained by the following figure.



According to the Ohm's law $E = \rho J = \rho I / 2\pi r^2$

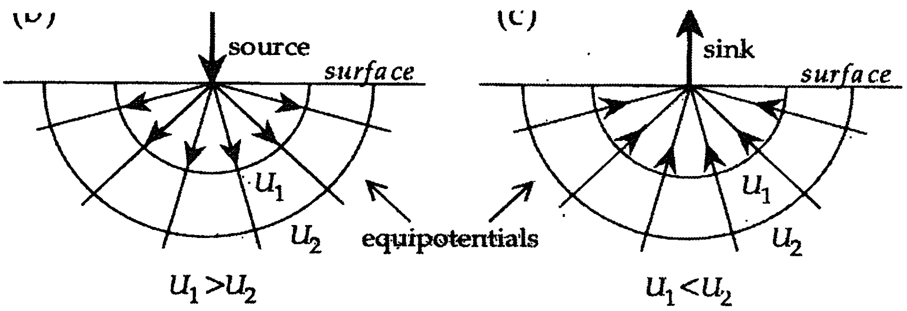
Where ρ -resistivity and J - current density.

The electric potential, U, at distance r from the electrode can be explained:

$$dU/dr = - \rho I / 2\pi r^2 = \rho I/2\pi r$$

The above condition satisfied only if the ground is homogeneous and uniform.

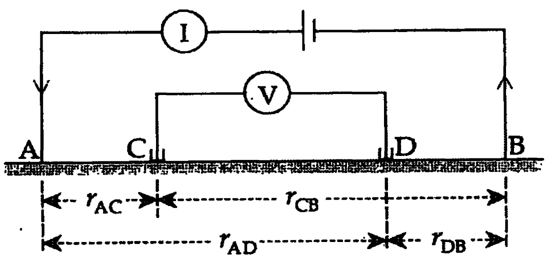
(b) Two Current Electrodes



In practice, two current electrodes are required for ground measurements. One act as the source and the other is the sink. The source is considered to be positive and the sink is negative

However, the current dose not flow from one electrode to another, if there is no potential difference. Hence, in order to drive the current through the earth, two potential electrodes are used. Therefore, four-electrode system is the common practice in resistivity surveys.

(c) Four-Electrode System



Consider the four-electrode system that a pair of electrodes acts as the current electrodes, A and B, and the other two electrodes, C and D, provide a potential difference.

At the detection electrode C,

The potential due to source	$A = +\rho I / (2\pi r_{AC})$
The potential due to sink	$B = +\rho I / (2\pi r_{CB})$
The combined potential at	$C = \rho I / 2\pi\ (1/r_{AC} - 1/r_{CB})$
Similarly, potential at	$D = \rho I / 2\pi\ (1/r_{AD} - 1/r_{DB})$

The potential difference between C and D,

$$V = \rho I / 2\pi\ [(1/r_{AC} - 1/r_{CB}) - (1/r_{AD} - 1/r_{DB})]$$

$$\rho = 2\pi\ V/I\ \underbrace{\left[\frac{1}{[(1/r_{AC} - 1/r_{CB}) - (1/r_{AD} - 1/r_{DB})]}\right]}_{K}$$

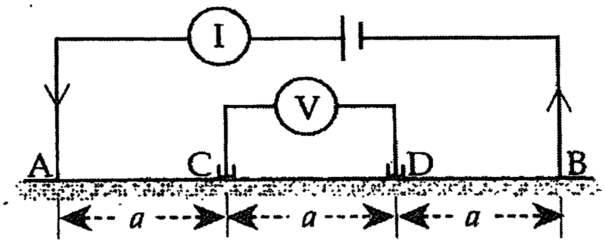
$$\rho = 2\pi\ V/I\ K$$

The geometrical factor of the equation is called K. Different survey methods are built up with changing the electrode configuration.

2.3 Commonly Used Electrode Configurations

Wenner and Schlumberger configuration are the most common arrays that use in the resistivity surveys. The former array is design for profiling and the latter is for sounding. In profiling the whole array shifted in a constant distance that enables to profile the subsurface at a constant depth. In sounding the two current electrodes are spread over the mid point, which investigate depth beneath the mid point. The following figures explain the two configurations. 0

(a) Wenner Array



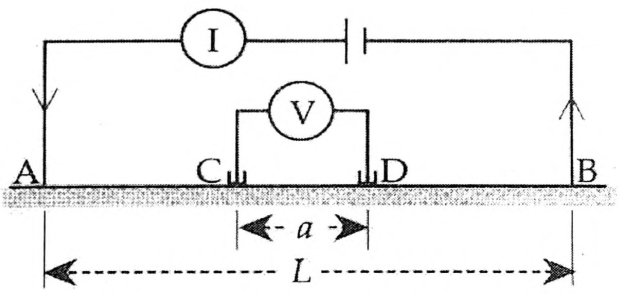
By substituting relevant distances for the geometrical factor of the previous equation, the following relationship can be obtained for Wenner Arrangement.

$K = 2\pi\ a$

$\rho = 2\pi\ a\ (V/I)$

Where, ρ is Resistivity and a is the distance between the electrodes.

(b) Schlumberger Array



For Schlumberger Configuration,

$$K = \pi \ (L^2 - a^2) / 4a$$

$$\rho = 2\pi \ a \ (V/I)$$

Where, ρ is Resistivity and **a** and **L** are the distances between potential and current electrodes, respectively.

The above equations are derived for homogeneous half-space. However, in reality the earth is not homogeneous, but consists of different layers with different electrical properties.

2.4 Apparent Resistivity Values

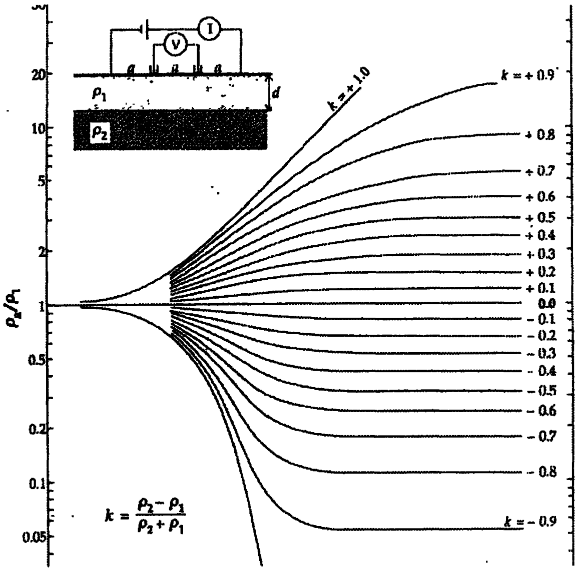
The measured resistivity in the field is called 'apparent resistivity' values. If the measurements are done with the presence of one layer, the apparent resistivity is almost equals to the true resistivity. In multi-layer cases, the upper layers influenced on the lower layers and the measured resistivity is an average value of the different layers.

2.5 Multi-Layered Subsurface

The current distribution of the subsurface varies according to the layer resistivity. The current reflect and refract at the boundaries of the layers. The behavior of the current at such boundaries is similar to optics. As shown in the figure the layer thickness and the apparent resistivity values can be calculated by the resistivity methods.

(a) Two – Layer Case

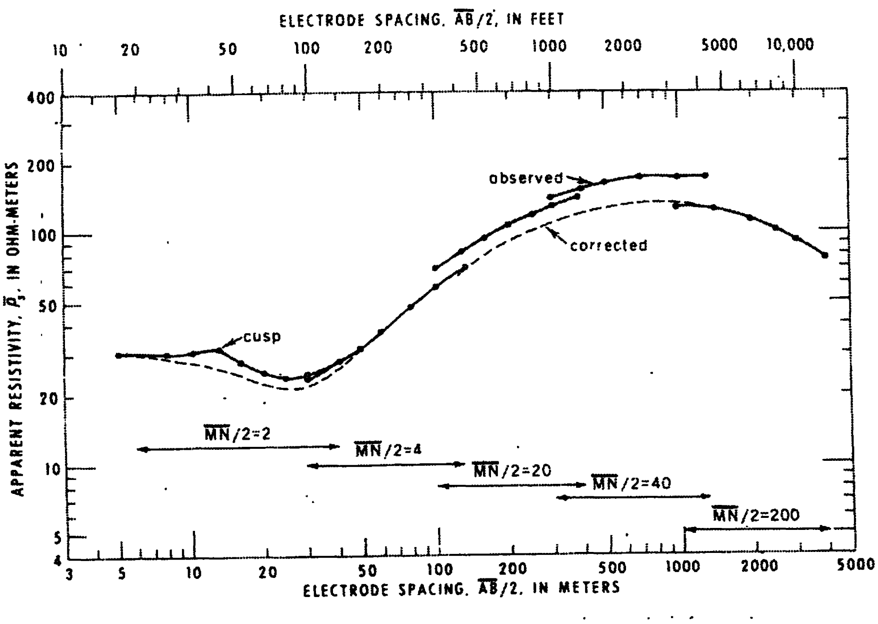
According to the apparent resistivity values of the two layers, a set of curves can be observed as shown in the following figure.



According to the shape of the curve, the apparent resistivity of each layer and approximate thickness of the layers can be determined.

(b) Three-Layer case

In the presence of three layers the number of options can be classified as follow.



If the survey area consists of more than three layers, then the layers are segmented either into two or three layers. These curve segments can be interpreted separately.

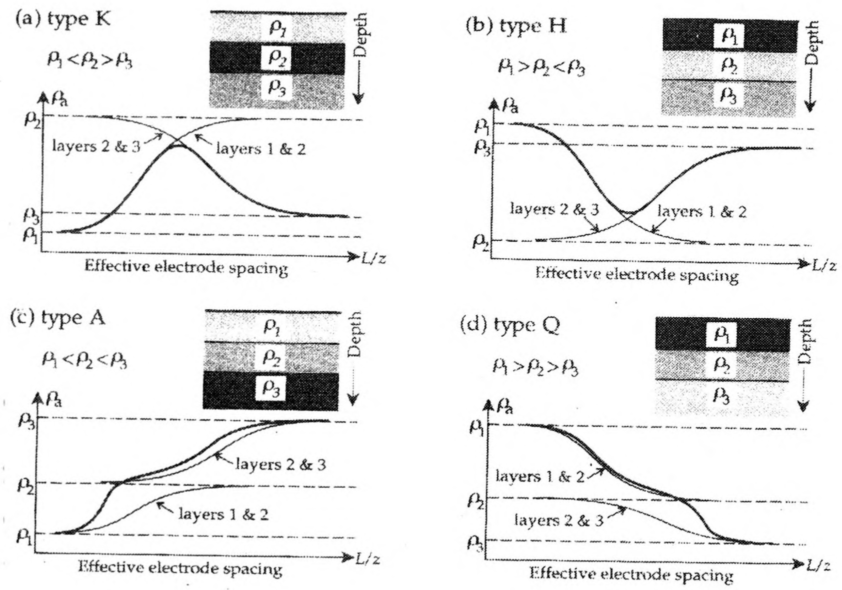
2.6 Interpretation

(a) Curve Matching

The old and manual method of interpretation is the curve matching. As explained in the two-layer and three-layer cases, master curves are established to compare the field data. Initially the field data is refined in a way that the data points falls into a curve. Then the numbers of layers are set according to the curve pattern. Finally the curve is matched with the master curves and calculates the thickness and the true resistivity values for each layer.

(b) Field Estimation to Identify Basement Rock

Estimation of depth to the basement is one of the common practices in resistivity method. In most cases the basement is a solid rock where the resistivity values are very high with compared to the overburden resistivities. If the last layer is highly resistive, the following pattern occurs in the field curve.



Once the resistivity values are plotted against the depth (AB/2), on a double log paper, the latter part of the curve rises at a 45^0 angle. This method is frequently used in the filed to decide the electrode spread of the sounding.

(c) Computer based interpretation techniques

Computer software plays a vital role in resistivity interpretation, as it is rapid and more accurate. The manual curve matching techniques were no longer in use; however, the principles remain same. A given set of results of a survey will be fitted to the most appropriate curve, and the relevant results will be displayed by a computer program. Though, the curve matching process is rapid, there is no guarantee of the outcome if the program allows to interpret the data alone.

2.7 2-D Resistivity Surveys (Electrical Imaging Surveys)

2.7.1 Introduction

We have seen the greatest limitation of the resistivity sounding method is that it does not take into account horizontal changes in the subsurface resistivity. A more accurate model of the subsurface is a two-dimensional (2-D) model where the resistivity changes in the vertical direction, as well as in the horizontal direction along the survey line. In this case, it is assumed that resistivity does not change in the direction that is perpendicular to the survey line. In many situations, particularly for surveys over elongated geological bodies, this is a reasonable assumption. In theory, a 3-D resistivity survey and interpretation model should be even more accurate. However, at the present time, 2-D surveys are the most practical economic compromise between obtaining very accurate results and keeping the survey costs down. Typical 1-D resistivity sounding surveys usually involve about 10 to 20 readings, while 2-D imaging surveys involve about 100 to 1000 measurements. In comparison, 3-D surveys usually involve several thousand measurements.

The cost of a typical 2-D survey could be several times the cost of a 1-D sounding survey, and is probably comparable with a seismic survey. In many geological situations, 2-D electrical imaging surveys can give useful results that are complementary to the information electrical imaging surveys can give useful results that are complementary to the information electrical imaging surveys can give useful results that are complementary to the information in mapping discrete bodies such as boulders, cavities and pollution plumes. Ground radar surveys can provide more detailed pictures but have very limited depth penetration in areas with conductive unconsolidated sediments, such as clayey soils. Two-dimensional electrical surveys should be used in conjunction with seismic or GPR surveys as they provide complementary information about the subsurface.

2.7.2 Field survey method - instrumentation and measurement procedure

One of the new developments in recent years is the use of 2-D electrical imaging/tomography surveys to map areas with moderately complex geology. Such surveys are usually carried out using a large number of electrodes, 25 or more, connected to a multi-core cable. A laptop microcomputer together with an electronic switching unit is used to automatically select the relevant four electrodes for each measurement (Bellow Figure). At present, field techniques and equipment to carry out 2-D resistivity surveys are fairly well developed. The necessary field equipment is commercially available from a number of international companies. These systems typically costs from about US$15,000 upwards. Some institutions have even constructed "home-made" manually operated switching units at a nominal cost by using a seismic cable as the multi-core cable.

Bellow Figure shows the typical setup for a 2-D survey with a number of electrodes along a straight line attached to a multi-core cable. Normally a constant spacing between adjacent electrodes is used. The multi-core cable is attached to an electronic switching unit which is connected to a laptop computer. The sequence of measurements to take, the type of array to use and other survey parameters (such the current to use) is normally entered into a text file which can be read by a computer program in a laptop computer. Different resistivity meters use different formats for the control file, so you will need to refer to the manual for your system. After reading the control file, the computer program then automatically selects the appropriate electrodes for each measurement. In a typical survey, most of the fieldwork is in laying out the cable and electrodes. After that, the measurements are taken automatically and stored in the computer. Most of the survey time is spent waiting for the resistivity meter to complete the set of measurements.

To obtain a good 2-D picture of the subsurface, the coverage of the measurements the Wenner electrode array for a system with 20 electrodes. In this example, the spacing between adjacent electrodes is "**a**". The first step is to make all the possible measurements with the Wenner array with an electrode spacing of "**a**". For the first measurement, electrodes number 1, 2, 3 and 4 are used. Notice that electrode 1 is used as the first current electrode C1, electrode 2 as the first potential electrode P1, electrode 3 as the second potential electrode P2 and electrode 4 as the second current electrode C2. For the second measurement, electrodes number 2, 3, 4 and 5 are used for C1, P1, P2 and C2 respectively. This is repeated down the line of electrodes until electrodes 17, 18, 19 and 20 are used for the last measurement with "**a**" spacing. For a system with 20 electrodes, note that there are 17 (20 - 3) possible measurements with "**a**" spacing for the Wenner array.

After completing the sequence of measurements with "**a**" spacing, the next sequence of measurements with "**2a**" electrode spacing is made. First electrodes 1, 3, 5 and 7 are used for the first measurement. The electrodes are chosen so that the spacing between adjacent electrodes is "**2a**". For the second measurement, electrodes 2, 4, 6 and 8 are used. This process is repeated down the line until electrodes 14, 16, 18 and 20 are used for the last measurement with spacing "**2a**". For a system with 20 electrodes, note that there are 14 (20 - 2x3) possible measurements with "**2a**"spacing.

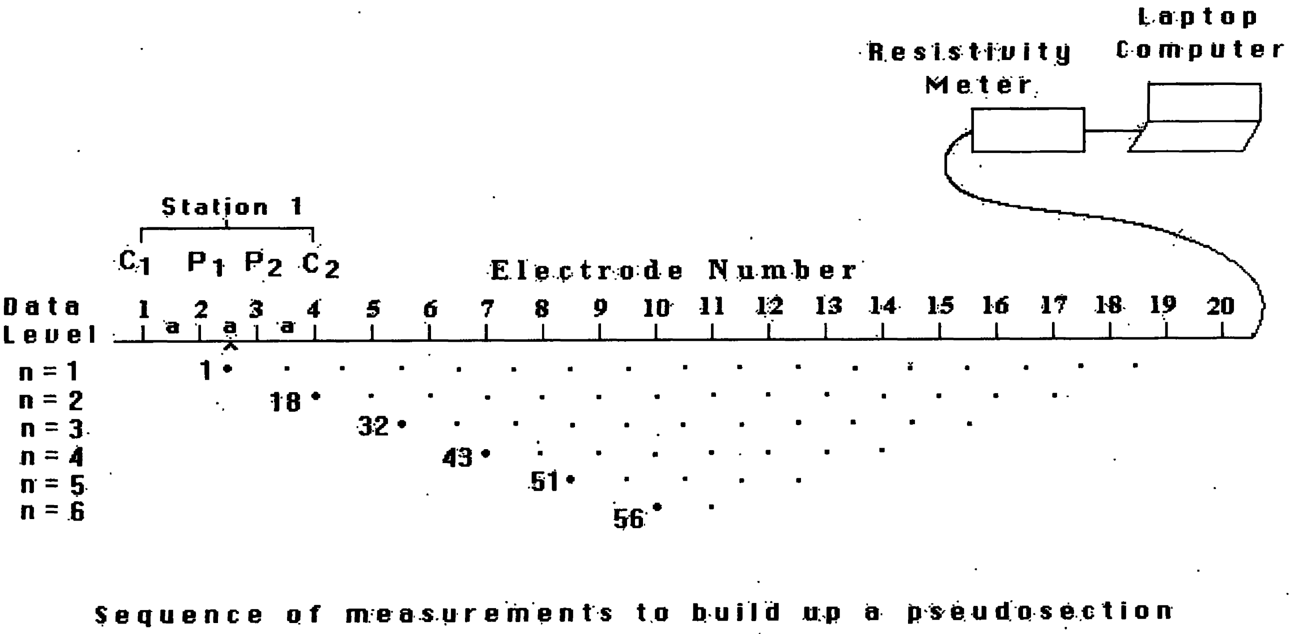


Figure 2.1: The arrangement of electrodes for a 2-D electrical survey and the sequence of measurements used to build up a pseudo section

The same process is repeated for measurements with "**3a**", "**4a**", "**5a**" and "**6a**" spacing's. To get the best results, the measurements in a field survey should be carried out in a systematic manner so that, as far as possible, all the possible measurements are made. This will affect the quality of the interpretation model obtained from the inversion of the apparent resistivity measurements.

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

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

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

One technique used to extend horizontally the area covered by the survey, particularly for a system with a limited number of electrodes, is the roll-along method. After completing the sequence of measurements, the cable is moved past one end of the line by several unit electrode spacing's. All the measurements which involve the electrodes on part of the cable which do not overlap the original end of the survey line are repeated.

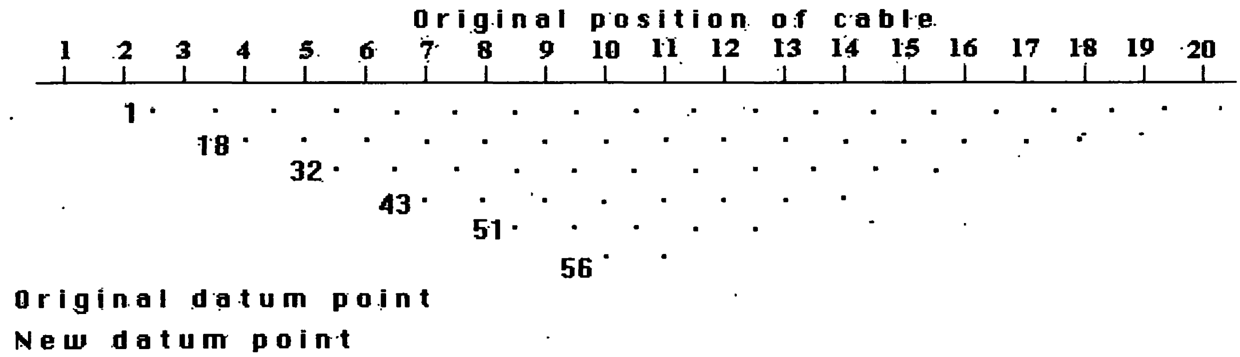


Figure 2.2: The use of the roll-along method to extend the area covered by a survey.

CHAPTER 03

METHODOLOGY

A stretch of land with minimum disturbances was selected to conduct the test. A 2D survey was conducted with an electrode spacing of 2m covering a 52m profile. The results were compiled into an image via inversion techniques (AGI advanced System).

A set of 1D resistivity sounding was conducted along the same line with an interval of 4m station spacing (Vertical Electric Sounding - VES). 1D inversion was carried out for each and every set of data produced by VES locations, 27 in total. 1d inversion program Resist was considered for curve matching.
The same technique that was built in the 2D imaging system for girding will be applied to grid 1D data and synthesized an image of the subsurface.

3.1 Site Selection:

An undisturbed site was selected for the above objective. As discussed with the GSMB authority the site was a close-by locality to the Head Office. The survey was conducted within a period of time with minimum interference from changing weather conditions.

3.2 Instrumentation

1-D survey was conducted by deploying the following instrument in the field.

ABEM Terrameter SAS 300C

Interpretation software: Resist 1D inversion

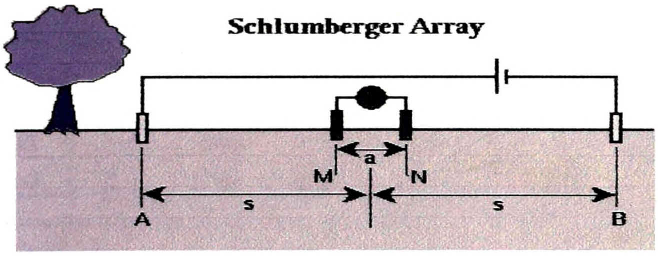
2-D survey was conducted by deploying the following instrument in the field.

Advanced Geosciences Inc. (AGI)

Instrument was utilized to acquire 2-D survey along the same line which the 1-D survey was conducted.

3.3 Survey Design and Instrument Specifications (1-D)

Vertical Electrical Sounding (VES) has been conducted to measure subsurface resistivity as 1D survey. VES data was collected according to Schlumberger configuration allowing to asses vertical variation of resistivity with the depth. Twelve VES soundings were carried out with 2m station spacing.



$$\rho_a = \frac{\pi(s^2 - a^2/4)}{a}\frac{\Delta V}{i}$$

Figure 1: Schlumberger configuration
A, B = Current electrodes
M, N = Potential Electrodes
S = AB/2 = half of current electrode spacing
a/2= MN/2= half of potential electrode spacing
i= input current
π (S² –a²/4) / a = Geometrical constant
ΔV/ i = Resistance
ρa = Apparent Resistivity value

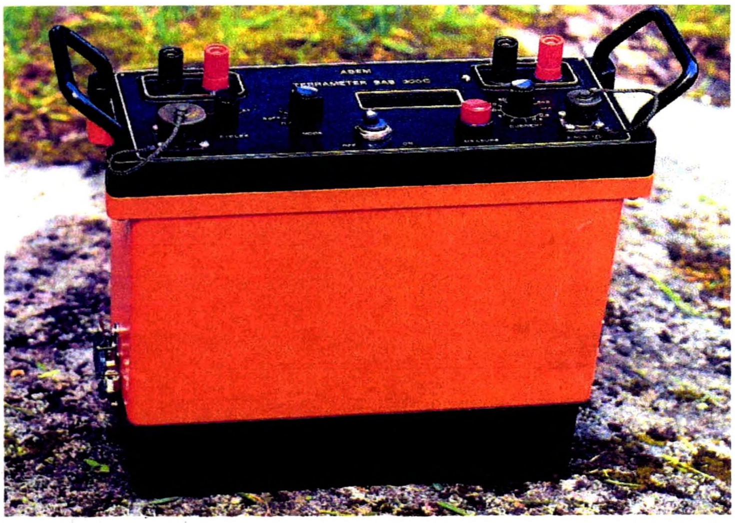


Figure2: ABEM TERAMETER
Model: 800 SAS
Input current: 10A
Battery Voltage: 12.5 (max)

3.4 Raw data collection and inversion software:

Collection of raw data (1-D) has been conducted according to the Schlumberger array with current and electrode spacing as shown in the following table, Table 3.1. Resistively values were plotted agilest half of the current electrode separation (AB/2, see Figure 1) while on the filed for quality assurance (Figure 1). One-D data have been processed with an assistance of RESIST software.

AB/2	MN/2	K(m)	R(Ω)	ρ(Ωm)
1.5	0.5	6.3	16.64	104.83
2	0.5	11.8	7.42	87.56
3	0.5	27.5	1.706	46.92
3	1	12.6	4.34	54.68
5	1	37.7	0.44	16.59
7	1	75.4	0.107	8.07
10	1	155.5	0.037	5.75
10	2.5	58.9	0.11	6.48
15	2.5	137.5	0.05	6.86
20	2.5	247.5	0.035	8.66
30	2.5	562	0.026	14.61
40	2.5	1001	0.016	16.42

Table 3.1: Data table for 1D data collection and calculation of apparent resistivity values.

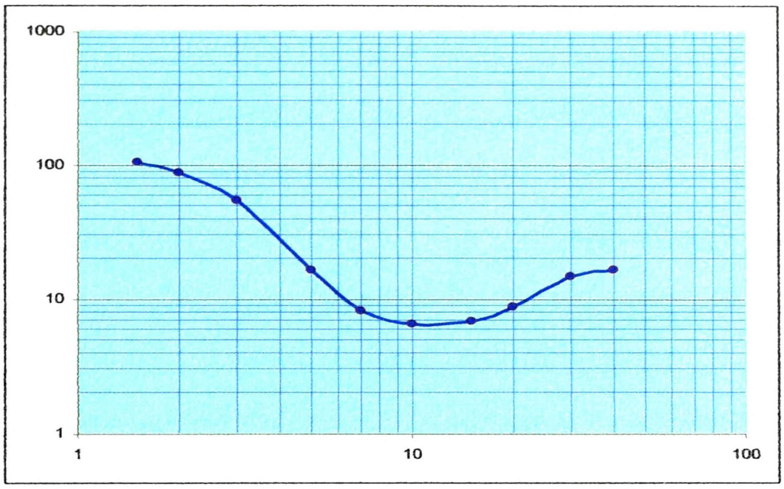


Figure 3.1: VES station 6. AB/2 plotted against calculated apparent resistivity values as appeared in the Table 3.1 The values are plotted on double-Log paper.

3.5 Two-D (2D)Survey Design and Instrument Specifications

The system considered for comparison is 2D AGI (Advance Geophysical Instruments) type that is available in GSMB. The system is equipped with 28 electrodes with a total spread of 162m. The system works with a mechanical device that is designed to assign varying current electrode separation (AB/2) and potential electrode separation MN/2 while on data acquisition. The collected data invert to form a resistivity image that represents a slice of the earth where the survey has been conducted.

Two-D profile has been obtained along the same line as 1D survey with 2m electrode spacing with length of 54m.

Figure 3.2: AGI resistivity imaging system that was deployed in the field for data acquisition and comparison purposes. Twenty-eight electrodes have been deployed along the same line where the 1D VES stations were places with an interval of 2m electrode spacing.

Figure 3.3: Placing electrodes on the ground prior to data acquisition. According to the theory, the electrodes were stationed on a straight line and water is added to maintain a proper contact with the ground.

CHAPTER 04

RESULTS AND DISCUSSION

AB - Distance between Current Electrodes

MN - Distance between Potential Electrodes

K -Geometrical Constant

ρ -Resistivity

R -Resistance

4.1 Survey Results

4.1.1 Resistivity Values

AB/2 / Loc	1.5	2.0	3.0	5.0	7.0	10.0	15.0	20.0	30.0	40.0
0-0 (VES 01)	119.95	64.66	56.59	19.68	13.50	10.23	114.13	31.43	34.84	
0-4 (VES 02)	171.36	109.15	53.50	15.91	8.07	7.19	93.50	106.92	21.36	
0-8 (VES 03)	243.81	144.08	61.51	13.42	8.90	7.90	87.04	112.61	21.08	
0-12(VES 04)	340.83	210.98	70.82	13.31	8.21	13.95	83.88	106.67	20.01	
0-16(VES 05)	388.08	208.27	67.36	14.48	8.32	7.87	110.28	120.04	22.54	
0-20(VES 06)	104.83	87.56	50.89	16.59	8.07	6.12	6.86	8.66	14.61	16.42
0-24(VES 07)	1.4.14	81.86	49.38	18.13	9.27	7.40	6.60	9.92	9.44	20.52
0-28(VES 08)	95.00	76.58	53.74	20.21	10.03	7.90	9.54	10.40	20.18	16.32
0-32(VES 09)	79.25	67.97	47.78	21.04	10.99	7.04	7.56	8.91	14.61	17.02
0-36(VES 10)	94.75	61.24	46.16	21.19	11.46	8.16	6.74	7.92	12.93	267.27
0-40(VES 11)	82.47	63.72	43.55	19.15	10.93	7.34	7.69	9.21	12.31	15.52
0-44(VES 12)	71.51	57.82	38.78	21.38	12.06	8.13	7.70	9.41	13.49	
0-48(VES 13)	71.51	61.48	47.39	22.58	11.48	8.16	5.56	8.37	13.38	
0-52(VES 14)	82.72	68.56	47.85	24.01	12.73	7.50	6.82	8.54	13.77	

Table 4.1: Apparent Resistivity Values

4.1.2 One-D Inversion Results

Following is a schematic diagram that displays the VES location which the results are provided in this section.

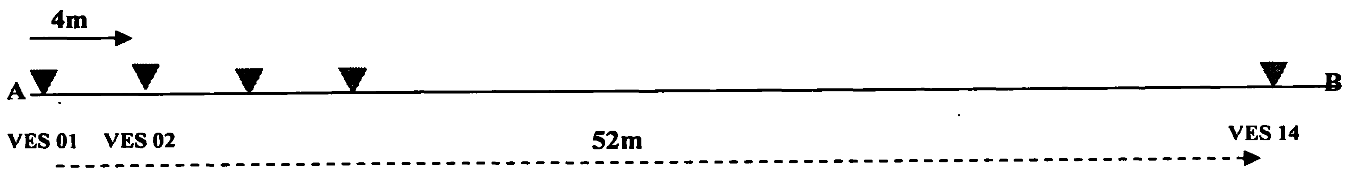


Figure 4.1: VES station spacing of the survey at 4m station intervals. Along the profile AB

Both 1 and 2D results were presented here for comparison. It is identified that data from first five stations appear with high deviations that is almost impossible to fit a reliable curve to the data set. However VES locations from VES6 onwards were considered for inversion. As discussed in the above the first five locations turned out to be not reliable for processing. The following figure, Figure 4.2.

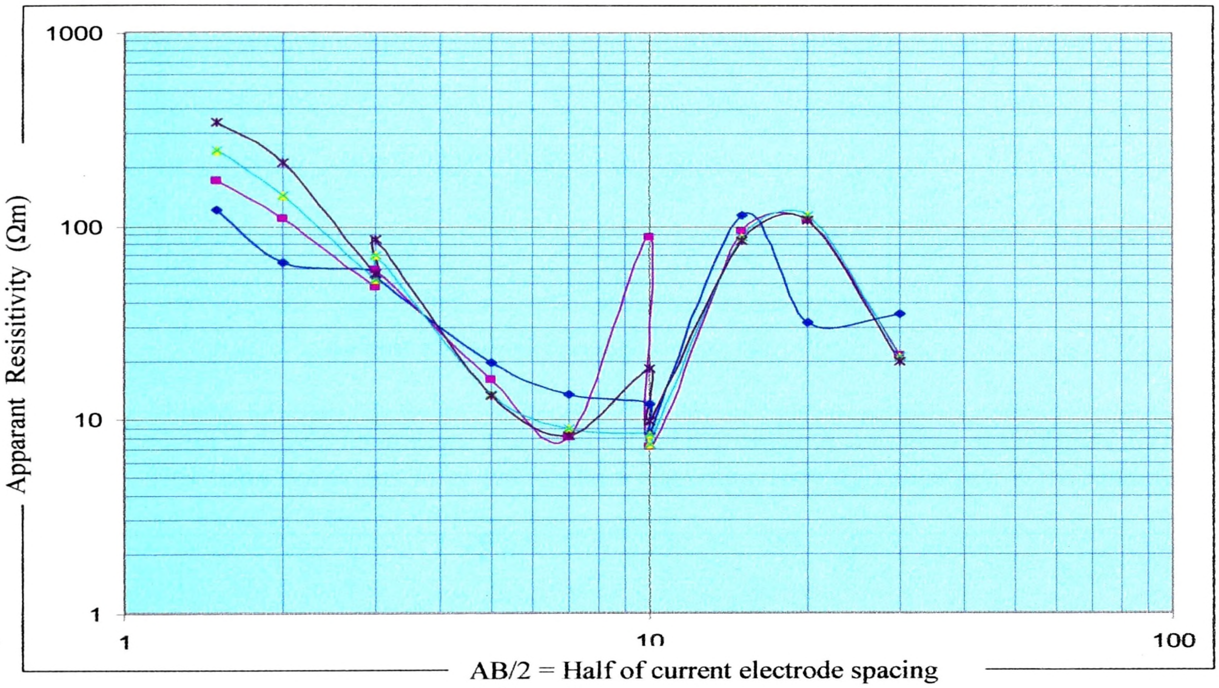
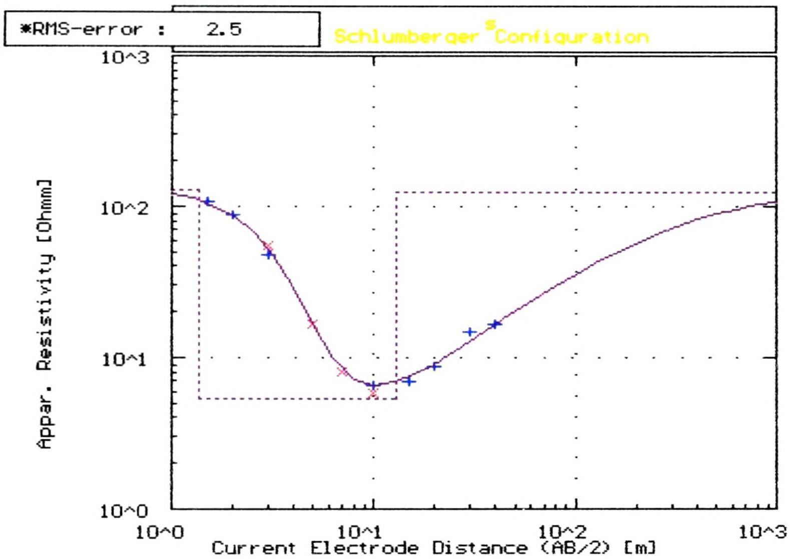


Figure 4.2: Results of first four VES stations plotted resistivity values against AB/2, which is comparable to depth. Though all the curves display a same character, data inversion is almost impossible by fitting reliable curves.

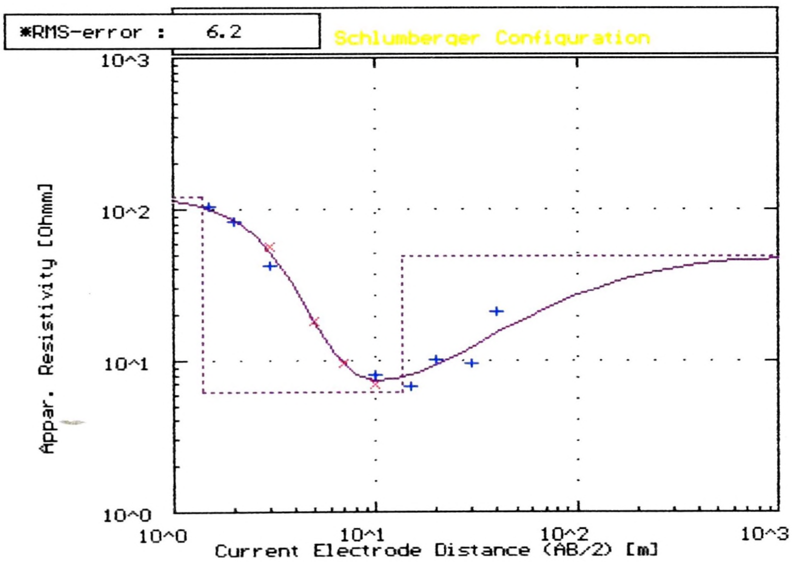
The following is 1D data analysis of curves from VES6 to VES 14 with an aid of RESIST 1D inversion software package.



No	Res	Thick	Depth
1	126.3	1.4	1.4
2	5.3	11.4	12.8
3	122.7	-.-	-.-

* RMS on smoothed data

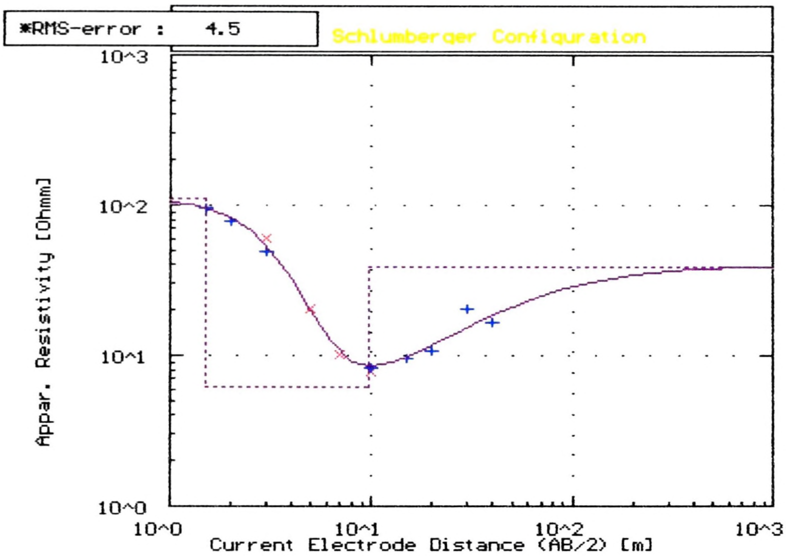
*Figure 4.3: VES 06 distance 20m from the point of origin **A** (as shown in the Figure 4.1). This curve represents three layers which the true resistivity values and corresponding depths are provided in the box.*



No	Res	Thick	Depth
1	120.4	1.4	1.4
2	6.1	12.2	13.6
3	47.8	-.-	-.-

* RMS on smoothed data

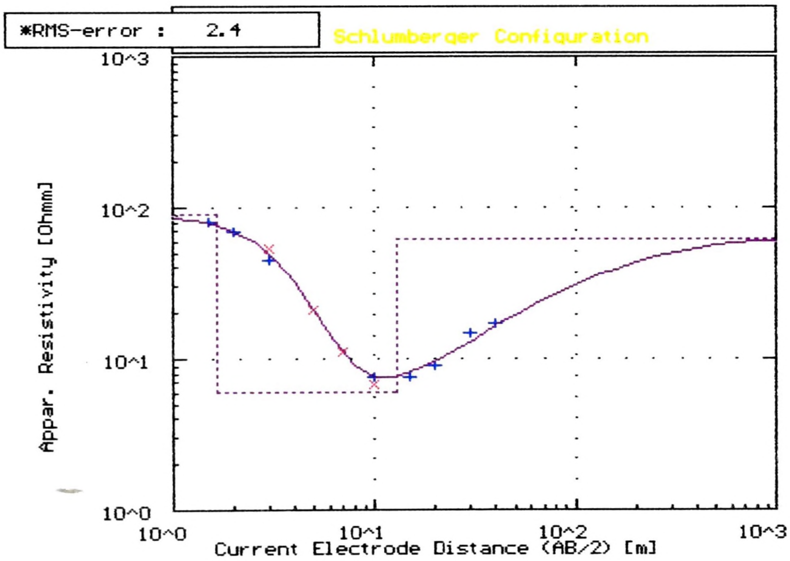
*Figure 4.4: VES 07 distance 24m from the point of origin **A***



No	Res	Thick	Depth
1	109.2	1.5	1.5
2	6.1	8.1	9.6
3	38.7	-.-	-.-

■ RMS on smoothed data

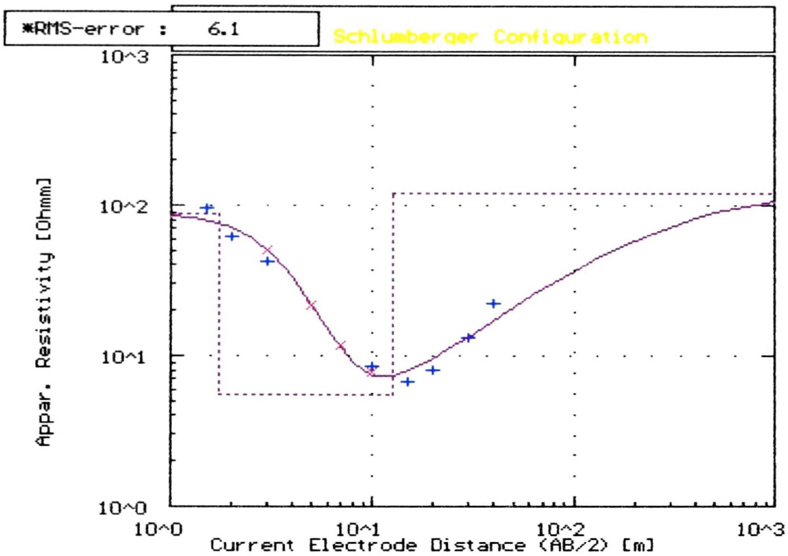
Figure 4.5: VES 08 distance 28m from the point of origin ***A***



No	Res	Thick	Depth
1	87.9	1.7	1.7
2	5.8	11.1	12.7
3	61.8	-.-	-.-

■ RMS on smoothed data

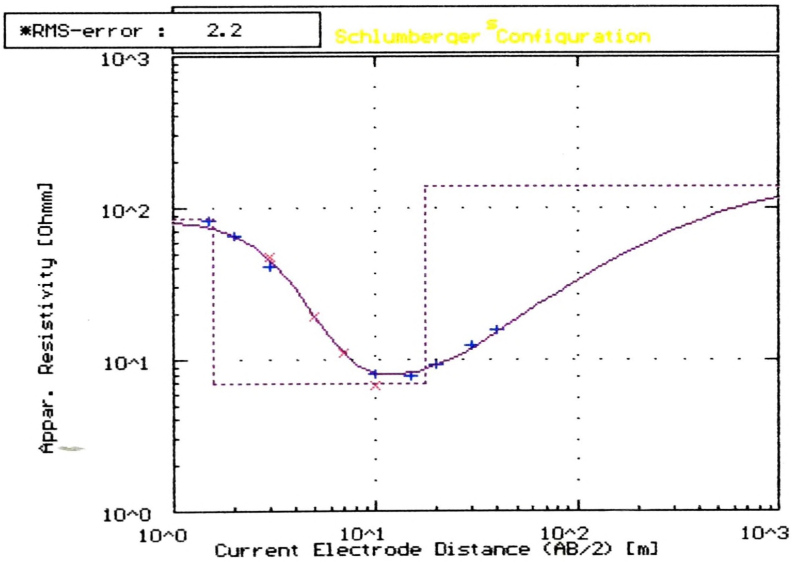
Figure 4.6: VES 09 distance 32m from the point of origin ***A***



No	Res	Thick	Depth
1	86.8	1.7	1.7
2	5.4	10.9	12.6
3	119.3	-.-	-.-

■ RMS on smoothed data

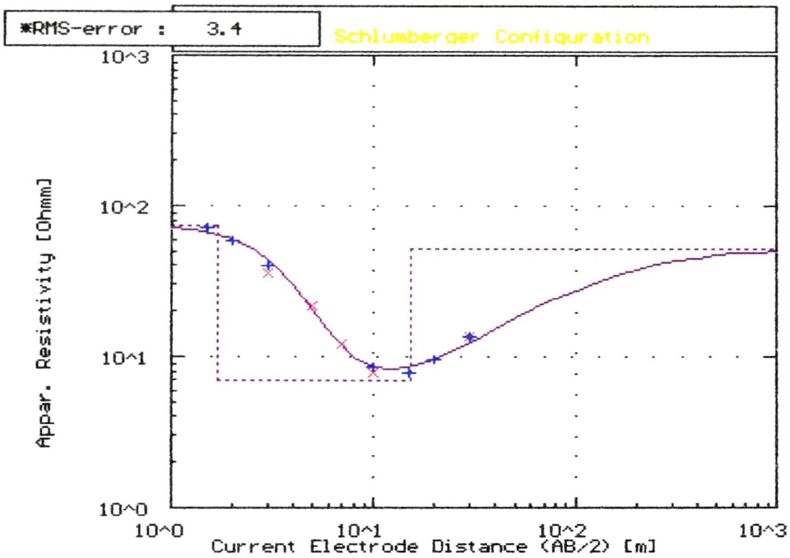
Figure 4.7: VES 10 distance 36m from the point of origin ***A***



No	Res	Thick	Depth
1	83.9	1.6	1.6
2	6.8	16.1	17.7
3	137.4	-.-	-.-

■ RMS on smoothed data

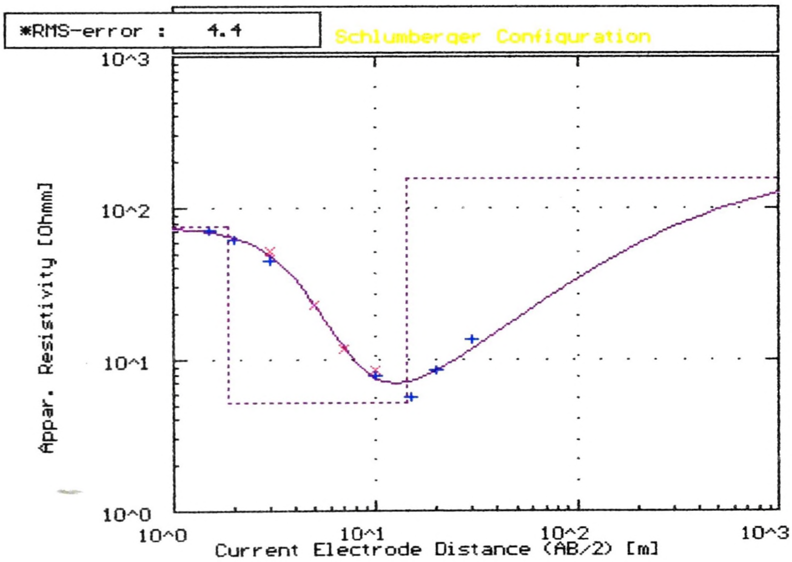
Figure 4.8: VES 11 distance 40m from the point of origin ***A***



No	Res	Thick	Depth
1	72.5	1.7	1.7
2	6.8	13.6	15.3
3	50.7	-.-	-.-

* RMS on smoothed data

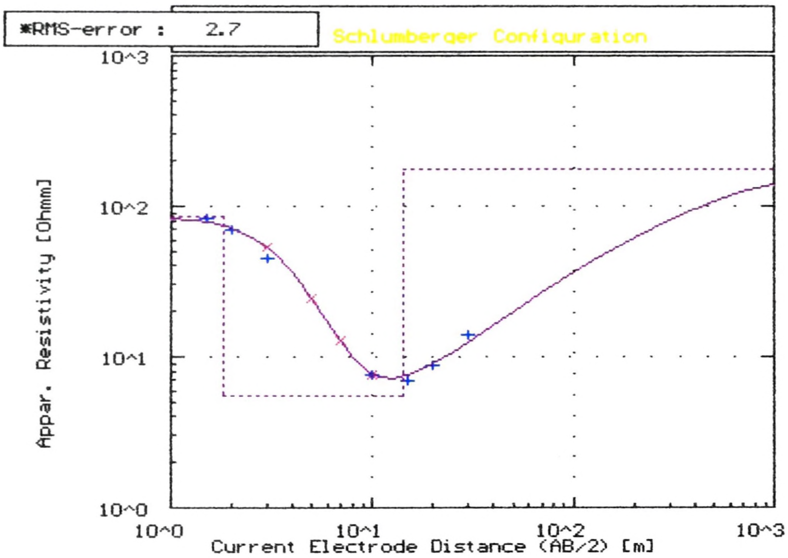
Figure 4.9: VES 12 distance 44m from the point of origin ***A***



No	Res	Thick	Depth
1	75.2	1.9	1.9
2	5.1	12.3	14.1
3	155.6	-.-	-.-

* RMS on smoothed data

Figure 4.10: VES 13 distance 48m from the point of origin ***A***



No	Res	Thick	Depth
1	84.5	1.8	1.8
2	5.5	12.3	14.2
3	174.6	-.-	-.-

* RMS on smoothed data

Figure 4.11: VES 14 distance 52m from the point of origin ***A***

While on inversion the following criterion has been adopted for all of the above curves.

- Three layer type curve has been considered as a model where apparent resistivity changes with the relationship of $\rho_1 > \rho_2 < \rho_3$ where ρ_1, ρ_2 and ρ_3 represents resistivity values of layers.

- Field data fit with a mathematical curve and iterate to obtain best fit where the RMS (Root Mean Squire) values become below 5%.

VES Station	Distance(m)	Layer	Resistivity (Ωm)	Thickness (m)	Depth (m)
6	20	1	126.3	1.4	1.4
		2	5.3	11.4	12.8
		3	122.7		
7	24	1	120.4	1.4	1.4
		2	6.1	12.2	13.6
		3	47.8		
8	28	1	103.2	1.5	1.5
		2	6.1	8.1	9.6
		3	38.7		
9	32	1	87.9	1.7	1.7
		2	5.8	11.1	12.7
		3	61.8		
10	36	1	86.8	1.7	1.7
		2	5.4	10.9	12.6
		3	119.3		
11	40	1	83.9	1.6	1.6
		2	6.8	16.1	17.7
		3	137.4		
12	44	1	72.5	1.7	1.7
		2	6.8	13.6	15.3
		3	50.7		
13	48	1	75.2	1.9	1.9
		2	5.1	12.3	14.1
		3	155.6		
14	52	1	84.5	1.8	1.8
		2	5.5	12.3	14.2
		3	174.6		

Table 4.2: Summery of 1D curve interpretation based on RESIST software. Almost similar results were obtained with three-layer earth model.

4.1.3 Two-D Interpretations and Results

Following are the survey results of 2D data inversion which is conducted with an aid of EarthImager 2D software.

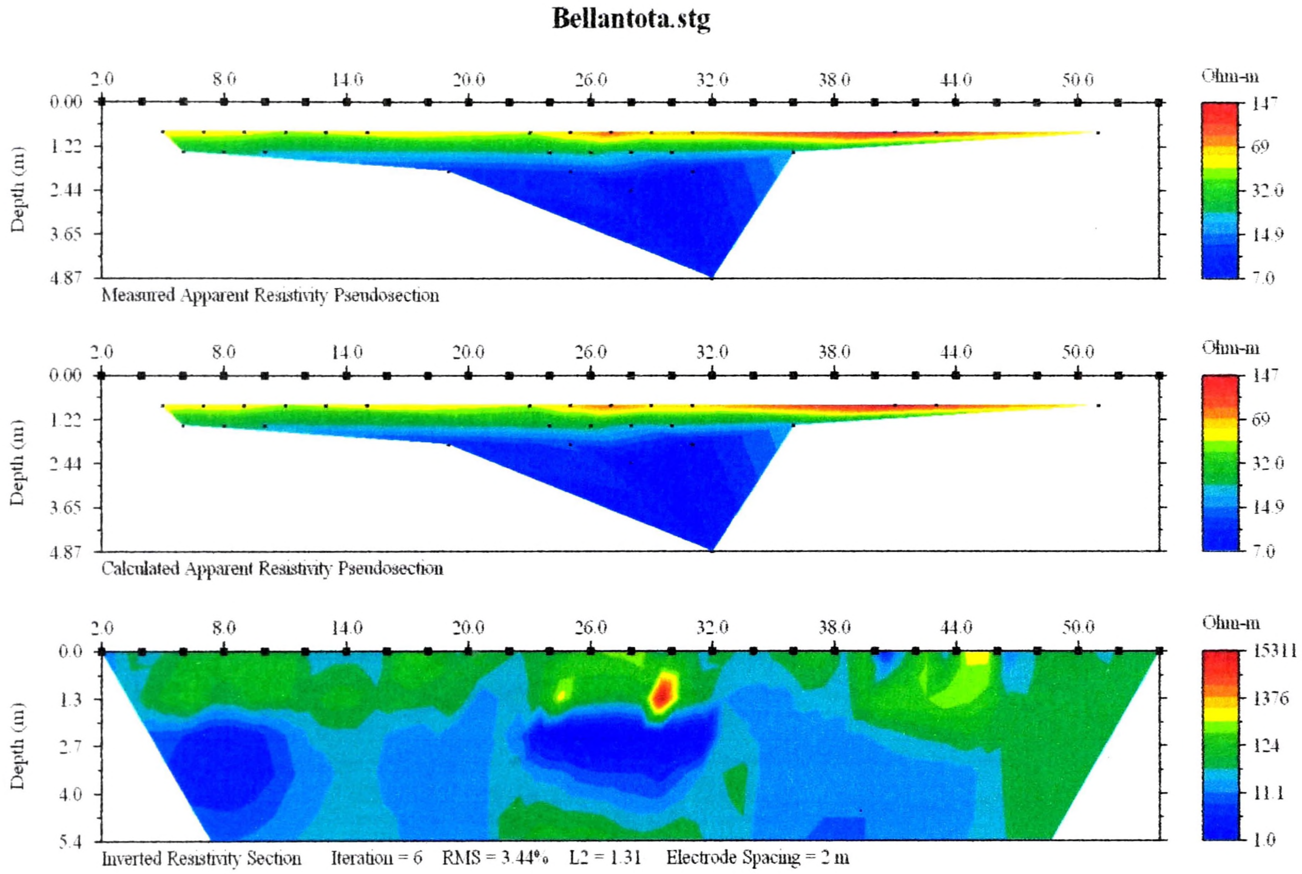


Figure 4.12: 2D data inversion with an aid of EarthImager 2D software. As explained the electrode spacing is at 2m interval and coincides with 1D VES stations as outlined in the Figure 4.2 Resistance values were inverted and true layer resistivity were calculated by assigning the geometry (in automated processing).The image with the least RMS error has been considered for comparison with 1Dinversion results.

CHAPTER 05

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

For our conclusions the following figure has been synthesized to compare and contrast results of the two systems. One-D inversion results were plot on the 2D image according to the resistivity values at particular depths.

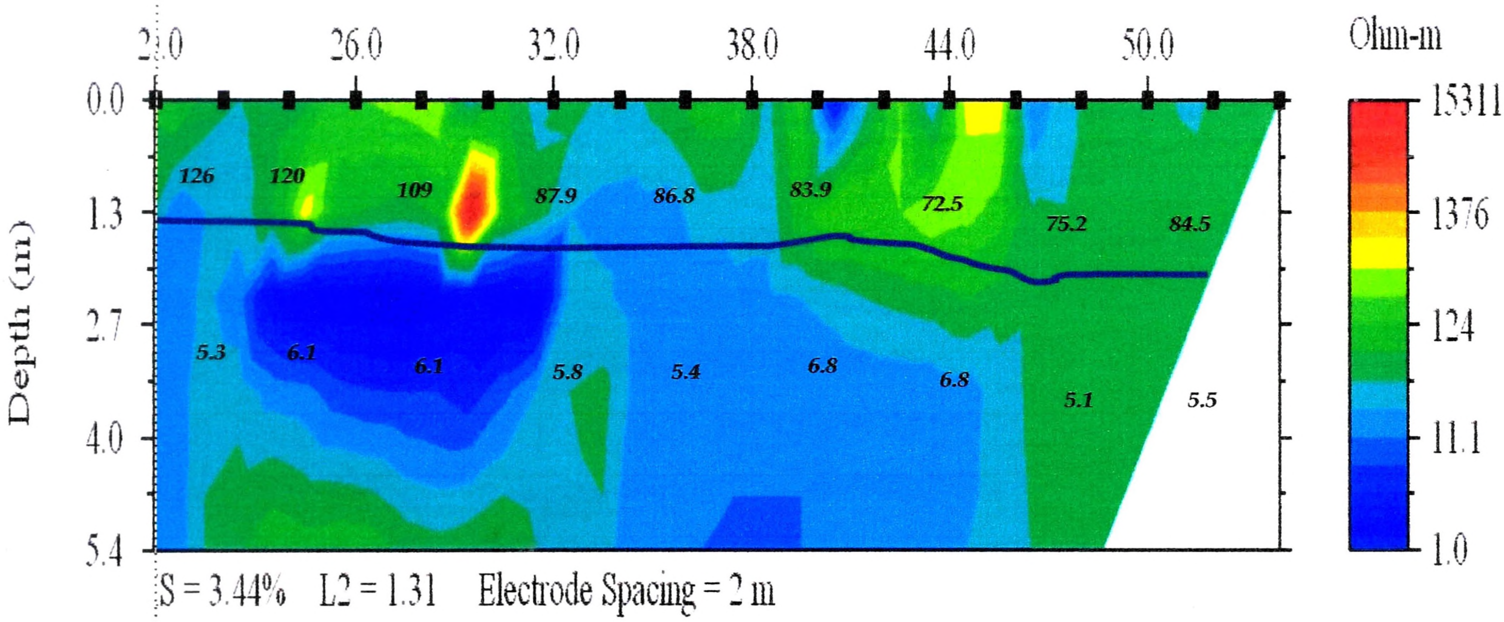


Figure 5.1: 1D inversion results plotted on 2D image

- The comparison indicates that there is a fair agreement for the upper layer particularly zones where there is no abrupt change of resistivity values. As an example 36m to 52m reveal the close correlation.

- The comparison shows that there is no fair agreement at the second layer particularly the low resistivity zone, 22m to 32m at a depth of about 1.5m to 3.5m, is not indicative in the 1D analysis.

- In general there is a fair agreement between the two systems. However further analysis, that outlined in the recommendations, should be carry out for better conclusions of the two systems.

5.2 Recommendations

- As the depth penetration of 2-D imaging system is very limited, data would be acquired along a longer stretch either with more electrodes (the present spread is with 28 electrodes) or at greater electrode spacing.

- One-D data would be girded with an aid of a sophisticated software package, for instance OasisMontaj – GEOSFOT Version, enabling to compare 2-D and 1-D results with higher degree of certainty.

- The above results are largely depend on the subsurface characters, hence it is recommended to (to the GSMB) a similar tests (by considering the above two recommendations) should be carried out for different subsurface formations.

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Telford W.M, Geldent L.P, Sheriff R.E, Keys D.A, (1978-Twice), Applied Geophysics, Cambridge University Press, 442- 491pp, 632-701 pp.

Catt L. M., West J, Clark R. A, Comparison of 1D, 2D and 2.5D Constrained Inversion of Electrical Resistivity Data, American Geophysical Union, Fall Meeting 2007, (abstract #NS31A-04)

Catt L. M., West J, Clark R. A, Comparison of 1D, 2D and 2.5D Constrained Inversion of Electrical Resistivity Data, American Geophysical Union, Fall Meeting 2008, (abstract #NS45A-13)

Appendix

GEOLOGICAL SURVEY & MINES BUREAU
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Tel.: 0094-1-739307 Fax: 0094-1-735752

VERTICAL ELECTRICAL SOUNDING (VES) SURVEY
SCHLUMBERGER CONFIGURATION

DATE : PROJECT : INSTRUMENT :

PLACE : SOUNDING NO. : OPERATOR :

AB/2 (m)	MN/2 (m)	K (m)	R (Ω)	ρ (Ωm)	Remarks
1.5	0.5	6.3			
2.0	0.5	11.8			
3.0	0.5	27.5			
3.0	1.0	12.6			
5.0	1.0	37.7			
7.0	1.0	75.4			
10.0	1.0	155.5			
10.0	2.5	58.9			
15.0	2.5	137.5			
20.0	2.5	247.5			
30.0	2.5	562.0			
40.0	2.5	1001.0			
50.0	2.5	1567.0			
50.0	10.0	377.0			
70.0	2.5	3075.0			
70.0	10.0	754.0			
100.0	10.0	1555.0			
150.0	10.0	3520.0			
200.0	10.0	6270.0			
300.0	10.0	14120.0			
200.0	40.0	1508.0			
300.0	40.0	3470.0			
400.0	40.0	6220.0			
500.0	40.0	9750.0			

(a) Loc-01 (0-0)

AB/2	MN/2	K(m)	R(Ω)	ρ(Ωm)
1.5	0.5	6.3	19.040	119.95
2.0	0.5	11.8	5.480	64.66
3.0	0.5	27.5	2.141	58.88
3.0	1.0	12.6	4.310	54.31
5.0	1.0	37.7	0.522	19.68
7.0	1.0	75.4	0.179	13.50
10.0	1.0	155.5	0.077	11.97
10.0	2.5	58.9	0.144	8.48
15.0	2.5	137.5	0.830	114.13
20.0	2.5	247.5	0.127	31.43
30.0	2.5	562.0	0.062	34.84

(b) Loc-02 (0-4)

AB/2	MN/2	K(m)	R(Ω)	ρ(Ωm)
1.5	0.5	6.3	27.200	171.36
2.0	0.5	11.8	9.250	109.15
3.0	0.5	27.5	1.742	47.91
3.0	1.0	12.6	4.690	59.09
5.0	1.0	37.7	0.422	15.91
7.0	1.0	75.4	0.107	8.07
10.0	1.0	155.5	0.561	87.24
10.0	2.5	58.9	0.122	7.19
15.0	2.5	137.5	0.680	93.50
20.0	2.5	247.5	0.432	106.92
30.0	2.5	562.0	0.038	21.36

(c) Loc-03 (0-8)

AB/2	MN/2	K(m)	R(Ω)	ρ(Ωm)
1.5	0.5	6.3	38.7000	243.81
2.0	0.5	11.8	12.2100	144.08
3.0	0.5	27.5	1.9120	52.58
3.0	1.0	12.6	5.5900	70.43
5.0	1.0	37.7	0.3560	13.42
7.0	1.0	75.4	0.1180	8.90
10.0	1.0	155.5	0.0537	8.35
10.0	2.5	58.9	0.1264	7.44
15.0	2.5	137.5	0.6330	87.04
20.0	2.5	247.5	0.4550	112.61
30.0	2.5	562.0	0.0375	21.08

(d) Loc-04(0-12)

AB/2	MN/2	K(m)	R(Ω)	ρ(Ωm)
1.5	0.5	6.3	54.1000	340.83
2.0	0.5	11.8	17.8800	210.98
3.0	0.5	27.5	2.0580	56.60
3.0	1.0	12.6	6.7500	85.05
5.0	1.0	37.7	0.3530	13.31
7.0	1.0	75.4	0.1089	8.21
10.0	1.0	155.5	0.1167	18.15
10.0	2.5	58.9	0.1656	9.75
15.0	2.5	137.5	0.6100	83.88
20.0	2.5	247.5	0.4310	106.67
30.0	2.5	562.0	0.0356	20.01

(e) Loc-05 (0-16)

AB/2	MN/2	K(m)	R(Ω)	ρ(Ωm)
1.5	0.5	6.3	61.6000	388.08
2.0	0.5	11.8	17.6500	208.27
3.0	0.5	27.5	1.9620	53.96
3.0	1.0	12.6	6.4100	80.77
5.0	1.0	37.7	0.3840	14.48
7.0	1.0	75.4	0.1104	8.32
10.0	1.0	155.5	0.0526	8.18
10.0	2.5	58.9	0.1283	7.56
15.0	2.5	137.5	0.8020	110.28
20.0	2.5	247.5	0.4850	120.04
30.0	2.5	562.0	0.0401	22.54

(f) Loc-06 (0-20)

AB/2	MN/2	K(m)	R(Ω)	ρ(Ωm)
1.5	0.5	6.3	16.640	104.83
2.0	0.5	11.8	7.420	87.56
3.0	0.5	27.5	1.706	46.92
3.0	1.0	12.6	4.340	54.68
5.0	1.0	37.7	0.440	16.59
7.0	1.0	75.4	0.107	8.07
10.0	1.0	155.5	0.037	5.75
10.0	2.5	58.9	0.110	6.48
15.0	2.5	137.5	0.050	6.86
20.0	2.5	247.5	0.035	8.66
30.0	2.5	562.0	0.026	14.61
40.0	2.5	1001.0	0.016	16.42

(g) Loc-07 (0-24)

AB/2	MN/2	K(m)	R(Ω)	ρ(Ωm)
1.5	0.5	6.3	16.530	104.14
2.0	0.5	11.8	6.920	81.66
3.0	0.5	27.5	1.534	42.19
3.0	1.0	12.6	4.490	56.57
5.0	1.0	37.7	0.481	18.13
7.0	1.0	75.4	0.123	9.27
10.0	1.0	155.5	0.045	6.94
10.0	2.5	58.9	0.134	7.87
15.0	2.5	137.5	0.048	6.60
20.0	2.5	247.5	0.040	9.92
30.0	2.5	562.0	0.017	9.44
40.0	2.5	1001.0	0.021	20.52

(h) Loc-08 (0-28)

AB/2	MN/2	K(m)	R(Ω)	ρ(Ωm)
1.5	0.5	6.3	15.080	95.00
2.0	0.5	11.8	6.490	76.58
3.0	0.5	27.5	1.741	47.88
3.0	1.0	12.6	4.730	59.60
5.0	1.0	37.7	0.536	20.21
7.0	1.0	75.4	0.133	10.03
10.0	1.0	155.5	0.049	7.62
10.0	2.5	58.9	0.139	8.19
15.0	2.5	137.5	0.069	9.54
20.0	2.5	247.5	0.042	10.40
30.0	2.5	562.0	0.036	20.18
40.0	2.5	1001.0	0.016	16.32

(i) Loc-09 (0-32)

AB/2	MN/2	K(m)	R(Ω)	ρ(Ωm)
1.5	0.5	6.3	12.580	79.25
2.0	0.5	11.8	5.760	67.97
3.0	0.5	27.5	1.587	43.64
3.0	1.0	12.6	4.120	51.91
5.0	1.0	37.7	0.558	21.04
7.0	1.0	75.4	0.146	10.99
10.0	1.0	155.5	0.042	6.55
10.0	2.5	58.9	0.128	7.54
15.0	2.5	137.5	0.055	7.56
20.0	2.5	247.5	0.036	8.91
30.0	2.5	562.0	0.026	14.61
40.0	2.5	1001.0	0.017	17.02

(j) Loc-10 (1-36)

AB/2	MN/2	K(m)	R(Ω)	ρ(Ωm)
1.5	0.5	6.3	15.040	94.75
2.0	0.5	11.8	5.190	61.24
3.0	0.5	27.5	1.520	41.80
3.0	1.0	12.6	4.010	50.53
5.0	1.0	37.7	0.562	21.19
7.0	1.0	75.4	0.152	11.46
10.0	1.0	155.5	0.050	7.78
10.0	2.5	58.9	0.145	8.54
15.0	2.5	137.5	0.049	6.74
20.0	2.5	247.5	0.032	7.92
30.0	2.5	562.0	0.023	12.93
40.0	2.5	1001.0	0.268	268.27

(k) Loc-11 (0-40)

AB/2	MN/2	K(m)	R(Ω)	ρ(Ωm)
1.5	0.5	6.3	13.090	82.47
2.0	0.5	11.8	5.400	63.72
3.0	0.5	27.5	1.481	40.73
3.0	1.0	12.6	3.680	46.37
5.0	1.0	37.7	0.508	19.15
7.0	1.0	75.4	0.145	10.93
10.0	1.0	155.5	0.043	6.69
10.0	2.5	58.9	0.136	7.99
15.0	2.5	137.5	0.056	7.69
20.0	2.5	247.5	0.037	9.21
30.0	2.5	562.0	0.022	12.31
40.0	2.5	1001.0	0.016	15.52

(l) Loc-12 (0-44)

AB/2	MN/2	K(m)	R(Ω)	ρ(Ωm)
1.5	0.5	6.3	11.350	71.51
2.0	0.5	11.8	4.900	57.82
3.0	0.5	27.5	1.410	38.78
3.0	1.0	12.6	0.370	4.66
5.0	1.0	37.7	0.567	21.38
7.0	1.0	75.4	0.160	12.06
10.0	1.0	155.5	0.050	7.78
10.0	2.5	58.9	0.144	8.48
15.0	2.5	137.5	0.056	7.70
20.0	2.5	247.5	0.038	9.41
30.0	2.5	562.0	0.024	13.49

(m) Loc-13 (0-48)

AB/2	MN/2	K(m)	R(Ω)	ρ(Ωm)
1.5	0.5	6.3	11.350	71.51
2.0	0.5	11.8	5.210	61.48
3.0	0.5	27.5	1.600	44.00
3.0	1.0	12.6	4.030	50.78
5.0	1.0	37.7	0.599	22.58
7.0	1.0	75.4	0.152	11.48
10.0	1.0	155.5	0.055	8.51
10.0	2.5	58.9	0.133	7.82
15.0	2.5	137.5	0.040	5.56
20.0	2.5	247.5	0.034	8.37
30.0	2.5	562.0	0.024	13.38

(n) Loc-14 (0-52)

AB/2	MN/2	K(m)	R(Ω)	ρ(Ωm)
1.5	0.5	6.3	13.130	82.72
2.0	0.5	11.8	5.810	68.56
3.0	0.5	27.5	1.592	43.78
3.0	1.0	12.6	4.120	51.91
5.0	1.0	37.7	0.637	24.01
7.0	1.0	75.4	0.169	12.73
10.0	1.0	155.5	0.048	7.50
10.0	2.5	58.9	0.127	7.50
15.0	2.5	137.5	0.050	6.82
20.0	2.5	247.5	0.035	8.54
30.0	2.5	562.0	0.025	13.77

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