# INTEGRATION OF GROUND PENETRATING RADAR, 2D ELECTRICAL RESISTIVITY AND MAGNETICS METHODS FOR MAPPING BURIED UTILITIES.

A BSc. PROJECT

BY

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DEPARTMENT OF GEOSCIENCE

MOUNTAIN TOP UNIVERSITY.

# CERTIFICATION

I hereby certify that this project titled, **INTEGRATION OF GROUND PENETRATING RADAR, 2D ELECTRICAL RESISTIVITY AND MAGNETIC METHODS FOR MAPPING BURIED UTILITIES**, was prepared and submitted by **BIODUN-HERBERT ADEYEMI** with matriculation number, **16010401008** in partial fulfilment for the award of **BACHELOR OF SCIENCE IN GEOPHYSICS**, Department of Geosciences is hereby accepted by

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# DEDICATION

This project is dedicated to God almighty and Mountain Top University.

# ACKNOWLEDGEMENTS

I am most appreciative to almighty God for the gift of life and continuous strength for not only leading me through this project but also for the successful completion of my study. My profound gratitude to the Vice Chancellor Prof. E.A. Ayolabi for his immeasurable effort and support. I also acknowledge the effort of my supervisor, Mr. R.P. Akinwale for his constructive suggestions, understanding, and useful comments. My amiable lecturers, especially Dr. O. Balogun, Dr. J. Adeoye, Mr. M.O. Okunubi, and the technologist, Mr. E. Dayo of the department of Geoscience for the seed you have sown in my life through your lectures and words of wisdom which has helped me so far in my journey in this institution.

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# ABSTRACT

Buried utilities of different shapes and sizes are characteristics of built-up areas and carry different materials such as gas, water, waste water, electrical cables and communication cables. This requires careful identification in order not to constitute danger to the life and property when further development is needed. This research was therefore carried out in three selected locations within Mountain Top University to provide information about the location, lateral extent and depth of buried utilities using Ground Penetrating Radar (GPR), 2D Electrical Resistivity Imaging (ERI) and Magnetic methods. Data was acquired at the locations to map four major buried pipes. GPR survey using monostatic antennas with frequencies of 450 Hz and 750 Hz were carried out along three traverses at location 1 and 3, and along six traverses at location 2. 2D ERI data using dipole-dipole array with electrode spacing of 0.1 m was collected along three traverses at all three locations, while magnetics survey at 0.1 m station spacing was carried out along three traverses at location 1 and 3, and along six traverses at location 2. Although, the magnetic response is subtle for the buried plastic pipes; magnetic survey at location 3 indicated a conspicuous magnetic low approximately 2 m wide. The conspicuous magnetic low was interpreted as a geologic structure relating to a buried stream/river channel. Integration of the 2D ERT model sections and radargram show that the depth to the top of the buried pipe in location 1 is approximately 0.2 m, and 0.2 m wide, at location 2, the depth of the buried pipe detected and its lateral extent is approximately 0.16 m and 0.28 m respectively, while, the results obtained at location 3 reveals that pipe 1 and pipe 2 are buried at the depth of 0.31 m and 0.2 m respectively with respective diameters of 0.28 m and 0.25 m. The result of this study further corroborates the fact that the integration of 2D ERT and GPR surveys allows for a better identification of buried utilities.



**Keywords:** Electrical Resistivity Imaging, GPR, Magnetics, Location, Lateral extent, Radargram.

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# CHAPTER ONE

# INTRODUCTION

## 1.0 Background of Study

The importance of identifying buried utilities cannot be over emphasized as its neglection can cause a lot of problems (Ganiyu et al 2020). Lives can be lost because of metal coming in contact with an electric cable. Utilities could be damaged during construction and renovation, which leads to unnecessary waste of time in repairing or replacing them. The preservation and maintenance of buried utilities in an urban landscape are fundamentally important if modern living is to be preserved. Failure to maintain these buried utilities can rapidly result in the breakdown of the service the utilities provide. This problem stems from the inability to precisely locate buried utilities within the earth subsurface without some form of excavation (Ganiyu et al 2020).

Excavation of land will be the ideal method to locate, repair, or replace damaged buried utilities. However, once the land is excavated, it cannot be returned back to its original state. Hence, this method of accessing buried utilities within the earth subsurface is environmentally unfriendly. This method aside from being environmentally unfriendly and not practicable in all sites are also tedious and suffer from different limitation due to waste of time and project cost efficiency (Hazreek et al. 2016).

Thus, there is a need to adopt a non-invasive alternative method to delineate buried utilities. Buried utilities must be located before repair and replacement work. The integration of geophysical methods in engineering site investigation is considered the best method of locating subsurface structures (Cardarelli et al. 2010, 2014; Bharti et al. 2016a; Ungureanu et al. 2017; Pazzi et al. 2018).

Geophysics is a branch of natural science which studies the physical processes and properties of the Earth and its surrounding, using quantitative methods for their analysis. Engineering Geophysics can be described as the application of geophysical methods to the investigation of sub-surface materials. Geophysical methods respond to physical properties of the earth such as acoustic impedance (which is a measure of the product of density and velocity), magnetic susceptibility, electrical conductivity, permittivity etc. (Reynold, 2011). These properties when measured produce a recognizable anomaly, which helps to detect subsurface structures.

The successful adoption of geophysical method for detection of buried utilities depends on the ability to reach the target at a particular depth with the appropriate resolution (Cardarelli et al. 2009; Mahato 2018). Furthermore, the integration of more than one method to identify buried structures has resulted in a more precise definitions and interpretation (Cardarelli et al., 2014; Pueyo et al. 2013; Pazzi et al. 2018). The information about subsurface structures is derived through the measurement of contrasts in physical properties (Mochales et al. 2008).

Geophysical methods such as Electrical Resistivity Tomography (ERT) and Ground Penetrating Radar (GPR) provide a non-destructive and on-site method for detection of subsurface structures (Ramirez et al. 1996). The ERT detects and identifies buried structures with varying resistivity values relative to the surrounding soil (Sun et al. 2017); while GPR identifies subsurface electromagnetic properties based on varying dielectric properties of the subsurface structures (Rehman et al. 2016).

The electrical resistivity of a soil depends on several parameters such as soil structure, texture, porosity, mineral fluid contents, degree of water saturation in the rock and soil physical parameters depending on the level of soil solution, temperature, and soil moisture content (Michot 2003; Samouelian et al. 2005; Bharti et al. 2016a; Mishra et al. 2018). On the other hand, the calculated

parameters of GPR (travel time and amplitudes of reflected signals) depend on dielectric constant, magnetic permeability of the medium, and conductivity of the material (Xu et al. 2002) with dielectric constant as the most important subsurface property controlling the signal propagation velocity, the vertical and horizontal resolution, as well as the reflection coefficient (Metwaly 2013; Sagnard and Tarel 2016).

### 1.1 Statement of Problem

Mountain Top University is a growing private tertiary institution, which may require various renovations, constructions of structures over time. Loss of property, especially buried utilities such as internet fibre cables, water pipes, electrical cables, waste pipes during new construction and renovation are imminent if their locations and depth are not known. Buried electrical cables can also lead to loss of life during excavation besides the waste of time and unnecessary delay arising from damaged buried utilities. Other problems that are inherent when the locations of buried utilities are not known includes lack of plan for future maintenance and replacement and pollution of environment due to damage of waste pipes.

Ground Penetrating Radar, Electrical Resistivity and Magnetics methods are considered the best method in locating buried utility (Cardarelli et al. 2010, 2014; Bharti *et al.* 2016a; Ungureanu et al. 2017; Pazzi *et al*. 2018). This research therefore seeks to provide Mountain Top University with a quality information about some of her buried utilities using geophysical methods such as Ground Penetrating Radar, 2D Electrical Resistivity and Magnetic method. Precise information about the location, size and depth of these buried utilities present at the investigated part of the University will be provided.

## 1.2 Aim and Objectives

### Aim

The aim of this project is to integrate Ground Penetrating Radar, 2D Electrical Resistivity and Magnetic method to provide information about the location, lateral extent and depth of buried utilities for selected part of Mountain Top University.

### Objectives

The application of GPR, 2D ERT and Magnetics methods will help achieve the following objectives:

i. Characterize the earth's subsurface based on the contrast in physical properties such as dielectric, resistivity and magnetic susceptibility within the earth subsurface, presented by the application of geophysical methods.
ii. Identify the various types of buried utilities
iii. Delineate the depth and diameter of these buried utilities
iv. Interpret the various geophysical methods deployed and appraise its application in detecting buried utilities.

## 1.3 Location and Accessibility

The study area, Mountain Top University is located in Mountain of Fire and Miracle Ministries (MFM) Prayer City, at KM 12, Lagos – Ibadan express way, Ibafo, Ogun State Nigeria with geographic coordinates of Lat. 6° 43' 38.14" N to 6° 43' 52.72" N and Long. 3° 24' 51.89" to 3° 24' 39.35" E (Figure 1). The campus is accessible through the Lagos – Ibadan express way.

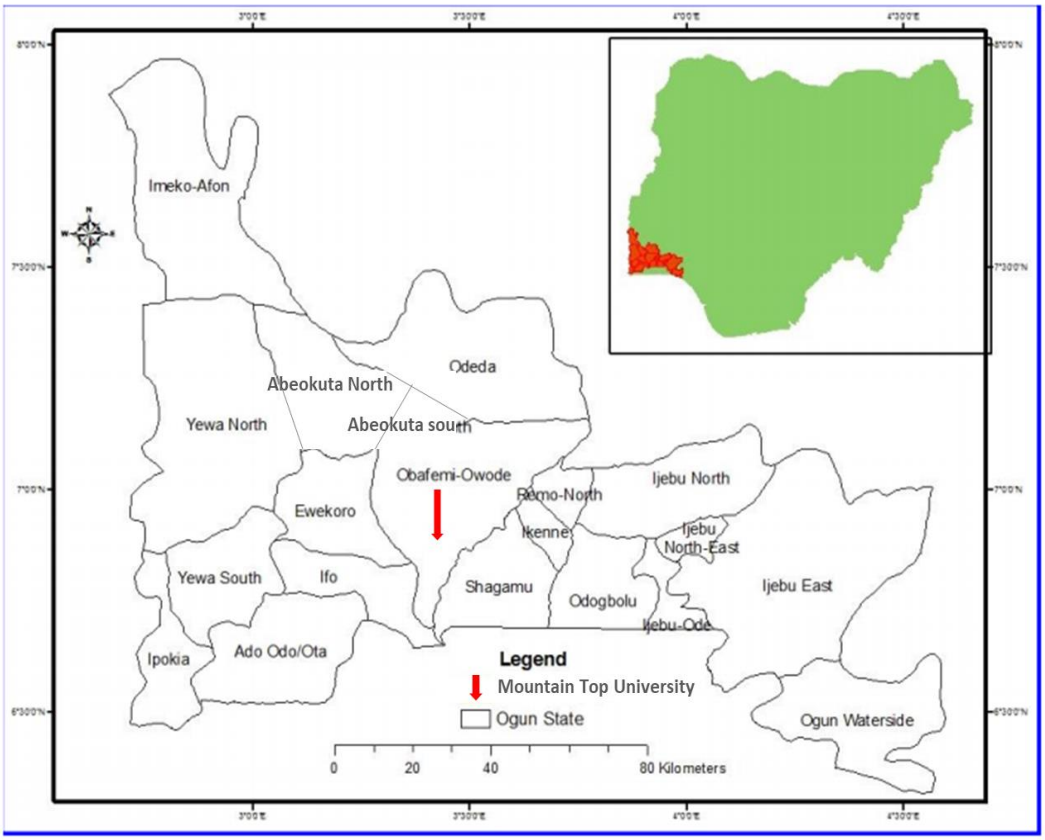



Figure 1.1 Map showing the survey area (inset map of Nigeria showing location of Ogun state within Nigeria). Modified after Oyedepo *et al*., 2013.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.0 Review of Previous Works Done

In the Detection of buried agricultural drainage pipe, Allred *et al*. 2004, tested the ability of four surface geophysical methods which include geomagnetic surveying, electromagnetic induction, resistivity, and ground penetrating radar (GPR). Of these four methods, only GPR was confirmed to be capable of finding agricultural drainage pipe. Consequently, although more research was certainly warranted, the use of ground penetrating radar method in the detection of the agricultural drainage pipe appears to have outstanding potential.

Neal, 2013 used three different Geophysical methods, including electrical resistivity, electromagnetic induction, and ground penetrating radar, to image a known buried stream channel in the Burn Run watershed near Shippensburg University campus in Pennsylvania. Interpretation of the data revealed layers of fill and alluvial deposits above underlying residual clay. When GPR and ER profiles were overlaid, the locations of anomalies were verified.

The study made by Hazreek et al, 2016 was focused on the evaluation of electrical resistivity method (ERM) for buried object detection and its relationship due to the different stiffness of material. This study found that the Electrical Resistivity Value (ERV) of concrete cube for grade 20, 25 and 30 were 170 Ωm, 227 Ωm and 503 Ωm, respectively. Hence, this study shows that the ERV has a strong relationship with different stiffness of material thus applicable to be a useful alternative tool in underground structure detection.

A geophysical study was carried out in Indian Institute of Technology Kanpur, India by Malik *et al*., 2019, for detecting accurate location, size, depth, and type of subsurface utilities using the ground penetrating radar (GPR) method. After processing and the analyzing the resulting data, it was concluded that there are various hyperbolic reflections due to the presence of underground bodies. The utility pipes are represented the hyperbolics signature which are at a depth of about 30-35 cm, and their orientation on the ground discussed briefly.

Ganiyu *et al.,* 2020, integrated 2D Electrical Resistivity Imaging and Ground Penetrating Radar in the detection of buried utilities in the Federal University of Agriculture, Abeokuta, Nigeria. The goals of the surveys were to determine the effectiveness of the applied methods in detection of buried utilities locations and their depths as well as verification of obtained depths to the top of target by excavation method. Integrated interpretation showed that GPR can effectively provide information about buried utilities compared to ERT.

The integration of more than one method to identify buried structures has resulted in a more precise definitions and interpretation (Cardarelli *et al.,* 2003, 2014; Pueyo *et al*. 2013; Pazzi *et al*. 2018). The information about subsurface structures is derived through the measurement of contrasts in physical variables such as density, soil resistivity, magnetic susceptibility, dielectric properties, etc. (Mochales *et al*., 2008). Geophysical methods such as Electrical Resistivity Tomography (ERT) and Ground Penetrating Radar (GPR) provide a non-destructive and on-site methods for detection of subsurface structures (Ramirez *et al.,* 1996). The ERT detects and identifies buried structures with varying resistivity values relative to the surrounding soil (Sun *et al.,* 2017); while GPR identifies subsurface electromagnetic properties based on varying dielectric properties of the subsurface structures (Rehman *et al.,* 2016).

## 2.1 Geology of the study area

### 2.1.1 Regional geology of Benin (Dahomey) Basin

The Dahomey Basin is a combination of inland/ coastal/ offshore basin that stretches from southern Ghana through Togo and the Republic of Benin to southwestern Nigeria as shown in figure 2.1. The Nigerian section of the Benin (Dahomey) Basin is located in the southwestern Nigeria covering three different states, namely; Lagos, Ogun and Ondo (Olabode *et al*, 2016) shown in figure 2.2. It is separated from the Niger delta by the Okitipupa ridge.

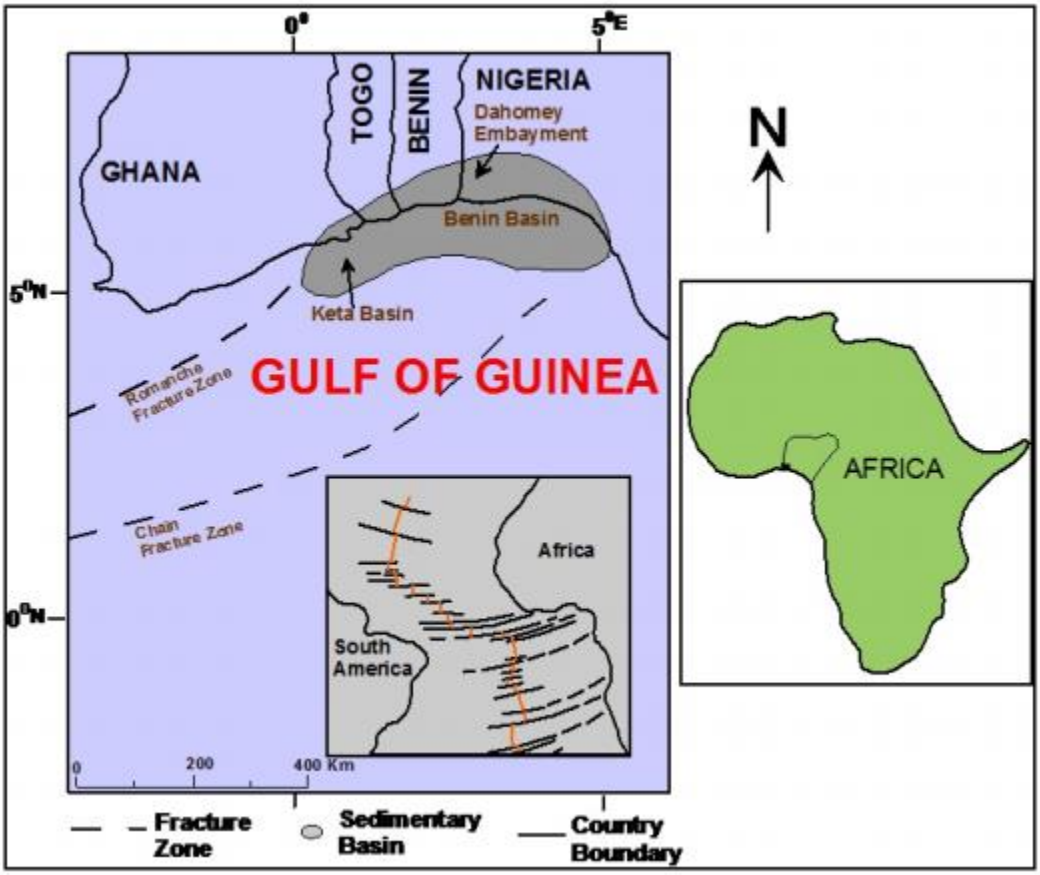



Figure 2.1 Regional map of the Gulf of Guinea showing the location of Benin (Dahomey) Basin in relation to other basins (Olabode *et al*, 2016).

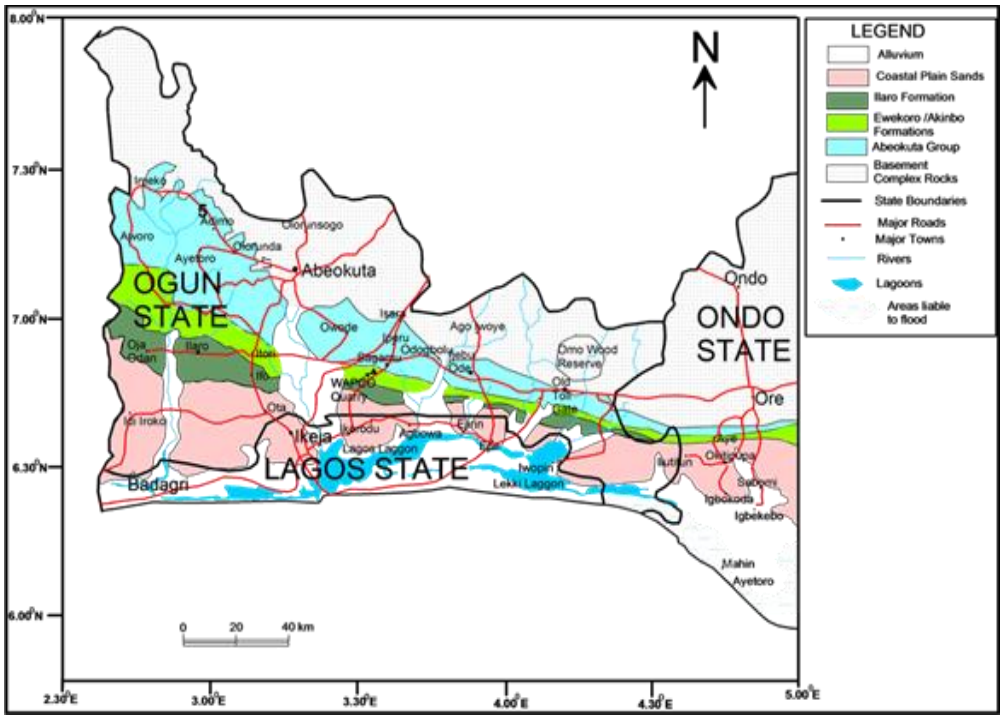



Figure 2.2 Geological map of Dahomey Basin in the Nigeria sector and the states located on the basin, (Olabode *et al*, 2016).

### 2.1.2 Stratigraphic setting of Benin (Dahomey) Basin

Early study on the basin stratigraphy by Jones & Hockey (1964) recognized both Cretaceous and Tertiary sediments. Other subsequent workers recognized three chronostratigraphic units:

a) Pre-lower Cretaceous folded sequence,

b) Cretaceous sequence and

c) Tertiary sequence (Table 2.1).

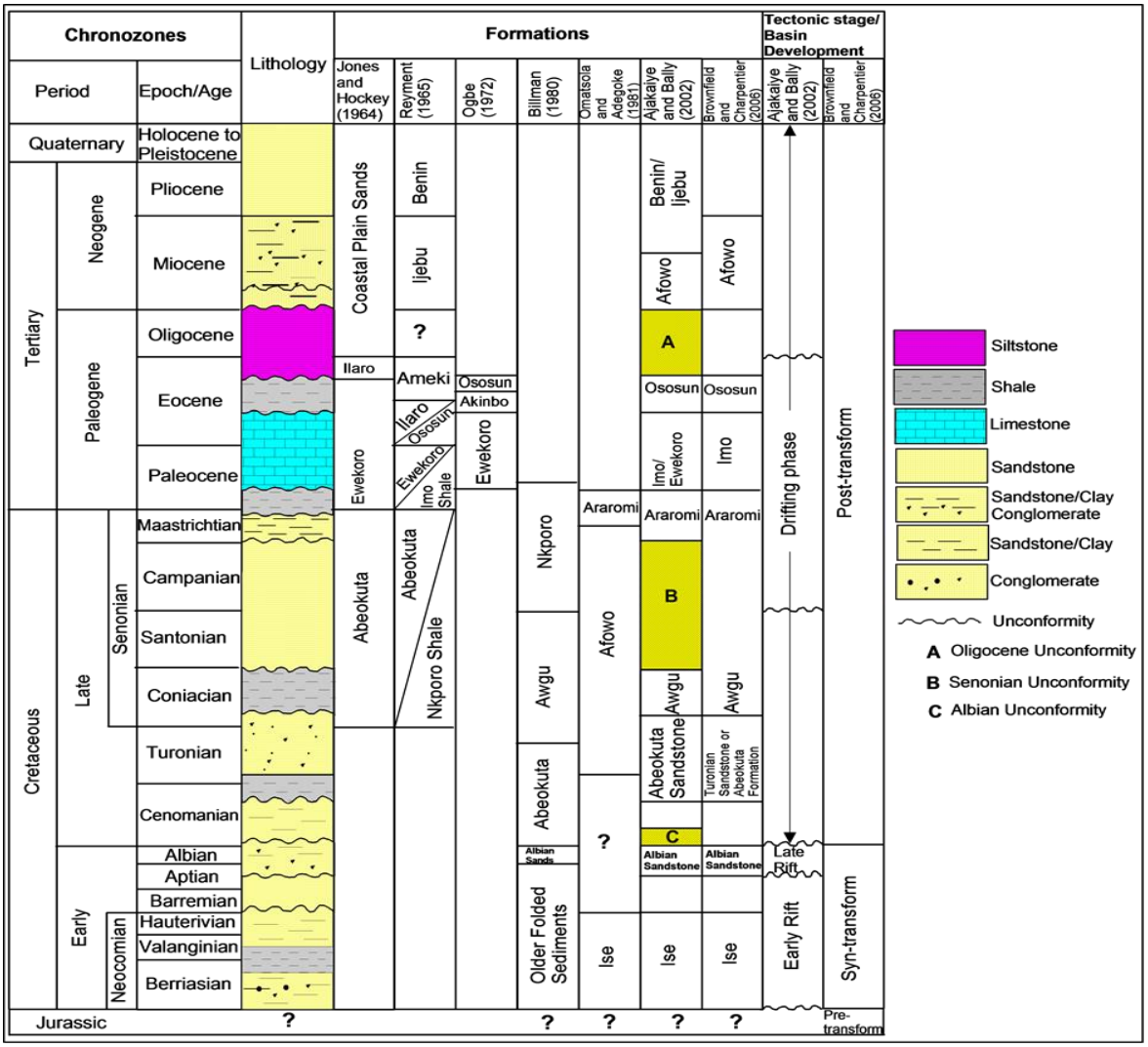
The Cretaceous stratigraphy as compiled from outcrop and borehole records consists Abeokuta Group sub-divided into three informal formational units namely Ise, Afowo and Araromi, Omatsola & Adegoke (1981). Olabode (2016) described the formations as follows; Ise Formation unconformably overlies the basement complex and comprises coarse conglomeratic sediments. Afowo Formation is composed of transitional to marine sands and sandstone with variable but thick interbedded shales and siltstone. Araromi is the uppermost formation and is made up of shales and siltstone with interbeds of limestone and sands (Table 2.1). The Tertiary sediments consist of Ewekoro, Akinbo, Oshosun, Ilaro and Benin (Coastal Plain Sands) Formations (Table 2.1).

The Ewekoro Formation is made up of fossiliferous well bedded limestone while Akinbo and Oshosun Formations are made up of flaggy grey and black shales. Glauconitic rock bands and phosphatic beds define the boundary between Ewekoro and Akinbo Formations. Ilaro and Benin Formations are predominantly coarse sandy estuarine, deltaic and continental beds.

A lot of controversy exists between the stratigraphy of the Cretaceous and Tertiary Formations in the Nigerian sector of the basin. This is due primarily to different stratigraphic names that have been proposed for the same Formation in different localities in the basin (Billman, 1992 & Coker,

2002). This situation can be fairly blamed on the lack of good borehole coverage and adequate outcrops for detailed stratigraphic studies.

Table 2.1 Generalized stratigraphic column showing age, lithology, and sequence of the formations and tectonic stage of basin development in the Nigerian sector of the Benin (Dahomey) Basin. (Olabode *et al*, 2016).




Jones & Hockey (1964) established the name Abeokuta Formation for the mainly arenaceous strata with mudstone, silt, clay and shale interbeds that crop out onshore. Billman (1976) subdivided the Abeokuta Formation into three lithostratigraphic units: The “Unnamed Older Folded Sediments”, “Unnamed Albian Sands” and Abeokuta Formation. On the basis of age equivalence, he referred

the remaining Cretaceous strata to the Awgu and Nkporo Shales. Omatsola & Adegoke (1981) disagreed with this nomenclature on two main grounds.

The first of these is that a rule of accepted stratigraphic practice is contravened because when the Abeokuta Formation was subdivided the same name was used for only one part of the succession. The second is that the application of the well-established Anambra Basin names: Nkporo and Awgu Shales to the Dahomey Basin solely on the basis of age is invalid. As a result, they proposed three new lithostratigraphic units, the Ise, Afowo and Araromi Formations, and referred these to the Abeokuta Group. In their classification, the Ise Formation is equivalent to the Unnamed Older Folded Sediments and the Unnamed Albian Sands, the Afowo Formation to the outcropping Abeokuta Formation, and the Araromi Formation to the Awgu and Nkporo Shales. The view that Anambra Basin lithostratigraphic names should not be used in the Dahomey Basin solely on the basis of age was supported by Okosun (1990). Furthermore, it is inappropriate to use the same names for lithostratigraphic units situated in different basins which are both widely separated from each other and have had different geologic history. This is also true if material for comparison of complex lithologic sequences is only present in deep well cores that are not readily available for study. Thus, the strata previously referred to as the Nkporo Shale were renamed Araromi Formation by Okosun (1990). The lithology of Ise and Afowo formations as defined by Omatsola & Adegoke (1981) show a high degree of similarity. Both are essentially sands and sandstones, but the latter contains thick interbeds of shale. This difference is not sufficient to warrant the establishment of separate lithostratigraphic units. The two formations were considered synonymous by Okosun (1990). In that study, it was observed that the Ise, Afowo and Abeokuta formations have similar lithologic and electric log characters.

The uppermost beds of Abeokuta Formation which crop out in the Ijebu-Ode area and in the shallow boreholes, at Itori, Wasimi and Ishaga onshore, consist mainly of fine- to coarsegrained sand and interbeds of shale, mudstone, limestone and silt, Okosun (1990). These lithofacies correlate well with the upper portion of the neostratotype in the Ojo-1 Borehole. studied by Okosun (1990). Although the Afowo Formation contains shale interbeds, Okosun (1990) emphasized that its essentially sandy character qualifies it along with the arenaceous Ise Formation, for inclusion in the Abeokuta Formation which also contains shale interbeds as demonstrated in the neostratotype described by him and as seen also in many surface outcrops. The use of the names Ise and Afowo. Formations was therefore discontinued and replaced by the Abeokuta Formation which has priority of publication and a wider accepted usage. The Abeokuta Formation was defined by Jones & Hockey (1964) to consist of grits, loose sand, sandstone, kaolinitic clay and shale. It was further characterized as usually having a basal conglomerate or a basal ferruginised sandstone, (Obaje, 2009).

## 2.2 Basic Theories

Various geophysical methods are applied to environmental site investigations. These methods use different principles of physics and mathematics to model geologic strata and subsurface features. Some methods are based on the injection of electrical current into the subsurface in order to observe the flow paths. Other methods use sound waves or propagate electromagnetic waves in the subsurface. All of the methods create anomalies (strong responses above or below the background levels) based on the differing ways that earth materials respond to the propagating signal. Popular geophysical methods used for environmental monitoring include electrical resistivity (transmission of an electrical current), seismic reflection and refraction (transmission of sound), ground penetrating radar (transmission of an electromagnetic signal), electromagnetic induction (transmission an electromagnetic signal), and gravity (measurement of density changes in the subsurface). The specific methods used in this study are discussed in more detail in the following sections.

### 2.2.1 Electrical Resistivity (ER)

Electrical resistivity is a fundamental and diagnostic physical property that can be determined by a wide variety of techniques, including electromagnetic induction (Kearey *et al*, 2002).

The resistance (R) is proportional to the length (L) of the resistive material and inversely proportional to the cross-sectional area (A); the constant of proportionality is the 'true' resistivity ($\rho$). According to Ohm's law, the ratio of the potential drop to the applied current (V/I) also defines the resistance (R) of the cylinder and these two expressions can be combined to form the product of a resistance ($\Omega$) and a distance (area/length; meters) as shown in equation (2.0); hence, the unit of resistivity is ohms-meter ($\Omega$m).

$$\rho = \frac{VA}{IL}[\Omega m] \qquad \textbf{(2.0)}$$

In the resistivity method, artificially generated electric currents are introduced into the ground and the resulting potential differences are measured at the surface. Deviations from the pattern of potential differences expected from homogenous ground provide information on the form and electrical properties of the subsurface inhomogeneities (Kearey *et al*., 2002).

The resistivity of a material is defined as the resistance in ohms between the opposite faces of a unit cube of the material. For a conducting cylinder of resistance ∂R, length ∂L and cross-sectional area ∂A (Figure. 2.3), the resistivity (ρ) is given by equation (2.1).

$$\rho = \frac{\partial \mathrm{R}\,\partial \mathrm{A}}{\partial \mathrm{L}} \qquad \textbf{(2.1)}$$

The SI unit of resistivity is ohms-meter (Ωm) and the reciprocal of resistivity is termed conductivity (Siemens per meter ($Sm^{-1}$)).

Consider the element of homogenous material shown in Figure 2.4, current (I) is passed through the cylinder causing a potential drop ∂V between the ends of the element. The potential gradient *(∂V/∂L)* associated with this current density (*j*) is represented in equation (2.2):

$$\frac{\partial \mathrm{V}}{\partial \mathrm{L}} = -\frac{\rho l}{\partial \mathrm{A}} = -\rho j \qquad \textbf{(2.2)}$$

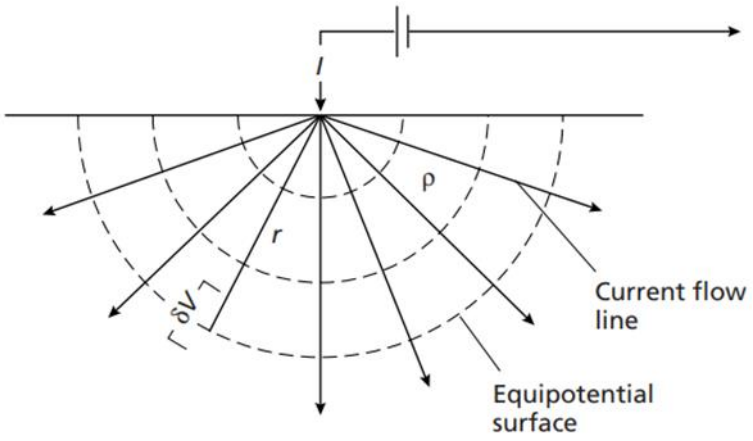



Figure 2.3: The parameters used in defining Resistivity (Kearey *et al.*, 2002)

Where $\partial V/\partial L$ represents the potential gradient through the element in voltm$^{-1}$ and j the current density in Am$^{-2}$.

Now consider a single current electrode on the surface of a medium of uniform resistivity ρ (Figure 2.4). The circuit is completed by a current sink at a large distance from the electrode. The current flows radially away from the electrode so that the current distribution is uniform over hemispherical shells centred on the source. At a distance from the electrode the shell has a surface area of $2\pi r^2$, so the current density ($j$) is given by equation (2.3).

$$j = \frac{I}{2\pi r^2} \qquad \textbf{(2.3)}$$

From equation (2.2), the potential gradient associated with this current density in equation (2.3) can be written as equation (2.4).

$$\frac{\partial \mathrm{V}}{\partial \mathrm{r}} = -\rho j = -\frac{\rho I}{2\pi r^2} \qquad \textbf{(2.4)}$$

The potential $V_r$ at distance r is then obtained by integration of equation (2.4).

$$V_r = \int \partial V = -\int \frac{\rho I \partial r}{2\pi r^2} = \frac{\rho I}{2\pi r^2} \qquad \textbf{(2.5)}$$

The constant of integration is zero since Vr = 0 when r = ∞. Equation (2.5) allows the calculation of the potential at any point on or below the surface of a homogenous half-space. The hemispherical shells in Figure 2.3. mark surfaces of constant voltage and are termed equipotential surfaces (Kearey et al., 2002). Figure 2.4 shows the flow pattern of the current in a vertical section through 'tubes' in a uniform half-space.

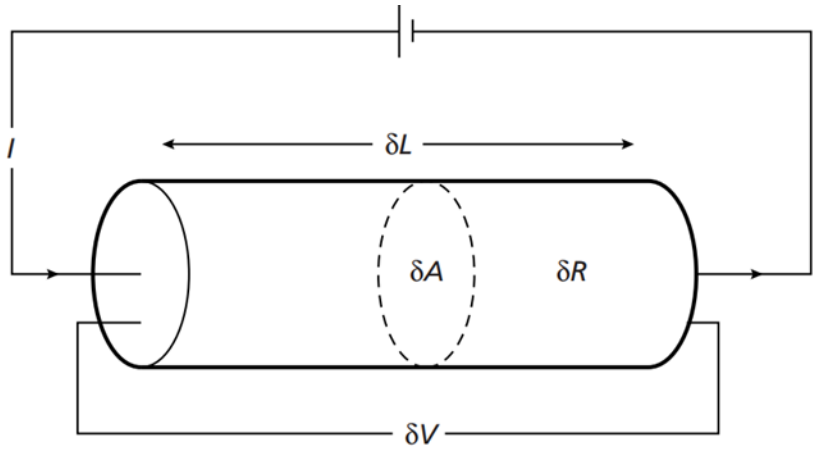



Figure 2.4: Current Flow from a Single Surface Electrode (Kearey *et al.*, 2002)

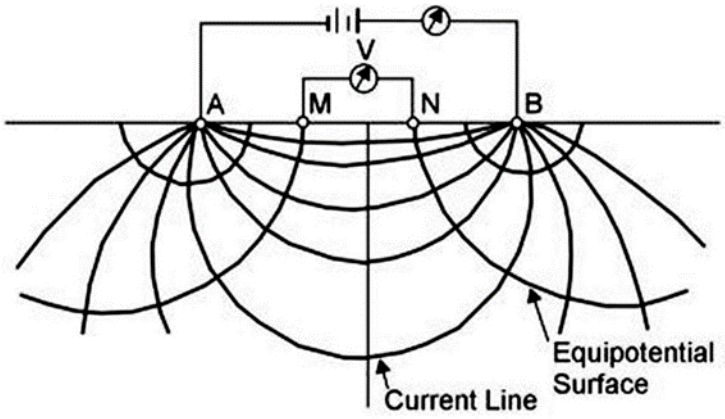



Figure 2.5: Equipotential and Current lines for a pair of current electrodes A and B on a homogenous half-space (Kearey *et al.*, 2002)

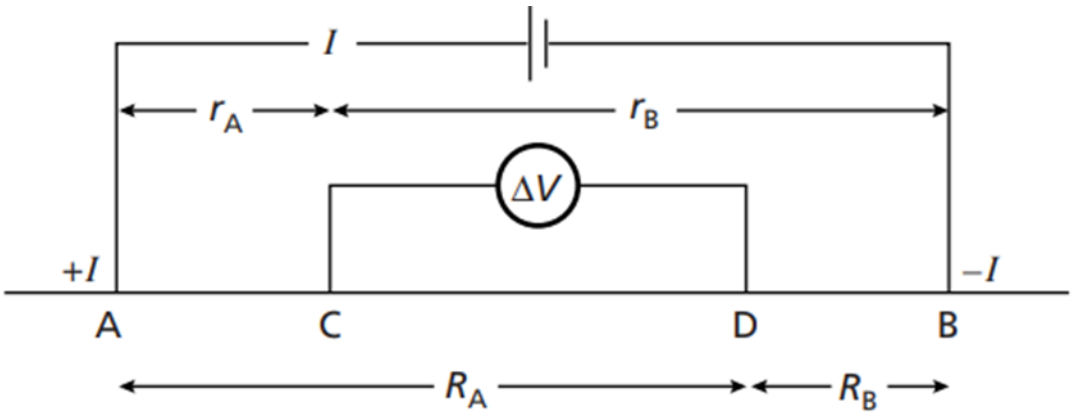



Figure 2.6: The Generalized form of the Electrode Configuration (Kearey *et al.*, 2002)

Geometric factors are not affected by interchanging current and voltage electrodes but voltage electrode spacing are normally kept small to minimize the effects of natural potential.

i. A and B represents the current electrodes

ii. C and D represents the potential electrodes

iii. I represent current

iv. ΔV represents Potential differences.

The generated form of the electrode configuration used in resistivity measurement was shown in Figure 2.6. $V_C$, at an internal electrode C, is the sum of the potential contributions $V_A$ and $V_B$ from the current source at A and the sink at B.

$$V_C = \frac{\rho I}{2\pi}\left[\frac{1}{r_A} - \frac{1}{r_B}\right] \qquad \textbf{(2.6)}$$

Similarly, also $V_D$ in equation (2.7) is also generated as:

$$V_D = \frac{\rho I}{2\pi}\left[\frac{1}{R_A} - \frac{1}{R_B}\right] \qquad \textbf{(2.7)}$$

Absolutely potentials are difficult to monitor so the potential difference ΔV between electrodes C and D is measured as shown in equation (2.8),

$$\Delta V = V_C - V_D = \frac{\rho I}{2\pi}\left\{\left[\frac{1}{r_A} - \frac{1}{r_B}\right] - \left[\frac{1}{R_A} - \frac{1}{R_B}\right]\right\} \qquad \textbf{(2.8)}$$

Thus, equation (2.8) can be written for ρ as stated in equation (2.9),

$$\rho = \frac{2\pi\Delta V}{I\left[\left[\frac{1}{r_B} - \frac{1}{r_B}\right] - \left[\frac{1}{R_A} - \frac{1}{R_B}\right]\right]} \qquad \textbf{(2.9)}$$

Where the ground is uniform, the resistivity calculated from equation (2.9) should constant and independent of both electrodes spacing and surface location. When subsurface inhomogeneities exist however, the resistivities will vary with the relative positions of the electrodes. Any computed value is then known as the apparent resistivity $\rho_a$ and will be a function of the form of the inhomogeneity. In effect therefore, depth of current penetration increases with increase in current electrode separation in homogenous layers (Telford *et al.*, 1990).

**Electrode Configuration**

The electrical resistivity method utilizes different electrode configurations (or arrays) to probe the subsurface and, although several are occasionally employed in specialized surveys, only two are in common use (Kearey *et al.,* 2002). This configuration depends on the mode of arrangement of the current and potential electrodes relative to one another. The various types of electrode configurations include but not limited to Wenner, Schlumberger, Dipole-Dipole, Gradient and Square arrays (Reynolds, 2011).

### i. Wenner Electrode Array

In the Wenner configuration (Figure 2.7), the current and potential electrode pairs have a common mid-point and the distances between adjacent electrodes are equal to "a". Substituting this condition into equation (2.9) generates equation (2.10) as shown as:

$$\rho_a = 2\pi a \frac{\nabla V}{I} \qquad \textbf{(2.10)}$$

During Vertical Electrical Sounding (VES), the spacing "a" is gradually increased about a fixed central point and in Constant-separation traversing (CST) the whole spread is moved along a profile with a fixed value of "a".

i. C1 and C2 – current electrodes

ii. P1 and P2 – potential electrodes

iii. k – Geometric factor

iv. a – Electrode spacing.

### ii. Schlumberger Electrode Array

In the Schlumberger configuration (Figure 2.8), the current and potential pairs of electrodes often also have a common mid-point, but the distances between adjacent electrodes differs. Let parameter "a" represents the distances between one of the current electrodes to the reference point while "b" denotes the distance between two potential electrodes. In substituting the parameter $\left[a - \frac{b}{2}\right]$ and $\left[a + \frac{b}{2}\right]$ into equation (2.9), yields $\rho_a$ as expressed in equation (2.11),

$$\rho_a = \frac{\pi a^2}{b}\left[1 - \frac{b^2}{4a^2}\right]R; \text{ a} \geq 5\text{b} \qquad \textbf{(2.11)}$$

i. C1 and C2 – current electrodes

ii. P1 and P2 – potential electrodes

iii. a – Distance of the current electrode spacing to the reference point

iv. b – Distance between the two potential electrodes.

v. x – Reference point.

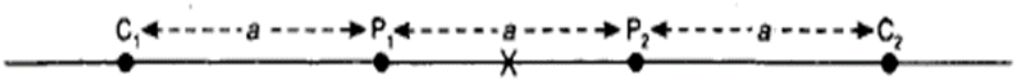



Figure 2.7: Wenner Configuration Array Type (Reynolds, 2011)

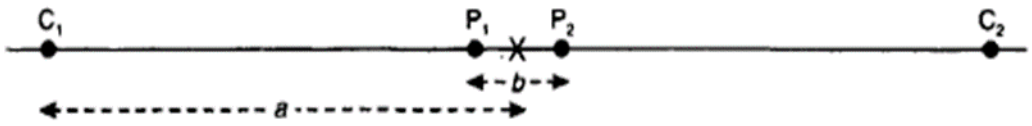



Figure 2.8: Schlumberger Configuration Array Type (Reynolds, 2011)

**Factors Affecting Resistivity of Subsurface Materials**

The factors affecting earth resistivity include the following:

i. **Porosity:** The empirical formula developed by Archie (1942) in equation (2.12) for the effective resistivity of a rock formation which takes into account the porosity (φ), the fraction(s) of the pores containing water, and the resistivity of the water $\rho_w$ is expressed as:

$$\rho = a\varphi^{-m}s^{-n}\rho_w \qquad \textbf{(2.12)}$$

Where ρ and $\rho_w$ are the effective rock resistivity, and the resistivity of the pore water, respectively; φ is the porosity; s is the volume fraction of pores with water; a, m and n are constants where 0.5 ≤ a ≤2.5, 1.3 ≤ m ≤ 2.5, and n ≈ 2.

The ratio $\frac{\rho}{\rho_w}$ is known as the Formation factor (F).

ii. **Permeability:** Archie's relationship notwithstanding, a rock with a non-conducting matrix must be permeable as well as porous to conduct electricity. Permeability (k) has a direct relationship with porosity and logarithmic relationship as shown in equation (2.13) and (2.12) (Olorunfemi and Griffiths, 1985):

$$\varphi = aK^b \qquad \textbf{(2.13)}$$

$$Log\varphi = Loga + LogK \qquad \textbf{(2.14)}$$

φ= porosity, k = permeability, a and b are constants.

These relationships hold for clean sand and saline water saturated shaly sand. The clean sand shows that the resistivity decreases with increase in permeability while the shaly sand resistivity increases with permeability.

iii. **Temperature:** The mobility of ion and the viscosity of fluid are affected by temperature. The lower the viscosity the more mobile the ions become which is caused by higher temperature. Hence, the resistivity becomes lower and the conductivity tend to be higher. According to Keller and Frischknecht (1966), the resistivity of rock at temperature t is given by the equation (2.15).

$$\rho_t = \frac{\rho_{18}}{1+a\,(t-18)} \qquad \textbf{(2.15)}$$

Where $\rho_t =$ Resistivity of rock at temperature t

$\rho_{18} =$ Resistivity of rock at 18ºC

a = Temperature coefficient of resistivity

t = Temperature

iv. **Volume and concentration of electrolyte:** From the Archie equation Archie (1942) has expressed in equation (2.16),

$$\rho_r = a\varphi^{-m}S^{-n}\rho_w \qquad \textbf{(2.16)}$$

$S_w$ is the degree of fluid saturation and $\rho_w$ is the resistivity of fluid.

As the concentration of ions in the electrolyte, $\rho_w$ decreases causing the conductivity to increase in the medium.

v. **Matrix Resistivity:** If the matrix resistive, the resistivity of the rock itself increases as shown by the equation (2.17) (Patnode and Wyllie, 1950),

$$\frac{1}{\rho_r} = \frac{1}{\rho_m} + \frac{1}{F\rho_w} \qquad \textbf{(2.17)}$$

Where $\rho_r$ is the resistivity of rock (bulk), $\rho_m$ is the matrix resistivity, $\rho_w$ is the saturated fluid resistivity and F is the formation factor.

The equation (2.17) is applicable to shaly sand or sandstone.

vi. **Rock Type:** Resistivity of rocks varies with one rock type to another due to variation in textural type as well as variations in the geological processes that gave rise to the rock.

**Vertical Electronic Sounding (VES)**

Vertical Electronic Sounding (VES) which is also known as 'electrical drilling' or 'expanding probe' is one of the simplest and most widely used geophysical method used in mainly in the study of horizontal or near-horizontal interfaces. The current and potential electrodes are maintained at the same relative spacing and the whole spread is progressively expanded about a fixed point (Kearey *et al.*,2002). The technique is extensively used for various geophysical survey such as groundwater exploration by citing a borehole site, determining depth to bedrock, aquifer system, suitable site of landfill, assessing extent of leachate contamination at landfill site etc. (Keller and Frischknecht, 1966)

## 2D Electrical Resistivity Tomography (ERT)

Electrical Resistivity Tomography (ERT) is a well-established geophysical subsurface-imaging technique for environmental and engineering site investigation, and is routinely applied to the detection of pollution (Daily *et al*., 1998; Goes and Meekes, 2004), the characterization of geological (Meads *et al.,* 2003) and engineered structure (Daily and Ramirez, 2000), and hydrogeological studies (Binley *et al.,* 2002; Sandberg *et al.,* 2002). This technique employs two current electrodes and potential electrode in measuring the differences in the resistivity of the sub-surface. The advantage of ERT is that it provides a relatively lo cost, non-invasive and rapid means of generating spatial models of physical properties of the sub-surface.

## Limitations of the Electrical Resistivity Method

**i.** Ambiguity in the interpretation. Thus, there is need for independent geophysical and geological controls to discriminate between valid alternative interpretations of the resistivity data (Kearey *et al.,* 2002).

**ii.** Limitation of interpretation to simple structural configurations. Any deviation from these simple situations may be impossible to interpret.

**iii.** Effects of near-surface resistivity and topography variations can mask the effects of deeper variations (Kearey *et al.,* 2002).

**iv.** Limitation of depth of penetration by the maximum electrical power that can be introduced into the ground and by the physical difficulties of laying out long length of cables (Kearey *et al.,* 2002).

### 2.2.2 Ground Penetrating Radar (GPR)

Ground penetrating radar (GPR) utilizes propagating electromagnetic (EM) waves that respond to changes in the electromagnetic properties of the shallow subsurface. The propagation velocity of EM waves, which is the principal controlling factor on the generation of reflections, is determined by the relative permittivity contrast between the background material and the target (or the contrast between layers). Relative permittivity is defined as the ability of a material to store and then permit the passage of EM energy when a field is imposed on the material and can be measured in the lab or in situ.

A typical GPR unit consists of a transmitting and receiving antenna, where the transmitting antenna generates an EM pulse that travels into the subsurface and then reflects off an interface or scatters off point sources (both caused by a contrast in relative permittivity). This reflected/scattered energy then travels back to the surface, where it is recorded by the receiving antenna. The time it takes for the wave to travel down to an interface and back up to the surface is called the travel time, and it is used to determine the in-situ propagation velocity of the subsurface material. The velocity (distance/travel time) for an EM wave in Earth's atmosphere at or near sea level is 0.33 m/ns. Because the relative permittivity of all earth materials is greater than the permittivity of air, the velocity of an EM wave in all earth materials will be less than the EM propagation velocity in air— typical materials range between 0.05 and 0.15 m/ns (e.g., Daniels *et al.*, 1995).

Although the propagation velocity of an EM wave is dependent on the relative permittivity of the material, the amplitude and attenuation of a propagating wave is dependent on the magnetic permeability and the electrical conductivity of the material. Magnetic permeability is the ability of the material to become magnetized when an EM field is imposed on the material. As magnetic permeability increases, amplitude attenuation increases; therefore, increased magnetic

permeability results in poorer data quality and/or penetration depth. Electrical conductivity also affects the propagation of EM waves. Materials with a high electrical conductivity tend to attenuate EM signals; therefore, highly conductive materials will produce poor GPR data and/or reduce penetration depth. Table 2.2 shows the expected value ranges of relative permittivity, magnetic susceptibility, and conductivity for different geological materials.

Table 2.2 Relative permittivity and EM velocity for selected geologic materials (Daniels *et al.*, 1995)

| Material | $\varepsilon_r$; Davis and Annan (1989) | $\varepsilon_r$; Daniels (1996) | Velocity (m/ns) | Velocity (ft/ns) |
|---|---|---|---|---|
| Air | 1 | 1 | 0.3 | 0.98 |
| Distilled water | 80 | | 0.03 | 0.11 |
| Fresh water | 80 | 81 | 0.03 | 0.11 |
| Sea water | 80 | | 0.03 | 0.49–0.57 |
| Fresh water ice | 3–4 | 4 | 0.15–0.17 | 0.35–0.49 |
| Sea water ice | | 4–8 | 0.11–0.15 | 0.28–0.35 |
| Snow | | 8–12 | 0.09–0.11 | 0.35–0.50 |
| Permafrost | | 4–8 | 0.11–0.16 | 0.40–0.57 |
| Sand, dry | 3–5 | 4–6 | 0.12–0.17 | 0.18–0.31 |
| Sand, wet | 20–30 | 10–30 | 0.05–0.09 | 0.57–0.70 |
| Sandstone, dry | | 2–3 | 0.17–0.21 | 0.31–0.44 |
| Sandstone, wet | | 5–10 | 0.09–0.13 | 0.35–0.49 |
| Limestones | 4–8 | | 0.11–0.15 | 0.37 |
| Limestone, dry | | 7 | 0.11 | 0.35 |
| Limestone, wet | | 8 | 0.11 | 0.25–0.44 |
| Shales | 5–15 | | 0.08–0.13 | 0.33–0.40 |
| Shale, wet | | 6–9 | 0.10–0.12 | 0.18–0.44 |
| Silts | 3–30 | | 0.05–0.13 | 0.16–0.44 |
| Clays | 5–40 | | 0.05–0.13 | 0.16–0.44 |
| Clay, dry | | 2–6 | 0.12–0.21 | 0.40–0.70 |
| Clay, wet | | 15–40 | 0.05–0.08 | 0.16–0.25 |
| Soil, sandy dry | | 4–6 | 0.12–0.15 | 0.40–0.49 |
| Soil, sandy wet | | 15–30 | 0.05–0.08 | 0.18–0.25 |
| Soil, loamy dry | | 4–6 | 0.05–0.08 | 0.40–0.49 |
| Soil, loamy wet | | 15–30 | 0.07–0.09 | 0.22–0.31 |
| Soil clayey dry | | 4–6 | 0.12–0.15 | 0.40–0.49 |
| Soil, clayey wet | | 10–15 | 0.08–0.09 | 0.25–0.31 |
| Coal, dry | | 3.5 | 0.16 | 0.53 |
| Coal, wet | | 8 | 0.11 | 0.35 |
| Granites | 4–6 | | 0.12–0.15 | 0.40–0.49 |
| Granite, dry | | 5 | 0.13 | 0.44 |
| Granite, wet | | 7 | 0.11 | 0.37 |
| Salt, dry | 5–6 | 4–7 | 0.11–0.15 | 0.37–0.49 |

A typical reflection schematic is shown in Figure 2.9. The diagram shows a ray path that travels to the interface and reflects back to the surface at the incidence angle. When a wave traveling through the subsurface encounters an object with different electromagnetic properties than the surrounding material, the portion of the wave that hits the object will change direction by a process called scattering.

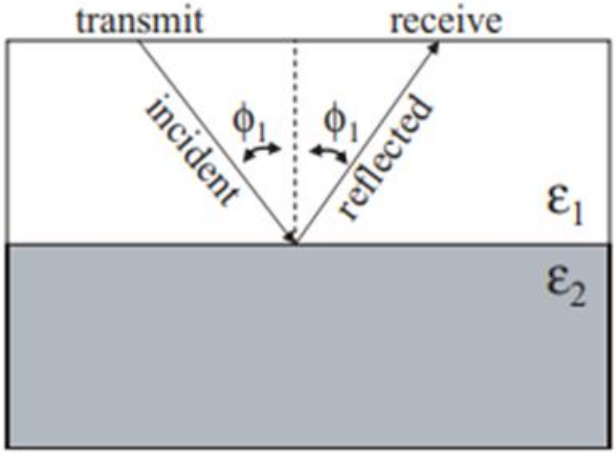



Figure 2.9 Schematic drawing of a typical reflection ray path from the source (labeled "transmit") to the receiver (labeled "receive"). The ray is shown reflecting off a horizontal subsurface interface. (Modified from Daniels *et al.*, 1995)

There are four main types of scattering:

i. spectral reflection scattering
ii. diffraction scattering
iii. resonant scattering, and
iv. refraction scattering.

Figure 2.10 shows the basic principle of spectral reflection at a horizontal interface. Spectral reflection scattering is the primary type of scattering targeted in most surveys and is described below. For details on the other types of scattering, see Daniels *et al.*, (1995).

Spectral reflection scattering is based on the law of reflection, where the angle of incidence (angle at which the wave hits the interface) is equal to the angle of reflection (angle at which the wave reflects off the interface). Some energy will not reflect from the interface but will refract through the interface into the underlying medium (as seen in Fig. 2.10). This energy will then travel downward until it encounters another interface layer that has different electromagnetic properties.

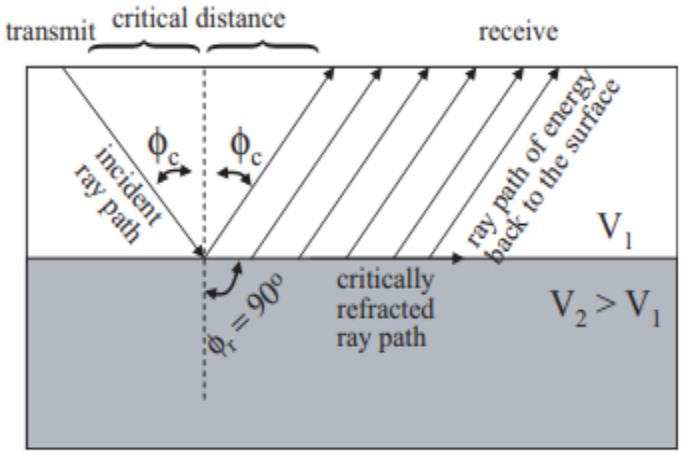



Figure 2.10 Schematic diagram showing wave behavior at a subsurface interface. Part of the wave is reflected back to the surface, whereas part of the wave is refracted. (Modified from Daniels, 1995)

At this second interface, some energy will reflect off the interface and travel back to the surface, and some energy will refract down into the third medium. In this multiple interface case, there will be several reflections in the GPR data as the down-going EM waves encounter each interface. The preceding overview represents the basic knowledge available to nearly all practitioners of GPR. What follows is a more detailed explanation of the critical variables, parameters, and principal equations that dictate how EM waves behave and respond to changes in subsurface electromagnetic properties.

**Relative Permeability**

The literature pertaining to GPR and EM theory invariability contains the terms dielectric constant (κ), relative permittivity (εr), dielectric permittivity (κε), and permittivity (ε). Dielectric constant, relative permittivity, and dielectric permittivity are equivalent, relative, and dimensionless terms. Permittivity is not equivalent to the previous terms and has the dimensions of Farads per meter (F/m), as described above. A Farad is a measure of charge stored per unit of potential difference and is the Système International d'Unités (SI) unit of capacitance. The terms permittivity, relative permittivity, and dielectric constant are commonly found in physics and electrical engineering literature. The term dielectric permittivity is apparently unique to geophysical literature. Therefore, researchers requiring an indepth discussion of EM theory as it pertains to GPR may encounter some initial confusion regarding the use of these terms when reviewing papers from various other disciplines. To minimize confusion, the term relative permittivity (εr) rather than dielectric constant or dielectric permittivity will be used herein due to its explicitness and common usage in physics, electrical engineering, and some geophysics texts. Be aware, however, that dielectric permittivity is often the typical term used in GPR publications within geology- or geophysics-centered journals. The real and imaginary components of permittivity are related to relative permittivity via

$$\varepsilon_r = \left( \frac{\varepsilon'}{\varepsilon_o} - i \frac{\varepsilon''}{\varepsilon_o} \right) \text{[dimensionless]}, \qquad (2.18)$$

Relative permittivity is a critical parameter in GPR studies in that it controls signal propagation velocity and thus wavelength, where wavelength is, of course, critical in determining resolution constraints. For example, material that has low relative permittivity will yield high GPR signal

propagation velocities and, thus, long wavelengths (allowing only lower resolution). This relationship is shown in equations (2.19) and (2.20) and is applicable only for materials with low conductivities and for high-frequency signals (as discussed in later sections):

$$v = \frac{c}{\sqrt{\varepsilon_r}} \text{ [m/s]}, \tag{2.19}$$

$$\lambda = \frac{c}{\sqrt{\varepsilon_r}} \cdot \frac{1}{f} \text{ [m]}, \tag{2.20}$$

where: v = velocity (m/s)

λ = wavelength (m)

c = speed of light in a vacuum (299,792,458 m/s)

f = frequency (hertz)

### 2.2.3 Magnetic Methods

**Flux density, field strength and permeability**

Around a bar magnet, a magnetic flux exists, as indicated by the flux lines in the Figure 2.9, and converges near the ends of the magnet, which are known as the magnetic poles. If such a bar magnet is suspended in free air, the magnet will align itself with the Earth's magnetic field with one pole (the positive north-seeking) pointing towards the Earth's north pole and the other (the negative south-seeking) towards the south magnetic pole. Magnetic poles always exist in pairs of opposite sense to form a dipole. When one pole is sufficiently far removed from the other so that it no longer affects it, the single pole is referred to as a monopole. If two magnetic poles of strength m1 and m2 are separated by a distance r, a force exists between If the poles are of the same type, the force will repel but will attract if they are of opposite polarity, and will draw the poles towards each other.

$$F = \frac{m_1 m_2}{4\pi\mu r^2} \qquad (2.21)$$

The relationship is similar to gravitational or electrical fields i.e., inverse square law where μ is the magnetic permeability of the medium separating the poles; $m_1$ and $m_2$ are pole strengths and r the distance between them. The closeness of the flux lines shown in the Figure 2.9, the flux per unit area, is the flux density B (and is measured in weber/$m^2$ = teslas). B, which is also called the 'magnetic induction', is a vector quantity.

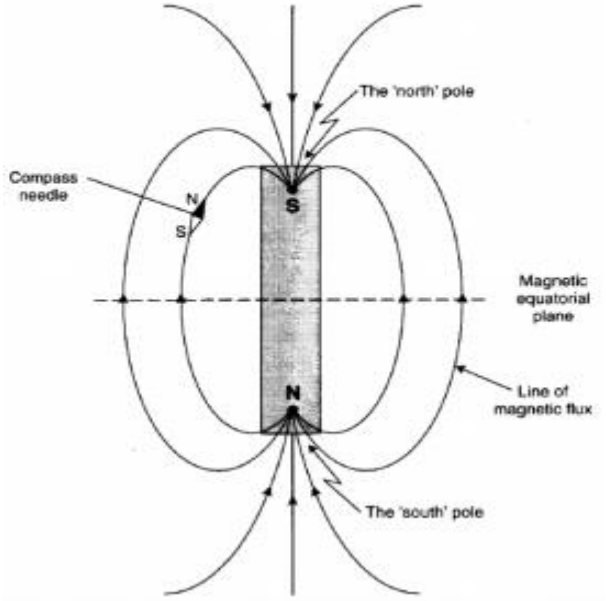



Figure 2.11 Magnetic flux (Telford, 1990)

The magnetic field can also be defined in terms of a force field which is produced by electric currents. This magnetising field strength H is defined, following Biot-Savart's Law, as being the field strength at the centre of a loop of wire of radius r through which a current I is flowing such that H = I/2r. Consequently, the units of the magnetising field strength H are amperes per metre (A/m). The ratio of the flux density B to the magnetising field strength H is a constant called the absolute magnetic permeability (μ). Practically, the magnetic permeability of water and air can be taken to be equal to the magnetic permeability of free space (a vacuum), denoted μo which has the value $4\pi \times 10^{-7}$ $WbA^{-1}m^{-1}$. For any medium other than a vacuum, the ratio of the permeabilities of a medium to that of free space is equal to the relative permeability μr such that $\mu_r = \mu / \mu_o$ and, as it is a ratio, it has no units. Susceptibility It is possible to express the relationship between Band H in terms of a geologically diagnostic parameter, the magnetic susceptibility κ Susceptibility is in

essence a measure of how susceptible a material is to becoming magnetised. For a vacuum, μr = 1 and κ= 0. Although susceptibility has no units, to rationalise its numerical value to be compatible with the SI or rationalised system of units, the value in c.g.s. equivalent units (e.g., unrationalised units such as e.m.u. - electromagnetic units) should be multiplied by 4π.

**Relationship between magnetic flux density B, magnetising force H, and susceptibility κ**

Given that $\boldsymbol{B} = \mu\boldsymbol{H}$

Since $\mu = \mu r\mu o$

It can be written that, and $\boldsymbol{B} = \mu r\mu o\boldsymbol{H}$

For a vacuum, μr = 1 and κ= 0

Therefore, κ= μr – 1 and B can be rewritten as

$\boldsymbol{B} = \mu o\boldsymbol{H} - \mu o\boldsymbol{H} + \mu r\mu o\boldsymbol{H}$

$= \mu o\boldsymbol{H} + \mu o(\mu r - 1)\boldsymbol{H}$

$= \mu o\boldsymbol{H} + \mu ok\boldsymbol{H}$

$= \mu o\boldsymbol{H} + \mu o\boldsymbol{J}$

Hence, = B = $\mu o\boldsymbol{H}(1 + k)$ ***(2.22)***

**Induced and remanent magnetisation**

In many cases, in the absence of an applied field (H), there is still a measurable intensity of magnetisation which is sustained by the internal field strength due to permanently magnetic particles. The intensity of this permanent or remanent magnetisation is denoted by $J_r$ (Figure 2.12). A rock mass containing magnetic minerals will have an induced as well as a remanent magnetisation. These magnetisations may have different directions and magnitudes of intensity.

The magnitude and orientation of the resultant J dictate both the amplitude and shape of a magnetic anomaly, respectively.

Consequently, interpretation of magnetic data is complicated by having greater degrees of freedom of the magnetic parameters and physical properties compared with gravity, which is largely dependent upon only rock density.

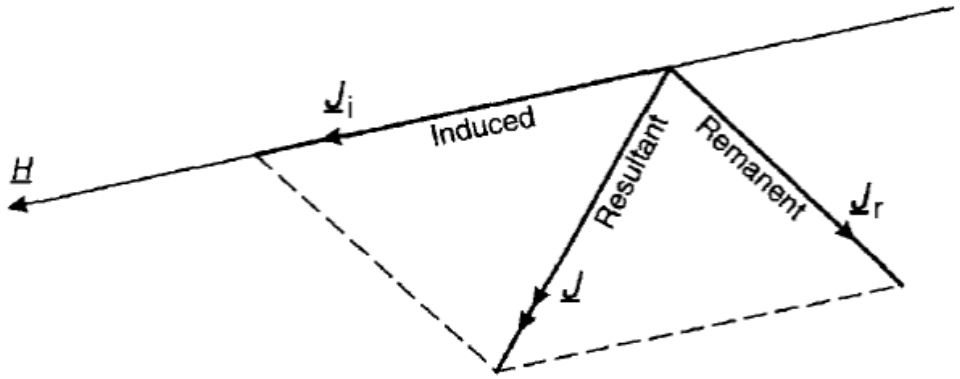



Figure 2.12 Induced and remanent magnetisation denoted by $J_r$ and $J_i$ respectively (Telford, 1990)

Similarities and Differences between magnetic and electric fields:

i. Like the electric field, the magnetic field is directly proportional to the magnetic force. But unlike E, which is parallel or antiparallel to the electric force, the direction of B is perpendicular to the magnetic force.

ii. Like E, the magnetic field may be defined through the force experienced by a small test charge, but unlike E, the speed and direction of the test charge must be taken into consideration when relating magnetic forces and fields.

iii. Because the magnetic force is perpendicular to the velocity at every instant, the component of the force in the direction of the displacement is zero, and the work done by the magnetic field is therefore always zero.

iv. Whereas electrostatic fields are produced by electric charges, magnetostatic fields are produced by electric currents.

**Susceptibility of rocks and minerals**

Magnetic susceptibility is an extremely important property of rocks and is to magnetic exploration methods what density is to gravity surveys. Rocks that have a significant concentration of ferro- and/or ferri-magnetic minerals tend to have the highest susceptibilities.

Consequently, basic and ultrabasic rocks have the highest susceptibilities, acid igneous and metamorphic rocks have intermediate to low values, and sedimentary rocks have very small susceptibilities in general.

Metamorphic rocks are dependent upon their parent material. Susceptibilities depend upon the alignment and shape of the magnetic grains dispersed throughout the rock. Table 2.3 shows the different magnetic susceptibility of different materials.

Table 2.3 Magnetic susceptibility of different materials (Telford, 1990)

| Mineral or rock type | Susceptibility* |
|---|---|
| *Sedimentary* | |
| Dolomite (pure) | −12.5 to +44 |
| Dolomite (impure) | 20000 |
| Limestone | 10 to 25000 |
| Sandstone | 0 to 21000 |
| Shales | 60 to 18600 |
| **Average for various** | **0 to 360** |
| *Metamorphic* | |
| Schist | 315 to 3000 |
| Slate | 0 to 38000 |
| Gneiss | 125 to 25000 |
| Serpentenite | 3100 to 75000 |
| **Average for various** | **0 to 73000** |
| *Igneous* | |
| Granite | 10 to 65 |
| Granite (m) | 20 to 50000 |
| Rhyolite | 250 to 37700 |
| Pegmatite | 3000 to 75000 |
| Gabbro | 800 to 76000 |
| Basalts | 500 to 182000 |
| Oceanic basalts | 300 to 36000 |
| Peridotite | 95500 to 196000 |
| **Average for acid igneous** | **40 to 82000** |
| **Average for basic igneous** | **550 to 122000** |
| *Minerals* | |
| Ice (d) | −9 |
| Rocksalt (d) | −10 |
| Gypsum (d) | −13 |
| Quartz (d) | −15 |
| Graphite (d) | −80 to −200 |
| Chalcopyrite | 400 |
| Pyrite (o) | 50 to 5000 |
| Hematite (o) | 420 to 38000 |
| Pyrrhotite (o) | 1250 to $6.3 \times 10^6$ |
| Ilmenite (o) | 314000 to $3.8 \times 10^6$ |
| Magnetite (o) | 70000 to $2 \times 10^7$ |

**Elements of the magnetic field**

The geomagnetic field can be described in terms of the declination, D, inclination, I, and the total force vector F.

A freely suspended magnetised needle will align itself along the F vector so that at the magnetic (dip) north, the inclination is 90°; i.e., the needle will point vertically downwards. At the south magnetic (dip) pole, the needle will point vertically upwards. At the magnetic equator, the needle will lie horizontally.

**Time variable field**

**Diurnal Variation**: Of more direct significance in magnetic prospecting are the smaIler but more rapid oscillations in the earth's field which have a periodicity of about a day and an amplitude averaging about 25 gammas known as Diurnal variations.

The records generally show two types of variations, the quiet day and the disturbed day. The quietday variation is smooth, regular, and low in amplitude; it can be separated into predictable components having both solar and lunar periodicities. The disturbed-day variation is less regular and is associated with magnetic storms.

The diurnal variations are caused by changes in the strength and direction of currents in the ionosphere. On a magnetically 'quiet' (Q) day, the changes are smooth and are on average around 50 nT but with maximum amplitudes up to 200 nT at the geomagnetic equator. The changes are least during the night when the background is almost constant, and decrease in amplitude from dawn to midday where upon they increase to the daily maximum about mid-late afternoon before settling down to the night-time value.

**Secular Variation**: Slow changes in the earth's field which take place progressively over decades or centuries are known as secular variations. Such changes are noted in all the magnetic elements at magnetic observatories everywhere in the world. Secular variation is a slow, progressive, temporal change in all the geomagnetic elements.

**Magnetic Storms**: In addition to the predictable short-term variations in the earth's field, there are transient disturbances which by analogy with their meteorological counterparts are called magnetic storms. Such storms cause considerable disruption in magnetic prospecting operations. The oscillations that take place while they are going on are so rapid and unpredictable that it usually is not feasible to correct for them as with diurnal variations. Magnetic surveys must generally be

discontinued during storms of any severity. From the equator to latitudes of 60°, the oscillations during such storms may have amplitudes as great as 1000 gammas. In Polar Regions, particularly during auroral displays, the storms may be accompanied by much greater amplitudes of magnetic variation. Their frequency correlates with the extent of sunspot activity. As the sun rotates, carrying sunspots away and toward the earth, some prediction of magnetic storms can be accomplished. The more intense storms begin suddenly, rage simultaneously all around the world, and usually last for several days.

**International Geomagnetic Reference Field (IGRF):** defines the theoretical undisturbed magnetic field at any point on the Earth's surface. In magnetic surveying, the IGRF is used to remove from the magnetic data those magnetic variations attributable to this theoretical field. The formula is considerably more complex than the equivalent Gravity Formula used for latitude correction.

**Corrections for Magnetic Variations**

**Secular Variation**: The need to tie different surveys, observed at different times, together and so compare individual magnetic responses in different areas has led to the development of models of the estimated value and the annual change of the main magnetic field of the earth. One such model is the International Geomagnetic Reference Field (IGRF). The IGRF is a mathematical model of the earth's main field and its temporal variations and consists of a series of spherical harmonics based on worldwide magnetic observatory data. The model was developed in 1968 and is periodically updated. It has become standard processing practice for magnetic surveys that the applicable IGRF (updated to the time of the survey) is subtracted from the observed values of the total magnetic intensity.

**Diurnal Variation**: The correction for the observed diurnal variation is more problematical, because the daily variation of the earth's magnetic field is highly variable and cannot easily be approximated by a mathematical model. Diurnal variations are subject to amplitude and phase changes, depending on the geographic location of the observer, and can also be influenced by geological conditions, such as rock susceptibility, at the place of observation. The necessary corrections are mostly attempted by the continuous observation of a base-station magnetometer located in or near the survey area. The measured magnetic field in the survey area is then corrected for the observed diurnal changes, either through a direct subtraction of the two data sets or through the manual removal of corresponding anomalies from the observed survey data. For most marine magnetic surveys or airborne magnetic surveys in remote localities, the placement of a base magnetometer in or near the survey area can present a logistical problem. Significant phase and/or amplitude differences in the observed diurnal data from the base station and the survey area can be present and may require additional techniques, such as a cross correlation method, to effectively remove the diurnal events in the observed total field. In some cases, the effects of diurnal variation can be minimized by a tie-line analysis of the observed data set.

**Magnetic Storms**: The variations in the magnetic field due to magnetic storms can be so rapid, unpredictable, and of such large amplitude, that normally no corrections can be made. Magnetic surveying is therefore generally discontinued under these conditions.

# CHAPTER THREE

# METHODOLOGY

## 3.1 Data Collection

This section provides a detailed description of the three geophysical techniques and methodology used for data collection and processing. These methods were selected because of their application in determining the position, depth, and lateral extent of buried utilities.

### 3.1.1 Electrical Resistivity (ER)p

The SuperSting R8 system manufactured by American Geoscience Institute (AGI) was used during data collection for the 2D electrical resistivity survey. The SuperSting R8 system is made up of resistivity/IP meter, 112 electrodes that are connected via cable, and an energy source that is used to power the resistivity/IP meter. These components were set up during acquisition as shown in Figure 3.1.

For the measurement, the resistivity meter was set for two-cycle stacking and the standard error of measurements of less than 10%.

Data were collected at three different locations using Dipole – Dipole array. At location 1, three traverses were established. Each traverse was 3 meters apart and 11.2 meters long. The electrodes were placed at a 0.1-meter interval in order to ensure high resolution and be able to delineate the buried pipe. Figure 3.2 shows how the traverses were established from Google Earth.

At location 2, three traverses were also established. The first two traverses were 5 meters apart while the third traverse was established 10 meters away from the second traverse (Figure 3.3). The traverses were 11.2 meters long with an electrode spacing of 0.1 meter.

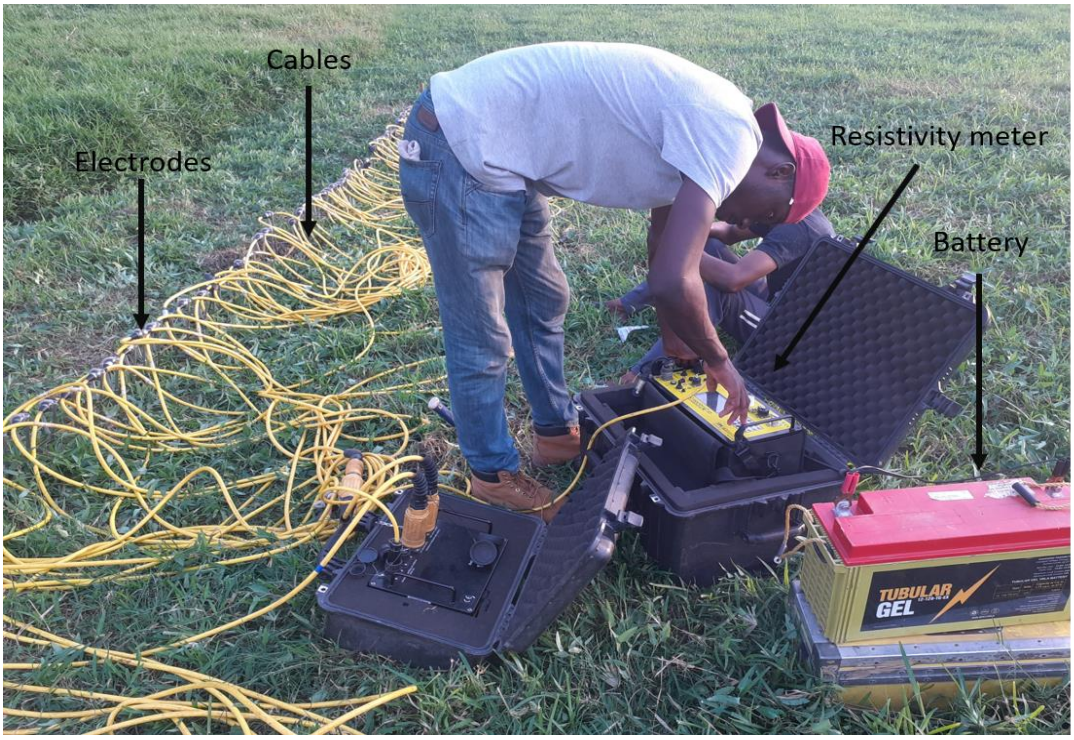



Figure 3.1 The setup of the SuperSting R8


Figure 3.2 Map showing 2D resistivity traverses at Location 1


Figure 3.3 Map showing 2D resistivity traverses at Location 2

Data collection at location 3 was divide into two; the first sets of traverses were established at the middle of the survey area to map the first pipe, and the other at one edge of the survey area to map the second pipe (Figure 3.4). Similarly, each of the traverses was 11.2 meters long with an electrode spacing of 0.1 meter.


Figure 3.4 Map showing 2D resistivity traverses at Location 3

### 3.1.2 Ground Penetrating Radar (GPR)

The MALA Ground Explorer (Figure 3.5) was used in the investigation because it can map the subsurface with high resolution and good for mapping shallow buried utilities. The GPR system is composed of a shielded antenna, a control unit, and a MALA rough terrain cart. The MALA Ground Explorer has a full surveying capability with interchangeable shielded antennas range of 80 – 750 MHz. Each of these antennas have different resolution and different depth of investigation (DOI) due to their different frequencies. The higher the frequency, the higher the resolution and shallow DOI. Also, the lower the frequency, the lower the resolution and deeper DOI.

Figure 3.5 MALA Ground Explorer

For this study, two antennas were used: 450MHz and 750MHz. The 450 MHz and the 750MHz antennas were chosen to produce a high resolution of the shallow subsurface. Proper settings were adjusted, signals were released by a trigger connected to the measuring wheel. Data were collected at three different locations. Location 1, 2, and 3 are represented by Figure 3.6, Figure 3.7, and

Figure 3.8 respectively. The red lines on the maps represent the traverses that were taken during the survey in each of the locations. The 3D GPR is represented by black boxes at each of the respective locations. Table 3.1 summarizes the GPR survey at each of the three locations.

Table 3.1 Table showing the number of traverses in each location

| Location | Number of Traverses | Length of Traverse (m) | 3D GPR |
|---|---|---|---|
| 1 | 3 | 30 | 6 by 6m at 1m interval |
| 2 | 6 | 11 | 3 by 3m at 0.5m interval |
| 3 | 3 | 65 | 3 by 3m at 0.5m interval |

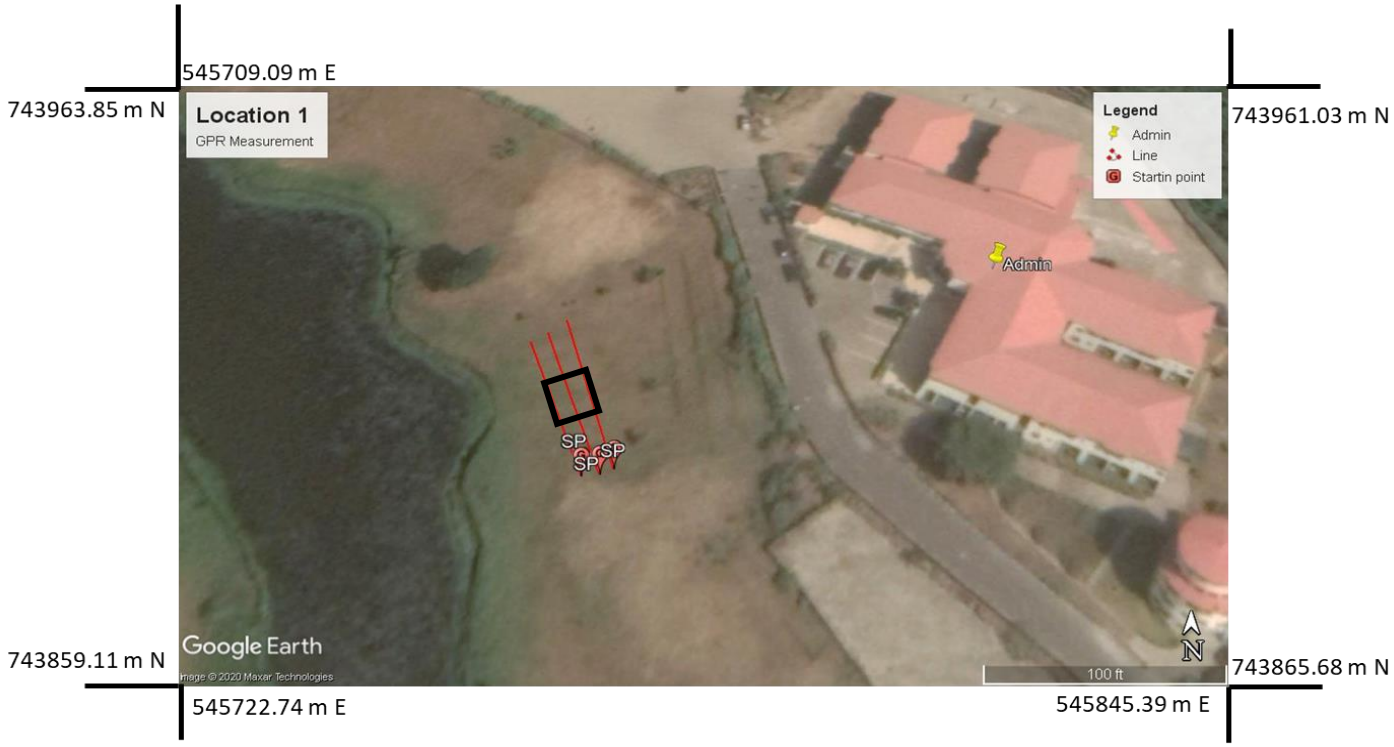



Figure 3.6 Map showing GPR traverses and 3D GPR at Location 1


Figure 3.7 Map showing GPR traverses and 3D GPR at Location 2

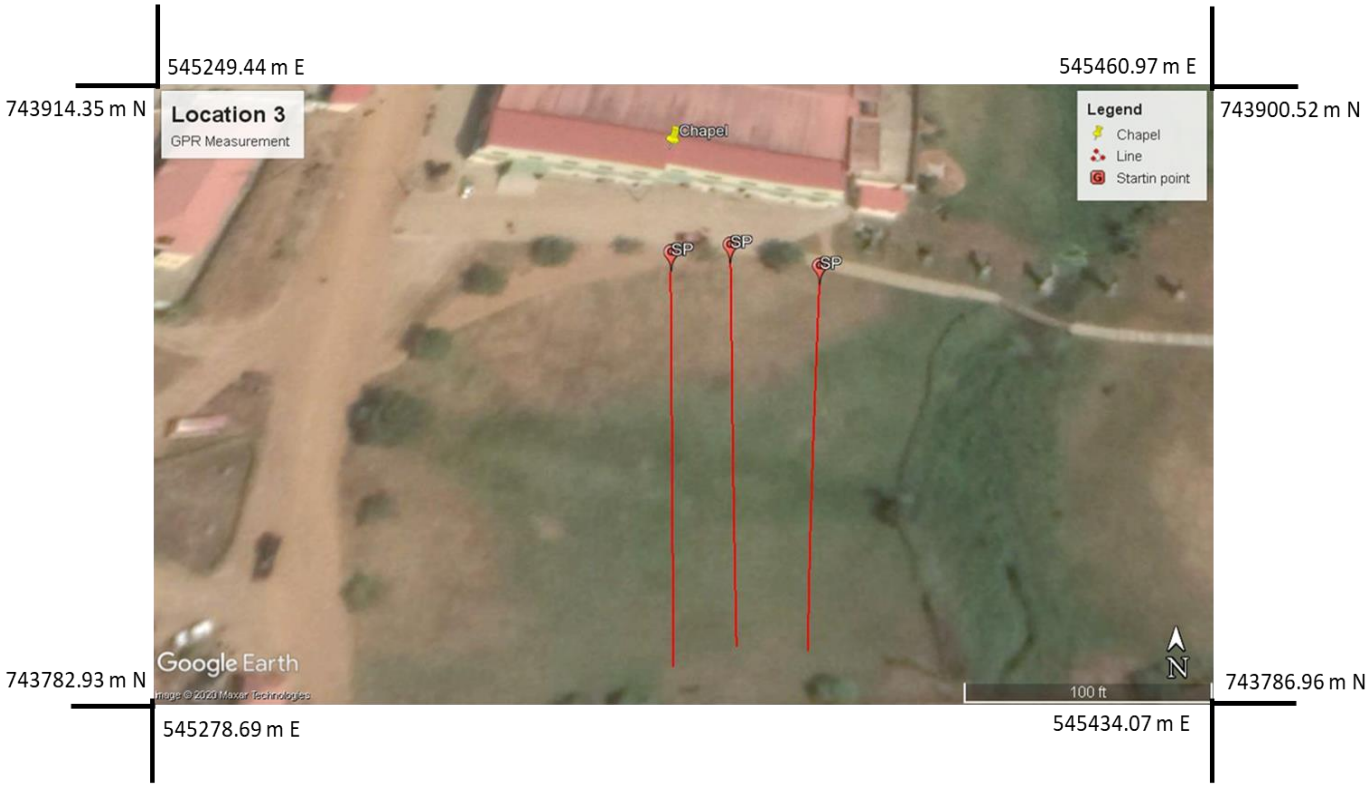



Figure 3.8 Map showing GPR traverses and 3D GPR at Location 3

### 3.1.2 Magnetics Methods

The Scintrex ENVI PRO magnetometer was used to record the total magnetic fields of the study areas. The ENVI PRO is a lightweight, portable proton precession magnetometer with integrated GPS and versatile design that offers users. The ENVI PRO system is composed of a control unit, a GPS antenna, a total field sensor and/or gradiometer sensor, sensor staff and, a backpack (Figure 3.9).

Data were collected along three traverses, 30 meters long and 3 meters apart at Location 1 (Figure 3.10). At location 2, data were collected along six traverses, 11 meters long and 5 meters apart (Figure 3.11).


Figure 3.9 ENVI PRO during data acquisition


Figure 3.10 Map showing magnetic traverses at Location 1

Lastly, at location 3, data was collected over 3 traverses; the first and the third traverse were collected over 40 meters while the third traverse was collected over 65 meters (Figure 3.12). The interstation spacing for all three locations was 0.1 meter to ensure high resolution.

Base stations were established at each of the locations in other to correct for the diurnal variation. Diurnal variation is the oscillation of the earth's magnetic field which occurs during the day. Repeated readings were taken at each station and base station to check for high amplitudes and inconsistencies in the magnetic field which is likely to be due to magnetic storms. The resulting data was first processes using Microsoft Excel to correct for the diurnal variation in the earth's magnetic field and to generate profiles for each location.

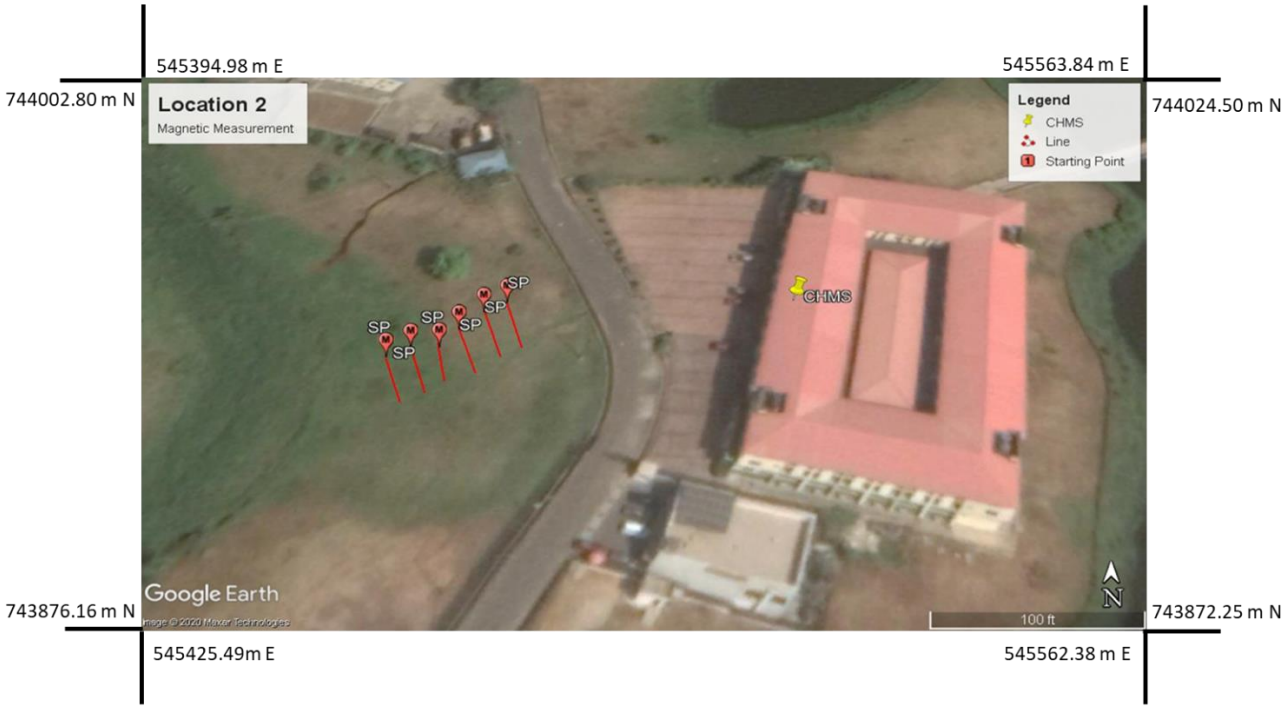



Figure 3.11 Map showing magnetic traverses at Location 2

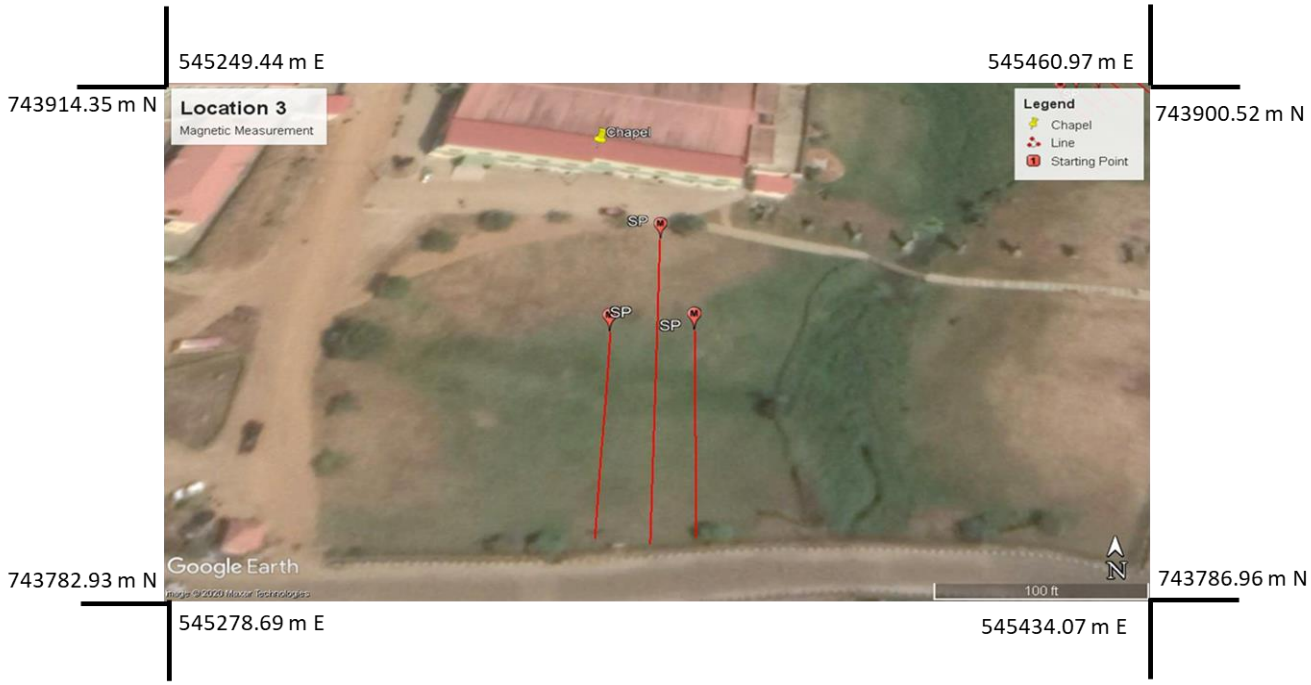



Figure 3.12 Map showing magnetic traverses at Location 3

## 3.2 Data Processing and Interpretation

### Magnetic Method

Repeated readings were taken at each station and base station to check for high amplitudes and inconsistencies in the magnetic field which is likely to be due to magnetic storms. The resulting data was first processes using Microsoft Excel to correct for the diurnal variation in the earth's magnetic field and to generate profiles for each location.

### Electrical Resistivity (ER)

The processing program (AGI EarthImager) inverted the data creating the apparent resistivity and final models. The final models were obtained by comparing the calculated data with the observed (raw data) and represents the true distribution of subsurface resistivity underneath each traverse. Figure 3.13 shows an example of a 2D resistivity section obtained along a traverse. (a) shows the raw data, the middle (b) shows the calculated apparent resistivities, and the inverted model is shown in (c). The inverted 2D ERT section is presented and discussed.

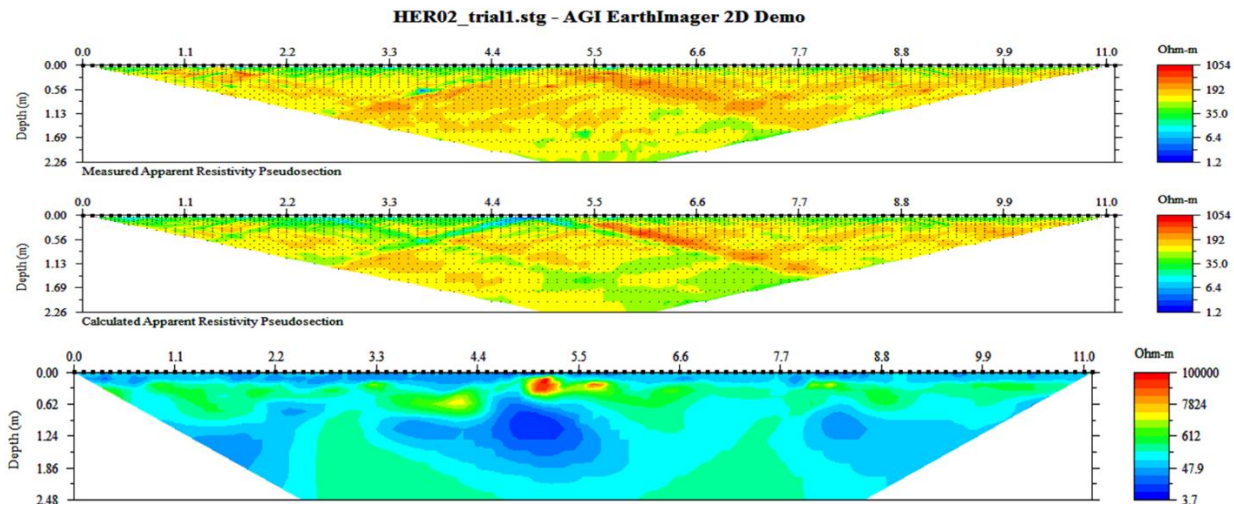



Figure 3.13: a.) Raw apparent resistivity data, b.) calculated apparent resistivity, and c.) Final resistivity model.

**Ground Penetrating Radar**

The data were processed and analyzed with ReflexW, GPR viewer and manufacturer's cloud-based processing software at https://malavision.guidelinegeo.com/ for the 3D GPR processing. The following filters: gain control, time zero adjustment, background removal, and topographic correction were applied. The major aim of GPR data processing was to improve the reflected signals from buried utilities and attenuate the noise signals.

Gain control was applied in order to enhance the low amplitude reflections on the radargram. Time zero adjustment adjusts the all the traces to a common zero position so that zero equals ground level and the true depth of the utility is obtained. Background removal all remove interference that is more pronounced than the data and thus presents a clearer image.

# CHAPTER FOUR

## RESULTS AND DISCUSSION

### 4.1 Introduction

As discussed in previous chapters, the three geophysical methods used in this study include Magnetics Survey, Electrical Resistivity (ER) Survey, and Ground Penetrating Radar (GPR). The result and discussion are presented in this chapter for each of the geophysical method.

### 4.2 2D Electrical Resistivity Imaging (ERI)

#### Location 1

Figure 4.1a is the interpreted inverted 2D electrical resistivity section along Traverse 2. The resistivity along this section ranges from 3.7 Ωm to about 100 kΩm and a depth of about 2.48m was investigated.

The 2D electrical resistivity section can be characterized into three geoelectric layers based on its vertical and lateral variation in electrical resistivity values. The first region is the topsoil with electrical resistivity range of about 3.7 Ωm to 47.9 Ωm and thickness range of 0.2 to 0.3 m.

The second geoelectric layer is with relatively higher electrical resistivity range of 171 to 612 Ωm and delineated to a depth range of 0.9 to 1m. Along the lateral distance of about 5 to 5.22m an anomalously high electrical resistivity of about 7824 to 100kΩm can be observed which is suggestive of buried pipe at a depth range of 0.2 to 0.5m. Therefore, the average diameter of the delineated pipe is about 0.22m.

The third geoelectric layer is represented by resistivity range of 3.7 to 121Ωm expressive of Clay/Sand layer.

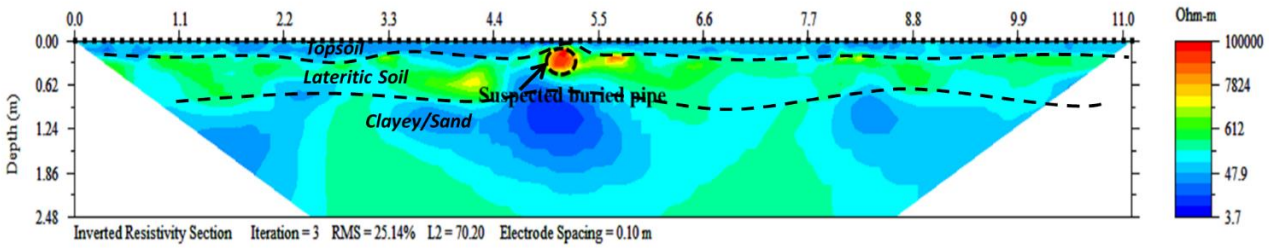



Figure 4.1a. Interpreted inverse model resistivity results for traverse 2

The 2D electrical resistivity section along traverse 3, (Fig 4.1b) is with resistivity value ranging from 1.8 Ωm – 52 kΩm and a depth of about 2.48 m was investigated.

Similarly, the 2D electrical resistivity section is characterized to three geoelectric layers. The first layer is the topsoil with electrical resistivity range of about 1.8 to 23.8 Ωm and thickness range of 0.2 to 0.3 m.

The second geoelectric layer is with relatively higher electrical resistivity range of 85.9 to 1117 Ωm and delineated to a depth range of 0.47 to 0.5 m. Along the lateral distance of about 4.9 to 5.1 m an anomalously high electrical resistivity of about 4026 Ωm to 52kΩm can be observed which is suggestive of buried pipe and at a depth range of 0.2 to 0.5m. Therefore, the average diameter of the delineated pipe is about 0.2 m.

The third geoelectric layer is represented by relatively low resistivity range of 23.8 to 85 Ωm expressive of Clay/Sand layer.

An augmented 3D view of the inverted 2D sections at location 1 is presented in Figure 4.1c. The augmented 3D view has shown the continuity of the anomaly associated to the pipe across the two traverses.

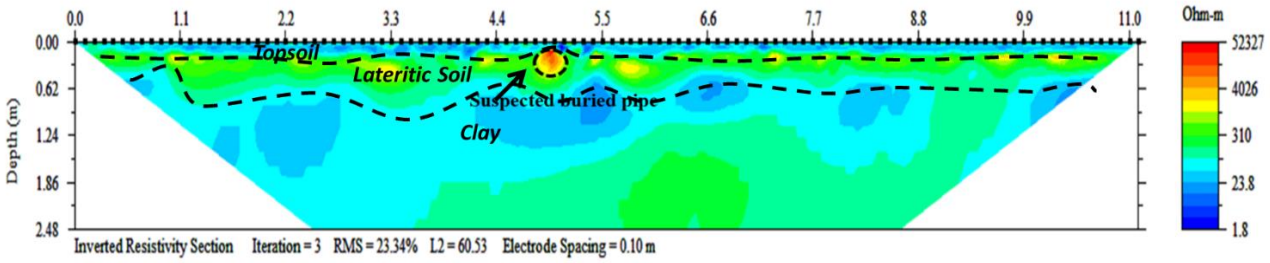



Figure 4.1b. Interpreted inverse model resistivity results for traverse 2.

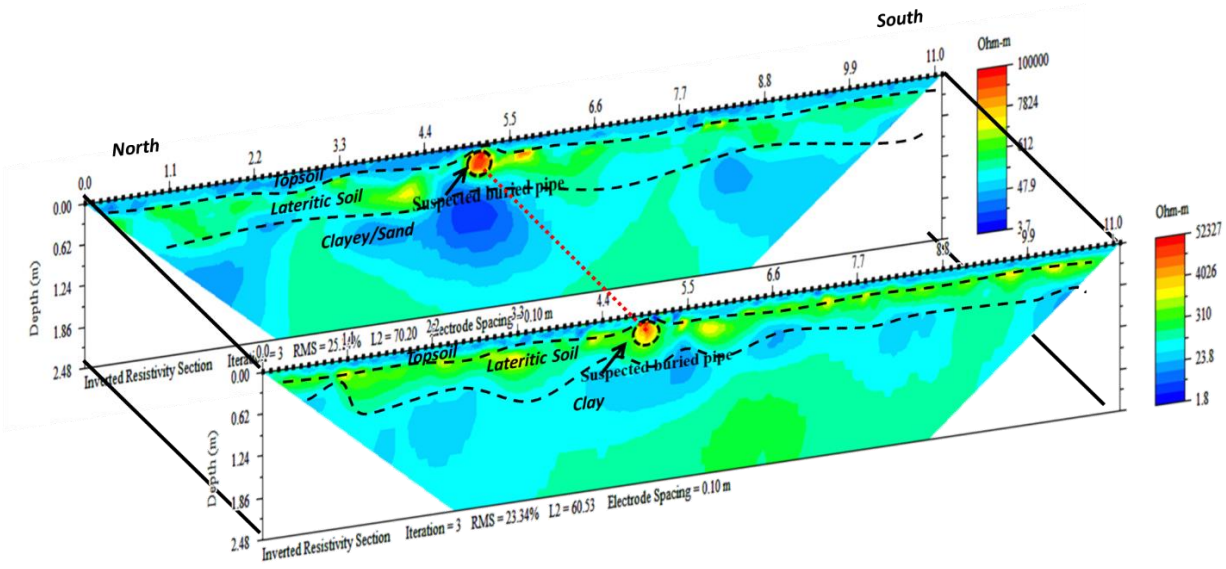



Fig 4.1c Augmented 3D view of the inverted 2D ERT sections at Location 1

## Location 2

**Traverse 1:** Figure 4.2a represents the interpreted inverted 2D electrical resistivity section along Traverse 1 in location 2. The resistivity along this section ranges from 7.7 to 1910 Ωm and a depth of about 2.48 m was investigated.

The 2D electrical resistivity section can be characterized into three geoelectric layers based on its vertical and lateral variation in electrical resistivity values. The first region is the topsoil with electrical resistivity range of about 7.7 to 30.6 Ωm and thickness range of 0.2 to 0.3 m.

The second geoelectric layer is with relatively higher electrical resistivity range of 60.8 to 283.3 Ωm and delineated to a depth range of 0.5 to 0.6 m. Along the lateral distance of about 5.50 to 5.78 m an anomalously high electrical resistivity of about 481 to 958 Ωm can be observed which is suggestive of buried pipe and at a depth range of 0.16 to 0.41 m. Therefore, the average diameter of the delineated pipe is about 0.25 m.

The third geoelectric layer is represented by resistivity range of 7.7 to 30.6Ωm expressive of Clay layer.

**Traverse 2:** Figure 4.2b representing the interpreted inverted 2D section along traverse 2 has a resistivity range of range of 8.7 to 1766 Ωm and a depth of about 2.48 m. The 2D electrical resistivity section can be characterized into four geoelectric layers based on its vertical and lateral variation in electrical resistivity values. The first geoelectric layer is the topsoil with electrical resistivity range of about 16.9 to 32.8 Ωm and thickness range of 0.2 to 0.3 m.

The second geoelectric layer is with relatively higher electrical resistivity range of 121 to 481 Ωm and delineated to a depth range of 0.5 to 0.9 m. An anomalously high electrical resistivity of about 481 to 1910 Ωm can be observed along the lateral distance of about 5.41 to 5.67 m which is suggestive of buried pipe and at a depth range of 0.16 to 0.41 m. Therefore, the average diameter of the delineated pipe is about 0.25 m.

An augmented 3D view of the inverted 2D sections at location 2 is presented in Figure 4.2c. The augmented 3D view has shown the continuity of the anomaly associated to the pipe across the two traverses.

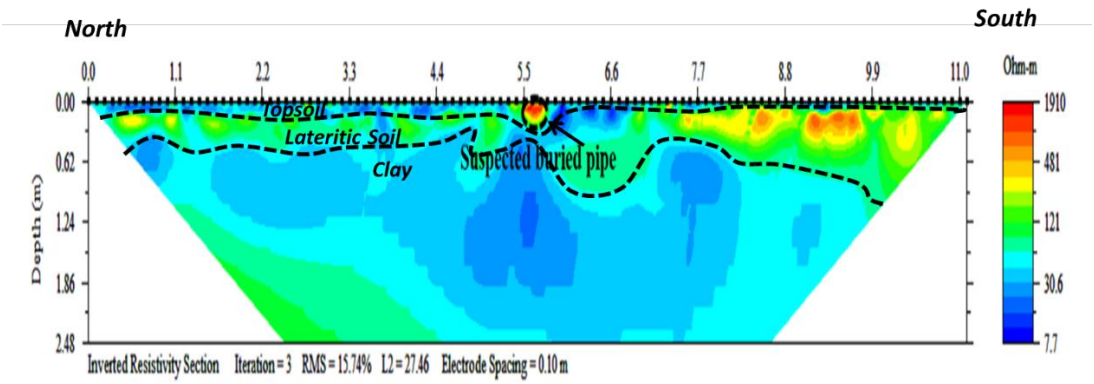



Figure 4.2a. Interpreted inverse model resistivity results for traverse 1.

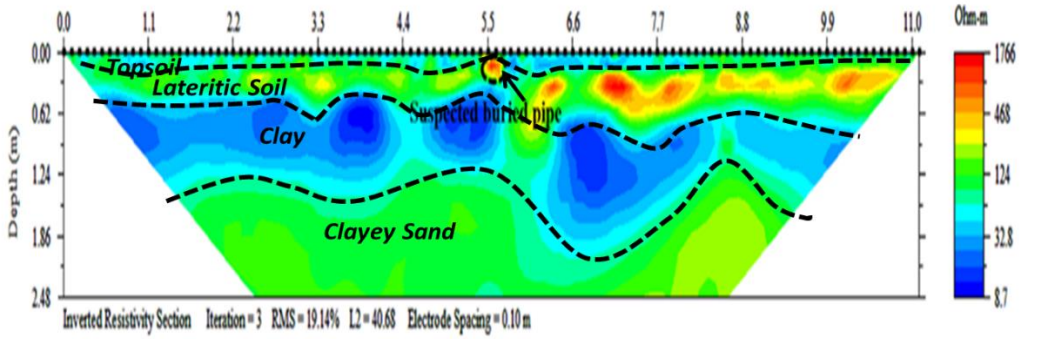



Figure 4.2b. Interpreted inverse model resistivity results for traverse 2.

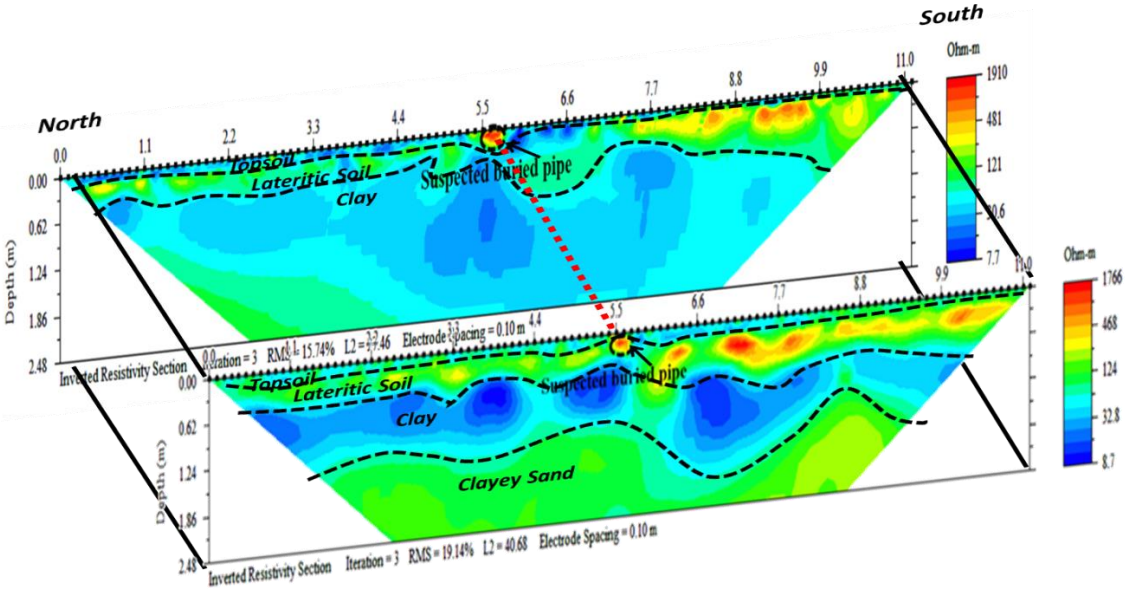



Fig 4.2c Augmented 3D view of the inverted 2D ERT sections at Location 2

**Location 3**

**Pipe 1:**

The 2D electrical resistivity inverted section of traverse 1 (Figure 4.3) fails to map the buried pipe. It does not show an interpretable anomaly for the buried pipe. Hence, it could not be resolved.

However, Figure 4.4a is the interpreted inverted 2D electrical resistivity section along traverse 2. The resistivity along this section ranges from 10.9 to 752 Ωm and a depth of about 2.48 m was investigated.

The 2D electrical resistivity section can be characterized into four geoelectric layers based on its vertical and lateral variation in electrical resistivity values. The first layer is the topsoil with electrical resistivity range of about 18.5 to 53.5 Ωm and thickness range of 0.2 to 0.3 m.

The second geoelectric layer is with relatively higher electrical resistivity range of 91 to 261 Ωm and delineate to a depth range of 0.58 to 0.6 m. Along the lateral distance of about 5.41 to 5.69 m an anomalously high electrical resistivity of about 154 to 443 Ωm can be observer which is suggestive of buried pipe and at a depth of 0.29 m.

The third geoelectric layer is represented by resistivity range of 10.9 to 91Ωm expressive of Clay Sand layer. The fourth geoelectric layer is represented by resistivity of about 91 to 154 Ωm expressive of Clayey Sand layer.

Figure 4.4b is the interpreted inverted 2D electrical resistivity section along traverse 2. The resistivity along this section ranges from 10.9 to 752 Ωm and a depth of about 2.48 m was investigated.

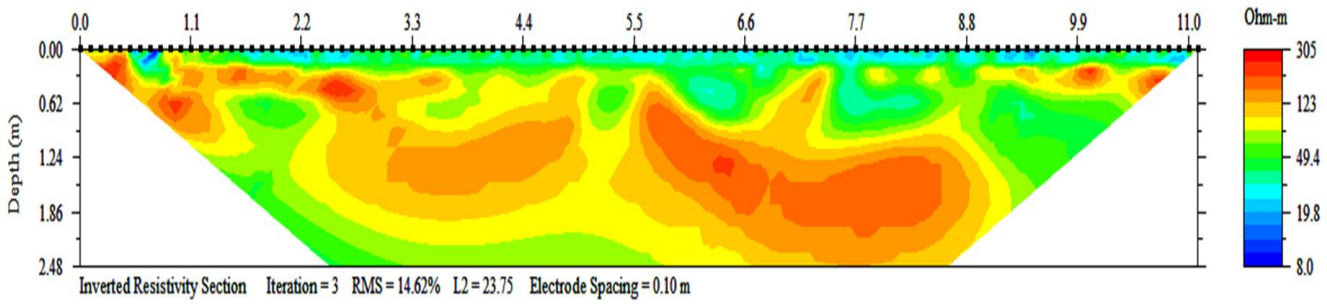



Figure 4.3 Inverse model resistivity results for traverse 1.

The 2D electrical resistivity section can be characterized into three geoelectric layers based on its vertical and lateral variation in electrical resistivity values. The first layer is the topsoil with electrical resistivity range of about 10.9 to 18.5 Ωm and thickness range of 0.2 to 0.3 m.

The second geoelectric layer is with relatively higher electrical resistivity range of 31.5 to 91 Ωm and delineated to a depth range of 0.31 to 0.61 m. Along the lateral distance of about 5.2 to 5.49 m an anomalously high electrical resistivity of about 154 to 261 Ωm can be observer which is suggestive of buried pipe and at a depth of 0.31 m.

The third geoelectric layer is represented by resistivity range of 10.9 to 31.4 Ωm expressive of Clayey layer. An augmented 3D view of the inverted 2D sections is presented in Figure 4.4c and have shown the continuity of the anomaly associated to the pipeline across the two traverses.

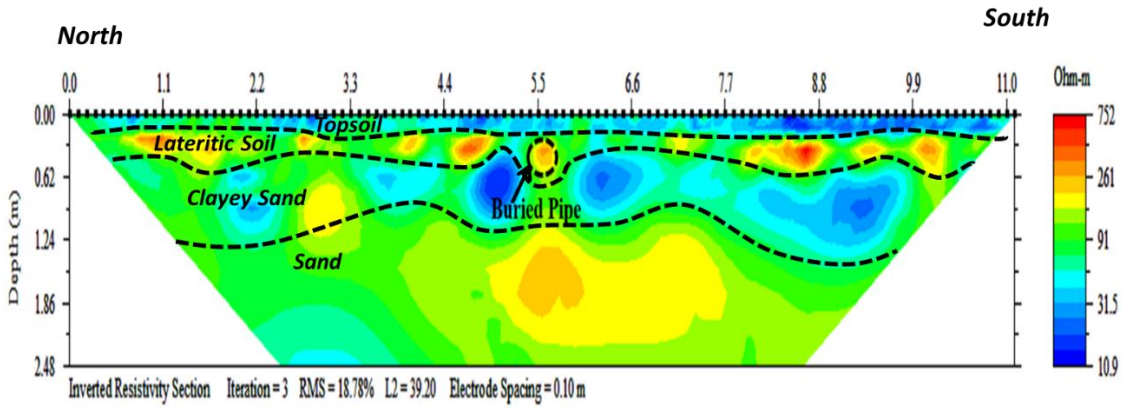



Figure 4.4a. Interpreted inverse model resistivity results for traverse 2.

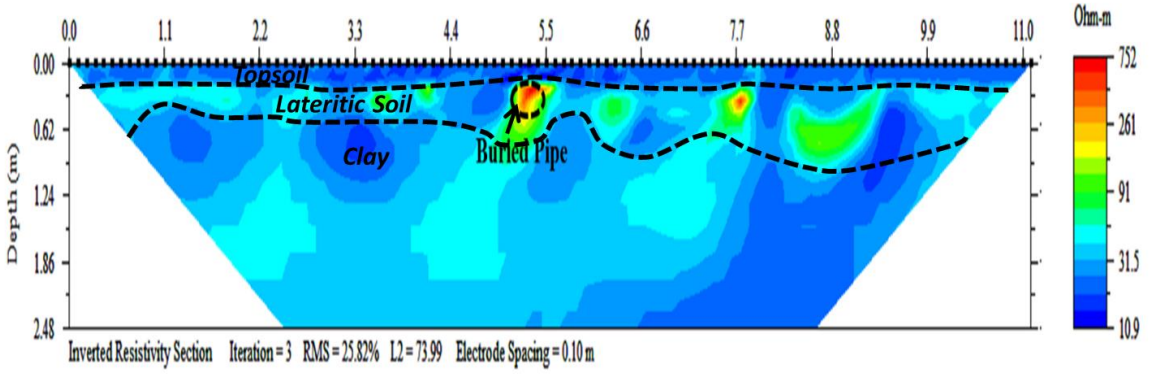



Figure 4.4b. Interpreted inverse model resistivity results for traverse 3.

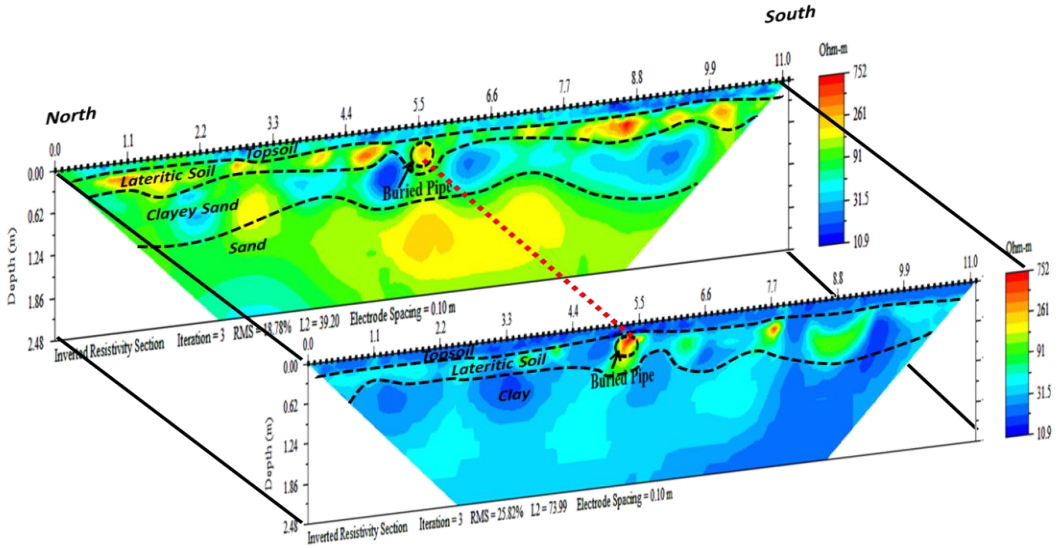



Figure 4.4c. Augmented 3D view of the inverted 2D ERT sections for pipe 1 at Location 3 (Pipe 1).

**Pipe 2:**

Similarly, Figures 4.5a and 4.5b are the interpreted inverted 2D electrical resistivity sections along traverses 2 and 3 around Pipe 2 at location 3. On traverse 2, anomalously high electrical resistivity of about 1152 to 16763 Ωm can be observed along the lateral distance of about 5.8 to 6.05 m which is suggestive of buried pipe and at a depth of 0.25 m.

Likewise, on traverse 3, an anomalously high electrical resistivity of about 7342 to 100 kΩm can be observed along the lateral distance of about 5.6 to 5.85 m which can be associated to the buried pipe (Figure 4.5b). An augmented 3D view of the inverted 2D sections is presented in Figure 4.5c and have shown the continuity of the anomaly associated to the pipeline across the two traverses.

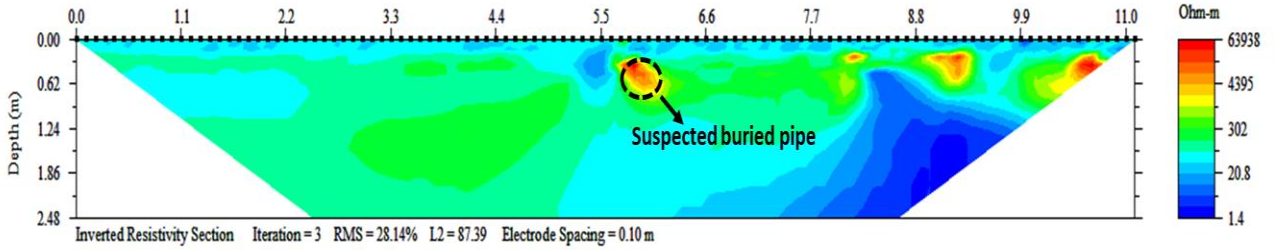



Figure 4.5a. Interpreted inverted 2D ERT for traverse 2 at Pipe 2, Location 3.

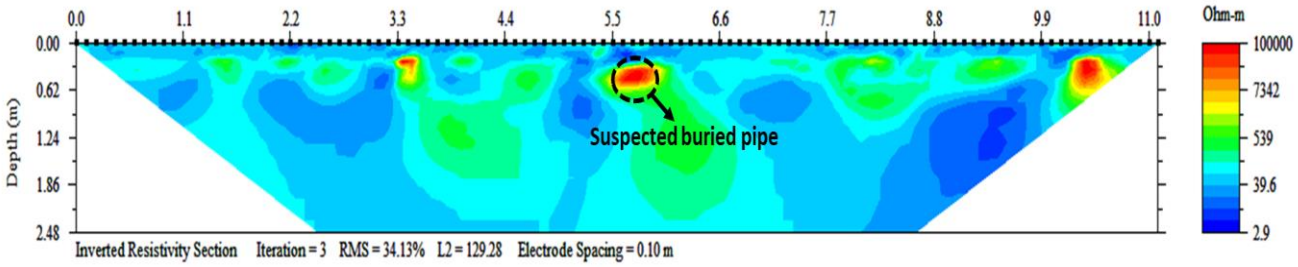



Figure 4.5b. Interpreted inverted 2D ERT for traverse 3 at Pipe 2, Location 3.

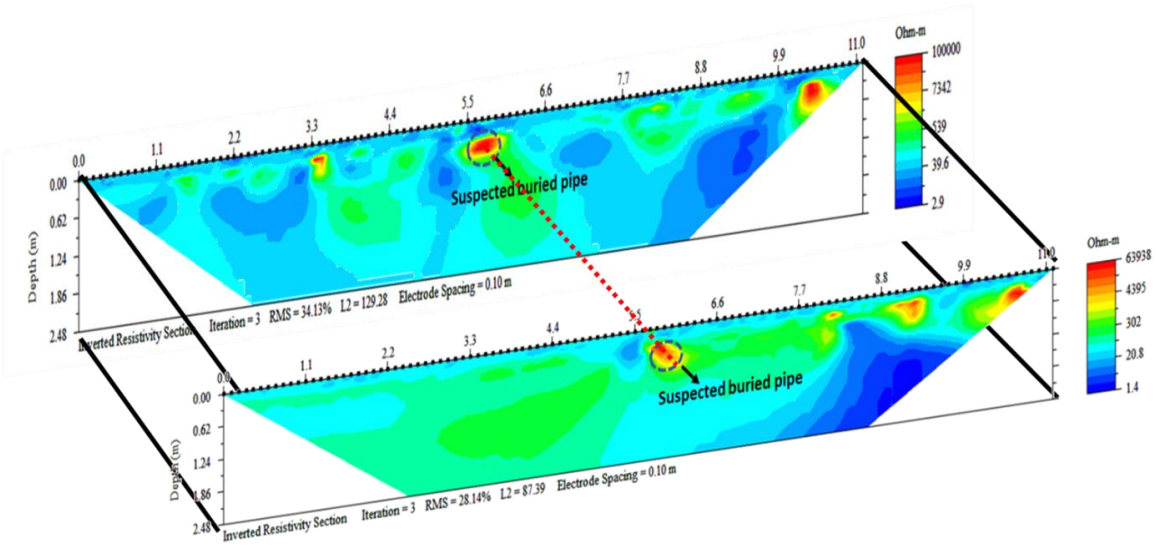



Figure 4.5c. Augmented 3D view of the inverted 2D ERT sections for pipe 2 at Location 3.

## 4.2 Magnetics Method

Generally, the observer magnetic anomalies in the region were rather subtle due to the abundance of cultural noises and lateral inhomogeneity resulting from sand filling/ landscaping of the environment. The data quality was also not the best. it was dominated by spikes and steps. However, attempts were still made to deduce reasonable interpretation. Presented are the figures showing the results obtained from the magnetic profile at each location. The drift corrected data are however, presented in Appendix A.

### Location 1

Figure 4.6 shows the magnetic profile of traverse 1 and 3 showing an attempted interpretation of the buried pipe in location 1. The signature indicates that the pipe is located at 16 m mark along the traverse. The profile for traverse 2 (presented in Appendix A) did not show an interpretable signature.

Shown in figure 4.6 (a.), 4.6(b.) and 4.6(c) are magnetic profiles 1, 2 and 3. Signatures likely to be buried be buried pipe were identified at a distance 16 m from the beginning of the lines on profile 1 and 3 while no interpretable signature was identified on profile 2.

Similar signature is observed on traverse 3 which also indicates that the pipe is located at 16 m mark.

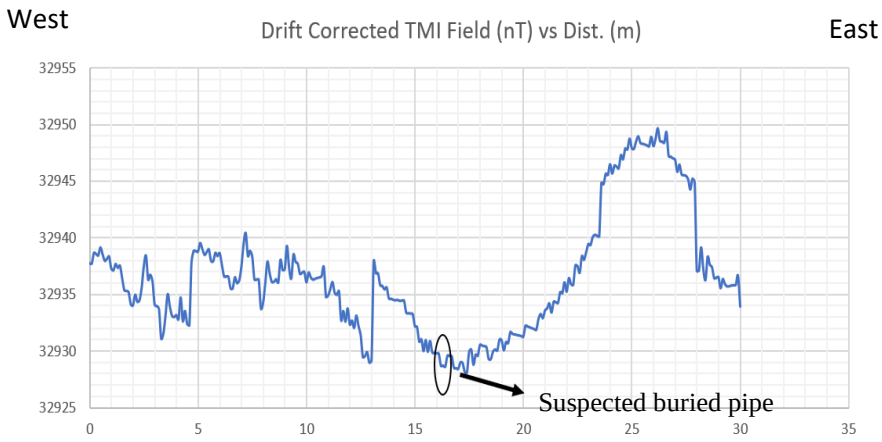



Figure 4.6(a)i. Total magnetic intensity (TMI) plot for profile 1.

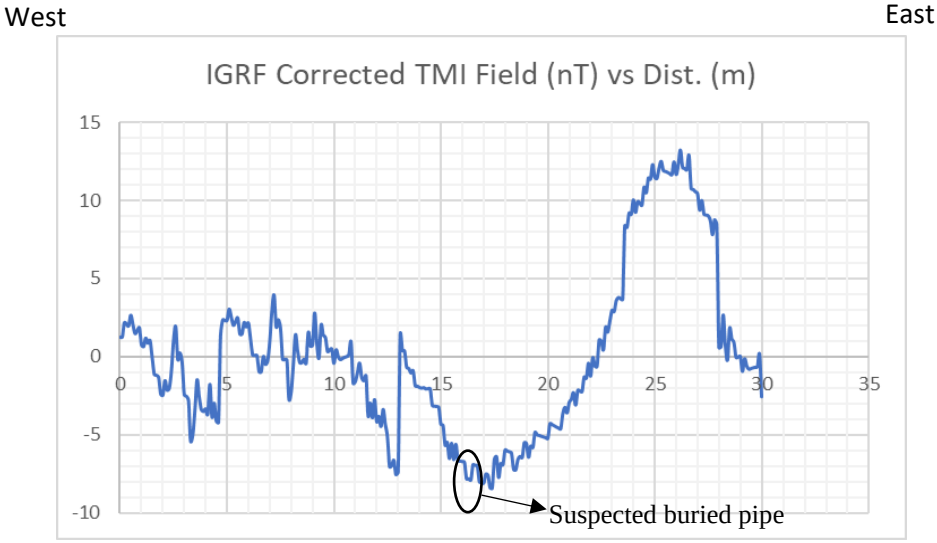



Figure 4.6(a)ii. IGRF corrected TMI plot for profile 1.

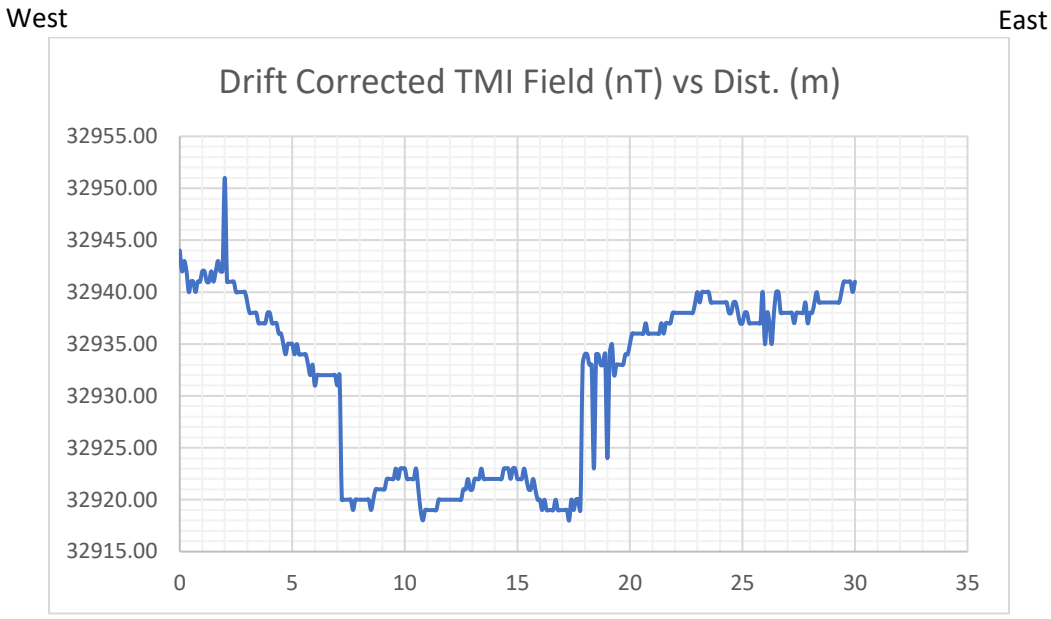



Figure 4.6(b)i. Total magnetic intensity (TMI) plot for profile 2.

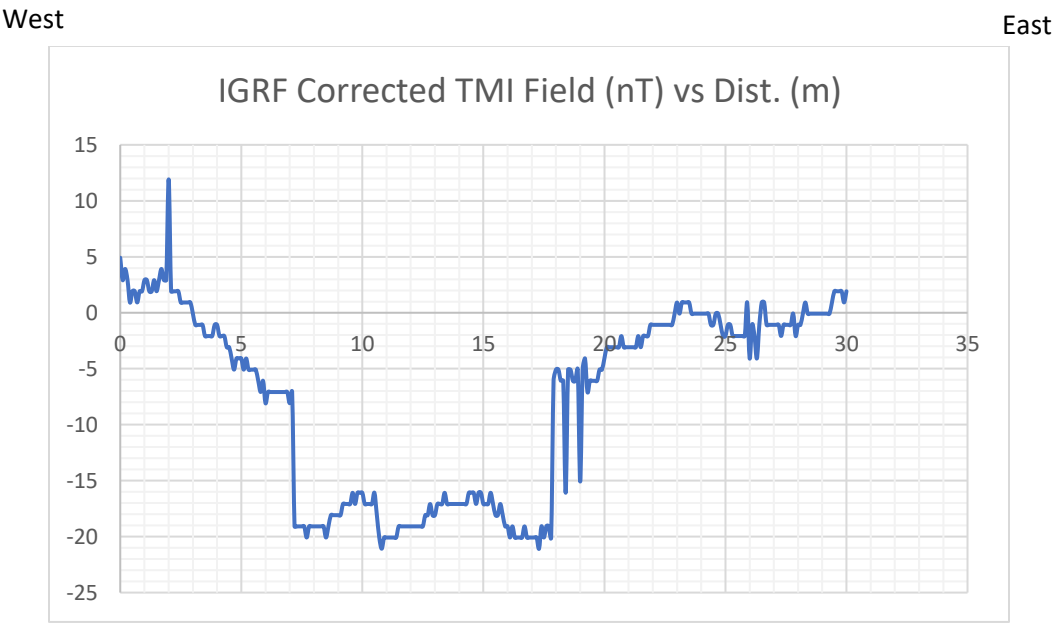



Figure 4.6(b)ii. IGRF corrected TMI plot for profile 2.

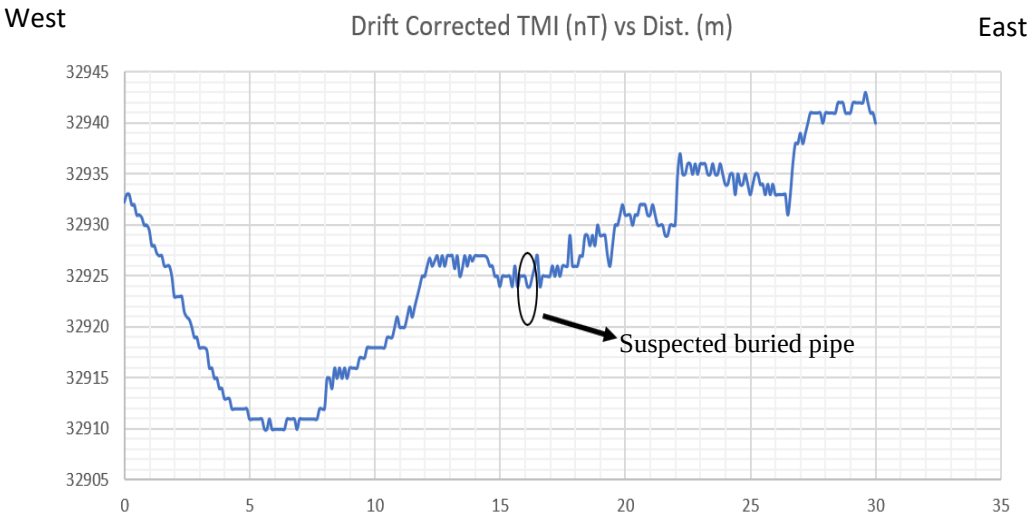



Figure 4.6(c)i. Total magnetic intensity (TMI) plot for profile 3.

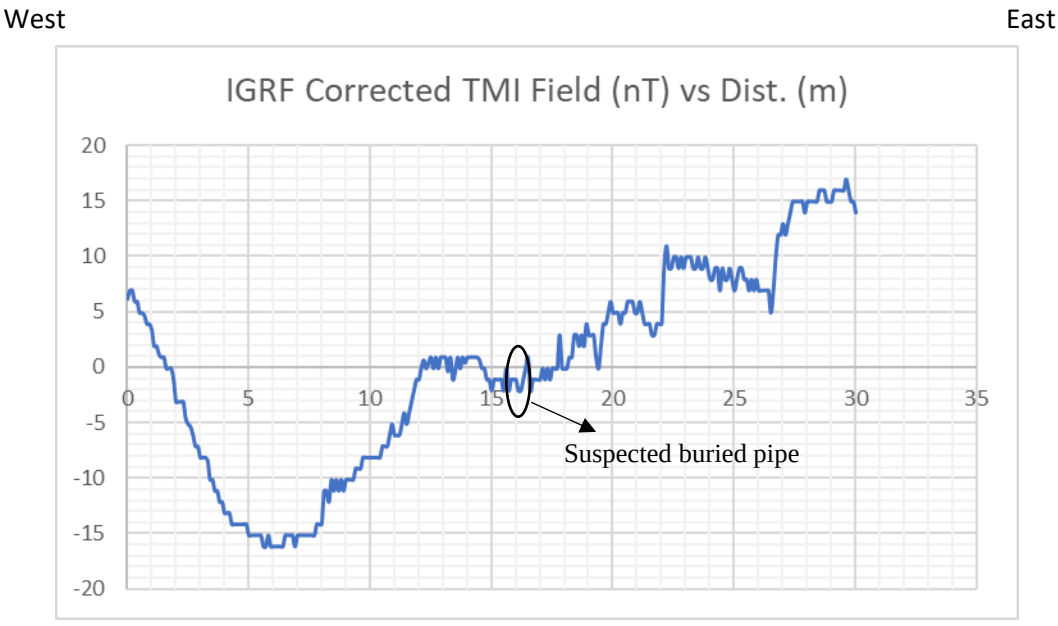



Figure 4.6(c)ii. IGRF corrected TMI plot for profile 3.

**Location 2**

Shown in Figure 4.7(a), 4.7(b) and 4.7(c) are magnetic profiles 1, 2 and 4 at location 2. The position of the pipe across the three (3) profiles varies. it was mapped at 4.4 m from the start of the profile 1, 4.7 m on profile 2 and 6.2 m on profile 4. This validates that the buried pipe was trending in the NW-SE direction. Profile 3, 5 and 6 (presented in Appendix A) did not show any appreciable signature that can be interpreted as the buried pipe.

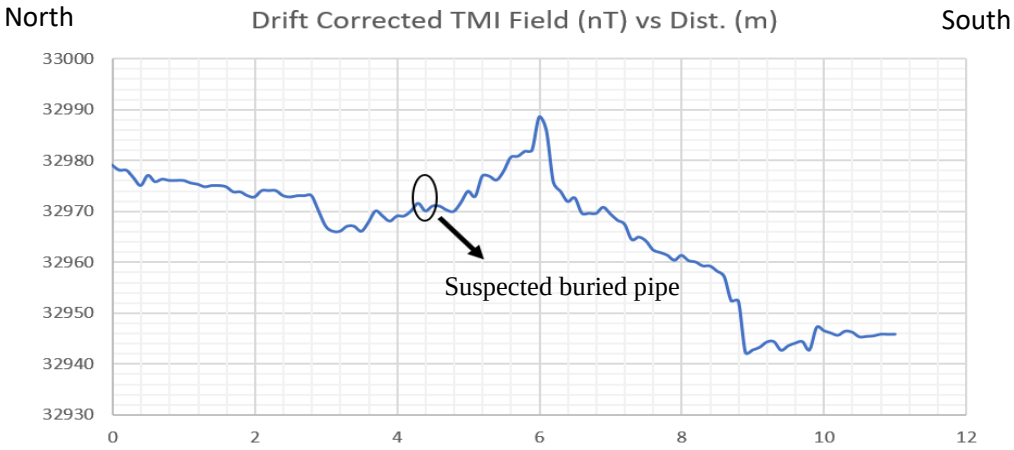



Figure 4.7(a)i. Total magnetic intensity (TMI) plot for profile 1.

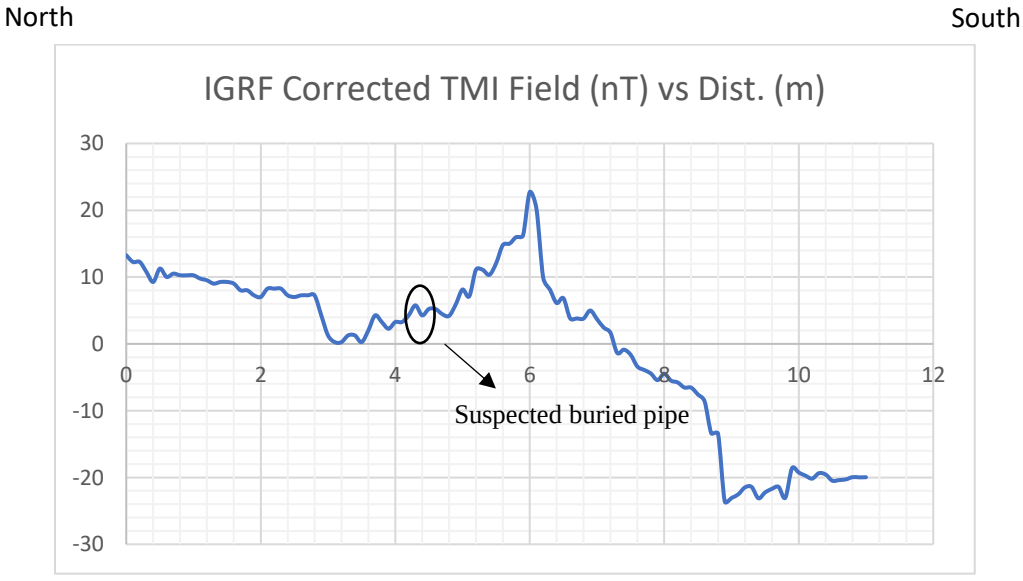


Figure 4.7(a)ii. IGRF corrected TMI plot for profile 1.

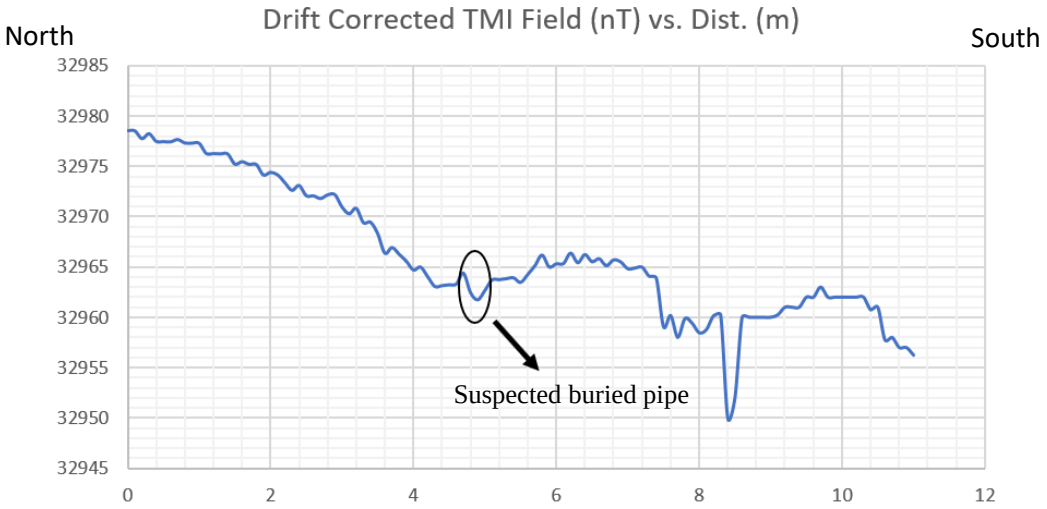



Figure 4.7(b)i. Total magnetic intensity (TMI) plot for profile 2

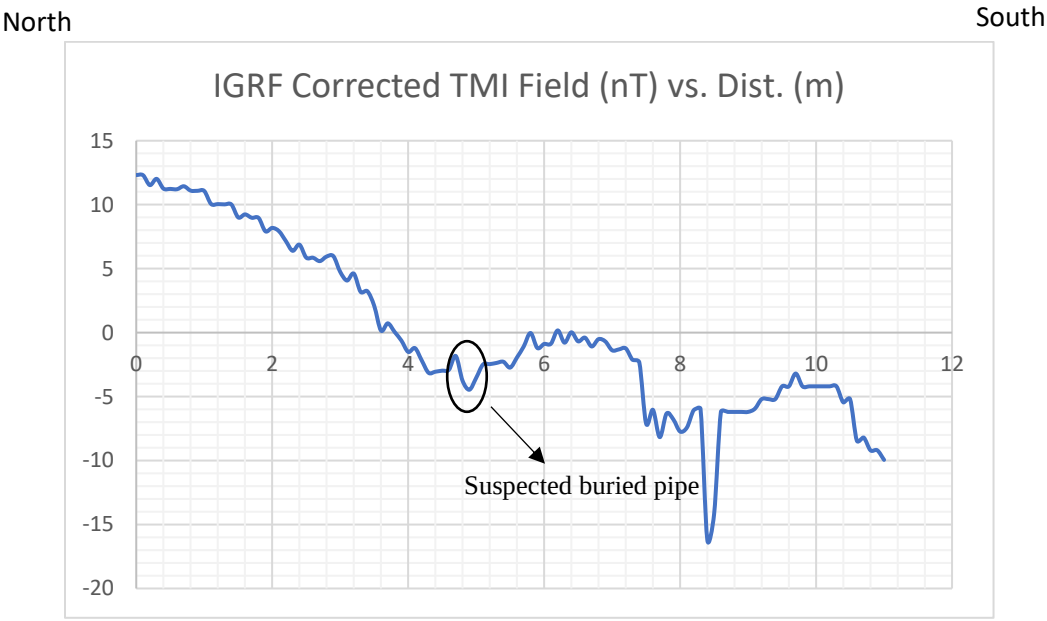



Figure 4.7(b)ii. IGRF corrected TMI plot for profile 2.

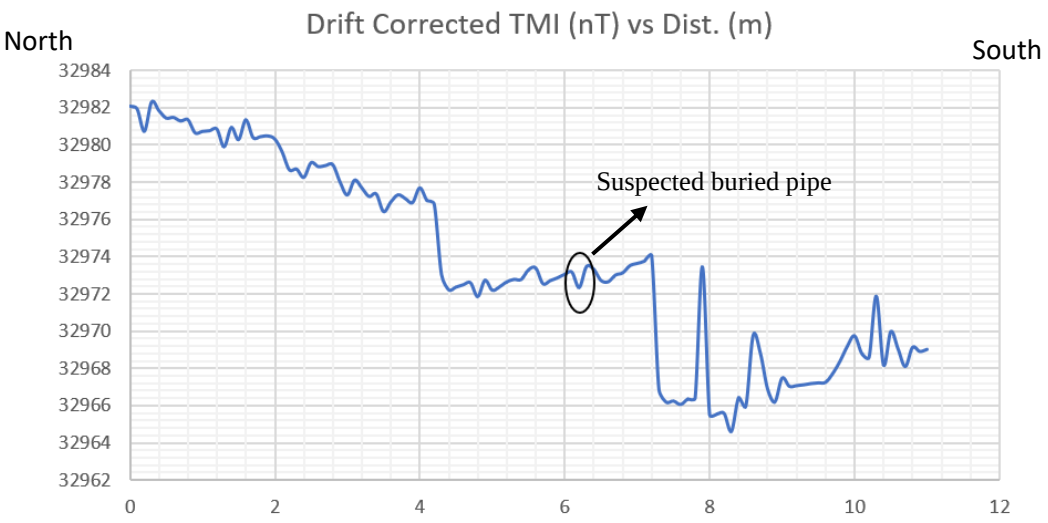



Figure 4.7(c)i. Total magnetic intensity (TMI) plot for profile 4

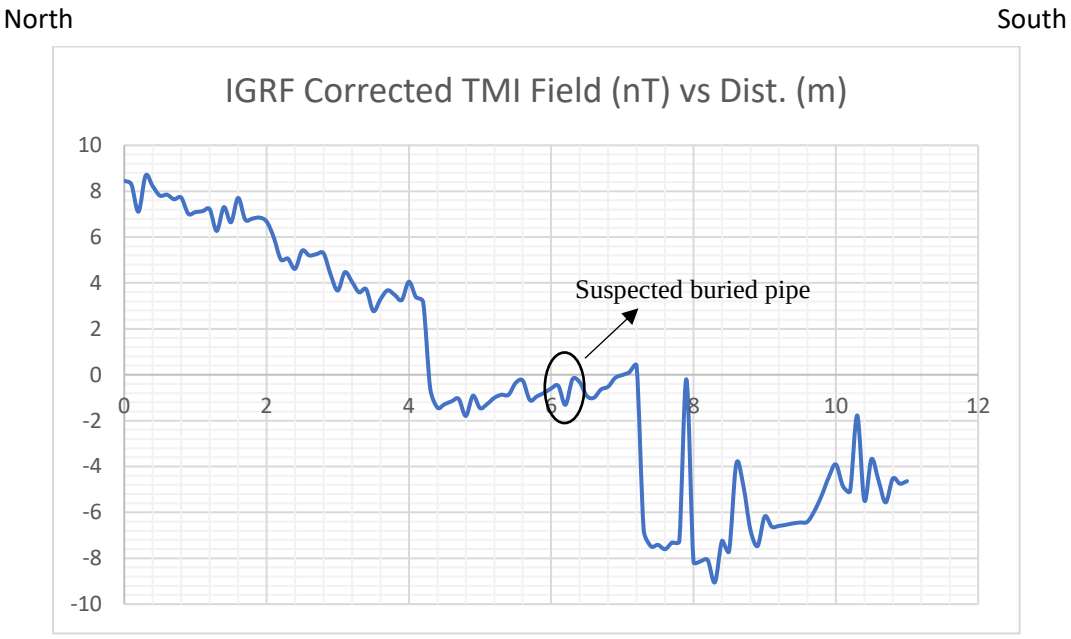



Figure 4.7(c)ii. IGRF corrected TMI plot for profile 4.

**Location 3**

Three magnetic profiles were acquired in the approximate N – S direction in this location. Only two of the three profiles, only two were interpretable. Presented in Figures 4.8(a) and 4.8(b) are the two interpretable profiles. Although, no conspicuous signature due to a buried pipe was found, a conspicuous magnetic low approximately 2 m wide (occurring between 40.7 m to 42.7 m from the start of profile one 4.8(a) and 45.2 m to 47.5 m form the start of the of profile two 4.8(b)) was delineated. The conspicuous magnetic low was interpreted as a geologic structure relating to a buried stream/river channel.

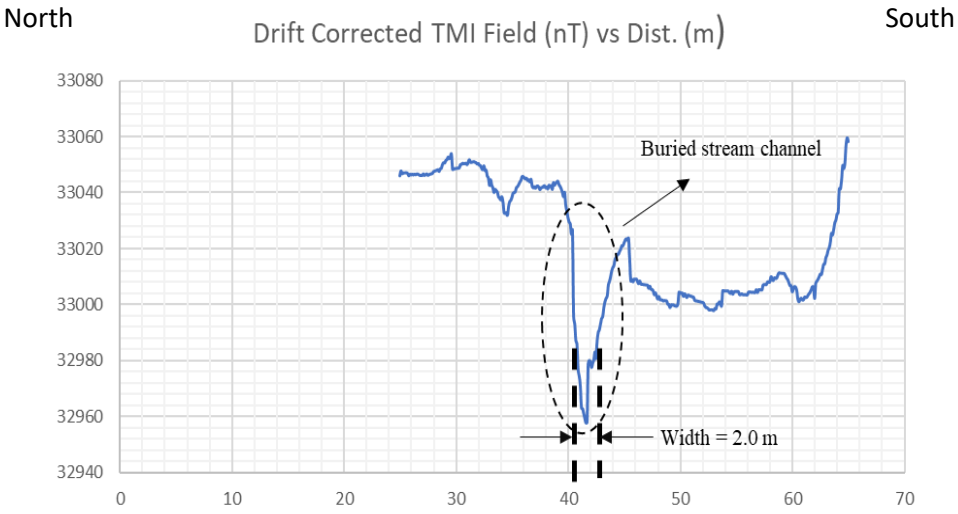



Figure 4.8(a)i. Total magnetic intensity (TMI) plot for profile 1

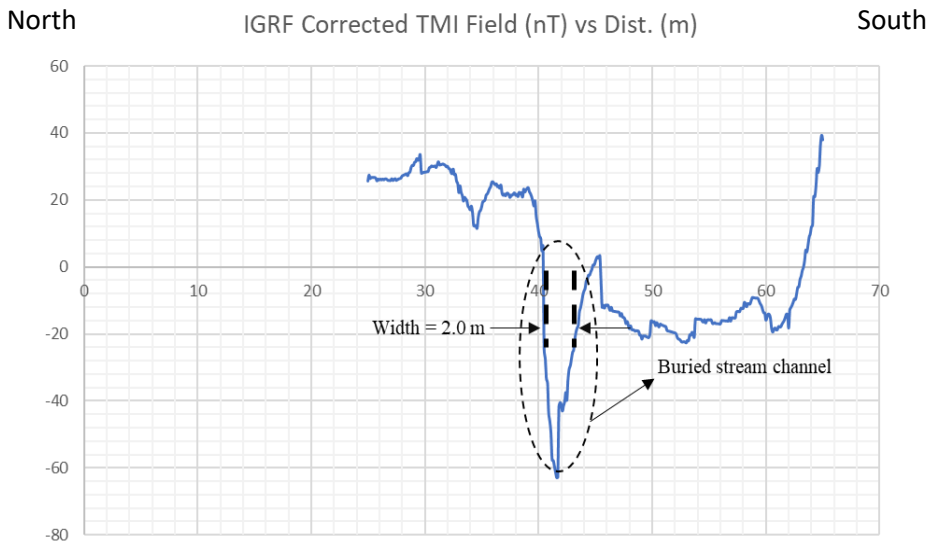



Figure 4.8(a)ii. IGRF corrected TMI plot for profile 1.

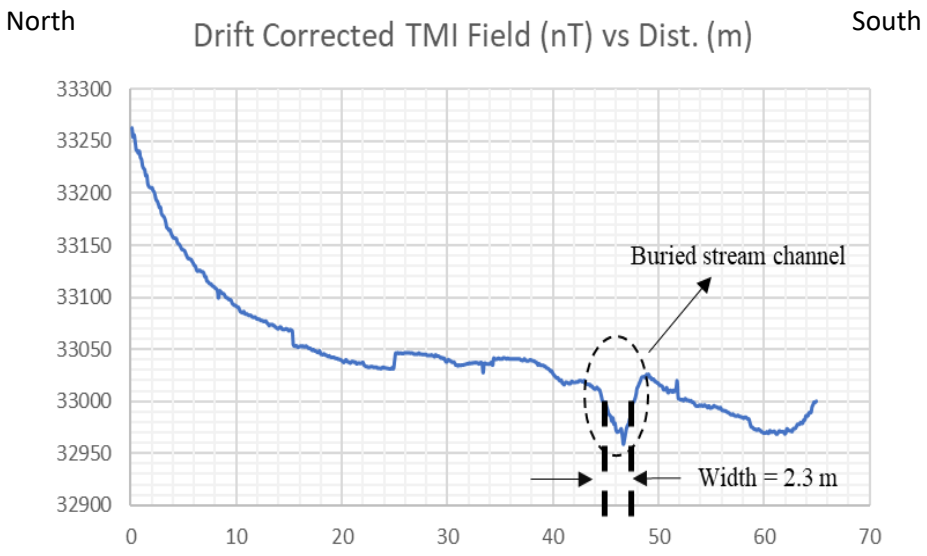



Figure 4.8(b)i. Total magnetic intensity (TMI) plot for profile 2

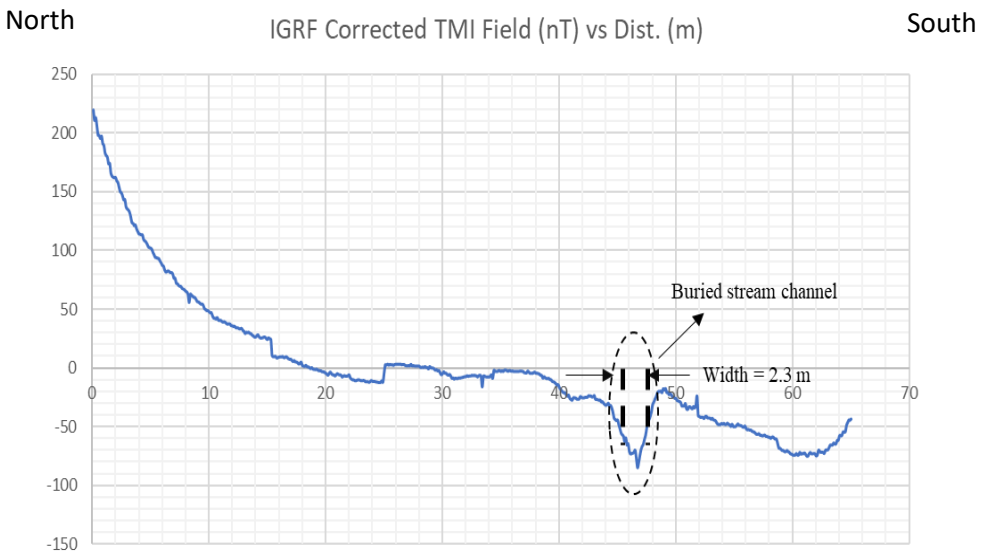



Figure 4.8(b)ii. IGRF corrected TMI plot for profile 2.

## 4.3 Ground Penetrating Radar

As discussed in the previous chapter two antennas (450 MHz and 750MHz) were used to acquire data at each of the location. The interpreted results acquired on each individual traverse at each of the location is presented and discussed below. The produced radargram for each frequency is included in Appendix B.

### Location 1

Figure 4.9a shows the GPR radargram obtained on traverse 1 using the 750 MHz antenna. The hyperbolic signature indicates the suspected buried pipe at the depth of 0.22 m. The top of the hyperbolic signature indicates the middle of the buried pipe which is at a lateral distance of 15 m. A 3D augmented view of the interpreted radar section of other traverses at location 1 is presented in Figure 4.9b which shows the continuity of the anomaly.

The 3D GPR have been presented as an interpreted 3D volume in Figure 4.9c(i). The lines perpendicular to the strike of the pipe in the 3D volume have been interpreted which have shown the position of the pipe in the investigated area (Figure 4.9c(ii)).

The interpreted time slice of the 3D GPR at 0.1m interval is presented in Figure 4.9d. The time slice at 0.2m shows the buried pipe indicated by the yellow box, distinctively.

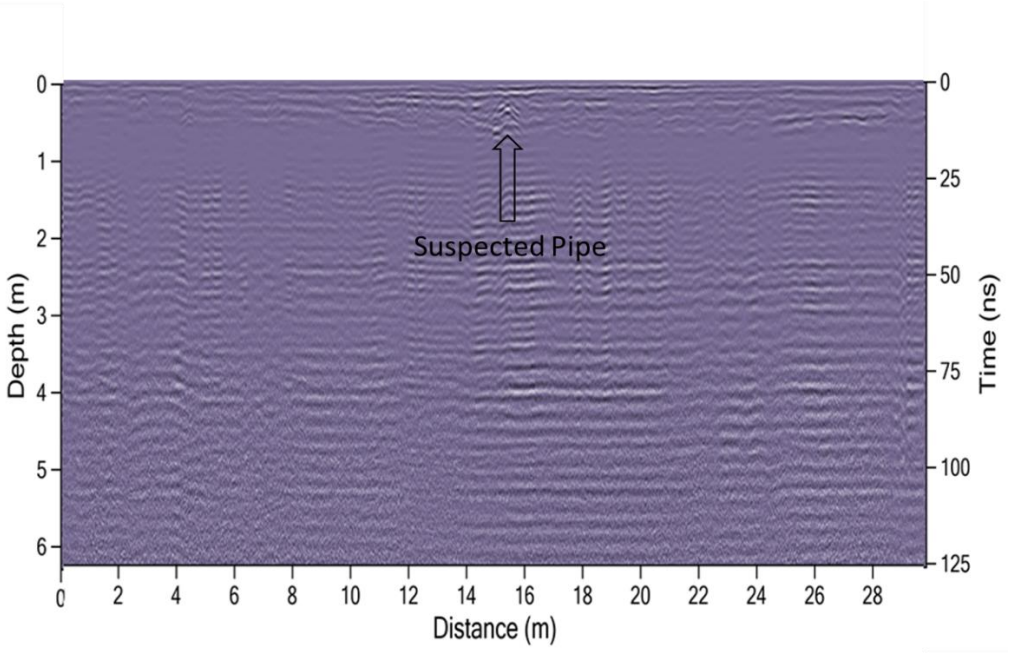



Figure 4.9a Interpreted GPR radargram using the 750 MHz antenna along traverse 1 at Location 1.

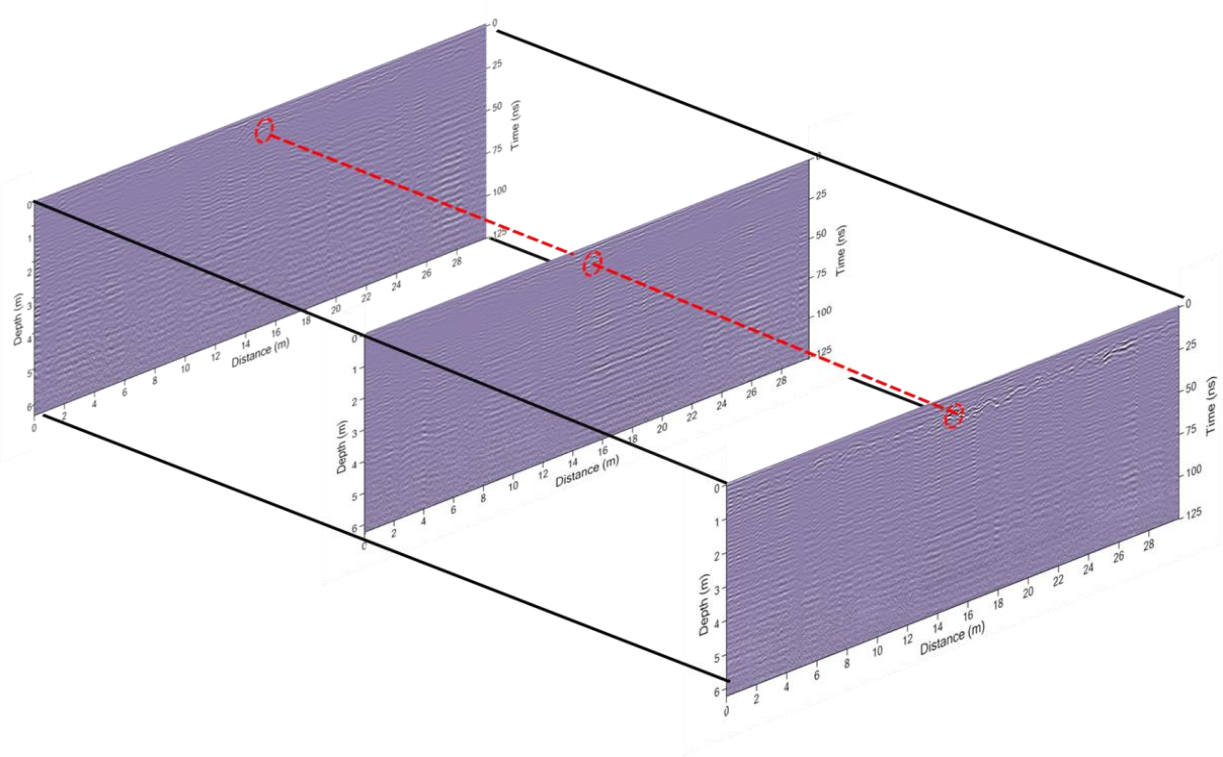



Figure 4.9b Augumented 3D view of the GPR radagram for Location 1.

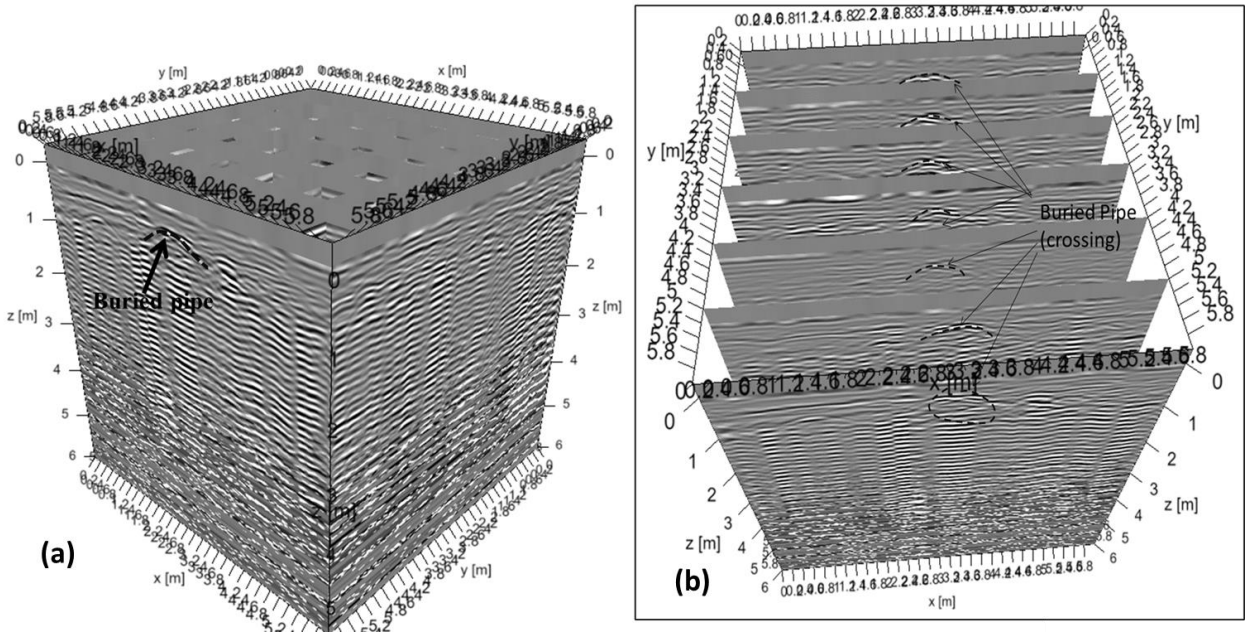



Figure 4.9c Interpeted 3D GPR (i) volume and (ii) dip lines at Location 1

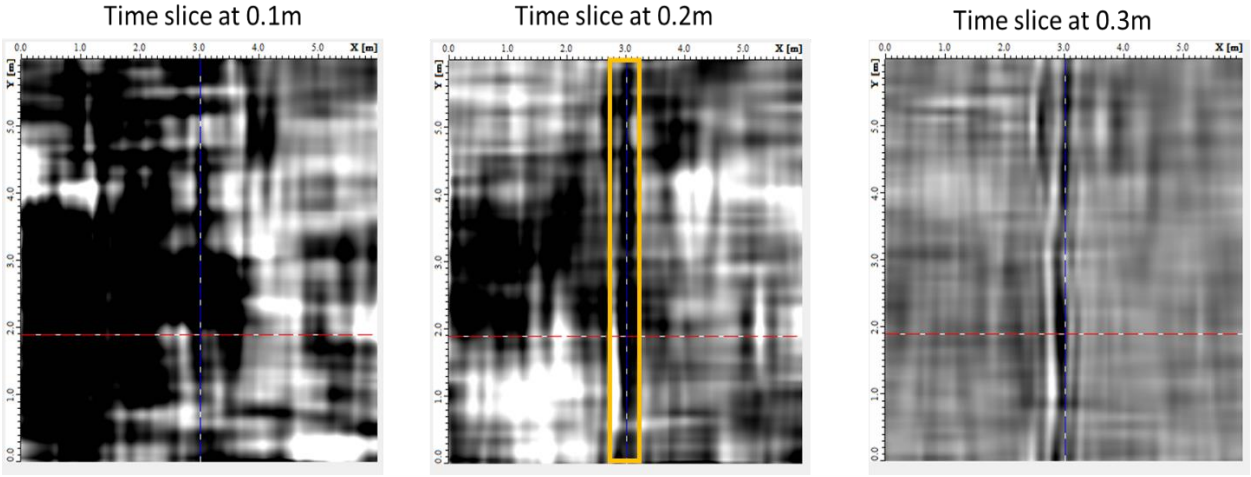



Figure 4.9d Intepreted Time slice of 3D GPR for Location 1.

**Location 2**

Figure 4.10a shows the GPR radargram obtained on traverse 1 using the 750 MHz antenna. The hyperbolic signature indicates the suspected buried pipe at the depth of 0.16 m. The top of the hyperbolic signature indicates the middle of the buried pipe which is at 5.5 m mark. A 3D augmented view of the interpreted radar section of other traverses at location 2 is presented in Figure 4.10b which shows the continuity of the anomaly.

The 3D GPR have been presented as an interpreted 3D volume in Figure 4.10c(i). The lines perpendicular to the strike of the pipe in the 3D volume have been interpreted which have shown the position of the pipe in the investigated area (Figure 4.10c(ii)).

The interpreted time slice of the 3D GPR at 0.1m interval is presented in Figure 4.10d. The time slice at 0.15m shows the buried pipe indicated by the yellow box, distinctively.

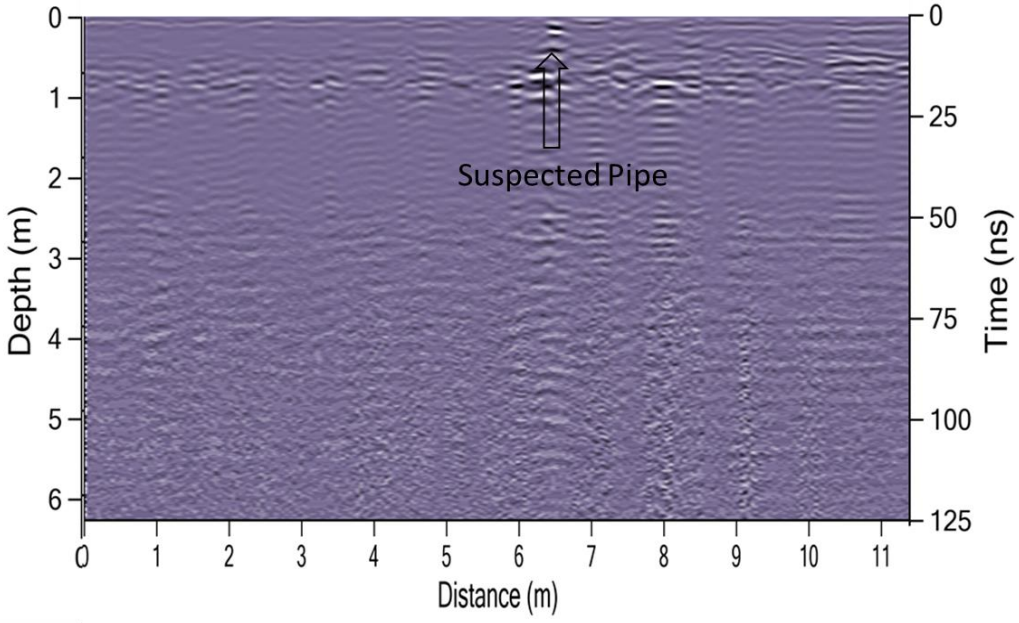



Figure 4.10a Interpreted GPR radargram using the 750 MHz antenna along traverse 1 at Location 2.

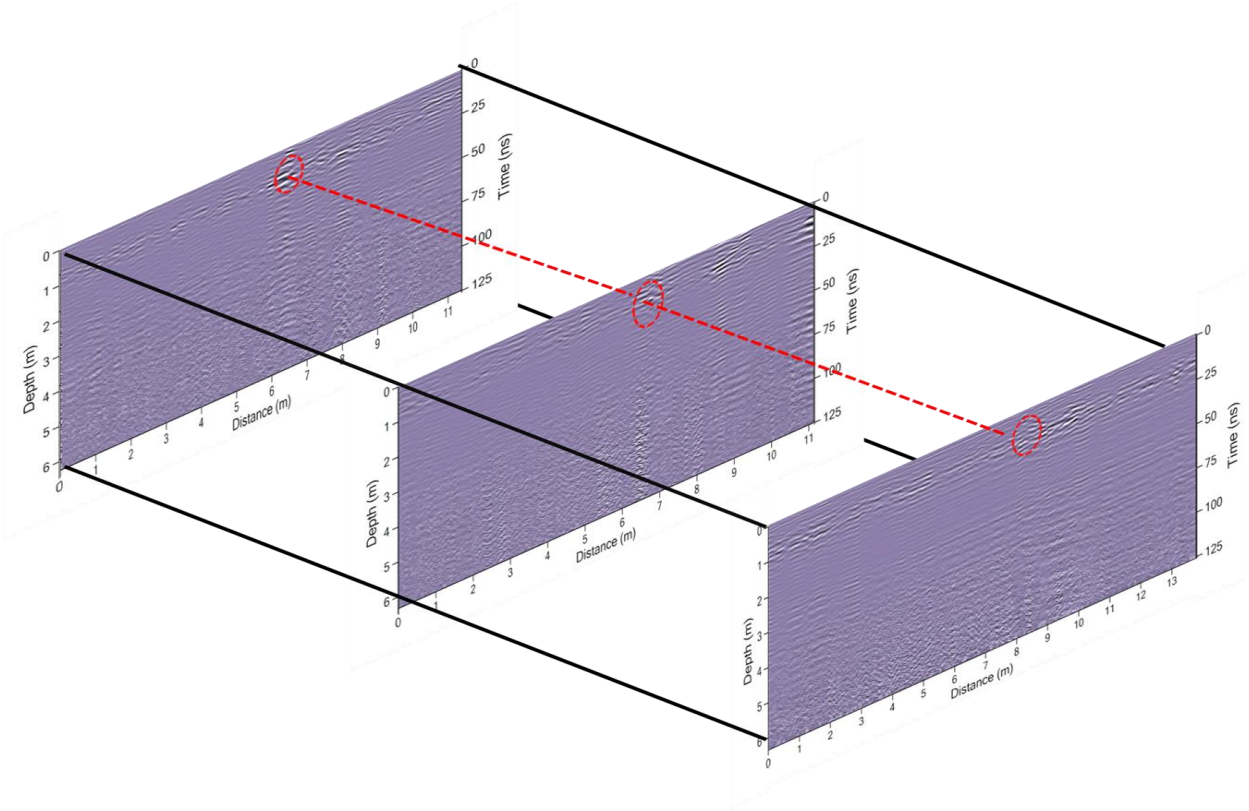



Figure 4.10b Augumented 3D view of the GPR radagram for Location 2.

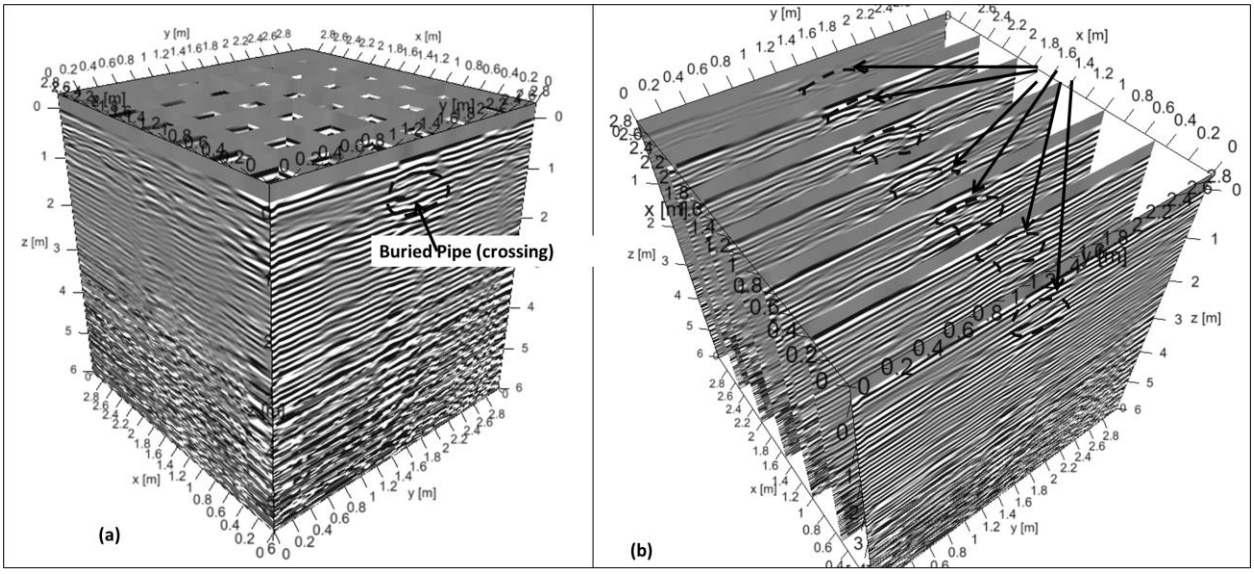



Figure 4.10c Interpeted 3D GPR (i) volume and (ii) dip lines at Location 2

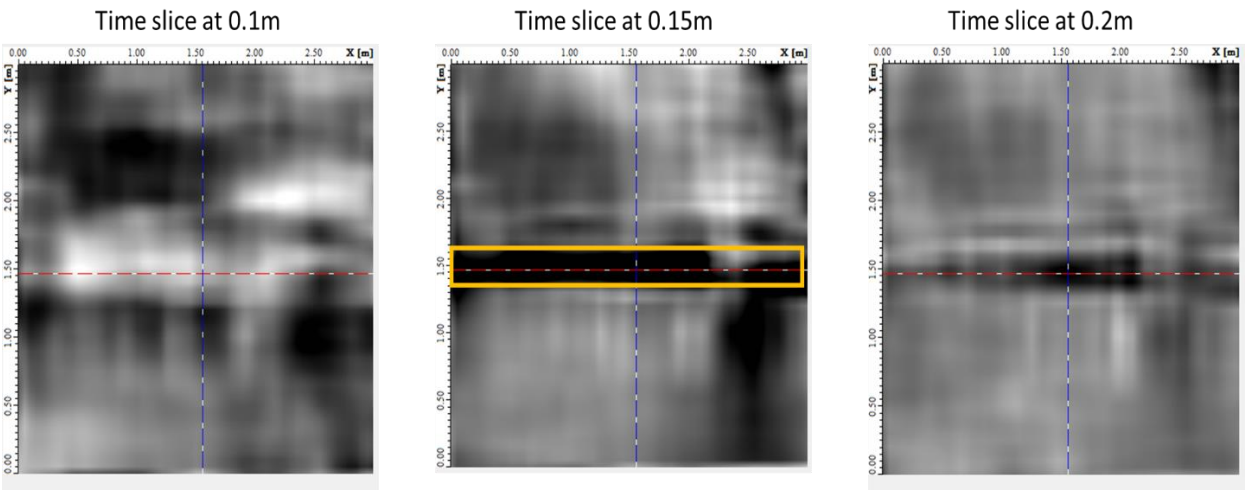



Figure 4.10d Intepreted Time slices of 3D GPR for Location 2.

**Location 3**

At this location, the result of the GPR obtained using the 750 MHz (Figure 4.11a) show two buried pipes at the depth of 0.31 m and 0.18m respectively. The top of the hyperbolic signatures indicate the middle of the buried pipes at 32 m and 55 m mark respectively. Therefore, the pipes are estimated to be 23 m apart. Figure 4.11b presents an augmented 3D view of the radargram obtained along the traverses.

The 3D GPR have been presented as an interpreted 3D volume in Figure 4.11c(i). The lines perpendicular to the strike of the pipe in the 3D volume have been interpreted which have shown the position of the pipe in the investigated area (Figure 4.9c(ii)).

Figure 4.11d shows the time slice 0.1 interval of the 3D GPR that was carried out. The time slice at 0.2m shows the pipe 2 indicated by the yellow box, distinctively

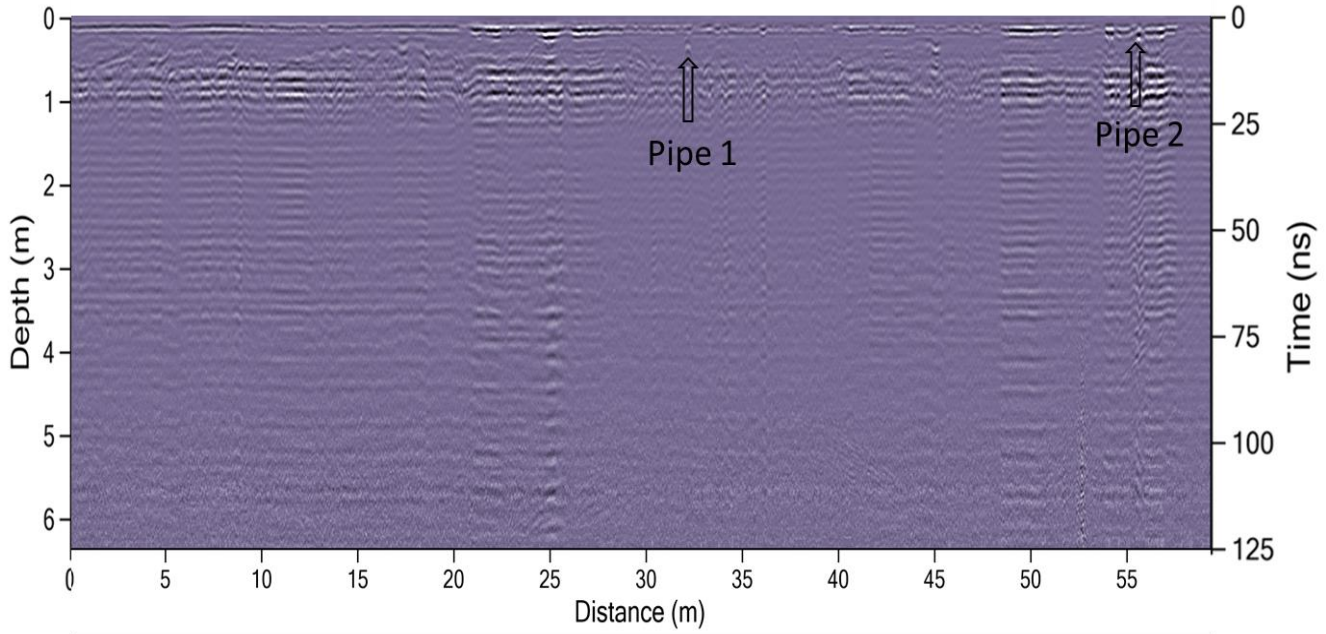



Figure 4.11a Interpreted GPR radargram using the 750 MHz antenna along traverse 1 at Location 3.

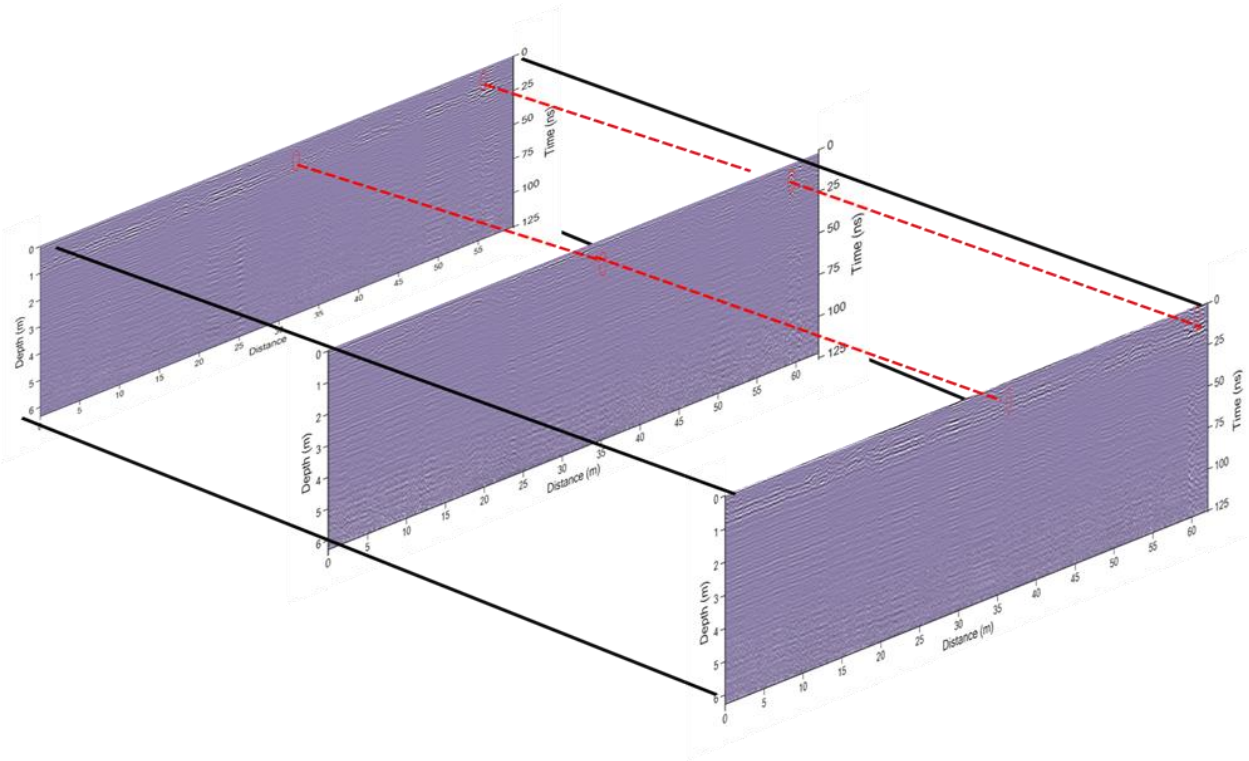



Figure 4.11b Augumented 3D view of the GPR radagram for Location 3.

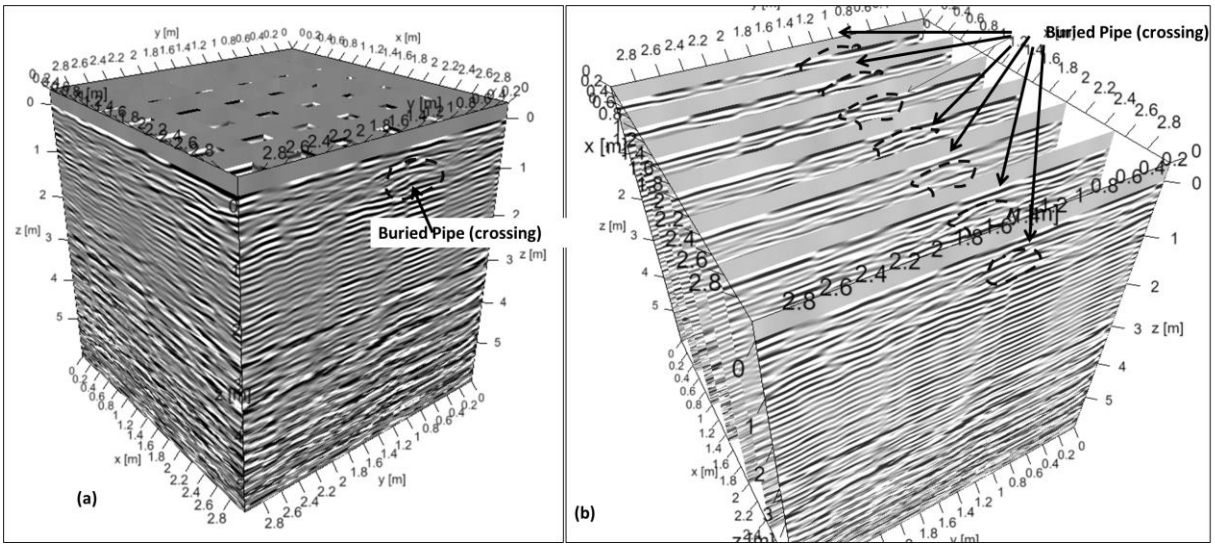



Figure 4.11c Interpreted 3D GPR (i) volume and (ii) dip lines at Location 3

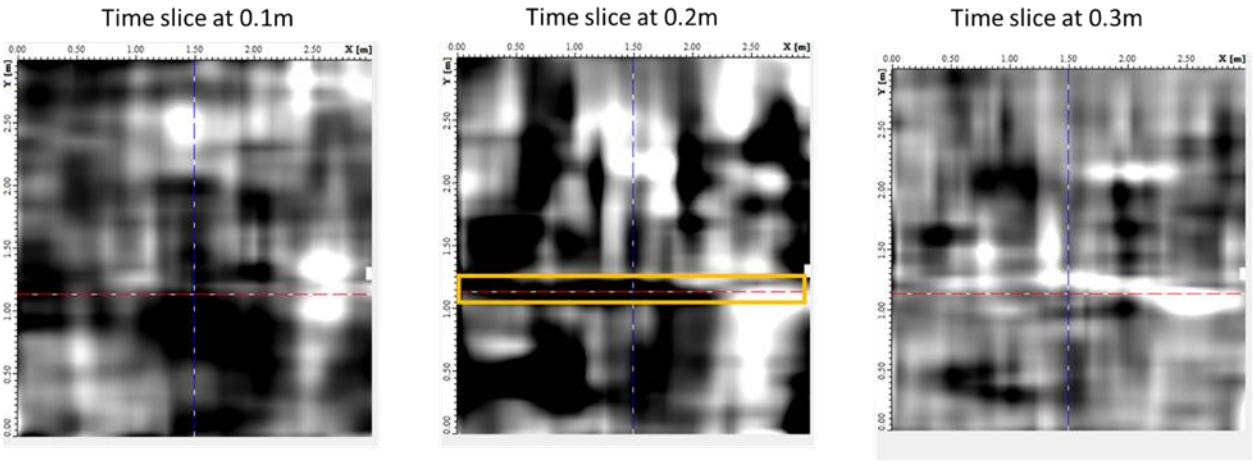



Figure 4.11d 3D GPR Time slice for pipe 2, Location 3.

## 4.4 Integration of methods

The geophysical methods deployed have been integrated to appraise the consistency of the results.

### Location 1

The 2D resistivity inverted section in Figure 4.12a indicates that the buried pipe is located at the depth of 0.2 m from the surface and lateral extent of 0.22 m wide. The interpretation obtained from the radargram (Figure 4.12b) correlates with the 2D ERT section and shows that the pipe is buried at the depth of approximately 0.2 m from the surface.

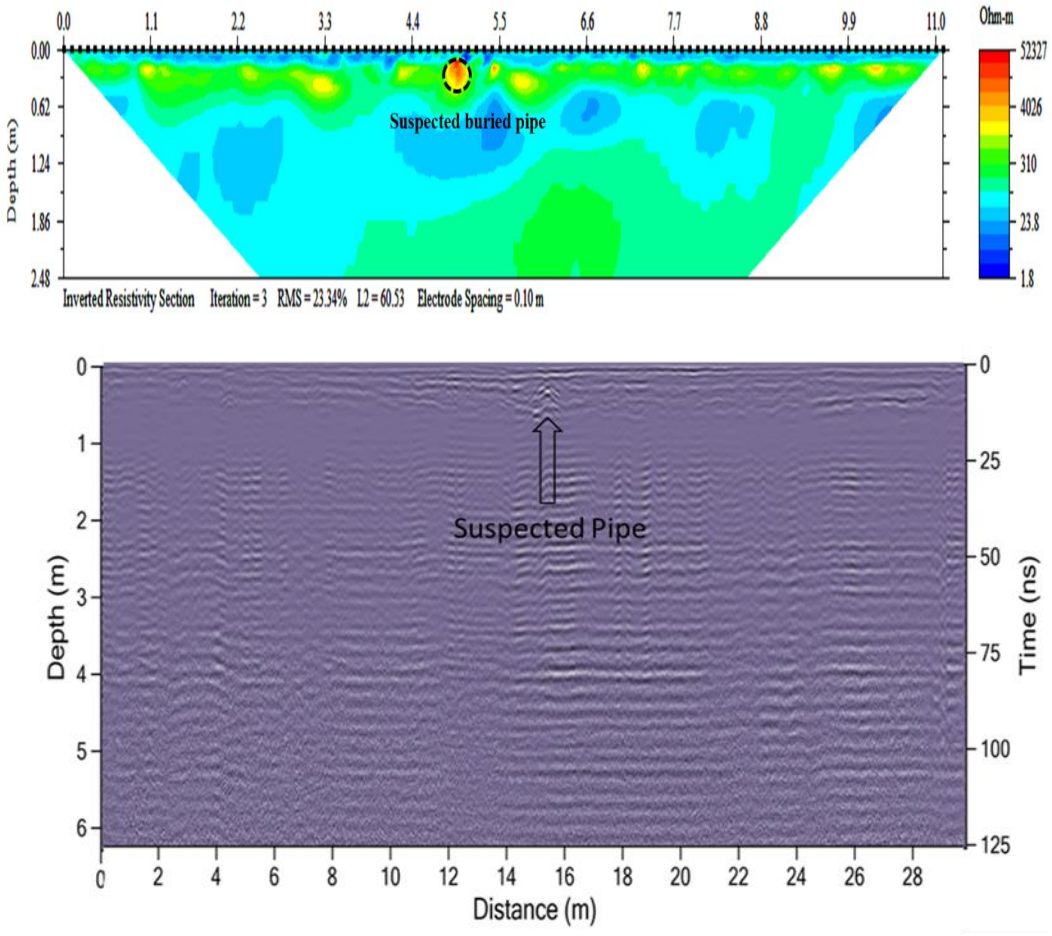



Figure 4.12 A comparison of interpreted results of a.) the final resistivity model and b.) 750 MHz GPR antenna for traverse 1 at Location 1.

**Location 2**

The 2D resistivity inverted section in Figure 4.13a indicates that the buried pipe is located at a depth 0.16m from the surface and 0.28 m wide. The radargram in Figure 4.13b on the other hand, indicates that the pipe is buried the depth of about 0.16 m from the surface. It also indicates that the buried pipe is located at 5.5 m mark along the traverse from the beginning.

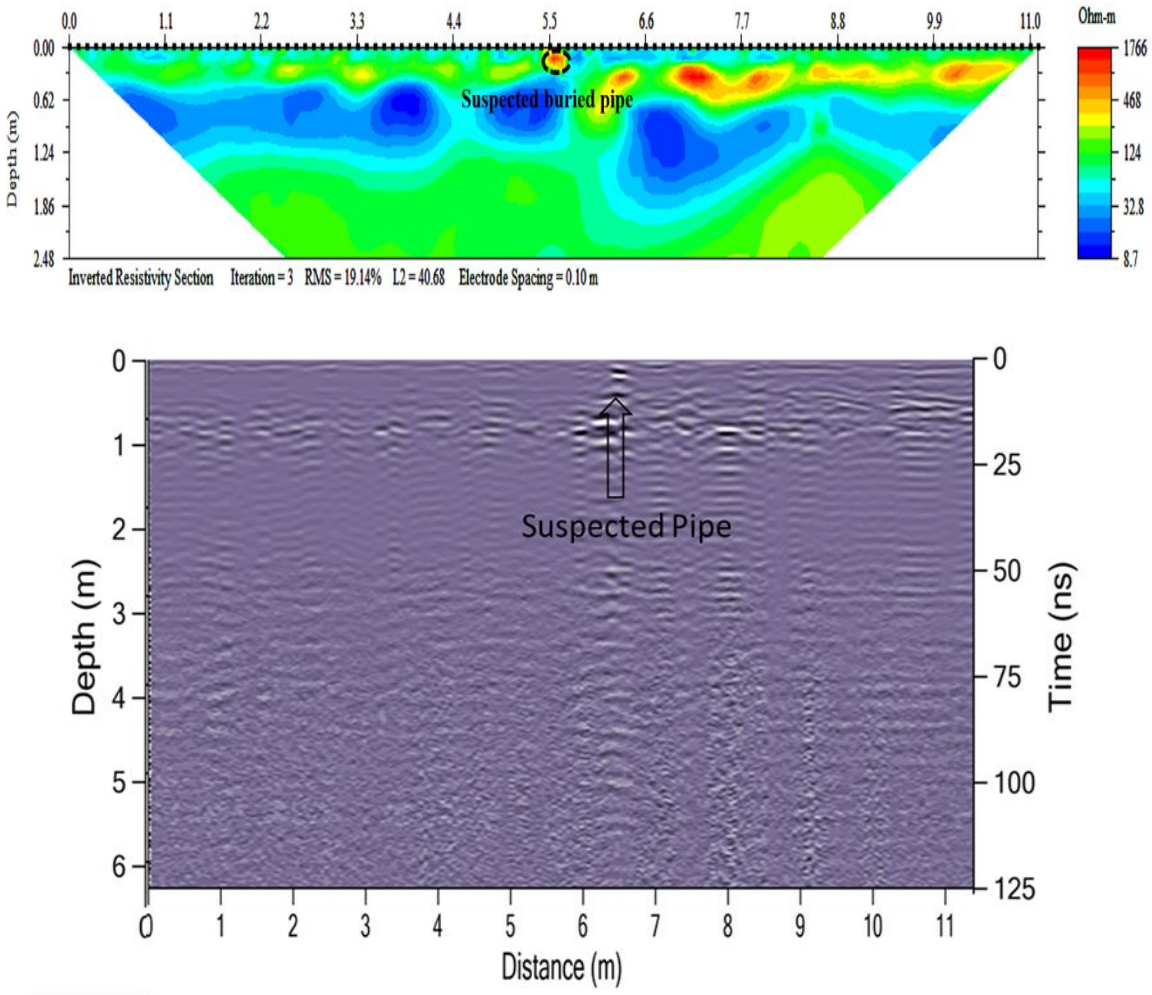



Figure 4.13 A comparison of interpreted results of a.) the final resistivity model and b.) 750 MHz GPR antenna for traverse 1 at Location 2.

**Location 3**

The 2D resistivity inverted section in Figure 4.14a indicates that pipe 1 is buried at the depth of about 0.29 m form the surface and lateral extent of about 0.29 m wide. Figure 4.14b indicates that pipe 2 is buried at the depth of 0.18m. The radargram in Figure 4.14c confirms that pipe 1 and pipe 2 are buried at the depth of about 0.31 m and 0.18 m respectively from the surface. It also indicates that pipe 1 and pipe 2 are located at 32 m and 55 m mark respectively along the traverse from the beginning.

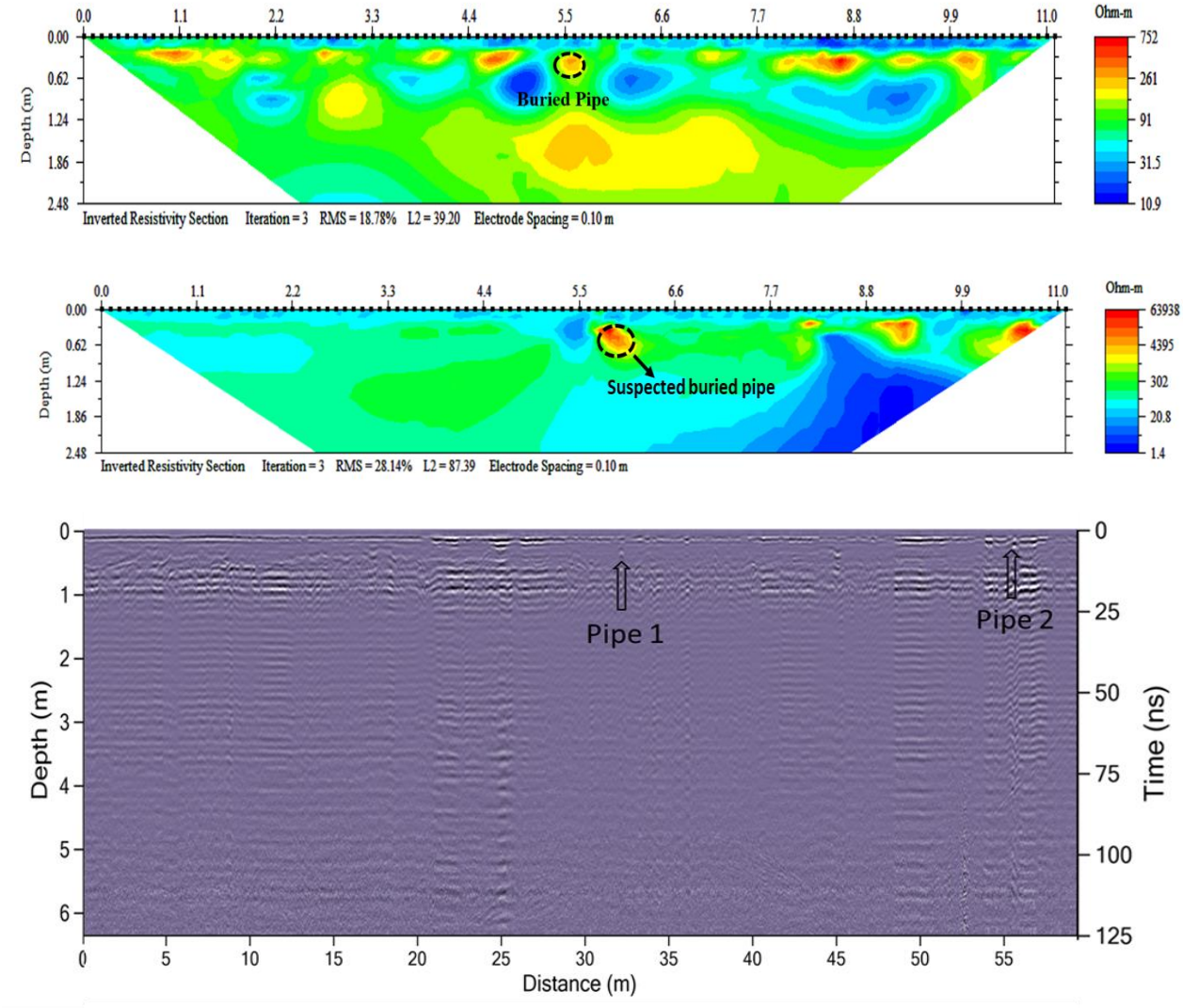



Figure 4.14 A comparison of interpreted results of a.) the final resistivity model for pipe 1 b.) the final resistivity model for pipe 2 and c.) 750 MHz GPR antenna for traverse 1 at Location 3.

# CHAPTER FIVE

## CONCLUSION AND RECOMMENDATION

### 5.1 Conclusion

An integrated geophysical survey involving magnetic, 2D ERT, and GPR were used to collect data that provides information about the location, lateral extent and depth of buried utilities at selected area within Mountain Top University. From the result gathered, the buried pipes were detected are suspected to be plastic pipes which was further subjected to ground confirmation. Although, magnetic method is not consistent in the detection of the buried plastic pipes, 2D ERT and GPR have proven to show significant anomalies that are consistent in delineating the buried plastic pipes with different level of precision.

Magnetic survey at location 3 indicated a conspicuous magnetic low approximately 2 m wide. The conspicuous magnetic low was interpreted as a geologic structure relating to a buried stream/river channel which is conspicuous as a visible depression on the ground.

On the 2D ERT, the pipeline is represented by relatively high electrical resistivity value range of 700 to 100k Ωm. The high resistivity contrast is suggestive of air-filled plastic pipes. The pipeline has shown hyperbolic anomalies on the GPR and have been more pronounced on the 3D GPR time slice as lineament features.

Based on the interpretation of the 2D ERT model sections and radargram, the depth to the top of the buried pipe in location 1 is approximately 0.2 m, and 0.2 m wide. At location 2, the depth of the buried pipe detected and its lateral extent is approximately 0.16 m and 0.28 m respectively. Lastly, the results obtained at location 3 reveals that pipe 1 and pipe 2 are buried approximately at the depth of 0.31 m and 0.2 m respectively with respective diameter of 0.28 m and 0.25 m.

The result of this study further corroborates the fact that the integration of 2D ERT and GPR surveys allows for a better identification of buried utilities.

### 5.2 Recommendation

To prevent damages of buried utilities during construction and renovation at other part of Mountain Top University, more geophysical survey should be carried out to delineate other buried utilities such as fibre cables, electric cables, water pipes and similar utilities. As built map can be developed for buried utilities within the university campus which will serve as guide for construction works and can be updated as more facilities are installed.

2D ERT (with small electrode spacing for high resolution) and GPR (with high frequency) is recommended for detection of buried utilities.

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# APPENDIX A

**Magnetic Profiles**

**Location 2**

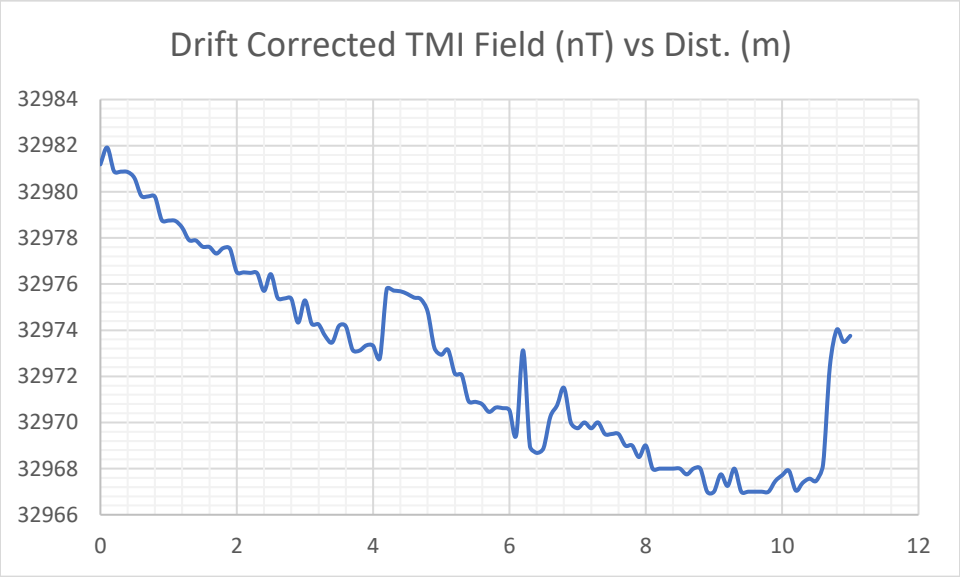


Figure A1: Magnetic profile along traverse 3

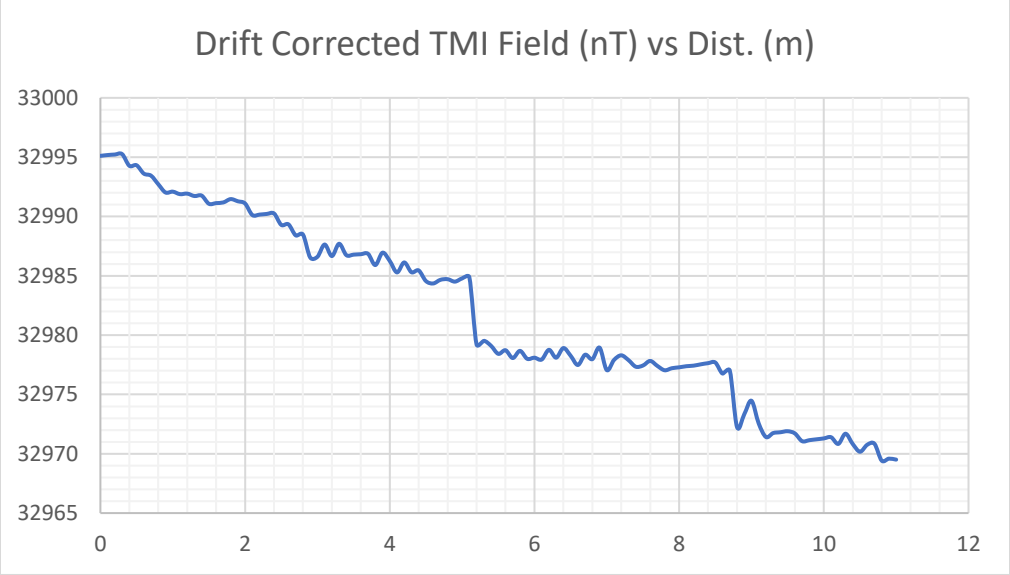


Figure A2: Magnetic profile along traverse 5

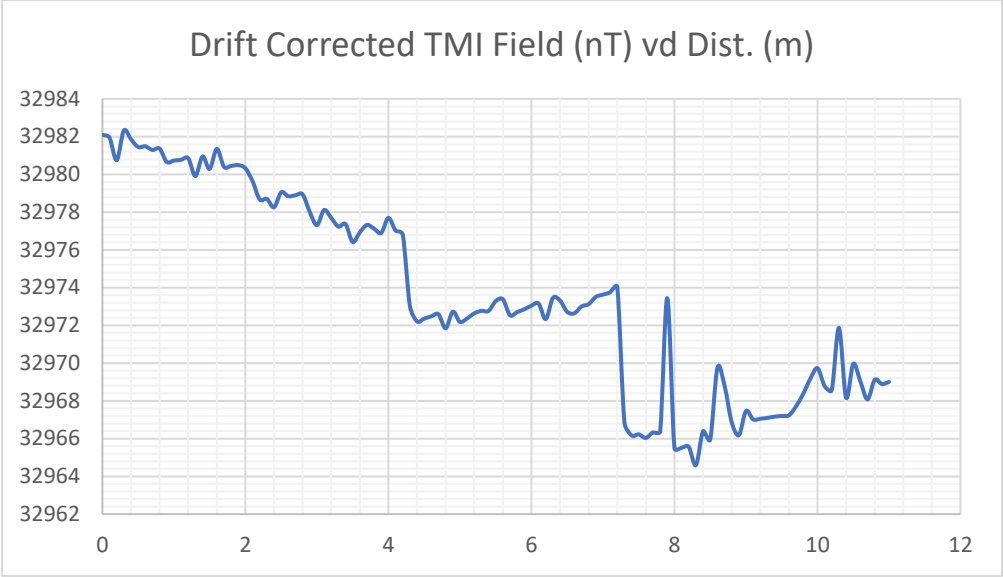


Figure A3: Magnetic profile along traverse 6

**Location 3**

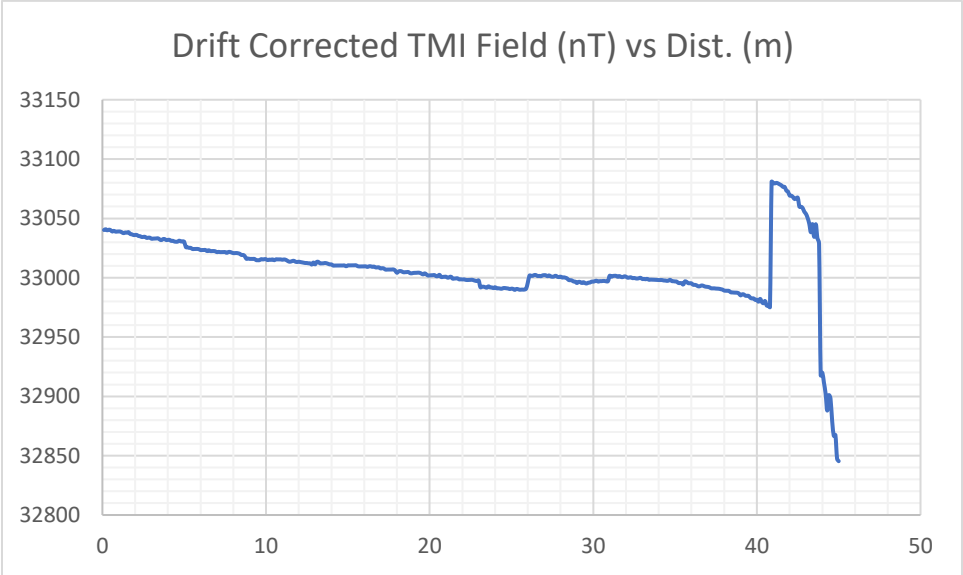


Figure A4: Magnetic profile along traverse 3

**Location 1**

| LINE 1 | | | | | LINE 2 | | | | | LINE 3 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SN | Time | | | TMI (Ave) | SN | Time | | | TMI (Ave) | SN | Time | | | TMI (Ave) |
| | H | M | S | | | H | M | S | | | H | M | S | |
| BS 0 | 3 | 1 | 39 | 32949 | BS1 | 13 | 40 | 30 | 32951.25 | BS 1 | 1 | 48 | 3 | 32968 |
| 1 | 3 | 3 | 18 | 32938 | 1 | 13 | 43 | 57 | 32943.25 | 1 | 1 | 51 | 10 | 32961.25 |
| 2 | 3 | 3 | 46 | 32939 | 2 | 13 | 45 | 10 | 32941.25 | 2 | 1 | 52 | 6 | 32962 |
| 3 | 3 | 4 | 19 | 32939 | 3 | | | | | 3 | 1 | 52 | 41 | 32962 |
| 4 | 3 | 5 | 5 | 32939 | 4 | 13 | 48 | 58 | 32942 | 4 | 1 | 53 | 9 | 32961 |
| 5 | 3 | 5 | 29 | 32939.75 | 5 | 13 | 49 | 57 | 32939 | 5 | 1 | 53 | 58 | 32961 |
| 6 | 3 | 6 | 6 | 32939.25 | 6 | 13 | 53 | 4 | 32940 | 6 | 1 | 54 | 45 | 32960 |
| 7 | 3 | 6 | 31 | 32938.75 | 7 | 13 | 53 | 58 | 32939.5 | 7 | 1 | 55 | 16 | 32960 |
| 8 | 3 | 7 | 1 | 32939 | 8 | 13 | 54 | 37 | 32939 | 8 | 1 | 55 | 45 | 32959.75 |
| 9 | 3 | 7 | 22 | 32939.25 | 9 | 13 | 56 | 30 | 32939 | 9 | 1 | 56 | 20 | 32959 |
| 10 | 3 | 7 | 50 | 32938.25 | 10 | 13 | 57 | 36 | 32939 | 10 | 1 | 57 | 11 | 32959 |
| 11 | 3 | 8 | 37 | 32938.25 | 11 | 13 | 58 | 31 | 32940 | 11 | 1 | 57 | 37 | 32958.5 |
| 12 | 3 | 9 | 54 | 32939 | 12 | 13 | 59 | 50 | 32940 | 12 | 1 | 58 | 51 | 32957 |
| 13 | 3 | 10 | 23 | 32938.75 | 13 | 14 | 0 | 43 | 32939 | 13 | 1 | 59 | 22 | 32957 |
| 14 | 3 | 10 | 50 | 32939 | 14 | 14 | 1 | 31 | 32939 | 14 | 2 | 0 | 4 | 32956.25 |
| 15 | 3 | 11 | 18 | 32938 | 15 | 14 | 2 | 23 | 32939.25 | 15 | 2 | 0 | 56 | 32956 |
| 16 | 3 | 11 | 47 | 32937 | 16 | 14 | 4 | 5 | 32939 | 16 | 2 | 1 | 30 | 32956 |
| 17 | 3 | 12 | 13 | 32937 | 17 | 14 | 4 | 54 | 32939 | 17 | 2 | 1 | 54 | 32955 |
| 18 | 3 | 12 | 59 | 32937 | 18 | 14 | 6 | 8 | 32940 | 18 | 2 | 2 | 38 | 32955 |
| 19 | 3 | 13 | 25 | 32936 | 19 | 14 | 7 | 0 | 32939 | 19 | 2 | 3 | 3 | 32955 |
| 20 | 3 | 13 | 56 | 32936 | 20 | 14 | 8 | 51 | 32939 | 20 | 2 | 3 | 46 | 32954 |
| 21 | 3 | 14 | 19 | 32937 | 21 | 14 | 9 | 35 | 32948 | 21 | 2 | 5 | 36 | 32952 |
| 22 | 3 | 15 | 4 | 32936.5 | 22 | 14 | 12 | 2 | 32938 | 22 | 2 | 6 | 8 | 32952 |
| 23 | 3 | 15 | 50 | 32936.75 | 23 | 14 | 12 | 56 | 32938 | 23 | 2 | 6 | 50 | 32952 |
| 24 | 3 | 16 | 47 | 32938 | 24 | 14 | 13 | 30 | 32938 | 24 | 2 | 7 | 57 | 32952 |
| 25 | 3 | 17 | 17 | 32940 | 25 | 14 | 14 | 4 | 32937 | 25 | 2 | 8 | 41 | 32950.5 |
| 26 | 3 | 17 | 45 | 32941 | 26 | 14 | 15 | 3 | 32936 | 26 | 2 | 9 | 28 | 32950 |
| 27 | 3 | 18 | 23 | 32939 | 27 | 14 | 15 | 31 | 32936 | 27 | 2 | 9 | 55 | 32949.75 |
| 28 | 3 | 18 | 53 | 32939.5 | 28 | 14 | 16 | 5 | 32936 | 28 | 2 | 10 | 35 | 32949 |
| 29 | 3 | 19 | 22 | 32939 | 29 | 14 | 17 | 8 | 32935.75 | 29 | 2 | 11 | 20 | 32948 |
| 30 | 3 | 19 | 51 | 32937 | 30 | 14 | 17 | 58 | 32936 | 30 | 2 | 12 | 29 | 32948 |
| 31 | 3 | 20 | 32 | 32937 | BS 2 | 14 | 20 | 37 | 32947 | 31 | 2 | 13 | 37 | 32947 |
| 32 | 3 | 22 | 13 | 32937 | 31 | 14 | 28 | 24 | 32934 | 32 | 2 | 14 | 6 | 32947 |
| 33 | 3 | 22 | 48 | 32934.5 | 32 | 14 | 30 | 8 | 32933 | 33 | 2 | 14 | 37 | 32947 |

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| 34 | 3 | 23 | 24 | 32935 | 33 | 14 | 30 | 31 | 32933 | 34 | 2 | 15 | 56 | 32946.75 |
| 35 | 3 | 24 | 23 | 32936.75 | 34 | 14 | 31 | 57 | 32933 | 35 | 2 | 17 | 39 | 32945 |
| 36 | 3 | 24 | 54 | 32938.75 | 35 | 14 | 32 | 42 | 32932 | 36 | 2 | 18 | 49 | 32945 |
| 37 | 3 | 25 | 22 | 32937.75 | 36 | 14 | 33 | 22 | 32931.75 | BS 2 | 2 | 20 | 15 | 8488.5 |
| 38 | 3 | 25 | 54 | 32937 | 37 | 14 | 34 | 15 | 32931 | BS 3 | 19 | 29 | 29 | 32934 |
| 39 | 3 | 26 | 35 | 32937 | 38 | 14 | 34 | 59 | 32931 | 35 | 19 | 32 | 0 | 32916 |
| 40 | 3 | 27 | 8 | 32937.25 | 39 | 14 | 35 | 57 | 32931 | 36 | 19 | 32 | 39 | 32916 |
| 41 | 3 | 27 | 45 | 32937 | 40 | 14 | 36 | 57 | 32931.75 | 37 | 19 | 33 | 6 | 32915 |
| 42 | 3 | 28 | 16 | 32939 | 41 | 14 | 37 | 59 | 32932 | 38 | 19 | 33 | 38 | 32915 |
| 43 | 3 | 28 | 53 | 32937 | 42 | 14 | 40 | 42 | 32931 | 39 | 19 | 34 | 18 | 32914 |
| 44 | 3 | 29 | 29 | 32938 | 43 | 14 | 42 | 12 | 32930.75 | 40 | 19 | 35 | 3 | 32915 |
| 45 | 3 | 30 | 22 | 32937 | 44 | 14 | 44 | 44 | 32930 | 41 | 19 | 35 | 28 | 32914 |
| 46 | 3 | 31 | 2 | 32937 | 45 | 14 | 45 | 54 | 32929 | 42 | 19 | 36 | 8 | 32914 |
| BS 1 | 3 | 32 | 42 | 32954 | 46 | 14 | 47 | 2 | 32928.75 | 43 | 19 | 36 | 41 | 32914 |
| 47 | 3 | 38 | 54 | 32935.75 | 47 | 14 | 49 | 20 | 32928 | 44 | 19 | 37 | 4 | 32913 |
| 48 | 3 | 39 | 29 | 32936 | BS 3 | 14 | 52 | 44 | 32944 | 45 | 19 | 37 | 35 | 32913 |
| 49 | 3 | 40 | 9 | 32935.75 | 48 | 14 | 55 | 3 | 32926.25 | 46 | 19 | 38 | 23 | 32913 |
| 50 | 3 | 40 | 57 | 32936.25 | 49 | 14 | 55 | 48 | 32926.75 | 47 | 19 | 39 | 12 | 32913 |
| 51 | 3 | 41 | 36 | 32936.75 | 50 | 14 | 56 | 58 | 32927 | 48 | 19 | 39 | 51 | 32913 |
| 52 | 3 | 42 | 37 | 32936 | 51 | 14 | 58 | 8 | 32927 | 49 | 19 | 40 | 29 | 32913 |
| 53 | 3 | 43 | 7 | 32936 | 52 | 14 | 58 | 39 | 32926 | 50 | 19 | 41 | 6 | 32913 |
| 54 | 3 | 43 | 49 | 32936 | 53 | 14 | 59 | 12 | 32927 | 51 | 19 | 41 | 33 | 32912 |
| 55 | 3 | 44 | 16 | 32935.75 | 54 | 15 | 0 | 50 | 32925.75 | 52 | 19 | 42 | 28 | 32912 |
| 56 | 3 | 44 | 45 | 32935 | 55 | 15 | 2 | 3 | 32925 | 53 | 19 | 43 | 0 | 32912 |
| 57 | 3 | 45 | 27 | 32937 | 56 | 15 | 2 | 51 | 32925 | 54 | 19 | 43 | 34 | 32912 |
| 58 | 3 | 46 | 4 | 32935.5 | 57 | 15 | 4 | 0 | 32925 | 55 | 19 | 44 | 0 | 32912 |
| 59 | 3 | 46 | 54 | 32935 | 58 | 15 | 4 | 27 | 32924 | 56 | 19 | 44 | 23 | 32912 |
| 60 | 3 | 47 | 24 | 32936 | 59 | 15 | 6 | 27 | 32923 | 57 | 19 | 45 | 21 | 32912 |
| 61 | 3 | 48 | 13 | 32936 | 60 | 15 | 7 | 35 | 32924 | 58 | 19 | 45 | 48 | 32912 |
| 62 | 3 | 48 | 42 | 32936 | 61 | 15 | 8 | 49 | 32922 | 59 | 19 | 46 | 24 | 32912.25 |
| 63 | 3 | 49 | 35 | 32935 | 62 | 15 | 10 | 36 | 32922 | 60 | 19 | 46 | 57 | 32912 |
| 64 | 3 | 50 | 33 | 32936 | 63 | 15 | 13 | 9 | 32922 | 61 | 19 | 47 | 43 | 32912 |
| 65 | 3 | 51 | 6 | 32936 | 64 | 15 | 13 | 41 | 32922 | 62 | 19 | 48 | 8 | 32912 |
| 66 | 3 | 51 | 38 | 32935.75 | 65 | 15 | 16 | 9 | 32922 | 63 | 19 | 48 | 35 | 32912 |
| 67 | 3 | 52 | 23 | 32937 | 66 | 15 | 17 | 21 | 32922 | 64 | 19 | 48 | 58 | 32912 |
| 68 | 3 | 53 | 5 | 32935 | 67 | 15 | 18 | 21 | 32922 | 65 | 19 | 49 | 35 | 32912 |
| 69 | 3 | 53 | 39 | 32936 | 68 | 15 | 19 | 10 | 32922 | 66 | 19 | 50 | 31 | 32913 |
| 70 | 3 | 54 | 23 | 32937.25 | 69 | 15 | 19 | 37 | 32922 | 67 | 19 | 51 | 15 | 32913 |
| 71 | 3 | 55 | 16 | 32935 | 70 | 15 | 20 | 54 | 32921.5 | 68 | 19 | 51 | 45 | 32913 |

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| 72 | 3 | 55 | 49 | 32934.75 | 71 | 15 | 21 | 32 | 32920.75 | 69 | 19 | 52 | 16 | 32913 |
| 73 | 3 | 56 | 23 | 32935 | 72 | 15 | 24 | 42 | 32921 | 70 | 19 | 52 | 50 | 32912.25 |
| 74 | 3 | 58 | 29 | 32936 | BS 4 | 15 | 26 | 56 | 32940 | 71 | 19 | 53 | 20 | 32913 |
| 75 | 3 | 59 | 5 | 32936 | 73 | 15 | 34 | 30 | 32919.25 | 72 | 19 | 54 | 2 | 32913 |
| 76 | 3 | 59 | 35 | 32936 | 74 | 15 | 35 | 56 | 32919 | 73 | 19 | 54 | 29 | 32913 |
| 77 | 4 | 0 | 14 | 32937 | 75 | 15 | 36 | 42 | 32919 | 74 | 19 | 54 | 56 | 32913.25 |
| 78 | 4 | 1 | 14 | 32938 | 76 | 15 | 37 | 28 | 32918.75 | 75 | 19 | 55 | 43 | 32914 |
| 79 | 4 | 2 | 18 | 32939 | 77 | 15 | 38 | 7 | 32919 | 76 | 19 | 56 | 11 | 32914 |
| 80 | 4 | 3 | 5 | 32938.25 | 78 | 15 | 38 | 43 | 32918 | 77 | 19 | 56 | 40 | 32914 |
| 81 | 4 | 4 | 2 | 32940 | 79 | 15 | 39 | 26 | 32918 | 78 | 19 | 57 | 9 | 32914 |
| 82 | 4 | 6 | 48 | 32939 | 80 | 15 | 40 | 5 | 32918 | 79 | 19 | 58 | 17 | 32914.75 |
| 83 | 4 | 7 | 22 | 32940 | 81 | 15 | 40 | 54 | 32918 | 80 | 19 | 58 | 52 | 32915 |
| 84 | 4 | 7 | 51 | 32938 | 82 | 15 | 41 | 31 | 32918 | 81 | 19 | 59 | 22 | 32914.5 |
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| 86 | 4 | 9 | 20 | 32939 | 84 | 15 | 43 | 48 | 32917.5 | 82 | 20 | 2 | 27 | 32915 |
| 87 | 4 | 10 | 10 | 32938.5 | 85 | 15 | 44 | 43 | 32917.5 | 83 | 20 | 3 | 2 | 32914.75 |
| 88 | 4 | 10 | 37 | 32939 | 86 | 15 | 45 | 30 | 32917 | 84 | 20 | 3 | 32 | 32914.5 |
| BS 2 | 4 | 12 | 18 | 32955 | 87 | 15 | 46 | 8 | 32917.25 | 85 | 20 | 5 | 2 | 32915.75 |
| 89 | 4 | 13 | 36 | 32937 | 88 | 15 | 48 | 11 | 32918.25 | 86 | 20 | 5 | 48 | 32915.25 |
| 90 | 4 | 14 | 6 | 32937 | 89 | 15 | 49 | 15 | 32918 | 87 | 20 | 6 | 19 | 32916 |
| 91 | 4 | 14 | 36 | 32939 | 90 | 15 | 50 | 42 | 32918.25 | 88 | 20 | 6 | 50 | 32915 |
| 92 | 4 | 15 | 4 | 32937 | 91 | 15 | 53 | 47 | 32918 | 89 | 20 | 7 | 56 | 32916 |
| 93 | 4 | 15 | 37 | 32936 | 92 | 15 | 55 | 18 | 32918 | 90 | 20 | 8 | 59 | 32915.5 |
| 94 | 4 | 16 | 31 | 32938 | 93 | 15 | 56 | 39 | 32918.5 | 91 | 20 | 9 | 33 | 32916 |
| 95 | 4 | 17 | 25 | 32937.25 | BS 5 | 15 | 58 | 8 | 32936 | 92 | 20 | 10 | 24 | 32916 |
| 96 | 4 | 18 | 12 | 32937 | 94 | 16 | 0 | 28 | 32917.75 | 93 | 20 | 11 | 0 | 32916 |
| 97 | 4 | 19 | 6 | 32936 | 95 | 16 | 1 | 15 | 32918 | 94 | 20 | 11 | 32 | 32916 |
| 98 | 4 | 19 | 54 | 32936 | 96 | 16 | 2 | 8 | 32918 | 95 | 20 | 13 | 11 | 32917 |
| 99 | 4 | 20 | 28 | 32936 | 97 | 16 | 2 | 42 | 32918.25 | 96 | 20 | 13 | 49 | 32917 |
| 100 | 4 | 21 | 11 | 32935 | 98 | 16 | 3 | 30 | 32918 | 97 | 20 | 14 | 27 | 32917 |
| 101 | 4 | 22 | 5 | 32935.75 | 99 | 16 | 4 | 38 | 32918 | 98 | 20 | 15 | 10 | 32918 |
| 102 | 4 | 22 | 36 | 32935.25 | 100 | 16 | 6 | 20 | 32918 | 99 | 20 | 15 | 48 | 32918 |
| 103 | 4 | 23 | 6 | 32935 | 101 | 16 | 8 | 31 | 32917.5 | 100 | 20 | 16 | 37 | 32919 |
| 104 | 4 | 23 | 44 | 32935 | 102 | 16 | 10 | 55 | 32917 | 101 | 20 | 17 | 27 | 32919 |
| 105 | 4 | 24 | 22 | 32935 | 103 | 16 | 14 | 31 | 32916 | 102 | 20 | 17 | 52 | 32919 |
| 106 | 4 | 24 | 45 | 32935 | 104 | 16 | 16 | 43 | 32916.25 | 103 | 20 | 18 | 20 | 32919 |
| 107 | 4 | 25 | 46 | 32935 | 105 | 16 | 20 | 25 | 32915.75 | 104 | 20 | 18 | 43 | 32919 |
| 108 | 4 | 26 | 15 | 32935.75 | 106 | 16 | 21 | 6 | 32916.5 | 105 | 20 | 19 | 24 | 32919 |
| 109 | 4 | 27 | 6 | 32933 | 107 | 16 | 24 | 5 | 32914 | 106 | 20 | 20 | 25 | 32920 |

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| 110 | 4 | 28 | 5 | 32933 | 108 | 16 | 27 | 9 | 32911.25 | 107 | 20 | 20 | 58 | 32920 |
| 111 | 4 | 28 | 38 | 32933.5 | 109 | 16 | 29 | 6 | 32910.75 | 108 | 20 | 21 | 49 | 32920 |
| 112 | 4 | 29 | 33 | 32934 | BS 6 | 16 | 31 | 1 | 32929 | 109 | 20 | 22 | 22 | 32921 |
| 113 | 4 | 30 | 3 | 32933 | 110 | 16 | 32 | 46 | 32911 | 110 | 20 | 23 | 15 | 32922 |
| 114 | 4 | 30 | 38 | 32932.75 | 111 | 16 | 33 | 51 | 32911 | 111 | 20 | 23 | 44 | 32921 |
| 115 | 4 | 31 | 8 | 32933 | 112 | 16 | 34 | 35 | 32911 | 112 | 20 | 24 | 34 | 32921 |
| 116 | 4 | 32 | 43 | 32930.25 | 113 | 16 | 35 | 25 | 32911 | 113 | 20 | 25 | 40 | 32921 |
| 117 | 4 | 33 | 15 | 32931 | 114 | 16 | 36 | 14 | 32911 | 114 | 20 | 27 | 34 | 32922 |
| 118 | 4 | 33 | 49 | 32930 | 115 | 16 | 36 | 43 | 32910.75 | 115 | 20 | 28 | 35 | 32923 |
| 119 | 4 | 35 | 11 | 32931 | 116 | 16 | 38 | 37 | 32911 | 116 | 20 | 29 | 35 | 32922 |
| 120 | 4 | 35 | 52 | 32929.5 | 117 | 16 | 39 | 16 | 32911 | 117 | 20 | 30 | 5 | 32923 |
| 121 | 4 | 36 | 37 | 32929.75 | 118 | 16 | 40 | 7 | 32911 | BS 5 | 20 | 31 | 31 | 32937 |
| 122 | 4 | 37 | 33 | 32929 | 119 | 16 | 40 | 39 | 32911 | BS 6 | 21 | 13 | 15 | 32939 |
| 123 | 4 | 38 | 13 | 32930 | 120 | 16 | 41 | 27 | 32911 | 118 | 21 | 15 | 31 | 32923 |
| 124 | 4 | 38 | 51 | 32929 | 121 | 16 | 42 | 3 | 32911 | 119 | 21 | 16 | 33 | 32924 |
| 125 | 4 | 40 | 27 | 32928 | 122 | 16 | 42 | 34 | 32911 | 120 | 21 | 16 | 55 | 32925 |
| 126 | 4 | 41 | 4 | 32926 | 123 | 16 | 43 | 3 | 32911 | 121 | 21 | 17 | 23 | 32925 |
| 127 | 4 | 41 | 36 | 32926 | 124 | 16 | 43 | 56 | 32910.75 | 122 | 21 | 18 | 12 | 32926 |
| 128 | 4 | 42 | 25 | 32926.25 | 125 | 16 | 44 | 57 | 32911 | 123 | 21 | 18 | 54 | 32926.75 |
| 129 | 4 | 43 | 5 | 32925.25 | 126 | 16 | 45 | 37 | 32910.25 | 124 | 21 | 19 | 24 | 32926 |
| 130 | 4 | 44 | 29 | 32925.25 | 127 | 16 | 46 | 26 | 32911.25 | 125 | 21 | 20 | 23 | 32926.5 |
| BS 3 | 4 | 45 | 38 | 32951 | 128 | 16 | 47 | 9 | 32911.5 | 126 | 21 | 21 | 0 | 32927 |
| BS 4 | 21 | 13 | 14 | 32962 | 129 | 16 | 47 | 49 | 32911.75 | 127 | 21 | 21 | 52 | 32926 |
| 131 | 21 | 14 | 36 | 32938 | 130 | 16 | 48 | 57 | 32911.5 | 128 | 21 | 22 | 18 | 32927 |
| 132 | 21 | 15 | 10 | 32937 | 131 | 16 | 49 | 18 | 32911 | 129 | 21 | 23 | 7 | 32926 |
| 133 | 21 | 15 | 37 | 32937 | 132 | 16 | 49 | 59 | 32911.75 | 130 | 21 | 23 | 39 | 32927 |
| 134 | 21 | 16 | 16 | 32936 | 133 | 16 | 51 | 54 | 32912 | 131 | 21 | 24 | 48 | 32927 |
| 135 | 21 | 17 | 29 | 32936 | 134 | 16 | 53 | 47 | 32911 | 132 | 21 | 25 | 22 | 32927 |
| 136 | 21 | 18 | 11 | 32935.75 | 135 | 16 | 54 | 34 | 32912 | 133 | 21 | 26 | 50 | 32925.75 |
| 137 | 21 | 19 | 43 | 32936 | 136 | 16 | 55 | 16 | 32911 | 134 | 21 | 27 | 32 | 32927 |
| 138 | 21 | 19 | 6 | 32935 | 137 | 16 | 56 | 10 | 32911 | 135 | 21 | 28 | 27 | 32925 |
| 139 | 21 | 19 | 32 | 32935 | 138 | 16 | 56 | 41 | 32911 | 136 | 21 | 29 | 14 | 32925.75 |
| 140 | 21 | 20 | 55 | 32935 | 139 | 16 | 57 | 17 | 32911 | 137 | 21 | 30 | 16 | 32927 |
| 141 | 21 | 21 | 40 | 32935 | 140 | 16 | 57 | 55 | 32911 | 138 | 21 | 31 | 18 | 32926 |
| 142 | 21 | 21 | 4 | 32935 | 141 | 16 | 58 | 26 | 32911 | 139 | 21 | 32 | 7 | 32927 |
| 143 | 21 | 22 | 28 | 32935 | 142 | 16 | 59 | 7 | 32911 | 140 | 21 | 32 | 36 | 32926.5 |
| 144 | 21 | 22 | 5 | 32935 | 143 | 17 | 0 | 32 | 32910.5 | 141 | 21 | 33 | 16 | 32927 |
| 145 | 21 | 22 | 19 | 32935 | 144 | 17 | 1 | 52 | 32911 | 142 | 21 | 34 | 10 | 32927 |
| 146 | 21 | 23 | 19 | 32934 | BS 7 | 17 | 3 | 50 | 32930 | 143 | 21 | 35 | 0 | 32927 |

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| 147 | 21 | 23 | 53 | 32934 | 145 | 17 | 6 | 10 | 32911 | 144 | 21 | 36 | 4 | 32927 |
| 148 | 21 | 24 | 27 | 32934 | 146 | 17 | 8 | 2 | 32911 | 145 | 21 | 36 | 40 | 32927 |
| 149 | 21 | 25 | 14 | 32934 | 147 | 17 | 8 | 53 | 32910.5 | 146 | 21 | 37 | 36 | 32926.75 |
| 150 | 21 | 26 | 17 | 32933 | 148 | 17 | 9 | 44 | 32910 | 147 | 21 | 38 | 8 | 32926 |
| 151 | 21 | 27 | 42 | 32933 | 149 | 17 | 10 | 35 | 32910 | 148 | 21 | 39 | 4 | 32926 |
| 152 | 21 | 27 | 59 | 32931.75 | 150 | 17 | 12 | 0 | 32910 | 149 | 21 | 39 | 46 | 32925 |
| 153 | 21 | 28 | 56 | 32932 | 151 | 17 | 14 | 36 | 32909 | 150 | 21 | 40 | 21 | 32925 |
| 154 | 21 | 29 | 24 | 32931 | 152 | 17 | 18 | 17 | 32909 | 151 | 21 | 40 | 56 | 32924 |
| 155 | 21 | 29 | 56 | 32932 | BS 8 | 17 | 22 | 36 | 32931 | 152 | 21 | 41 | 47 | 32925 |
| 156 | 21 | 30 | 28 | 32931 | BS 9 | 9 | 44 | 18 | 32957 | 153 | 21 | 42 | 16 | 32925 |
| 157 | 21 | 31 | 1 | 32932 | 150 | 9 | 49 | 45 | 32936 | 154 | 21 | 42 | 46 | 32925 |
| 158 | 21 | 31 | 31 | 32931 | 151 | 9 | 50 | 48 | 32937 | 155 | 21 | 43 | 13 | 32925 |
| 159 | 21 | 31 | 57 | 32931 | 152 | 9 | 51 | 58 | 32936 | BS 7 | 21 | 44 | 35 | 32939 |
| 160 | 21 | 32 | 37 | 32931 | 153 | 9 | 52 | 18 | 32937 | 156 | 21 | 45 | 48 | 32924 |
| 161 | 21 | 33 | 7 | 32931 | 154 | 9 | 54 | 0 | 32936 | 157 | 21 | 46 | 17 | 32925.75 |
| 162 | 21 | 34 | 12 | 32930 | 155 | 9 | 54 | 46 | 32935 | 158 | 21 | 47 | 14 | 32924 |
| 163 | 21 | 34 | 4 | 32930 | 156 | 9 | 55 | 31 | 32935 | 159 | 21 | 47 | 45 | 32925 |
| 164 | 21 | 35 | 29 | 32930 | 157 | 9 | 56 | 3 | 32936 | 160 | 21 | 48 | 31 | 32924.75 |
| 165 | 21 | 35 | 57 | 32931 | 158 | 9 | 56 | 40 | 32935.75 | 161 | 21 | 50 | 20 | 32925 |
| 166 | 21 | 36 | 21 | 32931 | 159 | 9 | 57 | 33 | 32935 | 162 | 21 | 51 | 1 | 32924 |
| 167 | 21 | 36 | 46 | 32931 | 160 | 9 | 58 | 0 | 32935 | 163 | 21 | 51 | 56 | 32924 |
| 168 | 21 | 37 | 13 | 32930 | 161 | 9 | 58 | 46 | 32934 | 164 | 21 | 52 | 23 | 32925 |
| 169 | 21 | 37 | 39 | 32930 | 162 | 9 | 59 | 17 | 32934.5 | 165 | 21 | 53 | 5 | 32926 |
| 170 | 21 | 38 | 34 | 32930 | 163 | 10 | 0 | 1 | 32934 | 166 | 21 | 54 | 6 | 32927 |
| 171 | 21 | 41 | 25 | 32930.75 | 164 | 10 | 5 | 47 | 32935 | 167 | 21 | 54 | 44 | 32924 |
| 172 | 21 | 42 | 18 | 32930.75 | 165 | 10 | 8 | 9 | 32935 | 168 | 21 | 55 | 19 | 32925 |
| 173 | 21 | 43 | 10 | 32930 | 166 | 10 | 11 | 47 | 32935.5 | 169 | 21 | 55 | 53 | 32925 |
| 174 | 21 | 43 | 43 | 32930 | 167 | 10 | 12 | 14 | 32936 | 170 | 21 | 56 | 56 | 32925.75 |
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| 175 | 21 | 45 | 52 | 32930 | 169 | 10 | 18 | 49 | 32936 | 172 | 21 | 59 | 23 | 32926.75 |
| 176 | 21 | 46 | 21 | 32930.25 | BS 10 | 10 | 21 | 29 | 32961.75 | 173 | 22 | 0 | 21 | 32926 |
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| 183 | 21 | 51 | 28 | 32931 | 176 | 10 | 39 | 1 | 32940 | 180 | 22 | 6 | 56 | 32927 |
| 184 | 21 | 51 | 50 | 32930 | 177 | 10 | 40 | 45 | 32940 | 181 | 22 | 7 | 33 | 32927 |

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| 186 | 21 | 53 | 7 | 32930.75 | BS 11 | 11 | 30 | 55 | 32970 | 183 | 22 | 9 | 30 | 32928 |
| 187 | 21 | 53 | 34 | 32931 | 179 | 11 | 33 | 52 | 32946.25 | 184 | 22 | 10 | 11 | 32928 |
| 188 | 21 | 54 | 21 | 32931 | 180 | 11 | 37 | 0 | 32947 | 185 | 22 | 11 | 29 | 32930 |
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| 190 | 21 | 55 | 21 | 32932 | 182 | 11 | 38 | 55 | 32946.75 | 187 | 22 | 12 | 43 | 32929 |
| 191 | 21 | 56 | 35 | 32931.25 | 183 | 11 | 39 | 37 | 32947 | 188 | 22 | 13 | 39 | 32930 |
| 192 | 21 | 56 | 53 | 32932 | 184 | 11 | 40 | 47 | 32937 | 189 | 22 | 14 | 9 | 32929 |
| 193 | 21 | 57 | 43 | 32932 | 185 | 11 | 42 | 0 | 32947.25 | 190 | 22 | 14 | 43 | 32931 |
| 194 | 21 | 58 | 8 | 32933 | 186 | 11 | 43 | 30 | 32948 | 191 | 22 | 15 | 32 | 32930 |
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| 203 | 22 | 3 | 42 | 32934 | 195 | 11 | 56 | 20 | 32947.75 | 209 | 22 | 23 | 40 | 32932 |
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| 206 | 22 | 5 | 39 | 32934 | 198 | 11 | 59 | 43 | 32948.75 | 212 | 22 | 26 | 30 | 32933 |
| 207 | 22 | 6 | 4 | 32935 | 199 | 12 | 0 | 17 | 32949 | 213 | 22 | 27 | 4 | 32932 |
| 208 | 22 | 6 | 51 | 32935.5 | BS 12 | 12 | 1 | 56 | 32972 | 214 | 22 | 27 | 58 | 32932 |
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| 211 | 22 | 9 | 9 | 32936.25 | 202 | 12 | 4 | 38 | 32949 | 217 | 22 | 29 | 48 | 32930.75 |
| 212 | 22 | 9 | 51 | 32936.75 | 203 | 12 | 5 | 20 | 32949 | 218 | 22 | 30 | 38 | 32932 |
| 213 | 22 | 10 | 20 | 32936 | 204 | 12 | 6 | 51 | 32949 | 219 | 22 | 31 | 8 | 32932.25 |
| 214 | 22 | 10 | 48 | 32937 | 205 | 12 | 7 | 28 | 32949 | 220 | 22 | 31 | 43 | 32932 |
| 215 | 22 | 11 | 15 | 32937 | 206 | 12 | 9 | 5 | 32949 | BS 9 | 22 | 34 | 18 | 32943 |
| 216 | 22 | 11 | 41 | 32937 | 207 | 12 | 9 | 54 | 32949.25 | BS 10 | 23 | 10 | 46 | 32948 |
| 217 | 22 | 12 | 19 | 32938 | 208 | 12 | 10 | 47 | 32949 | 221 | 23 | 12 | 31 | 32935 |
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| 230 | 22 | 19 | 30 | 32943 | 221 | 12 | 19 | 48 | 32950 | 234 | 23 | 21 | 33 | 32936.75 |
| 231 | 22 | 20 | 14 | 32943 | 222 | 12 | 20 | 29 | 32950 | 235 | 23 | 22 | 39 | 32937.5 |
| 232 | 22 | 20 | 47 | 32943.75 | 223 | 12 | 21 | 3 | 32950 | 236 | 23 | 23 | 10 | 32937 |
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| 234 | 22 | 22 | 0 | 32944 | 225 | 12 | 22 | 10 | 32950 | 238 | 23 | 24 | 29 | 32937.75 |
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| BS 7 | 22 | 23 | 48 | 32968 | 227 | 12 | 23 | 34 | 32950.25 | 240 | 23 | 26 | 20 | 32935.75 |
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| 238 | 22 | 26 | 20 | 32946 | 230 | 12 | 26 | 8 | 32952 | 243 | 23 | 28 | 52 | 32938 |
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| 243 | 22 | 28 | 59 | 32947 | 235 | 12 | 30 | 39 | 32952 | 248 | 23 | 32 | 6 | 32938 |
| 244 | 22 | 30 | 0 | 32947 | BS 13 | 12 | 32 | 21 | 32971 | 249 | 23 | 33 | 9 | 32937 |
| 245 | 22 | 30 | 45 | 32948.25 | 236 | 12 | 34 | 40 | 32952.25 | 250 | 23 | 33 | 56 | 32936.5 |
| 246 | 22 | 31 | 32 | 32948 | 237 | 12 | 35 | 29 | 32952 | 251 | 23 | 34 | 42 | 32937 |
| 247 | 22 | 31 | 57 | 32949 | 238 | 12 | 36 | 11 | 32952.25 | 252 | 23 | 35 | 23 | 32938 |
| 248 | 22 | 32 | 30 | 32949 | 239 | 12 | 37 | 29 | 32952 | 253 | 23 | 35 | 54 | 32938.25 |
| 249 | 22 | 32 | 57 | 32950 | 240 | 12 | 38 | 17 | 32952 | 254 | 23 | 37 | 10 | 32938 |
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| 251 | 22 | 34 | 1 | 32949.25 | 242 | 12 | 39 | 37 | 32952 | 256 | 23 | 38 | 36 | 32937 |
| 252 | 22 | 34 | 43 | 32950 | 243 | 12 | 40 | 14 | 32952 | 257 | 23 | 39 | 18 | 32938 |
| 253 | 22 | 35 | 9 | 32950.5 | 244 | 12 | 40 | 46 | 32951 | 258 | 23 | 40 | 8 | 32937 |
| 254 | 22 | 35 | 43 | 32950 | 245 | 12 | 41 | 56 | 32951 | 259 | 23 | 40 | 34 | 32937.75 |
| 255 | 22 | 36 | 13 | 32950 | 246 | 12 | 42 | 26 | 32951.75 | 260 | 23 | 41 | 31 | 32937.75 |
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| 271 | 22 | 47 | 9 | 32949 | 262 | 12 | 57 | 28 | 32949.5 | 275 | 23 | 52 | 17 | 32940.5 |
| 272 | 22 | 48 | 7 | 32949.75 | 263 | 12 | 58 | 20 | 32947.5 | 276 | 23 | 53 | 5 | 32940 |
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| 275 | 22 | 49 | 51 | 32949 | 266 | 1 | 1 | 56 | 32952.25 | 279 | 23 | 55 | 11 | 32939 |
| 276 | 22 | 50 | 16 | 32948.75 | BS 14 | 1 | 3 | 0 | 32967 | 280 | 23 | 55 | 48 | 32940 |
| 277 | 22 | 51 | 19 | 32948 | 267 | 1 | 4 | 29 | 32950 | 281 | 23 | 56 | 15 | 32939.5 |
| 278 | 22 | 51 | 42 | 32949 | 268 | 1 | 5 | 23 | 32950 | 282 | 23 | 57 | 39 | 32940 |
| 279 | 22 | 52 | 8 | 32948.75 | 269 | 1 | 5 | 51 | 32950 | 283 | 23 | 58 | 8 | 32939.25 |
| BS 8 | 22 | 53 | 25 | 32972 | 270 | 1 | 6 | 22 | 32950 | 284 | 23 | 59 | 5 | 32939 |
| 280 | 22 | 54 | 19 | 32949 | 271 | 1 | 7 | 27 | 32950 | 285 | 23 | 59 | 41 | 32940 |
| 281 | 22 | 55 | 5 | 32949.75 | 272 | 1 | 8 | 2 | 32950 | 286 | 24 | 0 | 41 | 32940 |
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| 283 | 22 | 56 | 29 | 32950 | 274 | 1 | 9 | 24 | 32949.75 | 288 | 24 | 2 | 18 | 32939.25 |
| 284 | 22 | 57 | 18 | 32950 | 275 | 1 | 10 | 2 | 32950 | 289 | 24 | 2 | 57 | 32939.25 |
| 285 | 22 | 57 | 52 | 32950 | 276 | 1 | 10 | 47 | 32950 | 290 | 24 | 3 | 38 | 32939 |
| 286 | 22 | 58 | 46 | 32949 | 277 | 1 | 11 | 29 | 32950 | 291 | 24 | 4 | 9 | 32940 |
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| 288 | 22 | 59 | 40 | 32950 | 279 | 1 | 13 | 15 | 32949 | 293 | 24 | 5 | 28 | 32939.5 |
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| 293 | 23 | 2 | 32 | 32949 | 284 | 1 | 17 | 36 | 32950 | 298 | 24 | 9 | 24 | 32938 |
| 294 | 23 | 3 | 21 | 32949 | 285 | 1 | 18 | 14 | 32950.25 | 299 | 24 | 10 | 7 | 32938 |
| 295 | 23 | 3 | 49 | 32949 | 286 | 1 | 18 | 58 | 32950 | 300 | 24 | 10 | 34 | 32937 |
| 296 | 23 | 4 | 31 | 32949 | 287 | 1 | 19 | 29 | 32950 | BS 12 | 24 | 11 | 35 | 32950 |

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| 297 | 23 | 5 | 2 | 32950 | 288 | 1 | 19 | 51 | 32950 | | | | | |
| 298 | 23 | 5 | 34 | 32949 | 289 | 1 | 20 | 35 | 32950 | | | | | |
| 299 | 23 | 6 | 9 | 32950 | 290 | 1 | 21 | 9 | 32950.25 | | | | | |
| 300 | 23 | 6 | 40 | 32950 | 291 | 1 | 21 | 38 | 32950 | | | | | |
| BS 9 | 23 | 7 | 45 | 32971 | 292 | 1 | 21 | 55 | 32950 | | | | | |
| | | | | | 293 | 1 | 22 | 15 | 32950.25 | | | | | |
| | | | | | 294 | 1 | 23 | 2 | 32951.5 | | | | | |
| | | | | | 295 | 1 | 23 | 42 | 32952 | | | | | |
| | | | | | 296 | 1 | 25 | 31 | 32952 | | | | | |
| | | | | | 297 | 1 | 26 | 30 | 32952 | | | | | |
| | | | | | 298 | 1 | 27 | 8 | 32952 | | | | | |
| | | | | | 299 | 1 | 28 | 12 | 32951 | | | | | |
| | | | | | 300 | 1 | 29 | 25 | 32952 | | | | | |
| | | | | | BS 15 | 1 | 30 | 35 | 32969 | | | | | |

## Location 2

| LINE 1 | | | | | LINE 2 | | | | | LINE 3 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SN | Time | | | TMI (Ave) | SN | Time | | | TMI (Ave) | SN | Time | | | TMI (Ave) |
| | H | M | S | | | H | M | S | | | H | M | S | |
| BS1 | 1 | 30 | 15 | 32924 | BS1 | 20 | 43 | 0 | 32916 | BS1 | 22 | 25 | 42 | 32925 |
| 1 | 1 | 31 | 53 | 32979 | 1 | 20 | 44 | 19 | 32969 | 1 | 22 | 27 | 38 | 32981.25 |
| 2 | 1 | 33 | 46 | 32978 | 2 | 20 | 44 | 46 | 32968 | 2 | 22 | 28 | 20 | 32982 |
| 3 | 1 | 34 | 36 | 32978 | 3 | 20 | 45 | 34 | 32967.25 | 3 | 22 | 29 | 10 | 32981 |
| 4 | 1 | 35 | 4 | 32976.5 | 4 | 20 | 46 | 36 | 32966.75 | 4 | 22 | 29 | 40 | 32981 |
| 5 | 1 | 35 | 39 | 32975 | 5 | 20 | 47 | 9 | 32967 | 5 | 22 | 30 | 11 | 32981 |
| 6 | 1 | 36 | 6 | 32977 | 6 | 20 | 48 | 2 | 32967 | 6 | 22 | 30 | 35 | 32980.75 |
| 7 | 1 | 36 | 34 | 32975.75 | 7 | 20 | 48 | 29 | 32966.75 | 7 | 22 | 31 | 13 | 32980 |
| 8 | 1 | 37 | 19 | 32976.25 | 8 | 20 | 48 | 55 | 32966 | 8 | 22 | 32 | 0 | 32980 |
| 9 | 1 | 37 | 47 | 32976 | 9 | 20 | 49 | 20 | 32966 | 9 | 22 | 32 | 28 | 32980 |
| 10 | 1 | 38 | 11 | 32976 | 10 | 20 | 49 | 52 | 32965.75 | 10 | 22 | 32 | 50 | 32979 |
| 11 | 1 | 38 | 39 | 32976 | 11 | 20 | 50 | 19 | 32966 | 11 | 22 | 33 | 27 | 32979 |
| 12 | 1 | 39 | 20 | 32975.5 | 12 | 20 | 50 | 42 | 32965.25 | 12 | 22 | 33 | 57 | 32979 |
| 13 | 1 | 40 | 13 | 32975.25 | 13 | 20 | 51 | 24 | 32965.25 | 13 | 22 | 35 | 17 | 32978.75 |
| 14 | 1 | 40 | 44 | 32974.75 | 14 | 20 | 52 | 36 | 32965.25 | 14 | 22 | 36 | 25 | 32978.25 |
| 15 | 1 | 40 | 59 | 32975 | 15 | 20 | 53 | 24 | 32964.25 | 15 | 22 | 36 | 56 | 32978.25 |
| 16 | 1 | 41 | 13 | 32975 | 16 | 20 | 53 | 56 | 32965 | 16 | 22 | 37 | 37 | 32978 |
| 17 | 1 | 41 | 56 | 32974.75 | 17 | 20 | 54 | 42 | 32965 | 17 | 22 | 38 | 5 | 32978 |
| 18 | 1 | 42 | 46 | 32973.75 | 18 | 20 | 55 | 39 | 32964 | 18 | 22 | 39 | 7 | 32977.75 |
| 19 | 1 | 43 | 15 | 32973.75 | 19 | 20 | 56 | 24 | 32964 | 19 | 22 | 39 | 35 | 32978 |
| 20 | 1 | 43 | 44 | 32973 | 20 | 20 | 56 | 55 | 32964.25 | 20 | 22 | 40 | 20 | 32978 |
| 21 | 1 | 44 | 50 | 32972.75 | 21 | 20 | 57 | 44 | 32963 | 21 | 22 | 40 | 45 | 32977 |
| 22 | 1 | 45 | 50 | 32974 | 22 | 20 | 58 | 14 | 32963.25 | 22 | 22 | 41 | 8 | 32977 |
| 23 | 1 | 46 | 17 | 32974 | 23 | 20 | 58 | 53 | 32962.25 | 23 | 22 | 41 | 53 | 32977 |
| 24 | 1 | 46 | 52 | 32974 | 24 | 20 | 59 | 53 | 32962.5 | 24 | 22 | 42 | 22 | 32977 |
| 25 | 1 | 47 | 22 | 32973 | 25 | 21 | 0 | 23 | 32962.25 | 25 | 22 | 42 | 52 | 32976.25 |
| 26 | 1 | 47 | 46 | 32972.75 | 26 | 21 | 1 | 3 | 32962.25 | 26 | 22 | 43 | 36 | 32977 |
| 27 | 1 | 48 | 33 | 32973 | 27 | 21 | 1 | 35 | 32962.75 | 27 | 22 | 44 | 27 | 32976 |
| 28 | 1 | 49 | 49 | 32973 | 28 | 21 | 2 | 34 | 32962.75 | 28 | 22 | 45 | 12 | 32976 |
| 29 | 1 | 50 | 24 | 32973 | 29 | 21 | 3 | 14 | 32963 | 29 | 22 | 45 | 38 | 32976 |
| 30 | 1 | 52 | 14 | 32970 | 30 | 21 | 3 | 48 | 32963 | 30 | 22 | 46 | 44 | 32975 |
| 31 | 1 | 52 | 52 | 32967 | 31 | 21 | 4 | 30 | 32962.25 | 31 | 22 | 47 | 47 | 32976 |
| 32 | 1 | 53 | 23 | 32966 | 32 | 21 | 5 | 15 | 32961.75 | 32 | 22 | 48 | 15 | 32975 |
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| 34 | 1 | 57 | 32 | 32967 | 34 | 21 | 8 | 26 | 32962 | 34 | 22 | 49 | 40 | 32974.5 |

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| 35 | 1 | 58 | 9 | 32967 | 35 | 21 | 8 | 51 | 32963 | 35 | 22 | 50 | 9 | 32974.25 |
| 36 | 1 | 59 | 37 | 32966 | 36 | 21 | 9 | 14 | 32963.25 | 36 | 22 | 51 | 8 | 32975 |
| 37 | 2 | 0 | 22 | 32967.75 | 37 | 21 | 9 | 46 | 32964 | 37 | 22 | 51 | 46 | 32975 |
| 38 | 2 | 1 | 48 | 32970 | 38 | 21 | 10 | 12 | 32964.25 | 38 | 22 | 52 | 32 | 32974 |
| 39 | 2 | 2 | 24 | 32969 | 39 | 21 | 10 | 36 | 32965 | 39 | 22 | 53 | 26 | 32974 |
| 40 | 2 | 3 | 8 | 32968 | 40 | 21 | 11 | 11 | 32965 | 40 | 22 | 54 | 13 | 32974.25 |
| 41 | 2 | 3 | 42 | 32969 | 41 | 21 | 11 | 39 | 32966 | 41 | 22 | 54 | 42 | 32974.25 |
| 42 | 2 | 4 | 30 | 32969 | 42 | 21 | 12 | 15 | 32966 | 42 | 22 | 55 | 31 | 32973.75 |
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| 44 | 2 | 5 | 41 | 32971.5 | 44 | 21 | 13 | 20 | 32965 | BS3 | 23 | 13 | 58 | 32927 |
| 45 | 2 | 6 | 13 | 32970 | BS2 | 21 | 14 | 20 | 32920 | 43 | 23 | 17 | 25 | 32976 |
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| 46 | 2 | 10 | 2 | 32971 | 46 | 21 | 16 | 5 | 32966 | 45 | 23 | 18 | 59 | 32976 |
| 47 | 2 | 10 | 41 | 32971 | 47 | 21 | 16 | 39 | 32967 | 46 | 23 | 20 | 46 | 32976 |
| 48 | 2 | 11 | 11 | 32970.25 | 48 | 21 | 17 | 8 | 32967 | 47 | 23 | 23 | 20 | 32976 |
| 49 | 2 | 11 | 50 | 32970 | 49 | 21 | 17 | 41 | 32967.25 | 48 | 23 | 24 | 27 | 32976 |
| 50 | 2 | 12 | 58 | 32971.75 | 50 | 21 | 18 | 23 | 24808.25 | 49 | 23 | 25 | 7 | 32975.5 |
| 51 | 2 | 14 | 6 | 32974 | 51 | 21 | 19 | 38 | 32969 | 50 | 23 | 26 | 18 | 32974 |
| 52 | 2 | 14 | 44 | 32973 | 52 | 21 | 20 | 20 | 32968.25 | 51 | 23 | 27 | 0 | 32973.75 |
| 53 | 2 | 15 | 24 | 32977 | 53 | 21 | 20 | 54 | 32969 | 52 | 23 | 27 | 39 | 32974 |
| 54 | 2 | 15 | 49 | 32977 | 54 | 21 | 21 | 34 | 32968.25 | 53 | 23 | 28 | 13 | 32973 |
| 55 | 2 | 16 | 16 | 32976.25 | 55 | 21 | 22 | 21 | 32968.75 | 54 | 23 | 29 | 6 | 32973 |
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| 59 | 2 | 19 | 43 | 32982 | 59 | 21 | 24 | 40 | 32968.75 | 58 | 23 | 34 | 39 | 32971.75 |
| 60 | 2 | 20 | 28 | 32982.25 | 60 | 21 | 25 | 10 | 32968.25 | 59 | 23 | 35 | 38 | 32972 |
| 61 | 2 | 21 | 1 | 32988.75 | 61 | 21 | 25 | 45 | 32968.25 | 60 | 23 | 36 | 3 | 32972 |
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| 67 | 2 | 27 | 2 | 32970 | 67 | 21 | 31 | 1 | 32968 | 66 | 23 | 43 | 44 | 32970.75 |
| 68 | 2 | 28 | 5 | 32970 | 68 | 21 | 31 | 38 | 32968 | BS4 | 23 | 46 | 0 | 32929 |
| 69 | 2 | 28 | 49 | 32970 | 69 | 21 | 32 | 13 | 32968 | 67 | 23 | 47 | 52 | 32970.25 |
| 70 | 2 | 30 | 53 | 32971.25 | 70 | 21 | 33 | 6 | 32968 | 68 | 23 | 48 | 31 | 32970.75 |
| 71 | 2 | 32 | 31 | 32970 | 71 | 21 | 33 | 51 | 32967.75 | 69 | 23 | 49 | 14 | 32971.5 |
| 72 | 2 | 33 | 9 | 32968.75 | 72 | 21 | 34 | 24 | 32967 | 70 | 23 | 49 | 55 | 32970 |

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| 73 | 2 | 33 | 52 | 32968 | 73 | 21 | 34 | 56 | 32967 | 71 | 23 | 50 | 42 | 32969.75 |
| 74 | 2 | 34 | 42 | 32965 | 74 | 21 | 35 | 51 | 32967 | 72 | 23 | 51 | 27 | 32970 |
| 75 | 2 | 35 | 28 | 32965.5 | 75 | 21 | 36 | 29 | 32967 | 73 | 23 | 52 | 42 | 32969.75 |
| 76 | 2 | 35 | 52 | 32964.75 | 76 | 21 | 38 | 15 | 32967 | 74 | 23 | 54 | 24 | 32970 |
| 77 | 2 | 36 | 19 | 32963 | 77 | 21 | 38 | 44 | 32966.75 | 75 | 23 | 55 | 23 | 32969.5 |
| 78 | 2 | 37 | 5 | 32962.5 | 78 | 21 | 39 | 42 | 32966 | 76 | 23 | 56 | 51 | 32969.5 |
| 79 | 2 | 37 | 52 | 32962 | 79 | 21 | 40 | 18 | 32966 | 77 | 23 | 57 | 26 | 32969.5 |
| 80 | 2 | 38 | 13 | 32961 | 80 | 21 | 41 | 5 | 32966.25 | 78 | 23 | 58 | 12 | 32969 |
| 81 | 2 | 39 | 32 | 32962 | 81 | 21 | 41 | 44 | 32967 | 79 | 23 | 58 | 34 | 32969 |
| 82 | 2 | 41 | 19 | 32961 | 82 | 21 | 42 | 9 | 32967.75 | 80 | 23 | 59 | 18 | 32968.5 |
| 83 | 2 | 42 | 17 | 32960.75 | 83 | 21 | 42 | 41 | 32967.25 | 81 | 23 | 59 | 53 | 32969 |
| 84 | 2 | 42 | 52 | 32960 | 84 | 21 | 43 | 18 | 32967 | 82 | 24 | 0 | 59 | 32968 |
| 85 | 2 | 43 | 25 | 32960 | 85 | 21 | 44 | 3 | 32967 | 83 | 24 | 2 | 8 | 32968 |
| 86 | 2 | 44 | 17 | 32959 | BS3 | 21 | 45 | 52 | 32925 | 84 | 24 | 2 | 42 | 32968 |
| 87 | 2 | 45 | 29 | 32958 | 86 | 21 | 47 | 50 | 32966 | 85 | 24 | 3 | 32 | 32968 |
| 88 | 2 | 47 | 57 | 32953.25 | 87 | 21 | 48 | 26 | 32965 | 86 | 24 | 4 | 8 | 32968 |
| 89 | 2 | 49 | 34 | 32953.25 | 88 | 21 | 48 | 56 | 32965.5 | 87 | 24 | 4 | 41 | 32967.75 |
| BS3 | 2 | 51 | 27 | 32925 | 89 | 21 | 50 | 9 | 32966 | 88 | 24 | 6 | 30 | 32968 |
| BS4 | 15 | 35 | 22 | 32918 | 90 | 21 | 50 | 58 | 32966 | 89 | 24 | 6 | 59 | 32968 |
| 90 | 15 | 37 | 26 | 32942 | 91 | 21 | 52 | 51 | 32964 | 90 | 24 | 7 | 26 | 32967 |
| 91 | 15 | 37 | 52 | 32942.5 | 92 | 21 | 53 | 28 | 32964.25 | 91 | 24 | 8 | 1 | 32967 |
| 92 | 15 | 38 | 24 | 32943 | 93 | 21 | 54 | 2 | 32964 | 92 | 24 | 8 | 45 | 32967.75 |
| 93 | 15 | 38 | 59 | 32944 | 94 | 21 | 54 | 33 | 32964 | 93 | 24 | 9 | 25 | 32967.25 |
| 94 | 15 | 39 | 59 | 32944 | 95 | 21 | 55 | 20 | 32964 | 94 | 24 | 10 | 1 | 32968 |
| 95 | 15 | 40 | 49 | 32942.25 | 96 | 21 | 55 | 49 | 32964 | 95 | 24 | 10 | 41 | 32967 |
| 96 | 15 | 42 | 43 | 32943 | 97 | 21 | 56 | 24 | 32964.25 | 96 | 24 | 11 | 17 | 32967 |
| 97 | 15 | 43 | 8 | 32943.5 | 98 | 21 | 57 | 2 | 32964.5 | 97 | 24 | 12 | 8 | 32967 |
| 98 | 15 | 43 | 55 | 32943.75 | 99 | 21 | 57 | 33 | 32964.75 | 98 | 24 | 12 | 37 | 32967 |
| 99 | 15 | 45 | 38 | 32942 | 100 | 21 | 58 | 5 | 32964 | 99 | 24 | 13 | 2 | 32967 |
| 100 | 15 | 48 | 13 | 32946.25 | 101 | 21 | 59 | 18 | 32965 | BS5 | 24 | 14 | 9 | 32929 |
| 101 | 15 | 49 | 42 | 32945.5 | 102 | 22 | 0 | 19 | 32964.75 | 100 | 24 | 15 | 22 | 32967 |
| 102 | 15 | 50 | 12 | 32945 | 103 | 22 | 1 | 0 | 32964.5 | 101 | 24 | 16 | 2 | 32967 |
| 103 | 15 | 51 | 7 | 32944.5 | 104 | 22 | 1 | 50 | 32965 | 102 | 24 | 16 | 33 | 32967 |
| 104 | 15 | 52 | 0 | 32945.25 | 105 | 22 | 2 | 12 | 32965 | 103 | 24 | 16 | 56 | 32966 |
| 105 | 15 | 52 | 45 | 32945 | 106 | 22 | 2 | 55 | 32965 | 104 | 24 | 17 | 48 | 32966 |
| 106 | 15 | 53 | 50 | 32944 | 107 | 22 | 3 | 44 | 32964.75 | 105 | 24 | 18 | 17 | 32966 |
| 107 | 15 | 55 | 13 | 32944 | 108 | 22 | 5 | 4 | 32964 | 106 | 24 | 18 | 42 | 32965.75 |
| 108 | 15 | 56 | 42 | 32944 | 109 | 22 | 5 | 58 | 32965.75 | 107 | 24 | 19 | 54 | 32966 |
| 109 | 15 | 57 | 57 | 32944.25 | 110 | 22 | 6 | 39 | 32965.75 | 108 | 24 | 28 | 30 | 32967 |

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| 110 | 16 | 1 | 15 | 32944 | BS4 | 22 | 8 | 1 | 32923 | 109 | 24 | 30 | 4 | 32968 |
| BS5 | 16 | 4 | 52 | 32916 | | | | | | 110 | 24 | 31 | 20 | 32967 |
| | | | | | | | | | | BS6 | 24 | 32 | 40 | 32922 |

| LINE 4 | | | | | LINE 5 | | | | | LINE 6 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SN | Time | | | TMI (Ave) | SN | Time | | | TMI (Ave) | SN | Time | | | TMI (Ave) |
| | H | M | S | | | H | M | S | | | H | M | S | |
| BS1 | 2 | 24 | 15 | 32920 | BS1 | 24 | 17 | 6 | 32945.75 | BS1 | 2 | 25 | 19 | 32937 |
| 1 | 2 | 25 | 37 | 32982.25 | 1 | 24 | 18 | 25 | 32995 | 1 | 2 | 26 | 19 | 32982 |
| 2 | 2 | 27 | 54 | 32981.25 | 2 | 24 | 19 | 16 | 32995 | 2 | 2 | 27 | 21 | 32981.75 |
| 3 | 2 | 28 | 17 | 32981.25 | 3 | 24 | 19 | 46 | 32995 | 3 | 2 | 27 | 59 | 32980.5 |
| 4 | 2 | 28 | 40 | 32981.5 | 4 | 24 | 20 | 12 | 32995 | 4 | 2 | 28 | 46 | 32982 |
| 5 | 2 | 29 | 3 | 32981 | 5 | 24 | 20 | 22 | 32994 | 5 | 2 | 29 | 9 | 32981.5 |
| 6 | 2 | 29 | 36 | 32981 | 6 | 24 | 20 | 54 | 32994 | 6 | 2 | 30 | 8 | 32981 |
| 7 | 2 | 30 | 13 | 32981 | 7 | 24 | 21 | 28 | 32993.25 | 7 | 2 | 30 | 33 | 32981 |
| 8 | 2 | 30 | 50 | 32981 | 8 | 24 | 22 | 21 | 32993 | 8 | 2 | 31 | 7 | 32980.75 |
| 9 | 2 | 31 | 15 | 32981 | 9 | 24 | 22 | 43 | 32992.25 | 9 | 2 | 31 | 53 | 32980.75 |
| 10 | 2 | 32 | 28 | 32980.25 | 10 | 24 | 23 | 22 | 32991.5 | 10 | 2 | 32 | 21 | 32980 |
| 11 | 2 | 33 | 6 | 32981 | 11 | 24 | 24 | 11 | 32991.5 | 11 | 2 | 33 | 9 | 32980 |
| 12 | 2 | 33 | 39 | 32980 | 12 | 24 | 24 | 38 | 32991.25 | 12 | 2 | 33 | 33 | 32980 |
| 13 | 2 | 34 | 3 | 32980 | 13 | 24 | 25 | 10 | 32991.25 | 13 | 2 | 34 | 30 | 32980 |
| 14 | 2 | 34 | 37 | 32980 | 14 | 24 | 25 | 44 | 32991 | 14 | 2 | 35 | 2 | 32979 |
| 15 | 2 | 35 | 37 | 32979.75 | 15 | 24 | 26 | 9 | 32991 | 15 | 2 | 35 | 27 | 32980 |
| 16 | 2 | 36 | 17 | 32979.75 | 16 | 24 | 26 | 53 | 32990.25 | 16 | 2 | 39 | 6 | 32979 |
| 17 | 2 | 36 | 54 | 32979.75 | 17 | 24 | 27 | 34 | 32990.25 | 17 | 2 | 39 | 45 | 32980 |
| 18 | 2 | 37 | 20 | 32979.25 | 18 | 24 | 28 | 16 | 32990.25 | 18 | 2 | 40 | 17 | 32979 |
| 19 | 2 | 37 | 50 | 32979 | 19 | 24 | 28 | 35 | 32990.5 | 19 | 2 | 40 | 48 | 32979 |
| 20 | 2 | 38 | 28 | 32978.75 | 20 | 24 | 29 | 25 | 32990.25 | 20 | 2 | 41 | 15 | 32979 |
| 21 | 2 | 39 | 40 | 32980 | 21 | 24 | 30 | 8 | 32990 | 21 | 2 | 42 | 7 | 32978.75 |
| 22 | 2 | 40 | 11 | 32979 | 22 | 24 | 30 | 30 | 32989 | 22 | 2 | 42 | 49 | 32978 |
| 23 | 2 | 40 | 36 | 32978.75 | 23 | 24 | 30 | 54 | 32989 | 23 | 2 | 43 | 8 | 32977 |
| 24 | 2 | 41 | 11 | 32979 | 24 | 24 | 31 | 34 | 32989 | 24 | 2 | 43 | 32 | 32977 |
| 25 | 2 | 41 | 58 | 32980 | 25 | 24 | 32 | 2 | 32989 | 25 | 2 | 44 | 7 | 32976.5 |
| 26 | 2 | 42 | 25 | 32979 | 26 | 24 | 32 | 31 | 32988 | 26 | 2 | 44 | 33 | 32977.25 |
| 27 | 2 | 42 | 51 | 32979 | 27 | 24 | 33 | 1 | 32988 | 27 | 2 | 44 | 59 | 32977 |
| 28 | 2 | 43 | 46 | 32978.25 | 28 | 24 | 33 | 53 | 32987 | 28 | 2 | 45 | 35 | 32977 |
| 29 | 2 | 44 | 11 | 32978.75 | 29 | 24 | 34 | 42 | 32987 | 29 | 2 | 46 | 3 | 32977 |

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| 30 | 2 | 44 | 38 | 32978 | 30 | 24 | 35 | 30 | 32985 | 30 | 2 | 46 | 47 | 32976 |
| 31 | 2 | 45 | 28 | 32978 | 31 | 24 | 36 | 10 | 32985 | 31 | 2 | 47 | 21 | 32975.25 |
| 32 | 2 | 46 | 21 | 32978 | 32 | 24 | 36 | 35 | 32986 | 32 | 2 | 47 | 53 | 32976 |
| 33 | 2 | 47 | 5 | 32978.25 | 33 | 24 | 36 | 57 | 32985 | 33 | 2 | 48 | 46 | 32975.5 |
| 34 | 2 | 50 | 29 | 32978 | 34 | 24 | 37 | 21 | 32986 | 34 | 2 | 49 | 12 | 32975 |
| 35 | 2 | 51 | 4 | 32978 | 35 | 24 | 37 | 49 | 32985 | 35 | 2 | 50 | 37 | 32975 |
| 36 | 2 | 51 | 32 | 32978 | 36 | 24 | 38 | 22 | 32985 | 36 | 2 | 51 | 9 | 32974 |
| 37 | 2 | 52 | 0 | 32977 | 37 | 24 | 38 | 47 | 32985 | 37 | 2 | 51 | 17 | 32974.5 |
| 38 | 2 | 52 | 28 | 32977 | 38 | 24 | 39 | 11 | 32985 | 38 | 2 | 52 | 48 | 32974.75 |
| 39 | 2 | 53 | 19 | 32977 | 39 | 24 | 39 | 48 | 32984 | 39 | 2 | 53 | 20 | 32974.5 |
| 40 | 2 | 53 | 39 | 32977 | 40 | 24 | 40 | 19 | 32985 | 40 | 2 | 53 | 39 | 32974.25 |
| 41 | 2 | 54 | 4 | 32976 | 41 | 24 | 40 | 57 | 32984.25 | 41 | 2 | 54 | 8 | 32975 |
| 42 | 2 | 54 | 32 | 32976.25 | 42 | 24 | 41 | 22 | 32983.25 | 42 | 2 | 54 | 52 | 32974.25 |
| 43 | 2 | 55 | 4 | 32976 | 43 | 24 | 42 | 25 | 32984 | 43 | 2 | 55 | 19 | 32974 |
| 44 | 2 | 55 | 33 | 32976 | 44 | 24 | 44 | 30 | 32983 | BS2 | 2 | 57 | 20 | 32934 |
| 45 | 2 | 56 | 70 | 32975 | 45 | 24 | 46 | 18 | 32983 | 44 | 3 | 1 | 10 | 32972 |
| 46 | 2 | 56 | 37 | 32975.25 | 46 | 24 | 47 | 33 | 32982 | 45 | 3 | 1 | 50 | 32971 |
| 47 | 2 | 57 | 4 | 32975 | 47 | 24 | 48 | 8 | 32981.75 | 46 | 3 | 2 | 22 | 32971 |
| 48 | 2 | 57 | 33 | 32974.25 | 48 | 24 | 48 | 48 | 32982 | 47 | 3 | 2 | 50 | 32971 |
| 49 | 2 | 58 | 7 | 32973.5 | 49 | 24 | 49 | 26 | 32982 | 48 | 3 | 3 | 14 | 32971 |
| 50 | 2 | 58 | 46 | 32974 | 50 | 24 | 49 | 58 | 32981.75 | 49 | 3 | 4 | 11 | 32970 |
| 51 | 2 | 59 | 19 | 32973 | 51 | 24 | 50 | 12 | 32982 | 50 | 3 | 4 | 40 | 32970.75 |
| 52 | 2 | 59 | 41 | 32973 | 52 | 24 | 51 | 26 | 32982 | 51 | 3 | 5 | 27 | 32970 |
| 53 | 3 | 0 | 14 | 32972.75 | BS2 | 24 | 52 | 47 | 32942.75 | 52 | 3 | 6 | 7 | 32970 |
| BS 2 | 3 | 1 | 36 | 32921 | 53 | 24 | 54 | 18 | 32979 | 53 | 3 | 7 | 7 | 32970 |
| 54 | 3 | 3 | 10 | 32972 | 54 | 24 | 54 | 49 | 32979.25 | 54 | 3 | 7 | 37 | 32970 |
| 55 | 3 | 3 | 27 | 32972 | 55 | 24 | 55 | 24 | 32978.75 | 55 | 3 | 8 | 32 | 32969.75 |
| 56 | 3 | 3 | 44 | 32970.75 | 56 | 24 | 55 | 56 | 32978 | 56 | 3 | 9 | 31 | 32970 |
| 57 | 3 | 4 | 32 | 32970 | 57 | 24 | 56 | 20 | 32978.25 | 57 | 3 | 9 | 54 | 32970 |
| 58 | 3 | 4 | 59 | 32970.5 | 58 | 24 | 57 | 2 | 32977.5 | 58 | 3 | 10 | 28 | 32969 |
| 59 | 3 | 5 | 48 | 32969 | 59 | 24 | 57 | 48 | 32978 | 59 | 3 | 11 | 5 | 32969 |
| 60 | 3 | 6 | 17 | 32969 | 60 | 24 | 58 | 24 | 32977.25 | 60 | 3 | 11 | 38 | 32969 |
| 61 | 3 | 7 | 31 | 32967.75 | 61 | 24 | 59 | 6 | 32977.25 | 61 | 3 | 12 | 21 | 32969 |
| 62 | 3 | 8 | 11 | 32965.75 | 62 | 24 | 59 | 48 | 32977 | 62 | 3 | 12 | 46 | 32969 |
| 63 | 3 | 8 | 54 | 32966.25 | 63 | 1 | 0 | 19 | 32977.75 | 63 | 3 | 13 | 25 | 32968 |
| 64 | 3 | 9 | 45 | 32965.5 | 64 | 1 | 0 | 58 | 32977 | 64 | 3 | 13 | 52 | 32969 |
| 65 | 3 | 10 | 32 | 32964.75 | 65 | 1 | 1 | 25 | 32977.75 | 65 | 3 | 14 | 17 | 32968.75 |
| 66 | 3 | 11 | 48 | 32963.75 | 66 | 1 | 2 | 12 | 32977 | 66 | 3 | 14 | 51 | 32968 |
| 67 | 3 | 12 | 16 | 32964 | 67 | 1 | 3 | 50 | 32976 | 67 | 3 | 15 | 29 | 32967.75 |

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| 68 | 3 | 12 | 38 | 32963 | 68 | 1 | 4 | 40 | 32976.75 | 68 | 3 | 15 | 54 | 32968 |
| 69 | 3 | 13 | 2 | 32962 | 69 | 1 | 5 | 37 | 32976.25 | 69 | 3 | 16 | 21 | 32968 |
| 70 | 3 | 13 | 59 | 32962 | 70 | 1 | 7 | 16 | 32977 | 70 | 3 | 17 | 47 | 32968 |
| 71 | 3 | 14 | 51 | 32962 | 71 | 1 | 8 | 3 | 32975 | 71 | 3 | 18 | 14 | 32968 |
| 72 | 3 | 15 | 40 | 32962 | 72 | 1 | 8 | 51 | 32975.75 | 72 | 3 | 18 | 41 | 32968 |
| 73 | 3 | 16 | 27 | 32963 | 73 | 1 | 9 | 53 | 32976 | 73 | 3 | 19 | 45 | 32968 |
| 74 | 3 | 17 | 6 | 32961 | 74 | 1 | 10 | 36 | 32975.5 | BS3 | 3 | 22 | 23 | 32927.25 |
| 75 | 3 | 17 | 40 | 32960.25 | 75 | 1 | 12 | 4 | 32974.75 | 74 | 3 | 24 | 1 | 32966.75 |
| 76 | 3 | 19 | 34 | 32961 | 76 | 1 | 12 | 48 | 32974.75 | 75 | 3 | 24 | 46 | 32966 |
| 77 | 3 | 20 | 1 | 32962 | 77 | 1 | 13 | 49 | 32975 | 76 | 3 | 25 | 37 | 32966 |
| 78 | 3 | 20 | 23 | 32962 | 78 | 1 | 14 | 22 | 32974.5 | 77 | 3 | 26 | 29 | 32965.75 |
| 79 | 3 | 21 | 24 | 32962 | 79 | 1 | 15 | 24 | 32974 | 78 | 3 | 27 | 8 | 32966 |
| 80 | 3 | 22 | 23 | 32962 | 80 | 1 | 16 | 41 | 32974 | 79 | 3 | 27 | 52 | 32966 |
| 81 | 3 | 22 | 52 | 32961.5 | 81 | 1 | 17 | 14 | 32974 | 80 | 3 | 28 | 40 | 32973 |
| 82 | 3 | 23 | 16 | 32962.25 | 82 | 1 | 17 | 56 | 32974 | 81 | 3 | 29 | 14 | 32965 |
| 83 | 3 | 24 | 30 | 32963 | 83 | 1 | 18 | 18 | 32974 | 82 | 3 | 29 | 45 | 32965 |
| 84 | 3 | 25 | 4 | 32964 | 84 | 1 | 19 | 8 | 32974 | 83 | 3 | 30 | 21 | 32965 |
| 85 | 3 | 25 | 54 | 32962.75 | 85 | 1 | 19 | 51 | 32974 | 84 | 3 | 30 | 53 | 32964 |
| 86 | 3 | 26 | 37 | 32963 | 86 | 1 | 20 | 15 | 32974 | 85 | 3 | 31 | 39 | 32965.75 |
| 87 | 3 | 26 | 49 | 32963 | 87 | 1 | 20 | 45 | 32973 | 86 | 3 | 32 | 27 | 32965.25 |
| 88 | 3 | 27 | 15 | 32964 | 88 | 1 | 22 | 41 | 32973 | 87 | 3 | 32 | 58 | 32969 |
| 89 | 3 | 27 | 43 | 32963 | BS3 | 1 | 24 | 25 | 32938.5 | 88 | 3 | 33 | 49 | 32968 |
| 90 | 3 | 28 | 21 | 32963.75 | 89 | 1 | 25 | 51 | 32972 | 89 | 3 | 34 | 46 | 32966 |
| 91 | 3 | 28 | 50 | 32963 | 90 | 1 | 26 | 17 | 32973 | 90 | 3 | 35 | 34 | 32965.25 |
| 92 | 3 | 29 | 16 | 32963.25 | 91 | 1 | 27 | 10 | 32974 | 91 | 3 | 36 | 5 | 32966.5 |
| 93 | 3 | 29 | 55 | 32962.5 | 92 | 1 | 27 | 42 | 32972 | 92 | 3 | 36 | 52 | 32966 |
| 94 | 3 | 30 | 42 | 32963 | 93 | 1 | 28 | 23 | 32970.75 | 93 | 3 | 37 | 23 | 32966 |
| 95 | 3 | 31 | 26 | 32962.75 | 94 | 1 | 28 | 53 | 32971 | 94 | 3 | 38 | 3 | 32966 |
| 96 | 3 | 32 | 5 | 32962 | 95 | 1 | 29 | 19 | 32971 | 95 | 3 | 38 | 59 | 32966 |
| 97 | 3 | 32 | 50 | 32962 | 96 | 1 | 29 | 51 | 32971 | 96 | 3 | 39 | 30 | 32966 |
| 98 | 3 | 33 | 44 | 32962 | 97 | 1 | 30 | 15 | 32970.75 | 97 | 3 | 39 | 57 | 32966 |
| 99 | 3 | 34 | 50 | 32961 | 98 | 1 | 30 | 51 | 32970 | 98 | 3 | 43 | 10 | 32966.25 |
| 100 | 3 | 35 | 20 | 32960.75 | 99 | 1 | 31 | 22 | 32970 | 99 | 3 | 45 | 29 | 32966.75 |
| BS3 | 3 | 36 | 43 | 32917.75 | 100 | 1 | 31 | 50 | 32970 | 100 | 3 | 46 | 12 | 32967.5 |
| 101 | 3 | 37 | 36 | 32959 | 101 | 1 | 32 | 17 | 32970 | 101 | 3 | 47 | 5 | 32968 |
| 102 | 3 | 38 | 22 | 32960 | 102 | 1 | 32 | 55 | 32970 | 102 | 3 | 47 | 45 | 32967 |
| 103 | 3 | 39 | 31 | 32957.75 | 103 | 1 | 34 | 4 | 32969.25 | 103 | 3 | 48 | 24 | 32966.75 |
| 104 | 3 | 40 | 25 | 32959.5 | 104 | 1 | 34 | 44 | 32970 | 104 | 3 | 49 | 0 | 32970 |
| 105 | 3 | 40 | 56 | 32959 | 105 | 1 | 35 | 34 | 32969 | 105 | 3 | 49 | 42 | 32966.25 |

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| 106 | 3 | 41 | 26 | 32958 | 106 | 1 | 36 | 11 | 32968.25 | 106 | 3 | 50 | 20 | 32968 |
| 107 | 3 | 42 | 3 | 32958.25 | 107 | 1 | 36 | 43 | 32968.75 | 107 | 3 | 51 | 19 | 32967 |
| 108 | 3 | 50 | 44 | 32958.75 | 108 | 1 | 37 | 15 | 32968.75 | 108 | 3 | 51 | 59 | 32966 |
| 109 | 3 | 51 | 42 | 32958.75 | 109 | 1 | 37 | 44 | 32967.25 | 109 | 3 | 52 | 31 | 32967 |
| 110 | 3 | 52 | 15 | 32958.75 | 110 | 1 | 38 | 46 | 32967.25 | 110 | 3 | 52 | 55 | 32966.75 |
| BS4 | 3 | 54 | 26 | 32916 | BS4 | 1 | 39 | 56 | 32936 | BS4 | 3 | 54 | 19 | 32925 |
| BS5 | 23 | 37 | 47 | 32948 | | | | | | | | | | |
| 110 | 23 | 40 | 0 | 32987 | | | | | | | | | | |
| 111 | 23 | 40 | 36 | 32987 | | | | | | | | | | |
| 112 | 23 | 41 | 10 | 32987 | | | | | | | | | | |
| 113 | 23 | 41 | 33 | 32987 | | | | | | | | | | |
| 114 | 23 | 42 | 57 | 32987 | | | | | | | | | | |
| 115 | 23 | 43 | 19 | 32987 | | | | | | | | | | |
| 116 | 23 | 43 | 2 | 32987.25 | | | | | | | | | | |
| 117 | 23 | 43 | 50 | 32988 | | | | | | | | | | |
| 118 | 23 | 44 | 47 | 32988 | | | | | | | | | | |
| 119 | 23 | 45 | 15 | 32988 | | | | | | | | | | |
| 120 | 23 | 45 | 56 | 32989 | | | | | | | | | | |
| 121 | 23 | 46 | 21 | 32989 | | | | | | | | | | |
| 122 | 23 | 46 | 46 | 32990 | | | | | | | | | | |
| 123 | 23 | 47 | 28 | 32989 | | | | | | | | | | |
| 124 | 23 | 47 | 58 | 32989 | | | | | | | | | | |
| 125 | 23 | 48 | 25 | 32989 | | | | | | | | | | |
| 126 | 23 | 49 | 25 | 32989 | | | | | | | | | | |
| 127 | 23 | 49 | 51 | 32989 | | | | | | | | | | |
| 128 | 23 | 50 | 33 | 32989 | | | | | | | | | | |
| 129 | 23 | 51 | 7 | 32987.75 | | | | | | | | | | |
| 130 | 23 | 51 | 39 | 32988 | | | | | | | | | | |
| 131 | 23 | 53 | 40 | 32984.75 | | | | | | | | | | |
| 132 | 23 | 54 | 14 | 32985 | | | | | | | | | | |
| 133 | 23 | 54 | 55 | 32984 | | | | | | | | | | |
| 134 | 23 | 55 | 39 | 32984 | | | | | | | | | | |
| 135 | 23 | 56 | 36 | 32983.25 | | | | | | | | | | |
| BS6 | 23 | 58 | 28 | 32945 | | | | | | | | | | |

## Location 3

| LINE 1 | | | | | LINE 2 | | | | | LINE 3 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SN | Time | | | TMI (Ave) | SN | Time | | | TMI (Ave) | SN | Time | | | TMI (Ave) |
| | H | M | S | | | H | M | S | | | H | M | S | |
| BS1 | 24 | 37 | 26 | 33035.25 | BS1 | 23 | 54 | 11 | 33032 | BS1 | 1 | 43 | 37 | 33018 |
| 1 | 24 | 39 | 40 | 33046 | 1 | 23 | 57 | 30 | 33262.75 | 1 | 1 | 44 | 59 | 33040 |
| 2 | 24 | 41 | 27 | 33047.75 | 2 | 23 | 58 | 35 | 33254 | 2 | 1 | 45 | 58 | 33040.5 |
| 3 | 24 | 44 | 26 | 33046.75 | 3 | 24 | 1 | 13 | 33256 | 3 | 1 | 46 | 29 | 33039.5 |
| 4 | 24 | 45 | 33 | 33047 | 4 | 24 | 2 | 57 | 33249 | 4 | 1 | 46 | 58 | 33040 |
| 5 | 24 | 46 | 24 | 33047 | 5 | 24 | 3 | 28 | 33241 | 5 | 1 | 47 | 39 | 33039.5 |
| 6 | 24 | 47 | 3 | 33047 | 6 | 24 | 4 | 1 | 33240.75 | 6 | 1 | 48 | 14 | 33038.25 |
| 7 | 24 | 47 | 50 | 33047 | 7 | 24 | 4 | 26 | 33238 | 7 | 1 | 48 | 48 | 33038.75 |
| 8 | 24 | 48 | 26 | 33046.75 | 8 | 24 | 5 | 53 | 33240 | 8 | 1 | 49 | 14 | 33038 |
| 9 | 24 | 49 | 11 | 33046 | 9 | 24 | 6 | 17 | 33233.75 | 9 | 1 | 49 | 38 | 33038 |
| 10 | 24 | 50 | 22 | 33046.5 | 10 | 24 | 6 | 55 | 33232 | 10 | 1 | 50 | 15 | 33038 |
| 11 | 24 | 51 | 11 | 33046.25 | 11 | 24 | 7 | 54 | 33225.5 | 11 | 1 | 51 | 3 | 33037.75 |
| 12 | 24 | 51 | 52 | 33046.5 | 12 | 24 | 8 | 22 | 33223.25 | 12 | 1 | 51 | 33 | 33037 |
| 13 | 24 | 53 | 9 | 33046.25 | 13 | 24 | 9 | 6 | 33222 | 13 | 1 | 52 | 14 | 33036.25 |
| 14 | 24 | 54 | 34 | 33046.5 | 14 | 24 | 10 | 54 | 33216 | 14 | 1 | 52 | 59 | 33036.75 |
| 15 | 24 | 55 | 30 | 33046.25 | 15 | 24 | 11 | 22 | 33216.5 | 15 | 1 | 53 | 13 | 33036.5 |
| 16 | 24 | 56 | 43 | 33046.5 | 16 | 24 | 12 | 14 | 33208 | 16 | 1 | 54 | 46 | 33036.75 |
| 17 | 24 | 58 | 7 | 33046.5 | 17 | 24 | 12 | 35 | 33205.5 | 17 | 1 | 55 | 54 | 33035 |
| 18 | 24 | 59 | 16 | 33046.25 | 18 | 24 | 13 | 36 | 33204.5 | 18 | 1 | 56 | 4 | 33034.75 |
| 19 | 1 | 0 | 5 | 33046 | 19 | 24 | 14 | 11 | 33204 | 19 | 1 | 56 | 49 | 33034 |
| 20 | 1 | 1 | 0 | 33046 | 20 | 24 | 14 | 39 | 33204.25 | 20 | 1 | 57 | 8 | 33034 |
| 21 | 1 | 1 | 46 | 33046 | 21 | 24 | 15 | 26 | 33201.25 | 21 | 1 | 57 | 32 | 33034 |
| 22 | 1 | 2 | 20 | 33046.5 | 22 | 24 | 15 | 56 | 33200 | 22 | 1 | 58 | 19 | 33033 |
| 23 | 1 | 3 | 23 | 33046 | 23 | 24 | 16 | 52 | 33196 | 23 | 1 | 58 | 46 | 33032.75 |
| 24 | 1 | 3 | 57 | 33046.25 | 24 | 24 | 17 | 35 | 33192 | 24 | 1 | 59 | 14 | 33032 |
| 25 | 1 | 4 | 53 | 33046.5 | 25 | 24 | 18 | 42 | 33191 | 25 | 1 | 59 | 39 | 33032 |
| 26 | 1 | 7 | 25 | 33046 | 26 | 24 | 19 | 20 | 33188.25 | 26 | 2 | 0 | 19 | 33032 |
| BS2 | 1 | 9 | 3 | 33035 | 27 | 24 | 20 | 21 | 33184.75 | 27 | 2 | 0 | 52 | 33031 |
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| 34 | 1 | 18 | 19 | 33046 | 34 | 24 | 30 | 36 | 33166.5 | 35 | 2 | 5 | 37 | 33029 |
| 35 | 1 | 18 | 58 | 33046 | 35 | 24 | 32 | 20 | 33165.75 | 36 | 2 | 6 | 30 | 33028.25 |
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| 38 | 1 | 21 | 24 | 33046 | 38 | 24 | 33 | 40 | 33160.75 | 39 | 2 | 8 | 49 | 33028 |
| 39 | 1 | 25 | 23 | 33046.5 | 39 | 24 | 34 | 34 | 33158.5 | 40 | 2 | 9 | 26 | 33028 |
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| 43 | 1 | 29 | 52 | 33047.25 | 43 | 24 | 37 | 51 | 33155.25 | 44 | 2 | 12 | 8 | 33026.25 |
| 44 | 1 | 30 | 32 | 33048 | 44 | 24 | 38 | 27 | 33151.25 | 45 | 2 | 12 | 40 | 33026 |
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| 62 | 1 | 47 | 29 | 33049.25 | 63 | 24 | 50 | 22 | 33122 | 63 | 2 | 28 | 48 | 33023 |
| 63 | 1 | 47 | 59 | 33050 | 64 | 24 | 51 | 45 | 33122.25 | 64 | 2 | 29 | 15 | 33022 |
| 64 | 1 | 48 | 23 | 33049 | 65 | 24 | 52 | 29 | 33122.75 | 65 | 2 | 30 | 8 | 33022.75 |
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| 67 | 1 | 50 | 7 | 33049 | 68 | 24 | 54 | 29 | 33121 | 68 | 2 | 31 | 43 | 33022 |
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| 72 | 1 | 52 | 49 | 33047.25 | 72 | 1 | 7 | 44 | 33115 | 73 | 2 | 35 | 1 | 33021 |
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| 76 | 1 | 54 | 53 | 33046.75 | 76 | 1 | 11 | 17 | 33112 | 77 | 2 | 37 | 34 | 33021 |
| 77 | 1 | 55 | 29 | 33045 | 77 | 1 | 11 | 53 | 33110.25 | 78 | 2 | 38 | 9 | 33021 |
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| 79 | 1 | 57 | 2 | 33042.75 | 79 | 1 | 13 | 43 | 33109 | 80 | 2 | 39 | 41 | 33020 |
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| 81 | 1 | 58 | 5 | 33039.25 | 81 | 1 | 15 | 11 | 33107 | 82 | 2 | 40 | 58 | 33020 |
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| 85 | 2 | 1 | 15 | 33036.25 | 85 | 1 | 21 | 24 | 33104 | 86 | 2 | 44 | 47 | 33018.25 |
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| 87 | 2 | 2 | 3 | 33036.75 | 87 | 1 | 23 | 2 | 33102 | BS | 2 | 46 | 52 | 33012 |
| 88 | 2 | 3 | 42 | 33036 | 88 | 1 | 23 | 34 | 33101.75 | 88 | 2 | 48 | 50 | 33016 |
| 89 | 2 | 4 | 11 | 33034.25 | 89 | 1 | 24 | 2 | 33100 | 89 | 2 | 49 | 29 | 33016.25 |
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| 91 | 2 | 5 | 18 | 33033 | 91 | 1 | 25 | 33 | 33098 | 91 | 2 | 50 | 46 | 33016 |
| 92 | 2 | 5 | 49 | 33034 | 92 | 1 | 27 | 45 | 33097 | 92 | 2 | 51 | 26 | 33016 |
| 93 | 2 | 6 | 13 | 33032 | 93 | 1 | 28 | 22 | 33096 | 93 | 2 | 52 | 12 | 33016 |
| BS4 | 2 | 8 | 50 | 33024 | 94 | 1 | 29 | 21 | 33096 | 94 | 2 | 52 | 45 | 33015 |
| 94 | 2 | 11 | 17 | 33031.5 | 95 | 1 | 30 | 28 | 33095 | 95 | 2 | 53 | 11 | 33015 |
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| 96 | 2 | 12 | 14 | 33031 | 96 | 1 | 34 | 11 | 33094 | 97 | 2 | 56 | 54 | 33016 |
| 97 | 2 | 13 | 4 | 33029.75 | 97 | 1 | 34 | 46 | 33093 | 98 | 2 | 58 | 3 | 33015.75 |
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| 104 | 2 | 17 | 15 | 33036 | BS5 | 1 | 49 | 11 | 33023 | 105 | 3 | 2 | 18 | 33015.25 |
| 105 | 2 | 18 | 4 | 33037 | BS6 | 3 | 29 | 14 | 33032 | 106 | 3 | 2 | 45 | 33016 |
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| 110 | 2 | 21 | 44 | 33039 | 107 | 3 | 34 | 1 | 33084 | 111 | 3 | 5 | 24 | 33016 |
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| 119 | 2 | 26 | 49 | 33033 | 116 | 3 | 39 | 10 | 33076 | 120 | 3 | 10 | 28 | 33014.25 |
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| 122 | 2 | 29 | 14 | 33031 | 119 | 3 | 41 | 1 | 33073.75 | 123 | 3 | 12 | 26 | 33013.5 |
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| 124 | 2 | 31 | 10 | 33030.75 | 121 | 3 | 42 | 45 | 33072.25 | 125 | 3 | 13 | 38 | 33013.25 |
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| 139 | 2 | 43 | 20 | 33024.75 | 136 | 3 | 50 | 24 | 33062.5 | 139 | 3 | 24 | 27 | 33011 |
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| 141 | 2 | 44 | 53 | 33025 | 138 | 3 | 51 | 35 | 33060 | 141 | 3 | 25 | 23 | 33010 |
| 142 | 2 | 45 | 21 | 33025 | 139 | 3 | 51 | 49 | 33059 | 142 | 3 | 25 | 49 | 33010 |
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| 149 | 2 | 50 | 0 | 33014 | 146 | 3 | 55 | 18 | 33056.75 | 149 | 3 | 28 | 47 | 33009.25 |
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| 156 | 2 | 55 | 30 | 32996.75 | BS7 | 4 | 0 | 42 | 33017 | 157 | 3 | 33 | 18 | 33009 |
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| 161 | 3 | 0 | 16 | 32982.25 | 158 | 4 | 4 | 52 | 33051.75 | 162 | 3 | 35 | 46 | 33008.5 |
| 162 | 3 | 1 | 58 | 32981 | 159 | 4 | 5 | 14 | 33052 | 163 | 3 | 36 | 35 | 33009 |
| 163 | 3 | 4 | 24 | 32976.75 | 160 | 4 | 5 | 50 | 33052.5 | 164 | 3 | 37 | 1 | 33009 |
| 164 | 3 | 5 | 15 | 32977.75 | 161 | 4 | 6 | 35 | 33052.75 | 165 | 3 | 37 | 47 | 33008.5 |
| 165 | 3 | 5 | 43 | 32976.75 | 162 | 4 | 7 | 20 | 33052.5 | 166 | 3 | 38 | 18 | 33008.75 |
| 166 | 3 | 6 | 58 | 32976.75 | 163 | 4 | 7 | 58 | 33053 | 167 | 3 | 39 | 3 | 33008 |
| 167 | 3 | 7 | 44 | 32976.25 | 164 | 4 | 8 | 20 | 33052 | 168 | 3 | 39 | 25 | 33008 |
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| 171 | 3 | 14 | 25 | 32979.5 | 169 | 4 | 12 | 1 | 33050.5 | 173 | 3 | 43 | 50 | 33006 |
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| 173 | 3 | 16 | 46 | 32979 | 171 | 4 | 13 | 31 | 33049.5 | 175 | 3 | 45 | 16 | 33006 |
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| 175 | 3 | 17 | 59 | 32983 | 173 | 4 | 14 | 59 | 33049.25 | 177 | 3 | 46 | 19 | 33006 |
| 176 | 3 | 19 | 6 | 32980.75 | 174 | 4 | 15 | 42 | 33048 | 178 | 3 | 47 | 18 | 33006 |
| 177 | 3 | 19 | 37 | 32987 | 175 | 4 | 16 | 41 | 33048 | 179 | 3 | 47 | 38 | 33005 |
| 178 | 3 | 20 | 14 | 32990 | 176 | 4 | 17 | 28 | 33047.25 | BS | 3 | 48 | 52 | 33012 |
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| 181 | 3 | 21 | 52 | 32995 | 179 | 4 | 19 | 25 | 33047.75 | 182 | 3 | 51 | 14 | 33005.25 |
| 182 | 3 | 22 | 59 | 32995.75 | 180 | 4 | 19 | 58 | 33044.75 | 183 | 3 | 52 | 8 | 33004.75 |
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| 186 | 3 | 26 | 41 | 33003 | 184 | 4 | 22 | 17 | 33043.75 | 187 | 3 | 54 | 12 | 33004 |
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| 188 | 3 | 27 | 42 | 33008.25 | 186 | 4 | 23 | 38 | 33043 | 189 | 3 | 55 | 3 | 33002.75 |
| 189 | 3 | 28 | 22 | 33010 | 187 | 4 | 24 | 24 | 33042.25 | 190 | 3 | 55 | 28 | 33003 |
| 190 | 3 | 29 | 34 | 33012 | 188 | 4 | 24 | 35 | 33043 | 191 | 3 | 56 | 1 | 33003 |
| 191 | 3 | 31 | 25 | 33013.25 | 189 | 4 | 25 | 49 | 33041.75 | 192 | 3 | 56 | 23 | 33003 |
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| 193 | 3 | 33 | 4 | 33016.25 | 191 | 4 | 26 | 57 | 33041.25 | 194 | 3 | 57 | 34 | 33002.75 |
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| 204 | 3 | 39 | 24 | 33023 | 201 | 4 | 36 | 11 | 33038 | 205 | 4 | 4 | 20 | 32999 |
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| 206 | 3 | 40 | 21 | 33023.25 | 203 | 4 | 37 | 3 | 33038.75 | 207 | 4 | 5 | 48 | 32998 |
| BS7 | 3 | 42 | 2 | 33023 | 204 | 4 | 37 | 53 | 33039.75 | 208 | 4 | 6 | 23 | 32998 |
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| 206 | 19 | 39 | 31 | 33010 | 206 | 4 | 39 | 22 | 33037.5 | 210 | 4 | 7 | 21 | 32998 |
| 207 | 19 | 40 | 0 | 33009 | 207 | 4 | 40 | 3 | 33037.25 | 211 | 4 | 8 | 33 | 32997 |
| 208 | 19 | 41 | 8 | 33009.75 | 208 | 4 | 40 | 47 | 33036.5 | 212 | 4 | 9 | 5 | 32997.25 |
| 209 | 19 | 41 | 46 | 33009 | 209 | 4 | 41 | 44 | 33037.5 | 213 | 4 | 9 | 28 | 32997.75 |
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| 211 | 19 | 43 | 2 | 33010 | 211 | 4 | 43 | 19 | 33037.5 | 215 | 4 | 10 | 28 | 32996 |
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| 213 | 19 | 44 | 22 | 33009.5 | 213 | 4 | 44 | 48 | 33037 | 217 | 4 | 11 | 46 | 32996 |
| 214 | 19 | 46 | 4 | 33009 | 214 | 4 | 45 | 12 | 33035.5 | 218 | 4 | 12 | 18 | 32995 |
| 215 | 19 | 46 | 27 | 33010 | 215 | 4 | 45 | 59 | 33036 | 219 | 4 | 12 | 46 | 32995 |
| 216 | 19 | 46 | 56 | 33009 | 216 | 4 | 47 | 32 | 33036.5 | 220 | 4 | 13 | 35 | 32994.75 |
| 217 | 19 | 47 | 37 | 33009 | 217 | 4 | 48 | 9 | 33036 | 221 | 4 | 13 | 54 | 32994.75 |
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| 221 | 19 | 49 | 17 | 33009 | 221 | 4 | 51 | 25 | 33034.5 | 225 | 4 | 16 | 13 | 32994 |

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| 222 | 19 | 49 | 58 | 33009 | 222 | 4 | 51 | 54 | 33033.5 | 226 | 4 | 16 | 38 | 32994 |
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| | | | | | 428 | 23 | 8 | 38 | 33016 | 431 | 22 | 43 | 14 | 33052 |
| | | | | | 429 | 23 | 9 | 46 | 33016 | 432 | 22 | 45 | 2 | 33047.25 |
| | | | | | 430 | 23 | 10 | 6 | 33017 | 433 | 22 | 45 | 30 | 33040 |
| | | | | | BS14 | 23 | 11 | 42 | 33036 | 434 | 22 | 46 | 32 | 33047 |
| | | | | | 431 | 23 | 13 | 22 | 33016.75 | 435 | 22 | 47 | 2 | 33036.25 |
| | | | | | 432 | 23 | 14 | 32 | 33016.5 | 436 | 22 | 47 | 31 | 33047 |
| | | | | | 433 | 23 | 15 | 22 | 33016.25 | 437 | 22 | 48 | 0 | 33035 |
| | | | | | 434 | 23 | 15 | 49 | 33015.75 | 438 | 22 | 48 | 28 | 33030.75 |
| | | | | | 435 | 23 | 16 | 25 | 33016 | 439 | 22 | 49 | 41 | 32919.75 |
| | | | | | 436 | 23 | 17 | 5 | 33014.25 | 440 | 22 | 50 | 26 | 32922 |
| | | | | | 437 | 23 | 17 | 58 | 33014.5 | 441 | 22 | 50 | 55 | 32913.5 |
| | | | | | 438 | 23 | 19 | 11 | 33013 | 442 | 22 | 51 | 32 | 32904.5 |
| | | | | | 439 | 23 | 19 | 42 | 33012 | 443 | 22 | 52 | 50 | 32890.25 |
| | | | | | 440 | 23 | 20 | 21 | 33011.25 | 444 | 22 | 53 | 42 | 32903.25 |
| | | | | | 441 | 23 | 21 | 0 | 33012 | 445 | 22 | 54 | 32 | 32900.5 |
| | | | | | 442 | 23 | 21 | 38 | 33013 | 446 | 22 | 56 | 15 | 32881.75 |
| | | | | | 443 | 23 | 22 | 30 | 33011 | 447 | 22 | 57 | 14 | 32869.25 |
| | | | | | 444 | 23 | 23 | 12 | 33011 | 448 | 22 | 58 | 5 | 32870 |
| | | | | | 445 | 23 | 23 | 34 | 33008.75 | 449 | 22 | 58 | 56 | 32850.25 |
| | | | | | 446 | 23 | 24 | 31 | 33005 | 450 | 23 | 1 | 50 | 32848.25 |
| | | | | | 447 | 23 | 25 | 43 | 33000 | BS | 23 | 3 | 15 | 33038 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 448 | 23 | 26 | 48 | 32999 | | | | | |
| | | | | | 449 | 23 | 27 | 31 | 32998 | | | | | |
| | | | | | 450 | 23 | 28 | 30 | 32998.5 | | | | | |
| | | | | | 451 | 23 | 29 | 44 | 32994.5 | | | | | |
| | | | | | 452 | 23 | 31 | 6 | 32991 | | | | | |
| | | | | | 453 | 23 | 31 | 52 | 32987.25 | | | | | |
| | | | | | 454 | 23 | 32 | 43 | 32985.75 | | | | | |
| | | | | | 455 | 23 | 33 | 27 | 32984.5 | | | | | |
| | | | | | 456 | 23 | 34 | 0 | 32980 | | | | | |
| | | | | | 457 | 23 | 36 | 20 | 32983 | | | | | |
| | | | | | 458 | 23 | 36 | 52 | 32977 | | | | | |
| | | | | | 459 | 23 | 37 | 47 | 32978 | | | | | |
| | | | | | BS15 | 23 | 41 | 15 | 33035 | | | | | |
| | | | | | BS16 | 24 | 21 | 6 | 33034 | | | | | |
| | | | | | 460 | 24 | 23 | 0 | 32972 | | | | | |
| | | | | | 461 | 24 | 24 | 33 | 32969.5 | | | | | |
| | | | | | 462 | 24 | 29 | 14 | 32969 | | | | | |
| | | | | | 463 | 24 | 31 | 2 | 32969 | | | | | |
| | | | | | 464 | 24 | 34 | 27 | 32969 | | | | | |
| | | | | | 465 | 24 | 38 | 7 | 32970 | | | | | |
| | | | | | 466 | 24 | 39 | 30 | 32971.5 | | | | | |
| | | | | | BS17 | 24 | 41 | 29 | 33030 | | | | | |
| | | | | | BS18 | 1 | 57 | 52 | 33022 | | | | | |
| | | | | | 466 | 1 | 59 | 18 | 32958 | | | | | |
| | | | | | 467 | 1 | 59 | 55 | 32958.75 | | | | | |
| | | | | | 468 | 2 | 0 | 22 | 32963 | | | | | |
| | | | | | 469 | 2 | 1 | 3 | 32969 | | | | | |
| | | | | | 470 | 2 | 1 | 46 | 32974 | | | | | |
| | | | | | 471 | 2 | 2 | 12 | 32977 | | | | | |
| | | | | | 472 | 2 | 2 | 45 | 32978.75 | | | | | |
| | | | | | 473 | 2 | 3 | 11 | 32983 | | | | | |
| | | | | | 474 | 2 | 4 | 1 | 32986.75 | | | | | |
| | | | | | 475 | 2 | 4 | 33 | 32993.25 | | | | | |
| | | | | | 476 | 2 | 5 | 43 | 32999 | | | | | |
| | | | | | 477 | 2 | 6 | 19 | 33000 | | | | | |
| | | | | | 478 | 2 | 7 | 0 | 33003 | | | | | |
| | | | | | 479 | 2 | 7 | 23 | 33007 | | | | | |
| | | | | | 480 | 2 | 8 | 37 | 33013 | | | | | |
| | | | | | 481 | 2 | 9 | 4 | 33015 | | | | | |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 482 | 2 | 9 | 28 | 33017.75 | | | | | |
| | | | | | 483 | 2 | 11 | 2 | 33020 | | | | | |
| | | | | | 484 | 2 | 11 | 23 | 33023 | | | | | |
| | | | | | 485 | 2 | 12 | 9 | 33024.25 | | | | | |
| | | | | | 486 | 2 | 12 | 58 | 33024.25 | | | | | |
| | | | | | 487 | 2 | 13 | 27 | 33024.75 | | | | | |
| | | | | | 488 | 2 | 14 | 3 | 33023.5 | | | | | |
| | | | | | 489 | 2 | 15 | 3 | 33026.75 | | | | | |
| | | | | | 490 | 2 | 15 | 25 | 33025.75 | | | | | |
| | | | | | 491 | 2 | 16 | 19 | 33027 | | | | | |
| | | | | | 492 | 2 | 17 | 1 | 33023.75 | | | | | |
| | | | | | 493 | 2 | 17 | 34 | 33024 | | | | | |
| | | | | | 494 | 2 | 18 | 12 | 33022 | | | | | |
| | | | | | 495 | 2 | 18 | 56 | 33022.75 | | | | | |
| | | | | | 496 | 2 | 20 | 2 | 33022 | | | | | |
| | | | | | 497 | 2 | 20 | 35 | 33020.25 | | | | | |
| | | | | | 498 | 2 | 20 | 57 | 33020.25 | | | | | |
| | | | | | 499 | 2 | 21 | 53 | 33019 | | | | | |
| | | | | | 500 | 2 | 22 | 21 | 33019 | | | | | |
| | | | | | 501 | 2 | 23 | 29 | 33017.25 | | | | | |
| | | | | | 502 | 2 | 24 | 0 | 33017 | | | | | |
| | | | | | 503 | 2 | 24 | 50 | 33016.5 | | | | | |
| | | | | | 504 | 2 | 25 | 18 | 33015.75 | | | | | |
| | | | | | 505 | 2 | 25 | 40 | 33012.75 | | | | | |
| | | | | | 506 | 2 | 26 | 11 | 33013 | | | | | |
| | | | | | 507 | 2 | 26 | 45 | 33012.75 | | | | | |
| | | | | | 508 | 2 | 27 | 30 | 33015 | | | | | |
| | | | | | 509 | 2 | 27 | 49 | 33010.5 | | | | | |
| | | | | | 510 | 2 | 28 | 17 | 33010 | | | | | |
| | | | | | BS19 | 2 | 29 | 14 | 33024 | | | | | |
| | | | | | 511 | 2 | 30 | 18 | 33010 | | | | | |
| | | | | | 512 | 2 | 30 | 39 | 33010 | | | | | |
| | | | | | 513 | 2 | 31 | 9 | 33009 | | | | | |
| | | | | | 514 | 2 | 31 | 44 | 33008.25 | | | | | |
| | | | | | 515 | 2 | 32 | 26 | 33010 | | | | | |
| | | | | | 516 | 2 | 33 | 8 | 33008.75 | | | | | |
| | | | | | 517 | 2 | 33 | 33 | 33011 | | | | | |
| | | | | | 518 | 2 | 34 | 9 | 33036 | | | | | |
| | | | | | BS20 | 2 | 34 | 59 | 33023 | | | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | BS21 | 3 | 34 | 44 | 33022 | | | | | |
| | | | | | 518 | 3 | 37 | 9 | 33002 | | | | | |
| | | | | | 519 | 3 | 37 | 41 | 33002.5 | | | | | |
| | | | | | 520 | 3 | 38 | 33 | 33002 | | | | | |
| | | | | | 521 | 3 | 38 | 54 | 33001 | | | | | |
| | | | | | 522 | 3 | 39 | 31 | 33001.25 | | | | | |
| | | | | | 523 | 3 | 40 | 22 | 33001 | | | | | |
| | | | | | 524 | 3 | 41 | 28 | 33000 | | | | | |
| | | | | | 525 | 3 | 42 | 11 | 33001.5 | | | | | |
| | | | | | 526 | 3 | 43 | 18 | 33001.75 | | | | | |
| | | | | | 527 | 3 | 43 | 40 | 33000.25 | | | | | |
| | | | | | 528 | 3 | 44 | 33 | 33000.25 | | | | | |
| | | | | | 529 | 3 | 45 | 35 | 33000 | | | | | |
| | | | | | 530 | 3 | 46 | 49 | 32999 | | | | | |
| | | | | | 531 | 3 | 47 | 49 | 32999.75 | | | | | |
| | | | | | 532 | 3 | 48 | 34 | 32998.25 | | | | | |
| | | | | | 533 | 3 | 49 | 47 | 32998 | | | | | |
| | | | | | 534 | 3 | 50 | 26 | 32997.25 | | | | | |
| | | | | | 535 | 3 | 51 | 16 | 32995.25 | | | | | |
| | | | | | 536 | 3 | 51 | 34 | 32994.25 | | | | | |
| | | | | | 537 | 3 | 52 | 4 | 32994.25 | | | | | |
| | | | | | 538 | 3 | 52 | 32 | 32994 | | | | | |
| | | | | | 539 | 3 | 53 | 9 | 32995 | | | | | |
| | | | | | 540 | 3 | 53 | 36 | 32994.25 | | | | | |
| | | | | | 541 | 3 | 53 | 58 | 32995 | | | | | |
| | | | | | 542 | 3 | 54 | 34 | 32994 | | | | | |
| | | | | | 543 | 3 | 55 | 3 | 32994 | | | | | |
| | | | | | 544 | 3 | 55 | 58 | 32995 | | | | | |
| | | | | | 545 | 3 | 56 | 31 | 32994 | | | | | |
| | | | | | 546 | 3 | 57 | 0 | 32993.5 | | | | | |
| | | | | | 547 | 3 | 57 | 29 | 32992.25 | | | | | |
| | | | | | 548 | 3 | 58 | 0 | 32994 | | | | | |
| | | | | | 549 | 3 | 58 | 29 | 32992 | | | | | |
| | | | | | 550 | 3 | 58 | 50 | 32992 | | | | | |
| | | | | | 551 | 3 | 59 | 17 | 32992 | | | | | |
| | | | | | 552 | 4 | 0 | 17 | 32993 | | | | | |
| | | | | | 553 | 4 | 1 | 27 | 32994 | | | | | |
| | | | | | 554 | 4 | 2 | 11 | 32992.75 | | | | | |
| | | | | | 555 | 4 | 2 | 43 | 32992.75 | | | | | |

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| | | | | | 556 | 4 | 3 | 8 | 32992.25 | | | | | |
| | | | | | 557 | 4 | 3 | 47 | 32991.5 | | | | | |
| | | | | | 558 | 4 | 4 | 21 | 32991 | | | | | |
| | | | | | 559 | 4 | 4 | 56 | 32992 | | | | | |
| | | | | | BS22 | 4 | 6 | 2 | 33020 | | | | | |
| | | | | | 560 | 4 | 7 | 34 | 32991.75 | | | | | |
| | | | | | 561 | 4 | 8 | 17 | 32990.5 | | | | | |
| | | | | | 562 | 4 | 8 | 58 | 32990.75 | | | | | |
| | | | | | 563 | 4 | 10 | 41 | 32990 | | | | | |
| | | | | | 564 | 4 | 11 | 18 | 32990 | | | | | |
| | | | | | 565 | 4 | 11 | 46 | 32989 | | | | | |
| | | | | | 566 | 4 | 12 | 15 | 32988.5 | | | | | |
| | | | | | 567 | 4 | 12 | 48 | 32988 | | | | | |
| | | | | | 568 | 4 | 13 | 21 | 32987 | | | | | |
| | | | | | 569 | 4 | 13 | 46 | 32986 | | | | | |
| | | | | | 570 | 4 | 14 | 18 | 32986 | | | | | |
| | | | | | 571 | 4 | 14 | 54 | 32986.5 | | | | | |
| | | | | | 572 | 4 | 15 | 34 | 32985 | | | | | |
| | | | | | 573 | 4 | 16 | 0 | 32985 | | | | | |
| | | | | | 574 | 4 | 16 | 30 | 32984.25 | | | | | |
| | | | | | 575 | 4 | 16 | 52 | 32984.75 | | | | | |
| | | | | | 576 | 4 | 17 | 24 | 32985 | | | | | |
| | | | | | 577 | 4 | 17 | 48 | 32983.75 | | | | | |
| | | | | | 578 | 4 | 18 | 12 | 32983.75 | | | | | |
| | | | | | 579 | 4 | 18 | 38 | 32983 | | | | | |
| | | | | | 580 | 4 | 18 | 57 | 32983 | | | | | |
| | | | | | 581 | 4 | 19 | 22 | 32982 | | | | | |
| | | | | | 582 | 4 | 20 | 12 | 32982.75 | | | | | |
| | | | | | 583 | 4 | 20 | 37 | 32983 | | | | | |
| | | | | | 584 | 4 | 21 | 10 | 32982 | | | | | |
| | | | | | 585 | 4 | 21 | 30 | 32981 | | | | | |
| | | | | | 586 | 4 | 22 | 6 | 32981 | | | | | |
| | | | | | 587 | 4 | 22 | 29 | 32980.75 | | | | | |
| | | | | | BS23 | 4 | 23 | 34 | 33018 | | | | | |
| | | | | | BS24 | 4 | 56 | 10 | 33013 | | | | | |
| | | | | | 587 | 4 | 57 | 37 | 32975.75 | | | | | |
| | | | | | 588 | 4 | 58 | 22 | 32975.25 | | | | | |
| | | | | | 589 | 4 | 59 | 20 | 32975 | | | | | |
| | | | | | 590 | 4 | 59 | 49 | 32974 | | | | | |

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| | | | | | 591 | 5 | 0 | 53 | 32973 | | | | | |
| | | | | | 592 | 5 | 1 | 16 | 32973 | | | | | |
| | | | | | 593 | 5 | 1 | 36 | 32972 | | | | | |
| | | | | | 594 | 5 | 1 | 58 | 32972 | | | | | |
| | | | | | 595 | 5 | 2 | 46 | 32973 | | | | | |
| | | | | | 596 | 5 | 3 | 7 | 32972 | | | | | |
| | | | | | 597 | 5 | 3 | 30 | 32971.5 | | | | | |
| | | | | | 598 | 5 | 4 | 10 | 32970 | | | | | |
| | | | | | 599 | 5 | 4 | 37 | 32970 | | | | | |
| | | | | | 600 | 5 | 5 | 7 | 32969 | | | | | |
| | | | | | 601 | 5 | 5 | 32 | 32969 | | | | | |
| | | | | | 602 | 5 | 5 | 54 | 32969 | | | | | |
| | | | | | 603 | 5 | 6 | 38 | 32970.25 | | | | | |
| | | | | | 604 | 5 | 6 | 57 | 32969 | | | | | |
| | | | | | 605 | 5 | 7 | 27 | 32969 | | | | | |
| | | | | | 606 | 5 | 7 | 55 | 32971.25 | | | | | |
| | | | | | 607 | 5 | 8 | 54 | 32969.75 | | | | | |
| | | | | | 608 | 5 | 9 | 26 | 32970.25 | | | | | |
| | | | | | 609 | 5 | 10 | 27 | 32970 | | | | | |
| | | | | | 610 | 5 | 10 | 48 | 32970.75 | | | | | |
| | | | | | 611 | 5 | 11 | 13 | 32969.5 | | | | | |
| | | | | | 612 | 5 | 11 | 43 | 32968 | | | | | |
| | | | | | 613 | 5 | 12 | 25 | 32968 | | | | | |
| | | | | | 614 | 5 | 12 | 52 | 32970 | | | | | |
| | | | | | 615 | 5 | 13 | 24 | 32971 | | | | | |
| | | | | | 616 | 5 | 13 | 49 | 32970 | | | | | |
| | | | | | 617 | 5 | 14 | 27 | 32970 | | | | | |
| | | | | | 618 | 5 | 15 | 9 | 32970 | | | | | |
| | | | | | 619 | 5 | 15 | 39 | 32970 | | | | | |
| | | | | | 620 | 5 | 16 | 26 | 32968 | | | | | |
| | | | | | 621 | 5 | 17 | 17 | 32968.75 | | | | | |
| | | | | | 622 | 5 | 18 | 8 | 32972.75 | | | | | |
| | | | | | 623 | 5 | 18 | 46 | 32972 | | | | | |
| | | | | | 624 | 5 | 19 | 36 | 32971 | | | | | |
| | | | | | 625 | 5 | 20 | 7 | 32971 | | | | | |
| | | | | | 626 | 5 | 20 | 44 | 32971 | | | | | |
| | | | | | 627 | 5 | 21 | 17 | 32970 | | | | | |
| | | | | | 628 | 5 | 21 | 56 | 32972.75 | | | | | |
| | | | | | 629 | 5 | 23 | 12 | 32973 | | | | | |

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| | | | | | 630 | 5 | 23 | 33 | 32973 | | | | | |
| | | | | | 631 | 5 | 24 | 26 | 32974.75 | | | | | |
| | | | | | 632 | 5 | 25 | 7 | 32977 | | | | | |
| | | | | | 633 | 5 | 25 | 35 | 32977 | | | | | |
| | | | | | 634 | 5 | 25 | 57 | 32977 | | | | | |
| | | | | | 635 | 5 | 26 | 51 | 32978.75 | | | | | |
| | | | | | 636 | 5 | 27 | 21 | 32978 | | | | | |
| | | | | | 637 | 5 | 28 | 3 | 32978 | | | | | |
| | | | | | 638 | 5 | 28 | 38 | 32981 | | | | | |
| | | | | | 639 | 5 | 29 | 0 | 32981 | | | | | |
| | | | | | 640 | 5 | 29 | 29 | 32985 | | | | | |
| | | | | | 641 | 5 | 30 | 8 | 32985 | | | | | |
| | | | | | 642 | 5 | 30 | 29 | 32985 | | | | | |
| | | | | | 643 | 5 | 31 | 18 | 32988 | | | | | |
| | | | | | 644 | 5 | 31 | 55 | 32988 | | | | | |
| | | | | | 645 | 5 | 32 | 24 | 32988.25 | | | | | |
| | | | | | 646 | 5 | 32 | 39 | 32993.75 | | | | | |
| | | | | | 647 | 5 | 33 | 54 | 32996 | | | | | |
| | | | | | 648 | 5 | 35 | 13 | 32998.25 | | | | | |
| | | | | | 649 | 5 | 35 | 43 | 32998 | | | | | |
| | | | | | 650 | 5 | 36 | 21 | 32999 | | | | | |
| | | | | | BS25 | 5 | 39 | 0 | 32912 | | | | | |

# APPENDIX B

## Appendix B: GPR Radargrams

### Location 1: 450 MHz

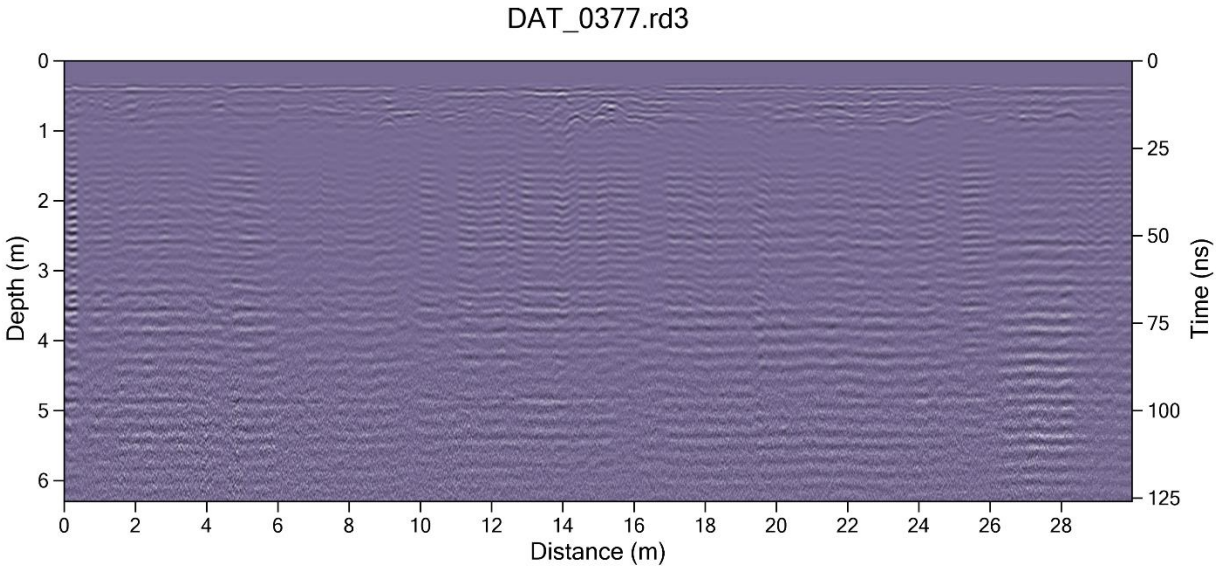


Figure B1: GPR radargram using the 450 MHz antenna along traverse 1

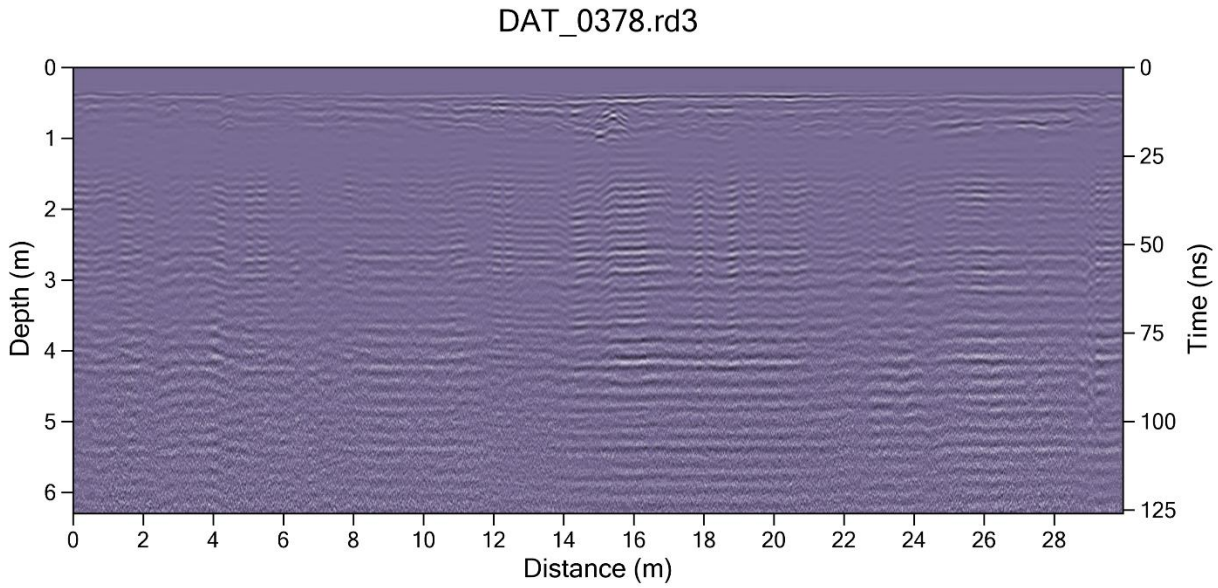


Figure B2: GPR radargram using the 450 MHz antenna along traverse 2

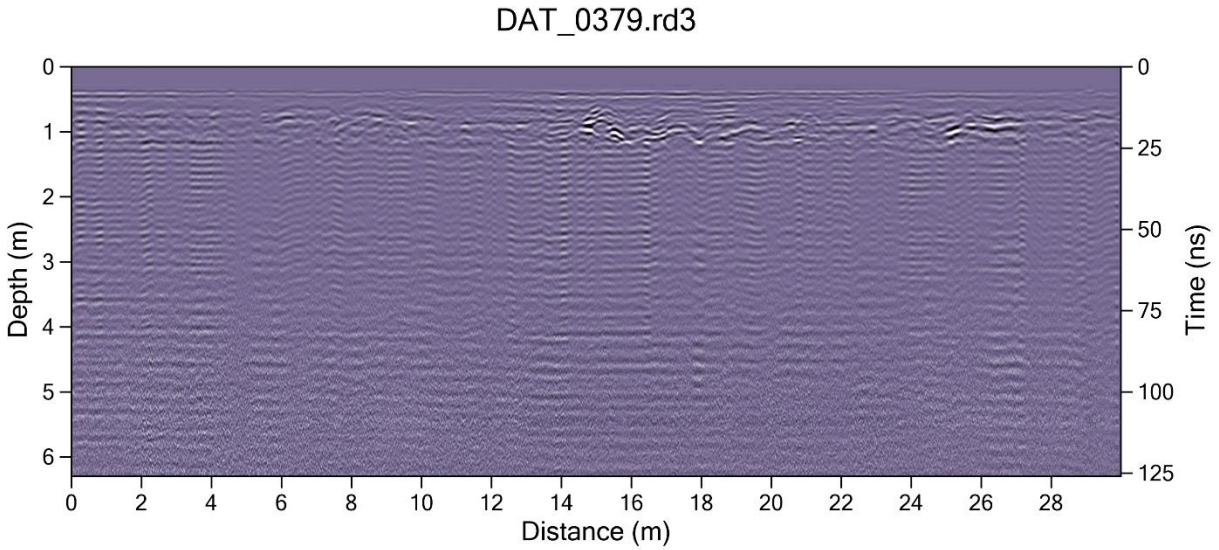


Figure B3: GPR radargram using the 450 MHz antenna along traverse 3

**Location 2: 450MHz**

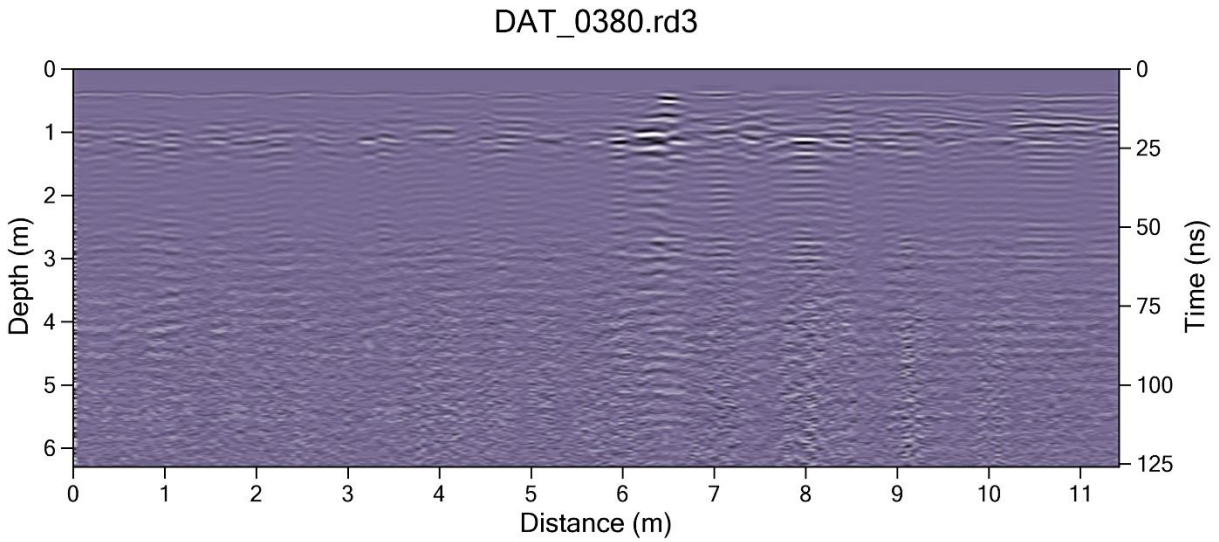


Figure B4: GPR radargram using the 450 MHz antenna along traverse 1

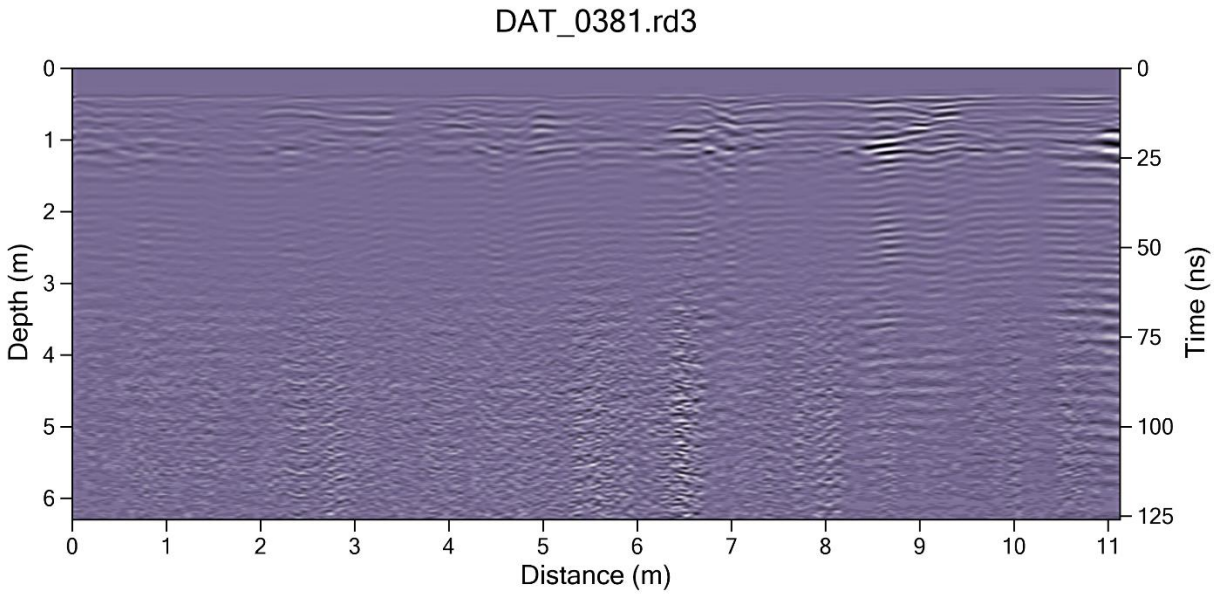


Figure B5: GPR radargram using the 450 MHz antenna along traverse 2

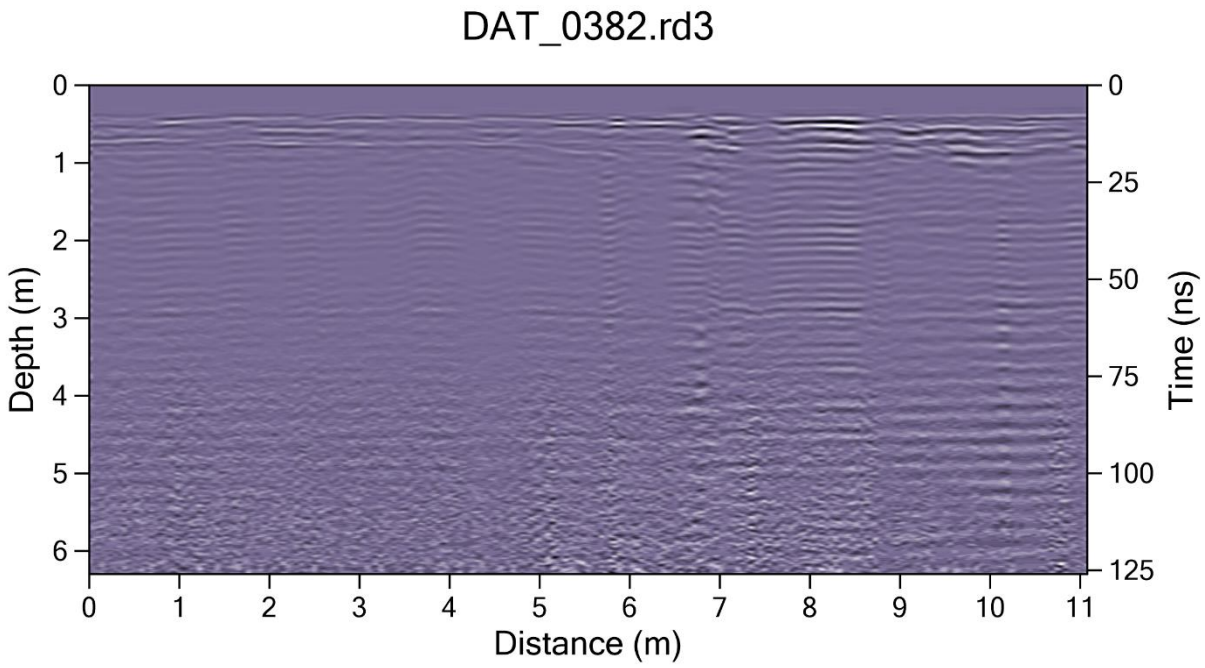


Figure B6: GPR radargram using the 450 MHz antenna along traverse 3

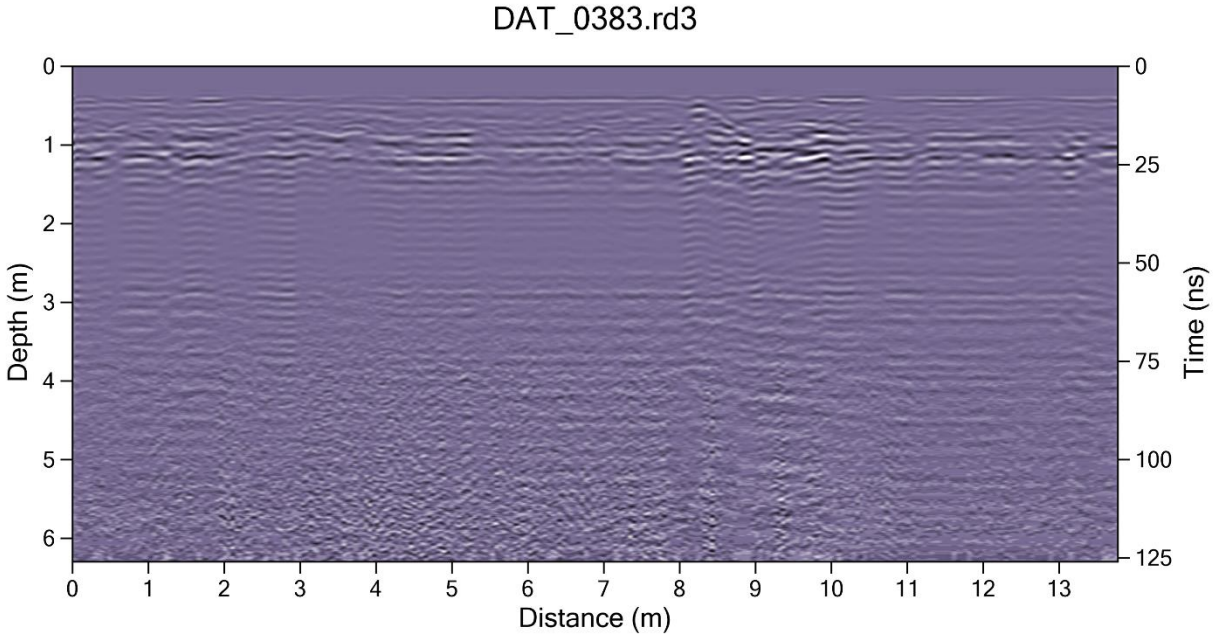


Figure B7: GPR radargram using the 450 MHz antenna along traverse 4

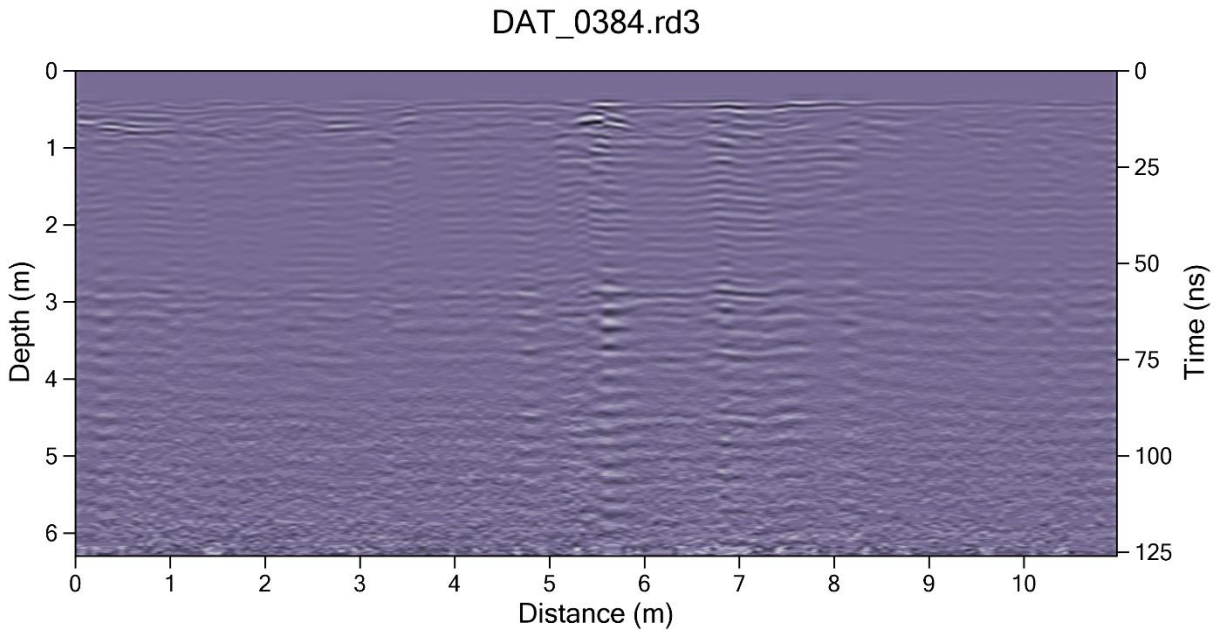


Figure B8: GPR radargram using the 450 MHz antenna along traverse 5

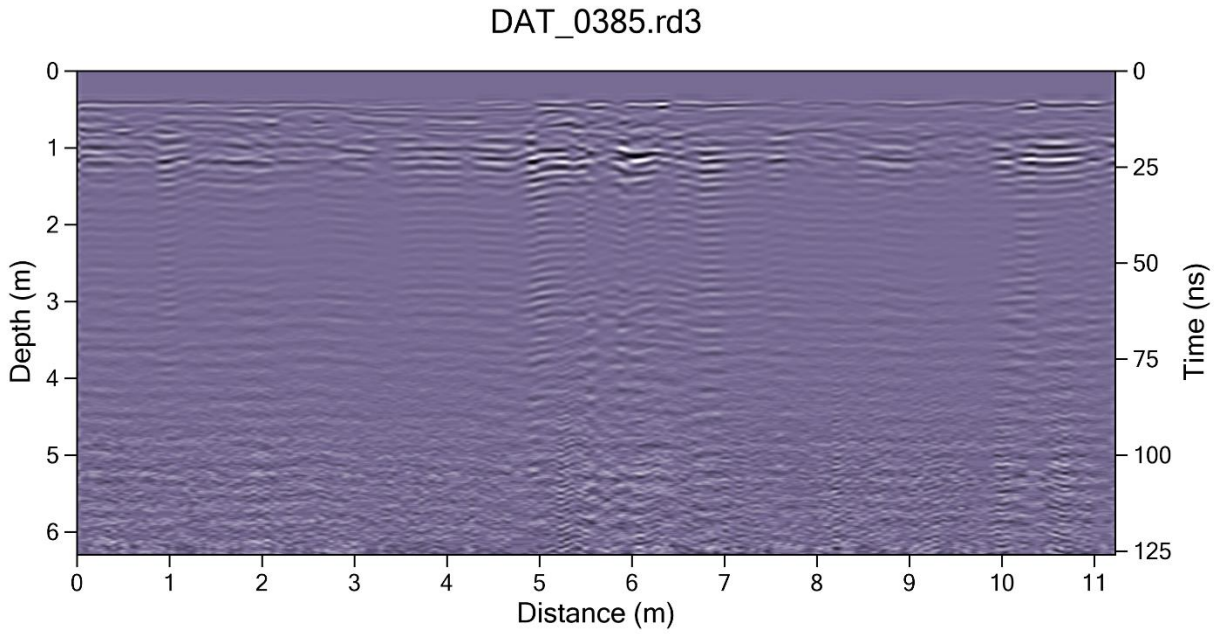


Figure B9: GPR radargram using the 450 MHz antenna along traverse 6

**Location 3: 450MHz**

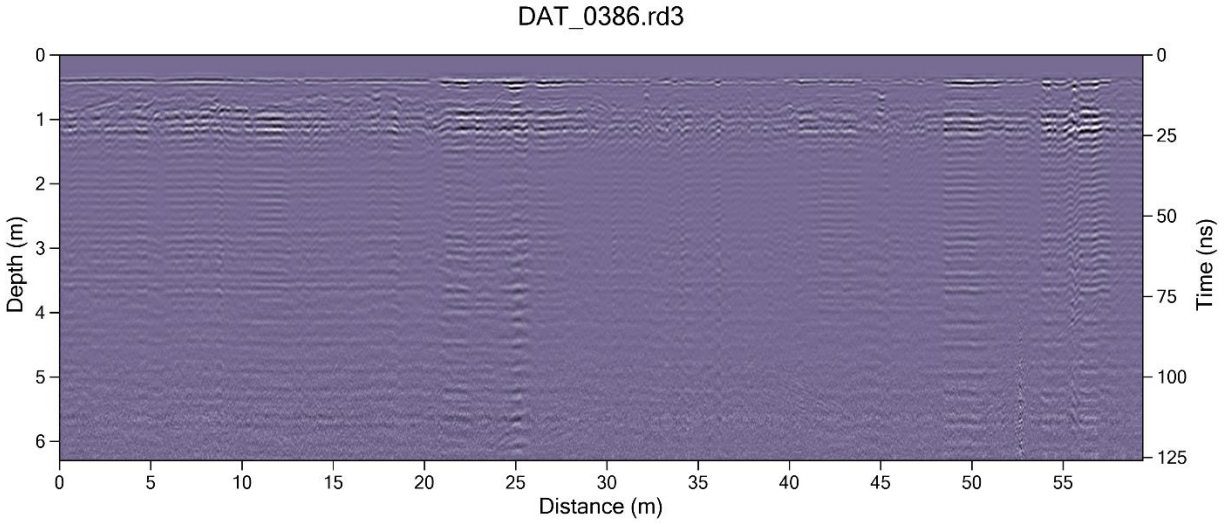


Figure B10: GPR radargram using the 450 MHz antenna along traverse 1

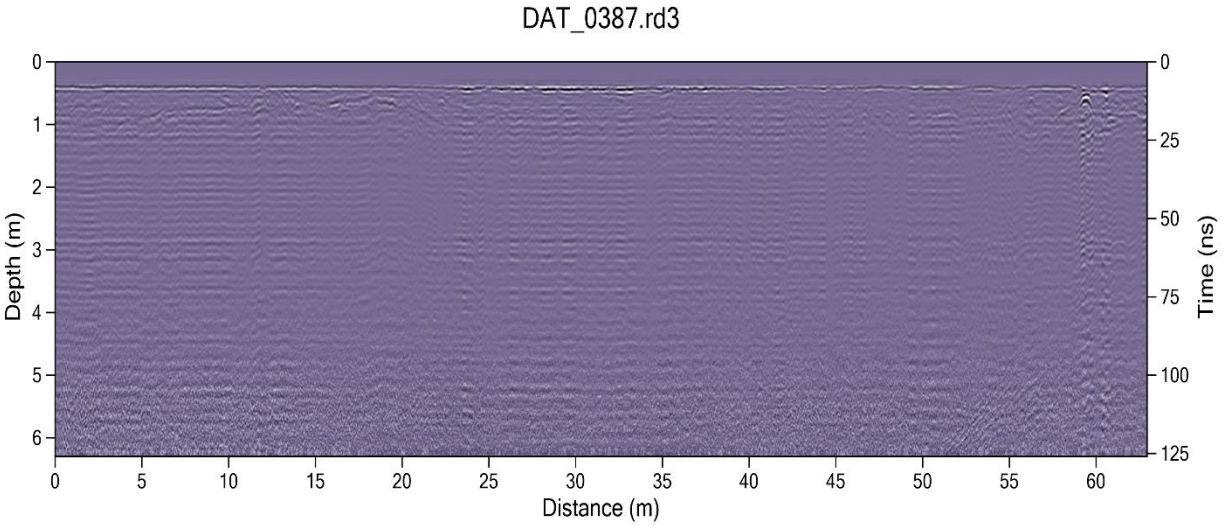


Figure B11: GPR radargram using the 450 MHz antenna along traverse 2

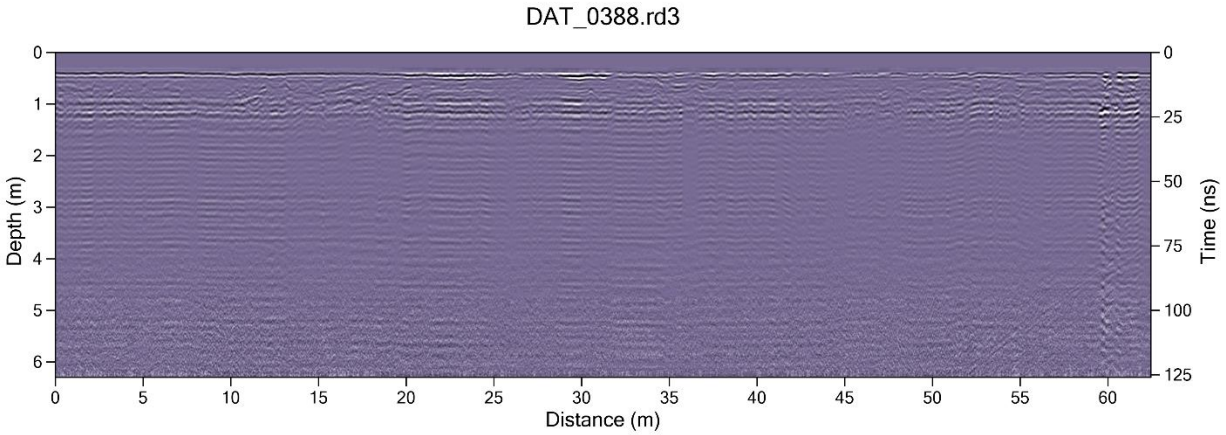


Figure B12: GPR radargram using the 450 MHz antenna along traverse 3

**Location 1: 750MHz**

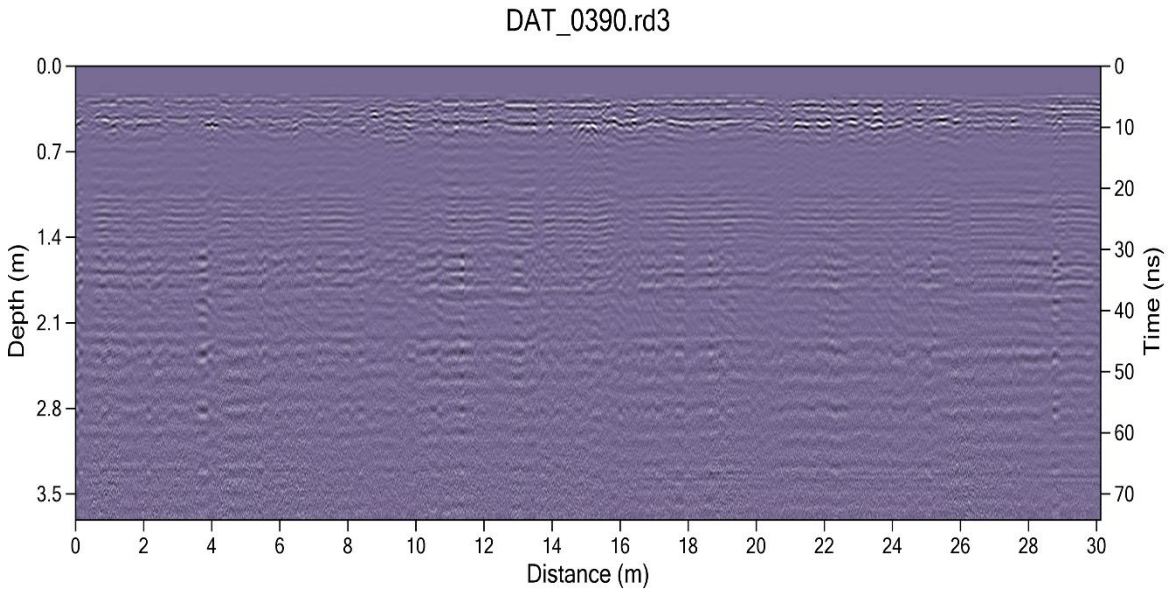


Figure B13: GPR radargram using the 750 MHz antenna along traverse 1

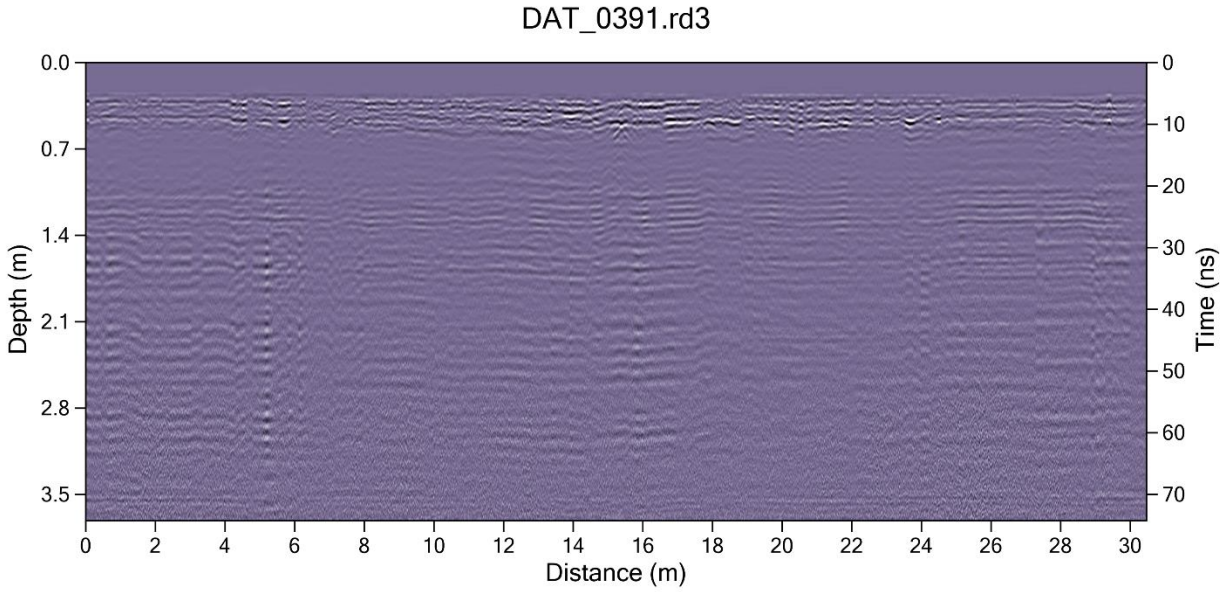


Figure B14: GPR radargram using the 750 MHz antenna along traverse 2

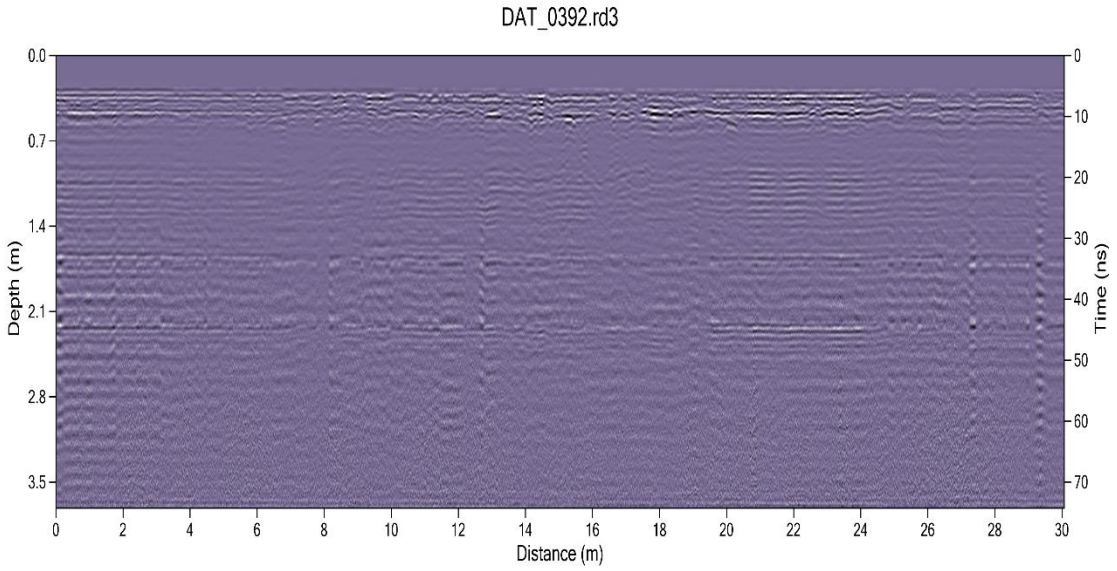


Figure B15: GPR radargram using the 750 MHz antenna along traverse 3

**Location 2: 750MHz**

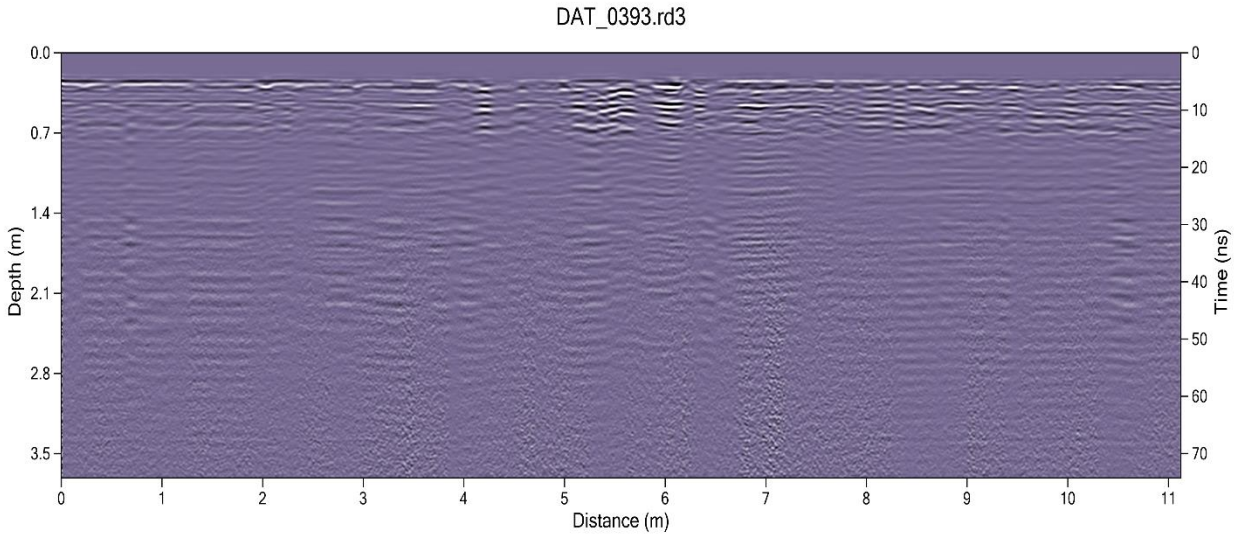


Figure B16: GPR radargram using the 750 MHz antenna along traverse 1

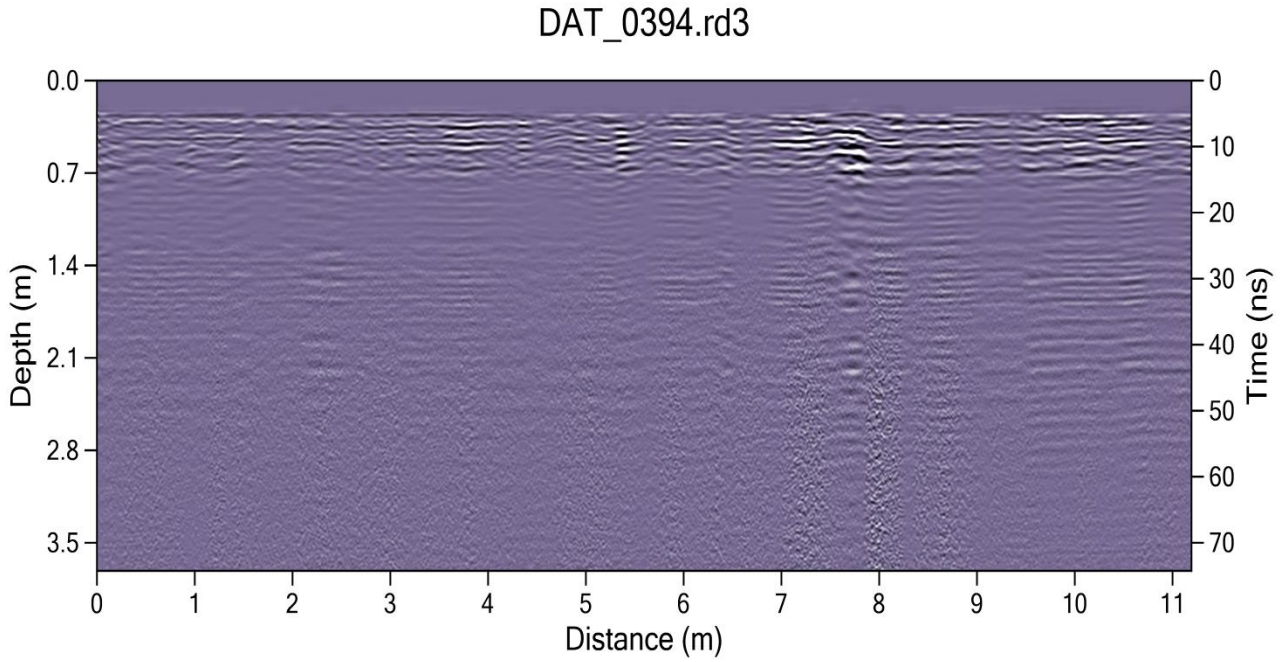


Figure B17: GPR radargram using the 750 MHz antenna along traverse 2

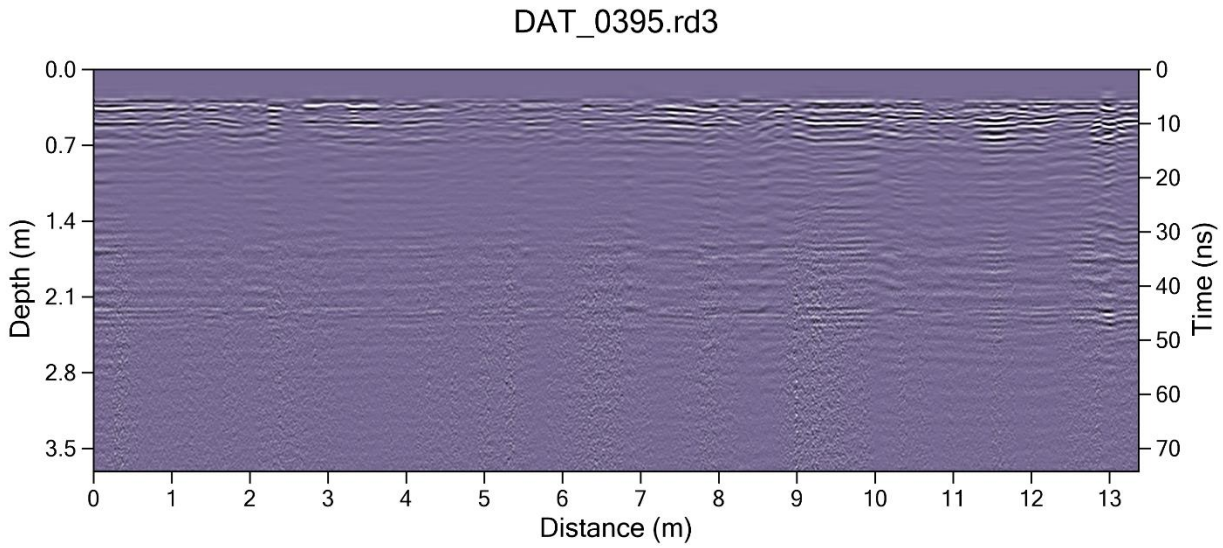


Figure B18: GPR radargram using the 750 MHz antenna along traverse 3

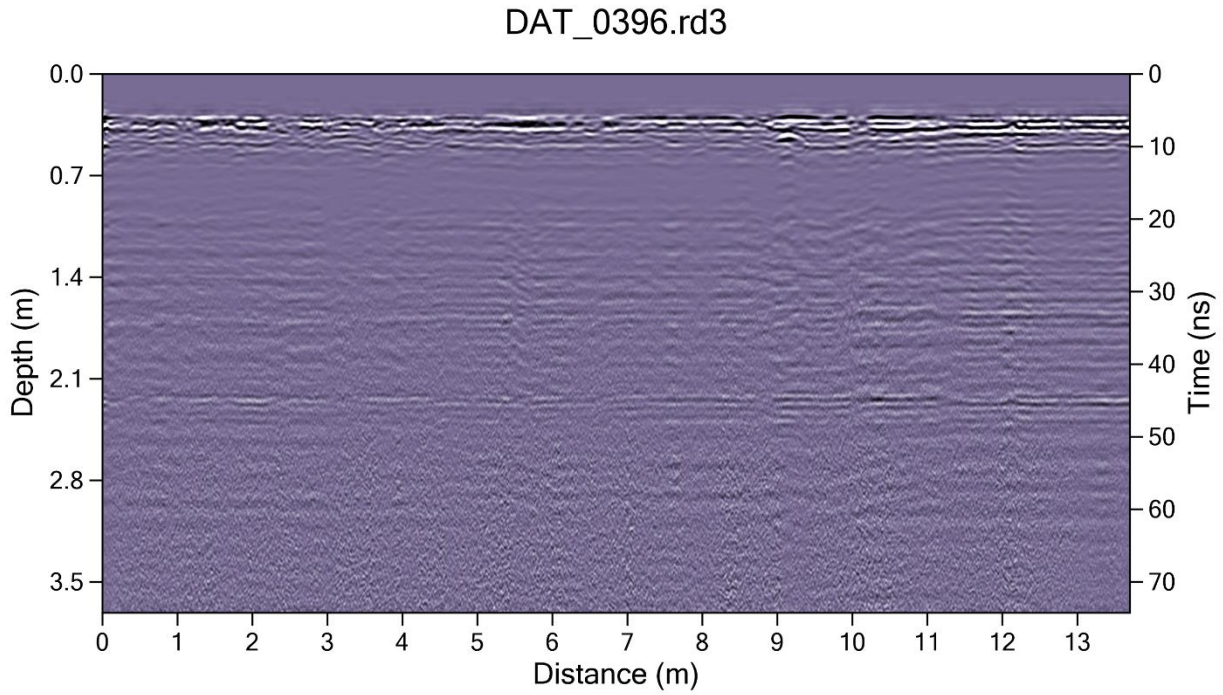


Figure B19: GPR radargram using the 750 MHz antenna along traverse 4

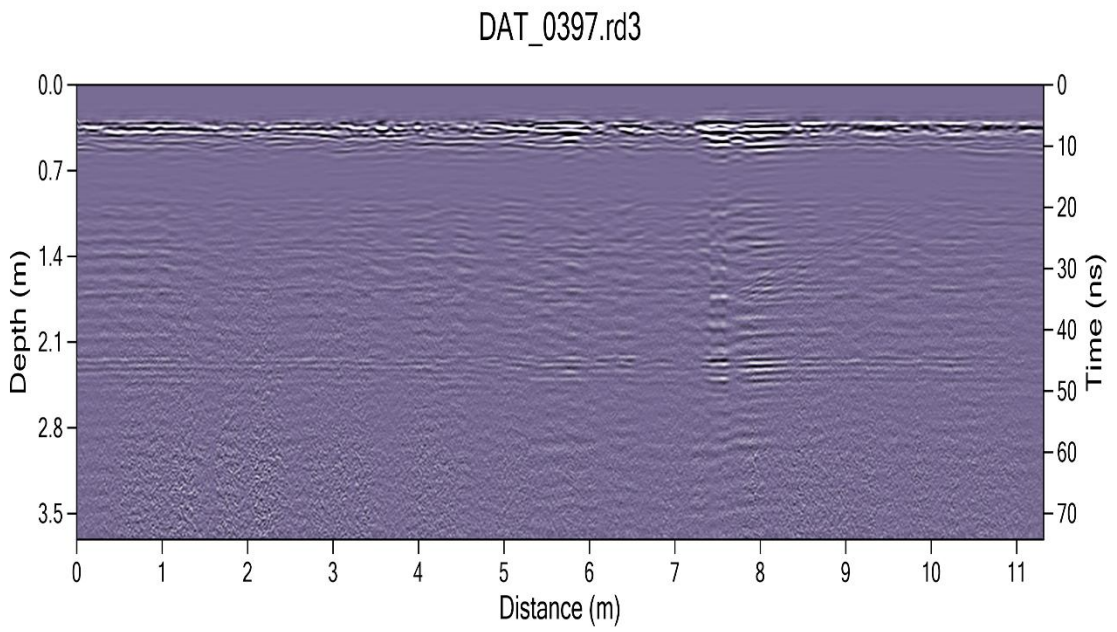


Figure B20: GPR radargram using the 750 MHz antenna along traverse 5

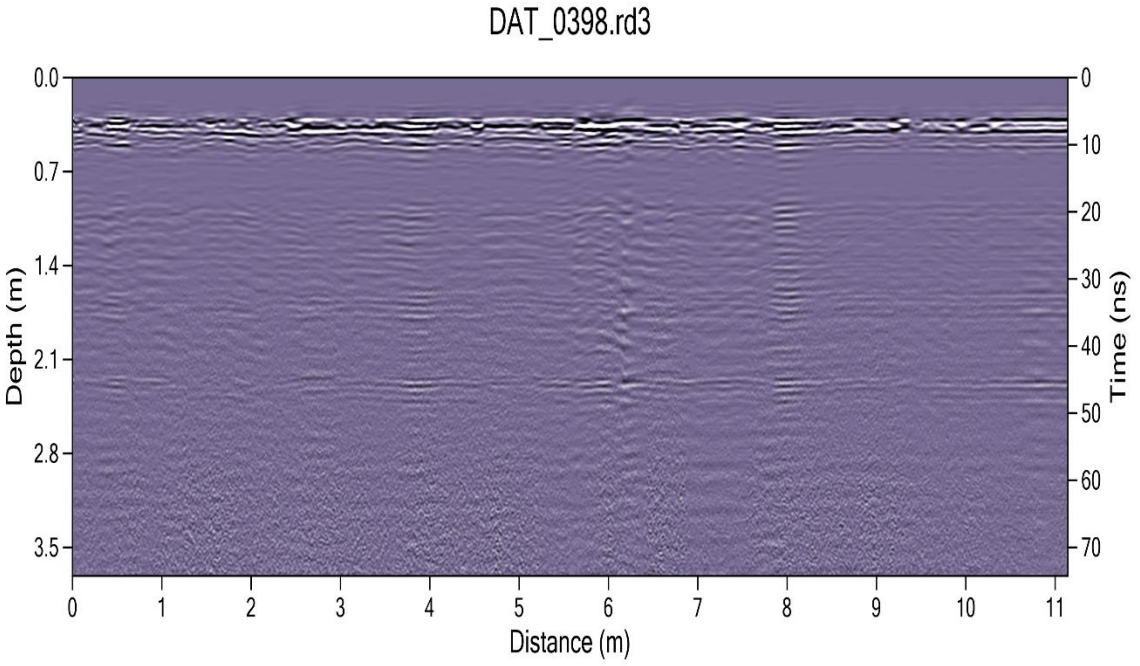


Figure B21: GPR radargram using the 750 MHz antenna along traverse 6

**Location 3: 750MHz**

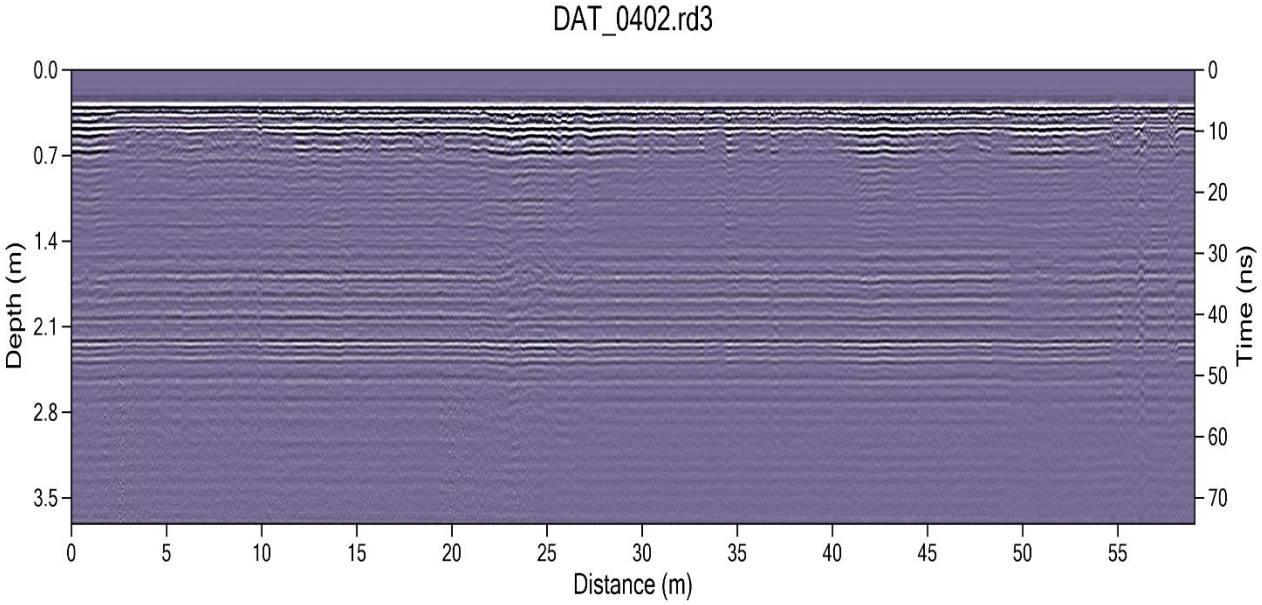


Figure B22: GPR radargram using the 750 MHz antenna along traverse 1

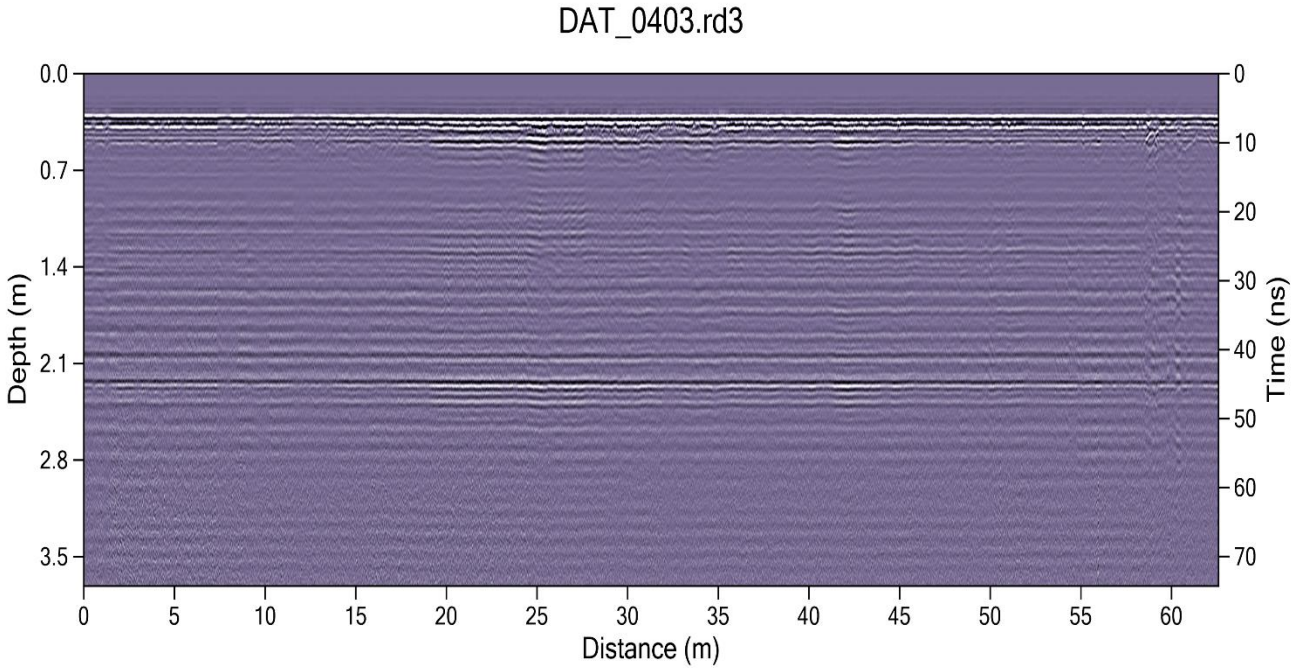


Figure B23: GPR radargram using the 750 MHz antenna along traverse 2

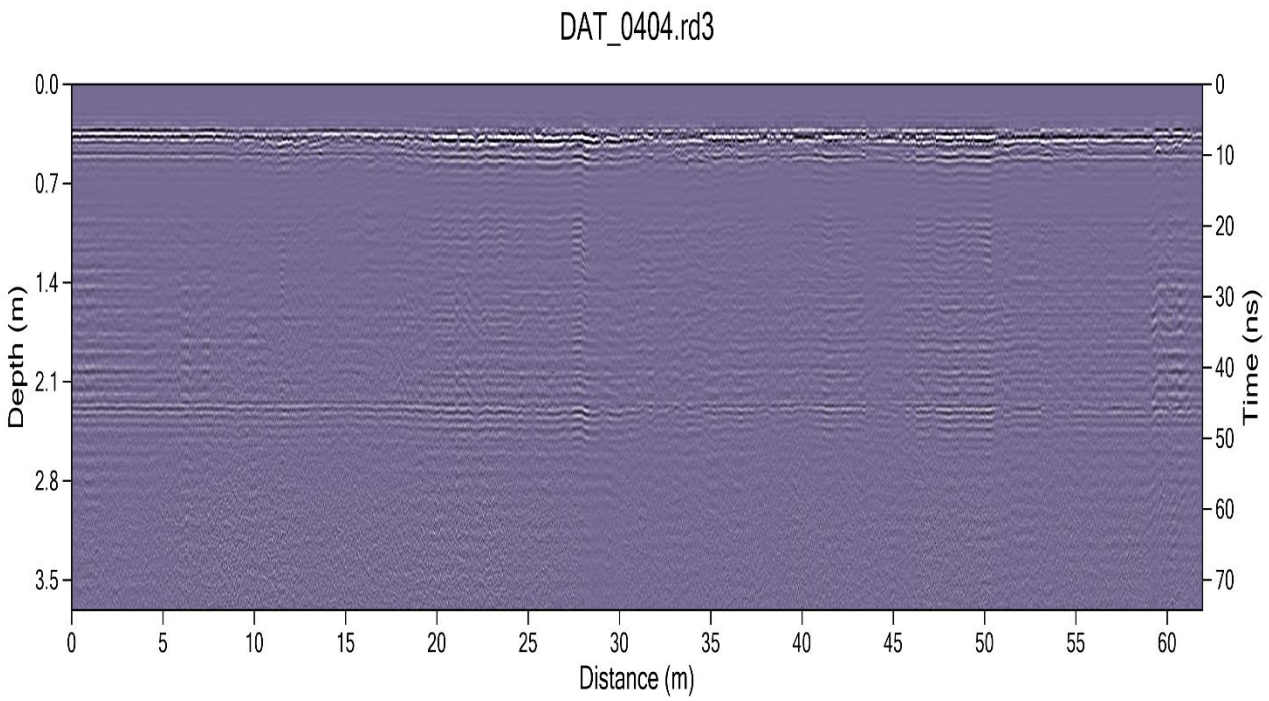


Figure B24: GPR radargram using the 750 MHz antenna along traverse 3