Predicting Improved Near-Surface Detection Methods for Forensic Investigations

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Abstract

The detection of clandestine burials using near surface geophysical methods is a critical challenge in forensic investigations due to the variability of environmental conditions and the complexity of subsurface targets. This thesis seeks to address the challenge by enhancing the understanding and application of these methods, specifically examining the effects of long-term environmental variations on the effectiveness of burial identification. The central research question investigates whether geophysical techniques can consistently and reliably locate buried targets under varying site conditions over extended periods. It further explores the potential for developing criteria for algorithms that rank the suitability of various near surface geophysical methods, raising the question of whether method selection could be delegated to a computer tool or system.

To address the problem, expert opinions were gathered through interviews and scenario-based questionnaires aimed at capturing the implicit knowledge and intuitive practices of experienced practitioners. The insights from these practitioners provided a detailed understanding of the decision-making process currently used in the field. This information was systematically analysed to inform the development of algorithm criteria. The feedback also highlighted common challenges and areas for improvement in applying geophysical methods, ensuring the proposed algorithms are both practical and grounded in real-world experience.

To further understand the problem, a series of surveys were conducted at four variable test sites. One of these sites was revisited repeatedly over a twelve-month period, where different geophysical methods, such as Electrical Resistivity Imaging (ERI) and Ground Penetrating Radar (GPR), were deployed to monitor detectability of simulated clandestine pig burials. Additionally, magnetometry, along with ERI and GPR, was used at all four sites to detect a forensic metal target burial and at one site where simulated clandestine pig burials which had been interred for 28 months. These methods were employed to capture changes in subsurface profiles pre- and post-burial of forensic targets, focusing on how soil moisture and seasonal fluctuations influence detection success.

The results reveal that environmental conditions significantly impact the efficacy of detection methods. ERI consistently detected burials in wetter environments, while GPR and magnetometry showed variable success depending on soil composition and moisture levels. The detectability of burials varied across sites and seasons, emphasising the importance of context-specific approaches. These findings suggest that optimal detection strategies must account for environmental and temporal factors, as detection is highly dependent on the environmental conditions surrounding the burial site. Based on these observations, this study proposes an approach go develop a tool that could provide tailored recommendations for forensic practitioners, thereby enhancing the accuracy and reliability of locating clandestine burials.

The development of algorithm descriptions focused on several critical factors: the nature of the target, burial depth, parent material and soil characteristics, properties being detected, instrument sensitivity, field conditions, and spatial density of measurements. These algorithms described are designed to provide a systematic framework for method selection, ensuring robustness and applicability in diverse field conditions.

This study’s scope was limited to specific environmental conditions and target types, and further research is needed to generalise the findings across broader contexts. Even so, the implications of this study are significant, providing a foundation for more effective forensic investigations and the future development of an adaptive and context-aware detectability prediction tool, as proposed in this thesis. Future work may explore integrating emerging technologies and refining algorithm descriptions for improved accuracy.

In conclusion, this research aims to advance the field of forensic geophysics by demonstrating the critical influence of environmental dynamics on detection methods. It highlights the need for a mechanism that allows surveyors to observe findings directly and take site-specific measurements, thereby enhancing survey practice. Such practices should be universally adopted, and the results and observations of these studies or investigations should be made widely available to the profession, ultimately improving forensic investigation outcomes and influencing policy and practical applications in forensic geophysics.

Declaration

I declare that no portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

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From working part-time to becoming a full-time college lecturer and helping to shape the minds of the future, I also reluctantly had to complete a PGCE as part my contractual obligations which I finished in May 2024, shortly followed by the completion of this PhD in August (viva voce in October and corrections completed in December).

Thankful that this part of my life is over now, and I can enjoy post-PhD and PGCE life. No more degrees for me!

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Abbreviations

AI – artificial intelligence

DL – deep learning

EM - electromagnetic

ERT – electrical resistivity tomography

GHz - gigahertz

GPR – ground penetrating radar

MHz - megahertz

ML – machine learning

NGO – non-governmental organisation

NT - nanotesla

Ω / Ωm - ohm / ohm-meter

UAV – unmanned aerial vehicle

Chapter One

Introduction

1.1 Rationale

It is crucial, during forensic surveys, to locate buried targets accurately and quickly in order to further advance an investigation. Police investigators are often limited by numerous factors in the search for buried targets due to a lack of training or resources (Schultz, 2012). Consequently, forensic archaeologists and geoscientists who have more advanced training and specific skill sets necessary for this type of investigation are regularly employed to contribute to the investigation (Schultz, 2012). One such contribution involves detecting buried human remains and associated forensic evidence using archaeological field methods, for example, conducting near-surface geophysical surveys (France et al., 1992; Mellet, 1992; Strongman, 1992; Davenport, 2001; Schultz et al., 2006; Schultz, 2007, 2008; Ruffell et al., 2009a; Larson et al., 2011; Barone et al., 2016; Dupras et al., 2016).

Most near-surface geophysical methods are non-invasive which means they do not disturb the soil; these methods are favoured in forensic investigations as they reduce the risk of destroying evidence therefore preserving a crime scene (Davenport, 2001; Killam, 2004; Schultz, 2007, 2008; Dupras et al., 2016). The success of near-surface geophysical methods in locating areas of forensic interest, often leading to positive identification of a clandestine burial, has resulted in them being frequently adopted by forensic investigators (Bevan, 1991; France et al., 1992; Owsley, 1995; Miller, 1996; Nobes, 2000; Davenport, 2001; Pye and Croft, 2004; Ruffell and McKinley, 2005; Morgan and Bull, 2007; Schultz, 2007).

However, near-surface detection methods are still considered an emerging discipline, albeit there being a significant recognition of the value of near-surface geophysical methods in locating buried forensic targets (Pringle et al., 2012c). The reason for these detection methods not being used more often in forensic investigations could be due to the lack of understanding by forensic investigators of how the operation of the various systems work and the advantages and disadvantages of each method (Hunter et al., 2013). This is detailed below.

There is a common misunderstanding by non-geoscientists that one method of near-surface detection is applicable to all types of environments during forensic investigations (Davenport, 2001; Pringle et al., 2012c). Both the media portrayal of forensic geophysics and the common parlance of the police gives the impression that Ground Penetrating Radar (GPR) is synonymous with forensic geophysics under all circumstances. For example, changes in substrate (soil type, hydrology, or composition), or environmental conditions (a change from boreal to temperate conditions, or terrain), will require different methods of near-surface detection for the successful identification of a buried target (Pringle et al., 2012a, 2012b, 2012c; Molina et al., 2015, 2016a, 2016b). It is possible to identify the location of a buried target using near-surface geophysical methods where there is a contrast between some physical properties of the buried target and the medium in which it is buried (Barone et al., 2015). The various near-surface geophysical methods record different properties of the soil and therefore identify anomalous behaviour in different ways so should not be considered substitutes for one another (Hunter et al., 2013). Conventionally several different geophysical methods, such as GPR, electrical resistivity and magnetometry are used to map and investigate the sub-surface which can provide a valuable contribution to locating buried targets (Nuzzo et al., 2008; Donnelly and Harrison, 2010).

Even though there is case-based documentation of the location of buried bodies using geophysical methods through controlled research (as discussed in Chapter 2), the presence or non-presence of human remains cannot be validated without excavation because no reliable technique is currently available (Powell, 2004). As discussed by Donnelly and Harrison (2010), choices of near-surface geophysical methods are often made based on personal preference, equipment availability, unguided trial and error and success at a past site. Conducting searches in this way, without prior knowledge of the target, site environment and site history can result in the search being compromised due to poor choice of equipment (Pringle et al., 2012c). This results in loss of time, increased costs and the risk of missing buried targets (Powell, 2004) despite the demonstrable potential of the methods. In order to address this, it is perhaps worth asking whether it might be possible to create a tool which improves how those in the profession decide how to locate buried targets, such as clandestine burials? If so, it is necessary to identify the necessary information required for such a tool to work well by systemising and analysing what is currently done. With the advancements of artificial intelligence (AI) in society (Yijun et al., 2023) and research into how it can be used in geophysics (Yu and Ma, 2021; Yijun et al., 2023; Shakhatova et al., 2024; Singh et al., 2024) there is potential to later improve the proposed tool towards an accurate predictive system which becomes increasingly accurate as it develops and becomes increasingly able to define its own limitations through deep learning (DL) and machine learning (ML).

To ensure the use of near-surface geophysical methods evolves, both qualitative and quantitative user feedback is required (Hunter et al., 2013). Currently there is little evaluation of past work to learn from, therefore a critical review of past work in order to assess what worked, what did not and why must be conducted such as the review conducted by Jordan (2009) in the Northwest of England. As such, there is a requirement for research to be carried out with the aim of quantifying both target and site variables, to observe how the variables alter over time which may affect the optimal conditions for a geophysical method to work (Nuzzo et al., 2008). Simultaneously it is equally important to understand what sub-surface variable has caused a geophysical response, e.g., where there is no buried target found following an excavation from a positive geophysical response. Negative feedback is equally as important as positive feedback to help improve the use of geophysical methods in the search for buried targets. As discussed by Hunter et al. (2013), “in all techniques there is some responsibility on the part of the practitioner to pursue a wider goal in the development of the discipline rather than to treat each scene independently as a ‘one-off’ job”. Barone et al. (2015) suggest that introducing closer interdisciplinary collaborations between the different geo-forensic sub-disciplines will result in more promising protocols to be developed and from this a new awareness of the optimal use of near-surface geophysical methods during forensic investigations (Nuzzo et al., 2008). Which is the overarching aim of this thesis.

1.2 Aims and Objectives

Employing near-surface geophysics for locating forensic targets has proven to be effective. However, the efficacy is partly hindered by insufficient understanding of the decision-making process for selecting the appropriate method or approach. Currently, there is a lack of objective and thorough discussion considering all available options and their respective merits. A review of how decisions are made is necessary, as a rational decision is important in order to get a good result and there are currently some good starting points in experience and theory to be explored further. It is therefore essential that existing experiences are captured adequately, so a standard feedback mechanism can be implemented. As described previously, current decisions on choice of method or approach are not always optimal for the search and there is also a lack of open reporting of failed surveys in the literature which therefore gives a biased view of the effectiveness of surveys. This therefore provides an opportunity to ensure research is conducted to improve the best current practices of choosing near-surface geophysical methods to detect and locate forensic buried targets.

A motivation of this thesis is to improve the detection rate of buried forensic targets by proposing the criteria needed for the design of a computer-based tool in which an algorithm will rank near-surface geophysical methods for suitability by considering the properties of the target and its depositional environment. The aim of this thesis is to consolidate knowledge and current best practice on behalf of the profession, this is supported by the main objectives:

1. to capture existing experience and practice by asking the profession how they currently make decisions by means of a questionnaire to investigate what practitioners do currently, i.e., what surveys they do and how they decide the methods to use.
2. to understand what is already known of the way detection works i.e., the ability of methods to detect and the properties of targets which makes them detectable to each method, in order to predict detectability of given targets in specific locations.
3. to bring the above two elements of ‘expertise’ together by describing the algorithm development that would be needed for the design of a combined system to predict the best way to detect a specific target in a specific environment.

There were anticipated problems and limitations associated with the methodologies that will be later described in this thesis, such as lack of practitioner cooperation, variable method effectiveness, environmental variability, complexity of burial scenarios and resource constraints. However, the anticipated benefits outweigh them, such as enhanced detection success, consistency in method choices, cross-disciplinary collaboration (e.g., between archaeology and forensics) and explicit decision-making processes. In addition to these benefits, it is also an ambition to provide educational value and a potential for algorithm refinement. At present, the choices of detection method to use are not always optimal. This is particularly important when conducting surveys for criminal investigations as it could mean that some surveys fail in locating the target where a different method or approach might have succeeded. Additionally, another aim of the research is to challenge the profession by proposing an approach that summarises the current knowledge and best practice of geophysical methods at the physical properties they detect, as well as current survey practices. The descriptions of the algorithm development presented in this thesis will then be provided to a panel of experts following submission. Their feedback will be solicited to determine if they agree with the proposed algorithms and to gather insights on how these algorithms could be improved to enhance the success of target detection.

1.3 Structure of the thesis

The thesis consists of five components each with a separate chapter. Chapter Two provides a review of the literature which evaluates near-surface detection methods in the search for forensic buried targets, the impact decomposition has on the effectiveness of the methods and the purpose of controlled geophysical research. Furthermore, in this chapter, a supplementary review of the controlled research which scores the methods used was assembled. Chapter Three outlines the methodologies employed to address the aims and objectives of this research. These methodologies include collecting expert opinion through scenario-based questionnaires, conducting case studies across four different environments, and analysing multiperiod geophysical data. Additionally, this chapter proposes the criteria for designing an algorithm(s) that will rank the suitability of near-surface geophysical methods based on the properties of the target and its depositional environment. The results are presented in Chapter Four and are discussed in Chapter Five. Chapter Six draws conclusions based on the findings of the research and makes recommendation for future research.

Chapter Two

Literature Review

2.1 Literature review

During forensic investigations it is important that areas of interest are detected and defined promptly and non-destructively, particularly when the search involves clandestine burials or if a suspect is being held in custody for a limited period and it is essential to acquire the necessary evidence quickly. A range of geophysical methods can be deployed by forensic archaeologists and geoscientists who are employed to assist with this task (Donnelly and Harrison, 2010; Schultz, 2012; Barone et al., 2016). There are many potential near-surface geophysical methods that could be used to search for clandestine graves and other buried forensic evidence e.g., metallic weapons, drugs, etc. (Rezos et al 2010, 2011; Dionne et al., 2011; Solla et al., 2012; Richardson and Cheetham, 2013), although a few have become popular in geo-forensics due to their success in archaeological investigations. As discussed by Cheetham (2005), the most frequently used near-surface geophysical methods in forensic investigations are ground penetrating radar (GPR), electrical resistivity, and magnetometry which are described in the literature as complementing each other (Barone et al., 2015).

For near-surface geophysical methods to be regarded as effective, surveyors should be able to quickly and non-invasively survey a site while determining the buried target and its properties such as depth and size (Nuzzo et al., 2008). It is assumed that those investigating a crime would employ all geophysical equipment available to them, however due to time and cost constraints this is not always possible. Identifying the methods which are most effective and thus more efficient comes with experience (Barone et al., 2015). Here follows a short introduction into the most frequently used geophysical methods and how they operate:

2.1.1 GPR

GPR is a non-invasive electromagnetic (EM) geophysical method. It is the most commonly used in forensic investigations involving the search for buried targets and is also considered the most useful (Ruffell and McKinley, 2005; Doolittle and Bellantoni, 2010; Pringle et al., 2012c, Barone et al., 2015, 2016). It has been argued that the main reason for GPR being considered most useful is due to the quick acquisition of high-resolution data (Vaughn, 1986) whilst determining the target depth (Pringle et al., 2012c; Solla et al., 2012). However, another reason for this could in fact be due to practitioners inputting less effort into investigating the use of other geophysical methods resulting in the limitations of GPR (described below) being disregarded (Cox and Hunter, 2005). Additionally, another reason for GPR being considered the most used method is that people believe it produces clear images of the target in real time which unrealistically fulfils their dreams of seeing through the soil (Schultz, 2012).

As discussed by Davenport (2001), Pringle and Jervis (2010) and Reynolds (2011), factors which limit GPR include, but are not limited to:

- antenna frequency

- site conditions e.g., soil type, subsurface and surface obstacles (such as trees and its roots, cables, and pipes)
- sample spacing.
- the equipment spatial and temporal resolution
- the need for extensive user experience in order to obtain good results.

GPR operates by transmitting EM waves from an antenna, which propagate through the ground and reflect back to the surface, where they are detected by a receiving antenna (Ruffell, 2005, Ruffell and McKinley, 2008; Jol, 2009; Ruffell et al., 2009b; Conyers, 2013). These reflections occur due to differences in dielectric permittivity between the soil medium and the buried target. The electrical conductivity of the soil affects how much energy is lost during the transmission of these waves (Davis et al., 2000; Ruffell, 2005; Cassidy, 2009a, 2009b; Barone et al., 2016). The electrical properties of soils vary with moisture content; for example, dry sands typically exhibit low electrical conductivity, while silts and clays display medium to high electrical conductivities, respectively (Milsom and Eriksen, 2011). The velocity of EM waves is dependent on the permittivity of the medium they traverse; lower permittivity allows faster travel. However, waves can lose energy, resulting in signal attenuation, primarily due to the conductive medium. As more EM energy is transmitted, it converts to thermal energy through interactions with the medium, which GPR cannot detect, leading to signal loss (Reynolds, 2011; Bergslien, 2012). Consequently, GPR is less effective in wet, clay-rich, and saline conditions because these environments are more electrically conductive, leading to poor radar penetration and attenuated EM waves. This attenuation makes detecting buried targets and underground features more challenging (Ruffell and McKinley, 2005; Cassidy, 2009b; Pringle et al., 2012b, 2012c; Solla et al., 2012). Therefore, other near-surface geophysical methods must be used. This is discussed in a review of environmental factors that affect GPR detection by Ruffell (2005), describing how GPR works best in sandy soils.

GPR antenna frequencies typically range between 10 MHz and 4 GHz, but for the purpose of forensic investigations the most commonly used frequencies are 100 MHz to 900 MHz (Ruffell and McKinley, 2005; Cassidy, 2009b; Harrison and Donnelly, 2009; Martin, 2010; Milsom and Eriksen, 2011; Pringle et al., 2012c) which facilitates objects of all sizes (small to large) to be identified in the near surface. A lower frequency antenna will allow for a greater depth of the subsurface to be investigated, however this will decrease the resolution of smaller subsurface features. When choosing an antenna to use it is important to take into consideration the penetration depth and resolution of the subsurface required (Martin, 2010). In the search for clandestine burials, it is suggested by Ruffell et al. (2009a) to use a mid-range frequency antenna (200-400 MHz), however dependent upon specific site factors, such as the soil type, the range of frequency antenna to use varies (Dick et al., 2017). There are, however, differing views on the optimal frequency to use, for example, Schultz and Martin (2011) were able to successfully detect simulated clandestine pig burials using 250 MHz and 500 MHz antennae, but others recommend higher frequencies such as 900 MHz (Pringle et al., 2012c). A 250 MHz antenna provides an increased penetration depth compared to a 500 MHz antenna, however vertical subsurface resolution is lower, but it can result in a better discrimination of forensic targets as there may be fewer false reflection features detected (Martin, 2010). It is possible to get a good compromise between penetration depth and subsurface resolution, both vertically and horizontally. This can be accomplished by using a 500

MHz frequency antenna and is frequently used in forensic investigations, as well as archaeological investigations (Schultz, 2008; Schultz et al., 2006). With a higher frequency antenna, the electromagnetic wave will penetrate less deeply, but with increased resolution of subsurface features (Schultz, 2012). Equally, the higher antenna can also detect false anomalies created by objects beneath the subsurface (e.g., pipes, roots, rocks) or changes in the properties of the subsurface (e.g., moisture content, soil material, etc.) which can impede the detection of the target being sought. Nevertheless, it is unanimous amongst researchers that the optimal antenna frequency for detecting buried targets is ultimately dependent on the size of the target, depth of the target below ground level (bgl), geology and soil type (Pringle et al., 2012c). It is worth noting that that the nominal centre frequency of an antenna may not be the actual frequency range of the antenna coupled with the soil which tends to be considerably lower. It is therefore important that practitioners have a good understanding of soil science in order to choose the optimal antenna frequency for the search, this will be discussed in more detail later in the thesis. However, as new antenna technologies emerge that cover a wide frequency range, choosing the exact antenna frequency is becoming less of an issue.

The receiving antenna of the GPR records the relative amplitude (strength) of the returning wave against the arrival time since transmission which is transformed and stored as a digital image (radargram) to be converted into depths when processing the data (Hansen and Pringle, 2013). Knowing the estimated depth of the target is advantageous in a search as the investigators can excavate more accurately and reduce the waste of resources and cost of the investigation. This is made possible by analysing the diffraction hyperbola or by acquiring a propagation velocity average through the medium (Milsom and Eriksen, 20114; Reynolds, 2011). Subsurface variations in the dielectric properties, are characteristically recognisable as hyperbolic reflections in 2D GPR profiles which are a product of the wide angle of the radar pulse transmitted by the GPR (Dupras et al., 2006; Milsom and Eriksen, 2011). The antenna will detect a subsurface feature prior to being directly above it, when above it and after having passed the feature (see Fig. 1).

GPR cannot be used to identify the cause of an anomalous feature prior to excavation. The data output will show that the anomaly has distinguishing electrical properties compared to the surrounding medium and that the feature is a relative size, orientation, and depth below ground level (Hunter et al., 2013). However, Powell (2010) noted that rather than the presence of the body being the cause of the anomaly, it could be a result of disturbance of the soil caused when burying the body or the gradual natural compaction of the burial over time (Hunter et al., 2013).

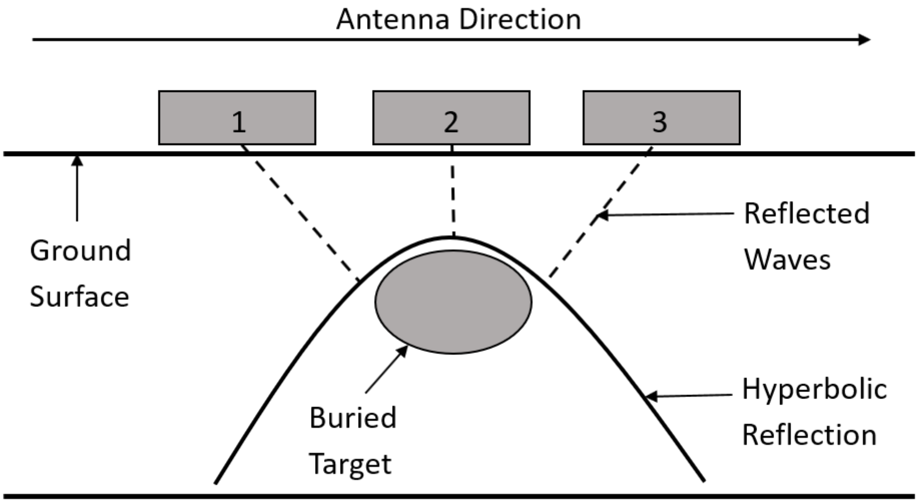


Figure 1: A schematic diagram showing how a GPR antenna passing over a buried object at positions 1, 2 and 3 produce a detectable response and hyperbola in a 2D profile. Adapted from Dupras et al. (2006).

2.1.2 Electrical Resistivity

Electrical resistivity surveying has, over the years, become a preferred alternative method to GPR in the search for recent disturbances to the subsurface, particularly for forensic investigations (Larson et al., 2011, Bergslien, 2012). Like GPR, electrical resistivity is also a non-invasive geophysical method and is often used when GPR is not considered to be the most appropriate method for a forensic search, for example, when the ground conditions are not optimal for GPR to work (Jervis et al., 2009a, 2009b). However, as discussed by Jervis and Pringle (2014), there is a lack of understanding of certain elements of grave detection with electrical resistivity methods such as the effect seasonal changes and rainfall has on the geophysical response of a grave.

Electrical resistivity has commonly been deployed in forensic investigations involving clandestine burials, but also for environmental forensics and is frequently used in controlled experiments (Molina et al., 2015, 2016a, 2016b) such as the one conducted in this thesis. It has been frequently reported how effective electrical resistivity has been at delineating clandestine burials, cemetery graves and mass graves (e.g., Jervis et al., 2009a, 2009b; Pringle and Jervis, 2010; Pringle et al., 2012a, 2012b, 2012c; Jervis and Pringle, 2014; Dick et al., 2015; Nero et al., 2016). The success of a buried target being detected using electrical resistivity is influenced by its depositional environment in a similar way to GPR, i.e., soil type, water/ion content, nature of the target(s) and its electrical properties (Molina et al., 2015, 2016a, 2016b).

To understand how electrical resistivity works it is important to understand the principles behind it. Ohm's law defines the relationship between the current (I, measured in amps, A), voltage (V, measured in volts, V) and resistance (R, measured in Ohms, Ω) as follows:

$$R = V/I$$

Resistance describes the difficulty with which an electrical current to travel through a medium whereas resistivity is a measure of the resistance of a given size of a specific material to electrical conduction. Resistivity (ρ, measured in Ωm) is quantitatively equal to the resistance of a specimen such as a wire, multiplied by its cross-sectional area (*A*) and divided by its length (l):

$$p = RA/l$$

Electrical resistivity surveys involve highly conductive, hard material electrodes, such as steel or copper, being inserted into the ground, the depth they are inserted can vary between surveys, but are generally inserted no greater than 0.2 m and therefore still considered a non-invasive method (Jervis et al., 2009a). To conduct the survey an electrical current is introduced into the ground surface through the current electrodes (C) and measuring the subsequent potential difference in the ground surface determined by the potential electrodes (P) (Reynolds, 2011; Bergslien, 2012).

The electrode spacing dictates the depth to which the electrical current flows in the subsurface, the greater the electrode distance the greater depth and width the electrode current will flow however doing this reduces the resolution of smaller targets in the near surface (Jervis et al., 2009a). In the instance of forensic searches, the depth required for the search is generally no greater than 1.0 m, therefore a smaller electrode spacing is required and will help to distinguish smaller targets near the ground surface. For this reason, forensic searches would generally use interval spacing of less than 0.5 m where possible, however time constraints would need to be considered as well as the size of the search as electrical resistivity surveys can be time consuming (Cavalcanti et al., 2018). Surveys can also be conducted using several different electrode configurations known as arrays which include but are not limited to Dipole-dipole, Schlumberger, Wenner and twin arrays (Milsom and Eriksen, 2011; Reynolds, 2011; Bergslien, 2012). Here follows a description of the four commonly used electrode configurations in forensic investigations (Dahlin and Zhou, 2004; Stummer, 2004; Leucci, 2020):

Dipole-dipole (Fig. 2A) consists of pair of current electrodes (C) on one side and the pair of potential electrodes (P) on the other side of the survey line (Fig. 2A). This array is sensitive to horizontal changes in the subsurface and heterogeneity of the buried materials (Cavalcanti et al., 2018), but provides poor vertical resolution compared to other arrays (Reynolds, 2011; Leucci, 2020).

Schlumberger (Fig. 2B) involves unevenly spaced electrodes with the pair of potential electrodes (P) in the middle of the two current electrodes (C). This array type penetrates deeper into the medium being investigated than the Dipole-dipole array and has a greater vertical resolution while providing a better resolution of the lateral boundaries of a burial (Reynolds, 2011; Cavalcanti et al., 2018). The greater the electrode spacing the more reduced the horizontal resolution becomes (Leucci, 2020).

Wenner (Fig. 2C) consists of four electrodes evenly spaced a distance (*a*) apart with two current electrodes (C) on the outside and the two potential electrodes (P) on the inside. As electrode separation increases, a greater percentage of the current will penetrate deeper into the subsurface (Milsom and Eriksen, 2011; Reynolds, 2011). Theoretically, the depth of penetration by a Wenner array is approximately equal to the probe separation distance divided by five. Like the Schlumberger array this makes the Wenner array useful for vertical profiling of the subsurface, but by increasing the electrode spacing reduces the horizontal coverage (Bergslien, 2012; Leucci, 2020). Wenner is preferred for surveys in noisy sites due to its high signal strength (Leucci, 2020).

Twin electrode array (Fig. 2D) consists of one current (C1) and one potential (P1) electrode pair which are mobile and are separated by a short, fixed distance, typically 0.50 m for forensic investigations. The depth of penetration of electricity is generally 1 to 2 times the C1-P1 distance, therefore this is ideal for a forensic investigation where burial depths generally do not exceed 1 meter. The other current (C2) and potential (P1) electrode pair are equally distanced apart as the C1 and P1, however they are located a remote, fixed distance away from the C1 and P1 and remain stationary throughout the survey.

Further information about the above arrays and other electrode arrays available are described by Loke (2004), Milsom and Eriksen (2011) and Reynolds (2011) in greater detail.

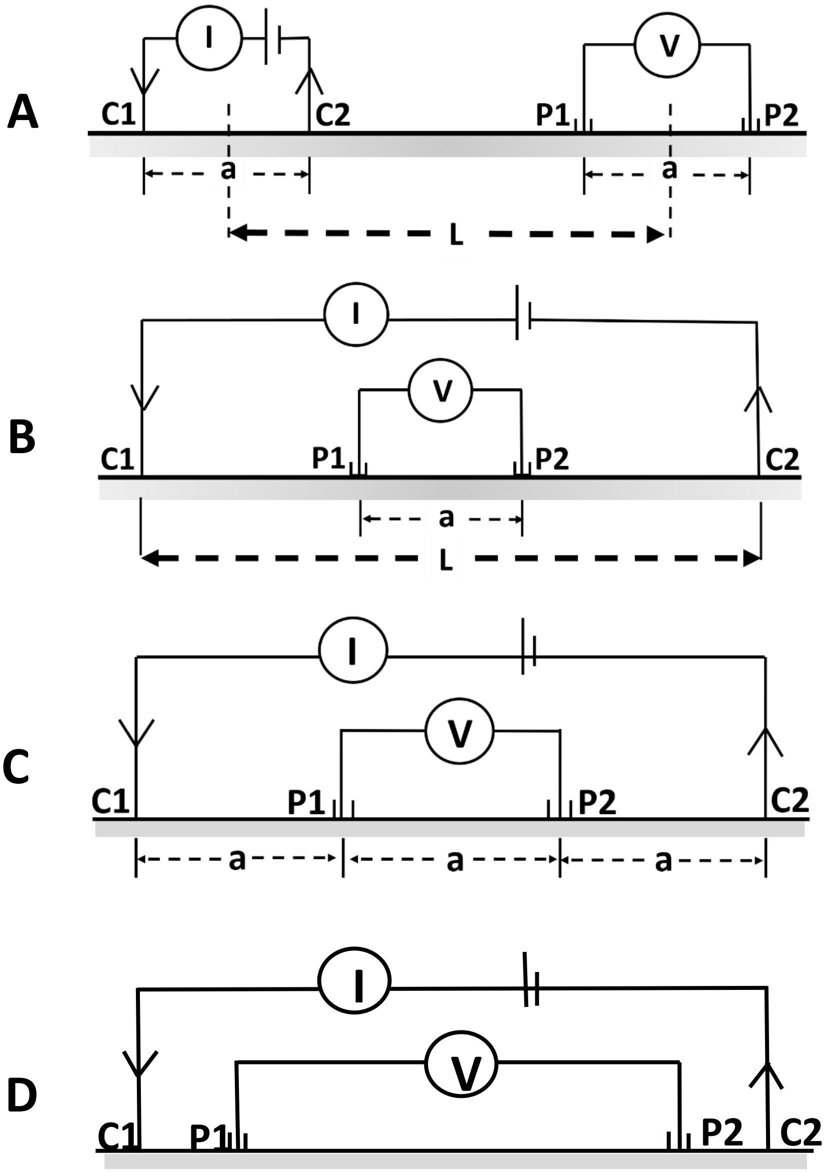


Figure 2: (A) Dipole-Dipole, (B)Schlumberger, (C) Wenner and Twin (D) electrode arrays which are the most used arrays in forensic investigations. C1 and C2 refers to the current pair of electrodes and P1 and P2 refers to the potential pair of electrodes. Diagrams A-C are adapted from Bergslien (2012), and Diagram D is adapted from Bevan (2000).

For an electrical resistivity survey to detect a buried target there must be a significant resistivity contrast between the target and the medium in which it is buried. Electrical resistivity is sensitive to the changes in moisture content and can detect the spatial resistivity variations in the subsurface which can be a result of the decomposing cadaver (Pringle et al., 2008). Researchers suggest the electrical resistivity methods are successful at detecting clandestine burials due to the disturbed soil of the grave which results in the increased porosity of the soil causing greater water retention which modifies the overall resistivity of the soil (Cheetham, 2005; Scott and Hunter, 2004; Larson et al., 2011).

Electrical resistivity surveys can be conducted using a non-conductive frame with the C1 and P1 electrodes attached. This involves the use of electrical measurements to assess the subsurface resistivity distribution in a 2D area. In a typical 2D ER survey, a predetermined electrode configuration is used known as a fixed array and can be any of the electrode configurations described previously (e.g., dipole-dipole, Schlumberger, Wenner, etc.). In a fixed array survey, a set of electrodes are placed in the ground surface in a fixed pattern or grid, most typically in a linear or rectangular array. An electrical current is injected into the ground through specific electrode pairs, and voltage measurements are recorded between other pairs of electrodes. The process is repeated systematically, most often in straight line transects with spacing typically less than 0.5 m apart when searching for targets of forensic interest (Milsom and Eriksen, 2011; Reynolds, 2011). In forensic contexts, 2D ER fixed array surveys have been utilised to aid in the location of buried forensic targets or clandestine grave sites. By conducting resistivity surveys over an area of interest, investigators can identify anomalies or areas with contrasting resistivity values that may indicate the presence of buried objects or disturbances in the subsurface. The resistivity data collected can then be further analysed using inversion techniques or compared with known resistivity signatures of different materials. This permits forensic investigators to make informed decisions about excavation targets or areas that require additional investigation.

Surveys can also be set up using a multi-electrode system which involves inserting equally spaced electrodes in the ground attached by a multi-core cable and laptop/PC to automatically control the collection of the data, this type of set up is called electrical resistivity imaging (ERI) (Milsom and Eriksen, 2011; Reynolds, 2011). As described by Milsom and Eriksen (2011), “ERI uses arrays of electrodes at multiple separations to generate resistivity-depth cross-sections (pseudo-sections)”. The pseudo-sections can be displayed as colour contoured images that provide a general visualisation of the way in which resistivity varies across the area being investigated both vertically and horizontally (Milsom and Eriksen, 2011; Cavalcanti, 2018).

There are very few published papers/studies that discuss the use of ERI surveys, often referred to in literature as electrical resistivity tomography (ERT), being used in forensic searches despite its demonstrable evaluation of delineating mass graves (Pringle et al., 2012a, 2012b, 2012c). ERI is more commonly used at this scale for archaeological surveys such as searches for WWII bunkers (Ainsworth et al., 2018; Carr et al., 2020), archaeological graves (Dick et al., 2015; Fernández-Álvarez et al., 2016) and environmental forensic surveys (Ruffell and Kulessa, 2009). Potentially, its under-use could be because it is comparatively more time consuming to set up and to acquire data than other methods (Reynolds, 2011). ERI is often used as a supplementary method if an area of interest has already been located with a different geophysical method and the practitioner needs to explore the area further prior to an excavation being agreed.

Like any geophysical method, electrical resistivity also has its limitations and can be less successful in waterlogged, very dry, frozen, or very hard soils, but is less restricted by soil typology or geology as compared to GPR (Larson et al., 2011; Bergslien, 2012). However, tree roots in heavily wooded areas, soils that are disturbed by ploughing or modern activity, saline conditions, and coarse-grained soil types (Pringle et al., 2012a, 2012b, 2012c) can detract from the effectiveness of electrical resistivity in detecting buried targets (Larson et al., 2011). ERI is not commonly used in smaller scale forensic investigations as it is time consuming and labour intensive, however it can yield very detailed 2D and 3D colour contoured cross-sectional images of the near-surface resistivity (Reynolds, 2011). Unlike GPR, electrical resistivity methods are not sensitive to above ground interferences such as cultural or electrical noise (Bergslien, 2012; Pringle et al., 2012a, 2012b, 2012c) and work better in clay-rich soil types as compared to GPR (Pringle and Jervis, 2010).

2.1.3 Magnetometry

Magnetometry detects buried targets by measuring the associated anomalies in the earths total magnetic field. The intensity of the anomaly produced is dependent on the target’s size, shape, depth of burial and the magnetic susceptibility, the greater the magnetic susceptibility the more detectable the target becomes e.g., targets of ferromagnetic nature have higher magnetic susceptibilities than non-ferromagnetic targets and are therefore more detectable using magnetometry (Richardson and Cheetham, 2013; Deng et al., 2020). Magnetometry cannot be used to directly detect buried bodies as they have very low magnetic susceptibilities (Fenning and Donnelly, 2004; Bergslien, 2011), however it has been frequently used to detected buried metal, such as metallic weapons, i.e., handguns and knives (Deng et al., 2020). Magnetometry has also been used to locate fired objects such as bricks or where surface fires once were, this can be useful in archaeological searches for locating building structures (Reynolds, 2011). There must also be consideration to the fact a lot of metallic objects are alloys which affects how well targets of this material can be detected using magnetometry and whether this is a suitable method to use in a search (Richardson and Cheetham, 2013).

Most of the magnetometers employed still require corrections to be applied for temporal and regional variation in the Earth’s magnetic field for effects such as diurnal variations and magnetic storms for example (Reynolds, 2011; Milsom and Eriksen, 2011; Everett, 2013; Deng et al., 2020). It is equally important to note that it is highly advisable to keep any magnetic objects away from the search area which can cause magnetic noise resulting in additional anomalies in the data, e.g., wristwatch, keys, steel-capped boots.

There is a range of magnetometer equipment available for use depending on the accuracy required for the search, however cost is also a contributing factor. As described by Reynolds (2011), magnetometers can be classified into: torsion balance, fluxgate and, proton free procession and alkali vapour types, however for forensic purposes only fluxgate, proton free precession and alkali vapour types are mostly used. Here is an explanation of the different types of magnetometers covered by these groups which are most used in forensic investigations:

Proton free-precession magnetometers (which are classed as total-field magnetometers) have been used in forensic and archaeological investigations in the past (Reynolds, 2011). The proton magnetometer has a sensor which is comprised of a container containing a hydrogen-rich liquid (such as water, alcohol, or kerosene) which is then wrapped by a copper coil connected to a measuring device (Reynolds, 2011; Davenport, 2017; Leucci, 2020). These types of magnetometers make use of the precession of protons in the liquid when an electric current is passed through the coil generating a magnetic field and then switched off. Prior to the magnetometer being used, most protons in the liquid align parallel to the Earth's magnetic field with the remaining few positioned anti-parallel which results in the liquid developing a net magnetic moment in the direction of the ambient field (Milsom and Eriksen, 2011; Reynolds, 2011). Following an electrical current being applied to the coil, a magnetic field of about 5-10 nT is created (which is 50 to 100 times greater than the earth's) resulting in the protons aligning to this introduced magnetic field. The electrical current is switched off, halting the magnetic field, causing the protons to precess around the pre-existing magnetic field of the earth (Leucci, 2020). The precession frequency is measured, which is proportional to the magnetic field strength.

Alkali-vapour magnetometers are usually classified as total field instruments which are affected by proximal ferromagnetic materials. This type of instrument can collect ten measurements per second and can be used to survey large areas at a quicker rate with a greater sensitivity to changes in the magnetic field than using a proton magnetometer (Milsom and Eriksen, 2011; Reynolds, 2011; Davenport, 2017). Alkali-vapour magnetometers consist of alkali metal vapours (often caesium or potassium) and a buffer gas (usually helium or nitrogen) in a glass container through which a laser beam passes (Milsom and Eriksen, 2011). The laser beam works by exciting the free electron in the outer shell of the alkali metal vapour to a higher energy state which results in a photon being emitted falling to a lower energy state, this is then measured by the photon detector in the equipment. When an external change in the earth's magnetic field due to buried ferromagnetic material is present, it causes a disruption to the lower energy state of the electrons energising them back to the higher energy state which is then measured (Milsom and Eriksen, 2011; Reynolds, 2011). This type of magnetometer has typically been used for detecting unexploded ordnance (UXOs) due to their much higher sensitivity (Davenport 2017).

Fluxgate magnetometers are capable of continuously measuring the relative changes in the earth's magnetic field, usually in the vertical direction but do not measure absolute fields and therefore require calibration (Milsom and Eriksen, 2011; Davenport, 2017). Fluxgate magnetometers typically involve two parallel rods of ferromagnetic material with two copper coils wrapped around each rod in opposite directions, whereby an alternating current is passed through one coil (primary) which produces an alternating magnetic field that induces an alternating current in the other coil (secondary) which is measured continually (Milsom and Eriksen, 2011; Leucci, 2020). Changes in the external magnetic field results in a change in the magnetic field of the secondary coil which is then measured to determine the magnitude of the external field (Reynolds, 2011).

The above magnetometers can also be used in tandem as a gradiometer (Milsom and Eriksen, 2011), which involves two of the same types of sensors positioned either vertically or horizontally separated by a small distance, generally between 0.5 m to 1.5 m (Reynolds, 2011; Leucci, 2020).

The distance between the sensors determines the depth of the investigation, i.e., the further the separation the deeper the sensor will detect (Deng et al., 2020). Gradiometers can measure both the earth's total magnetic field and the magnetic gradient between the sensors (measured in nanotesla per meter, nT/m) which provides additional information that is useful for delineating subsurface targets as they are more sensitive to changes (Milsom and Eriksen, 2011; Reynolds, 2011). In general, fluxgate sensors are used as gradiometer pairs because they are almost entirely sensitive along their axis, so can only practically be used as a 3-axis triple-sensor or as a gradiometric pair.

Information regarding the other types of magnetometers available are described in detail by Milsom and Eriksen (2011) and Reynolds (2011).

2.1.4 Alternative geophysical methods used in forensic investigations.

There are alternative methods that are less frequently used in forensic investigations as described below.

Electromagnetic (EM) conductivity meters consist of two copper coils, one that transmits an electromagnetic wave creating a magnetic field in the ground and the second which detects the induced magnetic field produced by a buried metal target e.g., a metallic weapon. The conductivity of the target is measured by calculating the difference between the magnetic field of the copper coil and that of the buried target (measured in milli Siemens per meter, mS/m) (Killam, 2004; Dupras et al., 2006). Conductivity meters have a real but unused potential for forensic investigations, but there are very few studies which show how it can be used in the search for buried targets of forensic interest. Conductivity meters have the capability of being able to detect metallic targets, but it has also been reported that it can detect a buried body (Nobes, 2000). However, there is little evidence to suggest that the conductivity meter is directly detecting the buried body, instead it could be detecting the contrast of the redeposited soil, microbes, decompositional fluid, etc. against the background values (Powell, 2006). As electrical resistivity methods have been successful at detecting buried bodies, conductivity meters should be equally as successful as conductivity is the inverse of resistivity.

Conductivity meters could be used in place of electrical resistivity methods as it can survey an area more quickly and can be used on all types of terrain including over pavements, concrete, etc., which is a hinderance to electrical resistivity meters. This is because electrical resistivity methods require electrodes to be inserted into the ground, whereas conductivity meters do not. Conductivity meters can also be much more effective in conductive environments where sufficient current can be induced in the ground. However, one disadvantage of using a conductivity meter is that it is highly sensitive to surrounding metal objects which can affect the accuracy of the readings (Dionne et al., 2011).

Magnetic susceptibility meters have also shown an underused potential for forensic investigations evident in a paper by Pringle et al. (2015b). Magnetic susceptibility measures how susceptible an object or medium is to being magnetised (measured in SI, dimensionless units), this is established by passing an electric current through a copper coil, which creates a low intensity AC magnetic field, in the meter magnetising any material beneath it. Magnetic susceptibility can collect measurements relatively quickly; however, it is strongly affected by magnetic materials which are naturally present in the subsurface e.g., ferro- and ferri-magnetic minerals (Milsom and Eriksen, 2011; Reynolds, 2011) and therefore not suitable in all search scenarios.

The alternative geophysical methods described above will not feature as methods used to detect the buried targets being sought in thesis, this is due to the availability of resources and limited time in the field.

The effectiveness and applicability of all the above methods in the search for organic buried targets, such as a clandestine burial, can be affected by the stage of decomposition taking place at the time of the search. It is therefore important to understand the processes that a decaying cadaver will go through, the intrinsic and extrinsic factors that can impede or expedite the process and how this can impact the burial medium.

2.2 Decomposition processes of a buried cadaver

Forensic taphonomy is the study of how organisms' decay (i.e., a human cadaver) applied in a legal context. The purpose of forensic taphonomy is to establish post-mortem interval (PMI), cause of death, the location of clandestine burials and the identification of the remains (Haglund and Sorg, 2001; Sorg and Haglund, 2002). There is a comprehensive understanding of the effects of a deposition site on a decomposing cadaver (Carter, 2005; Carter and Tibbett, 2008; Carter et al., 2010; Turner et al., 2013). However, little research has been conducted into the environmental geophysical effects of a decomposing cadaver and its optimal detection as time passes. Understanding the biochemical changes that occur in the soil as a result of a decomposing cadaver (Benninger et al., 2008) is the first step into understanding how this could affect the geophysical properties of the soil and how this could hinder detectability of buried forensic targets. Analysing how a buried target affects the surrounding environment regarding its geophysical properties and subsurface features (Hochrein, 2002), (e.g., soil disturbance resulting in a change in compaction and aeration of the soil, mixing of the soil layers, increase/decrease in water/ion content, soil pH, change in vegetation growth) is equally important to the effect the extrinsic factors have on a decomposing cadaver.

To understand the factors affecting the success of detecting a clandestine burial, the processes of decomposition need to be understood. Payne (1965) suggests that the processes of decomposition encompass six main stages, however this has been slightly condensed down into five main stages by Dekeirsschieter et al., 2009, see Table 1.

Although these stages have been determined through observations, as discussed by Schoenly and Reid (1987) they are not a discrete series, but a continuum of gradual changes. In addition to the above stages of decomposition which describe the changes that occur it is important to also acknowledge that the rate of decomposition can be affected by burrowing animals (e.g., worms and rodents) which can often increase the rate of decomposition by eating or putrefying the flesh (Sorg and Haglund, 1996). Burrowing rodents will exploit soft soil around decayed corpses for their burrows and may displace bones. Plants, especially tree, roots will invade corpses to extract nutrients and may physically lever bones apart. The escaping decompositional fluids from the body into the soil can also affect the biogeochemistry of the soil which can impede or accelerate further decomposition depending on the soil condition originally present.

Table 1: the stages of decomposition with a description of what is expected to be observed during each stage.

Fresh	This stage begins immediately following death and lasts until the first signs of bloating occur. Subsequently, an oxygen deficit creates an anaerobic environment in which the chemical activity of bacterial decomposers is stimulated causing the commencement of autolysis or ‘self-digestion’ (Gill-King, 1997; Vass, 2001).
Bloated	The process of putrefaction begins which is defined by Vass (2001) as being the breakdown “of the soft tissues of the body by the action of microorganisms”. This produces a build-up of gases and decompositional fluids resulting in the body bloating (Finley et al., 2015). The bloating is first observed in the abdomen and then spreads across the rest of the body (Dekeirsschieter et al., 2009; Gennard, 2012) resulting in anaerobic fermentation.
Active decay	The accumulated gases and decompositional fluids will either purge from the body via the nose, mouth and/or rectum (Clark et al., 1997), but in some instances have ruptured the body due to the internal pressures caused by the build-up (Vass, 2001). Skin slippage due to the breakdown of the cells also begins to occur allowing decompositional gases to escape and the body beginning to deflate (Gennard, 2012). Protein sources, such as the muscles, are broken down into fatty acids by bacteria (Vass, 2001; Vass et al., 2002; Gennard, 2012).
Advanced decay	In the later stages of decay, all that remains are the skin, cartilage, hair and bones, any remnants of flesh are usually dried (Gennard, 2012), autolysis is accelerated, and the next stage of decomposition occurs rapidly (Galloway, 1997).
Dry remains	At this stage, all that remains are bones and hair, this is generally the final stage of decomposition (Gennard, 2012). Further breakdown of the remains can occur during a process called diagenesis (Vass, 2001; Gennard, 2012; Langley and Tersigni-Tarrant, 2017) which involves the breakdown of organic collagen and inorganic components (hydroxyapatite, calcium, magnesium) of the bones into components of the soil. This can be caused by environmental factors such as the soil, water content, microbial activity, and plant growth but also the biochemical properties of the decompositional fluids.

Most of the literature on the rate of decomposition reports on those deposited aboveground, with less experimental consideration to the processes in belowground deposition (Tibbett and Carter, 2009). Due to a more comprehensive understanding of the cadaveric effects on the environment, geophysical detection methods which will be most effective have been deployed in the search for clandestine burials (Carter et al., 2007; Carter et al., 2008). Cadaver decomposition is generally slower in belowground environments compared to aboveground due to the remains being more protected from insect and carnivore activity as well as lower temperatures (Pinheiro, 2006; Jaggers and Rogers, 2009). However, decomposition can vary between bodies and environments, and as discussed by Pinheiro (2006) and Olakanye and Ralebitso-Senior (2018) the variables which can affect decomposition include, but not limited to: temperature, water content, soil type, burial depth, and additional buried artefacts, for example, clothing and wrapping. Clothing or wrapping the body in any material (e.g., tarpaulin) will inhibit the movement of moisture from both the surrounding soil and the decompositional fluids from the body, which may impede the rate of decomposition (Olakanye and Ralebitso-Senior, 2018). This should create a distinct contrast in the electrical conductivity of the body and the surrounding soil (Nobes, 2000). Additionally, clothing and wrapping provide the physical context within which the body is decomposing and are thus part of the geophysical ‘equation’. The materials used for clothing or wrapping can influence the decomposition process and the subsequent geophysical anomaly detected by near-surface detection methods. For example, different fabrics and wrappings have varying degrees of permeability and insulation, which will affect moisture retention, gas exchange, and microbial activity around the decomposing body. These factors will equally impact the soil’s physical properties such as resistivity and permittivity, as well as the chemical properties, affecting the success or failure of near-surface detection methods in locating the buried body by affecting the accuracy and interpretation of the survey data. Therefore, understanding the role of clothing and wrapping is crucial for accurately modelling and detecting clandestine burials using near-surface detection methods.

Henderson (1987) declared that bodies buried in light porous soils will have an increased rate of decomposition compared with bodies buried in dense clay which will impede decomposition. This is due to there being a greater aerobic environment in sandy soils compared to clay soils which tend to have a more dominantly anaerobic environment (Junkins and Carter, 2017). Burial depth is also a contributing factor to the rate of decomposition. Deeper burials and soils with a higher water content have a reduced availability of oxygen which introduces an anaerobic environment resulting in a reduction in the rate of decomposition (Henderson, 1987; Gill-King, 1997; Olakanye and Ralebitso-Senior, 2018). However, in respect of clandestine burials it is relatively uncommon for the burials to be any deeper than around 0.5 m – 1.0 m as it not practical and takes a lot of time and energy (Pinheiro, 2006).

Many clay-rich soils are found in environments where the surface dries out during the summer, leading to cracking. This creates distinct geophysical effects, particularly relevant to forensic investigations, as clandestine burials in such soils are often significantly shallower than those in sandy soils or clay soils that do not dry out at the surface. These shallower burials result from the difficulty of digging in hard, dry clay. Consequently, these burials are more likely to be located within the superficial zone where the soil dries out. The relationship between parent material and soil texture, and burial conditions, often has many exceptions, as demonstrated by the scenario described above. This highlights the importance of gathering actual examples of environments and buried targets by integrating observations into routine survey-then-excavation practice, rather than relying solely on theoretical models of burial behaviour, which often lacks general validity.

2.2.1 The effect of decomposition on the effectiveness of near-surface geophysical methods

The geophysical response produced during a search for a buried, decomposing human body, will depend upon the stage of decomposition the body is going through during the time of the search as this will influence the properties of the surrounding soil (Miller et al., 2002). As previously described in Table 1, after death, the body's oxygen levels decrease, creating anaerobic conditions that stimulate bacterial decomposers to start autolysis (self-digestion). This quickly leads to putrefaction, which produces gases and fluids that build up in the body, causing it to bloat and change its electrical properties relative to the surrounding environment (Miller et al., 2002). Eventually, the pressure inside the body forces these decompositional products to be released, and the release of these ion-rich fluids will further change the electrical properties of the surrounding medium (France et al., 1992; Nobes, 2000; Vass et al., 2001; Jervis et al., 2009a, 2009b). These changes result in an area of low resistivity or reciprocally as high conductivity allowing both GPR and electrical resistivity methods to detect the buried cadaver (Pringle et al., 2015a). This can also be due to an increased porosity of the backfilled soil resulting in greater moisture being held by the grave compared to the surrounding undisturbed soil (France et al., 1992; Owsley, 1995; Nobes, 2000; Scott and Hunter, 2004; Jervis and Pringle, 2014). Research has shown that the ion-rich decompositional fluids are preserved and can be detectable for a significant time post-burial (Dick et al., 2017) which can be considered useful for forensic searches involving cold cases. As described by Miller et al. (2002), after the body has bloated and all the decompositional fluids and gases have purged from the body, a void in the grave is created typically in the calvarium beneath the ribcage, but also around the innominate (pelvic area). The air-filled void created will create an area of low conductivity/high resistivity which has been demonstrated to be successfully detected by GPR and electrical resistivity methods (Bevan, 1991; Mellett, 1992). After some time, however, the soil will ultimately fill the void creating a depression in the surface of the soil which in turn will alter the properties of the soil.

2.3 Controlled research using near-surface geophysics for forensic investigations.

In real-world forensic settings, applying near-surface geophysical methods to detect buried targets poses several limitations, such as variability in soil types and environmental conditions, but forensic investigations often occur under time constraints which may result in a comprehensive survey and analysis being omitted as well as sites having restricted access to external personnel. In addition, forensic practitioners will often work with incomplete information regarding the nature and age of the target, which can further complicate the selection and success of geophysical methods. As discussed by Nuzzo et al. (2008) the available background literature on geophysical methods being used in forensic investigations is scarce due to the legally sensitive nature of the searches conducted. Therefore, it is difficult to determine how often forensic geophysics has been used in real cases, as opposed to the demonstration of how useful they can be in controlled research which can be considered as artificial environments. Guidance for forensic geophysics is not currently available, therefore publications provided by English Heritage (now known as Historic England), European Archaeological Council (EAC) and British Archaeology Job and Resources (BAJR) have been referred to instead.

Geophysical survey guidelines from 2008 produced by Historic England are no longer available and have been archived which only provided guidance for geophysics in archaeological field evaluation. Abingdon Archaeological Geophysics on behalf of British Archaeological Jobs Resource (BAJR) produced its own short guide for archaeological geophysics which was last revised in 2008. It notes in the first paragraph of the document that the purpose of the guide is 'to seek to establish what geophysics is good and bad at and to give some information concerning the methods which are used'. The intention of the produced guide is not to be 'comprehensive or universal' but to be general information to those seeking to use geophysics who may not necessarily be considered 'experts' with a disclaimer that the geophysics field is fast changing, and opinions will differ between users. The guide has a short section regarding how useful geophysics will be at the site the user is investigating by advising the user to check the Historic England database of geophysical surveys which is freely available online at request. It advises to do this to determine whether the soil conditions in the search area would be suitable for the geophysical methods to be employed. Additionally, it states the user can obtain a survey from another site with known archaeological features, like those being sought at the user's site, providing it is on the same type of drift geology as the users intended site to establish optimum geophysical methods for the search. It has already been identified in Chapter One and further reiterated in this chapter that choosing geophysical methods based on success at a past site can result in wasted time and effort and a risk of missing the buried target(s) (Powell, 2004; Donnelly and Harrison, 2010), as sites are much more complex than just the underlying geology and/or buried features.

The European Archaeological Council (EAC) produced its own geophysics report in archaeological guidelines in 2015 which integrated some of the information from the 2008 Historic England guidelines to be used across Europe, although it should be noted that this was a publication aimed at archaeologists and not directly applicable to forensic investigations. The aim of the guidelines is stated in the executive summary of the guide as 'an overview of the issues to be considered when undertaking or commissioning geophysical survey in archaeology'. This guide, however, highlights that there is not a 'one size fits all' with regards to the best geophysical method to use due to the variability in geological and environmental conditions, this could be between sites or within the same site at different times of the day or year. The guide acknowledges that currently 'there is no formalised standard for the conduct of geophysical survey in archaeology, mainly because there are many parameters that determine the outcome, and there are various purposes for which the results may be used'. When compared to the BAJR short guide, this guide provides a more comprehensive overview of the methods including justification for a survey, data interpretation and archiving, producing a survey report and dissemination of the results.

To date, no further guidelines have been produced specific to England and/or the UK with Historic England referring users to the EAC guidelines, which again there is no updated version of the 2015 document. Considering the guides described above have been in circulation for at least eight years there is still a lack of consistency in the way geophysical methods are currently chosen between practitioners. It is therefore imperative that an updated version of the documents is produced, but equally one that includes guidelines for the use of geophysical methods in forensic surveys which is a closely related discipline to archaeology. In addition to this, there is a need to ensure that information about geophysics from excavation analysis is accumulated and built into geophysical best practice for archaeology and for forensics.

To understand how archaeological geophysics can be applied to forensic geophysics, controlled research has been conducted. Such research is carried out under controlled conditions to test how well geophysical methods can be used for forensic purpose and determine the impact of specific variables on subsurface target detection. Conducting controlled research whereby different variables are altered enables a comparison to be made of how well the different methods work which can lead to improving the current standards followed for deploying the methods in forensic investigations (Rezos, 2009). To create or improve current guidelines for forensic searches the results must be replicable in the real world, therefore the methods used in controlled settings must be the same or like those used in the field.

GPR and electrical resistivity surveys (including ERI) have frequently been used for controlled research to investigate simulated clandestine graves in a forensic context under different conditions (soil type burial depth, climate, etc.) including adding artefacts into the grave such as hydrated lime, bed sheet, construction debris, and a plastic bag (Cavalcanti et al., 2018). Cavalcanti's research (2018) compared both GPR (400 MHz) and ERI (dipole-dipole and Wenner-Schlumberger arrays) across fourteen different burial scenarios (including a control burial with nothing interred) at one site in Brasilia, Brazil (clayey slate substrate). GPR produced varying hyperbolic reflections between the fourteen different burial scenarios, but successfully located the buried pig carcasses with the geophysical response presented as an attenuation of the signal. They state the attenuation of the signal corresponds to the top of the additional buried artefacts in the burials, in particular the wood coffin and hydrated lime burial scenarios.

GPR with different antenna frequencies have also been used to compare how the same buried target can be detected successfully or missed during a search (e.g., Schultz and Martin, 2011, 2012; Pringle et al. 2012b, 2016). Pringle et al. (2016) conducted controlled research using 110 MHz, 225 MHz, 450 MHz and 900 MHz GPR to locate a naked pig carcass and wrapped pig carcass up to 6 years post-burial. The two lower frequency antennae GPR worked best and were able to successfully detect the naked buried target up to 18 months post-burial. After the initial 18 months, the 225 MHz GPR worked poorly in the winter months up to 5 years post-burial. The 225 MHz and 450 MHz GPR were observed to be the most optimal to locate the wrapped pig carcass, although the 110 MHz GPR also resolved the wrapped pig successfully throughout the entire study period which could be a result of the geophysical contrast produced by the tarpaulin used to wrap the pig.

GPR has previously been used to detect landmines and it was therefore suggested that it would be useful when applied to the search for buried metallic weapons (Richardson and Cheetham (2013). The two authors wanted to test the effectiveness of geophysical techniques in detecting a range of buried metallic weapons, one of the methods they deployed was GPR. The results showed that the 500 MHz GPR produced good results when looking at two replica handguns, for the other metallic weapons it had variable success. Weak to moderate anomalies were produced for the axe and hammer at all depths and some of the orientations (perpendicular and flat, and on edge, and parallel and flat). When the non-handgun metallic weapons were buried parallel and on edge, perpendicular and on point, and the parallel and on point orientations there was no anomaly detected. The 800 MHz had less success detecting the buried metallic weapons when compared to the 500 MHz GPR, as it mainly produced weak to moderate anomalies and for some of the weapons was not able to detect an anomaly when orientated parallel and flat. Richardson and Cheetham (2013) recognised that an additional advantage of using GPR in the search for buried metallic weapons during their controlled research was that it can ‘detect the soil disturbance and help in the differentiation of shallow non-forensic anomalies’.

Electrical resistivity methods have been used during controlled research for the search of simulated clandestine pig burials, an example being the research conducted by Molina et al. (2015, 2016a, 2016b). Molina et al. created two of each burial scenario (domestic pig carcass with bottom half wrapped in cloth, skeletonised human remains with bullet casings, beheaded skeletonised and burnt human remains, and blank control grave), all of which are common burial scenarios in Columbia, South America. As well as using GPR and magnetic susceptibility/conductivity, they also used an electrical resistivity meter in a pole-pole array configuration to locate the burials in a red clay-rich andisol loam formed from lacustrine sediments and volcanic ash. Electrical resistivity was found to be good at resolving the burials, although the 12-month summer surveys were not deemed to be optimal at detecting the burials and were more clearly detectable during the 15-month autumn and 18-month winter surveys. However, overall, their findings suggest that the disturbed grave soil was better detected than the targets themselves.

Magnetometers have been used in controlled research in the search for clandestinely buried metallic weapons (Richardson and Cheetham, 2013; Deng et al., 2020) and clandestine burials (Pringle et al., 2008; Juerges et al., 2010) with varying levels of success, although there is a lack of methodological research. Juerges et al. (2010) used magnetometry (fluxgate gradiometer and potassium vapour magnetometer) across three different sites across the UK with varying geologies to search for clandestine burials. The research concluded that the potassium vapour magnetometer was the optimal magnetic technique to use at any of the three sites to locate the burials. However, the researchers stated that it is not clear whether the success of the method is due to the biological activity creating an increase in magnetic material or due to the disturbed ground. They instead acknowledged that the results could be validated further by investigating the graves further over a longer period as the disturbed soil will become more settled as more time passes.

When searching for metallic weapons, Richardson and Cheetham (2013) found they could use a fluxgate gradiometer to successfully detect the larger weapons (e.g., axe, hammer, replica handguns) in all scenarios, but was unable to detect the smaller weapons such as the non-magnetic screwdriver and knives. The strength of the response produced by the larger weapons was affected by the depth the target was buried and the orientation of the weapon relative to the instrument. Whereas the non-magnetic screwdriver and all the knives did not produce a geophysical response in any scenario, except for the largest knife when the orientation of the weapon was changed. As the magnetometer could not detect all the smaller weapons in all orientations, it is not suitable for searching for these types of weapons in forensic searches as it would be a waste of time and resources. Deng et al. (2020) used an Overhauser magnetic gradiometer (not described in this thesis, but information about how it functions can be found in Reynolds, 2011), to search for three decommissioned rifles and three decommissioned handguns that have been buried in controlled settings. They concluded that the magnetic gradiometer could successfully detect a variety of firearms buried to 1.80 m below ground level and believe the method is underused in forensic searches.

Further reading on the use of geophysical methods in controlled research for forensic investigations is readily available, e.g., Schultz, 2006, 2009; Murphy and Cheetham, 2008; Rezos, 2011; Molina et al., 2015, 2016a, 2016b; Salsarola et al., 2015). Even though controlled research has been beneficial for researching the applicability of different geophysical methods in a range of different environments and burial scenarios, they do not capture the full complexity of operational environments that exist within forensic investigations. As a result they cannot be relied upon solely as comparison to real-life forensic scenarios. As with any research, further studies need to be conducted to further validate the findings from controlled research and more publications from real-world applications in forensic investigations are required to further improve the field.

2.3.1 Controlled research scoring

Following an extensive review of the literature, it has been noted that there are very few papers that evaluate the data by providing a score which represents the geophysical anomaly visibility for the methods used to detect the buried forensic target or the effectiveness of the methods (details of those papers can be found below). Producing scores allows a comparison to be made and potentially an objective basis for method and configuration choices.

A generalised overview on how different geophysical and remote sensing methods would work when searching for various forensic targets during terrestrial searches was produced by Pringle et al. (2012c, 2015) and for aquatic searches was produced by Ruffell et al. (2017). The potential search techniques for each search type were provided by each of the authors assuming the optimal configurations for the equipment and provided a generic score of how they are expected to work in the given situation (Fig. 3 and Fig. 4). Pringle et al. (2012c, 2015) provide a basic summary on how the methods would work comparing clay and sand soil types for simplicity but are non-specific on the effect of other variables e.g., hydrology, specific geology, target size, target depth and climate. They provide how a search environment (e.g., woods, rural, urban and coastal) can influence the effectiveness of the chosen method. Similarly, Ruffell et al. (2017) provide the same information except it is a summary of the methods in an aqueous environment and provides the sediments as sand and mud. Both authors provide a key of good, medium, and poor, which are the expected chances of success in a search for the methods in the diagram.

A scoring method which is used for analysing the geophysical surveys conducted for controlled research purposes was found to be created by Schultz and Martin (2012) for using GPR to detect pig burials and was later adapted by Pringle et al. (2012d, 2016) for other methods such as electrical resistivity (see table 2 for a description of the scores).

Table 2: Description of each score to describe the visibility of the anomaly in the geophysical profile taken directly from Schultz and Martin (2012) and Pringle et al. (2012d, 2016).

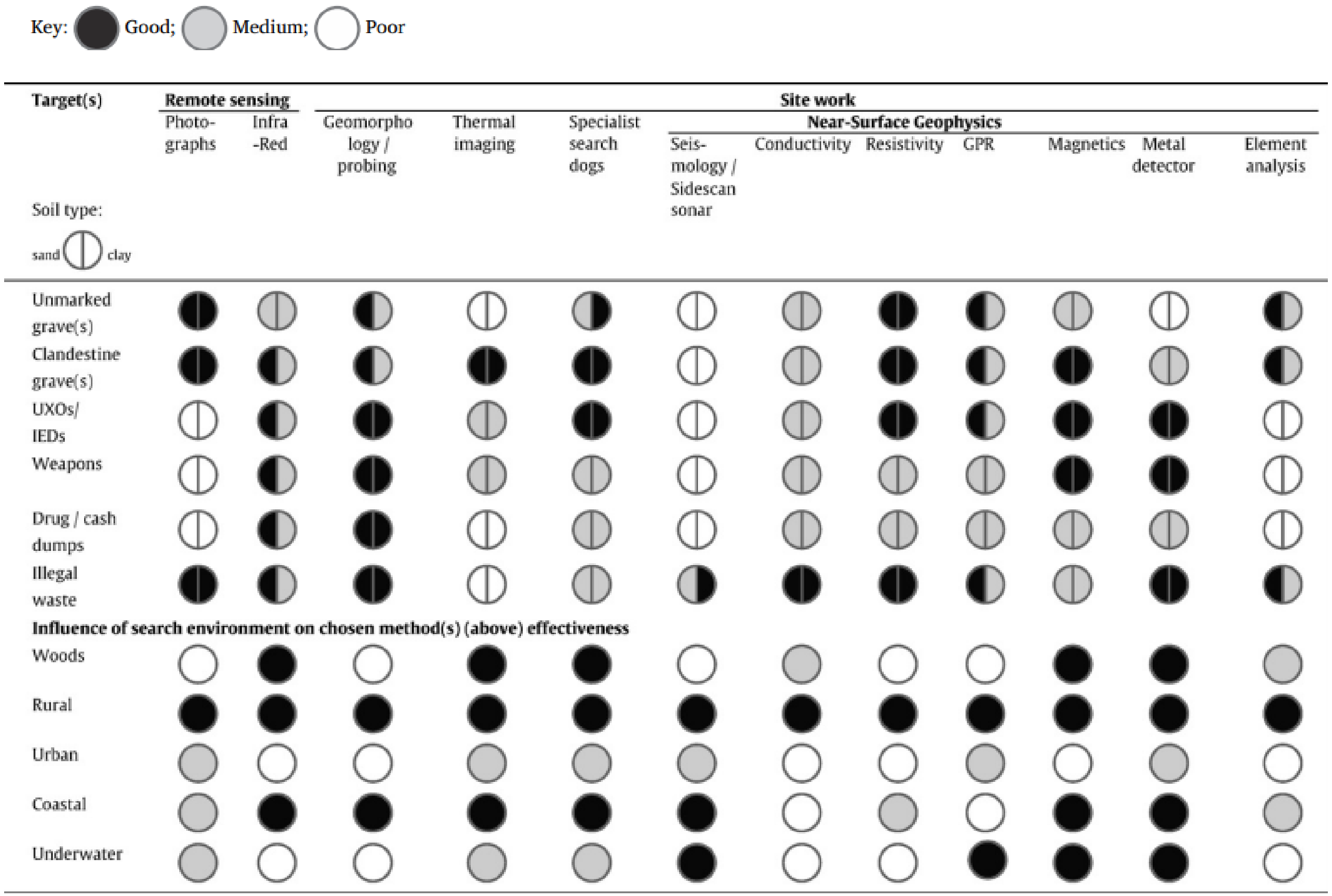
Score	Description
None	Target not detected
Poor	A slightly discernible geophysical anomaly
Good	A clear geophysical anomaly that would be discernible in the field
Excellent	A clearly discernible and prominent anomaly

2.4 Summary

In summary, geophysical methods have proven to be highly effective in their application to forensic investigations. The potential of these techniques to aid in the search for buried targets is evident. However, one major challenge currently faced is the lack of consistency in decision-making regarding which geophysical method to employ. Further research is necessary to better understand the interplay between depositional sites, decomposing cadavers, and the suitability of geophysical methods. This knowledge would greatly enhance the ability to select the most appropriate method and configuration for a given scenario.

Moreover, the evaluation of both successful and unsuccessful applications of geophysical methods is essential. By systematically assessing the visibility of geophysical anomalies, it becomes possible to develop standardised scoring systems. These scores can provide valuable guidance when choosing the most effective geophysical method and configuration. This process would intend to promote informed decision-making and optimise the utilisation of geophysical techniques in forensic investigations and provide a solid foundation for the proposed tool to be built upon.

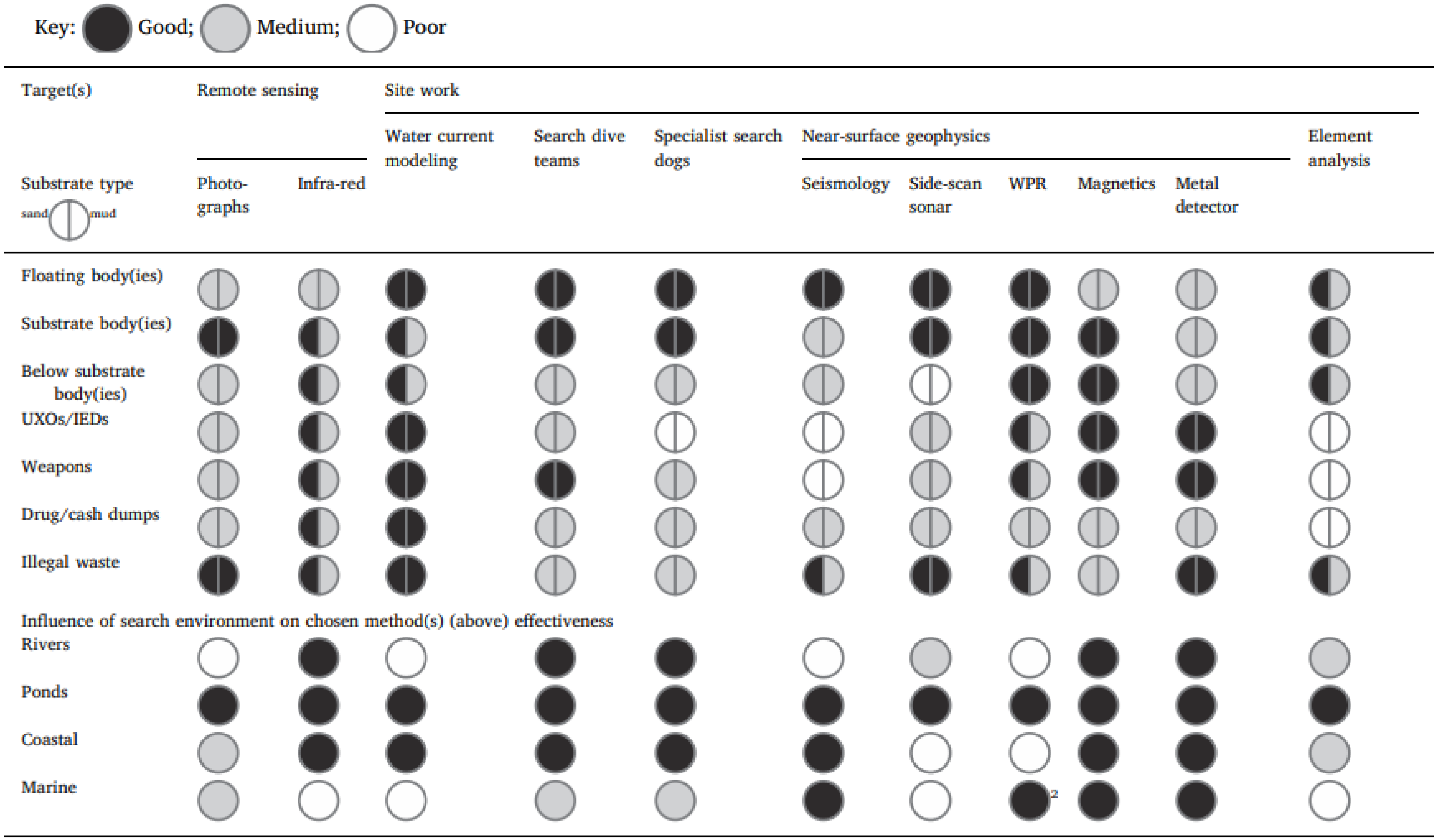
Overall, the integration of geophysical methods into forensic practices has the potential to develop the search for buried targets. However, addressing the current inconsistencies in decision-making, conducting further research on the influence of depositional sites and decomposing cadavers, and implementing comprehensive evaluation methods are critical steps to harnessing the full capabilities of geophysical methods in forensic investigations. This thesis aims to address this in the following chapters and proposes a way in which methods could be chosen more effectively to increase chances of a successful search, particularly for forensic investigations.



Key: ● Good; ◍ Medium; ○ Poor

Target(s)	Remote sensing		Site work									
						Near-Surface Geophysics						
Soil type: sand | clay	Photographs	Infra-Red	Geomorphology / probing	Thermal imaging	Specialist search dogs	Seismology / Sidescan sonar	Conductivity	Resistivity	GPR	Magnetics	Metal detector	Element analysis
Unmarked grave(s)	●|●	◍|◍	●|◍	○|○	◍|●	○|○	◍|◍	●|●	●|◍	◍|◍	○|○	●|◍
Clandestine grave(s)	●|●	●|◍	●|◍	●|●	●|●	○|○	◍|◍	●|●	●|◍	●|●	◍|◍	●|◍
UXOs/ IEDs	○|○	●|◍	●|●	◍|◍	●|●	○|○	◍|◍	●|●	●|◍	●|●	●|●	○|○
Weapons	○|○	●|◍	●|●	◍|◍	◍|◍	○|○	◍|◍	◍|◍	◍|◍	●|●	●|●	○|○
Drug / cash dumps	○|○	●|◍	●|●	○|○	◍|◍	○|○	◍|◍	◍|◍	◍|◍	◍|◍	◍|◍	○|○
Illegal waste	●|●	●|◍	●|●	○|○	◍|◍	◍|●	●|●	●|●	●|◍	◍|◍	●|●	●|◍
Influence of search environment on chosen method(s) (above) effectiveness												
Woods	○	●	○	●	●	○	◍	○	○	●	●	◍
Rural	●	●	●	●	●	●	●	●	●	●	●	●
Urban	◍	○	○	◍	◍	◍	○	○	◍	○	◍	○
Coastal	◍	●	●	●	●	●	○	◍	○	●	●	◍
Underwater	◍	○	○	◍	◍	●	○	○	●	●	●	○

Figure 3: A generalised overview taken directly from Pringle et al. (2012c, 2015) 'to indicate potential of search techniques success for buried target(s) assuming optimum equipment configurations. Note this table does not differentiate between target size, burial depth and other important specific factors'. The key provides the expected chances of success in a search for the methods. [1]Time post-burial dependent. [2]Water Penetrating Radar (WPR).



Key: ● Good; ◍ Medium; ○ Poor

Target(s)	Remote sensing		Site work								
			Water current modeling	Search dive teams	Specialist search dogs	Near-surface geophysics					Element analysis
Substrate type sand ○|○ mud	Photo-graphs	Infra-red				Seismology	Side-scan sonar	WPR	Magnetics	Metal detector	
Floating body(ies)	◍|◍	◍|◍	●|●	●|●	●|●	●|●	●|●	●|●	◍|◍	◍|◍	●|◍
Substrate body(ies)	●|●	●|◍	●|◍	●|●	●|●	◍|◍	●|●	●|●	●|●	◍|◍	●|◍
Below substrate body(ies)	◍|◍	●|◍	●|◍	◍|◍	◍|◍	◍|◍	○|○	●|●	●|●	◍|◍	●|◍
UXOs/IEDs	◍|◍	●|◍	●|●	◍|◍	○|○	○|○	◍|◍	●|◍	●|●	●|●	○|○
Weapons	◍|◍	●|◍	●|●	●|●	◍|◍	○|○	◍|◍	●|◍	●|●	●|●	○|○
Drug/cash dumps	◍|◍	●|◍	●|●	◍|◍	◍|◍	◍|◍	◍|◍	◍|◍	◍|◍	◍|◍	○|○
Illegal waste	●|●	●|◍	●|●	◍|◍	◍|◍	●|◍	●|●	●|◍	◍|◍	●|●	●|◍
Influence of search environment on chosen method(s) (above) effectiveness											
Rivers	○	●	○	●	●	○	◍	○	●	●	◍
Ponds	●	●	●	●	●	●	●	●	●	●	●
Coastal	◍	●	●	●	●	●	○	○	●	●	◍
Marine	◍	○	○	◍	◍	●	○	●[2]	●	●	○

Figure 4: Generalised summary taken directly from Ruffell et al. (2017) 'to indicate potential of search techniques(s) success for aqueous target(s) assuming optimum equipment configurations'. WPR = Water Penetrating Radar. The key provides the expected chances of success in a search for the methods.

Chapter Three

Methodology

3.1 Introduction

The research presented in this thesis aims to improve the overall success rate of detecting buried forensic targets, such as clandestine burials and weapons caches. This is intended to be achieved by consolidating existing knowledge and best practices within the profession. This thesis focuses on describing the necessary criteria and the algorithms that would need to be developed for a future development of a usable, open-source tool. It is anticipated that this will help those working with near-surface geophysics to make better decisions towards their choice of geophysical method(s) to employ in various buried target scenarios, but also to make the way decisions are made between practitioners more consistent. The methodologies which are described in this chapter form the approaches to creating an algorithm(s) which is later proposed to be implemented in an appropriate open-source software, most likely Python, moving towards practical development of the proposed system following submission of this thesis. These algorithm approaches include:

1. capturing what the experts expect each method will find for each given scenario and extract from this a judgment about the best choice for new scenarios. This is intended to form an ‘expert judgment’ element of the proposed tool.
2. capturing what routine field experience shows each method actually found in real cases. This is intended to establish an ‘experimental feedback’ element of the proposed tool.

The above approaches will then form a description of a proposed open source ‘detectability predictor’ tool which is intended to rank detection methods based on most to least suitable for the given target and environmental conditions.

The information collated in this chapter which is evaluated and discussed in later chapters is not intended to be a negative critique of the profession. However, as the problem regarding decision-making about which near-surface geophysical method(s) to use is complex, better consistency in choices is required. As a professional field using near-surface geophysics, more feedback about reasons for success and failure need to become a routine part of all work conducted and thus this research is developing a mechanism to do so. It is necessary to be more critical about positive and negative responses, but also false positive and false negative responses and to provide scientific reasons as to what could have happened, why and how this can be corrected in future.

3.2 Questionnaires

Currently in practice it is normal to expect that a desk-based assessment is conducted prior to a search, to assess the potential of locating a buried target at a site without having visited the site or conducting any fieldwork. A desk-based assessment, also referred to as a desktop study, is accomplished by utilising aerial photographs, maps (e.g., geological, ordnance survey, historic) and any additional site data available to aid decisions about what methods are appropriate for the site. However, the fact remains that there is a lack of thorough feedback at the end of a geophysical survey that discusses the success and failure of the search conducted and scientific explanations as to what physical properties may have caused the phenomena.

To tackle the issues addressed above it was necessary to discuss with current practitioners their thoughts about the current state of research and technology available in this area, what they would like to see happen or change, and how they currently make choices about which detection method(s) to use. Additionally, it was important to understand their views on whether they would like to see a computer-based tool be developed to help decision-making regarding near-surface geophysics that also allow them to input their own findings. This was established in two parts: 1) a questionnaire was distributed to practitioners in the field to gain an overview of the profession and 2) a second questionnaire was distributed with specific scenario-based examples for the participant to score each method on how well they believe it would work in the given scenario (1 = does not work to 5 = very good, adapted from Schultz and Martin, 2011). This study received ethical approval from Liverpool John Moores' Research Ethics Committee reference 17/NSP/002 on 26th January 2017. The request for participants to be involved was emailed out to various professional bodies such as Chartered Institute for Archaeologists (CIfA), International Society for Archaeological Prospection (ISAP) and British Archaeological Jobs Resource (BAJR), as well as general calls on social media to reach a wider audience. This was to ensure that the responses received were as representative as possible of the collective profession.

3.2.1 Overview of the profession

A questionnaire was designed to establish the use of near-surface geophysical methods in forensics and associated fields such as archaeology. The aim of the questionnaire was to determine how consistently decisions are made with regards to the choices of geophysical methods to use in the search for buried targets in the near surface.

To be able to take part in the survey the practitioner had to meet all eligibility criteria which were set out in the participant information sheet (see Appendix 1). Questions to establish the expertise of the participants and gain a full understanding of their past experiences and education and whether they were suitable to participate in the survey as part of a vetting process were asked:

- Level of education and qualifications gained.
- Previous experience/education in near-surface geophysical methods and searching for buried targets.
- Current job role, department, and duration of employment with current employer.

The information collected from the above questions will remain completely anonymous and will not be featured in this thesis to protect the identities of the participants involved. Eight expert practitioners responded from the UK, one from USA and one from Australia, they were assigned a letter A-J for anonymity. Some participants opted to complete the survey as a questionnaire and others were interviewed via voice call with the responses being immediately noted and recorded by hand. Those who participated in the survey by voice call had to also complete a consent form (see Appendix 2) to ensure they were happy to participate, consented to be a part of the study and for the data to be used as described in the participant information sheet. This statement was also included at the beginning of the questionnaire version of the survey and by completing it agreed to the above statement. An example questionnaire can be found in Appendix 3.

To meet the aims of the questionnaire and this study several questions were asked to tackle key areas, see Table 3 which includes a justification for the questions asked in the questionnaire.

Table 3: A justification of why each of the questions were included in the initial questionnaire.

Question	Justification
How are decisions currently made with regards to which geophysical method(s) to use when searching for buried targets.	To understand how the practitioner is currently deciding what method(s) to use for a given search. Is the way they decide on a method(s) to use consistent for all sites, i.e., do they review the same types of resources to make an informed decision such as geology, aerial images, topographic maps, etc.
What information does the practitioner need before deciding on a search strategy, what data sources do they use and do they implement any modelling of the site e.g., computational, or numerical.	To discover what resources practitioners use frequently in order to aid their decision making which can then be considered as forming part of the proposed tool.
Examples of environments they have conducted geophysical surveys and have been successful in locating a buried target; how well did the chosen method work, were there any constraints on the search e.g., time and cost, any limitations of the method and would they repeat the search in the same way.	To observe if the practitioners have a range of experience of near-surface geophysics and surveying varying environments. How do they determine the success or failure of a search? What limitations should be considered and implemented in the proposed tool?
Can searches using geophysical methods be improved e.g., technology or decision-making.	To understand if the practitioners feel that the search for buried targets using near-surface geophysics is working or being used optimally or do they feel improvements could be made and if so, how?
Their thoughts on an open-source tool that would rank detection methods on a scale of most to least applicable.	To gain insight as to whether the proposed tool would be welcome by practitioners and to understand any reservations they may have about the idea.

The responses from the questionnaire were collated and evaluated to see if those who contributed had different opinions regarding current best practice, how they make their decisions and what could be improved when conducting a search. The data was used to help decide what data sources and search criteria would need to be included in the algorithms to be encoded in the proposed open-source tool and whether the practitioners would be interested in using it but also in adding knowledge to it.

3.2.2 Site specific detection

Following on from the first questionnaire, which provides an overview of the current profession, a second questionnaire was produced with the aim of qualitatively analysing each method based on its applicability in each scenario. The purpose of the questionnaire was to observe how each participant scores each method on how well it would work at the given site; how consistent the responses were between participants.

The scenarios were generated based on a preliminary model outline that reflects the intended functionality of the proposed tool (see Fig. 5). The components within the dotted line represent the input variables, which encompass various factors such as buried target, soil, land use, climate, and topography, as well as search constraints like time, climate, and vegetation. These inputs are intended to be utilised by a ranking algorithm(s) encoded within the proposed tool to generate outputs in the form of detectability maps and lists. The validity of these outputs would need to be confirmed through validation by conducting actual field surveys. This would work to provide evidence that the initial assumptions from the expert practitioners (those who complete the secondary questionnaire) about the targets and sites' physical properties are accurate, and the optimal tool or tool configuration will be used in the search. Equally, it could also inform that the assumptions are inaccurate and will need to be corrected in the algorithm(s) and reevaluated through further surveys to ensure they become valid. These new observations can arise from related research, experiments (both in laboratory and field settings), and practical experiences gained from excavations, archaeological investigations, and civil-engineering site studies.

The responses from the secondary questionnaires were collated to become part of the 'expert judgment' element of the algorithm which is intended to capture the efficacy of the methods based on the expectations of the experts on a scale of 1 to 5 (the scoring system is discussed later). The expectation of this algorithm (see Section 3.2.3 for description of the method 4.2.3 for analysis of the results) is to rank the detection methods in order of most to least applicable to survey the site in each scenario based on the participants' responses. This was established by requiring the participants to score each method independently of every other method. The questionnaire was devised by choosing eight different environments in the UK with varying geology, hydrology, topography, etc. and providing the target specifics such as burial depth, target, climate, and rainfall.

This study does not seek to redefine detection methods or their technologies, but to explore and improve the choices of detection methods by professionals. Part of the point of this study is to see how far the responsibility of choosing optimal near-surface detection methods can be devolved to a tool which everybody can refer to as a statement of best practice. This is intended to create an environment for future learning from which the profession will be able to improve its current practice and provide a rational, explicit basis by which current practice can be challenged by practitioners themselves.

Like the initial questionnaire, there were eligibility criteria which the participant had to meet which was set out in the participant information sheet (see Appendix 4). Mirroring the initial questionnaire, the same questions as above in 3.2.1 were asked to establish the participants' expertise and past experiences to ensure they were eligible to take part in the questionnaire. The personal data collected will not be featured in this thesis and will remain completely anonymous to protect the identities of the participants involved, each was assigned a letter from K-P.

Each of the eight scenarios are real locations situated in England, UK and each has a different environment (i.e., geology, soil, hydrology, topography, and land use) to allow a comparison of expert opinion on best method(s) to use between the different sites (see Fig. 6 for an example environment). The full questionnaire with all scenarios can be found in Appendix 5. The burial scenarios depict simplified clandestine burials of an average sized adult male i.e., no clothing or buried artefacts, to ensure that anything else that could potentially cause an anomaly in a geophysical survey would not influence the participants' decisions. The burial depth given is typical of clandestine burials found with bodies being typically buried at a depth of no more than 0.5 m below ground level (Hunter and Cox, 2013).

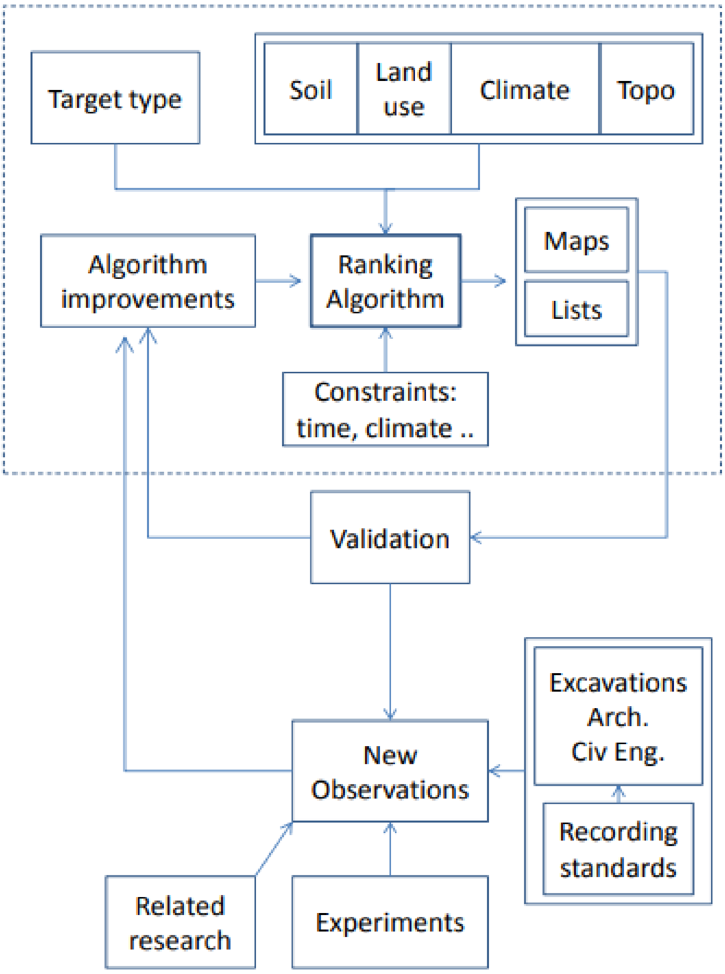


Figure 5: A provisional model schematic diagram of how the proposed open-source tool will work. The dotted line signifies what variables, however not limited to, will be included in the program and how the output is then validated through further research and experimentation.

Location:	Lancaster 54° 0'5.51"N 2°47'23.40"W
Geology:	Glacial diamicton, forming drumlins, over complex sandstones, siltstones, shales, mudstones and thin coal seams of the Upper Carboniferous coal measures. The till is stoney, containing well-rounded pebbles and cobbles of a broad metamorphic and igneous lithology.
Soil:	Cambic stagnogley of the Brickfield 2 association
Hydrology:	slowly permeable soil and parent material. Water ponding is reflected in redoximorphic colouring in the lower soil profile and archaeological sections.
Topography:	very gently sloping site on SW toe of a drumlin
Land use:	pasture

Figure 6: An example scenario from the questionnaire which provides the location of the site, the environmental variables (geology, soil, hydrology, topography, and land use) and the satellite images of the site with a second close-up aerial photograph. The placement of the burial is denoted with a silhouette of an adult human.

To gain as much information as possible from the responses, it was decided to include two different time since burial and two different climate situations that are at opposite ends of the ranges i.e., time since burial (six months and 5 years post-burial) and seasonal weather (summer and winter). The states of decomposition for the two different times since burial situations have been taken from research conducted by Schultz et al. (2006) using pig carcasses. The state of decomposition of the body six months after burial is described as having ‘extensive soft tissue preservation’ and the body five years after burial is described as ‘near complete skeletonisation of the body with some retention of desiccated skin and soft tissue of the torso’. Temperature and rainfall data have been taken directly from the long-term study by Pringle et al. (2016) and is typical of UK weather. Summer is described as an average of 50 mm monthly rainfall and average monthly temperature of 15˚ c and winter as an average of 150 mm monthly rainfall and average monthly temperature of 3˚ c. In all circumstances the fresh body was interred immediately following the grave being dug and refilled without delay.

Instructions to complete the questionnaire were provided by explaining the scoring system in place. The scoring system has been adapted from the scoring system used by Schultz and Martin (2011) for GPR surveys using 250 MHz and 500 MHz antennae for various forensic burial scenarios. Pringle et al. (2012d; 2016) later used this scoring system for ERI and different frequency antennae GPR systems (110 MHz, 225 MHz, 450 MHz, and 900 MHz). All three papers use a four-point system of none, poor, good, and excellent to describe the visibility of the anomaly in the geophysical profile for the respective survey (Table 2). The four-point scale was revised into a five-point scoring scale for the purpose of the scenario-based questionnaires. Rather than describing the visibility of a geophysical anomaly, this five-point scoring scale was created for the purpose of scoring how well the participant believed the method would work in each scenario searching for the specified buried target. Each method was scored on a scale of 1 to 5 (1 = does not work, 2 = very poor, 3 = poor, 4 = good and 5 = very good).

It was important that all the environmental variables for each of the scenarios was provided as some methods work better under certain conditions (e.g., dry/wet, sand/clay, etc.). Including this information allowed the participant to make an informed decision as to whether it would work in the ground conditions at the site in the scenario. The success of geophysical methods is dependent on multiple variables such as soil type and hydrology, and the difference of one variable could result in the method working optimally at that time or not. Equally, the stage of decomposition the cadaver is at will also affect how well the geophysical method will work. For example, as a cadaver decomposes it releases highly conductive fluids which will result in a low resistivity when employing electrical resistivity methods or reciprocally as an area of high conductivity using a conductivity meter. Whereas the increased water content in the soil can result in GPR waves being attenuated which could result in the target being ‘lost’.

3.2.3 Analysis of the scores

The results from the secondary questionnaire were initially collated in an excel spreadsheet as tallies to gain an overview of the data and obtaining an idea of the rank of the methods from the initial responses. The data in the excel spreadsheet was then revised into a single line of data to be converted into a comma separated value (csv) file with each participant being given an ID number from 1 to 6. Each following column in the file consisted of the site (denoted by a number from 1 to 8), the time since burial (TSB) of the target (A or B), season (S or W), and method within one column e.g., site 1, TSB A, summer and GPR became the heading 1ASGPR, and underneath each column heading was the score for that scenario given by each participant. The csv file was then ready to be read using a program written in Python. Python was chosen as this is the intended coding language to be used for the proposed open-source tool as it is easy to use, powerful, adaptable, and free (Doty, 2008). It is also the main programming language for geographic information systems (GIS) and can be used across multiple different platforms (Etherington, 2016). This will be beneficial for the future of the proposed tool as it is intended that resources from anywhere can be accessed and then imported into the algorithm.

The data collected from the secondary questionnaire will be used as a starting point for the code which encodes the ‘expert judgment’ part of the algorithm. This algorithm takes the collated data from the secondary questionnaire completed by expert practitioners to calculate what methods are most to least suitable for any given target and environmental conditions. The algorithm was developed by using the data collected by the author who explained the expected function (i.e., rank the detection methods in order of most to least suitable at each depositional environment) to Andy Symons, a member of the computing staff at Liverpool John Moores University, who then coded it in Python. Following submission of this thesis, it is intended that the proposed tool, should it be developed, will be open to responses and improvements by experts who are actively involved in forensic searches using geophysical methods. They would be invited to contribute in order to improve the algorithm based on expert judgment.

Writing the code is essentially giving the computer a set of instructions to follow to achieve the intended outcome, therefore before reading in the csv file created, the output headings needed to be enumerated so that it could be easily understood by anyone accessing the tool. The headings were enumerated down into the names of each of the sites (Lancaster, Nantwich, Aspatria, Sawley, Newborough, Berkhamsted, Crowborough and Saddleworth Moor), the methods (GPR, electrical resistivity, magnetic susceptibility, electromagnetics and magnetometry) and seasons with time since burial (summer 6 months, summer 5 years, winter 6 months and winter 5 years).

Once the output headings had been defined the code then instructs the data file to be opened and to read in the headings line along with the first line of data and then declaring and initialising the global variables i.e., user count = 1, qrlist (file data), results (the result count) and r2 (the scores). Following this, the three data structures to hold the above variables was coded. The first line of data was processed sequentially while inputting the data structure, to do this the data had to be split into a list for each site, each season/TSB, and each method, and then append the data to each other. To read in the next line of data from the file, the increment of the user count must be defined as +1.

The data was then processed into the counts for each scenario ensuring any zeroes were removed. Part of this step involves setting up the count results in a list for a method in each given scenario e.g., [0.0,0.0,0.0,0.0,0.0] and then storing them in the coding environment. User 4 data was removed from the algorithm at this stage as they are an expert in GPR and did not provide a response for the other methods which created a bias in the results. The scores were then worked out and stored in the r2 data structure by calculating the applicability of each method and the agreement between participants for each method. The overall score of the two above scores combined was not included in this thesis as it skewed the results and did not add anything useful to the collected data. The results were then output for each scenario by sorting the methods in the ‘overall’ score order.

The additional information provided in the comments box by the participants that chose to include this was taken into consideration when deciding what information was necessary to create a usable and realistic ‘detectability predictor’ for the proposed tool. Due to COVID-19 at the time of developing this code it was not possible to expand further on this element of the algorithm due to lockdowns and then latterly other external commitments but will be developed in the future following the submission of this thesis.

3.3 Study sites

Four contrasting sites were chosen to be examples to test the three most commonly used geophysical methods (GPR, ER in the form of ERI, and magnetometry) to observe which geophysical method would be deemed optimal at each site and also document the different environment and target variables, as would be done during a desk top survey, that could impact the effectiveness of the methods being employed. The four sites that were chosen are within a short travel distance of Liverpool John Moores University which meant that the sites could be surveyed without travelling long distances. As well as the sites being local and familiar to the author, they each had varying geology, topography and vegetation which were expected to provide contrasting results when using the geophysical methods enabling a comparison to be made about what was expected to work at each site (geophysical knowledge) and what actually worked or did not work. The sources used to determine the site properties were Digimap® which provided maps (geology, environment/land use, lidar) and aerial photography, and Landis Soilscapes which provided additional information about the soil (typology, texture, land coverage, drainage, and land use). The four sites are described below:

3.3.1 Taphonomic Research in Anthropology: Centre for Experimental Studies (TRACES)

The first site chosen to gather data to provide a basis for algorithm development and subsequent testing for the proposed tool is in Burnley, UK. This site forms part of the estate administered by the University of Central Lancashire (UCLAN) and has been surveyed regularly since 2018 for the purpose of this thesis to collect multi-period data and is described in more detail in 3.4. However, rather than using the site information recorded from survey, the above sources described have been utilised to replicate a desktop study prior to survey. The latitude and longitude of the site are roughly 53.764, -2.231. The site lies on slowly permeable, seasonally wet acid loamy and clayey gley soils formed in glacial diamicton, this soil type covers an estimated 8.2% of England and Wales, with a sandstone bedrock. As the soil is slowly permeable the drainage is impeded resulting in the upper soil profile maintaining wetness throughout the year. The site mainly is covered by grassland and forestry.

3.3.2 Yorkshire Moorlands

The site situated in the Yorkshire Moorlands is not far from the TRACES site in Burnley at about 53.746, -2.099 latitude and longitude. The soil is predominantly blanket bog peat which covers around 2.2% of England and Wales, with an upper and lower Kinderscout Grit sandstone bedrock adjacent to a Millstone Grit mudstone and siltstone bedrock, both of which are exposed in some areas. The site is covered by a naturally wet heather moor with flushes with a relatively high-water table, typical land use of sites with similar soils is for moorland rough grazing and forestry.

3.3.3 Formby

A grassed area of Larkhill Lane field dune slack in Formby (near Liverpool, England) was the third site to be studied located at around 53.560, -3.085 latitude and longitude. The soil at the site consists of blown sand with an underlying Singleton Mudstone bedrock. The soil is described as a naturally wet very acid sandy and loamy soil by Soilscapes which covers about 1.7% of England and Wales. Land cover consists of mainly arable, and horticulture use with some wet lowland heath.

3.3.4 Norris Farm

Norris Farm is a site situated on the outskirts of Formby at 53.565 latitude and -3.033 longitude. The soil at the site is described as loamy and sandy soils with naturally high groundwater and a peaty surface (covering around 1.3% of England and Wales) with a Singleton Mudstone bedrock. The site consists of mostly soil commonly used for agriculture by the farmer who owns the land.

3.3.5 Buried targets at the test sites

The targets chosen to be interred at each of the four sites were simulated clandestine pig burials, buried to around 0.5 m below ground level and a simulated forensic metal target composed of three steel rods buried to around 0.3 m below ground level. As described by Hunter and Cox (2013), clandestine burials have generally been located at no greater than 0.5 m deep in the subsurface, therefore this was the depth the burials were modelled at. This is more than likely due to the difficulty of digging a hole that is both long and deep enough to fit a body in it without exerting too much time and energy which may increase the chance of being caught in the act. Whereas, for the forensic metal target burials they have been modelled to 0.3 m as they are much smaller and easier to conceal in the ground. The Human Tissue Act (2004) regulates activities pertaining to the use of human tissue, due to this act it is not possible to bury human cadavers for controlled research purposes in the UK at the time of writing this thesis. To enable researchers to conduct forensic geophysical research involving the search for clandestine burials in the UK, pig carcasses are used as human proxies (Connor et al., 2018). However, due to the rules and regulations that surround the burial of biological material as defined by the Department for Environment, Food and Rural Affairs (DEFRA), it was not possible to bury pig carcasses at all the test sites. TRACES was the only site which had prior authority granted by DEFRA to bury biological material on site and therefore it was decided to bury a different forensic target at each of the other three sites. The pig cadavers that were being surveyed at this site had been buried since July 2018, 28 months, at the time of the surveys. A simulation forensic metal target was buried at each of the four sites which consisted of three steel rods 0.3 m in length at a depth of 0.3 m. It is expected that this will have slightly different properties compared to various real forensic metal targets (e.g., knives, handguns, rifles, etc.) as the volume, metal content, etc. will not be the same as well as the additional materials that will not be present such as plastic or leather which are often components of a handle for many forensic metallic weapons.

As previously described, the sites were chosen as they are easily accessible by car from the main research institute (Liverpool John Moores University) and in the case of TRACES it is protected from members of the public. The local climate at each of the sites is temperate which is typical for the United Kingdom, the average monthly temperature (° c) and total monthly rainfall (mm) for the date of the survey was collected from AccuWeather (https://www.accuweather.com) which the website states to have the largest and best collection of real-time data (see Fig. 7). This collection of weather data was used as there was no weather station set up locally on each of the sites at the time of the surveys taking place. It is understood that the data presented is not completely accurate for the specific site as there will be local variations in the weather within a short distance.

The facility at TRACES has three different areas of the facility which had already been set up for experimentation as part of the controlled research set up in 3.4 and it was decided to reuse one of the areas for the purpose of comparing to the other three test sites and adding further information about the site. The lowest site which is on a plateau closest to the entrance of the facility was chosen to be surveyed for this part of the thesis. The survey areas at the other sites were chosen due to their proximity to the entrance to the site as in theory the topography of the location would not be optimal to carry a body a long distance and then bury it without exerting a lot of energy.

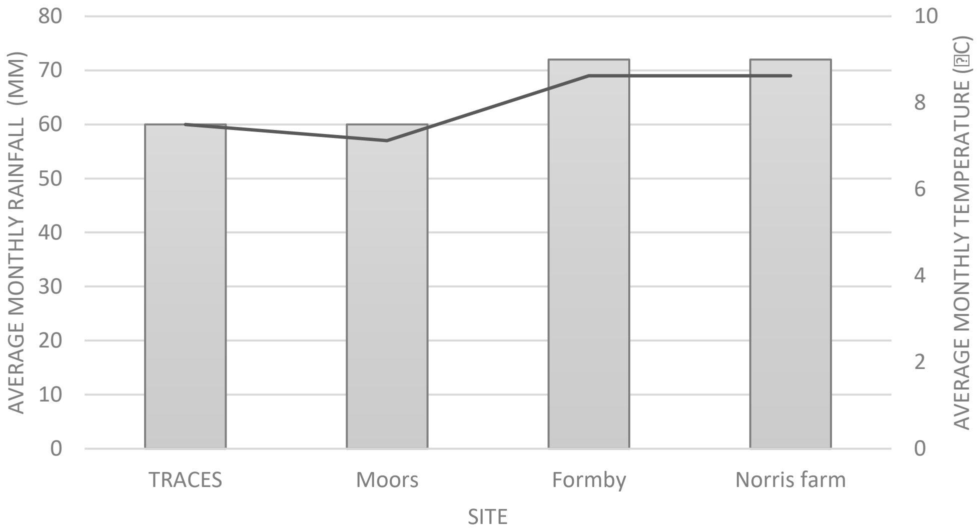


Figure 7: A summary of the monthly study site statistics for average monthly rainfall, mm (line) and average monthly temperature, ˚C (bars) data, from AccuWeather (https://www.accuweather.com) for Burnley for the month of November when the surveys were conducted.

While on site any site conditions which made the practicality of conducting the surveys more difficult were noted to be included in the criteria needed to be included in the descriptions of the experimental feedback element of the algorithm. This will be held as information for future searches at these sites and additionally will be used to improve the predictions of how the vegetation, slope, uneven ground, etc. affects how easily the geophysical methods can be deployed and/or how to affects the data collected during the survey.

3.3.6 Geophysical methods

Two survey lines were set up at TRACES and one survey line was set up at each of the other three sites using a tape measure. AT TRACES, the lines were 12.5 m in length and covered the lowest burial on the site with the control line set up about 2.0 m away from and parallel to the burials. Once the control line had been surveyed the simulation forensic metal target was then buried at the mid-point of the survey line to then be surveyed. At each of the other three sites one 12.5 m line was initially set up using a tape measure to collect the control data and then immediately after surveying the control line, the simulation forensic metal target was buried at the mid-point of the survey line and resurveyed.

The three methods used to survey each of the four sites were 250 MHz MALA GPR, Syscal Pro 72 switch electrical resistivity meter and a Geoscan FM18 50cm fluxgate magnetometer (with values in nT deflection in vertical magnetic field gradient), all of which have been described as the most used geophysical methods in forensics (see Chapter 2) and were readily available for use from the university resources. The four sites were surveyed, and the outcomes documented by simply comparing the pre-burial and post-burial surveys to observe whether an anomaly would be produced that would correspond with the buried target, therefore documenting a ‘detected or not detected’ criteria.

While on site considerations were made as to what variables needed to be included in the algorithms for the proposed tool. Variables such as practical or logistical difficulties (steepness, slippiness of surface, depth of vegetation, etc.) that impose on the speed and efficiency of each survey, and on the quality of data (e.g., rough terrain can produce a lot of swinging of the GPR antenna resulting in ‘noise’ in the data which reduces the detectability of weak targets). The site visits were carried out over two days, TRACES and Yorkshire Moors on 4th November 2020 and the Formby dune slack and Norris Farm the following day on 5th November 2020.

3.3.7 Data acquisition and processing

At each site, when surveying the forensic metal target, a control line was surveyed first using magnetometry, GPR and then ERI. The forensic metal target was then buried at the midpoint of the survey line and then surveyed again but using ERI first as it was already set up and ready then followed by either GPR or magnetometry. This was to ensure that the sites were being surveyed most efficiently and made the most of the time at each of the sites over the two days.

3.3.7.1 Electrical Resistivity Imaging (ERI) Data Acquisition and Processing

A 2D ERI survey line was set up along the tape measure at each of the four sites. The pre-burial ERI control surveys were carried out first to be compared with the post-burial survey profiles. The equipment used to carry out the ERI surveys was a Syscal Pro 72 (Iris Instruments) using 36 electrodes making use of two multi-channel cables and set the interval spacing to 0.35 m. This electrode interval spacing was chosen due to the comparatively small spatial size of the targets and the requirement to cover all three of the graves in one 2D survey profile (Pomfret, 2006; Dionne et al., 2010; Schultz et al., 2012). Rather than using the forensic standard expected interval spacing of 0.25 m, 0.35 m was used due to a fault within the Syscal Pro 72 which prevented the user being able to use more electrodes and also as a compromise between line length and spacing given the reduced number of electrodes. The electrodes were placed roughly 0.1 – 0.2 m into the ground at each interval and the survey was collected semi-automatically using the Syscal. Before each survey began the electrode contact resistances were checked so any abnormal resistances or lack of contact could be corrected. The electrode array used was dipole-dipole which is detailed in Chapter 2 with an explanation of how the process works. This is a commonly used array in forensic searches and has been documented in many literatures which can then be used as a comparison to the data collected here.

Following the survey being conducted the data was downloaded from the Syscal onto a computer using data acquisition software called Prosys which was used to remove data points which may skew the data and to export it in the correct format for processing. The data was imported to be processed and inverted into resistivity model sections using RES2DINV (Geotomo Software) which show the vertical and lateral resistivity distribution of the subsurface as 2D colour contoured models that correlate with low resistivity values (blue hues), to mid-range resistivity values (green and yellow/brown hues) to high resistivity values (red and purple hues). The inverse sections produced were displayed by applying user defined logarithmic contour intervals so that contours with the same resistivity value will have the same colour for easier comparison. The inversion error amongst the survey datasets ranged between 0.69% to 2%. Information pertaining to the physical properties of the sub-surface medium and the buried targets can be obtained from the inverse resistivity model sections produced.

3.3.7.2 Ground Penetrating Radar (GPR) Data Acquisition and Processing

Pre-burial and repeat post-burial GPR surveys were collected with the transmitter antenna leading for consistency as described by Pringle et al. (2012) along the same survey line over the tape measure. As discussed by Pringle et al. (2012) many published forensic case studies using GPR use a medium (200-500 MHz) frequency antennae (e.g., Nobes, 2000; Ruffell et al., 2009; Novo et al., 2011). Martin (2010) states that a 250 MHz antenna provides an increased penetration depth into the soil as compared to a 500 MHz antenna, the vertical subsurface resolution is lower, but can produce a better discrimination of forensic targets since it produces less false reflections by objects which are not the target of the search e.g., rocks, tree roots, pipes, etc. Therefore, a 250 MHz MALA GPR was employed which will discriminate small targets such as a burial and a forensic metal target but can also be compared to the published literature which states that medium frequency antenna will be successful in locating the forensic targets in this study and whether it is suitable for the environments being investigated. Following GPR data being acquired it was downloaded on to a portable USB device and uploaded into GPR Viewer (Conyers, 2024). This software was to enable the fast and simple processing of the GPR data which allows the user to re-gain profiles, remove background, change scales and convert times to depth. It is also possible to calculate velocity from hyperbolas and other common processing steps to produce images of the soil profiles.

3.3.7.3 Magnetometry Data Acquisition and Processing

Before surveying the sites using the fluxgate magnetometer it first required calibration based on the Earth’s magnetic north, south, east, and west fields. To verify the accuracy of the calibration and ensure proper balance, a test recording was taken without the forensic metal target and buried pig cadavers, providing a blank reading. The fluxgate magnetometer was then configured to acquire readings every 0.25 cm along the survey line, expressed in nT (nanotesla) as deflection in the vertical magnetic field. This frequency allowed for the detection of disturbances around the buried target site without generating an overly dense data set with all data being saved automatically to the magnetometer. The collected data was quantitative, and the raw data was originally stored as an Excel spreadsheet (see Appendix 6) and then converted into line graphs to allow for a visual analysis and comparison to be made.

Following the data acquisition and processing, the results were analysed to compare whether the outcomes were as expected or not, considering the scientific reasoning for positive and/or negative geophysical responses.

3.4 Multiperiod-controlled research data at TRACES

The multiperiod-controlled research conducted in this thesis refers to studies which were repeated at intervals, in this instance it was monthly. The studies were repeated so that results could be compared, and variations identified i.e., how the detectability of a burial changes over time and throughout the year and whether this produces similar outcomes as other multiperiod studies conducted by other researchers. This will show how the background and target electrical resistivity changes and how the combination of the two alters the detectability of the target. Additionally, any site conditions that affected how well the methods could be deployed (e.g., slope steepness, vegetation, trees, etc.) could also be noted and included in the algorithm. Following the observations from the surveys, the data collected will be used to form part of the ‘experimental feedback’ element of the proposed tool. Some of the information collated on the site will be used to define what information is required to create a pseudocode for the proposed tool which will include the variables that need to be taken into consideration so that reliable outcomes could be output by the tool.

Secondary to the main aim, the controlled research also provides additional knowledge in the search for clandestine burials and contributes to the increasing studies in this area. This knowledge can then be applied to real crime investigations involving searches for buried murder victims. During the 12-month monthly surveys the data produced can be observed and interpreted to answer additional questions:

- Can the geophysical methods used successfully locate all the simulated clandestine pig burials at each of the three different areas of the site?
- How long after burial are the simulated clandestine pig burials geophysically detectable?
- Is there an optimal time post-burial that the simulated clandestine pig burials were most detectable e.g., time since burial, seasonally, etc.?

3.4.1 Study site

The test site is located at the secured facility TRACES which is based in Burnley, Lancashire, UK. It is owned and managed by the University of Central Lancashire (UCLAN). The site was chosen as it is a controlled site which is easily accessible by car from the main research institute (Liverpool John Moores University) and is protected from members of the public. The local climate is temperate which is typical for the United Kingdom, the average monthly temperature (° c) and total monthly rainfall (mm) for the 12-month survey period for Burnley was collected from AccuWeather (https://www.accuweather.com) which is stated to have the largest and best collection of real-time data, they collect their data from ‘governments and partners; observations from land, ships, and aircraft; crowdsourced reports; satellites; and radar sets from 40 countries’. From this real-time data they use proprietary AI algorithms and meteorologist insights to provide the most accurate weather information. This collection of weather data was used as there was no weather station set up locally on site at the time of the surveys taking place. It is understood that the data presented is not completely accurate for the specific site. A graph showing the monthly data for the twelve-month period can be found in Figure 8.

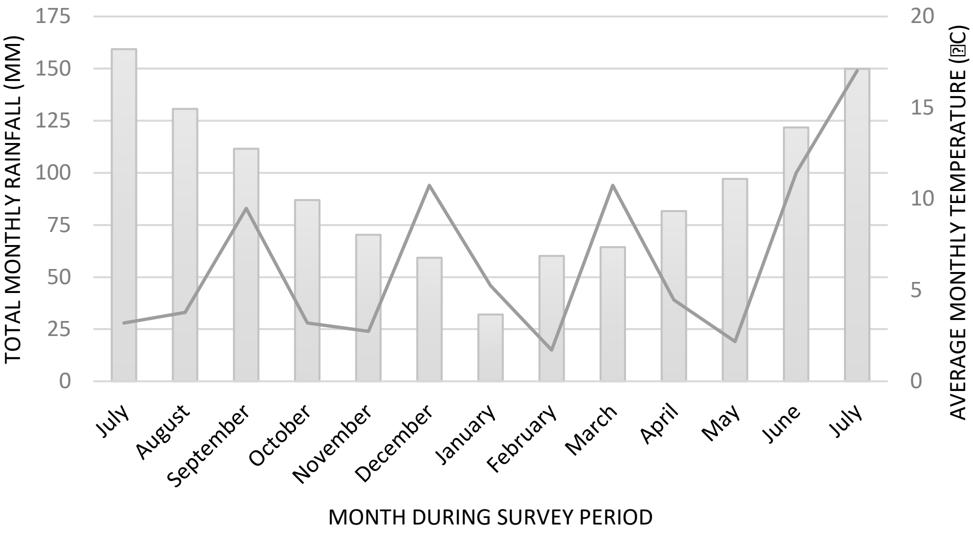


Figure 8: A summary of the monthly study site statistics of total monthly rainfall, mm (line) and average monthly temperature, ˚C (bars) data, from AccuWeather (https://www.accuweather.com) for Burnley over the 12-month study period.

In this study geophysical methods were tested on simulated clandestine pig burials in three different areas at the secured TRACES facility. All three areas are mapped as lying on a single solid and drift geology though variations in lithology across the site are expected to occur. Each area has contrasting slope, drainage, vegetation, and tree density. The site is formed on a slowly permeable seasonally wet acid loamy and clayey soil (Landis - Soilscapes) derived from the underlying Carboniferous sandstone Coal Measures. The site is consistent with the typical types of soils found in the previously glaciated UK, with Boulder Clay deposits of glacial origin, characterised by very compact stony, often silty-sandy, clays (Earp et al., 1961). The site generally has impeded drainage throughout due to the clayey nature of the subsurface which is very compact, lacking porosity and causes waterlogging in parts of the site, more so on the flatter areas of the site. The landcover is mainly grassland with some arable and forestry, the trees on the site were added to help with the drainage of the site. Prior to the controlled research taking place, two test pits were dug to about 1.0 m below ground level to evaluate the soils and soil hydrology of the site in December 2017. The test pits confirmed the information collected using geology maps from online resources were present on site (Digimap and Soilscapes). Table 4 and 5 provides the soil profiles of each of the test pits dug on site by Dr David Jordan, who is qualified and experienced to record such profiles as a trained soil scientist, along with the author assisting in digging the test pits and recording Dr David Jordan’s notes.

Table 4: the soil profile present in test pit dug on the intermediate slope of the facility on the same gradient that site two burial was created.

Sample	**Depth of lower boundary (m)**	**Colour 1**	**Colour 2**	**Colour 3**	**Texture**	**Structure 1**	**Structure 2**	**Structure 3**	**Wetness**	**Organic matter**	**Inclusions**	**Stones**	**Lower boundary**	**Comments**
1	0.05	Brown grey	Medium dark	Weak	Silty clay	Apedal	n/a	n/a	Very wet	Very humic	None	None	Clear	Slight H_2S smell
2	0.22	Brown grey	Light	Weak	Silty clay	Angular-blocky	Medium	Weak	Moist to wet	Slight	Occasional stones	Few	Sharp	
3	0.7	Brown grey (orange in patches)	Light	Variable	Silty clay*	Angular blocky	Medium	Weak	Moist	Non-humic	None	Abundant	Gradual	Strong redox over short distances
4	Not seen	Red brown, yellow	Medium	Weak to strong (very variable)	Silty clay	Apedal			Moist	Non-humic	None	Abundant	Not seen	Slightly weathered till parent material – contained coal fragments and cobbles

*predominantly silty clay, very variable with sandy patches where the sandstone is weathering

Table 5: the soil profile present in test pit dug on the plateau of the facility on the same gradient that site one burial was created.

Sample	**Depth of lower boundary (m)**	**Colour 1**	**Colour 2**	**Colour 3**	**Texture**	**Structure 1**	**Structure 2**	**Structure 3**	**Wetness**	**Organic matter**	**Inclusions**	**Stones**	**Lower boundary**	**Comments**
1	0.07	Brown grey	Dark	Weak	Silty clay	Apedal			Moist	Organic	None	None	Clear	Surface root matt
2	0.25	Brown grey	Dark	Weak	Clay loam	Granular, angular-blocky	Medium	Medium	Moist	Organic >80%	None	None	Sharp	
3	0.44	Brown grey	Light	Weak	Clay loam	Angular-blocky to prismatic	Medium	Weak	Moist	Slight	Abundant roots in cracks	Few	Clear	Zone of downwards incorporates of peaty organic material into parent material surface
4	0.95	Variable to grey with some brown mottles	Light to medium	Weak	Clay loam and some sand	Prismatic	Medium	Weak	Moist	Slight	None	Abundant	Gradual	Upper part of weathered till parent material
5	Not seen	Grey with some mid-orange/brown	Light	Weak	Clay loam to sandy clay loam	Apedal			Moist	Non-humic	None	Abundant	Not seen	

Rather than the typical open area used in a lot of controlled studies of this nature, the areas were intentionally selected as similar to those likely to be chosen to dispose of a body based on ease of access and concealment (Harrison and Donnelly, 2009). As argued by Nuzzo et al. (2008) it is necessary to conduct research over simulated clandestine burials in realistic conditions.

The three grave sites were dug in soils on a drier upper slope, an intermediate mid-slope, and a wetter lower plateau. This choice of site allowed us to test a range of geophysical methods under a range of conditions and geological compositions. Like the study by Cavalcanti et al. (2018) the burials were dug across the slope due to the downward slope in the northerly direction to reduce the possibility of the leachate plumes cross-contaminating between the burials. Each of the chosen sites are set away from the cleared path that runs across the site into the open field and are within the treeline which provides cover from observers. Figure 9 provides a GIS map of the site with the three areas of the site denoted with stars.

Plastic pegs and flags were placed at the start and end positions of the survey lines for each of the three sites orientated in an east to west direction. The survey line ran laterally across the middle of each grave and remained in place throughout the duration of the project to ensure the same positions were surveyed. The original survey line was 13.25m long, but after month 4 the survey line had to be shortened to 12.25m due to an equipment failure discussed later in the chapter. The mid-point of the original survey line was located before laying out the new shorter survey line to maintain the mid-point in the same place.

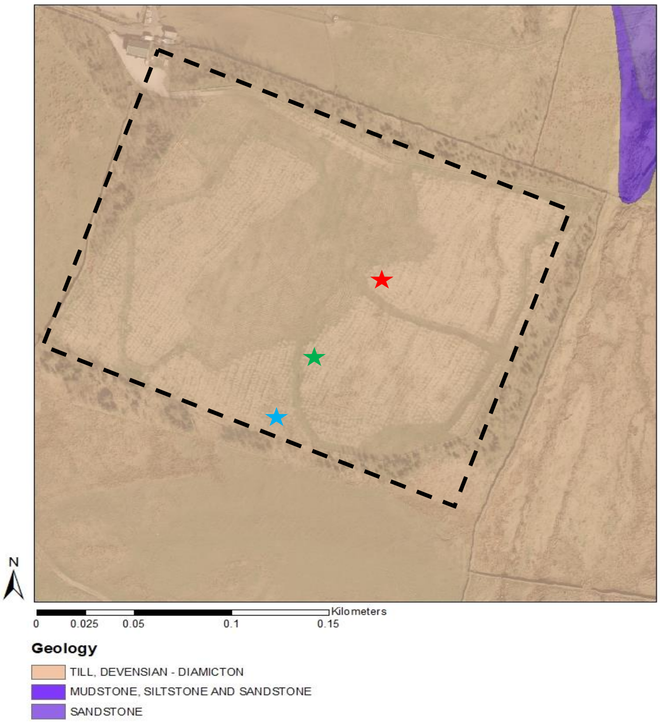


Figure 9: A GIS map of TRACES facility showing the boundaries of the site (dashed line), the soil type and underlying geology, the location of each of the three areas of the site where the graves were buried (stars; site 1 = red, site 2 = green, site 3= blue).

3.4.2 Simulated clandestine graves.

Clandestine graves are defined by Vass (2008) as being the result of “an illicit act where human remains are buried in hastily dug, shallow graves” which are generally unrecorded (Pringle et al., 2008; 2012). Pigs have been used in the study in this thesis, with the intention of not treating the pig carcasses as direct substitutes for human cadavers, but to observe the general trends produced by a decomposing carcass in the ground and the use of near-surface geophysics to detect it. In this study three simulated clandestine burials at each of the three sites have been dug to around 0.5 m depth below ground level and the dimensions are large enough to fit a pig carcass (Fig. 10) before backfilling with the excavated soil in the same way as Hunter and Cox (2013). The nine graves were dug using a mechanical digger due to the number of burials needed, the locations of the burials on the site and the difficult ground conditions for digging all burials by hand in one day. This potentially may have caused some isolated soil compaction due to mechanical excavation, but the effects should be minimal as the nature of the soil is relatively compacted.

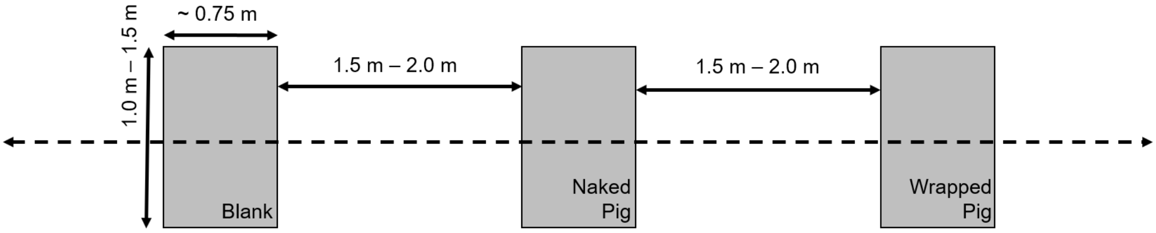


Figure 10: Schematic plan view diagram of the three graves, showing burial type and the orientation of the graves to each other. Space between graves differs between sites due to the difference in density of trees at each site. The dotted line relates to the geophysical survey line across the middle of the burials.

In this study, six pig carcasses were used to simulate buried murder victims, as the research was taking place in the UK the use of human cadavers was not permitted (Human Tissue Act, 2004). The pig carcasses were sourced from a local abattoir in the Northwest of England with prior permission granted by the UK’s Department for Environment, Food and Rural Affairs (DEFRA) to UCLAN to carry out this type of research at their site. The pigs had been euthanased the morning they were due to be buried in the ground by an Official Veterinary Surgeon using a captive bolt pistol to the head and bagged immediately to prevent early insect access (Cross and Simmons, 2010; Card et al., 2015). All pig carcasses were interred into the burials with their head at the north end of the grave. Following interment, the soil was redeposited using hand tools and tamped by standing on the soil which resulted in slight mounds remaining over the burials, any vegetation that was originally on the topsoil has now been mixed in with the redeposited soil. As the graves were all dug to the same depth and the pigs are similar in size, the amount of soil covering is at least close to being uniform. Table 6 provides the details for each of the burials at each of the three areas of the site including the pig weight and burial conditions. At each of the three sites there are three graves which involve the following:

- a blank control grave which is an empty grave that was backfilled with the excavated soil without interring a pig carcass in the ground.
- a naked pig carcass
- a pig carcass wrapped in tarpaulin.

As with the research conducted by Pringle et al. (2008; 2012), the two burial scenarios described above were used with the same understanding that there are other potential burial scenarios other than those used in this study, and this is not a true representation of all clandestine burial scenarios (Schultz and Martin, 2012). Cavalcanti et al. (2018) for example explored some alternative burial scenarios to those used in this study such as wrapping in a bed sheet, adding cement in the grave, adding hydrated lime to the grave, and adding construction debris on top of the carcass before reintroducing the removed soil. They discuss how the different materials that can be used to envelope a body can influence the rate of decomposition, but also alters the depositional environment. A blank grave was constructed for the purpose of acting as a control to the graves with a pig carcass interred, this follows a recommendation by France et al. (1997), but also in line with other literature on controlled research. Hunter et al. (2013) explains a control grave may be problematic as they may produce a geophysical anomaly that does not relate to a buried body; however, this should still be considered as it allows for a comparison of the geophysical anomaly produced by a grave with a body and that of a grave without.

This study allows for a comparison of the effect of the pig carcass being enveloped in tarpaulin to the pig carcass that is naked and the difference in rates of decomposition, however this will not be explored in this thesis. It is not possible to explore the differential decomposition between the burials in this study currently as the pigs have not been excavated at any point in the survey and continue to be interred in the ground for future surveys.

Table 6: Summary of each of the graves, the weight of the pig carcass interred in the grave (weighed prior to burial without tarpaulin) and the burial conditions; each grave number relates to the locations on the GIS map (Fig. 9).

Site number	Grave No.	Pig weight (kg)	Burial Conditions
1	1	N/A	Blank control grave
1	2	34	Naked pig
1	3	29.5	Wrapped in tarpaulin
2	4	N/A	Blank control grave
2	5	33	Naked pig
2	6	24	Wrapped in tarpaulin
3	7	N/A	Blank control grave
3	8	15	Naked pig
3	9	31	Wrapped in tarpaulin

3.4.3 Geophysical methods

A desktop study of the site was conducted prior to surveying, as would be done in practice to determine site and environmental conditions and from this to choose which method(s) would work best at the site. Given the clay-rich nature of the soil at this site, electrical resistivity (as ERI) was selected as the optimal method for this study. The literature review in Chapter 2 revealed that this method is particularly effective in clay-rich soils, as evidenced by the referenced studies.

Conversely, the literature indicated that GPR is less effective in such soil conditions, making it a less optimal choice of surveying clandestine graves in this environment. Additionally, the decision to use both ERI and GPR was supported by the availability of equipment for the entire survey period, ensuring comprehensive and consistent data collection. This enabled a comparison of the two methods against what the studies determined to be most and least effective in the soil type at this site. Table 7 provides the details of the monthly site visits including the date, days since burial and confirmation of the methods deployed each month. Information about the equipment used and the parameters that were implemented are discussed below.

Table 7: Dates of visits to the site with confirmation of ERI and GPR surveys being conducted (✓ = yes, X = no) showing time since burial, no surveys were conducted on month 0. * *For site 1 only*.

Month Visit	Date	Days since burial	ERI	GPR
Pre-burial	24/05/2018	N/A	✓	✓
0	20/07/2018	0	X	X
1	29/08/2018	40	✓*	✓
2	26/09/2018	68	✓	✓
3	17/10/2018	89	✓	✓
4	21/11/2018	124	✓	✓
5	12/12/2018	145	✓	X
6	23/01/2019	187	✓	✓
7	06/03/2019	229	✓	✓
8	20/03/2019	243	✓	✓
9	17/04/2019	271	✓	✓
10	22/05/2019	306	✓	✓
11	19/06/2019	334	✓	✓
12	17/07/2019	362	✓	✓

3.4.3.1 Electrical Resistivity Imaging (ERI) Data Acquisition and Processing

A 2D ERI survey line was set up between the two plastic orientation pegs mentioned earlier in an east to west direction. The pre-burial ERI control surveys were carried out in May 2018 to be compared with the post-burial survey profiles which were conducted at roughly monthly intervals beginning one month after burial (July 2018) for 12 months. It must be noted that no ERI surveys were able to be conducted for month 1 for site 2 and site 3 due to a fault with the equipment. The equipment used to carry out the ERI surveys was a Syscal Pro 72 (Iris Instruments) and for the first four months of the study 54 stainless steel electrodes were set up at 0.25 m interval spacing using three multi-channel cables and a connector switch box. However, following a fault in the Syscal which could not be repaired between survey dates, a decision was made to reduce the number of electrodes to 36, the number of multi-channel cables to 2 and increase the interval spacing slightly to 0.35 m. This reduced the survey line by 0.5m on each end as the mid-point of the survey line was maintained. The original 0.25 m and later 0.35 m electrode interval spacing was chosen due to the comparatively small spatial size of the targets and the requirement to cover all three of the graves in one 2D survey profile (Pomfret, 2006; Dionne et al., 2010; Schultz et al., 2012). The electrodes were placed roughly 0.1 – 0.2 m into the ground at each interval and the survey was collected semi-automatically using the Syscal. Before each survey began the electrode contact resistances were checked so any abnormal resistances or lack of contact could be corrected. The electrode array used during this study was dipole-dipole which is detailed in Chapter 2 with an explanation of how the process works.

Following the survey being conducted the data was downloaded from the Syscal onto a computer using data acquisition software called Prosys (Syscal software) which was used to remove data points which may skew the data and to export it in the correct format for processing. The data was imported to be processed and inverted into inverse resistivity model sections using RES2DINV (Geotomo Software; Loke, 2004) which show the vertical and lateral resistivity distribution of the subsurface as 2D colour contoured models that correlate with low resistivity values (blue hues), to mid-range resistivity values (green and yellow/brown hues) to high resistivity values (red and purple hues). The inverse sections produced were displayed by applying user defined logarithmic contour intervals so that contours with the same resistivity value will have the same colour for easier comparison. The inversion error amongst the survey datasets ranged between 0.84 to 4.6 %, the average inversion error was 2.32%. Information pertaining to the physical properties of the sub-surface medium and the buried targets can be obtained from the inverse resistivity model sections produced. It is imperative that the profiles produced are interpreted taking careful consideration of the underlying geology and how that impacts on the electrical properties.

3.4.3.2 Ground Penetrating Radar (GPR) Data Acquisition and Processing

Pre-burial and repeat post-burial GPR surveys were collected with the transmitter antenna leading for consistency as described by Pringle et al. (2012) along the same survey line between the two plastic pegs centred over the middle of the graves. Surveys were conducted from month one to the end of the survey period, excluding month five as no GPR survey took place due to a user error. As discussed by Pringle et al. (2012) many published forensic case studies using GPR use a medium (200-500 MHz) frequency antennae (e.g., Nobes, 2000; Ruffell et al., 2009; Novo et al., 2011). Martin (2010) states that a 250 MHz antenna provides an increased penetration depth into the soil as compared to a 500 MHz antenna, the vertical subsurface resolution is lower but can produce a better discrimination of forensic targets since it produces less false reflections by non-targets (e.g., possible rocks, tree roots, etc.). As a 250 MHz GPR was readily available to be used throughout the survey period on a regular basis, it was decided to use this frequency GPR in the field experiments conducted in this thesis. Additionally, in line with the findings of other published research discussed above it allowed for a comparison to be made as to whether this frequency antenna GPR would be suitable for this depositional environment.

Following GPR data being acquired it was downloaded on to a portable USB device and uploaded into GPR Slice for processing (Goodman, 2004), see Appendix 7 for a table of the processing steps followed. It should be noted that there are many other radargram signal processes that can be applied to process and amplify the data in the software, therefore the user should consult the GPR-Slice software user’s manual.

Following data processing of all the data collected during the multiperiod surveys, the results were analysed by simply observing the images produced, comparing them to the baselines that were carried out prior to the burials being created.

3.5 Detectability Predictor

Following the original provisional model schematic diagram of the proposed tool (Fig. 5), a description of a ‘detectability predictor’ tool was developed by utilising existing physical models, knowledge of important practical variables when conducting surveys such as slope steepness or vegetation density (e.g., tall heather on a moorland or abundance of tree roots above ground and crops pre-harvest) and the surveys conducted as part of this thesis. It is equally important to consider not just the geophysical variables, but those of practical importance when deciding whether it is possible or even worthwhile to conduct a survey. In addition to this, the cost and time required to conduct such surveys will be considered. Criminal investigations in the UK currently involve search strategists who will look to conduct searches that produce a high probability of successfully detecting the buried target while considering the most cost-effective way (Harrison and Donnelly, 2009).

Such a ‘detectability predictor’ might provide an initial platform to be refined following further surveys in a larger variety of sites across the UK with different substrates and underlying geology and, also a challenge to the profession to respond as to whether they agree or disagree with the pseudocode and the proposed tool.

3.5.1 Detectability predictor

The author, along with the support of Dr David Jordan, explored the potential structure and functions of a proposed ‘detectability predictor’ tool to observe whether such a thing might be feasible. The exploratory work is what is described in this thesis. Should it prove realistic a next step might be to develop code to turn it into a useable tool, however this is not part of this thesis since the key steps are to develop the idea and a description of how it might function. Firstly, an outline of how the tool might predict the success of detecting the buried target was created related to the way in which practitioners currently assess how well a specific method might work, based on elements which affect this. These elements were included a table of properties that was created that the code could draw information from (e.g., instrument sensitivity, targets, vegetation, and so on). From this a pseudo-code was created which obtains information about the target, its depth and location from the user and then uses a combination of data reference tables and maps to work out the detectability of the target using a set of geophysical techniques (GPR, electrical resistivity, magnetometry and conductivity).

The properties tables were created by the author by considering the different environmental and target variables that can affect the effectiveness of the detection methods in locating a target and defining them further, for example, the field conditions element includes sub-elements such as vegetation. This sub-element describes the way in which the nature and height of vegetation degrades the quality of the data gathered by specific survey methods. Tall vegetation, for example, disturbs the way in which a fluxgate magnetometer can be carried and thus adds noise to the magnetic gradient measurements. The properties table also includes information about the sensitivity of the equipment for each of the four methods for several instruments produced by different companies (e.g., Syscal, Tigre, Geoscan, etc.). Geophysical instruments created by different companies can have different characteristics which result in different sensitivities of the equipment. This is often less important if looking at electrical resistivity equipment than for magnetometry where the instrument noise characteristics are closer to the values that are often being looked for when conducting a search or survey.

The pseudocode starts with user inputs to define the following:

- target (from the properties table)
- the depth
- the location (from topographic map using perimeter tracing method)
- the vegetation (from the properties table)
- the surface (from the properties table)
- the soil/parent-material (from soil/parent material map from the location)
- calculate the slope angle (from topographic map using the location and slope calculator).

For each of the methods, the detectability of the target and the time required to survey the location was calculated assuming the measurement line spacing (interval spacing) was 0.5 m apart, this would also provide an estimate of the cost to conduct the survey for the user-defined environment and target. A separate set of calculations was performed to calculate whether the target would be detected using that method under the environmental conditions at the time of the search at each of the four sites.

Following the submission of this thesis, the proposed algorithm will be released to colleagues actively working in either archaeological geophysics or forensic geophysics for feedback on their thoughts about the pseudocode starting with a small number of colleagues for detailed comments. Following feedback and adjustment of the model it is intended that it will then be released to a wider, but still private, group before being produced into a working electronic version of the code to be assessed in the field. Following this thesis and the production of the tool to be assessed in the field it is intended that there will be a chance for longer term feedback and review.

3.6 Summary

This chapter has detailed the comprehensive methodologies undertaken to support the overarching aims of this thesis: to enhance the success rate of detecting buried forensic targets by producing the criteria for the design of a practical, open-source tool for the profession that is intended to integrate expert knowledge and best practices. The multi-faceted approach employed, including extensive surveying of practitioners, and investigating different ‘test sites’ with different geophysical methods, was designed to gather critical insights and data to inform the development of the criteria for the design of this proposed ‘detectability predictor’ tool.

The first key method involved surveying practitioners within the field of archaeological and forensic geophysics to gather their perspectives on the current state of research and available technology. By questioning practitioners, the intention was to capture a broad spectrum of opinions on existing methods, identifying both their strengths and limitations. This approach ensured that the proposed tool that may be developed is grounded in the realities of current practice and addresses the actual needs and challenges faced by professionals in the field. Additionally, the survey sought practitioners’ views on desired advancements and changes within the field, particularly regarding decision-making processes and method selection. This was crucial for understanding the future direction practitioners wish to see and for ensuring the proposed tool aligns with these expectations. The inclusion of these perspectives is vital for the tool's relevance and potential to be used by the professional community.

A secondary, more focused questionnaire was designed to qualitatively analyse the applicability of various detection methods in different scenarios. Participants were asked to score each method based on their perceived effectiveness at specific sites, allowing detailed and context-specific data to captured. This method was essential for understanding the practical performance and reliability of each detection technique, ensuring that algorithm outputs are based on empirical practitioner feedback. Furthermore, the method involved assessing the consistency of responses among different practitioners. This step was important for validating the reliability of the data collected and for identifying consensus or divergence in practitioner opinions. Consistent scoring patterns provide a robust foundation for the development of the proposed tool, ensuring that it will reflect commonly held views and reliable practices.

To complement the practitioner surveys, field studies were conducted at four different local sites using different geophysical methods (GPR, ERI and magnetometry). These methods were employed to gather empirical data on their effectiveness in different environmental and soil conditions. By comparing the results from these different geophysical techniques, it is possible to assess their relative strengths and weaknesses. This data is crucial for the proposed tool's detectability predictions, ensuring that it could be able to suggest the most appropriate method for specific site conditions, thereby improving detection success rates. In addition to the site surveys, a longitudinal study was conducted over twelve months, involving the burial of pig cadavers to simulate human decomposition and burial scenarios. This study provided continuous data on how two different detection methods (ERI and GPR) perform over time as the decomposition process progresses. By monitoring changes and detecting the pig cadavers at various intervals, valuable insights could be gained into the temporal aspects of forensic detection, which will be considered as part of the algorithms that may be encoded and integrated into the proposed tool to offer time-sensitive recommendations.

In summary, the methodologies, discussed in this chapter have been meticulously designed to gather comprehensive and relevant data to support the descriptions of algorithms that may be encoded as part of the development of an open-source tool aimed at improving the detection of buried forensic targets. Through detailed practitioner surveys, qualitative analyses, and empirical field studies, it has been ensured that the approach in this thesis is grounded in professional practice and responsive to the needs and insights of the forensic detection community.

Chapter Four

Results

4.1 Introduction

This chapter provides the results of each of the different elements that form this thesis. Firstly, the responses to the initial questionnaires were evaluated to observe practitioners' views on the application of near-surface detection methods, how they can be improved and how they felt about a computer-based tool to aid decision making. Secondly, the follow-up scenario-based questionnaire were assessed for applicability of each method in the given scenario and the agreement of scores for each of the methods between the participants. The data collected formed the 'expert judgment' element of the algorithm. The third part is reviewed by analysing the data collected using GPR, ERI and magnetometry at four contrasting test sites to observe the success or failure of the geophysical methods at detecting the buried target(s). The fourth part, multi-period data from controlled research utilising near-surface detection methods was evaluated to analyse the detectability of the buried pig cadavers over a 12-month period using two contrasting methods (GPR and ERI) across three areas of the site. Lastly, a description of the algorithms and network model were produced focusing on several critical factors including nature of the target, burial depth and nature of the parent material and soil.

4.2 Questionnaires

All participants had at least 5 years' experience using near-surface geophysical methods, at least a Master's degree in a related subject and currently working in the field actively using near-surface geophysical methods, therefore it was found that all participants were suitable to be involved in the study. There was a lack of uptake in participating in the questionnaires which may have been due to some reluctance among colleague to reveal their methods and discuss their limitations, this resulted in a limited response and outlook into the current profession, this will be discussed in further detail in Chapter 5.

4.2.1 Overview of the profession

Practitioners had conducted surveys in a wide variety of environments throughout their careers. From many places between John O'Groats and Lands' End in the UK and further afield in places such as Iceland, Ukraine, South Africa, USA, Mexico, and Australia to name a few. Their searches have varied from searching for Roman villas, Holocaust burials, historical buildings and WWI air shelters to toxic waste, unexploded ordnances, mass graves and clandestine burials. The fact that there are only a few practitioners who took part in the initial questionnaire, and they have worked in such diverse environments, means that while the collective experience in the profession is extensive, the amount of experience in detecting specific targets in specific environments is much more limited. This experience is likely concentrated in common environments and target types, thus limiting the opportunities for "learning by experience across the profession". Below is a summary of the responses from the practitioners to the questions in the survey.

How do you base your decisions on what detection method to use in a given environment, when searching for a specific target?

It was the consensus among most of the participants that their opinion on current best practice in relation to decision making was to conduct a desktop study or similar that takes into consideration the target (such as size/dimensions, depth, and physical/material properties) and the search area (for example, geology, topography, hydrology and size of the search area). By taking this all into consideration it should allow the user to “make an informed decision on what detection method would be best to search for the target, what detection method can identify the contrasts and deal with any sources of interference”, Expert I.

The set parameters of the method are also a factor to keep in mind, for example Expert B states “there is no point in doing a resistivity survey that looks 40 to 50 meters below the ground if the target you are searching for in the first two meters of the subsurface”. Expert G mentions that other things in addition to the above need to be factored in before conducting a search, such as, what is the budget for the search, how much time do they have, are there any risks (unexploded ordnances for example if working in high-risk areas) and what equipment is available. However, this was not the agreement for all participants as Expert F declared that they “generally apply magnetics first, followed by resistivity/conductivity, GPR and magnetic susceptibility”. Expert F then continues by stating their decision-making does depend on the situation and expected targets, but often base their survey design on previous archaeological investigations. Expert C concludes that in archaeological investigations a magnetometry survey is often the first technique to be used, but this is not always the best decision.

Unfortunately, in the experience of Expert E, decisions about which detection method to use is based on the availability of equipment due to funding being scarce in community geophysics and the cost of equipment being too high.

It was also not common practice among the participants surveyed to conduct numerical modelling or computational modelling of the site before the survey Expert H states their reasoning for this is that creating models leads to preconceived ideas which can bias the investigation process. However, Expert A would sometimes use a computational model after the search to validate findings when no excavation has taken place. Expert C proclaims that in commercial archaeology there is no time to be producing models pre- or post-survey, and as sites are often heterogenous it is not suitable to model a site before a survey as the information is not reliable. This opinion of modelling is also that of Expert D as they state that appropriate parameters cannot be accurately measured prior to a survey.

Sources of data frequently used by the practitioners included but not limited to; Google Maps, BGS maps, borehole resources, GIS databases, previous site investigations and any intelligence that could be obtained from locals, as Expert B states “never underestimate the knowledge of a local”.

How could searching for buried targets be improved currently?

As part of the desktop survey, it was the opinion of Expert J that a “much better appraisal of a site before starting the investigation should be conducted and to consider the science as well as the variability of the site and target. The constraints are different for each detection method, if it does not work in the environment being worked in then record why and record it properly”. Expert A, Expert B, Expert E and Expert I repeated this sentiment I specifically in their responses to this question. Expert A states that as a profession “we are moving to a stage were acquisition is getting increasingly rapid, and we are expected to cover larger areas of ground more efficiently than previously. What is lacking is some form of guide or interpretive framework that does not remove the human element of validation entirely”.

Other elements of the search that were suggested to be improved included:

- All equipment being GPS located.
- Improving the knowledge of the user of the equipment being used.
- Automating the use of equipment e.g., not being hand-held.
- Greater integration of technologies between disciplines.

The idea behind this research with regards to having a better understanding of why targets are detectable in the near-surface and being more critical of why a target is detected or not detected, including false positives and false negatives was also the opinion of Expert A in response to this question. Expert C believes that by making the reporting of what is considered ‘poor’ data more common i.e., where no geophysical response was detected or a false response was detected, it will challenge the status quo and allow more findings to be published in peer-review journals. Expert G agrees that a better understanding of the pros and cons of different technologies among practitioners would be beneficial.

The main constraints of a search are time and money. As Expert B asserted that “clients never want to pay more money than they think the survey is worth to them”. Expert C provided an example of a client who wanted real time data using GPR, so they had to mark potential targets with paint on the ground rather than doing a map report throughout. Another client of theirs kept changing the deliverables of the survey by increasing the length of the survey and ended up leaving the business before the survey was completed.

How well did your choice of detection methods work?

Expert B stated that in past searches where they have utilised geophysical methods, they chose methods which worked well as they undertook a thorough desk top study and fully understood the constraints of the site prior to doing the fieldwork. However, there was one example provided were GPR was used to determine the extents of a colliery spill which was not an optimal method to use due to the site conditions and the data was useless. It was not entirely a wasted day as other methods were employed, GPR was conducted as the opportunity was there to collect additional data.

There has been a mixed bag of successes and failures of detecting a buried target from the responses, especially in community geophysics whereas mentioned before the lack of funding and equipment reduced the quality of the survey in Expert E’s experience. Expert F who works in archaeological geophysics in USA found that frequently a magnetic survey provided the best results, however each technique has their usefulness. If they were to repeat the surveys, they would use the same method(s) again but would also try to incorporate other techniques where time allowed. Expert G’s search expertise is metal detection, so where searches for shallow metal targets has been conducted a metal detector has been effective. Expert H stated their methods worked well, they would repeat the survey in the same way and the reason for the success was because the method(s) work.

How do you feel about an open-source tool that would rank detection method based on the environment and target being sought?

There was a mixed review as to whether the participant thought the proposed tool was a good idea or could work with the very variable environments that can be experienced, especially in the UK. Expert D believes that implementing the tool into a GIS program may not be dependable enough (e.g., GIS does not manage well the all-important temporal dimension).

Expert B liked the idea that the tool would be open source, “software should not just be available for the big profitable companies”, but accessible by everyone who has a genuine use for the tool. This opinion was agreed by Expert E. Expert C would like to ensure that a proper representation of the data was included, i.e., not always the ‘best’ data but true data. They also had the ‘fear’ that people who could be considered the ‘problem’ in prospection will not engage in the tool. If the tool works as intended then it would be a great asset to have, especially if practitioners are open-minded enough to use it.

Expert F feels the tool could be helpful in general terms, as it may be an effective way to identify the use of potential methods over others, however each site is unique and needs to be taken fully into consideration. Environmental conditions can affect active methods daily making the selection of a single method difficult, one still needs the flexibility to change the methodology to meet the existing field conditions. Expert H feels the idea is very risky as each site is different and each will provide ‘surprises’. They advise to list the methods available, but not rank them as each provides different information about the site and target. In their experience they believe that practitioners should try everything and see what works best, to be led by the data and not preconceived notions.

Expert G states there is a conflict in providing training and ensuring there is a role in future work. This is the real dilemma, as the more people a current practitioner trains to conduct surveys, the more competition there is in the field and less work available for all. That is a commercial reality, as it is a limited field with limited work and as a current practitioner Expert G needs to consider how to stay at the top of the field. Expert I believe the tool will be useful, but a little worried it could be a bit of a ‘black box’, for example curators using the tool may just input the site and target information and look at the output without too much thought. Overall, Expert J feels the tool could be great and extremely useful if it works as intended.

Would you contribute to improving it in the future through experimentation, research and practice?

There was a resounding yes from all experts except for Expert C, Expert D and Expert G, who were either not able to due to their current role or had some reservations to contributing. For example, Expert D would contribute in principle, however, feels that the work to be done needs to be targeted and the fundamental science needs to be addressed and properly incorporated first. “There should be no short cuts or assumptions; there are already too many of them out there (the

HE and EAA guidelines being both a case in point)". Expert G would be involved providing that considerations to the points they made in the response to the previous question were made.

Despite Expert H's notions towards the idea of the tool in the above question, they would in fact be happy to contribute, "there is a lot more that needs to be done, for without understanding the processes you will always be guessing to some extent". As well as being involved in future, Expert I would be willing to put in their own data collected through their past research to help improve the tool and Expert J would specifically input GPR data which is this practitioner's speciality.

What would you like to see or happen from the proposed tool?

There were many different thoughts among the participants about what they would like to see happen from the tool but there was a general agreement about what they do want e.g., progress and change, wide involvement across disciplines and an easy interface with reliable outputs.

Expert B would like it to be a resource that anyone that is interested in searching for buried targets with near-surface geophysics can go to find what technique would be most applicable in the environment they want to search in. This is also the expectation of Expert E who would like to see people using it, especially those of different abilities to make use of it. A lot of geophysical searches, particularly in community geophysics, are done by amateur groups and their input could be useful.

Expert E would also like to see a large amount of data included, not just from research, but also from commercial work as part of the baseline data. That the output would be an easy enough interface for curators to get hold of the information they need, that the tool can be disseminated and continue to be contributed to. Following on from this opinion about the outputs, Expert D would want to ensure the tool includes reliable outputs that predicts the failure of the methods, not just the success of the method. They assert that success is "a subjective label based upon context at the point of commissioning, whereas methodological failure is always a failure. However, temporally, today's failure could be next week's success". Expert F's main concern is that such a problem could end up being the driving force rather than an aid to assist in investigations particularly in detecting buried archaeological resources.

Expert G, Expert H and Expert J would like to see a better understanding of the detection methods and their applications. Expert H would particularly like to see a better understanding of the fundamentals of anomaly formation in both a geochemical and geophysical context as this will allow for a better interpretation of results and increases success in detecting buried targets.

Do you feel the tool will benefit those who actively use near-surface geophysical methods to locate buried targets?

Overall, the general response was either yes, with the proviso of accurate data and guided decision outputs or potentially, with the proviso of flexible outputs being incorporated into the tool.

Expert B feels it will benefit those actively involved in the search for buried targets using near-surface geophysics, as people cannot know everything and having a resource as a go to would be great. Expert F agrees with Expert B and states the tool has the potential to be useful and affirms "one has to be aware that the investigators already perform these activities mentally before a project. While a tool may be faster at evaluations on a given set of variables, it lacks the experience of an individual”. Expert D claimed the tool can be beneficial provided adequate input data exists and the decisions are made with geophysical guidance, so their context and the tool’s limitations are understood. “Anything must be better than the current situation with archaeology”.

Expert C feels that the proposed tool will have negligible impact on commercial field archaeology as there has been little development or progression in the field since the 1980s, and with surveys costing less than they did (commercially) more survey work can be conducted.

How would you like to see funding used on improving survey practice for forensics and archaeology (or other disciplines using near-surface geophysical methods)?

Expert A would endeavour to ensure there is extensive training for people to use the equipment better and interpreting the data produced, ensuring users fully understand the limits of the methods. Expert H agrees with this statement and would like to see better education of practitioners as to what techniques are available, how to integrate them and best use of a combination of methods to achieve better outcomes more efficiently and effectively. Expert A continues to state that there is no real need for improvements of the equipment or methods themselves as the physics is all there, however Expert G disagrees and would like to see funding invested in the development of the current detection technologies.

Like Expert A and Expert H, Expert B also feels that by getting people to understand the fundamentals of what they are using and why they are using it to search for a specific target in a specific environment then it will improve their knowledge of applying the method(s) to future searches and when it is most useful.

Expert D would like to see funding used on research undertaking detailed geophysically-driven soils research across the agricultural, forensic, and archaeological sectors, developing benchmark studies and comprehensive and scalable sensing technologies. Expert F would like funding to be used on the education of potential practitioners as well as the establishment of a strong network where ideas could be developed.

In addition to the specific responses above, the participants would also like to see funding used on open-source software/hardware, education and research, wider multidiscipline involvement, equipment, and data interpretation training.

4.2.2 Site specific detection

The six participants who agreed to partake in the scenario-based questionnaire provided scores to each of the methods in each of the given scenarios, with five participants providing comments for some of the scenarios as to why they gave the score they did for each method and one participant (Expert L) providing an overview of using the methods in all scenarios. The scores and recommendations provided are based on the participants’ past fieldwork experience, knowledge of geophysical methods and/or understanding of the physical properties of soils.

Expert L stated that ‘given these scenarios involve the same spatial specification, i.e., a single-occupancy grave at the same depth of 0.5m, survey resolution does not significantly change across sites and scenarios although there may be differences in modes of deployment. The following notes describe the methodological logic behind the site-specific responses; the scores assume nothing beyond the information provided, except for the note about ploughing’. They would have preferred if an additional score option of ‘OK’ was provided between ‘good’ and ‘poor’. Their reasoning is that ‘’good' implies a certainty that might not exist whereas 'poor' implies it should be avoided. Something rated as 'poor' might be worth using anyway as a secondary technique and especially if the primary technique is only rated as 'good’’.

They provided an additional note about the sites which are arable and how ploughing can affect the detectability of the buried targets. The responses they have provided to the sites in an arable environment are assumed to have been ploughed or harrowed since both burial styles, as it was not stated if this was not the case. They provided an example in the scenario with a body six month since burial and a site which has not been ploughed since burial that the geophysical response would be different and therefore their scores for the methods would have been different. Additionally, they advised that for arable sites where ploughing or harrowing has occurred since burial that a field walking exercise should take place, even if conducted alongside a geophysical survey to search for surface evidence brought up by the machinery e.g., clothing shreds, bone fragments, etc. This is suggested that the body in the scenarios are buried at a depth of 0.5 m below ground level and plough machinery penetrates the subsurface to around 0.3 – 0.4m depth and could be a quicker way of locating the buried target.

Expert L would in practice not rely on only one method to successfully detect a buried target and isolate an area of interest and would typically use two methods, especially at sites where the target location is poorly constrained. They also state that ‘given that all these sites are fields, we would prefer to survey a minimum of 20m x 20m centred on the target location so that it is possible to quantify 'background' variation which may be larger than that due to the target’. They then provided comments for each of the methods and how they would deploy them generally and when they would expect the methods to work optimally.

GPR: unless the area to be searched is huge, Expert B recommend using a 0.25 m profile separation, 0.025 m along the survey line and allow for at least 1.0 m below ground level minimum penetration. They advise avoid using GPR over clay-rich soil, unless the grave is deemed to be filled with different material, using 250 MHz antenna over damp soil and 450-500 MHz antenna over dry soil. However, the response will vary as per the electrical resistance of the subsurface to some extent, although it will be more affected by raised soil moisture levels and the surface soils need to be dry to be most effective. It would be interesting to compare their results to the findings and thoughts to research conducted by de Castro et al., (2024) where they compared the influence of different sand-clay ratio of burial medium of forensic targets using GPR (between dry and rainy season data). This study found that, generally, the experimental graves containing 85% sand to 15% clay had the most favourable conditions when observing both dry and rainy seasons. However, when looking at specific burial types and sand-clay soil compositions the results varied (refer to de Castro, 2024, for more detail). Expert B states that summer surveys are more likely to be more successful than during winter at each of the scenarios at the eight sites and makes the difference between being able to locate a target successfully and not being able to for each of the burial types (6 months since burial and 5 years since burial). They state it will more likely be possible to locate a dynamic situation such as an active decomposing body as compared to skeletal remains. With reference to their comments above regarding ploughing, Expert L advises to align profiles along the direction of ploughing (direction of harrowing is subservient) otherwise the effect of the relative dielectric permittivity variations due to the topsoil movement will be difficult to reduce when processing the data.

Electrical Resistivity: Expert L recommends using a 0.5 m x 0.5 m resolution along with a 0.5 m twin pole array or a 0.5 m square array with both alpha and gamma configurations. They state that providing there is a moisture contrast between the target and burial medium this technique will work well, especially for detecting the grave fill. Therefore, they state it is invariably good on freely draining soils but poor on poor-draining soils if these also wet, e.g., in winter.

For example, in Scenario A (buried body, 6months since burial) the primary target is highly conductive decomposition products. In well-drained soil these may be lost so on the Quartz sand ridge (Site 3) results may be poor in all conditions, i.e., drainage is too good to retain much moisture in the subsurface and does not create enough of a contrast between the target and surrounding medium.

Magnetic Susceptibility: Expert L asserts that magnetic susceptibility would not be useful at any of the sites for any burial scenario or season. They mention that there is insufficient information to suggest surface post-burial soils to be significantly different than pre-burial. Additionally, they declare that ‘the survey resolution would need to be very high to detect meaningful lateral variation. A site ploughed since burial could not be meaningfully surveyed with this technique’.

Electromagnetic induction (EMI): Expert L did not seek clarification with regards to what was meant by EMI in the questionnaire and therefore assumed that EMI referred to the ‘quadrature electrical conductivity (ECa) component’. Their assumption was correct as the intention of offering EMI as a method in the questionnaire was to see how the participants scored the method based on exploiting the electrical properties, i.e., conductivity, of the subsurface and the buried target. For an EMI survey, Expert L recommends the use of a Slingram type instrument with coil separation of roughly 1.0 m. They then suggest survey best practice for using this type of instrument by proceeding with coil orientation inline, to permit a 0.5m crossline interval. If the land is in cultivation and especially if recently ploughed (and harrowed) then assume vertical dipole operation to decrease sensitivity to surface conditions. If not, then horizontal dipole can be used but if in doubt use both orientations. They state the technique works best in dry soils so is rated as poor if the soil is not free draining except in summer for Scenario A burial. In this scenario, so less than 6 months old and seeking conductive decomposition products rather than the disturbed soil of the grave, it is rated as good. For Scenario B the target is the grave fill and presumed differential moisture retention.

To reiterate, the aim of this part of the study was to qualitatively analyse the applicability of each geophysical method across various scenarios, focusing on expert participant perspectives and recommendations of each method’s effectiveness. The questionnaire asked participants to score each method on a five-point scale (1= does not work, 5 = very good) for its expected performance in specific conditions, which included two different burial durations (six months and give years) and two opposite climate scenarios (summer and winter). This approach allowed for a structured comparison of participant responses. Below are the results for each scenario presented as overall tallies for each score from all the participants (Tables 8-15), with the additional comments provided explain their thought process behind choosing the scores. Some participants provided more detailed comments than others, however any information provided was useful. The scenarios from the questionnaire are included as figures (11-18) with the accompanying site description.

Figure 11: Site 1 from the scenario-based questionnaire featuring a satellite image and an aerial photograph of the site, with the accompanying site description to the right. The body is symbolised with a silhouette of a human body.

Location:	Lancaster 54° 0'5.51"N 2°47'23.40"W
Geology:	Glacial diamicton, forming drumlins, over complex sandstones, siltstones, shales, mudstones and thin coal seams of the Upper Carboniferous coal measures. The till is stoney, containing well-rounded pebbles and cobbles of a broad metamorphic and igneous lithology.
Soil:	Cambic stagnogley of the Brickfield 2 association
Hydrology:	slowly permeable soil and parent material. Water ponding is reflected in redoximorphic colouring in the lower soil profile and archaeological sections.
Topography:	very gently sloping site on SW toe of a drumlin
Land use:	pasture

Table 8: A tally of scores for each of the methods at Site 1 for each of the different sub-scenarios, i.e., burial type A in summer, burial type B in summer, burial type A in winter and burial type B in winter.

Burial Type	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***
Season	**Summer**										**Winter**									
Score	**1**		**2**		**3**		**4**		**5**		**1**		**2**		**3**		**4**		**5**	
GPR				2	1	3	3	1	2			1	1	3	3	2	2			
ER				2		2	4	1	1			1		1	2	2	2	1	1	
MagSus	1	1		1	1	1	2	1			1	1	1	2			2	1		
EM		1	1	2	1	1	3	1				2	1	2	3		1	1		
Mag				1	1	1	1							1	1	1	1			

Site 1: Lancaster

Expert K suggests using a GPR with an antenna frequency between 400 and 900 MHz as they believe this will give the best results. Additionally, they propose using electrical resistivity with the probes mounted on a frame which will provide a fixed distance between the probes (constant separation traversing, CST), but they do not state which electrical array would be best. For both methods they recommend using 0.5 m and 1.0 m interval spacing. They mention that GPR would be used as complimentary technique to electromagnetic (EM) methods and magnetometry, as it would be very time consuming to survey the whole area. They explain that GPR and electrical resistivity methods would work less optimally during the winter due to the soil being saturated with water owing to the increased rainfall during these months.

Expert K endorses using EM methods and magnetometry at 2.0 m interval spacing over the site to gain a general understanding of what is detectable in the subsurface and if any anomalous features present themselves. This then allows the user to target the feature with other techniques. These methods will work particularly well if the buried body is wearing something metallic, or the body has decomposed enough to introduce iron into the soil which will change the soil composition slightly. It is expected that these methods will work well in both summer and winter months.

In comparison to Expert K who suggests using a mid to high frequency antenna, Expert M advocates the use of a low frequency antenna (110 MHz) GPR for this soil type and target. They state that providing good processing has been applied to the data (e.g. background removal) then useful data in clay-rich soils can be gained. Due to the soil type they do advise that the data quality will worsen with increased burial age but will work better during winter than summer. Expert K continues to confirm that the clay-rich soil will retain the decompositional leachates from the body within the grave cut which is highly conductive which can be readily detected using electrical resistivity methods. They suggest using CST surveys with the probes set at 0.5m distance apart, again like Expert K they do not provide an electrical array. It is worth noting that the decompositional fluids will only be present in relatively recent burials and the research conducted by Expert M shows that electrical resistivity methods do not work as optimally after 5 years post burial unless the body has been wrapped were the decompositional fluids are retained in the material for longer. Their data demonstrates that the winter surveys were more optimal compared to summer surveys which frequently picked up heterogeneous soil drying rather than the intended target. Electrical resistivity imaging (ERI) could also be utilised if the target location is good, then they suggest it would be worth collecting series of 2D profiles to gain more depth information more than a CST survey.

Expert M suggest that a magnetic susceptibility meter would be great to detect disturbed soil, but the anomaly detected due to the disturbed soil would decrease as the burial age increases and is not affected by seasonal variables. In their view they also believe that EM methods are generally not burial age or seasonal specific but do feel that a mini explorer would give better resolution than an EM31. Again, they also confirm that magnetic gradiometry would not be affected by the seasonality of the survey and if the body was buried with metal, then the equipment would be sensitive enough to detect it.

Expert N is a specialist in GPR and therefore only provided a score and comment on the use of GPR in each scenario. They are also from overseas and not familiar with the soils found in the UK, but still suggest that GPR would be possible to detect a body in both scenarios with a 250 MHz frequency antenna. They recommend starting with 0.5 m interval spacing to begin with when surveying a large area but would prefer to use 0.25 m interval spacing as looking for a relatively small target. They state that once the remains become skeletonised that detection should still occur due to the soil disturbance which was initially created when the body was interred in the ground i.e., ground disturbance.

Expert O provided scores for all the methods provided and states that lower scores given for the methods in scenario B is primarily due to the reduction in volume of the target between scenario A (6 months post burial) and scenario B (5 years post burial) because of the decomposition of the body. They provided comments for all methods except for electrical resistivity without any given reason. They endorse the use of a 900 MHz central frequency antenna as most suitable as a compromise for the target depth and resolution of the data. They state that EM would not be suitable for a single burial and is more suitable when searching for a bulk ground contrast e.g., a mass burial. Expert O states that magnetic susceptibility could be a useful method as it ‘has been used to demonstrate a significant geophysical contrast between grave soil and surrounding soil’. They further comment that the method does not detect the buried body itself, instead the magnetic contrast of the backfilled grave and the surrounding subsurface. For example, the backfill in comparison to the surrounding soil would have a lower magnetic susceptibility value and it is this contrast which is detectable.

Expert P begins by declaring that many of the specifications of the equipment (e.g., antenna frequency, electrical array, etc.) depends on the size of the survey area. As per the satellite image in Figure 14 the general location of the burial is known, which Expert P states that a relatively small area could be surveyed densely (i.e., small interval spacing). They expanded further by saying if the general burial location is unknown then the entire field would need to be surveyed which would require sparser surveys to be conducted (i.e., increased interval spacing between survey lines) due to the effort and time required to survey such large areas.

Figure 12: Site 2 from the scenario-based questionnaire featuring a satellite image and an aerial photograph of the site, with the accompanying site description to the right. The body is symbolised with a silhouette of a human body.

Location:	Nantwich 53° 4'16.15"N 2°31'31.55"W
Geology:	fine grained Holocene alluvium and adjacent till. The solid geology is Triassic Upper Keuper salt-bearing beds.
Soil type:	typical sandy gley of the Blackwood association grading into cambic gleys similar to Wigton Moor association
Hydrology:	moderately permeable soil and parent material with variable groundwater depth, on a largely flat site with some underdrainage. Water ponds within the soil profile.
Topography:	largely flat site on a low (2nd) river terrace

Table 9: A tally of scores for each of the methods at Site 2 for each of the different sub-scenarios, i.e., burial type A in summer, burial type B in summer, burial type A in winter and burial type B in winter.

Burial Type	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***
Season	**Summer**										**Winter**									
Score	**1**		**2**		**3**		**4**		**5**		**1**		**2**		**3**		**4**		**5**	
GPR		1			1	3	2	2	3				1	4	1	1	2		1	
ER		1	1	1	1	2	1	1	2				1	3	1		1	1	1	
MagSus	1	2	1		1	2	1				1	2	2	1						
EM		2	2		1	2	2	1				1	2	2	2	1				
Mag					1	2	1						1	1						

Site 2: Nantwich

Expert K explained that the gley soil would retain a lot of water which will prevent the propagation of radar waves and ‘disrupt’ the electrical resistivity values, both of which would cause the target to be ‘lost’ in the subsurface. The site is defined as having water ponding in the soil profile, due to this Expert K feels that both GPR and electrical resistivity methods should be avoided. Whereas they described that EM and magnetometry would be unaffected by the water content in the soil, especially as they do not touch the ground surface. They would work to identify the bulk ground properties and would work better during the summer months as there will be a more significant contrast in the ground conditions and the burial, however it should still be attempted in the winter months.

Expert M expects a medium frequency antenna GPR would be optimal at this site, particularly if the site is as described (i.e., moderately permeable and not clay-rich), however they would expect that the quality of the data collected would worsen as the burial age increases but would work better in the winter months rather than the summer months. They would also expect that electrical resistivity methods would also work best during the winter months, as again the surveys conducted during the summer months would detect the heterogeneous soil drying rather the target. They would also anticipate that this method would work better for more recent burials compared to older burials (e.g., like the burial described in scenario B) due to the decompositional leachate spreading from the grave being more detectable. Their comments about magnetic susceptibility, EM and magnetic gradiometry reflect those provided by them for Site 1.

Expert N, again, would prefer to use a 0.25 m interval spacing for surveying but would start with a 0.5 m spacing to survey a large area quickly using a relatively low frequency antenna GPR (250 MHz). They imagine that at this site that detection would be possible using GPR for scenario A, however, would be more difficult for scenario B particularly during the drier months (i.e., summer, albeit UK summers are not always dry). They expect that detecting the burial in scenario B could be possible where there is increased soil water content (i.e., during the winter months).

Expert O did not provide extensive comments for site 2 like they provided for site 1 and chose only to comment on GPR. Following the description of the site, Expert O believes that the GPR waves would be attenuated due to the water ponds present in the soil type which would create difficulty in locating the target successfully. However, they would expect a mid-frequency antenna GPR (450 MHz) would provide a compromise of gaining an appropriate penetration depth and resolution of the subsurface.

Expert P would provide the same considerations to this site as they did for site 1 and declaring that this would be a good environment for GPR to work optimally. Due to the ground conditions at this site, i.e., some underdrainage and moderately permeable soil, they expect these factors would result in minimal water retention and there would be a small EM anomaly if any. They anticipate there would not be much of a contrast for magnetometry to detect.

Location:	Aspatria 54°48'8.58"N 3°22'21.80"W
Geology:	Quartz sand ridge
Soil type:	typical brown sands of the Newport 1 association
Hydrology:	very well drained throughout due to high permeability
Topography:	gentle slopes and plateau
Land use:	pasture

Figure 13: Site 3 from the scenario-based questionnaire featuring a satellite image and an aerial photograph of the site, with the accompanying site description to the right. The body is symbolised with a silhouette of a human body.

Table 10: A tally of scores for each of the methods at Site 3 for each of the different sub-scenarios, i.e., burial type A in summer, burial type B in summer, burial type A in winter and burial type B in winter.

Burial Type	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***
Season	**Summer**										**Winter**									
Score	**1**		**2**		**3**		**4**		**5**		**1**		**2**		**3**		**4**		**5**	
GPR		1				2	1	2	5	1				2		2	4	2	2	
ER		1	1		1	3	1	1	2					1	2	3	3	1		
MagSus	1	2	1	1	1	1	1				1	2	2	2			1			
EM		2	2			2	3	1				1	1	2	2	1	2	1		
Mag						2	2							1	1	1	1			

Site 3: Aspatria

Expert K expects that both GPR and electrical resistivity methods would work well in these ground conditions, especially during the wetter months. Whereas it could become problematic during summer months due to the well-draining properties of the soil for resistivity meter readings. They would use EM and magnetometry to gain bulk survey data to locate any possible anomalies in the subsurface which would require further investigating.

Expert M reiterated some of the comments that they provided for site 1 and site 2, such as GPR data quality worsening with increasing burial age but surveys would be better in winter and electrical resistivity methods being able to detect recent burials better than older ones. They did not add anything different than they had already stated for the last two sites for magnetic susceptibility, EM and magnetic gradiometry. These comments are generally repeated throughout the remaining site scenarios.

Expert N repeated their preferences for interval spacing and antenna frequency when conducting GPR surveys as previously stated in their comments on the previous two sites. They presume that GPR would again work for both burial scenarios at this site but become more difficult to detect the body when skeletonised and the soil disturbance would be less detectable over time.

Expert O considers the geology at this site to be promising for GPR to work well and would expect a high frequency antenna, such as a 900 MHz, to be the best choice for surveys in both the summer and winter months. Then elaborated by explaining GPR would work better in the summer due to the reduced soil hydrology as during the winter when it is wetter it will result in GPR waves being more readily attenuated.

Expert P states that the site conditions would be ideal for GPR to work well as the drainage is described as better than site 2 and is also a generally flat environment which would mean the GPR would move smoothly across the soil surface. They expect that the site conditions are not optimal for EM or resistivity meters to work well and would be unsure what magnetometry would be able to detect in the subsurface.

Location: Sawley 53°54'32.22"N 2°20'42.81"W

Geology: Holocene alluvium and adjacent till. The solid geology is Early to Mid-Mississippian limestone

Soil type: loamy

Hydrology: freely draining floodplain soils, local groundwater feeding into river.

Topography: broad lowlands river valley

Land use: grassland some arable

Figure 14: Site 4 from the scenario-based questionnaire featuring a satellite image and an aerial photograph of the site, with the accompanying site description to the right. The body is symbolised with a silhouette of a human body.

Table 11: A tally of scores for each of the methods at Site 4 for each of the different sub-scenarios, i.e., burial type A in summer, burial type B in summer, burial type A in winter and burial type B in winter.

Burial Type	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***
Season	**Summer**										**Winter**									
Score	**1**		**2**		**3**		**4**		**5**		**1**		**2**		**3**		**4**		**5**	
GPR		1	1			4	3	1	2					3	3	2	2	1	1	
ER				2	1	2	1	1	3					2	3	3	2			
MagSus	1	1		1	2	2	1				1	1	1	2	1	1	1			
EM		1	1	2	2	1	2	1				1	2	3	1		2	1		
Mag				1	1	1	1						1	1		1	1			

Site 4: Sawley

Expert K would again use EM and magnetometry to conduct a reconnaissance survey of the site to quickly identify any features of interest to be targeted by other methods. They anticipate that due to the possibility of saturated soils during the winter that it would inhibit the collection of useable data when conducting GPR and electrical resistivity surveys, but summer would be fine.

Expert M explains that as the soil at this site is permeable and sand-rich it should allow a medium frequency antenna GPR to work well and detect any targets in the underlying subsurface. Again, they expect that electrical resistivity methods would work well for a recent burial and would be optimal during winter surveys. Comments regarding magnetic susceptibility, EM and magnetic gradiometry remain the same for this site as previous sites.

Expert N would continue utilising their preference for interval spacing for this site as they suggested for previous sites and expect that GPR would have difficulty at detecting targets in the loamy soils in both burial scenarios and would recommend using electrical resistivity instead. Expert O did not provide any comments for this site.

Expert P also stated that GPR would not work as well at this site, however the site conditions would be better suited for magnetometry and EM or electrical resistivity to an extent. They would also expect for the clay content in the loam to be detected by a magnetic susceptibility meter. Nevertheless, they continue by stating they are not convinced that any technique is optimal at this site.

Location:	Newborough 52°38'45.70"N 0°14'37.47"W
Geology:	Flandrian age alluvium with adjacent Nordelph peat, Oxford clay bedrock.
Soil type:	loamy and clayey
Hydrology:	floodplain soils with natural high groundwater, naturally wet
Topography:	flat lowland near sea level
Land use:	grassland some arable

Figure 15: Site 5 from the scenario-based questionnaire featuring a satellite image and an aerial photograph of the site, with the accompanying site description to the right. The body is symbolised with a silhouette of a human body.

Table 12: A tally of scores for each of the methods at Site 5 for each of the different sub-scenarios, i.e., burial type A in summer, burial type B in summer, burial type A in winter and burial type B in winter.

Burial Type	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***
Season	**Summer**										**Winter**									
Score	**1**		**2**		**3**		**4**		**5**		**1**		**2**		**3**		**4**		**5**	
GPR	1	2	2	3	2			1	1		2	3	2	1		2	2			
ER			1	2		2	1	1	3				2	3	1	2	2			
MagSus	1	1		1	1	1	2	1			1	1	1	2			2	1		
EM		1	1	1	2	2	1	1	1		1	2	2	2	1		1	1		
Mag					1	2	1						1	1		1	1			

Site 5: Newborough

Expert K expects the target to be difficult to locate due the field being ploughed. In the hope that the buried body had something metallic on its person e.g., jewellery, belt buckle, etc. they would use EM and magnetometry which would detect this. To resolve any features of interest they would then use GPR and/or electrical resistivity methods to complement the search.

Expert M anticipates that a low-medium frequency antenna GPR may work at the site, though as the soil is naturally wet and mostly saturated due to high groundwater it may prove to be problematic. Whereas the clay-rich soil would allow for the conductive decompositional leachates to be retained by the soil which enables electrical resistivity methods to detect the burial well. As explained for previous sites, this will work better for relatively recent burials and during winter surveys as the data quality worsens with increased burial age and summer surveys tend to detect the heterogeneous soil drying rather than the target. No additional comments were made for magnetic susceptibility, EM and magnetic gradiometry than were already noted for the previous sites.

Expert N also expects there to be limited detectability when using GPR and electrical resistivity should be used instead. Expert O agrees that electrical resistivity methods would be better suited for this site and recommends if deploying GPR then to use a medium frequency antenna GPR (450 MHz).

Expert P states that due to the wetness and high-clay content of the site that GPR would not work as optimally as it could, they suggest using a lower frequency antenna, but this will reduce the resolution of the data and the target could be lost. They believe that a magnetic susceptibility meter could be good at detecting disturbed clay from the process of digging the grave and they expect it would work better during summer surveys.

Location:	Berkhamsted 51°46'8.94"N 0°33'22.74"W
Geology:	Miocene to Pleistocene clay with flints formation, undifferentiated late-Cretaceous chalk bedrock
Soil type:	slightly acid loamy and clayey
Hydrology:	impeded drainage, drains to stream network
Topography:	broad valley bottom in low rolling hills
Land use:	arable and grassland

Figure 16: Site 6 from the scenario-based questionnaire featuring a satellite image and an aerial photograph of the site, with the accompanying site description to the right. The body is symbolised with a silhouette of a human body.

Table 13: A tally of scores for each of the methods at Site 6 for each of the different sub-scenarios, i.e., burial type A in summer, burial type B in summer, burial type A in winter and burial type B in winter.

Burial Type	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***
Season	**Summer**										**Winter**									
Score	**1**		**2**		**3**		**4**		**5**		**1**		**2**		**3**		**4**		**5**	
GPR	1	2	1	2	2	1	1	1	1		2	3	1	2	2	1	1			
ER				3	1	2	4							4	4	1			1	
MagSus	1	1		1	2	2	1				1	1	1	2	1	1	1			
EM		1	1	3	2		2	1				1	2	3	2		1	1		
Mag				1	1	1	1						1	1		1	1			

Site 6: Berkhamsted

Expert K would expect the conditions at the site, in particular the saturated soils, to impede quality data collection during winter surveys but believe that summer surveys would not be impacted. They would utilise EM and magnetometry to conduct a recon survey of the site to quickly locate any areas of interest to target further with other methods.

Due to the saturated soils at the site, Expert M states that a low to medium frequency antenna GPR may work but may experience problems such as wave propagation. With regards to electrical resistivity methods, they reiterate the comments they have provided for the previous sites, i.e., good for recent burials in clay-rich soil due to the retention of decompositional leachates and winter surveys would be better than summer surveys. Again, no additional comments have been provided for magnetic susceptibility, EM or magnetic gradiometry than what has been stated for previous sites.

Expert N expects that detecting the target using GPR will be limited, and electrical resistivity should be used in its place. Expert O anticipates there would be high contact resistance between the electrodes and the ground when using electrical resistivity as the ground would contact large soil particles such as cobbles and the lighter soil particles would be washed out by the drainage.

Expert P states that the site conditions would be too wet for GPR and to prioritise other methods such as magnetometry. They expect that the clay content in the soil may mask the detectability of any targets seasonally (i.e., summer vs. winter) for EM and electrical resistivity methods.

Location:	Crowborough 51° 2'42.74"N 0° 6'23.30"E
Geology:	Milocene to Pleistocene clay with flints formation, undifferentiated late-Cretaceous chalk bedrock
Soil type:	slightly acid loamy and clayey
Hydrology:	impeded drainage, drains to stream network
Topography:	rolling downland heath
Land use:	arable and grassland

Figure 17: Site 7 from the scenario-based questionnaire featuring a satellite image and an aerial photograph of the site, with the accompanying site description to the right. The body is symbolised with a silhouette of a human body.

Table 14: A tally of scores for each of the methods at Site 7 for each of the different sub-scenarios, i.e., burial type A in summer, burial type B in summer, burial type A in winter and burial type B in winter.

Burial Type	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***
Season	**Summer**										**Winter**									
Score	**1**		**2**		**3**		**4**		**5**		**1**		**2**		**3**		**4**		**5**	
GPR	1	2	1	3	3			1	1		2	3	1	1	1	2	2			
ER				4	1		2	1	2					3	3	2	2			
MagSus	1	1		1	2	2	1				1	1	1	2	1	1	1			
EM		1	1	3	2		2	1				1	2	3	2		1	1		
Mag				1	1	1	1						1	1		1	1			

Site 7: Crowborough

Expert K reiterated their previous comments that saturated soils during winter surveys will inhibit the collection of quality data using GPR and electrical resistivity methods, however summer surveys should be unaffected. Additionally, the repeated that they would use EM and magnetometry to carry out recon over the site to locate features of interest to be investigated further using other methods.

Expert M repeated a lot of the comments they had previously stated for the other site scenarios for each of the methods (GPR, electrical resistivity, magnetic susceptibility, EM and magnetic gradiometry). There was nothing new to add.

Expert N repeated that GPR would have limited success at detecting any buried targets at this site and electrical resistivity methods should be used instead, again there was no further comment than what had already been stated for previous sites. Expert O chose not to provide any comment for this site.

Expert P expects that it would be difficult to detect buried targets using GPR at this site due to the environment, they anticipate it would be tough to maintain ground coupling regardless of the geology. They advise other methods would be better suited for this environment such as EM and electrical resistivity methods, especially during summer surveys as the groundwater is expected to pool in the grave cut.

Location:	Saddleworth Moor, Hollin Brown Knoll 53°33'8.38"N 1°56'27.66"W
Geology:	Quaternary peat with lower Kinderscout grit bedrock
Soil type:	blanket bog peat
Hydrology:	naturally wet, drains to stream network
Topography:	dissected peat moorland plateau
Land use:	Moorland rough grazing and forestry

Figure 18: Site 8 from the scenario-based questionnaire featuring a satellite image and an aerial photograph of the site, with the accompanying site description to the right. The body is symbolised with a silhouette of a human body.

Table 15: A tally of scores for each of the methods at Site 8 for each of the different sub-scenarios, i.e., burial type A in summer, burial type B in summer, burial type A in winter and burial type B in winter.

Burial Type	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***	***A***	***B***
Season	**Summer**										**Winter**									
Score	**1**		**2**		**3**		**4**		**5**		**1**		**2**		**3**		**4**		**5**	
GPR	2	4	2	1			1	1	1		2	3	2	2	1	1	1			
ER		3	3	1	1			1	1			2	3	2	1	1	1			
MagSus	1	3	2		1	1					1	3	3	1						
EM		2	3	2			2	1				3	4	1			1	1		
Mag			1	1	1	2	1						1	1	1	2	1			

Site 8: Saddleworth Moor

Expert K is sceptical that any method would be successful in detecting a buried target at this site, as they claim that a surveyor has ‘got more chance of crawling around and finding the buried victims than you would with geophysics in this area’. They would still try using geophysics, possibly to test the limitations of the equipment, and would use tightly spaced grids.

Expert L suggested using a magnetometer due to the site consisting of blanket peat bog it is expected that background variation would be low allowing for the detection of small ferro-magnetic elements within the burial possible e.g. belt buckles, etc. They advise to use non-gradiometric total field measurements rather than gradiometric vertical component as it would have a slightly higher chance of successful detection.

Expert M is not convinced that GPR would be a suitable method at this site as the soil conditions are very wet and peaty. They also expect that any decompositional leachates would be lost in the saturated soil so electrical resistivity would not be a good method to use for older burials. They reiterated their comments about winter surveys being more optimal for this method than summer surveys due to the heterogeneous soil drying being more likely to be detected over the target. For the past sites they have suggested magnetic susceptibility as a possible suitable method to detect the soil disturbance of a grave, but it would be more difficult at this site due to the peaty subsurface. No new comments were provided for EM and magnetic gradiometry than had been for the previous sites.

Expert N was honest and advised they have no experience with surveying a peat bog with GPR, however they expect it would not work well for either scenario (A or B), regardless of the season the survey is conducted. However, Expert O believes that both a 450 MHz and 900 MHz frequency antenna would be successful at detecting the target at the site. In addition to this, they expect that electrical resistivity would be optimal as the high soil moisture content would support easy flow of an electrical current through the ground.

Expert P thinks that the terrain at this site would be the major issue rather than the soil itself when trying to detect the buried target. They state that due to the amount of ‘clutter’ present it could mask a grave response and would be particularly problematic for the grave in scenario B as the skeletonised remains would be too subtle to be ‘seen’ above the background noise of the survey.

4.2.3 Analysis of the scores

The python code used to analyse the data from the secondary questionnaire can be found in Appendix 8 with the output in Appendix 9. By analysing the scores (Tables 8-15) the applicability of each method (%) to the scenario as well as the agreement between the participants (%) was calculated, see Tables 16-23. As can be seen from the analysed score tables, the agreement of scores between the practitioners was variable across all sites, methods and burial scenarios. 100% agreement of scores between the practitioners was only seen four times.

For site 1 (Table 16), it was found that the methods to use at this site for a summer survey with burial A in order of applicability (high % score to low % score) were electrical resistivity, GPR, magnetometry, EM and then magnetic susceptibility. For a summer survey with burial B the methods in order of applicability were magnetometry, GPR, electrical resistivity and EM equally applicable and then magnetic susceptibility. For a winter survey with burial A the methods in order of applicability were GPR, electrical resistivity, magnetic susceptibility and magnetometry were equally applicable and then EM. Finally, for a winter survey with burial B the methods in order of applicability were electrical resistivity, magnetometry, magnetic susceptibility, GPR and then EM.

Table 16: the analysed scores for each of Site 1 for each scenario providing applicability of the methods (%), agreement between the participants (%) and the combined overall result (%). (*AP = applicability, AG = agreement*).

Scenario	***Summer Burial A***		***Summer Burial B***		***Winter Burial A***		***Winter Burial B***	
Method	**AP**	**AG**	**AP**	**AG**	**AP**	**AG**	**AP**	**AG**
GPR	79.17	50	54.17	50	45.83	50	29.17	50
ER	80	80	50	60	45	40	40	40
MagSus	50	50	43.75	50	37.5	25	31.25	50
EM	60	60	50	60	35	40	25	40
Mag	62.5	50	62.5	50	37.5	50	37.5	50

For site 2 (Table 17), it was found that the methods to use at this site for a summer survey with burial A in order of applicability (high % score to low % score) were GPR, electrical resistivity, magnetometry, EM and then magnetic susceptibility. For a summer survey with burial B the methods in order of applicability were magnetometry, GPR, electrical resistivity and EM equally applicable and then magnetic susceptibility. For a winter survey with burial A the methods in order of applicability were GPR and magnetometry equally applicable, electrical resistivity, EM and then magnetic susceptibility. Finally, for a winter survey with burial B the methods in order of applicability were electrical resistivity, GPR and magnetometry equally applicable, EM and then magnetic susceptibility.

Table 17: the analysed scores for each of Site 2 for each scenario providing applicability of the methods (%), agreement between the participants (%) and the combined overall result (%). (*AP = applicability, AG = agreement*).

Scenario	***Summer Burial A***		***Summer Burial B***		***Winter Burial A***		***Winter Burial B***	
Method	**AP**	**AG**	**AP**	**AG**	**AP**	**AG**	**AP**	**AG**
GPR	83.33	50	70.83	33.33	50	50	37.5	66.67
ER	70	40	65	40	40	40	40	60
MagSus	37.5	25	31.25	50	18.75	50	12.5	50
EM	50	40	45	40	35	40	35	40
Mag	62.5	50	50	50	50	100	37.5	50

For site 3 (Table 18), it was found that the methods to use at this site for a summer survey with burial A in order of applicability (high % score to low % score) were GPR, magnetometry, electrical resistivity, EM and then magnetic susceptibility. For a summer survey with burial B the methods in order of applicability were GPR, electrical resistivity, magnetometry, EM and then magnetic susceptibility. For a winter survey with burial A the methods in order of applicability were GPR, magnetometry, electrical resistivity, EM and then magnetic susceptibility. Finally, for a winter survey with burial B the methods in order of applicability were GPR and electrical resistivity equally applicable, magnetometry, EM and then magnetic susceptibility.

Table 18: the analysed scores for each of Site 3 for each scenario providing applicability of the methods (%), agreement between the participants (%) and the combined overall result (%). (*AP = applicability, AG = agreement*).

Scenario	***Summer Burial A***		***Summer Burial B***		***Winter Burial A***		***Winter Burial B***	
Method	**AP**	**AG**	**AP**	**AG**	**AP**	**AG**	**AP**	**AG**
GPR	95.83	83.33	83.33	66.67	58.33	33.33	50	33.33
ER	70	40	65	60	40	40	50	60
MagSus	37.5	25	31.25	50	18.75	50	12.5	50
EM	55	60	55	40	35	40	35	40
Mag	75	100	62.5	50	50	100	37.5	50

For site 4 (Table 19), it was found that the methods to use at this site for a summer survey with burial A in order of applicability (high % score to low % score) were electrical resistivity, GPR, magnetometry, EM and then magnetic susceptibility. For a summer survey with burial B the methods in order of applicability were GPR, electrical resistivity, EM and magnetometry equally applicable and then magnetic susceptibility. For a winter survey with burial A the methods in order of applicability were GPR, electrical resistivity, magnetometry, EM and then magnetic susceptibility. Finally, for a winter survey with burial B the methods in order of applicability were GPR, electrical resistivity, magnetometry, EM and then magnetic susceptibility.

Table 19: the analysed scores for each of Site 4 for each scenario providing applicability of the methods (%), agreement between the participants (%) and the combined overall result (%). (*AP = applicability, AG = agreement*).

Scenario	***Summer Burial A***		***Summer Burial B***		***Winter Burial A***		***Winter Burial B***	
Method	**AP**	**AG**	**AP**	**AG**	**AP**	**AG**	**AP**	**AG**
GPR	75	50	66.67	50	45.83	66.67	41.67	50
ER	85	60	60	60	45	40	40	60
MagSus	43.75	50	37.5	25	31.25	50	25	50
EM	55	40	50	40	35	40	30	60
Mag	62.5	50	50	50	37.5	50	37.5	50

For site 5 (Table 20), it was found that the methods to use at this site for a summer survey with burial A in order of applicability (high % score to low % score) were electrical resistivity, magnetometry, EM, magnetic susceptibility and then GPR. For a summer survey with burial B the methods in order of applicability were electrical resistivity and magnetometry were equally applicable, magnetic susceptibility, EM and then GPR. For a winter survey with burial A the methods in order of applicability were magnetometry, electrical resistivity, EM, magnetic susceptibility and then GPR. Finally, for a winter survey with burial B the methods in order of applicability were magnetometry, electrical resistivity, magnetic susceptibility, EM and then GPR.

Table 20: the analysed scores for each of Site 5 for each scenario providing applicability of the methods (%), agreement between the participants (%) and the combined overall result (%). (*AP = applicability, AG = agreement*).

Scenario	***Summer Burial A***		***Summer Burial B***		***Winter Burial A***		***Winter Burial B***	
Method	**AP**	**AG**	**AP**	**AG**	**AP**	**AG**	**AP**	**AG**
GPR	41.67	33.33	33.33	33.33	25	50	20.83	50
ER	80	60	50	40	45	40	35	60
MagSus	50	50	43.75	50	37.5	25	31.25	50
EM	60	40	35	40	40	40	25	40
Mag	62.5	50	50	50	50	100	37.5	50

For site 6 (Table 21), it was found that the methods to use at this site for a summer survey with burial A in order of applicability (high % score to low % score) were electrical resistivity, magnetometry, EM, GPR and then magnetic susceptibility. For a summer survey with burial B the methods in order of applicability were electrical resistivity, magnetometry, EM, magnetic susceptibility and then GPR. For a winter survey with burial A the methods in order of applicability were magnetometry, electrical resistivity, magnetic susceptibility, EM and then GPR. Finally, for a winter survey with burial B the methods in order of applicability were magnetometry, electrical resistivity and EM were equally applicable, magnetic susceptibility and then GPR.

Table 21: the analysed scores for each of Site 6 for each scenario providing applicability of the methods (%), agreement between the participants (%) and the combined overall result (%). (*AP = applicability, AG = agreement*).

Scenario	***Summer Burial A***		***Summer Burial B***		***Winter Burial A***		***Winter Burial B***	
Method	**AP**	**AG**	**AP**	**AG**	**AP**	**AG**	**AP**	**AG**
GPR	50	33.33	33.33	33.33	29.17	33.33	16.67	50
ER	70	80	60	80	35	60	30	80
MagSus	43.75	50	37.5	25	31.25	50	25	50
EM	55	40	45	40	30	60	30	60
Mag	62.5	50	50	50	37.5	50	37.5	50

For site 7 (Table 22), it was found that the methods to use at this site for a summer survey with burial A in order of applicability (high % score to low % score) were electrical resistivity, magnetometry, EM, GPR and then magnetic susceptibility. For a summer survey with burial B the methods in order of applicability were electrical resistivity, magnetometry, EM, then GPR and magnetic susceptibility were equally applicable. For a winter survey with burial A the methods in order of applicability were magnetometry, electrical resistivity, magnetic susceptibility, EM and then GPR. Finally, for a winter survey with burial B the methods in order of applicability were magnetometry, electrical resistivity, EM, magnetic susceptibility and then GPR.

Table 22: the analysed scores for each of Site 7 for each scenario providing applicability of the methods (%), agreement between the participants (%) and the combined overall result (%). (*AP = applicability, AG = agreement*).

Scenario	***Summer Burial A***		***Summer Burial B***		***Winter Burial A***		***Winter Burial B***	
Method	**AP**	**AG**	**AP**	**AG**	**AP**	**AG**	**AP**	**AG**
GPR	45.83	50	37.5	33.33	25	50	20.83	50
ER	80	40	60	60	35	80	35	60
MagSus	43.75	50	37.5	25	31.25	50	25	50
EM	55	40	45	40	30	60	30	60
Mag	62.5	50	50	50	37.5	50	37.5	50

For site 8 (Table 23), it was found that the methods to use at this site for a summer survey with burial A in order of applicability (high % score to low % score) were magnetometry, electrical resistivity and EM were equally applicable, GPR and then magnetic susceptibility. For a summer survey with burial B the methods in order of applicability were magnetometry, electrical resistivity, EM, GPR and then magnetic susceptibility. For a winter survey with burial A the methods in order of applicability were magnetometry, EM, electrical resistivity, GPR and then magnetic susceptibility. Finally, for a winter survey with burial B the methods in order of applicability were magnetometry, electrical resistivity and EM were equally applicable, GPR and then magnetic susceptibility.

Table 23: the analysed scores for each of Site 8 for each scenario providing applicability of the methods (%), agreement between the participants (%) and the combined overall result (%). (*AP = applicability, AG = agreement*).

Scenario	***Summer Burial A***		***Summer Burial B***		***Winter Burial A***		***Winter Burial B***	
Method	**AP**	**AG**	**AP**	**AG**	**AP**	**AG**	**AP**	**AG**
GPR	37.5	33.33	29.17	33.33	16.67	66.67	16.67	50
ER	45	60	40	60	20	60	20	40
MagSus	25	50	18.75	75	12.5	75	6.25	75
EM	45	60	35	80	25	40	20	60
Mag	50	33.33	50	33.33	41.67	66.67	41.67	66.67

4.3 Study sites

The four different study sites were surveyed using three different geophysical methods (ERI, GPR and magnetometry) to compare the methods to each other (which one identified the burials best) and to compare between the sites (which methods worked best at the different sites). Note, there were no pig burials at the Yorkshire Moors, Formby and Norris Farm sites due to DEFRA regulations so only forensic metal target burials were interred temporarily for the duration of the surveys. The results of those surveys are below.

4.3.1 TRACES

The original control line which was used throughout the survey period when conducting the multiperiod-controlled research at the site (see section 4.4 multiperiod surveys) was surveyed first as a control line for both the long-term pig burials at site 1 of the site and as the pre-burial line before the forensic metal target was buried.

The control/pre- burial ERI profile using dipole-dipole array for this site are shown in Figure 19A for comparison to the post-burial surveys. Following the forensic metal target being buried the ERI was carried out again to identify any changes in the electrical profile of the subsurface. At roughly 4.90 m across the survey line is where the forensic metal target was buried (Fig. 19B) and shows on the ERI profile as an area of slightly higher resistivity (yellow-orange hues) compared to the control line (green hues).

The burials (Fig. 19C) are located roughly at the following points along the survey line; wrapped burial 3.50 m, naked burial 5.95 m and blank control burial 8.00 m. The blank control burial can no longer be observed in the ERI profile after 28 months, whereas the wrapped and naked burials are still clear as areas of low resistivity (blue hues) compared to the background values. The wrapped burial has produced a smaller anomaly as compared to the naked burial.

The GPR radargram taken over the control line at TRACES showcased many weak hyperbolas throughout the subsurface (Fig. 20A), most likely to be stone/rock deposits evident of the glacial till geology present at the site. Following the forensic metal target being interred (Fig. 20B), it produced a stronger hyperbola at the location of where the forensic metal target was buried along the survey line. When observing the pig burials (Fig. 20C), only the naked pig produced an observable hyperbola compared to the wrapped pig burial and the control burial. The wrapped pig burial and control burial were not discernible against the background values in the GPR radargram.

The magnetometry data for the control line (Fig. 21A) showed an initial peak of high magnetometry and then steady readings across the length of the survey line, however when the forensic metal target burial (Fig. 21B) was situated and the magnetometry readings were repeated a new peak was produced up to 20 nT at the position of the forensic metal target burial. The peak was only small, but noticeable in comparison to the background readings. Whereas the readings over the pig burials (Fig. 21C) showed varying size peaks across the survey line, it was not possible at the time of this survey to take pre-burial readings as they had been interred for roughly 28 months. The peaks roughly coincide with the burial positions of the pigs.

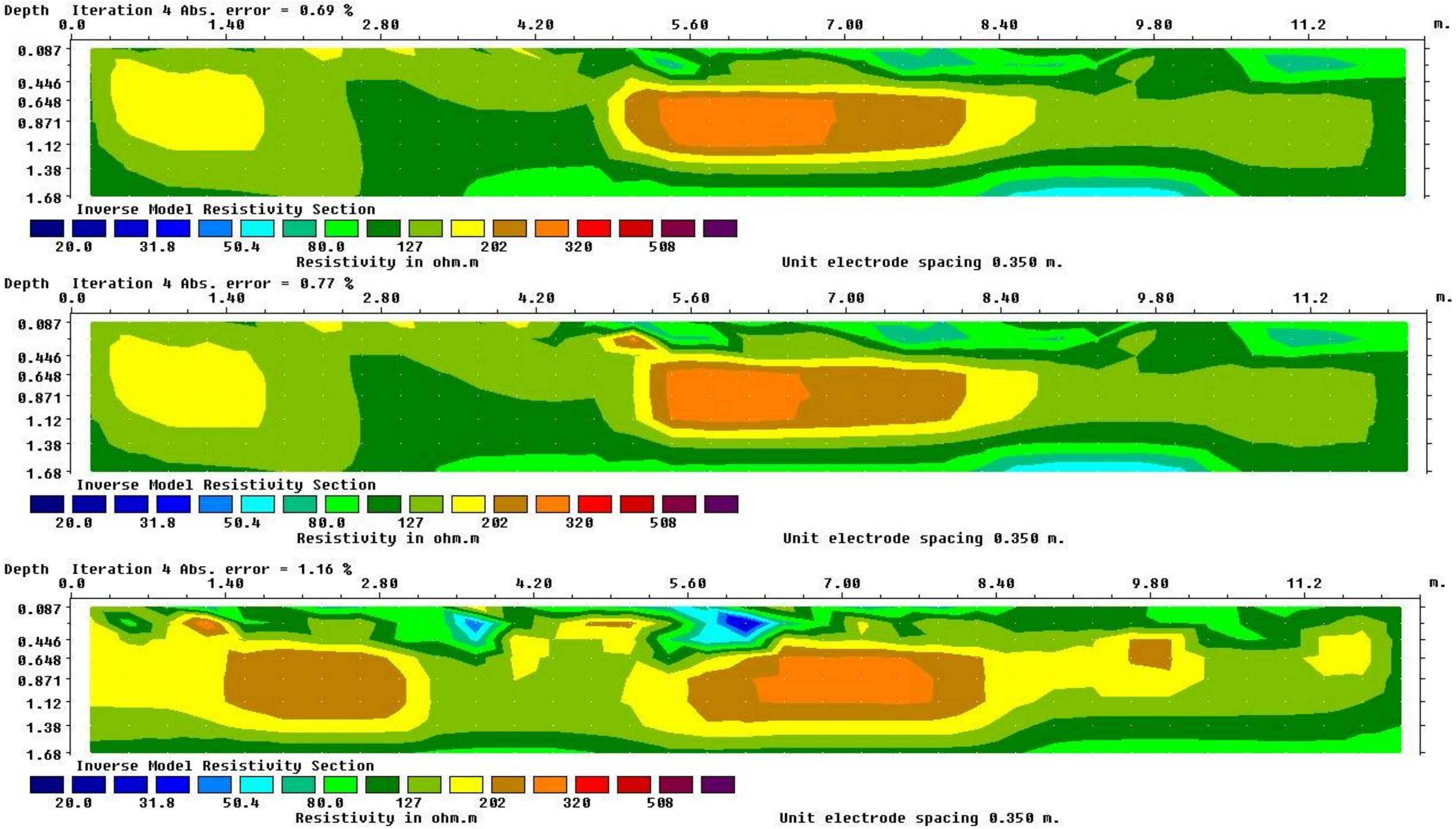


Figure 19: Site 1 ERI surveys at TRACES. A) shows a dipole-dipole array of the control line (pre-burial of the forensic metal target) which is situated about 2.0 m away from the burials B) shows a dipole-dipole array of the forensic metal target and C) shows a dipole-dipole array of the burials at twenty-eight months post-burial (wrapped burial 3.50 m. naked burial 5.95 m and the blank control burial 8.00 m).

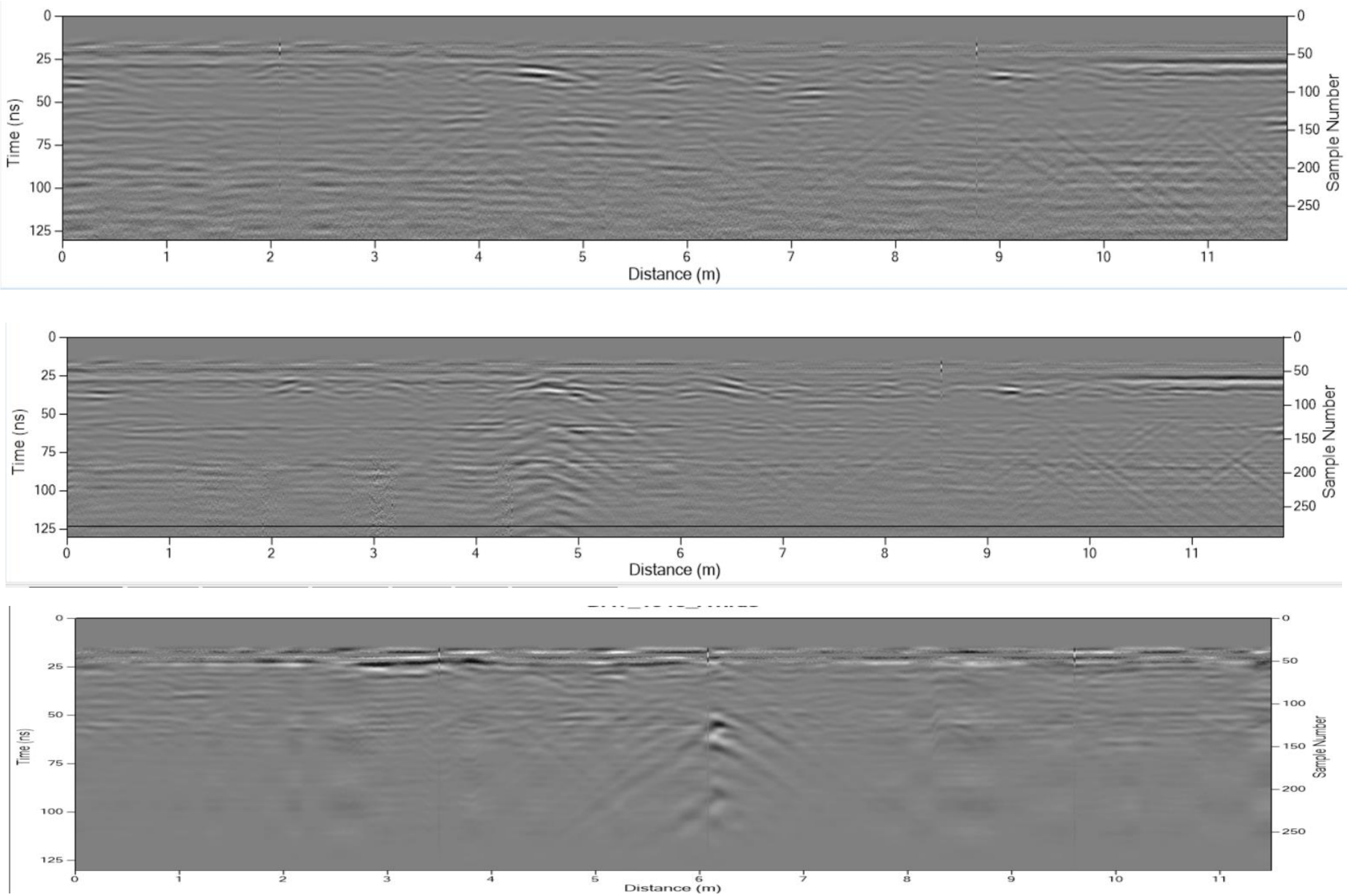
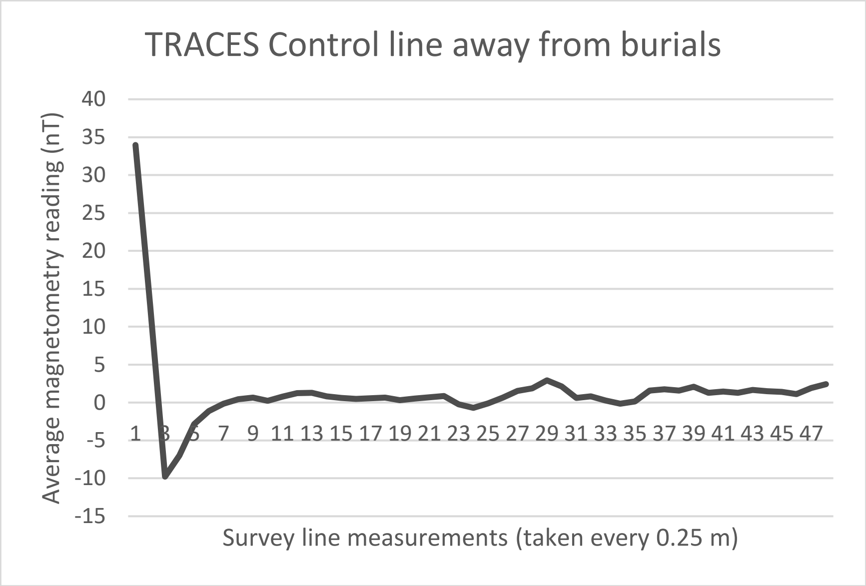
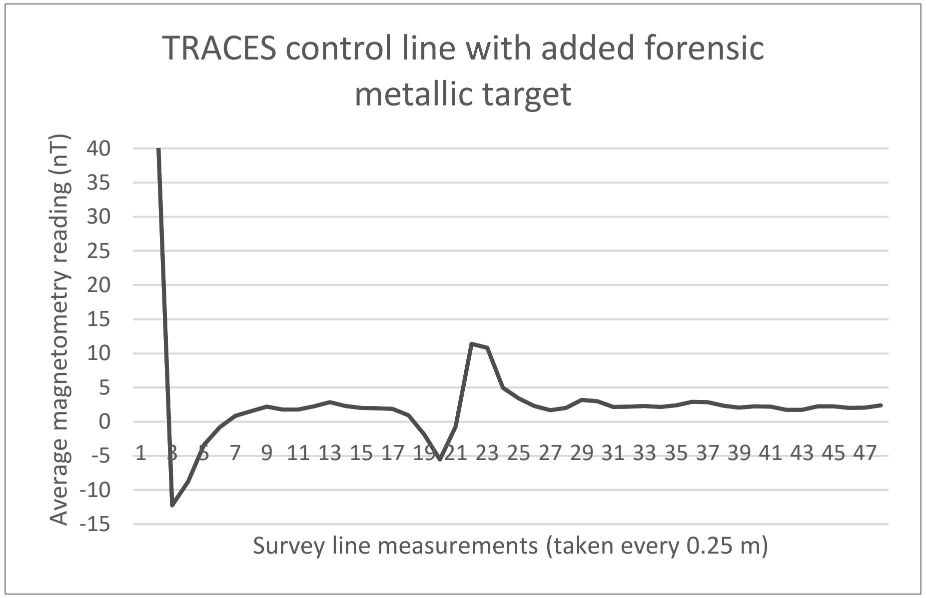


Figure 20: Site 1 GPR surveys using 250 MHz MALA GPR system at TRACES. A) shows the control line roughly 2 m away from the pig burials prior to the forensic metal target being buried B) shows the forensic metal target burial, the forensic metal target has been buried at roughly 5 m along the survey line. C) shows the pig burials at twenty-eight months post-burial (wrapped burial 3.50 m. naked burial 5.95 m and the blank control burial 8.00 m).





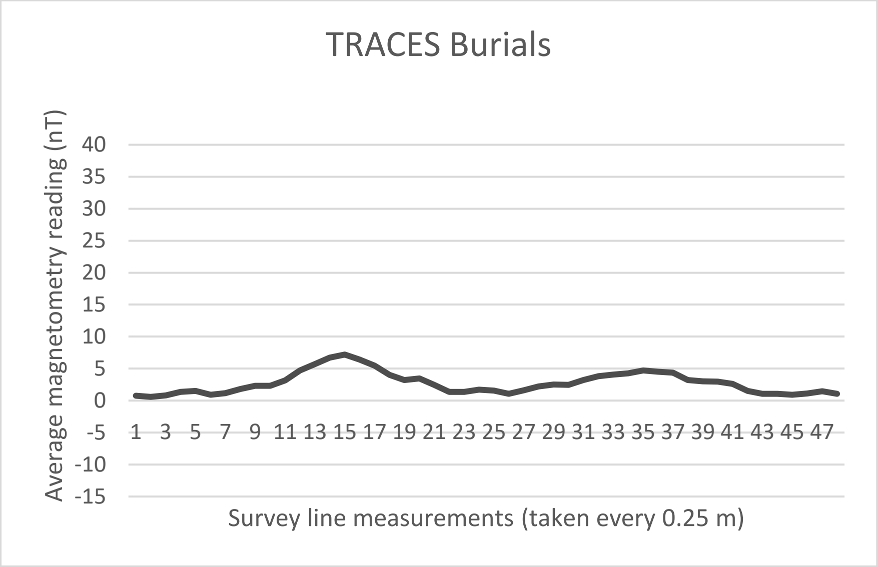


Figure 21: magnetometry surveys at site 1 at TRACES, A) shows the control line/pre-burial line, B) shows the control line following the simulated forensic metal target being buried and C) shows the magnetometry surveys over the pig burials 28 months after burial.

4.3.2 Yorkshire Moors

Whilst deploying ERI, the control line (Fig. 22A) produced a predominantly uniform subsurface with low resistivities (around 200-400 Ω.m with a slightly higher resistivity (around 600-1000 Ω.m) directly beneath up to around 0.65 m below the ground surface, then directly below this there was a much higher resistivity (roughly 1600-2500 Ω.m) which covered from 0.65 m to 1.70 m below ground level (the depth limit of the survey). Following the forensic metal target burial (Fig. 22B) being interred the background values remained consistent with the control survey, however there was a small anomaly produced at roughly 5.60 m along the survey line directly in line with where the forensic metal target was buried. It produced values of around 1500 Ω.m in the electrical resistivity survey.

When comparing the GPR radargram of the control survey (Fig. 23A) and the survey post-burial of the forensic metal target (Fig. 23B) there is a weak hyperbola produced which is barely noticeable at around 5 m along the survey line. Generally, the background in both surveys is quite noisy, similarly to the site at TRACES as they sit on similar geologies that often cause EM waves to be attenuated if the conditions are not ideal (i.e., wet and clay-rich).

The magnetometry data for the control line (Fig. 24A) similarly to the survey at TRACES initially produced high readings at the beginning of the survey line and were mostly unform across the survey line at around 4-6 nT. Whereas when the forensic metal target was buried (Fig. 24B) in the ground midway along the survey line it produced a slightly higher reading of around 8 nT, which in comparison to the background readings is not necessarily significantly different.

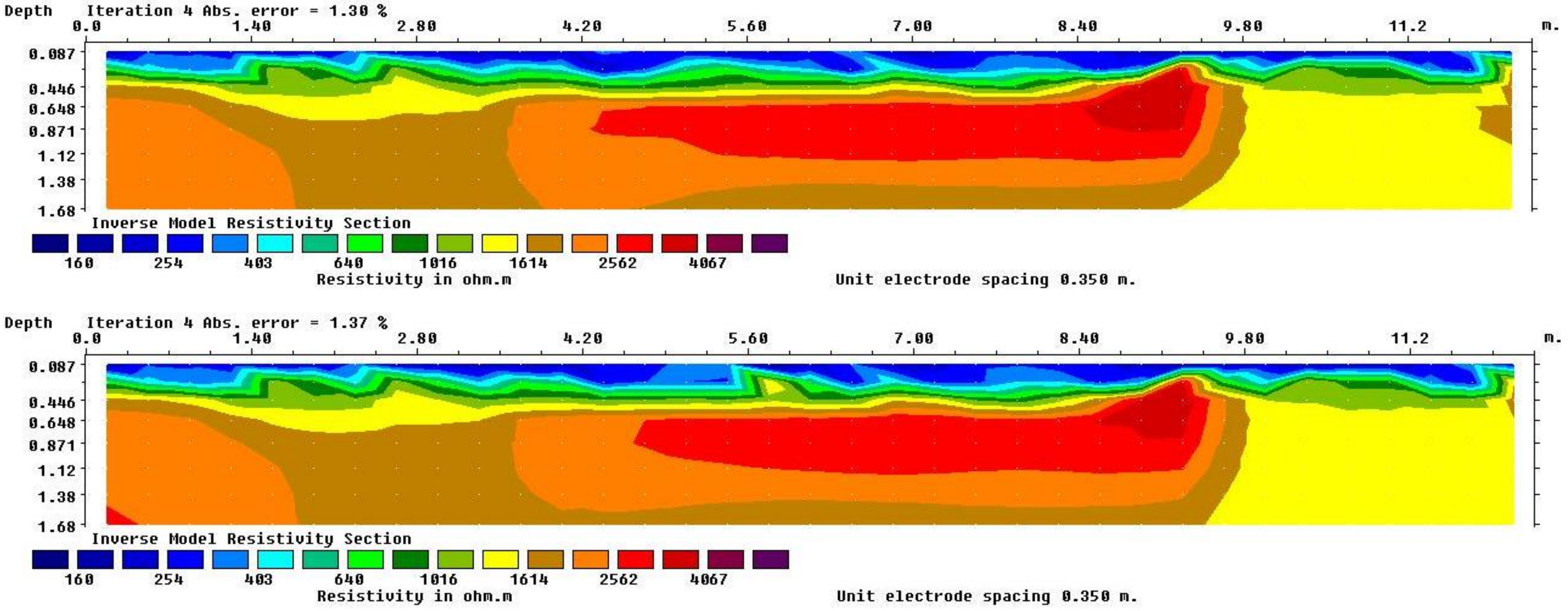


Figure 22: ERI surveys at the site located in the Yorkshire Moors. A) shows a dipole-dipole array of the control line (pre-burial of the forensic metal target) and B) shows a dipole-dipole array of the forensic metal target.

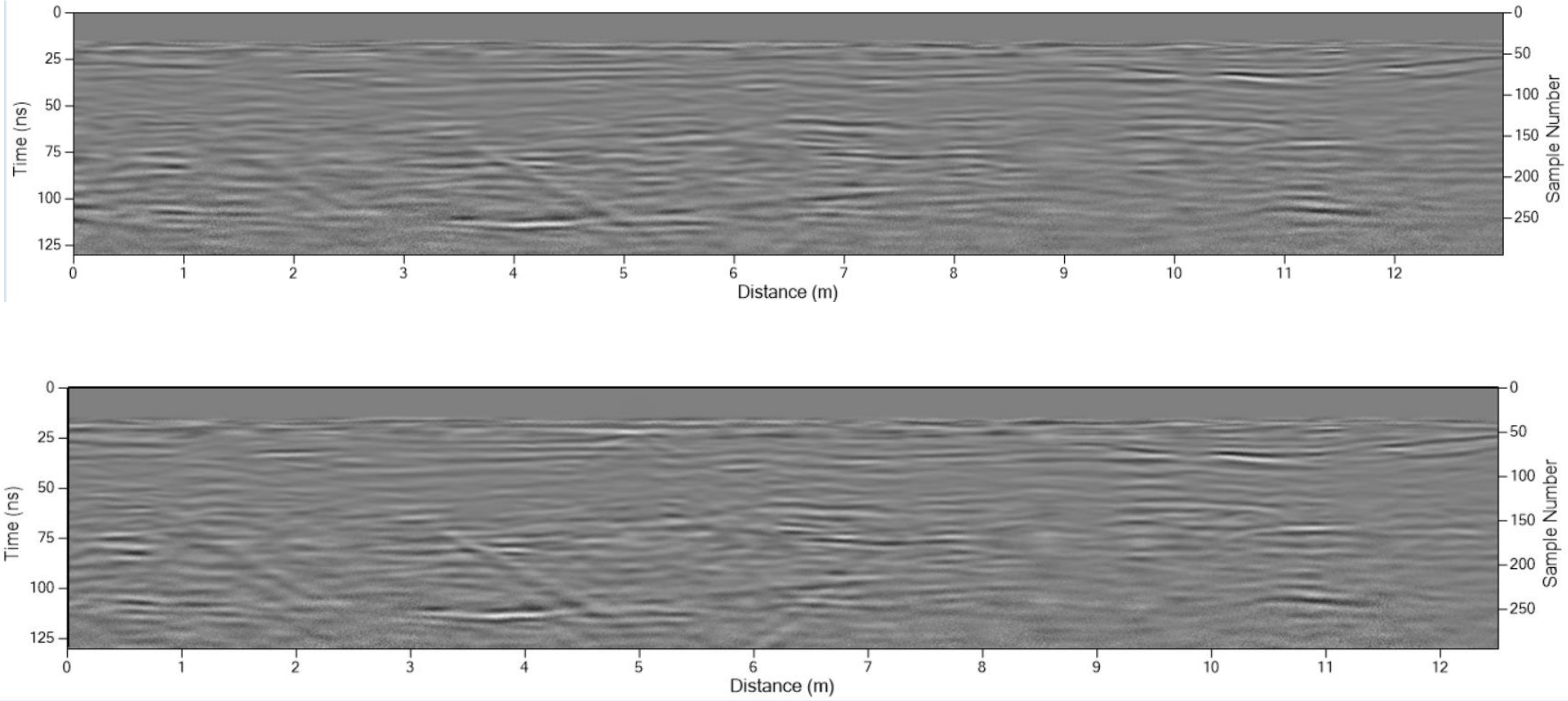


Figure 23: GPR surveys using 250 MHz MALA GPR system at the site in the Yorkshire Moors. A) shows the control line prior to the forensic metal target being buried B) shows the forensic metal target burial, the forensic metal target has been buried at roughly 5 m along the survey line.

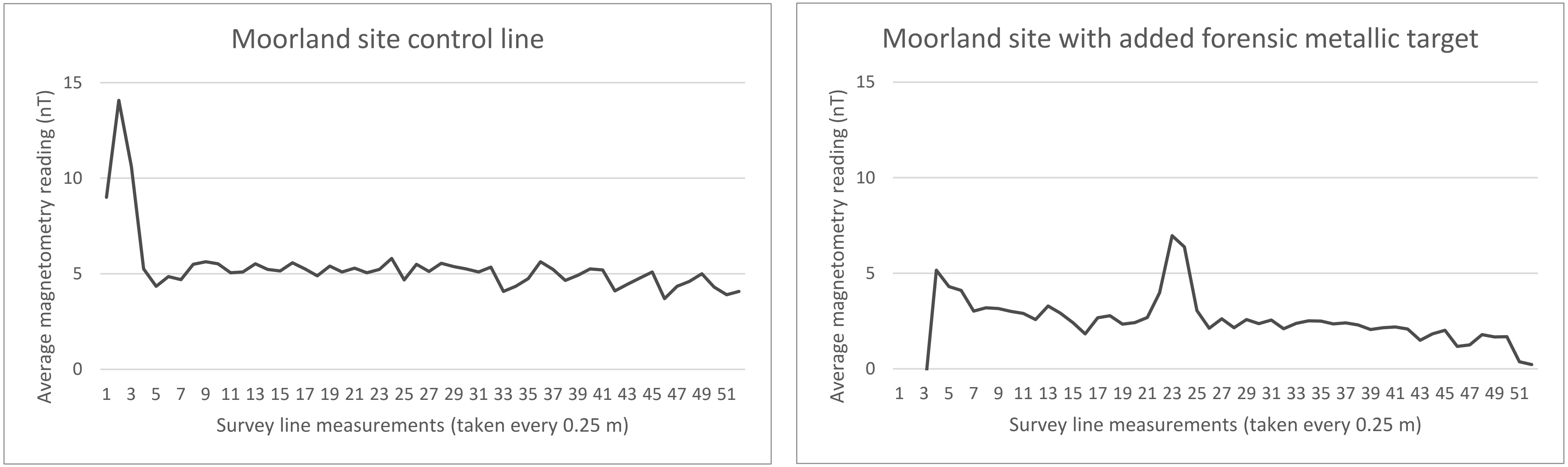


Figure 24: Magnetometry surveys at the site in the Moors, A) shows the control line/pre-burial line and B) shows the control line following the simulated forensic metal target being buried.

4.3.3 Larkhill, Formby

The ERI survey produced images of the subsurface along the control survey line (Fig. 25A) which showed very variable resistivity values (mostly patches of higher resistivity values, 2000-3000 Ω.m , dispersed through areas of mid resistivity values 700-1200 Ω.m) across the survey line to depths of around 0.65m and then below that was much more consistent to the depths of the survey limits with much lower values (around 200 Ω.m). Following the forensic metal target burial (Fig. 25B) being interred at around 5.60 m along the survey line, it produced a barely noticeable change in values at around 0.65m depth which was below the depth of the burial, but no difference in the values within the burial dimensions.

Similarly to the sites at TRACES and the Yorkshire Moors, the GPR radargrams at the Larkhill site in Formby are noisy with weak hyperbolas present throughout the subsurface survey. When comparing the survey following the burial of the forensic metal target (Fig. 26A) and the control survey (Fig. 26B) there is no obvious difference to identify a buried target such as a weapon.

The magnetometry produced generally consistent readings across the control line (Fig. 27A), until the end of the survey line where it produced two higher peaks at around 13 nT and 8 nT respectively. However, following the forensic metal target being interred into the burial (Fig. 27B) at around 5.60 m along the survey line it produced a higher anomaly of around 25-30 nT (across repeats).

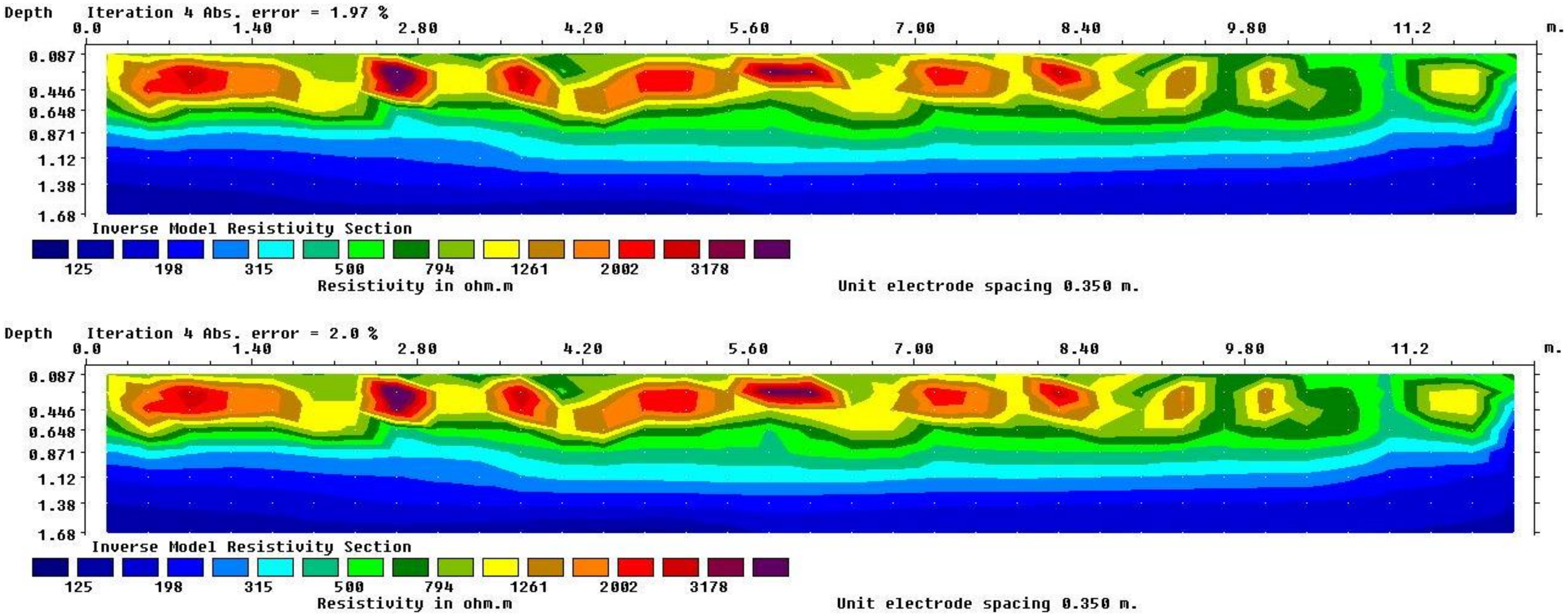


Figure 25: ERI surveys at the site located in Formby. A) shows a dipole-dipole array of the control line (pre-burial of the forensic metal target) and B) shows a dipole-dipole array of the forensic metal target.

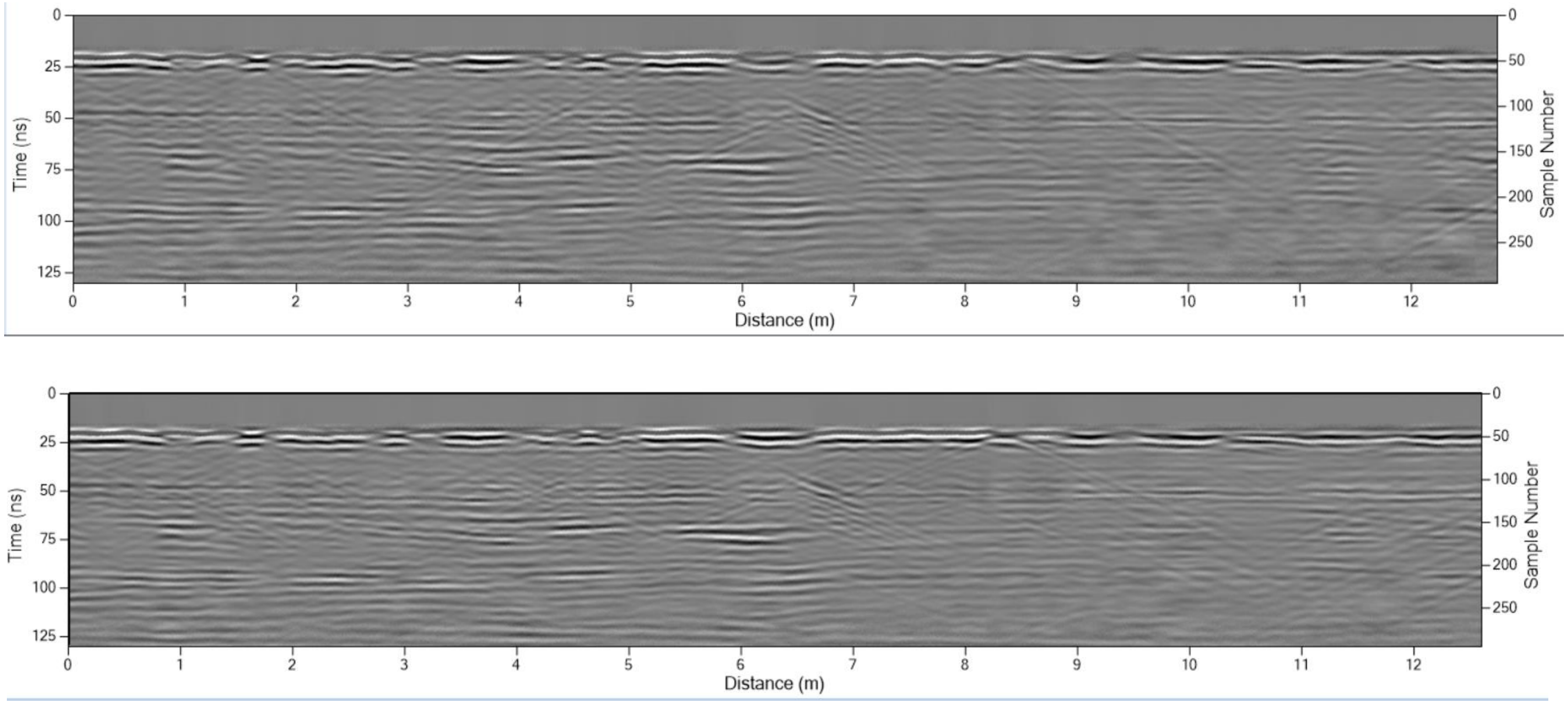
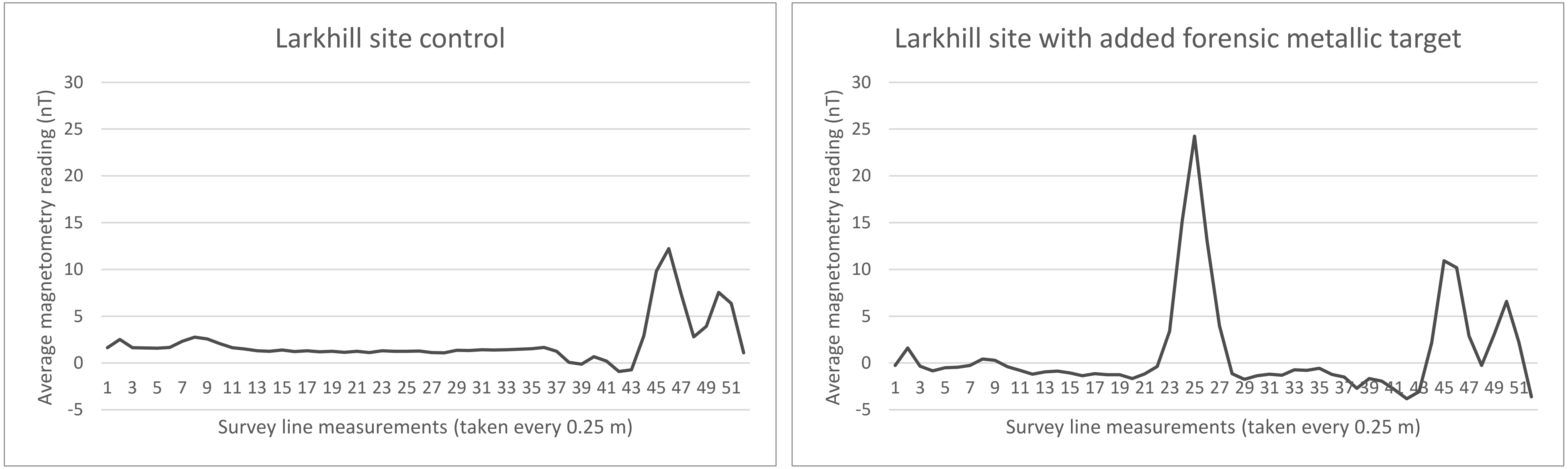


Figure 26: GPR surveys using 250 MHz MALA GPR system at the Larkhill site in Formby. A) shows the control line prior to the forensic metal target being buried B) shows the forensic metal target burial, the forensic metal target has been buried at roughly 5 m along the survey line.



Larkhill site control

Larkhill site with added forensic metallic target

Figure 27: magnetometry surveys at the Larkhill site in Formby, A) shows the control line/pre-burial line and B) shows the control line following the simulated forensic metal target being buried.

4.3.4 Norris Farm

Like the other three sites, Norris Farm was also surveyed along the control line (Fig. 28A) using ERI which produced a mostly uniform subsurface of high resistivity to around 0.20 m below ground level, with a slightly lower resistivity layer with mid-range values from 0.20-0.70 m beneath it followed by much lower values consistently across the survey to the depth limited by the survey parameters. As with the other surveys at the other sites the forensic metal target was again buried at around 5.60 m along the survey lime, which produced a barely noticeable difference in the survey (Fig. 28B). There is no difference in the immediate subsurface, but there is a slight decrease in resistivity values (yellow changed to green hues) within the dimension of the burial at the position the forensic metal target is interred.

Due to the set up at the site on the day of the surveys, the forensic metal target was interred into the ground and a GPR survey was conducted, the forensic metal target was then removed, and the 'control' survey was then conducted. The GPR radargram for the 'control line' shows a small hyperbola present which correlates with where the forensic metal target was buried and latterly removed, this hyperbolic reflection present is more than likely due to the disturbance of the soil (Fig. 29A) and had the survey been carried out before the soil was disturbed in anyway this hyperbolic reflection may not have been present. The post-burial survey with the forensic metal target interred (Fig. 29B), shows a slightly stronger albeit still small hyperbolic reflection at the location of the burial on the survey line. The background noise in both surveys is consistent and relatively 'quiet', i.e., without any background noise producing small hyperbolic reflections throughout the subsurface survey.

The magnetometry readings produced along the control survey line were consistently low until the end where a high peak reading was produced (Fig. 30A). There was very little difference in the readings following the forensic metal target being buried midway along the survey line (Fig. 30B), it produced a slightly lower reading, making it barely noticeable in comparison to the background values.

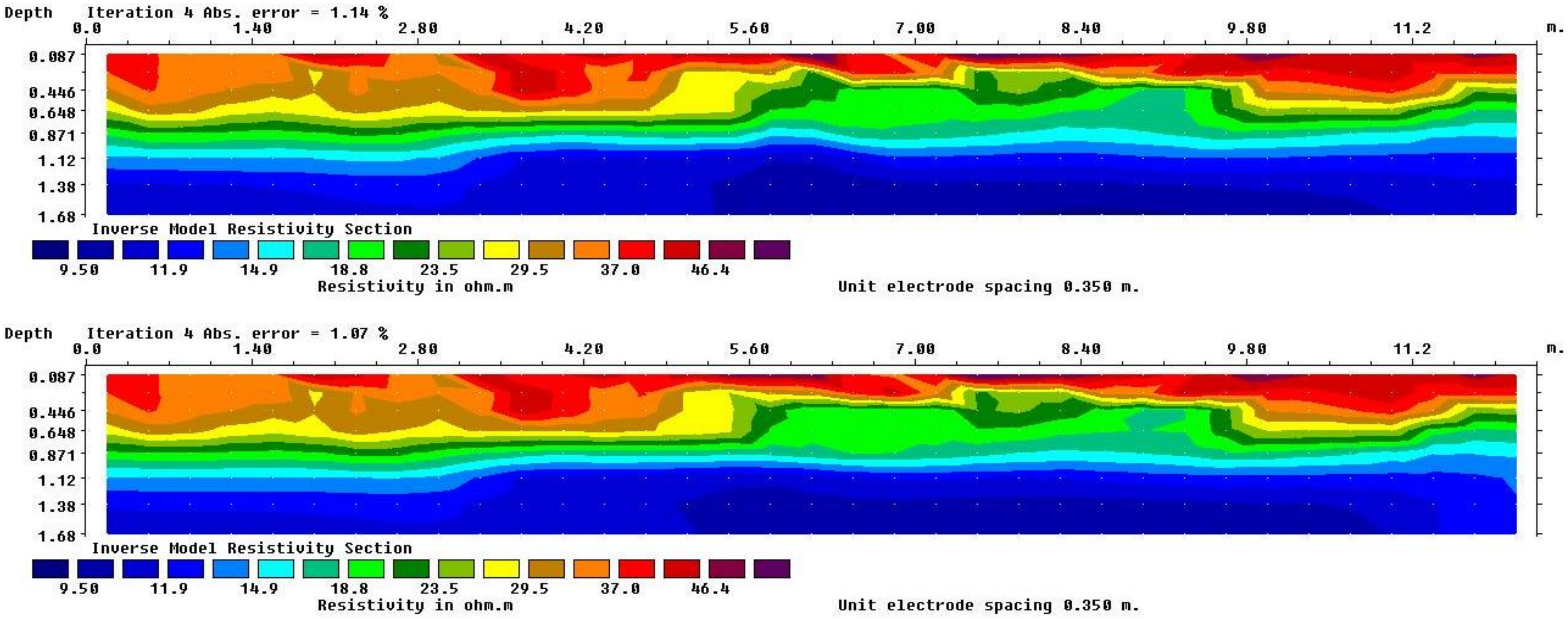


Figure 28: ERI surveys at the site located at Norris Farm. A) shows a dipole-dipole array of the control line (pre-burial of the forensic metal target) and B) shows a dipole-dipole array of the forensic metal target.

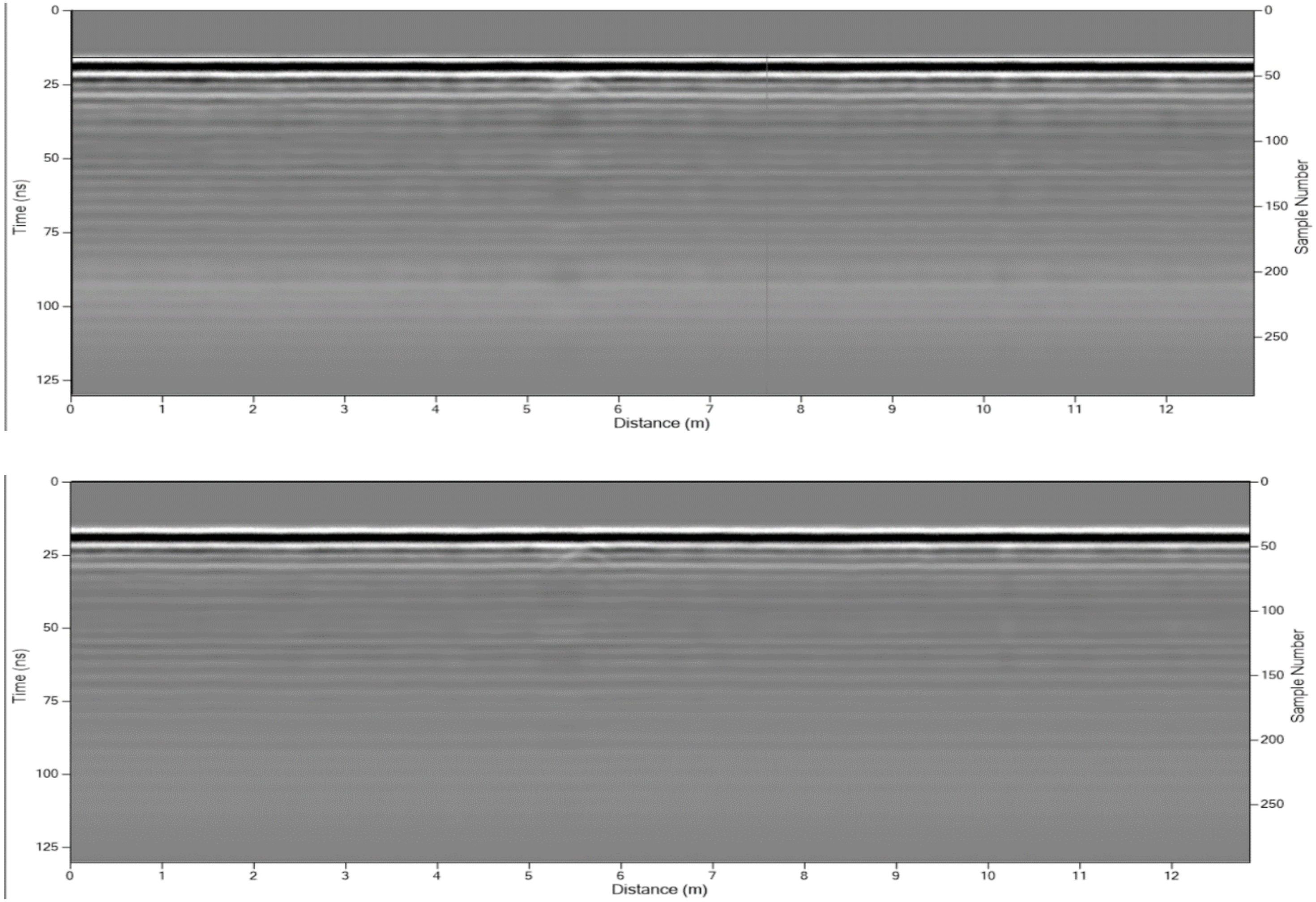


Figure 29: GPR surveys using 250 MHz MALA GPR system at the Norris Farm site. A) shows the control line prior to the forensic metal target being buried B) shows the forensic metal target burial, the forensic metal target has been buried at roughly 5 m along the survey line.

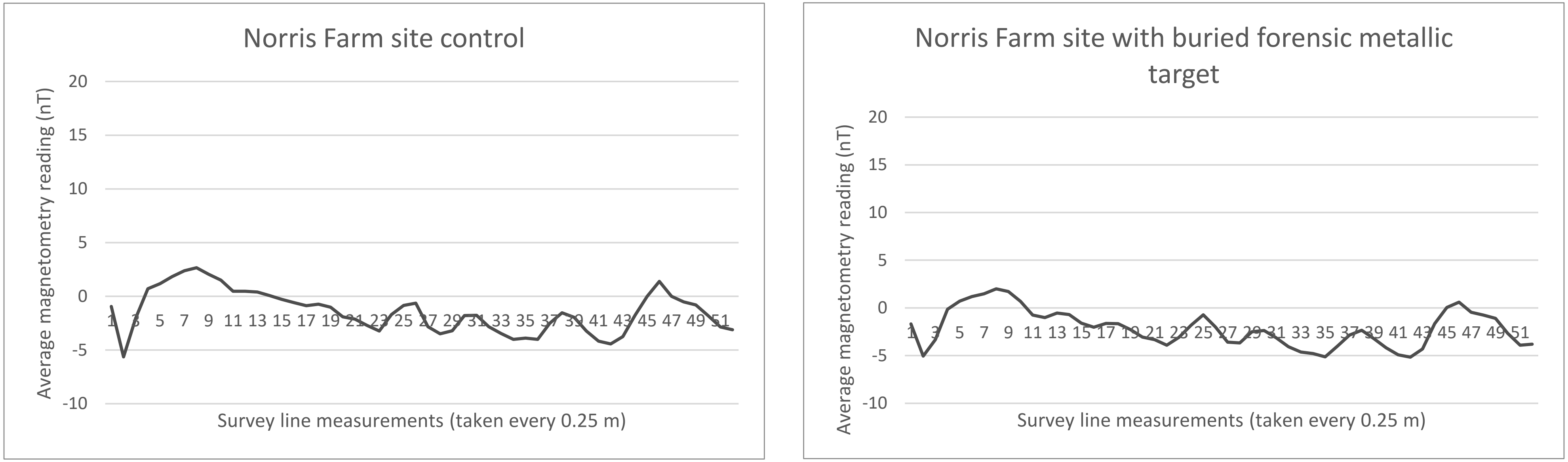


Figure 30: magnetometry surveys at Norris Farm, A) shows the control line/pre-burial line and B) shows the control line following the simulated forensic metal target being buried.

4.4 Multiperiod surveys

The three locations of the TRACES facility (plateau, intermediate slope and top of the slope) were surveyed over a twelve-month period once a month to observe the effectiveness of ERI and GPR under changing conditions (climate and decomposition being the main two). The data was meticulously collected and analysed to understand how factors such as soil moisture, seasonal variations, and terrain diversity impact the performance of the chosen geophysical methods.

4.4.1 ERI surveys

Pre- burial ERI profiles using dipole-dipole and Schlumberger array for each of the three areas of the site are shown in Figure 5.3 for comparison to the post-burial surveys. The post burial ERI profiles from month 1 to month 12 are shown in Figures 31-42 (see Fig. 9 for respective site locations and Fig. 10 for plan view of the burials) with the exclusion of site 2 and site 3 for month 1, this is due to an equipment failure.

The pre-burial surveys indicated varying resistivity values between the three sites which was expected due to variations in moisture content and soil composition as a result of the heterogeneity of the sub-surface.

Site 1: The pre-burial ERI survey shows generally mid-range resistivity values throughout the profile with an area of higher resistivity in the middle of the survey profile which is consistently observed throughout the post-burial surveys.

The burials with pig carcasses buried in them are clearly identified consistently as low resistivity values throughout the whole survey period. There is little to no discernible difference in the appearance of the geophysical anomaly produced by the wrapped pig as compared to the naked pig. The blank control grave produces a mid-high resistivity value in month 1 which then disappears and becomes part of the background resistivity values.

Site 2: The pre-burial ERI survey shows higher resistivity values than those observed at site 1. Higher resistivity background values are noted throughout the post-burial surveys, however slightly lower in areas compared to the control profile.

The naked pig is much clearer on the post-burial surveys as a consistent area of low resistivity as compared to the wrapped pig. The wrapped pig is observed as areas of low-mid resistivity values, but slightly higher than those of the naked pig. There is no month 1 ERI profiles for site 2, however from observations of month 2, the control burial is shown as a high resistivity value at the very near-surface and is not observed again until month 9 as a slightly larger anomaly of high resistivity. The control burial is then not easily detectable again after this.

Site 3: The pre-burial ERI survey shows a more variable survey area compared to site 1 and site 2 with mid-high resistivity values throughout, with the mid-range resistivity values focused in the upper near-surface and the higher resistivity values deeper in the subsurface. Again, these resistivity values from the pre-burial controls conducted are observed in the background values of the post-burial surveys.

The wrapped pig is generally observed as mid-range resistivity values throughout the survey period except for month 5, 9 and 11 where it can be observed as slightly lower resistivity values. The naked pig starts off as low resistivity values, becoming slightly higher to mid-range resistivity values from month 5 onward and remains at or around this range of resistivity values. The control burial is not easily evident from the background resistivity values throughout the survey period.

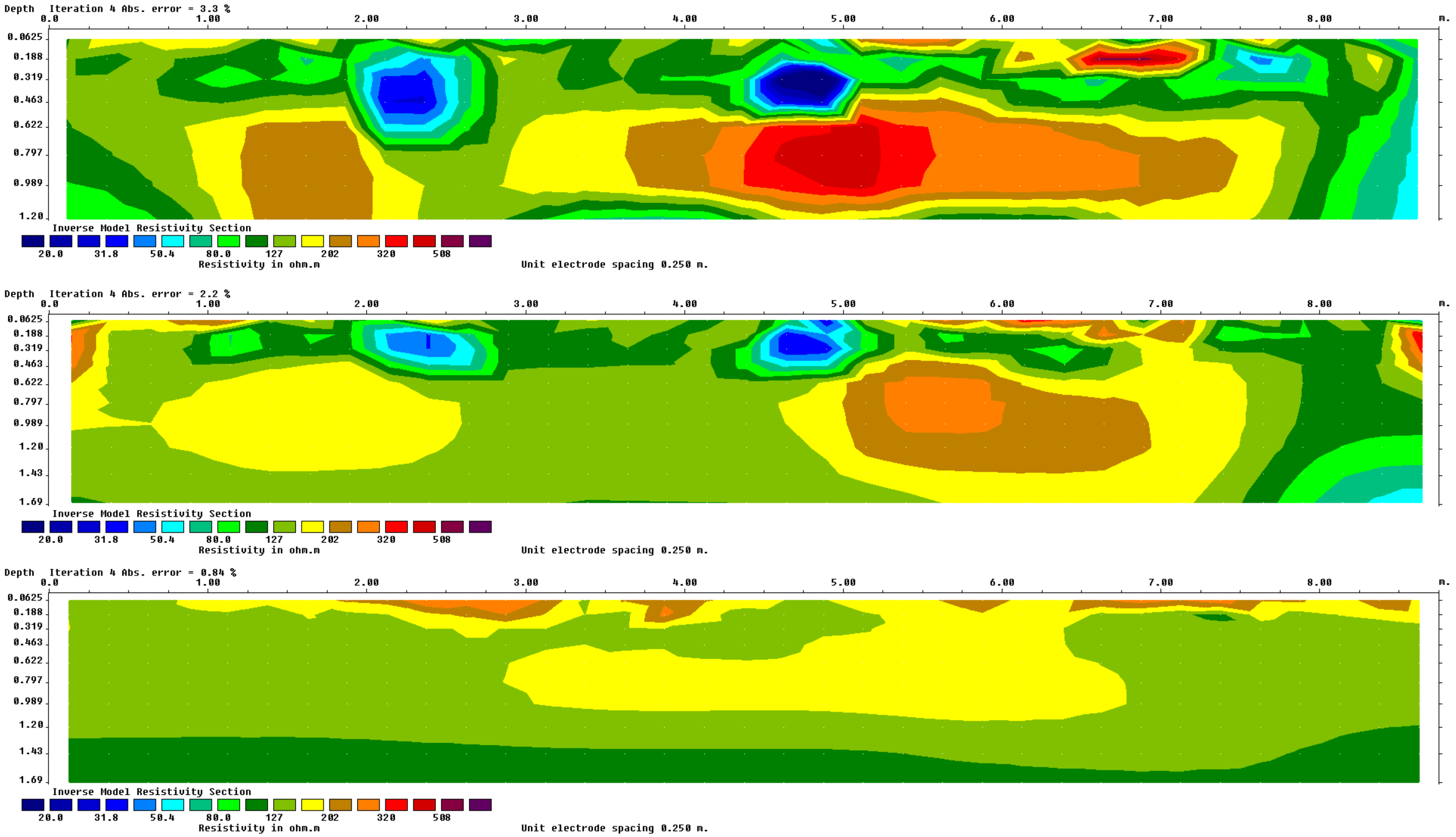


Figure 31: Site 1 ERI surveys at one month post burial. A) shows a dipole-dipole array of the burials, B) shows a Schlumberger array of the burials and C) shows a Schlumberger array of the control line which is situated about 2.0 m away from the burials.

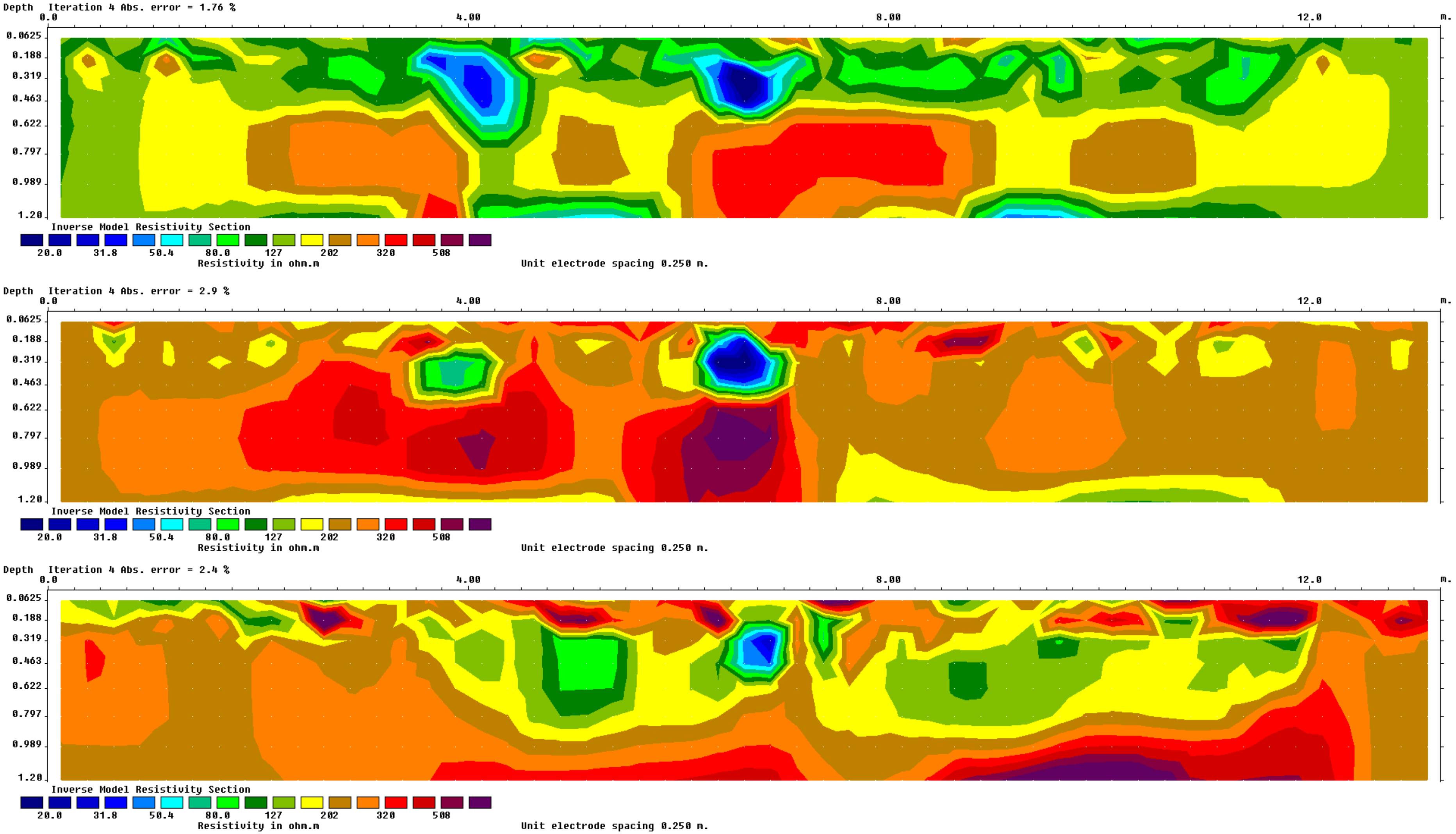


Figure 32: ERI surveys at two months post burial. A) shows a dipole-dipole array of the burials at site 1, B) shows a dipole-dipole array of the burials at site 2 and C) shows a dipole-dipole array of the burials at site 3.

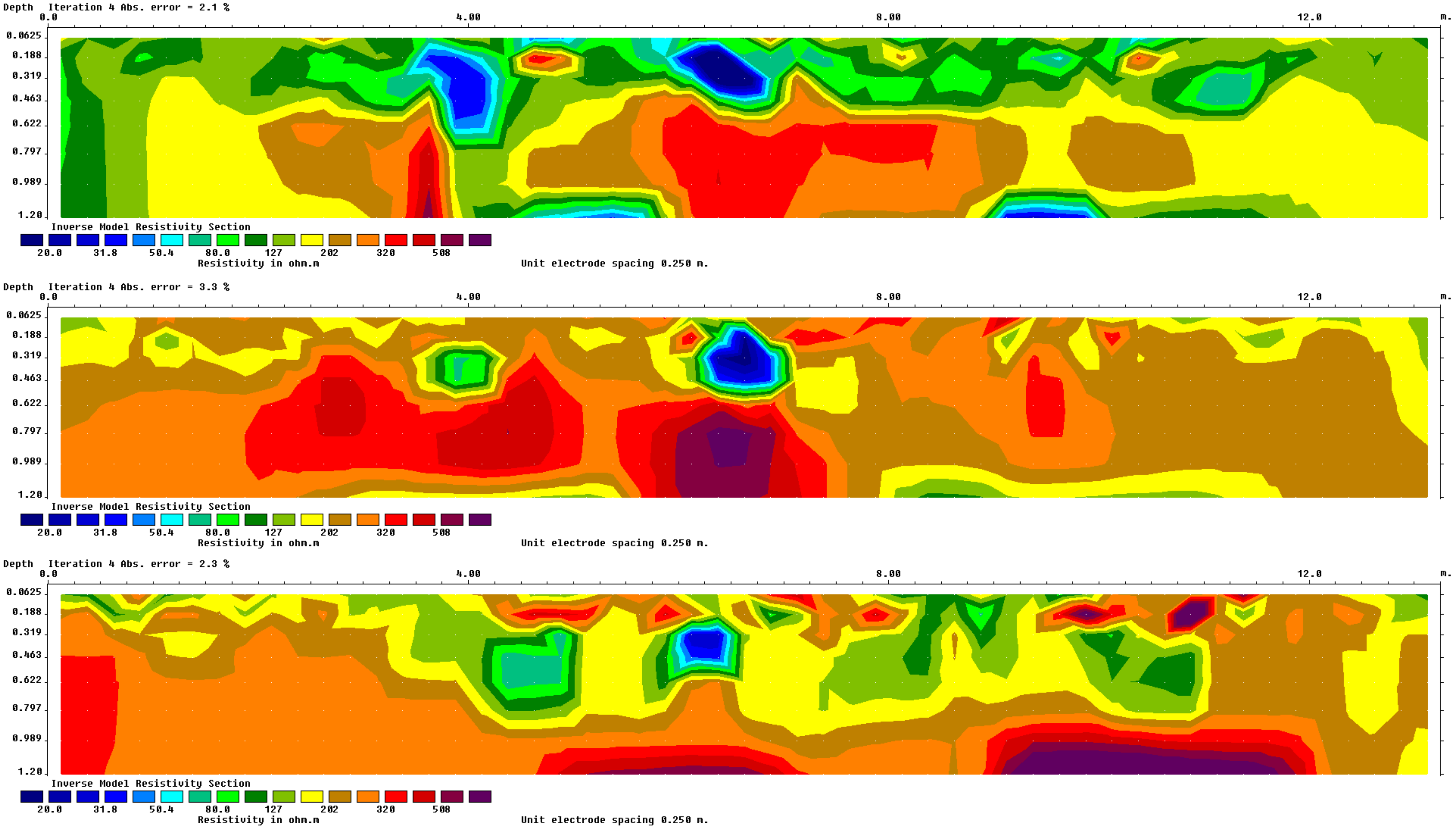


Figure 33: ERI surveys at three months post burial. A) shows a dipole-dipole array of the burials at site 1, B) shows a dipole-dipole array of the burials at site 2 and C) shows a dipole-dipole array of the burials at site 3.

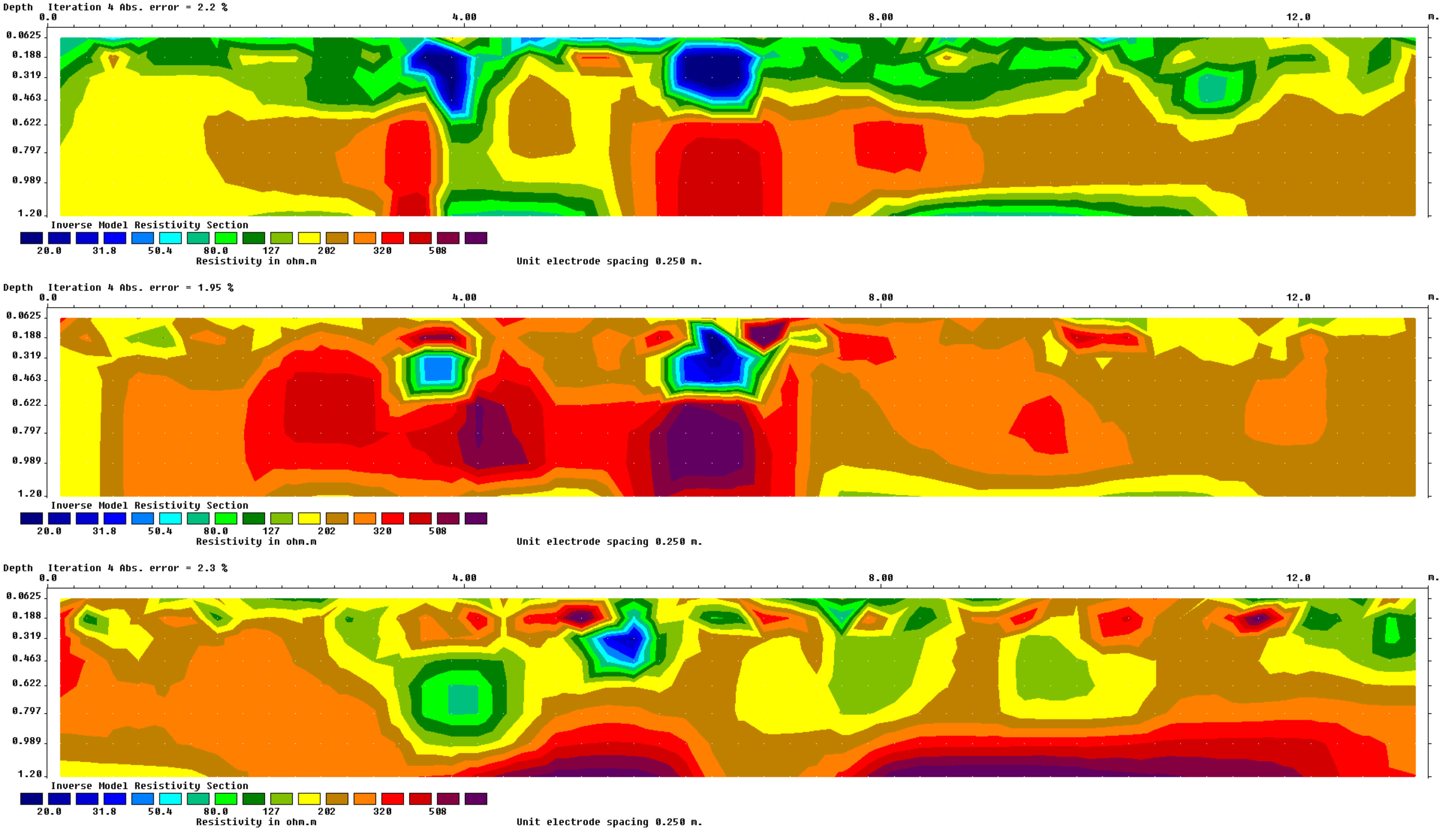


Figure 34: ERI surveys at four months post burial. A) shows a dipole-dipole array of the burials at site 1, B) shows a dipole-dipole array of the burials at site 2 and C) shows a dipole-dipole array of the burials at site 3.

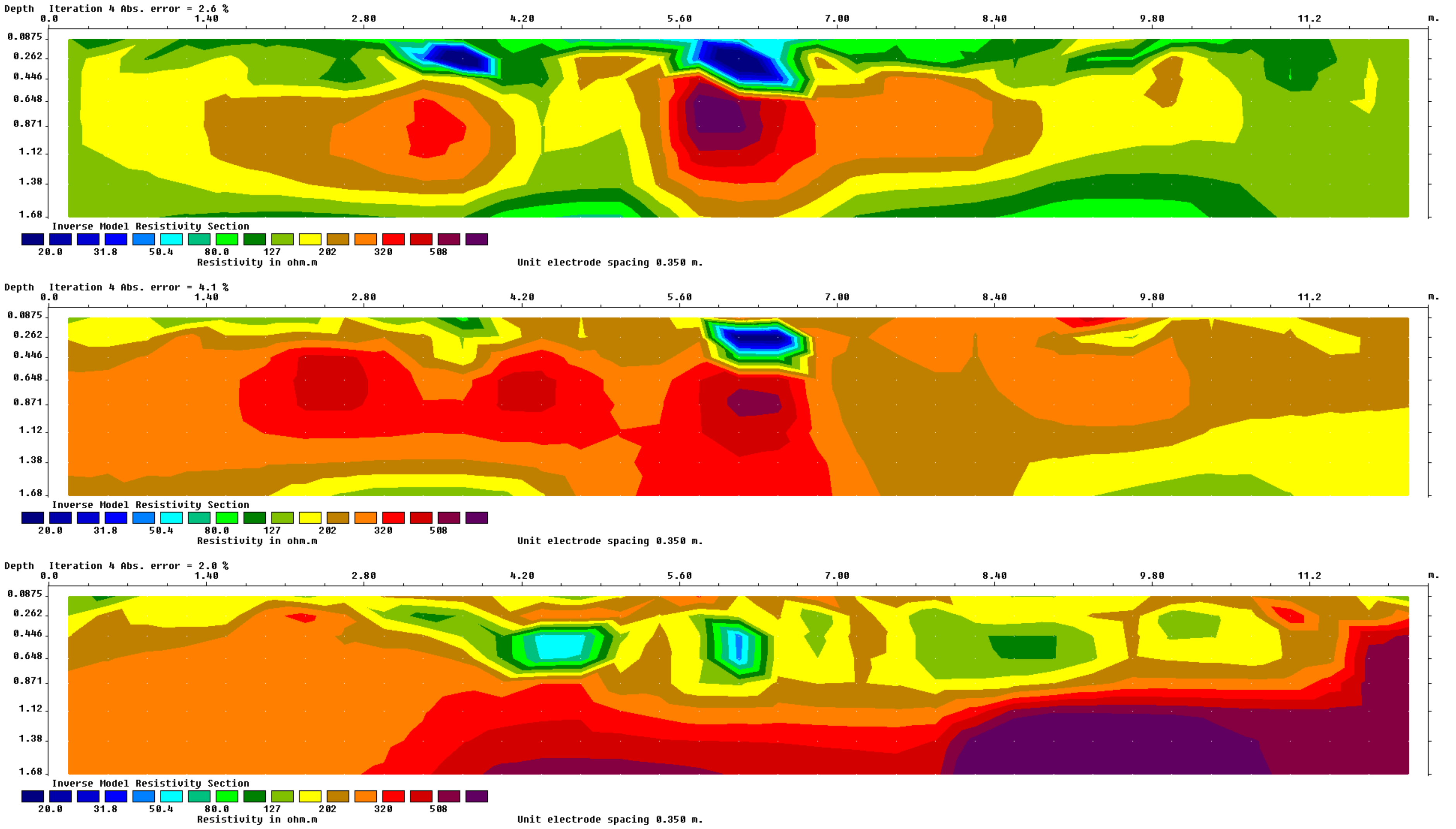


Figure 35: ERI surveys at five months post burial. A) shows a dipole-dipole array of the burials at site 1, B) shows a dipole-dipole array of the burials at site 2 and C) shows a dipole-dipole array of the burials at site 3.

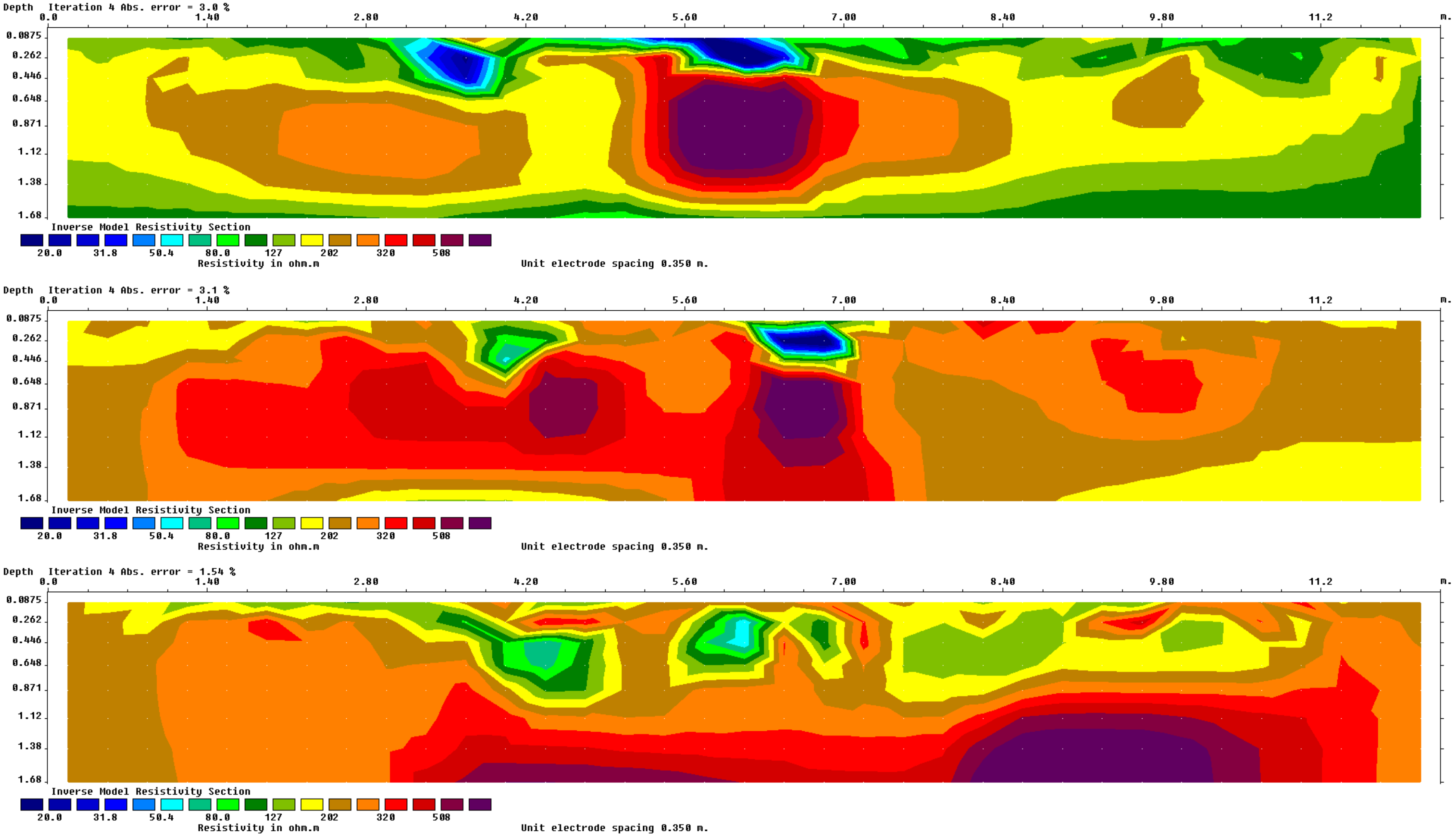


Figure 36: ERI surveys at six months post burial. A) shows a dipole-dipole array of the burials at site 1, B) shows a dipole-dipole array of the burials at site 2 and C) shows a dipole-dipole array of the burials at site 3.

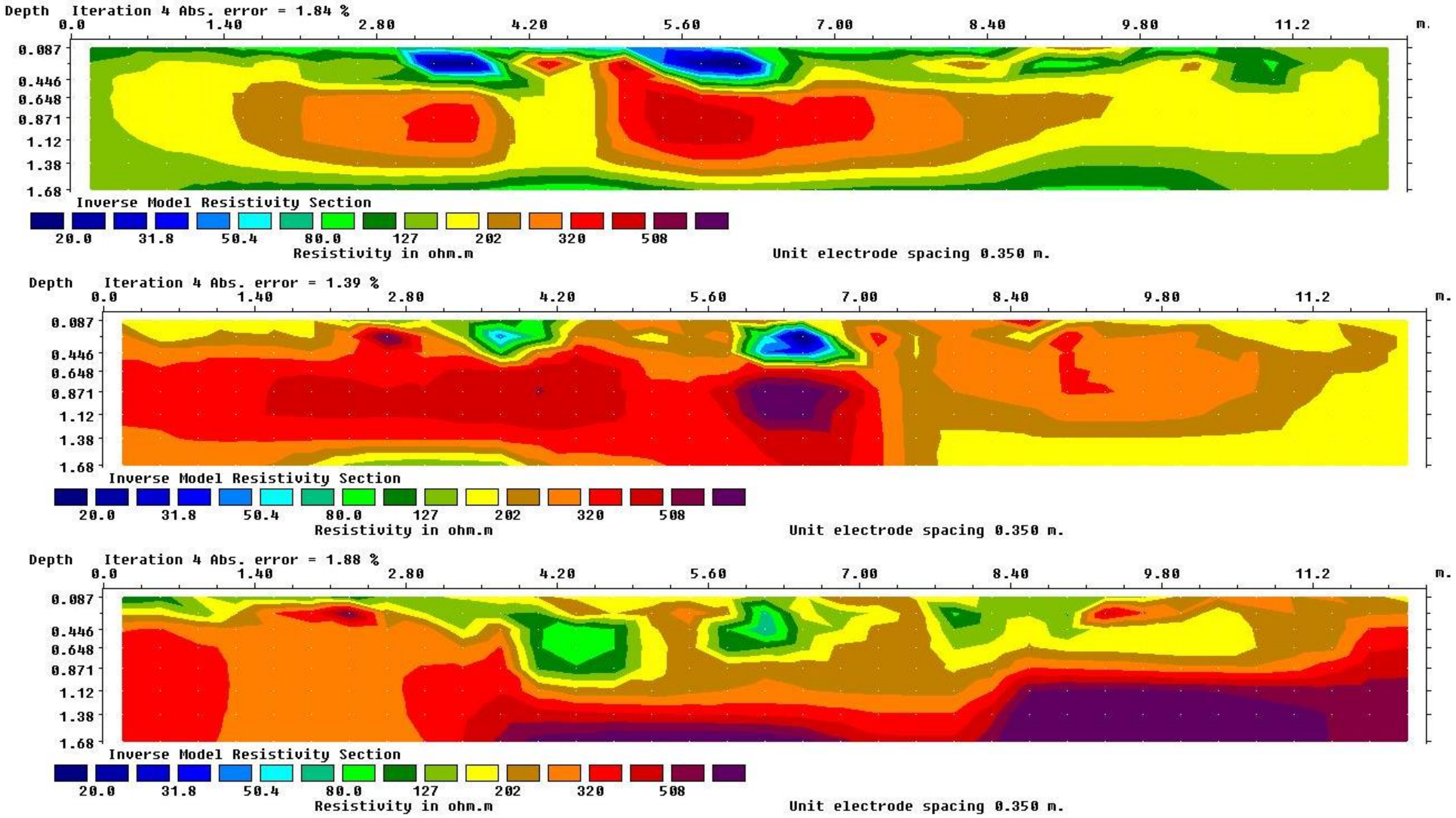


Figure 37: ERI surveys at seven months post burial. A) shows a dipole-dipole array of the burials at site 1, B) shows a dipole-dipole array of the burials at site 2 and C) shows a dipole-dipole array of the burials at site 3.

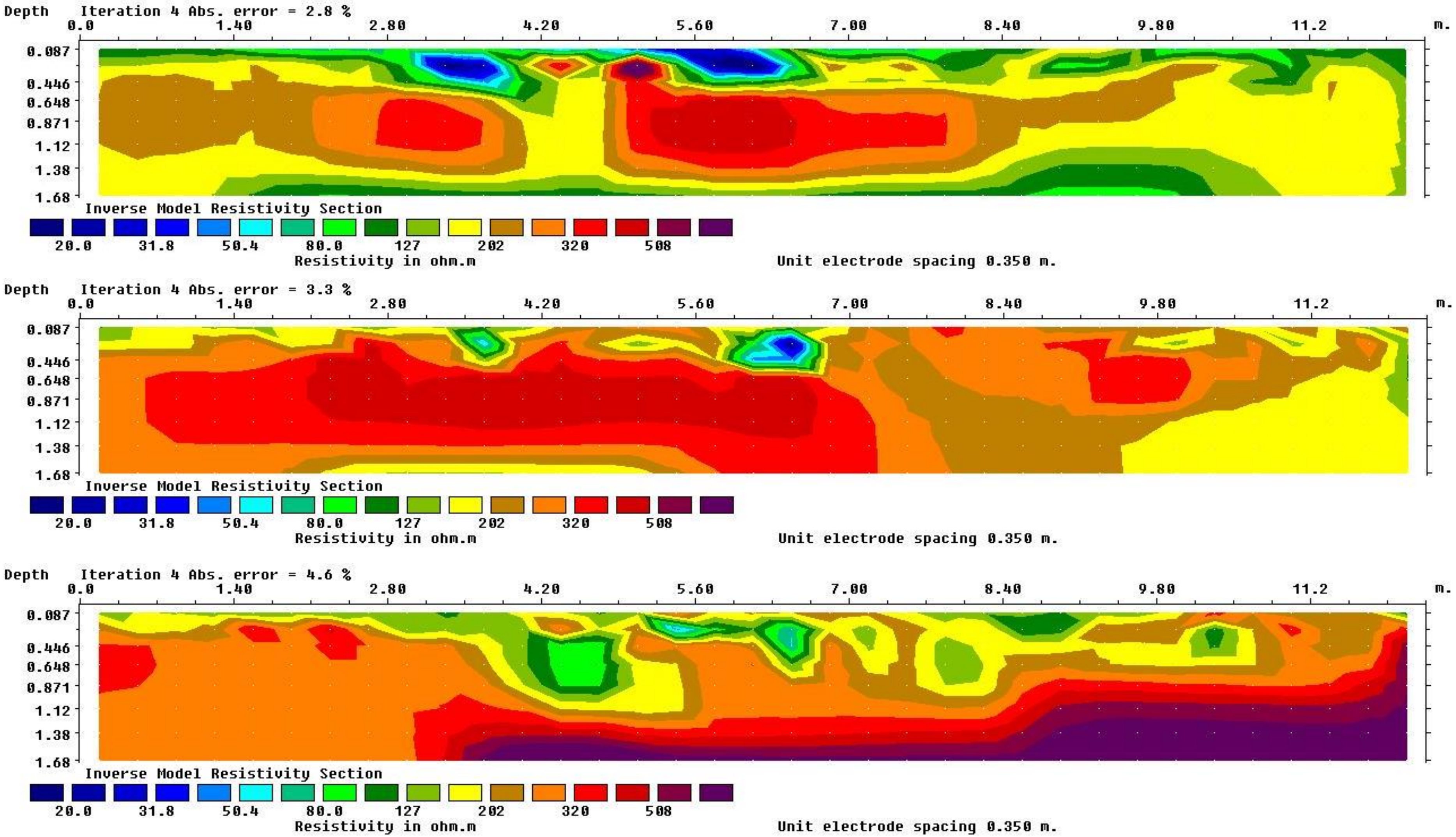


Figure 38: ERI surveys at eight months post burial. A) shows a dipole-dipole array of the burials at site 1, B) shows a dipole-dipole array of the burials at site 2 and C) shows a dipole-dipole array of the burials at site 3.

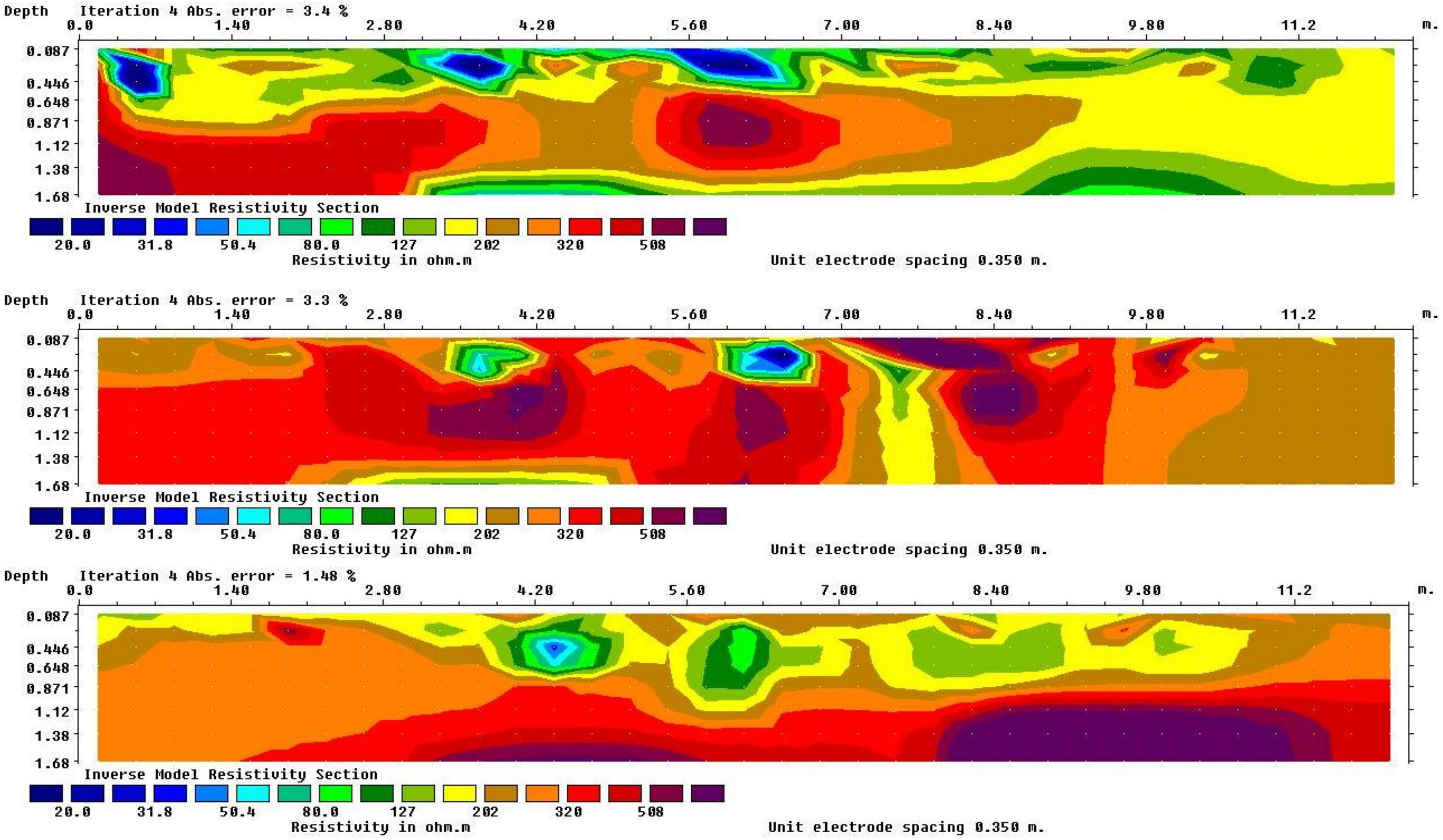


Figure 39: ERI surveys at nine months post burial. A) shows a dipole-dipole array of the burials at site 1, B) shows a dipole-dipole array of the burials at site 2 and C) shows a dipole-dipole array of the burials at site 3.

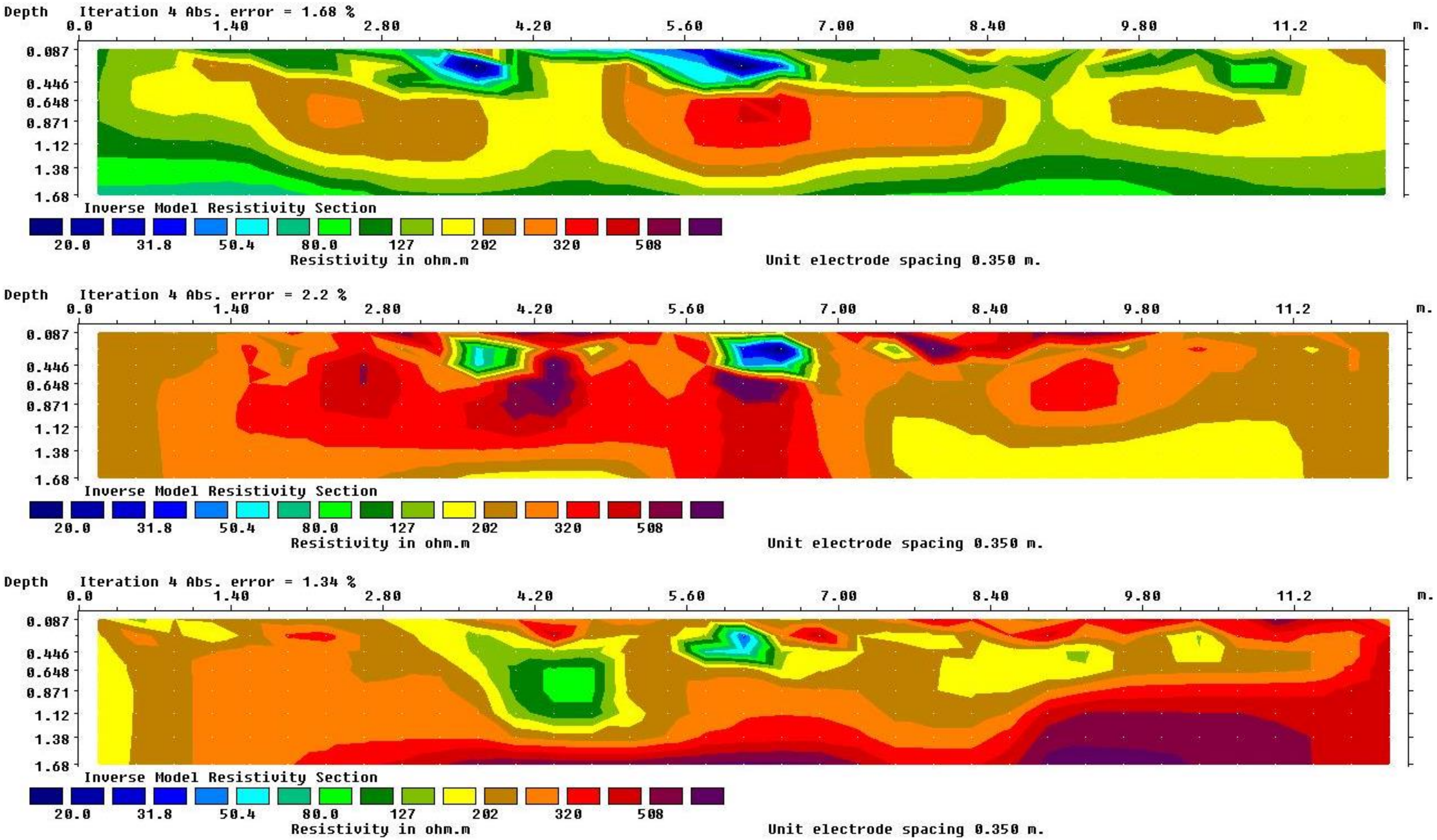


Figure 40: ERI surveys at ten months post burial. A) shows a dipole-dipole array of the burials at site 1, B) shows a dipole-dipole array of the burials at site 2 and C) shows a dipole-dipole array of the burials at site 3.

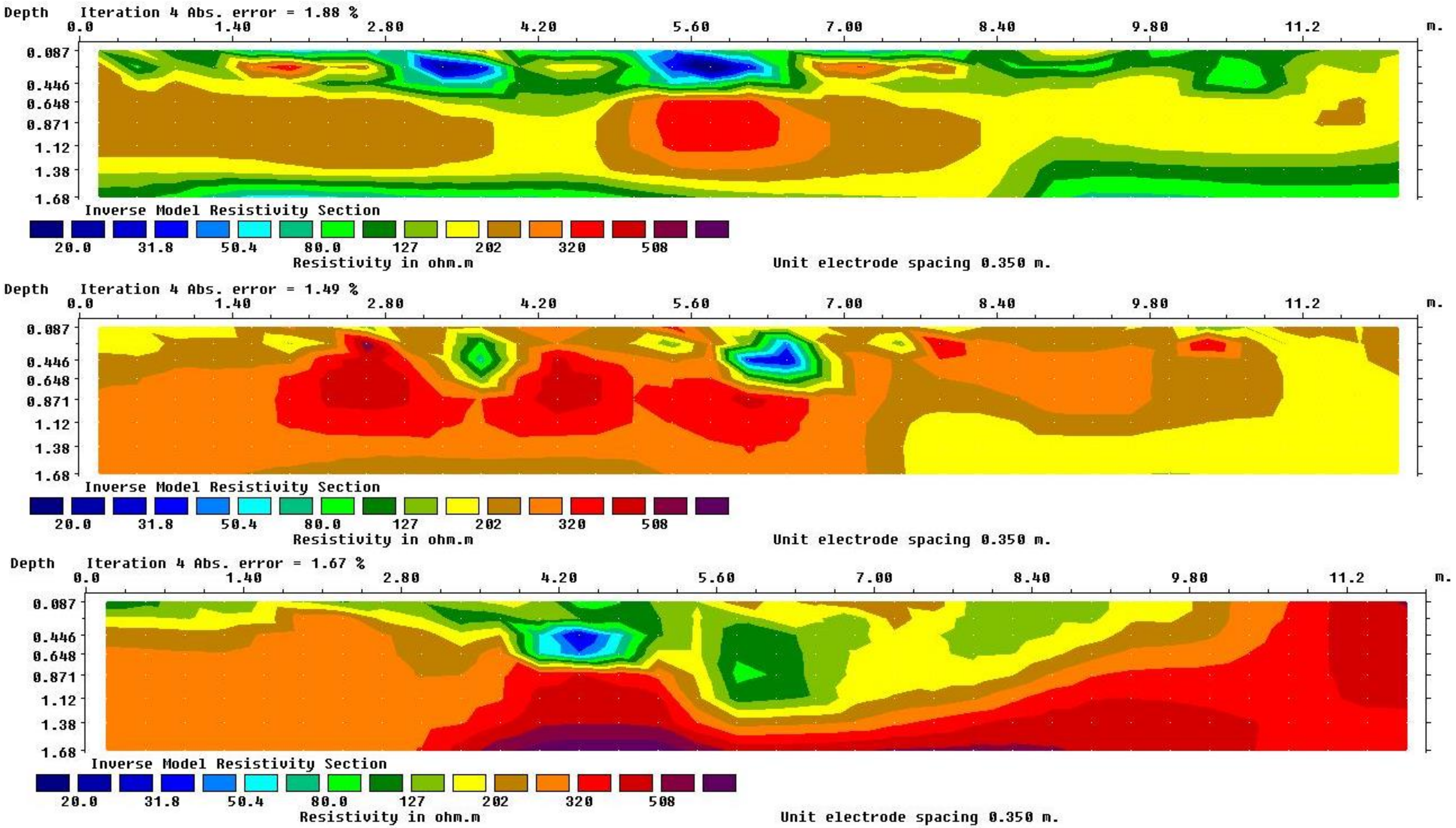


Figure 41: ERI surveys at eleven months post burial. A) shows a dipole-dipole array of the burials at site 1, B) shows a dipole-dipole array of the burials at site 2 and C) shows a Schlumberger array of the burials at site 3 as there was a fault during the dipole-dipole which was unable to be identified at the site.

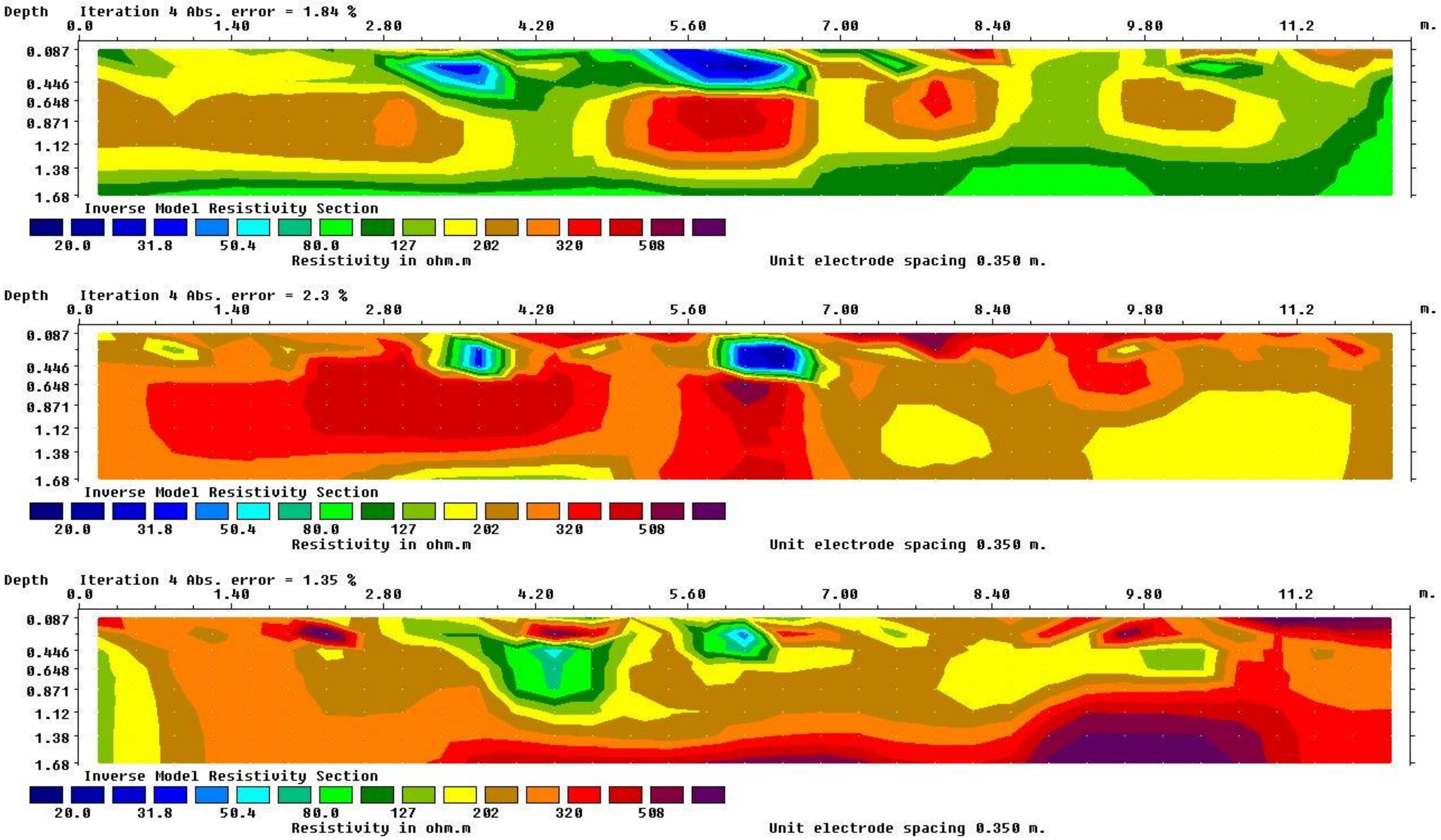


Figure 42: ERI surveys at twelve months post burial. A) shows a dipole-dipole array of the burials at site 1, B) shows a dipole-dipole array of the burials at site 2 and C) shows a dipole-dipole array of the burials at site 3.

4.4.2 GPR surveys

GPR profiles acquired pre-burial and post-burial throughout the survey period are shown in Figures 46-56 except for month 5, described previously, and therefore no dataset was acquired. (see Fig. 9 for respective site locations and Fig. 10 for plan view of the burials). Throughout all the surveys over the twelve-month survey period there is considerable background ‘noise’ and non-target hyperbolas, complicating the detection of the buried pigs. GPR did manage to locate the burials successfully on a number of occasions throughout the survey period, however it was very inconsistent across all three sites. The noise present in the radargrams from these surveys will be due to the frequency antenna GPR used (MALA 250 MHz), which increased the penetration depth into the soil, but has a lower vertical subsurface resolution than a higher frequency antenna GPR. This resulted in reflections being detected for other non-forensic targets in the soil such as large stones, glacial deposits and large tree roots.

Martin (2010) states that a 250 MHz antenna provides an increased penetration depth into the soil as compared to a 500 MHz antenna, the vertical subsurface resolution is lower

Site 1 (A, on figures 43-53) which was on a plateau at the bottom of the slope on which the other two burial sites were located. The control burial was not evident as a hyperbolic reflection on any of the post-burial GPR surveys throughout the twelve-month survey period. The naked burial was not apparent in all post-burial GPR surveys against the background noise in the radargrams, the burial was only successfully identified from month six and remains detectable throughout the remaining months of the survey period. The wrapped burial was not detected in any of the post-burial surveys during the twelve-month survey period.

The burials at site 2, which was halfway up the intermediate slope (B, on figures 43-53), were a little more successful at being detected compared to site 1. The control burial, like at site 1, was not detected throughout the survey period using GPR. The naked burial was observed as a hyperbolic reflection in all month’s post-burial, however the degree at which a strong hyperbola was produced varied across the survey period. The clearest hyperbolae were produced from four-months post-burial onward, with only very weak barely noticeable hyperbolic reflections being produced prior to four months. The wrapped burial was inconsistently detected across the survey period, with a clear reflection present in months one and seven, in the remaining months there is either no anomaly present or there is a lot of noise which could be disguising a potential hyperbolic reflection.

At site 3 (C, on all figures 43-53), due to compaction of the soil in the naked grave and the decomposition of the pig the grave was mostly sunken for the majority of the survey period which caused an uneven terrain for the GPR to move across causing anomalies to occur in the radargram at the location of this burial. This caused the grave to often be ‘lost’ due to the noise which could have been masking a potential hyperbolic reflection from the grave itself. The naked grave was observed a clear hyperbolic reflection during month ten but was otherwise disguised by noise in all other survey months. The wrapped pig burial and the control burial was not observed during any month of the survey period.

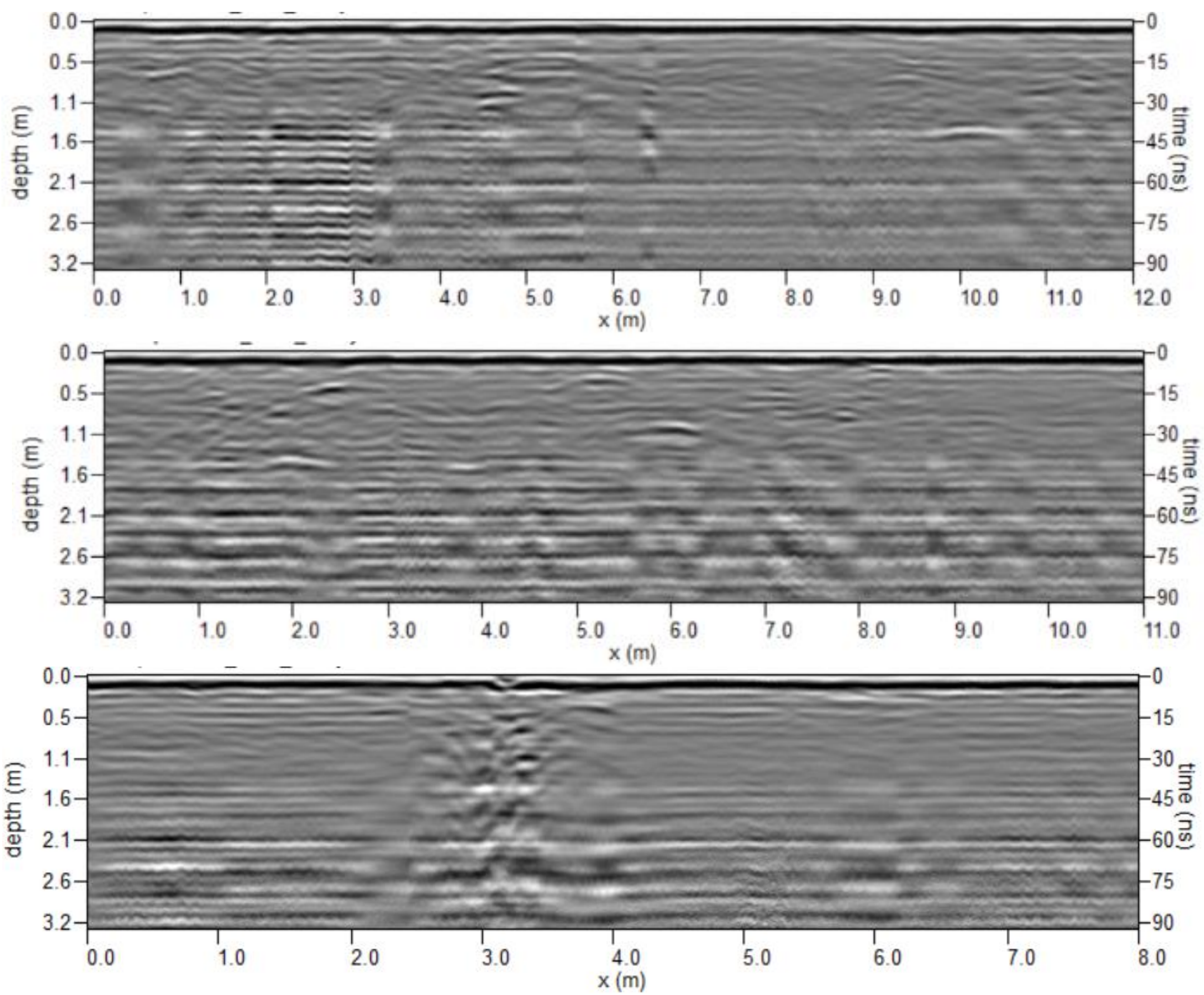


Figure 43: GPR time-slice surveys at one month post burial, all burials are in an east to west orientation. A) site 1, B) site 2 and C) site 3.

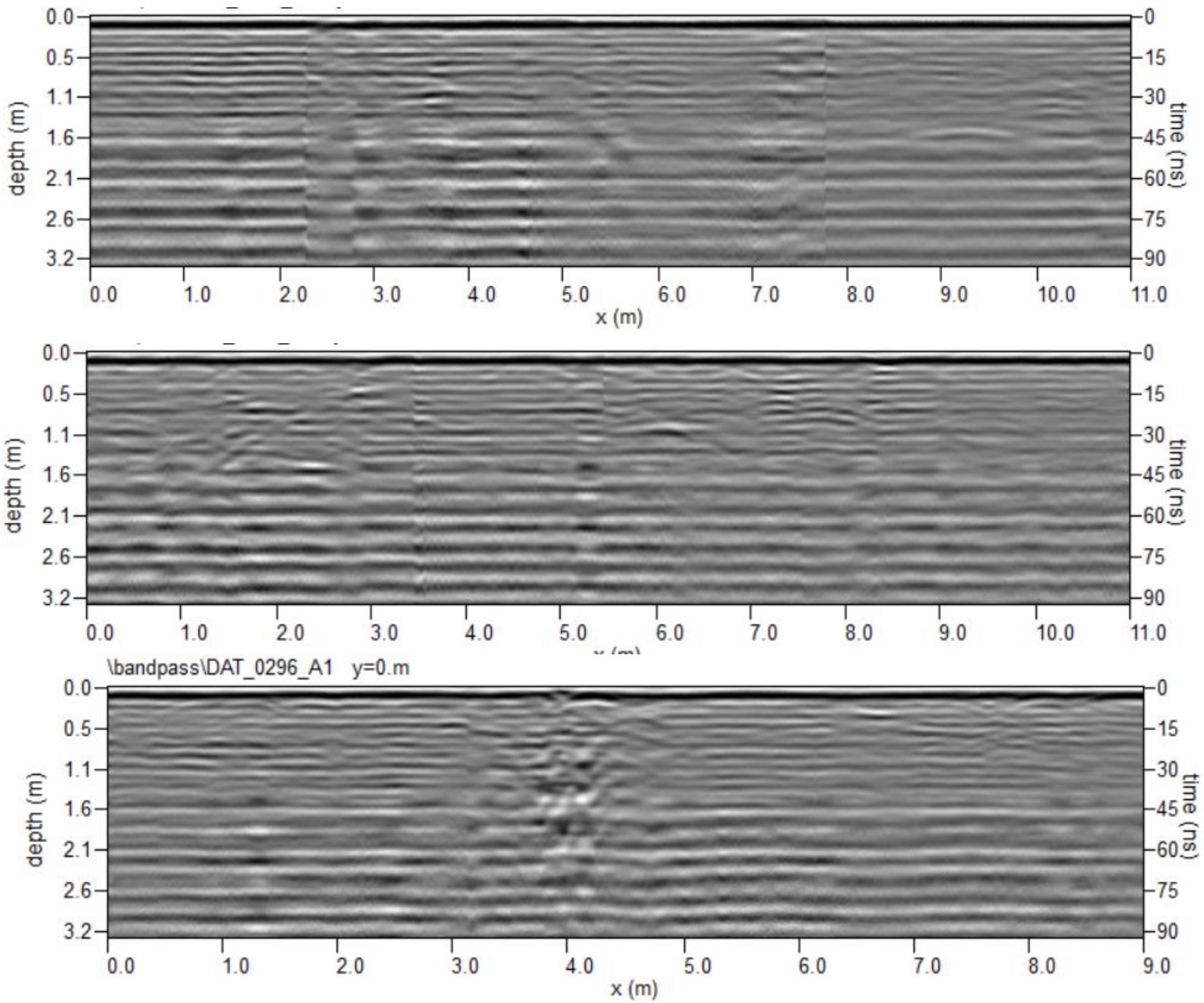


Figure 44: GPR time-slice surveys at two months post burial, all burials are in an east to west orientation. A) site 1, B) site 2 and C) site 3.

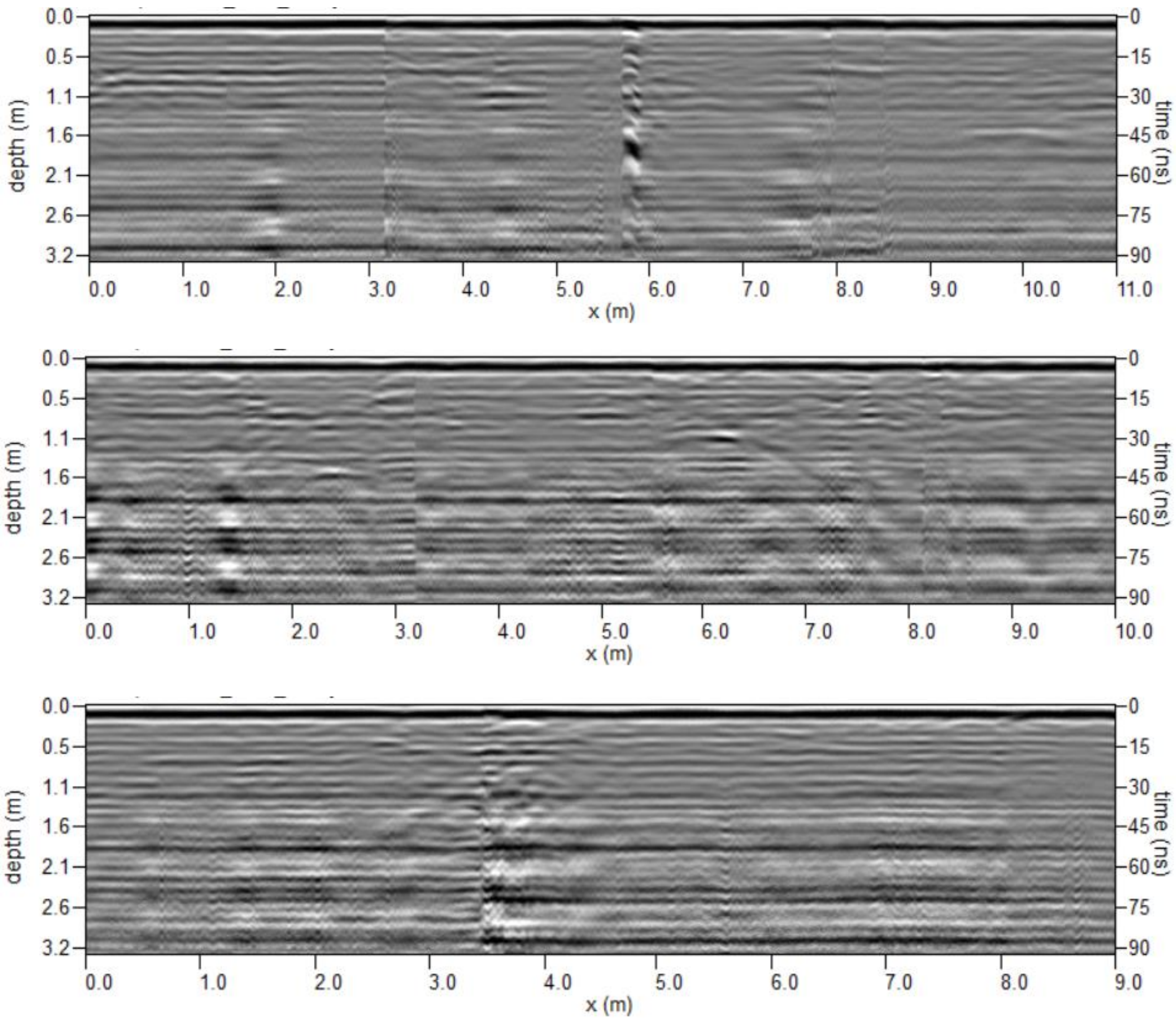


Figure 45: GPR time-slice surveys at three months post burial, all burials are in an east to west orientation. A) site 1, B) site 2 and C) site 3.

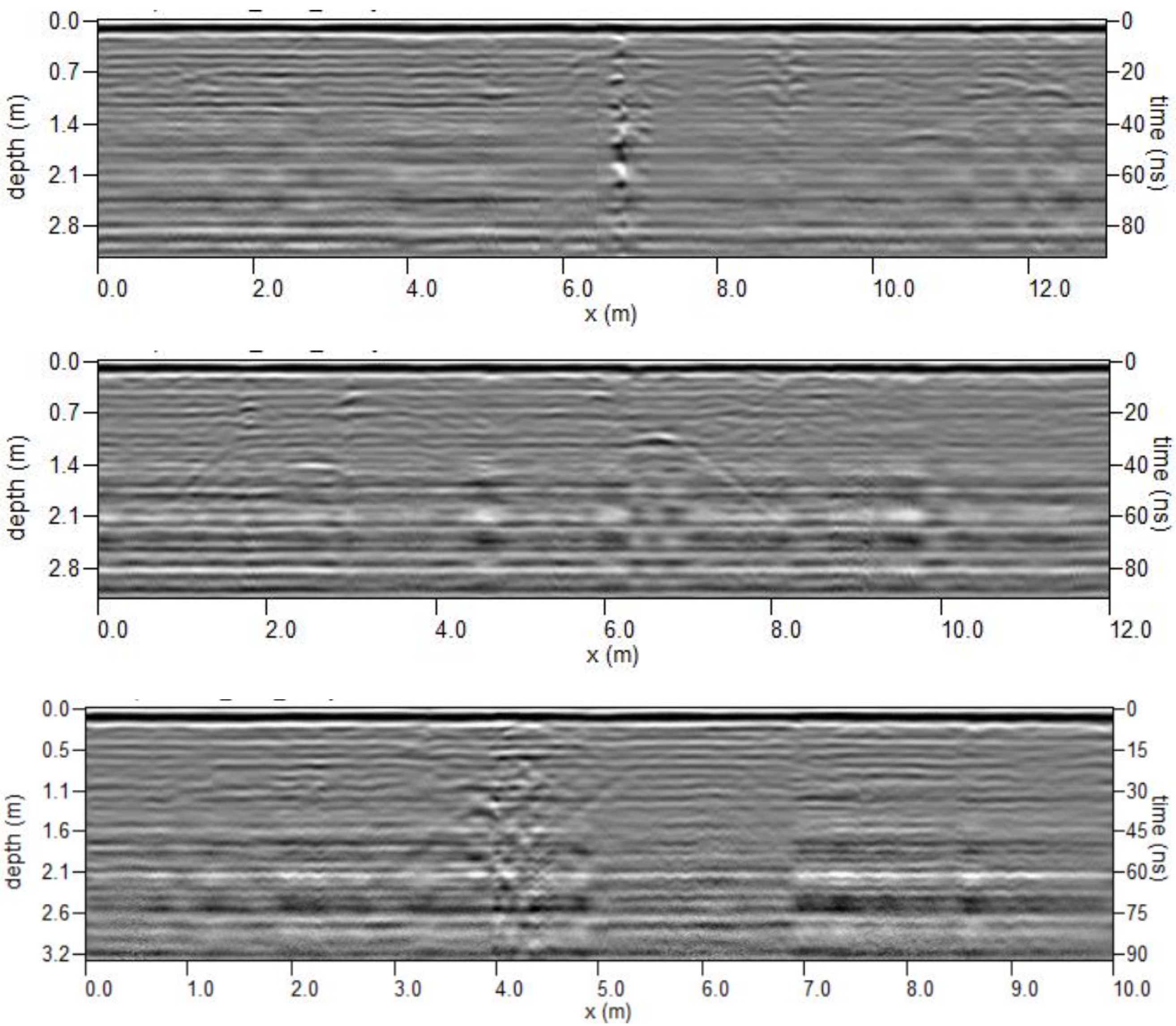


Figure 46: GPR time-slice surveys at four months post burial, all burials are in an east to west orientation. A) site 1, B) site 2 and C) site 3.

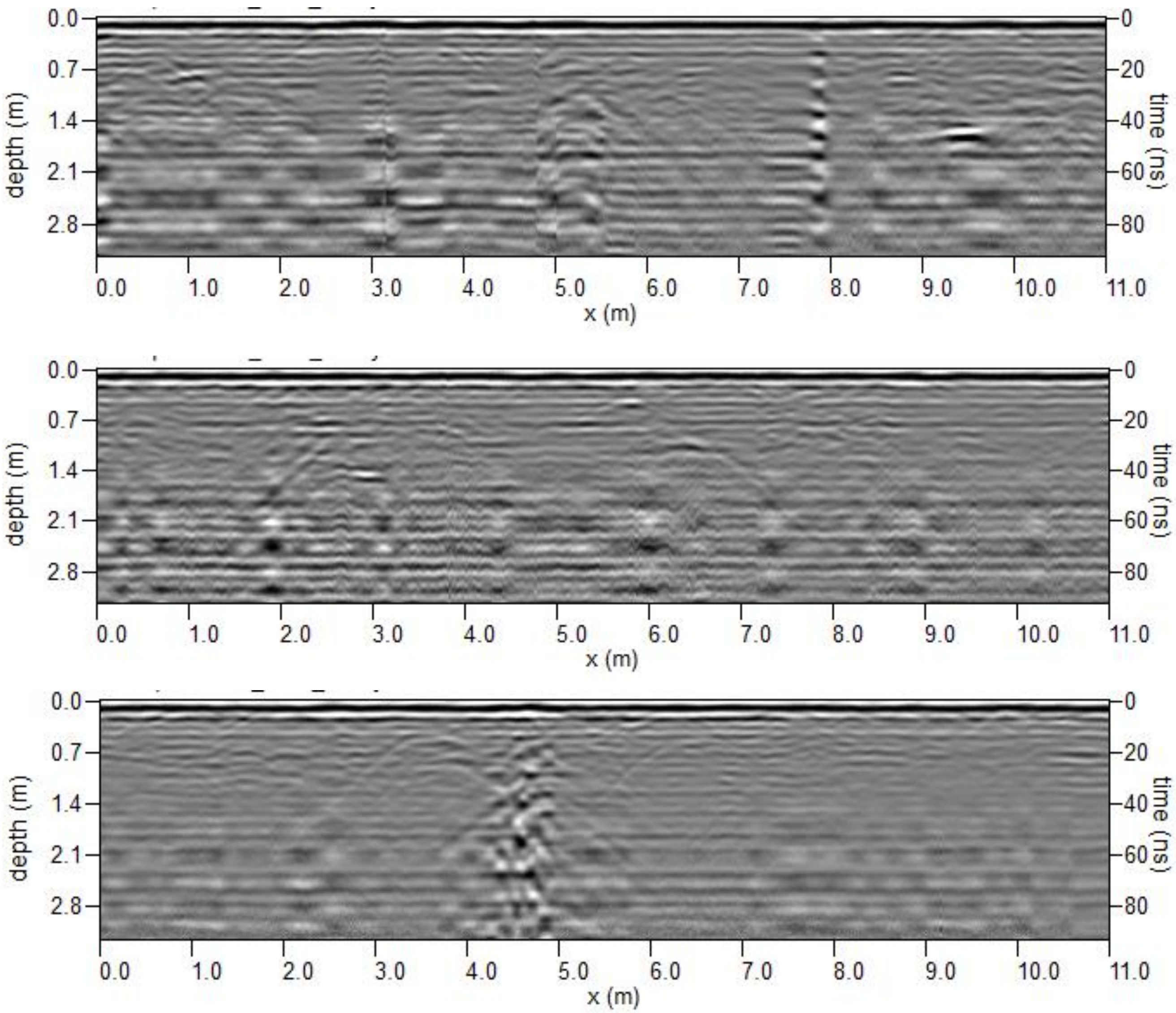


Figure 47: GPR time-slice surveys at six months post burial, all burials are in an east to west orientation. A) site 1, B) site 2 and C) site 3.

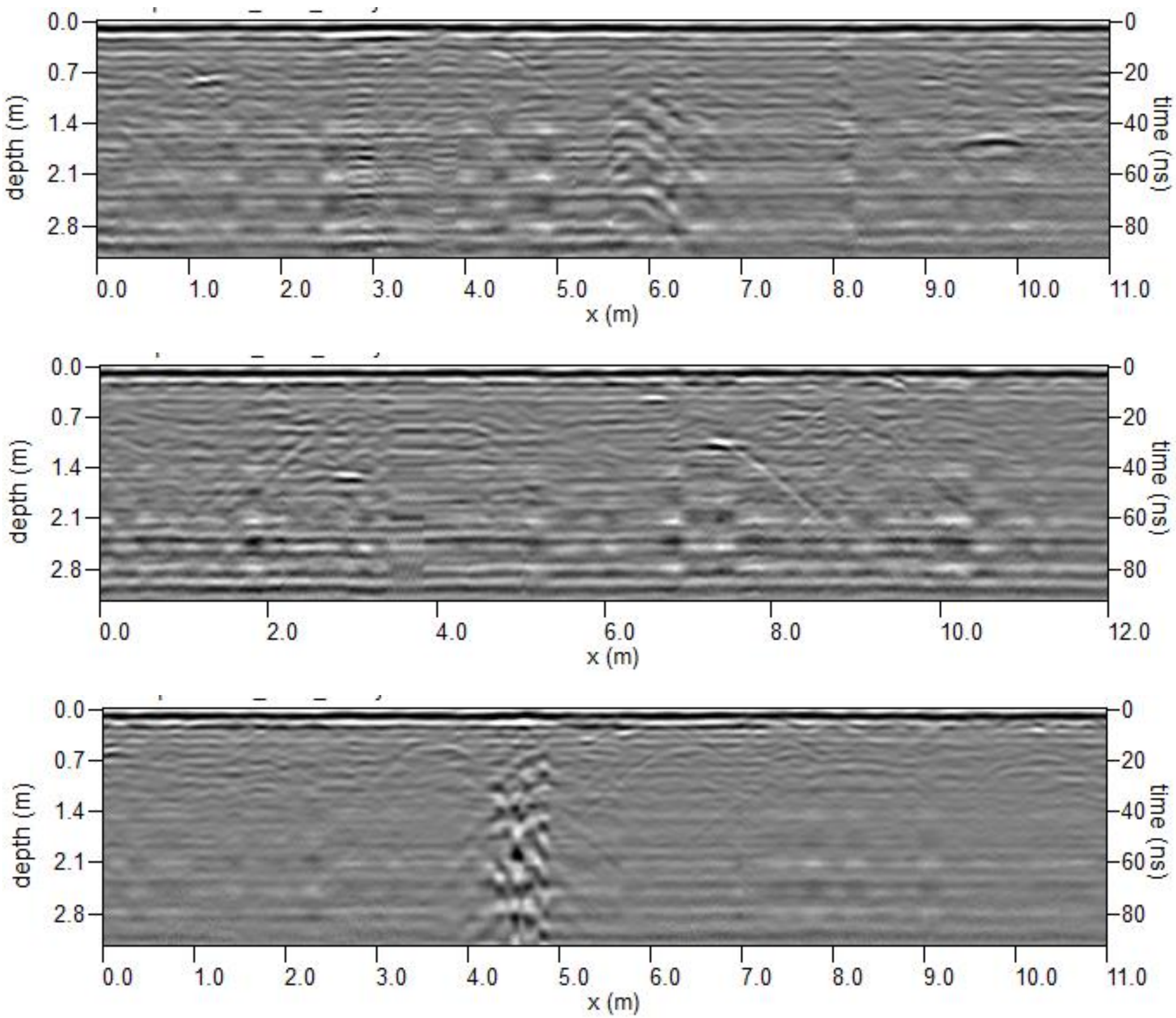


Figure 48: GPR time-slice surveys at seven months post burial, all burials are in an east to west orientation. A) site 1, B) site 2 and C) site 3.

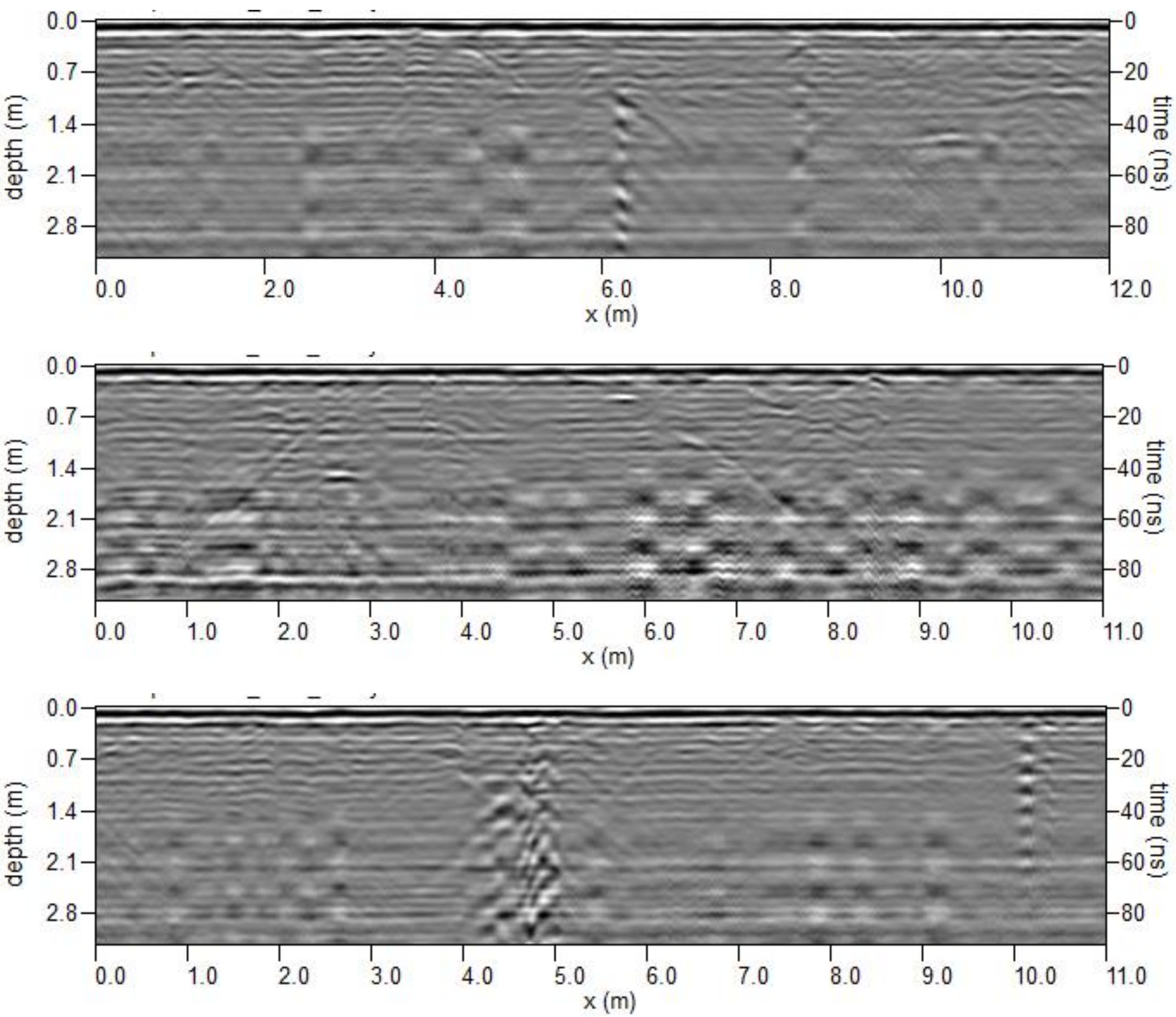


Figure 49: GPR time-slice surveys at eight months post burial, all burials are in an east to west orientation. A) site 1, B) site 2 and C) site 3.

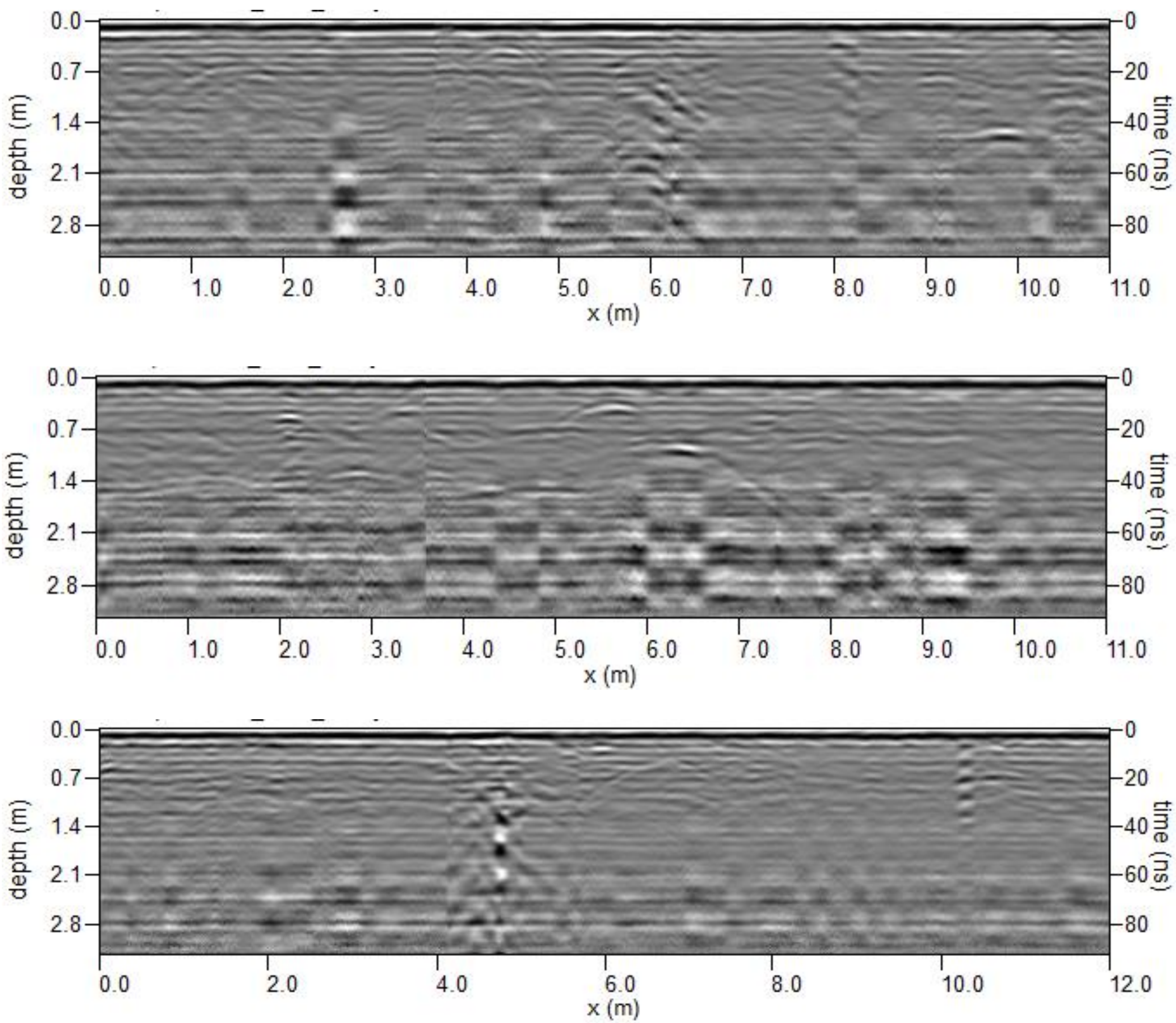


Figure 50: GPR time-slice surveys at nine months post burial, all burials are in an east to west orientation. A) site 1, B) site 2 and C) site 3.

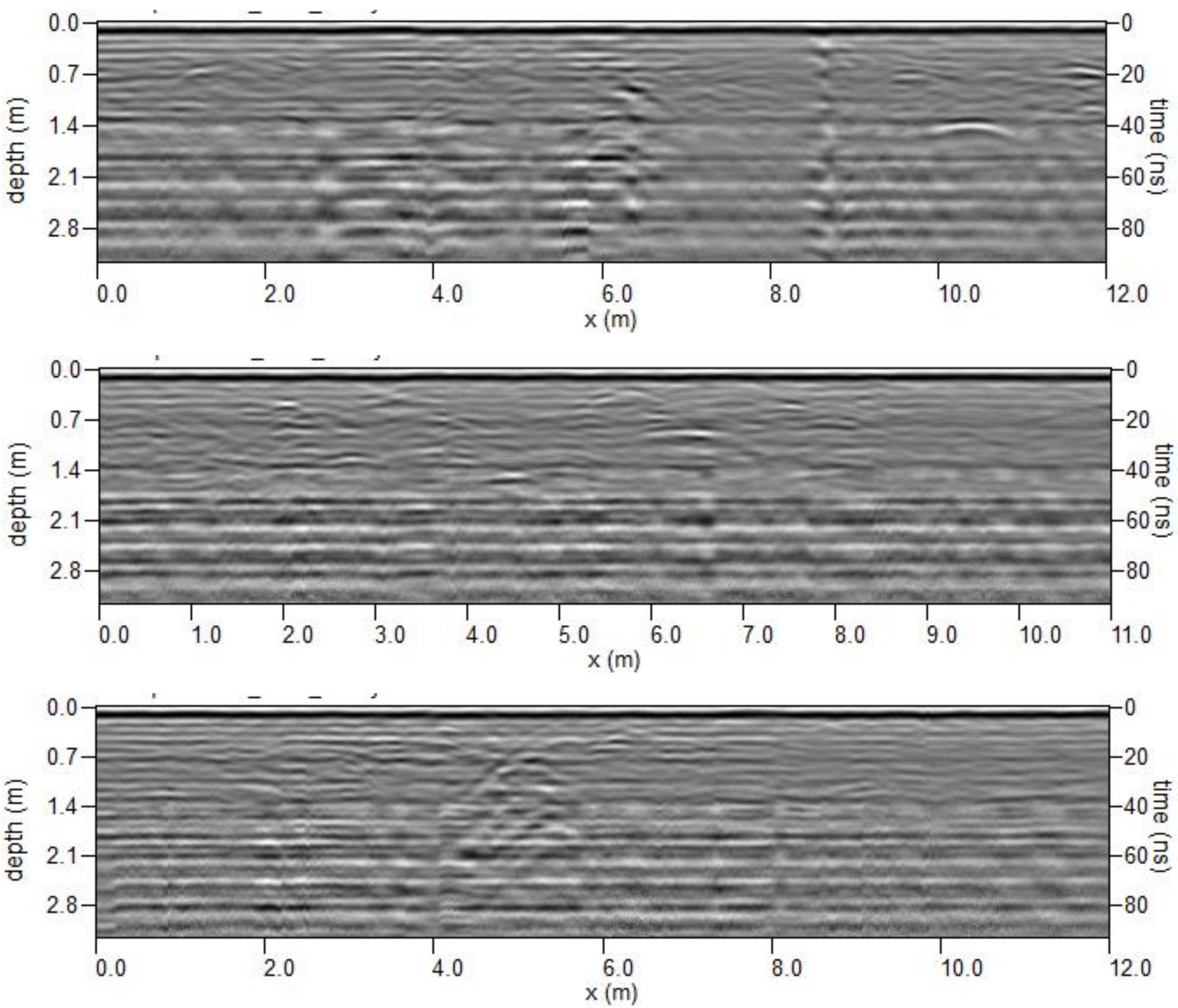


Figure 51: GPR time-slice surveys at ten months post burial, all burials are in an east to west orientation. A) site 1, B) site 2 and C) site 3.

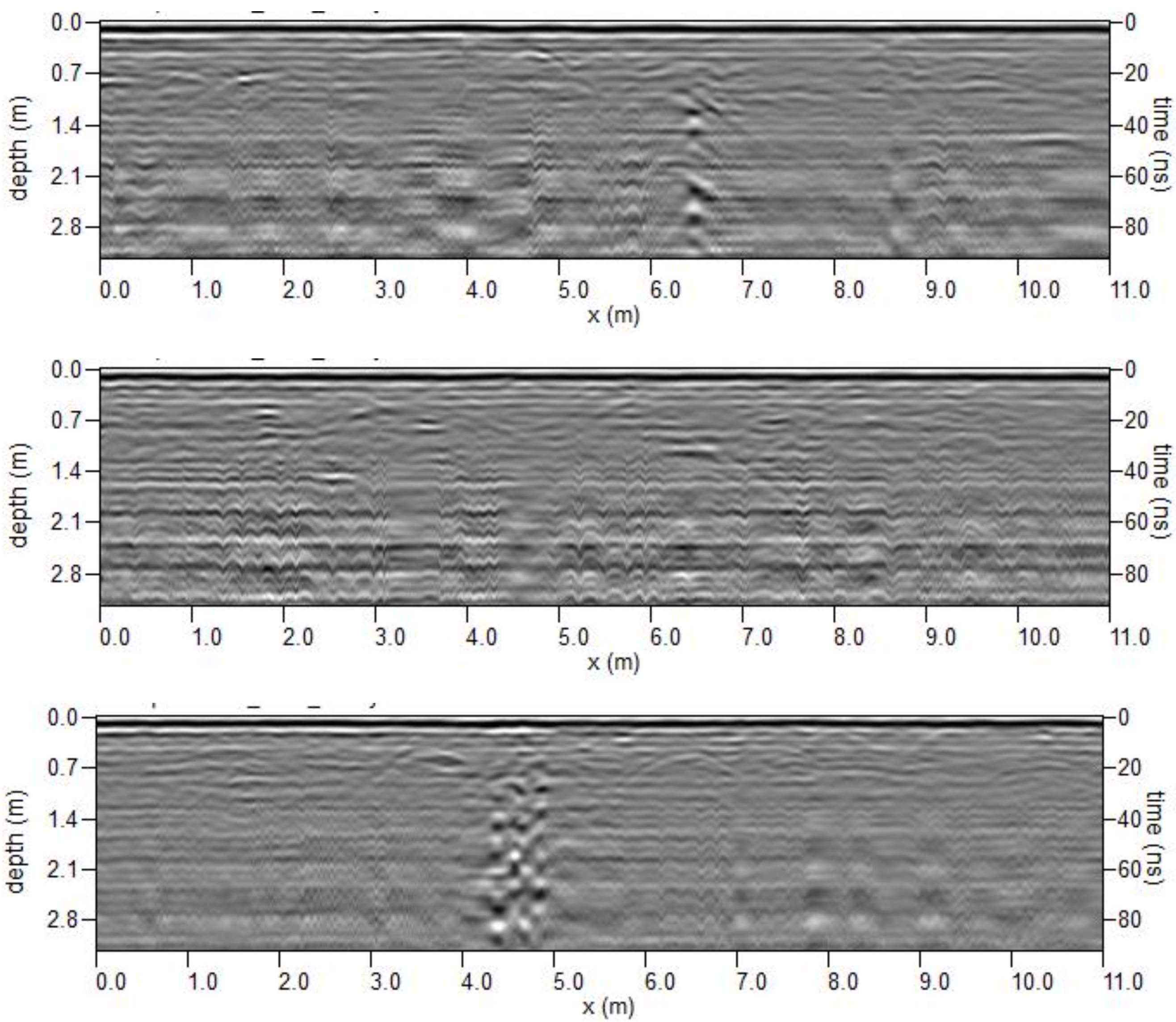


Figure 52: GPR time-slice surveys at eleven months post burial, all burials are in an east to west orientation. A) site 1, B) site 2 and C) site 3.

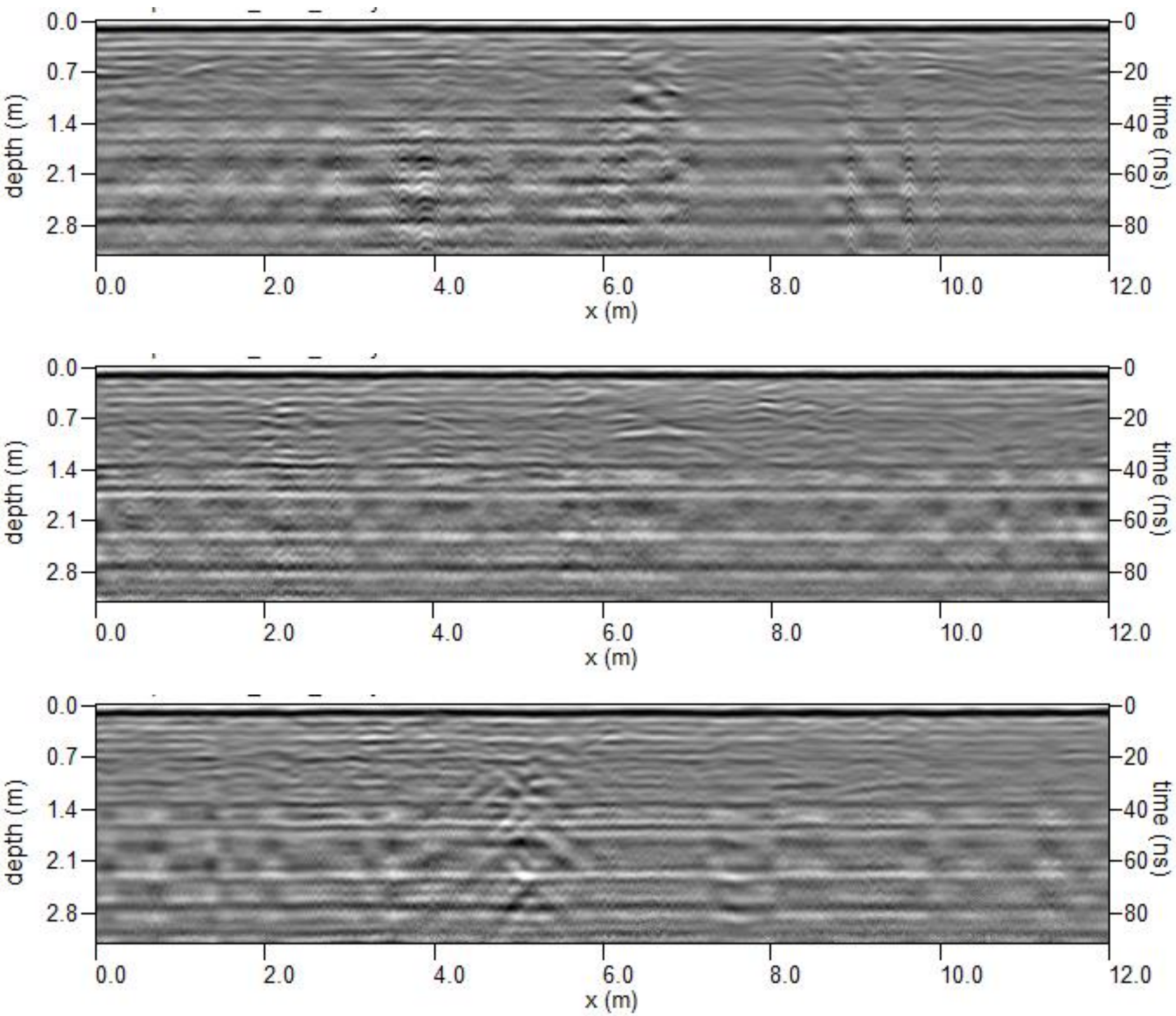


Figure 53: GPR time-slice surveys at twelve months post burial, all burials are in an east to west orientation. A) site 1, B) site 2 and C) site 3**.**

4.5 Detectability predictor

The network diagram of the elements that are intended to be included in the algorithm for the proposed ‘detectability predictor’ tool was created by Dr David Jordan for the purpose of this project (Fig. 54). This was further developed by the author following the survey work conducted as part of this thesis (questionnaires and geophysical data collection). The description of the tool was created in two parts based on current knowledge of geophysical properties of soils and targets, the data collected as part of this thesis by the author; 1) creating an outline of how the tool might predict the success of detecting the buried target (Fig. 54) and 2) creating the table of properties that the code could draw information from (e.g., instrument sensitivity, targets, vegetation, and so on). The purpose of the diagram (Fig. 54) outlining how such a tool might predict the success of detecting the buried target and the algorithmic approach it describes is to make explicit the process by which decisions can be made, and the information required in order for them to be made, concerning the likely success of a specific detection method in a specific environment for a specific target. It is also intended to describe a pathway to developing a tool based on such an approach.

Firstly, the key properties (found along the top of line of the algorithm network diagram) are described below, explaining how they may contribute to overall success of a geophysical method in any given context:

1. The properties of the target to be detected, such as size, material, and expected changes due to burial (e.g., decomposition)
2. The depth of the buried target can affect how well it can be detected by the geophysical methods.
3. The physical and chemical properties of the parent material of the soil and the environment, (e.g., the composition, electrical resistivity, magnetic susceptibility, dielectric permittivity) are the measurable properties that a specific geophysical method seeks to detect.
4. The sensitivity of the geophysical instrument determines its capability of detecting subtle difference in the measurable properties of the buried target.
5. The environmental conditions at the survey site (which could include climate, terrain, and accessibility) can impede on careful deployment of the geophysical methods and therefore the performance.
6. The spatial density of the measurements to be collected (both along a traverse and between traverse) could influence the resolution and accuracy of the survey data which in turn can affect the success or failure of detecting the buried target.

In the algorithm network diagram (Fig. 54) each property (described above) is represented as an element, and the connections between each element represent the influences and interdependencies among the properties. The below table (Table 24) provides a description of how the algorithm could function.

Table 24: a description of the main processes involved that could be involved in the algorithm development with a breakdown of the steps that would need to be carried out in each process.

Main processes involved in the algorithm	**Steps that will be undertaken in each process.**
Data input and processing	Gathering initial data on the target and environmental properties, expected burial, soil type, and other relevant site information.
	Ensuring all input data is in a consistent format and scale for processing.
Analysis and evaluation	Assess the target properties and expected changes due to burial (e.g., decomposition).
	Estimate the depth of the buried target and how this could affect the transmission of the geophysical signal to reach the target.
	Determine the composition of the soil and the properties (chemical and physical) that could affect the transmission of the geophysical signal.
	Identify which physical and chemical properties are most relevant for detection (e.g., electrical resistivity, dielectric permittivity, magnetic susceptibility).
	Evaluate whether the geophysical methods available are sensitive enough to detect the required property of the target at the necessary resolution.
	Assess the environmental factors that might affect the survey by hindering careful walking speed and therefore the careful deployment of the geophysical methods.
	Determine the optimal spatial density of measurements (both along a traverse and between traverse) needed for accurate results
Processing which applies the algorithm: this could include a combination of these two calculations or be one or the other.	Assign a scored ‘weight’ to each element based on its interdependencies and importance (e.g., factors more crucial to detection success would receive a higher ‘weight’). From this calculate a combined score for each geophysical method by adding together the ‘weighted’ score of the relevant factors. This could then be used to rank the geophysical methods based on their combined scores, highlighting the most to least suitable for any given context.
	See Table 25 for the alternative calculations that could be used for each geophysical method individually to predict the detectability of a target and the time required to survey the site in any given context.

Output recommendations	Provide recommendations for the most appropriate geophysical method based on either both or one of the two calculations above in Processing the algorithm.
	Provide explanations for the order of the ranked geophysical methods, detailing how each factor influenced the decision.
Feedback mechanism	Provide a place for feedback to be provided by expert practitioners based on findings from field work, experimentation, modelling, etc.

The aim of the properties tables are to describe a range of properties that can be measured so that specific cases may be explored by creating Monte Carlo simulations taking values within these ranges, the properties tables developed can be found in Appendix 10. Table 25 below shows the simplified calculations that might form part of the algorithm code in the proposed tool which is required in order to predict the detectability of each of the four methods initially included in the tool based on an analysis of current practice and the necessary steps needed. It will be intended to draw information from user input, properties tables and maps to produce an output of how likely the method will succeed in the given environment.

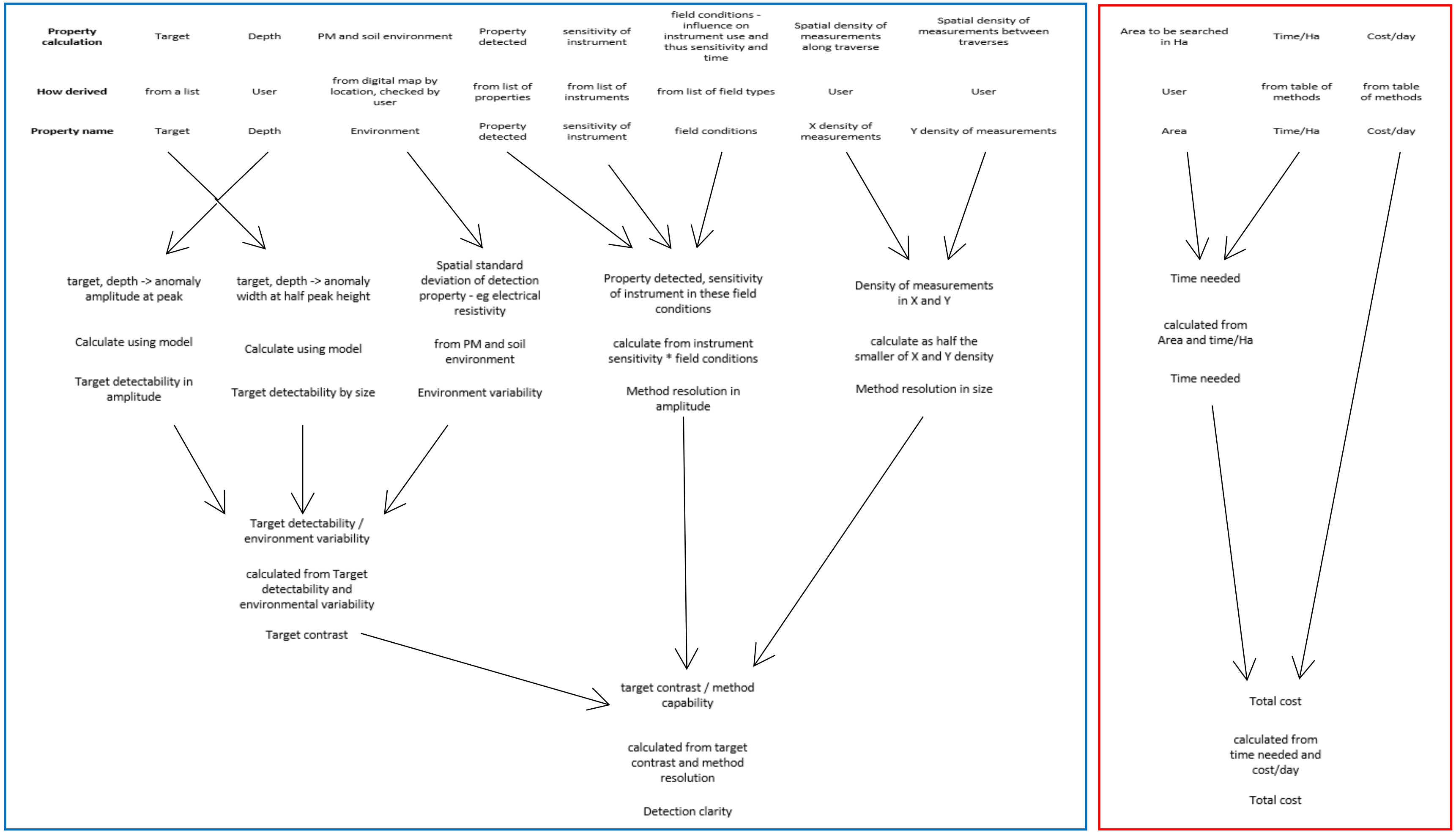


Figure 54: the schematic network diagram created by David Jordan showing an outline of how the tool might predict the success of detecting the buried target by defining the table properties, the calculation for the property and how it is derived (blue box). The time required to conduct the search and the total associated cost can be calculated by determining the area to be searched, the time required to search 1 Ha of the site using a given method and the cost of surveying the site per day (red box).

Table 25: the simplified calculations for each method to predict detectability of a target and the time required to survey the site.

Magnetometry
Calculate the magnetic amplitude of the target
Look up background magnetic amplitude distribution
Look up the detection capabilities of the sensor in these conditions
Calculate the magnetic detectability from contrast between target and background and the capabilities of the sensor in this environment
Calculate the time required to survey the area given the nature of the vegetation
2D Electrical Resistivity
Calculate the electrical resistance of the target from the ground surface in a homogenous earth with mean ER values using a 1m twin-electrode array
Look up background electrical resistance distribution for the soil/PM and electrode array
Look up the detection capabilities of the sensor in these conditions
Calculate ER detectability from contrast between target and background and the capabilities of the sensor in this environment
Calculate the time required to survey the area given the nature of the vegetation and surface
2D Electrical EMI conductivity
Calculate the electrical resistance of the target from the ground surface in a homogenous earth using a 2m EMI sensor
Look up the background electrical resistance distribution for the soil/PM and EMI sensor
Look up the detection capabilities of the sensor in these conditions
Calculate EMI electrical conductivity detectability from contrast between target and background and the capabilities of the sensor in this environment
Calculate the time required to survey the area given the nature of the vegetation and surface
GPR
Calculate the GPR reflection amplitude of the target
Look up background dielectric variance distribution
Look up the detection capabilities of the sensor in these conditions
Calculate the GPR detectability from contrast between target and background and the capabilities of the sensor in this environment
Calculate the time required to survey the area given the nature of the vegetation and surface.

4.6 Summary

The results presented in this chapter provide a comprehensive evaluation of various geophysical methods and their effectiveness in different forensic scenarios. Through detailed analysis of practitioner surveys, scenario questionnaires, and field data from multiple sites, several key insights have emerged.

Firstly, the results highlighted the variability in method applicability depending on environmental conditions and specific site characteristics. For instance, at Site 1 of the scenario-based questionnaire, the participants expectation of the effectiveness of methods like electrical resistivity, GPR and magnetometry, varied significantly between summer and winter, as well as between different burial scenarios. This highlights the necessity for a specific approach to method selection, tailored to the unique conditions of each forensic investigation. Secondly, the scenario-based questionnaire results revealed a moderate level of consensus on the most suitable methods for different scenarios, indicating both the value of expert opinion and the need for continued refinement of best practices. The variability in practitioner agreement also points to the importance of incorporating a diverse range of expert insights into the development of the algorithm for the proposed tool.

Additionally, the longitudinal study examining the impact of environmental variations on detection success emphasised the significance of considering seasonal and site-specific factors in predictive models. For instance, at the TRACES site, the relatively stable clay-rich soil conditions minimised the impact of seasonal changes, whereas other sites with sandy soils showed greater variability in method effectiveness.

These findings collectively reinforce the thesis's aim of describing the criteria and properties required to be considered for developing a data-driven, expert-informed tool to improve the selection and application of geophysical methods in forensic investigations. The results validate the proposed approach and provide a solid foundation for algorithm development and later the creation of a tool, ensuring it is grounded in real-world data and practitioner experience.

In summary, this chapter has demonstrated the critical factors influencing the success of near-surface detection methods and highlighted the need for a dynamic, adaptable tool to guide forensic practitioners. The insights gained here will directly inform the next phases of algorithm development and field testing, ultimately contributing to more effective and reliable forensic investigations. The results from this chapter will be discussed in more detail in the following chapter.

Chapter Five

Discussion

5.1 Introduction

The overarching motivation of this thesis is to improve the success rate of detecting buried forensic targets which aims to be achieved by consolidating expert knowledge and current best practices on behalf of the profession on suitable search algorithms and doing the groundwork for the later development of an open-source tool. This is intended to be achieved by carrying out a review and, from this, identifying and then codifying the elements required for a practical, open-source tool for the profession like the one proposed in this thesis. This chapter discusses how the data gathered from the comprehensive methodologies outlined previously addresses the fundamental questions posed by the thesis, particularly regarding the delegation of responsibility for selecting optimal near-surface detection methods to an expert system or the use of such a system to challenge and support expert judgements. This chapter synthesises the data from the different methods carried out in Chapter 4 to address how it supports the future development of an expert system of optimal method selection. The implications of the findings will be discussed and how they relate to the initial purpose and motivation of the thesis, and how they inform the creation of a practical, reliable tool for forensic professionals to support making explicit the processes experts now use to make decisions. Making clear the strengths and weaknesses of these processes is a key part of the work in this thesis. By examining the merging of practitioner insights, empirical field data, and longitudinal study results, it will indicate how the proposed tool could enhance decision-making and establish a new standard of best practice in forensic geophysics.

5.2 Questionnaires

An opinion survey was carried out in two parts, the first which will be discussed here was to gather comprehensive insights into the current state of method selection and usage, as well as to identify areas for improvement. By capturing opinions and experiences of professionals, it was sought to understand the challenges they face with existing technologies and methodologies, their preferences and expectations for future advancements, and their views on the potential development of a standardised, computer-based decision-making tool. The data collected here provides a foundational understanding of the profession's current practices and ambitions, guiding the algorithm development for an expert system to improve the selection and application of near-surface detection methods.

5.2.1 Overview of the profession

There was a lack of response to the call for participants to take part in the expert opinion survey with only ten people taking part, of which eight were from the UK. It was not unexpected that there would be a lack of response, this could have been for several reasons. Those who were involved more than likely recognise the problems in the field and want to see a change in the way things are done to improve the way searches are carried out by making decision-making more consistent across all practitioners. Those who took part in the survey may value the work being done as part of this thesis to help in improving the current decision-making process. Possible reasons for the lack of uptake could be down to several things such as:

- Non-participants may have been worried how they would be perceived when responding to the questions e.g., they may not be confident in their own decision-making currently or have many failures when searching for buried targets.
- Non-participants may not see a problem in how searches are currently conducted and therefore do not feel their input would make any difference.
- Non-participants may not want to mess with the current status quo of things or shine a bad light on the current practices.
- Non-participants may have had concerns about the confidentiality of their responses or worried about the repercussions of sharing candid feedback.
- Additionally, some practitioners might have felt that their input would not lead to meaningful change, resulting in apathy towards the survey.

The low uptake of responses to the questionnaire highlights a critical need for more open discussion within the profession. It highlights the importance of creating an environment where professionals can freely exchange experiences, identify what works and what does not, and understand the underlying reasons for these outcomes. To increase participation in the questionnaires, especially on a national and international scale, several factors need consideration to improve accessibility, relevance , and user experience. One key element is making the questionnaire more user-friendly, with clear and concise questions and an intuitive format that encourages completion. Rather than the questionnaires being in a word document format, it could be readapted to be suitable for mobile and desktop platforms to promote participants to engage with it on various devices, making it more convenient to complete. It is also important that the questionnaire appeals to a broader professional audience by addressing topics relevant to both national and international practitioners. This could involve including more context-specific questions or sections that address regional practices, conditions, and challenges in the field. Improving efforts to partner with professional associations, governmental organisations, non-governmental organisations (NGOs), etc. could maximise participation and increase the number of responses. Lastly, making a clear statement of how the results of the questionnaires will be used and highlighting the importance of geophysical surveys in forensic investigations and the potential to contribute to valuable research that could influence future practice.

It is acknowledged that a larger pool of responses is necessary to improve the potential accuracy and reliability of the proposed tools outputs based on expert opinion. A small pool of responses limits the ability to generalise the results as it is unlikely that it captures the diverse perspectives and experiences that exist within the professional field. A larger pool could enable statistical analyses to be included in the algorithms to enhance the accuracy of the model and its ability to represent a variety of environments and burial scenarios. This could improve any potential outputs of the proposed tool by reducing bias and help avoid overfitting the model to a narrow set of inputs, which could potentially skew the results or overlook the important variables that may affect method efficacy in diverse settings.

There was little consistency in the responses to the questions among the participants with differences of opinion throughout, although there was some agreement in parts. If the questions were more directed or if the researcher provided options to each question e.g. the participant ticks what they currently do to aid in their own decision-making from a list with a comments box at the end of the question to allow them to expand on their answers, then there may have been more consistency or overlapping of the participant responses. However, this could have biased the participants responses to a certain way of thinking. An option to improve the way the responses were recorded could have been to have an open panel to allow a back and forth of responses and opinions between expert practitioners, although some participants may have held back not wanting to be judged by their peers or chose not to take part at all for the same reason.

From the responses it was obvious that most participants conduct a desktop study prior to conducting a geophysical search, this is already incorporated into the ‘network’ diagram (Fig. 54), therefore it is intended to be incorporated more explicitly into the proposed tool so that the practitioners continue carrying out what is considered current best practice by inputting the different variables of the search area and target, but the tool will output the decision of the best detection method(s) to use. Consideration will be taken to ensure that there is leeway to allow the practitioner to make an informed decision based on the proposed tools recommendation(s) providing a common-sense approach to the tool’s parameters (for example, interval spacing and antenna frequency). There are no two sites the same, therefore applying the same method or combination of methods to all sites would be a waste of time and resources. Just because method X worked at site Y, does not mean it is going to work at site Z as well as it did at site Y. Applying methods in this unsystematic way does not provide evidence of the capability of the method, more support for the science behind the method is required and is beneficial for the field and future searches.

Conducting searches using all geophysical methods available without considering the science behind what methods are best to use in each environment is not productive, using all methods can be useful in research or academic work to evaluate or compare the methods, but this is not pragmatic to do in commercial settings where time and money is a major constraint on the search. This is also applicable to forensic searches where time is the main constraint on the search, as the longer it takes to locate evidence e.g., weapons, environmental waste, clandestine burials, etc. the higher the chance that the person responsible for the crime can go unpunished.

It is unfortunate that community geophysics groups often lack sufficient funding to afford many of the available geophysical methods or to use a combination of methods, which might be more beneficial for their searches. However, if the tool to be developed is available as open source, then those participating in community geophysics projects might be able to determine the optimal method(s) for the search and potentially source the equipment without having to use trial and error which in the long run will save them time and most importantly money.

Among the participants it was not common to produce models of the site prior to the search, however models can still be useful, as Box et al. (1987) states “all models are wrong; the practical question is how wrong do they have to be to not be useful”. In systems as complex as soil, useable models must be great simplifications of reality. There are mathematical models, made available through software tools, which can realistically model the magnetic behaviour of buried targets even in complex environments. Given that the magnetic responses of specific detection instruments are also available, it is feasible to extend and greatly expand predictions of the ability of magnetometers to detect buried artefacts using such modelling, and this can be validated using field experiments. This applies to all geophysical properties that are detectable and the means used to detect them and there is therefore a very strong motivation to greatly expand the use model-led prediction and interpretation of geophysical survey in forensic practice. Yet, there is a risk that a model too simple will only give obvious or wrong conclusions, but they can be wrong is a way that is useful. If the outcomes of simulations based on a model can be tested it can show that the simulation and reality differ which can provide lessons about the weaknesses of the current understanding of reality.

With regards to improving how searches are currently conducted there is a requirement for making decision-making more consistent, providing validation of search methods and better recording of the outcome of a search. From all the responses, it is interesting to note that the participants concentrated on the improvement of equipment rather than improving understanding of the environment for those involved in searches using geophysical detection methods. The proposed tool may deliver this as it would provide an opportunity for the users to take more consideration of the science behind the methods and to support the future of the proposed tool by allowing feedback to be input into the proposed tool of why a method did or did not work during the search. The proposed tool is not intended to remove the human element of appraising a site, but to make it more consistent between all users regardless of the professional field they conduct searches for. Overall, the proposed tool may improve the knowledge of the user of the geophysical methods, enhancing how they are currently used to search for buried targets and to also produce a greater integration of technologies between all disciplines.

Two Expert’s responses stated that they would not change the way they chose their methods or change the methods they did use if they repeated the same search under the same conditions. It is possible that their reasons for not wanting to change anything they had done is due to a lack of self-criticism or they are not being forthcoming with past failures when searching for buried targets. It could be the case that their methods did work well, but without the feedback following the search of why it worked well the search becomes an exercise of search and discovery without the scientific interpretation and validation of the results.

There was a mixed review as to whether the proposed tool was a good idea, whether its intended function will work and whether the programming language it will be built in is suitable. As discussed, Expert D believes that implementing the proposed tool in a program such as a Geographic Information System (GIS) would not be suitable as it may not be reliable enough with regards to temporal data.

This point will be fully explored when further developing the algorithms for the proposed tool and a different program may be considered for the implementation of the tool. There will be elements of the output of the proposed tool which will be down to the user's interpretation and common sense such as if an active method will be suitable at the time of the search due to environmental conditions changing hourly. The proposed tool is not intended to be a 'black box', it is intended to produce outputs by ranking methods on most suitable to least suitable based on science-based evidence which will form part of the algorithm. The proposed tool is intended to explicitly outline the process by which it reaches conclusions. The aim is to clarify how the profession, as a whole, makes such decisions by capturing and detailing the rational element of the decision-making process. The proposed tool will be a place for feedback on the output and allow input of future searches or research to improve the algorithm which will in turn improve future outputs. Expert H states the methods should not be ranked as each site can have hidden 'surprises', this is expected as sites are not just 'black and white' where a certain method will work all the time, they are very 'grey' and a method that may work on one day in the summer may not be suitable in the winter. To try and use all methods at the disposal of the user is not only 'poor science' where no thought has been put into its suitability for the site, but there is often not enough time to deploy all methods available and creates wasted resources, time and money.

There was some worry that the proposed tool could create conflict for the participants as it could reduce the amount of future work available for them, as the accessibility of the proposed tool will generate greater training opportunities but will also produce greater competition for work. This will always be the case in any field and is understandably a worry for those currently employed to undertake this work, but current practitioners are not always going to be around to do the work (e.g., retirement, moving from commercial sector to academia, other commitments, etc). It should always be a case of improving one's own training to be more competitive in the field, but also preparing the next generation of geophysicists regardless of the professional field to pass on knowledge and best practice.

There was some agreement where participants thought the proposed tool could be helpful in general terms, for example, identifying the use of potential methods over others, and could be great if it works as intended. Keeping the proposed tool as open source will enable everyone utilising geophysical methods for their searches to access the information available, yet there is still a need to ensure the proposed tool does not get into the wrong hands e.g., criminals. As the primary reason for the future development of the proposed tool is to improve forensic searches it is necessary to ensure that there will be some form of security on the tool so that only authorised users can have access. Following personal communications with Dr Chris Hunt (2024) via email, he stated "as someone who has done a fair amount of forensic science consultancy over the last 20 years, I have found practitioners to be a very mutually supportive bunch… there is always courtesy and respect between practitioners. I suspect that you underestimate the paranoia that develops in practitioners after years of exposure to our legal system, lawyers and criminals". He states that "there were people present during a trial taking notes of all forensic evidence, we were able to identify those people present through our PSNI contacts as linked to paramilitary groups, and they were there to learn from previous mistakes. Some members of these groups are remarkably forensically aware. I also experienced dirty tricks played by defence lawyers attempting to discredit forensic scientists and thus their evidence. This atmosphere makes us very defensive as a profession. Almost certainly there would be fear that an online tool would be hacked. This is particularly the case as you argue that it should be open source". These are great points made by Dr Hunt and something to consider when moving forward with the future development following the submission of this thesis, this is a real concern that needs to be fully thought through.

It was encouraging to see many of the participants would be willing to contribute towards the proposed tool not only to improve current best practice but to also improve the proposed tool by incorporating their own past, current and future search data. The more data that is included in the algorithm, the more accurately it will predict the most suitable method(s) as compared to the least. It remains understandable that not everyone would want to participate or is unable to due to work commitments for example.

There was a consensus among the participants about what they would like to see from the proposed tool which was progress and change, wide involvement across disciplines and an easy interface with reliable outputs. This can only be achieved by users being open-minded, willing to be involved to improve current practices and being upfront about failures as much as they are about successful searches. With the proviso of accurate data, guided decision-making and flexible outputs being assimilated into the proposed tool, the participants believe that the proposed tool will be greatly beneficial to those actively using near-surface geophysical method to search for and locate buried targets. The proposed tool will potentially enable users to produce faster evaluations in the first instance prior to conducting a survey, reducing the amount of time required to conduct a desktop study which will result in more time available in the field conducting the search. There was some discord with the above statements as Expert C believes the proposed tool will not change the current practices conducted in commercial archaeology as there has been little improvement or progress in the field in more than three decades. This may well be the case and the proposed tool does not create change in that field, but there is no harm in trying to improve things and there are still other fields that will benefit from the proposed tool.

5.2.2 Site specific detection

The scenario questionnaire was designed to qualitatively analyse the applicability and effectiveness of various near-surface detection methods based on the expert opinion of practitioners in the field who took part in the questionnaire. Participants were asked to evaluate different geophysical techniques across range of specific forensic scenarios. The goal was to gather detailed insights into how well the participants expect each method to perform under different conditions and contexts. By scoring each method based on its perceived effectiveness at specific sites, this questionnaire aimed to capture practitioner experiences and preferences. This data is crucial for informing the descriptions for developing of the 'expert judgment' algorithm element of the proposed tool that recommends the most appropriate detection methods for various forensic situations. The insights gained from these questionnaires will help to ensure that the proposed tool is grounded in practical, real-world applications and tailored to meet the needs of the forensic detection community.

The agreement among practitioners regarding which methods would be best to use across the sites in the questionnaire ranged from low agreement (25%) to high agreement (80%) and scores in-between. This variability in consensus highlights the inherent challenges in selecting optimal detection methods for different forensic scenarios. Despite this range, it has provided a foundation for the descriptions of the algorithms included in this thesis that may form part of the proposed expert system, which can be tested in the field following the production of the proposed tool post-PhD and put forward to those in the profession to challenge it and improve it. It highlights the importance of capturing a broad spectrum of professional insights to inform the proposed tool’s recommendations. By incorporating these varied yet consistently supported preferences, the proposed expert system is intended to offer balanced and well-informed guidance, enhancing the overall success rate of detecting buried forensic targets. This alignment with practitioner consensus is crucial for the credibility and practical utility of the proposed tool, reinforcing the aims of the thesis to consolidate expert knowledge and best practice, into a usable resource for the profession.

These results also highlight the importance of considering both seasonal variations and specific burial characteristics when selecting near-surface detection methods. The variability in method applicability highlights the need for an adaptable expert system that can recommend the most suitable methods based on detailed site and environmental parameters. By incorporating these findings, the proposed expert system can provide tailored recommendations that optimise detection success rates across diverse forensic scenarios. This reinforces the future motivations following the submission of this thesis to develop an informed, data-driven tool that aids practitioners in making optimal method selections, ultimately improving the efficacy and reliability of forensic investigations.

5.3 Test sites

The surveys conducted at the four different test sites incorporate a long-term pig burial (at TRACES only) and a forensic metal target burial, provided critical insights into the applicability and sensitivity of different geophysical methods – specifically ERI, GPR and magnetometry – under controlled conditions.

Following the surveys it was recognised that the orientation of the forensic metal target made up of steel rods significantly affects the magnetometry readings and, to a lesser extent, the GPR readings, unlike a real forensic metal target. When three bolts are placed horizontally in a hole the resulting magnetic field around them varies depending on whether they are aligned in parallel or in opposite directions. This alignment influences whether their remnant magnetisation reinforces or cancels out. For crossed bolts, a similar but more complex effect occurs to a lesser degree. Conversely, a handgun barrel or a knife blade will have a single, consistent orientation of remnant magnetisation. If carried out again, this would be better taken into consideration.

It is important to also acknowledge that the surveys conducted did not encompass the full range of potential sites and scenarios that may be encountered in forensic investigations involving buried targets. The focus was on specific environments, and while the findings provide valuable insights, they are not exhaustive. This limitation underscores the importance of further studies to validate and expand on the future algorithm's applicability across diverse conditions.

5.3.1 TRACES

The ERI data, collected using a dipole-dipole array, offered significant information on subsurface pre- and post-burial. The initial control line (Fig. 22A) displayed a relatively uniform resistivity profile, predominantly green hues indicative of consistent subsurface properties. Post-burial ERI results (Fig. 22B) revealed a small area of higher resistivity compared to the pre-burial survey at the location of the forensic metal target. This change suggests that ERI is sensitive enough to detect the metallic objects, even in relatively homogenous subsurface conditions such as those present at TRACES. For the long-term pig burials, the ERI profile (Fig. 22C) highlighted low-resistivity anomalies corresponding to the wrapped and naked burials at 3.50 m and 5.95 m respectively. Notably, the wrapped burial produced a smaller anomaly than the naked burial, indicating that wrapping may influence the detectability of organic targets. The blank control burial at 8.00 m along the survey line, however, was no longer discernible after 28 months, suggesting that the soil that was reinterred into the ground without anything added was able to settle to a point where it blends with the surrounding soil that was undisturbed at the time of the burials being created. Similar results of ER methods working well on these types of organic burials has been observed in other studies (e.g., Pringle et al., 2008; Jervis et al., 2009; Molina et al., 2015, 2016a, 2016b, 2024).

The GPR results further complement the ERI findings. The pre-burial radargram (Fig. 23A) exhibited multiple weak hyperbolas, likely caused by stone and rock deposits within the glacial till substrate. Post-burial, the forensic metal target produced a strong hyperbola is comparison to the background noise (Fig. 23B) confirming GPR's capability to detect metallic objects. However, when examining the pig burials (Fig. 23C), only the naked pig burial generated a discernible hyperbola. This suggests that the wrapping of organic targets can significantly attenuate the GPR signal, making wrapped burials less detectable compared to unwrapped ones at this site. The absence of hyperbolic reflections for the control burial also aligns with the ERI data, reinforcing the conclusion that certain organic materials may become undetectable over time as they decompose and integrate with the surrounding soil.

The magnetometry survey results presented a different but complementary perspective. The control line (Fig. 24A) indicated a stable magnetic field with minimal anomalies. Post-burial data for the forensic metal target (Fig. 24B) revealed a noticeable, though small, magnetic peak (up to 20 nT) at the burial location, indicating that magnetometry can detect metallic objects, albeit with less sensitivity compared to ERI and GPR. This compares well to the study by Deng et al. (2020) where the buried metallic weapons were detected. For the pig burials (Fig. 24C), magnetometry readings showed variable peaks that corresponded roughly with the burial locations. Although pre-burial readings were unavailable due to the long-term nature of the experiment, these peaks suggest that buried organic materials can alter the local magnetic field. However, the variability and smaller magnitude of these peaks compared to the forensic metal target burial highlight the method’s limitations in detecting organic targets consistently. Studies by Pringle et al. (2008) and Juerges et al. (2010) observed mixed successes in detecting simulated clandestine organic burials using magnetometry, similarly to the survey in this study where small peaks were observed which could have easily been missed when carrying out a survey where the location of the target is unknown.

5.3.2 Yorkshire Moors

The initial ERI control survey (Fig. 25A) revealed a predominantly uniform subsurface profile with low resistivity values ranging from 200-400 Ω.m . A slightly higher resistivity layer (600-1000 Ω.m) was detected just beneath the surface, extending to approximately 0.65 m depth, and a much higher resistivity layer (1600-2500 Ω.m) was observed from 0.65m to 1.70 m depth, the limit of the survey. Following the forensic metal target burial (Fig. 25B), the background resistivity values remained consistent with the control survey, indicating stability in the subsurface conditions. However, a small anomaly with resistivity values around 1500 Ω.m appeared at approximately 5.60 m along the survey line, directly correlating with the burial location of the forensic metal target. This anomaly, though subtle, suggests that ERI can detect small metallic objects in stable surface conditions like those at the Yorkshire Moors site.

The GPR radargrams further highlighted the detection capabilities under similar geological conditions. The control survey radargram (Fig. 26A) displayed a noisy background, characteristic of the sites’ geology, which attenuates electromagnetic waves, particularly in wet and clay-rich conditions. After the burial of the forensic metal target (Fig. 26B), a weak hyperbola emerged at around 5.00 m along the survey line. This hyperbola, though barely noticeable, indicates the presence of the buried target. The general noisiness of both radargrams underscores the challenges posed by the site’s geological conditions, similar to those observed at the TRACES site.

The magnetometry data mirrored the patterns observed in the other methods. The control survey (Fig. 27A) produced relatively uniform readings of around 4-6 nT along the survey line, with higher initial readings at the beginning of the line. Post-burial magnetometry (Fig. 27B) showed a slightly elevated reading of approximately 8 nT at the burial location of the forensic metal target, midway along the survey line. While this increase is noticeable compared to the background readings, it is not significantly different, suggesting that magnetometry’s sensitivity to small metallic objects in this context is limited.

5.3.3 Larkhill, Formby

The ERI survey results for the control line (Fig. 28A) revealed highly variable resistivity values in the upper 0.65 m of the subsurface. This upper layer exhibited patches of higher resistivity (2000-3000 Ω.m) interspersed with mid-range resistivity values (700-1200 Ω.m). Below 0.65 m, the resistivity values became much more consistent and lower, around 200 Ω.m , indicating a more homogenous subsurface layer. Following the burial of the forensic metal target at approximately 5.60 m along the survey line (Fig. 28B), the ERI profile showed a barely noticeable change in resistivity values at around

0.65 m depth, which was below the burial depth. There was no significant change within the actual burial dimensions, suggesting the ERI's ability to detect the small metallic object in this context was limited.

The GPR radargram at the Larkhill site, similar to those at the TRACES and Yorkshire Moors sites, displayed a noisy background with weak hyperbolas scattered throughout the subsurface (Fig. 29A). Comparing the post-burial GPR survey (Fig. 29B) with the control survey, there was no discernible difference to indicate the presence of the buried forensic metal target. The overall noisiness and weak signal responses underscore the challenges posed by the site's geological conditions, which likely attenuate the electromagnetic waves, making it difficult to detect small, buried objects like the forensic metal target.

The magnetometry data for the control line (Fig. 30A) showed generally consistent readings, with two higher peaks of around 13 nT and 8 nT towards the end of the survey line. After the forensic metal target was buried at around 5.60 m along the survey line (Fig. 30B), a higher anomaly of approximately 25-30 nT was observed. This increase was noticeable and consistent across repeated surveys, indicating that magnetometry was more sensitive to the presence of the small metallic object compared to ERI and GPR in this particular setting.

5.3.4 Norris Farm

The ERI survey of the control line at Norris Farm (Fig. 31A) revealed a predominantly uniform subsurface with high resistivity values down to approximately 0.20 m below ground level. Below this layer, a mid-range resistivity layer extended from 0.20-0.70 m, followed by consistently lower resistivity values to the survey's depth limit. After the forensic metal target was buried at around 5.60 m along the survey line (Fig. 31B), there was a barely noticeable change in resistivity values at the burial location. Although the immediate subsurface showed no significant difference, a slight decrease in resistivity values (indicated by a shift from yellow to green hues) was observed within the burial dimensions. This subtle change highlights the challenges of detecting small metallic objects using ERI in uniform subsurface conditions such as those at this site.

The GPR survey at Norris Farm presented a unique scenario due to the survey setup. The forensic metal target was interred, and a GPR survey was conducted before the control survey. The GPR radargram for the control line (Fig. 32A) displayed a small hyperbolic reflection at the forensic metal target burial location, likely due to the soil disturbance during the forensic metal target's interment and subsequent removal. This hyperbolic reflection may not have been present if the survey had been conducted before any soil disturbance. The post-burial GPR survey with the forensic metal target interred (Fig. 32B) showed a slightly stronger, yet still small, hyperbolic reflection at the burial site. The background noise in both surveys was relatively quiet, with minimal interference from other subsurface reflections. This quiet background facilitated the identification of the hyperbolic reflection, albeit its small size and subtle presence indicate the difficulty of detecting small objects like forensic metal targets using GPR.

The magnetometry data for the control survey line at Norris Farm (Fig. 33A) displayed consistently low readings, with a high peak towards the end of the survey line (Fig. 33B), the readings showed very little difference, producing only a slightly lower reading at the burial location. This minimal change made the anomaly barely noticeable against the background values. The magnetometer results at this site highlights the limitations of this method in detecting small metallic objects in environments with low magnetic noise and uniform subsurface conditions.

5.3.5 Overview of the test sites

The diverse terrains and environmental conditions at the test sites highlighted significant challenges that must be addressed in the descriptions of the algorithms needed for the proposed tool. Each site's unique characteristics influenced the effectiveness and operational feasibility of the geophysical methods, this highlights the need for a flexible and adaptive approach in the proposed tool's recommendations. Time and cost considerations would therefore be integral into the proposed tool's development had these surveys been part of a paid contract for a government body or organisation. This is important to ensure that it provides practical, efficient, and accurate guidance for forensic practitioners operating under varying field conditions.

There are limited peer-reviewed studies on the use of various geophysical methods to detect buried metallic weapons. Of the few available, some of their results were similar to those from the surveys in this thesis but possibly due to different depositional environments between the test sites and/or temporal differences encountered this was not always the case. A study by Murphy and Cheetham (2008) observed that magnetic methods struggled to distinguish between the buried weapons and the surrounding material. Similarly, GPR had difficulty locating the buried weapons when they were positioned in certain orientations. Richardson and Cheetham (2013) also recognised the importance of the orientation of the buried weapons with regards to the success or failure of being able to identify the targets using magnetometry. GPR provided weak to moderate anomalies in the study with the buried targets, again this could have been due to the orientation of the weapons. However, it could be possible that the anomalies were only produced due to disturbed soil rather than the detection of the buried target. This is further evidence that more research is required in order to better understand the success and failure of detecting buried metallic weapons.

Conducting the surveys at each of the four test sites had their own difficulties with regards to deploying the equipment. At TRACES there was very little issue when conducting the surveys for the control and forensic metal target burial as the surface was relatively flat pre- and post-burial, there was just a lot of overgrown grass which impeded a careful walking speed. Over the burials, due to compaction of the soil the ground was not flat which resulted in the GPR not being able to carefully move across the survey line which resulted in unclear and/or noisy radargrams. Additionally, as the burials are situated within and between trees it made it difficult to manoeuvre the GPR due to the trees themselves and/or their roots that were above ground. Even though the location of the burials at TRACES, a walk up a relatively steep incline was necessary to reach the burial location which sits on roughly 13 acres of land. If this site required a full survey of its full limits this would take an extensive amount of time and money to survey which would therefore need to be considered, which is why the tool must be able to consider time and cost as variables when predicting optimal detection methods for a given site. The site at the Yorkshire Moors had a lot of heather as well as exposed bedrock, both of which could impact the efficacy of the methods and how easy it would be to use them on the site. The site was also on an incline which impeded the speed at which you could do the surveys. Both the Larkhill and Norris Farm sites were relatively flat without much if any vegetation that would impede the ability to deploy the methods at these sites. All these factors were then considered for what information needs to be included in the algorithms and/or calculations that would need to be included for the proposed tool to predict the optimal geophysical detection methods in any given environment.

5.4 Multiperiod data

Each site presented unique challenges and characteristics that influenced the detection capabilities of these methods. By comparing pre-burial control surveys with post-burial surveys, significant anomalies and changes in subsurface profiles could be identified. The results of these surveys offer critical insights into the practical application of geophysical methods for forensic investigations and contribute to the descriptions of the algorithms which intend to be used in the future for the development of the proposed tool designed to recommend optimal detection methods based on site-specific conditions.

Data was gathered over the span of twelve months to observe the effects of long-term environmental variations on the success of detecting buried forensic targets. The gathered data over the twelve months provides a comprehensive understanding of how changes in environmental conditions, such as soil moisture and seasonal fluctuations, influence the effectiveness of various detection methods. It was important to understand what effect did changes in the environment at TRACES have on the detection of the buried targets. What information can the site offer about the importance of including time of year or time varying site conditions when predicting the optimal methods to use at a given site?

One of the aims of this thesis was to contribute to the current literature and research in this subject area to improve the understanding of near-surface geophysics in the search for clandestine burials and to answer the questions addressed:

- Can the geophysical methods used successfully locate all the simulated clandestine pig burials at each of the three different areas of the site?
- How long after burial are the simulated clandestine pig burials geophysically detectable?
- Is there an optimal time post-burial that the simulated clandestine pig burials were most detectable e.g., time since burial, seasonally, etc.?

The responses to the questions are addressed in the following sub-sections as per each method.

5.4.1 ERI profiles

- **Can the geophysical methods used successfully locate all the simulated clandestine pig burials at each of the three different areas of the site?**

Differences in the resistivity values in the ERI profiles for the pre-burial controls for each of the areas of the site can clearly be observed with generally lower resistivity values in site 1 which is the wetter plateau on the site compared to the mid-slope site 2 and upper-slope site 3 both of which are drier than the plateau where the water table is less far below ground level. Due to site 1 being wetter it has greater conductive properties than the other two sites, which reciprocally results in lower resistivity values. Areas of higher resistivity values in the ERI profiles could be due to increased number of glacial deposits consisting of rock debris and pebbles which lowers the conductive properties of the medium by slowing or preventing the flow of electrical current. The control profiles can be consistently viewed in the post-burial surveys as background resistivity values and any changes to these values can be accounted for by the changes in climate and rainfall which alters the physical properties of the soil. Additionally, any changes to the background resistivity profiles post-burial could be due to the leachate plumes produced by the decomposing carcass.

The high resistivity values identified in the first two months for the control graves could be due to voids within the soil caused by the digging and refilling of the grave which is filled with air. Due to the dielectric properties of air, it is highly resistant to an electric current passing through it, however as the soil begins to compact and the amount of rainfall increases the graves become less resistive to the electrical current and they become less obvious in the ERI profile merging into the background values.

ERI was successful in locating both burials at site 1 throughout the survey period consistently as a low resistivity shallow isolated anomaly. This could be explained by the plateau producing a wetter environment for the burials and due to the digging and redepositing of the soil it has created an increase in water retention and poor drainage. The exchange of conductive ions from the soil and the decompositional leachate with the water has created an area of lower resistivity in the burials than the surrounding undisturbed medium.

The naked burial is more easily detected at site 2 compared to the wrapped burial, this could be explained by the tarpaulin used to wrap the pig carcass preventing the electrical current to pass through easily creating an area of slightly higher resistivity than the naked burial. The wrapped burial can still be identified as an area of lower resistivity; however, it is not as easily distinguishable against the background values.

Detectability of the burials at site 3 are less consistent than site 1 and site 2 and are less obvious in the profile at varying times of the survey period. The wrapped burial is clearer in the profile than the naked burial as low-mid resistivity values throughout the survey, this could be due to the drier subsurface than the other two sites and the tarpaulin trapping the decompositional fluids within it.

- **How long after burial are the simulated clandestine pig burials geophysically detectable?**

There is varying detectability throughout the survey period amongst the three different areas of the site. At site 1 the burials were successfully detected throughout the whole survey period. The dimensions of the anomaly differed at times but always identified as a shallow isolated slightly circular anomaly, however, remained consistent in detectability. Similarly to site 1, the naked burial at site 2 is consistently detectable throughout the survey period as an area of low resistivity, however the wrapped burial is less obvious as a much smaller anomaly ranging from low to mid-resistivity values during the survey period. Site 3 was the most variable and lacked consistency in detecting the burials successfully throughout the survey compared to the other two sites. Overall, the burials were able to be identified at each of the sites regardless of the consistency or resistivity values in comparison to the background values and pre-burial controls throughout the survey period.

The ground and climatic conditions generally found in the UK can result in the rates of decomposition being slower than those in other countries (Turner and Wiltshire, 1999) resulting in the body taking many years to fully decompose and become skeletonised (Hunter et al., 2013). This could be a reason as to why the ERI profiles were able to detect the burials throughout the 12 months of the survey period as they are yet to reach the advanced stages of decomposition (dry remains).

- **Is there an optimal time post-burial that the simulated clandestine pig burials were most detectable e.g., time since burial, seasonally, etc.?**

There is a lack of evidence from the ERI survey profiles for an optimal time post-burial to detect the buried pig carcasses, particularly between the sites and between burial types. For example, site 1 burials are detectable throughout the whole survey period as noticeably clear low resistivity values compared to the pre-burial control and the post-burial background values.

When comparing site 2 to the pre-burial control and background values of the post-burial surveys the wrapped burials were better detected between month 2 and month 4 and, also month 12 as low resistivity values. During the other months of the survey period the burials were less obvious and harder to observe against the background values. As previously discussed, the naked burial at site 2 is easily observable as low resistivity values throughout the survey period, however the dimensions of the anomaly become noticeably smaller from month 5 to the end of the survey period.

The wrapped burial at site 3 is most geophysically detectable during month 11 where it is identified as an area of low resistivity values, however the remaining months of the survey period the wrapped burial has similar resistivity values to the pre-burial control and is only identifiable due to the slight change in values and the dimensions of the anomaly matching what would be expected from the burial. This, however, could be due to an unconscious bias of knowing the location of the burials rather than there being an actual discernible anomaly. The naked burial at site 3 is most clearly observed between month 2 and month 4 as low resistivity values, however the resistivity values increase after month 4 to almost similar values to the background until it is more difficult to observe.

The seasonal variation that is present between the burials and between sites can be attributed to the disparities in water retention properties of the ground and burials themselves, for example it can affect the depth of the resistivity measurements due to the changes in soil properties at the subsurface as described by Jervis and Pringle (2014).

5.4.2 GPR profiles

- **Can the geophysical methods used successfully locate all the simulated clandestine pig burials at each of the three different areas of the site?**

The 250 MHz GPR pre-burial control and post-burial datasets showed a lot of noise and anomalies that did not relate to a buried target which is evident of the heterogenous and conductive properties of the subsurface at the site which is clay dominant with a lot of glacial deposits of stones and rocks. This can also be reason for the variable success in detecting both the naked and wrapped pigs each month throughout the survey period post-burial as it creates additional noise and produces non-target hyperbola obscuring the buried targets. Hammon et al. (2000) suggested that there is a lack of contrast between a burial and adjacent clay soil making it more difficult to detect the reflected signals (Freeland et al., 2003).

Due to the settling of the burials and the soil compacting, the ground became less flat over the survey period making it steadily harder to deploy the GPR as the ground was no longer flat or even, particularly over the naked burial which compacted more than the wrapped burial and the control burial, this is apparent in the 2D GPR profiles.

- **How long after burial are the simulated clandestine pig burials geophysically detectable?**

As discussed by Schultz et al. (2012) it is important to understand how long a grave will be detected in various soil types and for extended post-mortem intervals. In certain soils, it may not be possible to detect a grave with GPR for short intermittent periods after decomposition of the body and grave compaction. The soil conditions at the TRACES site are less favourable for GPR to work which is evident from the 2D profiles where it was more difficult to observe hyperbolae consistently throughout the survey period for both burial types at all three sites. However, the naked pig burial had better success compared to the wrapped pig burial at being detected, particularly in the months following four-months post-burial.

- **Is there an optimal time post-burial that the simulated clandestine pig burials were most detectable e.g. time since burial, seasonally, etc.?**

At TRACES, the relatively stable clay-rich soil conditions suggest minimal impact on seasonal changes on detection success, as the buried pig targets remained detectable regardless of soil moisture variations. This stability indicates that in environments with similar characteristics, the inclusion of time of year or time varying site conditions in predictive models may not be critical. However, at other sites with different soil compositions, such as sandy soils, the detection success using methods like GPR and ER can vary significantly throughout the year. For instance, sandy sites exhibit good GPR penetration and strong ER contrasts when dry, but these conditions deteriorate when the soil is wet, dramatically affecting detection capabilities. This variability underlines the importance of incorporating temporal and environmental factors into predictive models to enhance accuracy and reliability in diverse forensic scenarios. By analysing the difference in background ER properties and the ER of the buried pig targets at TRACES through changes in soil moisture and target decay, it has illustrated the broader implications of time-varying site conditions on detection methodologies. The findings highlight the necessity of adaptive models that account for environmental dynamics, thereby improving the robustness and applicability of forensic detection tools across various site conditions. Therefore, this will all be taken into consideration when producing the descriptions of the algorithms needed for the future creation of the proposed tool discussed in this thesis.

5.5 Detectability predictor

The description for the algorithm for the proposed tool recommending optimal near-surface detection was methods was guided by the comprehensive data collection and analysis across multiple geophysical techniques at varied test sites over twelve months, along with knowledge of the physics behind the equipment and soil properties provided by Dr David Jordan, and the surveys amongst experts in the field conducted in this thesis. It was important to consider the detection capability of the methods at the different sites (i.e., how well did the method detect the buried target at each site), time sensitivity of the methods (i.e., how long can it detect decomposing organic material for) and environmental impact (i.e., what impact can the geology, surrounding vegetation and climate have). Terrain variability such as incline of the slope, tree roots, and uneven ground had an impact on how well the method could work and how it easy it was to conduct the survey efficiently to produce good results.

The algorithm is intended to represent the way in which expert practitioners assess geophysical methods by methodically analysing each relevant factor and evaluating their combined impact. Currently, as has been described in the interview process in this thesis, practitioners use their expertise to assess these factors based on their past experiences and empirical knowledge of the physical properties of the buried target and the environment in which the target is buried. The algorithm is intended to, similarly, integrate these factors into an interconnected network, providing data-driven and methodical approaches to method selection. This is to ensure that the decision-making process is not only consistent and reproducible but also transparent by providing clear explanations with the output of why certain methods have ranked higher or lower than others. By making the decision-making process explicit, this algorithm could highlight the strengths and weaknesses of current practices and reveal where additional data may be required to get the output right the first time. It could also reveal where certain geophysical methods consistently underperform which could lead to the continuous improvement of geophysical survey practices for forensic investigations. This description of the algorithm and the proposed tool is intended to be open to challenge by the profession to disagree and/or provide further information to improve it, so the outputs become more accurate for more contexts.

At a higher level, the proposed algorithm functions by integrating the factors of the network diagram (Fig. 57) into a decision-making framework. This network model showcases how the suitability of various geophysical methods could be conducted by systematically considering each element, as described below:

1. The algorithm would begin by inputting parameters related to the target, burial depth, soil type, and environmental conditions provided by the user.
2. Each method would be assessed against the evaluation criteria derived from the input parameters. For example, the algorithm is intended to evaluate how well GPR might detect a target at a specific depth in a clay-rich soil.
3. Methods would be scored based on their predicted effectiveness in the given scenario. Scores are assigned by comparing expected performance with field experience and empirical data.
4. The algorithm would output a ranked list of geophysical methods, providing a clear rationale for the rankings based on the evaluated criteria.

An element of the tool which will developed at a much later stage, once the main detectability predictions are producing feasible results, is the time and cost considerations for any given search. The length of time it would take to complete the survey, the cost efficiency and operational constraints are things that need to be considered when being contracted to conduct surveys as it would not be ideal to be using a method which takes longer and costs more money. The choice of geophysical methods must balance effectiveness with cost, in an ideal world this would not be necessary but currently this is something that needs to be considered.

Following the completion of this thesis, the descriptions of the algorithms for the proposed open-source tool for optimising the detection of buried forensic targets are intended to be developed and introduced to practitioners in the field. To ensure the effectiveness and practical utility, the algorithms would be subjected to rigorous testing and validation by practitioners. Practitioners would be invited to test the algorithms in real-world conditions and provide feedback on its performance. The primary questions to be addressed by practitioners include:

- The appropriateness of the algorithm and information base – it is intended that practitioners will evaluate the adequacy of the algorithm by comparing the predictions with their own actual survey outcomes. Specifically, it is hoped that they will assess whether the optimal methods predicted by the proposed to detect buried targets were indeed successful in practice. This comparison is intended to help determine the accuracy and reliability of the algorithm's recommendations. Practitioners' feedback on discrepancies between predicted and actual outcomes will be crucial for refining the algorithm and improving its predictive capabilities.
- Information requirements – another key aspect for practitioners to consider is whether additional information would have enhanced the accuracy of the algorithm's predictions from the outset. They would need to identify what specific data or insights could have improved the initial predictions. This discussion will address whether it is realistic to expect such information to be readily available in typical forensic scenarios or if the inherent variability and complexity of site conditions make precise predictions unrealistic.

By challenging the descriptions of the algorithms that intend to be encoded into the proposed tool and its outcomes, practitioners would play a vital role in iteratively refining and improving its functionality. Their feedback could help identify any gaps in the algorithm's logic or data inputs, leading to enhancements that increase the proposed tool's overall success and efficacy. The goal is to develop a robust, adaptable tool that can provide reliable recommendations across a wide range of forensic scenarios from the algorithms being described in this thesis, ultimately improving detection rates and standardising best practices in the field.

The iterative process of testing, feedback, and refinement could ensure that the proposed tool evolves based on practical experiences and expert insights. This approach could not only validate the proposed tool but also fosters a collaborative environment where professionals can contribute to and benefit from a shared resource, enhancing the collective knowledge and capabilities of the forensic detection community. The way forward involves encoding the algorithms described in this thesis into a usable tool and then publishing the proposed expert system and inviting colleagues to engage with it critically. By challenging practitioners to test the proposed tool and demonstrate its shortcoming, the profession can foster a culture of continuous improvement and collaborative learning. This approach not only aims to validate the algorithms but also encourages the accumulation and open sharing of collective expertise, ultimately enhancing the overall success of forensic detection practices.

5.6 Summary

This discussion chapter has highlighted several key findings from the results, shedding light on the complexities and subtleties involved in selecting near-surface detection methods for forensic investigations. The scenario questionnaire revealed significant variability in practitioner opinions, with agreement levels ranging from 25-80% on the most suitable methods for different scenarios. This inconsistency highlights the challenges in making optimal method selections and the need for a more structured and evidence-based approach. Despite the variability, the data collected provides a solid foundation for the future development of the described algorithms for the proposed tool. This proposed tool is intended to integrate the diverse insights and preferences of practitioners, ensuring that its recommendations are well-informed and grounded in practical, real-world applications. By capturing a broad spectrum of professional opinions, the proposed tool aims to offer balanced guidance that enhances the overall success rate of detecting buried forensic targets.

Furthermore, the findings emphasise the importance of considering seasonal variations and specific burial characteristics in method selection. This reinforces the need for an adaptable tool that can tailor recommendations based on detailed site and environmental conditions. The development and subsequent field testing of the proposed tool will be crucial in refining its functionality and ensuring its practical utility.

Overall, the discussion has emphasised the necessity of consolidating expert knowledge and best practices into a usable resource. The descriptions of the algorithms needed for the proposed tool represents a significant step forward in this direction, hoping to improve the efficacy and reliability of forensic investigations. By making method selection more consistent and scientifically grounded, the proposed tool aligns with the aims of the thesis of enhancing the profession’s ability to detect buried forensic targets effectively and efficiently.

Chapter Six

Conclusions

This concluding chapter consolidates and summarises the achievements of this thesis, highlight the advancements made, and outline the next steps for further development and application of the proposed tool for detecting buried forensic targets. The exploration undertaken during the thesis has not only deepened the understanding of the challenges and opportunities within forensic geophysics but has also paved way for innovative solutions aimed at improving detection success rates, such as with the development of the described algorithms needed for the proposed tool in this thesis. This chapter serves as a synthesis of the key learnings, anticipated future outcomes from the work in this thesis, and next steps in the ongoing pursuit of advancing forensic detection methodologies. This thesis set out to consolidate knowledge and current best practice on behalf of the profession on suitable search algorithms by doing the groundwork of identifying the criteria for the design of a tool to rank detection methods based on the depositional environment and buried target. Below concludes what this thesis found.

Considering the evidence provided in the participants responses it is clear that due to a lack of consistency in current decision-making there is a need for a better way to decide how to search for buried targets and in particular clandestine burials. From the results of the survey, it is necessary that appropriate methods and guidelines are developed which may be in the form of the proposed tool described in this thesis to support the systematic application of near-surface detection methods to locate buried targets in the UK and overseas.

The findings from the test site studies underlines the differential sensitivity and applicability of ERI, GPR and magnetometry in detecting various buried forensic targets under changing conditions. ERI and GPR proved effective in detecting both metallic and organic targets at TRACES, with notable differences in the detectability influenced by the nature of the burial (e.g., wrapped vs. naked). Magnetometry, while useful for detecting metallic objects, showed limitations in consistently identifying organic targets. Whereas at the Yorkshire Moors, ERI was able to detect the buried forensic metal target as a small resistivity anomaly, indicating its utility in stable subsurface conditions. GPR identified the buried target through a weak hyperbola despite a noisy background, highlighting its potential but also its susceptibility to geological interferences. Magnetometry showed minimal variation in readings post-burial, suggesting its limited sensitivity to small metallic objects in this specific setting. At the Larkhill site in Formby, the ERI surveys showed minimal changes in resistivity values post-burial, highlighting its limitations in identifying small metallic objects in a variable resistivity subsurface. GPR also struggled to produce clear indicators of the buried forensic metal target due to the noisy background and weak signal responses characteristic of the site’s geology. In contrast, magnetometry demonstrated greater sensitivity, detecting a significant anomaly at the burial location of the forensic metal target. The results from the geophysical method surveys at Norris Farm underlines the varying effectiveness of these methods in different subsurface conditions. The ERI showed minimal changes post-burial, reflecting its limitations in detecting small metallic objects in a relatively uniform subsurface. GPR detected a small hyperbolic reflection indicative of the buried forensic metal target, but its effectiveness was influenced by the sequence of the survey setup and the quiet background conditions. Magnetometry produced only a slight anomaly at the forensic metal target's burial location, indicating challenges in detecting small objects in low magnetic noise environments. The results from the test site studies emphasise the need for an expert system that incorporates a range of geophysical methods tailored to specific forensic scenarios, accounting for factors such as the type of target, burial conditions, and environmental variations.

Conducting research in realistic conditions such as those in this thesis (concealed amongst the density of the trees, rather than within an open field) allows for an observation to what would be expected when a criminal is burying a body (Harrison and Donnelly, 2009). Nuzzo et al. (2008) explains that new insights will be gained into the full optimisation of geophysical techniques and their ability to assist future forensic investigations at real crime scenes. In addition to the burials being more realistic, they have also been buried on a single environment with varying contrasting slope, drainage, vegetation, and tree density. It was observed that at one facility on a single environment, the three areas of the site where the simulated clandestine burials were situated had differences in detectability throughout the survey period. While differences are expected between different depositional environments at different sites on differing geologies, there was no research on the differences that may present themselves at a single site. Therefore, it is imperative that continuous research into controlled burial studies is conducted including multiple burials at single site with slightly varying environments as conducted in the multiperiod study at TRACES. However, it remains the fact that controlled research sites do not cover the wide variety of burial scenarios and the environments in which buried forensic targets are often discovered in both in the UK and overseas.

Hunter et al. (2013) describes how a recent grave has 'dynamic geophysical properties' relating to how quickly a body begins to decompose following death and subsequent burial, the responses produced by the burial are not always fully understood. These effects need to be taken into consideration when predicting the optimal method to use and the likely response of the burial when using that geophysical method. Controlled forensic geophysical research has proven to be a valuable resource and the information gathered from these studies has been applied to real-life forensic cases. The research is vital to understand the applicability of using geophysical methods for forensic applications and to understand the various factors that affect detection. As discussed by Pringle et al. (2008), the results from studies like this can help to establish geophysical protocols for forensic investigations. The research conducted emphasises the importance of tailoring geophysical methods to specific site conditions rather than employing a one-size-fits-all approach. More work into why geophysical results were achieved is required, this can only successfully by following up post-excavation of a site to discover the reasons as to what was producing the distinct geophysical property that was being detected by each detection method.

Through the methodologies and research conducted, algorithms have been described that could successfully be developed following submission of this thesis to accumulate expert opinion in the form of the proposed tool, which will be challenged and supported by ongoing surveys of professional opinion.

In conclusion, the algorithms described to be developed for the future creation of the proposed tool represents a significant step forward in the application of geophysical methods for forensic detection. It is intended, firstly, to identify and articulate the strengths and weaknesses of current decision-making processes that experts use in their field and, secondly, to allow for systematic evaluation and improvement of these choices. By engaging practitioners in its development and validation, the proposed tool could be continuously improved to meet the real-world needs of the profession, thereby reiterating the aims of the thesis of improving the overall success rate of detecting buried forensic targets. This iterative process of feedback and refinement would mark a major step forward in ensuring the proposed tool's accuracy and reliability. Additionally, it may create a means to efficiently advise on the appropriate geophysical methods to use in various forensic scenarios, representing another significant advance in the field. It is expected that there may be limitations of the proposed tool in relation to the accuracy and resolution of currently available maps, such as those depicting soil, geology, topography, and land use. These maps often lack the precision needed for specific sites; this could lead to potential inaccuracies in the detectability predictions of the proposed tool. Therefore, it would be important to ensure the highest resolution maps and information is available for the proposed tool. To enhance the accuracy of detectability predictions, it will be essential to improve the quality of maps on which it will rely upon. Gradual improvements could be made by increasing the spatial resolution of soil, geology, and topography maps, ensuring that land-use maps are frequently updated to reflect current conditions and incorporating more detailed and accurate data from recent technologies, such as unmanned aerial vehicle (UAV) mounted geophysical equipment.

Future work to further enhance the findings of this thesis would include describing what modelling says each method will find in each scenario with field experience (experimental and through casework) providing constraints and examples for the scenarios themselves. This integration is essential to advance the reliability and reproducibility of geophysical models for forensic investigations where time and accuracy is important. It would be necessary to ensure that all data inputs were standardised where the data has been systematically collected and there is a consistent framework of the information collected (i.e., data collection, analysis and reporting) for which the proposed tool provides a mechanism for. It will be important, as part of future work, to ensure a range of relevant data is input into the algorithms, these could come from collaborations with forensic and academic institutions, field data from police forms and forensic agencies, organisations (governmental bodies, non-governmental organisations (NGO's) and geophysics societies) and simulated controlled experiments. This could then be a further algorithm development to form part of the proposed tool. The next phase of work to be completed following the submission of this thesis may be to develop and codify the algorithms described and from this implement them into an open-source tool. The proposed tool would be dependent upon successful results demonstrated through methodological research, the availability of instruments appropriate to the environmental conditions, and the accompanying expertise in their application for purpose. From this it would be necessary to then carry out the following:

- Promote its use and gather experience – this is critical to ensure the proposed tool's uptake among forensic professionals and collecting extensive user experiences. This would provide valuable data to further refine and enhance the proposed tool's effectiveness. This will involve having a small council of experts to firstly test the algorithms within the proposed tool and discuss the adequacy of them and the information on which they are based in the light of actual survey outcomes (i.e., the optimal methods predicted to detect the graves compared with what actually detected them). Secondly, what additional information would have been required to get this right at the start? Is it realistic to require such information to be available or is accurate predictions of detectability unrealistic in these circumstances?
- Testing in diverse environments and for various targets – to validate the proposed tool's versatility, it is essential to assess it in a wide range of environmental conditions and with diverse types of forensic targets. This will help ensure the proposed tool's robustness and adaptability across diverse scenarios.

Due to developments in AI, ML and DL, there is a considerable potential to address some of the limitations discussed in this thesis by enhancing data processing, interpretive accuracy, and intuitive predictions of optimal geophysical methods in different scenarios. Algorithms can be 'trained' to self-learn (i.e., ML), this can be achieved by providing large standardised datasets, which could increase the likelihood of choosing optimal near-surface detection methods for a range of burial scenarios and environments. Research into AI in forensic geophysics is still in its infancy, but recent studies have demonstrated that machine learning algorithms could enhance detection rates (Yu and Ma, 2021; Yijun et al., 2023; Shakhatova et al., 2024; Singh et al., 2024). Integrating AI into the proposed tool could lead to faster, more accurate and more adaptable systems that learn from data input and validation of results.

The ongoing advancements in geophysical methods and technologies hold great promise for improving forensic investigations. The integration of geophysical equipment with UAVs could revolutionise the field by enabling rapid data collection over difficult terrains and larger areas. Something which will need to be considered in the future of the proposed tool. By addressing the limitations and continuously refining the proposed tool based on practical feedback and technological advancements, the success rate of detecting buried forensic targets can be significantly improved and will contribute to the evolution of best practices in forensic geophysics. This ongoing process of improvement and adaptation will ensure that the proposed tool remains a valuable resource for professionals in the field, enhancing the accuracy and efficiency of forensic investigations in the future. The proposed tool aims to offer progress and change across disciplines, offering an easy-to-use interface and reliable outputs. Its success would depend on the community's openness, willingness to participate, and commitment to transparency. With accurate data, guided decision-making, and adaptable outputs, the proposed tool aims to be a valuable asset for improving forensic geophysical searches, ultimately benefiting practitioners and advancing the field.

The future development of such a tool, informed by the comprehensive data and insights from this study, may enhance the accuracy and reliability of near-surface detection methods, thereby improving the success rates of forensic investigations. It is evident from the test site studies that there is a need for an adaptable and data-driven expert system that can recommend the most suitable detection methods based on specific site conditions and target characteristics. Incorporating these results into the development of the proposed tool could ensure it provides accurate and practical guidance for forensic investigations, aligning with the objectives of this thesis of improving the efficacy and reliability of near-surface geophysical detection methods.

In particular, the algorithms that will be further developed and codified from this thesis will help to improve the rate of success of locating buried forensic targets by creating consistency amongst practitioners and promoting the feedback of positive and negative results. By promoting evidence-based method selection and incorporating feedback from real-world searches, the proposed tool aims to enhance the credibility and efficiency of forensic investigations. The open-source nature of the proposed tool would ensure that it is accessible to the right people, including community geophysics projects, thereby promoting best practices and potentially leading to cost and time savings. This collaborative and iterative development process will not only improve the proposed tool’s accuracy and functionality but also contribute to the broader goal of advancing forensic geophysics and fostering a culture of continuous improvement and knowledge sharing among practitioners. It is therefore important as part of future works to also focus on forming partnerships with those regularly involved in forensic searches of the nature described in this thesis to establish shared data repositories and frameworks to continue the advancement of the field and create a universally accepted approach to forensic geophysical analysis.

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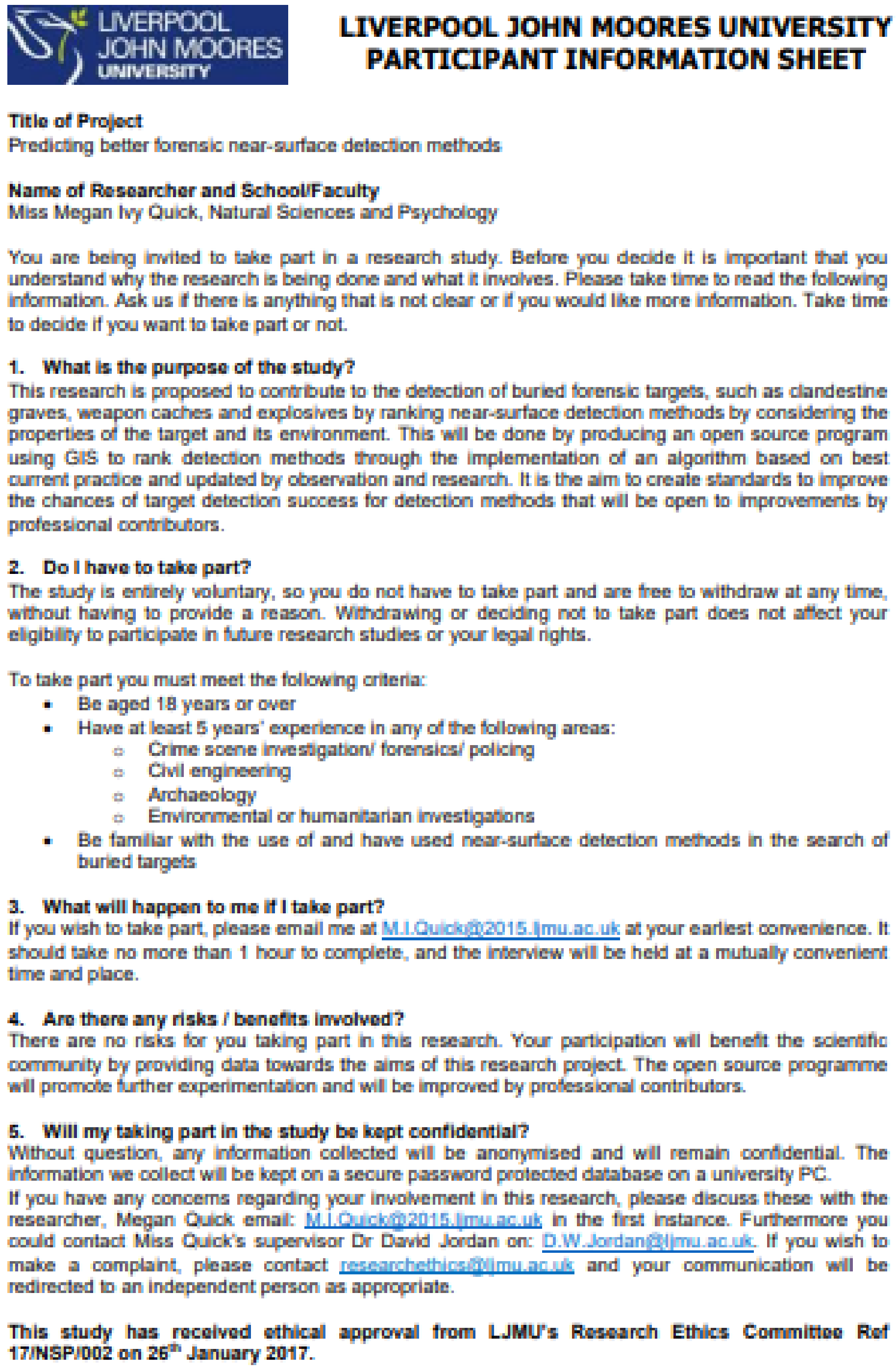
Appendix

Appendix 1: The participant information sheet for the initial questionnaire detailing the purposes of the study, the eligibility criteria, and any risks/benefits of participating. This was circulated to professional bodies such as CIfA, ISAP, BAJR and across social media to gain interest and recruit participants.



LIVERPOOL JOHN MOORES UNIVERSITY
PARTICIPANT INFORMATION SHEET

Title of Project
Predicting better forensic near-surface detection methods

Name of Researcher and School/Faculty
Miss Megan Ivy Quick, Natural Sciences and Psychology

You are being invited to take part in a research study. Before you decide it is important that you understand why the research is being done and what it involves. Please take time to read the following information. Ask us if there is anything that is not clear or if you would like more information. Take time to decide if you want to take part or not.

1. What is the purpose of the study?
This research is proposed to contribute to the detection of buried forensic targets, such as clandestine graves, weapon caches and explosives by ranking near-surface detection methods by considering the properties of the target and its environment. This will be done by producing an open source program using GIS to rank detection methods through the implementation of an algorithm based on best current practice and updated by observation and research. It is the aim to create standards to improve the chances of target detection success for detection methods that will be open to improvements by professional contributors.

2. Do I have to take part?
The study is entirely voluntary, so you do not have to take part and are free to withdraw at any time, without having to provide a reason. Withdrawing or deciding not to take part does not affect your eligibility to participate in future research studies or your legal rights.

To take part you must meet the following criteria:

- Be aged 18 years or over
- Have at least 5 years' experience in any of the following areas:
  - Crime scene investigation/ forensics/ policing
  - Civil engineering
  - Archaeology
  - Environmental or humanitarian investigations
- Be familiar with the use of and have used near-surface detection methods in the search of buried targets

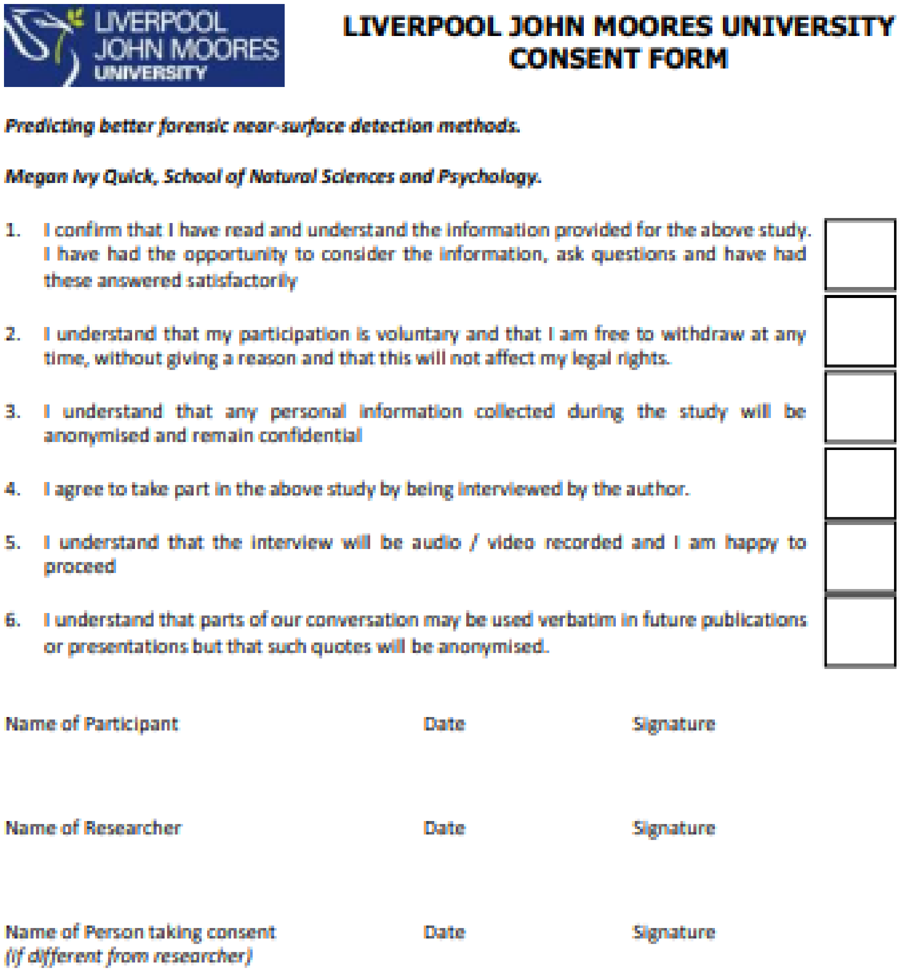
3. What will happen to me if I take part?
If you wish to take part, please email me at M.I.Quick@2015.ljmu.ac.uk at your earliest convenience. It should take no more than 1 hour to complete, and the interview will be held at a mutually convenient time and place.

4. Are there any risks / benefits involved?
There are no risks for you taking part in this research. Your participation will benefit the scientific community by providing data towards the aims of this research project. The open source programme will promote further experimentation and will be improved by professional contributors.

5. Will my taking part in the study be kept confidential?
Without question, any information collected will be anonymised and will remain confidential. The information we collect will be kept on a secure password protected database on a university PC.
If you have any concerns regarding your involvement in this research, please discuss these with the researcher, Megan Quick email: M.I.Quick@2015.ljmu.ac.uk in the first instance. Furthermore you could contact Miss Quick's supervisor Dr David Jordan on: D.W.Jordan@ljmu.ac.uk. If you wish to make a complaint, please contact researchethics@ljmu.ac.uk and your communication will be redirected to an independent person as appropriate.

This study has received ethical approval from LJMU's Research Ethics Committee Ref 17/NSP/002 on 26th January 2017.

Appendix 2: The consent form which was completed by the participants that chose to complete the survey over voice call.



LIVERPOOL JOHN MOORES UNIVERSITY
CONSENT FORM

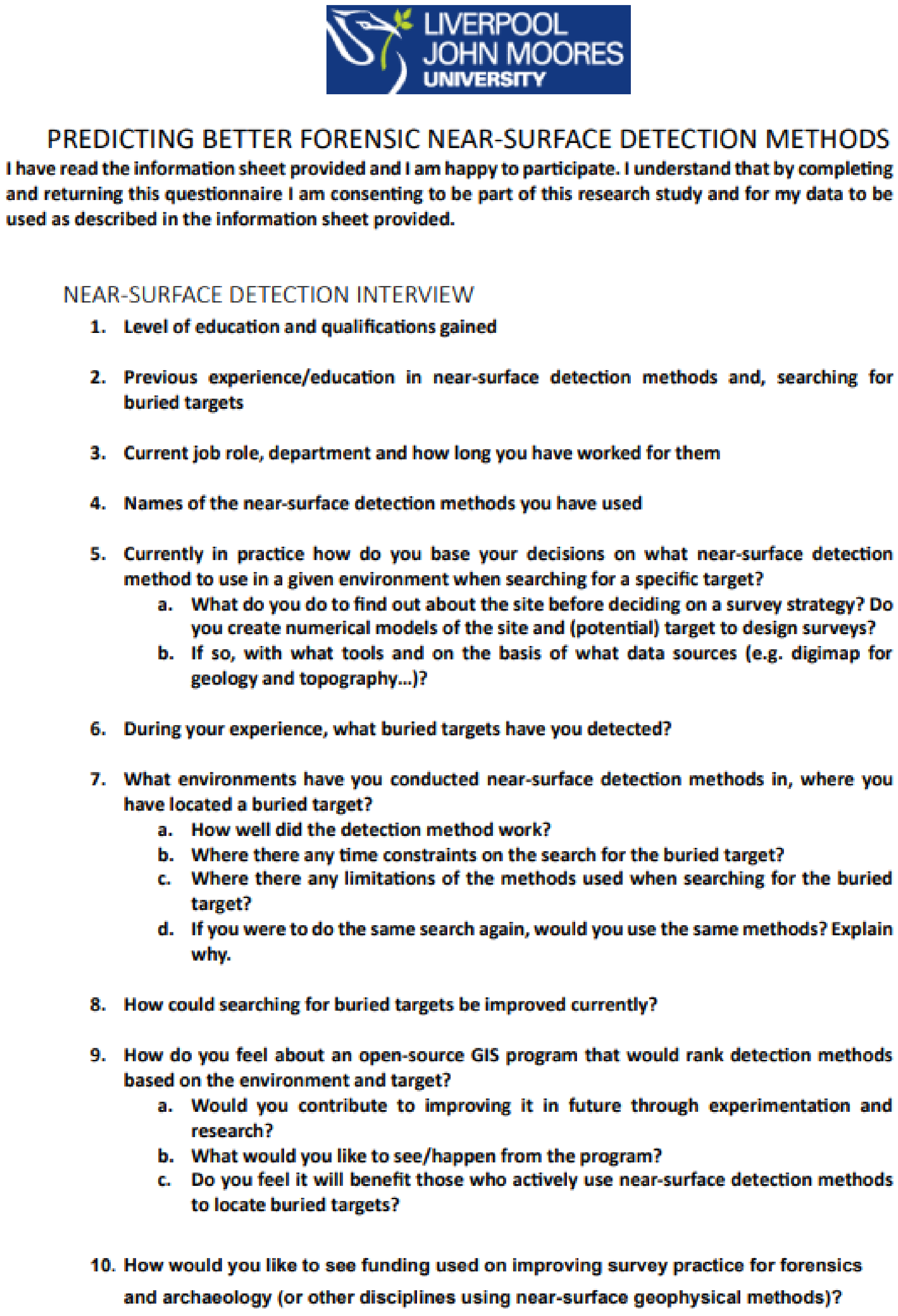
Predicting better forensic near-surface detection methods.

Megan Ivy Quick, School of Natural Sciences and Psychology.

1. I confirm that I have read and understand the information provided for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily ☐
2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving a reason and that this will not affect my legal rights. ☐
3. I understand that any personal information collected during the study will be anonymised and remain confidential ☐
4. I agree to take part in the above study by being interviewed by the author. ☐
5. I understand that the interview will be audio / video recorded and I am happy to proceed ☐
6. I understand that parts of our conversation may be used verbatim in future publications or presentations but that such quotes will be anonymised. ☐

Name of Participant	Date	Signature
Name of Researcher	Date	Signature
Name of Person taking consent *(if different from researcher)*	Date	Signature

Appendix 3: The initial questionnaire that was provided to expert practitioners actively working in relevant fields (such as forensics and archaeology).



LIVERPOOL JOHN MOORES UNIVERSITY

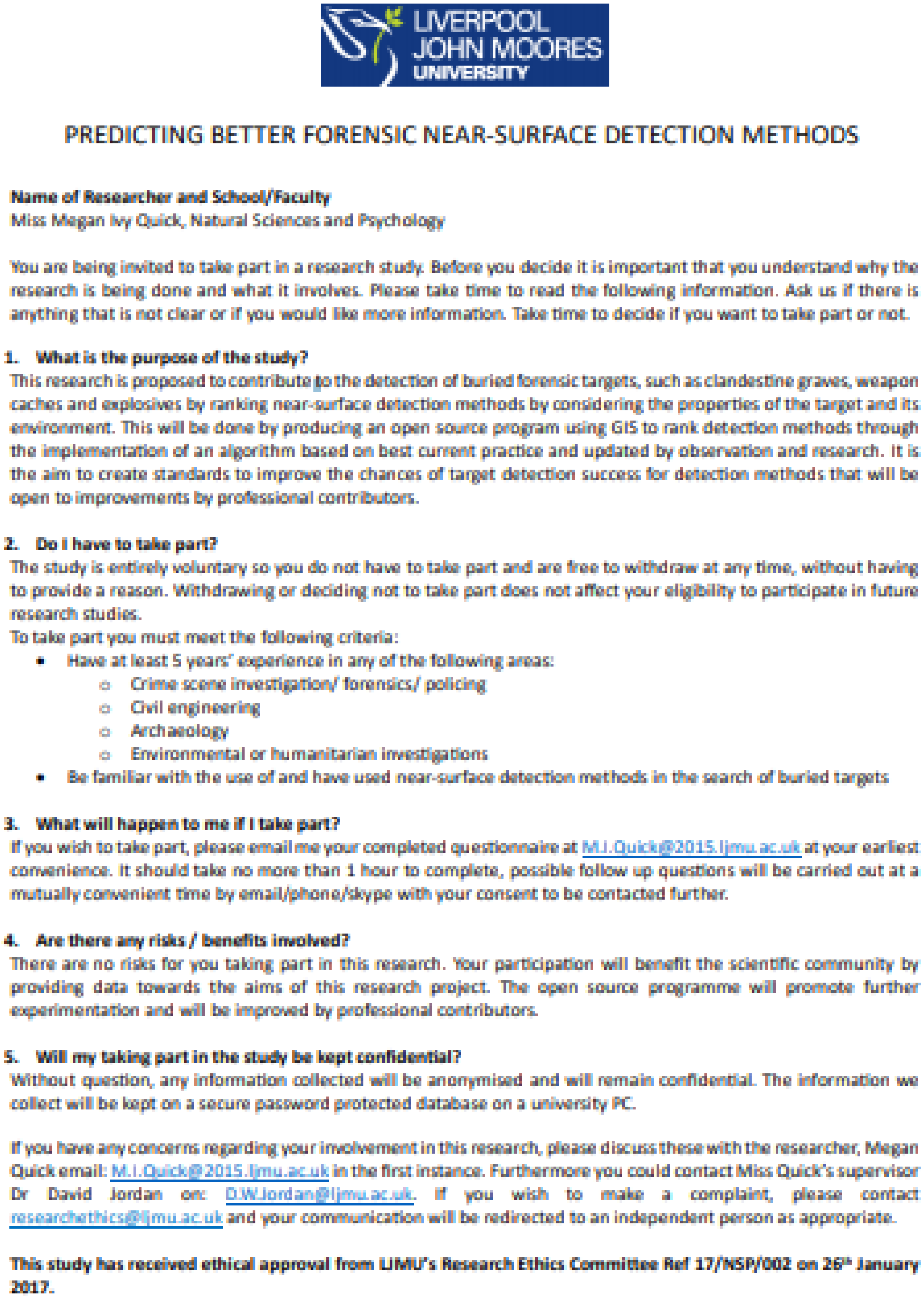
PREDICTING BETTER FORENSIC NEAR-SURFACE DETECTION METHODS

I have read the information sheet provided and I am happy to participate. I understand that by completing and returning this questionnaire I am consenting to be part of this research study and for my data to be used as described in the information sheet provided.

NEAR-SURFACE DETECTION INTERVIEW

1. **Level of education and qualifications gained**
2. **Previous experience/education in near-surface detection methods and, searching for buried targets**
3. **Current job role, department and how long you have worked for them**
4. **Names of the near-surface detection methods you have used**
5. **Currently in practice how do you base your decisions on what near-surface detection method to use in a given environment when searching for a specific target?**
    a. **What do you do to find out about the site before deciding on a survey strategy? Do you create numerical models of the site and (potential) target to design surveys?**
    b. **If so, with what tools and on the basis of what data sources (e.g. digimap for geology and topography…)?**
6. **During your experience, what buried targets have you detected?**
7. **What environments have you conducted near-surface detection methods in, where you have located a buried target?**
    a. **How well did the detection method work?**
    b. **Where there any time constraints on the search for the buried target?**
    c. **Where there any limitations of the methods used when searching for the buried target?**
    d. **If you were to do the same search again, would you use the same methods? Explain why.**
8. **How could searching for buried targets be improved currently?**
9. **How do you feel about an open-source GIS program that would rank detection methods based on the environment and target?**
    a. **Would you contribute to improving it in future through experimentation and research?**
    b. **What would you like to see/happen from the program?**
    c. **Do you feel it will benefit those who actively use near-surface detection methods to locate buried targets?**
10. **How would you like to see funding used on improving survey practice for forensics and archaeology (or other disciplines using near-surface geophysical methods)?**

Appendix 4: The participant information sheet for the secondary questionnaire detailing the purposes of the study, the eligibility criteria, and any risks/benefits of participating and the information sheet on how to complete the questionnaire. This was circulated to professional bodies such as CIfA, ISAP, BAJR and across social media to gain interest and recruit participants.



LIVERPOOL
JOHN MOORES
UNIVERSITY

PREDICTING BETTER FORENSIC NEAR-SURFACE DETECTION METHODS

Name of Researcher and School/Faculty
Miss Megan Ivy Quick, Natural Sciences and Psychology

You are being invited to take part in a research study. Before you decide it is important that you understand why the research is being done and what it involves. Please take time to read the following information. Ask us if there is anything that is not clear or if you would like more information. Take time to decide if you want to take part or not.

1. **What is the purpose of the study?**

This research is proposed to contribute to the detection of buried forensic targets, such as clandestine graves, weapon caches and explosives by ranking near-surface detection methods by considering the properties of the target and its environment. This will be done by producing an open source program using GIS to rank detection methods through the implementation of an algorithm based on best current practice and updated by observation and research. It is the aim to create standards to improve the chances of target detection success for detection methods that will be open to improvements by professional contributors.

2. **Do I have to take part?**

The study is entirely voluntary so you do not have to take part and are free to withdraw at any time, without having to provide a reason. Withdrawing or deciding not to take part does not affect your eligibility to participate in future research studies.
To take part you must meet the following criteria:

- Have at least 5 years' experience in any of the following areas:
    - Crime scene investigation/ forensics/ policing
    - Civil engineering
    - Archaeology
    - Environmental or humanitarian investigations
- Be familiar with the use of and have used near-surface detection methods in the search of buried targets

3. **What will happen to me if I take part?**

If you wish to take part, please email me your completed questionnaire at M.I.Quick@2015.ljmu.ac.uk at your earliest convenience. It should take no more than 1 hour to complete, possible follow up questions will be carried out at a mutually convenient time by email/phone/skype with your consent to be contacted further.

4. **Are there any risks / benefits involved?**

There are no risks for you taking part in this research. Your participation will benefit the scientific community by providing data towards the aims of this research project. The open source programme will promote further experimentation and will be improved by professional contributors.

5. **Will my taking part in the study be kept confidential?**

Without question, any information collected will be anonymised and will remain confidential. The information we collect will be kept on a secure password protected database on a university PC.

If you have any concerns regarding your involvement in this research, please discuss these with the researcher, Megan Quick email: M.I.Quick@2015.ljmu.ac.uk in the first instance. Furthermore you could contact Miss Quick's supervisor Dr David Jordan on: D.W.Jordan@ljmu.ac.uk. If you wish to make a complaint, please contact researchethics@ljmu.ac.uk and your communication will be redirected to an independent person as appropriate.

This study has received ethical approval from LJMU's Research Ethics Committee Ref 17/NSP/002 on 26th January 2017.

Instructions:

The purpose of this questionnaire is to consolidate knowledge and practice on behalf of the profession to help make better decisions of which detection method to use in a given scenario. You are asked to score each detection method based on how well it would work in the given scenario (A and B) on a scale of 1-5, the interval spacing you would use and to provide comment as to why you gave it that score giving consideration to the environmental and burial information.

Scores:

1= will not work
2= very poor
3= poor
4= good
5= very good

Scenario Information:

Summer: Average of 50mm monthly rainfall and average monthly temperature of 15°c*
Winter: Average of 150mm monthly rainfall and average monthly temperature of 3°c*

A: Average sized adult male, six months since burial, buried at 0.5m depth. It is expected that there is extensive soft tissue preservation of the body still**.
B: Average sized adult male, five years since burial, buried at 0.5m depth. It is expected that there is near complete skeletonisation of the body with some retention of desiccated skin and soft tissue of the torso**.
Note: the bodies were interred immediately following the grave being dug and refilled without delay.

* Average monthly rainfall and temperature data taken from Pringle et al. (2016) and the summary of the monthly study site statistics.
**State of decomposition statements have been taken from Schultz et al. (2006) and the description of the general decomposition state at the time of excavation of each human-proxy pig cadaver.

Note: If there are any detection methods you are not familiar with or have never used, please feel free to not score them.

References:

Pringle, J.K., Jervis, J.R., Roberts, D., Dick, H.C., Wisniewski, K.D., Cassidy, N.J. and Cassella, J.P., 2016. Long-term Geophysical Monitoring of Simulated Clandestine Graves using Electrical and Ground Penetrating Radar Methods: 4–6 Years After Burial. *Journal of forensic sciences*, *61*(2), pp.309-321.
Schultz, J.J., Collins, M.E. and Falsetti, A.B., 2006. Sequential monitoring of burials containing large pig cadavers using ground-penetrating radar. *Journal of Forensic Sciences*, *51*(3), pp.607-616.

I have read the information sheet provided and I am happy to participate. I understand that by completing and returning this questionnaire I am consenting to be part of this research study and for my data to be used as described in the information sheet provided.

Please complete the below questions:

1. **Level of education and qualifications gained**

2. **Previous experience/education in near-surface detection methods and, searching for buried targets**

3. **Current job role, department and how long you have worked for them**

☐ **Please tick this box if you are happy to be contacted for further comment on your responses – if you tick the box please provide your preferred contact details in the box below, e.g. email, phone, skype.**

Appendix 5: Blank secondary scenario-based questionnaire consisting of eight different sites.

Location:	Lancaster 54° 0'5.51"N 2°47'23.40"W
Geology:	Glacial diamicton, forming drumlins, over complex sandstones, siltstones, shales, mudstones and thin coal seams of the Upper Carboniferous coal measures. The till is stoney, containing well-rounded pebbles and cobbles of a broad metamorphic and igneous lithology.
Soil:	Cambic stagnogley of the Brickfield 2 association
Hydrology:	slowly permeable soil and parent material. Water ponding is reflected in redoximorphic colouring in the lower soil profile and archaeological sections.
Topography:	very gently sloping site on SW toe of a drumlin
Land use:	pasture

Method	Specifications E.g. frequency, array, etc.	Interval spacing (m)		Summer Score (1-5)		Winter Score (1-5)	
		A	B	A	B	A	B
GPR							
Electrical resistivity							
Magnetic Susceptibility							
EM							
Other (alternative method you would use)							

Provide reasons for the score you gave to each detection method (please go onto another sheet if required):

Location: Nantwich 53° 4'16.15"N 2°31'31.55"W

Geology: fine grained Holocene alluvium and adjacent till. The solid geology is Triassic Upper Keuper salt-bearing beds

Soil type: typical sandy gley of the Blackwood association grading into cambic gleys similar to Wigton Moor association

Hydrology: moderately permeable soil and parent material with variable groundwater depth, on a largely flat site with some underdrainage. Water ponds within the soil profile.

Topography: largely flat site on a low (2nd) river terrace

Land use: permanent pasture

Method	Specifications E.g. frequency, array, etc.	Interval spacing (m)		Summer Score (1-5)		Winter Score (1-5)	
		A	B	A	B	A	B
GPR							
Electrical resistivity							
Magnetic Susceptibility							
EM							
Other (alternative method you would use)							

Provide reasons for the score you gave to each detection method (please go onto another sheet if required):

Location:	Aspatria 54°48'8.58"N 3°22'21.80"W
Geology:	Quartz sand ridge
Soil type:	typical brown sands of the Newport 1 association
Hydrology:	very well drained throughout due to high permeability
Topography:	gentle slopes and plateau
Land use:	pasture

Method	**Specifications** E.g. frequency, array, etc.	**Interval spacing (m)**		**Summer Score (1-5)**		**Winter Score (1-5)**	
		A	**B**	**A**	**B**	**A**	**B**
GPR							
Electrical resistivity							
Magnetic Susceptibility							
EM							
Other (alternative method you would use)							

Provide reasons for the score you gave to each detection method (please go onto another sheet if required):

Location: Sawley 53°54'32.22"N 2°20'42.81"W

Geology: Holocene alluvium and adjacent till. The solid geology is Early to Mid-Mississippian limestone

Soil type: loamy

Hydrology: freely draining floodplain soils, local groundwater feeding into river.

Topography: broad lowlands river valley

Land use: grassland some arable

Method	Specifications E.g. frequency, array, etc.	Interval spacing (m)		Summer Score (1-5)		Winter Score (1-5)	
		A	B	A	B	A	B
GPR							
Electrical resistivity							
Magnetic Susceptibility							
EM							
Other (alternative method you would use)							

Provide reasons for the score you gave to each detection method (please go onto another sheet if required):

Location: Newborough 52°38'45.70"N 0°14'37.47"W

Geology: Flandrian age alluvium with adjacent Nordelph peat, Oxford clay bedrock.

Soil type: loamy and clayey

Hydrology: floodplain soils with natural high groundwater, naturally wet

Topography: flat lowland near sea level

Land use: grassland some arable

Method	Specifications E.g. frequency, array, etc.	Interval spacing (m)		Summer Score (1-5)		Winter Score (1-5)	
		A	B	A	B	A	B
GPR							
Electrical resistivity							
Magnetic Susceptibility							
EM							
Other (alternative method you would use)							

Provide reasons for the score you gave to each detection method (please go onto another sheet if required):

Location: Berkhamsted 51°46'8.94"N 0°33'22.74"W

Geology: Miocene to Pleistocene clay with flints formation, undifferentiated late-Cretaceous chalk bedrock

Soil type: slightly acid loamy and clayey

Hydrology: impeded drainage, drains to stream network

Topography: broad valley bottom in low rolling hills

Land use: arable and grassland

Method	Specifications E.g. frequency, array, etc.	Interval spacing (m)		Summer Score (1-5)		Winter Score (1-5)	
		A	B	A	B	A	B
GPR							
Electrical resistivity							
Magnetic Susceptibility							
EM							
Other (alternative method you would use)							

Provide reasons for the score you gave to each detection method (please go onto another sheet if required):

Location:	Crowborough 51° 2'42.74"N 0° 6'23.30"E
Geology:	Milocene to Pleistocene clay with flints formation, undifferentiated late-Cretaceous chalk bedrock
Soil type:	slightly acid loamy and clayey
Hydrology:	impeded drainage, drains to stream network
Topography:	rolling downland heath
Land use:	arable and grassland

Method	Specifications E.g. frequency, array, etc.	Interval spacing (m)		Summer Score (1-5)		Winter Score (1-5)	
		A	B	A	B	A	B
GPR							
Electrical resistivity							
Magnetic Susceptibility							
EM							
Other (alternative method you would use)							

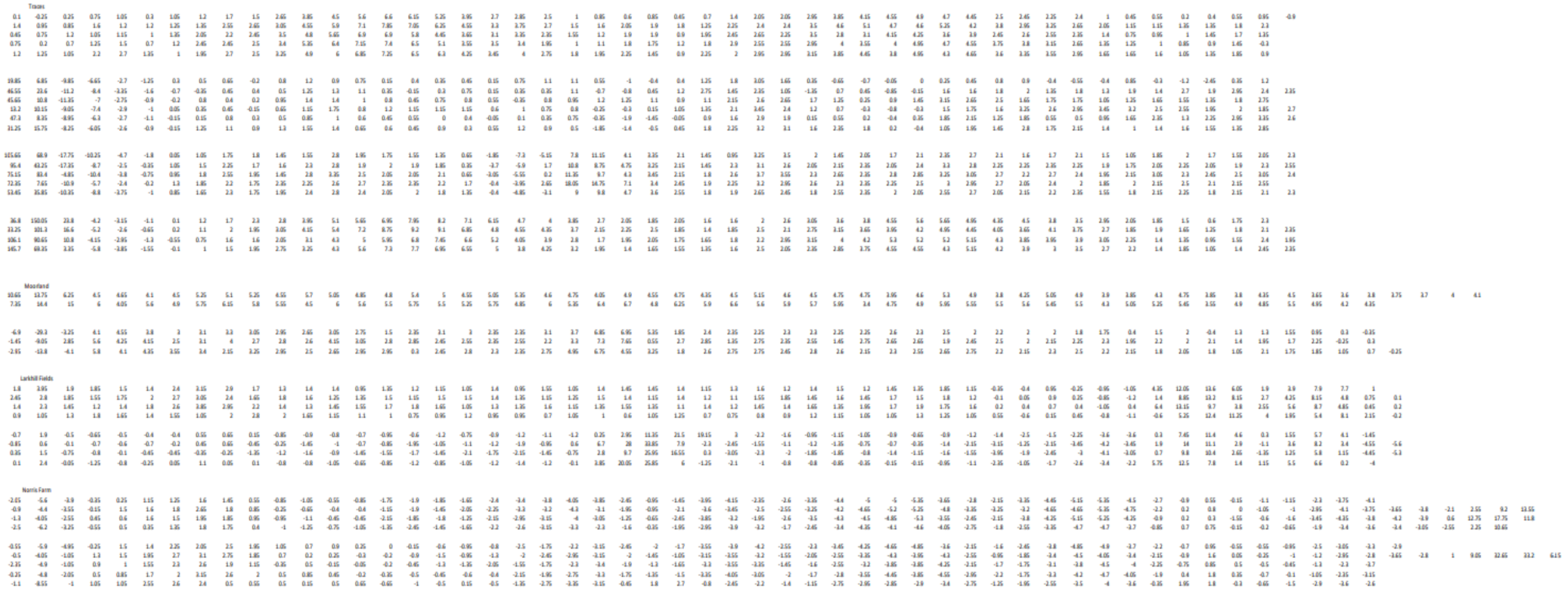
Provide reasons for the score you gave to each detection method (please go onto another sheet if required):

Location: Saddleworth Moor, Hollin Brown Knoll 53°33'8.38"N 1°56'27.66"W
Geology: Quaternary peat with lower Kinderscout grit bedrock
Soil type: blanket bog peat
Hydrology: naturally wet, drains to stream network
Topography: dissected peat moorland plateau
Land use: Moorland rough grazing and forestry

Method	Specifications E.g. frequency, array, etc.	Interval spacing (m)		Summer Score (1-5)		Winter Score (1-5)	
		A	B	A	B	A	B
GPR							
Electrical resistivity							
Magnetic Susceptibility							
EM							
Other (alternative method you would use)							

Provide reasons for the score you gave to each detection method (please go onto another sheet if required):

Appendix 6: Raw magnetometry data taken using a Geoscan FM18 50 cm fluxgate magnetometer every 0.25 m along the survey line. The lines of measurements (in the file) start at the left-hand end (column A) which represents the start of each line - at both TRACES, the Moorland site and the Norris Farm site this is the North end of the line on the ground while at the Larkhill Fields site in Formby it is at the West end of the line. There are six blocks of lines. The top block is at Traces, along a line crossing the middle of burials at site 1. The second is a parallel line to the west, away from the buried bodies, as a control. The third is the line across the burials with the "forensic metal target" buried in the line), the fourth is a repeat of the burial line with the forensic metal target removed again to check for variance. The fifth is the moorland hillside line without the forensic metal target. The sixth is the same with the forensic metal target buried in it. The 7th and 8th are Larkhill Fields, the 9th and 10th are Norris Farm.

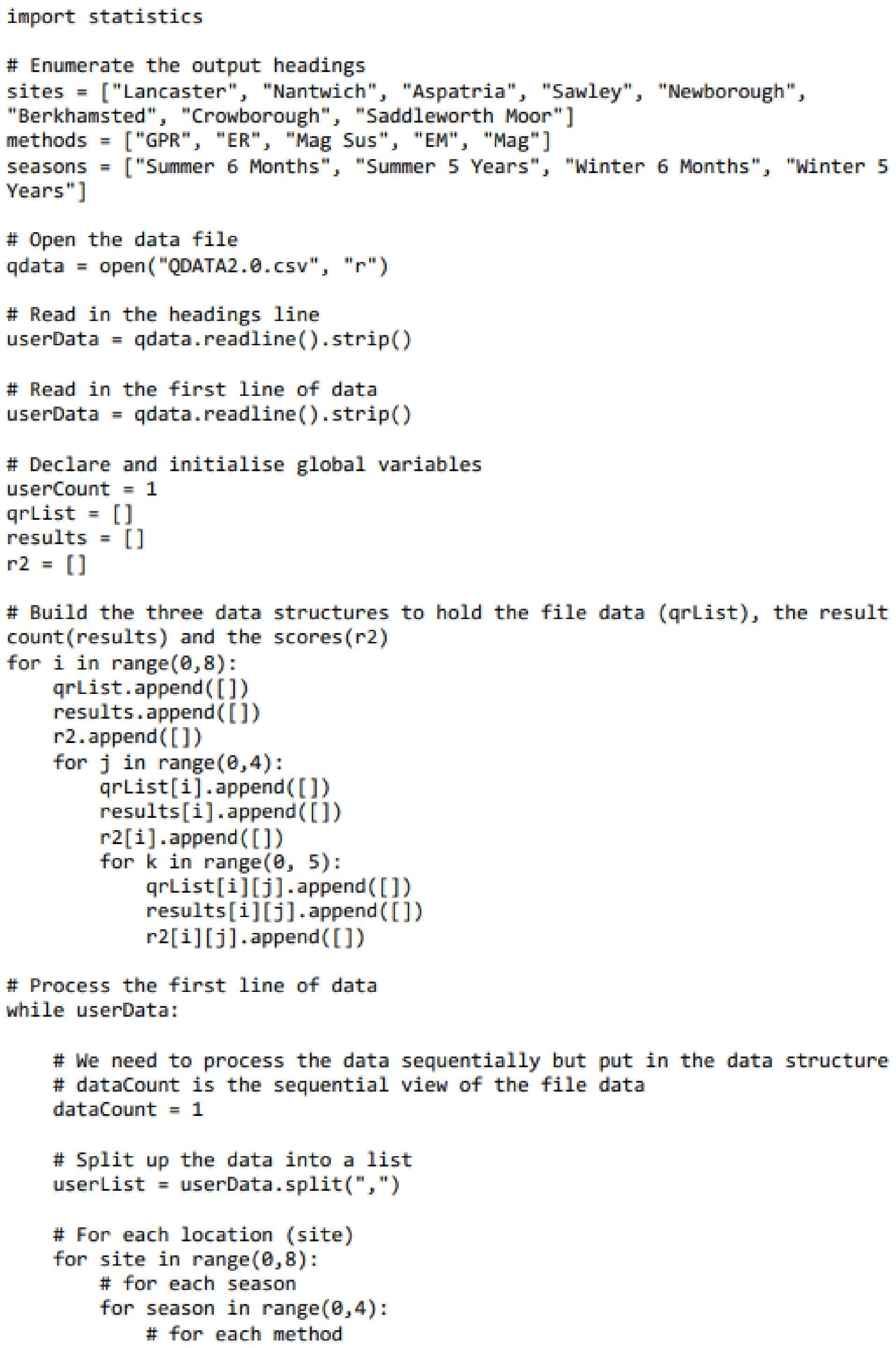


Appendix 7: Table of the steps followed for processing the GPR data collected at each of the four test sites using GPR-Slice software.

Step	What it involves
Create new project	• Located the folder which contains the raw data. • Typed in a name for the project, selected the equipment type e.g. MALA X3M and clicked *New Survey*. • Clicked *option* and ensured all appropriate options were selected (default measurements are set to cm, ensured this was changed to m for all datasets).
Transfer data	• Imported the raw radargram data into GPR-Slice.
Create new information	• XY start and end points were established, were X start = 0 and X end = the end of the survey line, Y start and end was both 0 as only a single line of data was produced to create 2D profiles. • Set the number of files to be used (i.e., 1 as only 1 line of data) and the data identifier (DAT_ for MALA X3M). • Clicked **.*radargram extension* followed by *Import-Create Info* to import the data.
Edit information file	• The line length can be edited or redefined based on the survey wheel calibration. However, that was not required for the data collected in this study and only needed to click *MALA get ts* which reads the radargram header to find the recording time window and the samples/scan for the radargram data. This button also tests to ensure all the radargrams (where there are multiple lines) have identical recording parameters.
Convert data	• All the data needed to be converted to GPR-Slice format by clicking *MALA 16 to 16 bit*. • A new window opened where *agc gain* was applied to see if there was a significant DC-drift and wobble noise. • Gain must not be applied during conversion therefore all gain was removed from the radargram by clicking *gain reset.* • If there is some wobble noise in the data in the previous steps then a pre-conditioning is applied to the data on conversion with the *batch gain – wobble* button which removed the low frequency noise. • The converted radargrams were written in to the relevant Project folder by the software.

Set navigation	• For data collected with a survey wheel the navigation set should always be *Artificial Markers*, this button will place marker tags on the scan(s) to define the range units recorded.
Time ‘0’ correction	• Time ‘0’ must be edited from the radargrams before range gain can be applied. • Set the *Nthreshold breach* for determining a time ‘0’ trigger to 0.2 (i.e., 20% of the maximum signal). • Clicked *Auto 0ns line-by-line edit* to detect time ‘0’ which uses the medium value across each individual line (where there are multiple lines of data).
Spectra+Gain settings	• Range gain and bandpass filters were applied to the radargrams. • Clicked *spectra+gain* which produced a new window • Clicked *agc* gain button to make a possible gain curve and adjusted the curve manually were necessary. • Set the *lo-cut* and *hi-cut* frequencies desired to bandpass the radargrams using the left and right mouse buttons on the spectral curve plot.
Bandpass filtering	• Once spectra+gain settings had been applied, bandpass filters were applied to the data which applies range gain and simultaneous bandpass filtering. • The processed radargrams are written into the relevant Project folder.
Slice / XYZ	• This step allowed for time slices of the data to be created. • Needed to ensure certain parameters had been set (e.g., the number of time slices (**1**), bins per mark (**4**), bin parameter (**abs amplitude**), the identifier to name the time slice(s) (**a**)). • Clicked *slice/xyz* to start the process and once completed a dialogue box opened.

Appendix 8: The data collected from the secondary questionnaire was used as a starting point for the code which encodes the ‘expert judgment’ part of the algorithm. This algorithm takes the collated data from the secondary questionnaire completed by expert practitioners to calculate what methods are most to least suitable for any given target and environmental conditions. The algorithm was developed by using the data collected by the author who explained the expected function (i.e., rank the detection methods in order of most to least suitable at each depositional environment) to Andy Symons, a member of the computing staff at Liverpool John Moores University, who then coded it in Python.

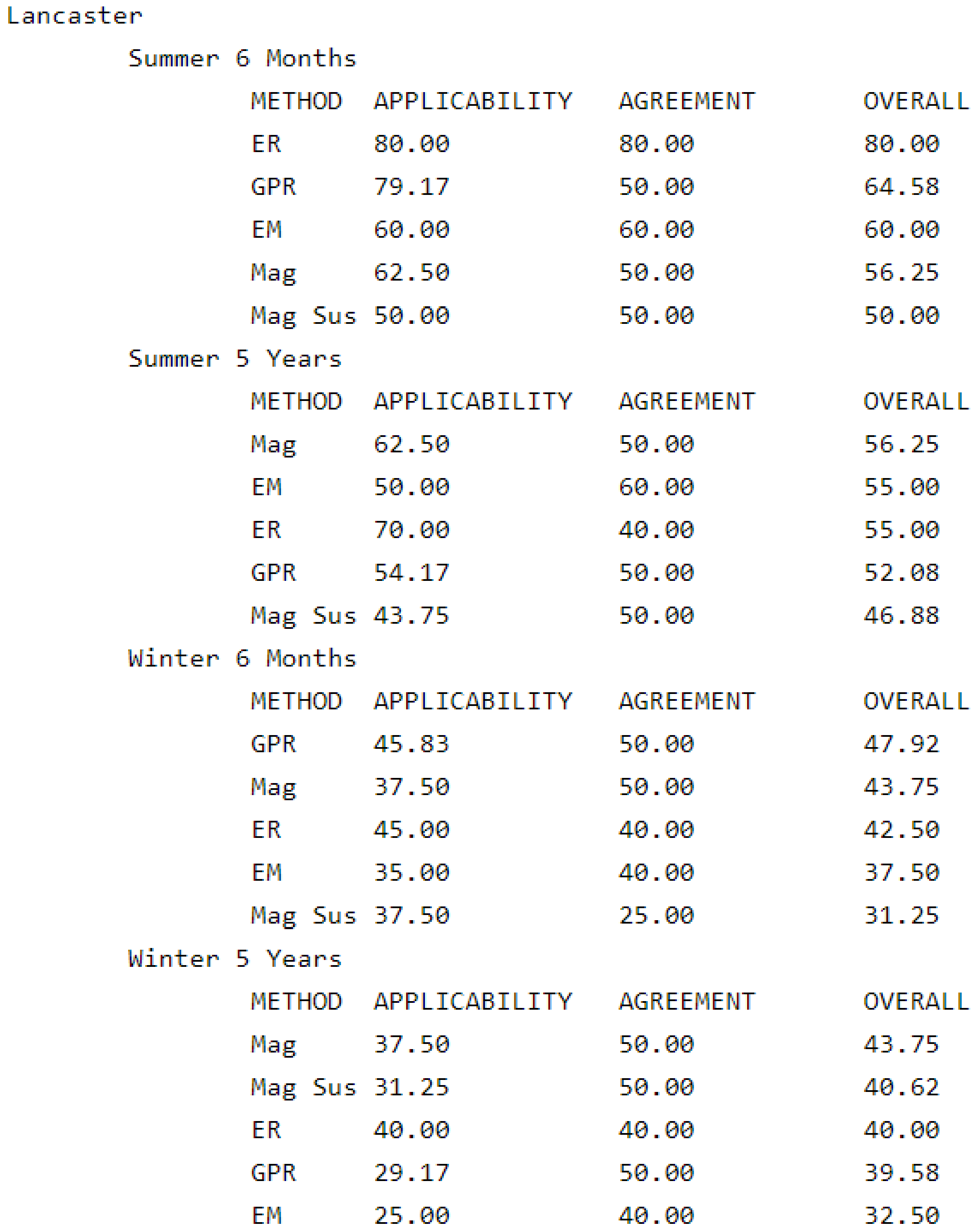


```
import statistics

# Enumerate the output headings
sites = ["Lancaster", "Nantwich", "Aspatria", "Sawley", "Newborough",
"Berkhamsted", "Crowborough", "Saddleworth Moor"]
methods = ["GPR", "ER", "Mag Sus", "EM", "Mag"]
seasons = ["Summer 6 Months", "Summer 5 Years", "Winter 6 Months", "Winter 5
Years"]

# Open the data file
qdata = open("QDATA2.0.csv", "r")

# Read in the headings line
userData = qdata.readline().strip()

# Read in the first line of data
userData = qdata.readline().strip()

# Declare and initialise global variables
userCount = 1
qrList = []
results = []
r2 = []

# Build the three data structures to hold the file data (qrList), the result
count(results) and the scores(r2)
for i in range(0,8):
    qrList.append([])
    results.append([])
    r2.append([])
    for j in range(0,4):
        qrList[i].append([])
        results[i].append([])
        r2[i].append([])
        for k in range(0, 5):
            qrList[i][j].append([])
            results[i][j].append([])
            r2[i][j].append([])

# Process the first line of data
while userData:

    # We need to process the data sequentially but put in the data structure
    # dataCount is the sequential view of the file data
    dataCount = 1

    # Split up the data into a list
    userList = userData.split(",")

    # For each location (site)
    for site in range(0,8):
        # for each season
        for season in range(0,4):
            # for each method
```

```
                for method in range(0, 5):
                    # Append the data to the method in the season in the site
                    qrList[site][season][method].append(float(userList[dataCount]))
                    # Increament the sequential data count
                    dataCount+=1

        # read in the next line of the data from the file
        userData = qdata.readline().strip()
        # Increment the user count
        userCount+=1

    # Process the data into the counts
    for site in range(0,8):
        for season in range(0,4):
            for method in range(0,5):
                # Remove zeroes
                endZ = False
                while not endZ:
                    try:
                        qrList[site][season][method].remove(0.0)
                    except Exception:
                        endZ = True

                # Set up a results list for the method in this season in this site
                results[site][season][method] = [0.0,0.0,0.0,0.0,0.0]

                # do the count and store
                for val in qrList[site][season][method]:
                    results[site][season][method][int(val) - 1] += 1.0

    # Work out the scores and store them in the r2 data structure
    for site in range(0,8):
        for season in range(0,4):
            for method in range(0,5):
                tot = 0
                resp = 0
                for index, num in enumerate(results[site][season][method]):
                    tot = tot + ((index+1) * num)
                    resp += num
                score1 = ((tot - resp)/((5 * resp) - resp))*100
                r2[site][season][method].append(score1)
                score2 = (max(results[site][season][method])/resp)*100
                r2[site][season][method].append(score2)
                score3 = (score1+score2)/2
                r2[site][season][method].append(score3)

    # Output the sites, seasons and methods in 'overall' score order
    for site in range(0,8):
        # Output site header
        print(sites[site])
        for season in range(0,4):
            # Output season header
            print("\t" + seasons[season])
```

```
        # Sort the methods
        index = [0, 1, 2, 3, 4]

        for i in range(0, 4):
            for j in range(i+1, 5):
                if r2[site][season][index[i]][2] <
r2[site][season][index[j]][2]:
                    index[i], index[j] = index[j], index[i]

        # Output the scores heading line
        print("\t\tMETHOD\tAPPLICABILITY\tAGREEMENT\tOVERALL")
        # output the methods in the sorted order
        for method in range(0,5):
            print("\t\t" + methods[index[method]] + "\t" +
f"{r2[site][season][index[method]][0]:.2f}", end="")
            print("\t\t" + f"{r2[site][season][index[method]][1]:.2f}" + "\t\t"
+ f"{r2[site][season][index[method]][2]:.2f}")
```

Appendix 9: The output from the coded algorithm in Appendix 8 using the data from the secondary questionnaires. The methods have been put in order from most to least suitable based on overall score.



```
Lancaster
        Summer 6 Months
                METHOD  APPLICABILITY   AGREEMENT       OVERALL
                ER      80.00           80.00           80.00
                GPR     79.17           50.00           64.58
                EM      60.00           60.00           60.00
                Mag     62.50           50.00           56.25
                Mag Sus 50.00           50.00           50.00
        Summer 5 Years
                METHOD  APPLICABILITY   AGREEMENT       OVERALL
                Mag     62.50           50.00           56.25
                EM      50.00           60.00           55.00
                ER      70.00           40.00           55.00
                GPR     54.17           50.00           52.08
                Mag Sus 43.75           50.00           46.88
        Winter 6 Months
                METHOD  APPLICABILITY   AGREEMENT       OVERALL
                GPR     45.83           50.00           47.92
                Mag     37.50           50.00           43.75
                ER      45.00           40.00           42.50
                EM      35.00           40.00           37.50
                Mag Sus 37.50           25.00           31.25
        Winter 5 Years
                METHOD  APPLICABILITY   AGREEMENT       OVERALL
                Mag     37.50           50.00           43.75
                Mag Sus 31.25           50.00           40.62
                ER      40.00           40.00           40.00
                GPR     29.17           50.00           39.58
                EM      25.00           40.00           32.50
```

```
Nantwich
        Summer 6 Months
                METHOD  APPLICABILITY   AGREEMENT       OVERALL
                GPR     83.33           50.00           66.67
                Mag     62.50           50.00           56.25
                ER      70.00           40.00           55.00
                EM      50.00           40.00           45.00
                Mag Sus 37.50           25.00           31.25
        Summer 5 Years
                METHOD  APPLICABILITY   AGREEMENT       OVERALL
                ER      65.00           40.00           52.50
                GPR     70.83           33.33           52.08
                Mag     50.00           50.00           50.00
                EM      45.00           40.00           42.50
                Mag Sus 31.25           50.00           40.62
        Winter 6 Months
                METHOD  APPLICABILITY   AGREEMENT       OVERALL
                Mag     50.00           100.00          75.00
                GPR     50.00           50.00           50.00
                ER      40.00           40.00           40.00
                EM      35.00           40.00           37.50
                Mag Sus 18.75           50.00           34.38
        Winter 5 Years
                METHOD  APPLICABILITY   AGREEMENT       OVERALL
                GPR     37.50           66.67           52.08
                ER      40.00           60.00           50.00
                Mag     37.50           50.00           43.75
                EM      35.00           40.00           37.50
                Mag Sus 12.50           50.00           31.25
```

```
Aspatria
        Summer 6 Months
                METHOD  APPLICABILITY   AGREEMENT       OVERALL
                GPR     95.83           83.33           89.58
                Mag     75.00           100.00          87.50
                EM      55.00           60.00           57.50
                ER      70.00           40.00           55.00
                Mag Sus 37.50           25.00           31.25
        Summer 5 Years
                METHOD  APPLICABILITY   AGREEMENT       OVERALL
                GPR     83.33           66.67           75.00
                ER      65.00           60.00           62.50
                Mag     62.50           50.00           56.25
                EM      55.00           40.00           47.50
                Mag Sus 31.25           50.00           40.62
        Winter 6 Months
                METHOD  APPLICABILITY   AGREEMENT       OVERALL
                Mag     50.00           100.00          75.00
                GPR     58.33           33.33           45.83
                ER      40.00           40.00           40.00
                EM      35.00           40.00           37.50
                Mag Sus 18.75           50.00           34.38
        Winter 5 Years
                METHOD  APPLICABILITY   AGREEMENT       OVERALL
                ER      50.00           60.00           55.00
                Mag     37.50           50.00           43.75
                GPR     50.00           33.33           41.67
                EM      35.00           40.00           37.50
                Mag Sus 12.50           50.00           31.25
```

```
Sawley
        Summer 6 Months
                METHOD  APPLICABILITY   AGREEMENT       OVERALL
                ER      85.00           60.00           72.50
                GPR     75.00           50.00           62.50
                Mag     62.50           50.00           56.25
                EM      55.00           40.00           47.50
                Mag Sus 43.75           50.00           46.88
        Summer 5 Years
                METHOD  APPLICABILITY   AGREEMENT       OVERALL
                ER      60.00           60.00           60.00
                GPR     66.67           50.00           58.33
                Mag     50.00           50.00           50.00
                EM      50.00           40.00           45.00
                Mag Sus 37.50           25.00           31.25
        Winter 6 Months
                METHOD  APPLICABILITY   AGREEMENT       OVERALL
                GPR     45.83           66.67           56.25
                Mag     37.50           50.00           43.75
                ER      45.00           40.00           42.50
                Mag Sus 31.25           50.00           40.62
                EM      35.00           40.00           37.50
        Winter 5 Years
                METHOD  APPLICABILITY   AGREEMENT       OVERALL
                ER      40.00           60.00           50.00
                GPR     41.67           50.00           45.83
                EM      30.00           60.00           45.00
                Mag     37.50           50.00           43.75
                Mag Sus 25.00           50.00           37.50
```

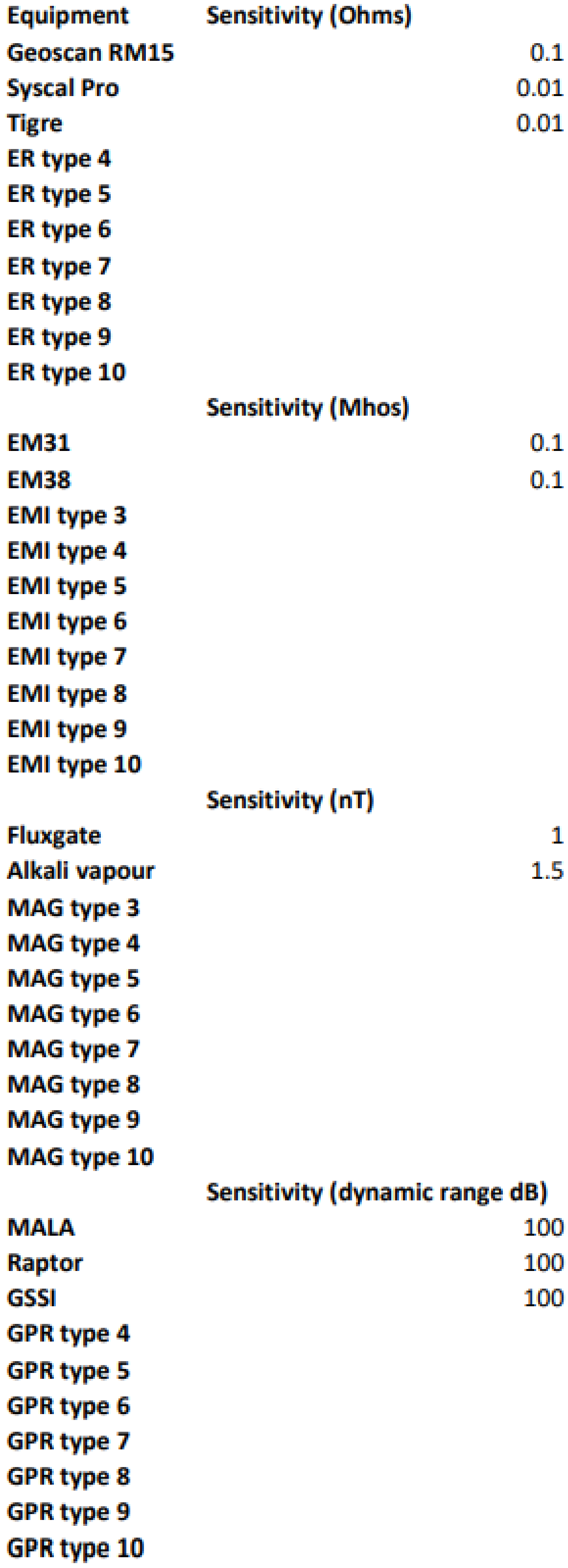
```
Newborough
        Summer 6 Months
                METHOD  APPLICABILITY   AGREEMENT       OVERALL
                ER      80.00           60.00           70.00
                Mag     62.50           50.00           56.25
                EM      60.00           40.00           50.00
                Mag Sus 50.00           50.00           50.00
                GPR     41.67           33.33           37.50
        Summer 5 Years
                METHOD  APPLICABILITY   AGREEMENT       OVERALL
                Mag     50.00           50.00           50.00
                Mag Sus 43.75           50.00           46.88
                ER      50.00           40.00           45.00
                EM      35.00           40.00           37.50
                GPR     33.33           33.33           33.33
        Winter 6 Months
                METHOD  APPLICABILITY   AGREEMENT       OVERALL
                Mag     50.00           100.00          75.00
                ER      45.00           40.00           42.50
                EM      40.00           40.00           40.00
                GPR     25.00           50.00           37.50
                Mag Sus 37.50           25.00           31.25
        Winter 5 Years
                METHOD  APPLICABILITY   AGREEMENT       OVERALL
                ER      35.00           60.00           47.50
                Mag     37.50           50.00           43.75
                Mag Sus 31.25           50.00           40.62
                GPR     20.83           50.00           35.42
                EM      25.00           40.00           32.50
```

```
Berkhamsted
        Summer 6 Months
                METHOD  APPLICABILITY   AGREEMENT       OVERALL
                ER      70.00           80.00           75.00
                Mag     62.50           50.00           56.25
                EM      55.00           40.00           47.50
                Mag Sus 43.75           50.00           46.88
                GPR     50.00           33.33           41.67
        Summer 5 Years
                METHOD  APPLICABILITY   AGREEMENT       OVERALL
                ER      60.00           80.00           70.00
                Mag     50.00           50.00           50.00
                EM      45.00           40.00           42.50
                GPR     33.33           33.33           33.33
                Mag Sus 37.50           25.00           31.25
        Winter 6 Months
                METHOD  APPLICABILITY   AGREEMENT       OVERALL
                ER      35.00           60.00           47.50
                EM      30.00           60.00           45.00
                Mag     37.50           50.00           43.75
                Mag Sus 31.25           50.00           40.62
                GPR     29.17           33.33           31.25
        Winter 5 Years
                METHOD  APPLICABILITY   AGREEMENT       OVERALL
                ER      30.00           80.00           55.00
                EM      30.00           60.00           45.00
                Mag     37.50           50.00           43.75
                Mag Sus 25.00           50.00           37.50
                GPR     16.67           50.00           33.33
```

```
Crowborough
        Summer 6 Months
                METHOD  APPLICABILITY   AGREEMENT       OVERALL
                ER      80.00           40.00           60.00
                Mag     62.50           50.00           56.25
                GPR     45.83           50.00           47.92
                EM      55.00           40.00           47.50
                Mag Sus 43.75           50.00           46.88
        Summer 5 Years
                METHOD  APPLICABILITY   AGREEMENT       OVERALL
                ER      60.00           60.00           60.00
                Mag     50.00           50.00           50.00
                EM      45.00           40.00           42.50
                GPR     37.50           33.33           35.42
                Mag Sus 37.50           25.00           31.25
        Winter 6 Months
                METHOD  APPLICABILITY   AGREEMENT       OVERALL
                ER      35.00           80.00           57.50
                EM      30.00           60.00           45.00
                Mag     37.50           50.00           43.75
                Mag Sus 31.25           50.00           40.62
                GPR     25.00           50.00           37.50
        Winter 5 Years
                METHOD  APPLICABILITY   AGREEMENT       OVERALL
                ER      35.00           60.00           47.50
                EM      30.00           60.00           45.00
                Mag     37.50           50.00           43.75
                Mag Sus 25.00           50.00           37.50
                GPR     20.83           50.00           35.42
```

```
Saddleworth Moor
        Summer 6 Months
                METHOD  APPLICABILITY   AGREEMENT       OVERALL
                ER      45.00           60.00           52.50
                EM      45.00           60.00           52.50
                Mag     50.00           33.33           41.67
                Mag Sus 25.00           50.00           37.50
                GPR     37.50           33.33           35.42
        Summer 5 Years
                METHOD  APPLICABILITY   AGREEMENT       OVERALL
                EM      35.00           80.00           57.50
                ER      40.00           60.00           50.00
                Mag Sus 18.75           75.00           46.88
                Mag     50.00           33.33           41.67
                GPR     29.17           33.33           31.25
        Winter 6 Months
                METHOD  APPLICABILITY   AGREEMENT       OVERALL
                Mag     41.67           66.67           54.17
                Mag Sus 12.50           75.00           43.75
                GPR     16.67           66.67           41.67
                ER      20.00           60.00           40.00
                EM      25.00           40.00           32.50
        Winter 5 Years
                METHOD  APPLICABILITY   AGREEMENT       OVERALL
                Mag     41.67           66.67           54.17
                Mag Sus 6.25            75.00           40.62
                EM      20.00           60.00           40.00
                GPR     16.67           50.00           33.33
                ER      20.00           40.00           30.00
```

Appendix 10: The properties tables developed that the proposed tool would source data from to produce a prediction of the optimal method to detect the buried target the user is searching for at their given site (consists of different geophysical equipment [sensors] and their sensitivities with space for more, targets and their properties, vegetation and surface).



Equipment	Sensitivity (Ohms)
Geoscan RM15	0.1
Syscal Pro	0.01
Tigre	0.01
ER type 4	
ER type 5	
ER type 6	
ER type 7	
ER type 8	
ER type 9	
ER type 10	
	Sensitivity (Mhos)
EM31	0.1
EM38	0.1
EMI type 3	
EMI type 4	
EMI type 5	
EMI type 6	
EMI type 7	
EMI type 8	
EMI type 9	
EMI type 10	
	Sensitivity (nT)
Fluxgate	1
Alkali vapour	1.5
MAG type 3	
MAG type 4	
MAG type 5	
MAG type 6	
MAG type 7	
MAG type 8	
MAG type 9	
MAG type 10	
	Sensitivity (dynamic range dB)
MALA	100
Raptor	100
GSSI	100
GPR type 4	
GPR type 5	
GPR type 6	
GPR type 7	
GPR type 8	
GPR type 9	
GPR type 10	

Buried target	Material	Mag Sus (SI x$10^{-5)}$	Electrical resistivity (ohm-metres)	Electrical conductivity (1/ohm-metres)	Relative dielectric permitivity	Volume cm^3	Mass kg
Derringer/9mm	Steel, chrome plated	1x10^-1	1.6 x 10^-7	6.2 x 10^6	1	2000	1.1
Pistol/0.25	Zinc alloy/steel, chrome plated	1x10^-1	5.9 x 10^-8	1.7 x 10^7	1	2000	1.1
Pistol/9mm (S&W)	Stainless steel	1x10^-1	1.6 x 10^-7	6.2 x 10^6	1	2000	1.1
Pistol/9mm (Glk)	Polymer frame/steel slide and firing pin, Blued/tenifer	1x10^-1	1.6 x 10^-7	6.2 x 10^6	4	2000	1.1
Revolver/0.357 Magnum	Stainless steel	1x10^-1	1.6 x 10^-7	6.2 x 10^6	1	2000	1.1
Revolver/0.22 Long rifle	Aluminium frame/steel barrel & cylinder, blued	1x10^-1	2.8 x 10^-8	3.5 x 10^7	1	2000	1.1
Shotgun/12 guage	Steel/polymer, blued	1x10^-1	1.6 x 10^-7	6.2 x 10^6	4	2000	1.1
Shotgun/12 guage	Steel, parkerised	1x10^-1	1.6 x 10^-7	6.2 x 10^6	1	2000	1.1
Pistol/ 0.45	zinc alloy/aluminium plated	1x10^-1	5.9 x 10^-8	1.7 x 10^7	1	2000	1.1
Adult, fresh	biological material	9x10^-6	50	0.020	30	80000	80
Adult, 1 month	biological material	9x10^-7	20	0.050	50	80000	80
Adult, 6 months	biological material	9x10^-8	20	0.050	50	70000	70
Adult, 1 year	biological material	9x10^-9	20	0.050	50	60000	60
Adult, <5 years	biological material	9x10^-10	25	0.040	50	50000	50
Adult >5 years	biological material	9x10^-11	40	0.025	40	30000	30
Mass grave 2<10 years	biological material	9x10^-12	20	0.050	30		
Mass grave 10<50 years	biological material	9x10^-13	15	0.067	30		
Mass grave50<100 years	biological material	9x10^-14	15	0.067	40		
Mass grave 100< years	biological material	9x10^-15	15	0.067	40		

Other ...

Vegetation	height (m)	% impede careful walking speed	% impede careful instrument disturbance
short grass	0.1	10	10
medium grass (30cm)	0.3	30	30
tall grass (50cm)	0.5	60	60
very tall grass (<80cm)	0.8	80	80
short shrubs	0.1	10	10
medium shrubs (30cm)	0.3	30	30
tall shrubs (50cm)	0.5	60	60
very tall shrubs (<80cm)	0.8	80	80
sparse trees - 10% obstructed	2.0 -30.0	10	10
close trees - 30% obstructed	2.0 -30.0	30	30
dense trees - 60% obstructed	2.0 -30.0	60	60
very dense trees - 80% obstructed	2.0 -30.0	80	80
cerial growing - early season	0.6	60	60
cerial growing - late season	1.2	90	90
root crop	0.2	20	20
short moorland vegetation	0.2	20	20
medium moorland vegetataion	0.6	60	60
tall moorland vegetation	1	90	90
short bracken	0.7	70	70
tall bracken	2	90	90
tall grass and sparse trees	0.6 grass and 2.0-30.0 trees	60	60

Surface	% impede careful walking speed
bare sand	10
bare soil firm	10
bare soil soft	30
shallow mud	30
deep mud	50
firm peat	50
soft peat	80
semi-liquid peat	90
soft-ploughed soil	60
rough-ploughed soil	70
very rough-ploughed soil	80
firm vegetated soil	5