Detecting Various Burial Scenarios In A Controlled Setting Using Ground-penetrating Radar And Conductivity

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DETECTING VARIOUS BURIAL SCENARIOS IN A CONTROLLED SETTING USING GROUND-PENETRATING RADAR AND CONDUCTIVITY

by

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B.S. University of Wisconsin-Milwaukee, 2007

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Arts in the Department of Anthropology in the College of Sciences at the University of Central Florida Orlando, Florida

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ABSTRACT

The use of geophysical tools to locate clandestine burials involving bodies has seen increasing popularity among forensic personnel. Often, these search methods are important to highlight certain areas where a body may or may not be located prior to utilizing invasive search techniques. Because of the success of these tools within real-life forensic searches, the use of controlled studies that monitor and detect cadavers over certain lengths of time have been increasingly utilized. However, these controlled studies have not monitored various burial scenarios that mimic real-life situations. This study focused on detecting and monitoring six burials containing pig carcasses used as proxies for human bodies and two control burials with a conductivity meter and ground-penetrating radar (GPR) with a 500-MHz and a 250-MHz antenna over a twelve month period. Each burial within this study represented a different forensic scenario that mimicked a real-life situation. Further, forensic use of GPR in both controlled settings as well as real-life searches have mainly focused on the use of a 500-MHz antenna. Therefore, this research also compared the use of a 250-MHz antenna with a 500-MHz antenna. Lastly, a number of GPR imagery options were utilized including reflection profiles and horizontal slices with various GPR software programs to compare the results obtained.

Results obtained from the conductivity meter were compared to the results obtained by both antennae of the GPR. Overall, the use of multiple GPR imagery options provided increased resolution of the burial scenarios. Results showed that the conductivity meter was not a beneficial geophysical tool because none of the burial scenarios were detected. On the other hand, the use of GPR showed that the graves with objects added to the pig carcasses provided
increased resolution compared to the graves containing only pig carcasses. Lastly, the 250-MHz antenna provided better resolution of the burial scenarios than the 500-MHz antenna due to easier discrimination of the forensic targets. Therefore, the use of a 250-MHz antenna would be a viable option to search for clandestine burials containing adult-sized bodies.
This work is dedicated to my mother, Bonnie. Your love and guidance throughout my life have made me the man I am today. I miss you more and more every day and I know you are going to be with me for every future step that I take.
ACKNOWLEDGMENTS

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I also want to express my appreciation to a number of students and friends at UCF who have assisted me in the field throughout this long process. Without your help this research may not have been possible. While there are a great number of students that have assisted me, I must personally recognize a few that have had the greatest impact. Thank you to Dennis Wardlaw for his assistance in both setting up this research and his support in training me with the GPR software. Thank you to Charles Dionne for his assistance both in the field and also with training me with the conductivity meter. Thank you to Holly Rascovich for her assistance in the field while also putting up with the horrible summer heat. Lastly, I would like to thank William Hawkins, Joanna Fletcher, and Christopher Alvarez for their countless hours spent in the field.

Finally I would like to thank my family and my wonderful girlfriend. You have been with me every step of the way and your love and support has been what has guided me throughout this experience.
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CHAPTER ONE: INTRODUCTION

The detection and recovery of buried bodies has not been a concern strictly limited to law enforcement personnel. Anthropologists and archaeologists have also played a major role in the field as well. Throughout forensic investigations, law enforcement agencies, medical examiners, and coroners have requested the assistance of personnel trained in forensic archaeology for body searches that may include decomposed or skeletal remains (e.g. France et al., 1992; Schultz et al., 2006; Schultz, 2007; Schultz, 2008; Strongman, 1992). The use of geophysical tools to locate clandestine graves and physical evidence associated with criminal activity has seen growing acceptance by criminal investigators (France et al., 1992; Davenport, 2001; Schultz, 2007). Further, there has been an attraction to the application of forensic geoscience in the field of criminal investigations (Davenport, 2001; Morgan and Bull, 2007; Pye and Croft, 2004; Ruffell and McKinley, 2004; Schultz, 2007). Often the search for buried bodies at a crime scene has frustrated investigators mainly because of the lack of an accurate means of remote sensing that could locate significant evidence associated with a forensic investigation (Strongman, 1992). The high cost of some geophysical equipment and the lack of training provided to law enforcement agencies is a problem that is often encountered within many different law enforcement groups. A criminal investigation involving human remains can benefit by having the assistance of a forensic archaeologist with experience using geophysical tools, as they can offer a variety of methods that law enforcement agencies have not been customarily trained to provide (Schultz, 2007; Schultz, 2008).
Search methods can be separated into intrusive and nonintrusive methods (Dupras et al., 2006; Hunter and Cox, 2005; Killam, 2004; Schultz, 2007). Intrusive methods include probes, shovels, coring, drilling, and heavy earthmoving equipment. One must take extreme caution when using intrusive methods because any disturbance of a burial site may result in a detrimental loss of evidence and information (Davenport, 2001; Killam, 2004; Schultz, 2007). Conversely, nonintrusive methods are nondestructive and do not disturb the ground surface (Conyers, 2004; Davenport, 2001; Killam, 2004; Schultz, 2007). These methods cause minimal damage to a site because the soil is not penetrated by search efforts (Conyers, 2004; Killam, 2004, Schultz et al., 2006; Schultz, 2007; Schultz, 2008) and the preservation and context of evidence within a forensic scene is maintained. Nonintrusive methods include the use of cadaver dogs, visually searching a scene, and the use of geophysical tools such as ground-penetrating radar (GPR) and conductivity meters.

There are two basic types of geophysical prospecting methods: passive and active. Both methods involve the measurement of signals, either induced or natural (Killam, 2004). Passive methods measure natural signals generated by the earth which are inherent physical properties of the ground (Kearey et al., 2002; Killam, 2004). Active methods use human-made or induced signals transmitted into the ground, followed by a measurement of return signals by a receiver (Kearey et al., 2002; Killam, 2004). Ground-penetrating radar (GPR) and electromagnetic surveying, or ground conductivity, are active geophysical methods.
Controlled Research

“Forensic geoscience is defined as a subdiscipline of geoscience that is concerned with the application of geological and wider environmental science information and methods to investigations which may come before a court of law” (Pye and Croft, 2004:1). One important area of geoscience that combines forensics and archaeological investigations is the study of buried or hidden animal and human remains (Ruffell and McKinley, 2005). The success of ground-penetrating radar (GPR) in actual forensic settings has led to numerous controlled GPR studies that have simulated a forensic context. The most useful method for gaining experience performing geophysical surveys for the location of buried human remains is to set up a controlled research site to monitor and detect the cadavers for some length of time (France et al., 1992; Schultz et al., 2006; Schultz, 2007; Schultz, 2008; Strongman, 1992). Controlled forensic geophysical research often consists of burying pig carcasses as proxies for human bodies in known soils and monitoring the burials for certain lengths of time. This research has been important in exhibiting the use of this technology for grave detection, and as a result of this past controlled research, geophysical tools, especially GPR, is commonly used to locate clandestine burials of homicide victims (Davenport, 2001; Fenning and Donnelly, 2004; France et al., 1992; Schultz et al., 2006; Schultz, 2007; Schultz, 2008; Strongman, 1992). Further, an aspect of controlled GPR studies that has been shown to be important is the association of states of decomposition to GPR imagery characteristics (Schultz, 2003; Schultz et al., 2006, Schultz, 2008). There are a number of factors that may affect the detection of clandestine graves (Scott and Hunter, 2004) including the size of the target, the area of disturbance, the depth of the burial,
body wrapping, state of decomposition, climate, and ground saturation. Each of these factors are important to keep in mind when conducting controlled research. Lastly, an area of controlled GPR research that is important in the field of forensic archaeology is to address more real-life situations for body concealment. GPR studies should incorporate multiple burial scenarios including burying remains wrapped in blankets or tarpaulins, and covering the body with various materials including rocks, debris, or calcium hydroxide (Dupras et al., 2006; Hunter and Cox, 2005). To date, there are no studies that have incorporated different burial scenarios with the use of geophysical search instruments.

Numerous controlled studies that test the applicability of GPR under controlled conditions in the detection of buried bodies have been increasingly utilized. A Colorado based forensic organization, known as NecroSearch, has performed by far the most widespread controlled geophysical studies. Their studies have consisted of a number of law enforcement personnel and scientists who were called upon to perform a multidisciplinary study to locate buried pig carcasses using multiple geophysical methods (Davenport et al., 1990; France et al., 1992). Their research project included a number of different geophysical techniques including GPR, electromagnetics (EM), and magnetics (MAG), and has continued to expand as a research project intended to investigate methods and technologies that will prove even more useful in locating clandestine graves (France et al., 1992). Strongman (1992) successfully located three large animal carcasses that were buried and that simulated both young children and adult cadavers using a 500-MHz antenna. Schultz et al. (2006) determined that large pig carcasses buried in sand were easily detected with GPR in advanced stages of decomposition for periods
up to 21.5 months. Lastly, Schultz (2008) concluded that it is difficult to detect small pig carcasses buried in sand with a 500-MHz antenna for extended periods of time because a response may not be produced from the soil features or any items that may be placed in the grave with the body. On the other hand, controlled studies that test the applicability of a conductivity meter have not been utilized to a great extent. A study by Dionne (2009) demonstrated that the use of a conductivity meter in conjunction with GPR proved successful in detecting buried metallic weapons at various depths in a controlled setting.

There are a few published case studies on the applicability of geophysical search methods within forensic searches, especially with the use of ground-penetrating radar to locate buried bodies. GPR has been demonstrated to be a valuable method for investigators when searching for buried bodies in forensic contexts (e.g., Davenport, 2001; Mellet, 1992; Nobes, 2000; Schultz et al., 2006; Schultz, 2008). These searches have concentrated on locating cemetery graves from different time periods (Bevan, 1991) and on locating buried bodies in forensic contexts (Davenport, 2001; Mellett, 1992; Nobes, 2000). On the other hand, little has been published on the use of a conductivity meter in a forensic context. Nobes (2000) published an example about the use of the conductivity meter in conjunction with GPR in New Zealand to search for human remains that had been buried for almost 12 years. The study by Nobes (2000) demonstrated that whether for forensic investigations or for archaeological work, a combination of multiple geophysical techniques is suggested to assist in the location of buried human remains. Overall, however, conductivity has not proven to be a valuable tool in the search for clandestine burials up to this point.
Research Objectives

The objective of this research is to improve standard geophysical detection methods used to search for buried bodies in forensic contexts while focusing on different burial scenarios that represent real-life examples. Further, this research will (1) investigate the ability of the conductivity meter to detect buried bodies representing various real-life forensic scenarios; (2) investigate the ability of ground-penetrating radar using a 500-MHz antenna and a 250-MHz antenna to detect buried bodies; and (3) document the changes between both GPR antennae using various GPR imagery software programs. This thesis represents the first twelve months of data collection of a larger project encompassing a total of two-and-a-half years.

Thesis Outline

This thesis will be broken down into five chapters. The first chapter of this thesis provides an introduction to the research project; the second chapter presents the results of the conductivity meter; the third chapter presents the results of the 500-MHz antenna; the fourth chapter presents the results of the 250-MHz antenna; and finally, the fifth chapter will summarize the findings of the research project.
CHAPTER TWO: DETECTING VARIOUS BURIAL SCENARIOS IN A CONTROLLED SETTING USING A CONDUCTIVITY METER

Introduction

The location of clandestine graves containing a human body is a very challenging task for law enforcement officials. There are a number of limitations to the traditional methods in the location and exhumation of clandestine graves. Often, search methods can be a destructive process that may damage potential evidence. The use of geophysical methods is a nonintrusive search technique that does not cause any damage to the ground surface (Dupras et al., 2006; Schultz, 2007). Further, when performing a forensic search for buried bodies, a multidisciplinary methodology should be approached (Dupras et al., 2006; France et al., 1992; Killam, 1999; Schultz, 2008). Forensic cases involving buried bodies will benefit by having a forensic anthropologist or archaeologist on the scene with geophysical experience. Geophysical tools are usually not used by law enforcement agencies due to the high cost of the equipment and the specialized training that is involved (Schultz, 2007; Schultz, 2008). Because of these specialized skills required to operate geophysical tools, partnerships between law enforcement officials and trained geophysical personnel are important for death investigations (Schultz, 2007). Lastly, not only are geophysical techniques important in locating potential clandestine burials, they are also important in clearing suspected areas where a body was thought to be buried.
There are a number of published case studies involving the successful use of ground-penetrating radar when searching for buried bodies (Davenport, 2001; Nobes, 2000; Schultz, 2007), as well as its use in a controlled setting (France et al., 1992; Freeland, et al., 2003; Schultz, 2003; Schultz, 2006; Schultz, 2008). On the other hand, there is only one published case study on the use of a conductivity meter used in conjunction with GPR to locate a body that had been buried for several years (Nobes, 2000). With the lack of published material on the use of a conductivity meter to locate buried bodies, it is important to conduct research in a controlled setting that monitors real-life forensic scenarios in order to provide law enforcement agencies with the proper guidelines and limitations when using this methodology during a forensic search. This study will include a month by month analysis of the use of a conductivity meter when locating buried bodies throughout 12 months of data collection. The following questions will be addressed: 1) Is the conductivity meter a useful method for detecting buried bodies?; 2) If it is a useful geophysical search method then what burial scenarios provide the best and worst results?; and 3) If it is not a useful search method then what are the reasons that the conductivity meter is unsuccessful?

Conductivity Meter

Conductivity measures the ability of the soil to conduct an electric current (Clay, 2005). Electromagnetic instruments, such as a conductivity meter, contain a transmitter and a receiver that measure differences in electrical conductivity. According to Beauchaine and Werdemann (2006:2), “A signal is emitted from the transmitter end of the unit which produces eddy currents in the ground material. These eddy currents in turn produce a secondary electromagnetic field
which is measured by the receiver coil of the meter.” The difference in the electromagnetic wavelength is comparative to the conductivity of the ground material (Beauchaine and Werdemann, 2006). The most popular electromagnetic technology for forensic and archaeological contexts is the horizontal loop or slingram method that is operated by a single person where both transmitting and receiving coils are located with the frame (Dupras et al., 2006; Killam 2004).

The conductivity meter is not intended to be a metal detector, but highly conductive metals do generate strong signals in response to the meter. The conductivity meter is designed to measure the smaller signals produced by the conductivity of the soils (Clay, 2005). Ground conductivity meters measure differences in the conductivity of soils that are a product of their composition and formation (Clay, 2005). When soils have been moved around at a site, conductivity contrasts can be created that a conductivity meter might record. The presence of buried remains is likely to change the physical and chemical characteristics of soil compared with those of the surroundings due to changes in soil depth (Rowlands and Sarris, 2007), and a conductivity meter is crucial to detecting these changes.

Conductivity is measured in millisiemens per meter (mS/m). Higher millisiemens per meter means that the soil is a better conductor (Killam, 2004). Conductivity meters can be rotated 90 degrees to take measurements in the horizontal mode, where the instrument is laid on its side, or the vertical mode, where the instrument is held vertically (Clay, 2005). The horizontal mode records data at approximately one half the depth-sensitivity of the vertical mode and thus the vertical mode is the recommended mode of choice (Clay, 2005). The end product of
data collected with a conductivity meter is a contour map which reveals electromagnetic reflection features beneath the surface (Killam, 2004).

The conductivity meter can benefit a forensic investigation in a number of ways (see Table 1). It can identify almost all types of metallic objects and even some clandestine graves if the backfill displays a strong contrast with the environment, it can be used in all types of terrain and surfaces, and it provides a fairly quick way of surveying a questionable area as the inspector is able to get a direct reading of the ground conductivity (Bevan, 1983; Davenport, 2001). On the other hand, the conductivity meter is a very expensive piece of equipment that might not be available to all law enforcement agencies. Like GPR, the conductivity meter is also a complicated geophysical tool that requires training before it can properly be managed, unlike more common geophysical technologies such as metal detectors. Further, the conductivity meter provides less resolution of features compared to a GPR unit and there is difficulty in making depth discriminations between targets.

**Table 1: Advantages and Disadvantages of Using the Conductivity Meter**

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Can be used on all types of terrain</td>
<td>• Expensive</td>
</tr>
<tr>
<td>• Relatively quick data collection</td>
<td>• Requires training to operate</td>
</tr>
<tr>
<td>• Provides direct readings</td>
<td>• Provides less resolution of features compared to GPR</td>
</tr>
<tr>
<td>• Can be used in dry periods as well as wet</td>
<td>• Difficulty in making depth discrimination between targets</td>
</tr>
</tbody>
</table>
Materials and Methods

Field Site and Controlled Graves

The research site is located on the secured grounds of the Geotechnical Engineering Test Site on the main campus of the University of Central Florida in Orlando, Florida. The site is a flat, unused section of the campus that is covered by grass and is mowed periodically (Figure 1). Six pig carcasses (*Sus scrofa*) weighing approximately 90-100 pounds each were used as proxies for human bodies, and were buried at either a shallow (approximately 0.50 m) or deep (approximately 1.0 m) depth (Table 2). Each of the six pigs were euthanized by a single gunshot wound to the head with a .22 caliber handgun, and were brought directly back to the UCF campus where they were buried the same afternoon. Pig carcasses are commonly used as proxies for human bodies in controlled research that may emphasize human taphonomy because they are similar to humans in their fat-to-muscle ratio, and in the fact that their skin is not heavily haired (France et al., 1992). Further, France et al. (1992) mentions that pigs have been considered to be biochemically and physiologically similar enough to humans to be used in studies of patterns and rates of decay. A permanent grid measuring 11 meters on the north-south axis by 22 meters on the east-west axis was constructed and contained six pig graves and two control graves set up in two rows, with each grave measuring 1 meter wide and 1 meter long. The six graves containing pig carcasses (Figure 2) and the two control graves mimic a number of common forensic scenarios involving buried bodies:
1. A deep blank control grave consisting of only disturbed backfill (100-110 cm) to determine the geophysical response of only the disturbed soil and not the carcass and items that will be added to graves.
2. A shallow blank control grave consisting of only disturbed backfill (50-60 cm) to determine the geophysical response of only the disturbed soil and not the carcass and items that will be added to graves.
3. A deep pig carcass with nothing else added to the grave.
4. A shallow pig carcass with nothing else added to the grave.
5. A deep pig carcass wrapped in a vinyl tarpaulin.
6. A deep pig carcass wrapped in a cotton blanket.
7. A deep pig carcass with a layer of lime (calcium hydroxide) placed over the carcass.
8. A deep pig carcass with a layer of small rocks placed over the carcass.

Figure 1: Research Area at the Geotechnical Engineering Test Site on the Main UCF Campus in Orlando, Florida
Each of the pig carcasses were placed in the grave on their right side with the back facing the east wall and the head towards the north wall. Once the pigs were placed in the grave the depths of the pigs from three points on the body were measured below the surface, including from the surface to the head, abdomen area, and tail. Grave scenario 1C contained a layer of small rocks over the pig and five measurements were taken from the ground surface to the layer of rocks including the northwest corner, northeast corner, southwest corner, southeast corner, and the center of the grave. Table 3 shows the measurements for each of the six graves containing a pig carcass.
<table>
<thead>
<tr>
<th>Grid Location</th>
<th>Burial Date</th>
<th>Depth of Grave Floor (below surface)</th>
<th>Scenario</th>
<th>Pig Carcass Weight (lbs)</th>
<th>Pig Carcass Sex</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>1/30/2009</td>
<td>0.5 m</td>
<td>Shallow pig grave</td>
<td>90</td>
<td>Female</td>
</tr>
<tr>
<td>1B</td>
<td>1/30/2009</td>
<td>1.0 m</td>
<td>Deep pig grave</td>
<td>100</td>
<td>Male</td>
</tr>
<tr>
<td>1C</td>
<td>1/30/2009</td>
<td>1.0 m</td>
<td>Deep grave with layer of rocks covering pig</td>
<td>90</td>
<td>Male</td>
</tr>
<tr>
<td>1D</td>
<td>1/30/2009</td>
<td>1.0 m</td>
<td>Deep grave with pig wrapped in tarpaulin</td>
<td>98</td>
<td>Female</td>
</tr>
<tr>
<td>2A</td>
<td>1/30/2009</td>
<td>0.5 m</td>
<td>Shallow control hole</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>2B</td>
<td>1/30/2009</td>
<td>1.0 m</td>
<td>Deep control hole</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>2C</td>
<td>1/30/2009</td>
<td>1.0 m</td>
<td>Deep grave with layer of lime covering pig</td>
<td>95</td>
<td>Male</td>
</tr>
<tr>
<td>2D</td>
<td>1/30/2009</td>
<td>1.0 m</td>
<td>Deep grave with pig wrapped in blanket</td>
<td>97</td>
<td>Female</td>
</tr>
<tr>
<td>Calibration Unit (outside grid)</td>
<td>1/9/2009</td>
<td>1.0 m</td>
<td>Rebar hole</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Research Grid at the Geotechnical Engineering Test Site on the Main UCF Campus in Orlando, Florida

Figure 3: Geophysical Research Site Grid and Location of Burials
Table 3: Depths of Pig Carcasses in the Graves Taken Below the Ground Surface

<table>
<thead>
<tr>
<th>Grave Location</th>
<th>Measurement to Head</th>
<th>Measurement to Abdomen</th>
<th>Measurement to Tail</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>0.33 m</td>
<td>0.24 m</td>
<td>0.26 m</td>
</tr>
<tr>
<td>1B</td>
<td>0.86 m</td>
<td>0.76 m</td>
<td>0.77 m</td>
</tr>
<tr>
<td>1C*</td>
<td>0.83 m</td>
<td>0.75 m</td>
<td>0.77 m</td>
</tr>
<tr>
<td>1D</td>
<td>0.74 m</td>
<td>0.74 m</td>
<td>0.75 m</td>
</tr>
<tr>
<td>2C</td>
<td>0.83 m</td>
<td>0.76 m</td>
<td>0.78 m</td>
</tr>
<tr>
<td>2D</td>
<td>0.80 m</td>
<td>0.74 m</td>
<td>0.76 m</td>
</tr>
</tbody>
</table>

*Layer of rocks added over pig carcass  
Center of grave: 0.70 m

Data Collection

The conductivity meter used for this portion of the project was a Geonics EM38-RT with an Allegro CX data logger used to store the recorded conductivity measurements (Figure 4). The conductivity meter was calibrated to the soil of the research site prior to each data collection event. Data were collected in the vertical dipole mode, as is seen in Figure 4.

Figure 4: Data collection using the conductivity meter on its vertical dipole
The vertical dipole mode is recommended by the manufacturer for depths around or greater than 0.4 meters (Geonics, 2006). Data were collected for two soil components to evaluate the geophysical response of proxy graves: disturbed soil and undisturbed soil. Since disturbed soil may produce a geophysical response, two blank graves only containing disturbed soil were included in the grid to distinguish which component or components of the grave (the disturbed soil, the body, or anything else added to the grave) were producing the geophysical response when a grave was detected. Before the pigs were buried, conductivity data were taken on the site for comparative purposes with the grid that contained buried pig carcasses. The field data collection was performed approximately every two weeks and the results were monitored for a total of twelve months. The conductivity readings were collected following 0.25 m transects in a west to east direction while recording conductivity measurements every 0.25 m on each transect (Figure 5).

On data collection days, the moisture levels of the soil within the research grid were also measured using a soil moisture meter manufactured by Lincoln Irrigation Incorporation. The probe on the soil moisture meter measures 90 centimeters in length and moisture measurements were recorded on a scale of 1 to 10, with 10 being the wettest. The use of a soil moisture meter was necessary to determine if the moisture within the site would affect any data that was collected. The points within the research grid that were measured include each corner of the grid, one point on the west and east baselines, the northwest corner of the rebar hole, and each of the northwest corners of the burials within the grid. The shallow burials were measured at 0.25 m and 0.50 m and the deep burials were measured at 0.50 m, 0.75 m, and 0.90 m.
Figure 5: Geophysical Research Site Grid and Location of Burials with 0.25 m transects (West to East)
The last component of this research consisted of data processing, evaluation, and presentation of the conductivity data. Conductivity measurements were recorded with a hand held Allegro CX field computer that is connected to the conductivity meter. Data were then taken back to a desktop computer and transferred from the field computer. Data were processed using Geonics software DAT38 and then analyzed using Golden Software Surfer 8 (Version 8.4). Surfer offers a number of different 2-D and 3-D maps to display and analyze the data that was collected using the conductivity meter for this project. Contour maps are 2-D maps that use X and Y coordinates and the contour lines represent points of equal Z value, Z being the conductivity measurements of the targets in question. Default intervals of 0.5 mS/m were used to represent the differences between each contour line on the maps. Conductivity data were taken on the research grid prior to the burial of the pig carcasses for comparison purposes on the data taken when the pigs were buried. Overlay maps containing the exact locations of each of the burials were then constructed and compared over each of the contour maps of the conductivity data for each of the twelve months of data collection.

Results

Prior to the burial of the pigs within the grid, conductivity measurements were taken for comparative purposes once the pig carcasses were buried (Figure 6). The preburial contour map shows a number of reflection features throughout the grid. Prior to the burial of the pig carcasses, heavy clearing of the research grid was conducted. Several small trees were cut down during this preparation. These small trees may be attributed to the unknown features that are
seen throughout the preburial grid. The small stumps from these trees that were left directly beneath the ground surface may be what are producing these unknown reflection features. When the overlay map showing the locations of the burials is introduced, there are no reflection features that interfere with the placement of the graves. Located throughout the grid are a number of unknown reflection features that are clearly not attributed to the buried pig carcasses. The location of each of the unknown reflection features is important to take into mind when analyzing the maps for the rest of the twelve months of data collection.

After the pig carcasses had been buried for one month (Figure 7), the conductivity map for this time period resembles the preburial grid in a number of ways. First, each of the unknown reflection features present in the preburial grid were also present in the research grid at one month. There are no new reflection features present after the first month of burial that were not present when the conductivity data was taken for the preburial grid. Further, when the overlay map is placed on top of the contour map for one month after burial, there are no reflection features present within the location of any of the eight burials. Both control holes containing only disturbed soil, as well as the six burials containing a pig carcass and associated artifacts show no reflection features that may suggest that something is contained within those burials. Thus, both the preburial conductivity map and the conductivity map after one month of burial are remarkably similar.

When looking at the conductivity results for the remainder of the twelve months (Figures A1-A11 in Appendix A), the results are very similar to both the preburial grid and the grid one month after burial. Month three contains the same unknown reflection features
consistent in the previous months; however, there are a number of unknown reflection features located running down the center of the grid. These reflection features cannot be explained for this time period because not a single reflection feature from this month is shown for the months prior to and after month three.

---

**Conductivity Readings for Preburial Grid**

![Conductivity map for preburial grid](image1)

**Conductivity Readings for Pigs at One Month**

![Conductivity map for pig carcasses at month one](image2)

*Figure 6: Conductivity map for preburial grid*

*Figure 7: Conductivity map for pig carcasses at month one*
**Discussion**

Overall, the conductivity meter did not prove to be a valuable tool in the detection of buried bodies. There was not a single burial scenario that was detected by the conductivity meter. The six burials containing a pig carcass as well as both the shallow and deep control holes showed no differences whatsoever in their detection using the conductivity meter throughout the twelve months of data collection. There are a number of variables that may explain why the conductivity meter did not detect any of the burials throughout the twelve months of data collection. The first variable that may have affected the detection of the burials is the soil horizon within the research site. McNeill (1980) mentions that some of the factors that have an effect on conductivity include the clay content of the soil, and the temperature and phase state of the moisture within a soil. If soils have been moved around at a site, conductivity contrasts can be created which the meter may or may not record (Clay, 2004). The conductivity meter may pick up these contrasts only if there is variation in the soil composition within the soils located at the research site. Further, another important factor is the porosity of the ground material (Beauchaine and Werdemann, 2006). Bevan (1998:8) illustrated the typical ranges of conductivity in mS/m produced by certain soil types. In his interpretation of conductivity ranges that certain types of soil produce, sand/gravel produce a range of 0.1-1 mS/m. 0.1-1 mS/m is a very low range of measurements and this range illustrates very low conductivity readings. Since Florida is made up mostly of sand, this may directly explain the lack of detection of any of the burials due to the extreme porous nature of sand especially since the upper soil horizons in central Florida are made up mainly of sand. Clay (2004) also mentions that the contrast between
redistributed soils and the soils that are still in place are what are usually read by a conductivity meter. A conductivity meter may perform well if there is a significant contrast between fill and non-fill. The disturbed soil of the grave shafts from the burial process of the pig carcasses clearly did not provide a significant contrast between the fill that was taken out of the grave and then put back in compared to the soil that was not disturbed from the burial process. Moisture contained within the soil also affects conductivity readings as more moisture causes conductivity to rise (Beauchaine and Werdemann, 2006; Clay, 2004). However, whether during times of high moisture content during the rainy season or low moisture content within the research site, the conductivity readings did not change.

The next variable that may have affected detection is the depth of the burials. According to Clay (2004:7), “It is important to recognize that the technology is most sensitive to objects near ground surface, in fact, the EM38 conductivity signal primarily reflects mS/m within the top 50 cm of the soil below the meter.” There are two burials in this grid that are at 0.50 m or shallower. Scenario 1A is a shallow pig carcass with the top of the pig located at 0.24 m below the surface, and scenario 2A is a control hole at 0.50 m below the surface. Even at 0.24 m the shallow pig carcass was not detected by the conductivity meter.

The last variable that may have affected the detection of buried bodies were the artifacts that are located within the grave along with the bodies. Metals generate very high signals in response to the meter and this was proven in a study by Dionne (2009) where he illustrated that the conductivity meter proved to be a valuable tool in the detection of buried metallic weapons up to a depth of 0.75 m. Further, this study proved that the conductivity meter is more effective
in detecting larger metallic weapons than smaller ones, so the size of the artifact within the grave plays a direct role in the detection rates. None of the burials within this research site contained metallic artifacts, and this factor may have played a role in the absence of detection by the conductivity meter.

**Conclusion**

This controlled research has shown that a conductivity meter may not be a beneficial tool for the search of clandestine graves involving buried bodies. None of the burials were detected with the conductivity meter and even during high levels of moisture there were no changes in detection. The unknown reflection features that were detected within the preburial grid were consistent throughout every one of the twelve months that the data were collected, but again, none of those reflection features corresponded to any of the burials containing a pig carcass. A number of factors may have played a role in the lack of detection of the remains including depth of burial, the soils contained within the research site, and the artifacts that were included with some of the burials. The use of a conductivity meter has proven to be a valuable geophysical tool that can be utilized in certain forensic circumstances, especially when metallic objects are involved; however, this research has shown that other geophysical search methods should be pursued for the detection of clandestine burials involving human bodies.
CHAPTER THREE: DETECTING VARIOUS BURIAL SCENARIOS IN A CONTROLLED SETTING USING A GROUND-PENETRATING RADAR WITH A 500-MHZ ANTENNA

Introduction

Geophysical search methods have gained a broader acceptance in the forensic community as powerful tools to help locate buried bodies and associated evidence. Specifically, the use of ground-penetrating radar (GPR) has the potential to be a valuable asset in the search for buried remains and it has been especially effective in locating objects buried up to a few meters below the ground surface, but current law enforcement search methods do not focus on the use of geophysical instruments. Further, published case studies on the use of GPR to either locate buried bodies in a forensic context or to clear suspected areas where a body was thought to have been buried has increased over the years (Davenport, 2001a; Davenport, 2001b; Mellett, 1992; Nobes, 2000; Ruffel, 2005; Schultz, 2007). Not only is the use of geophysical search techniques important in locating buried remains and associated evidence, but it is equally important to clear suspected areas and save investigators valuable time searching (Dupras et al., 2006).

Geophysical search methods are useful in locating suspected areas of interest through the location of reflection features in the ground, without causing any damage to the site or associated evidence. Once areas of interest have been determined, invasive techniques can be applied and damage to associated evidence can be minimized.

The most useful method for gaining experience performing geophysical surveys for the location of buried human remains is to set up a controlled research site to monitor and detect the
cadavers for some length of time (France et al., 1992; Schultz et al., 2006; Schultz, 2007; Schultz, 2008; Strongman, 1992). Controlled GPR studies are also significant to learn how soil conditions and environment will affect GPR performance (Schultz, 2007). The results gained from controlled studies can provide certain guidelines that can be utilized while performing actual searches in a forensic setting. Further, controlled studies provide valuable experience for operators when using geophysical tools. This research has been important in exhibiting the use of this technology for grave detection, and as a result of this past controlled research, geophysical tools, especially GPR, is commonly used to locate clandestine burials of homicide victims (Davenport, 2001a; Fenning and Donnelly, 2004; France et al., 1992; Schultz et al., 2006; Schultz, 2007; Schultz, 2008; Strongman, 1992). Controlled forensic GPR research has also proven that studies performed on various geophysical tools used in a forensic setting have concluded that GPR was the most important geophysical tool used to delineate graves (France et al., 1992; France et al., 1997). On the other hand, there is no published literature on the use of GPR in a controlled setting that addresses more real-life scenarios for body concealment. No studies have incorporated multiple burial scenarios including burying remains wrapped in blankets or tarpaulins, and covering the body with various materials including rocks, debris, or calcium hydroxide. Further, no studies have focused on the use of horizontal slices in various GPR imagery programs and comparing horizontal slices of the grid data with reflection profiles of a single transect.
Ground-Penetrating Radar

Ground-penetrating radar data are acquired by transmitting pulses of radar energy into the ground from a surface antenna, reflecting, refracting, and scattering the energy off buried objects or features, and then detecting the reflected waves back at the ground surface with a receiving antenna (Conyers, 2004; Conyers and Cameron, 1998). The operation of the GPR unit begins with the placement of the antenna on, or near, the ground surface and it is then moved over the area being surveyed. The receiving portion of the antenna records the returning signal and sends it back to the control unit along a different line located within the cable. The main components of a GPR unit used for forensics and archaeology are a computer control unit, a monostatic antenna that stores a transmitter and a receiver, and a black-and-white or color display monitor to view the GPR imagery (Schultz, 2007). One of the greatest advantages of using a GPR unit is that it provides the best resolution out of all geophysical tools because the data is displayed on the monitor for immediate assessment in the field. Further, with the use of GPR, depth and size of subsurface features can be estimated with a reasonable degree of accuracy (Schultz, 2003; Schultz, 2007).

GPR antenna frequencies range in bandwidth from about 10- to 1500-MHz. Antennae come in standard frequencies that are selected corresponding to the peak power of the radiated spectrum, or center frequency (Conyers, 2004; Schultz, 2003). Antenna choice is important because it takes into account both depth of penetration and subsurface resolution. Antenna frequencies of 500-MHz provide an excellent compromise between depth of viewing and vertical resolution, as well as horizontal resolution and is a common antenna choice for archaeological
and forensic applications involving shallow surveys (Schultz, 2003; Schultz et al., 2006; Schultz, 2008). Lower frequency antennae, like a 250-MHz antenna, provide increased depth of viewing and less vertical resolution than a 500-MHz, and there may be less false reflection features detected, which results in easier discrimination of forensic targets. Applications involving the use of GPR in a forensic context both in real-world settings as well as controlled forensic geophysical research focuses on a 500-MHz antenna; however, the research does not focus on various burial scenarios.

GPR has many advantages for a forensic investigation (see Table 4). GPR has the greatest resolution of all the useful geophysical methods used on land, and in addition, depth of subsurface features can be estimated (Schultz, 2007). A continuous profile of subsurface data can be recorded and displayed in the field (Davenport, 2001a). Preliminary assessments can be made in the field before the data is taken back to the laboratory. GPR operators gain valuable experience searching for buried bodies that they will be able to utilize during real-life forensic searches (Schultz, 2007). Finally, GPR can also be used on concrete, blacktop, and even over fresh water. On the other hand, there are also some disadvantages in using GPR. The equipment is very expensive, it requires training to operate and interpret the imagery, and it cannot be used on all types of terrain (Table 4).
Table 4: Advantages and Disadvantages of Using Ground-Penetrating Radar

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>• No destruction to ground surface</td>
<td>• Expensive</td>
</tr>
<tr>
<td>• Depth and size of object can be estimated fairly accurately</td>
<td>• Requires training to operate</td>
</tr>
<tr>
<td>• Has the best resolution of subsurface features out of all geophysical tools</td>
<td>• Cannot be used on all types of terrain</td>
</tr>
<tr>
<td>• Can be used over concrete, blacktop, and fresh water</td>
<td></td>
</tr>
<tr>
<td>• Data can be collected and viewed while in the field</td>
<td></td>
</tr>
</tbody>
</table>

Purpose

Current issues with controlled forensic geophysical research using a GPR include overlooking the effects that various burial scenarios have on the detection of buried bodies. Further, research has not focused on the use of various imagery options outside of reflection profiles. This portion of the research will (1) investigate the ability of ground-penetrating radar with a 500-MHz antenna to detect buried bodies that mimic real-life forensic scenarios, (2) identify which burial scenarios provide the best and worst resolution throughout twelve months of data collection, and (3) compare the results throughout twelve months using various computer software programs including REFLEXW, version 4.5 and GPR-SLICE, version 7.0.

Materials and Methods

Field Site and Controlled Graves

The research site is located on the secured grounds of the Geotechnical Engineering Test Site on the main campus of the University of Central Florida in Orlando, Florida. The site is a
flat, unused section of the campus that is covered by grass and is mowed periodically (Figure 8). Six pig carcasses (*Sus scrofa*) weighing approximately 90-100 pounds each were used as proxies for human bodies, and were buried at either a shallow (approximately 0.50 m) or deep (approximately 1.0 m) depth (Table 5). Each of the six pigs were euthanized by a single gunshot wound to the head with a .22 caliber handgun, and were brought directly back to the UCF campus where they were buried the same afternoon. Pig carcasses are commonly used as proxies for human bodies in controlled research that may emphasize human taphonomy because they are similar to humans in their fat-to-muscle ratio, and in the fact that their skin is not heavily haired (France et al., 1992). Further, France et al. (1992) mentions that pigs have been considered to be biochemically and physiologically similar enough to humans to be used in studies of patterns and rates of decay. A permanent grid measuring 11 meters on the north-south axis by 22 meters on the east-west axis was constructed and contains six pig graves and two control graves set up in two rows, with each grave measuring 1 meter wide and 1 meter long. The six graves containing pig carcasses (Figure 9) and the two control graves mimicked a number of common forensic scenarios involving buried bodies:

1. A deep blank control grave consisting of only disturbed backfill (100-110 cm) to determine the geophysical response of only the disturbed soil and not the carcass and items that will be added to graves.

2. A shallow blank control grave consisting of only disturbed backfill (50-60 cm) to determine the geophysical response of only the disturbed soil and not the carcass and items that will be added to graves.

3. A deep pig carcass with nothing else added to the grave.

4. A shallow pig carcass with nothing else added to the grave.
5. A deep pig carcass wrapped in a vinyl tarpaulin.
6. A deep pig carcass wrapped in a cotton blanket.
7. A deep pig carcass with a layer of lime (calcium hydroxide) placed over the carcass.
8. A deep pig carcass with a layer of small rocks placed over the carcass.

Figure 8: Research Area at the Geotechnical Engineering Test Site on the Main UCF Campus in Orlando, Florida
Figure 9: Forensic scenarios of burials containing a pig carcass
Table 5: Detailed Grave Information for Each of the Burials

<table>
<thead>
<tr>
<th>Grid Location</th>
<th>Burial Date</th>
<th>Depth of Grave Floor (below surface)</th>
<th>Scenario</th>
<th>Pig Carcass Weight (lbs)</th>
<th>Pig Carcass Sex</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>1/30/2009</td>
<td>0.5 m</td>
<td>Shallow pig grave</td>
<td>90</td>
<td>Female</td>
</tr>
<tr>
<td>1B</td>
<td>1/30/2009</td>
<td>1.0 m</td>
<td>Deep pig grave</td>
<td>100</td>
<td>Male</td>
</tr>
<tr>
<td>1C</td>
<td>1/30/2009</td>
<td>1.0 m</td>
<td>Deep grave with layer of rocks covering pig</td>
<td>90</td>
<td>Male</td>
</tr>
<tr>
<td>1D</td>
<td>1/30/2009</td>
<td>1.0 m</td>
<td>Deep grave with pig wrapped in tarpaulin</td>
<td>98</td>
<td>Female</td>
</tr>
<tr>
<td>2A</td>
<td>1/30/2009</td>
<td>0.5 m</td>
<td>Shallow control hole</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>2B</td>
<td>1/30/2009</td>
<td>1.0 m</td>
<td>Deep control hole</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>2C</td>
<td>1/30/2009</td>
<td>1.0 m</td>
<td>Deep grave with layer of lime covering pig</td>
<td>95</td>
<td>Male</td>
</tr>
<tr>
<td>2D</td>
<td>1/30/2009</td>
<td>1.0 m</td>
<td>Deep grave with pig wrapped in blanket</td>
<td>97</td>
<td>Female</td>
</tr>
<tr>
<td>Calibration Unit (outside grid)</td>
<td>1/9/2009</td>
<td>1.0 m</td>
<td>Rebar hole</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Figure 10: Geophysical Research Site Grid and Location of Burials

Research Grid at the Geotechnical Engineering Test Site on the Main UCF Campus in Orlando, Florida

Figure 10: Geophysical Research Site Grid and Location of Burials
Each of the pig carcasses were placed in the grave on their right side with the back facing the east wall and the head towards the north wall. Once the pigs were placed in the grave the depths of the pigs from three points on the body were measured below the surface, including measurements from the surface to the head, abdomen area, and tail. Grave scenario 1C contained a layer of small rocks over the pig and five measurements were taken from the ground surface to the layer of rocks including the northwest corner, northeast corner, southwest corner, southeast corner, and the center of the grave. Table 6 shows the measurements for each of the six graves containing a pig carcass.

Table 6: Depths of Pig Carcasses in the Graves Taken Below the Ground Surface

<table>
<thead>
<tr>
<th>Grave Location</th>
<th>Measurement to Head</th>
<th>Measurement to Abdomen</th>
<th>Measurement to Tail</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>0.33 m</td>
<td>0.24 m</td>
<td>0.26 m</td>
</tr>
<tr>
<td>1B</td>
<td>0.86 m</td>
<td>0.76 m</td>
<td>0.77 m</td>
</tr>
<tr>
<td>1C*</td>
<td>0.83 m</td>
<td>0.75 m</td>
<td>0.77 m</td>
</tr>
<tr>
<td>1D</td>
<td>0.74 m</td>
<td>0.74 m</td>
<td>0.75 m</td>
</tr>
<tr>
<td>2C</td>
<td>0.83 m</td>
<td>0.76 m</td>
<td>0.78 m</td>
</tr>
<tr>
<td>2D</td>
<td>0.80 m</td>
<td>0.74 m</td>
<td>0.76 m</td>
</tr>
</tbody>
</table>

*Layer of rocks added over pig carcass
Center of grave: 0.70 m

Data Collection

The GPR unit used in this portion of the research project was the Mala RAMAC X3M with a 500-MHz antenna that was integrated into a cart and was hand pushed over the research grid (Figure 11). Two of the most important considerations to keep in mind when choosing an antenna are depth of viewing and vertical resolution. The 500-MHz antenna provides an excellent compromise between depth of viewing and vertical resolution, as well as horizontal resolution compared to an antenna of lesser frequency, and is a common antenna choice for
archaeological and forensic applications involving shallow surveys (Schultz, 2007; Schultz et al., 2006).

![Figure 11: MALA RAMAC X3M GPR unit integrated into a cart](image)

Data were collected for two soil components to evaluate the geophysical response of proxy graves: disturbed soil and undisturbed soil. Since disturbed soil may produce a geophysical response, two blank graves only containing disturbed soil were included in the grid to distinguish which component or components of the grave (the disturbed soil, the body, or anything else added to the grave) were producing the geophysical response when a grave was detected. Before the graves were constructed, GPR data were collected on the site for comparative purposes with the grid data that contained buried pig carcasses. The field data collection was performed approximately every two weeks and the results were monitored for a
total of twelve months. Data were collected along grid transects every 0.25 m in both an east-west direction and a north-south direction (Figures 12 and 13). The typical GPR survey collects grids of transects with profiles orientated in only one direction. A case study by Pomfret (2006) was performed to test the variables of profile orientation and transect spacing in an excavation area to test how important those factors are to subsurface resolution of targets. It is suggested that surveying in both transect orientations offers the best results for defining small subsurface features, and for maximum resolution, perpendicular transects would be the preferred collection method (Pomfret, 2006).

Prior to each data collection event, the GPR unit was calibrated to the soil of the research site to accurately estimate the depth of the reflection features within the grid. Using a known object buried at a known depth can help to determine the sensitivity of the instrument within the soil (Conyers, 2004; Strongman, 1992). For this project, a calibration test pit was dug approximately two meters away from the grid on the east end. This method provides the most accurate way to represent the depth of the buried pig carcasses compared to any other geophysical tool. The GPR unit was calibrated by running the GPR over a metal bar that was pounded into an excavation wall at a depth of one meter. Burying a metal bar at a known depth is the method suggested by Conyers (2004). The direct measurements yield both time and distance (depth) and allow for an approximation of the average radar velocity (Conyers, 2004; Conyers and Cameron, 1998). Once the response from the buried metal bar is detected by the GPR at approximately one meter, the depth of response can be set on the GPR monitor.
Figure 12: Geophysical Research Site Grid and Location of Burials with 0.25 m transects (West to East)
Research Grid at the Geotechnical Engineering Test Site on the Main UCF Campus in Orlando, Florida

Figure 13: Geophysical Research Site Grid and Location of Burials with 0.25 m transects (North to South)
On data collection days, the moisture levels of the soil within the research grid were measured using a soil moisture meter manufactured by Lincoln Irrigation Incorporation. The probe on the soil moisture meter measures 90 centimeters in length and moisture measurements were recorded on a scale of 1 to 10, with 10 being the wettest. The use of a soil moisture meter was necessary to determine if the moisture within the site would affect any data that were collected. The points within the research grid that were measured include the northwest corner of the rebar hole, and each of the northwest corners of the burials within the grid. The shallow burials were measured at 0.25 m and 0.50 m and the deep burials were measured at 0.50 m, 0.75 m, and 0.90 m.

Data Analysis

The last component of this portion of the project included processing, interpreting, and presenting the 500-MHz GPR data. The various imagery options used in this research test the ability of the GPR with a 500-MHz antenna to represent the data that were collected in both 2-D and 3-D advanced processing features, and can be a real benefit to body searches when focusing on multiple imagery options. A reflection profile consists of a single transect over the grid and the profiles shown were collected directly over the center of the graves. A reflection profile only represents length (left to right) and depth (top to bottom) for one transect. Reflection profiles were evaluated; however, more advanced processing that provided increased resolution of subsurface features and more advanced evaluation of the data were also utilized. A variety of different processing procedures were used to present the data in both 2-D and 3-D formats using either GPR-SLICE or REFLEXW, version 4.5, GPR software. Once the data were filtered, all of
the transects (reflection profiles) collected over the burials were viewed using REFLEXW, version 4.5. Next, all of the transects collected over the grid were then welded together to create a 3-D cube that was able to be viewed in multiple planes with GPR-SLICE. In particular, the horizontal slice option is an important view of the 3-D cube because it provides a planview representation of the grid data at different depths. A horizontal slice was constructed in the GPR-SLICE program that utilized all of the collected grid data. The program interpolates the space between each of the transects (reflection profiles). Because the GPR-SLICE program interpolates the space between each of the transects, the use of smaller transect spacing becomes an extremely important aspect of data collection.

Results

Reflection Profiles

When using grid transects of 0.25 m there were a total of five profiles that were collected over each of the graves in each direction as part of the grid data for the horizontal slices. Each of the five profiles collected over the graves illustrated very noticeable differences in imagery characteristics once the data were processed in the lab. The third profile, collected directly over the center of the graves where the back of the pig carcass was towards the east wall and the head was towards the north wall, clearly provided the best resolution of the reflection features. The profile taken directly over the center of the graves will be described in detail to show the specific changes throughout twelve months of data collection and how these characteristics changed over the duration of this study. Figures 14-18 illustrate each of the five reflection profiles for row 1.
after one month of burial to show the differences in imagery between each of the transects taken over the graves. Profile 1 represents the north wall of each of the graves and profile 5 represents the south wall. Profiles 2 and 4 represent the transects directly to the left and right of the middle transect. Profile 3 represents the middle transect over the graves and will be the profile that is described throughout this research.

*Figure 14: GPR reflection profile using the 500-MHz antenna of row 1, profile 1 for month one*

*Figure 15: GPR reflection profile using the 500-MHz antenna of row 1, profile 2 for month one*
Figure 16: GPR reflection profile using the 500-MHz antenna of row 1, profile 3 for month one

Figure 17: GPR reflection profile using the 500-MHz antenna of row 1, profile 4 for month one

Figure 18: GPR reflection profile using the 500-MHz antenna of row 1, profile 5 for month one
After one month of burial, the reflection profile directly over the center of the grave for row 1 showed three discernable reflection features (Figure 16). Two features were clearly more demarcated when looking at the reflection profile. The features produced for the shallow pig carcass (1A) and the pig carcass covered with a layer of rocks (1C) were clearly more distinct than the deep pig carcass (1B) and the pig carcass wrapped in tarpaulin (1D). The shallow pig carcass (1A) is located at the apex of the reflection feature, and when compared to the other three scenarios, it is clearly located at a shallower depth. The pig carcass covered with a layer of rocks (1C) clearly produced the most distinct response out of each of the burials. The layer of rocks showed a very distinct response located at around 0.70 m on the profile. On the other hand, the deep pig carcass (1B) showed the weakest response out of the four burials within the row.

When comparing the other four profiles in row 1 with the profile directly over the middle of the graves, none of the other four profiles demarcated any of the graves as clearly as the third profile. When looking at profiles 2 and 4 (Figures 15 and 17), the profiles located directly to the left and right of the middle profile, the only scenario that showed a response is the pig carcass covered with a layer of rocks (1C). Clearly, profiles 2 and 4 were not nearly as distinct as profile 3. The shallow pig carcass (1A) was not discernable when looking at the reflection features of profiles 2 and 4. Further, the deep pig carcass (1B) and the pig carcass wrapped in a tarpaulin (1D) showed a very small reflection feature, but neither one was strong enough to call a distinct response. Lastly, profiles 1 and 5 (Figures 14 and 18) did not produce any discernable responses because the GPR was hitting on both outside edges of each of the graves. Overall, profiles 1 and
5 did not show any discernable responses, and profiles 2 and 4 showed considerably decreased responses in all four grave scenarios.

Similar to row 1, the third profile, taken directly over the middle of the graves, for row 2 after one month of burial produced the best response compared to the other four profiles. In this row only two graves contained pig carcasses. The other two graves contained only disturbed backfill; scenario 2A with a depth of 0.50 m and scenario 2B with a depth of 1.0 m. However, when looking at row 2, only one of the pig carcasses showed a distinct reflection feature (Figure 19). The pig carcass covered with a layer of lime (2C), showed a very discernable feature starting at approximately 0.75 m. Conversely, the pig carcass wrapped in a blanket (2D), showed a very poor response. Further, the shallow grave containing only disturbed backfill (2A) and the deep grave containing only disturbed backfill (2B) showed no discernable responses. Due to the responses that are noticeable throughout both rows seen in the graves containing a pig carcass compared to the control holes only containing disturbed backfill, it is clear that the prominent reflection features seen throughout both rows were due to the pig remains and not the disturbed soil.
Reflection profiles for the remainder of the data collection time period (months 2-12) are located in Appendix B. Each image only showed the middle reflection profile as the one month data collection illustrated.

There were no noticeable changes from month one in the reflection profiles after the second and third months of data collection. After the fourth month of data collection however, very distinct differences in both row 1 and row 2 were apparent in the reflection features seen in each of the eight scenarios located within the grid. At month four, the moisture levels within the grid were noticeably higher than the previous three months due to increased rainfall from seasonal storms around this time of the year (see Appendix F).

The most favorable results occurred at month four (Appendix B, Figures B5 and B6). During this month all four burials in row 1 produced prominent reflection features that were easily detected. Compared to the three previous months, all of the scenarios produced much stronger responses after the fourth month. The pig carcass covered with a layer of rocks (1C)
again produced the strongest response by far between the three other burials in the row. On the other hand, the pig carcass wrapped in tarpaulin (1D) again produced the weakest response. However, compared to the previous months, the pig carcass wrapped in a tarpaulin (1D) produced a much stronger feature after the fourth month. The shallow pig carcass (1A) produced a prominent response at month four that was noticeably stronger than the previous months. One of the most notable differences seen in row 1 at month four was the deep pig carcass (1B). Not only did this scenario produce a strong reflection feature with prominent tails that extend to the bottom of the profile, but below the apex of the feature where the pig carcass is located, a double feature is displayed. This double feature may be attributed to the various soil horizons that are located near the bottom of the grave in this portion of the research grid and may have been more pronounced due to the higher moisture levels within the grave compared to the previous month. Overall, row 1 at month four illustrated excellent responses from each of the four scenarios, and when compared to the previous three months, it may have been a result of the higher levels of moisture that were measured within the grid.

Both graves containing pig carcasses in row 2 also showed more prominent reflection features after four months compared to the previous months. The pig carcass covered with a layer of lime (2C) showed a much stronger response compared to the previous months. The most notable difference was seen with the pig carcass wrapped in a blanket (2D). After the third month, the pig carcass wrapped in a blanket (2D) almost produced no visible response. On the other hand, after month four there was a clear feature present with distinctive tails extending below the apex of the reflection feature. Lastly, the deep control hole (2B) with only disturbed
backfill showed a slight response located below 1 m. This small feature may have been attributed to the various hard soil horizons located within this portion of the grid because there are no burials that were constructed below 1.0 m. Because the deep control hole (2B) did not exhibit a discernable response above 1.0 m, it is clear from the comparisons between the graves that the prominent grave features were due to the pig remains and not the disturbed soil.

After six months of data collection (Appendix B, Figures B9 and B10), no extreme changes were noted in any of the reflection features within row 1. The pig carcass covered with a layer of rocks (1C) still produced the best response out of all the scenarios; however, compared to the previous two months, the response was somewhat reduced. Further, each of the four burials in row 1 showed reduced responses from the previous two months. The biggest difference seen after six months of data collection was within row 2. Each of the four scenarios, including both graves that contained a pig carcass, produced poor reflection features. After six months of data collection, the responses from both scenarios that contained a pig carcass in row 2 decreased considerably.

After eight months of data collection (Appendix B, Figures B13 and B14), row 1 showed two prominent reflections. The shallow pig carcass (1A) and the pig carcass covered with a layer of rocks (1C) returned the most distinctive grave features in row 1. The shallow pig carcass (1A) showed a feature with the apex located around 0.25 m and was a very similar response when compared to the previous month. The pig carcass covered with a layer of rocks (1C) showed an excellent response located at approximately 0.70 m in depth and was noticeably stronger than the response from the previous month. On the other hand, the deep pig carcass
(1B) and the pig carcass wrapped in a tarpaulin (1D) showed poor responses. The deep pig carcass (1B) lacked a distinct feature that was present in the previous months, and the pig carcass wrapped in a tarpaulin (1D) showed no response whatsoever. The pig carcass wrapped in a tarpaulin (1D) has become less visible each month since its last strong response at month five. Finally, row 2 continued to show the same results as the previous two months, with both graves that contained pig carcasses showing poor responses. However, what was interesting to note was the small response located at and directly below 1 m for the deep control hole (2B). Since the apex of this response was located around 1 m, this feature could have possibly been attributed to the grave floor of scenario 2B.

After the tenth month of data collection (Appendix B, Figures B17 and B18), one of the most notable changes that occurred was the increase in resolution of the pig carcass wrapped in a tarpaulin (1D), and the decrease in resolution of the pig carcass covered with a layer of rocks (1C). Both of these scenarios displayed a much clearer resolution compared to the shallow pig carcass (1A) and the deep pig carcass (1B). Further, the pig carcass wrapped in a tarpaulin (1D) also produced a good response. Compared to the two previous months, the pig carcass wrapped in a tarpaulin (1D) was the only scenario that actually increased in resolution, while all of the other burials produced weaker responses. This increase in detection for the pig carcass wrapped in a tarpaulin (1D) may have been attributed to the presence of moisture contained within the tarpaulin from the decomposition fluid of the pig carcass. Lastly, each of the burials in row 2 again produced responses that were difficult to discern, the fifth month in a row in which this occurred.
The final two months of data collection, months eleven and twelve (Appendix B, Figures B19-B22), produced the same results. In both months, only two clear reflection features out of the eight burial scenarios were produced. The shallow pig carcass (1A) and the pig carcass covered with a layer of rocks (1C) were the only two scenarios that were clear during these data collection periods. Contrary to month ten, the pig carcass wrapped in tarpaulin (1D) did not produce a discernable response for either of the two following months. The shallow pig carcass (1A) is clearly located at a shallower depth than the other burials, and produced a clear response, especially after month twelve. In fact, after month twelve, the shallow pig carcass (1A) produced a stronger response than the pig carcass covered with a layer of rocks (1C). The pig carcass covered with a layer of rocks (1C) produced a reflection that was noticeably defined in month eleven compared to the previous month; however, the response for month twelve was one of the weaker responses for this scenario during the twelve months of data collection. Finally, in row 2, both the pig carcass covered with a layer of lime (2C) and the pig carcass wrapped in a blanket (2D) produced faint responses that were tough to discern due to the clutter of unknown reflection features that were detected around the area of both burial scenarios. Month five was the last month where a good response from both burials containing a pig carcass in row 2 was noted. Table 7 provides an overview of the GPR imagery results with the 500-MHz antenna for each month of data collection using reflection profiles.
<table>
<thead>
<tr>
<th>Month #</th>
<th>Overview of GPR Imagery Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The pig carcass covered with a layer of rocks (1C) produced the strongest response and the pig carcass wrapped in a blanket (2D) produced the weakest response.</td>
</tr>
<tr>
<td>2</td>
<td>The shallow pig carcass (1A) and scenario 1C produced the strongest responses with each scenario producing a response in row 1. Scenario 2D continued to produce the weakest response.</td>
</tr>
<tr>
<td>3</td>
<td>Scenario 1C produced the strongest response and both scenarios in row 2 produced poor responses.</td>
</tr>
<tr>
<td>4</td>
<td>Excellent detection of every scenario containing a pig carcass. The deep pig carcass (1B) and scenario 1C produced the strongest responses.</td>
</tr>
<tr>
<td>5</td>
<td>Excellent detection of every scenario containing a pig carcass. Scenarios 1B and 1C produced the strongest responses and the pig carcass covered with a layer of lime (2C) produced its strongest response yet.</td>
</tr>
<tr>
<td>6</td>
<td>Responses from each scenario in row 1 with scenarios 1A and 1C producing the best reflections. Poor reflections present in row 2.</td>
</tr>
<tr>
<td>7</td>
<td>Scenarios 1A, 1B and 1C produced responses with 1A and 1C producing the strongest responses. Row 2 again produced poor reflections.</td>
</tr>
<tr>
<td>8</td>
<td>Scenarios 1A and 1C were the only discernable responses with 1C producing the strongest response. Row 2 again produced poor reflections.</td>
</tr>
<tr>
<td>9</td>
<td>Excellent detection of scenario 1C. Decreased returns from scenarios 1A, 1B and the pig carcass wrapped in a tarpaulin (1D). Poor reflections present in row 2.</td>
</tr>
<tr>
<td>10</td>
<td>Decreased response from scenario 1A; however, a significant increase in resolution from scenario 1D. Poor reflections present in row 2.</td>
</tr>
<tr>
<td>11</td>
<td>Poor response from scenarios 1B and 1D. Excellent responses from scenarios 1A and 1C. Poor reflections present in row 2.</td>
</tr>
<tr>
<td>12</td>
<td>Decreased response from scenario 1C. Excellent response from scenario 1A. Poor responses from scenarios 1B and 1D. Poor reflections present in row 2.</td>
</tr>
</tbody>
</table>

**Horizontal Slices**

Using the software program GPR-SLICE, version 7, the data collected from the grid was imaged with 2-D options. In particular, the horizontal slice was an important view of the grid in the Z plane because it provided planview representations of the grid at different depths. Each
horizontal slice is a single slice of the grid data through the 3-dimensional cube that the GPR-SLICE program created. Each slice represents a different depth through the cube. Each horizontal slice shown is a representation of both the X and Y data appended into one grid. Data were collected for the grid prior to the burial of the pig carcasses for comparisons with the data once the pig carcasses were buried. Figures 20 and 21 illustrate the preburial grid at both a shallow and deep depth.

**Figure 20:** GPR horizontal slice using the 500-MHz antenna for the preburial grid. The horizontal slice is approximately 0.34 m in depth (10.29 ns)

**Figure 21:** GPR horizontal slice using the 500-MHz antenna for the preburial grid. The horizontal slice is approximately 0.80 m in depth (19.73 ns)
When the grid showing the location of each of the burials was overlaid on both the shallow and deep preburial grids (Figures 20 and 21) it was evident that there are no reflection features within any of the locations where the burials were placed. This is important to note when observing the data for the months after the pig carcasses were placed in the ground. The reflections that were imaged could have been attributed to a number of subsurface features including roots, stumps, or soil disturbances beneath the surface. There were a number of different soil horizons throughout the research grid that consisted of root mats, sand, clayey soil, and a hard spodic horizon. These soil horizons were especially numerous throughout the northwest corner of the grid where disturbed layers of soils were intermixed with thin sectioned layers of undisturbed soil. These soil horizons could have produced the unknown reflection features within the horizontal slices. Next, figures 22 and 23 show horizontal slices after one month of burial at a shallow and deep depth.
The purpose of including both a shallow and deep horizontal slice for month one was to illustrate the shallow burial containing a pig carcass as well as each of the deep burials containing pig carcasses. Since horizontal slices are images of a grid at different depths it was important to include both a shallow and deep slice together for month one in order to illustrate both the shallow burial scenarios and the deep burial scenarios together. However, when looking at the shallow horizontal slice after one month (Figure 22), at 0.35 m the shallow pig carcass...
(1A) was not represented even though there was definitely a pig carcass buried at that depth (see Table 6). This was not just the case for month one, as this scenario was not represented whatsoever in any of the following months. Since there is no response from the shallow pig carcass (1A), for months two through twelve (Appendix C) only a deep horizontal slice will be represented illustrating the six deep burial scenarios.

After one month, four out of the five scenarios that contained a pig carcass were represented within the horizontal slice. The only burial that produced a poor response was the pig carcass wrapped in a blanket (2D). The pig carcass covered with a layer of rocks (1C) produced the best response. Further, the deep pig carcass (1B) also produced a strong response; however, there are a number of unknown reflection features around the area of the burial. These may have been attributed to the different soil horizons within this area of the grid including a hard spodic horizon as well as a hard clayey soil. Lastly, when compared to the deep horizontal slice of the preburial grid, it is clear that the reflection features present after month one within the deep horizontal slice were a result of the pig carcasses and associated grave artifacts.

Months two and three showed very similar results compared to the first month; however, like the reflection profiles, starting at month four was when the horizontal slices provided the most favorable results throughout the data collection period. After the fourth month of data collection (Appendix C, Figure C3), all of the deep burial scenarios produced excellent responses, including the deep control hole (2B). At a deeper depth, close to 1.0 m, the control hole was apparent. This feature may have been attributed to the grave floor of the deep control hole (2B) because the soil horizon at this depth was a hard spodic soil. On the other hand, as the
depth began to become shallower, this feature disappeared. The pig carcass covered with a layer of rocks (1C) and the pig carcass covered with lime (2C), produced the best response out of all the scenarios, with the pig carcass covered with a layer of rocks (1C) producing the best feature by far. Lastly, the pig carcass wrapped in a tarpaulin (1D), and the pig carcass wrapped in a blanket (2D), produced similar responses. The pig carcass wrapped in a blanket (2D) showed its best response compared to the previous months during this time period.

The data collection for months six through eight (Appendix C, Figures C5-C7) produced fairly similar results. The pig carcass covered with a layer of rocks (1C) produced the best response by far compared to all of the other scenarios. This scenario showed an excellent response throughout these three months. On the other hand, the deep pig carcass (1B) produced no results for any of the three months. Month five is the last month where a response was noted for this scenario. Both pig carcasses that were wrapped (1D and 2D) continued to provide a response; however, as the pig carcass wrapped in a tarpaulin (1D) continued to provide a decent response, the response for the pig carcass wrapped in a blanket (2D) continually deteriorated. Overall, through eight months of data collection for each of the deep scenarios, the pig carcass covered with a layer of rocks (1C) provided by far the best response, while the deep pig carcass with nothing added to the grave (1B) provided the worst response.

Month nine (Figure C8) produced the biggest changes overall in the grid since month four. During this month, only two scenarios produced good reflection features. The pig carcass covered with a layer of rocks (1C) and the pig carcass wrapped in a tarpaulin (1D) continued to produce the most favorable responses. Both of these scenarios have produced favorable
responses continuously throughout every month of data collection at this point. The only change that occurred for the following month was the reemergence of the pig carcass covered with a layer of lime (2C). However, at month eleven (Figure C10), this scenario produced a poor reflection feature. Once again, at month eleven, the pig carcass covered with a layer of rocks (1C) and the pig carcass wrapped in a tarpaulin (1D) produced the best responses, with the pig carcass covered with a layer of rocks (1C) producing one of its best responses throughout all of the previous months of data collection. The pig carcass covered with a layer of lime (2C) and the pig carcass wrapped in a blanket (2D) produced very faint responses at month eleven; however, neither one can be called a discernable response. It appears that the pig carcass covered with a layer of rocks (1C) and the pig carcass wrapped in a tarpaulin (1D) continuously produced the best response because both scenarios can be detected at various deep depths. On the other hand, the detection of the pig carcass covered with a layer of lime (2C) and the pig carcass wrapped in a blanket (2D) seem to fluctuate at certain depths within the grid. Lastly, the horizontal slice for month twelve (Appendix C, Figure C11) was very similar to month eleven. Again, the pig carcass covered with a layer of rocks (1C) continued to produce an excellent reflection feature. The only other scenario that is noticeable during this time period was the pig carcass wrapped in a tarpaulin (1D); however, it produced a much smaller feature. The pig carcass covered in lime (2C) and the deep pig carcass (1B) did not produce good responses for month twelve. The deep pig carcass (1B) has produced a poor reflection feature since its last good response at month five. Table 8 below provides an overview of the GPR imagery results for each month of data collection using horizontal slices.
Table 8: Summary information describing the GPR horizontal slices with a 500-MHz antenna for each month of data collection

<table>
<thead>
<tr>
<th>Month #</th>
<th>Overview of GPR Imagery Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Five out of six deep burials including the deep control hole detected. The pig carcass covered with a layer of rocks (1C), produced the best response, while the pig carcass wrapped in a blanket (2D) produced a poor response.</td>
</tr>
<tr>
<td>2</td>
<td>Scenario 1C produced the best response while the deep pig carcass (1B), and the pig carcass covered with lime (2C), produced good responses. Scenario 2D produced a poor response.</td>
</tr>
<tr>
<td>3</td>
<td>Scenario 1C again produced the best response while both scenario 1B and 2D produced poor responses at this depth.</td>
</tr>
<tr>
<td>4</td>
<td>All deep scenarios produced responses with scenario 1C producing an excellent response. Both wrapped scenarios produced similar results. Deep control hole (2B) produced a response at this depth.</td>
</tr>
<tr>
<td>5</td>
<td>All deep scenarios containing pig carcass detected. Scenarios 1C and the pig carcass wrapped in a tarpaulin (1D), produced excellent responses. Overall detection was very good during this month.</td>
</tr>
<tr>
<td>6</td>
<td>Excellent response from scenario 1C. Scenario 2C produced a very faint response. Poor response from scenario 1B.</td>
</tr>
<tr>
<td>7</td>
<td>Excellent response from scenario 1C. Good responses from scenarios 1D and 2C. Reduced response from scenario 2D and poor response from scenario 1B.</td>
</tr>
<tr>
<td>8</td>
<td>Excellent response from scenario 1C. Good responses from scenarios 1D and 2D. Poor responses from 1B and 2C.</td>
</tr>
<tr>
<td>9</td>
<td>Only two out of the six deep scenarios detected. Excellent responses from both scenarios 1C and 1D.</td>
</tr>
<tr>
<td>10</td>
<td>Good responses from scenarios 1C and 1D with scenario 2C showing a minimal response at the depth for this month.</td>
</tr>
<tr>
<td>11</td>
<td>Very similar results to previous month with scenario 1C producing an excellent response and scenario 1D producing a good response. Scenarios 2C and 2D show reduced responses.</td>
</tr>
<tr>
<td>12</td>
<td>Similar results to the previous month. Scenario 1C produced an excellent response, while scenario 1D produced a reduced response. Scenarios 1B and 2C produced poor responses.</td>
</tr>
</tbody>
</table>

Discussion

In this study, a number of factors played a role in the detection of the burials. The soils that the pig carcasses were buried in, the various burial scenarios, the levels of moisture, and the various imagery options all affected whether a distinctive response was discernable over the
duration of the study. Overall, the combination of various imagery options in multiple views allowed for maximum delineation of the buried pig carcasses. One of the greatest advantages of using GPR is that an in-field assessment can be made while the data are being collected. However, what this research has proven is that after the data have been collected, processing and interpretation in the lab is extremely advantageous and results in increased resolution of the data with both reflection profiles and horizontal slices. The reflection profiles were an excellent option that showed a single transect over the center of the graves, while the horizontal slices provided delineation of the whole grid. The inclusion of both the shallow and deep control holes (scenarios 2A and 2B) were important to illustrate the difference between what was actually producing the geophysical response. The shallow control hole (2A) was never visible in either the reflection profiles or the horizontal slices. When compared to the shallow pig carcass (1A) it is clear that the reflection features that were present were due to the pig carcass and not the disturbed soil. When comparing the deep pig carcass (1B) to the deep control hole (2B), it is important to point out that the small responses that were seen in the reflection profiles can be attributed to the grave floor or a response to the type of soil located within this portion of the grid. The feature that was present for the deep control hole (2B) was located below one meter. Since none of the burials were constructed below one meter, the response could possibly be attributed to the soil in the area. Because the feature for the deep control hole (2B) was small and located below one meter, when compared to the larger feature that was located well above one meter for the deep pig carcass (1B), it is clear that the response was due to the pig carcass and not the disturbed soil. Overall, when looking at all of the imagery options available for each
of the twelve months of data collection, there was a consensus that the pig carcasses with items added to the grave increased the resolution of the features in both the reflection profiles and the horizontal slices because the extra artifacts were able to highlight the location of the grave by increasing the contrast of the pig carcass.

**Burial Scenarios**

The detection of the pig carcasses using the 500-MHz antenna was also largely affected by the various burial scenarios throughout the research grid. Each of the burial scenarios located within the grid mimicked a different real-life scenario that could involve clandestine burials involving human bodies. Overall, it is clear that in both the reflection profiles and the horizontal slices throughout each of the twelve months of data collection that the pig carcass covered with a layer of rocks (1C) provided the best resolution and delineation out of all of the scenarios. This was most likely due to the fact that there was a considerable amount of small rocks placed over the pig carcass and even if the pig carcass decomposed throughout the twelve months of data collection, the rocks were always present. Further, the rocks not only covered the pig carcass, but also the surrounding grave floor around the carcass, which was a much larger area than just a pig carcass in a grave, for example. Also, prior to covering the pig carcass with the layer of small rocks, dirt was placed around the carcass so that the layer of small rocks could completely cover the pig carcass. The characteristics of this scenario is best illustrated with the horizontal slices that showed that the feature produced for the pig carcass covered with a layer of rocks (1C) was consistently larger throughout the 12 months compared to the other scenarios. Lastly, compared to the pig carcass covered in a layer of lime (2C), it was apparent that the layer of lime
was not being detected at a high rate like the layer of rocks, even though the displacement of the lime also covered the whole pig carcass and the areas surrounding the carcass on the grave floor. Like the pig carcass covered with a layer of rocks (1C), this scenario also had a layer of dirt placed around the pig carcass prior to the placement of the lime.

Next, the pig carcass wrapped in a tarpaulin (1D) was consistently detected at a much higher rate than the pig wrapped in a blanket (2D). In fact, the pig carcass wrapped in a tarpaulin (1D) was the only other scenario to be detected every month in the horizontal slices like the pig carcass covered with a layer of rocks (1C). Conversely, the other wrapped scenario, the pig carcass wrapped in a blanket (2D), provided the worst resolution out of these two scenarios. In fact, starting after month six this scenario was not depicted in either the reflection profiles or the horizontal slices. This may have been a result in the differences between the materials that make up each of the objects used to wrap the carcass. The plastic of the tarpaulin was being detected at a higher rate than the thin cotton materials of the blanket. The materials that make up the tarpaulin are more conductive than the materials that make up the blanket and thus when coupled with the levels of moisture within the grave, it produced much more favorable results from the GPR. Further, due to the differences in the thickness of the materials, the rates of decomposition of each of the carcasses may have varied throughout the twelve months which may have also affected detection rates using the GPR.

Finally, the results between the shallow pig carcass (1A) and the deep pig carcass (1B) showed some intriguing results. First, neither scenario was depicted well throughout the horizontal slices. The deep pig carcass (1B) was never detected after the sixth month and the
shallow pig carcass (1A) was not detected at all throughout twelve months. The reason why the shallow pig carcass (1A) was not detected in the horizontal slices may have been due to the contrasting soils around the area of the grid where this burial was located. Whereas the reflection profiles hit on a specific area on the grid because they represent a single transect, the horizontal slices covered a larger area and the interpolations or spaces between each of the grid slices may have been masked by the disturbed area of the research grid. On the other hand, when viewing the reflection profiles, even though both scenarios were being detected, the shallow pig carcass (1A) was being detected at a much higher rate throughout every month of data collection, not only compared to the deep pig carcass (1B), but compared to every scenario in the grid besides the pig carcass covered with a layer of rocks (1C). The deep pig carcass (1B) was being detected well up to around the eighth month, but the following four months produced no features. Conversely, the shallow pig carcass (1A) maintained excellent detection throughout the twelve months, especially between months four through twelve.

Imagery Options

It was important to include multiple imagery options of the research grid to provide a more detailed report of what was producing the geophysical response. Applying further processing to the data after it was collected in the field was also extremely important because each of the different imagery options provided maximum delineation of each of the burial scenarios within the research grid. The reflection profiles were advantageous because they provided a relatively accurate depth determination of each of the features in a single row. The reflection profiles were also better able to illustrate the various changes that occurred month to
month between the different burial scenarios. A small transect spacing of 0.25 m was also important because when reflection profiles are spaced in closely spaced transects, a very important three-dimensional cube can be created, which can produce very precise images of features that may go undetected (Conyers, 2006b). Further, Bevan (1991) and Conyers (2006a) mention that measuring physical and chemical changes in the ground and mapping them in three dimensions, including horizontal slices, is one of the best methods to map cemetery graves because spatial distribution and approximate depth of the graves can be determined. Reflection profiles were an excellent imagery option to look at individual transects over the graves and compare which transects produced better results. The reflection features showed a hyperbolic shape due to the wide angle of the transmitted radar wave from the antenna (Schultz et al., 2006; Schultz, 2008). This was important to illustrate because GPR detects subsurface objects prior to arriving directly over them, when the GPR is directly over them, and even after passing them.

The horizontal slices were also an excellent imagery option for looking at the whole grid. This plane was able to show the spatial distribution of the graves throughout the grid and the differences in the reflection features as the slices become shallower and deeper. Lastly, one of the greatest advantages of horizontal slices compared to reflection profiles is that data collected in both the X and Y directions can be appended together to produce a grid representing data in both XY data sets. Thus, the imagery results of horizontal slices illustrate more data which can maximize the results that were obtained.
Moisture

The effects of moisture within the grid also may have had a large effect on the results obtained throughout the twelve months of data collection. Table F1 in Appendix F gives the moisture levels for each scenario for every month. Months four through eight produced some of the best results in all of the twelve months of data collection. Further, months four and five produced the best features seen in both the reflection profiles and the horizontal slices. When these results are correlated with the moisture data in Appendix F, there are clear relationships between the higher levels of moisture within the grid compared to the favorable results obtained for these months. Special attention should be paid to the differences between months three and four. Not only at month four did the reflection profiles and horizontal slices produce much more favorable results compared to month three, but when comparing the different levels of moisture between the two months, it was clear that month four had noticeably higher levels of moisture within the grid. At the fourth month, five out of six graves that contained a pig carcass had moisture levels of 10 at the deepest depth of the grave that was able to be measured. Further, all the graves buried at deep depths contained moisture levels of 5 and higher at 0.75 m, which is still considered wet, with two graves still showing levels at 10. These higher levels of moisture within each of the burial scenarios coupled with the pig carcasses and associated grave artifacts may have played a direct role in the increased resolution of the features starting at month four.

When comparing the various burial scenarios together, not only did the shallow pig carcass (1A) produce a better response throughout the twelve months of data collection compared to the deep pig carcass (1B), but the moisture levels between those two scenarios were
noticeably different. The moisture for the shallow pig carcass (1A) produced a measurement of 10 (the most wet) for every month starting with month five. These levels were higher compared to the deep pig carcass for almost every month. This may have been the case because the shallow burial was buried at a depth half that of the deep burial and thus consistently contained more moisture due to its shallow depth of 0.5 m.

Next, it was tough to determine what types of effects moisture played on the pig carcasses that were covered (1C and 2C). Each of the burials had high moisture levels throughout the twelve months of data collection; however, the most important factor into why the pig carcass covered with a layer of rocks (1C) was detected higher than any other scenario has more to do with the large surface area and density of the rocks that were placed over the pig carcass than the amount of moisture in the grave.

Next, when comparing the wrapped scenarios (1D and 2D) it is clear that the pig carcass wrapped in a tarpaulin (1D) was consistently detected at a higher rate compared to the pig carcass wrapped in a blanket (2D). As was mentioned earlier, this could have been due to the materials that make up each of the grave artifacts, as the plastic of the tarpaulin was detected at a much higher rate than the material of the blanket. However, when looking at the moisture readings, this scenario was clearly the wettest throughout all twelve months of data collection. In fact, every month produced the wettest reading of 10 for this scenario. The pig carcass wrapped in a tarpaulin was detected in the horizontal slices at every month, and the plastic material of the tarpaulin together with the high levels of moisture may have had a lot to do with the high resolution of this scenario. Further, coupled with the moisture in the grave, another
reason why the pig carcass wrapped in a tarpaulin (1D) was consistently detected at a higher rate than the pig carcass wrapped in a blanket (2D) may have also been because of the moisture contained within the tarpaulin. As the pig carcass decomposed, decomposition fluid may have been contained within the tightly wrapped tarpaulin, thus increasing the resolution of the feature. On the other hand, as the pig carcass wrapped in the blanket decomposed, the thin cotton material of the blanket may not have been able to contain the moisture from the decomposition fluid.

Lastly, when comparing the two control holes (2A and 2B) with the rest of the burials in the grid, each of these scenarios showed by far the lowest levels of moisture. Even though there was not a pig carcass in either grave, both scenarios illustrated the lowest levels of moisture and thus were detected very poorly throughout the twelve months.

Soil

In this study, the soil horizons throughout the grid and around the pig carcasses may have had a large effect on whether a distinctive reflection feature was discernable. Studies by Schultz et al. (2006) and Schultz (2008) prove that carcasses buried in predominately sandy soils were easily detected up to 21.5 months because there was a strong enough contrast between the pig carcass and the surrounding soils. On the other hand, the research grid used in this study was made up of denser soil horizons including clayey soils and a hard spodic horizon. Spodic horizons are characterized by dark organic layers that may contain small traces of aluminum, carbon, and iron. Many of the burial scenarios were located within these dense horizons and thus were somewhat masked by the different soils. Detecting a clandestine body in soils with soil
horizons made up of clay can be a result of imaging the body, soil disturbances, or both (Schultz et al., 2006). This study confirmed the results from the study conducted by Schultz et al. (2006) that it became more difficult to image the pig carcasses buried in denser soils including clay especially after six months of data collection. Many of the burials in this study were located within the dense soil horizon or right below it and they were difficult to discern because the GPR detected these burials as natural undulations of the soil horizon. A 500-MHz antenna also has limited depth penetration compared to an antenna of lower frequency and it also may detect more unknown features beneath the surface due to the higher resolution. In this study the 500-MHz antenna detected the dense horizons and became another factor limiting the depth penetration of the radar waves. The soil horizons masked the detection of the pig carcasses to a degree. The study performed by Schultz et al. (2006:614) stated that “It was not a surprise that the cadavers buried in the clay became difficult to detect because clay is a limiting factor that significantly reduces the ability to detect forensic and cemetery graves using GPR”. The results from this study were very similar to that of Schultz et al. (2006) when focusing on the limitations of certain soil horizons to detect buried pig carcasses.

Guidelines

From the results obtained using ground-penetrating radar with a 500-MHz antenna, there are a number of factors that law enforcement personnel can take into account when conducting a search for a clandestine burial involving a buried body. First, it is essential to have a forensic anthropologist or archaeologist with geophysical experience at a scene to assist with the use of a GPR. The application of the GPR takes training both in the field as well as in the laboratory.
involving data interpretation. Not only can a forensic archaeologist with geophysical experience potentially locate an area that may contain a buried body, but they are also trained to clear suspected areas where a body was thought to be located. Next, it is important to utilize tight transect spacing usually no more than 0.25 m when conducting a search. It is important to use a transect spacing that will minimize the chance of not detecting a body or associated evidence because transects that are spaced too wide may overlook potentially vital areas. Lastly, it is important for forensic personnel to gain as much information as they can about the burial prior to the search, as they can adapt the search to what they are looking for. Heavily wooded areas can pose problems for a GPR search because the ground will be uneven and the various debris in the area will more than likely hinder the results. Also, the depth of the burial, the time since burial, and the associated grave artifacts may also have an effect on the geophysical response. From the results of this study, the different objects used to conceal a body will produce various responses in GPR imagery.

**Conclusion**

Controlled research was important to illustrate the applicability of a GPR with a 500-MHz antenna to detect buried bodies that mimic common forensic burial scenarios. Overall, the 500-MHz antenna was a valuable tool when searching for buried pig carcasses mimicking various forensic contexts. Further, the inclusion of multiple imagery options including reflection profiles and horizontal slices allowed for maximum delineation of the various burial scenarios. This study has shown that different burial scenarios produce different responses in imagery.
throughout twelve months of data collection. The pig carcass covered with a layer of rocks (1C) produced the best resolution out of all the scenarios, while the deep pig carcass (1B) and the pig carcass wrapped in a blanket (2D) produced the poorest responses, overall. It is clear that the burial scenarios with items added to the grave produced the best responses compared to the burial scenarios only containing a pig carcass. Further, the blank control graves (2A and 2B), only containing disturbed backfill, were very important in illustrating that the reflection features were primarily a result of the pig carcass and not the disturbed soil. It was also vital to take the data that was collected in the field and apply further processing in the lab for maximum delineation. The reflection profiles were important to show a single transect over the center of the graves in order to see what transects produced the best results. Further, the horizontal slices were important to illustrate the grid data as a whole at different depths. Lastly, moisture played a large role in the results obtained as higher levels of moisture resulted in enhanced imagery of the burial scenarios.
CHAPTER FOUR: DETECTING VARIOUS BURIAL SCENARIOS IN A
CONTROLLED SETTING USING A GROUND-PENETRATING RADAR
WITH A 250-MHZ ANTENNA

Introduction

The use of geophysical tools, specifically ground-penetrating radar (GPR), in a forensic
setting to locate buried bodies has seen increasing acceptance. Not only is GPR often used to
search for buried bodies and associated evidence, but it is also utilized to clear suspected areas
where a body was thought to have been buried. When site conditions are appropriate GPR offers
investigators an excellent option for the search for clandestine burials involving buried bodies
because it is a noninvasive tool that does not cause any destruction to the ground surface or any
associated evidence. The best way to demonstrate the ability of GPR for detecting buried bodies
is by setting up controlled studies that consist of burying pig carcasses that are often used as
proxies for human bodies, and then monitoring the burials for some length of time (France et al.,
1992; France et al., 1997; Freeland, 2003; Schultz, 2006; Schultz, 2008). Because of the
successful use of GPR to locate buried bodies in a controlled setting, GPR has also been utilized
in actual forensic settings. In particular, examples of the successful use of GPR in homicide
investigations involving buried bodies have been reported in the published literature (Davenport,
2001a; Nobes, 2000; Schultz, 2007).

While the use of GPR in both controlled settings and actual forensic investigations have
been reported in the published literature, most of the literature reports on the use of antenna sizes
ranging from 400-MHz to 900-MHz, and the use of lower frequency antennae, specifically a 250-MHz antenna, has not been utilized. Further, the use of a 500-MHz antenna seems to be the most common antenna choice in both a controlled setting and within actual forensic investigations involving buried bodies. In a controlled setting, France et al. (1992) reported that a GPR system with an 80-MHz, 300-MHz, and 900-MHz antenna was utilized to locate six pig carcasses that were buried across a ranch in Colorado; however, this research did not offer any results for the detection of the carcasses and the differences in detectability using the various antennae sizes. A study by Schultz (2003) compared the use of a 900-MHz antenna and a 500-MHz antenna to locate buried pig carcasses at various depths and various time periods in Florida and determined that the imagery of the 500-MHz antenna was preferred over the higher resolution of the 900-MHz antenna. In an extension off of previous research, Schultz et al. (2006) also used a 500-MHz antenna to monitor large pig carcasses at a shallow and deep depth and concluded that the carcasses in sand were easily detected up to 21.5 months, while the deep pig carcasses located near the clay horizon were difficult to image over the first year of burial. Freeland et al. (2003) used a 400-MHz antenna and a 900-MHz antenna to detect buried human cadavers in shallow grave plots in Tennessee and concluded that neither antenna was able to penetrate beyond one meter in depth in the clay-rich soil, with the 900-MHz antenna only able to penetrate approximately 30 cm below the surface. Lastly, Schultz (2008) used a 500-MHz antenna to monitor small pig carcasses buried at shallow and deep depths and concluded that it may be difficult to detect small carcasses buried in sand and that carcasses buried at deeper depths may be detected for longer periods of time due to reduced decomposition rates.
Multiple forensic case studies have also been published on the use of GPR to locate buried bodies. Nobes (2000) used a 200-MHz antenna along with electrical conductivity to locate a body in New Zealand that had been buried for 12 years. He concluded that the use of multiple geophysical methods should be used to complement each other instead of just relying on one method. Davenport (2001a) successfully used GPR to locate a buried body under a concrete slab 28 years after burial; however, the antenna size used in the search was not reported. Lastly, Schultz (2007) successfully used GPR with a 500-MHz antenna both to clear an area in a backyard where a body was thought to be located as well as to locate a buried body underneath a concrete slab in a garage of a residence.

Standard GPR systems used for forensics consist of a monostatic antenna, a computer control unit, and a monitor to view the GPR imagery. The components can usually be integrated into a cart with a built-in survey wheel used to measure distance. The different antennae used come in a variety of frequencies and sizes and are the main interchangeable component of GPR systems (Schultz, 2007). Depth of penetration and vertical resolution are important to consider when choosing an antenna size. Better resolution is obtained from higher frequency antennae, while greater depth penetration is obtained from lower frequency antennae (Davenport, 2001a). Lower frequency antennae (e.g., 250-MHz) will increase the depth of penetration and decrease the resolution. Higher frequency antennae (e.g., 900-MHz) will decrease the depth of penetration and increase the resolution. Usually a 500-MHz antenna provides an excellent compromise between depth of penetration and vertical resolution. Lower frequency antennae like a 250-MHz antenna may decrease the resolution but it also detects less false reflection
features or unknown objects beneath the surface which may result in easier discrimination of forensic targets.

Purpose

Current issues with controlled forensic geophysical research using a GPR include overlooking the effects that various burial scenarios have on the detection of buried bodies. Applications involving the use of GPR in a forensic context both in real-world settings as well as controlled forensic geophysical research often focus on the use of a 500-MHz antenna, and the published literature on the use of a 250-MHz antenna is minimal. This portion of the research will (1) investigate the ability of ground-penetrating radar with a 250-MHz antenna to detect buried bodies that mimic real-life forensic scenarios; (2) identify which burial scenarios provide the best and worst resolution throughout twelve months of data collection; and (3) compare the results throughout twelve months using various computer software programs including REFLEXW, version 4.5 and GPR-SLICE, version 7.0.

Materials and Methods

Field Site and Controlled Graves

The research site is located on the secured grounds of the Geotechnical Engineering Test Site on the main campus of the University of Central Florida in Orlando, Florida. The site is a flat, unused section of the campus that is covered by grass and is mowed periodically (Figure 24). Six pig carcasses (*Sus scrofa*) weighing approximately 90-100 pounds each were used as proxies for human bodies, and were buried at either a shallow (approximately 0.50 m) or deep
(approximately 1.0 m) depth (Table 9). Each of the six pig carcasses were euthanized by a single gunshot wound to the head with a .22 caliber handgun, and were brought directly back to the UCF campus where they were buried the same afternoon. Pig carcasses are commonly used as proxies for human bodies in controlled research that may emphasize human taphonomy because they are similar to humans in their fat-to-muscle ratio, and in the fact that their skin is not heavily haired (France et al., 1992). Further, France et al. (1992) mentions that pigs have been considered to be biochemically and physiologically similar enough to humans to be used in studies of patterns and rates of decay. A permanent grid measuring 11 meters on the north-south axis by 22 meters on the east-west axis was constructed and contains six pig graves and two control graves set up in two rows, with each grave measuring 1 meter wide and 1 meter long. The six graves containing pig carcasses (Figure 25) and the two control graves mimicked a number of common forensic scenarios involving buried bodies:

1. A deep blank control grave consisting of only disturbed backfill (100-110 cm) to determine the geophysical response of only the disturbed soil and not the carcass and items that will be added to graves.
2. A shallow blank control grave consisting of only disturbed backfill (50-60 cm) to determine the geophysical response of only the disturbed soil and not the carcass and items that will be added to graves.
3. A deep pig carcass with nothing else added to the grave.
4. A shallow pig carcass with nothing else added to the grave.
5. A deep pig carcass wrapped in a vinyl tarpaulin.
6. A deep pig carcass wrapped in a cotton blanket.
7. A deep pig carcass with a layer of lime (calcium hydroxide) placed over the carcass.
8. A deep pig carcass with a layer of small rocks placed over the carcass.

Figure 24: Research Area at the Geotechnical Engineering Test Site on the Main UCF Campus in Orlando, Florida

Figure 25: Forensic scenarios of burials containing a pig carcass
Table 9: Detailed Grave Information for Each of the Burials

<table>
<thead>
<tr>
<th>Grid Location</th>
<th>Burial Date</th>
<th>Depth of Grave Floor (below surface)</th>
<th>Scenario</th>
<th>Pig Carcass Weight (lbs)</th>
<th>Pig Carcass Sex</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>1/30/2009</td>
<td>0.5 m</td>
<td>Shallow pig grave</td>
<td>90</td>
<td>Female</td>
</tr>
<tr>
<td>1B</td>
<td>1/30/2009</td>
<td>1.0 m</td>
<td>Deep pig grave</td>
<td>100</td>
<td>Male</td>
</tr>
<tr>
<td>1C</td>
<td>1/30/2009</td>
<td>1.0 m</td>
<td>Deep grave with layer of rocks covering pig</td>
<td>90</td>
<td>Male</td>
</tr>
<tr>
<td>1D</td>
<td>1/30/2009</td>
<td>1.0 m</td>
<td>Deep grave with pig wrapped in tarpaulin</td>
<td>98</td>
<td>Female</td>
</tr>
<tr>
<td>2A</td>
<td>1/30/2009</td>
<td>0.5 m</td>
<td>Shallow control hole</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>2B</td>
<td>1/30/2009</td>
<td>1.0 m</td>
<td>Deep control hole</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>2C</td>
<td>1/30/2009</td>
<td>1.0 m</td>
<td>Deep grave with layer of lime covering pig</td>
<td>95</td>
<td>Male</td>
</tr>
<tr>
<td>2D</td>
<td>1/30/2009</td>
<td>1.0 m</td>
<td>Deep grave with pig wrapped in blanket</td>
<td>97</td>
<td>Female</td>
</tr>
<tr>
<td>Calibration Unit</td>
<td>1/9/2009</td>
<td>1.0 m</td>
<td>Rebar hole</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Research Grid at the Geotechnical Engineering Test Site on the Main UCF Campus in Orlando, Florida

Figure 26: Geophysical Research Site Grid and Location of Burials
Each of the pig carcasses were placed in the grave on their right side with the back facing the east wall and the head towards the north wall. Once the pigs were placed in the grave the depths of the pigs from three points on the body were measured below the surface, including measurements from the surface to the head, abdomen area, and tail. Grave scenario 1C contained a layer of small rocks over the pig and five measurements were taken from the ground surface to the layer of rocks including the northwest corner, northeast corner, southwest corner, southeast corner, and the center of the grave. Table 10 shows the measurements for each of the six graves containing a pig carcass.

Table 10: Depths of Pig Carcasses in the Graves Taken Below the Ground Surface

<table>
<thead>
<tr>
<th>Grave Location</th>
<th>Measurement to Head</th>
<th>Measurement to Abdomen</th>
<th>Measurement to Tail</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>0.33 m</td>
<td>0.24 m</td>
<td>0.26 m</td>
</tr>
<tr>
<td>1B</td>
<td>0.86 m</td>
<td>0.76 m</td>
<td>0.77 m</td>
</tr>
<tr>
<td>1C*</td>
<td>0.83 m</td>
<td>0.75 m</td>
<td>0.77 m</td>
</tr>
<tr>
<td>1D</td>
<td>0.74 m</td>
<td>0.74 m</td>
<td>0.75 m</td>
</tr>
<tr>
<td>2C</td>
<td>0.83 m</td>
<td>0.76 m</td>
<td>0.78 m</td>
</tr>
<tr>
<td>2D</td>
<td>0.80 m</td>
<td>0.74 m</td>
<td>0.76 m</td>
</tr>
</tbody>
</table>

*Layer of rocks added over pig carcass
Center of grave: 0.70 m

Data Collection

The GPR unit used in this portion of the research project was the Mala RAMAC X3M with a 250-MHz antenna that was integrated into a cart and was hand pushed over the research grid (Figure 27). The 250-MHz antenna increases the depth of penetration and decreases the vertical resolution. This usually produces less false reflection features detected, which may result in easier discrimination of forensic targets.
Data were collected for two soil components to evaluate the geophysical response of proxy graves: disturbed soil and undisturbed soil. Since disturbed soil may produce a geophysical response, blank graves only containing disturbed soil were included in the grid to distinguish which component or components of the grave (the disturbed soil, the body, or anything else added to the grave) were producing the geophysical response when a grave was detected. Before the graves were constructed, GPR data were collected on the site for comparative purposes with the grid data that contained buried pig carcasses. The field data collection was performed approximately every two weeks and the results were monitored for a total of twelve months. Data were collected along grid transects every 0.25 m in both an east-west direction and a north-south direction (Figures 28 and 29). The typical GPR survey collects
grids of transects with profiles orientated in only one direction. A case study by Pomfret (2006) was performed to test the variables of profile orientation and transect spacing in an excavation area to test how important those factors were to the subsurface resolution of targets. It is suggested that surveying in both transect orientations offers the best results for defining small subsurface features, and for maximum resolution, perpendicular transects would be the preferred collection method (Pomfret, 2006).

Prior to each data collection event, the GPR unit was calibrated to the soil of the research site to accurately estimate the depth of the reflection features within the grid. Using a known object buried at a known depth can help to determine the sensitivity of the instrument within the soil (Conyers, 2004; Strongman, 1992). For this project, a calibration test pit was dug approximately two meters away from the grid on the east end. This method provides the most accurate way to represent the depth of the buried pig carcasses compared to any other geophysical tool. The GPR unit was calibrated by running the GPR over a metal bar that was pounded into an excavation wall at a depth of one meter. Burying a metal bar at a known depth is the method suggested by Conyers (2004). The direct measurements yield both time and distance (depth) and allow for an approximation of the average radar velocity (Conyers, 2004; Conyers and Cameron, 1998). Once the response from the buried metal bar is detected by the GPR at approximately one meter, the depth of response can be set on the GPR monitor.
Figure 28: Geophysical Research Site Grid and Location of Burials with 0.25 m transects (West to East)
Figure 29: Geophysical Research Site Grid and Location of Burials with 0.25 m transects (North to South)
On data collection days, the moisture levels of the soil within the research grid were also collected using a soil moisture meter manufactured by Lincoln Irrigation Incorporation. The probe on the soil moisture meter measures 90 centimeters in length and moisture measurements were recorded on a scale of 1 to 10, with 10 being the wettest. The use of a soil moisture meter was necessary to determine if the moisture within the site would affect any data that was collected. The points within the research grid that were measured include the northwest corner of the rebar hole, and each of the northwest corners of the burials within the grid. The shallow burials were measured at 0.25 m and 0.50 m and the deep burials were measured at 0.50 m, 0.75 m, and 0.90 m.

**Data Analysis**

The last component of this portion of the project composed of processing, interpreting, and presenting the 250-MHz GPR data. The various imagery options used in this research test the ability of the GPR with a 250-MHz antenna to represent the data that were collected in both 2-D and 3-D advanced processing features, and can be a real benefit to body searches when focusing on multiple imagery options. A reflection profile consists of a single transect over the grid, and the profiles shown were collected directly over the center of the graves. A reflection profile only represents length (left to right) and depth (top to bottom) for only one transect. Reflection profiles were evaluated; however, more advanced processing that provided increased resolution of subsurface features and more advanced evaluation of these data were also utilized. A variety of different processing procedures were used to present these data in both 2-D and 3-D formats using either GPR-SLICE or REFLEXW, version 4.5, GPR software. Once these data
were filtered, all of the transects (reflection profiles) collected over the burials were viewed using REFLEXW, version 4.5. Next, all of the transects collected over the grid were then welded together to create a 3-D cube that was able to be viewed in multiple planes with GPR-SLICE. In particular, the horizontal slice option is an important view of the 3-D cube because it provides a planview representation of the grid data at different depths. A horizontal slice was constructed in the GPR-SLICE program and utilized all of the grid data that were collected. The program interpolates the space between each of the transects (reflection profiles). Because the GPR-SLICE program interpolates the space between each of the transects the use of smaller transect spacing becomes an extremely important aspect during data collection.

Results

Reflection Profiles

When using grid transects of 0.25 m there were a total of five profiles that were collected over each of the graves in the west to east direction as part of the grid data for the horizontal slices. Each of the five profiles collected over the graves illustrated very noticeable differences in imagery characteristics once the data were processed in the lab. The third profile, collected directly over the center of the graves where the back of the pig carcass was towards the east wall and the head was towards the north wall, clearly provided the best resolution of the reflection features. The profile taken directly over the center of the graves will be described in detail to show the specific changes throughout twelve months of data collection and how these characteristics changed over the duration of this study. Figures 30-34 illustrate each of the five
reflection profiles for row 1 after one month of burial to show the differences in imagery between each of the transects taken over the graves. Profile 1 represented the north wall of each of the graves and profile 5 represented the south wall. Profiles 2 and 4 represented the transects directly to the left and right of the middle transect. Profile 3 represented the middle transect over the graves and will be the profile that is described throughout this research.

Figure 30: GPR reflection profile using the 250-MHz antenna of row 1, profile 1 for month one

Figure 31: GPR reflection profile using the 250-MHz antenna of row 1, profile 2 for month one

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Figure 32: GPR reflection profile using the 250-MHz antenna of row 1, profile 3 for month one

Figure 33: GPR reflection profile using the 250-MHz antenna of row 1, profile 4 for month one
After one month of burial, the reflection profile directly over the center of the graves for row 1 showed four discernable reflection features (Figure 32). The shallow pig carcass (1A), the pig carcass covered with a layer of rocks (1C), and the pig carcass wrapped in a tarpaulin (1D) all produced good responses. The deep pig carcass (1B) showed a discernable response but it was a bit more reduced compared to the three other reflection features in the row. The shallow pig carcass (1A) was clearly located at a shallower depth compared to the three other scenarios in row 1. The reflection features for each of the four scenarios were somewhat masked by the presence of a hard spodic horizon near the location of the burials, but the features were clearly discernable by the presence of hyperbolic tails that extended towards the bottom of the profile.

When comparing the other four profiles in row 1 with the profile directly over the middle of the graves, none of the other four profiles demarcated any of the graves as clearly as the third profile. When looking at profiles 2 and 4 (Figures 31 and 33), the profiles located directly to the left and right of the middle profile, both profiles produced responses that were clearly not as
demarcated as the third profile running directly over the center of the graves. Profile 2 showed hyperbolic tails that extended towards the bottom of the profile, but the apex of each reflection feature was not as demarcated as profile 3. The reflection features in profile 4 were clearly the least defined compared to both profiles 2 and 3. Lastly, profile 1 (Figure 30), located at the left edge of the graves, showed a decreased response that was tough to discern. This profile more than likely detected a reduced signal from the pig carcasses even though it was located at the edge of the grave due to the large size of the 250-MHz antenna. On the other hand, profile 5 (Figure 34), located on the right edge of the graves, did not show any discernable responses. Overall, profiles 1 and 5 showed very poor responses, and profiles 2 and 4 showed considerably decreased responses in all four grave scenarios compared to the third profile running directly over the center of the graves.

Similar to row 1, the third profile, taken directly over the middle of the graves, for row 2 after one month of burial produced the best response compared to the other four profiles (Figure 35). In this row only two graves contained pig carcasses. The other two graves contained only disturbed backfill; scenario 2A with a depth of 0.50 m and scenario 2B with a depth of 1.0 m. Both graves containing a pig carcass showed a discernable response in this row. The pig carcass covered with a layer of lime (2C) produced a good reflection feature with hyperbolic tails that extended to the bottom of the profile. The pig carcass wrapped in a blanket (2D) showed a decreased response but was still noticeable due to the presence of tails in the profile. Lastly, the deep control hole (2B) also showed a response due to the presence of disturbed backfill in the grave. The backfill is noticeable towards the top of the reflection profile.
Reflection profiles for the remainder of the data collection time period (months 2-12) are located in Appendix D. Each image only shows the middle reflection profile as the one month data collection illustrated.

Months two and three (Appendix D, Figures D1-D4) showed very similar results in both row 1 and 2. The pig carcasses in row 1 for both months showed discernable responses; however, each of the burials were masked by the hard spodic soil horizon located around the depth where the pig carcasses were buried. In row 2 for both months, the pig carcass covered with a layer of lime (2C) showed a good response compared to a poor response from the pig carcass wrapped in a blanket (2D). After the fourth month of data collection however, very distinct differences in both row 1 and row 2 were apparent in the reflection features seen in each of the eight scenarios located within the grid. At month four, the moisture levels within the grid

Figure 35: GPR reflection profile using the 250-MHz antenna of row 2, profile 3 for month one
were noticeably higher than the previous three months due to increased rainfall from seasonal storms around this time of the year (see Appendix F).

By far, the most favorable results took place at month four, and this lasted through month eight (see Appendix D). Starting at month four, the six burials in both rows 1 and 2 produced excellent reflection features. These excellent reflection features lasted through month eight. Each of the burials produced large reflection features with hyperbolic tails that extended towards the bottom of the reflection profile. Each of the burial scenarios that contained a pig carcass produced excellent responses that were very comparable to one another. The pig carcass covered with a layer of rocks (1C) showed the best response at its apex, as this was more than likely due to the presence of the layer of rocks at this depth. The apex for this burial is more defined than the other burial scenarios. Even with the presence of the spodic horizon at these depths, each burial scenario showed excellent reflection features. Lastly, for each month between months four through eight, the deep control hole (2B) produced a good response; however, the apex of this reflection feature for this scenario was located just below one meter and may be attributed to the soils at or directly beneath the grave floor. None of the eight burials within the grid were constructed below one meter, and because the deep control hole (2B) did not exhibit a discernable response above 1 m, it is clear from the comparisons between the graves that the prominent grave features were due to the pig remains and not the disturbed soil.

After the tenth month of data collection (Appendix D, Figures D17 - D18), the resolution of the burial scenarios began to decrease. The shallow pig carcass (1A) showed a very poor response compared to the previous months. In fact, this scenario produced some of the weaker
reflection features over the past two months. Similar to the shallow pig carcass (1A), the deep pig carcass (1B) also produced a poor reflection feature. On the other hand, the remaining burials that contained a pig carcass produced good responses. The apex of each of the burials were somewhat masked by the presence of the hard spodic soil horizon again, but each was clearly visible due to prominent hyperbolic tails that extended towards the bottom of the reflection profile.

After month twelve, many of the burial scenarios produced decreased responses compared to the previous few months. The hyperbolic tails that were seen in the previous months that made the reflection features much easier to discern, showed decreased resolution. The shallow pig carcass (1A) and the deep pig carcass (1B) showed poor responses. The deep pig carcass (1B) was severely masked by the presence of the spodic horizon at that depth. The pig carcass covered with a layer of rocks (1C) produced an excellent reflection feature that stood out among the rest of the burial scenarios during that month. The pig carcass wrapped in a tarpaulin produced a good response and a hyperbolic tail from the feature was present for this scenario. Row 2 produced decreased responses in each of the scenarios compared to the previous months and the features were noticeably decreased compared to the features for the burials in row 1. The pig carcass covered with a layer of lime (2C) produced a very poor response and the pig carcass wrapped in a blanket (2D) produced a reduced response where hyperbolic tails extending to the bottom of the profile were slightly present. The deep control hole (2B) produced a response, but since the apex of the feature was located below one meter, the feature was attributed to something other than the disturbed backfill of the burial. Table 11
provides an overview of the GPR imagery results with the 250-MHz antenna for each month of data collection using reflection profiles.

Table 11: Summary information describing the GPR reflection profiles with a 250-MHz antenna for each month of data collection

<table>
<thead>
<tr>
<th>Month #</th>
<th>Overview of GPR Imagery Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The deep pig carcass (1B) and the pig carcass wrapped in a blanket (2D) produced the weakest responses. The remaining deep scenarios containing pig carcasses produced good responses</td>
</tr>
<tr>
<td>2</td>
<td>The shallow pig carcass (1A) and the pig carcass covered with a layer of lime (2C) produced good responses. Scenario 2D produced the weakest response out of all the scenarios</td>
</tr>
<tr>
<td>3</td>
<td>All of the scenarios in row 1 produced reduced responses while scenario 2C was the only scenario that produced a good response overall</td>
</tr>
<tr>
<td>4</td>
<td>Excellent detection of every burial scenario containing a pig carcass</td>
</tr>
<tr>
<td>5</td>
<td>Excellent detection of every burial scenario containing a pig carcass</td>
</tr>
<tr>
<td>6</td>
<td>Excellent detection of every burial scenario containing a pig carcass</td>
</tr>
<tr>
<td>7</td>
<td>Excellent detection of every burial scenario containing a pig carcass</td>
</tr>
<tr>
<td>8</td>
<td>Excellent detection of every burial scenario containing a pig carcass</td>
</tr>
<tr>
<td>9</td>
<td>Good detection of scenario 1A, scenario 1B, and scenario 2C. Excellent detection of the pig carcass covered with a layer of rocks (1C), the pig carcass wrapped in a tarpaulin (1D) and scenario 2D</td>
</tr>
<tr>
<td>10</td>
<td>Poor and reduced detection of scenarios 1A and 1B. The remaining scenarios were easily detected</td>
</tr>
<tr>
<td>11</td>
<td>Reduced and poor detection of scenarios 1A and 1B again. The remaining scenarios were easily detected</td>
</tr>
<tr>
<td>12</td>
<td>Scenario 1C and scenario 1D were the only scenarios to produce a response that was easily detected</td>
</tr>
</tbody>
</table>

Horizontal Slices

Using the software program GPR-SLICE, version 7, the data collected from the grid was imaged with 2-D options. In particular, the horizontal slice was an important view of the grid in the Z plane because it provided planview representations of the grid at different depths. Each horizontal slice is a single slice of the grid data through a 3-dimensional cube that the GPR-SLICE program created. Each slice represents a different depth through the cube. Each
horizontal slice shown is a representation of both the X and Y data appended into one grid. Data were collected for the grid prior to the burial of the pig carcasses for comparisons with the data once the pig carcasses were buried. Figures 36 and 37 illustrate the preburial grid at both a shallow and deep depth.

Figure 36: GPR horizontal slice using the 250-MHz antenna for the preburial grid. The horizontal slice is approximately 0.34 m (5.82ns)

Figure 37: GPR horizontal slice using the 250-MHz antenna for the preburial grid. The horizontal slice is approximately 0.85 m (25.72ns)
When the grid showing the location of each of the burials was overlaid on both the shallow and deep preburial grids (Figures 36 and 37) it was evident that there are no reflection features within any of the locations where the burials were placed. This is important to note when observing the data for the months after the pig carcasses were placed in the ground. The reflections that were imaged could have been attributed to a number of subsurface features including roots, stumps, or soil disturbances beneath the surface. There were a number of different soil horizons throughout the research grid that consisted of root mats, sand, clayey soil, and a hard spodic horizon. These soil horizons were especially numerous throughout the northwest corner of the grid where disturbed layers of soils were intermixed with thin sectioned layers of undisturbed soil. These soil horizons could have produced the unknown reflection features within the horizontal slices. Next, figures 38 and 39 show horizontal slices after one month of burial at a shallow and deep depth. The purpose of including both a shallow and deep horizontal slice for month one was to illustrate the shallow burial containing a pig carcass as well as each of the deep burials containing pig carcasses. Since horizontal slices are images of a grid at different depths it was important to include both a shallow and deep slice together for month one in order to illustrate both the shallow burial scenarios and the deep burial scenarios together. However, when looking at the shallow horizontal slice after one month (Figure 38), at 0.31 m the shallow pig carcass (1A) was not represented even though there was definitely a pig carcass buried at that depth (see Table 10).
This was not just the case for month one, as this scenario was not represented whatsoever in any of the following months. Since there was no response from the shallow pig carcass (1A), for months two through twelve (Appendix E) only a deep horizontal slice will be represented illustrating the six deep burial scenarios.

For months one, two, and three a shallow horizontal slice from the GPR-SLICE program was used along with a deep horizontal slice from the REFLEXW, version 4.5 program. The
deep horizontal slice from REFLEXW was only used for these three months because the depth setting that was originally set during these first three months was set at too deep of a depth in the field prior to data collection and affected the imagery in the GPR-SLICE program. At month one, when viewing the horizontal slice from the REFLEXW program, the deep pig carcass (1B) and the pig carcass wrapped in a blanket (2D) showed a reduced response, while the remaining burial scenarios containing a pig carcass produced good responses. The pig carcass covered with a layer of rocks (1B) and the pig carcass wrapped in a tarpaulin (1D) produced the strongest responses out of all of the burial scenarios. When the horizontal slice for month one is compared to the horizontal slice for the preburial grid, it is clear that the reflection features present after month one within the deep horizontal slice were a result of the pig carcasses and associated grave artifacts.

Months two and three (Appendix E, Figures E1-E4) produced similar results. Appendix E shows both a shallow and a deep horizontal slice for each month. The shallow horizontal slice was constructed with GPR-SLICE and the reflection features that were present represented the disturbed backfill of the graves. At 0.10 m for month two, and 0.13 m for month three, the backfill for each of the graves was detected with the 250-MHz antenna. None of the reflection features could be attributed to the pig carcasses or associated grave artifacts because the depth is too shallow. When looking at the deep horizontal slices constructed in REFLEXW, version 4.5, both months two and three produced similar results. The pig carcass covered with a layer of rocks (1C) and the pig carcass wrapped in a tarpaulin (1D) both produced the most favorable results for both months. Further, both burials containing a pig carcass in row 2 (2C and 2D)
produced discernable results. On the other hand, the deep pig carcass (1B) was the only scenario that produced poor results for both months.

Similar to the reflection profiles, the horizontal slices for months four through eight (Appendix E, Figures E5-E9) produced the most favorable results during the whole data collection time period. During these months, each of the burial scenarios containing a deep pig carcass produced clear discernable reflection features. Each of the burials containing a deep pig carcass produced clear reflection features during this period, with the pig carcass covered with a layer of rocks (1C), the pig carcass wrapped in a tarpaulin (1D), and the pig carcass wrapped in a blanket (2D) producing excellent results for each of the five months. Overall, the results obtained for each of the deep burial scenarios containing a pig carcass for months four through eight produced the most favorable reflection features throughout the whole data collection time period.

Month nine (Appendix E, Figure E10) was the first month where many of the reflection features started to reduce. During this month only the pig carcass covered with a layer of rocks (1C) and the pig carcass wrapped in a tarpaulin (1D) produced excellent responses. The remaining scenarios all produced poor responses. The responses for month ten were very similar to the previous month. The pig carcass covered with a layer of rocks (1C) and the pig carcass wrapped in a tarpaulin (1D) again produced excellent responses. The only difference that occurred was the presence of a reduced reflection feature for the pig carcass wrapped in a blanket (2D).
Months eleven and twelve (Appendix E, Figures E12 - E13) both produced similar results. Further, similar to the previous two months, the pig carcass covered with a layer of rocks (1C), the pig carcass wrapped in a tarpaulin (1D), and the pig carcass wrapped in a blanket (2D) produced the most favorable results for both months out of all of the burials. Both the pig carcass wrapped in a tarpaulin (1D) and the pig carcass wrapped in a blanket (2D) produced reduced reflection features for each of the final two months of the data collection period. Table 12 provides an overview of the GPR imagery results for each month of data collection using horizontal slices.

*Table 12: Summary information describing the GPR horizontal slices with a 250-MHz antenna for each month of data collection*

<table>
<thead>
<tr>
<th>Month #</th>
<th>Overview of GPR Imagery Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The pig carcass covered with a layer of rocks (1C) and the pig carcass wrapped in a tarpaulin (1D) produced the best responses. The deep pig carcass (1B) produced the poorest resolution.</td>
</tr>
<tr>
<td>2</td>
<td>Each of the deep burials containing a pig carcass were detected. Scenario 1C and the pig carcass covered with a layer of lime (2C) produced the best resolution.</td>
</tr>
<tr>
<td>3</td>
<td>Scenario 1C, scenario 1D and scenario 2C produced the best resolution. Scenario 1B produced the poorest resolution.</td>
</tr>
<tr>
<td>4</td>
<td>Each of the deep burials containing a pig carcass produced excellent reflection features.</td>
</tr>
<tr>
<td>5</td>
<td>Each of the deep burials containing a pig carcass produced excellent reflection features.</td>
</tr>
<tr>
<td>6</td>
<td>Each of the deep burials containing a pig carcass produced excellent reflection features.</td>
</tr>
<tr>
<td>7</td>
<td>Each of the deep burials containing a pig carcass produced excellent reflection features.</td>
</tr>
<tr>
<td>8</td>
<td>Each of the deep burials containing a pig carcass produced excellent reflection features.</td>
</tr>
<tr>
<td>9</td>
<td>Scenario 1C and scenario 1D produced excellent responses. The remaining scenarios produced poor responses.</td>
</tr>
<tr>
<td>10</td>
<td>Scenario 1C and scenario 1D produced excellent responses. Scenario 2D showed reduced responses</td>
</tr>
<tr>
<td>11</td>
<td>Three of the deep scenarios containing a pig carcass were detected. Scenario 1C was the only scenario to produce a good response.</td>
</tr>
<tr>
<td>12</td>
<td>Three of the deep scenarios containing a pig carcass were detected. Scenario 1C was the only scenario to produce a good response.</td>
</tr>
</tbody>
</table>
Discussion

Published literature on the use of a 250-MHz antenna in controlled forensic research is rare, and the use of a 250-MHz antenna to detect buried bodies that mimic real-life forensic scenarios has not been pursued. Overall, the use of a 250-MHz antenna proved to be an excellent option to detect buried bodies that mimic real-life burial scenarios, and the combination of various imagery options in multiple views allowed for maximum delineation of the buried pig carcasses. After the data were collected in the field, one of the greatest observations within this portion of the research was the importance of post-processing in the lab. The processing and interpretation of the 250-MHz data was extremely advantageous because it resulted in increased resolution of the data with both the reflection profiles and horizontal slices. This was also extremely vital because with the lack of published results on the use of a 250-MHz antenna, the increase in resolution of the reflection features and subsequent excellent results was unknown prior to the start of this research project. The inclusion of reflection profiles was important to highlight the reflection features of a single transect over the center of the graves. The horizontal slices were important for showing the entire grid data at different depths and illustrating the spatial distribution of the burial scenarios. Together, the inclusion of both GPR imagery options is vital for any controlled research project or actual forensic case because when both imagery options are viewed together, the various burial scenarios are imaged in greater detail and thus provided maximum results.

The use of a tight transect spacing around 0.25 m was important because a tighter transect spacing provided increased data to create the 3-D cube within the GPR-SLICE program. A tight
transect spacing with a 250-MHz antenna also provided more valuable data because of the larger size of the antenna compared to an antenna of higher frequency. Compared to a 500-MHz antenna, the 250-MHz antenna is larger and covers more ground surface, thus providing more valuable data when viewing the reflection profiles. Because of the large size of a 250-MHz antenna, certain transects that do not detect buried objects with an antenna of higher frequency, may be detected by the 250-MHz antenna.

Due to the lower frequency of the antenna, the pig carcasses and associated grave artifacts were detected at a very high rate throughout each of the twelve months of data collection. Higher frequency antennae (e.g., 500-MHz) are used for shallower surveys, but due to the high resolution of the subsurface targets, a higher frequency antenna may generate so much extra detail that the target may not be easily identified (Schultz, 2003). A lower frequency antenna like the 250-MHz antenna used in this portion of the research increases the depth of investigation but decreases the vertical resolution thus resulting in less false reflection features being detected beneath the surface, which results in easier discrimination of the forensic targets (Schultz et al., 2006; Schultz, 2007; Schultz, 2008). This was the case in this portion of the research project with the 250-MHz antenna. Because there was less unknown features detected with the 250-MHz antenna, the responses for each of the burial scenarios emerged as strong reflection features highlighted by the presence of significant hyperbolic tails that extended towards the bottom of the profiles.

The hard spodic soil horizon was also not a factor in the detection of the various burial scenarios when viewing the reflection profiles. Because the 250-MHz antenna detects less false
reflection features and provides an easier discrimination of the forensic targets, the burial scenarios were not masked by the presence of the hard spodic horizon like what may be the case with an antenna of a higher frequency. This was definitely the case during the middle months of this research project where the results were the most favorable and the reflection features were easy to discern. During the first three months of data collection, the spodic horizon was the most visible within the reflection features. Even though the apex of each of the reflection features for the deep burial scenarios was usually located right near this soil horizon, the features were never difficult to discern due to the prominent hyperbolic tails that were present for each of the burial scenarios. Because of the large size of the 250-MHz antenna, the large radar wave from the antenna was able to penetrate the ground more powerfully than an antenna of a higher frequency, as well as generate a large cone-shaped wave that could detect the forensic targets both before and after the GPR had been passed directly over them on the surface.

Burial Scenarios

With the use of a 250-MHz antenna, each of the different burial scenarios resulted in excellent detection throughout the twelve months of data collection with both the reflection profiles and horizontal slices. The pig carcass covered with a layer of rocks (1C) provided the best resolution throughout the data collection period out of all of the various burial scenarios. This scenario produced good or excellent results in ten out of the twelve months when viewing the reflection profiles and in all of the twelve months when viewing the horizontal slices. There was never a month when this scenario was not detected. The pig carcass wrapped in a tarpaulin (1D) was also detected well throughout the twelve months. This scenario produced excellent or
good results in ten out of the twelve months of data collection with both the reflection profiles and the horizontal slices. Both the pig carcass covered with a layer of rocks (1C) and the pig carcass wrapped in a tarpaulin (1D) produced the best results due to the materials that were used to cover the carcasses. The thick layer of rocks that covered the carcass was always present and took up a lot of space throughout the grave. Further, prior to the placement of the rocks within the grave, backfill was placed around the pig carcass so that the layer of rocks could completely cover the carcass. Coupled with the presence of the pig carcass, the amount of rocks in the grave produced very strong results. The pig carcass wrapped in a tarpaulin (1D) was also detected at a high rate due to the thickness of the tarpaulin as well as the plastic material itself. Further, due to the thickness of the tarpaulin, the decomposition rate of the pig carcass in this grave was more than likely slower compared to many of the other carcasses, thus resulting in a greater detection rate. Lastly, as the pig carcass decomposed within the tarpaulin, decomposition fluid may have been contained within the tightly wrapped tarpaulin which may have resulted in increased resolution of the feature. As previous results showed, higher levels of moisture have increased the detection of the burials, and the increased moisture within the tarpaulin may have played a direct role in the higher detection rates of this scenario, especially in the later months of data collection.

Imagery Options

The reflection profiles and horizontal slices were both excellent imagery options to utilize within this research project because both options provided maximum resolution and delineation of the various burial scenarios. Further, both imagery options were important to use together
because they provided more data for interpretation than just a single imagery option. The reflection profiles were beneficial because they were able to detect depth more accurately than the horizontal slices. The reflection profiles were also better able to illustrate the various changes that occurred month to month between the different burial scenarios. With an antenna of a larger size, like the 250-MHz antenna used in this portion of the research, the reflection profiles were also important to look at the series of individual transects that took place over the graves, and whether certain transects detected the burial scenarios stronger than others.

Overall, with the 250-MHz antenna, the reflection profiles provided the best results for each of the burial scenarios. The importance of using two different imagery options was apparent when comparing the responses from the various burial scenarios because what may have been detected and imaged using one imagery option may not have been with the other. This was apparent in four out of the six scenarios that contained a pig carcass. First, the shallow pig carcass (1A) was not detected whatsoever with the horizontal slices, but in the reflection profiles the features were either detected as excellent or good in eight out of the twelve months of data collection. Next, in the final four months of data collection, the deep pig carcass (1B) had poor detection rates in the horizontal slices, but in two of the last four months this scenario produced a good response with the reflection profiles. Next, the pig carcass covered with a layer of lime (2C) produced poor results for the final four months of data collection when viewing the horizontal slices, but the features in the reflection profiles produced excellent or good responses in three out of the last four months. Finally, the pig carcass wrapped in a blanket (2D) produced poor or reduced responses during the final four months within the horizontal slices; however, the
reflection profiles produced excellent features in three out of the last four months. The differences in the detection rates of both responses may have had a great deal to do with how the spaces between each transect are interpreted within the horizontal slices. The reflection profiles were beneficial because each burial scenario produced a unique feature every time the GPR was passed over them. When over the graves, the GPR produced strong hyperbolic features that were different for each scenario throughout the twelve months of data collection. On the other hand, the horizontal slices consisted of data for the whole grid and had to account for the spaces between each transect line. The horizontal slices covered a larger area and the interpolations or spaces between each of the grid slices may have been masked by unknown features in the subsurface. The reflection features were able to hit on specific targets in the grid, whereas the horizontal slices had to account for the spacing between each of the transects. This is the reason why a small transect spacing when collecting data is one of the most important options to keep in mind. Vital amounts of data may be overlooked when a large transect spacing is utilized during data collection. Even though a transect spacing of 0.25 m for this research project was a proper choice for data collection, the differences between the detection of reflection features with each imagery option, especially during the last few months of data collection, may have been a direct result of the interpolations between each of the various transects.

Guidelines

From the results obtained using ground-penetrating radar with a 250-MHz antenna, there are a number of factors that law enforcement personnel can take into account when conducting a search for a clandestine burial involving a buried body. First, it is vital to have a forensic
anthropologist with experience using GPR at a forensic scene. The application of the GPR takes training both in the field as well as in the laboratory involving data interpretation. Not only can a forensic anthropologist with experience using GPR potentially locate an area that may contain a buried body, but they are also trained to clear suspected areas where a body was thought to be located. Next, it is important to utilize tight transect spacing around 0.25 m when conducting a search. It is important to use a transect spacing that will increase the chances of detecting a body or associated evidence because transects that are too widely spaced may ignore potentially vital areas. Lastly, it is very important to provide further processing and interpretation to the data in the laboratory after it has been collected in the field. Before this research project started, it was unknown how the 250-MHz antenna would detect the buried pig carcasses due to the lack of published literature on the uses of this antenna for forensic purposes both in a controlled setting and in a real-life situation. By applying further processing and interpretation to the data, the reflection features that were minimally present during the in-field assessment, were highlighted and resulted in excellent responses throughout the twelve months of data collection. By applying further processing to the data, features that may have been initially overlooked in the field resulted in increased resolution and much easier discrimination of the forensic targets.

Conclusion

Controlled forensic research has been vital to illustrate the use of ground-penetrating radar with a 250-MHz antenna in detecting buried bodies that mimic real-life forensic scenarios. Due to the lack of published literature on the use of a 250-MHz antenna in a forensic setting, the
results of this research have been exceptionally valuable for the detection of clandestine burials. Further, the inclusion of multiple imagery options including reflection profiles and horizontal slices allowed for maximum delineation of the various burial scenarios. This study has shown that different burial scenarios produce different responses in imagery throughout twelve months of data collection and that the use of a 250-MHz antenna is an excellent tool that can be utilized in real-world forensic scenarios. Due to the increased depth of investigation and easier discrimination of forensic targets, the 250-MHz antenna is an excellent option when searching for buried bodies. It was also vital to take the data that was collected in the field and apply further processing in the lab for maximum delineation. The use of multiple imagery options provided maximum delineation of the forensic targets and multiple options are recommended for the best results. The reflection profiles were excellent options to show a single transect over the center of the graves in order to view what transects produced the best results. The presence of hyperbolic tails that extended to the bottom of the reflection profiles resulted in excellent discrimination of the various burial scenarios. Further, the horizontal slices were important to illustrate the grid data as a whole at different depths to illustrate the spatial distribution between targets. Overall, the pig carcass covered with a layer of rocks (1C) and the pig carcass wrapped in a tarpaulin (1D) provided the best responses out of each of the burial scenarios. It is clear that the pig carcasses with items added to the graves produced better resolution compared to the pig carcasses with nothing added.
CHAPTER FIVE: SEARCH GUIDELINES AND CONCLUSIONS

Search Guidelines

This research has shown that there are a number of considerations that law enforcement personnel can take into account when preparing for a search as well as when conducting a search for a buried body using geophysical tools. Certain guidelines both prior to and after the search can benefit law enforcement by ensuring that the search is conducted both properly and effectively. First, it is extremely important to have a forensic anthropologist or archaeologist with geophysical experience at a scene to assist with the search. The knowledge that a forensic anthropologist has for basic body searches, as well as for operating geophysical tools can be extremely beneficial for a forensic case involving clandestine burials. Not only is it difficult to operate various geophysical tools, but the processing and interpretation of the data in the laboratory requires time and expertise that is usually not recognized by law enforcement personnel.

Second, there are many site conditions that need to be taken into consideration. If the target in question is located in a wooded area or an area filled with a lot of debris, both a GPR and a conductivity meter may not be the best option. GPR is best on a flat surface with minimal ground disturbances. GPR will detect certain disturbances including tree stumps, root mats, and other site disturbances and if the site is not flat and is interfered by natural disturbances, a GPR would not be a viable option. On the other hand, GPR is a good option for searches on concrete or blacktop. A GPR survey can be performed on these surfaces and if a certain area is highlighted, minimal invasive testing can be conducted in relation to the areas that are
highlighted. Sites that are heavily saturated can also affect the results that are obtained because too much moisture in the ground surface can affect the size of the reflection features that are detected. Sites with standing water are also not a viable option because water can ruin the operation of not only GPR, but many other geophysical tools. On the other hand, a little moisture can sometimes increase the resolution of a reflection feature because the moisture will be retained in the disturbed soil from the burial.

Third, it is important to include multiple geophysical tools to assist in the search, if time permits. The use of multiple geophysical tools can benefit a search by complementing the results or lack of results from the various tools. For example, this research has proven that a conductivity meter is not of beneficial use when locating buried bodies, and that although a 500-MHz antenna for a GPR is a beneficial tool, the 250-MHz antenna may be a better option. Whether for forensic investigations or for archaeological work, a combination of geophysical techniques is recommended (Nobes, 2000). A combination of geophysical techniques is always more reliable than just relying on one method. According to Nobes (2001:721), “Not only can one compare and contrast the anomalies, but some techniques are better suited to wide coverage in a short period of time, and others are better suited to detailed subsurface mapping.”

Fourth, proper transect spacing also needs to be kept in mind. If time permits, having a tight transect spacing during a forensic search is the most beneficial for maximum resolution and delineation of forensic targets. It is important to use a transect spacing that will minimize the chance of not detecting a body or associated evidence because transects that are spaced too wide may overlook potentially vital areas. A small transect spacing of 0.25 m was important because
when reflection profiles are spaced in closely spaced transects, an important three-dimensional cube was created that produced very precise images of features that may have gone undetected (Conyers, 2006b). Further, tighter transects result in more data, and the potential for the delineation of forensic targets that may have gone undetected with larger transect spacing. Transect spacing also should be chosen based on the needs of the forensic search. For large objects like human bodies, extremely small transects are not needed.

Lastly, it is important that after an initial assessment is made in the field when using GPR, that the data be taken back to the laboratory for further processing and interpretation. Not only is this important to increase the resolution of the reflection features that are detected, but it is equally as important to remove some of the clutter or unknown features that are associated around the burial. Schultz (2008) mentions that processing the GPR files by increasing the resolution can also be beneficial for interpretation of the grave characteristics and soil stratigraphy. Usually, an evaluation on the need for further data processing can be determined during the initial in-field assessment. If there is a reduced response from an older burial or clutter that may obscure the resolution of a reflection feature, processing of the data should be considered to increase the resolution of the targets in question (Schultz, 2008).

Conclusions

Controlled geophysical research has proven to be a very valuable asset that can be applied in real-life forensic cases. The information gathered from controlled research can offer investigators vital tools that can save time when searching for clandestine burials containing a
buried body, as well as the capability of ensuring that a search utilizing geophysical tools offers maximum results to either locate a buried body or clear a suspected area where a body was thought to have been buried. Controlled research also provides an opportunity for operators to gain valuable experience in order to maximize the benefits of a specific geophysical tool. Further, the environment that controlled research provides to study the effects of detecting clandestine burials can provide certain guidelines that investigators can apply during real-life forensic casework.

Overall, the outcome of this research produced a number of interesting results for detecting various burial scenarios with the use of GPR and conductivity. First, this research showed that GPR is recommended over a conductivity meter when searching for buried bodies. The conductivity meter may not be a viable option because this research showed that none of the various burial scenarios were detected throughout the twelve months of data collection. Second, both antennae for the GPR provided maximum resolution and delineation of the various burial scenarios. Both antennae were able to detect many of the burials throughout the twelve months of data collection. Third, the 250-MHz antenna may be a more viable option than the 500-MHz antenna. Even though a 500-MHz antenna provides increased resolution of the subsurface compared to a 250-MHz antenna, it also detects unknown features that may mask the forensic targets. The 250-MHz antenna provided much easier discrimination of the burial scenarios. Thus, a 250-MHz antenna may be a viable option during a forensic search. Lastly, the results from this research showed that if time permits, the use of multiple geophysical technologies, specifically, multiple GPR antennae, would be recommended instead of just relying on one
method, because if one geophysical method proves to be unsuccessful, the inclusion of another may result in maximum delineation and resolution of the forensic targets.

Utilizing multiple GPR imagery options including reflection profiles and horizontal slices also provided maximum resolution and delineation of the various burial scenarios. The use of multiple imagery options should be considered during a real-life forensic search for buried bodies. The reflection profiles provided excellent views of a single transect over the burials and comparisons of multiple profiles illustrated which transects provided the maximum results. The reflection profiles were also an excellent indicator into the approximate depth of each of the burials. The horizontal slices were an excellent option that showed the whole research grid at different depths. With the horizontal slices, the spatial distribution of each of the burials was able to be illustrated. The horizontal slices were also able to provide both the X and Y data together, thus maximizing the results from data that were collected. Overall, both imagery options provided delineation and resolution of the burials, and if both options can be included within a forensic search for a clandestine burial, maximum results can be obtained.

Lastly, this research indicated that the burials with items added to the pig carcasses provided increased resolution and delineation when viewing both the reflection profiles and horizontal slices compared to the pig carcasses with nothing added to the graves. The pig carcass covered with a layer of rocks (1C) and the pig carcass wrapped in a tarpaulin (1D) provided the best resolution throughout the twelve months of data collection. On the other hand, the deep pig carcass with nothing added to the grave (1B) and the pig carcass wrapped with a blanket (2D) produced the poorest resolution. The various soil horizons within the research grid
along with the levels of moisture within the burials also played a role in the levels of detection. The higher resolution from the 500-MHz antenna showed that the burials were somewhat masked by the presence of the hard spodic horizon within the grid. This was not as much of a concern with the 250-MHz antenna as the forensic targets were easier to discriminate. Finally, higher levels of moisture within the burials due to seasonal storms provided increased resolution of the targets especially during the middle months of the data collection period.
APPENDIX A: CONDUCTIVITY CONTOUR MAPS
Figure A1: Conductivity map for pigs two months after burial
Figure A2: Conductivity map for pigs three months after burial
Figure A3: Conductivity map for pigs four months after burial
Figure A4: Conductivity map for pigs five months after burial
Conductivity Readings for Pigs at Six Months

Figure A5: Conductivity map for pigs six months after burial
Figure A6: Conductivity map for pigs seven months after burial
Figure A7: Conductivity map for pigs eight months after burial
Figure A8: Conductivity map for pigs nine months after burial
Figure A9: Conductivity map for pigs ten months after burial
Figure A10: Conductivity map for pigs eleven months after burial
Figure A11: Conductivity map for pigs twelve months after burial
APPENDIX B: GROUND-PENETRATING RADAR 500-MHZ REFLECTION PROFILES
MONTH 2

Figure B1: GPR reflection profile using the 500-MHz antenna of Row 1 at 2 months

Figure B2: GPR reflection profile using the 500-MHz antenna of Row 2 at 2 months
MONTH 3

Figure B3: GPR reflection profile using the 500-MHz antenna of Row 1 at 3 months

Figure B4: GPR reflection profile using the 500-MHz antenna of Row 2 at 3 months
MONTH 4

Figure B5: GPR reflection profile using the 500-MHz antenna of Row 1 at 4 months

Figure B6: GPR reflection profile using the 500-MHz antenna of Row 2 at 4 months
MONTH 5

Figure B7: GPR reflection profile using the 500-MHz antenna of Row 1 at 5 months

Figure B8: GPR reflection profile using the 500-MHz antenna of Row 2 at 5 months
MONTH 6

Figure B9: GPR reflection profile using the 500-MHz antenna of Row 1 at 6 months

Figure B10: GPR reflection profile using the 500-MHz antenna of Row 2 at 6 months
MONTH 7

Figure B11: GPR reflection profile using the 500-MHz antenna of Row 1 at 7 months

Figure B12: GPR reflection profile using the 500-MHz antenna of Row 2 at 7 months
MONTH 8

Figure B13: GPR reflection profile using the 500-MHz antenna of Row 1 at 8 months

Figure B14: GPR reflection profile using the 500-MHz antenna of Row 2 at 8 months
MONTH 9

Figure B15: GPR reflection profile using the 500-MHz antenna of Row 1 at 9 months

Figure B16: GPR reflection profile using the 500-MHz antenna of Row 2 at 9 months
MONTH 10

Figure B17: GPR reflection profile using the 500-MHz antenna of Row 1 at 10 months

Figure B18: GPR reflection profile using the 500-MHz antenna of Row 2 at 10 months
MONTH 11

Figure B19: GPR reflection profile using the 500-MHz antenna of Row 1 at 11 months

Figure B20: GPR reflection profile using the 500-MHz antenna of Row 2 at 11 months
MONTH 12

Figure B21: GPR reflection profile using the 500-MHz antenna of Row 1 at 12 months

Figure B22: GPR reflection profile using the 500-MHz antenna of Row 2 at 12 months
APPENDIX C: GROUND-PENETRATING RADAR 500-MHZ
HORIZONTAL SLICES
MONTH 2

Figure C1: GPR horizontal slice using the 500-MHz antenna at 2 months. The horizontal slice is approximately 0.87 m in depth (14.93 ns).
Figure C2: GPR horizontal slice using the 500-MHz antenna at 3 months. The horizontal slice is approximately 0.76 m in depth (12.13 ns).
MONTH 4

Figure C3: GPR horizontal slice using the 500-MHz antenna at 4 months. The horizontal slice is approximately 0.95 m in depth (28.72 ns).
Figure C4: GPR horizontal slice using the 500-MHz antenna at 5 months. The horizontal slice is approximately 0.84 m in depth (25.46 ns).
MONTH 6

Figure C5: GPR horizontal slice using the 500-MHz antenna at 6 months. The horizontal slice is approximately 0.89 m in depth (17.14 ns).
MONTH 7

Figure C6: GPR horizontal slice using the 500-MHz antenna at 7 months. The horizontal slice is approximately 0.94 m in depth (28.59 ns).
MONTH 8

Figure C7: GPR horizontal slice using the 500-MHz antenna at 8 months. The horizontal slice is approximately 0.85 m in depth (14.27 ns).
MONTH 9

Figure C8: GPR horizontal slice using the 500-MHz antenna at 9 months. The horizontal slice is approximately 0.80 m in depth (24.32 ns).
MONTH 10

Figure C9: GPR horizontal slice using the 500-MHz antenna at 10 months. The horizontal slice is approximately 0.71 m in depth (21.59 ns).
MONTH 11

Figure C10: GPR horizontal slice using the 500-MHz antenna at 11 months. The horizontal slice is approximately 0.78 m in depth (23.56 ns).
MONTH 12

Figure C11: GPR horizontal slice using the 500-MHz antenna at 12 months. The horizontal slice is approximately 0.80 m in depth (28.55 ns).
APPENDIX D: GROUND-PENETRATING RADAR 250-MHZ REFLECTION PROFILES
MONTH 2

Figure D1: GPR reflection profile using the 250-MHz antenna of Row 1 at 2 months

Figure D2: GPR reflection profile using the 250-MHz antenna of Row 2 at 2 months
MONTH 3

Figure D3: GPR reflection profile using the 250-MHz antenna of Row 1 at 3 months

Figure D4: GPR reflection profile using the 250-MHz antenna of Row 2 at 3 months
MONTH 4

Figure D5: GPR reflection profile using the 250-MHz antenna of Row 1 at 4 months

Figure D6: GPR reflection profile using the 250-MHz antenna of Row 2 at 4 months
MONTH 5

Figure D7: GPR reflection profile using the 250-MHz antenna of Row 1 at 5 months

Figure D8: GPR reflection profile using the 250-MHz antenna of Row 2 at 5 months
MONTH 6

Figure D9: GPR reflection profile using the 250-MHz antenna of Row 1 at 6 months

Figure D10: GPR reflection profile using the 250-MHz antenna of Row 2 at 6 months
MONTH 7

Figure D11: GPR reflection profile using the 250-MHz antenna of Row 1 at 7 months

Figure D12: GPR reflection profile using the 250-MHz antenna of Row 2 at 7 months
MONTH 8

Figure D13: GPR reflection profile using the 250-MHz antenna of Row 1 at 8 months

Figure D14: GPR reflection profile using the 250-MHz antenna of Row 2 at 8 months
MONTH 9

Figure D15: GPR reflection profile using the 250-MHz antenna of Row 1 at 9 months

Figure D16: GPR reflection profile using the 250-MHz antenna of Row 2 at 9 months
MONTH 10

Figure D17: GPR reflection profile using the 250-MHz antenna of Row 1 at 10 months

Figure D18: GPR reflection profile using the 250-MHz antenna of Row 2 at 10 months
MONTH 11

Figure D19: GPR reflection profile using the 250-MHz antenna of Row 1 at 11 months

Figure D20: GPR reflection profile using the 250-MHz antenna of Row 2 at 11 months
MONTH 12

Figure D21: GPR reflection profile using the 250-MHz antenna of Row 1 at 12 months

Figure D22: GPR reflection profile using the 250-MHz antenna of Row 2 at 12 months
APPENDIX E: GROUND-PENETRATING RADAR 250-MHZ HORIZONTAL SLICES
MONTH 2
(shallow)

Figure E1: GPR horizontal slice using the 250-MHz antenna at 2 months. The horizontal slice is approximately 0.10 m in depth (4.49 ns)
MONTH 2
(deep)

Figure E2: GPR horizontal slice using the 250-MHz antenna at 2 months. The horizontal slice is approximately 0.74 m in depth (21.73 ns)
MONTH 3
(shallow)

Figure E3: GPR horizontal slice using the 250-MHz antenna at 3 months. The horizontal slice is approximately 0.13 m in depth (3.80 ns).
MONTH 3
(deep)

Figure E4: GPR horizontal slice using the 250-MHz antenna at 3 months. The horizontal slice is approximately 0.71 m in depth (20.92 ns)
Figure E5: GPR horizontal slice using the 250-MHz antenna at 4 months. The horizontal slice is approximately 0.80 m in depth (32.84 ns)
MONTH 5

Figure E6: GPR horizontal slice using the 250-MHz antenna at 5 months. The horizontal slice is approximately 0.80 m in depth (31.20 ns)
Figure E7: GPR horizontal slice using the 250-MHz antenna at 6 months. The horizontal slice is approximately 0.83 m in depth (27.60 ns)
Figure E8: GPR horizontal slice using the 250-MHz antenna at 7 months. The horizontal slice is approximately 0.90 m in depth (31.0 ns)
MONTH 8

Figure E9: GPR horizontal slice using the 250-MHz antenna at 8 months. The horizontal slice is approximately 0.95 m in depth (28.97 ns)
MONTH 9

Figure E10: GPR horizontal slice using the 250-MHz antenna at 9 months. The horizontal slice is approximately 0.89 m in depth (26.98 ns)
MONTH 10

Figure E11: GPR horizontal slice using the 250-MHz antenna at 10 months. The horizontal slice is approximately 0.82 m in depth (24.71 ns)
MONTH 11

Figure E12: GPR horizontal slice using the 250-MHz antenna at 11 months. The horizontal slice is approximately 0.93 m in depth (30.16 ns).
Figure E13: GPR horizontal slice using the 250-MHz antenna at 12 months. The horizontal slice is approximately 0.83 m in depth (25.18 ns).
APPENDIX F: MONTHLY GPR IMAGERY RESULTS AND MOISTURE DATA TABLES
### 500-MHz Antenna

**Table F1: Moisture data for each burial scenario (500-MHz antenna)**

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**Table F2: Monthly imagery results for each burial scenario based on reflection profiles (500-MHz antenna)**

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Table F3: Monthly imagery results for each burial scenario based on horizontal slices
(500-MHz antenna)

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### 250-MHz Antenna

#### Table F4: Moisture data for each burial scenario (250-MHz antenna)

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#### Table F5: Monthly imagery results for each burial scenario based on reflection profiles (250-MHz antenna)

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Table F6: Monthly imagery results for each burial scenario based on horizontal slices  
(250-MHz antenna)

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