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Mass Grave Detection with the use of Geophysics

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Introduction

Since the 1980s and the investigations into the crimes committed by the Argentine Military Juntas, there has been an increase in international forensic investigations into war crimes, genocide, and crimes against humanity. Such investigations have taken place in the former Yugoslavia, Rwanda, Guatemala, and many other countries around the world and a multitude of mass graves have been found. The investigations that surround crimes involving mass graves have brought upon research on how to best find clandestine graves. Archaeo-geophysical surveys are of interest in attempts to find clandestine graves as they are non-invasive and can be conducted rather quickly, as opposed to traditional archaeological methods.

The Anthropology Research Facility (ARF) at the University of Tennessee allows for this type of research to be conducted with human remains, due to the body donation program. In 2013, the Mass Graves Project was started by Dr. Amy Mundorff. This project researches the many factors of mass graves, including their detection. A six-person grave was dug in February 2013 with the unclothed remains of donors who had not undergone the decomposition process. At the same time, a three- person grave, a single-person grave, and a 32 person grave were also incorporated at ARF.

Beginning in October 2017, I began to investigate different archaeo-geophysical techniques to detect mass graves. My aim was to identify which geophysical survey equipment was best able to detect the presence of clandestine graves. The investigation also aimed to determine if seasonality and length of time affect the detection of clandestine graves. For this study, clandestine graves are defined as unmarked, non-traditional burials (meaning the absence of a casket and hand-dug), less than one meter deep.

Literature Review/Background

Archaeo-geophysical surveys are relatively new to American archaeology. To detect a site, traditional practices with the United States utilized shovel test pits (STPs). Shovel test pits are time consuming, expensive, and usually yield low-frequency results (Kvamme 2003). Geophysical surveys cover a much larger area in shorter time when compared to STPs (Kvamme 2003 and Ch'ng et al 2011). Due to this, they are also more cost efficient. The equipment used to conduct these surveys are ground penetrating radar machines, resistivity machines and their variants, and magnetometers and their variants. The output data images from these machines are given in continuous gray scales which allows researchers to see contrasts more easily (Kvamme 2003). Contrasts within the gray-scale images are referred to as anomalies (Kvamme 2003). These machines are typically used within archaeological surveys to find cultural material beneath the ground, such as collapsed walls or hearths. Only recently, have these instruments been applied to the detection of graves.

Magnetometers have been popular in use due to their success in finding cultural features. Magnetometers are able to pick up various types of anomalies because they detect magnetism. Magnetometers yield high positive readings when a pit is dug and filled back in with topsoil because topsoil is rich in minerals, including ferrous minerals, which are highly magnetic (Fassbiner 2015). However, when a pit is dug and immediately filled back in with the same soil, a magnetometer will yield a highly negative reading due to the disturbance and intermixing of the mineral rich topsoil and the rest of the underlying soil (Fassbinder 2015). This is highly useful when looking for recently dug graves. Moreover, the magnetometer yields massive, high frequency signals from burned material because the way in which fire carbonizes material (Fassbinder 2015). This could prove useful for a site with burned remains. Finally, in graves where bones are decomposing, the magnetometer may obtain a high reading due to the calcium leaked into the soil (Fassbinder 2015). This could be important for older graves.

However, there are downsides to the use of a magnetometer. Magnetometers experience a high rate of background noise and interference. The type of bedrock underlying a site can give very high readings, for something like granite, or very low readings for limestone and similar rocks (Fassbinder 2015). Similarly, if the surveyed site is surrounded by a metal gate or powerlines, or even if the researcher has some metal on their person (such as the button on jeans), the magnetometer reading may yield inconclusive results due to interference. Sabrina Buck experienced this in her 2003 study to locate graves. The readings from the magnetometer were unusable to which she suspected interference from a fence as the cause (Buck 2003). Furthermore, there is no baseline magnetic reading for soils and soil types across the world because soil magnetism depends on a multitude of factors within a given environment (Fassbinder 2015). For this study, a gradiometer was used. A gradiometer has two vertically oriented magnetometers that measure the "local magnetic field gradient over a sample position" between them (Pringle et al 2008:1406). Consequently, gradiometers are even more sensitive to background noise than magnetometers since they have two magnetometers.

Resistivity also yields great results in archaeo-geophysical surveys. Electrical resistivity sends electrical currents through the ground and measures the amount of resistance. There is also electrical conductivity which measures the opposite of resistivity. Similarly, there is electrical resistivity tomography (ERT) which allows for depth slice maps (Büyüksarac et al 2013). However, for this study, I will focus on electrical resistivity. Electrical resistivity yields low signals when the ground moisture is high. This is due high water content, which leads to less resistance when the electricity is pulsing through the ground. Given this, drier, thicker soils will yield higher resistance values. Additionally, when the electric pulses encounter an object, such as brick from a collapsed wall, the resistance values read higher than the surroundings and indicate an anomaly. Areas in which there is significant moisture content compared to the surrounding soil will also yield an anomaly, with the resistivity signal low. However, resistivity can be laborious and time consuming. So, if there are time and labor constraints, this is not the best method to use for archaeo-geophysical surveys.

Furthermore, ground penetrating radar (GPR) has also been a popular method to investigate large archaeological sites. GPR works quickly and with relative ease in open areas. In heavily wooded areas, the size of the machine can make the survey difficult, but not impossible. In most of the literature, researchers state that GPR does not work well within clay soils. This is incorrect because smaller MHz antennae used (<400MHz) in conjunction with the correct dielectric constant for the clay/loam soil type (9), yield similar results to other soil types (Ruffell 2005 and Buck 2008). GPR works by sending radar pulses into the ground that reflect back to the antenna. The antenna measures the speed and strength in which the signal returns. If there is an anomaly in the soil, the signal will return to the antenna at a different rate than the surrounding area. These anomalies are seen as hyperbolae when running the equipment (Pringle et al 2008). In addition, GPR allows for three-dimensional imaging. 3D imaging "provides multiple perspectives from which to view and analyze the subsurface" and also allows for more accurate interpretations of the "subsurface reflection patterns" (Doolittle and Bellantoni 2010:942). 3D imaging also allows for the data to be looked at in time/depth slices, so each layer of the subsurface can be analyzed. Downsides to the use of GPR include its susceptibility to interference, although less than magnetometers, and that it can yield false positives due to the environment and natural objects within soil.

Research involving archeao-geophysical surveys for the detection of graves is relatively new. Studies yield mixed results within cemeteries and for clandestine graves. Different environments and different burial types yield different results for all three equipment types, magnetic imaging, resistivity, and GPR, with no clear best method. However, GPR has been used the most in the search for clandestine graves.

Carlo Piga and his colleagues conducted a study in 2014 over an urban archaeological site. Piga et al (2014) used GPR and thermal infrared survey to detect different archaeological Punic burial tombs in Villamar, Italy. When they used the two technologies together, their results showed location and type of tomb. The GPR detected collapsed walls and the larger tombs, but was unable to detect the smaller tombs (Piga et al 2014). The thermal survey was able to detect all of the tombs and the GPR results were then used to verify the thermal images (Piga et al 2014). Areas where the GPR struggled to get a reading included a well, so there could have been too much noise from the structure of the well or the ground could have been too saturated in that area. However the thermal survey was able to detect anomalies around the well. The GPR did not yield any false positives in this study and the authors suggest using the two methods together for accurate results (Piga et al 2014).

More studies have also had high success when using GPR within cemeteries. Alastair Ruffell (2005) successfully identified a known burial in a cemetery in Northern Ireland but was unable to detect a clandestine burial thought to be in the cemetery. The GPR was correct in not detecting an anomaly, as the burial of the individual was found elsewhere (Ruffell 2005). Ruffell (2005) used a 400 MHz antenna to compensate for the clay soils in Northern Ireland and obtained accurate results. Bruce Bevan (1991) also had high success with GPR in multiple cemetery sites. The GPR was able to identify multiple burials across multiple sites, while resistivity and magnetometers were not as consistent (Bevan 1991).

Moreover, Pringle et al (2008) had success with electrical resistivity in their study that simulated a single forensic burial. Due to laws in the UK, Pringle et al (2008) used plastic remains covered with meat from the local store and saline to represent body tissue and fluid. Electrical resistivity detected the burial at one and three months, with the best results at three months. They saw an expansion of the readings at the three month collection, suggesting some decomposition fluid had spread within the ground (Pringle et al 2008). The magnetometer was unable to detect the burial at both the one and three month collections. However, GPR was able to detect anomalies at both collections when data was processed into 3D time slices; when the data was processed in 2D, anomalies could not be seen (Pringle et al 2008). From their results, Pringle et al (2008) suggests using resistivity for recent burials as it detected decomposition fluids.

Recently, research into detecting clandestine burials in the field and experimental studies on clandestine burials has garnered attention. These studies and experiments are no longer in the classic cemetery setting, so they have less detectable objects, as headstones and caskets are not present. However, these studies yield more mixed results. Sabrina Buck (2003) used GPR, resistivity, and a magnetometer over a few sites. From her research, GPR yielded the best results, but these were still not substantial (Buck 2003). After the first trial, Buck had to stop using the resistivity machine as it was too time consuming and did not yield results from a burial in a field (Buck 2003). The magnetometer was also not used frequently due to its susceptibility to background noise (Buck 2003). Buck (2003) attempted to read the GPR results ‘real time,’ which means looking at the hyperbolae while the machine running. While the GPR picked up many anomalies, the anomalies were not human remains. In a backyard search for a human burial, the GPR detected a diaper and two dog skeletons (Buck 2003). Moreover, the data had to be processed instead of using 'real time' interpretation (2003). While it is significant that the GPR detected anomalies, it was unable to detect human remains in the field (Buck 2003). However, this does not mean that geophysical surveys always yield insufficient results.

A few studies have been conducted using pig remains to simulate clandestine burials. Salsarola et al (2015) conducted a 30 month study on clandestine graves with the use of 11 pig carcasses in Italy. The pigs were buried individually, except for two which were buried together (Salsarola et al 2015). Pigs have similar weights and fat to muscle ratios to adult humans, which is why they were used (Salsarola et al 2015). The results of this study found that GPR detected the burials up to 52 weeks (Salsarola et al 2015). After 52 weeks, GPR was no longer able to detect the remains. At this point, the remains were skeletonized (Salsarola et al 2015). This is known due to systematic excavations of the pig burials at different points during the study (Salsarola et al 2015). After each data collection, one of the graves was dug up and the rate of decomposition on the remains was assessed (Salsarola et al 2015). The results from this study gave strong evidence for GPR and clandestine grave detection for more recent burials.

Molina et al (2015) conducted a similar study, however they were able to use some human remains to simulate older burials. Molina et al (2015) used pig remains to represent recent burials and obtained archaeological, skeletonized human remains to use and represent older burials. There were also burials in which human remains were burnt and beheaded, as this is common in Columbia (Molina et al 2015). Additonally, they used two different grave depths seen in Columbia, these depths are 0.8m and 1.2m below ground level (graves in the United States usually average 1m or less) (Molina et al 2015). This study only used GPR to detect the simulated burials (Molina et al 2015). The GPR detected the fresh pig burials up to 7 months (Molina et al 2015). For the skeletonized and burnt remains, GPR was largely unable to detect the burials (Molina et al 2015). However, the soil moisture content was unusually high when the study was conducted, at over 50% (Molina et al 2015). The high moisture content of the soil could have affected the results of the GPR data. In addition, a magnetometer may be better suited to detect burnt remains. Nevertheless, the results of this study are important as they show a threshold of less than a year for GPR to detect clandestine burials. Salsorola et al (2015) had a threshold of about one year for the GPR to detect their simulated clandestine burials.

While the studies above and others similar are valuable, the most important studies pertaining to this paper are from Büyüksarac et al (2013) and Fernández-Álvarez et al (2016). Büyüksarac et al (2013) conducted a study over a Turkish cemetery at Gallipoli Peninsula in Turkey from WWI. The burials in this cemetery were mass without caskets present, as the casualties at this site were large (Büyüksarac et al 2013). Büyüksarac et al (2013) used GPR and resistivity over the site and detected a large anomaly at the southern part of the suspected cemetery. This anomaly is thought to be a mass burial (Büyüksarac et al 2013). Other anomalies were identified but they were not as large and are not thought to represent grave. While it is highly likely that the anomaly detected in the southern part of the cemetery is a burial, it is not conclusive as Turkish law prohibits excavations at the site (Büyüksarac et al 2013). Nevertheless, these findings are valuable as a probable burial was detected decades after internment.

Similarly, Fernández-Álvarez et al (2016) conducted a GPR survey over a suspected mass grave form the Spanish Civil War (1936-1939). The GPR detected a large anomaly and after an archaeological excavation of the area where the anomaly presented, a mass grave was found (Fernández-Álvarez et al 2016). The conclusive mass burial results provide evidence of GPR detection of mass burials after significant time. I theorize that GPR detects these old, mass graves due to the amount of remains present. Other studies had fewer remains or a high moisture within the soil, possibly leading to the lack of detection.

Materials and Methods

Geophysical techniques were used to examine the differences between disturbed soil and disturbed soil with interred human remains. Data were collected at the Anthropology Research Facility (ARF) over a six-person grave, a grave with the same dimensions without human remains, and a undisturbed control unit, using a Ground Penetrating Radar (GPR) TerraSIRch Subsurface Interface Radar (SIR) System 4000, a GPR SIR 3000, a resistivity RM15 meter and a Bartington Grad601 single access gradiometer meter. Both graves measure 70cm in depth. Replicate data were collected on three separate occasions to examine potential seasonal influences (Table 1).

The six-person and disturbed graves each measured 2m x 4m. The control area measures two meters across and is between the two graves. The soil at the site mainly consists of clay. To collect consistent data between trials and accurately record transects, a 7m x 11m grid that encompassed the entire site was established with 50cm markers, 25cm markers were later added. GPS points for the grid and graves were taken using a Trimble GeoXH 6000, a Tornado antenna of 1.7m length, and the S Bas corrective system. However, these data points projected incorrectly in ArcGIS and hand meter measurements of the graves' placement were taken to orient them within the data output images.

Ground Penetrating Radar

Below, Table 1 outlines the data collections for GPR.

Table 1: GPR Data Collections

Date	October 2017	August 2018	January 2019
GPR	SIR 4000	SIR 4000	SIR 3000 *4000 was unavailable*
Antenna	350 MHz	350 MHz	400 MHz *Antenna used for 3000*
Direction	NW to SE	SW to NE	SW to NE
Transects	50cm	25cm	25cm
Axis Collected	X and y-axis	y-axis	y-axis
Grid Size	7m (x) x 10m (y)	7m (x) x 10m (y)	7m (x) x 10m (y)

Only the first data collection went over both axes at 50cm transects. It was discovered after this collection that 25cm transects yielded better results and excluded the need to run the machine over both axes. The direction of movement was changed because the machines were better able to orient themselves starting at the southwest corner. Data collection began on the first meter, making the grid 7m x 10m as the first meter was heavily covered with trees and brush. Data was collected in a single direction, as opposed to a zigzag.

For all collections, the gain was set to 6 and the dielectric to 9. Nine was used for the dielectric constant to compensate for the clay-like soil at the site. The error rate is estimated at +/- 21 cm for all of these collections. Additionally, significant clearing of the site took place before all of these collections. Lots of brush and tree branches were cleared using hedge clippers and machetes. Nothing was pulled out of the ground in order to not disturb the soil. Moreover, leaves and grass were never cleared from the ground.

Once the collections were finished, I analyzed the raw data with RADAN for windows 8. I processed the data into time-slice depth images using the 3D QuickDraw.

Resistivity

Electrical resistivity data were collected in October 2017 using the RM15 resistivity meter. An unidentified animal dug a section over the six-person grave measuring approximately 120cm long and 35cm wide. However, it was surface digging so no remains were exposed. The same grid was used to collect the resistivity as the GPR, including starting on the 1st meter instead of the zero meter. However, the x-axis was shortened to 5 meters as there were natural obstacles preventing collection over the last 2 meters. Likewise, the electrical resistivity machine used only works in 5s and 10s of meters. We started data collection in the southwest corner along the y-axis and walked north. The data was collected in a zigzag along 50cm transects, as there was no need to collect in a single direction since a 3D grid was not being made. The last three rows were dummied out due to natural obstacles.

To process the resistivity meter, I used Terrasurveyor. The processed data was then transferred into jpeg images.

Resistivity data was only collected in October 2017 due to part of the equipment going missing and time constraints. This will be discussed in more detail in the limitations section.

Gradiometer

Also in October 2017, data was collected using the Bartington Grad601 single access gradiometer meter. The previously established grid was extended to 10m along the x-axis as the gradiometer can work around natural obstacles and only works in 10s of meters. For this, data was collected over a 10m by 10m grid, with the majority in the original 7m x 11m grid. Data collection started in the southwest corner and walked north like the resistivity. The transects were every 50cm and there were 16 counts per transect. The gradiometer data was also collected in a zigzag pattern.

To process gradiometer data, I used Terrasurveyor. For the gradiometer I switched the color scheme, so the dark gray represents high signals, while lighter gray and white represent lower signals.

Gradiometer data was only collected in October 2017 due to time constraints and lack of access. This will be discussed in more detail in the limitations section.

Results

Ground Penetrating Radar

The processed GPR results for all three data collections show a clear, high-frequency anomaly within the six-person grave. The disturbed soil section without remains and the control, sterile soil show almost no anomalies with all three data collections. Below, the following figures show the GPR processed image results at different time slice depths for all three data collections (Figures 1-6).

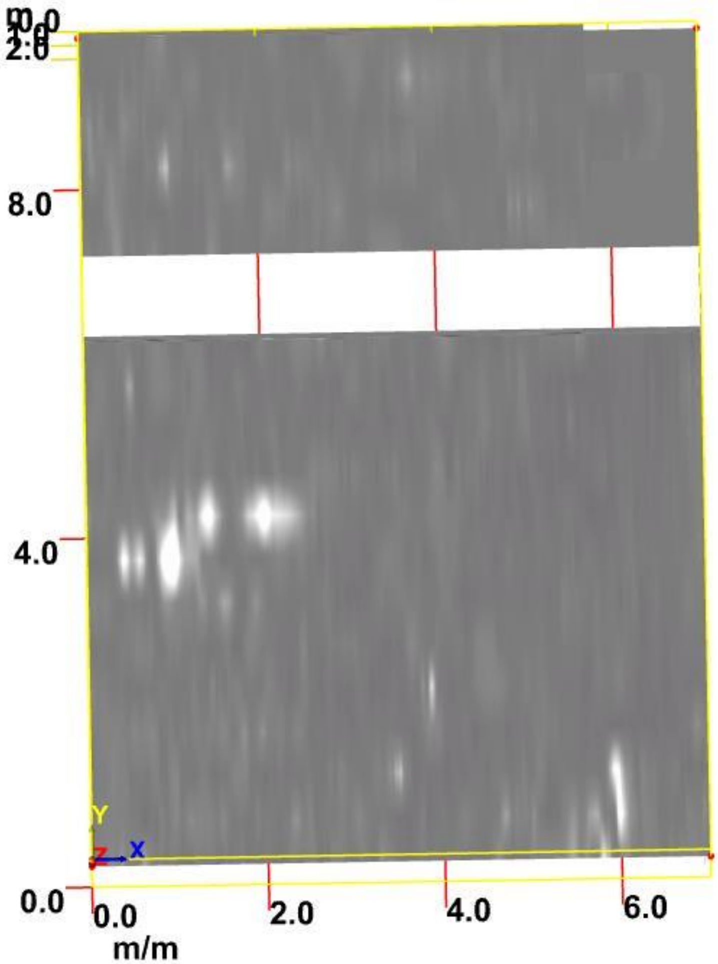

Figure 1: October 2017, 50cm depth; +/- 21cm error, 6 gain, 9 dielectric constant, 10cm thickness.

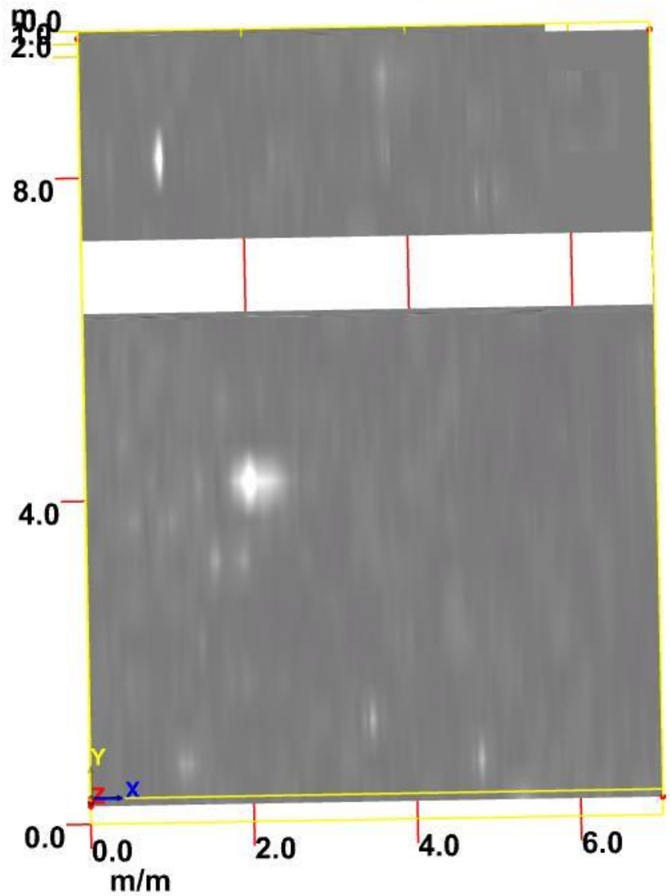

Figure 2: October 2017, 60cm depth; +/- 21cm error, 6 gain, 9 dielectric constant, 10cm thickness.

The blank white section seen in Figures 1 and 2 indicate corrupted data. The data was corrupted due to unknown reasons and is over the undisturbed, sterile soil. The six-person grave is within the 3m-5m on the y-axis and the 0.5m-4.5m on the x-axis with a 0.5m error rate (Figures 1 and 2). Both figures show a high-frequency, white signal coming from within the six-person grave dimensions. These frequencies represent an anomaly within the soil of the six-person grave. The disturbed soil control spans 7.5m-9.5m on the y-axis and has the same dimensions as the six-person along the x-axis (0.5 meter error). In Figure 1, there is a high frequency signal at the 6th meter on the x-axis and in Figure 2 there is a small signal coming from the outer dimension of the disturbed soil with no remains. The rest of the image shows a relatively continuous gray, with very little differentiation between signals.

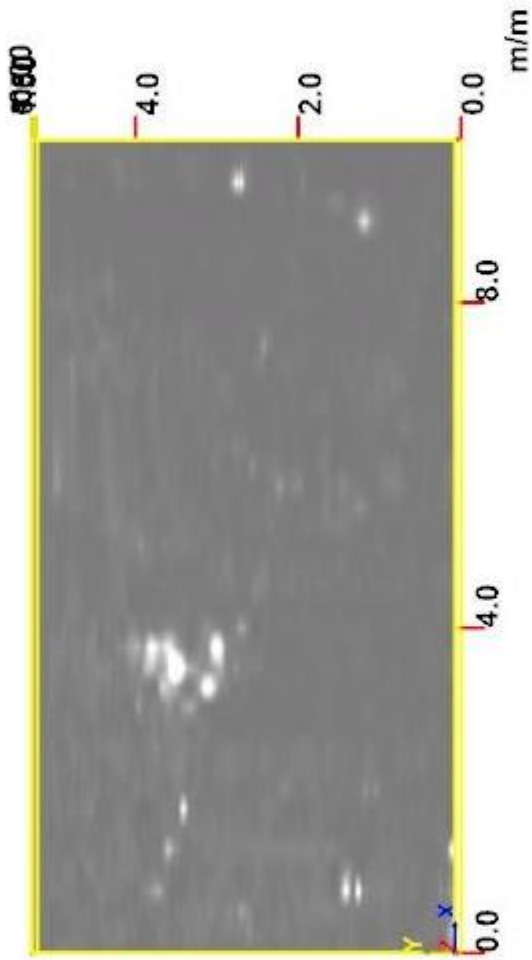

Figure 3: August 2018, 50cm depth, +/-21cm error, 6 gain, 9 dielectric constant, 10cm thickness

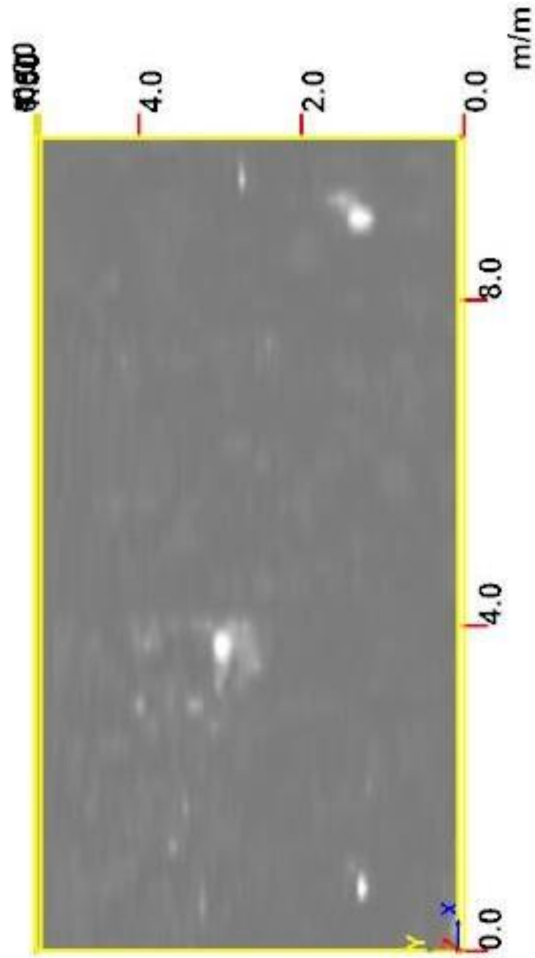

Figure 4: August 2018, 60cm depth, +/-21cm error, 6 gain, 9 dielectric constant, 10cm thickness

Figures 3 and 4 show similar results to Figures 1 and 2. The directionality was switched when this data was collected, so now the graves are within 2.5m-6.5m on the x-axis (short axis), with a 0.5m error. The y-axis (long axis) dimensions for the graves are the same as those on Figures 1 and 2. Once again, there is a strong, white signal within the six-person grave at both depths with almost no signals coming from elsewhere in the grid (Figures 3 and 4).

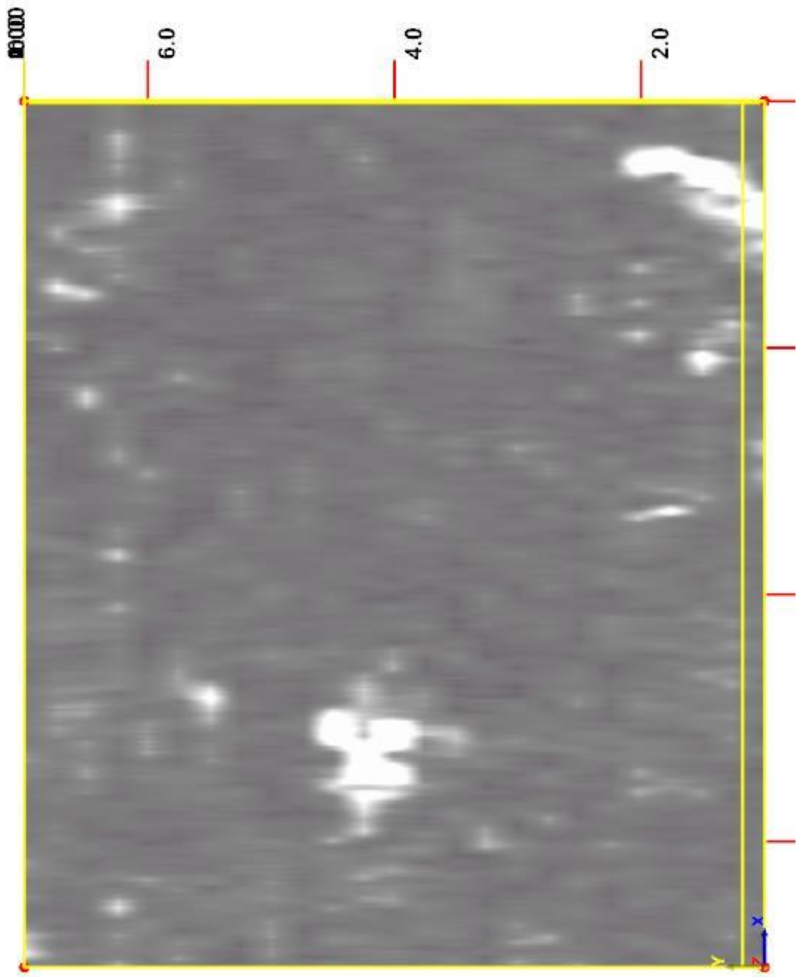

Figure 5: January 2019, 50cm depth, +/-21cm error, 6 gain, 9 dielectric constant, 10cm thickness

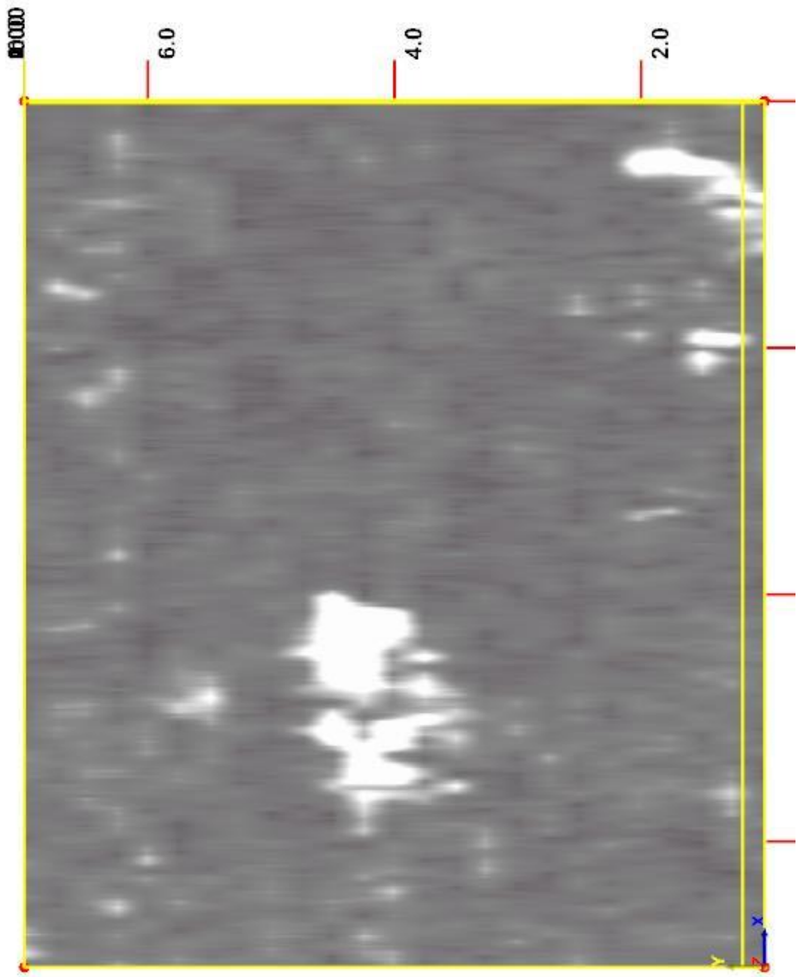

Figure 6: January 2019, 60cm depth, +/-21cm error, 6 gain, 9 dielectric constant, 10cm thickness

Figures 5 and 6 represent the January 2019 GPR 3000 collection. These images (Figures 5 and 6) have the same dimensions as Figures 3 and 4 because they have the same directionality. Once again, a high frequency, white signal appears within the dimensions of the six-person grave. In figure 5, the signal is appearing a little lower on the y-axis, between the 2nd and 4th

meters, however the signal is still within the six-person grave dimensions, just closer to the edge. The signal within Figure 6 closely aligns with Figures 1-4.

Resistivity

The placement of the graves and control section within Figure 7 are the same as in Figures 1 and 2. The resistivity data showed an anomaly slightly outside of the six-person grave in red and yellow (Figure 7). The six-person grave and undisturbed control section showed no anomalies. They also both yielded the same low resistance readings, seen in blue (Figure 7). The grave of disturbed soil with no remains yielded a higher resistance reading seen in red (Figure 7). The gray patches seen in the image are where the machine had to be dummied (Figured). The machine had to be dummied because the site is in a heavily wooded area and the electrical resistivity machine was unable to work around branches and rocks. The differences in the readings of the disturbed grave with no remains are directly next to areas where the machine was dummied.

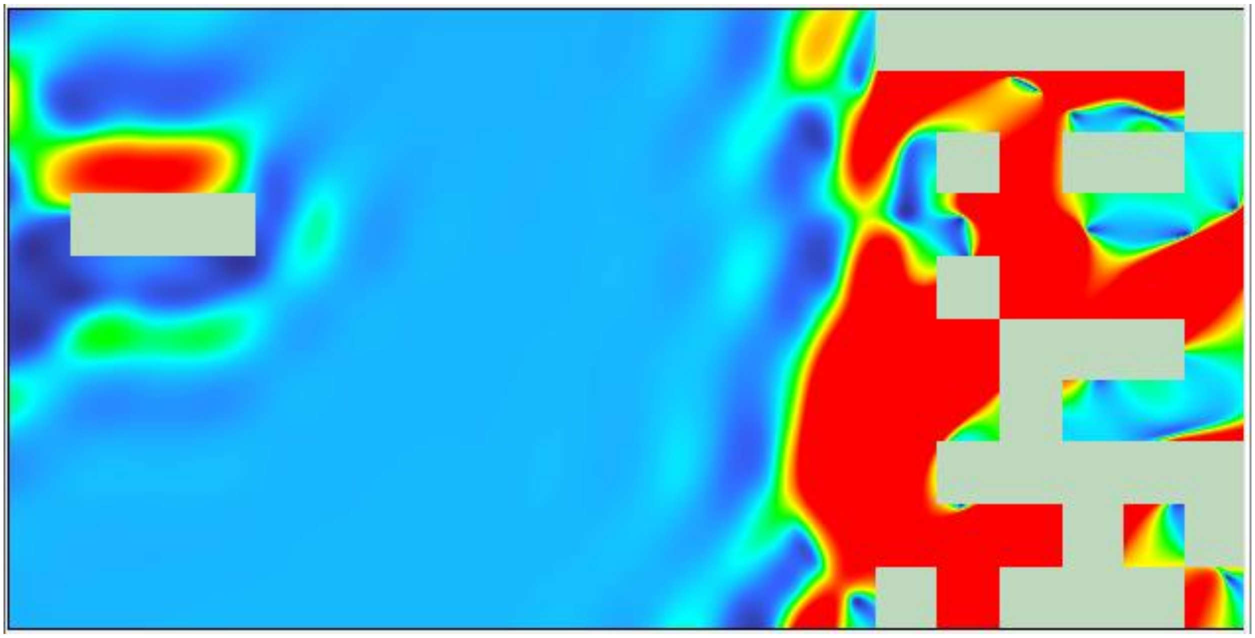

Figure 7: October 2017 Electrical Resistivity Collection

Gradiometer

The dimensions and placement of the graves and control within the grid in Figure 8 are the same as the dimensions in Figures 1 and 2. The gradiometer yielded one large, low-frequency anomaly located at the upper portion of the disturbed section with no remains (Figure 8). This reason for this low frequency is unknown. There is one high frequency anomaly connected to a low frequency anomaly on the outer edge of the six-person grave (Figure 8). The high frequency anomaly connected to the low frequency anomaly is at about the 3 meter mark on the y-axis and spans from the 3m to 5m mark on the x-axis. The y-axis is shown horizontally in this image, while the x-axis is the vertical axis (Figure 8). The rest of the image yields a continuous gray scale (Figure 8). It is important to note that the color scheme is reversed in this image, so the bright white anomalies are very low frequencies, while the dark gray and black anomalies are high frequencies. The green-gray blank areas in the image are places where the machine was dummied out.

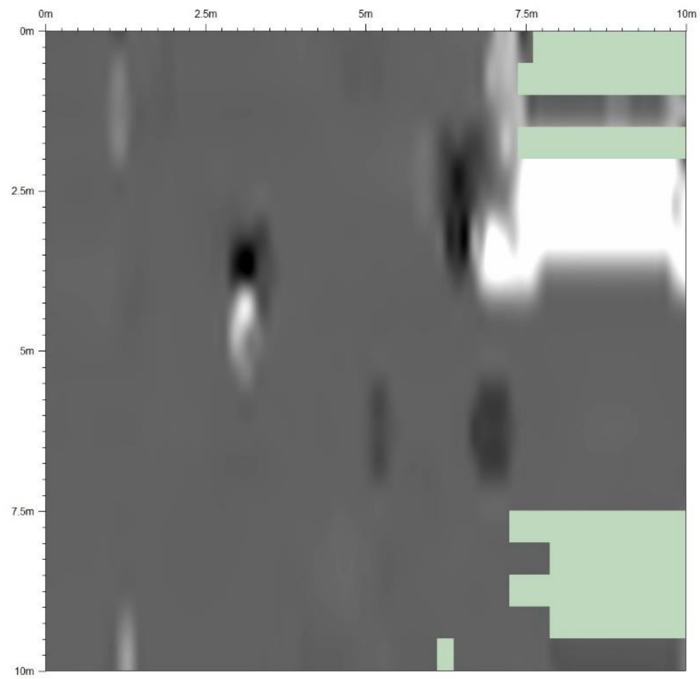

Figure 8: October 2017 Gradiometer Data

Discussion

Overall, the GPR data yielded the best results. The high frequency anomaly within the six-person grave represents the bodies interred there. The six bodies are stacked on top of one another, so the GPR is detecting this mass. The lack of anomalies throughout the rest of the grid demonstrates that the GPR was able to pick up the bodies and was not obtaining false positives within the undisturbed control or the disturbed with no remains. The GPR 3000 with the 400 MHz had the largest signal perhaps indicating the 400 MHz antenna was better for the environment of the site.

The GPR data has important implications for research into the detection of mass graves. For one, the GPR was able to detect graves that, at the first data collection, were 4.5 years old and at the last data collection, were 6 years old. This length of time extends well beyond the time frame of most previous studies conducted. Büyüksarac et al (2013) demonstrated a significant length of time but results could not be verified due to laws within Turkey. Equally important, seasonality did not affect the results of the GPR. This is important as the soil moisture content is extremely different between seasons, and previous studies struggled to acquire readings from GPR when the soil was either too wet or too dry (Molina et al 2015). Furthermore, many studies claimed GPR did not work well within clay soils. This study shows that the instrument can work within clay soils when a smaller MHz antenna is used, such as the 350 and 400 MHz used for this research. The antennae also measure deeper within the ground (up to 2 meters) which is useful when looking into graves, especially in places where clandestine graves may be deeper than 1 meter, such as in Columbia (Molina et al 2015).

Furthermore, the results suggest GPR is the ideal archaeo-geophysical survey method for the climate in Tennessee when attempting to locate clandestine graves. Areas with a similar climate should yield similar results. Additionally, the results from this study suggest GPR should be used to detect older burials. The results show that GPR provides a reliable starting point for forensic specialists when searching for clandestine mass graves. Forensic specialists could conduct a survey using GPR and find areas where a grave is more likely, cutting down search and excavation time. This could be extremely valuable for investigations that are time and cost sensitive.

The resistivity data, unfortunately, did not yield conclusive results. The differences in resistance levels within the disturbed grave with no remains surrounded areas where the machine was dummied. Implying that the different readings were probably coming from the objects that were blocking the neighboring areas from obtaining a reading. The area over the grave of disturbed soil had a significant amount of rocks, trees, and greenery. The tree and greenery roots are the probable cause for the high red readings and the low blue readings are most likely from the pockets of air surrounding the roots. The resistivity meter also had a loose probe, which could cause inaccurate readings. The loose probe could also explain why the resistivity was not picking up many anomalies. Furthermore, the anomaly that is directly to the left of the six-person grave could also be from branches. There was a bush that was clipped there, but not pulled out as to not disturb the soil. Since the bush was only trimmed, its branches and roots are still within the ground, likely leading to the anomaly seen there. Finally, the remains are more than likely skeletonized. It is probable that the resistivity meter is unable to pick up skeletonized remains, as other studies have not been able to obtain readings from graves with skeletonized remains while using a resistivity meter. However, more research needs to be conducted to conclude this.

The gradiometer data also yielded insufficient results within the six-person grave. The low, white reading at the edge of the six-person grave most likely shows the plastic datum located there. As for the dark, high reading connected to the datum, the cause is unknown. Moreover, the cause for the low reading over the top portion of the grave with only disturbed soil is also unknown. It would be expected to see the low reading over the entire grave as it was dug and immediately refilled with the same soil, however, this is not the case. An explanation could be that the latter half of the grave only containing disturbed soil has a rock face next to it. The high signal of the rock and the low signal of the grave could be balancing each other out. Furthermore, a similar explanation could attribute to the gray color seen over the six-person grave. As stated earlier, when bones begin to decompose, they leak calcium into the soil. A high calcium soil content will yield a high magnetic reading (Fassbinder 2015). However, like the grave with only disturbed soil, the six-person grave was dug and immediately filled back in with the same soil, which would yield a low signal. Therefore, a high and low signal could be mixing over the six-person grave, causing its gray color. However, the site is surrounded by a metal gate, which is the most likely cause for the lack of anomalies. As stated earlier, gradiometers are particularly sensitive to background noise, and the metal gate in the vicinity was probably detected by the gradiometer. Nevertheless, more research needs to be conducted.

Limitations

This study experienced a lot of difficulties. Large time constraints prevented the resistivity meter and gradiometer from being used in the second and third data collections. Moreover, the GPR SIR 3000 was used in the third data collection, as the 4000 was unavailable at the time. Additionally, I had to take hand measurements for the placement of the graves within the grid, as ArcGIS continuously projected the graves incorrectly. The GPS points that were taken to pinpoint the graves within the grid were also projected incorrectly within ArcGIS by over two meters. The reason for the incorrect projections is currently unknown. These incorrect projections led to my reliance on hand measurements when presenting my results, which are less accurate. Furthermore, different people operated the GPR machine each time, which could produce error within the results.

Future Directions

Multiple studies can be conducted from the results of this research project and others. More research involving the gradiometer and electrical resistivity machine needs to be conducted. Additionally, investigations into burned remains would be an interesting study to conduct with the gradiometer. However, more surveys over the current site should be done with the gradiometer first, to see if there was a confounding variable, such as the gate, which led to the lack of anomalies within this study. More research using the electrical resistivity machine over recent graves should also be conducted. Pringle et al (2008) had success using resistivity over a more recent grave, however, they were unable to use human remains. So, conducting a similar study with human remains could provide useful information for which machines should be used based on the age of a grave. Finally, studies looking into the vegetation that in context with mass graves could also be interesting.

Conclusion

The Mass Graves Project at the ARF allows for unique studies like this one. While this study had its difficulties, the implications are still important. GPR appears as the most reliable method to detect aged mass burials. GPR can also be used in a wide range of environments and study areas, making it more accessible than resistivity and gradiometers. Resistivity and gradiometers should be used in highly specific investigations due to their time consumption and susceptibility to interference, respectively. Furthermore, these methods may allow for mass burials to be found faster and more efficiently, leading to less cost. Due to this, more money could be allocated for identifications, the most important aspect of investigations surrounding mass graves.

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