Delineation and Resolution of Cemetery Graves Using a Conductivity Meter and Ground-Penetrating Radar

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ABSTRACT

This study was designed to compare the applicability of two geophysical instruments, a conductivity meter and ground-penetrating radar (GPR), to detect historical- and modern-period graves at Greenwood Cemetery in Orlando, Florida. A modern-period grid was set up in a section containing primarily shallow, vaulted, and marked burials. Conversely, an historical-period grid was constructed in an older section containing only five headstones that was believed to include multiple deep, nonvaulted, and unmarked graves. Both instruments detected multiple vaulted burials in the modern-period grid, while only the GPR detected the older nonvaulted burials in the historical-period grid. Neither instrument detected the backfill of the vertical grave shafts that consisted of homogenous sands. The use of various processing techniques allowed for determination of the best data collection procedures for maximum resolution of GPR grave anomalies when using horizontal slices. A transect interval spacing of 0.25 m was preferable to 0.5 m, and is recommended when performing surveys of cemeteries containing unmarked graves. Furthermore, if time constraints allow collecting data in one direction only, transects should be oriented perpendicular to the burials, if this orientation is known. When time is not an issue, maximum delineation and resolution of graves is obtained using a composite grid containing transects oriented in both X and Y directions.

Introduction

Geophysical instruments are routinely used to assist with the noninvasive detection of unmarked burials from a variety of contexts. In particular, ground-penetrating radar (GPR) has become a popular geophysical option for grave detection (Vaughn 1986; Bevan 1991; King et al. 1993; Nobes 1999; Davis et al. 2000; Conyers 2006a; Jones 2008). Archaeologists commonly use GPR at sites containing burials to document the location of unmarked graves for either creating accurate cemetery maps or for excavation of burials. This technology has proven useful for cemetery management by identifying areas containing unmarked graves. For example, GPR is important for locating unmarked burials that may be impacted during road-expansion activities near cemeteries. Also, the ability to locate unmarked graves is essential in cultural resource management (CRM) contexts because the discovery of unmarked burials in endangered areas can lead to stabilization and preservation efforts to protect burials from harm (Conyers 2006b). While GPR has become a popular option, the importance of locating unmarked graves illustrates the need for the improvement of various geophysical survey methodologies, as well as testing the limitations of different instruments in specific contexts.

Since the mid-1980s, GPR has been commonly used for CRM work in cemetery settings, and several published studies have specifically addressed methodological considerations for GPR surveys involving graves, with particular attention to variables affecting detection and resolution (Vaughn 1986; Bevan 1991; King et al. 1993; Nobes 1999; Davis et al. 2000; Conyers 2006b). For GPR surveys that include cemeteries and archaeological sites, Pomfret (2006), Conyers (2006b), and Jones (2008) have provided guidelines concerning transect spacing and profile orientation, both of which will be tested in this study. On the other hand, there is a lack of literature on the use of conductivity for locating unmarked graves in historical cemeteries. This project was designed to test the ability of two geophysical instruments to locate and map marked and unmarked graves at a cemetery with interments dating from the historical period through the present day. The goals of the research were to (1) test the utility of a conductivity meter and GPR to detect marked and unmarked graves, (2) compare the results between the two geophysical instruments, and (3) generate recommendations for future surveys using these instruments.

Materials and Methods

The cemetery selected for this project was Greenwood Cemetery, which, at approximately 68.7 acres, is the largest cemetery owned and operated by the city of Orlando, Florida. The choice of Greenwood Cemetery was optimal for this study for several reasons. In addition to the large size of the cemetery, interments span more than a century, with graves dating from 1880 to the present. Also, there are areas known to contain unmarked burials and there has been no previous published research performed at the cemetery using geophysical instruments. At the various depths tested, the cemetery consists of sandy soils that are ideal for conductivity meter and GPR in central Florida. The soil is classified as Florahome-Urban land complex, which is a moderately drained soil and consists of fine sand at the depths studied. The data were collected under dry conditions. Two sections of the cemetery were chosen to test the abilities of the conductivity meter and GPR to detect different types of burials from different periods. A modern-period area with interments ranging from 1957 to 2002 consisted of burials which had primarily followed the modern practice of placing coffins in shallowly buried cement vaults. Conversely, the historical-period area (burials older than 75 years) had not received any recent interments. The interments consisted of unmarked and deeper, nonvaulted burials using what were most likely wooden coffins.

The modern-period grid measured 11 x 23 m and contained 30 marked headstones with multiple, double interments forming four distinct rows, the burials dating between 1957 and 2002. Cemetery records were analyzed to determine the types of interments present in the modern-period grid. The majority of interments were coffins placed in buried cement vaults, while only five were placed in buried wooden coffins. Modern burials at Greenwood Cemetery are required to be placed in cement burial vaults. It is common practice in the United States to bury coffins in underground vaults to prevent ground instability due to the deterioration and subsequent collapsing of coffins. The five wooden coffins, dating from 1958 to 1962, were among the oldest burials contained within the grid. Furthermore, two headstones contained no interment, and three burials had no information available.

A 25 × 30 m historical-period grid was constructed in an open section of the cemetery. The area chosen for the test grid was advantageous for this study because there were no trees that could affect the quality of the GPR results, and with few obstructions (only five headstones) it was easier to perform a grid survey. The five headstones dated from 1895 to 1920, but no rows were visible based on the locations of the headstones. While the area is known to contain numerous unmarked interments, there is no documentation available specifying the number of rows and the number of burials present in this section of the cemetery.

The two geophysical instruments used in this study were a conductivity meter and GPR. The conductivity meter used for this study was a meter-long Geonics EM-38 with an Allegro CX handheld data logger. This instrument consists of a transmitting coil that emits an electromagnetic wave which produces a primary magnetic field in the ground, and a receiving coil that detects the secondary magnetic field formed by conductive objects in the subsurface strata. The difference between the two magnetic fields is proportional to the conductivity of the feature located below the ground surface. Therefore, subsurface objects are detected when the conductivity of the area surrounding the object differs from the natural conductivity of the soil (Sharma 1997; Killam 2004). In historical cemeteries, the conductivity meter is used to locate areas containing contrasting soil properties. According to Clay (2006), differences between the grave fill and the surrounding undisturbed soil can create an anomaly strong enough to be detected by the instrument. In addition, air pockets within the coffins or metallic coffin materials such as nails may also contribute to grave detection using the conductivity meter (Bevan 1991).

Conductivity can be measured in two ways: through an automatic mode that takes readings every second or through a manual mode in which readings are taken by pressing a button at specific locations. This instrument is able to record the inphase (magnetic susceptibility) of the ground by also using the automatic and manual data-collection modes. Magnetic susceptibility refers to the degree to which a subsurface feature can be magnetized. Conductivity and inphase measurements can also be taken in one of two dipoles or orientations: the vertical dipole (when the instrument is held vertically) is best for detecting data at greater depths, while the horizontal dipole (when the instrument is held horizontally) is better suited for detecting objects near the ground surface (Geonics 2006). The conductivity meter measures ground conductivity in millisiemens per meter (mS/m). There is a direct relationship between conductivity and mS/m, as a better conductor will result in a greater value in mS/m (Killam 2004). If the conductivity meter is in close proximity to a very conductive object, however, the readings can reach negative values. This is caused by the strong eddy currents between the two coils and those located beyond the receiving coil (Ward 1990). Conductivity values from a grid survey can also be entered as Z values, enabling the surveyor to create contour maps showing the variations of conductivity throughout the survey area (Killam 2004). Unfortunately, conductivity readings do not provide depth information for underground targets.

The modern-period grid was set up to minimize the number of transect lines interfering with the headstones present. The conductivity data were collected along the Y direction for both grids using a transect spacing of 0.5 m, following the recommendation of the manufacturer that transect spacing should be equal to half the instrument's length (Geonics 2006). It should be noted that a few transects adjacent to headstone rows were changed to 0.25 m spacing to avoid any interference from headstone footers. On each transect, conductivity recordings were also collected every 0.5 m. Measurements were recorded using an Allegro CX field computer that was connected to the conductivity meter. Files were then transferred from the field computer to a desktop computer, where they were processed using the Geonics software DAT 38 and analyzed using the Golden Software Surfer 8 software (version 8.4). The Surfer software was used to create contour maps of the conductivity readings of the research site using the default intervals with each contour line representing a difference of 0.5 mS/m. An overlay containing the locations of the headstones in each area was later added to each conductivity map to determine which anomalies were associated with a headstone and which anomalies represented unmarked graves.

The GPR unit used for this project was a MALA RAMAC X3M with a 500 MHz antenna mounted on a cart containing a survey wheel. The 500 MHz antenna was used because it provides an excellent compromise between depth of viewing and vertical resolution and is commonly used for archaeological and forensic applications (Sternburg and McGill 1995; Schultz et al. 2006; Schultz 2007). Before data collection the GPR unit was calibrated using a variation of the reflected wave method (Conyers and Lucius 1996) by pulling the GPR over a cement burial vault that was probed to obtain the depth of the vault below the ground surface. The velocity was then calibrated until the depth of the reflection hyperbola was accurate. Data from the modern grid were collected using 0.5 m transect spacing in the Y direction only. Offsets were made to survey around the headstones within the grid. The historical-period grid was surveyed using the GPR with a transect interval spacing of 0.25 m, and data were collected in both X and Y directions. Offsets were also required for the five headstones within the grid.

All GPR processing was performed using GPR-SLICE (version 6) for horizontal slice imagery and REFLEXW (version 5) for reflection profiles. Both the modern-period grid and the historical-period grid were subject to the same postprocessing procedures, which included background removal and a boxcar smoothing filter. In order to make a direct comparison with the results from the conductivity meter, the historical-period grid GPR data were first processed using a 0.5 m transect interval spacing and a horizontal slice at a shallow depth of 0.2 m (3–5 ns). Next, the historical-period grid was processed in both directions, X and Y, at 0.25 m and an XY composite at 0.25 m in order to determine the effects of decreased transect interval spacing and profile orientation. In order to create the horizontal slices using a transect interval of 0.5 m, data collected with 0.25 m transect intervals were used and every other transect was removed.

Results

Modern-Period Grid

Both instruments obtained similar results in the modern grid. The conductivity meter detected multiple anomalies oriented in an east–west direction in all four rows contained within the grid (Figure 1). The majority of the anomalies noted on the conductivity map were found to be in association with existing headstones. In addition, cemetery records confirmed that all conductivity anomalies detected in the modern-period grid were associated with burials containing a cement vault. According to the conductivity map, a total of five headstones did not have an anomaly detected in close proximity. Cemetery records indicated that three of these headstones contained interments made using a wooden coffin, while the remaining two headstones did not contain interments. The GPR results for the modern grid were similar to the conductivity meter results (Figure 2). A horizontal slice, representing an approximate depth of 0.4 m (12–14 ns), was compared to the conductivity meter overlay to determine that the anomalies were again mostly associated with the existing headstones. Analysis of the modern-period grid showed that the GPR was able to successfully detect all cement vaults present. Furthermore, a reflection profile (Figure 3) was selected from the third row within the modern grid in order to provide reflection data from a GPR profile. The location of the reflection profile is indicated by the white line on the horizontal slice (Figure 2). The reflection profile clearly demonstrated a row of contiguous, hyperbolically shaped anomalies produced by the shallow cement burial vaults of the modern-period grid at a depth of approximately 0.5 m. Overall, the shape and orientation of the detected burials was consistent with the cemetery reflection data provided by Conyers (2006b).

Historical-Period Grid

The conductivity meter detected only one anomaly during the historical-grid survey. This linear anomaly was oriented in approximately the north–south direction across the length of the grid (Figure 4). This anomaly later proved

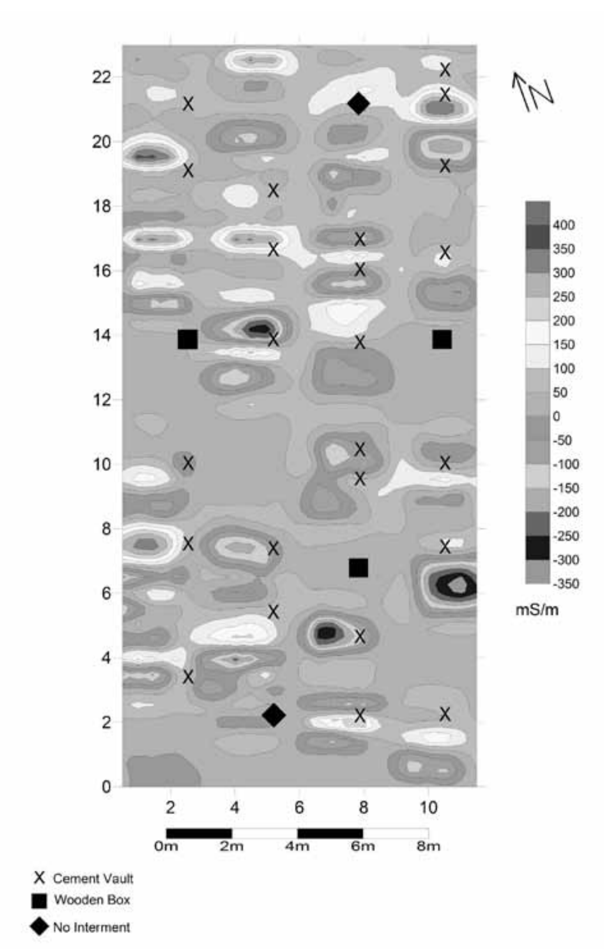

Figure 1. Conductivity map of the modern grid with interment type overlay. The overlay represents marked burials and identifies the type of interment. (Map by Charles Dionne, 2010)

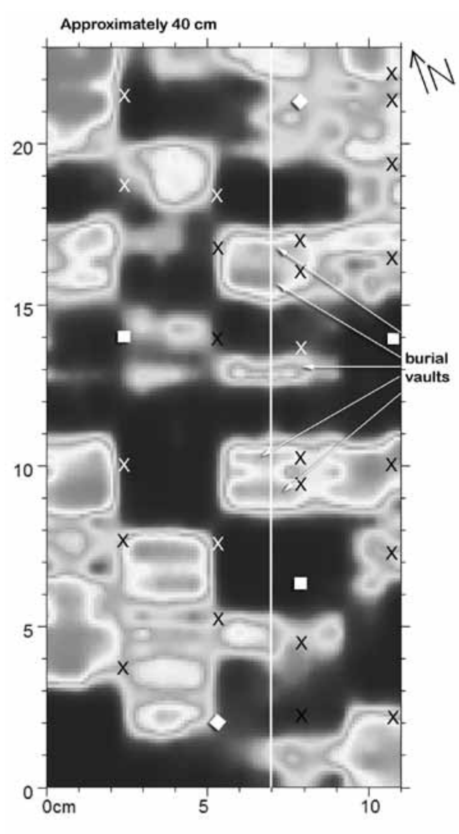

Figure 2. GPR horizontal slice of the modern grid at an approximate depth of 0.4 m (12–14 ns) indicating anomalies created by burial vaults. The white line indicates the location of the modern-grid reflection profile; see also Figure 4. (Figure by John Schultz, 2010)

to have been caused by a shallow metallic irrigation pipe. No other anomalies were noted by the conductivity meter as neither the backfill nor the interments were detected.

The GPR also detected the shallow irrigation pipe on a horizontal slice at an approximate depth of 0.2 m, or 3–5 ns (Figure 5). Because no other anomalies were present on the shallow horizontal slice, it is clear that the backfill from each grave shaft was not being detected by the GPR and that the anomalies seen on the deeper horizontal slices confirmed the presence of interments. Using horizontal slices at an approximate depth of 0.85 m, or 21–23 ns (Figures 6–9), the GPR survey detected a large number of deep anomalies aligned in eight contiguous rows, with the burials oriented in the east–west direction. The results of the data collected in the Y direction survey using a 0.5 m transect interval spacing (Figure 6)

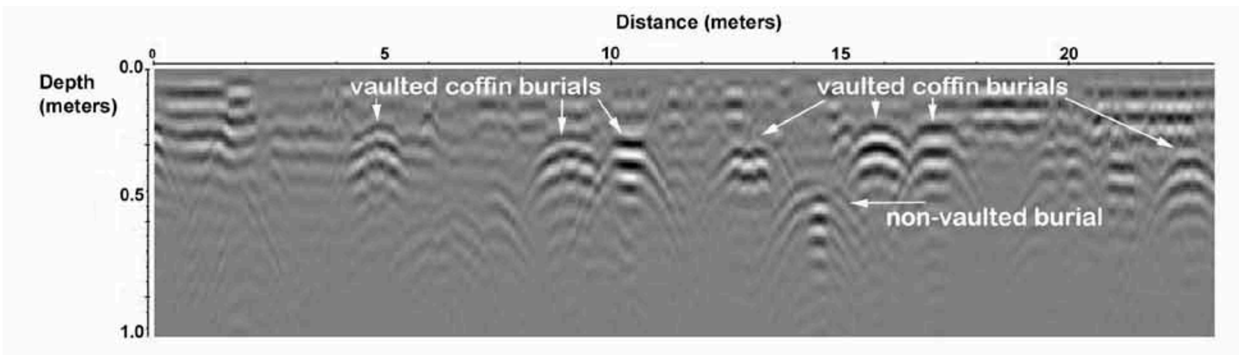

Figure 3. Modern grid reflection profile from Figure 2 showing a row of contiguous anomalies produced by the shallow vaulted coffin burials at an approximate depth of 0.25 m. Note the deep anomaly suspected to represent an unmarked, nonvaulted burial. (Figure by John Schultz, 2010)

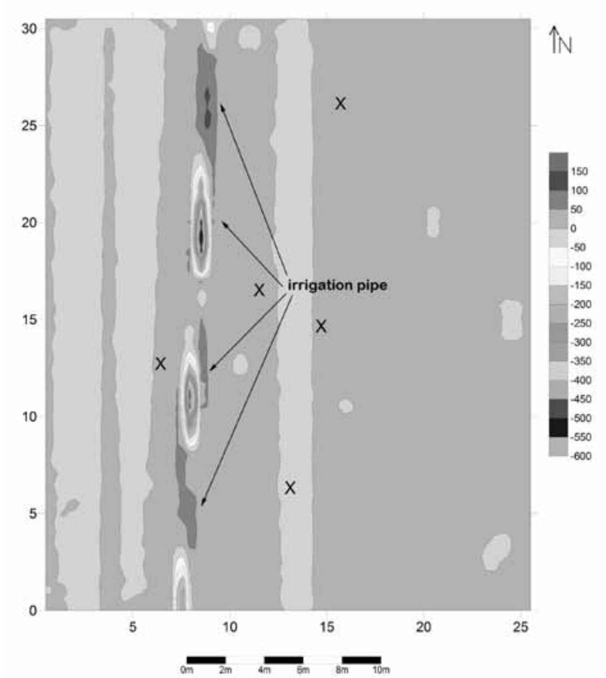

Figure 4. Conductivity map of the historical grid indicating the locations of the five aboveground grave markers (×) and the long anomaly created by an irrigation pipe (*center*). (Figure by Charles Dionne, 2010)

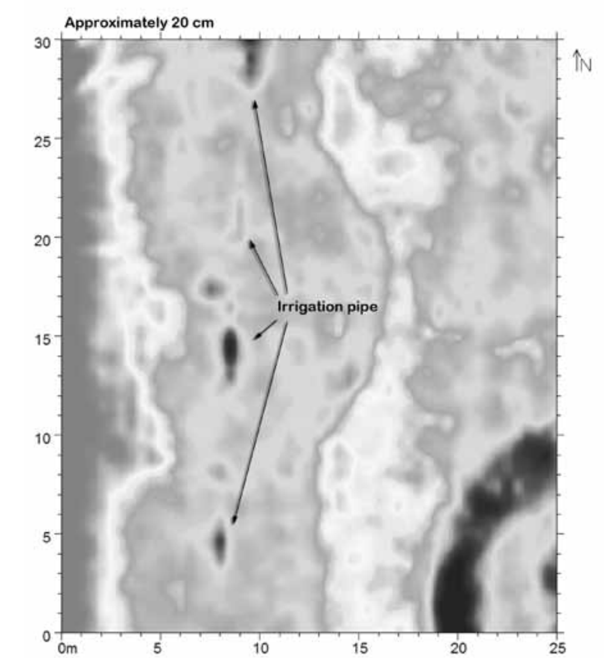

Figure 5. Shallow horizontal slice of the historical grid showing the irrigation pipe detected at a depth of 0.2 m (3–5 ns). (Figure by Dennis Wardlaw, 2010)

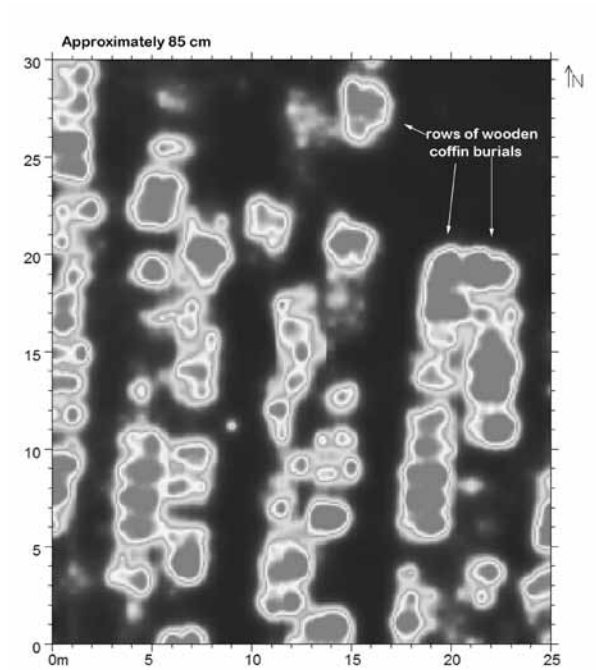

Figure 6. GPR horizontal slice of nonvaulted, wooden coffins in the historical grid at a depth of 0.85 m (21–23 ns) using 0.5 m transect spacing in the Y direction only. (Figure by Dennis Wardlaw, 2010.)

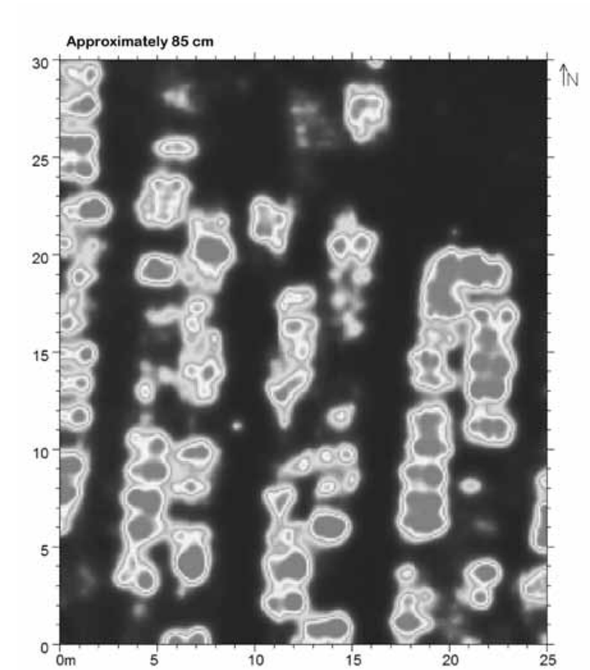

Figure 7. GPR horizontal slice of the historical grid at a depth of 0.85 m (21–23 ns) using 0.25 m transect spacing in the Y direction only. (Figure by Dennis Wardlaw, 2010.)

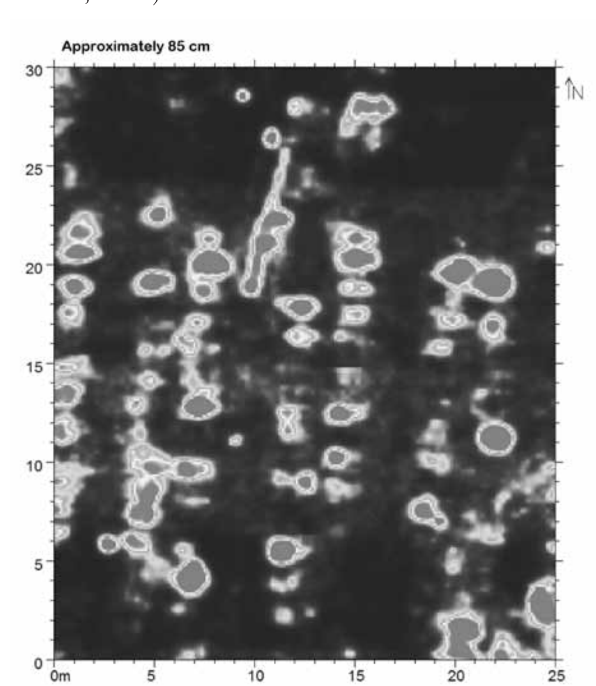

Figure 8. GPR horizontal slice of the historical grid at a depth of 0.85 m (21–23 ns) using 0.25 m transect spacing in the X direction only. (Figure by Dennis Wardlaw, 2010)

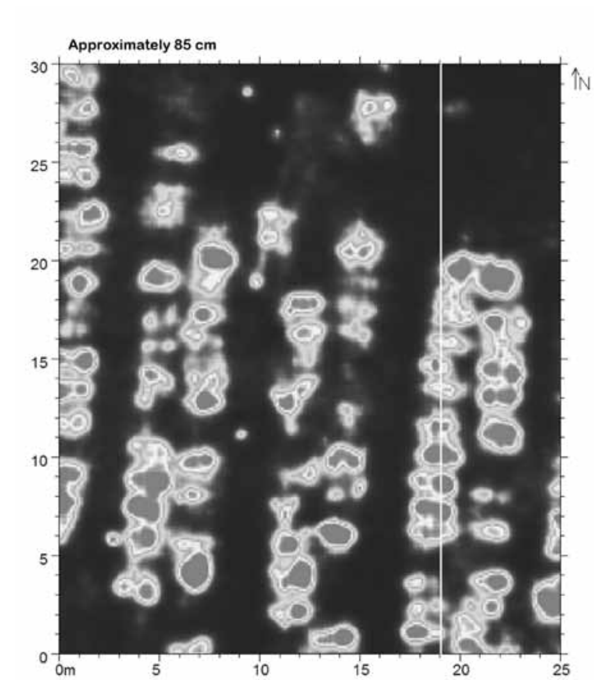

Figure 9. GPR horizontal slice of the historical grid at a depth of 0.85 m (21–23 ns) using 0.25 m transect spacing incorporating both X and Y directions. The white line indicates the location of the historical-grid reflection profile; see also Figure 11. (Figure by Dennis Wardlaw, 2010)

produced multiple anomalies, but they were distorted due to the wider transect interval spacing and the increased interpolation required for processing. When the data were processed using 0.25 m transect intervals in the Y direction (Figure 7), results demonstrated a sharper resolution and delineation of the anomalies compared to the horizontal slice processed with a 0.5 m transect interval spacing. The results of the horizontal slice collected in the X direction using a 0.25 m transect spacing (Figure 8) indicated a decreased resolution of the anomalies, and fewer burials were detected compared to the horizontal slice using the same transect spacing in the Y direction. Finally, the data processed as a composite X-Y grid using 0.25 m interval spacing (Figure 9) demonstrated the best results, as this grid included both orientations, minimized the offsets for each headstone, and thus provided the highest resolution of anomalies within the grid as well as having detected the greatest number of burials.

A GPR reflection profile (Figure 10) was selected from this last horizontal slice (Figure 9) for further analysis. The number of hyperbolically shaped anomalies represented in Figure 10 coincides with the number and locations of anomalies observed on the horizontal slice in Figure 9 and are approximately 1.0 m deep. The exact location of the reflection profile is represented in Figure 9 as a white line. In order to confirm that the anomalies detected in the reflection profile from the historical-period grid (Figure 10) were unmarked, nonvaulted burials, a comparison was made with a reflection profile (Figure 11) from a different section of the cemetery that contained nonvaulted burials (independently confirmed by probing the graves) ranging in time from the 1930s to the 1940s. Overall, both reflection profiles show similarity in shape, orientation, and depth-of-grave anomalies, which is consistent with the cemetery reflection data provided by Conyers (2006b). Therefore, the reflection data from the historical-period

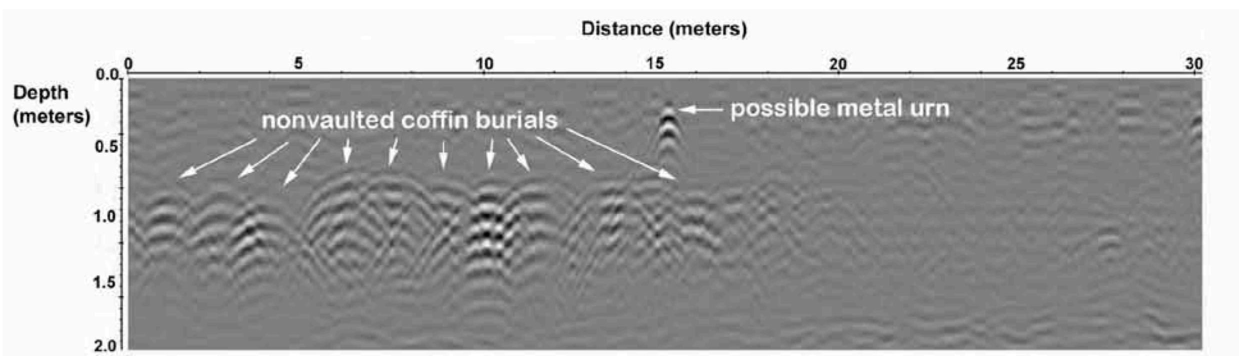

Figure 10. Historical grid reflection profile from Figure 9 showing a row of contiguous anomalies between 0.5 and 1.0 m produced by the deep, nonvaulted wooden burials that were unmarked and a possible metal urn between 0.0 and 0.5 m. (Figure by Dennis Wardlaw, 2010)

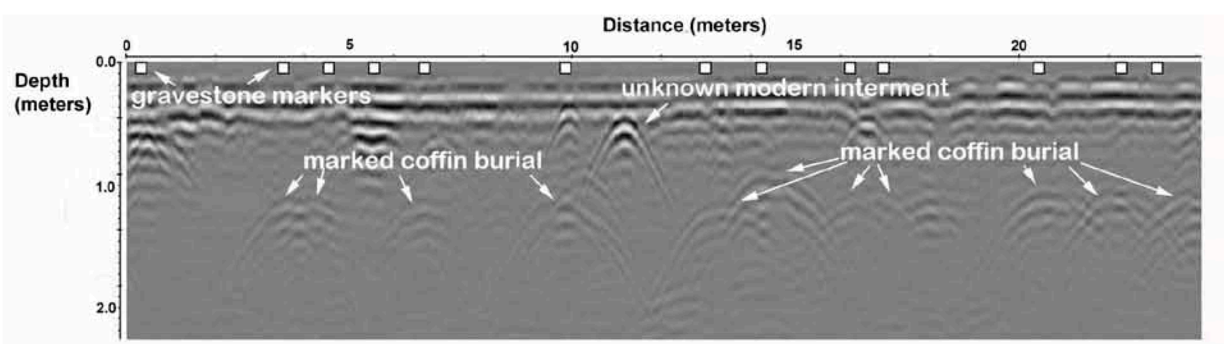

Figure 11. Reflection profile representing a row of contiguous anomalies produced by deep, nonvaulted wooden burials at a depth of approximately 1.0 m that were marked with headstones, and an unknown modern interment at a depth of approximately 0.5 m. (Figure by Dennis Wardlaw, 2010)

grid reinforced the conclusion that eight contiguous rows of unmarked, nonvaulted graves were detected within the horizontal slice from this grid.

Discussion and Conclusions

The results obtained clearly demonstrate differences between the conductivity meter and GPR in their ability to detect different types of interments. According to Conyers (2006b), a cemetery grave may be detected with GPR by imaging four features that include the undisturbed soil below and surrounding the grave; the displaced backfill used to fill the vertical grave shaft; the interment that includes the coffin, human remains, and associated grave artifacts; and any surface sediment or soil that has accumulated over the interment. If the wooden coffin has collapsed, thereby eliminating the void space, however, what is left of the decayed coffin wood and human remains may not provide enough of a physical or chemical contrast to be detected with GPR. If the grave shaft has been dug through soil comprised of distinctly different horizontal strata, however, the grave shaft may be detected due to different physical and chemical changes in the backfill or as a disruption of the natural and undisturbed stratigraphy surrounding the grave (Bevan 1991; King 1993; Conyers 2006b).

GPR provided the best resolution and delineation of the deeper nonvaulted burials in the historical grid. The combination of using GPR profile reflection data (Figure 3) with the horizontal slices (Figures 6–9) further supports the conclusion that unmarked graves were detected in the horizontal slices. Overall, there were a couple of differences between the grave reflections produced from both grids. Since coffins in cement vaults were only buried to a maximum depth of 0.5 m below the ground surface, the reflections were much shallower (Figure 3) than reflections from the older wooden coffins typically buried at a depth of 1.0 m (Figure 10). The reflections from the cement burial vaults were much stronger due to the contrast in physical and/or chemical properties between the sand and the cement vault, and/or the preserved void space. According to Conyers (2006b), burial vaults made of brick or stone also can preserve void spaces, aiding in detection of interments.

Soil type can also influence the success of detecting older cemetery graves. For example, soils comprised of weathered bedrock, gravelly or cobble-rich sediment, boulders, and natural lenses of contrasting soil can result in difficulty discerning graves because of extensive clutter on the reflection profile (Bevan 1991; King 1993; Conyers 2006b). In addition, while a number of authors have listed conductive clayey soils as limiting factors for cemetery grave detection (Wynn 1986; Bevan 1991) and the discovery of forensic graves (Davenport 2001; Dupras et al. 2005; France et al. 1992; Killam 2004; Schultz et al. 2006), it may still be possible to detect graves in clayey soils by noting gaps or truncations in the stratigraphy where other types of soil fill the vertical grave shafts. In this study, the soil type consisted of homogenous sands and the backfill in grave cuts was thus indistinct and could not be detected when analyzing shallow GPR horizontal slices and reflection profiles. However, grave shafts dug through soil comprised of distinctly different horizontal strata may be more amenable to detection with GPR (Conyers 2006b; Schultz 2008; Schultz et al. 2006). In uniform sandy soil, detection of graves without vaults may be problematic because the collapsed wooden coffin and skeleton may not provide enough of a physical and chemical contrast to be detected by GPR.

Also, when comparing the GPR imagery using the 0.25 m and 0.5 m transect interval spacing, the smaller transect spacing is preferred for better resolution and delineation of burials. While Conyers (2006b) and Jones (2008) recommend using a transect interval spacing of 0.5 m or less for historical-cemetery surveying with GPR, this research demonstrated that a transect interval of 0.25 m is ideal when surveying nonvaulted cemetery graves. Although positive results will still be obtained using a transect interval of 0.5 m, when time permits a transect interval of 0.25 m should be used. When performing geophysical surveys on archaeological sites, Pomfret (2006) recommended transects that are oriented perpendicular to the survey targets and the inclusion of both profile orientations for greater resolution of linear subsurface features. While Pomfret (2006) did not refer specifically to burials, his recommendations are also supported by the findings in this study. If the geophysical survey can only be performed in one direction due to time constraints, transects should be oriented perpendicular to the graves, usually south to north, in order to obtain maximum resolution of the burials.

While the GPR results for detection of cemetery graves were favorable for both the modern and historical grids, the results differed for the conductivity meter. The detection of the shallow irrigation pipe in the historical grid (Figure 4) demonstrated the excellent capability of the conductivity meter for detecting buried metallic objects. The conductivity meter also detected the shallow cement vaults in the modern grid (Figure 1), but did not detect any of the older, deeper, wooden coffins in the historical grid (Figure 4). It is not surprising that the cement vaults were detected, because Bevan (1983) previously documented the ability of the conductivity meter to detect conductivity changes between subsurface stone or voids and the surrounding soil on archaeological sites. In addition, the conductivity meter's manufacturer stated that the construction of modern, cement burial vaults can contribute to the detection of these features during a conductivity survey because they may have a high clay content and may be reinforced with rebar or iron bars (Mike Catalano 2006, pers. comm.).

The conductivity meter did not detect the graves for the deep, nonvaulted historical burials in wooden coffins. These graves were not detected for a number of reasons. First, the backfill of the vertical grave shaft was not detected, which was also noted with the GPR. Since the soil was composed of homogenous sands, the backfill comprising the grave shaft did not provide enough chemical and physical contrast to be detected. Another reason can be related to the depth of penetration of the small conductivity unit. According to the manufacturer, the strength peaks at a depth of 0.4 m in the vertical dipole orientation, and then the strength decreases as depth increases (Geonics 2006). Since the older wooden coffins were at a depth of 1.0 m, what remained of the interments was not conductive enough to be detected at the depth limit of the conductivity unit.

While GPR is generally the preferred option for locating unmarked burials, the conductivity meter can prove useful in a number of situations. As this research has demonstrated, a conductivity unit can successfully locate interments consisting of shallowly buried vaults or metal coffins. This geophysical instrument can also prove useful in environments where GPR use is limited. For example, there can be extensive near-surface clutter on the GPR reflection profile from tree roots, the disturbed soil surface, and irrigation lines. In these instances where soil disturbances can be detected using geophysical tools, a conductivity survey can be incorporated with the GPR survey to provide possible additional data for delineation of the vertical grave shafts. Also, there may be instances where it may not be possible to maneuver the GPR in straight rows due to obstructions from brush and stumps, and a conductivity unit may be beneficial since it can be used in areas with brush and will not detect the near-surface roots.

Ground-penetrating radar is a valuable geophysical tool that is commonly used in the United States in cemetery management and CRM work for the detection and documentation of graves. By following proper surveying methods using GPR, archaeologists can often accurately locate older unmarked burials. When possible, surveys should be performed with a transect interval spacing of 0.25 m perpendicular to the orientation of the grave rows, and analysis of the GPR imagery should include both GPR profile reflection data and horizontal slices. Therefore, GPR research similar to that of this study is necessary in other settings to determine optimal survey methodologies for unmarked burials located in areas of contrasting environmental conditions and multiple time periods. Due to the effect of environmental conditions and soil compositions, cemetery research with various geophysical methods such as GPR, conductivity, resistivity, or magnetometry is important to identify the variables affecting detection of graves. In addition, depending on the soil characteristics, a combination of geophysical technologies may provide the highest success for locating and delineating unmarked graves, particularly when surveying areas containing graves from different time periods or different types of interments.

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