GPR Survey at Behavior Cemetery, Sapelo Island, Georgia

LAMAR Institute Publication Series, Report Number 155

By Daniel T. Elliott

The LAMAR Institute, Inc.
Savannah, Georgia,
2010
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Submitted to:
Dr. Nicholas Honerkamp
Jeffrey L. Brown Institute for Archaeology
University of Tennessee at Chattanooga
Chattanooga, Tennessee 37403

Submitted by:
The LAMAR Institute, Inc.
P.O. Box 2992
Savannah, Georgia 31402

Authored by Daniel T. Elliott

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I. Introduction

This report presents the findings of a Ground Penetrating Radar (GPR) survey by the LAMAR Institute on a portion of Behavior Cemetery on Sapelo Island, McIntosh County, Georgia (Figure 1). The survey was conducted in coordination with a University of Tennessee at Chattanooga (UTC) 2010 Archaeological Field School taught by Professor Nicholas Honerkamp. Ground Penetrating Radar services were provided for the project by Daniel T. Elliott of The LAMAR Institute, Inc. The GPR survey provides a better understanding of the historic resources in the Behavior Cemetery, as well as some preliminary information on resources located outside of the cemetery. The archaeological portion of the project is reported elsewhere by Honerkamp (2010). The present report addresses the methods, findings, and interpretations of the GPR portion of the project.

Figure 1. Behavior Cemetery, Sapelo Island, Georgia (Google Earth 2010).
II. Research Methods

Ground Penetrating Radar, or GPR, is an important remote sensing tool used by archaeologists. The technology is particularly effective in mapping historic cemeteries. The technology uses high frequency electromagnetic waves (microwaves) to acquire subsurface data. The device uses a transmitter antenna and closely spaced receiver antenna to detect changes in electromagnetic properties beneath them. The antennas are suspended just above the ground surface and the antennas are shielded to eliminate interference from sources other than directly beneath the device. The transmitting antenna emits a series of electromagnetic waves, which are distorted by differences in soil conductivity, dielectric permittivity, and magnetic permeability. The receiving antenna records the reflected waves for a specified length of time (in nanoseconds, or ns). The approximate depth of an object can be estimated with GPR, by adjusting for electromagnetic propagation conditions.

The GPR sample block in this study area was composed of a series of parallel transects, or traverses, which yielded a two-dimensional cross-section or profile of the radar data. These samples are termed radargrams. This two-dimensional image is constructed from a sequence of thousands of individual radar traces. A succession of radar traces bouncing off a large buried object will produce a hyperbola, when viewed graphically in profile. Multiple large objects that are in close proximity may produce multiple, overlapping hyperbolas, which are more difficult to interpret. For example, an isolated historic grave may produce a clear signal, represented by a well-defined hyperbola. A cluster of graves, however, may produce a more garbled signal that is less apparent.

The GPR signals that are captured by the receiving antenna are recorded as an array of numerals, which can be converted to gray scale (or color) pixel values. The radargrams are essentially a vertical map of the radar reflection off objects and other soil anomalies. It is not an actual map of the objects. The radargram is produced in real time and is viewable on a computer monitor, mounted on the GPR cart.

GPR has been successfully used for archaeological and forensic anthropological applications to locate relatively shallow features, although the technique also can probe deeply into the ground (Conyers 2002; Conyers and Goodman 1997; DeVore 2006). Higher frequency antennas are more useful at shallow depths, which is most often the case in archaeology. Also, the longer the receiving antenna is set to receive GPR signals (measured in nanoseconds, or ns), the deeper the search. The effectiveness of GPR in various environments on the North American continent is widely variable and depends on solid conductivity, metallic content, and other pedo-chemical factors. The machine is adjusted for optimal search by the use of different frequency range antennas.

GPR signals cannot penetrate large metal objects and the signals are also significantly affected by the presence of salt water. Although radar does not penetrate metal objects, it does generate a distinctive signal that is usually recognizable, particularly for larger metal
objects, such as a cast iron cannon or man-hole cover. The signal beneath these objects is often canceled, which results in a pattern of horizontal lines on the radargram. For smaller objects, such as a scatter of nails, the signal may ricochet from the objects and produce a confusing signal. Rebar-reinforced concrete, as another example, generates an unmistakable radar pattern of rippled lines on the radargram.

Using the same RAMAC X3M GPR system as that used in the present study, Elliott has conducted several GPR studies of 18th and 19th century archaeological sites in coastal Georgia. The first study was at the New Ebenezer town site in Effingham County, Georgia. The results of the GPR work at New Ebenezer were quite exciting and included the delineation of a large portion of a British redoubt palisade ditch and the discovery of several dozen previously unidentified human graves (both within and beyond the known limits of the Jerusalem Lutheran Church cemetery). GPR survey was conducted with satisfactory results by Elliott and his colleagues at Fort Morris and at Sunbury Cemetery (Liberty County), Sansavilla Bluff (Wayne County), Woodbine Plantation cemetery (Camden County), and Garden Homes/Waldburg Street in Savannah (Chatham County), the Gould-Bethel Cemetery (Chatham County), Bullhead Bluff Cemetery (Camden County), Fort Saint Andrews (Camden County) and numerous other sites. The same equipment has been used successfully for GPR surveys on seven of Georgia’s barrier islands, including Cumberland, Jekyll, Ossabaw, Sapelo, St. Catherines, St. Simons, and Tybee islands (Elliott 2003a-c, 2004, 2005, 2006a-d, 2007,2008a-b, 2009a-b; Elliott and Burns 2007).

The equipment used for this study consisted of a RAMAC/X3M Integrated Radar Control Unit, mounted on a wheeled-cart and linked to a RAMAC XV11 Monitor (Firmware, Version 3.2.36). A 500 megahertz (MHz) shielded antenna was used for the data gathering. MALÅ GeoScience’s Ground Vision (Version 1.4.5) software was used to acquire and record the radar data (MALÅ GeoScience USA 2006a). The radar information was displayed as a series of radargrams. Output from the survey was first viewed using GroundVision. This provided immediate feedback about the suitability of GPR survey in the area and the effective operation of the equipment.

The time window that was selected allowed data gathering to focus on the upper 1.5 meters of soil, which was the zone most likely to yield archaeological deposits. Additional filters were used to refine the radar information during post-processing. These include adjustments to the gain. These alterations to the data are reversible, however, and do not affect the original data that was collected.

Upon arrival at the site, the RAMAC X3M Radar Unit was set up for the operation and calibrated. Several trial runs were made on parts of the site to test the machine’s effectiveness in the site’s soils. The following machinery settings were employed by the survey.
**GPR Block A**

**Machine Settings, Block A**
- Time Window: 80 ns
- Number of Stacks: 4
- Number of Samples: 632
- Sampling Frequency: 7,462 MHz

Antenna: 500 MHz shielded
Antenna Separation: 0.18 m
Trigger: 0.02 m
Radargram orientation: East to West (bearing 296 degrees)
Radargram progress: South to North
Radargram Spacing: 50 cm
Total Radargrams:
Dimensions: 138 m N-S by 56 m E-W
Note: Comprised of original GPR Blocks A, B and C, which form a contiguous polygon.

GPR Block A was a large sample that consisted of 5.36 km of radar data collected along 371 radargrams. The grid arrangement of these radargrams in Block A is shown in Figure 2. The block examined an area measuring 56 meters east-west by 138 meters north-south. The GPR Datum was 416.06N, 420.05E. The GPR grid was oriented approximately 26 degrees east of Magnetic North. GPR Blocks B and C were originally given distinct designations but these blocks were later merged into Block A.

*Figure 2. GPR Grid, Block A, Behavior Cemetery.*
**GPR Block D**

**Block D**

**Machine Settings**
- Time Window: 80 ns
- Number of Stacks: 4
- Number of Samples: 632
- Sampling Frequency: 7,462 MHz
- Antenna: 500 MHz shielded
- Antenna Separation: 0.18 m
- Trigger: 0.02 m
- Radargram orientation: East to West
- Radargram progress: South to North
- Radargram Spacing: 50 cm
- Total Radargrams:
- Dimensions: 10 m E-W by 10 m N-S

GPR Block D consisted of 206 m of radar collection, which were collected along 23 radargrams. The grid arrangement of these radargrams in Block D is shown in Figure 3. The block examined an area measuring 10 meters east-west by 10 meters north-south, or 100 m².

![Figure 3. GPR Grid, Block D, Behavior Cemetery.](image)

**Post-Processing**

The GPR data from the present study was processed with *GPR-Slice* (Version 7.0). Dean Goodman’s *GPR-Slice* program is recognized as the world leader in GPR imaging and it has proven quite effective in mapping historic cemeteries (Goodman 2006, 2010). Mapping in 3D entailed merging the data from the series of radargrams for each block. Once this was accomplished, horizontal slices of the data were examined for important anomalies and patterns of anomalies, which were likely of cultural relevance. These data were displayed as aerial plan maps of the sample areas at varying depths below ground surface. These horizontal views, or time-slices, display the radar information at a set time depth in nanoseconds (ns). Time-depth can be roughly equated to depth below ground. This equivalency relationship can be calculated using a mathematical formula.
III. Results and Interpretation

The LAMAR Institute GPR survey of a portion of Behavior Cemetery examined two portions of the cemetery and an area east of the graveyard (as it is presently understood). The two GPR samples are identified as Block A and Block D. A total of 5,567.75 meters of radargrams was collected from these two samples.

GPR Block A is a large irregular polygon which spans nearly all of the cemetery on its north-south axis (138 m) and a sample portion on its east-west axis (56 m). It originally consisted of three blocks (A, B, and C) but these were later merged to create one contiguous block. The southern portion of Block A (original Block A) was the largest sampled area and its eastern boundary was the drainage ditch. GPR survey further to the east in this vicinity was not feasible in 2010 because of the dense vegetation.

The southern boundary of Block A was defined by a metal fence and dense forest cover. Original Block B extended the search eastward where the forest floor was more open. Original Block C was located further east of the known cemetery. This sample blanketed the area identified by UTC archaeology as an enslaved African-American habitation area and/or other plantation buildings. No marked graves or obvious rectangular grave-like depressions were noted east of the drainage ditch feature. The GPR survey of Block A represents 5,361.75 linear meters (approximately 5.4 km), comprised of 371 radargrams, which represents a large GPR dataset.

GPR Block D is a 10 m by 10 m sample located on the northwestern portion of the cemetery. It was placed over an area where a series of four rectangular shallow depressions suggested unmarked burials were present. The GPR map reinforces their interpretation as four human burials and other features (possibly including more burials, but also a very large area that is probably not burial-related) were also mapped within this area. This sample also included one grave marked by a horizontal slab (Tombstone Number 158. Rosa L. Rogers, died 2002).

As expected, the GPR survey identified approximately 185 potential graves in the Behavior Cemetery. The GPR mapping also generated images of known graves except in areas where the tombstones or other obstacles prevented data collection. Quantifying the potential graves in the cemetery from the GPR data is problematic. The recognition on plan maps of many of the graves is straightforward. In other instances, clusters of graves that are closely spaced generated more amorphous “large blobs” and it is not readily apparent how many individual graves these radar reflections represent. Further complicating the issue is the great likelihood that a portion of the strong radar reflections in the data represent aboriginal or historic features that are not cemetery-related. Large trees also confuse the interpretation of the cemetery data by creating large radar reflections that often masked historic graves. In some cases the large reflections generated by tree stumps and tree roots are very difficult to distinguish from clusters of burials or shallow, infant burials.
GPR Radargrams

Radargrams provide a profile view of the radar reflections. This class of information is useful when studying cemeteries because graves often create characteristic radar profiles. Depending on the spacing of the graves, a grave may be recognized by the hyperbola that is a reflection from the top of coffin, by the steep slope created by the grave shaft excavation, by the disturbed soil conditions within the grave pit relative to the less disturbed matrix soils, and sometimes by a reverse hyperbola created by the radar pulses reflecting off of the base of the grave excavation pit. Burials with high metal content (typically more massive coffin hardware and than simply coffin nails), may generate distinctive signatures. A grave with a metal vault cover or a metal coffin creates its own distinctive profile. When graves are clustered and closely spaced, however, it becomes more difficult to distinguish individual graves. In these cases, large areas of soil disturbance may be recognized.

Several radargram examples from the present survey are illustrated in the following. Figure 4 shows Radargram 100, which is located 35 meters north of the beginning line in Block A. It is a cross-section of a 15.5 meter portion of the cemetery from east to west that contains multiple strong radar reflections. This cross-section may include eight or more burials. At least two of these appear to contain some larger metal objects, although some of this may represent shallow, buried metal objects that are unrelated to the burials. At the western end of this radargram (from about 12.5-14.5 m) a large area of soil disturbance is indicated, which may represent multiple, closely spaced graves. Alternatively, it may represent a natural, large tree stump disturbance.

Figure 4. Radargram 100 in Block A, Behavior Cemetery.
Figure 5 shows Radargram 160, which is located 65.5 meters north of the beginning line in Block A. This radargram covers a distance of about 25 meters and it likely contains multiple human burials. These are clustered into two major groups. The first group extends from about 7-15 meters and contains at least seven burials. Two of these appear to include some metal content. The second cluster extends from about 20-25 meters and it includes five likely burials. Some slight metal content is indicated in this area. Several shallow hyperbolas are visible in this radargram, which may represent reflections of tree roots.

![Figure 5. Radargram 160 in Block A, Behavior Cemetery.](image)

Figure 6 shows Radargram 265, which is located 102 meters north of the beginning line in Block A. The center of the drainage ditch is located about 11 meters out this line and it is barely distinguishable in the radargram. A more pronounced soil disturbance appears from 16-20 meters out this line. Its function is undetermined, although it appears to be a substantial excavation in the soil and it may represent a feature other than a burial, such as a large pit or cellar.

![Figure 6. Radargram 265 in Block A, Behavior Cemetery.](image)
Figure 7 shows Radargram 278, which is located 106 meters north of the beginning line in Block A. The center of the drainage ditch is located at 10.75 meters in this view and this feature is barely distinguishable in the radargram. Several probable human burials are located at 19-25 meters along this line.

**Figure 7. Radargram 278 in Block A, Behavior Cemetery.**

![Radargram 278 in Block A, Behavior Cemetery.](image)

**GPR Time Slice Maps**

Presented in this section are a series of time slice maps, which show the radar reflections at selected depths below ground in Block A. Figure 8 shows a time slice of Block A from 4-7 nanoseconds time depth. Many of the radar anomalies in this view relate to shallow disturbances, such as tree roots and animal burrows, that are unrelated to the human burials. This view is not very useful for addressing the burial issues.

Figure 9 shows a time slice of Block A from 9-13 nanoseconds time depth. In this view are numerous dendritic radar reflections. Many of these may represent reflections caused by large tree roots. Others may be the result of heavy ground disturbance created by multiple graves within a defined area. With increasing time depth this confusion achieves relative clarity and the suspect grave outlines become more recognizable.

Figure 10 shows a time slice of Block A from 15-18 nanoseconds time depth. At this depth the grave reflections become more distinct, although many of the deeper graves are not yet visible.

Figure 11 shows a time slice of Block A from 20-24 nanoseconds time depth. Many of the radar anomalies present in the previous view, a number of which are likely human grave reflections, have disappeared from this view.

Figure 12 shows a time slice of Block A from 26-29 nanoseconds time depth. Some problems with the radar imaging appear in this view, namely mosaic patterning. This problem can be corrected with GPR-Slice software. Many of the strong, large radar anomalies in this view mask multiple grave reflections.
Figure 8. Plan of GPR Block A, 4-7 ns, Behavior Cemetery GPR Grid North is to top of page; Each tick mark represents 5 meters.
Figure 9. Plan of GPR Block A, 9-13 ns, Behavior Cemetery (Each tick mark represents 5 meters).
Figure 10. Plan of GPR Block A, 15-18 ns, Behavior Cemetery (Each tick mark represents 5 meters).
Figure 11. Plan of GPR Block A, 20-24 ns, Behavior Cemetery (Each tick mark represents 5 meters).
Figure 12. Plan of GPR Block A, 26-29 ns, Behavior Cemetery (Each tick mark represents 5 meters).

Figure 13 shows a time slice of Block A from 31-35 nanoseconds time depth. Figure 14 shows a time slice of Block A from 37-40 nanoseconds time depth. Figure 15 shows a time slice of Block A from 42-46 nanoseconds time depth. Many of the strong, large radar anomalies in this view mask multiple grave reflections.
Figure 13. Plan of GPR Block A, 31-35 ns, Behavior Cemetery (Each tick mark represents 5 meters).
Figure 14. Plan of GPR Block A, 21-37 ns, Behavior Cemetery (Each tick mark represents 5 meters).
**GPR Overlay Maps**

As may be observed, anomalies are most pronounced at various depths, which mean that any single time slice is not a complete record of the strong radar anomalies that are present in an area. In order to address this deficit these data may be viewed as overlay maps, where layers of radar reflections are overlain to create a single map. To create these overlay maps only the intermediate portion of the time slice record was used. The
uppermost time slices and the lowest time slices contained extraneous data that were not conducive to crisp imagery of strong radar reflections. Two overlay variations of Block A, created with different color palettes and filter strength, are illustrated (Figures 16 and 17). The latter of these was used to tabulate an estimate of graves within Block A.
Figure 17. Overlay Plan of Block A, Behavior Cemetery (This version was used for estimating the number of human burials within Block A; Each tick mark represents 5 meters).
**Grave Estimates**

We estimate that at least 180 human graves lie within GPR Block A and five graves in Block D, or approximately 185 graves total. This estimate is derived by counting the likely grave reflections in the overlay plan. This conservative estimate likely under-represents the total number of graves within the sampled area. The classes of graves that are likely under-represented include infants and small children and multiple grave clusters in close proximity. Figure 18 shows the previous overlay plan map with suspected graves shown as an additional layer.

Figure 19 shows the suspected grave map without the GPR layer. The red “x” marks on these two maps define the horizontal extent of the GPR sample. GPR Grid North is to the top in this view and the main GPR datum (416N, 420E, approximately) is shown on the lower left. Each blue rectangle represents one suspected human grave. The locations shown in this map are approximate (within 1 meter) and should not be used for legal purposes. Some of the anomalies that are identified as human graves may represent other types of cultural features and some may represent natural disturbances, such as tree stumps. The vast majority, however, are likely graves.

**Block D**

GPR Block D was a 10 m by 10 m sample that was separate from Block A. It was located in the vicinity of four shallow, rectangular depressions that were not defined by any grave markers. These depressions were generally thought to represent four graves and GPR coverage was desired to ascertain a more complete understanding.

**Time Slice Maps**

Figure 21 shows a time slice of Block D from 7-11 nanoseconds time depth. None of the suspected graves are indicated in this view. A large irregular area of radar reflections is visible in the northwestern quadrant of the sample. This anomaly represents a substantial soil disturbance over a large area. It is also visible in several of the following views. Its age and function remains a mystery but it does not appear to represent human burials.

Figure 22 shows a time slice of Block D from 13-16 nanoseconds time depth. Figure 23 shows a time slice of Block D from 18-22 nanoseconds time depth. The four suspected graves that were recognized by their shallow, rectangular surface depressions are apparent on the eastern side of this view. The southernmost grave is the least well-defined.

Figure 24 shows a time slice of Block D from 24-27 nanoseconds time depth. Figure 25 shows a time slice of Block D from 29-33 nanoseconds time depth. Figure 26 shows a time slice of Block D from 34-38 nanoseconds time depth. Figure 27 shows a time slice of Block D from 40-43 nanoseconds time depth. Figure 28 shows a time slice of Block D from 45-49 nanoseconds time depth.
Figure 18. Suspected Graves, Block A, Behavior Cemetery (with GPR Layer; Each tick mark represents 5 meters).
Figure 19. Suspected Graves, Block A, Behavior Cemetery.
Figure 20. Plan Map Showing Marked Graves (indicated by red circles) and Probable Graves (blue rectangles), Behavior Cemetery.
Figure 21. Plan of GPR Block D, 7-11 ns, Behavior Cemetery (GPR Grid North is to top of page. Each tick mark represents 1 meter).

Figure 22. Plan of GPR Block D, 13-16 ns, Behavior Cemetery.

Figure 23. Plan of GPR Block D, 18-22 ns, Behavior Cemetery.
Figure 24. Plan of GPR Block D, 24-27 ns, Behavior Cemetery.

Figure 25. Plan of GPR Block D, 29-33 ns, Behavior Cemetery.

Figure 26. Plan of GPR Block D, 34-38 ns, Behavior Cemetery.
Figure 27. Plan of GPR Block D, 40-43 ns, Behavior Cemetery.

Figure 28. Plan of GPR Block D, 45-49 ns, Behavior Cemetery.

**Overlay Map**

Figure 29 is an overlay map of Block D. In this view the four suspected graves are clearly represented by rounded rectangular anomalies on the eastern one-half of the block. These reflections are evenly spaced and they correspond to the surface depressions. The other anomalies observed in this view, however, have no corresponding surface indications. It remains unclear what these anomalies represent. They may be associated with a very large tree root system (such as an ancient live oak tree), or they may have cultural relevance. At any rate, the anomaly exhibits circular-to-oval characteristics with a “hollow” center, or a “donut-like” reflection. This reflection remains quite strong at depths below those generated by the four grave reflections, which may indicate that it is a thick zone of soil disturbance that extends for possibly 2 meters below ground.
Figure 29. Overlay Plan Map of GPR Block D, Behavior Cemetery.
IV. Summary

The LAMAR Institute GPR Survey at the Behavior Cemetery collected approximately 5.6 kilometers of radargram data from two discrete sample blocks. The sample represents complete coverage of approximately one third to one half of the cemetery site. This GPR coverage represents only a sample of the entire site. Nevertheless, this sample yielded excellent results. Approximately 185 probable human graves were identified within the two sample blocks. Figure 20, presented earlier, is an overlay map showing the graves identified by grave markers versus those identified by GPR. While some overlap is apparent in these two datasets, the GPR data fills in many of the void areas where no grave markers are evident. Strong radar reflections, which are likely related to cultural activities, are pervasive in the distribution maps. Most of these strong reflections probably represent human burials. Others may represent various types of cultural features or natural disturbances, such as tree stumps, tree roots, or tree root casts. The eastern most portion of Block A contains many features that are not likely cemetery related. These include buried structural ruins and refuse features, which are associated with the Behavior plantation. A full understanding of the meaning and identification of these reflections, however, would require additional “ground truthing”. The radar equipment and software used in this study produced very useful information and additional GPR survey of this unexplored portion of Behavior Cemetery is recommended.
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