Natural Resources Conservation Service
National Soil Survey Center
Federal Building, Room 152
100 Centennial Mall North
Lincoln, NE 68508-3866

Phone: (402) 437-5499
FAX: (402) 437-5336

Subject: Cultural Resources – Geophysical **Date:** 9 December 2013

To: Kasey L. Taylor
State Conservationist
USDA, Natural Resources Conservation Service
1221 College Park Drive, Suite 100
Dover, DE 19904

Purpose:
Ground-penetrating radar (GPR) was used to ascertain whether there are unmarked graves within a portion of Hopkins Cemetery near Felton, Delaware, and to demonstrate NRCS's commitment to the protection and enhancement of our nation's cultural resources and historic properties.

Principal Investigators:
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Phillip S. King, Soil Scientist, USDA-NRCS, Georgetown, Delaware
Sally L. Griffith-Kepfer, State Resource Conservationist, USDA NRCS, Dover, DE
Joseph Hughes, Caretaker, Hopkins Cemetery, Felton, DE
Lawrence J. Tennity, State Conservation Engineer, USDA-NRCS, Dover, DE
Blake Thompson, Student-Trainee, Hopkins Cemetery, Felton, DE
Dastina Wallace, Public Affairs Specialist, USDA NRCS, Dover, DE
Steven Westra, Field Assistant, Hopkins Cemetery, Felton, DE

Activities:
All activities were completed on December 4, 2013.

Summary:

1. An 18 by 8 meter grid was established across an area within Hopkins Cemetery that contains no headstones and was marked as "promiscuous" on an historical map of the cemetery. Thirty-three, closely spaced (25-cm intervals), parallel radar traverses were conducted with a 400 MHz antenna across this area. Each radar traverse was 18 m long.

2. Two-dimensional radar records, three-dimensional pseudo-images, and time sliced imaging revealed the presence of three high-amplitude, rectangular anomalies within the gridded area. One of these anomalies was probed revealing the top of an arched brick burial vault. Based on this observation, it is assumed that the other two similar features also represent arched brick burial vault.

3. Additional, more weakly expressed and ambiguous reflection patterns were also observed on radar records and images from the grid area. These spatial reflection patterns appear to be similarly aligned, orientated in an east to west direction, and occurring at a similar depth. These factors suggest the likelihood of additional, more disintegrated burials within the gridded area.

It was the pleasure of Jim Doolittle and the National Soil Survey Center to work in Delaware and be of assistance to you, your staff, and your cooperators.

JONATHAN W. HEMPEL
Director
National Soil Survey Center

cc:
Deborah T. Anderson, Acting Soil Survey Regional Director, NRCS, Raleigh, NC
Sarah Bridges, Archaeologist, USDA-NRCS, Washington, DC
James Doolittle, Research Soil Scientist, Soil Survey Research & Laboratory, NSSC, MS 41, USDA-NRCS, Newtown Square, PA
Sally L. Griffith-Kepfer, State Resource Conservationist, USDA NRCS, Dover, DE
Philip King, Resource Soil Scientists, USDA-NRCS, Georgetown, DE
J. Cameron Loerch, Acting National Leader, Soil Survey Research & Laboratory, NSSC, MS 41, NRCS, Lincoln, NE
David Smith, Director, Soil Science Division, USDA-NRCS, Washington, DC
Lawrence J. Tennity, State Conservation Engineer, USDA-NRCS, Dover, DE
Wes Tuttle, Soil Scientist (Geophysical), USDA-NRCS-NSSC, Wilkesboro, NC
Zamir Libohova, Research Soil Scientist/Liaison SSR-03, Soil Survey Research & Laboratory, NSSC, MS 41, USDA-NRCS, Lincoln, NE

Technical Report

Jim Doolittle

Background:
Hopkins Cemetery was established in 1799. Many of the cemetery's earliest headstones are for the Coombe and Hopkins families, who settled the surrounding lands in the mid-eighteenth-century. The Coombe family was slave owners until the early-nineteenth century when the family began to free their slaves. An open area within the Hopkins Cemetery is believed to contain the unmarked graves of slaves and indentured servants. On an older map of the cemetery, this open area is identified as "promiscuous". Definitions of the word "promiscuous" include: "lacking standards of selection; indiscriminate; casual; random; and consisting of diverse, unrelated parts or individuals." As Hopkins Cemetery was originally a Quaker cemetery, "promiscuous: could refer to an area where non-Quakers had been buried. The cemetery's caretaker and the board of volunteers want to confirm the presence of unmarked graves within this area and, if present, place an engraved granite boulder over the site to honor these people. This GPR investigation was conducted to identify unmarked graves and as a demonstration of NRCS's commitment to the protection and enhancement of our nation's cultural resources and historic properties.

Equipment:
Ground-penetrating radar or *GPR* is a time-scaled system. This geophysical tool measures the time it takes for pulses of electromagnetic energy to travel from an antenna to a subsurface interface (boundary) and back. Whenever a transmitted pulse contacts an interface separating materials with different dielectric properties, a portion of the energy is reflected back to the receiving antenna. The more abrupt and contrasting the dielectric properties on opposing sides of an interface, the greater the amount of energy that is reflected back to the antenna and the greater the amplitude of the recorded signal.

The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (here after referred to as the SIR-3000), manufactured by Geophysical Survey Systems, Inc. (GSSI; Salem, NH).[1] The SIR-3000 consists of a digital control unit (DC-3000) with keypad, SVGA video screen, and connector panel. A 10.8-volt lithium-ion rechargeable battery powers the system. The SIR-3000 weighs about 4.1 kg (9 lbs) and is backpack portable. With an antenna, the SIR-3000 requires two people to operate. Jol (2009) and Daniels (2004) discuss the use and operation of GPR. A relatively high frequency, 400 MHz antenna was used in this investigation. In the profiled soils, the 400 MHz antenna provided excellent resolution and suitable depths of investigation. A distance-calibrated survey wheel with encoder was bolted onto the antenna and provided control over signal pulse transmission and data collection along radar traverse lines.

The RADAN for Windows (version 7.0) software program (developed by GSSI) was used to process the radar records shown in this report [1]. Processing methods used included: header editing, setting the initial pulse to time zero, color table and transformation selection, signal stacking, and horizontal high pass filtration (refer to Jol (2009) and Daniels (2004) for discussions of these techniques). In addition, range gain adjustments were used on radar records to improve pattern recognition.

Calibration of GPR:
Ground-penetrating radar is a time scaled system. The system measures the time that it takes electromagnetic energy to travel from an antenna to an interface (e.g., soil horizon, stratigraphic layer, buried cultural feature) and back. To convert the travel time into a depth scale, either the velocity of pulse propagation or the depth to a reflector must be known. The relationships among depth (D), two-way pulse travel time (T), and velocity of propagation (v) are described in equation [1] (after Daniels, 2004):

---

[1] Manufacturer's names are provided for specific information; use does not constitute endorsement.

$$v = 2D/T \qquad [1]$$

The velocity of propagation is principally affected by the relative dielectric permittivity (E_r) of the profiled material(s) according to equation [2] (after Daniels, 2004):

$$E_r = (C/v)^2 \qquad [2]$$

In equation [2], C is the velocity of light in a vacuum (0.3 m/ns). Typically, velocity is expressed in meters per nanosecond (ns). In soils, the amount and physical state (temperature dependent) of water have the greatest effect on the E_r and v. Dielectric permittivity ranges from 1 for air, to 78 to 88 for water (Cassidy, 2009). Small increments in soil moisture can result in large increases in the relative permittivity of soils (Daniels, 2004).

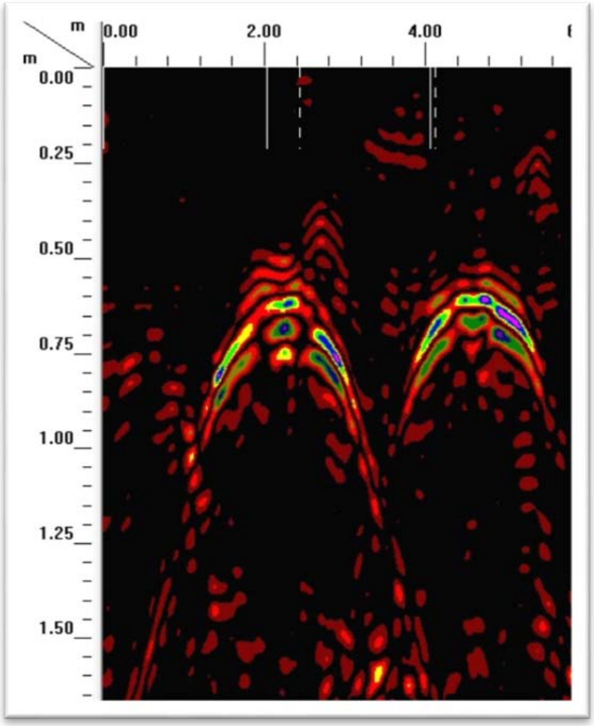

Figure 1. On this radar profile, the two reflection hyperbolas are from buried coffins. The depth and distance scales are expressed in meters.

To calibrate the depth scale, a preliminary GPR traverse was conducted across two recent (post-2000) grave sites. Figure 1 is the radar record from this traverse. In Figure 1, the horizontal (distance) and vertical (depth) scales are expressed in meters. Two highly-contrasting reflectors are evident on the radar record shown in Figure 1. Each reflector has produced a high-amplitude reflection hyperbola. These hyperbolas have a characteristic inverted-*U* or –*V* shape depending on depth and dielectric properties of the object and the surrounding soil matrix. Each hyperbola is the result of a buried coffin. Over the center of the first hyperbola shown in Figure 1, the depth (50 cm) to the top of the coffin was determined with a probe. Using this depth, the recorded two-way travel time to this interface (11.76 ns), and equation [1], the average velocity of signal propagation was estimated to be 0.0850 m/ns. Using equation [2], the average E_r was estimated to be 12.4. This information was used to depth scale the radar records.

3D Pseudo-Images and Amplitude Slice Analysis:
In recent years, the use of advanced signal-processing software has enabled the enhancement of radar signals and significant improvements in reflection pattern-recognition on radar records. Some of the signal processing methods used to improve the interpretability of subsurface archaeological features appearing on radar records are discussed by Sciotti et al. (2003) and Conyers (2004).

Three-dimensional (3D) GPR is commonly used in archaeological investigations to provide more comprehensive spatial coverage and higher resolution of subsurface structural features. Three-dimensional GPR relies on the construction of a 3D pseudo-image of the subsurface within a gridded area. The gridded area is typically relatively small (between 1 to 2500 m^2) and is intensively surveyed with multiple, closely-spaced (typically, 0.1 to 1.0 m), parallel GPR traverse lines. This relatively dense network of grid lines is necessary to resolve the geometries and sizes of different subsurface features and to prevent spatially aliasing the data (Grasmueck and Green, 1996). Following data collection in the field, the radar data are processed into a 3D pseudo-image of a grid site. Once a 3D pseudo-image is constructed of a grid site, arbitrary cross-sections, insets, and time slices can be extracted from the data set. Interactive software packages enable the 3D pseudo image to be viewed from nearly any perspective (Junck and Jol, 2000). The RADAN 7.0 software program allows the users to animatedly travel through the entire data volume (Grasmueck, 1996).

One advanced signal processing method that is commonly used in archaeological investigations is *amplitude slice analysis* (Conyers, 2004). This analysis technique explores differences in signal amplitudes within the 3D pseudo-image in "*time-slices*" (or depth-slices). In each time-sliced image, the reflected radar energy is averaged horizontally among adjacent, parallel radar traverses and in specified time (or depth) windows. Each time-sliced image displays changes in signal amplitudes within specific depth intervals of the soil (Conyers, 2004). Each amplitude time-slice image shows the distribution of reflected signal amplitudes, which can indicate changes in soil properties or the presence of buried artifacts and burials. In many instances, amplitude time-slice images have been used to distinguish and identify potential artifacts and to reduce interpretation uncertainties. Although the terms “time-slice” and “depth slice” are used interchangeably, only the term “depth-slice” will be used in this report.

Study Site:
Hopkins Cemetery (39.0012^o N, 75.6206 ^{o} W) is located about 3.8 km west-southwest of Felton near the intersection of Burnite Mills and Hopkins Cemetery roads in Kent County, Delaware. Figure 2 is a soil map of the survey area. This soil map is from the Web Soil Survey[2]. The cemetery is located in delineations of Ingleside sandy loam, 2 to 5 % slopes (IgB) and Pineyneck loam, 0 to 2 % slopes (PyA). These delineations transition and the surface slopes towards the south and southeast into a unit of Carmichael loam, 0 to 2 % slopes (CaA). The very deep, well drained Ingleside, moderately well drained Pineyneck, and poorly drained Carmichael soils formed in loamy eolian deposits over fluviomarine sediments. The taxonomic classifications of these soils are listed in Table 1. The approximate location of the GPR survey grid is shown in Figure 1. The survey grid was located in an area of Ingleside sandy loam, 2 to 5 % slopes. Because of the low clay and soluble salt contents, Ingleside soils are considered well suited to deep exploration depths with GPR.

Table 1. Taxonomic classification of the soils identified at Hopkins Cemetery.

Soil Series	Taxonomic Classification
Carmichael	Coarse-loamy, mixed, active, mesic Typic Endoaquults
Ingleside	Coarse-loamy, siliceous, semiactive, mesic Typic Hapludults
Pineyneck	Coarse-loamy, mixed, active, mesic Aquic Hapludults

---

[2] Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at http://websoilsurvey.nrcs.usda.gov/. Accessed [12/05/2013].

Figure 2. On this soil map of Hopkins Cemetery the approximate location of the GPR grid is enclosed by segmented, yellow lines.

Figure 3. Radar traverses were completed at Hopkins Cemetery using the SIR-3000 system and a 400 MHz antenna with an attached survey wheel.

Survey Procedures:
A survey grid, with dimensions of 18 by 8 meters, was established across the area of interest within Hopkins Cemetery. To facilitate the construction of the grid, two parallel survey lines were laid out and

served as grid axis lines. Along these two parallel axis lines, survey flags were inserted into the ground at a spacing of 25 cm (see Figure 3). A rope was stretched between matching survey flags on these two axis lines, which were located on opposing sides of the grid area, and the 400 MHz antenna was towed along the rope for guidance. Following data collection along the line, the rope was sequentially displaced 25-cm to the next pair of survey flags to repeat the process. Multiple GPR traverses were completed by pulling the 400 MHz antenna along the ground surface (Figure 3). Each radar traverse was stored as a separate file.

Results:

Spatial patterning of subsurface anomalies appearing on radar records can provide indications of potential graves. An "anomaly" is a contrasting subsurface feature or irregularity, which in an archaeological context, may represent a burial or buried artifact. Ground-penetrating radar detects, but does not identify subsurface anomalies. Tacit knowledge, historical records, apparent surface features, and ground-truth excavations are all used to support GPR interpretations.

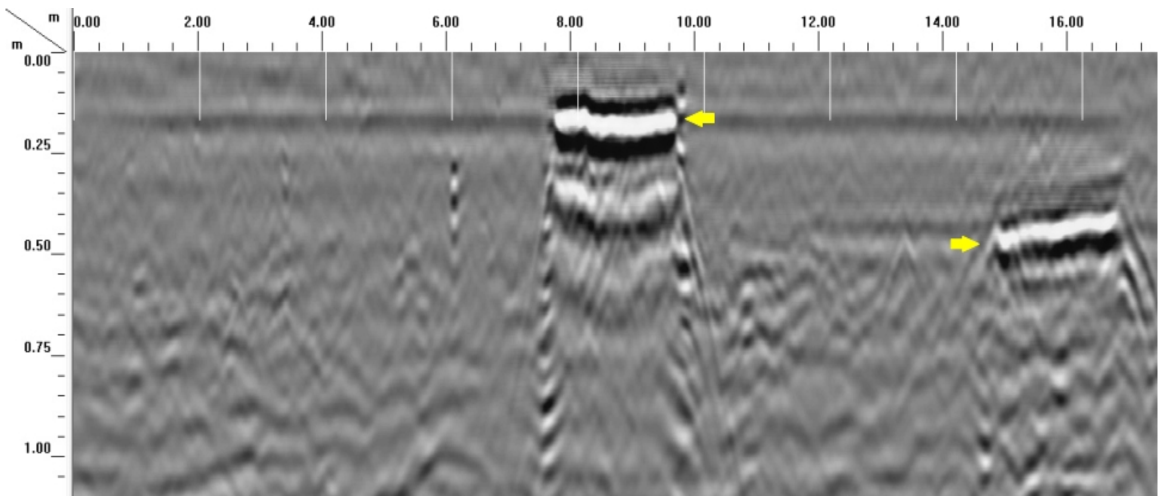

Figure 4. On this 2D radar record, the two conspicuous high-amplitude subsurface reflectors have been identified and are believed to represent arched brick burial vaults.

Figure 4 is the two-dimensional (2D) radar record from grid line Y = 3 m. On this radar record the horizontal (distance) and vertical (depth) scales are expressed in meters. The traverse was conducted essentially from east (left) to west (right). On this radar record, two noticeable, high-amplitude *anomalies* have been identified with yellow arrows. The more deeply buried, planar reflector on the right was probed and identified as the top of a buried arched brick vault. The more shallowly buried planar reflector on the left was excavated and identified as discarded cement wastes. However, the underlying reflection patterns and the geometry of this feature suggest that the concrete may overlie another brick vault. Ground-truth probings are required to confirm this *interpretation*.

The radar record shown in Figure 4 contains a number of reflection hyperbolas of moderate to low signal amplitudes that occur at different depths. These features are considered anomalous in Coastal Plain soils and sediments and some may represent remnants of burials or buried artifacts.   Soil and stratigraphic layers are poorly expressed on this radar record. As a consequence, the disruption and mixing of these layers in grave shafts are not apparent.

Figure 5 is a three-dimensional (3D) pseudo-image of the grid area. This 3D pseudo-image was constructed from the computer analysis and synthesis of a series of closely-spaced, two-dimensional (2D) radar records. In order to construct this 3D pseudo-image, GPR data were collected along a series of 33, closely-spaced (25 cm) traverse lines that were parallel with the x-axis (foreground). Each traverse line was 18 m long. These procedures produced the 18 by 8 m (144 m^2) grid area shown in Figure 5.

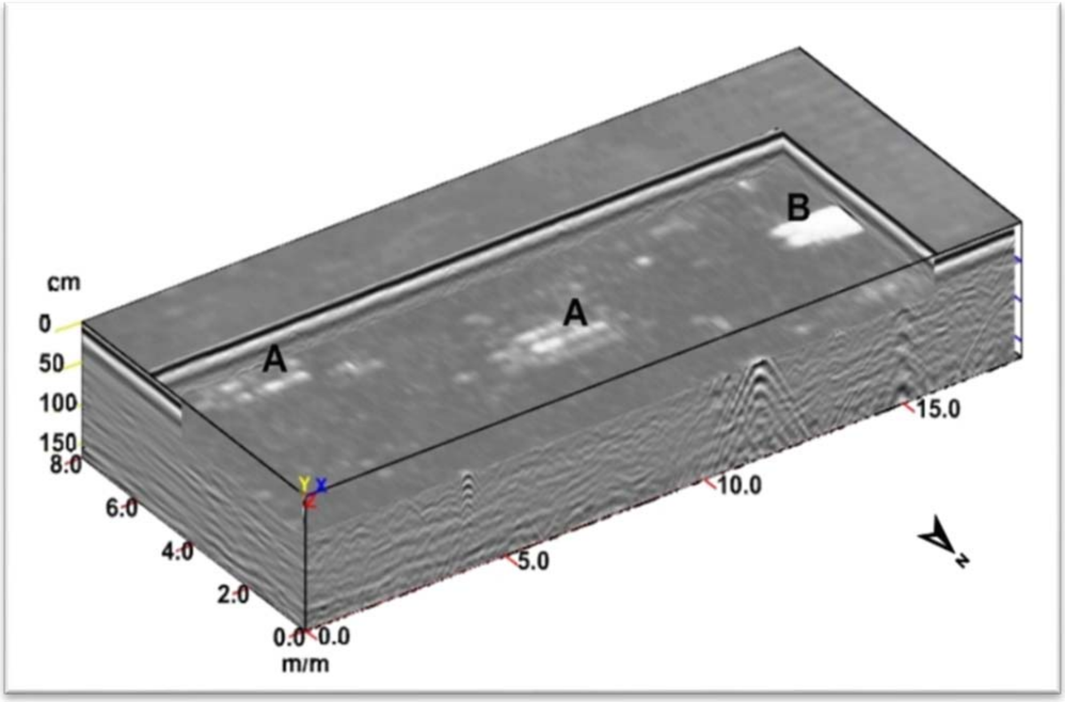

Figure 5. This 3D pseudo-image of the grid site has a 16.0 by 6.0 by 0.50 m inset cube graphically removed. The high amplitude (white colored) linear features along the base of the inset cube are believed to represent arched brick burial vaults.

In Figure 5, the 3D pseudo-image has a 16 by 6 by 0.5 m inset cube graphically removed to reveal three noticeable clusters of high-amplitude (white-colored) reflections along its base (at depth of 50 cm). These reflections are believed to represent the tops of three arched brick burial vaults. Ground-truth probing revealed that the cluster of high-amplitude reflectors at B represents the top of an arched brick burial vault. Features labeled “A” on this pseudo-image are similar in form and geometry. They occur at a common depth. These features, though unconfirmed, are also believed to represent arched brick burial vaults. The western most (right-hand) of these features underlies a patch of discarded cement waste, which was identified in the field through a shallow excavation.

Figure 6 contains three depth-sliced image of the 3D pseudo-image shown in Figure 4. These depth-sliced images are for the 50 cm depth interval. Each image was generated for a 15 cm (6 inch) depth window. Each depth slice image synthesizes the collected radar data over the entire grid area. In these depth-slices, the grid area is viewed from directly overhead. No conspicuous reflection pattern is apparent in the 0 cm depth slice. This is not unexpected as the grid area was uniformly covered by a grass mat. Three, elongated (in an east-west orientation) clusters of high-amplitude reflections are evident on the 50 cm depth slice image. These reflectors are believed to represent the tops of three arched brick burial vaults. The common depth and geometry of these high-amplitude reflectors on the 50 cm depth-sliced image helped to confirm the identification and location of these features. In Figure 6, these features are more poorly expressed and seemingly displace on the 100 cm depth- slice image.

The shape, orientation, depth, and size of burials affect GPR interpretations. On the depth-sliced images shown in Figure 6, a subsurface anomaly that is narrow (about twice the width of a body) and linear (about 100–200 cm long) will suggest a possible burial. In general, burials appear between depths of 50 and 150 cm on radar records. On 3D pseudo-images constructed from closely-spaced radar traverses, anomalous features appearing at a common depth and having an elongated, linear geometry represent potential grave sites. In addition, burials are commonly oriented in an east-to-west direction.

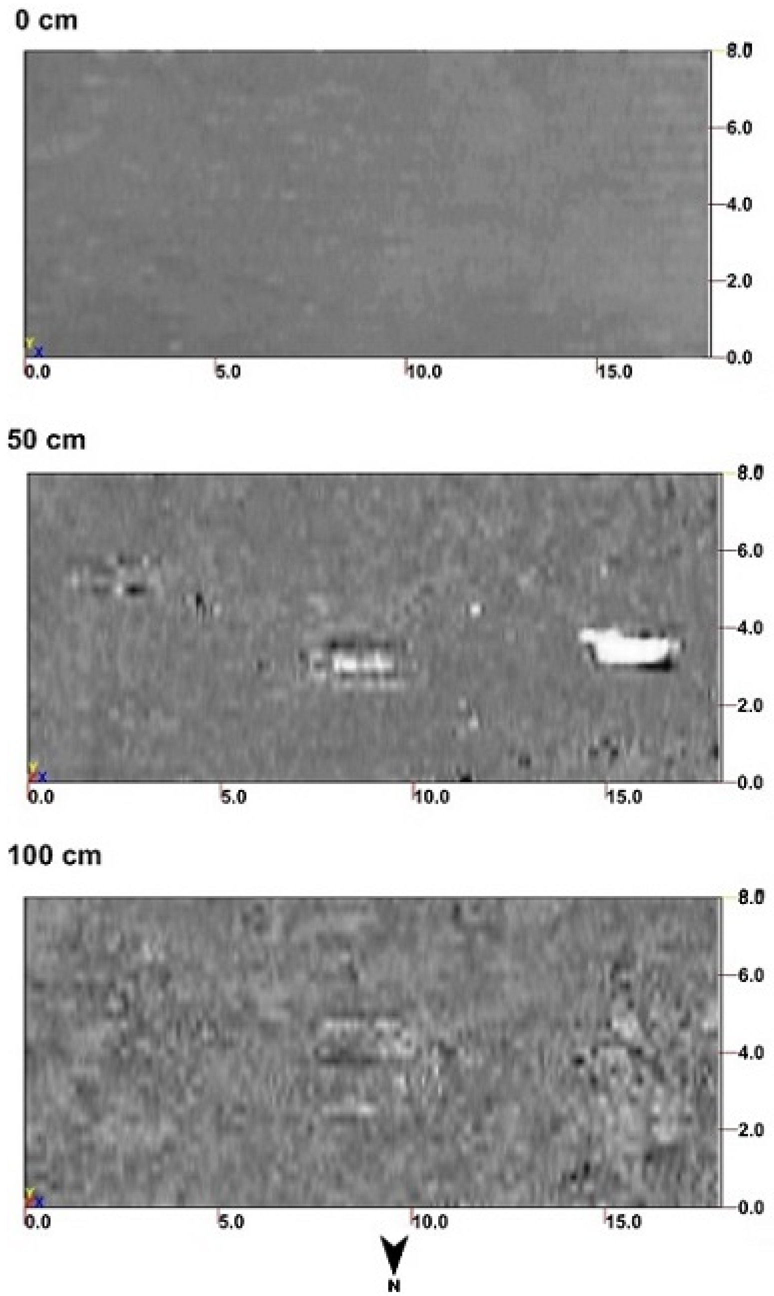

Figure 6. These three depth-sliced images of the grid area are viewed from directly overhead. The distance scales are expressed in meters.

The depth -sliced images shown in Figure 7 are the same as those shown in Figure 8. The only difference in these images is that the locations and outlines of the three suspected buried arched brick vaults have been outlined on the 50 and 100 cm depth slices in Figure 7.

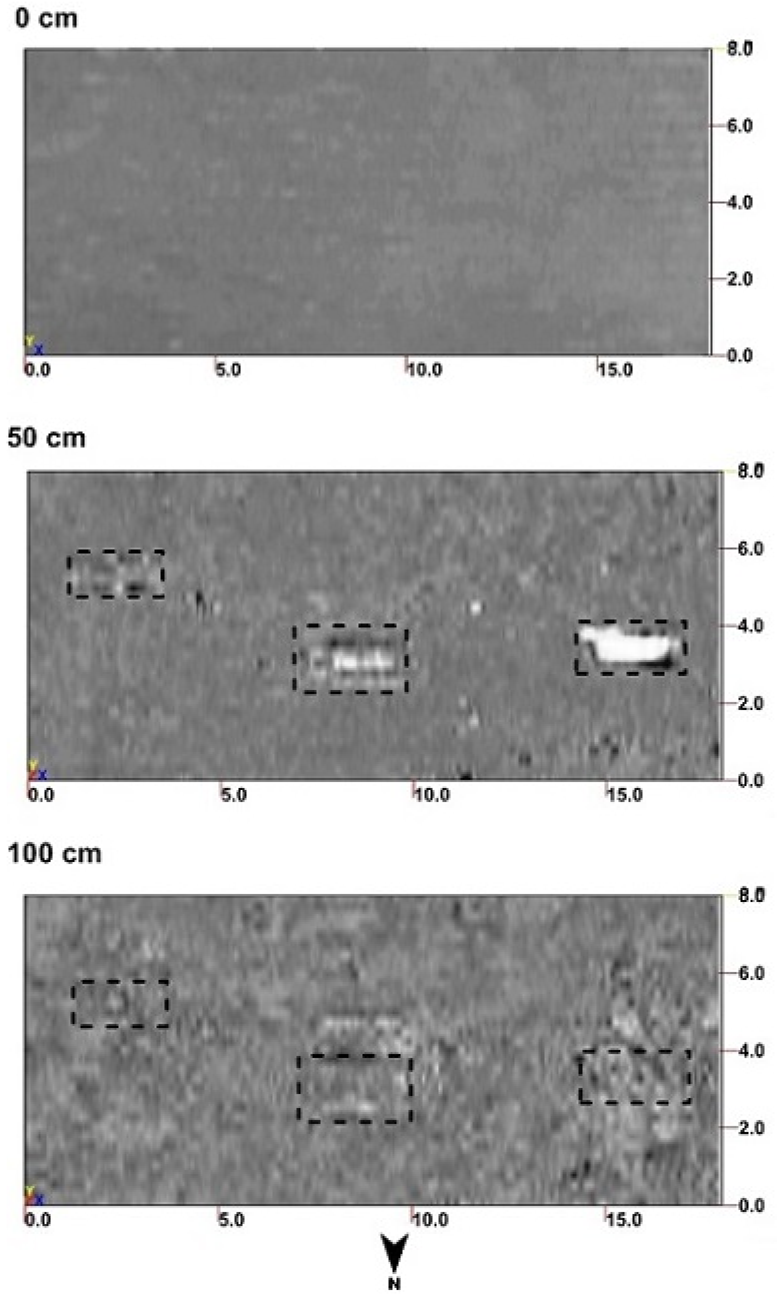

Figure 7. On these three depth-sliced images of the grid area, the location and outline of the three suspected arched brick burial vaults have been shown on the 50 and 100 cm depth-sliced images. Each image is viewed from directly overhead looking down. In each image, the distance scales are expressed in meters.

On the 100 cm depth-sliced image in Figures 6 and 7 a number of weakly expressed apparently linear features can be projected. The apparent geometry of some of these features has been outlined by segmented white-colored lines on the 100 cm depth-sliced image in Figure 8. In Figure 8, the outline of the three suspected arched brick burial vaults has also been presented by the black-colored segmented lines on the 50 and 100 cm depth -sliced images. All of the features identified in the 100 cm depth-sliced image of Figure 8, are rectangular and elongated in an east-west direction. In general, multiple, similarly aligned, elongated subsurface anomalies occurring at a common depth on depth-sliced images suggest possible burials. The additional features outlined on the 100 cm depth-slice image are indistinct and highly interpretive. However, these features and spatial amplitude patterns do suggest that other burials, besides the three identified arched brick vaults, may be present in the area labelled "promiscuous" on an early map of Hopkins Cemetery.

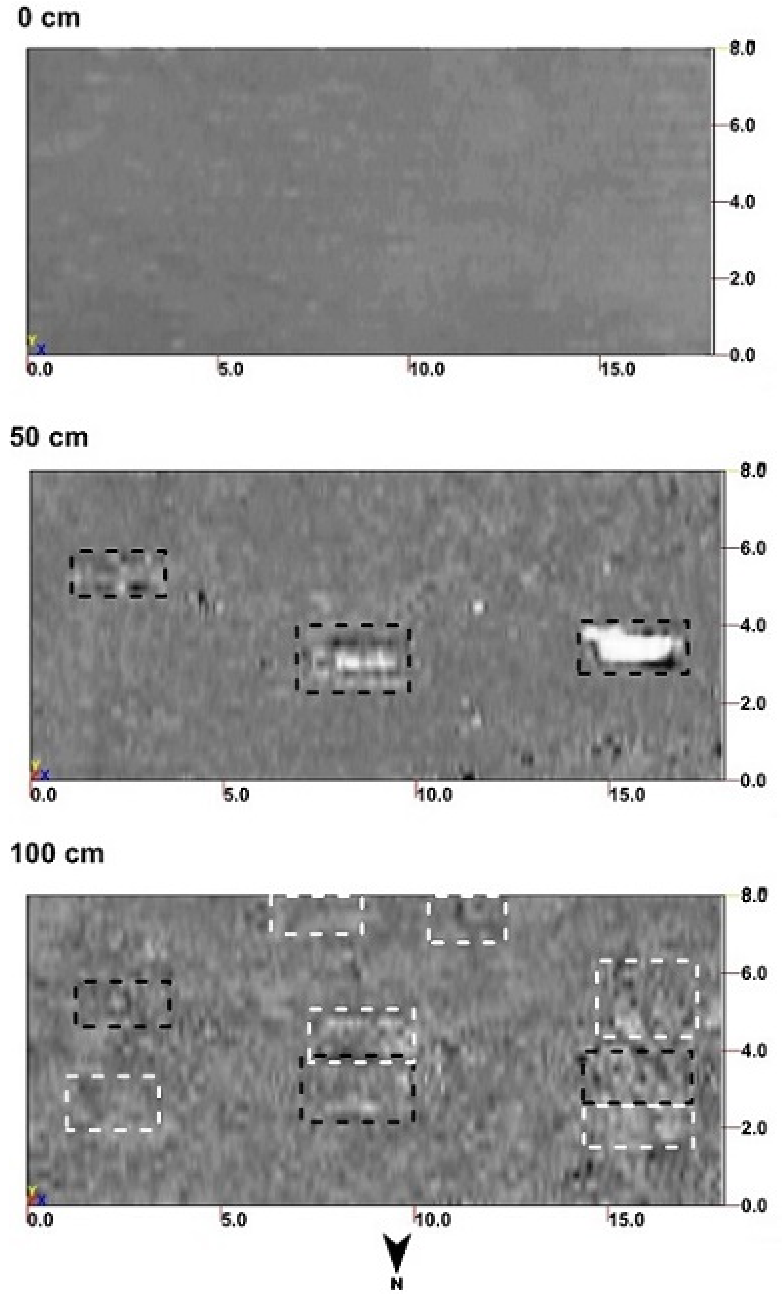

Figure 8. The same three depth-sliced images of the grid area are shown with some additional, more weakly expressed features outlined on the 100 cm image. In each image, the distance scales are expressed in meters.

The arched brick burial vaults, which are more lasting and contrasting features to GPR, are also a measure of wealth and status, as only the more well-to-do could probably afford them and other more permanent burial markers. In general, many early farmers, slaves, and other poor and marginalized people were wrapped in shrouds or in wooden boxes (coffin), buried, and given wooden markers or no marker at all. These wooden boxes and wooden markers have long since disintegrated and are no longer present in these relatively acid soils. Over the centuries, depending on wealth and social status, people have been buried in caskets made from wood, cast iron, steel, fiberglass, glass, bamboo, wicker and even gold. Cast iron and fiberglass caskets are more lasting and visible to GPR than wooden caskets. The first cast-iron casket was patented in 1848. Today stainless steel caskets are mainly used for burials. This accounts for the *visibility* of the modern graves used to calibrate the radar (see Figure 1).

References:
Cassidy, N.J. 2009. Electrical and magnetic properties of rocks, soils, and fluids. In *Ground Penetrating Radar: Theory and Applications*, ed. H. M. Jol, 41-72 pp. Elsevier Science, Amsterdam, The Netherlands.

Conyers, L.B., 2004. Ground-Penetrating Radar for Archaeology. Altamira Press, Walnut Creek, California (2004)

Daniels, D.J., 2004. *Ground Penetrating Radar; 2nd Edition*. The Institute of Electrical Engineers, London, United Kingdom.

Grasmueck, M., 1996. 3-D ground-penetrating radar applied to fracture imaging in gneiss. *Geophysics* 61(4): 1050-1064.

Grasmueck, M, and A.G. Green, 1996. 3-D georadar mapping: Looking into the subsurface. *Environmental and Engineering Geoscience* Vol II (2): 195-220.

Jol, H., 2009. *Ground Penetrating Radar: Theory and Applications*. Elsevier Science, Amsterdam, The Netherlands.

Junck, M.B., and H.M. Jol, 2000. Three-dimensional investigation of geomorphic environments using ground penetrating radar. 314-318 pp. In: Noon, D. (editor) Proceedings Eight International Conference on Ground-Penetrating Radar. May 23 to 26, 2000, Goldcoast, Queensland, Australia. The University of Queensland.

Sciotti, M., F. Colone, D. Pastina, and T. Bucciarelli, 2003. GPR for archaeological investigations: Real performance assessment for different surface and subsurface conditions. 2266-2268 pp. IN: Proceedings 2003 IEEE International Geoscience and Remote Sensing (IGARSS 2003), 21-25 July 2003, Toulouse, France.