United States Department of Agriculture

NRCS

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SUBJECT: MGT – Trip Reports, Geophysical Field Assistance Delaware, July 20, 2009

July 29, 2009

TO: Russell Morgan
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NRCS, Dover, DE

File Code: 330-20-7

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Purpose:
At the request of the Dorothy Abbot and local historians, ground-penetrating radar (GPR) surveys were conducted at the historic Parson Thorne Mansion, in Milford, Delaware. Local historians and curators wish to locate the perimeter of a small 'Delaware-historic' cemetery, which is located behind the historic Thorne Mansion. During recent land-grading activities around two sides of the cemetery, several unmarked, vaulted gravesite were uncovered. The GPR surveys attempted to identify the outer boundary of the cemetery and to confirm whether additional gravesites are located within a small, wall-enclosed family plot (circa 1820-1829) of a noted Delaware statesman and his family. There are three grave markers within this family plot, but more headstones and markers are presumed to have been removed by vandals.

Principal Participants:
Dorothy Abbot, Extension Agent, University of Delaware, Dover, DE
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Justin Ford, Summer Intern, USDA-NRCS, Dover, DE
Arthur Walker, Geographic Information Systems Specialists, USDA-NRCS, Dover, DE

Activities:
All activities were completed on July 20, 2009.

Summary:

1. Detailed GPR grid surveys of three small areas revealed subsurface features believed to be burials. The locations, geometry, and extent of these features were successfully imaged using 3D GPR and time-slice imaging techniques. As many of these features were closely spaced and some perhaps stacked, the exact number could not be confirmed from radar records and interpretations alone.

2. While three small grids within the study area revealed the possible presence of additional unmarked graves, the actual extent and outer perimeter of the former cemetery was, unfortunately, not ascertained by the three GPR grid surveys.

3. A larger area near the historic Thorne Mansion was requested to be survey with GPR, but constraints imposed by other obligations would not permit the survey at this time. The survey of this area could be completed in ½ day. If requested, I will gladly assist this undertaking.

It was my pleasure to work in Delaware and to be of assistance to you, your staff and our cooperators.

With kind regards,

/s/
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Study Sites:
The site is located in a relatively open wooded area (38.914039 ^{o} N. Latitude, 75.435472 ^{o} W. Longitude) located just to northwest of the Thorne Mansion in Middletown, Delaware (Figure 1). Figure 1 is a Google Earth image of the site. In Figure 1, the historic Thorne Mansion is located to the west (left) of "A". The wall-enclosed family plot is located near "B", and the area of recent extensive land-grading activity is located near "C".

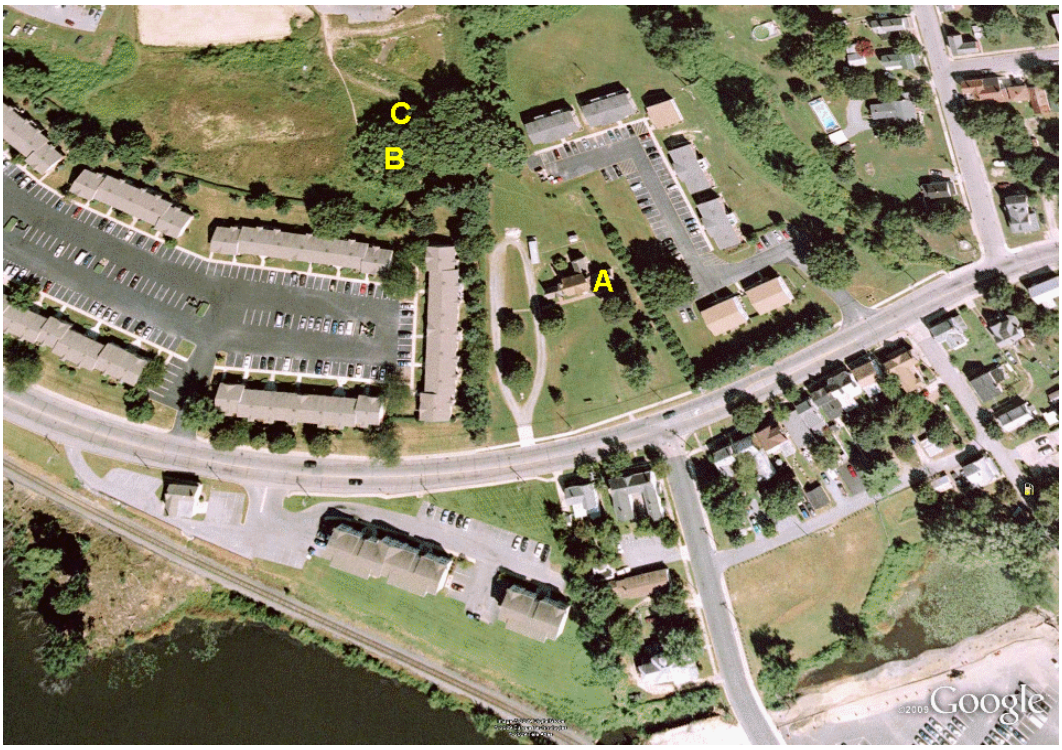

Figure 1. Shown on this Google Earth image are the approximate locations of the Thorne Mansion (A), the wall-enclosed family plot (B), and the area of recent land-grading activity (C).

The study site is located in areas of Sassafras sandy loam on 0 to 2 % slopes (SaA) and Ingleside-Urban land complex on 0 to 5 % slopes (IuB). The very deep, well drained Sassafras and Ingleside soils formed in stratified, sandy marine and alluvial sediments. Sassafras is a member of the fine-loamy, siliceous, semiactive, mesic Typic Hapludults family. Ingleside is a member of the coarse-loamy, siliceous, semiactive, mesic Typic Hapludults family. Because of their moderate and low clay contents and siliceous mineralogy, Sassafras and Ingleside soils are considered to have moderate and high potentials for GPR, respectively (http://soils.usda.gov/survey/geography/maps/GPR/methodology.html).

Equipment:
The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (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 9 lbs (4.1 kg) and is backpack portable. With an antenna, the SIR-3000 requires two people to operate. Daniels (2004) and Jol (2008) discuss the use and operation of GPR. A 400 MHz antenna was used in this study.

The RADAN for Windows (version 6.6) software program (GSSI) was used to process the radar records.[1] Basic processing steps, which were applied to all radar records, included: header editing, setting the initial pulse to time

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

zero, color table and transformation selection, display range gain adjustments. All radar records used to prepare the 3D pseudo-images shown in this report were collectively subjected to more sophisticated processing procedures to improve visualizations and interpretations. The added processing included signal stacking and migration (see Daniels (2004) and Jol (2008) for discussions of these processing techniques).

The use of digital signals and sophisticated signal-processing software, have enabled signal enhancement and improved pattern-recognition on radar records in some soils. Processing algorithms used to improve the interpretability of subsurface archaeological features appearing on radar records are discussed by Sciotti et al. (2003) and Conyers and Goodman (1997). In recent years, an advanced type of GPR data manipulation, known as *amplitude slice-map analysis*, has been used in archaeological investigations (Conyers and Goodman, 1997). For this analysis, a 3D pseudo-image of a small gridded area is constructed from the computer analysis and synthesis of a series of closely-spaced, two-dimensional radar records. Amplitude differences within the 3D pseudo-image are analyzed in "*time-slices*" that examine changes within specific depth intervals in the ground (Conyers and Goodman, 1997). In this process, the reflected radar energy is averaged horizontally between adjacent, parallel radar records and in specified time (or depth) windows to create a time-slice (or depth-slice) image. Each amplitude time-slice shows the spatial distribution of reflected wave amplitudes, which may indicate changes in soil properties or the presence of subsurface features. In many instances, 3D GPR imaging techniques have been used to distinguish and identify potential targets and to reduce interpretation uncertainties.

Ground-penetrating radar:
Ground-penetrating radar is an impulse radar system designed for shallow, subsurface investigations. This system operates by transmitting short pulses of electromagnetic energy into the ground from an antenna. Each pulse consists of a spectrum of frequencies distributed around the center frequency of the transmitting antenna. Whenever a pulse contacts an interface separating layers of differing dielectric permittivity (E), a portion of the energy is reflected back to the receiving antenna. The receiving unit amplifies and samples the reflected energy, and converts it into a similarly shaped waveform in a lower frequency range. The reflected waveforms are displayed on a video screen and are stored on a hard disk for future playback, processing, and/or display.

Ground-penetrating radar is a time scaled system. This system measures the time that it takes electromagnetic energy to travel from the antenna to an interface (e.g., soil horizon, buried archaeological feature) and back. To convert the travel time into a depth scale, 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 the following equation (Daniels, 2004):

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

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

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

Where C is the velocity of propagation in a vacuum (0.298 m/ns). 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. Because of the sensitivity of the study area, no corings were made to confirm interpretations or to correctly depth-scale the imagery. The depth scale used on the radar records shown in this report was based on an E_r (13.13) and v (0.08224 m/ns). These rather conservative values are based on similar experiences on moist, coarse-loamy soils. The relative depths to subsurface interfaces and features identified on the enclosed radar records and pseudo-images, therefore, should only be considered as close approximations of the actual depths.

Survey Procedures:
Three small survey grids were established at site. Survey grids are necessary to collect the data required for the construction of 3D GPR pseudo-images. At each grid site, 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 50 cm. Though relatively coarse for archaeological investigations, this interval allowed rapid reconnaissance surveys

of the three grid areas. A distance-graduated rope was stretched between matching survey flags on these two axis lines, which were located on opposing sides of the grid. GPR traverses were conducted along this line. The 400 MHz antenna was towed along the graduated rope on the soil surface and, as it passed each 100-cm graduation, a mark was impressed on the radar record. Following data collection along the line, the distance-graduated rope was sequentially displaced 50-cm to the next pair of survey flags to repeat the process.

Grid Site 1:
A 10 by 12 m grid was established over an open area that is located to the immediate east of the wall-enclosed, family plot. Figure 2 is a 2D radar record from this site. The horizontal and vertical scales on this radar record are expressed in meters. This radar traverse is spaced 1 m away and parallels the wall enclosing the family plot. The traverse was conducted in an essentially south (left) to north (right) direction. On this radar record, several very shallow (<50 cm) point anomalies have been identified (Figure 2, see A, B, C, and D). Point anomalies are identifiable by their characteristic hyperbolic pattern (^), which is a manifestation of the radar antenna sensing a subsurface object before and after passing directly over it. This characteristic of wave propagation produces the convex-upwards or hyperbolic pattern. Many of these features identified in Figure 2 are suspected to represent reflections of larger roots from a nearby large oak tree that is located within the adjoining family plot. As there are high amplitude, reverberated signals beneath anomaly "A", this feature is suspected to be composed of metallic materials, which are responsible for the ringing pattern. This anomaly is located to the north (right) of a footpath that crosses the grid area from west to east.

Burials are difficult to identify with certainty in many soils because of the presence of other scattering bodies (e.g., rock fragments, tree roots, animal burrows, and modern cultural features or debris), which confound interpretations. As evident in Figure 2, scattering bodies produce undesired subsurface reflections, which clutter and complicate radar records, mimic reflections from some burials, and mask or obscure the presence of other burials. While the radar detects, it does not identify subsurface features. Without greater clarity, the large number of point anomalies that appear on this radar record would be prohibitive to investigate.

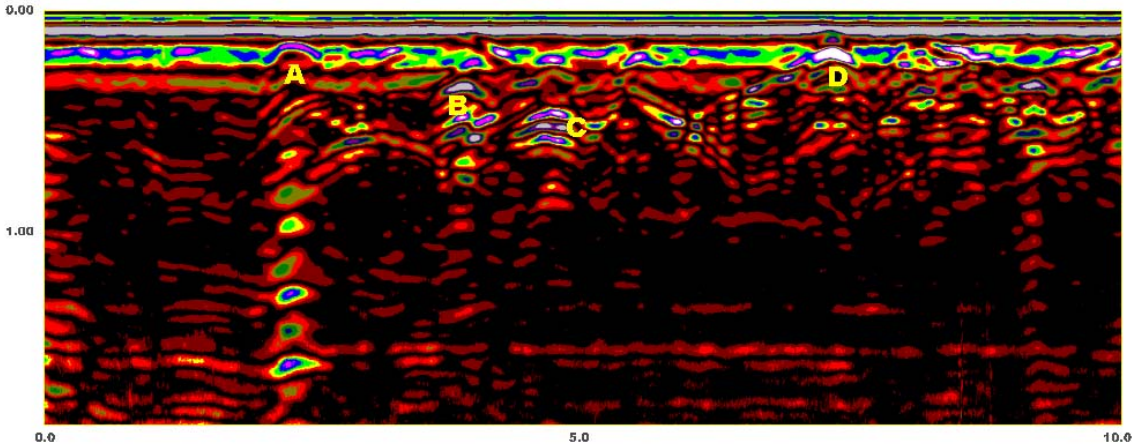

Figure 2. In the upper part of this radar record from Grid Site 1, scattering bodies, many suspected to be tree roots, confounds interpretations of potential grave sites.

Figure 3 contains three pseudo-images of Grid Site 1, each constructed from 25 closely spaced, parallel radar records. With the exception of the 0-cm slice, in each image a 10 by 12 m inset cube has been removed from the 3D pseudo-image. The base of these three cutout cubes are at depths of 50 and 150 cm, in the middle and lower images, respectively. All radar traverses were conducted parallel to the X axis (right foreground). As a result, traces were more continuously sampled and reflectors are strongly represented with little distortion to the data in this direction (essentially, north-south). Along the Y axis, however, data were not continuously recorded but interpolated over a 50-cm interval (the distance between radar traverses). As a result, some subsurface information

was lost during interpolation and data along the Y-axis appear slightly smudged, less resolved, and more generalized.

The exposed sidewalls of each cube show planar reflections, which are representative of stratified, loamy alluvial and marine sediments. The surface of the uppermost 3D pseudo-image (0 cm depth) appears relatively uniform and homogenous in composition as it essentially lacks high-amplitude (colored white) reflections. In the 3D pseudo-image with the inset cube removed to a depth of 50 cm, high-amplitude reflections are apparent in the west-central (upper, center-left) portion of the grid area. The upper (western) boundary of the survey area is located adjacent to the base of a wall, which encloses the family plot. The west-central portion of the survey area is nearest a large oak tree, which occupies much of the southern portion of the enclosed family plot. Reflections evident along this portion of the base of the cutout cube are believed to represent larger tree roots. Along the base and near the center foreground of the 3D pseudo-image with the inset cube removed to a depth of 100 cm, faint rectangular areas (Figure 3 lower plot, A, B, and C) are evident. These patterns persist on slices cut 30 cm above and below the base shown on this image and appear to contain two distinct features. These areas extend in an east-west direction and may represent remnants of gravesites.

Even with favorable soil properties (e.g., dry, electrically resistive, sandy soils) the detection of burials is never guaranteed with GPR. Detection is affected by: the electromagnetic gradient that exists between the buried feature and the soil; the state of preservation, size, shape, and depth of burial; and the presence of scattering bodies within the soil. The detection of burials with GPR often depends upon the materials used to contain the corpse. Within a cemetery, burials will produce different geophysical responses not only because of differences in states of preservation and spatial differences in soil properties, but differences in burial practices over time (Nobes, 1999). Within a given cemetery, materials used to enclose corpses may consist of shrouds, body bags, wooden caskets, stone, brick, or concrete vaults, and/or fiberglass, composite or metal coffins. Early settlers often buried their dead wrapped in shrouds and placed in coffins made of wood (Owsley and Compton, 1997). Preservation of these early burials and their identification with GPR depends on soil conditions, but is generally poor (Owsley and Compton, 1997).

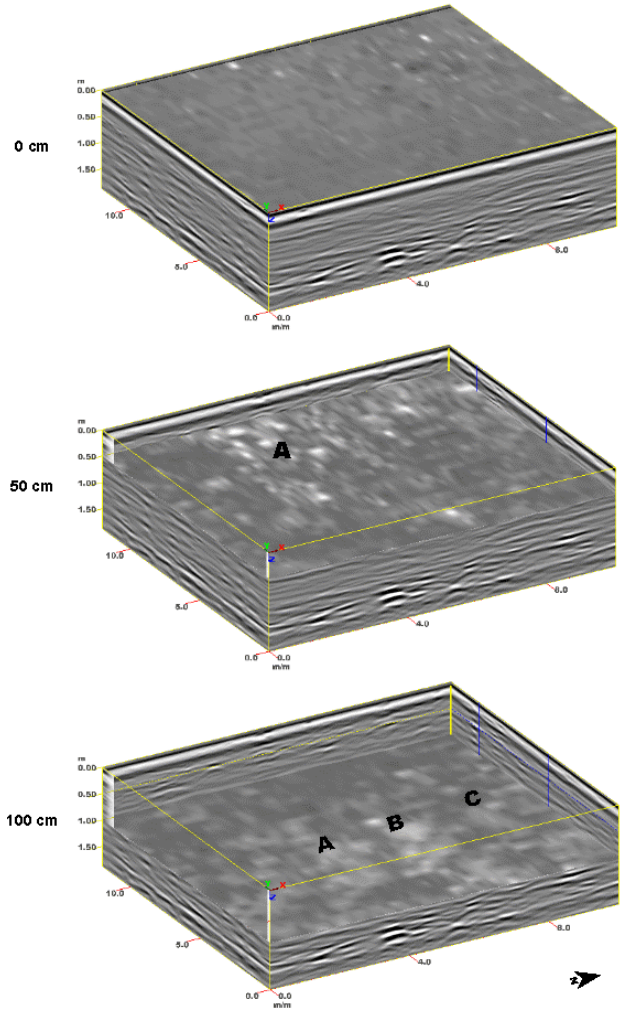

Figure 3. Three, 3D GPR pseudo-images of Grid Site 1 with inset cubes removed at different depths.

At Grid Site 1, GPR failed to provide any strong indications that would suggest the presence of additional burials. Considering the absence of strong and more meaningful reflection patterns, the grid area is viewed as containing no well preserved burials. This does not mean that burials a re not present beneath the grid area. It means that burials, if present, because of their state of preservation or size, are not detectable with GPR.

Grid Site 2:

A 10 by 10 m grid was established over an open, sloping area that is located to the northeast of the wall-enclosed, family plot. It was in this area, that brick vaults were unearthed during land-grading activities. The grid area was located 1 m east of a north-south trending portion of a recently erected iron-rod fence and immediately south of a small brick pile constructed from the scattered bricks of the disturbed vaults.

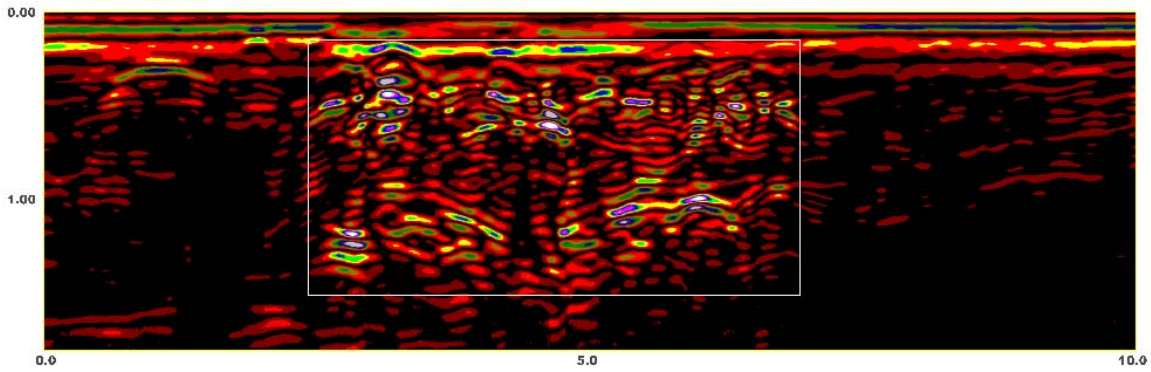

Figure 4. The rectangular box encloses a subsurface area that contains high-amplitude reflections. The general pattern and intensities of radar reflections in this area contrast noticeably with adjoining areas of more undisturbed soil materials.

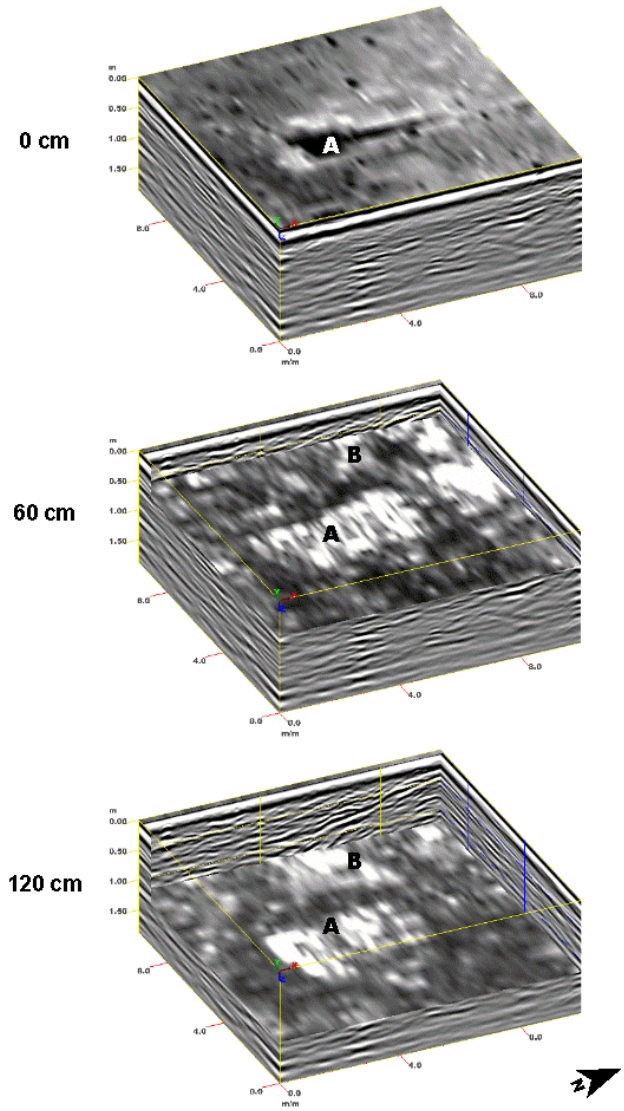

Figure 5. Three, 3D GPR pseudo-images of Grid Site 2 with inset cubes removed at different depths.

Figure 4 is a 2D radar record from Grid Site 2. The horizontal and vertical scales of this radar record are expressed in meters. This traverse line essentially extends in a south (left) to north (right) direction. In Figure 4, a rectangular box has been used to emphasize an area with a larger number of higher-amplitude reflectors than the surrounding areas. This contrasting area has abrupt vertical boundaries, which suggest an artificial rather than a natural feature. Knowledge of the presence of brick-lined underground, burial chambers, which were disturbed in this area during land-grading operations, provides confirmation to this interpretation. The large number of closely spaced, rather chaotically arranged point reflectors provides few clues as to their identities.

Figure 5 contains three pseudo-images of Grid Site 2, each constructed from 21 closely spaced, parallel radar records. With the exception of the 0-cm slice, in each image a 10 by 10 m inset cube has been removed from the 3D pseudo-image. The base of these three cutout cubes are at depths of 60 and 120 cm, in the upper, middle, and lower images, respectively. The exposed sidewalls of each cube show planar reflections, which are representative of the underlying, stratified, loamy alluvial and marine sediments. In each pseudo-image, an area with conspicuously high-amplitude reflections is identified by "A". A second, more segmented area of high-amplitude signals is identified at "B". This area corresponds with the general locations of the buried, brick burial vaults. The area appears rectangular in form on the base of the 60 and 120 cm cutout cubes. Judging from internal spatial patterns, the generalized area appears to consist of multiple, closely-spaced, elongated features. The elongated forms are arranged in a general north-south orientation, which follows the down slope curvature of the ground surface.

Grid Site 3:

A 5 by 4 m grid was established within the wall-enclosed, family plot. Space was restricted because of the presence of a large oak tree in the southern part of plot. Figure 6 is a 2D radar record from Grid Site 3. The horizontal and vertical scales of this radar record are expressed in meters. The radar record shown in Figure 6 represents the first traverse line, which was orientated in a south (left) to north (right) direction and passed immediately to the east of a large pedestal monument (located at the 4 m distance mark) commemorating James, Sarah, and Elizabeth Clayton (circa 1820 to 1829). Four hyperbolas (A, B, C, D) are apparent in the upper 80 cm of this radar record. Hyperbola "A" is closest to the oak tree and may represent a large root. Hyperbolas "B" and "C" are to the south (left) while "B" is to the north (right) of the monument (located at the 4.0 m distance mark). These may represent burial. Deeper, higher-amplitude reflections "F" and "G" are located immediately below (40 to 50 cm) reflections "B" and "C". Without ground-truth observations a large amount of uncertainty is attached to any interpretation of these features. These reflections may represent stacked burials or the tops and bottoms of two burials (the upper reflections are lower-amplitude and therefore could represent a more highly weathered or less contrasting material than the lower reflections). All this is speculative though. The multiple (ringing), high-amplitude reflections beneath the 5.0 m distance mark are artifacts caused by passing too close to a metallic pin flag, which was used to reference the grid line.

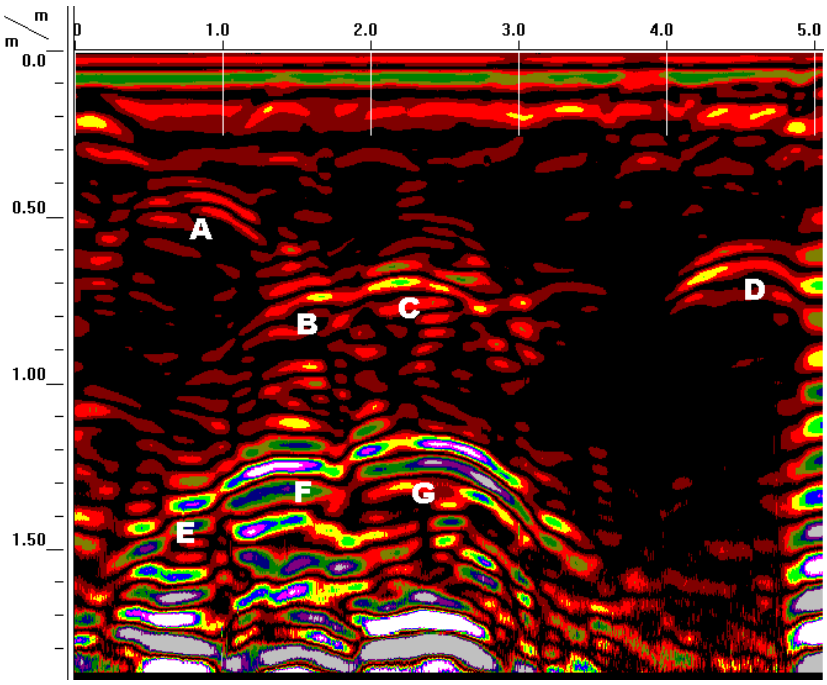

Figure 6. Three separate, high-amplitude subsurface hyperbolas (E, F, and G) identify the most probable locations of three burials.

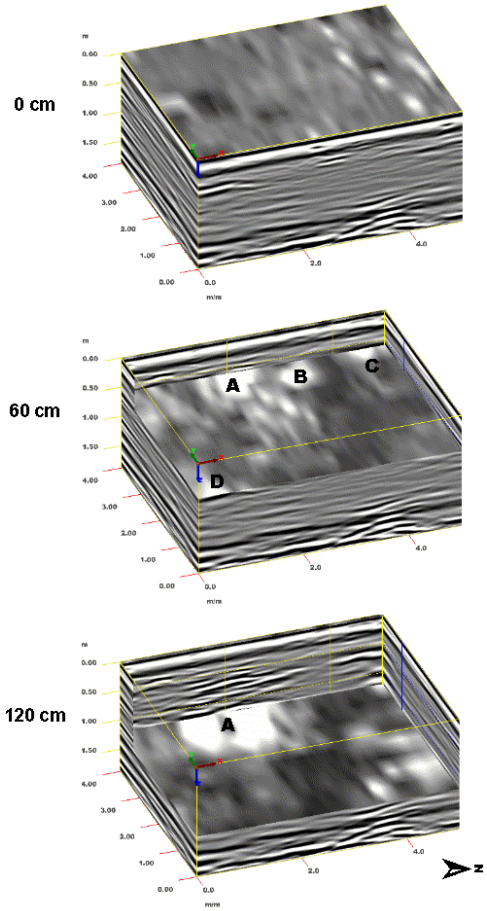

Figure 7. Three, 3D GPR pseudo-images of Grid Site 3 with inset cubes removed at different depths.

Figure 7contains three pseudo-images of Grid Site 3, constructed from 9 closely spaced, parallel radar records. With the exception of the 0-cm slice, in each of the other two 3D pseudo-images a 5 by 4 m inset cube has been removed. The base of these cutout cubes are at depths of 60 and 120 cm, in the middle and lower images, respectively. Once again, the exposed sidewalls of each cube show planar reflections, which represent stratified alluvial or marine sediments. In the middle (60 cm depth) image, four conspicuous, high amplitude reflectors have been identified. Reflectors "A", "B", and "C" correspond to reflectors "B", "C", and "D" in Figure 6. Reflectors "A" and "B" extend 100 cm into the plot and have an east-west orientation. The presents of similarly located (both spatial and depth) images on three or more successive radar records spaced 100 cm apart, helps to confirm a probable burial. The high-amplitude reflector "D" is situated near and to the immediate southeast of a headstone and is therefore suspected to be a burial also. The high-amplitude reflectors "E", "F", and "G" in Figure 6, are too closely spaced resulting in the superpositioning of reflected signals and the two relatively broad, high-amplitude reflections near "A" on the base of the 120 cm inset cube. The geometry of these features suggests burials.

References:

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