United States Department of Agriculture	**Natural Resources Conservation Service**	**11 Campus Boulevard Suite 200 Newtown Square, PA 19073**

Subject: -- Geophysical Assistance -- **Date:** 23 November 2004

To: William Gradle
State Conservationist
USDA-Natural Resources Conservation Service
2118 West Park Court
Champaign, IL 61821

Purpose:
The purpose of this investigation was to evaluate the feasibility of using ground-penetrating radar (GPR) to locate unmarked graves or gravesites with headstones only in the Charleston Cemetery.

Participants:
Andy Cervin, District Conservationist, USDA-NRCS, Charleston, IL
Greg Clark, Soil Scientist, USDA-NRCS, Charleston, IL
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Zack Weber, Soil Scientist, USDA-NRCS, Charleston, IL
Roger Windhorn, Resource Soil Scientist, USDA-NRCS, Champaign, IL
Dan Withers, Cartographic Technician, USDA-NRCS, Champaign, IL

Activities:
The study was conducted on 17 November 2004.

Results:

1. Because of inherent physical and chemical properties, areas of Miami soil are considered to have moderate to low potential for ground-penetrating radar. Results from the Charleston Cemetery demonstrate that GPR can be successively used for archaeological and forensic investigations in areas of Miami soils.

2. Radar traverses were conducted in front of a row of seven headstones. Three high amplitude, aligned, and elongated anomalies were distinguish on radar records and 3D images at estimated depths ranging from 1 to 1.3 m. These features are near modern headstones and assumed to represent burials. Additional, low amplitude subsurface anomalies could be discerned, but interpretations were more ambiguous for these features.

3. The results of this study confirm that GPR can be used to detect and locate relatively recent burials within the Charleston Cemetery. Ground-penetrating radar clearly identified three subsurface features near modern headstones. Near four other headstones, no unambiguous indications of burial were observed on radar records. While ground-truth coring would have been helpful, results indicate that older burials will be more difficult to identify and locate.

It was my pleasure to work in Illinois and to assist Andrew Ceren in this project.

With kind regards,

James A. Doolittle
Research Soil Scientist
National Soil Survey Center

cc:
B. Ahrens, Director, USDA-NRCS, National Soil Survey Center, Federal Building, Room 152, 100 Centennial Mall North, Lincoln, NE 68508-3866
A. Cerven, District Conservationist, USDA-NRCS, 990 W State Street, Charleston, IL 61920-1037
M. Golden, Director of Soils Survey Division, USDA-NRCS, Room 4250 South Building, 14th & Independence Ave. SW, Washington, DC 20250
J. Kimble, Acting National Leader, Soil Investigation Staff, USDA-NRCS, National Soil Survey Center, Federal Building, Room 152, 100 Centennial Mall North, Lincoln, NE 68508-3866
R. Mcleese, State Soil Scientist, USDA-NRCS, 2118 West Park Court, Champaign, IL 61821
W. Tuttle, Soil Scientist (Geophysical), USDA-NRCS-NSSC, P.O. Box 974, Federal Building, Room 206, 207 West Main Street, Wilkesboro, NC 28697

The detection of gravesites with GPR:
A favorable feature of ground-penetrating radar (GPR) is its ability to detect soil disturbances and the intrusion of foreign materials. It is therefore a useful geophysical tool for locating unmarked and unknown burials (Vaughan, 1986; Bevan, 1991; Mellett, 1992; Unterberger, 1992; King et al., 1993; Miller, 1996, Nobes, 1999 and 2000; Davis et al., 2000; Gracia et al., 2000; Davenport, 2001; Dittmer, 2004). However, results vary with soil conditions. In some soils (i.e. saline, sodic, or fine-textured soils), rates of signal attenuation are so severe that GPR cannot provide satisfactory profiling depths. Even under favorable site conditions (i.e. dry, coarse-textured soils) the detection of a burial is never certain with GPR.

The detection of burials is affected by the electromagnetic gradient existing between a burial and the soil; the size, depth, and shape of the buried feature; and the presence of scattering bodies in the soil (Vickers et al., 1976). The amount of energy reflected back to an antenna from a burial is a function of the contrast in dielectric properties that exists between the buried feature and the soil. The greater and more abrupt the difference in electromagnetic properties between the buried feature and the soil, the greater the amount of energy that is reflected back to the antenna, and the more intense will be the amplitude of the reflection recorded on the radar record. In many instances, the contrast between a buried feature and the soil materials is small resulting in a lower chance of detection.

At many sites, the most distinctive feature of a grave is the disturbed soil materials that fill the grave shaft (Bevan, 1991). Bevan (1991) noted that it is more likely for GPR to detect the disturbed soil materials within a grave shaft, a partially or totally intact coffin, or the chemically altered soil materials, which directly surrounds a burial rather than the bones themselves. Refilled grave shafts contain disturbed soil materials that can have electrical properties that contrast with the surrounding, undisturbed soils (Bevan, 1991; Miller, 1996). However, in soils that lack contrasting horizons or geologic strata, the detection of disturbances or grave shafts is more challenging and improbable. In addition, with the passage of time, the signs of disturbances are erased by natural soil-forming processes.

The depth and size of a burial affect detection. Burials may range in depth from shallow (<50 cm) to very deep (>150 cm). Large, electrically contrasting features reflect more energy and are easier to detect than small, less contrasting features. Remains may be buried in sacks, body bags, or in wooden, fiberglass, composite, or metal caskets. Metallic or lead coffins and burial vaults provided large and contrasting interfaces that produce strong, recognizable radar reflections. If a coffin is intact, an air-filled void exists, which can be detected with GPR. Bevan (1991) used GPR to detected intact coffins, but was not successful in detecting collapsed or soil-filled coffin, or bones alone.   Small, deeply buried features (i.e. urns, children's coffins) are difficult to discern on radar records. Bones are generally too small to be distinguished with GPR (Killam, 1990; Bevan, 1991).

The shape and orientation of a subsurface anomaly may provide clues to its identity. A subsurface anomaly that is narrow and linear may suggest a burial. Burials may be uniformly spaced or aligned in a particular direction. Multiple, aligned, elongated subsurface anomalies occurring at a common depth suggest burials.

Burials are difficult to distinguish in soils that contain rock fragments, tree roots, animal burrows, modern cultural features, or highly stratified or segmented soil layers. These scattering bodies produce undesired subsurface reflections that complicate radar records and mask the presence of burials. Under such conditions, burials are often indistinguishable from background clutter. In soils with scattering bodies, GPR often provide little meaningful information to supplement traditional sampling methods (Bruzewicz et al., 1986). Vaughan (1986) and Bevan (1991) found the detection of graves reduced by rock fragments, which introduced unwanted clutter on radar records.

In the search for burials with GPR, success is never guaranteed. Even under ideal site and soil conditions, some burials will be missed with GPR. The usefulness of GPR for site assessment purposes depends on the amount of uncertainty or omission that is acceptable.

Study site:
The Charleston Cemetery is located along Cassell Creek in the northwest corner of Charleston, Illinois. The selected test site (88.20520 W. longitude; 39.50500 N. latitude) is located in a portion of the cemetery known as Mound Cemetery. The test site is in an area that had been mapped as Miami silt loam, 10 to 15 percent slopes, eroded (Hamilton, 1993). The very deep, moderately well drained Miami soil formed in as much as 18 inches of loess or silty material overlying loamy till. Miami is moderately deep to dense till. Miami is a member of the fine-loamy, mixed, active, mesic Oxyaquic Hapludalfs family. Because of its moderate clay content (27 to 35%), CEC (12 to 24 meg/100g), and, at lower depths, calcium carbonate content (15 to 40%), Miami soil is considered to have moderate to low potential for GPR applications.

Equipment:
The use and operation of GPR are discussed by Daniels (2004). The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (here after referred to as the SIR System-3000), manufactured by Geophysical Survey Systems, Inc.[1] The SIR System-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 System-3000 weighs about 9 lbs and is backpack portable. With an antenna, this system requires two people to operate.   The 200 and 400 MHz antennas were used in this investigation.

The RADAN for Windows (version 5.0) software developed by Geophysical Survey Systems, Inc, was used to process the radar records.[1] Processing included setting the initial pulse to time zero, color transformation, marker editing, distance normalization, signal stacking, migration, and gain adjustments. Radar records were processed into three-dimensional images using the 3D QuickDraw for RADAN Windows NT software developed by Geophysical Survey Systems, Inc.[1]   Once processed, arbitrary cross sections and time slices were viewed and selected images attached to this report.

Survey Procedures:
Prior to field work, a test site was selected by the Cemetery's staff. To expedite field work, two equal length and parallel lines were established at the test site. These lines were located between and orthogonal to two rows of headstones. The two parallel lines defined a rectangular grid area with dimensions of 15.3 by 3.04 m. Survey flags were inserted in the ground at equal intervals along each of the two lines. For surveys conducted with the 200 and

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

400 MHz antennas, the interval between the survey flags was 50 and 60 cm, respectively. For positional accuracy, surveys were completed by stretching and sequentially moving a 15.3-m long reference line between similarly numbered flags on the two parallel grid lines.

Pulling an antenna along the reference line that was stretched between similarly numbered flags on the two parallel survey lines completed a GPR traverse. Along the reference line, marks were spaced at 90 cm intervals. As the antenna was towed passed each reference point, a vertical mark was impressed on the radar record. Walking, in a back and forth manner, along the reference line, which was moved sequentially between similarly numbered flags on the two parallel survey lines, completed the GPR survey.

Calibration of GPR:

Ground-penetrating radar is a time scaled system. This system measures the time taken by electromagnetic energy traveling from an antenna to an interface (e.g., buried artifact, soil horizon, and stratigraphic layer) 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 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). This relationship is expressed in the equation (Daniels, 2004):

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

Where C is the velocity of propagation in a vacuum (0.2998 m/nanosecond). Velocity is expressed in meters per nanosecond (ns). A nanosecond is one billionth of a second. The amount and physical state of water (temperature dependent) have the greatest effect on the E_r of earthen materials.

The velocity of propagation is temporally and spatially variable. At the time of this study, soils were moist. Based on hyperbola-matching processing techniques (the shape of a hyperbola is dependent on signal velocity), the velocity of propagation decreased with increasing depth, but within the upper part of the soil profile averaged about 0.11 m/ns (E_r of 7.3) with the 200 MHz antenna, and 0.067 (E_r of 20) with the 400 MHz antenna. For both antennas, rates of signal attenuation restricted the effective profiling depth to less than 2 m.

Radar Interpretations:

Figure 1 is a radar record that was collected with the 200 MHz antenna in front of seven headstones at the test site. In Figure 1, the vertical scale is based on equation [1] and a propagation velocity of 0.11 m/ns. The horizontal scale is a distance scale. The white, vertical marks at the top of the radar record were impressed by the radar operator at intervals of 90 cm. Three high amplitude, point anomalies (see "A," "B," and "C") are evident on this radar record. These subsurface anomalies occur at estimated depths of 1.0 to 1.25 m. They are located near headstones, whose centers occur at distances of 1.5, 2.3, 11.0, and 12.8 m along this traverse line. While the high amplitude reflectors do not exactly align themselves with headstones, they are assumed to represent coffins or back-filled materials within the grave shafts. Backfilled materials contain mixed soil materials that contrast with the surrounding, undisturbed soil. For these materials, contrasts in grain size distributions and moisture contents may be sufficient to provide discernible reflections on radar records.

Two older headstones occur at distances of 4.8 and 6.4 m along this traverse line. In addition, a more recent headstone occurs at a distance of 9.8 m along this traverse line. No obvious reflector is evident in front of these headstones. Very faint reflectors do appear at distances of about 6.6, 9.0, and 10.4 m on this radar record. If burials exist at these locations, they are indistinct and interpretations are ambiguous.

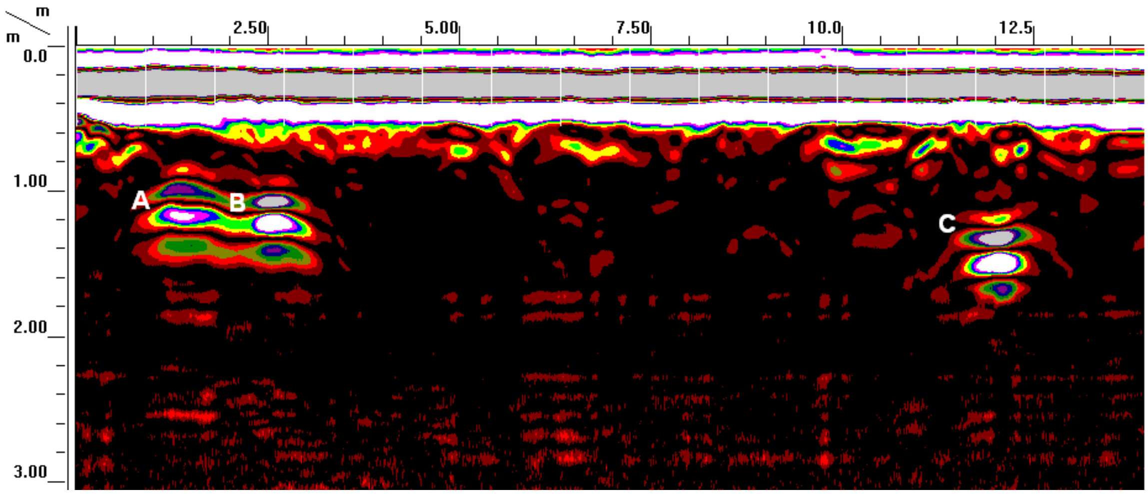

Figure 1. High-amplitude subsurface reflectors indicate recent burials.

Time-slice analysis:
On radar records, the depth, shape, size, and location of subsurface features are used to identify burials. In the past, these features could only be identified and associated on two-dimensional radar records such as shown in Figure 1. In soils with complex stratigraphy or high amounts of background noise, features that produced low or moderate amplitudes reflections are difficult to detect and easily missed or misidentified on radar records. Three-dimensional (3D) imaging techniques are presently being used to augment radar interpretations, distinguish coherent noise components, reduce interpretation uncertainties, and aid identification of potential targets (Pipan et al., 1999). Three-dimensional interpretations of GPR data have being used to identify burials, middens, and other cultural features (Conyers and Goodman, 1997; Whiting et. al, 2000; Goodman et al., 2004).

For 3D interpretations, a series of closely-spaced, parallel radar records are used to create a 3D dataset. To generate a 3D display, processing software examines and interpolates the area between each radar record to create a solid cube of data. In general, the quality and detail of the 3D dataset increase as the number of radar traverse lines increases and the distance between each line decreases. The manufacturer recommends a minimum of 20 lines for good results (Geophysical Survey Systems, Inc., 2003). However, in this study, because of economy and limited time, intervals of 50 or 60 cm were used and the numbers of lines were 5 and 6 for data collected with the 200 and 400 MHz antenna, respectively.

Figure 2 is a solid cube of the 3D dataset from the test site. In this image, a portion of the cube has been removed. An inset to the 3D cube was removed from X = 0 to 12 m; Y = 0 to 1.6 m; and a depth of 0 to 1.3 m. Several high amplitude (colored blue, green, and yellow) subsurface reflections are evident in this image. Based on their locations, alignment, orientation, and appearances, a majority of these reflections are believed to represent burials and/or disturbed soils. However, as no ground-truth coring was made at the time of this study, interpretations contained in this report are unconfirmed and speculative.

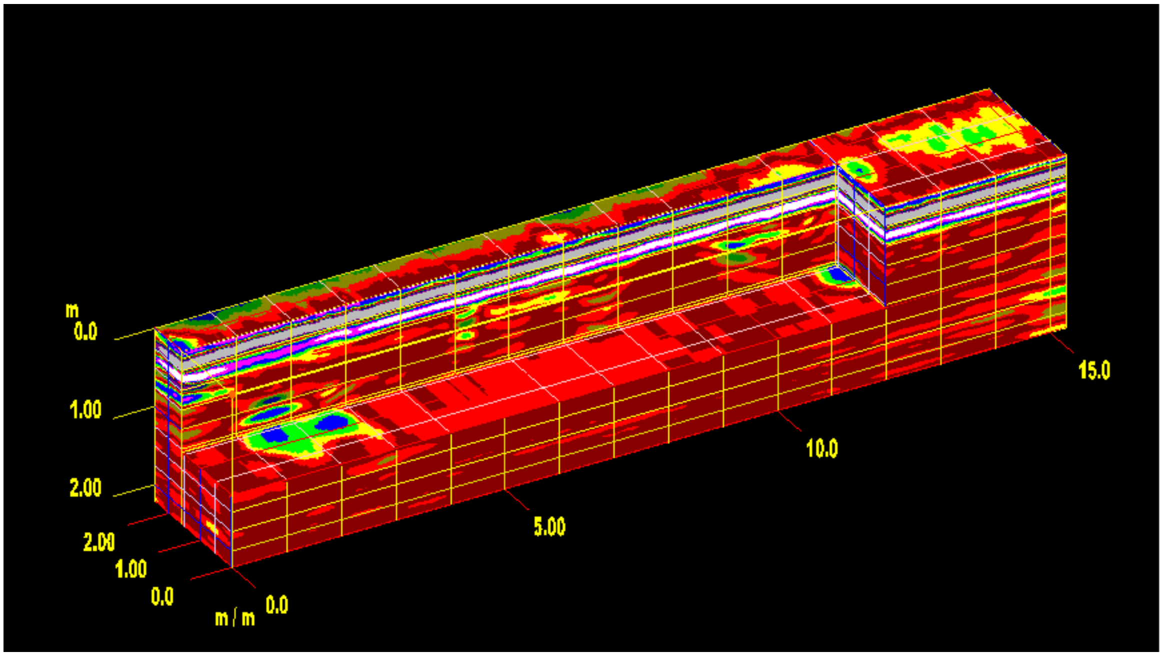

Figure 2. Multiple, closely-spaced, parallel radar records have been combined into this 3D image of the test site .

In recent years, a sophisticated type of GPR data manipulation has been used in archaeological investigations. Known as *amplitude slice-map analysis* (Conyers and Goodman, 1997), horizontal maps showing differences in reflected wave amplitudes are created from 3D datasets. Through this process, amplitude differences within the 3-D image are analyzed in "time-slices" that examine spatial patterns within specific depths intervals (Conyers and Goodman, 1997).

Figure 3 contains time-slice data from depths of 0, 60, 120, and 180 cm. The results are analogous to removing the soil overburden to the specified depths. Each slice was created using spatially averaged maximum amplitudes in 3.2 ns time windows. Each amplitude time-slice shows the spatial distribution of reflected wave amplitudes. In each slice, the view is from directly overhead. The approximate locations and relative sizes of the headstones are shown by filled-boxes in each slice.

In the slice of the surface, variations in soil density and moisture and/or clay contents are believed to be principally responsible for the spatial patterns. The high amplitude reflections near "A" are believed to have been caused by interference from the metallic flags which were placed along the survey line to mark the grid interval.

Patterns appearing on the 60 cm slice essential mimic the patterns that are apparent in the surface slice. These are reverberated signals, produced by the same features or properties manifested in the surface layer.

Three high amplitude (colored blue, green, and yellow), aligned and elongated anomalies (see A, B, and C) are evident in the 120 cm slice. These high amplitude anomalies are located near headstones and are believed to represent burials. Additional lower amplitude and seemingly elongated anomalies (see 1, 2, 3, and 4) also suggest burials. It is unfortunate that the features in this slice were not properly identified through soil corings to confirm interpretations.

One high amplitude anomaly (see A) persists in the 180 cm slice. This anomaly is also present in the 120 cm slice. However, the amplitude of this anomaly increases with depth. Other features apparent in the 180 cm slice are believed to represent background noise.

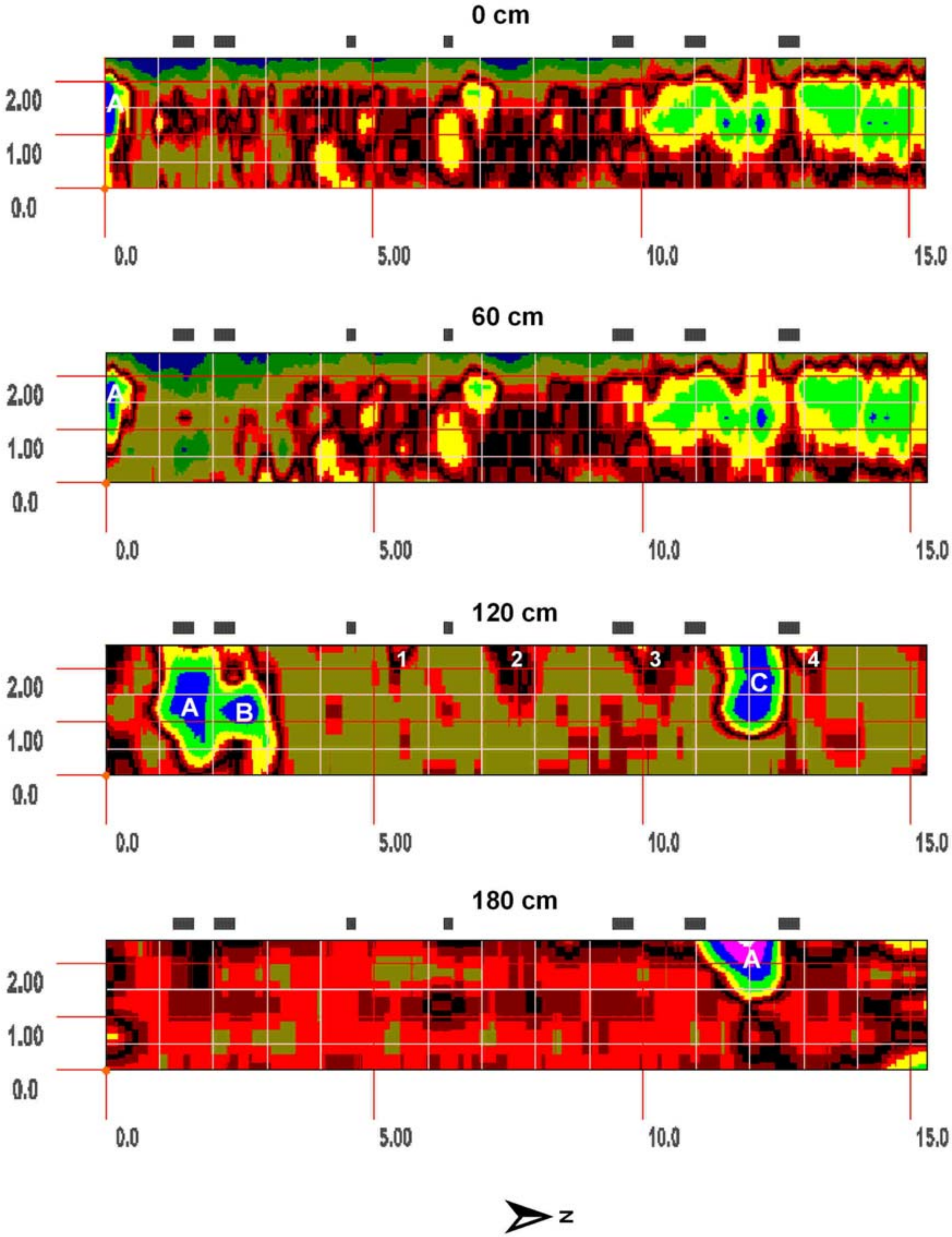

Figure 3. Amplitude anomalies are evident in these three-dimensional time-slices of the survey area. Horizontal time-slices made at depths of 0, 60, 120, and 180 cm.

References:

Bevan, Bruce W. 1991. The search for graves. Geophysics 56(9):1310-1319.

Bruzewicz, A. J., C. R. Smith, D. E. Berwick, and J. E. Underwood. 1986. The use of ground-penetrating radar in cultural resource management. Technical Papers 1986 ACSM-ASPRS Annual Convention Vol. 5: 233-242.

Conyers, L. B., and D. Goodman. 1997. Ground-penetrating radar; an introduction for archaeologists. AltaMira Press, Walnut Creek, CA.

Daniels, D. J. 2004. Ground-penetrating radar; 2nd Edition. The Institute of Electrical Engineers, London, United Kingdom.

Davenport, G. C. 2001. Remote sensing applications in forensic investigations. Historical Archaeology 35(1):87-100.

Davis, J. L., J. A. Heginbottom, A. P. Annan, R. S. Daniels, B. P. Berdal, T. Bergan, K. E. Duncan, P. K. Lewin, J. S. Oxford, N. Roberts, J. J. Skehel, and C. R. Smith. 2000. Ground penetrating radar surveys to locate 1918 Spanish flu victims in permafrost. J. Forensic Science 45(1): 68-76.

Dittmer, J. 2004. Principles of GPR forensic search. 425-436 pp. IN: Daniels, D. J. (editor). Ground-penetrating radar; 2nd Edition. The Institute of Electrical Engineers, London, United Kingdom

Geophysical Survey Systems, Inc., 2003. RADAN for Windows, Version 5.0, Users Manual. Manual MN143-162 Revision A. Geophysical Survey Systems, Inc., North Salem, New Hampshire.

Goodman, D., S. Piro, Y. Nishimura, H. Patterson. 2004. Discovery of a 1st century AD Roman amphitheater and other structures at the Forum Novum by GPR. Journal of Environmental & Engineering Geophysics, 9(1): 35-41.

Gracia, V. P., J. A. Canas, L. G. Pujades, J. Clapes, O. Caselles, F. Garcia, and R. Osorio. 2000. GPR survey to confirm the location of ancient structures under Valencian Cathedral (Spain). Journal of Applied Geophysics 43: 167-174.

Hamilton, G. 1993. Soil Survey of Coles County, Illinois. USDA-NRCS and the Illinois Agricultural Experiment Station. U.S. Government Printing Office, Washington, D.C.

Killam, E. W. 1990. The detection of human remains. Charles C. Thomas Publisher, Springfield, Illinois.

King, J. A., B. W. Bevan, and R. J. Hurry. 1993. The reliability of geophysical surveys at historic-period cemeteries: An example from plains Cemetery, Mechanicsville, Maryland. 1993. Historical Archaeology 27(3): 4-16.

Mellett, James S. 1992. Location of human remains with ground penetrating radar. 359-365 pp. IN: Hanninen, P. and S. Autio (eds.) Fourth International Conference on Ground Penetrating Radar. June 8-13, 1992. Rovaniemi, Finland. Geological Survey of Finland, Special Paper 16.

Miller, P. S. 1996. Disturbances in the soil: finding buried bodies and other evidence using ground penetrating radar. J. Forensic Science 41: 648-652.

Nobes, D. C. 1999. Geophysical surveys of burial sites: a case study of the Oaro Urupa. Geophysics 62: 357-367.

Nobes, D. C. 2000. The search for “Yvonne”: A case example of the delineation of a grave using near-surface geophysical methods. J. Forensic Science 45(3): 715-721.

Pipan, M., L. Baradello, E. Forte, A. Prizzon, and I. Finetti. 1999. 2-D and 3-D processing and interpretation of multi-fold ground penetrating radar data: a case history from an archaeological site. Journal of Applied Geophysics 41: 271-292.

Unterberger, R. R. 1992. Ground penetrating radar finds disturbed earth over burials. 351-357 pp. IN: Hanninen, P. and S. Autio (eds.) Fourth International Conference on Ground Penetrating Radar. June 8-13, 1992. Rovaniemi, Finland. Geological Survey of Finland, Special Paper 16.

Vaughan, C. J. 1986. Ground-penetrating radar surveys in archaeological investigations. Geophysics 51(3): 595-604.

Vickers, R., L. Dolphin, and D. Johnson. 1976. Archaeological investigations at Chaco Canyon using subsurface radar. 81-101 pp. IN: Remote Sensing Experiments in Cultural Resource Studies, assembled by Thomas R. Lyons, Chaco Center, USDI-NPS and University of New Mexico.

Whiting, B. M. D., McFarland. D. P., S. Hackenberger. 2000. Preliminary results of three-dimensional GPR-based study of a prehistoric site in Barbados, West Indies. 260-267 pp. IN: (Noon, D. Ed.) Proceedings Eight International Conference on Ground-Penetrating Radar. May 23 to 26, 2000, Goldcoast, Queensland, Australia. The University of Queensland.