United States Department of Agriculture | **Natural Resources Conservation Service** | **100 Campus Boulevard Suite 200 Newtown Square, PA 19073**

Subject: Archaeology -- Geophysical Assistance **Date:** 16 August 2005

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Purpose:
At the request of the Connecticut State Archaeologist and local historians, ground-penetrating radar (GPR) surveys were conducted at the Glastonbury Historical Society Building (Glastonbury), the First Church and Meeting House (Waterford), the North Cemetery (Hampton), an unmarked historic cemetery (Sandy Hook), the historic Little Liberia Church cemetery, (Bridgeport), the Merriman Cemetery (Southington), and the Harriet Beecher Stowe House (Hartford) in an attempt to locate buried cultural features, outbuildings, or unmarked burials. Also, at the request of the Connecticut State Archaeologist, and the Stamford and New York City Police Departments, a possible crime scene was investigated with GPR in Stamford.

Principal Participants:
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Activities:
All field activities were completed during the period of 25 and 29 July 2005.

Summary:

1. Although the radar worked well at all sites providing adequate penetration depths and resolution of subsurface features, interpretation were plagued by undesired clutter. The level of clutter and the absence of clearly defined and specific targets fostered ambiguities and weaken confidence in interpretations.

2. The relatively coarse-textured soils of Connecticut are ideally suited to deep penetration with GPR. In most soils, the depth of penetration provided by even higher frequency (>400 MHz) antennas is more than adequate for most archaeological investigations. Because of low rates of signal attenuation, higher frequency antenna can be effectively used to provide high resolution of subsurface features.

Unfortunately, Connecticut soils that have formed in glacial till contain large amounts of rock fragments and typically lack well express horizons. These features confound interpretations and limit the effectiveness of GPR in discriminating gravesites. The presence of tree roots adds further complexity to radar interpretations of gravesites.

3. Although GPR provided exceptional radar records of each study area, I was often perplexed and lacked confidence in making interpretations. Radar detects but does not identify subsurface features. Confidence in identifying gravesites is lowered in soils having large numbers of rock fragments and tree roots, and lacking well-expressed horizons and layers. With the passage of time, signs of burials (wooden coffins, grave shaft, disturbed soil materials, and human remains) will be largely obliterated and reflections will become increasingly weak and difficult to discriminate with GPR.

4. As GPR provides non-specific results, extraction of information beyond the detection of subsurface reflectors was limited at the investigated sites. Through association, those subsurface point reflectors that occur near headstones are often assumed to represent potential burials. Point reflectors occurring in unmarked areas and not conforming to a measured interval or depth are assumed to represent rock fragments, tree roots, or segmented soil horizons. Interpretations are therefore predisposed.

5. At most sites, the use of three-dimensional time-sliced imagery did not significantly improve radar interpretations. Two-dimensional radar records require fewer resources and, at many sites, provide more immediate and often more useful information on buried cultural features than did three-dimensional, processed radar images.

6. The GPR survey of a potential crime scene in Stamford, Connecticut, was greatly appreciated by the Stamford and New York City Police Departments. While no feature relating to the crime was uncovered by GPR at this site, the intense and comprehensive coverage afforded by this tool, help determined the reliability of an informant's testimony and brought closure to the criminal investigation at this site.

It was my pleasure to work in Connecticut and to be of assistance to you.

With kind regards,

James A. Doolittle
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Ground-Penetrating Radar and Archaeological Investigations:
Ground-penetrating radar (GPR) has been used extensively in support of archaeological, crime scene, and terrorism investigations. Ground-penetrating radar provides and expedient and effective tool for these investigations. Ground-penetrating radar often detects disturbances and the intrusion of foreign materials in soils. However, results vary with soils and soil properties. Soils with low clay, moisture, and soluble salt contents are considered well suited to GPR. In Connecticut, well drained and excessively drained, coarse-textured soils formed in glacial drift provide an exceptional environment for deep (0 to 15 m) profiling with GPR. In the less frequently encountered, clayey and salt-affected soils, rates of signal attenuation are severe and GPR often fails to provide satisfactory penetration depths. Even under favorable site conditions (i.e. dry, coarse-textured soils) the detection of buried cultural features and graves is never assured with GPR. The detection of these features is affected by (1) the electromagnetic gradient existing between the feature and the soil, (2) the size, depth, and shape of the buried feature, and (3) the presence of scattering bodies within the soil (Vickers et al., 1976).

The amount of energy reflected back to an antenna by a buried object is a function of the contrast in dielectric properties that exists between the object and the surrounding soil. The greater and more abrupt the difference in dielectric properties, the greater the amount of energy that is reflected back to an antenna, and the more intense will be the amplitude of the reflected signals on the radar record. The *reflective coefficient* is a measure of the differences in dielectric properties between two adjoining materials. The *reflection coefficient* is dependent upon the difference in the relative *dielectric permittivity* (E_r) that exists between two adjoining materials. The E_r of a material is strongly dependent upon its moisture content. As a consequence, the amount of energy reflected back from a boundary or interface is dependent on the abruptness and difference in moisture contents between the two materials.

The size and depth of a buried feature affect detection. Large objects reflect more energy and are easier to detect than small objects. The reflective power of a buried feature decreases with the fourth power of the distance to the feature (Bevan and Kenyon, 1975).

On radar records, the depth, shape, size, and location of subsurface features may be used as clues to infer buried cultural features or interments. In the past, subsurface reflections were identified and correlated on two-dimensional radar records alone. Today, three-dimensional imaging techniques can be used to distinguish and identify potential targets and to reduce interpretation uncertainties (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.

The use of digital signals and sophisticated signal-processing software, have enabled signal enhancement and improved pattern-recognition on some radar records. In recent years, a sophisticated type of GPR data manipulation, known as *amplitude slice-map analysis*, has been used in archaeological investigations (Conyers and Goodman, 1997). A 3-D image of a site is derived from the computer analysis of a series of closely-spaced, two-dimensional radar records (Conyers and Goodman, 1997). Amplitude differences within the 3-D image are analyzed in time-slices that examine only changes within specific depths in the ground (Conyers and Goodman, 1997). Time-slice data are created using spatially averaged reflection amplitudes. Reflection amplitudes are averaged horizontally between sets of parallel radar records in specified time windows to create a time-slice of grid areas. Each amplitude time-slice shows the spatial distribution of reflection amplitudes, which may be used to provide clues as to changes in soil properties or the presence of buried cultural features.

In many soils, GPR has been successful in locating burials and identifying unmarked gravesites (Freeland et al., 2004; Miller et al., 2004; Gracia et al., 2000; Mellett, 1992; Bevan, 1991; King et al., 1993; and Vaughan, 1986). For burials, the rate of decay or weathering varies with the materials used to contain the corpse. Corpses may be buried in sacks, body bags, wooden caskets, or in fiberglass, composite, or metal coffins. If a casket or coffin is partially intact, an air-filled void may exist, which is generally detectable with GPR. Prior to 1850, most corpses were buried in sacks or wooden caskets, which rapidly decay in the acid soils of Connecticut and left little to be discerned with GPR. Coffins were not patent until the 1840s (Nick Bellantoni, personal communication 2005). At first, most buried objects generally contrast with the surrounding soil matrix. However, with the passage of time, buried objects decay or weather and become less electrically contrasting with the soil. Body fluids, salts, and gases in decomposing tissue are electrically conductive and will absorb the radiated radar energy resulting in a "whiteout" area (zone of no signal return) beneath recently buried corpse (Miller et al., 2004; Mellett, 1992). In highly acid soils, such as found in Connecticut, human skeletal remains and evidence of burials will not persist (Mellett, 1992).

Most bones are too small to be distinguished with GPR (Bevan, 1991; Killam, 1990). Bevan (1991) noted that it is more likely that GPR will detect the disturbed soil within a grave shaft, a partially or totally intact coffin, or the chemically altered soil materials that directly surrounds a burial rather than the bones themselves. Soil alkalinity increases and reactions differences as much as 2.1 pH levels have been measured near buried corpses (Rodriguez and Bass, 1985). However, in soils that lack contrasting soil horizons or geologic strata, the detection of soil disturbances or grave shafts is more difficult. In addition, with the passage of time, natural soil-forming processes erase the signs of disturbances.

Burials are difficult to distinguish in soils having numerous rock fragments, tree roots, animal burrows, modern cultural features, or segmented horizons and layers. These scattering bodies produce undesired subsurface reflections that complicate radar records. Under these adverse conditions, buried cultural features and burials may be indistinguishable from the background clutter. In soils having numerous scattering bodies, GPR often provide little meaningful information to supplement traditional sampling methods (Bruzewicz et al., 1986). The identification of buried cultural features was complicated by scattering bodies in radar surveys conducted by Bevan (1991), Dolphin and Yetter (1985), Doolittle (1988), and Vaughan (1986). Poorly expressed horizons and the prevalence of stone in the glacial soils of Connecticut foretell the difficulties that will often be encountered when interpreting radar records and attempting to identify buried cultural features and burials.

Equipment:
The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000, manufactured by Geophysical Survey Systems, Inc. (North Salem, New Hampshire).[1] The SIR System-3000 weighs about 9 lbs (4.1 kg) and is backpack portable. With an antenna, this system requires two people to operate. Relatively high frequency (400 and 900 MHz) antennas were used in this investigation. However because of superior balance of penetration depth and resolution, the 400 MHz antenna was deemed the most suitable for the studies addressed in this report.

Radar records contained in this report were processed with the RADAN for Windows (version 5.0) software program (Geophysical Survey Systems, Inc).[1] Processing included setting the initial pulse to time zero, color transformation, marker editing, distance normalization, horizontal stacking, background removal, migration, and range gain adjustments. At grid sites, radar records were processed into three-dimensional images using the 3D QuickDraw for RADAN Windows NT software (Geophysical Survey Systems, Inc).[1] Once processed, arbitrary cross sections and time slices were viewed and selected images attached to this report.

Survey Procedures:
GPR traverses were completed at each site. Grid surveys were completed at the Glastonbury, Waterford, Sandy Hook, Southington, and Beecher Home sites. At each of these sites, grids were constructed using two equal length and parallel lines, which formed the opposing sides of a rectangular area. These two parallel lines defined a grid area. Except at the Glastonbury and Waterford sites, survey flags were inserted in the ground at intervals of 50-cm along each of these two lines. At the Glastonbury and Waterford sites the interval was 100-cm. Figure 1 shows two parallel lines of equally spaced (50-cm) survey flags that were used to form a grid at the First Meeting House of the First Baptist Church site in Waterford, Connecticut. For positional accuracy, GPR traverses were completed along a reference line, which was stretched and sequentially moved between corresponding flags on the two parallel grid lines.

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

For grid surveys, pulling the 400 MHz antenna along the reference line completed a GPR traverse. Along the reference line, marks were spaced at intervals of 1 m. 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.

At several sites *wild cat* surveys were completed. *Wild cat* surveys consist of random walks with the GPR across open and accessible areas within a site. The intent of a *wild cat* survey is to quickly provide adequate spatial coverage of a site and to locate areas for more detailed investigations.

Based on hyperbola-matching processing techniques (the shape of a hyperbole is dependent on signal velocity) or the known depth to a buried reflector, the velocity of propagation was determined at each site. These data were used to depth scale the radar records. The velocity of propagation varied among and within sites, and generally decreased with depth.

Figure 1. Grid survey area at the commemorative site of the First Meeting House of the First Baptist Church in Waterford.

Soils:

The taxonomic classification of each soil discussed in this report is listed in Table 1. Soils at several sites were mapped in complex with areas of *Urban land*. *Urban land* is a miscellaneous land type consisting of impervious areas that contain little or no soil and support little or no vegetation. Areas of *Urban land* consist of paved areas, shopping centers, industrial parks, buildings, institutional sites, and houses.

With the exception of Chatfield soil, all soils are very deep (> 150-cm) to bedrock. Chatfield soil is moderately deep (50 to 100-cm) to bedrock. Soils are well drained or excessively drained and very deep to water table. These soils have very low clay and soluble salt contents, and contain considerable amounts of rock fragments of varying sizes (gravel, cobbles, and stones). The low clay, soluble salt, and moisture contents of these soils produce low rates of signal attenuation, which favor deep penetration with GPR. Because of the low rates of signal attenuation in these soils, high frequency (> 400 MHz) antennas can be used. These antennas provided higher resolution of subsurface features than low frequency (< 200 MHz) antennas. Rock fragments produce unwanted subsurface reflections, which clutter radar records and thwart interpretations. Unless limed, these soils have extremely acid to moderately acid reactions. The acidic conditions foster a rapid decomposition of buried artifacts.

Table 1.

Taxonomic Classification of Soils

Soil	Classification
Canton	Coarse-loamy over sandy or sandy-skeletal, mixed, semiactive, mesic Typic Dystrudepts
Charlton	Coarse-loamy, mixed, active, mesic Typic Dystrudepts
Chatfield	Coarse-loamy, mixed, superactive, mesic Typic Dystrudepts
Hinckley	Sandy-skeletal, mixed, mesic Typic Udorthents
Merrimac	Sandy, mixed, mesic Typic Dystrudepts
Windsor	Mixed, mesic Typic Udipsamments

Glastonbury Historical Society Building, Glastonbury, Connecticut:
The purpose of this investigation was to detect remnants of a former Meeting House that once stood in the immediate vicinity of the Glastonbury Historical Society Building. The site is located in Glastonbury, near the intersection of Main and Hubbard Streets. In 1673, a former Meeting House was built on this site. This building has long since disappeared. The Glastonbury Historical Society Building, which serves as a museum, was built between 1839 and 1840 as the Town House. The survey area is located in a grassed area of Windsor loamy fine sand, 0 to 3 percent slopes (Soil Survey of Connecticut). Windsor soil formed in stratified, sandy, glacial outwash.

<u>Survey Procedures:</u>
Two grids were established on the lawn adjoining the eastern side of the Glastonbury Historical Society Building. The dimensions of *Grid 1* was 7-m by 15-m. This grid consisted of 8, 15-m long GPR survey lines, orientated in essentially a north to south direction, and spaced 100-cm apart. The origin of this grid was located in the northwest corner of the survey area and adjacent to the Glastonbury Historical Society Building. Also, a 5-m by 20-m grid, *Grid 2,* consisting of 6 survey lines, was laid out next to the eastern border of *Grid 1*. The origin of this grid was located in its northwest corner. Survey lines were 20-m long, orientated in essentially a north to south direction, and spaced 100-cm apart.

<u>Results</u>
A radar record from this site is shown in Figure 2. In this figure, all scales are in meters. Based on hyperbola-matching techniques (the shape of a hyperbole is dependent on signal velocity), the velocity of propagation decreased with depth (0.111 m/ns surface layers; 0.083 m/ns at a depth of 1.5 m). An averaged propagation velocity of 0.097 m/ns (dielectric constant of 9.4) was used to depth scale the radar records.

In Figure 2, a large number of point anomalies can be seen especially in the upper 50-cm. Point anomalies are identifiable by their characteristic hyperbolic pattern (^). The cluster of point anomalies on both sides of the letter "A" are associated with roots from a nearby tree. Other anomalies almost certainly represent roots, rock fragments, but some could represent small buried artifacts. 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. In general, within the surveyed areas, relatively few subsurface reflectors and no indication of a former structure were evident between depths of 50 and 100-cm. In Figure 2, planar reflectors evident below a depth of 1.25-m (see "B" in Figure 2) represent stratigraphic layers, which typify the substratum of Windsor soil.

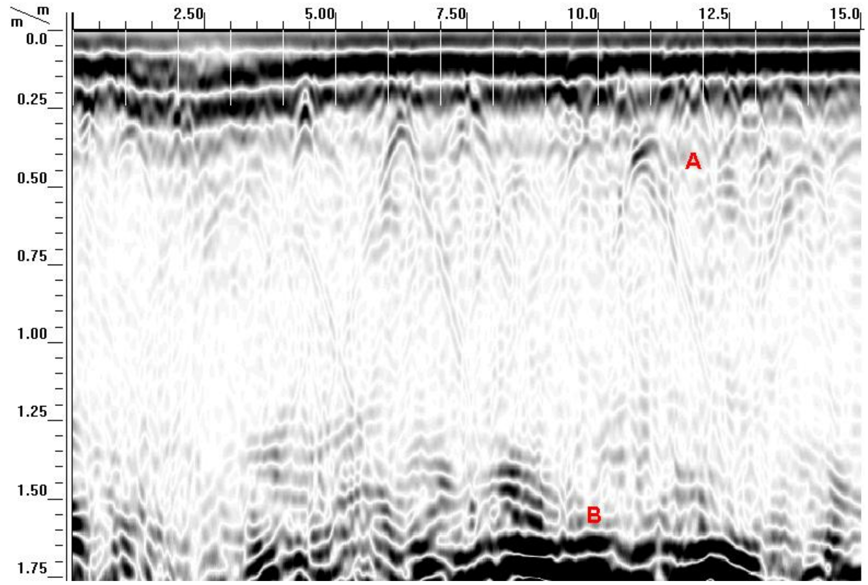
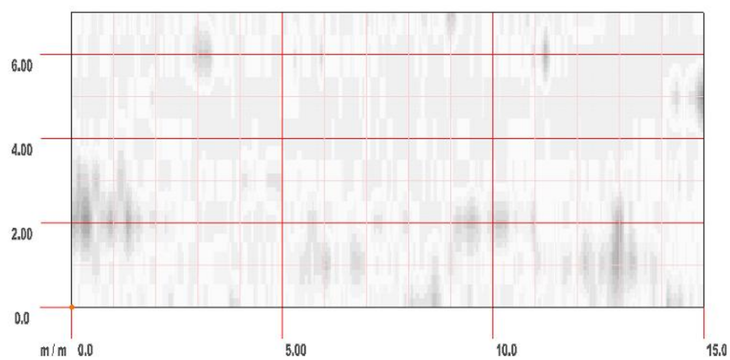


Figure 2. Radar record of traverse line 1, Grid 1, Glastonbury Historical Society Building.

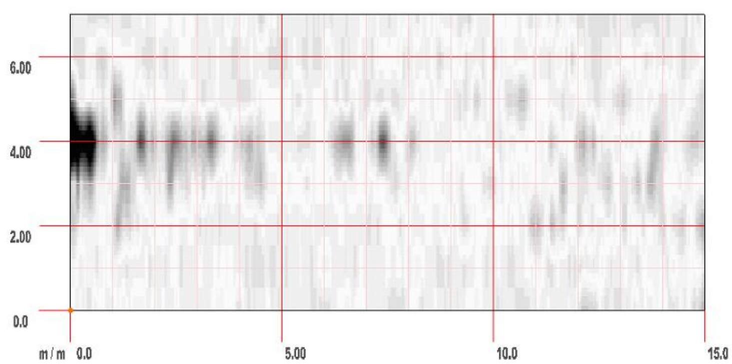
Figure 3 contains three time-slice images of the area surveyed in Grid 1. Each image of the grid area is viewed from directly overhead with reflections from the soil above the specified depth removed. In Figure 3, all measurements are expressed in meters. The origin is located in the lower left-hand corner (northwest corner of grid area) of each slice. The three horizontal time-slices represent depths of about 60-, 120-, and 180-cm. These depths were based on an averaged propagation velocity of 0.097 m/ns through the soil. The width of each time-slice is about 30-cm.

In Figure 3, the shallowest (60-cm) slice is relatively nondescript and consists of mostly low (white-colored) amplitude signals that do not form any noteworthy or identifiable spatial patterns. No evidence is provides in this slice supporting the existence of remnants from a former structure. In the 120-cm slice, a linear feature can be identified extending across the grid area in a southward direction along the 4-m line (Y-axis). This feature is believed to represent a buried drainage line, which is located in a surface depression at the base of adjoining slopes. Because of differences in soil depth resulting from differences in surface topography, this feature appears intermittently expressed. The 180-cm slice is characterized by high (black-colored) amplitude reflections, which represent strata in the glacial outwash.

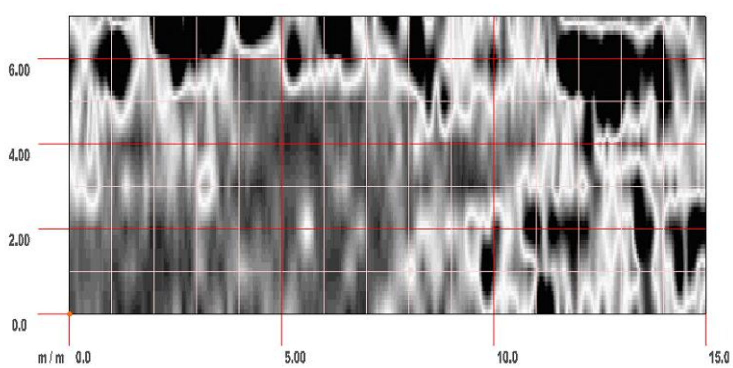
No significant subsurface features were detected within the adjoining Grid 2 area. As a consequence, a description of the time-slice analysis is omitted. At this site, GPR provided no evidence of the earlier Meeting House.



60-cm slice



120-cm slice



180-cm slice

Figure 3. Time-sliced images of the grid area within the Glastonbury Site

First Meeting House of the First Baptist Church, Waterford, Connecticut:
A stone marker commemorating the First Meeting House is located on Mullin Hill Road near Manitock Spring in Waterford (see Figure 1). A meeting house was erected on or near this site in 1788. The structure was occupied until 1848. The actual location of the Meeting House is unclear. The purpose of this GPR investigation was to identify subsurface features that would provide clues as to the location of First Meeting House of Waterford.

The site borders the north side of Mullin Hill Road and is enclosed on the other three sides by a low masonry wall (see Figure 1). A stone marker is located in the center of the site. The site is located in an area of Canton and Charlton soils, 3 to 8 percent slopes, very stony (Connecticut Soil Survey Staff). These soils formed in glacial till. The Canton soil has a loamy mantle, which overlies sandy till and ranges in thickness from about 45 to 90-cm. Both soils contain large amounts of rock fragments.

Survey Procedures:

Several large trees and the commemorative stone marker obstructed the establishment of a single grid within the area enclosed by the masonry wall. As a consequence, two grids were established across portions of this site. The dimensions of the grid located farthest from the road, along the backside of the site, was 5-m by 15-m. This grid will be referred to as *Grid 1*. The origin of *Grid 1* was located in the northeast corner of the site. Survey lines were 15-m long, orientated in essentially an east to west direction, and spaced 100-cm apart. Near the front of the site, a 7-m by 13-m grid was established. This grid will be referred to as *Grid 2*. The origin was located in the grid's northeast corner. Survey lines were 13-m long, orientated in essentially an east to west direction, and spaced 100-cm apart. The long axes of both grids paralleled the road and each other.

Results

A radar record from the memorial site of the First Meeting House of Waterford is shown in Figure 4. The depth and distance scales are in meters. Based on hyperbola-matching processing techniques, the velocity of propagation decreased with depth (0.108 m/ns surface layers; 0.088 m/ns at a depth of 1.5 m), but averaged 0.098 m/ns (dielectric constant of 9.2).

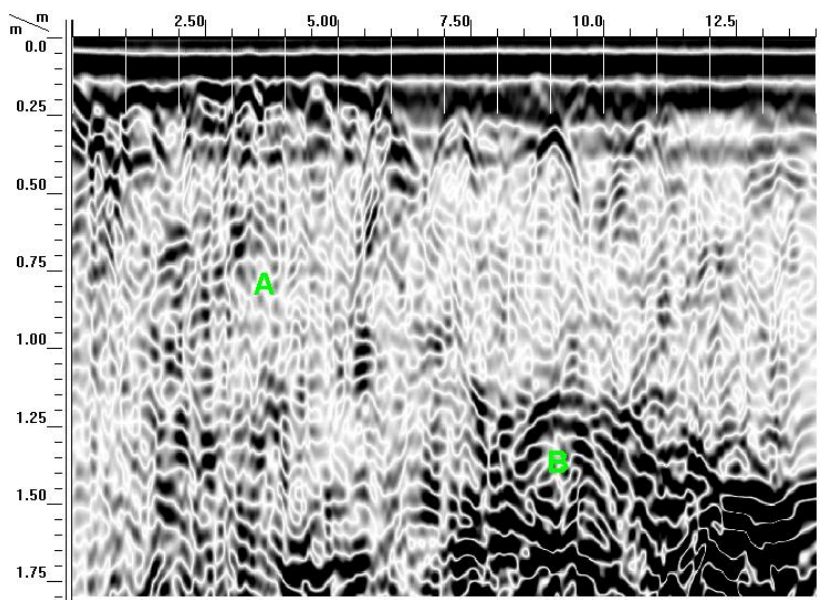
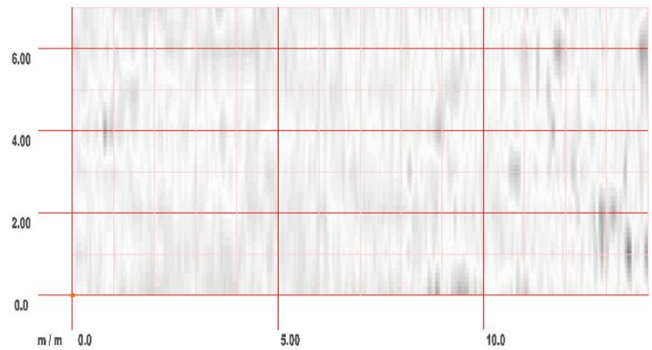


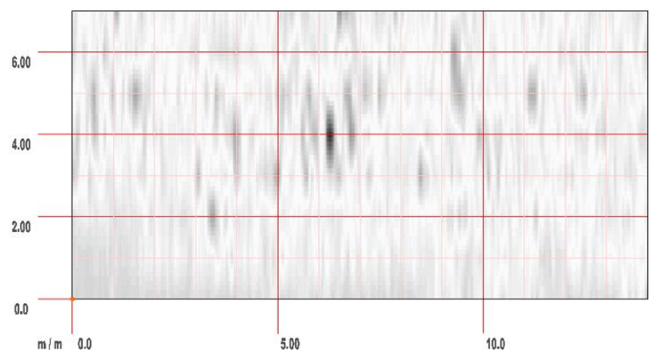
Figure 4. Radar record of traverse line 1, Grid 2, First Meeting House of Waterford.

The imagery impressed on the radar record shown in Figure 4 is characteristic of glacial till: a large number of chaotically arranged point reflectors (see near "A" in Figure 4). These point reflectors vary in size and are assumed to principally indicate rock fragments embedded in till. The upper left-hand portion of the radar record contains a cluster of point anomalies. As this portion of the radar record was near a large tree, many of these reflections are assumed to represent larger tree roots. The irregular pattern of high amplitude, planar reflectors in the lower right-hand portion of this radar record (see "B" in Figure 4) suggest parent rock.

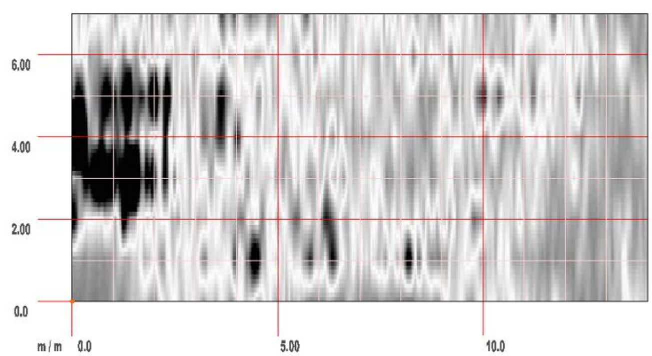
Figure 5 contains three time-slice images of the survey area in Grid 1. In Figure 5, all measurements are expressed in meters. Each image of the grid area is viewed from directly overhead with reflections from the soil above the specified depth removed. The origin is located in the lower left-hand corner (northeast corner of grid area) of each slice. The three horizontal time-slices represent depths of about 0-, 100-, 150-cm. These depths were based on an averaged propagation velocity of 0.097 m/ns through the soil. The width of each time-slice is about 30-cm.



0-cm slice



100-cm slice



150-cm slice

Figure 5. Time-sliced images of Grid 2, First Meeting House of Waterford.

In Figure 5, the shallowest (0-cm) slice is unremarkable and consists principally of low (white-colored) amplitude signals that do not form any identifiable spatial patterns indicative of a former structure. The number and amplitude of subsurface reflectors increased in the 100-cm slice, but the image remains void of significant features. In the 100-cm slice, reflectors are more obvious in the south-central portion of the grid area and have a noticeable north-south orientation. Many of these features appear to be 1- to 2-m in length. Although these features are believed to represent larger rock fragments and glacial flow features, the identity of some should be confirmed through excavations. Larger boulders and the presence of parent rock are suggested by the high amplitude reflections apparent in the eastern portion of the 150-cm slice. The GPR survey of this site provided no evidence supporting the presence of the former Meeting House.

North Cemetery, Hampton, Connecticut:
North Cemetery is located on Hammond Hill Road in Hampton, Connecticut. The study area consists of the older portion of the cemetery. In this area of the cemetery, headstones indicate that interments occurred between 1730 and 1810. The purpose of this investigation was to use GPR to locate possible unmarked gravesites and to confirm gravesites marked by headstones.

The site is located in an area of Hinckley gravelly sandy loam, 3 to 15 percent slopes (Connecticut Soil Survey Staff). Hinckley soil formed in water-sorted glacial materials. The survey was located on the top of a very steep sided, conical hill or kame.

<u>Survey Procedures:</u>
Traverses were conducted with the 400 MHz antenna along rows of headstones (see Figure 6). Traverses were conducted on both sides of the rows of headstones. As the antenna past each headstones a vertical mark was impressed on the radar record. Each headstone was identified by a number affixed on an adjoining wooden stake (see base of headstones in Figure 6). It was unclear as to which side of the headstone contained the burial. Changing burial traditions have occurred over the last 250 years. Presently, coffins are placed on the engraved side of headstones, but in earlier times, caskets were placed on the obverse, unengraved side (Mellett, 1992).

Figure 6. Conducting a reconnaissance GPR survey at the Hampton Cemetery.

<u>Results</u>
Numerous point reflectors occurred on the radar records collected at the North Cemetery in Hampton. Hinckley soil contains rock fragments of different sizes (gravel, cobbles, and stones) and amounts (individual horizons of the substratum can contain 10 to 55 percent gravel, 5 to 25 percent cobbles, and 0 to 5 percent stones). Undoubtedly, many of the subsurface point reflectors evident on the radar records collected at the North

Cemetery represent rock fragments. Some reflectors occurred near headstones and could represent burials. Ground-penetrating radar detects, but does not identify or categorize subsurface anomalies. As GPR provides non-specific results, extraction of information beyond the detection of subsurface reflectors is often limited. Through association, those point anomalies occurring near headstones are often assumed to represent burials. Point anomalies occurring in unmarked areas and not conforming to a measured interval or depth are perceived to represent rock fragments. Interpretations are therefore biased and predisposed. Commonly, in the glacial drift of Connecticut, rock fragments confound GPR interpretations of gravesites and the remnants of burials.

Point reflectors were evident on either side of headstones. If these anomalies represent burials, the GPR did not clarify which side of the headstone contained the burial. Many headstones lacked subsurface point reflectors that could be interpreted as burials. Many unmarked locations had subsurface anomalies that could be interpreted as potential burials.

Bennett Cemetery, Sandy Hook, Connecticut:

The site is located near the Housatonic River on Riverside Road in Sandy Hook, Connecticut. Known as the Bennett Cemetery, eight headstones were noted in a survey conducted in the early 1930s. At that time, inscriptions on the headstones revealed that the dates of interment ranged from 1815 to 1862. Two maps, a map prepared in 1923 and the town property map, show the location of this historic cemetery. No remnants of the cemetery are presently apparent and residential lawns, fences, and structures have violated the site. One landowner interviewed produced slabs of marble gravestones that were uncovered during the construction of a privacy fence. The purpose of this investigation was to detect gravesites or fallen and buried gravestones from the historic cemetery.

The site is located in an area of Merrimac-Urban land complex, 0 to 8 percent slopes (Connecticut Soil Survey Staff). The sandy Merrimac soil formed in glacial outwash. This material is stratified.

<u>Survey Procedures:</u>

Grid surveys were completed in accessible areas of the lawn between the house and garage at the Knoche family residence. Large trees and shrubbery thwarted the establishment of a single grid across the lawn. As a consequence, two grids were established across portions of the lawn that, according to existing maps, included the historic cemetery. The dimensions of the grid located nearest to a walkway was 6-m by 18-m. This grid will be referred to as *Grid 1*. The origin of the grid was located in the southwest corner of the lawn adjacent to a low masonry garden wall (south) and the walkway (west). Survey lines were 15-m long, orientated in essentially an east to west direction, and spaced 50-cm apart. A second grid, *Grid 2,* was established to the northeast of *Grid 1* in an area suspected to contain the cemetery. The dimensions of this grid were 4-m by 10-m. The origin of the grid was located in the southwest corner. Survey lines were 10-m long, orientated in essentially an east to west direction, and spaced 50-cm apart. The long axes of both grids paralleled each other.

A radar record from the site of the Bennett Cemetery is shown in Figure 7. The depth and distance scales are in meters. Based on hyperbola-matching processing techniques, the velocity of propagation decreased with depth (0.159 m/ns surface layers; 0.083 m/ns at a depth of 2-m). An averaged velocity of 0.123 m/ns (dielectric constant of 5.9) was used to depth scale the radar records.

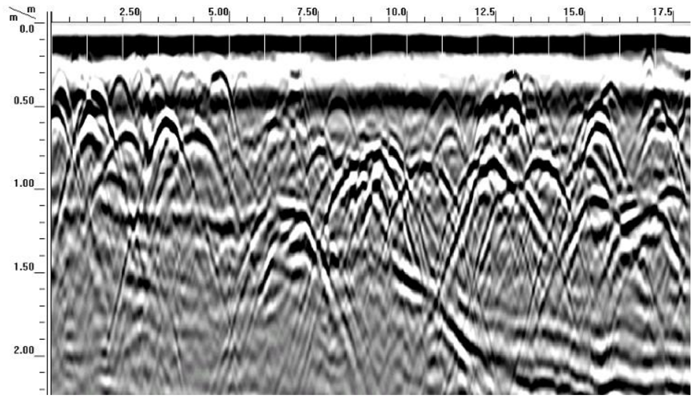


Figure 7. Radar record of traverse line 5, Grid 1, Bennett Cemetery.

The radar record shown in Figure 7 contains a large number of point anomalies. These anomalies produce hyperbolas with long diffraction tails, which complicate the radar imagery and mask some subsurface features. Prior to interpretation, all radar records are migrated. Migration is a processing procedure that reduces hyperbolic diffraction patterns and corrects the inclination of steeply dipping layers or strata shown on radar records. Figure 8 is the migrated image of the radar record shown in Figure 7. In Figure 8, the diffraction tails have been reduced. Hyperbolas should collapse into dots. In the upper part of this image, the hyperbolas have collapsed into "frown" indicating that the data has been under-migrated in this portion of the radar record.

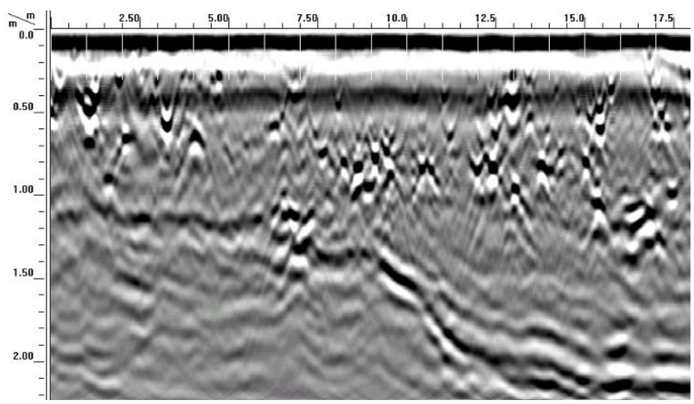


Figure 8. Migrated image of the radar record shown in Figure 7.

Figures 7 and 8 indicate that the soil contains a large number of point anomalies. These features represent tree roots, rock fragments, or artifacts. The large number of point reflectors with similar appearances makes individual identification based on ground-truth excavations impractical. Soils are weakly developed and soil horizons are poorly expressed in Figures 7 and 8. No clear patterns of soil disturbance suggesting burials are evident in these figures. A planar reflector extend across the lower part of the radar record from a depth of about 1- (left-hand portion of the radar records) to 2-m (lower right-hand portion of radar records). This reflector is presumed to represent an interface separating layers of different grain-sizes in the glacial outwash deposits.

Figure 9 contains three time-slice images of the survey area in Grid 1. In Figure 9, all measurements are expressed in meters. Each image of the grid area is viewed from directly overhead with reflections from the soil above the specified depth removed. The origin is located in the lower left-hand corner (southwest corner of grid area) of each slice. The three horizontal time-slices represent depths of about 0-, 50-, and 120-cm. These depths were based on an averaged propagation velocity of 0.123 m/ns through the soil. The width of each time-slice is about 30-cm.

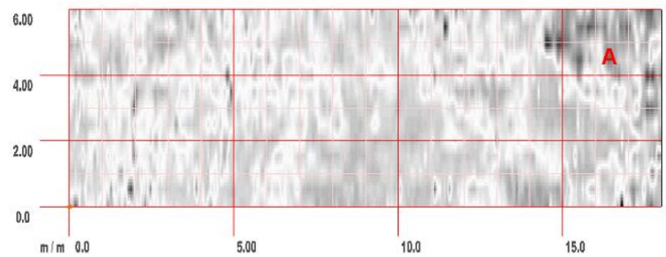
The 0-cm slice from Grid 1 shows broad patterns of principally low (white-colored) to moderate (grey-colored) signal amplitudes. The lack of variation in signal amplitudes suggests similar soil properties in the surface layer. A pattern of moderate to high (black-colored) signal amplitudes is evident in the extreme northeast (upper-right hand) corner (see "A" on 0-cm slice) of this image. Higher amplitudes suggest higher soil moisture contents or greater soil compaction. This pattern of higher signal amplitudes occurs near the edge of the lawn, is adjacent to a wooded privacy fence, and is located in an area that is thought to contain the historic cemetery. After the identification of the utility lines shown in the deeper slices, areas of disturbed soil from these features can be distinguished in the 0-cm slice.

The 50-cm slice from Grid 1 also shows broad patterns of principally low (white-colored) to moderate (grey-colored) signal amplitudes. High signal amplitudes are evident in discrete, linear, segmented bands that trend in a general north to south direction across the grid area. As the Merrimac soil formed in water sorted gravelly and sandy materials and contains considerable amounts of cobbles, many of these reflections could represent rock fragments. In addition, a large tree borders the north side of the grid area at X = 12-m. The high amplitude linear reflectors in this area of the grid are assumed to represent tree roots. In the western portion of the grid area, on the 50-cm slice, the north-northwest to south-southeast trace of a utility line is evident. This feature produces high amplitude signal reflections and has been highlighted with a red line.

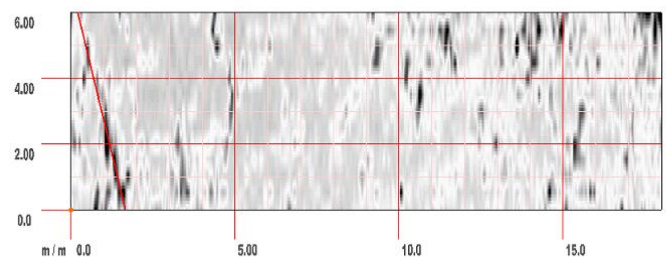
The 120-cm slice from Grid 1 shows broad patterns of principally low (white-colored) to moderate (grey-colored) signal amplitudes. The lack of variation in signal amplitudes suggests generally uniform or homogenous soil properties. Most patterns of moderate to high (black-colored) signal amplitudes are believed to reflect stratification in the underlying outwash deposits. These reflectors form curvilinear patterns, which appear to migrate across the image of the grid area as the depth of the slice is changed. One high amplitude, linear reflector remains stationary as the slice depths are varied. This reflector has been highlighted with a red line in the 120-cm slice and is believed to represent a buried drainage or utility line. This reflector trends in a north-northeast to south-southwest direction across the grid area between the house and the garage.

A close inspection of the individual radar records and the 3D-cube images failed to disclose any clear signs of soil disturbance in this area of Merrimac soil. As in many Connecticut soils, horizon development and differentiation is limited, and the soil and parent materials, though stratified, lack evidence of grave shafts or other forms of soil disturbance. Although buried utility and/or drainage lines are evident on the radar records and the 3D cube, only faint and inconsistent evidence of soil disturbance can be gleaned from close examinations of the radar records or the slices.

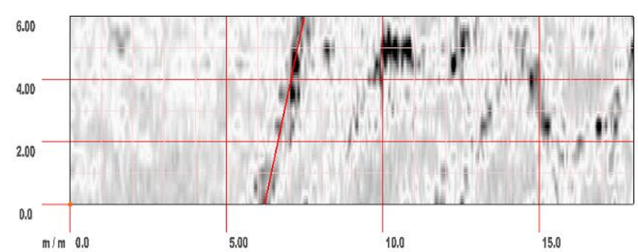
Figure 10 contains two time-slice images of the Grid 2 survey area. In Figure 10, all measurements are expressed in meters. Each image of the grid area is viewed from directly overhead with reflections from the soil above the specified depth removed. The origin is located in the lower left-hand corner (southwest corner of grid area) of each slice. The two horizontal time-slices represent depths of about 0- and 120-cm. These depths were based on an averaged propagation velocity of 0.123 m/ns through the soil. The width of each time-slice is about 30-cm.



0-cm slice



50-cm slice



120-cm slice

Figure 9. Time-sliced images of Grid 1at the Bennett Cemetery, Sandy Hook.

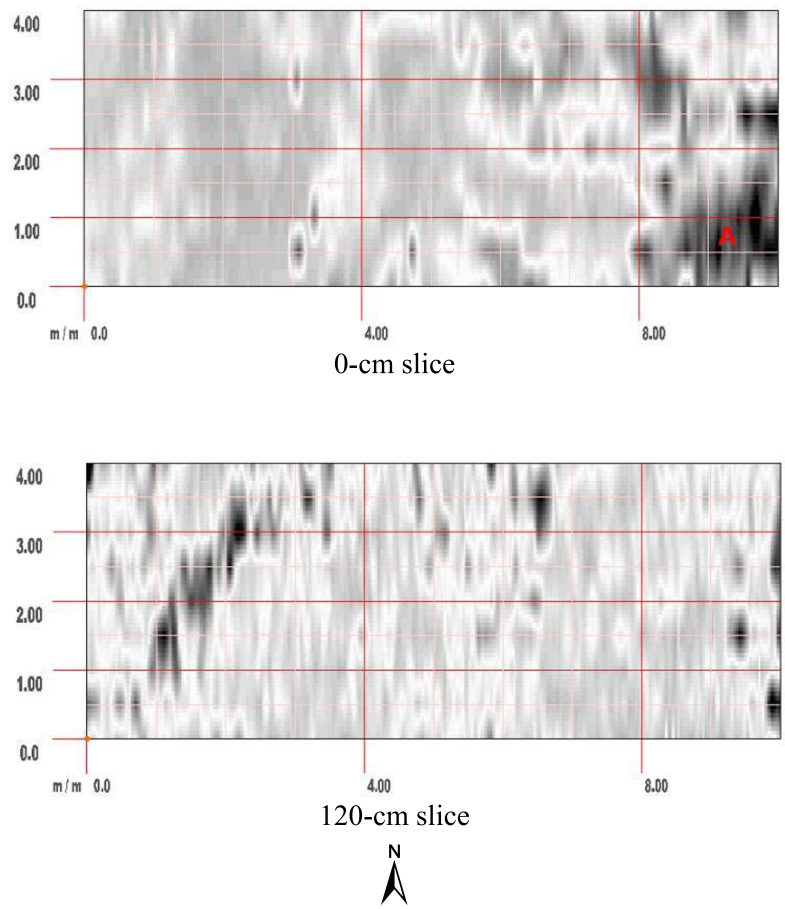


Figure 10. Time-sliced images of Grid 2 at the Bennett Cemetery, Sandy Hook.

In the 0-cm slice of Grid 2, moderate (grey-colored) and high (black-colored) amplitude reflections are evident in the southeast corner of the survey area (see "A" in Figure 10). This area represents the most probably location of the former cemetery. The broad spatial patterns of higher amplitude reflections in this portion of the survey area probably represent increases in soil moisture or soil compaction. Multiple, non-specific reflectors are aligned in a north-south direction across this slice. These reflectors do not conform to the established orientation of burials and may represent tree roots, rock fragments, or other artifacts.

In the 120-cm slice of Grid 2, broad curvilinear patterns of moderate (grey-colored) and high (black-colored) amplitude reflections extend across the survey area. When the slices are in put in motion, these reflectors migrate from west to east across the grid area as the depth is increased. These reflectors represent inclined strata in the underlying outwash materials.

Historic Cemetery, Bridgeport, Connecticut:
The site is located near the intersection of Broad and Gregory streets in downtown Bridgeport. A historic church and graveyard for freed blacks once stood on this site. The site is located in an area of *Urban land* (Connecticut Soil Survey Staff). The site had been paved over and is presently being prepared for the construction of a new church. The pavement has been ripped apart and the surface was highly irregular and cluttered with blocks of asphalt and brinks from the former church. Areas of exposed till were also evident. The purpose of this investigation was to detect gravesites from the historic cemetery.

A *wild cat* survey with the GPR was performed across the historic site. Debris littering the surface caused problems with antenna contact and advance. Figure 11 is a portion of the radar traverse from this site. The depth and distance scales are in meters. Based on hyperbola-matching processing techniques, the velocity of propagation decreased with depth (0.148 m/ns surface layers; 0.041 m/ns at a depth of about 1.5-m). An averaged velocity of 0.089 m/ns (dielectric constant of 11.1) was used to depth scale the radar records.

The red square in Figure 11 represents the approximate location of the former church building. Bricks littered the surface in this area. On the radar record shown in Figure 11, the area beneath the presumed site of the former church appears to have a greater number of subsurface point reflectors than the surrounding areas. This is attributed to structural debris from the suspected former building. A subsurface layer is evident at a depth of 50- to 70-cm within the area of the former church building. Below a depth of about 1.2-m, reflections weaken while levels of background noise increase. These are both signs of increased signal attenuation. The increased rate of signal attenuation at lower soil depths is attributed to higher moisture contents and salt water intrusion from nearby Bridgeport Harbor and Long Island Sound.

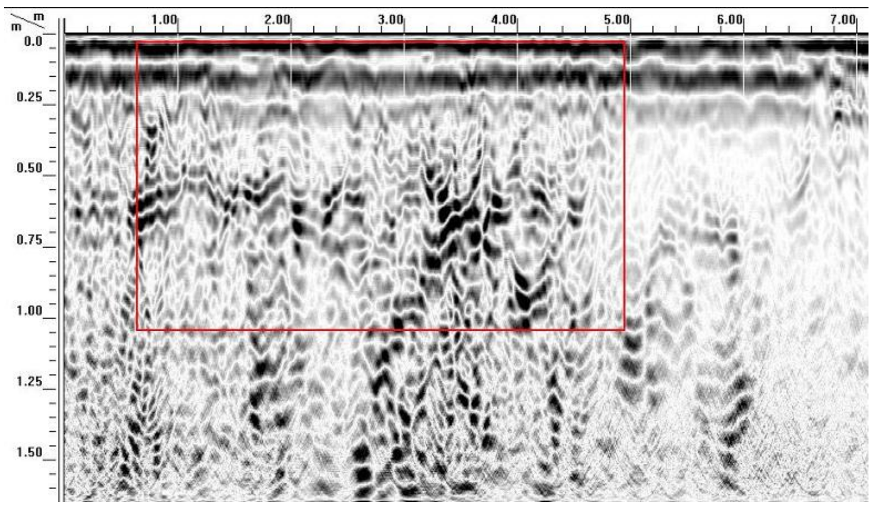


Figure 11 Radar record from the site of the Little Liberia Church.

Because of the rough and littered surface, this site was considered unsuited to detailed GPR grid operations. Although an underground storage tank was identified, radar records obtained during the *wild cat* survey were generally of poor interpretative quality. Considering the soil materials in this area, it is doubtful that GPR can detect relatively old, unmarked graves of poor individuals.

Crime Scene, Stamford, Connecticut.

During the summer of 1977 a 19 year old woman from New York City was believed to have been stalked and killed. Based on informant testimony, the body was purportedly buried in a shallow grave near a large tree and boulder on a steeply sloping, forested area that is located behind a house in Stamford Connecticut. The site is located in an area of Urban land-Charlton-Chatfield complex, rocky, 15 to 45 percent slopes (Connecticut Soil Survey Staff). Both Charlton and Chatfield soils formed in till. Chatfield soil is moderately deep (50- to 100-cm) and Charlton soil is very deep (>150-cm) to parent rock.

Large stones and boulders, and trees limited the area in which a body could have been buried and the GPR operated. Steep slopes and thick vegetation obstructed the GPR survey (see Figure 12). Crime scene investigators identified the area that the informant had described as the burial site. Three other sites were also identified based on relative openness and suitability for a shallow grave. At each of these sites, two GPR traverses, one parallel and one orthogonal with the slope contour were completed. In addition, random, *wild cat* GPR surveys were completed over accessible areas behind the suspected house and an adjoining house.

Each radar record collected at the four potential burial sites was explained, reviewed, and discussed before law enforcement officials (see Figure 13). The radar records from the site (Site 1) that the informant had identified were nondescript and revealed no noteworthy subsurface anomalous features. As part of investigative procedures, this area was cleared of debris and ground cover, and a shallow excavation made. The surface litter at this site was continuous, showed no signs of disturbance, and no uncharacteristic features were found by crime scene investigators. Several shallow hyperbolic patterns were evident on a radar record from Site 2. These features were associated with the roots of the nearby tree. No anomalous subsurface features were detected on the radar records from Site 3.

Figure 12. Conducting a GPR search survey at the alleged clandestine burial site in Stamford (photograph courtesy of John Spaulding).

Soil scientists helped to identified one site, Site 4, which showed visible signs of disturbance. This site consisted of a low mound with subsoil materials deposited on the surface. Radar traverses across this site revealed an anomalous feature, which was shallowly buried beneath the mound. Figure 14 is the radar record of the traverse that was conducted parallel with the slope contour at this site. In this figure, all scales are in meters. Based on hyperbola-matching processing techniques, the velocity of propagation decreased then increased with depth (0.241 m/ns surface layer; 0.092 m/ns at a depth of about 60-cm, and 0.103 m/ns at a depth of about 100-cm). This trend can be explained by relatively dry surface layers composed of duff underlain by moister subsurface layers overlying more electrical resistive parent rock. An averaged velocity of 0.119 m/ns (dielectric constant of 6.25) was used to depth scale all radar records.

Figure 13. All radar records of suspected sites were reviewed in the field (photograph courtesy of John Spaulding).

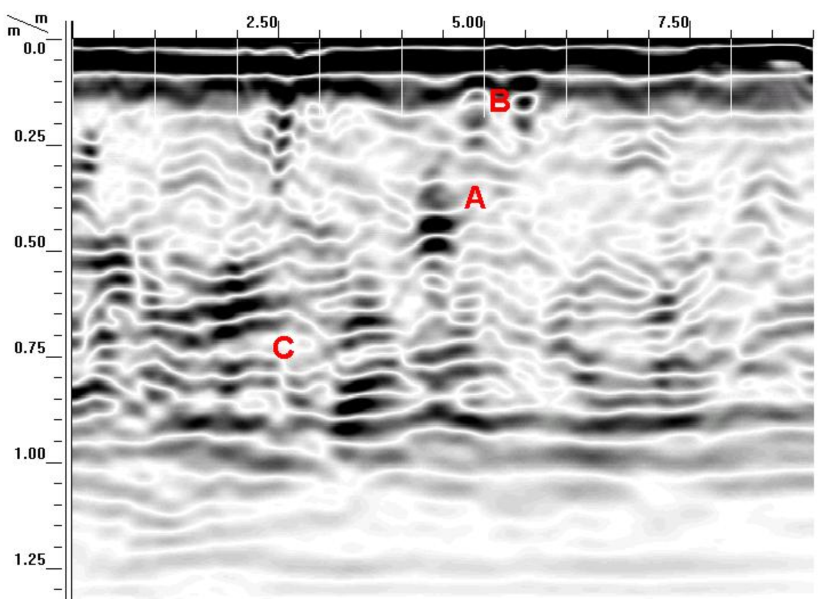


Figure 14. Radar record of a suspicious anomaly at site 4 at the suspected Stamford crime scene.

In Figure 14, the suspicious mound is situated between the 3- and 6-m horizontal marks (white vertical lines at the top of the radar record are spaced at 1-m intervals). The radar record has not been terrain corrected. As a consequence, the soil surface appears flat and does not represent the true micro-topography. The anomalous feature occurs at a depth of about 40-cm (16-inches) and is located to the immediate left of "A" in Figure 14. Point anomalies occurring on either side of "B" were later identified as representing rock fragments and a concrete block. The dark, nearly horizontal bands in the lower part of the radar record (see "C" in Figure 14) are characteristic of stress and fracture planes in parent rock.

Figure 15. Excavated pit at site 4 showing disturbed soil materials, a large rock fragment, and the bat handle (photograph courtesy of John Spaulding).

The Connecticut State Archaeologist and his team excavated this site. Soils were noticeably disturbed. A large flat rock fragment is believed to have caused the noteworthy reflection on the radar record (see "A" in Figure 14). Over the rock, a large overturned concrete fence post and a fragment of clear glass were also unearthed. Beneath the rock, the end of a plastic whiffleball bat (see Figure 15), a piece of garbage bag, and a calcine bone fragment were discovered. Though disturbed and containing artifacts, the mound was not considered related to criminal activities.

Wild cat surveys with GPR were conducted over accessible areas on the steep, wooded slopes behind the suspected house and an adjoining house. These surveys revealed no uncharacteristic features and no indications of soil disturbances or burials. Based on visual observation made during the course of excavations and the interpretative results of the radar surveys, crime scene investigators deemed that, with the exception of bulldozing the entire hill slope, all that could possibly be done to investigate this site had been accomplished. The informant's information was discredited

Merriman Cemetery, Southington, Connecticut:

Merriman Cemetery is the second oldest cemetery in Southington. Inscriptions on gravestones indicate that most burial occurred between 1764 and 1863. Records from a 1934 survey indicated that there were 37 marked gravesites in the Merriman Cemetery. Presently there are only 34 gravestones and officials believe that their may be an additional 10 unmarked gravesites. The purpose of this investigation was to confirm burials marked by gravestones and to identify any unmarked gravesites.

The site is located on Southington Road in Southington, Connecticut. Under the leadership of the Boy Scouts of America, the cemetery was recently cleared of debris and a low rock wall erected. The site is located in an area of Windsor loamy sand, 0 to 3 percent slopes (Connecticut Soil Survey Staff).

<u>Survey Procedures:</u>

Two grids were established across portions of the cemetery. The largest grid, Grid 1, had dimensions of 27-m by 34-m. Survey lines were 27-m long, orientated in essentially a north to south direction, and spaced 50-cm apart. The origin was located in the northwest corner of the grid. A smaller grid, Grid 2, with dimensions of 3-m by 4-m, was located along the northern border of Grid 1. Survey lines were 4-m long, orientated in essentially an east to west direction, and spaced 50-cm apart. The origin was located in the southwest corner of the grid.

Results:

A radar record from Merriman Cemetery is shown in Figure 16. In Figure 16, the depth and distance scales are in meters. Based on hyperbola-matching techniques, the velocity of propagation decreased with depth. An averaged velocity of 0.152 m/ns (dielectric constant of 3.8) was used to depth scale all radar records.

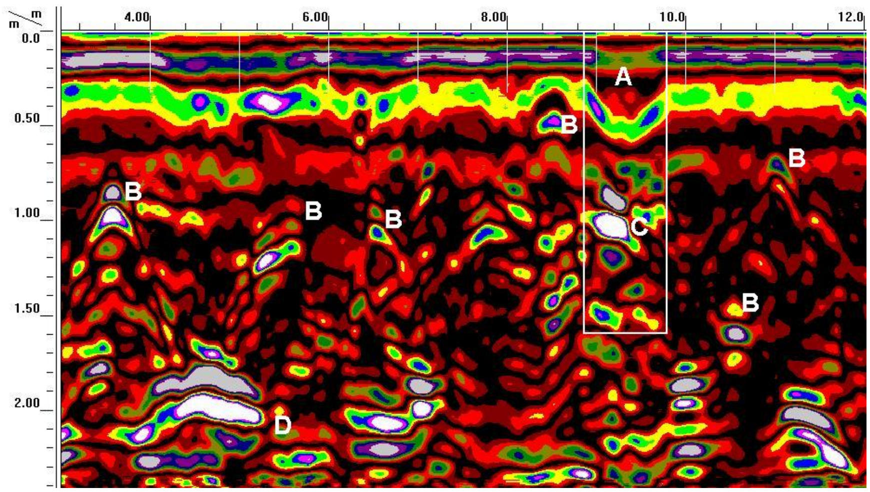
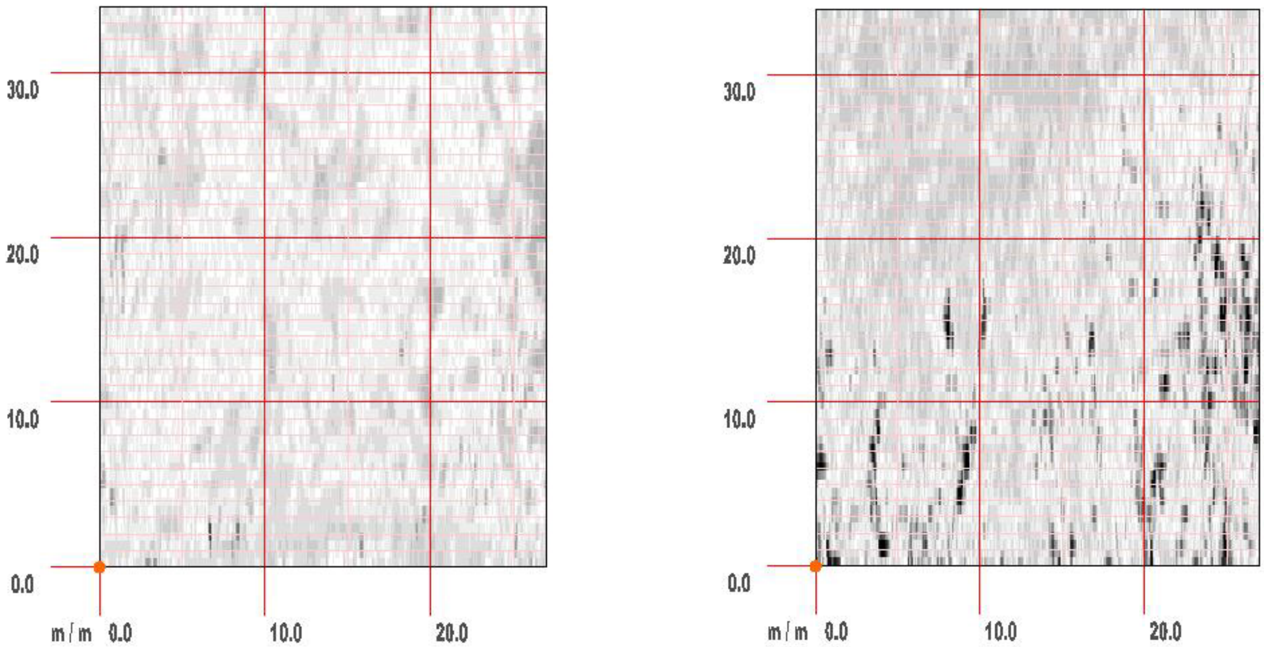


Figure 16. A representative radar record from Merriman Cemetery.

A noticeable feature on the radar record shown in Figure 16 is the filled depression near “A” and the underlying point anomalies. Combined, these features form the image of a grave shaft with remnants of a casket or coffin (“C” in Figure 16). Several prominent point anomalies (see “B” in Figure 16) are evident in the upper part of the radar record. Though rock fragments and roots can not be ruled out, those point anomalies occurring at depths of 1.0- to 1.5-m represent potential burials. The more planar reflectors in the lower part of the radar record are believed to represent strata in the glacial outwash deposits.

Figures 17 and 18 each contains two time-slice images of the Grid 1 survey area. In both figures, all measurements are expressed in meters. Each image of the grid area is viewed from directly overhead. In each image, reflections from within the overlying column of soil have been removed. The origin is located in the lower left-hand corner (northwest corner of grid area) of each slice. In Figure 17, the two horizontal time-slices represent depths of about 0- and 100-cm. In Figure 18, the two horizontal time-slices represent depths of about 125- and 150-cm. These depths were based on an averaged propagation velocity of 0.152 m/ns through the soil. The width of each time-slice is about 30-cm.

The 0-cm slice from Grid 1 is characterized by nondescript, low (white-colored) amplitude reflections. The lack of greater contrasts in reflected signal amplitudes signifies fairly homogeneous soil properties in the surface layers. Differences in reflected signal amplitudes are principally caused by differences in soil moisture and compaction. Broad spatial patterns, though indistinct are evident in the 0-cm slice. The south and west sides of the survey area contain areas of moderate signal amplitudes. These relatively open areas of the cemetery adjoin the entrance. Increased foot traffic is suspected to have caused the compaction of the soil in these areas. Increased soil compaction is believed responsible for the increased reflective signal amplitudes in this area. No pattern clearly suggests the occurrence of a gravesite on this slice.



0-cm slice   100-cm slice

Figure 17. Time-sliced images of Grid 1at the Merriman Cemetery, Southington

The 100-, 125-, and 150-cm slices are characterized by a large number of short, linear, high (black-colored) amplitude reflectors. These reflectors are widely dispersed across the grid area and cemetery. Some appear to be arranged in north to south trending rows. The long axes of these features appear to be aligned in an east to west direction. These characteristics suggest potential gravesites. A large number of these reflectors appear to come and go as the depth of the horizontal slice is changed. Others appear static and maintain their appearance, characteristics which suggest potential burial sites. Once again, the identification of these non-specific reflectors detected with GPR remains illusive. Had the outwash deposits been more uniformed in composition and lacked rock fragments and tree roots, the identity of these reflectors would be less ambiguous and could be more confidently associated with burials. Archaeologists are encouraged to compare the more stationary images that occur at depths of 100- to 150-cm with the locations of gravestones in the cemetery.

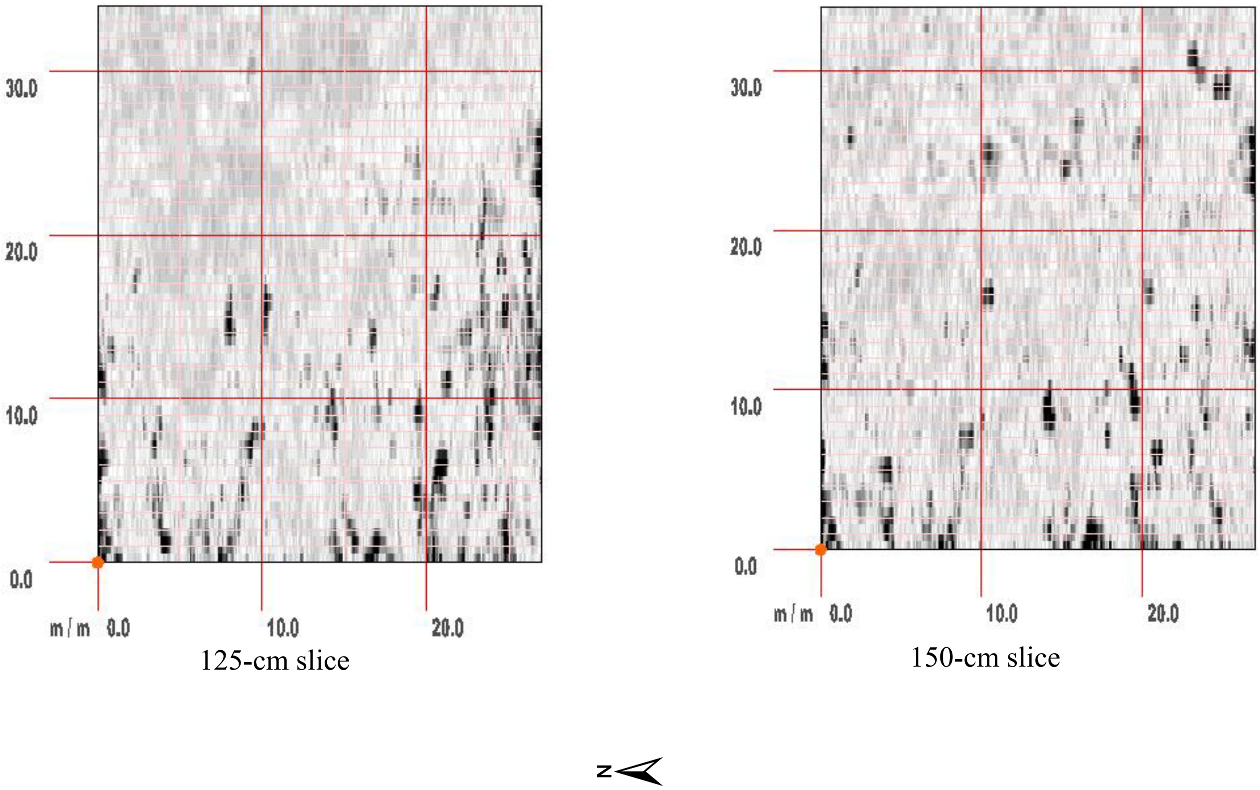


Figure 18. Time-sliced images of Grid 1at the Merriman Cemetery, Southington.

Figure 19 contains two time-slice images of the Grid 2 survey area at the Merriman Cemetery. In Figure 19, all measurements are expressed in meters. Each image of the grid area is viewed from directly overhead. In each image, reflections from the overlying column of soil have been removed. The origin is located in the lower left-hand corner (southwest corner of grid area) of each slice. The two horizontal time-slices represent depths of about 100- and 150-cm. These depths were based on an averaged propagation velocity of 0.152 m/ns through the soil. The width of each time-slice is about 30-cm.

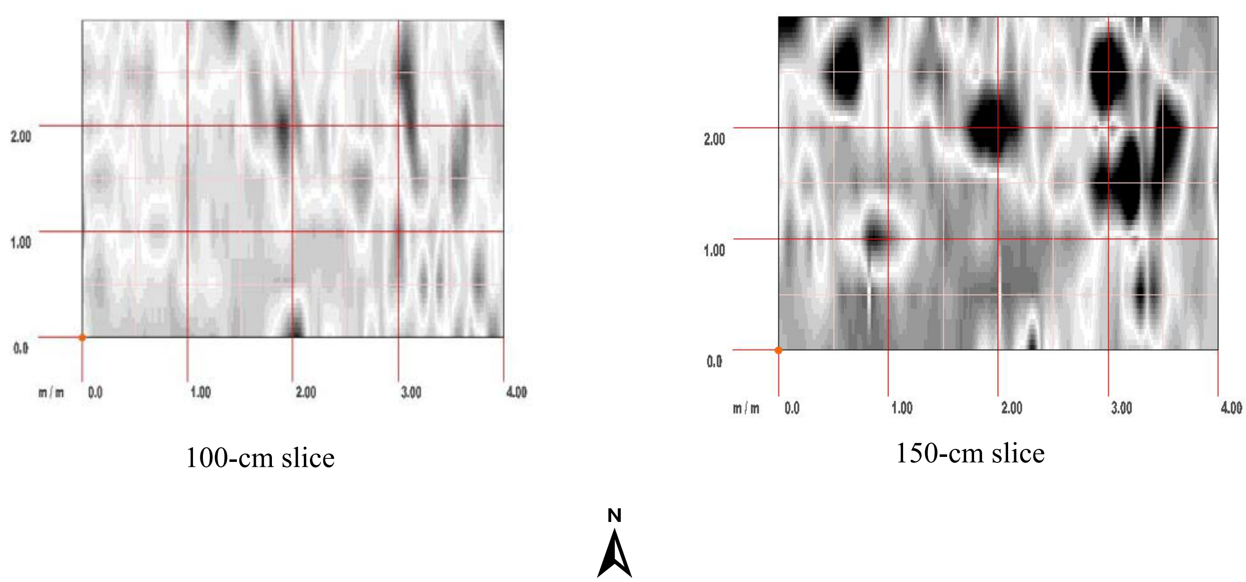


Figure 19. Time-sliced images of Grid 2at the Merriman Cemetery, Southington

The 100-cm slice from Grid 2 is characterized by principally low (white-colored) and moderate (grey-colored) amplitude reflections. These reflections appear in two broad bands that sweep across the central and eastern portions of the grid area in a northwest to southeast direction. This pattern suggests stratigraphic layers in the outwash deposits of Windsor soil rather than burials. This pattern is repeated in the 150-cm slice (see Figure 19). The reflected signal amplitudes are stronger in this slice. The locations of the more prominent reflectors have move, but the bands have maintained the same collective orientation.

Harriet Beecher Stowe House:
The house and the surrounding grounds were purchased in 1873 by Harriet Beecher Stowe, the author of *Uncle Tom's Cabin*. Harriet Beecher Stowe lived in the house with her husband until her death in 1896. The property adjoined the property once owned by Mark Twain. The Harriet Beecher Stowe house is surrounded by Victorian era gardens. A GPR survey was completed on the lawn that immediately borders the western side of the Stowe house. The purpose of this investigation was to identify remnants of fences erected in 1881 and 1923, and possible locations of privies or outbuildings.

A 10- by 12-m grid was established across the relatively open lawn to the immediate west of Stowe house. The longer axis extended from the house towards the Reception Center. A walkway extends across the central portion of the grid area from east to west. The Soil Survey of Connecticut shows the property as being mapped as Udorthents-Urban land complex.

Figure 20 is a representative radar record from the grid area at the Stowe House. In Figure 20, the depth and distance scales are in meters. Based on hyperbola-matching techniques, the velocity of propagation decreased with depth. An averaged propagation velocity of 0.130 m/ns (dielectric constant of 5.2) was used to depth scale all radar records. The radar record shown in Figure 20 was collected along a traverse line that ran from south (left-hand portion) to north (right-hand portion) across the grid area.

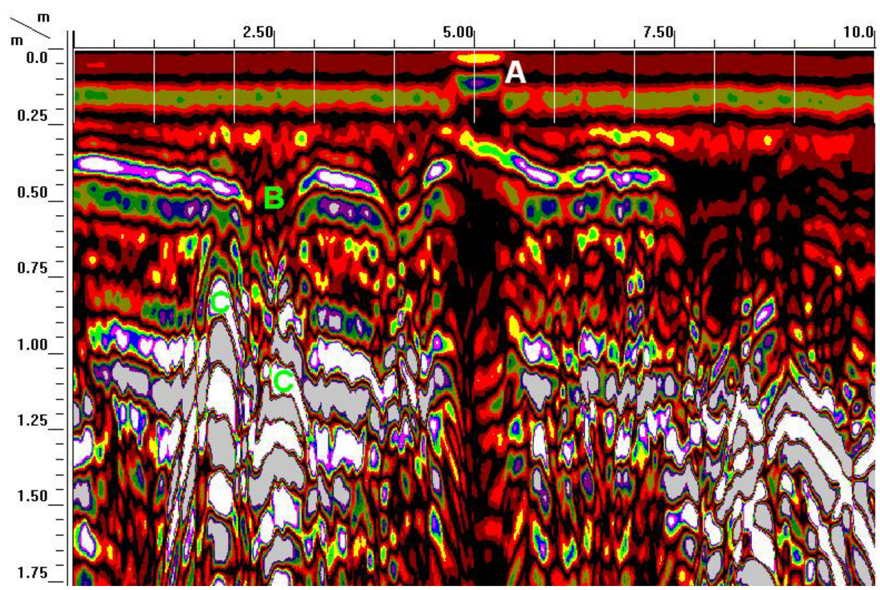


Figure 20. Radar record from the grid area at the Harriet Beecher House.

A conspicuous feature on the radar record shown in Figure 20 is the concrete walkway (see "A") that bisects the site from north to south. Compared with the surrounding soil, concrete has a lower water content and greater density. The concrete provides a denser, more contrasting interface than the soil surface. As a consequence, reflected signals have higher (yellow-colored) amplitudes, and because the propagation velocity is greater through the concrete than the adjoining soil, the reflected signals appear to rise on the radar record. The walkway is salted during winter months. Higher level of soluble salts within the concrete walkway results in a greater rate of signal attenuation. This results in the occurrence of lower amplitude reflections beneath the walkway.

In Figure 20, between depths of 25- and 50-cm, a planar reflectors can be identified in the first 7.5-m of the radar record. High (white- and pink-colored) reflected signal amplitudes signify a contrasting soil layer. It is believed that this layer represents a subsurface horizon or, more likely, a layer of fill materials. This layer is broken at “B.” Here, the soil has been excavated and two conspicuous, high-amplitude (white-colored) point reflectors (see “C” in Figure 20) are evident at depths of 75- and 100-cm. The point reflector that occurs at 100-cm continued across the grid area from east to west and is believed to represent a buried utility or drainage line. The high amplitude, planar reflectors that occur at a depth of about 100-cm and extends across this radar record probably represents strata of contrasting clays and silts associated with the underlying glacio-lacustrine materials from Glacial Lake Hitchcock.

Figure 21 contains two time-slice images of the grid area. In Figure 21, all measurements are expressed in meters. The origin is located in the lower left-hand corner (southeast corner of grid) of each slice. The two horizontal time-slices represent depths of about 0- and 50-cm. These depths were based on an averaged signal propagation velocity of 0.13 m/ns through the soil. The width of the time-slice is about 15-cm.

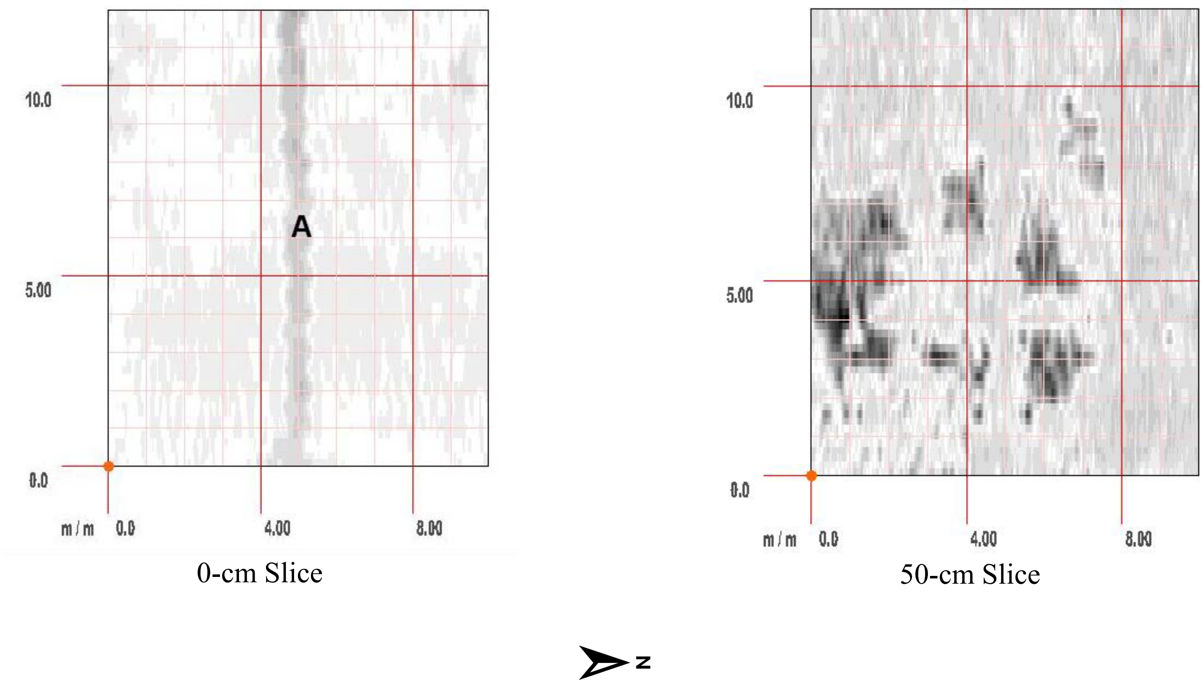


Figure 21. Time-sliced images showing a concrete walkway (0-cm slice) and a layer of fill materials (50-cm slice). Western lawn of Stowe House, Hartford.

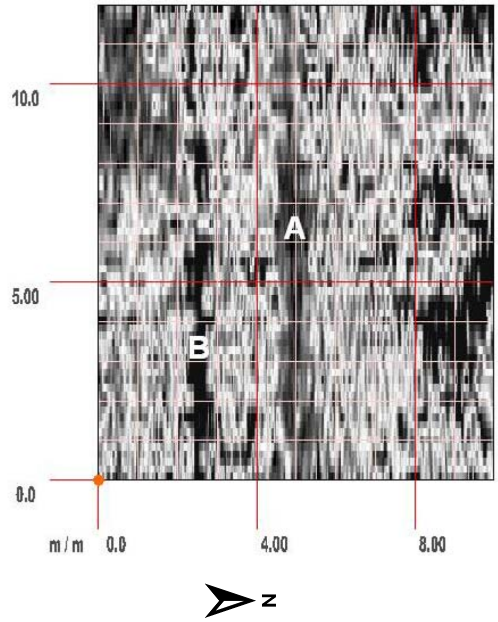


Figure 22. Time-sliced images (100 –cm depth) showing two lineal features underlying the western lawn of the Stowe House, Hartford.

In Figure 21, the shallowest (0-cm) slice reveals the location of the concrete walkway that extends away from the house towards the Reception Center. The 50-cm slice shows the extent of the conspicuous, high amplitude reflections produced by the soil layer shown in Figure 20. This layer of suspected fill materials is breached by two north-south trending lines (the walkway and a refilled trench). These features are apparent along the 3- and 5-m X-axis lines. An additional line of soil disturbance appears along portions of the 4-m Y-axis line.

Figure 22 shows the 100-cm slices of the grid area. Two linear patterns are evident in this slice: the dampen image of background noise and signal reverberations from the concrete walkway ("A") and the high amplitude reflections from a buried utility or drainage line ("B"). Other moderate and high amplitude reflectors evident on this slice represent strata of contrasting clays and silts. When the 3D images in put in motion, these reflectors migrate across the grid area as the depth is increased.

No evidence supporting the location of the former fences were discernible within the grid area. *Wild cat* surveys of neighboring portions of the lawn detected additional drainage or utility lines, but provided no indications of the former fences.

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