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**Subject:** MGT - Cultural Resources – Geophysical

**Date:** August 30, 2013

**To:** Lisa R. Coverdale  
State Conservationist  
NRCS, Tolland, Connecticut

**File Code:** 330-20-7

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**Purpose:**

Ground-penetrating radar was used to support eight cultural resources projects that are being carried out in cooperation with the Connecticut State Archaeologist, Connecticut Archaeology Center, University of Connecticut, and the Friends of the Office of State Archaeology. The NRCS is committed to the protection and enhancement of our nation's cultural resources and historic properties.

**Principal Investigators:**

Nicholas Bellantoni, Connecticut State Archaeologist, Connecticut Archaeology Center, University of Connecticut, Storrs, CT  
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA  
Debbie Surabian, State Soil Scientist, USDA-NRCS, Tolland, CT

**Activities:**

All activities were completed during the period of June 17-20, 2013.

**Summary:**

Ground-penetrating radar surveys conducted during this week were highly productive and successful. The following summarizes the results obtained at cultural sites:

1. Within the Indian Hill Cemetery in Middletown, Connecticut, several noteworthy reflection hyperbolas were observed between depths of 50 and 100 cm along the eastern boundary of the cemetery. Some of these reflection hyperbolas were associated with grave markers, some were slightly offset from grave markers, and others were in unmarked areas. No reflection hyperbola obtained in this portion of the cemetery provided unequivocal evidence of a burial other than by association with a headstone. As several hyperbolas occurred in unmarked areas, they may represent burials or other anomalies in the soil. A detailed grid survey using GPR would help to clarify interpretations and confirm the locations of the detected subsurface anomalies.
2. Within the Adath Israel Cemetery in Middletown, Connecticut, three relatively small, open areas were quickly scanned with GPR to ascertain whether there were any unmarked graves occupying these sites. No indications of burials were observed. Based on radar interpretations, these areas are open and suitable for future burials.



3. Ground-penetrating radar was used at a *cold case* site in Manchester, Connecticut, to help police locate a reported clandestine burial and to reduce their search zone to a few points containing the most anomalous or noteworthy subsurface reflection patterns. While no recorded reflection pattern could be conclusively identified as a burial, several locations having anomalous reflection patterns were identified and marked for the Manchester Police.
4. At the Adam Stanton House in Clinton, Connecticut, no anomalous, subsurface spatial pattern indicating the location of the former Abraham Pierson's house could be garnered from the collected GPR and EMI data.
5. At the South Burying Ground in Hartford, Connecticut, 2D radar records and 3D amplitude-slice image analysis revealed the presence of an apparently, orderly arranged set of high-amplitude reflection hyperbolas at depth of 100 and 150 cm. This set of reflectors extended across the western portion of the gridded area. These patterns suggest the possibility of burial sites and unmarked graves in this portion of the burying grounds.
6. Four detailed GPR grid surveys were conducted in relatively open areas of the Albany Road Burying Ground in Deerfield, Massachusetts. Using amplitude-slice imaging techniques, bands of elongated (in an east to west orientation), linear, subsurface reflections were apparent within two of these grids. As these reflectors appear orderly arranged and occur at a common depth, they suggest possible burial and unmarked graves. A GPR survey conducted over the mound containing the monument commemorating the victims of the 1704 French and Indian raid on Deerfield, revealed no evidence of a mass grave.
7. At the 19<sup>th</sup> Century Mine tunnel site near Litchfield, Connecticut, GPR detect a known tunnel, but could not map its extent, or detect other similar features under the existing terrain conditions. This steeply sloping, rocky, forested terrain is considered inhospitable to the methodical collection of radar data.
8. At the Deer Run site in Warren, Connecticut, GPR confirmed the presence of two marked and indicated the possibility of four to six unmarked grave sites.
9. Ground truth allows GPR image data to be related to real features and materials in the ground. Because of the diverse properties of soils and burials, the recognition of key reflection patterns and signatures was inadequately established in this study. Because of the lack of ground truth data, both errors of commission and omission may have occurred in the interpretations made in this report.

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



**ACTING**

JONATHAN W. HEMPEL  
Director  
National Soil Survey Center

Attachment (Technical Report)

cc: (cont'd next page)

David Smith, Director, Soil Science Division, USDA-NRCS, Washington, DC

Coverdale, page 3

cc: (cont'd)

Sarah Bridges, Archaeologist, NRCS, Washington, DC

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## Technical Report

Jim Doolittle

### Background:

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

Ground-penetrating radar (GPR) is widely used in archaeological investigations. The spatially continuous records of the subsurface provide by GPR are valuable to archaeologists. Being non-invasive, the use of GPR will minimally impact archaeological site. This geophysical tool has been used to identify areas of interest within cultural resource sites, locate buried archaeological features, clear suspected subsurface areas so that resources can be directed elsewhere, tests hypothesis, and confirm existing site knowledge. Differences in reflection amplitudes and patterns that appear on radar records are used to interpret the subsurface. Anomalous or contrasting reflection patterns may indicate buried artifacts. An “anomaly” is a contrasting subsurface feature or irregularity, which in an archaeological context, may represent a buried artifact. Ground-penetrating radar detects, but does not identify subsurface anomalies. Tacit knowledge, historical records, apparent surface features, and ground-truth excavations are all used to confirm GPR interpretations. The efficacy of GPR is highly site-specific and success is dependent on favorable soil and site conditions. Results vary with soils and soil properties. At many sites, the efficacy of cultural resource investigations can be improved through the combined use of GPR and traditional archaeological methods.

### Equipment:

The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (here after referred to as the SIR-3000), manufactured by Geophysical Survey Systems, Inc. (GSSI; Salem, NH).<sup>1</sup> The SIR-3000 consists of a digital control unit (DC-3000) with keypad, SVGA video screen, and connector panel. A 10.8-volt lithium-ion rechargeable battery powers the system. The SIR-3000 weighs about 4.1 kg (9 lbs) and is backpack portable. With an antenna, the SIR-3000 requires two people to operate. Jol (2009) and Daniels (2004) discuss the use and operation of GPR. A relatively high frequency, 400 MHz antenna was used in all but one of the investigations discussed in this report.

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

An electromagnetic induction (EMI) meter, the EM38-MK2 meter (Geonics Limited; Mississauga, Ontario), was used to survey the area surrounding the Adam Stanton House in Clinton, Connecticut.<sup>1</sup> The EM38-MK2 meter operates at a frequency of 14.5 kHz and weighs about 5.4 kg (11.9 lbs.). The EM38-MK2 provides measurement of both the quadrature phase (apparent conductivity) and in-phase (apparent magnetic susceptibility) components within two distinct depth ranges, all simultaneously, without any requirement for soil-to-instrument contact. The meter has one transmitter coil and two receiver coils,

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<sup>1</sup> Manufacturer's names are provided for specific information; use does not constitute endorsement.

which are separated from the transmitter coil at distances of 1.0 and 0.5 m. When operated in the vertical dipole orientation (VDO), this configuration provides two nominal exploration depths of 1.5 and 0.75 m.

The Geonics DAS70 Data Acquisition System was used with the EM38-MK2 meter to record and store both  $EC_a$  and GPS data. This acquisition system consists of the EMI meter, an Allegro CX field computer (Juniper Systems, Logan, Utah), and a Trimble Ag114 L-band DGPS (differential GPS) antenna (Trimble, Sunnyvale, CA).<sup>2</sup> With the acquisition system, the meter is keypad operated and measurements are automatically triggered. The RTmap38MK2 software program developed by Geomar Software Inc. (Mississauga, Ontario) was used with the EM38-MK2 meter and the Allegro CX field computer to record, store, and process both  $EC_a$  and GPS data.<sup>2</sup>

To help summarize the results of the EMI surveys, SURFER for Windows (version 10.0), developed by Golden Software, Inc. (Golden, CO), was used to construct the simulation shown in this report.<sup>2</sup> Grids of  $EC_a$  data were created using kriging methods with an octant search.

### **Calibration of GPR:**

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

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

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

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

In equation [2], C is the velocity of light in a vacuum (0.3 m/ns). Typically, velocity is expressed in meters per nanosecond (ns). In soils, the amount and physical state (temperature dependent) of water have the greatest effect on the  $E_r$  and v. Dielectric permittivity ranges from 1 for air, to 78 to 88 for water (Cassidy, 2009). Small increments in soil moisture can result in large increases in the relative permittivity of soils (Daniels, 2004). Using a 100 MHz antenna, Daniels (2004) observed that the relative dielectric permittivity of most dry mineral soil materials is between 2 and 10, while for most wet mineral soil materials, it is between 10 and 30.

No ground-truth verifications of the depth to known subsurface reflectors were attempted during this study to determine v and  $E_r$ . As a result, depth scales were approximated using hyperbolic velocity matching, which was carried out during post-processing. Hyperbolic velocity matching provides rough estimates of average v and  $E_r$ . Using hyperbolic matching, the average  $E_r$  was estimated to be 13, which resulted in an average v of 0.0832 m/ns. This information was used to depth scale the radar records.

### **3D Pseudo-Images and Amplitude Slice Analysis:**

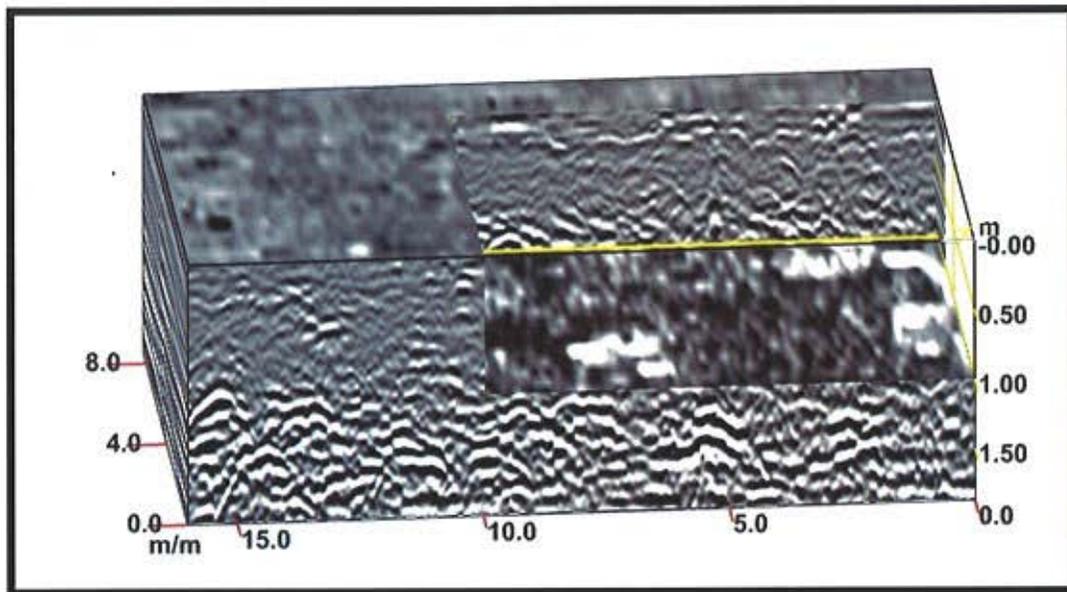
In recent years, the use of advanced signal-processing software has enabled the enhancement of radar signals and significant improvements in reflection pattern-recognition on radar records. Some of the signal processing methods used to improve the interpretability of subsurface archaeological features appearing on radar records are discussed by Sciotti et al. (2003) and Conyers (2004). Figure 1 is a three-

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<sup>2</sup> Manufacturer's names are provided for specific information; use does not constitute endorsement.

dimensional (3D) pseudo-image of a study area within the Deer Run archaeological site. This 3D pseudo-image was constructed from the computer analysis and synthesis of a series of closely-spaced, two-dimensional (2D) radar records. In order to construct this 3D pseudo-image, GPR data were collected along a series of 17, closely spaced (50 cm) traverse lines that were parallel with the x-axis (foreground). Each traverse line was 16 m long. These procedures produced the 16 by 8 m (128 m<sup>2</sup>) grid area.

The 3D pseudo-image shown in Figure 1 has a 10 by 7 by 1 m inset cube graphically removed to reveal several clusters of high-amplitude (white-colored) reflections along its base. These reflections are believed to represent burials. Because data were continuously recorded along the x-axis (foreground), greater detail is evident along this axis of the pseudo-images than along the y-axis (left-foreground), where data were collected at 50 cm intervals (traverse line spacing). Data shown along the y-axis are spatially aliased, notably “smeared”, and more poorly represented.



**Figure 1. This 3D pseudo-image of a 128 m<sup>2</sup> study area within the Deer Run Archaeological Site in Warren, Connecticut, has a 10 by 7 by 1 m inset cube graphically removed. The high-amplitude, white-colored reflections along the base of the inset cube are suspected to represent burials.**

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

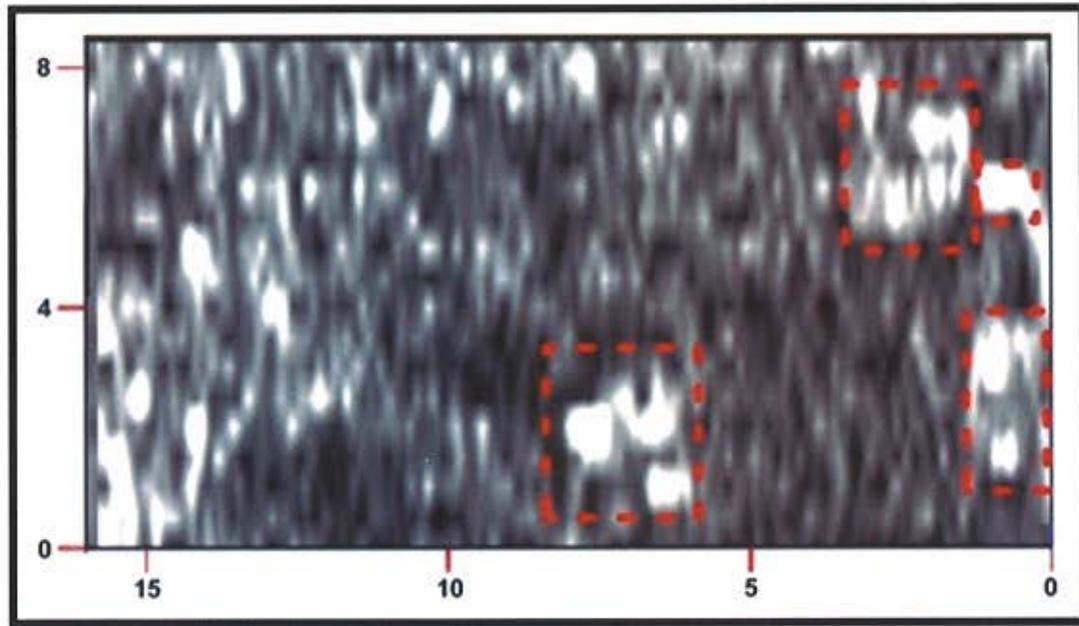


Figure 2. An amplitude sliced image of the 3D pseudo-image shown in Figure 1. The time or depth slice is for the 100 cm depth interval. Several clusters of high-amplitude reflections, which are enclosed in red-colored, segment lines, may possibly represent unmarked graves.

Figure 2 is a depth-sliced image of the 3D pseudo-image shown in Figure 1. This depth-sliced image is for the 100 cm depth interval. In Figure 2, the survey area is viewed from directly overhead. Several clusters of high-amplitude reflections are enclosed in red-colored, segment lines. These groups of reflectors are believed to represent unmarked graves. The common depth and geometry of these high-amplitude reflectors on this depth-sliced image helped to confirm the identification and location of possible grave sites within a family cemetery plot.

#### Study Sites:

The taxonomic classifications of the soils profiled with GPR at the archaeological site during this week are listed in Table 1. Because of their low clay, soluble salt and moisture contents, these soils are considered well suited to deep exploration depths with GPR.

Table 1. Taxonomic classification of the soils identified in the study sites.

Soil Series	Taxonomic Classification
Broadbrook	Coarse-loamy, mixed, active, mesic Oxyaquic Dystrudepts
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
Hollis	Loamy, mixed, active, mesic Lithic Dystrudepts
Merrimac	Sandy, mixed, mesic Typic Dystrudepts
Montauk	Coarse-loamy, mixed, subactive, mesic Oxyaquic Dystrudepts
Paxton	Coarse-loamy, mixed, active, mesic Oxyaquic Dystrudepts
Wethersfield	Coarse-loamy, mixed, active, mesic Oxyaquic Dystrudepts
Windsor	Mixed, mesic Typic Udipsamments

#### Indian Head Cemetery, Middletown:

The Indian Head Cemetery is located off of Middletown Street in Middletown, Connecticut. The purpose of this GPR study was to help insure that unmarked graves are not located in several areas of open space within the cemetery. The study areas are located in grassed, open areas of Wethersfield loam, 15 to 25 percent slopes (87D) and Paxton and Montauk fine sandy loams, 8 to 15 percent slopes (84C). The very deep, well drained Montauk, Paxton, and Wethersfield soils formed in glacial till on uplands. These soils are moderately deep to dense till. In contrast with Paxton soils, Wethersfield soils have 5YR or redder hues in their B and C horizons. Montauk soils have sandy substrata. These soils are suitable for archaeological and soil investigations with GPR. Random GPR traverses were conducted across portions of these soil map units that were selected by the cemetery's caretakers.

#### Adath Israel Cemetery, Middletown:

The Adath Israel Cemetery is located on Pine Street in Middletown, Connecticut. The purpose of this brief GPR investigation was to help insure that unmarked graves are not located in three areas of open space. The cemetery is located in an area of Wethersfield loam, 3 to 8 percent slopes (87B). Random GPR traverses were conducted across portions of the cemetery selected by a caretaker.

#### Manchester Cold Case:

The investigation site is located near Wyassup Road in North Stonington, Connecticut. The site is located in an area of Hinckley gravelly sandy loam, 3 to 15 percent slopes (38C). The very deep, excessively drained Hinckley soils formed in glaciofluvial materials on terraces and outwash plains. The purpose of this investigation was to locate a clandestine burial. In the 1970s, two women from the Vernon/Tolland area were reported missing. It was later reported that a man had been seen burying "something" in his backyard and garage. The man is considered a suspect in this case and his garage was searched as a possible location for the clandestine burial of the two women. No evidence was obtained by the police in this search. The time consuming excavation techniques employed by police are destructive as well as costly. In the present investigation, random GPR traverses were conducted in a back-and forth manner across accessible portions of the site. The purpose of this GPR investigation was to reduce the search area and to identify any subsurface features that may represent clandestine burials.

#### Adam Stanton House:

The Adam Stanton House and Store is located on East Main Street in Clinton, Connecticut. The Stanton House was built in 1789 on the former site of the Rector Abraham Pierson's house. From 1704 until 1707, the Reverend Pierson house was used to instruct students of the Collegiate School. Following Pierson's death, the school was removed to New Haven where, at the 1718 commencement, the Collegiate School was renamed Yale College. The purpose of this investigation was to use GPR and electromagnetic induction (EMI) to detect buried remnants of the former Reverend Pierson house. The study area is located in an area of Merrimac-Urban land complex, 0 to 8 percent slopes (234B). The very deep, somewhat excessively drained Merrimac soils formed in sandy outwash. These soils are well suited to deep penetration with GPR. Random pedestrian surveys were conducted with both GPR and electromagnetic induction (EMI) across the lawns of the Stanton House and an open playground area of the adjacent Abraham Pierson School. The approximate area that was surveyed with these geophysical tools is enclosed by red-colored lines on the Google Earth image shown in Figure 3.



**Figure 3. This Google Earth image shows the location of the area surveyed with GPR and EMI at the Adam Stanton House in Clinton, Connecticut.**

#### Old South Burying Grounds

Old South Burying Ground is located on Maple Avenue between Benton and Shultas Streets in Hartford, Connecticut. This is the city's second oldest burying ground. This burying ground was used between 1801 and 1872. The study site is located in an area of Broadbrook silt loam, 3 to 8 percent slopes (82B). The very deep, well drained Broadbrook soils formed in a silty mantle overlying dense, loamy till. The Broadbrook soils are very deep to bedrock and moderately deep to a densic contact. This soil is suitable for soil and archaeological investigations with GPR.



**Figure 4. This Google Earth image shows the approximate location of the GPR survey grid in the Old South Burying Ground, Hartford, Connecticut.**

A 15 by 10 meter grid was established across a portion of the burying ground (see Figure 4) that lacks grave stones. This area had been identified as having “apparent disturbed materials and loss of signal” in a previous GPR survey that was conducted by a different group.

Old Burying Ground, Deerfield, Massachusetts:

The Old Burying Ground is located along Albany Road on the western edge of the village of Deerfield, in north-central Massachusetts. This burying ground was principally used between the early 1700s and the early 1800s, and contains some of the oldest graves in the Connecticut River Valley. While the exact number of graves within this burying ground is unknown, over 493 grave stones (head and foot stones) have been recorded in the burying ground. It is suspected that some early wooden and stone grave markers were lost through disintegration, burial, or removal. The burying ground is believed to contain unmarked graves of Native Americans, African slaves, and transients. The oldest known grave within the burying ground is that of Joseph Barnard (1695) and the youngest grave is that of Edward Champney (1929). However, the majority of the graves are from the 1700s. The burying ground is also believed to contain a mass grave for the victims of the February 29, 1704, French and Indian raid. A mound and marker within the burying grounds is believed to overlie a mass grave for the 48 settlers that were killed during the raid (see Figure 5).



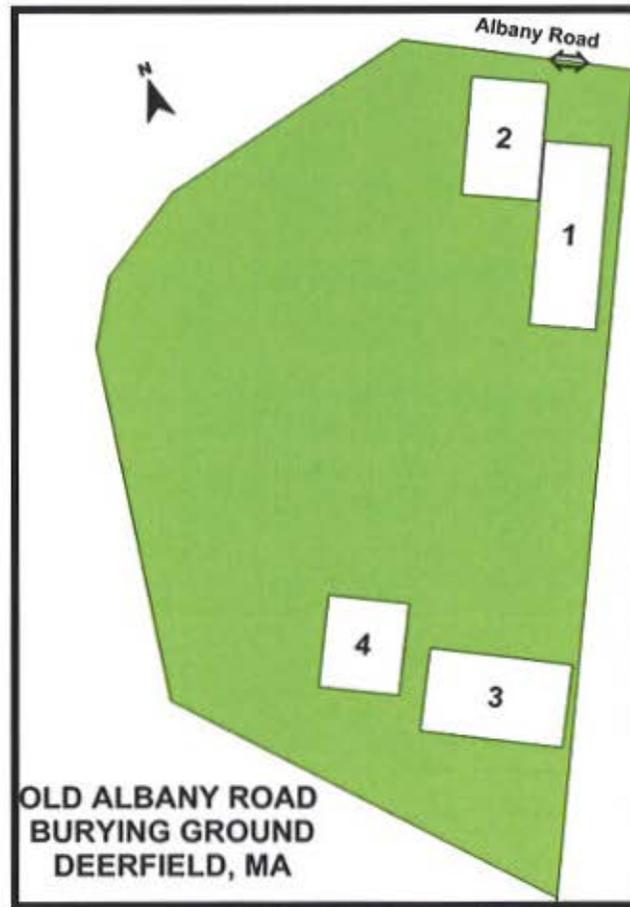
**Figure 5. The mound and marker seen in the foreground of this picture are believed to overlie a mass grave for the victims of the 1704 French and Indian raid on the Deerfield settlement.**

The Old Burying Ground is located in an area of Udorthents-Urban land complex (656) and is bordered to the west and south by more sloping areas of Windsor and Merrimac soils, 25 to 60 percent slopes (229F). The very deep, excessively drained Windsor soils formed in sandy outwash deposits.

The purpose of the GPR survey was to search for unmarked graves and a mass grave within the burying ground. Four GPR survey grids were laid out across relatively open areas of the burying grounds that contained no or very few grave markers (see Figure 6). The dimensions of the grids are listed in Table 2. The relative location and identification of these grids within the burying grounds are shown in Figure 6.

**Table 2. Dimensions of the four grids established at the Old Burying Ground in Deerfield, Massachusetts. All dimensions are in meters**

Grid	X-Axis	Y-Axis
1	24	8
2	11	15
3	9	14
4	10	12



**Figure 6. This map shows the approximate locations of the GPR survey grids within the Old Albany Road Burying Ground in Deerfield, Massachusetts.**

19th Century Mine Shaft and Tunnels, Litchfield:

Using a lower frequency, 70 MHz antenna, a wooded, steeply sloping area (41.7788 N latitude, 73.1603 W longitude) was searched for abandoned underground mine tunnels. The site is located about 4.11 km west-southwest of Torrington along US 202, in areas of Charlton-Chatfield complex, 3 to 15 percent slopes (73C) and Hollis-Chatfield-Rock outcrop complex, 15 to 45 percent slopes (75E). The well drained, very deep Charlton, and the well drained and somewhat excessively drained, moderately deep Chatfield and shallow Hollis soils formed in till derived from parent materials that are very low in iron sulfides. Although the soils are suitable for deep penetration with GPR, the steeply sloping, rocky, and forested terrain of this site was too hostile for the effective use of GPR.

### Deer Run Site, Indian and Colonial Burying Ground, Warren:

This site is currently under excavation and suspected to contain the encampments of early Native Americans. The site also contains the earliest burying ground in Warren (circa 1700). Three tombstones from this burying ground are visible above-ground with others not apparent. This active archaeological site (41.7066 north latitude, 73.3518 west longitude) is located about 3.4 km north of New Preston in an open area along the edge of a vineyard. The site is situated in areas of Canton and Charlton soils, 3 to 15 percent slopes, extremely stony (62C). The very deep, well drained Canton soils formed in a loamy mantle underlain by sandy till derived from parent materials that are very low in iron sulfides. The purpose of this investigation was to locate unmarked Colonial-era graves.

### **Survey Procedures:**

Random or *wild-cat* GPR surveys were conducted across accessible areas of most sites. In these surveys, areas of steep slopes or dense vegetation were avoided. With the exception of the mine shaft and tunnel site near Litchfield (where a 70 MHz antenna was used), multiple, GPR traverses were completed at each of the sites by pulling the 400 MHz antenna along the ground surface. For these surveys, a distance-calibrated survey wheel with encoder was bolted onto the antenna and provided better control over signal pulse transmission and data collection. The survey wheel experienced some slippage, which did result in some recorded line lengths (from the survey wheel) being slightly different from the actual lengths. Each radar traverse was stored as a separate file.

Radar traverses were, where possible, conducted in a general north-south direction to insure the greatest probability of passing over graves. It is assumed that most graves would be orientated in an east-west direction so that the body would face the rising sun.

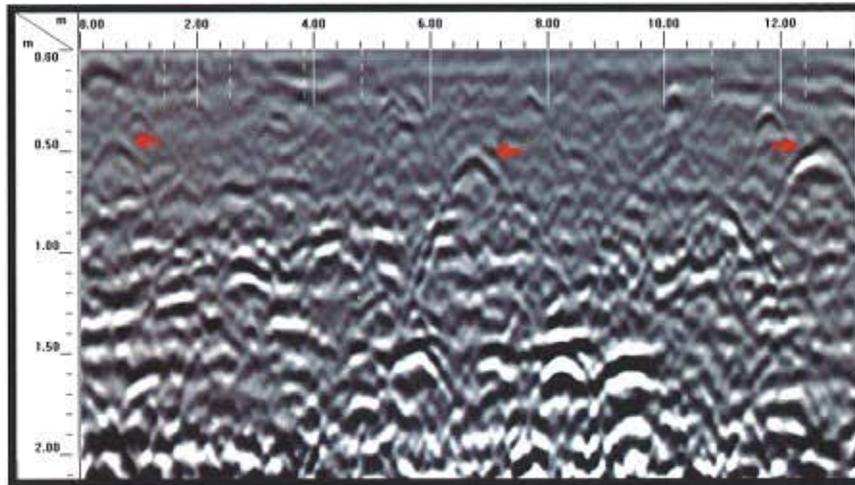
Grid surveys were completed with a 400 MHz antenna at the Old South Burying Ground (Hartford, CT), Old Burying Ground (Deerfield, MA), and the Deer Run Site (Warren, CT). To facilitate the construction of each grid, two parallel survey lines were laid out and served as grid axis lines. Along these two parallel axis lines, survey flags were inserted into the ground at a spacing of 50 cm. A rope was stretched between matching survey flags on these two axis lines, which were located on opposing sides of the grid area. The 400 MHz antenna was towed along the rope for guidance. Following data collection along the line, the rope was sequentially displaced 50-cm to the next pair of survey flags to repeat the process.

### **Results:**

#### Indian Hill Cemetery

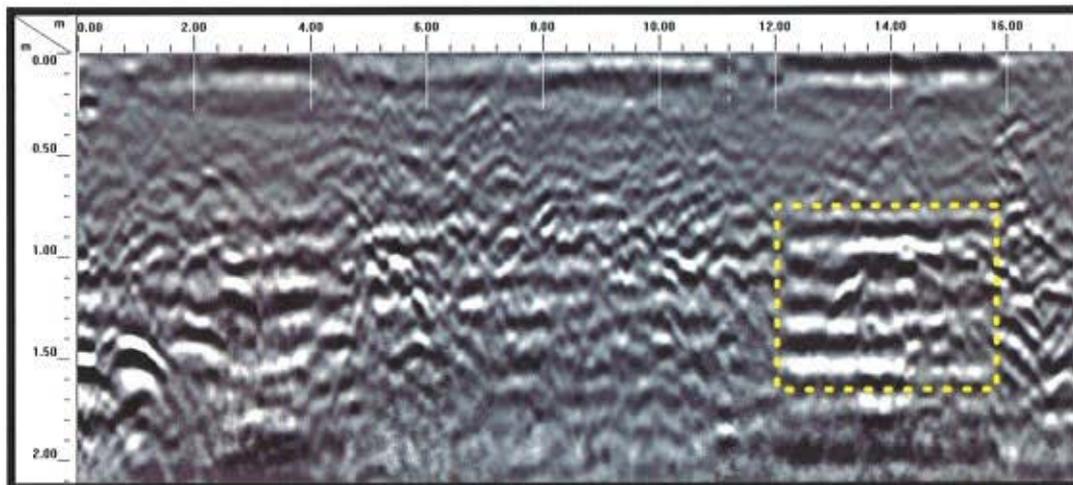
Random surveys were conducted across an open hilltop area in the southern portion of the Indian Hill Cemetery and also below this summit area, along the cemetery's forested eastern boundary. No noteworthy reflection patterns or reflection hyperbolas were observed on radar records from the hilltop area. However, several noteworthy, subsurface reflection patterns and reflection hyperbolas were observed on radar records collected along the eastern boundary of the cemetery.

Figure 7 shows a portion of a radar record that was obtained along the eastern border of the cemetery. On this radar record, all scales are expressed in meters. The red arrows indicate three, high-amplitude reflection hyperbolas believed to represent burials (because of their size, amplitude and location near grave markers). These three hyperbolas occur at a depth of about 50 cm. Other, smaller and more weakly-expressed reflection hyperbolas can be observed in the upper part of this radar record. These hyperbolas are believed to represent tree roots, rock fragments, animal burrows, and inhomogeneities in the soil. On this radar record, moderate to high-amplitude linear reflectors increase in number and prominence below a depth of about 70 cm. These reflectors are believed to represent layers of denser till that are characteristic of the soils in this area.



**Figure 7. This radar record was collected in the southern portion of the Indian Hill Cemetery and along its eastern boundary. The red arrows indicate three, high-amplitude reflection hyperbolas believed to represent burials.**

In Figure 7, the six, white colored, segmented lines at the top of the radar record correspond to the locations of grave markers and supposedly known burials. These vertical lines were impressed on the radar record as the 400 MHz antenna passed in front of headstones. While several reflection hyperbolas, which occur at varying depths, could be associated with these headstones, only three have been identified as “probable” burials. Other reflection hyperbolas, which are less clear or masked by other subsurface reflections may also represent burials but have escaped recognition.



**Figure 8. On this radar record, an area with contrasting reflection patterns has been enclosed by segmented lines.**

Further south along the eastern boundary of the Indian Hill Cemetery, a contrasting reflection pattern was noted on a radar record (see Figure 8). This feature was investigated with picks and shovels (Figure 9). While a noticeably strong, hollow echo and ground vibrations were noted when contact was made with a pick, the excavation revealed no artificial feature that would have produced the observed responses. In

this example, many of the participants felt that the GPR had detected a subsurface vault. A further excavation of this feature is needed to further improve interpretations.



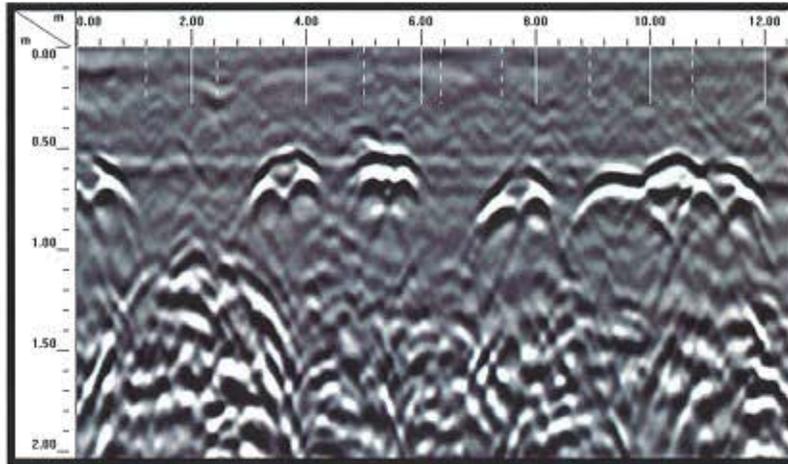
**Figure 9. A subsurface feature, which produced a contrasting reflection pattern on a radar record (see Figure 8), is investigated with picks and shovels at the Indian Hill Cemetery.**

The area surveyed along the eastern boundary in the southern portion of the Indian Hill Cemetery revealed several reflection hyperbolas between depths of 50 and 100 cm. Some were associated with grave markers, some were slightly offset from grave markers, and others were in unmarked areas. No reflection hyperbola provided unequivocal evidence of a burial other than by association with a headstone. As several hyperbolas occurred in unmarked areas, they may represent burials or other anomalies in the soil. A detailed GPR grid survey would help to clarify interpretations and confirm the locations of any detected anomalies.

#### Adath Israel Cemetery:

In the areas traversed with GPR, burials and coffins were easily detected and identified within the Adath Israel Cemetery. The straightforward detection and identification of the burials were attributed to the recency of burial and soil properties that are conducive to the use of GPR. Figure 10 is a representative radar record that was collected over seven known burials (see white-colored, segmented, vertical lines at the top of the radar record indicate the center of nearby headstones). The high-amplitude reflection hyperbolas from the burials clearly stand out. On this radar record, reflection hyperbolas typically occur in groups of two with overlapping reflection patterns. This pattern suggests the presence of two closely spaced graves.

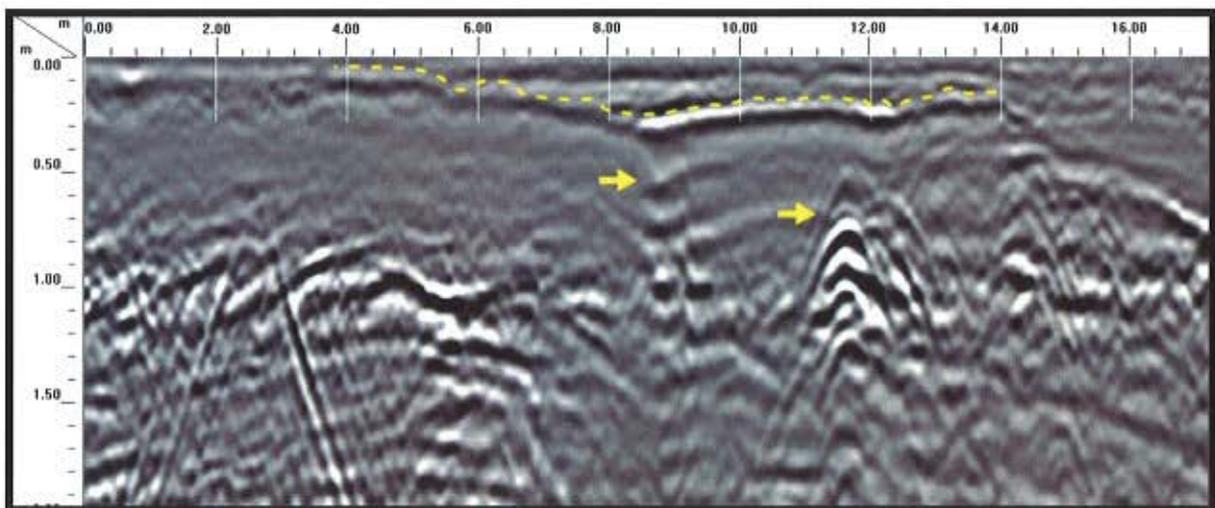
Within the Adath Israel Cemetery, three relatively small, open areas were scanned with radar to ascertain whether there were any unmarked graves occupying these sites. No indications of burials were observed. Based on radar interpretations, these areas are open and suitable for future burials.



**Figure 10.** This radar record, which was collected at the Adath Israel Cemetery, shows multiple burials at depths of approximately 50 cm.

Manchester Cold Case:

Two “wildcat” (random) and one crude grid survey (50 cm interval between parallel grid lines) of the backyard revealed seven *engaging anomalies* that could represent potential burials. At this site, a total of 36 radar traverses were completed across two terrace levels. On the upper terrace, radar traverses ranged from 11 to 116 m, but were mostly between 15 and 17 m long. A total of 9 radar traverses were completed across the lower, forested terrace level. On the lower terrace, traverses ranged from 10 to 17 m long. During the course of the radar survey, the antenna would be paused and backed over any noteworthy subsurface reflection pattern that appeared on the radar screen. These subsurface anomalies were flagged. On the upper terrace level (lawn area beside and behind the house), seven possible sites were identified and flagged. In a subsequent survey along the base of a wooded slope, one interesting subsurface anomaly was identified and flagged.

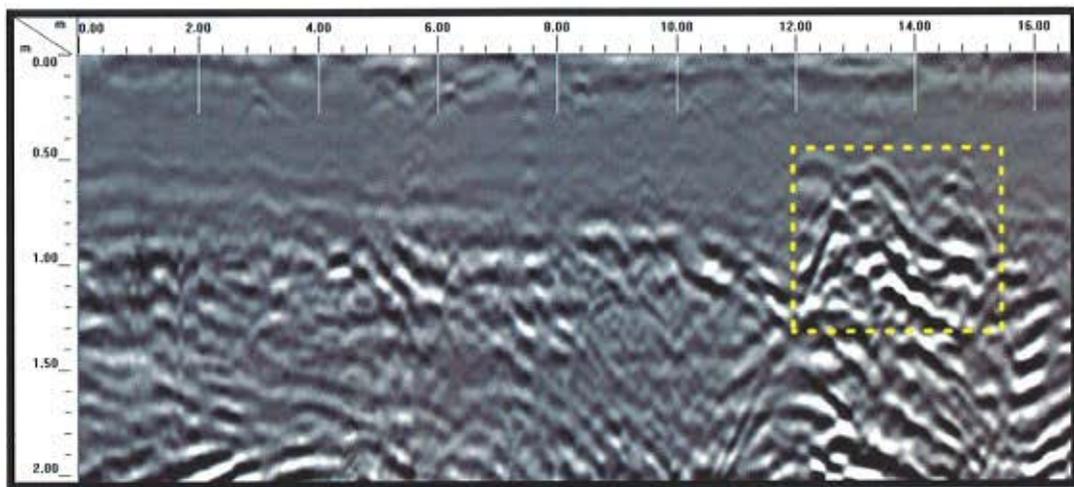


**Figure 11.** This radar record was obtained directly behind a house in Manchester, Connecticut. The two features identified by yellow arrows were flagged in the field.

Figure 11 is a portion of a record that contained the most intriguing set of radar reflections observed at this site. This radar record was obtained on the upper ground terrace, in an area immediately behind the

house. In Figure 11, near the 9 m distance mark, a shadowy, vertical reflection pattern suggests an intrusion or disturbance in the soil. The dashed, nearly level, yellow-colored segmented line above this feature highlights a linear reflector that believed to represent a contrasting soil horizon. As the house is nearby, this interface may represent the original soil surface that has been buried by layers of fill. The higher amplitude of this interface reflection between the 9 and 14 m distance marks more contrasting materials. At the 14 m distance mark a more weakly expressed but similar shadowy, vertical reflection pattern is evident. The locations of these two shadowy reflection patterns are below and at the limits of the well expressed soil horizon. These reflection patterns and their locations in relationship to the overlying soil horizon may represent a possible edge effect or seepage.

On the radar record shown in Figure 11, beneath the 11.5 m distance mark and at a depth of about 50 cm (20 inches) is an exceedingly high amplitude and anomalous reflection hyperbola. This is the most strongly expressed reflection hyperbola that was observed during the course of the survey. This reflection hyperbola was evident on three sequential and parallel radar traverses that spanned a distance of about 1 m. Because of this feature's strong contrast with the surrounding soil matrix and location behind the house, it was recommended for ground-truth excavation to confirm its identity.



**Figure 12.** This radar record contains the most anomalous subsurface feature (enclosed by segmented yellow-colored lines) observed on the lower, forested, terrace level at the Manchester Site.

On the lower, forested terrace level behind the house, only one subsurface reflection pattern caught our interest. In Figure 12, this reflection pattern is evident in the area enclosed by the segmented yellow-colored lines. The location of this subsurface feature was flagged.

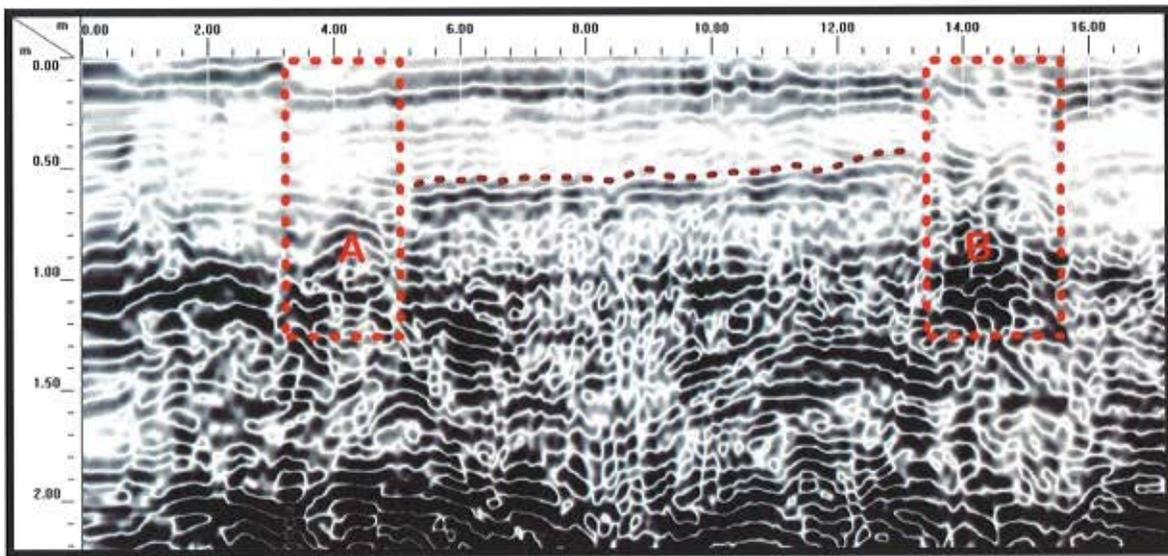
The search for clandestine burials is a labor-intensive and time-consuming task. Ground-penetrating radar was used in this study to help locate a suspected clandestine burial site and to reduce the search zone to a few points that displayed the most noteworthy subsurface reflection patterns. While no recorded reflection pattern could be conclusively identified as a burial, several locations having anomalous reflection patterns were identified and marked. The radar records shown in Figures 11 and 12 contain the most noteworthy subsurface reflection patterns on the upper (lawn) and lower (forested) terrace levels, respectively.

#### Stanton House, Clinton:

Random, "wildcat" GPR surveys were conducted with the 400 MHz antenna across accessible areas of the Stanton House's back and side yards. In addition, surveys were completed across portions of the

Abraham Pierson School's yards that bordered the Stanton House's property. No major buried structural features were recognized on the radar records from these survey areas.

Figure 13 contains a portion of a radar record that was collected along the east side of a drive located on the west side of the Stanton House. Two noticeable subsurface anomalies (A & B), as well as a soil horizon, have been identified on this radar record. On this radar record, the abrupt, vertical breaks in soil horizon reflections above and on either side of these features are considered unnatural or artificial. These vertical breaks and the intervening zones of contrasting or anomalous reflection patterns suggest two areas of disturbance which are believed to represent refilled trenches. The mixed, backfilled materials used to refill these trenches produced anomalous reflection patterns, which contrast with the undisturbed soil materials on either side of the refilled trenches. In addition, the soil materials used to fill these two trenches appear to have settled or collapsed. This results in slightly concave-upward or "bowl-like" radar reflection signatures at depths of about 10 (for "A") or 50 cm (for "B").



**Figure 13. This radar record was collected in an area adjacent to the drive on the west side of the Stanton House. Two (A & B) noteworthy anomalies have been enclosed and a soil horizon has been highlighted by segmented lines.**

A pedestrian survey was completed with the EM38-MK2 meter across the more accessible portions of the yard surrounding the Adam Stanton House and the school yard that adjoins the property to the north. The EM38-MK2 meter was operated in the deeper-sensing, vertical dipole orientation. The instrument was operated in the continuous mode with measurements recorded at a rate of 1/sec. Where possible, the long axes of the meter was orientated parallel to the direction of traverse, and held about 5 cm above the ground surface (see Figure 14). Walking in a back and forth manner across the study area, along essentially parallel traverse lines, a total of 6909 in-phase measurements were recorded with the meter.

Only the in-phase (IP) response measured with the EM38-MK2 meter was interpreted in this study. The in-phase response is considered proportional to and has been used as a proxy to infer the magnetic susceptibility of soils (Frischknecht et al., 1991). The in-phase response of an EMI meter is often referred to as the "metal detection" phase and has been used in archaeological investigations.

Table 3 provides basic statistics for the EMI data that were collected in this study. In Table 2, the headings for the two columns represent the intercoil spacings of the transmitter and receiver coils. In

Table 3, with the exception of “Number”, the unit of measure is parts per thousand (ppt). As evident in a comparison of the two depth measurements, the bulk averaged IP measurement increases, but becomes less variable with increasing depth.



Figure 14. Conducting a survey with an EM38-MK2 meter in the school yard adjacent to the Adam Stanton House.

Table 3. A Summary of the In-phase Data collected with the EM38-MK2 in the Vertical Dipole Orientation at the Adam Stanton House.

	IP - 100 cm	IP - 50 cm
<b>Number</b>	6909	6909
<b>Minimum</b>	-166.2	-253.8
<b>25%-tile</b>	28.4	-34.1
<b>75%-tile</b>	39.6	-6.8
<b>Maximum</b>	1170.4	1280.0
<b>Average</b>	39.1	-17.5
<b>Std. Dev.</b>	39.0	53.7

For measurements obtained in the shallower-sensing, 50-cm intercoil spacing, the in-phase ranged from about -254 to 1280 parts per thousand (ppt). However, one-half of these measurements were between about -34 and -6.8 ppt. For the deeper-sensing 100-cm intercoil spacing, the in-phase response ranged from about -166 to 1170 ppt. However, one-half of these measurements were between about 28.4 and 39.6 ppt. The unusually large ranges in the in-phase responses were attributed to the presence of iron-bearing artifacts (e.g. playground equipment, fencing, and buried metallic pipes and other artifacts) and the induced electric currents being significantly affected by their presence.

Figure 15 shows the spatial distributions of in-phase data that were collected with the deeper sensing 100 cm (left-hand plot) and shallower sensing, 50 cm (right-hand plot) intercoil spacings. These plots were

prepared from 6909 data points using a point kriging model with a default linear variogram model. The same color ramp has been used in both plots.

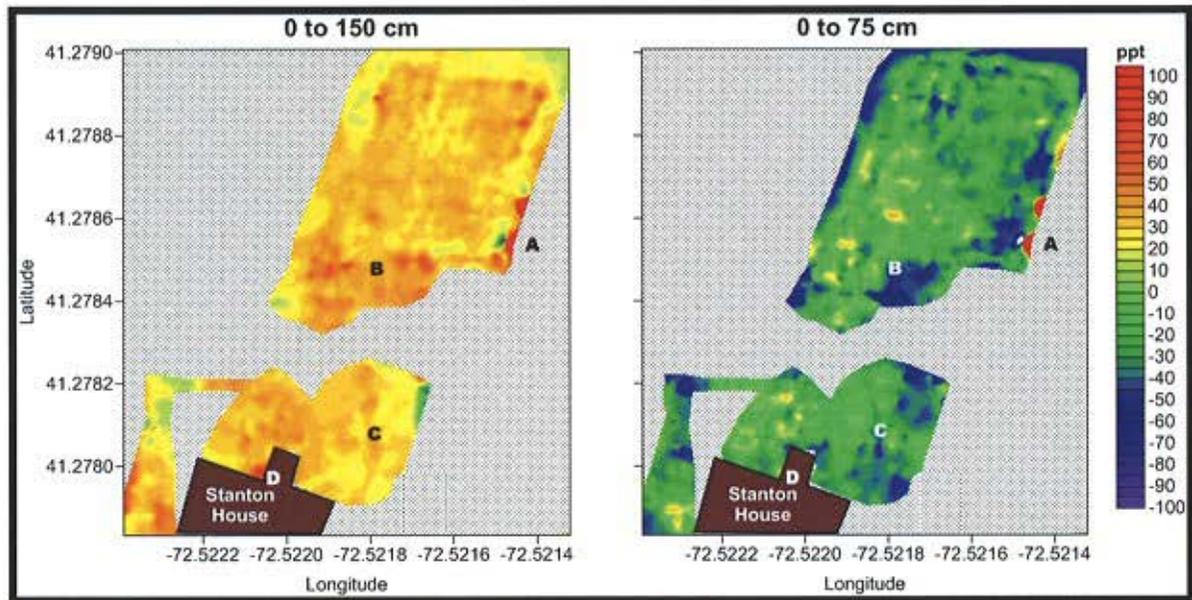


Figure 15. Plots of the in-phase response prepared from data collected with an EM38-MK2 meter at the Adam Stanton House. Relative exploration depths are indicated above each plot.



Figure 16. Students from the Abraham Pierson School were provided an impromptu class on archaeology and the use of geophysical tools in archaeological investigations.

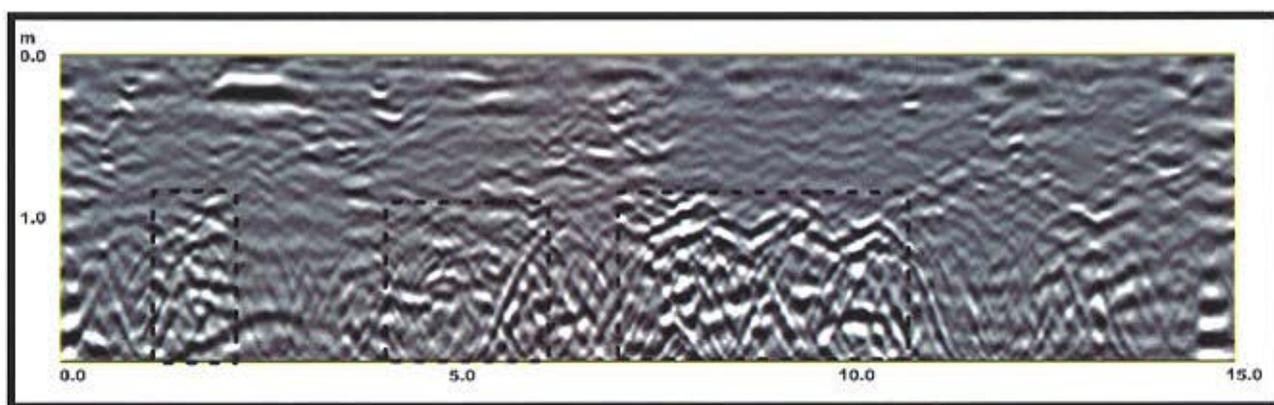
In the plots shown in Figure 15, several features have been identified. To the left of “A”, the meter passed too close to metallic playground equipment and produced the anomalously high IP response. Buried utility lines are believed to have produced the linear anomalies that extend away from “B” and “C”. These features are best expressed in the data collected with the deeper-sensing, 100 cm intercoil spacing (left-hand plot). The meter also passed too close to a metallic, outdoor grill producing the anomalous response at “D”.

No anomalous spatial pattern indicating the location of former structures could be gleaned from the GPR and EMI data collected at the Adam Stanton House.

During the course of this study, students from the Abraham Pierson School were invited outside and provided an impromptu class on archaeology and the use of geophysical tools in archaeological investigations (see Figure 16).

#### South Burying Ground, Hartford:

The South Burying Ground is located in an area of Broadbrook soils. The Broadbrook soils are very deep (> 150 cm) to bedrock and moderately deep (50 to 100 cm) to a densic contact. At this site, no continuous, subsurface reflectors were evident on the radar records suggesting the presences of either bedrock or the densic layer within the depth scanned by GPR (about 1.9 m). If present, it is possible that the transition to densic materials was too gradual or the interface was partially masked by variations in moisture content and clay contents, which obscured this soil boundary on the radar records.

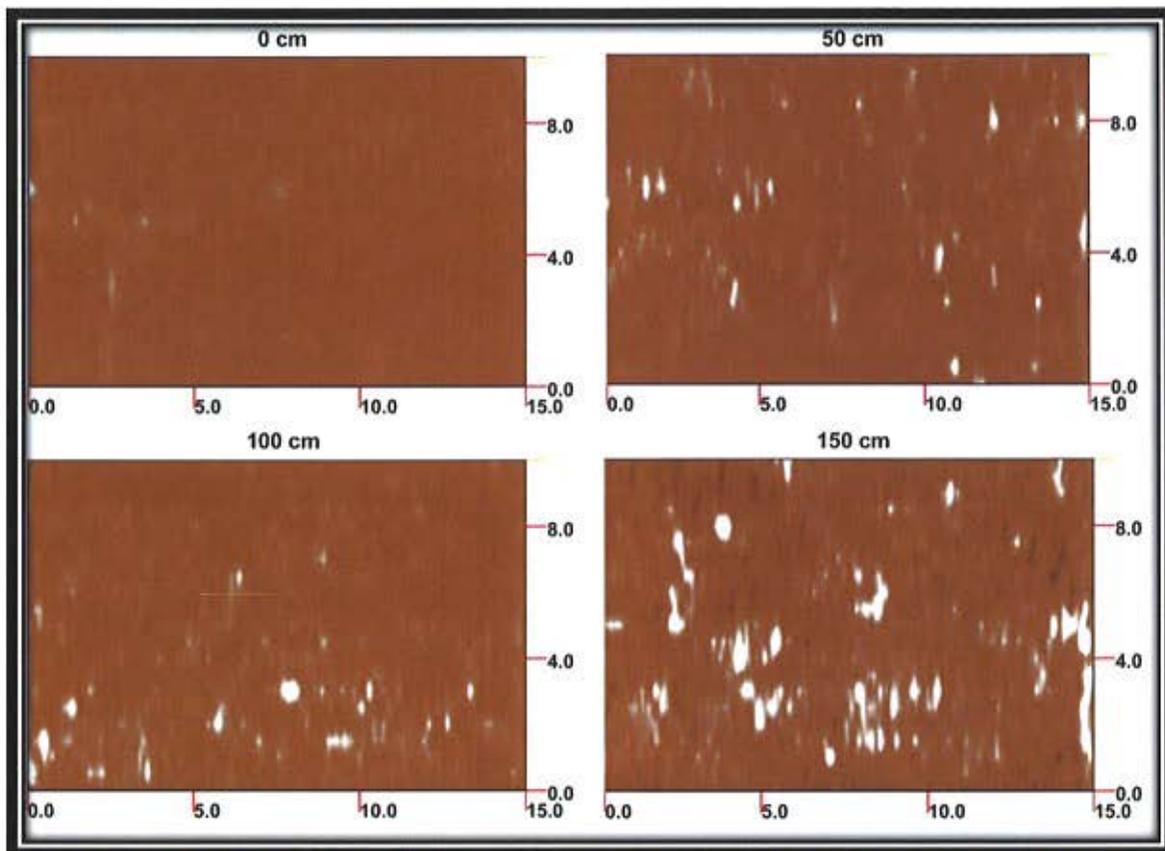


**Figure 17. This radar record was collected in the South Burying Ground, Hartford, Connecticut. The three areas enclosed by segmented lines contain higher-amplitude reflection hyperbolas that may be indicative of unmarked graves.**

No continuous subsurface interface that could be interpreted as a densic contact was observed within the upper 100 cm of the radar records from this site. Figure 17 is a representative radar record from the South Burying Ground. Below an approximate depth of 1.0 m, a noticeable increase in the number of reflection hyperbolas can be observed. This may be caused by the presence of densic materials characterized by varying physical properties (e.g., clay and moisture contents, bulk density). On the image shown in Figure 17, several areas with high-amplitude reflection hyperbolas have been identified. These patterns appear to occur in groups. It is possible that some of these high-amplitude reflection hyperbolas are produced by unmarked graves.

In order to help clarify interpretations, a detailed GPR grid survey was carried out across a relatively open area in the southeastern part of the South Burying Ground (see Figure 4). A 15 by 10 meter grid was established. The origin of the grid was located at the grid’s northwest corner. A total of 21, north-south

trending radar traverses were completed across the grid area. Each traverse was 15 m long and spaced 50 cm apart.



**Figure 18. These four depth-sliced images are for different soil depths within the gridded area at the South Burying Ground in Hartford.**

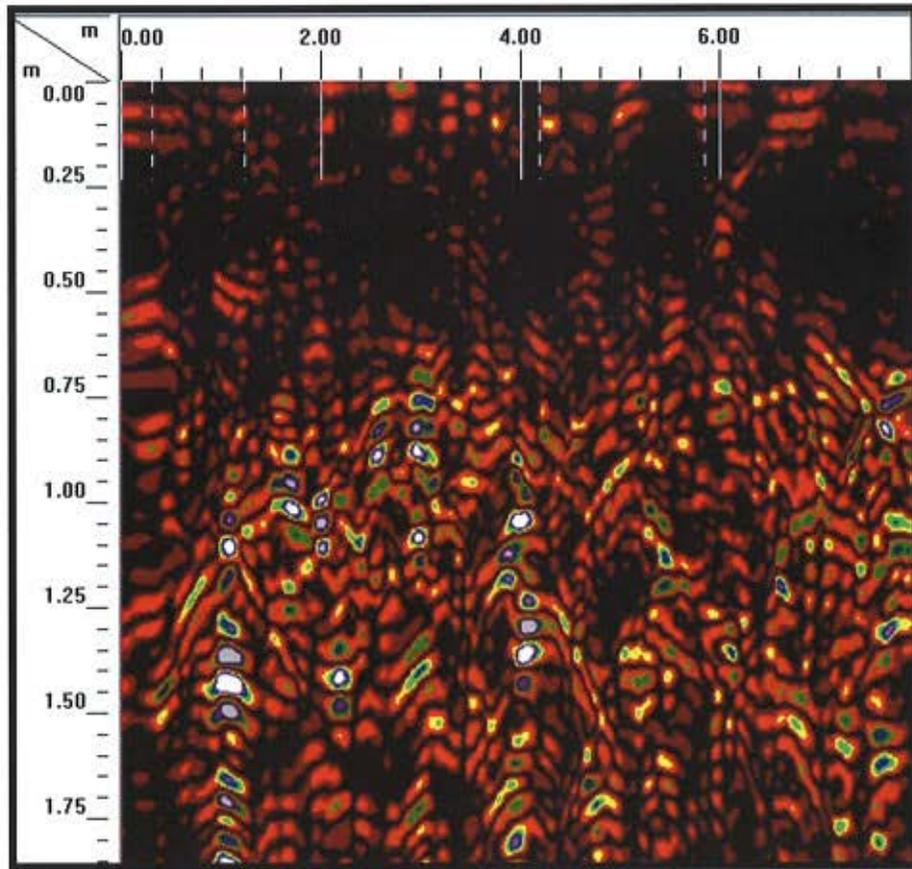
The results of the grid survey are displayed as depth-sliced images in Figure 18. Depth-sliced images are computer generated by comparing and spatially mapping the amplitudes of all reflected wave within defined time intervals on all radar profiles collected within the grid. Each depth-sliced image averaged the reflected amplitudes within a 19 cm depth interval. In Figure 18, depth-sliced images are shown of four soil depths (0, 50, 100 and 150 cm).

In Figure 18, the 0 and 50 cm depth-slice images show very few and some rather spurious, high-amplitude (colored white) reflections, respectively. The 100 cm and especially the 150 cm depth slice images show groups of linear reflectors that have a noticeable east to west extension or orientation. A major line of these reflectors may be seen extending across the lower portion (western portion) of each of these two depth-sliced images. These patterns suggest the possible present of burial sites and unmarked graves in this portion of the burying ground.

#### Albany Road Burying Ground, Deerfield, MA:

Within the Albany Road Burying Ground, the burials are principally from the 1700s. The detection of burials with GPR will depend upon the materials used to contain the corpse, differences in state of preservation of the burial, and spatial differences in soil properties. Early settlers were often buried in shrouds and placed in coffins made of wood (Owsley and Compton, 1997). Wood caskets were the commonly used burial receptacles until the mid-to-late 19th century (Haberstein and Lamers, 1981). Preservation of these early burials and their identification with GPR depends on soil conditions, but are

generally considered poor (Owsley and Compton, 1997). Wooden caskets will deteriorate relatively rapidly in the acid soils of New England.



**Figure 19. This 2D radar record was collected at the Old Albany Burying Ground. All measurements are expressed in meters. The segmented vertical lines at the top of this record represent the locations of headstones.**

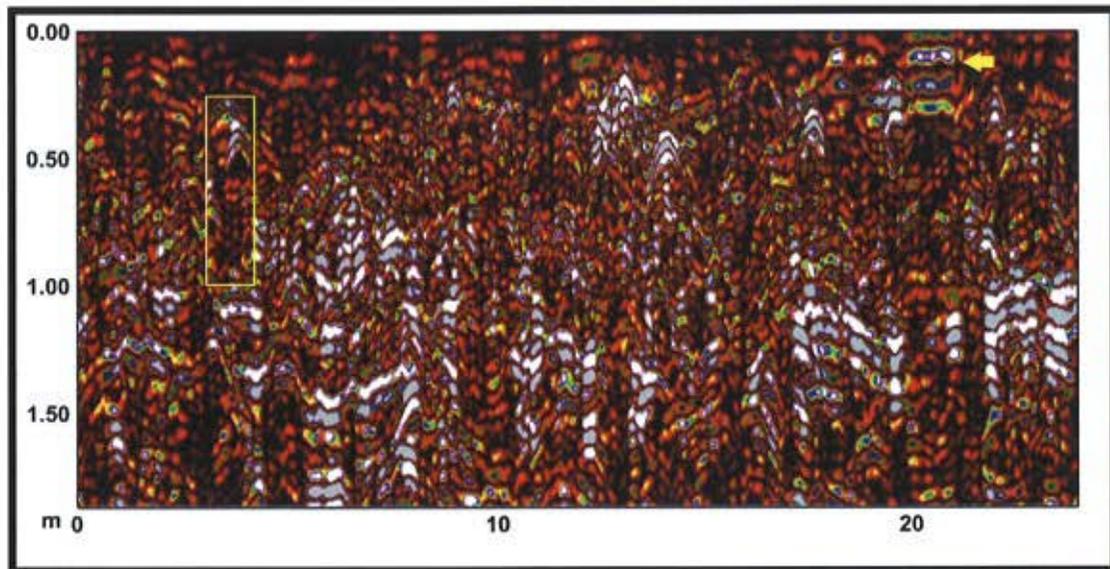
Figure 19 contains a representative radar record from the Old Albany Burying Ground. This 8-m long radar traverse passed over four marked burials that are dated from 1725 to 1821. On this image, the faintly expressed, vertical, segmented lines at the top of the radar record were impressed as the antenna past in front of headstones. However, on this radar record, there are no clear indications of soil subsidence over burials, grave shafts, disturbed soil materials, or remnants of the burials or skeletal remains. A large number of high-amplitude (colored white, yellow, green and blue) point reflectors dominant this radar record below depths of about 75 cm. Many of these reflections are assumed to have been produced by rock fragments and tree roots, but some may represent the remnants of burials. In this complex soil setting and because of the ages of the burials, the consistent distinction of rock fragments, roots, and burial remnants is not feasible on even processed radar records.

Three-dimensional visualization techniques can be used to display complex GPR data sets in a more easily understood format. The use of 3D pseudo-images and amplitude slice analysis can improve the quality and interpretability of complex radar data sets. However, even depth-sliced (or time-sliced) maps may not be a suitable visualization technique in situations of great subsurface complexity as false amplitude anomalies can occur when the slicing planes cross dipping or undulating reflectors (Nuzzo et al., 2002). However, even with these limitations, depth-sliced imagery is an effective and rapid method to

construct a view of subsurface spatial patterns (Nuzzo et al., 2002). To improve interpretations in this complex soil setting, four GPR survey grids of varying dimensions (see Table 2) were laid out across relatively open areas of the burying ground that contained no or very few grave markers (see Figure 6).

#### Grid 1:

Grid 1 extended along the eastern wall from a point several meters in (the area covered with trees) from the burying grounds' entrance on Old Albany Road (see Figure 6). The dimensions of this grid were 24 m by 8 m. The origin of the grid was located in the northwest corner of the gridded area. All traverses were conducted in a back and forth, north-south fashion that was parallel to the x-axis.



**Figure 20. This radar record is Grid 1 and from traverse line  $Y = 2.5$  m. A grave marker was passed by at distance mark  $X = 3.5$  m. This area has been enclosed by the yellow-colored rectangle. Note the numerous reflection hyperbolas between 25 and 50 cm. These do not correspond with any grave stones.**

Figure 20 is a representative radar record from Grid 1. On this radar record all scales are expressed in meters. Measured distances are from south to north. This radar traverse was conducted along line  $Y = 2.5$  m. Along this traverse line, the antenna passed by a grave marker near the 3.5 m distance mark. In Figure 20, a yellow colored rectangle marks the approximate location of this event. Within this rectangle, note the reflection hyperbola at a depth of about 35 cm and the relative clear zone beneath this reflector. Several other high-amplitude (colored white and grey) reflection hyperbolas are scattered across the upper part of this radar record. Some of these features may represent burials, though this interpretation would be misleading without some ground-truth excavations. Near the 21 m distance mark, a high-amplitude, planar reflector is evident within the upper 10 to 15 cm of the soil profile (indicated by yellow colored arrow). In the context of a burying ground, this may represent a buried grave stone. In the lower part of this radar record, inclined, planar reflectors indicate stratification within the underlying coarse-textured outwash.

Figure 21, contains four horizontal, depth-sliced images of Grid 1. Each depth-sliced image averages the reflected amplitudes within a 19 cm depth interval. In Figure 21, depth-sliced images of four soil depths (0, 50, 100 and 150 cm) are shown.

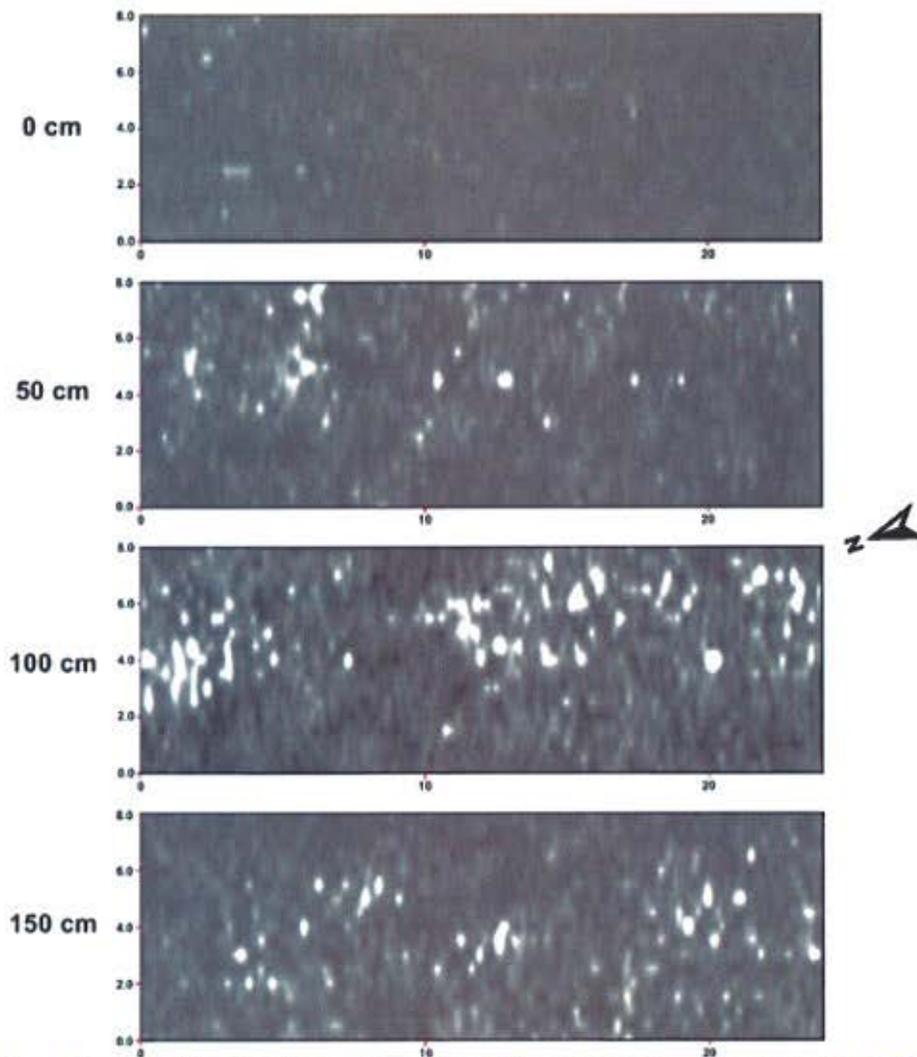
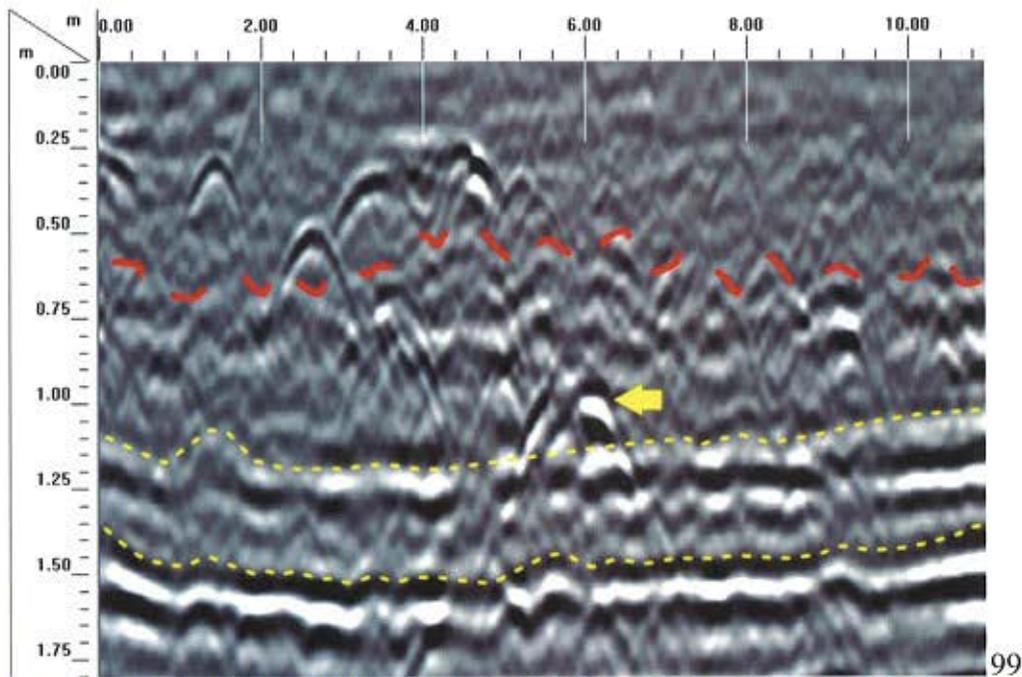


Figure 21. These four depth-sliced images are for different soil depths within the Grid 1 area at the Old Albany Burying Ground in Deerfield, Massachusetts.

In Figure 21, the 0 cm depth-slice images is rather unremarkable as it contains very few high- or moderate-amplitude (colored white) reflections. However, the general elongated appearance of the near-surface, linear reflection pattern identified in Figure 20, suggest a conceivable buried footstone. An increasing number of high-amplitude reflections appear in the 50 cm depth slice and these reflections further proliferate in the 100 cm depth slice. In the 100 cm depth-sliced image, many of these reflectors appear elongated with a noticeable east to west orientation. These reflectors form a major band that extends across the eastern portion of this grid from north to south. As these reflectors appear orderly arranged and at a fairly uniform depth, they suggest possible unmarked graves in this portion of the burying ground.

#### Grid 2:

The northeast corner of Grid 2 was located near a headstone that is 5 m south of the burying ground's entrance on Old Albany Road (see Figure 6). The dimensions of this grid were 11 by 15 m. The origin of the grid was located in the northwest corner of the gridded area. All traverses were conducted in a back and forth, north-south fashion that was parallel to the x-axis.



**Figure 22.** This radar record was obtained from Grid 2, line Y = 10. The bands highlighted by the yellow segmented lines in the lower part of this image represent contrasting layers of outwash deposits. A less contrasting, more gradational, and ill-defined layer has been highlighted by a red segmented line. A conspicuous, high-amplitude reflector is identified at a depth of about 1 m near the 6 m distance mark.

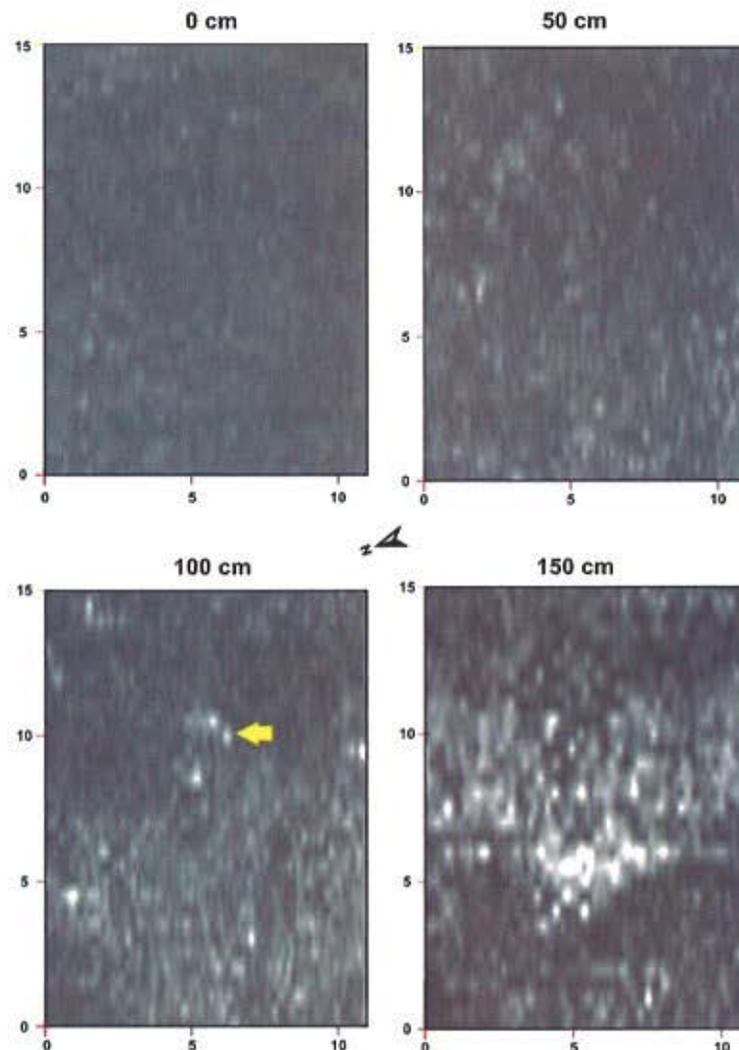
Figure 22 is a representative radar record from Grid 2. On this radar record all scales are expressed in meters. This radar traverse is 11 m long and was conducted along line Y = 10 m. On the radar record shown in Figure 22, yellow segmented lines have been used to highlight two major, contrasting stratigraphic layers in the underlying glacial outwash deposits. A third, shallower stratigraphic layer has been highlighted with a red, segmented line. The upper interface to this layer has a highly irregular topography, is weakly defined and difficult to trace laterally across the radar record. Its low to moderate reflection amplitudes suggest that this interface has properties that are transitional from the soil horizons above to the stratigraphic layers below.

In Figure 22, several high-amplitude (colored white and black) reflection hyperbolas are scattered across the upper part of the radar record. Many are clustered between the 1 and 5 m distance marks at depths ranging from about 20 to 65 cm. These reflection hyperbolas appear chaotically arranged and lack additional features (e.g., evidence of grave shaft, subsided layers, disturbed soil materials) that would suggest burials. Near the 6 m distance mark, at a depth of about 1 m, a prominent high-amplitude, reflection hyperbola is evident. In Figure 22, a yellow arrow identifies this reflection hyperbola. Other than appearing larger, more prominent, and with wider and more intense bands than the other reflection hyperbolas on this radar record, no further significance can be attached to this feature at this time.

Figure 23, contains four horizontal, depth-sliced images of Grid 2. Each depth-sliced image averages the reflected amplitudes within a 19 cm depth interval. The depth-sliced images shown in Figure 22 are for the 0, 50, 100 and 150 cm soil depths.

In Figure 23, the 0 and 50 cm depth-sliced images lack high-amplitude (white) reflectors and are nondescript. The high-amplitude reflection hyperbola that was not on the Y = 10 m radar record (Figure

22) has been identified by a yellow arrow on the 100 cm depth sliced image. Several clusters of high-amplitude reflection are evident on the 100 cm depth-sliced image, but these features appear haphazardly distributed across the grid area with no apparent organization, which, in my mind, would be expected of burials, if they are present and share similar physical properties.



**Figure 23. These four depth-sliced images are for different soil depths within the Grid 2 area at the Old Albany Burying Ground in Deerfield, Massachusetts.**

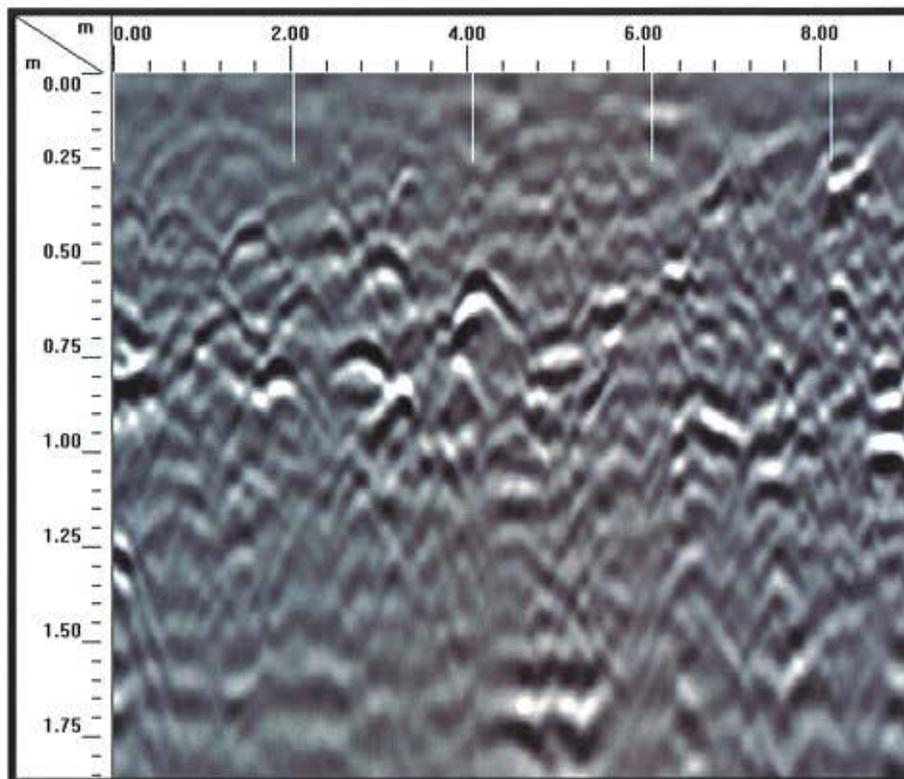
In the 100 cm depth-sliced image from Grid 2 (Figure 23), an area of weak to moderate amplitude reflections (lighter shades of grey) are noticeable in the middle and lower portions of the image. It is believed that these reflections are from the ill-defined and less contrasting subsurface layer whose upper surface was defined by a red segmented line in Figure 22. The area of high-amplitude reflections in the central portion of the 150 cm depth-sliced image is believed to represent an interface with one of the deeper, more contrasting stratigraphic layers appearing in Figure 22. If burials occur at this depth, they would be difficult to distinguish from the background noise caused by the stratigraphic layer.

### Grid 3:

Grid 3 was located along the eastern burying ground's wall in the relatively open area to the south of the monument mound commemorating the victims of the 1704 French and Indian raid on Deerfield (see Figure 6). The dimensions of this grid were 9 by 14 m. The origin of the grid was located in the

northwest corner of the gridded area. All traverses were conducted in a back and forth, north-south fashion that was parallel to the x-axis. Each traverse line was 9 m long.

Figure 24 is a representative radar record from Grid 3. On this radar record all scales are expressed in meters. This radar traverse was conducted along line Y = 2 m. On this radar record, a large number of reflection hyperbolas are evident between depths of 25 and 100 cm. As this traverse was located away from trees, roots are not suspected to have produced these features. In general, reflection hyperbolas were more numerous in the western part of Grid 3.



**Figure 24. This radar record was obtained from Grid 3, line Y = 2 m. A large number of reflection hyperbolas are evident on this radar record between depths of 25 and 100 cm.**

Figure 25, contains four horizontal, depth-sliced images from Grid 3. Each depth-sliced image averages the reflected amplitudes within a 19 cm depth interval. The depth-sliced images shown in Figure 25 are for the 0, 50, 100 and 150 cm soil depths. In each of these depth-sliced images, a greater number of high-amplitude reflections occur in the lower portion (western) of the grid area. This area of the grid is bordered on the west by two rows of grave stones. Some of the reflections in this portion of Grid 3 appear to form linear patterns that have a noticeable east-west orientation. Some of these may represent burials. However, in all the depth slices shown in Figure 24, there is a high level of low to moderate amplitude reflections that are suspected to represent rock fragments and other inhomogeneities in the underlying soil and stratigraphic layers.

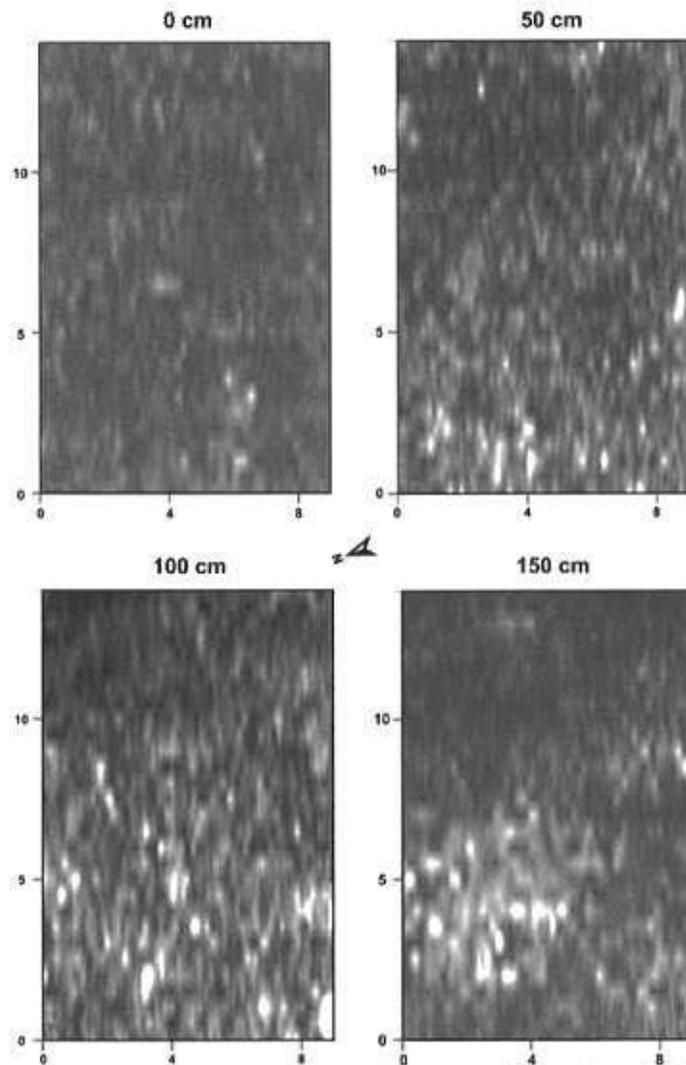


Figure 25. These four depth-sliced images are for different soil depths within the Grid 3 area at the Old Albany Burying Ground in Deerfield, Massachusetts.

Grid 4:

Grid 4 was located in the southern part of the burying ground and west of Grid 3 (see Figure 6). Two rows of grave stones for 8 known burials separate Grids 4 from 3 in an area that was not surveyed with GPR. Most of these graves date from the period of 1746 to 1775. However, two graves are dated 1800 and 1911. The dimensions of this grid were 10 by 12 m. The origin of the grid was located in the northwest corner of the gridded area. All traverses were conducted in a back and forth, north-south fashion that was parallel to the x-axis. Each traverse line was 10 m long.

Figure 26 is a representative radar record from Grid 4. On this radar record all scales are expressed in meters. This radar traverse was conducted along line Y = 11 m. On this radar record, several prominent reflection hyperbolas are evident in the upper 50 cm of the soil profile. The most strongly expressed and noteworthy of these reflection hyperbolas are at the 2.0, 3.8, and 7.0 m distance marks. This line of reflection hyperbolas parallels and is near the two rows of grave stones that separates Grids 3 and 4.

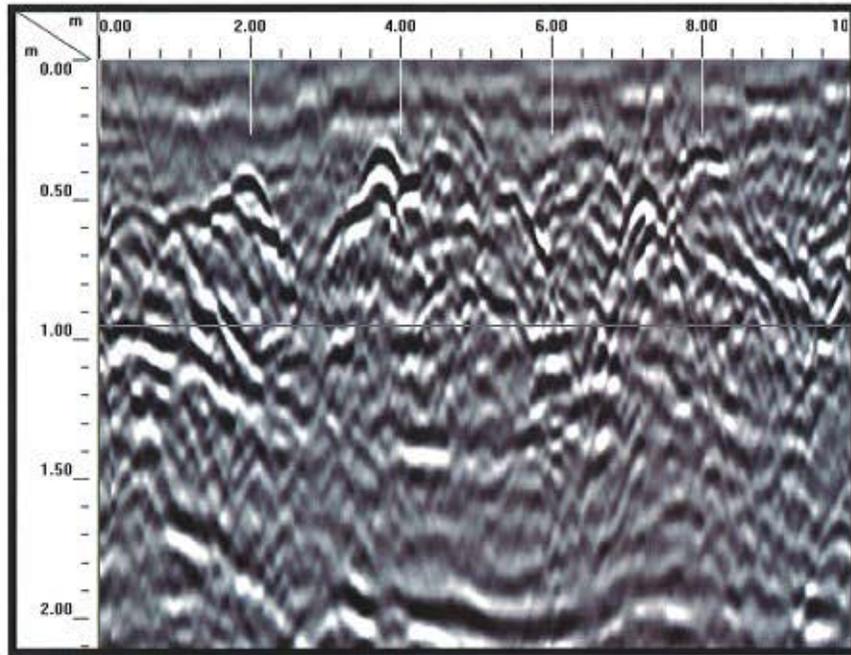


Figure 26. This radar record was obtained from Grid 4, line Y = 11 m. A large number of reflection hyperbolas are evident on this radar record between depths of 25 and 100 cm.

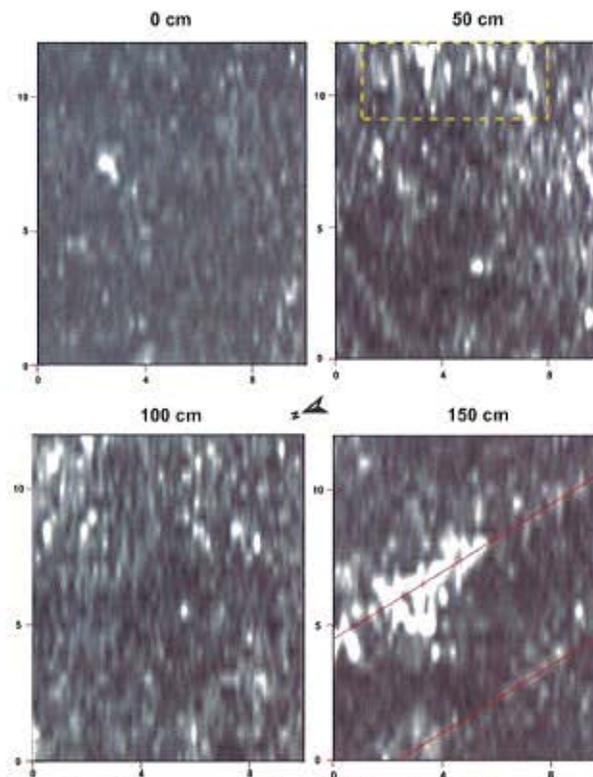


Figure 27. These four depth-sliced images are for different soil depths within the Grid 4 area at the Old Albany Burying Ground in Deerfield, Massachusetts. A noticeable band of east-west orientated linear reflections have been enclosed by yellow, segmented lines in the 50 cm depth-slice.

Figure 27, contains four horizontal, depth-sliced images from Grid 4. Each depth-sliced image averages the reflected amplitudes within a 19 cm depth interval. The depth-sliced images shown in Figure 27 are for the 0, 50, 100 and 150 cm soil depths. In both the 50 and 100 cm depth-sliced images, a number of high-amplitude reflections can be seen along the upper portion (eastern) of the grid area. This area of the grid is bordered on the east by two rows of grave stones. Principally on the 50 cm depth slice, several linear patterns that have a noticeable east-west orientation can be observed. Some of these may represent burials. On the 150 cm depth-sliced, two red color lines have been drawn to highlight the reflections from underlying strata. These reflections form linear patterns that extend across the grid area in a general north to south orientation. This linear trend represents the strike of the underlying stratigraphic layers.

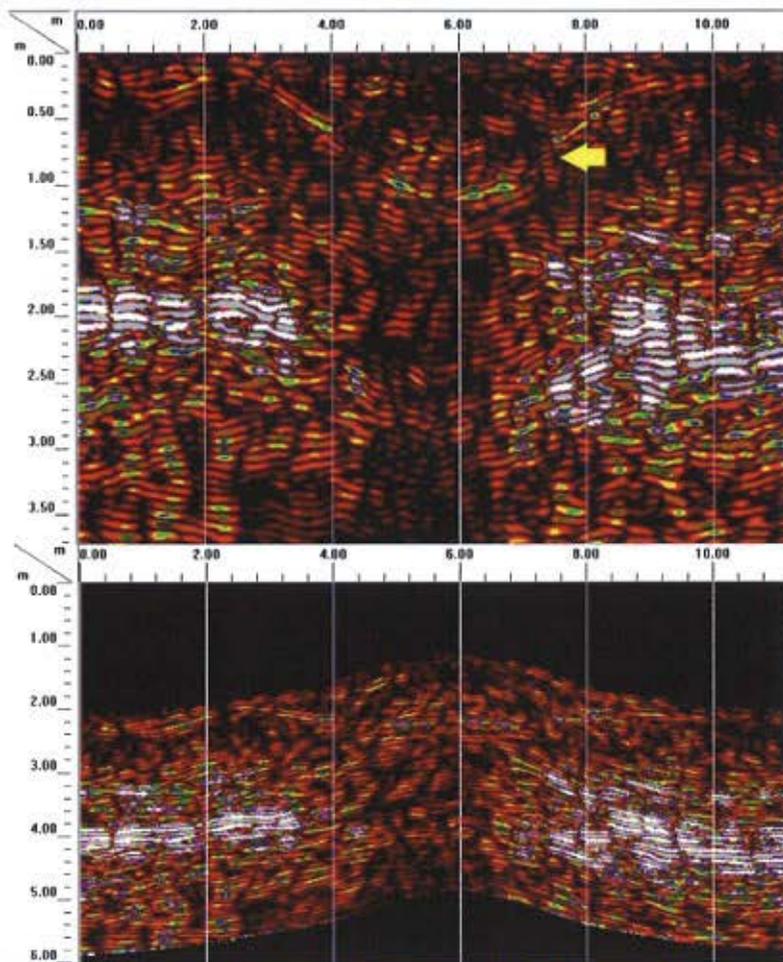


**Figure 28. This monument in the southern portion of the Old Albany Road Burying Ground commemorates the victims killed in the February 20, 1704 raid by the French and Indians on the frontier village of Deerfield.**

#### Memorial Mound:

A mound and monument (Figure 28) in the southern portion of the Old Albany Road Burying Ground commemorates victims killed in the February 20, 1704 raid by the French and Indians on the Deerfield settlement. It is believed by many that the remains of the 48 victims killed in this raid are buried in a mass grave beneath this marker and mound. This traditional belief was tested with GPR (see Figure 5).

Figure 29 contains two images of the same radar record that was collected along an east to west GPR traverse line that crossed the mound. The upper plot is a processed radar record; the lower plot is a “surface normalized” image of the upper plot. Surface normalization procedures are used to correct the reflection patterns on radar records for changes in elevation. This processing technique greatly aids interpretations and the association of subsurface reflectors with soil and surface features. No elevation data was collected at the site. In order to surface normalize the radar record, the original soil surface was first identified beneath the mound and the depth to this interface was measured on the radar record. In Figure 29, the yellow arrow in the upper plot identifies the original soil surface. It was assumed that this interface is level and the measured depths to this interface could be used to “correct” or “normalize” the surface to its existing topographic form.



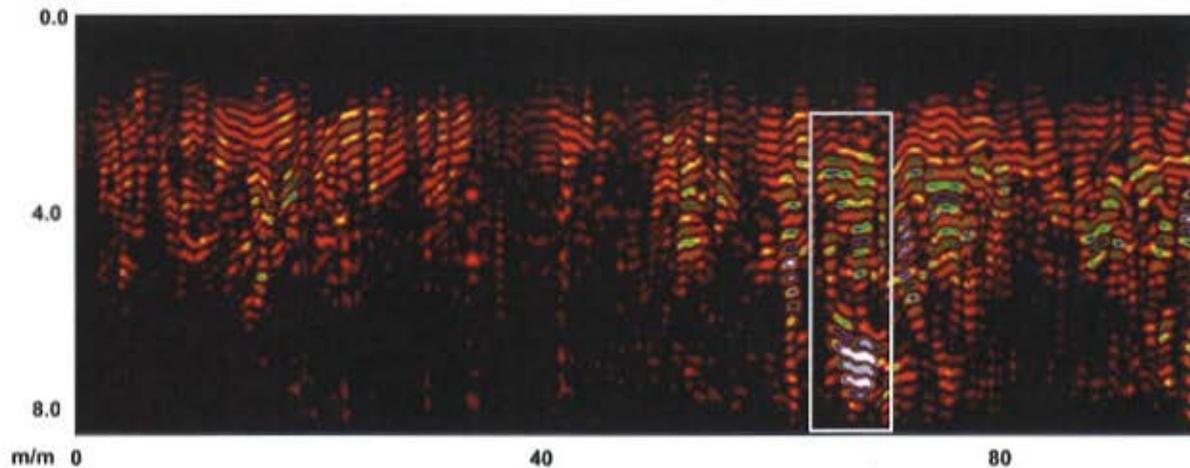
**Figure 29. These images are of the same radar record. The original soil surface beneath the Memorial Mound has been identified in the upper plot (yellow arrow). The lower plot is a surface normalized presentation of the radar record shown in the upper plot.**

In the lower, surface normalized plot of the mound shown in Figure 29, the original soil surface provides a continuous interface beneath the mound. No evidence of a disruption caused by an excavation is evident. High-amplitude (colored white) reflections in the lower part of the radar record represent contrasting strata in the underlying glacial outwash deposits. These strata appear continuous, but greatly attenuated beneath the mound. As perhaps more evident in the upper plot of Figure 29, beneath the mound, these strata conform to the general slope and topography of the original soil surface. The increased attenuation may be attributed to the greater radar pulse travel time (distance) to these interfaces beneath the mound, and/or dissimilar, more attenuating soil materials within the mound itself. The radar records shown in Figure 29 provide no reflection patterns that are indicative of a mass grave.

#### 19th Century Mine Shaft and Tunnels, Litchfield:

This was an extremely challenging site to work with GPR. Steep, rocky, forested slopes made traversing the area extremely difficult with a lower-frequency 70 MHz antenna. The lower-frequency antenna was used because it provides greater exploration depths and portability. The forest canopy prevented satellite reception and the use of GPS to georeference the radar traverse.

Figure 30 is a processed radar record from the study site in Litchfield, Connecticut. The radar record has been submitted to high pass filtration, stacking and range gain adjustments. Air and ground waves, as well as parallel bands of low frequency noise, have been removed from the upper 1.5 m of the profile. The white-colored rectangle marks the approximate location of a known mine tunnel. Within this rectangle, the lower, high-amplitude reflections (white colored), at approximate depths of 6.1 to 6.5 m, mark the bottom of the air-filled tunnel. No other similar radar reflections were observed in the areas traversed with GPR. While able to detect a known tunnel, GPR could not map its extent or detect other similar features under the inhospitable terrain conditions.



**Figure 30.** This processed radar record was collected with a 70 MHz antenna over an area of Charlton-Chatfield complex, 3 to 15 percent slopes near Litchfield, Connecticut. The area enclosed by the white rectangle is in the vicinity of a known 19<sup>th</sup> Century mine tunnel.

Deer Run Site, Indian and Colonial Burying Ground, Warren:

At the Deer Run Burying Ground, a grid was established across an open area that contained several grave stones. The dimensions of the grid were 16 by 9 m. The origin of the grid was located in the southwest corner of the gridded area. All traverses were conducted in a back and forth, north-south fashion that was parallel to the x-axis. Each traverse line was 16 m long and spaced 50 cm apart.

Figure 31 is a representative radar record from line Y = 2.0 m within the grid area. On this radar record, north is to the right. The two high-amplitude reflection hyperbolas at the 6.4 and 7.3 distance marks are located before grave stones. As a result, these reflections are believed to represent burials (approximate depths of 88 cm). Though not confirmed with soil probes the higher-amplitude, linear reflectors in the lower part of the radar record shown in Figure 31, may represent the contrasting strata of sandy till that is characteristic of Canton soils.

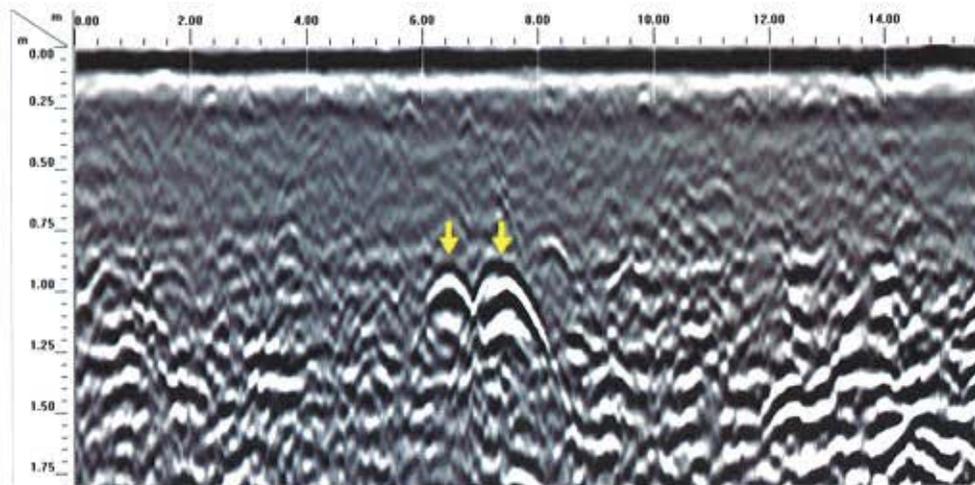


Figure 31. In this radar record from the Deer Run Site in Warren, Connecticut, two reflection hyperbolas that are believed to represent burials have been identified.

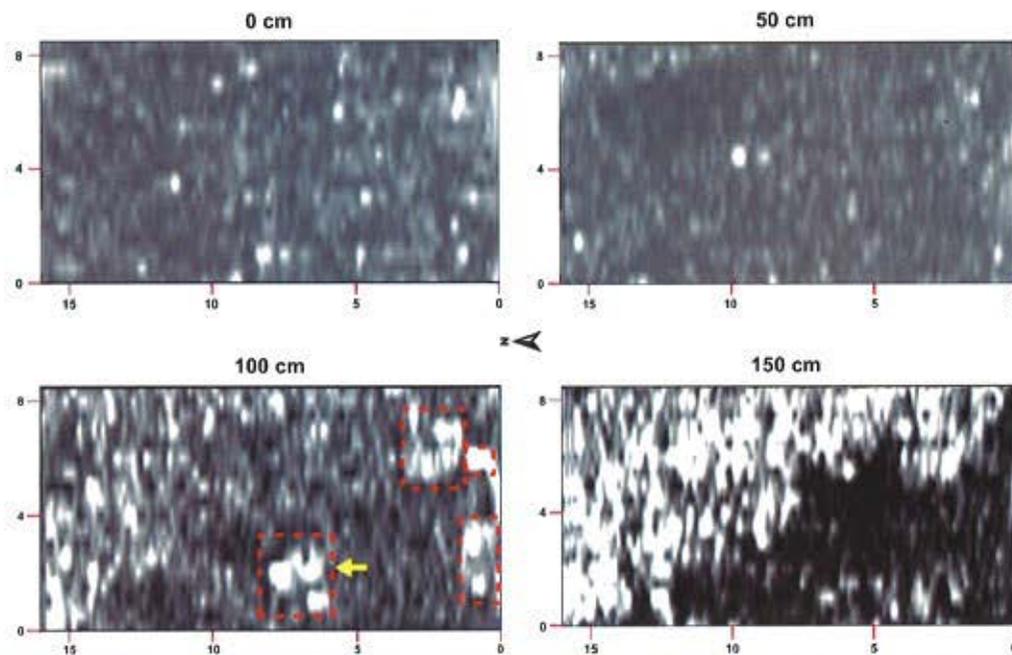


Figure 32. These four depth-sliced images are from the Deer Run Grid Site in Warren, Connecticut. Features suspected to represent potential burials have been enclosed by red, segmented lines on the 100 cm depth-slice image.

Figure 32, contains four horizontal, depth-sliced images from the Deer Run Site. Each depth-sliced image averages the reflected amplitudes within a 19 cm depth interval. These depth-sliced images are for the 0, 50, 100 and 150 cm soil depths. In the 100 cm depth-sliced images, reflection patterns that are suspected to represent possible burials have been enclosed by red, segmented lines. The yellow arrow indicates the two reflection hyperbolas identified on Figure 31. A cursory review of the 100 cm depth-sliced image suggest the possibility of four to six unmarked graves in the southern portion of the grid area. On the 150 cm depth-slice, a line drawn between the major reflections patterns (areas of white versus black) would indicate a transition or boundary between contrasting stratigraphic layers.

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