United States Department of Agriculture

Natural Resources Conservation Service

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Subject: ARCH-Geophysical Field Assistance **Date:** 12 November 2008

To: Douglas Zehner
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Purpose:
Training was provided to Debbie Surabian on the setup and operation of the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (SIR-3000). This ground-penetrating radar (GPR) unit was recently purchased by the Connecticut State Office. In addition, at the request of the Connecticut State Archaeologist and local historians, GPR surveys were conducted at sites located in Windsor and Bridgeport, Connecticut.

Principal Participants:
Nicholas Bellantoni, Connecticut State Archaeologist, Connecticut Archaeology Center, Univ. of Connecticut, Storrs, CT
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Shawn McVey, Assistant State Soil Scientist, USDA-NRCS, Tolland, CT
Debbie Surabian, Soil Scientist, USDA-NRCS, Tolland, CT

Activities:
All activities were completed during the period of 5 thru 7 November 2008.

Summary:

1. Training was provided to Debbie Surabian on the use and operation of the SIR-3000 system. Debbie is a quick learners and I am impressed by her interest and enthusiasm. All radar records contained in this report were collected by Debbie. It is recommended that once the RADAN software package is loaded into Debbie Surabian computer, I return to Connecticut to provide introductory training.

2. At the suspected sites of the Bradley crash in Windsor, GPR and EMI failed to identify subsurface features, which could be interpreted as remnants of Bradley's plane.

3. At the historic Freeman houses in Bridgeport, 2D and 3D GPR images revealed subsurface features, which may be of historic importance and worthy of future excavations by archaeologists.

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

With kind regards,

James A. Doolittle
Research Soil Scientist
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cc:

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Study Sites:

Bradley Field Site:

On August 21, 1941, Second Lieutenant Eugene M. Bradley crashed his Curtiss P-40 Fighter in a wooded area north of the main hanger of the then, Windsor Air Base. According to Tom Palshaw, Assistant Curator of the New England Air Museum, the spiraling downward P-40 impacted the ground with no explosion and with no visible wreckage; the engine was found 13 to 15 feet below the surface in the sandy soils (Palshaw, 2008). The airfield was renamed "Bradley Field" in 1942. Presently, a search is underway to relocate the crash site by the New England Air Museum, the Connecticut Archaeological Center, University of Connecticut, and the Friends of the State Archaeologist (FOSA). Much has changed at Bradley International Airport and the location of the crash site is unknown. Witness's accounts vary and critical field markers, on which these observations are based, have long since been removed or vanished.

Two sites were selected for this study. Both sites are located off of Russell Road in Windsor, Connecticut, in areas of Windsor loamy sandy, 0 to 3 % slopes (map unit 36A). These sites are situated to the immediate northwest of present day Bradley International Airport. The very deep, excessively drained Windsor soils formed in sandy glacial outwash. Windsor is a member of the mixed, mesic Typic Udipsamments family. Windsor soils are considered well suited to GPR applications.

Site 1 (long. 72.6961 E, and lat. 41.9387 N) is bounded by a security fence on two sides and large, buried water tanks on another. The buried tanks form a conspicuous rectangular mound of earthen materials, which provides the only open area on this site. The site is largely wooded. Site 2 (long. 72.6992 E, and lat. 41.9445 N) is in a densely wooded area. The northern portion of this site contains a small included area of Scarboro muck (map unit 15). The very deep, very poorly drained Scarboro soils formed in sandy glacial outwash. Scarboro is a member of the sandy, mixed, mesic Histic Humaquepts family. Scarboro soils are also considered well suited to GPR applications.

Because of dense underbrush, trees and fallen debris, both sites proved challenging to geophysical investigations. In general, only areas that were accessible on foot were surveyed. As a consequence, at both sites, some areas were omitted or sparsely sampled.

Freeman Houses:

Two houses, which were owned by Mary and Eliza Freeman, are the only surviving structures of "*Little Liberia*", a settlement of free African-Americans in Bridgeport, Connecticut. The *Little Liberia* settlement dates back to 1831. The settlement attained its greatest population just prior to the Civil War. The name, *Little Liberia*, reflected the identification of the early inhabitants of this community with the newly formed African nation, which was established for freed African slaves. In 1848, the Freeman sisters purchased two adjoining lots in *Little Liberia*. These homes were used by the sisters as rental properties. Remnants of the Freeman Houses are located on Main Street between Whiting and Kiefer Streets, in Bridgeport, Connecticut (see Figure 1). These structures are located in an area that is mapped as Urban land (map unit 307). Urban lands consist of soil materials covered by buildings, streets, parking lots, and other structures associated with urban areas. As no soil physical or chemical properties are available for Urban lands, the suitability of the underlying materials to GPR is unknown.

Based on the results of an EMI survey, which was completed by Debbie Surabian in early October 2008 (Surabian, 2008), a GPR survey was recommended to help indentify any subsurface features at this site. The small open area (long. 73.18621^{o} W, and lat. 41.16965^{o} N) behind the Freeman Houses, which is relatively cleared of rubble and debris, was surveyed with GPR.

Two small grid sites were established over this area (see Figure 1). The survey area was accessible through an alleyway of Whiting Street.

Figure 1. On this Goggle Earth image, the locations of the two GPR grids are shown to the immediate east of the Freeman Houses in Bridgeport, Connecticut.

Equipment:

The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (SIR-3000), manufactured by Geophysical Survey Systems, Inc. (GSSI; Salem, NH).[1] The SIR-3000 consists of a digital control unit (DC-3000) with keypad, SVGA video screen, and connector panel. A 10.8-volt lithium-ion rechargeable battery powers the system. The SIR-3000 weighs about 9 lbs (4.1 kg) and is backpack portable. With an antenna, the SIR-3000 requires two people to operate. Daniels (2004) discusses the use and operation of GPR. The antenna used in the reported studies has a center frequency of 400 MHz.

Radar records contained in this report were processed with the *RADAN* for Windows (version 6.6) software developed by GSSI.[1] Processing included: header editing, time zero adjustment, distance normalization, range gain adjustments, signal stacking, and migration (see Daniels (2004) for a discussion of these techniques). The Super 3D QuickDraw program developed by GSSI was used to construct three-dimensional (3D) pseudo-images of the radar records that were collected over grids established at the Freeman site.

The EM38-MK2-2 meter (Geonics Limited, Mississauga, Ontario) was used in the search for remnants of Bradley's plane.[1] This meter requires no ground contact and only one person to operate. The EM38-MK2-2 meter weighs about 2.8 kg (6.2 lbs) and operates at a frequency of 14,500 Hz. The meter has one transmitter coil and two receiver coils. The receiver coils are separated from the transmitter coil at distances of either 1.0 or 0.5 m. This configuration provides nominal penetration depths of 1.5 and 0.75 m (for the 1.0 and 0.5 m coil spacings, respectively) in the vertical dipole orientation, and 0.75 and 0.38 m in the horizontal dipole orientation. The EM38-MK2-2 meter can provide simultaneous measurements of both quadrature-phase (conductivity) and in-phase (susceptibility) components within two depth ranges. Operating procedures for the EM38-MK2-2 meter are described by Geonics Limited (2008).

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

The coordinates of each EC_a measurement were recorded with a Trimble AgGPS 114 L-band DGPS (differential GPS) antenna (Trimble, Sunnyvale, CA).[2] An Allegro CX field computer (Juniper Systems, North Logan, UT) was used to record and store both EMI and position data.[2] The TrackmakerEM38MK2 software program (Geomar Software Inc., Mississauga, Ontario) was used to record, store, and process EMI and GPS data.[2]

Survey Procedures:
For the EMI surveys of the suspected Bradley crash sites, the EM38-MK2-2 meter was operated in the deeper-sensing vertical dipole orientation (VDO). Apparent conductivity data were recorded for both the 50 and 100 cm intercoil spacings. The EM38-MK2-2 meter was operated in the continuous (measurements recorded at a rate of 2/sec) mode. Using the TrackmakerEM38MK2 program, both GPS and EC_a data were simultaneously recorded in the Allegro CX field computer. While surveying, the EM38-MK2-2 meter was held about 5 cm (about 2 inch) above the ground surface and orientated with its long axes parallel to the direction of traverse. Surveys were completed by walking in a random pattern across accessible areas at each site. The EC_a data discussed in this report were not temperature corrected.

To collect the data required for the construction of 3D GPR pseudo-images, two small survey grids were established at Freeman site in Bridgeport. The sizes of the grids were confined by fences, buildings, and piles of debris. The dimensions of the grids were 13 by 8 m, and 10 by 8 m. For each grid, two parallel lines (each set was either 8 or 9 m long (Grids 1 and 2, respectively)) were spaced either 10 or 13 m (for Grids 1 and 2, respectively) apart. Along each of these parallel lines, survey flags were inserted into the ground at a spacing of 50 cm. For both grids, a reference line was extended between matching survey flags on opposing sides of the grid using a distance-graduated rope. GPR traverses were conducted along the distance-graduated rope. For each grid, the 400 MHz antenna was towed along the graduated rope, and as it passed each 100-cm graduations, a mark was impressed on the radar record. Following data collection, the reference line was sequentially moved to the next pair of survey flags to repeat the process. A total of 17 and 19 traverses were completed at Grids 1 and 2, respectively.

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

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

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

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

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

Where C is the velocity of propagation in a vacuum (0.298 m/ns). Velocity is expressed in meters per nanosecond (ns). In soils, the amount and physical state (temperature dependent) of water have the greatest effect on the E_r and v. At the Bradley crash sites, based on a reflector buried at a depth of 49 cm, the estimated E_r and v through the upper part of the soil profile were 11.23 and 0.0889 m/ns, respectively. At the Freeman House site, based on hyperbola matching techniques, the estimated average E_r was 12.66, which resulted in a v of 0.0837 m/ns.

Results:
Bradley Field Sites:

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

Wild-cat radar surveys were conducted across accessible areas at each site by Debbie Surabian. The radar records contained no subsurface interface or feature that could be interpreted as remnants of Bradley's plane. At site 1, in the exact area that was suspected to contain remnants of the crashed plane, a conspicuous subsurface reflector was identified on a radar record (see *A* in Figure 2). Debbie noted that the high-amplitude (white colored), continuous interface that crosses this radar between depths of about 2 to 3 m represents the original soil surface. Above this interface were layers of sandy fill materials used to cover the nearby water tanks. As the reflector evident at *A* in Figure 2 did not form or penetrate the reflections from the original soil surface, Debbie correctly reasoned that it could not represent remnants of Bradley's plane and must represent inhomogeneities in the fill materials.

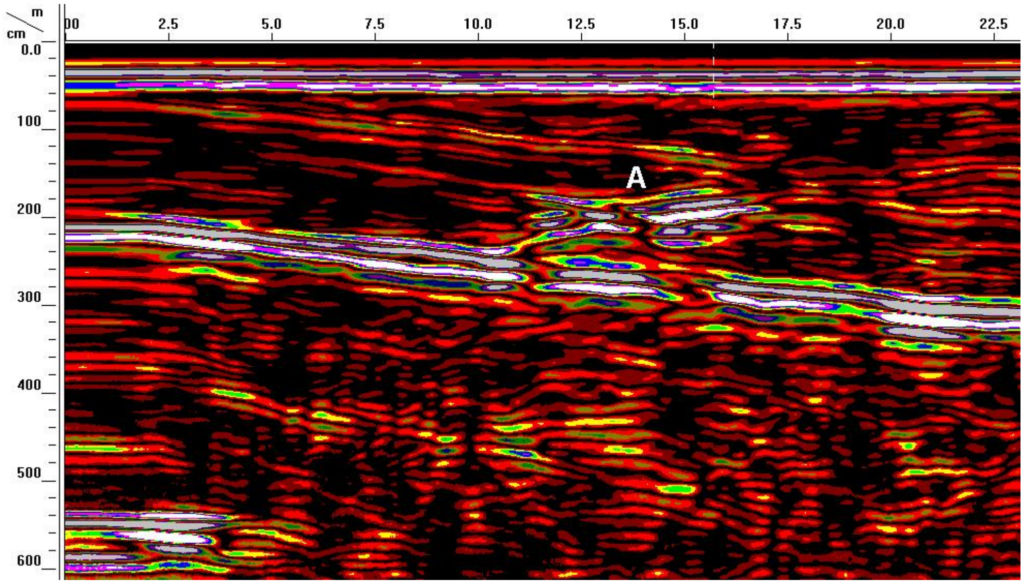

Figure 1. On this radar record from the first investigated Bradley crash site, a conspicuous subsurface reflector is evident at A.

At both suspected crash sites, EMI surveys failed to disclose a subsurface feature that could be interpreted as remnants of Bradley's plane. Table 1 provides the basic statistics for the EM surveys that were completed with the EM38MK2-2 meter operated in the vertical dipole orientation (VDO) at the two sites. At both sites, the range in EC_a was exceptionally large. In general, at both sites, the sandy soils displayed exceedingly low and relatively invariable EC_a. In addition, in these relatively dry, coarse-textured soils, which are very deep to water table, EC_a decreased with increasing depth. Measurements taken with the shallower-sensing, 50-cm intercoil spacing were higher than those taken with the deeper-sensing, 100-cm intercoil spacing. This depth relationship is attributed to recent rains and moister surface layers. Apparent conductivity will increase with increasing moisture contents. The large and anomalous range in EC_a across these two sites is attributed to the occurrence of nearby or buried metallic cultural features (e.g., debris, perimeter security fence, buried water tanks). While anomalous EC_a responses were present at each site, these responses were produced by shallow and/or known modern cultural features.

	Site 1	**Site 1**		**Site 2**	**Site 2**
	100-cm	***50-cm***		***100-cm***	***50-cm***
Observations	998	998		232	232
Minimum	-1084.41	10.70		-2.73	34.45
25%-tile	3.13	8.87		2.89	9.02
75%-tile	4.77	11.17		3.98	10.90
Maximum	1103.98	1279.96		5.59	21.41
Mean	47.31	98.94		3.38	9.96
Standard Deviation	164.09	252.60		0.94	3.63

Figure 3 contains plots of EC_a data collected at the first investigated site. The extensive areas of anomalous high (blue colored) or low (red colored) EC_a in the areas adjacent to the western and southern boundaries of the survey site are attributed to a security fence and buried water tanks. The security fence was closely approached with the meter along a narrow open area that paralleled the fence line. The water tanks were passed over by the meter on several traverse lines. Across the remainder of the survey area, EC_a remains relatively low (< 10 mS/m) and invariable. In either plot shown in Figure 3, noteworthy, but small anomalies are apparent, but at different locations within the site. As these anomalies do not occur in the same area, they represent different features. These features probably represent small, scattered cultural debris that is either on or near the surface (upper plot) or buried within depths of 150 cm (lower plot). If ground-truth investigations are required at this site, these two closely spaced anomalies would provide the most appropriate locations. However, because of their small size and EMI responses, these anomalies are not suspected as representing remnants of Bradley's plane.

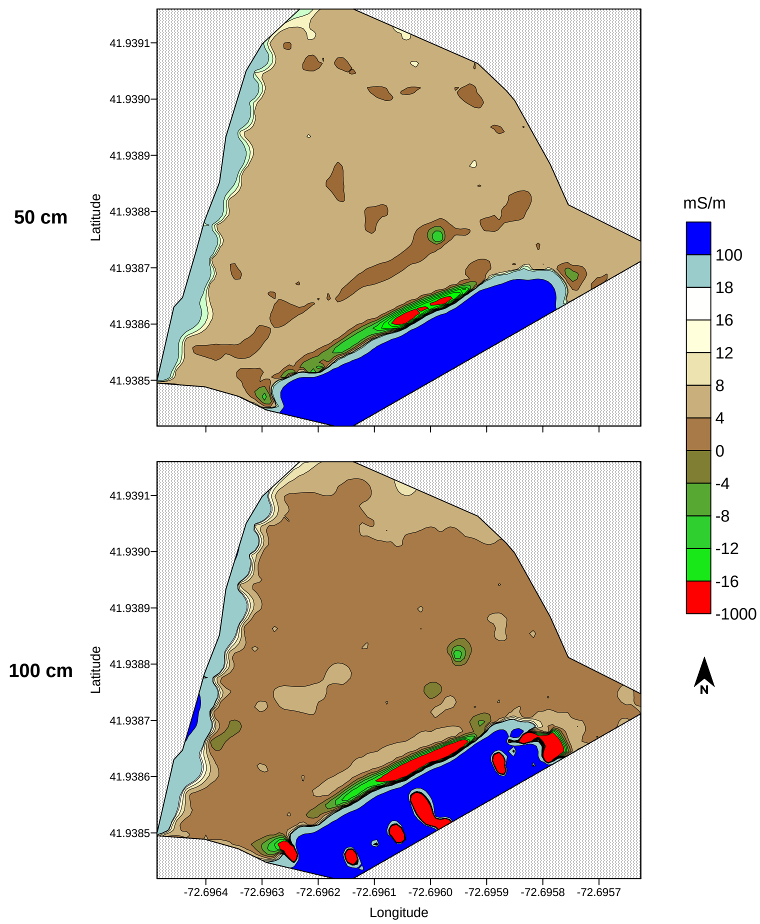

Figure 3. Spatial distribution of EC_a collected with the EM38-MK2-2 meter operated in the vertical dipole orientation (VDO) at the first investigated site at Bradley International Airport. Plots show data for the shallower-sensing, 50-cm (top) and the deeper-sensing, 100-cm (bottom) intercoil spacings.

Figure 4 contains plots of EC_a data collected at the second investigated site. With the exception of four anomalous features that appear in the upper plot, no spatial patterns are evident on these plots that would suggest debris from Bradley's plane. As these anomalous values are only evident in the data collected with the shallower-sensing, 50 cm intercoil spacing and are not evident in the data collected with the deeper-sensing, 100 cm intercoil spacing, they must be interpreted to represent surficial or shallowly buried, small features. These features are not suspected to represent debris form the Bradley's plane.

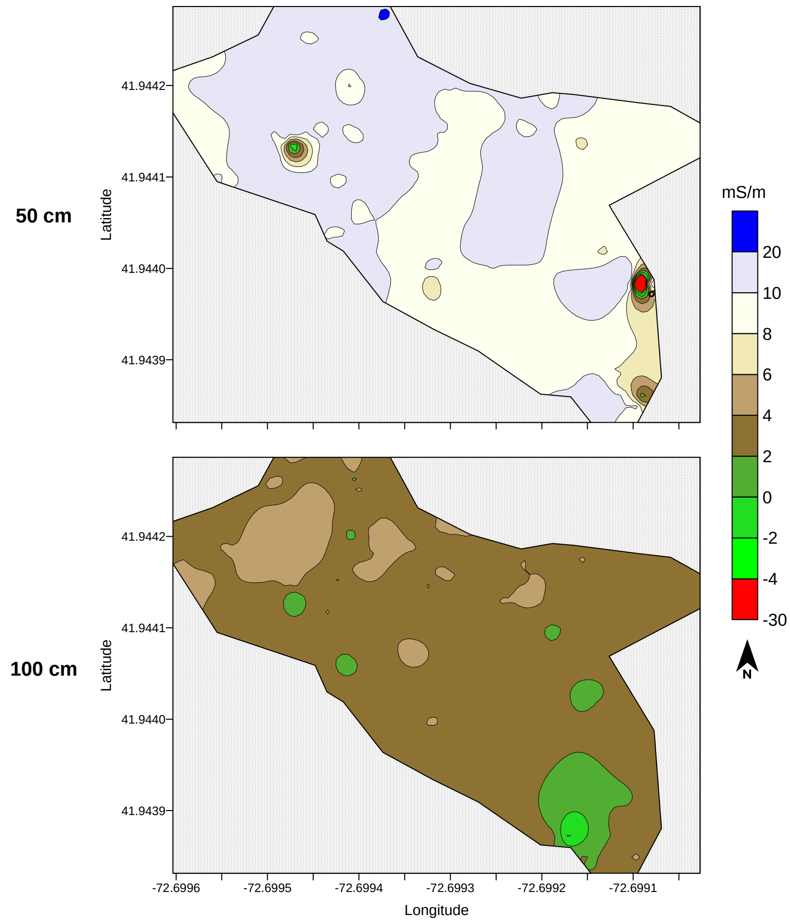

Figure 4. Spatial distribution of EC_a collected with the EM38-MK2-2 meter operated in the vertical dipole orientation (VDO) at the second investigated site at Bradley International Airport. Plots show data for the shallower-sensing, 50-cm (top) and the deeper-sensing, 100-cm (bottom) intercoil spacings.

<u>Freeman Houses:</u>
The use of digital signals and sophisticated signal-processing software has enabled signal enhancement and improved pattern-recognition on radar records in some soils. Processing algorithms used to improve the interpretability of archaeological features appearing on radar records are discussed by Sciotti et al. (2003) and Conyers and Goodman (1997). In recent years, an advanced type of GPR data manipulation, known as *amplitude slice-map analysis*, has been used in archaeological investigations (Conyers and Goodman, 1997). For this analysis, a three-dimensional (3D) pseudo image of a survey site is constructed from the computer analysis and synthesis of a series of closely-spaced, two-dimensional (2D) radar records. Amplitude differences within the 3-D pseudo image are analyzed in "*time-slices*" that examine changes within specific depth intervals in the ground (Conyers and Goodman, 1997). In this process, the reflected radar energy is averaged horizontally between adjacent, parallel radar records and in specified time (or depth) windows to create a time-slice (or depth-slice) image. Each amplitude time-slice shows the spatial distribution of reflected wave amplitudes, which may indicate changes in soil properties or the presence of subsurface features. In many instances, 3D GPR imaging techniques have been used to distinguish and identify potential targets and to reduce interpretation uncertainties.

Two GPR grid surveys were completed in an open area behind the Freeman houses for the purpose of constructing 3D pseudo images. It was hoped that these grids would provide clues and insight into the possibilities of additional archaeological features buried at this site. These grid areas were underlain by disturbed soil materials. In each grid areas, subsurface features were identified that may be of historic importance and worthy of future excavations by archaeologists.

Three horizontal time-slice images of the 13 by 8 m, Grid 1 (for location, see Figure 1) are shown in Figure 5. In the surface slice (0 cm), high-amplitude (colored white or black) reflections are generally lacking and spatial patterns are inferred to reflect differences in surface materials (asphalt, soil materials, debris). In the 60-cm slice, a conspicuous, linear, high-amplitude reflector (*A*) has been identified. In general, linear features are assumed to be artificial and not natural. Because of its size, extent, and prominence, the subsurface feature at *A* (on the 60 cm slice) may be deemed worthy of further attention by archaeologists. In the 120 cm slice, with very active imagination, a segmented, weakly-expressed, linear feature appears to cross the central portion of the grid area from right to left.

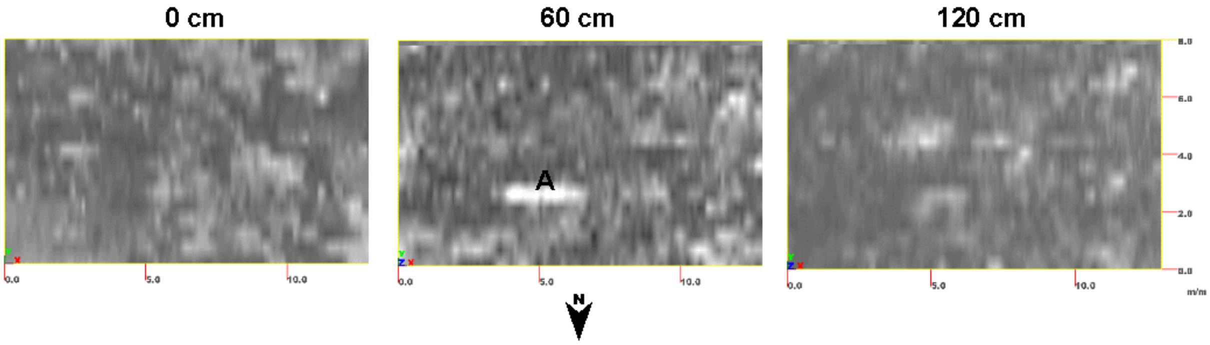

Figure 5. Three amplitude slice maps are shown for three different depths beneath grid site 1.

The most interesting subsurface feature that appeared of the time-sliced images of this grid site is *A*, in the 60 cm depth slice (Figure 5). Figure 6 is a 3D pseudo image of this grid site with an 800 by 250 by 80 cm inset cube removed. In this 3D pseudo images, the linear feature shown in the 60 cm time slice (Figure 5) is evident along the base and back wall of the cutout cube. Stratified layers of contrasting soil materials form horizontal reflectors on the sidewalls of the 3D pseudo image. Inhomogeneities along these layers are indicated by changes in reflection amplitudes.

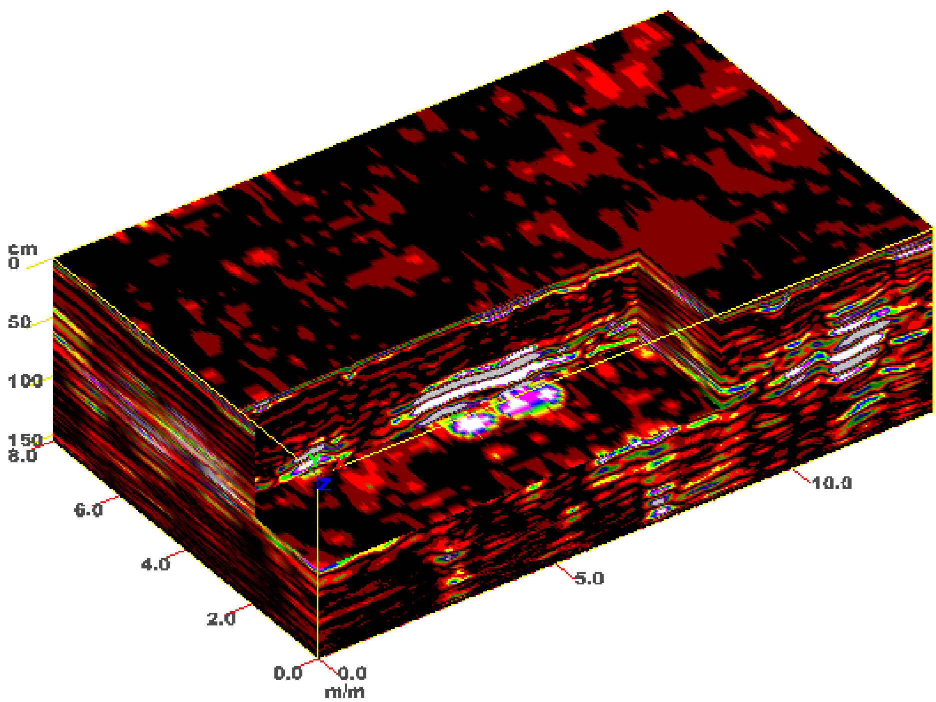

Figure 6. 3D Pseudo image of Grid 1 with an 8.5 by 2.5 by 0.8 m inset cube removed to show a conspicuous high-amplitude linear reflector that is located beneath the site.

Three horizontal time-slice images of the 10 by 9 m, Grid 2 (for location, see Figure 1) are shown in Figure 7. In the 60 cm slice, a large number of high-amplitude (colored black) reflections are evident. Most of these reflections are clustered in the western portion of the survey area; the portion that borders existing structures. Some of these reflectors appear to form a rectangular pattern that is outlined on both the 60 and 120 cm slice. Based on these reflections, the outlined area is identified as a promising area for any proposed archaeological excavations.

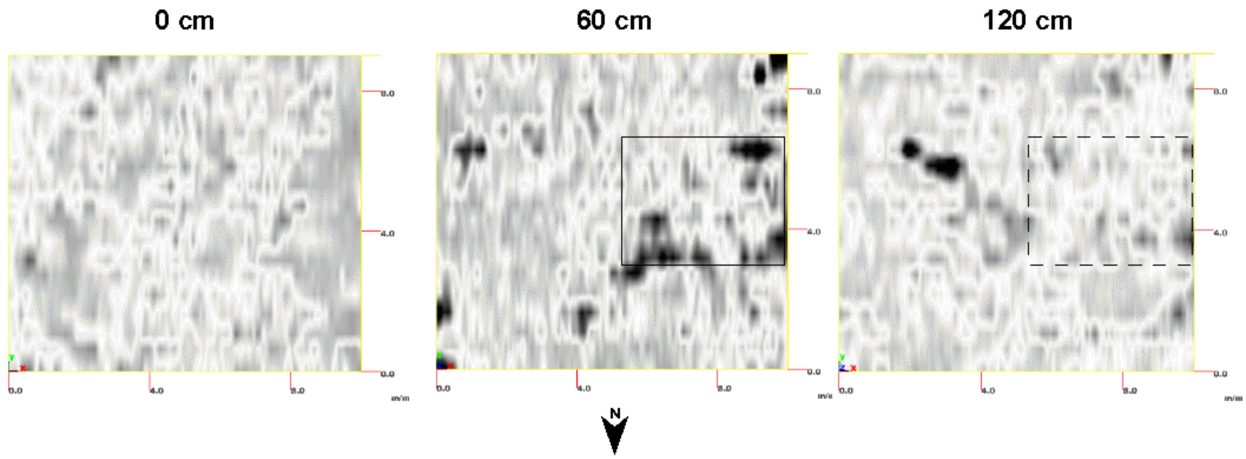

Figure 7. Three amplitude slice maps are shown for three different depths beneath grid site 2.

Figure 8 is a 3D pseudo image of Grid Site 2, with an 890 by 550 by 65 cm inset cube removed. In this 3D pseudo images, a portion of the area of interest shown in the 60 cm depth-slice (Figure 7) is exposed along the base and back walls of the cutout cube. Along the back walls, more clearly expressed, contrasting, horizontal layers (presumably fill materials) are apparent within the rectangular area that was defined in Figure 6. While no subsurface feature of archaeological significance can be unambiguously indentified on these images (Figure 6 and 7), the concentration and contrasts of graphic signatures within the defined rectangular area, may merit the attention of archaeologists. If archaeological excavations are planed for this site, based on radar imagery, this area of the Grid 2 would be recommended for sampling.

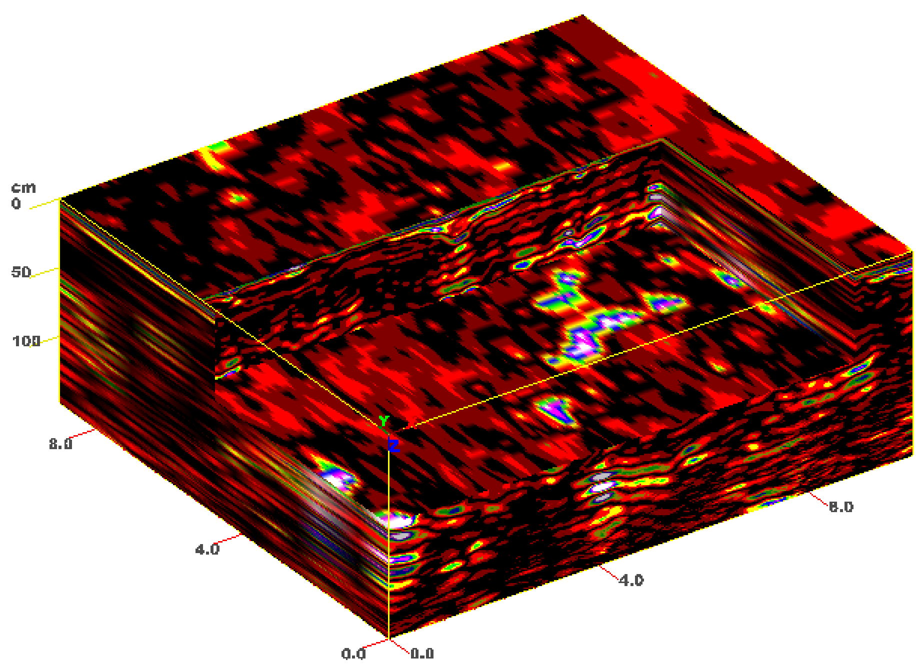

Figure 8. 3D Pseudo image of Grid 2 with an 8.9 by 5.5 by 0.65 m inset cube removed to show conspicuous high-amplitude linear reflectors that are located beneath the site.

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