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Subject: Soils – Geophysical Investigations **Date:** 3 April 2014

To: Jon Hall.
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Purpose:
The purpose of this visit was to demonstrate the use of ground-penetrating radar (GPR) and electromagnetic induction (EMI) methods and conduct brief surveys with these geophysical tools at Goshen Farm on the Broadneck Peninsula in Cape St. Claire, Maryland. Goshen Farm dates back to the mid to late 1700s and is on the Maryland Register of Historic Places. Many of the farm's former structures have disappeared and the full extent and contents of the archaeological site is presently unknown. Midshipmen from the United States Naval Academy have volunteered their time to assist in a project designed to increase public awareness of soil health. Ground-penetrating radar and electromagnetic induction were used to identify areas having buried cultural features and also areas in which no major, buried artifacts are present.

Activities:
All activities were completed on 22 March 2014.

Summary:
1. NRCS is working with the Goshen Farm Preservation Society, Inc. to preserve and protect this farm and to increase public awareness to soil health. Midshipmen from the U.S. Naval Academy have volunteered to clear invasive vines, underbrush, and trees from this idle former farmland and have dug a soil pit that will be used to demonstrate the complexity of soils and soil health issues.

2. The use of ground-penetrating radar and electromagnetic induction were discussed with the group of midshipmen. Several midshipmen were given the opportunity to operate an EMI sensor and a GPR unit. They conducted a reconnaissance EMI survey of the farm and detailed GPR surveys of two sites of interest near a former silo and a community garden.

3. The EMI survey revealed two areas with anomalous apparent conductivity measurements. These areas are believed to contain buried, metallic artifacts.

4. GPR surveys of a former barn site and along the western edge of the community garden revealed no subsurface remnants of former foundations or structural features.

It was the pleasure of Jim Doolittle and the National Soil Survey Center to work with members of your fine staff and be of assistance to you in this soil health project.

JONATHAN W. HEMPEL
Director
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Technical Report on geophysical investigation conducted at the Goshen Farm on 22 March 2014.

Jim Doolittle

Background:
The Maryland State NRCS staff, Anne Arundel Soil Conservation District, and midshipmen from the United States Naval Academy assisted the Goshen Farm Preservation Society, Inc., in a project designed to increase public awareness of soil health. The project is located at Goshen Farm, which is near the State NRCS Office in Annapolis, Maryland. Goshen Farm dates back to the mid to late 1700s and is on the Maryland Register of Historic Places. State Conservationist Jon Hall, Assistant State Soil Scientist Dean Cowherd, and Resource Soil Scientist Jim Brewer offered presentations to the midshipmen emphasizing the need to improve soil health and the many positive benefits derived from healthy soils (Figure 1).

Figure 1. Assistant State Soil Scientist Dean Cowherd explains the importance of soil health in a soil pit that was excavated and constructed by the midshipmen at Goshen Farm.

The midshipmen later cleared ground needed to expand a community garden and helped to construct an educational soil pit, where principals of soil health will be promoted through self-guided tours and public presentations to the community (Figure 1). The pit was excavated in Sassafras soil (fine-loamy, siliceous, semiactive, mesic Typic Hapludults); the state soil of Maryland.

A presentation on the use of ground-penetrating radar (GPR) and electromagnetic induction (EMI) to assess the spatial and temporal variability of soil properties that affect soil health was provided by the National Soil Survey Center (Figure 2). Later, midshipmen conducted surveys with these geophysical instruments to map soil apparent conductivity across portions of the former farmland, identify areas having buried artifacts, and insure that the public gardens were not expanded over buried archaeological features. As these geophysical methods are extensively used in precision agriculture to identify and map the spatial variability of soil properties, these tools are being embraced in soil health projects.

Figure 2. Jon Hall (State Conservationist of Maryland; on the far left) and Jim Brewer (Resource Soil Scientist; next on left) look on as GPR principles and operating procedures are explained to a group of midshipmen from the United States Naval Academy, members of the Goshen Farm Preservation Society, Inc., and earth team volunteers.

Geophysical Equipment:
The following is a brief description of the geophysical tools that were demonstrated to and operated by the midshipmen.

EMI:
The Profiler EMP-400 sensor (here after referred to as the Profiler) is manufactured by Geophysical Survey Systems, Inc. (Salem, NH).[1] The Profiler has a 1.22 m (4.0 ft) intercoil spacing and operates at frequencies ranging from 1 to 16 kHz. It weighs about 4.5 kg, (9.9 lbs.). The Profiler is a multifrequency EMI meter that can simultaneously collect data in as many as three discrete frequencies. For each frequency, in-phase and quadrature phase data are recorded. The calibration of the Profiler is optimized for 15 kHz and, as a consequence, EC_a is most accurately measured at this frequency (Dan Delea, GSSI, personal communication). Operating procedures for the Profiler are described by Geophysical Survey Systems, Inc. (2008). At Goshen Farm, the EMI survey was conducted with the sensor held in the deeper sensing VDO orientation (Figure 3). The sensor's electronics are controlled via Bluetooth communications with a Trimble TDS RECON-400 Personal Data Assistant (PDA).[1] To collect geo-referenced data, the PDA is configured with an integral 12-channel WAAS (Wide Area Augmentation System) GPS.

To help summarize the results of the EMI surveys, SURFER for Windows (version 10.0) software (Golden Software, Inc., Golden, CO) was used to construct the simulation shown in this report.

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

Figure 3. NRCS Cartographer and GIS specialist Michelle Guck records the location of an "anomaly" measured with a Profiler, as midshipmen flag the position.

Ground-penetrating radar:
Ground-penetrating radar is a non-invasive, high-resolution geophysical method that is used in soil and archaeological explorations. Ground-penetrating radars transmit short pulses of high to ultra-high frequency (center frequencies from 12.5 MHz to 2.6 GHz) electromagnetic energy into the ground to detect subsurface interfaces. A time-scaled system, GPR measures the time that it takes pulses of electromagnetic energy to travel from an antenna to a subsurface interface and back. Interfaces often correspond to boundaries of major soil, stratigraphic, and lithologic layers or features. Whenever a pulse contacts an interface separating layers with different relative dielectric permittivity (E_r), a portion of the energy is reflected back to a receiving antenna. The more abrupt and contrasting the E_r 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. To convert the travel time into a depth scale, the velocity of pulse propagation or the depth to a reflector must be known.

A TerraSIRch Subsurface Interface Radar (SIR) System-3000 (henceforth referred to as the SIR-3000), manufactured by Geophysical Survey Systems, Inc. (GSSI; Salem, NH), was used in this investigation (Figure 4).[2] 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. Jol (2009) and Daniels (2004) discuss the use and operation of GPR. A relatively high frequency, 400 MHz antenna was used in this study (Figure 4).

The RADAN for Windows (version 7.0) software program (developed by GSSI) was used to process the radar records.[2] The processing procedures that were used are: header editing, setting the initial pulse to time zero, color table and transformation selection, signal stacking, horizontal high pass filtration, and migration (refer to Jol (2009) and Daniels (2004) for discussions of these techniques). These processing techniques were used to improve pattern recognition.

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

Figure 4. Midshipmen conduct a detailed grid survey with the SIR-3000 and a 400 MHz antenna near the site of the old silo.

Survey Area:
Goshen Farm (39.0364 N latitude, 76.4433 W longitude) is located in the town of Cape St. Claire, Anne Arundel County, Maryland. The farm house is off of Radolf Road about 1.4 km northeast of the Maryland NRCS State Office. Figure 5 (left image) contains an aerial photograph of Goshen Farm. On this image, the approximate boundary of the Goshen Farm and the track of the EMI survey have been delineated by white-colored segmented lines and blue colored lines, respectively.

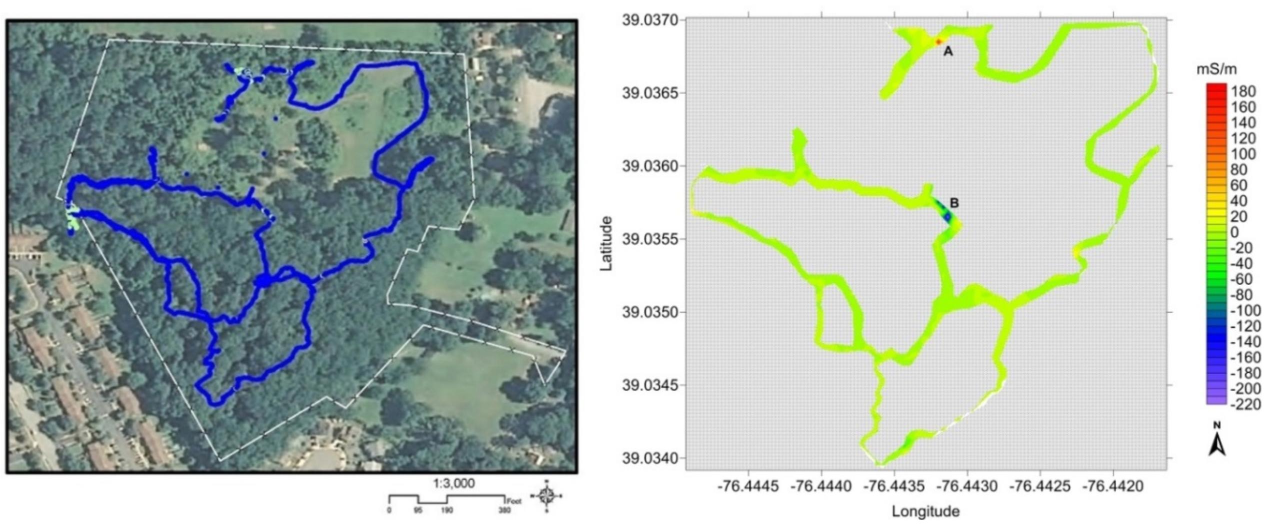

Figure 5. On aerial photograph shown on the left, the approximate locations of the Goshen Farm's property line (white) and the track of the EMI survey (blue) are presented. Values of apparent conductivity are shown along the EMI survey lines displayed on the simulated plot shown on the right.

Survey procedures:
The EMI survey was completed by randomly walking along forest trails (see Figure 5, left) and across open areas of the farm with the Profiler. The sensor was held in the VDO, about 5 cm above the ground surface, with its long axis parallel with the direction of traverse. During the survey, areas having anomalous EC_a readings were georeferenced and flagged (see Figure 3).

Ground-penetrating radar surveys were conducted in two areas by the midshipmen. A survey grid was established in a cleared area to the immediate north of the exposed base of a former silo (in Figure 5, right, silo is located near "A"). This grid was used to ascertain whether there were any buried remnants of structural features related to a former barn, which was located in this area. The dimensions of this grid were approximately 10 (X axis) by 11 (Y axis) meters. To facilitate the construction of the grid, two parallel, 11-m survey lines were laid out (spaced 10 m apart) and served as grid axis lines (Y axis). Along these two parallel axis lines, survey flags were inserted into the ground at a spacing of 50 cm. A line was stretched between matching survey flags on the two opposing axis lines. The 400 MHz antenna was towed along this line (Figure 4). Following data collection, the line was sequentially displaced 50 cm to the next pair of survey flags to repeat the process. A distance-calibrated survey wheel with encoder was bolted onto the antenna to provided control over signal pulse transmission and data collection. Each radar traverse was stored as a separate file.

Four GPR traverses were conducted in an area that was recently cleared of undergrowth and bushes, which bordered the community garden. The purpose of these traverses were to ascertain whether there were any structural features related to the former farm buried in this area.

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):

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

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):

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

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 E_r (Daniels, 2004). Based on the known depth (50 cm) to a metallic reflector buried in an area of Sassafras soil, the average E_r was estimated to be 15, which corresponds to an average v of 0.0774 m/ns. This information was used to depth scale the radar records.

Results:
Electromagnetic induction:
Although extensive areas of the farm were surveyed with EMI, the distance between the lines were too great for proper interpolation of the data. In addition, many portions of the farm land were not surveyed. Figure 5 (right) shows the EC_a measured along the EMI traverse lines. In general, EC_a was low and

relatively invariable along the survey lines. Two areas with anomalously high or low EC_a responses have been identified in this plot (see *A* and *B* in Figure 5, right). The EC_a responses in these two areas suggest the presence of buried, metallic artifacts.

Ground-penetrating radar:
Figure 6 is a two-dimensional (2D) radar record from line X = 0 m of the grid. This radar record is representative of the GPR data collected within the grid. Other than the GPR trace being adjusted to zero time (i.e., to correctly assign a position for the surface, which is dependent on the characteristics of the soil material in contact with the antenna), this radar record has not been processed. The distance and depth scales are expressed in meters. Reflections from the soil surface have produced the high amplitude (intense white and black colors) bands in the upper part (0 to 20 cm) of this radar record. Additional hyperbolas of lower and varying amplitudes are evident on this radar record, especially between the 0 and 5 m distance marks. As these reflectors occur in the upper part of the soil profile, many are assumed to represent tree roots. This area was recently cleared of underbrush by the midshipmen and many coarse roots and woody debris were evident on the soil surface. However, some of these hyperbolas may represent soil inhomogeneities, rock fragments, burrows, or artifacts related to former barn structure. A very strong hyperbola is also noticeable at a depth of about 50 to 55 cm near the 10 m distance mark. On 2D radar records it is difficult to identify features causing these anomalous reflections as GPR detects, but does not provide and identification for subsurface features.

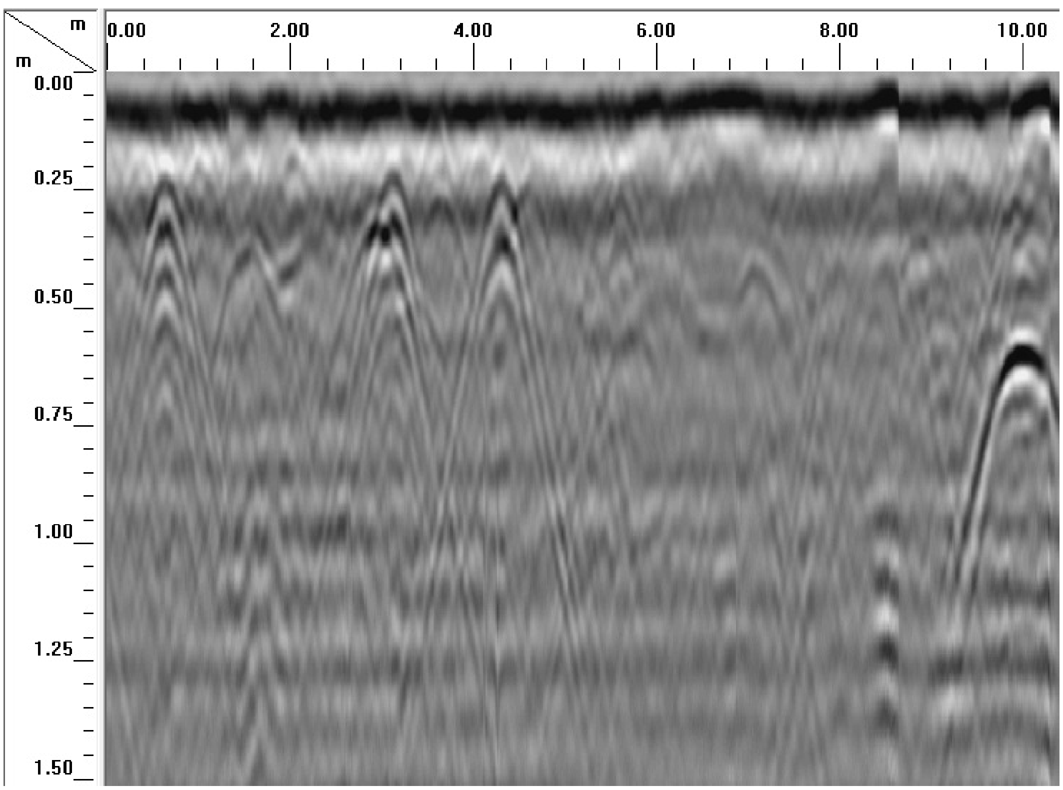

Figure 6. The hyperbolic reflections seen on this 2D radar record are from subsurface point reflectors believed to be roots.

3D Pseudo-Images and Amplitude Slice Analysis:
An effective visualization of radar data is the key to GPR interpretations. The analysis of subsurface structures, distributions, and geometries are often improved using three-dimensional (3D) pseudo-images of gridded sites. Three-dimensional GPR allows visualization of data volumes from different

perspectives and cross-sections (Beres et al., 1999). This can assist identification, outline the structure and geometry, and improve the interpretation of subsurface features. In areas of electrically resistive materials, Grasmueck and Green (1996) noted that, compared with 2D GPR, 3D GPR can provide superior resolution and detail of subsurface features. Beres et al. (1999) observed that 3D GPR improves the definition of subsurface structural trends and results in more complete and less ambiguous interpretations than traditional 2D GPR records.

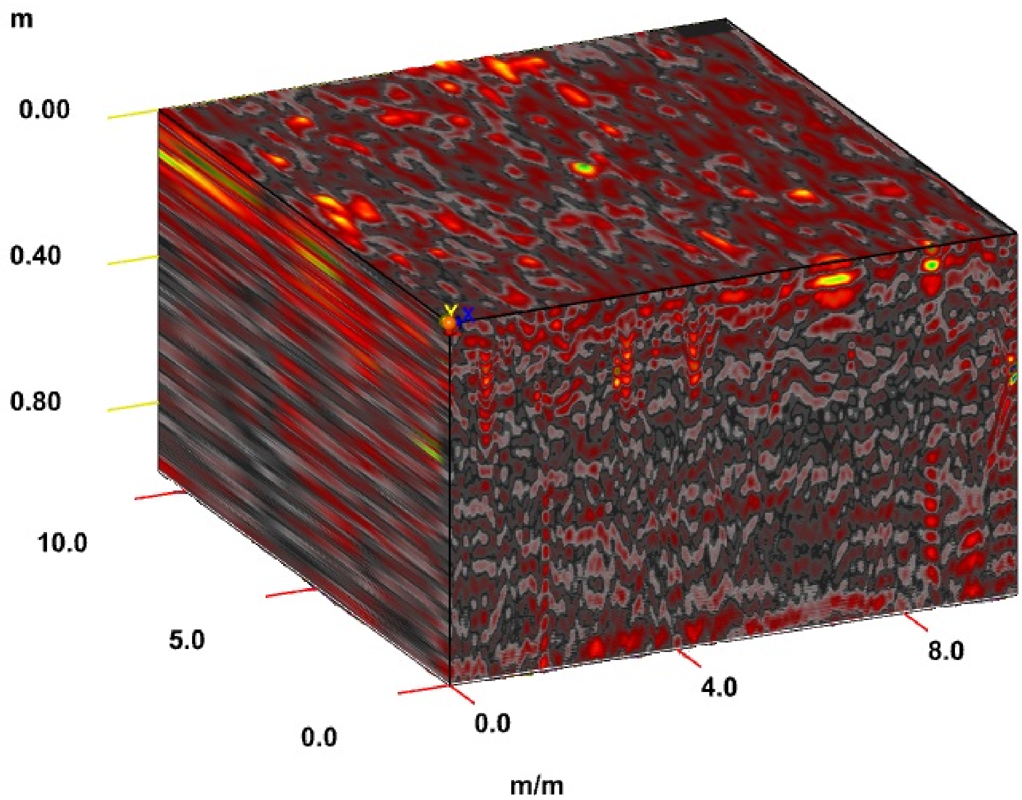

Figure 7. A 3D solid-cube pseudo-image of the grid located near the silo (remnants of the silo are off this grid in the near foreground).

Figure 6 is a 3D solid-cube pseudo-image of the grid site. In order to construct this 3D pseudo-image, GPR data were collected along a series of 24, closely spaced (50 cm) traverse lines that were aligned parallel with the x-axis (right-foreground). Each traverse line was approximately 10 m long. These procedures produced a 10 by 11 m (110 m^3) grid area. In the pseudo-image shown in Figure 6, all measurements are expressed in meter. Because data were continuously recorded along the x-axis (right-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). As a consequence, data shown along the y-axis are spatially aliased, “smeared”, and more poorly represented.

One advanced signal processing method that is commonly used in GPR investigations is *amplitude slice analysis* (Conyers, 2004). This analysis method 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 between adjacent, parallel radar traverses and in specified time (or depth) windows (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 buried artifacts. In many instances, amplitude time-slice images have been used to distinguish and identify artifacts and to reduce interpretation uncertainties.

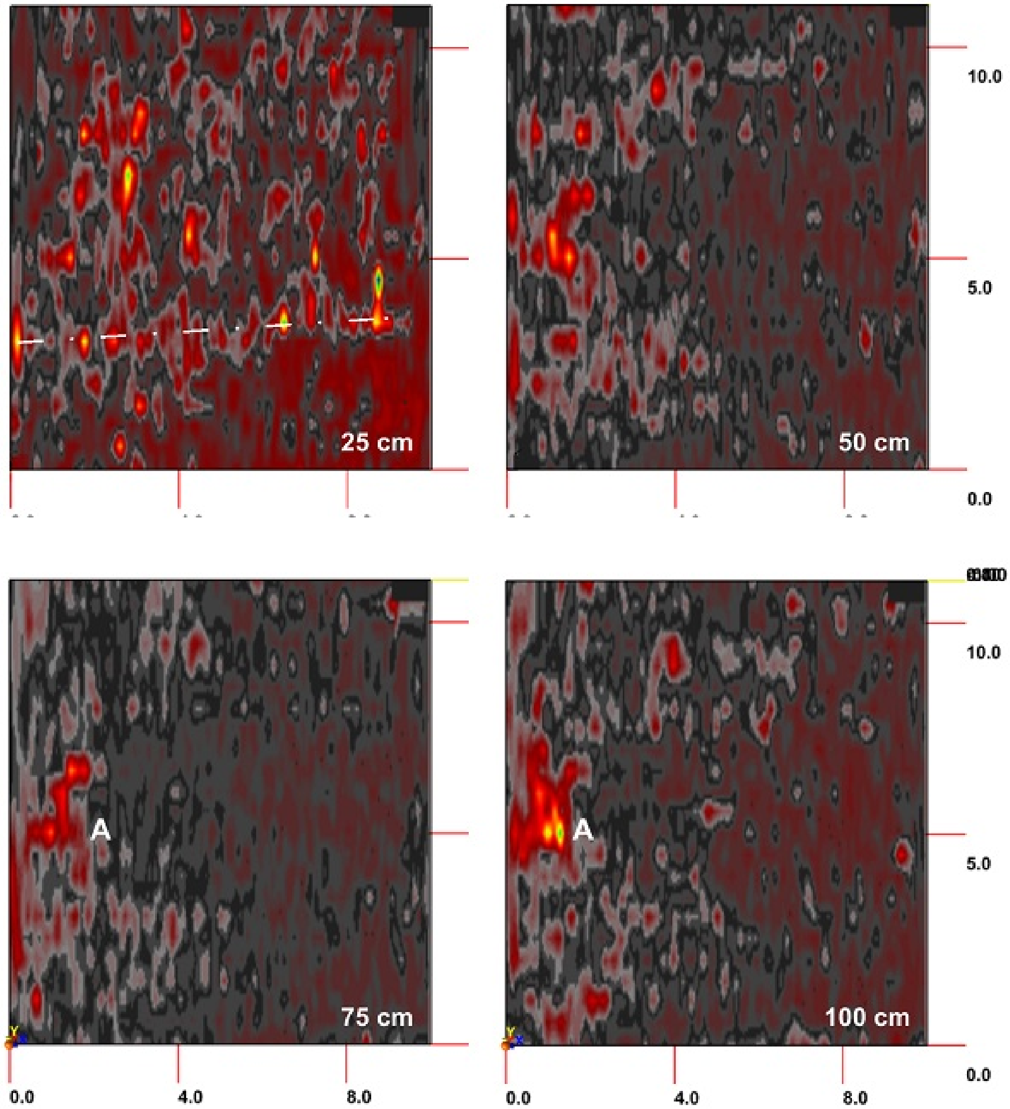

Figure 8. These four time-sliced images show reflected signal amplitudes at different soil depths.

Figure 8 contains four, time-sliced images from the 3D cubic pseudo image shown in Figure 7. In each of image, the survey area is viewed from directly overhead. These time-sliced images represent four different depths (25, 50, 75, and 100 cm). Each time-slice is about 14 cm thick. On each of these time-sliced images, clusters of high-amplitude (colored orange and yellow) reflectors are conspicuous in the western (left-hand) portion of the grid. A persistent, high-amplitude cluster near "A" in the 75 and 100 cm depth slices is anomalous and may be worthy of further investigation by an archaeologist. In addition, lower-amplitude spatial reflection patterns are more complex and variable in the western portion of the grid area. On each of these time-sliced images, a vertical line drawn in a north direction along X = 5 m, would partition the grid into two outwardly dissimilar areas. These two areas with seemingly different signal reflection patterns may represent differences in use and occupational history. While sporadically dispersed point reflectors are evident in each time slice, there is very little evidence of a former structure in these time sliced images. However, with some imagination, a linear feature is suggested in the 25 cm depth-sliced image. A white *dash and dot* line has been used in the 25 cm depth-sliced image to emphasize this apparent feature.

The community garden needs expansion and the midshipmen have cleared brush and debris along the western edge of the garden. Four radar traverses were conducted over this cleared area in search for buried foundations and a suspected privy. Figure 9 contains two, 2D radar records from this area. Each radar record is about 12 m long and was obtained in a southerly direction across the cleared area. Numerous, high amplitude (colored white, blue and green on these radar records) reflectors are evident within the upper 25 cm of the soil profile. While the identity of these features remains unclear, visual inspection of the grounds and one ground-truth observation confirmed that most probably represent tree roots.

A white-colored segmented line has been drawn in each of the radar records shown in Figure 9. These lines approximate the upper boundary of the Bt horizon of Sassafras soil (fine-loamy, siliceous, semiactive, mesic Typic Hapludults). Soils were wet at the time of this survey. The higher water content weakened the dielectric gradient across the BA/Bt horizons boundary, making it more weakly expressed and indistinct on the radar records. The higher-amplitude reflections in the lower parts of these radar records are believed to represent masses of ironstone.

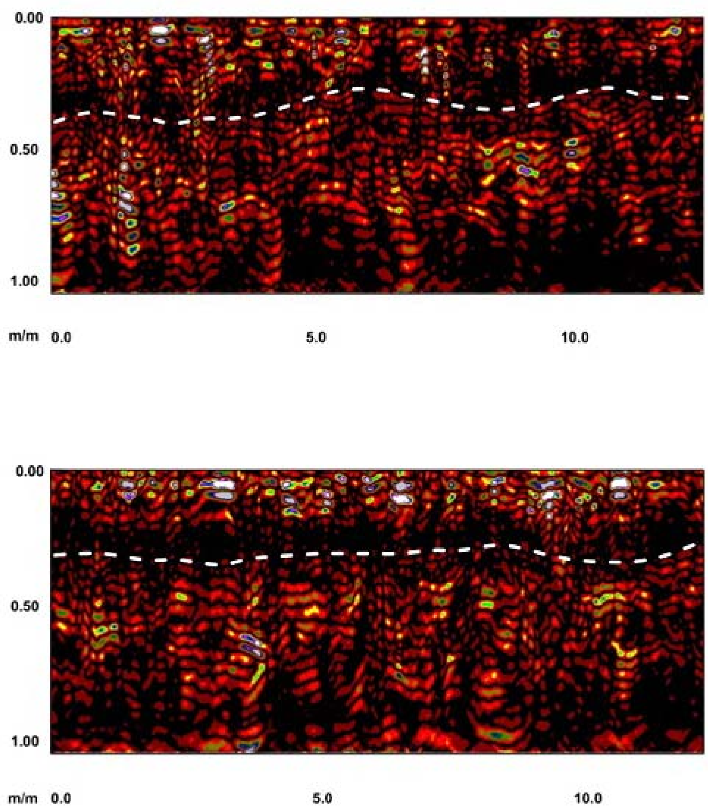

Figure 9. These 2D radar records are from the recently cleared area along western edge of the community garden. The white segmented lines represent the upper boundary of the Bt horizon.

The radar records shown in Figure 9 are believed to be representative the very deep, well drained Sassafras soil. Figure 10 shows a photograph and a radar record of Sassafras soil.

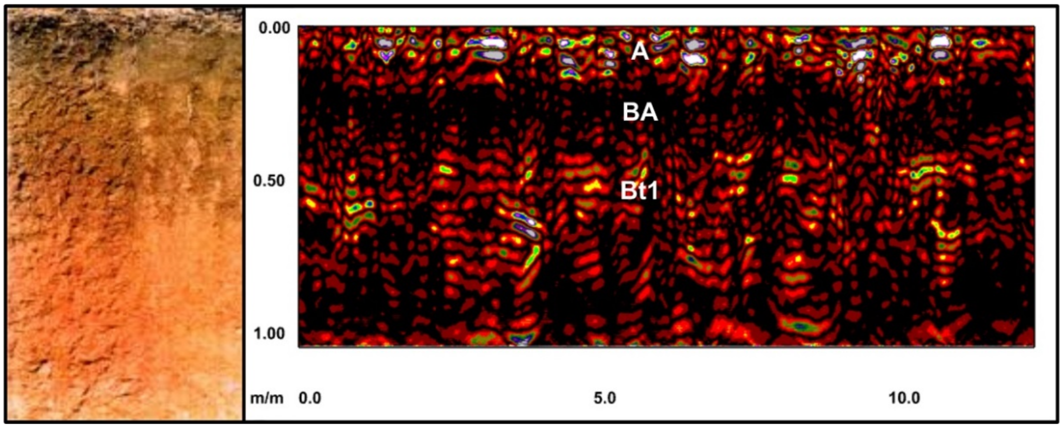

Figure 10. A soil and radar profile of forested Sassafras soil.

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