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

Subject: SOI – Geophysical Assistance Assistance **Date:** 7 April 2003

To: Robin E. Heard
State Conservationist
USDA-NRCS,
Suite 340, One Credit Union Place
Harrisburg, PA 17110-2993

Purpose:
To evaluate the suitability of ground-penetrating radar (GPR) and electromagnetic induction (EMI) in different soils on the Allegheny Front and the Ridge and Valley physiographic provinces of central Pennsylvania. In addition to conduct a GPR survey of a suspected burial site near Potters Mills, Pennsylvania.

Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Jake Eckenrode, Resource Soil Scientist, USDA-NRCS, Lamar, PA
Sarah Hillegas, Agricultural Engineer, USDA-NRCS, Lamar, PA
Pingping Jiang, PhD Student, Department Crop & Soil Science, PSU, University Park, PA
Rich Kerstetter, Reporter, Centre Daily Times, State College, PA
Chip Kogelmann, PhD Student, Department Crop & Soil Science, PSU, University Park, PA
Mike Miller, Landowner, Potters Mills, PA
Hangsheng Lin, Assistant Professor, Department Crop & Soil Science, PSU, University Park, PA
Yuri Plowden, Soil Scientist Aid Volunteer, USDA-NRCS, University Park, PA
Bruce Teeple, Curator, Penns Valley Area Historical Museum, Aaronsburg, PA
Chuck Walker, PhD Student, Department Crop & Soil Science, PSU, University Park, PA

Activities:
All field activities were completed on 18-20 March 2003.

Results:

1. Electromagnetic induction and ground-penetrating radar were demonstrated to Dr Hangsheng Lin and three of his PhD candidates, Department Crop & Soil Science, Pennsylvania State University. On the basis of this demonstration additional field studies are planned to assist his students in their hydropedology and solute transport research.

2. Meaningful GPR data on the depth to bedrock were restricted principally to areas with shallow and moderately deep soils. In areas of deep and very deep soils, rock fragments and rock pinnacles provide distinct and identifiable radar signatures. In areas of Murrill, Buchanan, Morrison, and Berks soils, high levels of background noise obscured subsurface information and restricted the appropriateness of GPR for soil investigations. On most radar records, several unidentified, continuous reflectors were apparent. These reflectors often overlapped one another, and were ambiguous and difficult to trace laterally. Where present, the argillic horizon was apparent on radar records.

3. I would like to return to the Opequon site and conduct a more detailed GPR survey. The data will be used to develop three-dimensional radar imagery that will be used too help characterize the underlying Colburn limestone.

4. Similar EMI responses were obtained in different soils, stratigraphic units, and lithologies within Clinton and Centre counties. As a consequence, in this setting, EMI does not appear at first glance to be a suitable tool for distinguishing soils, soil map units, and lithologies. As EMI has been used as a surrogate for detailed and reconnaissance soil surveys in some areas of the United States, this study has produced significant findings that should be useful to the expansion of this technology into the Allegheny Front and the Ridge and Valley physiographic provinces. More studies are recommended to better qualify these results.

5. No clearly identifiable subsurface reflectors that definitely represent burials were identified at the Potters Mills Cemetery. Rock fragments, tree roots, and segmented soil horizons may have masked reflections from burials and grave shafts and blurred interpretations. However, after processing, several graphic patterns appearing on radar records did suggest the possibility of burials. Results of the GPR survey provide unsubstantiated and highly speculative information.

It was my pleasure to work in Pennsylvania and with members of your fine staff.

With kind regards,

James A. Doolittle
Research Soil Scientist

cc:
B. Ahrens, Director, USDA-USDA-NRCS, National Soil Survey Center, Federal Building, Room 152,100 Centennial Mall North, Lincoln, NE 68508-3866
J. Eckenrode, Resource Soil Scientist, USDA-NRCS, 216 Spring Run Road, Room 102, Mill Hall, PA 17751
W. Maresch, Acting Director of Soils Survey Division, USDA-NRCS, Room 4250 South Building, 14th & Independence Ave. SW, Washington, DC 20250
C. Olson, National Leader for Soil Investigations, USDA-USDA, National Soil Survey Center, Federal Building, Room 152, 100 Centennial Mall North, Lincoln, NE 68508-3866
W. Tuttle, Soil Scientist (Geophysical), USDA-NRCS, National Soil Survey Center, P.O. Box 974, Federal Building, Room 206, 207 West Main Street, Wilkesboro, NC 28697
E. White, State Soil Scientist, USDA-NRCS, USDA-NRCS, Suite 340, One Credit Union Place, Harrisburg, PA 17110-2993

Equipment:
The radar unit is the Subsurface Interface Radar (SIR) System-2000, manufactured by Geophysical Survey Systems, Inc.[1] Morey (1974), Doolittle (1987), and Daniels (1996) have discussed the use and operation of GPR. The SIR System-2000 consists of a digital control unit (DC-2000) with keypad, VGA video screen, and connector panel. A 12-volt battery powers the system. This unit is backpack portable and, with an antenna, requires two people to operate. The antennas used in this study have center frequencies of 200 and 400 MHz. Hard copies of the radar data were printed in the field on a model T-104 printer.

The RADAN NT (version 2.0) software program developed by Geophysical Survey Systems, Inc., was used to process the radar records.[1] Processing included color transformation, marker editing, distance normalization, and range gain adjustments. Most radar records contained in this report were converted into bitmap images using the Radan to Bitmap Conversion Utility (version 1.4) developed by Geophysical Survey Systems, Inc.[1] GPR data from the Potters Mills site were processed into a three-dimensional image using the 3D QuickDraw for RADAN Windows NT software developed by Geophysical Survey Systems, Inc.[1] Once processed, arbitrary cross-sections and time slices were viewed and selected images saved to files.

The electromagnetic induction meter used in this study was the EM38DD, manufactured by Geonics Limited.[1] Geonics Limited (2000) describes the operation of the EM38DD meter. The EM38DD meter is portable and requires only one person to operate. No ground contact is required with this meter. The EM38DD operates at a frequency of 14,600 Hz. It has effective penetration depths of about 0.75 and 1.5 m in the horizontal and vertical dipole orientations, respectively. The EM38DD meter consists of two EM38 meters bolted together and electronically coupled. One meter acts as a master unit (meter that is positioned in the vertical dipole orientation and having both transmitter and receiver activated) and one meter acts as a slave unit (meter that is positioned in the horizontal dipole orientation with only the receiver switched on).

Survey Area:
Sites were selected in the southern parts of Centre and Clinton counties, Pennsylvania. In Centre County, traverses were completed with GPR and EMI in areas that had been mapped as Opequon-Hagerstown complex, 3 to 8 percent slopes; Murrill channery silt loam, 3 to 8 percent slopes; Buchanan very stony silt loam, 0 to 8 percent slopes; and Morrison sandy loam, 8 to 15 percent slopes (Braker, 1981). In Clinton County, traverses were conducted in an area of Berks channery silt loam, 15 to 25 percent slopes (Steputis, 1966).

The shallow, well drained Opequon soil formed in residuum weathered from limestone. Opequon is a member of the clayey, mixed, active, mesic Lithic Hapludalfs family. The very deep, well drained Hagerstown soil residuum weathered from limestone. Hagerstown is a member of the fine, mixed, semiactive, mesic Typic Hapludalfs family. The *deep*, well drained Murrill soil formed in colluvium derived largely from acid sandstones and shales. Murrill is a member of the fine-loamy, mixed, semiactive, mesic Typic Hapludults family. Murrill's solum thickness is greater than 60 inches thick. Depth to bedrock is greater than 6 feet. The very deep, moderately well drained Buchanan soil formed in colluvium that is weathered from acid sandstone, quartzite, siltstone, and shale. Buchanan is a member of the fine-loamy, mixed, semiactive, mesic Aquic Fragiudults family. The very deep, well drained Morrison soil formed in residuum of weathered dolomite and sandstone. Morrison is a member of the fine-loamy, mixed, active, mesic Ultic Hapludalfs family. The moderately deep, well drained Berks soil formed in residuum weathered from acid shale, siltstone and fine-grained sandstone. Berks is a member of the loamy-skeletal, mixed, active, mesic Typic Dystrudepts family.

GPR
Calibration:
Ground-penetrating radar is a time scaled system. The system measures the time it takes electromagnetic energy to travel from an antenna to an interface (i.e., soil horizon, bedrock, stratigraphic layer) and back. To convert travel time into a depth scale requires knowledge of the velocity of pulse propagation. Several methods are available to determine the

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

velocity of propagation. These methods include use of table values, common midpoint calibration, and calibration over a target of known depth. The last method is considered the most direct and accurate method to estimate propagation velocity (Conyers and Goodman, 1997). The procedure involves measuring the two-way travel time to a known reflector that appears on a radar record and calculating the propagation velocity by using the following equation (after Morey, 1974):

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

Equation [1] describes the relationship between the propagation velocity (V), depth (D), and two-way pulse travel time (T) to a subsurface reflector. During this study, the two-way radar pulse travel time was compared with measured depths to a known metallic reflector buried at each site. Though slight variations did occur, the estimated velocity of propagation through the upper part of the soils was about 0.07 m/ns. The dielectric permittivity was 18. These values were used to scale the radar records. Using a propagation velocity of 0.07 m/ns and a scanning time of 70 and 110 ns, the maximum penetration depth was about 2.4 and 3.8 m.

Opequon-Hagerstown complex, 3 to 8 percent slopes:
The site is in a cultivated field located southwest of the town of Fairbrook. The Coburn Formation underlies the site. This formation consists of well-bedded, medium gray to very dark gray, fossiliferous, shaly limestone. The formation has high permeability with joints, bedding planes, and solution openings providing a secondary porosity.

A 107-m (350-foot) traverse line was established across this unit. Survey flags were inserted in the ground at intervals of about 7.6-m (25 feet). This provided 15 reference points. The soil was moist throughout having experiences very recent rains. In general, the radar records were of good interpretative quality. Where the depth to bedrock was shallow (< 50 cm), the penetration depth was greater than 2.4 m. Where the depth to bedrock was deep (1 to 1.5 m) or very deep (>1.5 m), GPR observations were restricted to depths of less than 1.2 m.

Figure 1 is a portion of the radar record from this area of Opequon soil. The short, vertical lines at the top of the radar record represent equally spaced (7.6 m) reference points along the radar traverse. A vertical scale (in meters) appears along the left-hand margin of the record. The vertical scale is based a propagation velocity of 0.07 m/ns.

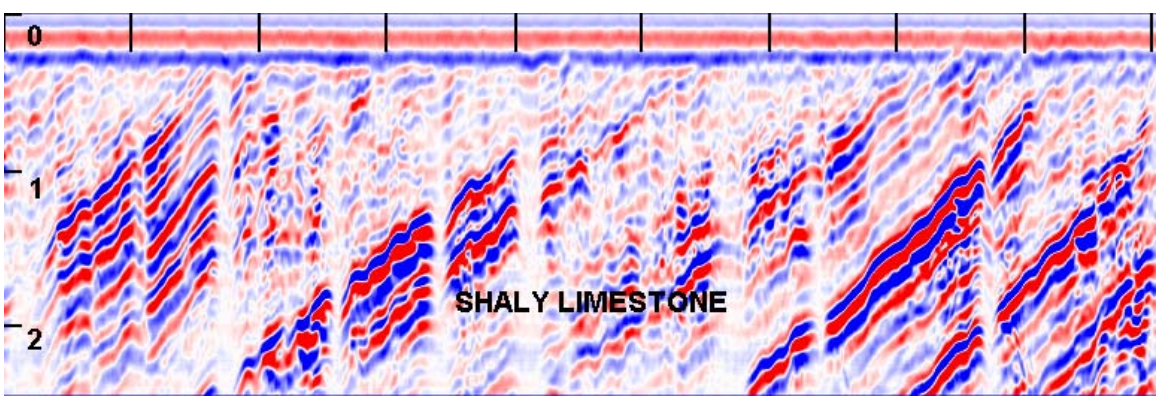

Figure 1. Radar record from an area of Opequon soil that is underlain by the Colburn Formation.

Reflections from multiple inclined strata are prominent on all portions of the radar record where the depth to bedrock was less than 1.2 m (see Figure 1). The closest point at which these strata approach the surface was identified as the depth to bedrock. At 15 reference points along this traverse line, the depth to bedrock averaged 47 cm and ranged from 0.24 to 1.0 m. Based on soil depth criteria, soils were shallow at 66 percent (Opequon soil) and moderately deep at 24 percent of the references points.

Strata varied in intensity and appearance. Higher amplitude reflections represent interfaces or strata with more contrasting dielectric properties. Differences in signal amplitudes were attributed primarily to differences in moisture content and density, and may indicate differences in fracturing and weathering. Conspicuous, vertical breaks in the inclined, planar reflections were attributed to solution features. These breaks or *whiteout* areas are caused by the higher clay and moisture contents of materials that fill solution features. These materials are more attenuating to the radar signals. In Figure 1, solution features appear relatively uniformly spaced and form conspicuous features on radar records. Solution features, joints, and bedding planes contribute to the secondary porosity of the Colburn Formation.

Murrill channery silt loam, 3 to 8 percent slopes:
The site is in a cultivated field located southwest of the town of Fairbrook. The Coburn Formation underlies the site. However, at this site, soils formed in colluvium weathered from the Reedsville and Bald Eagle formations. The Reedsville Formation consists of moderately-well bedded, dark gray shale that contains interbeds of thin sandy to silty shale. The Bald Eagle Formation consists of moderately-well developed, thick beds of gray to reddish gray, fine to coarse-grained, cross-bedded sandstone and quartz-pebble conglomerate.

A 122-m (400-foot) traverse line was established across the Murrill unit. Survey flags were inserted in the ground at intervals of about 7.6-m (25 feet). This provided 17 reference points. The soil was moist throughout having experiences very recent rains. Figure 2 is a portion of the radar record from this area of Murrill soil. The short, vertical lines at the top of the radar record represent equally spaced (7.6 m) reference points along the radar traverse. A vertical scale (in meters) appears along the left-hand margin of the record. The vertical scale is based a propagation velocity of 0.07 m/ns.

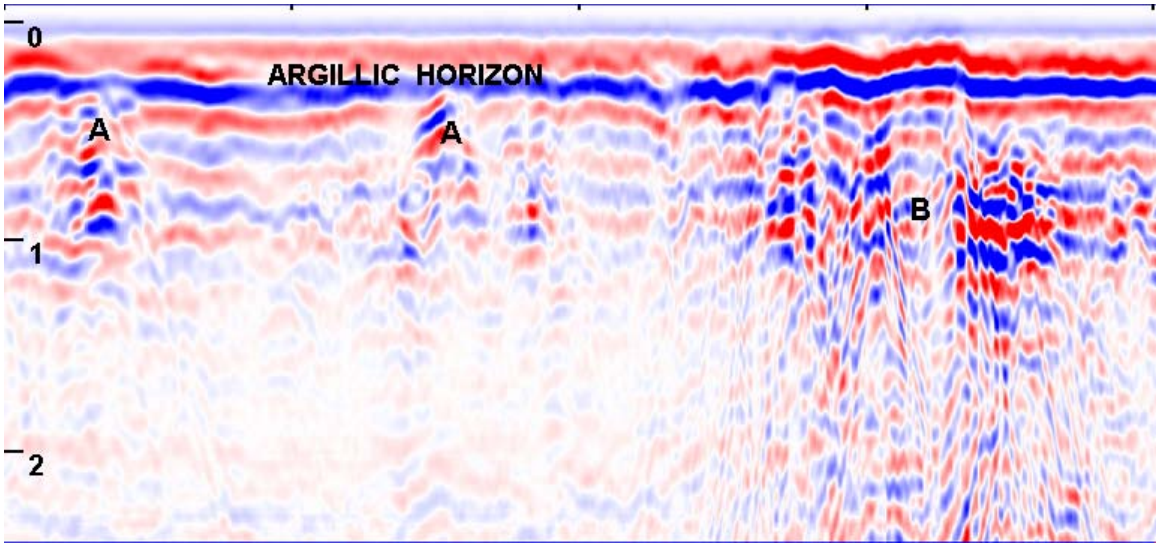

Figure 2. Radar record from an area of Murrill channery silt loam, 3 to 8 percent slopes.

In general, meaningful information was restricted to depths of less than 1 m, except in areas where soils are moderately deep or shallower to bedrock, or have a large number of rock fragments. In these soils, rates of signal attenuation are less and penetration depths are greater. The upper boundary of the argillic horizon (higher amplitude, wavy lines near the top of the radar record) is traceable across most portions of the radar record (see Figure 2). With the 200 MHz antenna, because of the very shallow depth to the argillic horizon, reflections from its upper boundary are partially obscured by reflections from the soil surface. Some indication of the concentration of rock fragments may be obtained from the radar records. Larger rock fragments or rock pinnacles provide a distinct and identifiable radar signature (see "*A*" in Figure 2). At "*B*," a large number of rock fragments or bedrock pinnacles underlie a shallow depression that was observed on the soil surface. An unidentified continuous reflector was traced across a large portion of the radar record at depths ranging

from 1.36 to 2.4 m. This reflector was faint, ambiguous, and difficult to trace laterally. Though not identified, this reflector is believed to represent a major stratigraphic break within the colluvium.

Buchanan very stony silt loam, 0 to 8 percent slopes:
The site is in a cultivated field located southwest of the town of Fairbrook. The Coburn Formation underlies the site. However, the soil formed in colluvium weathered from the Reedsville and Bald Eagle formations. The Reedsville Formation consists of moderately-well bedded, dark gray shale that contains interbeds of thin sandy to silty shale. The Bald Eagle Formation consists of moderately well developed, thick beds of gray to reddish gray, fine to coarse-grained, cross-bedded sandstone and quartz-pebble conglomerate.

A 61-m (200-foot) traverse line was established across this unit. Survey flags were inserted in the ground at intervals of about 7.6-m (25 feet). This provided 9 reference points. The soil was moist throughout having experiences very recent rains. Figure 3 is a portion of the radar record from this area of Buchanan soil. The short, vertical lines at the top of the radar record represent equally spaced (7.6 m) reference points along the radar traverse. A vertical scale (in meters) appears along the left-hand margin of the record. The vertical scale is based a propagation velocity of 0.07 m/ns.

In general high levels of background or *soil noise* obscured meaningful subsurface soil information. Reflections from several closely spaced and often interlaced interfaces are observable in the upper part of the radar record. These interfaces are difficult to individually distinguish. In Figure 3, a green line has been used to approximate the depth to a conspicuous high amplitude, continuous, planar reflector. Based on field observations, this reflector is believed to represent a stone line. Several undifferentiated, continuous reflectors can be traced across the radar record at depths ranging from 0.40 to 0.86 m. These reflectors overlap one another, vary in amplitude, and are ambiguous and difficult to trace laterally. These less pronounced reflectors may represent the argillic horizon or fragipan, but without additional soil cores, their identity and extent remains unknown.

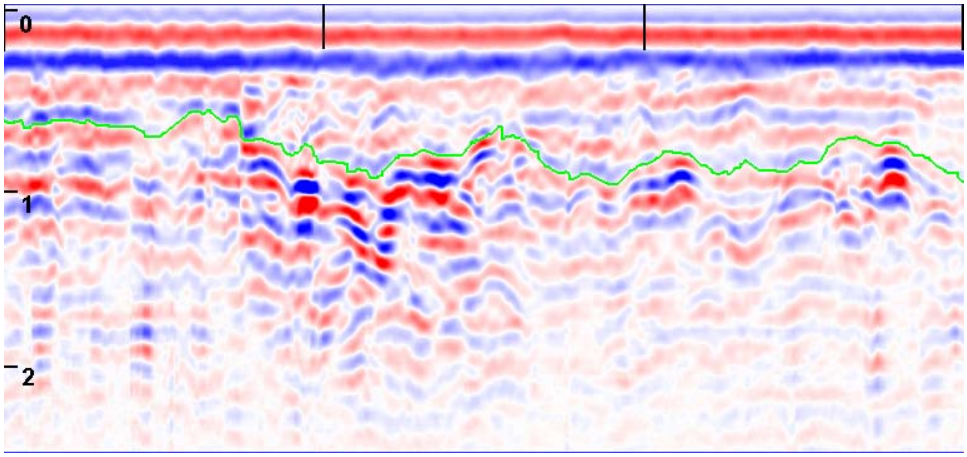

Figure 3. Radar record from an area of Buchanan very stony silt loam, 0 to 8 percent slopes.

Morrison sandy loam, 8 to 15 percent slopes:
The site is located north of State College in an open field. Lower members of the Gatesburg Formation underlie the site. The well-bedded Gatesburg Formation consists of gray, coarsely crystalline dolomite interbedded with sandstone.

A 61-m (200-foot) traverse line was established across this unit. Survey flags were inserted in the ground at intervals of about 7.6-m (25 feet). This provided 9 reference points. The soil was moist throughout having experiences very recent rains. Figure 4 is the radar record from this area of Morrison soil. The short, vertical lines at the top of the radar record

represent equally spaced (7.6 m) reference points along the radar traverse. A vertical scale (in meters) appears along the left-hand margin of the record. The vertical scale is based a propagation velocity of 0.07 m/ns.

In general most subsurface interfaces apparent on the radar record were intermixed, chaotic, and unintelligible. Large numbers of rock fragments, mostly 1 to 6 inches in size, produced these complex radar patterns. The density of these reflections on radar records can be used to distinguish areas with high and low concentrations of rock fragments. A continuous reflector has been traced across the upper part of this radar record (see green line in Figure 4). This interface represents the argillic horizon, but is ambiguous and difficult to trace laterally.

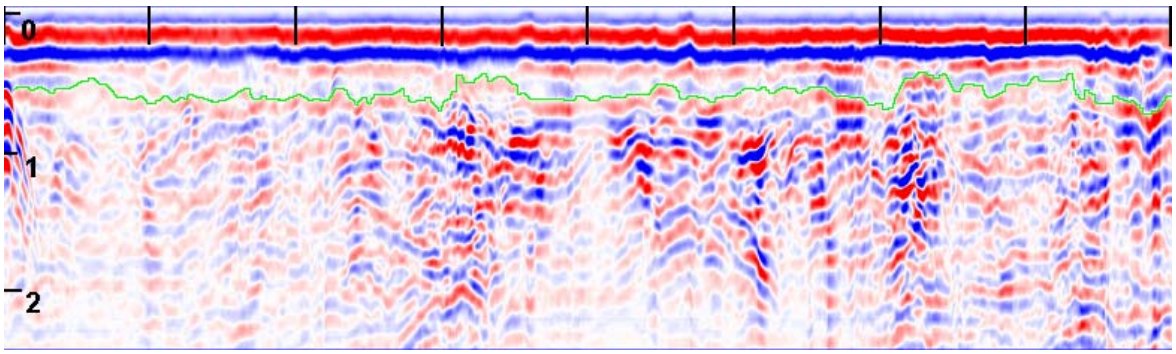

Figure 4. Radar record from an area of Morrison sandy loam, 8 to 15 percent slopes.

Berks channery silt loam, 15 to 25 percent slopes:
The site is located in an area of idle land northeast of Beech Creek in Clinton County. The Brallier and Harrell Formations, undifferentiated, underlie the site. The well and thinly bedded Brallier Formation consists of interbedded light-gray, siliceous siltstone and light gray, hard, silty shales. The Harrell Formation consists of well bedded, fissile to very thin, gray to black, silty shale with thin interbeds of argillaceous limestone, calcareous shale, and limestone nodules.

A 24-m (80-foot) traverse line was established across a portion of this unit. Survey flags were inserted in the ground at intervals of about 3-m (10 feet). This provided 9 reference points. The soil was moist throughout having experiences very recent rains. Figure 5 is the radar record from this area of Berks soil. The short, vertical lines at the top of the radar record represent equally spaced (7.6 m) reference points along the radar traverse. A vertical scale (in meters) appears along the left-hand margin of the record. The vertical scale is based a propagation velocity of 0.07 m/ns.

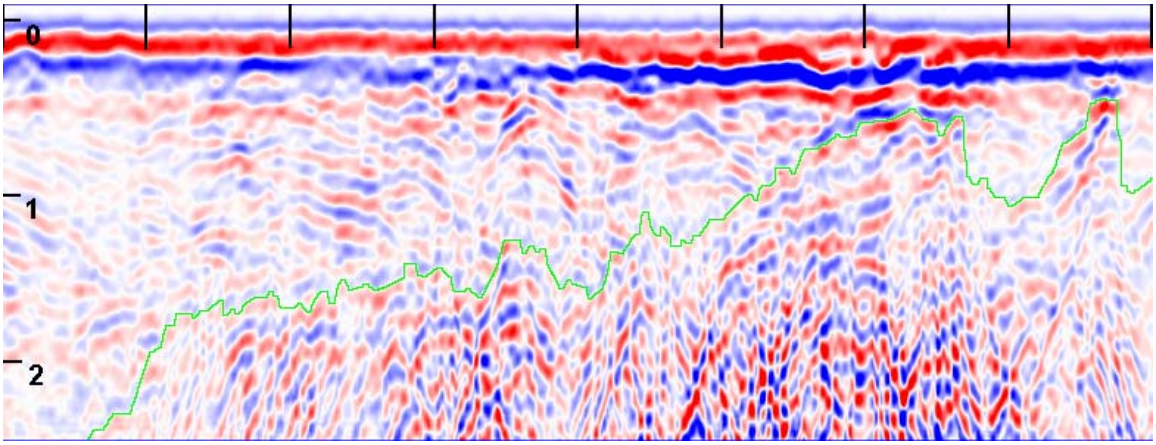

Figure 5. Radar record from an area of Berks channery silt loam, 15 to 25 percent slopes.

Berks soil contains large amounts of shale and siltstone fragments. Typically rock fragments range from 15 to 75 percent in the B horizons, and 35 to 90 percent in the C horizon. The abundance of rock fragments reduces the contrast in dielectric properties between the soil and the bedrock. As a consequence the soil/bedrock interface provides a low amplitude reflection that is difficult to trace across the radar record. In Figure 5, the soil/bedrock interface has been approximated with a green line. This interface is variable in expression, often obscured and highly irregular in topography. The underlying thinly bedded, fissile Brallier and Harrell formations are distinguishable by the large number of high amplitude point and planar reflectors. These reflectors provide a unique and easily identifiable pattern on the radar record. Inclined, planar reflectors evident in the upper part of the soil profile are believed to represent slumping and mass movement features.

EMI

At each of the sites in Centre and Clinton counties, an EMI survey was also conducted along the GPR traverse line. Measurements were obtained with the EM38DD meter in both the horizontal and vertical dipole orientations at each reference point. The purpose of these surveys was to determine weather these soils can be distinguished from one another on the basis of their EMI response.

Variations in electromagnetic response are produced by changes in the ionic concentration and the conductivity of earthen materials. Factors influencing the electromagnetic response include: volumetric water content, amount and type of ions in the soil water, and amount and type of clays in the soil matrix. For the soils studied, Table 1 lists some of the principal properties or groupings that are believed to influence EMI responses. Soils ranged from shallow to very deep to bedrock, and were mostly well drained and medium textured. Soils belonged to three taxonomic orders (Alfisols, Ultisols, and Inceptisols). Soils formed in materials that were principally derived from either limestone, sandstone, or shale.

Table 1. Characteristics of Soils Surveyed.

Soil	Drainage	Depth Class	Particle-size	Subgroup	Bedrock
Opequon	well	shallow	clayey	Lithic Hapludalfs	limestone
Murrill	well	deep	fine-loamy	Typic Hapludults	shale & sandstone
Buchanan	mod-well	very deep	fine-loamy	Aquic Fragiudults	shale & sandstone
Morrison	well	very deep	fine-loamy	Ultic Hapludalfs	dolomite
Berks	well	mod-deep	loamy-skeletal	Typic Dystrudepts	shale

Table 2. Basic Statistics obtained with the EM38 Meter in the Vertical Dipole Orientation.
(All measurements are in mS/m.)

	Opequon	Murrill	Buchanan	Morrison	Berks
Average	6.1	6.5	9.2	7.8	5.0
SD	1.7	1.3	1.8	1.4	1.5
Minimum	3.4	4.4	5.8	5.6	2.4
Maximum	8.3	8.9	11.6	10.4	7.5
1st-Quartile	4.5	5.4	8.1	7.0	4.5
3rd-Quartile	7.3	7.5	10.6	8.5	5.7

Table 2 summarizes some of the basic statistic from the EMI surveys. Statistics include the mean, standard deviation (SD), minimum and maximum values, and the first and third quartiles. In Figure 6, the distribution of EMI measurements along each traverse line is plotted. As can be seen in Table 2 and Figure 6, although these soils have different properties, apparent conductivity is similar for each soil. As a consequence of this obvious lack of contrast, in this setting, EMI does not appear at first glance to be a suitable tools for distinguishing soils, soil map units, and lithologies. It is noteworthy that the highest values were measured in the moderately well drained Buchanan soil. The relatively higher apparent

conductivity in this soils may be attributed to moister conditions and possibly shallower depths to the water table. The shallow depth to bedrock offset the higher clay content of the Opequon soil. The moderately deep Berks soil had the lowest average conductivity. The underlying shales are acid and shale fragments are numerous in the soil profile. Measurements should be higher in areas of marine shales.

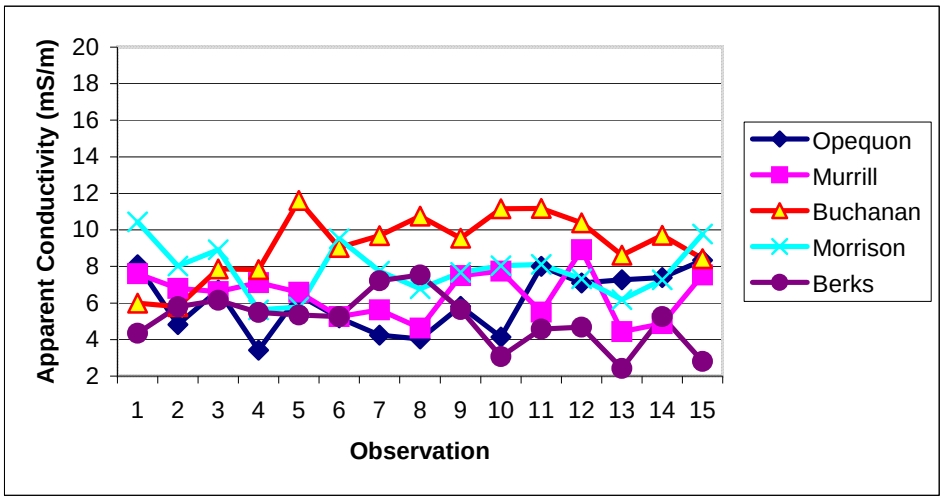

Figure 6. Apparent conductivity measurements obtain in different soils with the EM38 meter operated in the vertical dipole orientation.

As EMI and apparent conductivity have been used as a surrogate for detailed and reconnaissance soil surveys in some areas of the United States, this study has produced findings that should be useful to the application of this technology in the Allegheny Front and the Ridge and Valley physiographic provinces.

Potters Mills Cemetery:
The site is located in a wooded area that had been mapped as Laidig channery loam, 8 to 15 percent slopes (Braker, 1981). The site is located in an included area of more gently sloping soils (3 to 8 percent slopes). The very deep, well drained Laidig soils formed in colluvium from sandstone, siltstone, and shale. Laidig is a member of the fine-loamy, siliceous, active, mesic Typic Fragiudults family. The site is enclosed by what appears to be remnants of a low perimeter wall. Within this perimeter, several rows of equally spaced, shallow, rectangular depressions are evident. These depressions are artificial and believed to cover graves. There are no headstones or records of a cemetery at this location. However, a 1874 map has this area labeled as "cem" – cemetery. The site is suspected by historians to be a slave cemetery.

Background
A favorable feature of GPR is its ability to detect soil disturbances and the intrusion of foreign materials. GPR is therefore a useful tool to search for gravesites. Success varies with soil conditions. However, even with favorable site conditions (i.e. dry, coarse-textured soils) the detection of a burial is never guaranteed with GPR. The detection of burials is affected by (i) the electromagnetic gradient existing between a feature and the soil, (ii) the size and shape of the buried feature, and (iii) the presence of scattering bodies within the soil (Vickers et al., 1976).

The amount of energy reflected back to an antenna by an interface is a function of the dielectric gradient existing between the two mediums. The greater or more abrupt the difference in dielectric properties, the greater the amount of energy reflected back to the antenna, and the more intense will be the amplitude of reflections on the radar record. Many buried features contrast with the surrounding soil matrix. However, with the passage of time, buried features decay or weather and become less electrically contrasting with the surrounding soil matrix.

The size and depth of a grave affect detection. Large objects reflect more energy and are easier to detect than small objects. In addition, the reflective power of an object decreases proportional to the fourth power of the distance to the

object (Bevan and Kenyon, 1975). In many soils, signal attenuation limits observation depths. Bevan (1991) noted that it is more likely that GPR will detect the disturbed soil within a grave shaft, a partially or totally intact coffin, or the chemically altered soil materials, which directly surrounds a burial rather than the bones themselves. Killam (1990) believes that most bones are too small and not directly detectable with GPR. This author noted that it is the disruption of soil horizons that makes most graves detectable with GPR. However, in soils that lack contrasting horizons or geologic strata, the detection of a grave shafts is more improbable. In addition, with the passage of time, natural soil-forming processes erase the signs of disturbances.

Burials are difficult to distinguish in soils having numerous rock fragments, tree roots, animal burrows or stratified or segmented soil layers. These scattering bodies produce undesired subsurface reflections, which complicate radar records and can mask the presence of burials. Under such conditions, burials may be indistinguishable from the background clutter.

Survey Procedures:

A wildcat survey was conducted with the 400 MHz antenna across portions of the suspected cemetery site. The purpose of this survey was to calibrate the GPR while make a general assessment of soil and terrain conditions and the appropriateness of using this technology for the detection of burials within this site. Soils were considered suited to GPR, but the large number of rock fragments and roots would impair interpretations and reduce the probability of positive results.

Heavy rains were falling at the time of the survey. The harsh weather expedited field work and prompted a modification of survey procedures. Survey procedures were modified to facilitate the construction of a 3-D image and the interpretation of subsurface features. To construct three-dimensional display, the imagery between adjoining radar profiles is interpolated. A 9-m by 2.5-m grid was established across a row of three rectangular depressions. The long axes of the three depression were parallel to each other and orthogonal to the long axis of the grid. A GPR survey was completed by pulling a 400 MHz antenna along ten equally spaced (50 cm), essentially east-west trending grid lines. Each line was 9 m long with reference points spaced at 1 m intervals. Surveys were conducted by pulling the antenna in a back and forth manner along grid lines that were parallel to the x-axis. Along each line, as the antenna was towed passed a reference point, a vertical mark was impressed on the radar record. The RADAN NT (version 3.1) software program was used to process the radar records. Processing included color transformation, marker editing, distance normalization, migration, and range gain adjustments. The 3D QuickDraw for RADAN Windows NT software was used to create 3D images of the site.

Figure 6 is a representative radar record from the grid area. The short, vertical lines at the top of the radar record represent equally spaced (1 m) reference points along the grid line. The radar record is 9-m long. A vertical scale (in meters) appears along the left-hand margin of the record. The vertical scale is based a propagation velocity of about 0.064 m/ns. Using a scanning time of 60 ns, the depth of penetration was about 1.9 m.

Tree roots and rock fragments were present in the Laidig soil. These scattering bodies produce undesired subsurface reflections that complicate radar imagery and mask the presence of burials. In the upper left-hand portion of Figure 6, an area having noticeably higher concentrations of rock fragments is identified by the symbol “A.” Though shallow it would be very tempting to conjure the feature below “A” as a possible burial. The three rectangular blocks enclosed areas of slightly higher or lower signal amplitudes and segmented reflections that possibly represent truncated or mixed soil layers. These features suggest possible grave sites. However, no disruption of surface layers is detectable above these rectangular blocks. In addition, no subsurface point anomaly, such as a casket, is evident in these blocks. It is tantalizing to suppose that if these areas represent disturbances (they underlie shallow surface depressions) the remains were buried in woven materials or encased in a wooden box that has since weathered away. However, in Figure 6, no subsurface reflectors, in themselves, can be categorically identified as a burial. Results of the GPR survey provide unsubstantiated and highly speculative information.

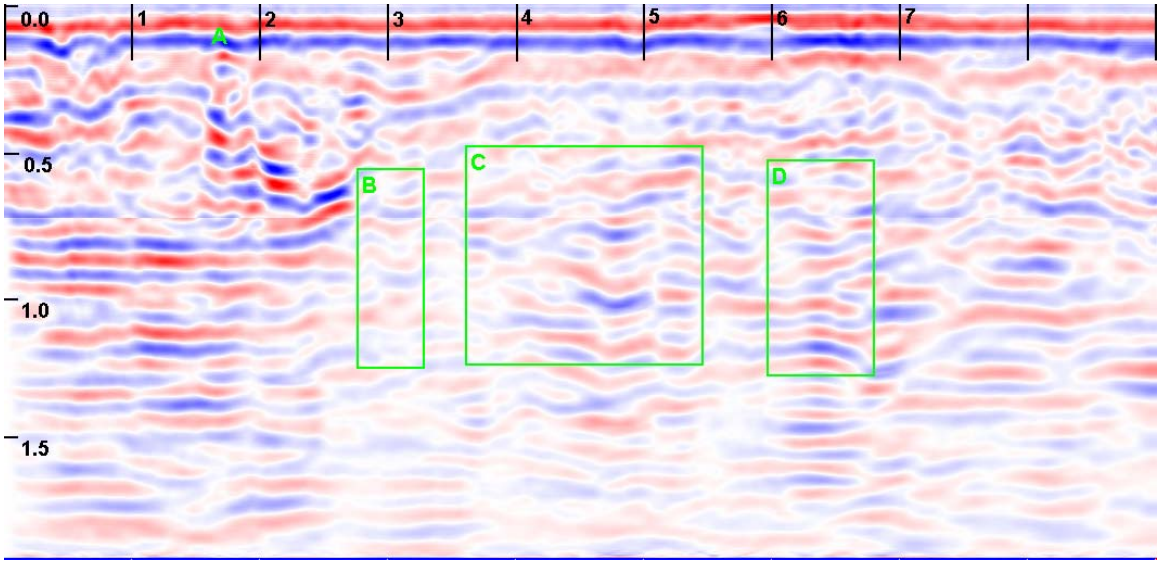

Figure 6. Radar record from the Potters Mills Cemetery.

Lacking adequate subsurface information, interpretations could be made and biased on the basis of the conspicuous surface features rather than from imagery appearing on radar records. Soil materials used to fill a grave shaft or excavation often settle, leaving an obvious depression. The orderly arrangement of rectangular depressions at this site suggests burials. However, no clearly unique and identifiable reflections were evident on the radar records.

<u>3D Time sliced image</u>

Three-dimensional interpretations of GPR data have been used to identify and burials, middens, and other cultural features (Conyers and Goodman, 1997, Whiting et. al, 2000). In the past, the use of 3-D images has been restricted because of the time required to conduct fieldwork over limited areas and the lack of sophisticated image processing software.

Figure 7 is a 3D time-sliced image of the grid area. All units of measurement are expressed in meters. The origin is located in the northeast corner of the grid. A 1-m grid has been overlaid on the cube. "Slices" were made across the cube at depths of 0, 0.64, 1.28, and 1.9 m. These depths were based on an assumption that the velocity of propagation remained constant (0.064 m/ns) with increasing depth through the soil. In all probability, the velocity decreased slightly with depth because of increasing moisture content.

No repeating rectangular pattern with dimensions suggesting a grave shaft is evident in the time-sliced diagram. Though weak, higher amplitude linear reflections are apparent at depths of 1.28 and 1.90 m at X axis positions of 3.2, 4.6, and 5.8 m. These positions correspond with the depressions and suggest possible remnants from burials. However, their lengths are only slightly greater than 1 m along the Y axis. Reflections at 0.64 m are believed to principally reflect soil horizons, rock fragments, and tree roots.

Results of the GPR survey are interpretative. The radar provided satisfactory penetration depths with observable subsurface reflections. Though numerous subsurface reflectors were apparent on radar records, no one feature could clearly and unmistakably be identified as a burial.

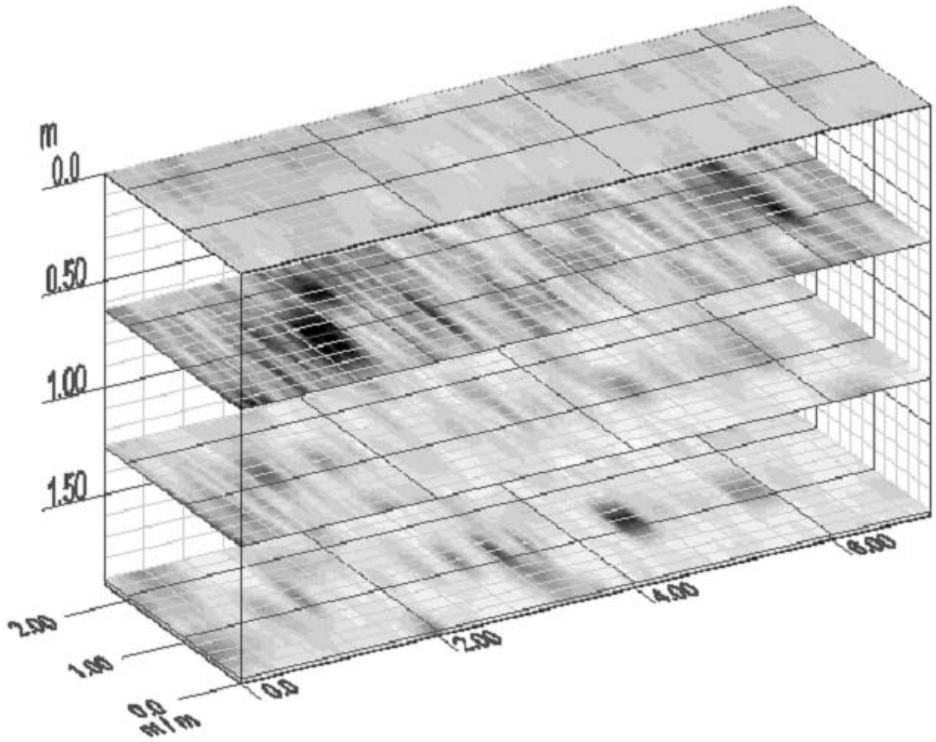

Figure 7. Time-sliced 3D radar imagery from the Potters Mills Cemetery.

References:

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

Bevan, B. and J. Kenyon. 1975. Ground-probing radar for historical archaeology. MASCA (Museum Applied Science Center for Archaeology) University of Pennsylvania, Philadelphia. Newsletter 11(2):2-7.

Braker, W. L. 1981. Soil Survey of Centre County, Pennsylvania. USDA-Soil Conservation Service in cooperation with Pennsylvania State University College of Agriculture, Pennsylvania Department of Environmental Resources and State Conservation Commission. Government Printing Office, Washington DC.

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

Daniels, D. J. 1996. Surface-Penetrating Radar. The Institute of Electrical Engineers, London, United Kingdom.

Doolittle, J. A. 1987. Using ground-penetrating radar to increase the quality and efficiency of soil surveys. pp. 11-32. In: Reybold, W. U. and G. W. Peterson (eds.) Soil Survey Techniques, Soil Science Society of America. Special Publication No. 20.

Geonics Limited. 2000. EM38DD ground conductivity meter: Dual dipole version operating manual. Geonics Ltd., Mississauga, Ontario.

Killam, E. W. 1990. The detection of human remains. Charles C. Thomas Publisher, Springfield, Illinois. p. 263

Morey, R. M. 1974. Continuous subsurface profiling by impulse radar. pp. 212-232. In: Proceedings, ASCE Engineering Foundation Conference on Subsurface Exploration for Underground Excavations and Heavy Construction, held at Henniker, New Hampshire. Aug. 11-16, 1974.

Steputis, W. 1966. Soil Survey of Clinton County, Pennsylvania. USDA-Soil Conservation Service in cooperation with Pennsylvania State University College of Agriculture, Pennsylvania Department of Environmental Resources and State Conservation Commission. Government Printing Office, Washington DC.

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

Whiting, B. M. D., McFarland. D. P., S. Hackenberger. 2000. Preliminary results of three-dimensional GPR-based study of a prehistoric site in Barbados, West Indies. 260-267 pp. IN: (Noon, D. Ed.) Proceedings Eight International Conference on Ground-Penetrating Radar. May 23 to 26, 2000, Goldcoast, Queensland, Australia. The University of Queensland. 908 p.