United States Department of Agriculture

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SUBJECT: SOI – Geophysical Assistance

November 13, 2009

TO: Juan Carlos Hernandez
State Conservationist
NRCS, Bangor, Maine

File Code: 330-7

Purpose: At the request of the State Soil Scientist, ground-penetrating radar (GPR) assistance was provided by the National Soil Survey Center to the NRCS Soil Staff in Maine. The purpose of this assistance was to use GPR to characterize the soils surrounding several sampled soil pedons, determine the composition of selected soil map units (by soil depth class), and assess the adequacy of soil mapping in the "Big Woods portions" of Piscataquis and Somerset Counties.

Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Maryjo Kimble, Soil Scientist, USDA-NRCS, Presque Isle, ME

Activities: All field activities were completed during the period of October 19-21, 2009.

Summary:

1. Radar traverses were conducted across areas of several map units in Piscataquis and Somerset Counties. Data from these radar traverses may be used by soil scientists to determine map unit composition (based on soil depth criteria) and improve soil interpretations. In addition, the collected radar data may help to validate mapping concepts used by soil scientists.

2. In Maine, GPR has been used as a quality control tool to document the composition of soil map units based on soil depth criteria. Radar data are used to support soil interpretations. In many areas of Maine, it is difficult to examine soil profiles and determine the depths to bedrock. Rock fragments and irregular or weathered bedrock surfaces limit the effectiveness of conventional probing tools. In these areas GPR is a more effective tool for determining the depth to bedrock than conventional soil survey tools. GPR allows the rapid and seemingly effortless collection of large amounts of information on the underlying lithology in the absence of a satisfactory number of cores or sufficient lateral or vertical soil exposures or outcrops. GPR interpretations are verified with a limited number soil cores and exposures.

3. A technical report summarizing the findings of this investigation will be forwarded to the State Soil Scientist and the MLRA Project Leader following the processing, analysis, and tabulation of the collected radar data.

/s/ Jonathan W. Hempel

JONATHAN W. HEMPEL
Director
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cc: See attached list

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Technical Report on Geophysical Investigations conducted in the "Big Woods portions" of Piscataquis and Somerset Counties on 19 to 21 October 2009.

James A. Doolittle

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) and Jol (2008) discuss the use and operation of GPR. The 200 and 400 MHz antennas were used in this investigation. A Trimble AgGPS 114 L-band DGPS (differential GPS) antenna (Trimble, Sunnyvale, CA) was used to georeferenced GPR data.[1]

The RADAN for Windows (version 6.6) software program (GSSI) was used to process the radar records.[1] Basic processing steps that were applied to all radar records include: header editing, setting the initial pulse to time zero, color table and transformation selection, display range gain adjustments. Migration and stacking processing procedures were also applied to improve the clarity and interpretability of subsurface interfaces.

The SIR-3000 system provides a setup for the simultaneous use of a GPS receiver and serial data recorder (SDR). This setup georeferences GPR data for display in imaging software such as geographic information systems (GIS). With this setup, each scan on a radar record is essentially georeferenced (position/time matched). GPR readings (scans) are not continuous, but are taken at set time intervals. In this study, the scanning rate was 40 scans/sec. Position data were recorded at a rate of one measurement/sec with the AG114 GPS receiver. In RADAN, the position of each radar scan is proportionally adjusted according to the time stamp of the two nearest positions recorded with the GPS receiver. As each scan of the radar is georeferenced, the integration of GPS with GPR results in incredibly large data sets.

Using the *Interactive Interpretation* module of the RADAN for Windows software program, depths to contrasting interfaces were quickly, automatically, and reasonably accurately picked and outputted to a worksheet (X, Y, Z format; containing latitude, longitude, depths to contrasting interface, and other useful data). Using the *Interactive Interpretation* module, radar data can be easily exported into GIS for plotting and visualization.

Field Procedures:
The presence of numerous stumps, felled debris, dense undergrowth, exposed rocks, and uneven soil surfaces makes it is very difficult to operate the GPR and collect radar records in the *Big Woods* of Maine. These features impair the steady movement of GPR antennas and/or cause unwanted reflections, which clutter radar records, mask reflections from desired interfaces, and impair interpretations. Because of the inhospitable environment of the *Big Wood*, GPR traverses are generally restricted to logging trails, which have minimum cut and fill, and to "more open areas" in this densely forested setting.

Each radar traverse was completed by pulling an antenna by hand. Because of its smaller physical size and portability, the 400 MHz antenna is preferred for soil investigations in the *Big Wood*. In addition,

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

compared with the 200 MHz antenna, the 400 MHz antenna provides adequate penetration depths, slightly higher resolution, and greater clarity of most subsurface interfaces.

Calibration of GPR:
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, stratigraphic layer) 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 the following equation (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 the equation (after 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 commonly expressed in meters per nanosecond (ns). In soils, the amount and physical state of water (temperature dependent) have the greatest effect on the E_r and v.

At most sites, E_r and v were determined by comparing the interpreted depth to a known, buried metallic reflector (whose image was identified on a radar record) with the two-way pulse travel time to this reflector on radar records. Based on the measured depth and the two-way travel time to the reflector, and equation [1], the E_r and v were estimated. At some sites, hyperbola matching techniques were used to confirm the relative dielectric permittivity and the velocity of propagation.
The relative dielectric permittivity and velocity of propagation varied with antenna frequency and with soils and landscape positions. At the time of this investigation, in the study areas, the relative dielectric permittivity ranged from 4.3 (area of Adams-like soils) to 10.0 (Roundabout soil).

Soils:
Table 1 provides the taxonomic classifications of soil series named in the mapping units that were traversed with GPR in Piscataquis and Somerset Counties.

Table 1
Taxonomic classifications of soils traversed with GPR in Piscataquis and Somerset Counties, Maine

Soil Series	Taxonomic Classification
Elliottsville	Coarse-loamy, isotic, frigid Typic Haplorthods
Kinsman	Sandy, isotic, frigid Typic Endoaquods
Monson	Loamy, isotic, frigid Lithic Haplorthods
Nicholville	Coarse-silty, isotic, frigid Aquic Haplorthods
Rag Muffin	Coarse-loamy, isotic, frigid Aquic Haplorthods
Roundabout	Coarse-silty, mixed, active, nonacid, frigid Aeric Epiaquepts
Searsport	Sandy, mixed, frigid Histic Humaquepts
Wonsqueak	Loamy, mixed, euic, frigid Terric Haplosaprists

Radar traverses were conducted in an area that had been mapped as Kinsman-Searsport association, 0 to 3 % slopes (4A). The very deep, poorly drained Kinsman and very poorly drained Searsport soils form in coarse and moderately-coarse textured glacial outwash, respectively. The area investigated with GPR was higher-lying and better drained than the typifying landscape for this map unit and contained a large number of boulders and small areas of exposed bedrock.

Radar traverses were conducted in areas that had been mapped as Roundabout-Nicholville association, 0 to 8 % slopes (16XB). The very deep, moderately well drained Nicholville soils form in wind or water deposited materials on lake plains and low benches. In Nicholville soils, the depth to contrasting deposits (2C horizon) is greater than 30 inches (76 cm). Typically, the contrasting deposits are coarser textured, single grain, massive, or have weak platy divisions associated with depositional layers. The very deep, poorly drained and somewhat poorly drained Roundabout soils formed in glaciolacustrine deposits. Compared with Nicholville soils, Roundabout soils are on lower-lying more concave landscape positions.

Radar traverses were conducted in areas mapped as Roundabout- Wonsqueak association, 0 to 3 % slopes (16XA). The very deep, very poorly drained Wonsqueak soils form in a mantle of well decomposed organic soil material over loamy mineral materials. Wonsqueak soils are in shallow depressions on glaciated landscape.

Multiple transects were conducted in areas of Ragmuff-Monson complex, 3 to 15 % slopes, rocky (89C); and Elliottsville-Monson complex, 15 to 35 % slopes rocky (89D). The moderately deep to bedrock, moderately deep to densic contact, moderately well drained Ragmuff; shallow, somewhat excessively drained Monson; and moderately deep, well drained Elliottsville soils form in glacial till.

Results:

Kinsman-Searsport association, 0 to 3 % slopes (4A):

The site (45.79264 N. Latitude, 68.90506 W. Longitude) is located just off the *Golden Road* in Piscataquis County. The site is relatively open and has been used as a source of sand and gravel. The area of this unit that was investigated with GPR is higher-lying and better drained than typical for this map unit and contained a large number of large boulders and small areas of exposed bedrock. Soils at this site appear more similar to the excessively and somewhat excessively drained Adams soils (sandy, isotic, frigid Typic Haplorthods). Soils at this site, however, are mostly, more shallow to bedrock than Adams soils.

Figure 1 is a representative radar record from this site. On this radar record, both vertical and horizontal scales are expressed in meters. In Figure 1, the overlying, coarse-textured outwash appears to lack high-amplitude, linear reflectors, which would indicate contrasting strata. A green colored line has been used to identify the interpreted soil/bedrock interface. The bedrock contains higher-amplitude reflections, which aids its identification. These reflectors appear as point, sigmoid, and planar patterns, which suggest inhomogeneities and complex layering within the bedrock. Based on multiple radar traverses, the average interpreted depth to bedrock is 115 cm with a range of 0 to 167 cm. At this site, one-half of the depth to bedrock interpretations is between 100 and 130 cm.

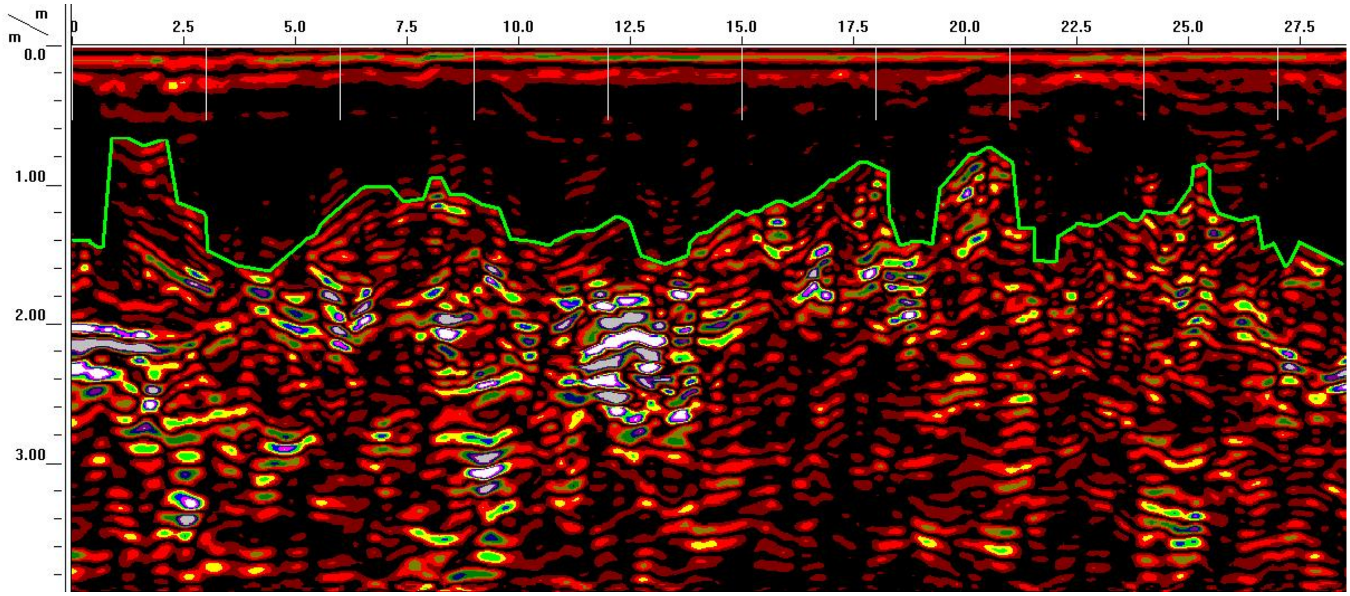

Figure 1. This radar record from the Kinsman-Searsport map unit is from a higher-lying, included area, which is shallower to bedrock. The green-colored line highlights the interpreted depth to bedrock. The soil materials overlying the bedrock are derived from sandy outwash and appear to lack contrasting strata.

Roundabout-Nicholville association, 0 to 8 % slopes (16XB):
Two sites in units of Roundabout-Nicholville association on 0 to 8 % slopes and were surveyed with GPR in Piscataquis County. These sites are located in thickly wooded areas near the *Golden Road* and off of *Fire Road 23* (45.7375 N. Latitude, 68.8486 W. Longitude) and *Baxter Road* (45.74375 N. Latitude, 68.8483 W. Longitude). Roundabout and Nicholville soils form in water-deposited materials that have a high content of silt and very fine sand. These soils typically lack coarse fragments. For Roundabout and Nicholville soils, the depth to bedrock is more than 60 inches (152 cm). Nicholville soils are described as having contrasting materials at depths greater than 30 inches (76 cm). Typically, the contrasting materials are coarser textured, single grain, massive, and/or have weak platy divisions associated with depositional layers.

Figure 2 is a radar traverse from an area of Roundabout-Nicholville association, 0 to 8 % slopes (45.7375 N. Latitude, 68.8486 W. Longitude). A sampled soil pit is located near the 26 meter distant mark (white vertical line at the top of the radar record) in the extreme right-hand portion of this radar record. On this radar record, both vertical and horizontal scales are expressed in meters. In Figure 2, the overlying, water-deposited sediments generally lack high-amplitude, linear reflectors, which would suggest water-deposited, contrasting strata. Point reflectors in the upper part of this radar record most likely represent larger roots and rock fragments. In Figure 2, a green-colored, segmented line has been used to approximate the depth to contrasting materials. These underlying materials contain high-amplitude reflections (colored white and gray), which signify contrasting layers or materials. Along this radar traverse, the average interpreted depth to the underlying, contrasting materials is 150 cm with a range of 110 to 208 cm. One-half of the radar interpreted depths to these contrasting materials are between 135 and 169 cm. Soils are dominantly deep (62 %) and very deep (38%) to contrasting materials. Unfortunately, the available soil probe was too short to identify the underlying, contrasting materials and confirm these depth estimates.

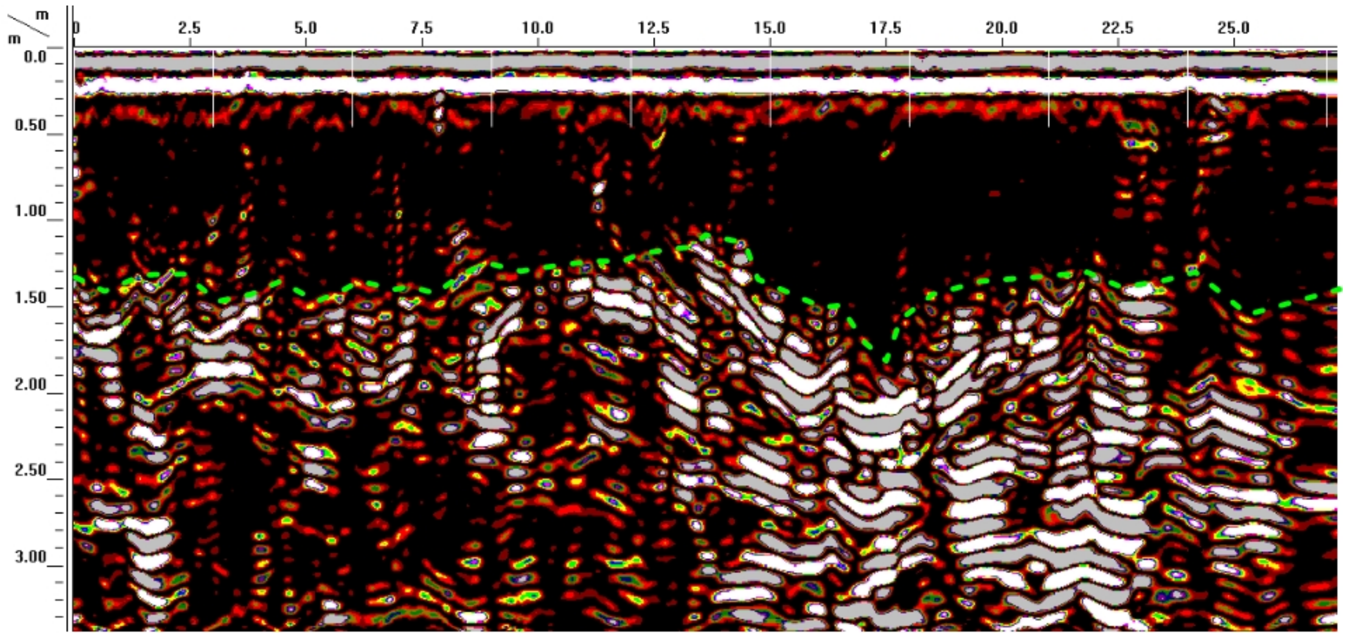

Figure 2. This radar record is from an area of Roundabout-Nicholville association on 0 to 8 % slopes. A green colored, segmented line has been used to indicate the interpreted depths to contrasting materials.

Data from the second area of Roundabout-Nicholville association, 0 to 8 % slopes (45.74375 N. Latitude, 68.8483 W. Longitude) revealed similar depth characteristics. Here, the averaged interpreted depth to the underlying, contrasting materials is 145 cm with a range of 104 to 192 cm. One-half of the radar interpreted depths to this interface are between 133 and 152 cm. Soils are mostly deep (70 %) and very deep (30%) to contrasting materials. Again, the lack of a suitable soil probe and difficulties in auguring through the overlying soil materials resulted in our inability to identify, measure, and confirm depths to these contrasting materials.

<u>Roundabout-Wonsqueak association, 0 to 3 % slopes (16XA):</u>
The sites are located just off the *Seboomook Dam Road* (45.8909 N. Latitude, 69.5779 W. Longitude) and the *Golden Road* (45.9291 N. Latitude, 69.6321 W. Longitude) in Piscataquis County. These sites are poorly drained and very densely vegetated. Standing water was observed in nearby sample pits. As both sites are thickly forested, radar traverse lines were restricted to the “more open areas” that were relatively free of fallen debris. Radar traverses were generally restricted to higher-lying areas of Roundabout soils. The areas traversed have an organic mantle that is less than 16 inches (40 cm) thick.

Figure 3 is a representative radar record from the *Golden Road* site (45.9291 N. Latitude, 69.6321 W. Longitude). On this radar record, both vertical and horizontal scales are expressed in meters. In Figure 3, a green-colored line has been used to approximate an interface that separates very fine sandy loam from denser, silt loam soil materials. Although the interface was observed and verified in soil cores extracted from this site, because of the large number of closely spaced interfaces, this denser layer was difficult to trace laterally with confidence across this radar record. The smooth, wavy interfaces in the lower part of this radar record are assumed to represent contrasting layers of glaciolacustrine deposits. The noticeably higher-amplitude (colored white, pink, blue and green) near-surface reflections suggest variations in the depth and the contrast in materials across the organic/mineral interface. More core observations, however, are needed to confirm interpretations.

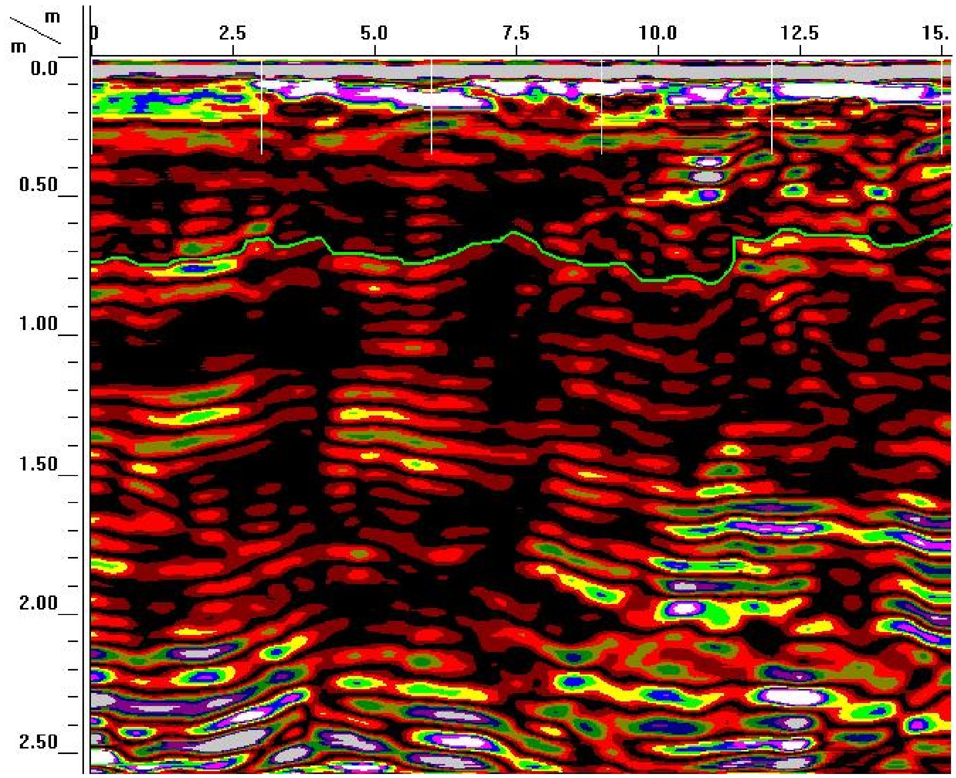

Figure 3. This radar record is from an area of Roundabout-Wonsqueak association, 0 to 3 % slopes (16XA). The green-colored line approximates an interface that separates very fine sandy loam (above) from denser silt loam (below) soil materials

<u>Ragmuff-Monson complex, 3 to 15 % slopes, rocky (89C); and Elliottsville-Monson complex, 15 to 35 % slopes rocky (89D):</u>

The selection of this site was random. The two adjoining map units are located on either side of two intersecting logging roads (45.9969 N. latitude and 70.0457 W. longitude) in western Somerset County (see Figure 5). As we approached this site, the absence of ledge and rock outcrops suggested that the soils are not shallow and moderately deep to bedrock as indicated in the map unit names, and that the areas may have been incorrectly mapped.

Figure 4 is a representative radar record from an area of Ragmuff-Monson complex, 3 to 15 % slopes, rocky. On this radar record, both vertical and horizontal scales are expressed in meters. In Figure 4, a green-colored, segmented line has been used to approximate the interpreted soil/bedrock interface. This interface is suspected to be highly fractured and to have an irregular topography. As a result, the radar image of the soil/bedrock interface is very segmented and variable in signal amplitude. The lack of continuity in expression makes the identification of the soil/bedrock interface rather ambiguous and "more interpretive" on radar records. Though unclear in portions of radar records, overall, interpretations are considered reasonably accurate. In Figure 4, the interface identified at "A" is believed to represent the base of a fill layer along the logging trail. A presumably denser soil layer can be crudely traced across the radar record at depths of about 100 to 150 cm. The boundaries of this contact appear, faint in expression and highly segmented and irregular in form.

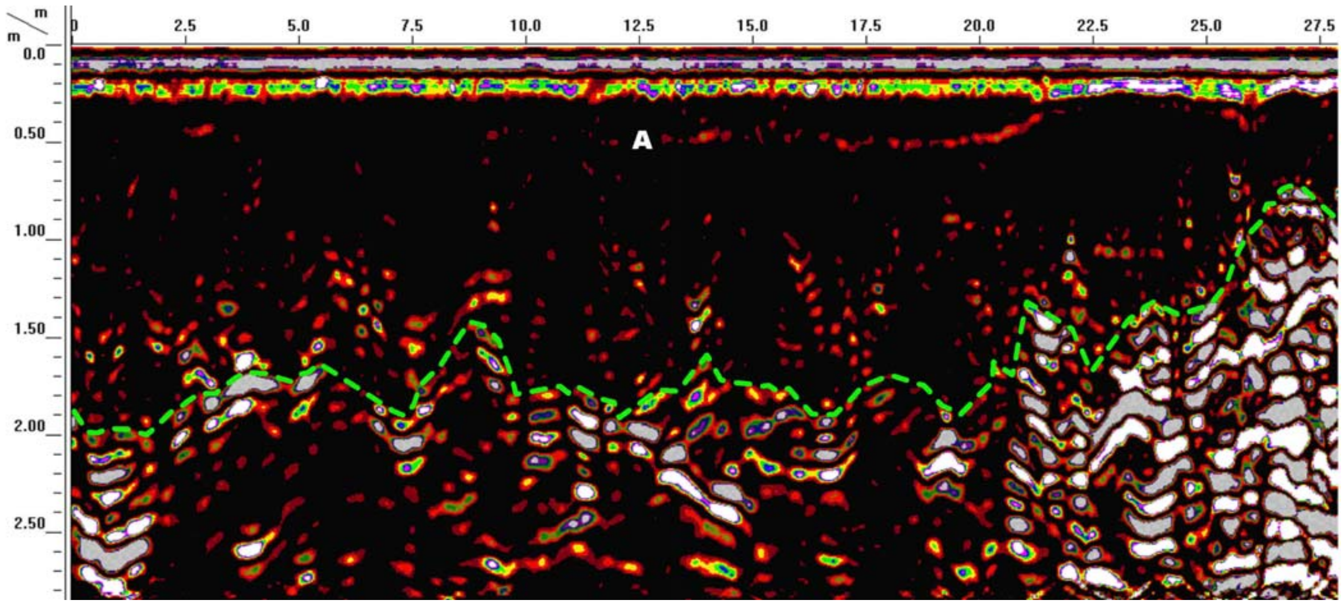

Figure 4. This radar record is from an area of Ragmuff-Monson complex, 3 to 15 % slopes, rocky (89C). The green-colored line approximates the interpreted soil/bedrock interface

Table 2 summarizes the frequency distribution of interpreted radar depth-to-bedrock measurements based on soil depth classes. Radar traverses 21, 22, 23, and 26 were conducted in area of Ragmuff-Monson complex, 3 to 15 % slopes, rocky (89C); and radar traverses 27 and 28 were conducted in an area of Elliottsville-Monson complex, 15 to 35 % slopes rocky (89D). For all traverses, soils are interpreted to be dominantly deep and very deep to bedrock. These soil depth classes do not represent the concepts of either soil map unit.

In areas of the Ragmuff-Monson complex, 3 to 15 % slopes, rocky (89C) map unit, based on 27,940 observations, the average depth to bedrock is 147 cm with a range of 36 to 265 cm. One half of the observations have depths to bedrock between 118 and 177 cm. In areas of the Elliottsville-Monson complex, 15 to 35 % slopes rocky (89D) map unit, based on 9982 observations, the average depth to bedrock is 140 cm with a range of 71 to 221 cm. One half of the observations have depths to bedrock between 123 and 158 cm. The two delineated areas looked very similar to me and Mary Jo, and the results of the radar surveys suggested similar depths to bedrock for each unit. These areas could be mapped as one unit. Figure 5 is a Google Earth image of the area that was traversed with GPR. The locations of the GPR traverse lines are shown in this image. Each traverse line is colored-coded based on the interpreted soil depth classes for the depth to bedrock. The dominance of very deep and deep soils is evident on this image.

Table 2

Frequency distribution of observation based on soil depth classes for radar traverse conducted in areas of Ragmuff-Monson complex, 3 to 15 % slopes, rocky (89C) (colored black), and Elliottsville-Monson complex, 15 to 35 % slopes rocky (89D) (colored red)

Transect	shallow	mod deep	deep	very deep
21	0.01	0.24	0.62	0.13
22	0.00	0.04	0.17	0.79

23	0.00	0.07	0.35	0.58
26	0.00	0.18	0.48	0.34
27	0.00	0.08	0.68	0.24
28	0.00	0.07	0.48	0.45

Figure 5. *In this Google Earth image, the locations of georeferenced GPR traverses, which were conducted in areas of Ragmuff-Monson complex on 3 to 15 % slopes, rocky (89C); and Elliottsville-Monson complex on 15 to 35 % slopes, rocky (89D), lines are shown. Colors indicate the depths to soil/bedrock contact according to soil depth classes. This contact is predominantly deep (100 to 150 cm) and very deep (> 150 cm) in areas traversed by GPR.*

References:

Daniels, D. J., 2004. Ground Penetrating Radar; 2nd Edition. The Institute of Electrical Engineers, London, United Kingdom.

Jol, H., 2008. Ground Penetrating Radar: Theory and Applications. Elsevier Science, Amsterdam, The Netherlands.