United States Department of Agriculture

Natural Resources Conservation Service

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Subject: SOI – Geophysical Field Assistance **Date:** 19 September 2004

To: Dr. Henry Lin
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Purpose:
Ground-penetrating radar (GPR) was used to assist the Pennsylvania State University's Hydropedology Team map spatial variations in soils and soil properties within a small watershed.

Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Jake Eckenrode, Resource Soil Scientist, USDA-NRCS, Lamar, PA
Henry Lin, Assistant Professor, Crop & Soil Sciences Department, Penn State University, University Park, PA
Brad Georgic, Senior Research Technologist, Crop & Soil Sciences Department, Penn State University, University Park, PA
Chip Kogelmann, PhD student, Crop & Soil Sciences Department, Penn State University, University Park, PA
Yuri Plowden, Soil Scientist, USDA-NRCS, University Park, PA
Chuck Walker, PhD student, Crop & Soil Sciences Department, Penn State University, University Park, PA

Activities:
All field activities were completed on 1 to 2 September 2004.

Summary:

1. In future studies of the Shale Hills Watershed, detailed radar investigations of small selected areas and the construction of 3D imagery may be used to improve knowledge of the variability of soils and soil properties.

2. Bitmap files of all radar records have been forwarded to Brad Georgic under a separate cover letter.

It was my pleasure to participate in this study and to work with the faculty and staff of Pennsylvania State University.

With kind regards,

James A. Doolittle
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cc:

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Shale Hills Watershed:

The Pennsylvania State University's Hydropedology Team is studying spatial and temporal variations in soil properties that influence the distribution and flow of soil water at different scales within the Shale Hills Watershed. The watershed is located near the Stone Valley Recreation Center in Huntingdon County (~15 miles from State College). This forested watershed is relatively small (7.8 ha) and well defined. Figure 1 shows the relative topography of the watershed. This map was prepared from GPS measurements. Based on these measurements, elevations range from 232.5 to 275.8 m within the watershed. In Figure 1, a segmented, blue-colored line has been used to indicate the approximate location of the small stream that drains the watershed. This stream is intermittent along most of its course through the watershed. Within the watershed, a continuous flow of water is maintained throughout the year only along the lower course of the stream. This portion of the stream lies beneath a thick canopy of evergreen trees. Also shown in Figure 1 are the locations of the radar traverse lines (colored either red or yellow) that were conducted during this study.

The watershed has been mapped principally as Berks-Weikert association, steep, and Ernest silt loam, 3 to 8 percent slopes (Merkel, 1978). The watershed also includes small areas of Berks-Weikert shaly silt loam, 15 to 25 percent slopes, and Berks shaly silt loam, 8 to 15 percent slopes (Merkel, 1978). The Pennsylvania State University's Hydropedology Team has completed an order-one soil survey of the watershed. On the high intensity soil map, Weikert soil dominates most of the higher-lying and more sloping plane and convex slopes of the watershed. Earnest and Blairton soils are restricted to the main stream channel. Berks and Rushtown soils have been mapped in swales or shallow ravines form by smaller, contributing intermittent streams. All soils contain large amounts of rock fragments and have varying depths to thinly bedded and highly fractured bedrock. Within the watershed, the underlying bedrock is Rose Hill shale.

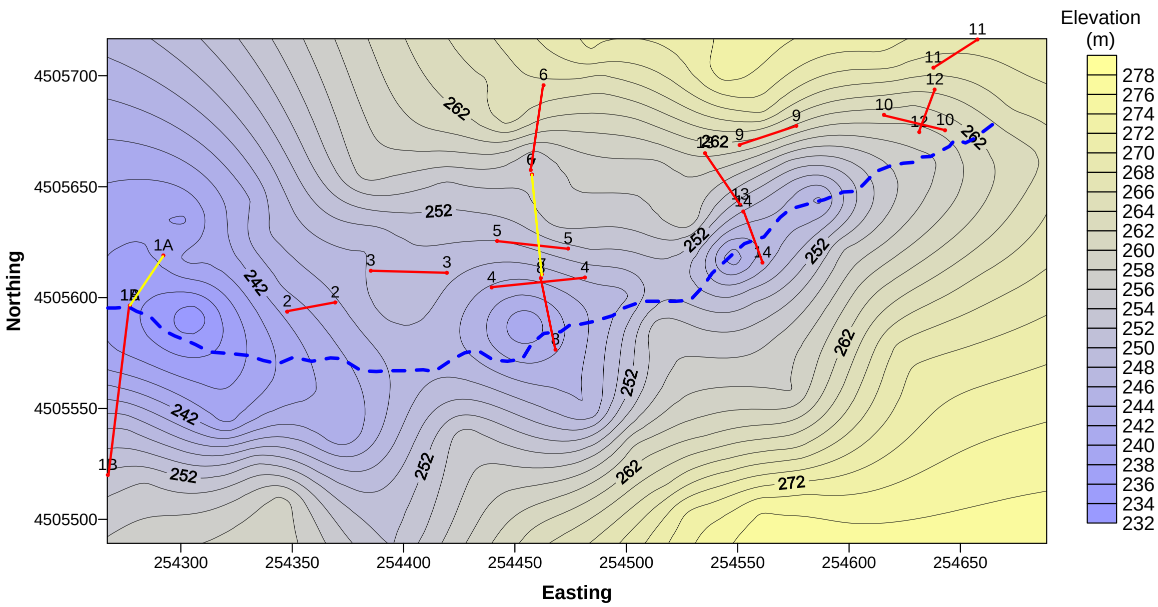

Figure 1. Relative topography of the Shale Hills Watershed (Based on GPS measurements).

All soils formed in materials weathered from shale. The well drained, shallow Weikert and moderately deep Berks soils are on gently sloping to very steep slopes. Weikert is a member of the loamy-skeletal, mixed, active, mesic Lithic Dystrudepts family. Depths to bedrock ranges from 25 to 50 cm in Weikert soil. The Berks soil is a member of the loamy-skeletal, mixed, active, mesic Typic Dystrudepts family. The moderately deep, somewhat poorly drained and moderately well drained Blairton soil is on swales and drainage heads. Blairton is a member of the fine-loamy, mixed, active, mesic Aquic Hapludults family. For Berks and Blairton soils, depths to bedrock range from 50 to 100 cm.

The very deep, moderately well drained Ernest soil is on foot slopes. Ernest is a member of the fine-loamy, mixed, superactive, mesic Aquic Fragiudults family. A fragipan is within depths of about 50 to 90 cm. The very deep, excessively drained Rushtown soil is on swales. Rushtown is a member of the loamy-skeletal over fragmental, mixed, active, mesic Typic Dystrudepts family. For Ernest and Rushtown soils, depths to bedrock are greater than 152 cm.

Equipment:
The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (here after referred to as the SIR System-3000), manufactured by Geophysical Survey Systems, Inc.[1] The SIR System-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 System-3000 weighs about 9 lbs (4.1 kg) and is backpack portable. With an antenna, this system requires two people to operate. A 400 MHz antenna was used in this study. The use and operation of GPR are discussed by Daniels (2004).

The RADAN for Windows (version 5.0) software program developed by Geophysical Survey Systems, Inc, was used to process the radar records. [1] Processing included setting the initial pulse to time zero, color table and transformation selection, marker editing, distance normalization, range gain adjustments, migration, and surface normalization. All radar records were migrated to remove hyperbola diffractions and to correct the geometry of steeply dipping layers. Surface normalization corrects the radar record for changes in elevation and, in this study, greatly improved interpretations and the association of subsurface reflectors with soils and landscape components.

Survey Procedures:
Radar traverses were completed along selected lines established across different landscape components and soil polygons (see Figure 1). These traverse lines were located on the south-facing slopes of the watershed. Along each line, reference flags were inserted in the ground at an interval of 3 m. Pulling the 400 MHz antenna along each line completed the GPR survey. Along each line, as the antenna was towed passed a reference point, a vertical mark was impressed on the radar record.

Three 5- x 5-m grids were located on different slope components along traverse line 6. To expedite field work, two equal length and parallel lines were set out at each grid site. These two parallel lines defined a rectangular grid area. Eleven survey flags were inserted in the ground (at 0.5 m intervals) along each of the two lines. For positional accuracy, surveys were completed by stretching and sequentially moving a reference line between similarly numbered flags on the two parallel grid lines.

Pulling the 400 MHz antenna along a reference line that was stretched between similarly numbered flags on the two parallel survey lines completed a GPR traverse. Along the reference line, marks were spaced at 1-m intervals. As the antenna was towed passed each reference point, a vertical mark was impressed on the radar record. At the conclusion of each traverse, the reference line was moved sequentially to the next flags on the two parallel survey lines. Walking, in a back and forth manner, along the reference line between similarly numbered flags on the two parallel survey lines completed a GPR survey.

Based on the depth to a known, buried reflector and a hyperbola-matching program in RADAN Windows NT, the velocity of propagation was observed to decrease with increasing depth, but averaged about 0.11 m/ns through the upper part of the relatively dry soil profile (dielectric permittivity of 7.3). Using this velocity, a scanning time of 60 nanoseconds provided a maximum penetration depth of about 3.3 m.

Results:
<u>GPR Survey:</u>
Multiple traverses were conducted with the 400 MHz antenna along lines located principally on south-facing slopes of the watershed. In general, observation depths and resolution of subsurface features were adequate for the determination of soil depths. However, because of the nature and complexity of subsurface reflectors, the delineation of soil and bedrock features was extremely challenging and subjective.

At each interface the radiated electromagnetic wave is partly reflected and partially transmitted. The intensity of the reflected wave will depend on the electromagnetic properties of the two materials, the angle of incidence, and the incident wave's polarization.

<u>Line 6:</u>

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

Line 6 extends principally along the center line of a long, narrow swale that cuts across the south-facing slope of the watershed. The swale extends from the crest of the ridgeline to the stream channel below. In addition, the line extends about 9 m up the north-facing slope on the opposite side of the stream channel. The line is 126 m long and consists of 43 flagged reference points that are spaced at an interval of about 3 m. Relief along the line is about 26.9 m.

The cross section of Line 6 is shown in Figure 3. The blue and red points along the line represent the equally spaced (3-m) reference points. The red points signify the approximate location of the three 5 x 5 m grids.

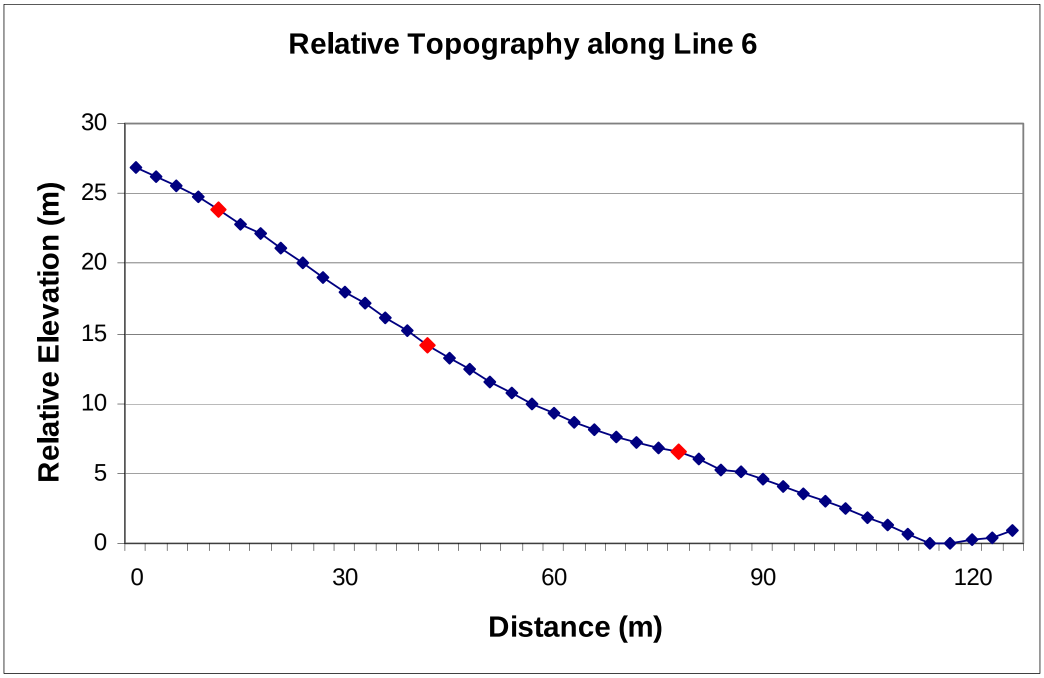

Figure 2. Cross sectional view of the topography along Line 6.

On slopes, radiated radar energy has a horizontal component that increases with the angle of the slope (Neal, 2004). This component is not fully accounted for and reflections are often significantly out of place on migrated data where slopes exceed 6^{o} (Neal, 2004). Figure 3 is the radar record from the convex summit area. This area is dominated by Weikert soil. The soil/bedrock interface is partially obscured by multiples of the strong surface reflection. Though partially obscured, the soil/bedrock interface appears at depths of 40 to 50 cm. At about the 10-m mark, reverberation from a buried metallic object are evident. Below the soil/bedrock interface, the bedrock is essentially free of high and medium amplitude reflections. Reflections that appear in the lower part of the radar record (below depths of 1.6 to 2 m) are noise. The bedrock is seemingly reflection-less. Bedding planes are highly inclined, fractured, and closely spaced (see Figure 4). High frequency propagation is often limited by scattering losses (important when the wavelength approaches the size of the reflector (Neal, 2004). Because of the large number and narrowness of these planes, the target scattering loss is increased.) Often, the propagated radar energy is scattered in random directions by scales of geological heterogeneity comparable to the wavelength. Scattering is both good and bad. If there is no scattering, then there is nothing for the radar to see. If there is too much scattering, then the radar can't see anything through the scatter. Desirable scattering is called a target or a reflector and undesirable scattering is called clutter

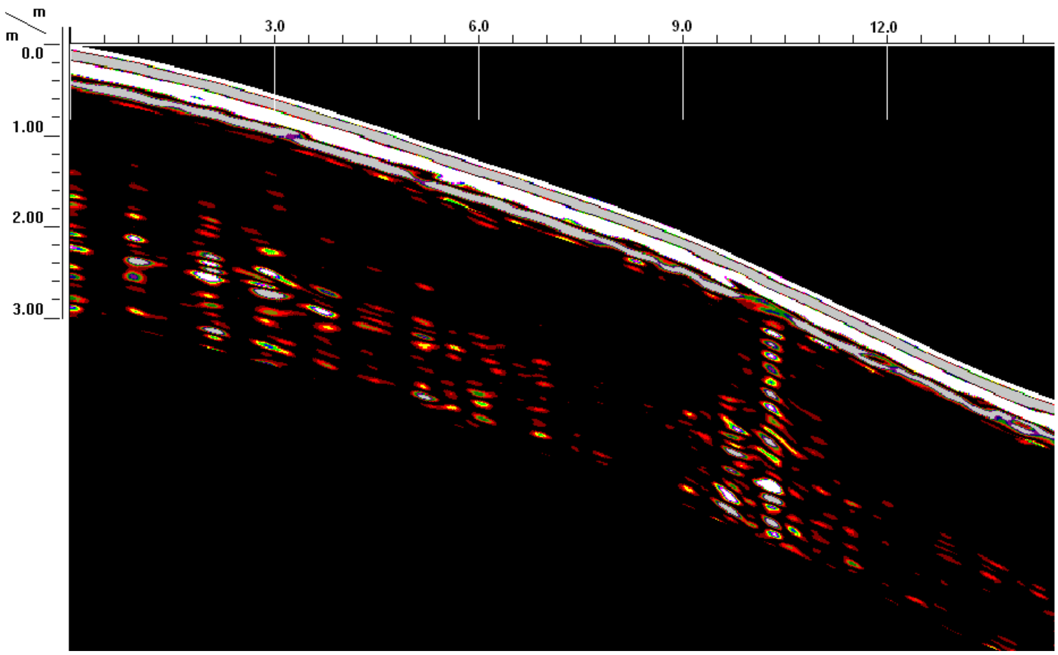

Figure 3. Scattering losses prevent desired radar reflections and noise clutters the lower part of this radar record from an area of Weikert soil near the summit area of Line 6.

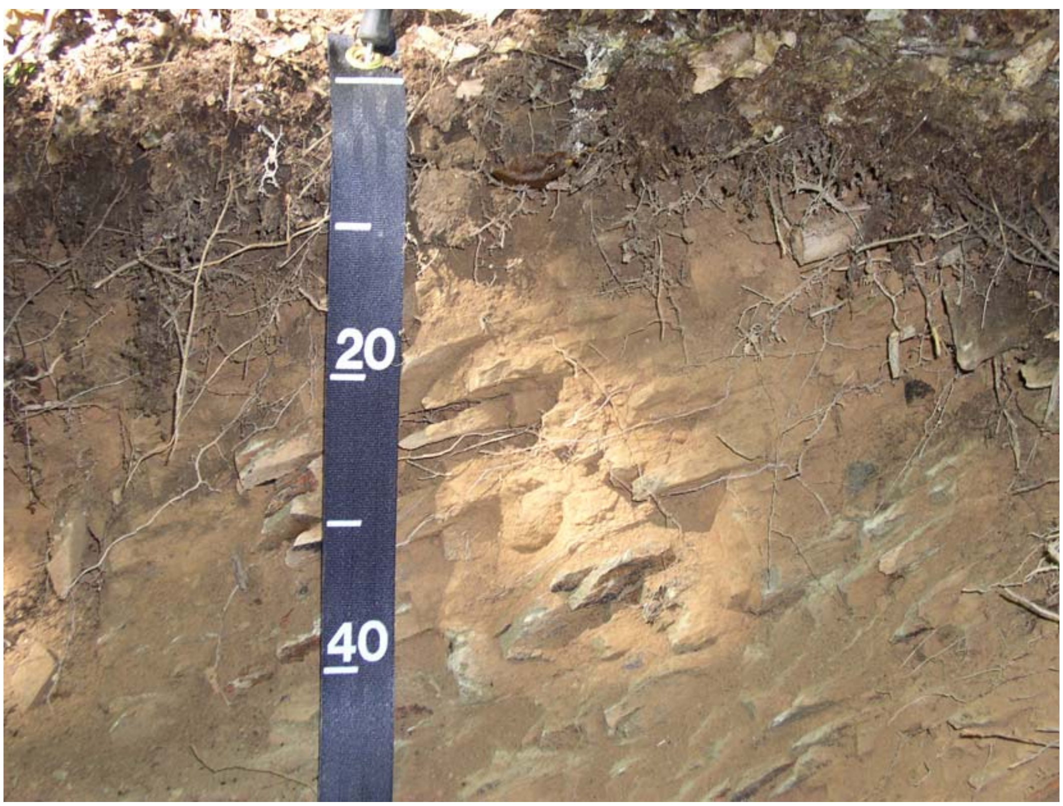

Figure 4. Highly inclined, fractured, and closely spaced bedding planes in a Weikert soil profile.

Near reference point 15-m, the side slopes of the swale become more pronounced and noticeable and the soil deepens over bedrock (see Figure 5). The interpreted depths to bedrock for the reference points that are numbered in Figure 5 are shown in Table 1. Over a lateral distance of 15-m the soil deepen by about 1.25m and transitions from the shallow to the very deep soil depth class.

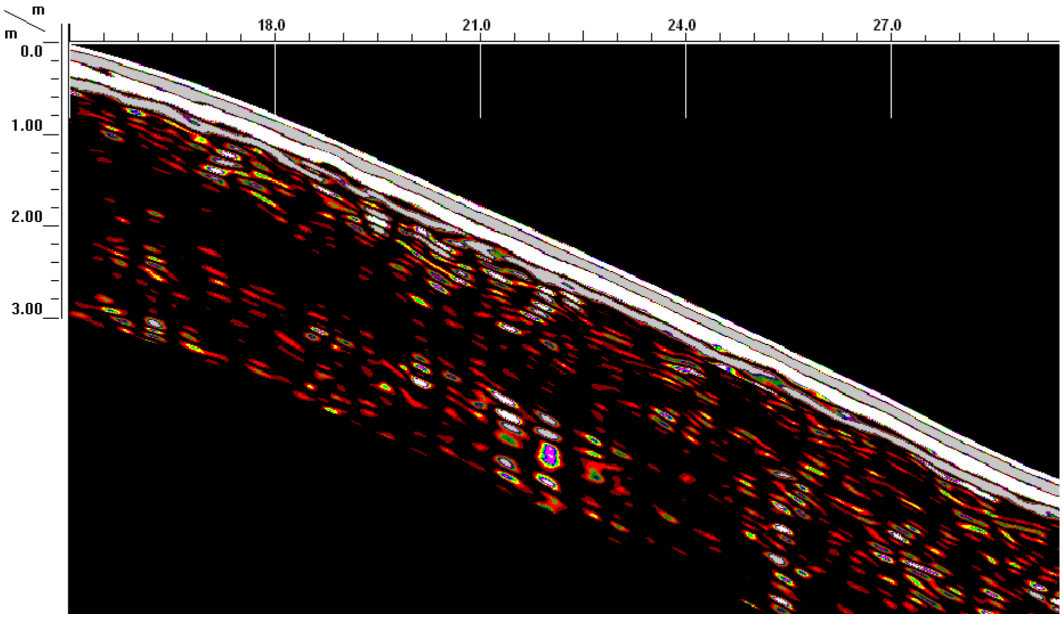

Figure 5. Deepening soil profiles composed of colluvium develop over short distances in the upper part of the swale along Line 6.

Table 1. Interpreted Depth to Bedrock at the Flagged reference points shown in Figure 5.

Reference Point	Soil Depth (m)
15	0.52
18	0.97
21	1.13
24	1.25
27	1.75

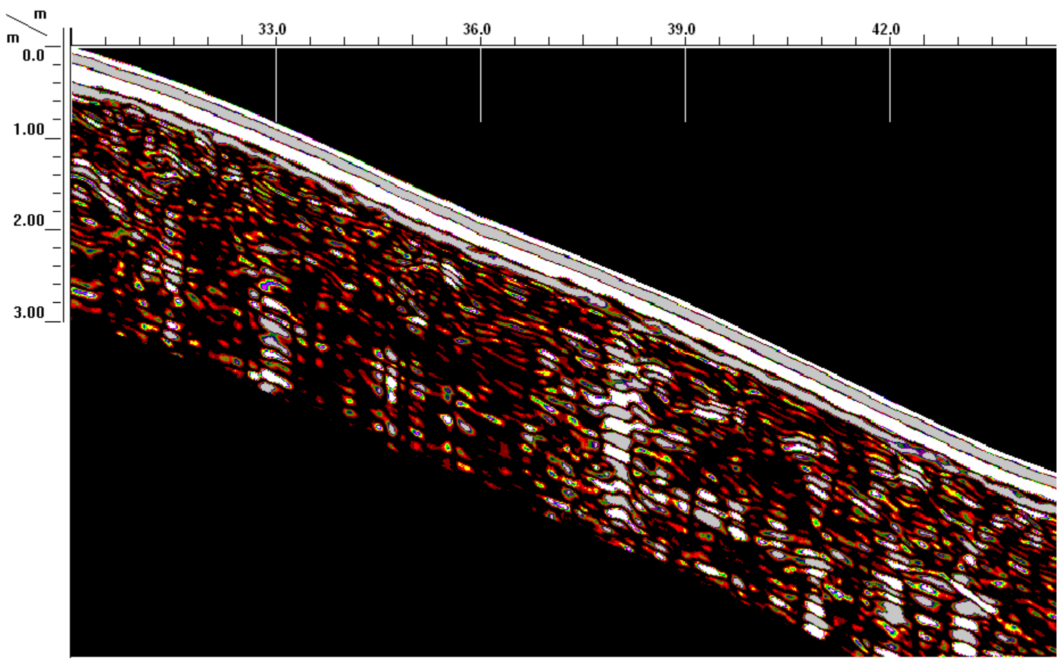

Figure 6. Very deep layers of colluvium occur on the higher portion of the swale on Line 6.

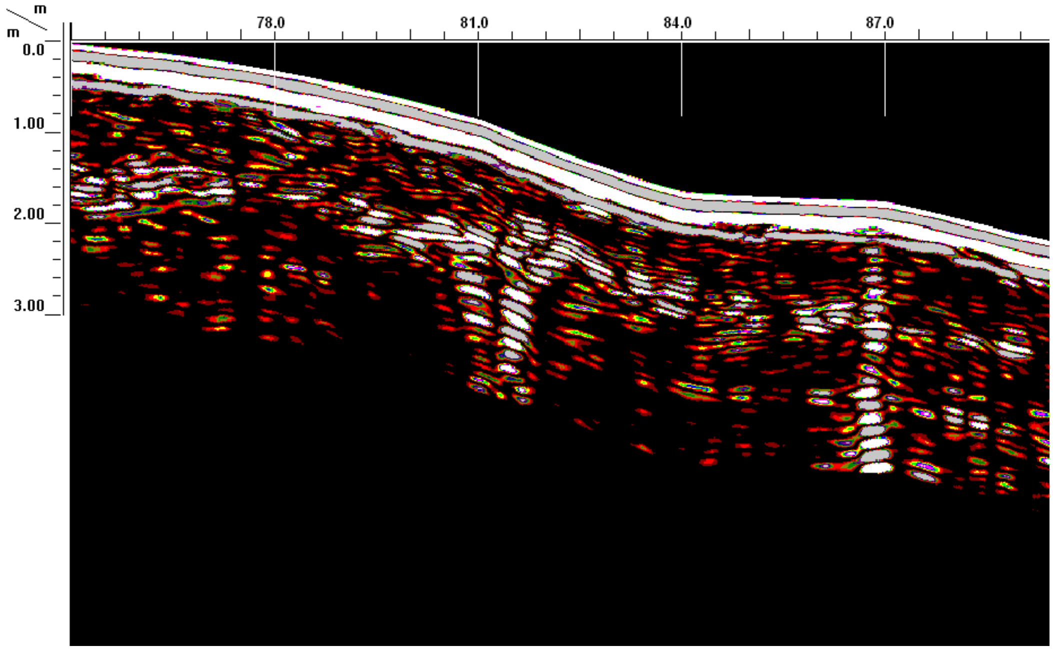

Figure 7 A conspicuous high-amplitude planar reflector is evident on the lower portion of the swale on Line 6.

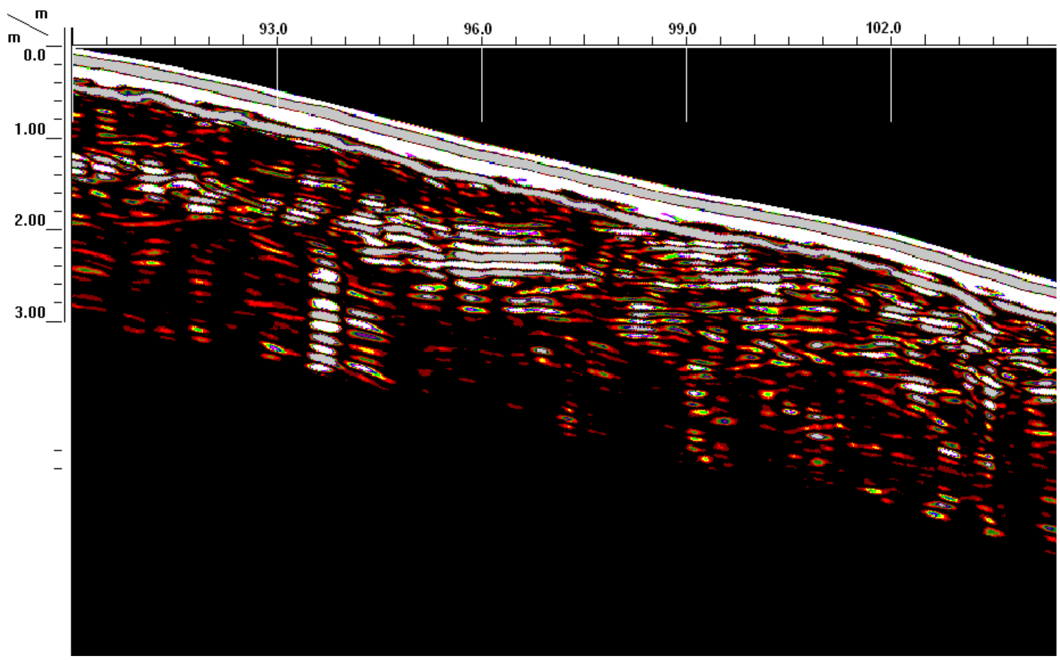

Figure 7 A nick point appears to be underlain by shallow to bedrock soils in the lower portion of the swale on Line 6.

3D images:

As done in this study, the form and geometry of subsurface features can be studied in detail from two-dimensional, intersecting radar profiles (van Heteren et al., 1998). Recently, with the advent of digital GPR outputs and advanced data processing software, it has become possible to analyze the structure or configuration of subsurface features from a three-dimensional perspective. Under favorable conditions, GPR and 3D imaging can provide additional information and perspectives of the subsurface. In order to better understand the structure or configuration of many subsurface features, a series of parallel radar records are obtained over soil, lithologic, and/or stratigraphic features.   Three-dimensional images allow the rapid display of the data volume from different cross-sections and directions (Beres et al., 1999). However, the acquisition of data for 3D images requires greater resources than the collection of 2D radar records. To construct 3D images, a relatively small area is intensively surveyed with closely spaced (often <1 m), parallel GPR traverses. Data from these lines are processed into a 3D image. Once processed, arbitrary cross-sections, insets, and time slices can be extracted from the 3D data set. The flexibility of 3D visualizations can facilitate the interpretation of spatial relationships and the analysis of soil, structural, and/or stratigraphic features. This imaging technique enables views of the subsurface from nearly any perspective (Junck and Jol, 2000). Detailed radar investigations of small selected areas and the construction of 3D imagery may improve our knowledge of the variability of soils and soil properties within the Shale Hills Watershed.

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