United States Department of Agriculture

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SUBJECT: SOI – Geophysical Assistance

June 9, 2014

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Purpose:
Northern Appalachian Ridges and Valley MLRA office conducted ground-penetrating radar (GPR) studies across five separate areas that are mapped as Montevallo soils in Carbon County, Pennsylvania. When mapped in Carbon County, Montevallo series was classified as a shallow Lithosols consisting of "thin, slightly developed soils over the parent C horizon of broken bedrock" [i.e., sandstone, shale, or siltstone]. The objective of this study is to collect information on the depth to bedrock in areas mapped as Montevallo soils with ground-penetrating radar (GPR) in preparation for an anticipated re-correlation of the Montevallo series.

Participants:
John Chibirka, Resource Soil Scientist, USDA-NRCS, Leesport, PA
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Yuri Plowden, Ecological Site Index Specialist/Soil Scientist, USDA-NRCS, Mill Hall, PA
Michael McDevitt, Soil Scientist, USDA-NRCS, University Park, PA
Aron Stattler, MLRA 147 Office Leader, USDA-NRCS, Mill Hall, PA

Activities:
Field activities were completed on 28 and 29 May 2014.

Summary:

1. Field studies like this exemplify how we can [and should] elevate some soil data collection to higher levels using geophysical methods. Over a two day period, 63 radar traverses were completed in Carbon County, Pennsylvania. These traverses covered 3.98 miles and provided continuous spatial data on the depth to bedrock in areas presently mapped as different phases of Montevallo soils. Based on 408,983 GPR measurements, the average depth to bedrock in these areas of Montevallo soils is 61 cm with an estimated depth range of

0 to 2.47 m. Based on the averages of 63 radar traverses, the distribution of soils according to soil depth classes is about: 33 % shallow, 60 % moderately deep, 7 % deep, and 0 % very deep in the areas of Montevallo soils that were traversed by GPR.

2. Ground-penetrating radar interpretations are largely based on the experience of the interpreter and the expression of the soil/bedrock interface appearing on radar records. Because of the large number of rock fragments and the presence of weathered (soft shale) and highly fractured bedrock surfaces in the scanned soils, radar reflections from the soil/bedrock interface were unclear in some areas. However, radar interpretations should be considered a close approximation of the actual depth to bedrock. Based on 11 ground-truth core measurements of the depth to bedrock, the average difference between auger measurement and GPR interpretation was only 3.91 cm. At these 11 observation points, differences in the depth to bedrock with the two methods ranged from 0 to 16 cm.

3. This study greatly expands the amount of information on the depth to bedrock in areas that are mapped as Montevallo soils in Carbon County, Pennsylvania. The use of GPR greatly increased the efficiency of collecting this important data that will be used to justify recorrelation decisions and map unit composition, which will lead to more accurate interpretations based on soil depth criteria.

4. An excel spreadsheet with all the compiled radar data from this study has been forwarded to the Aron Sattler under a separate cover letter. A summary of this data is included in the addendum to this report.

5. Aron Sattler is commended for this excellent handling and organization of this field study.

It was the pleasure of Jim Doolittle and the National Soil Survey Center to conduct this fieldwork and be of assistance to your staff.

/s/ Jonathan W. Hempel

JONATHAN W. HEMPEL

Director

National Soil Survey Center

cc:
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Technical report on ground-penetrating radar (GPR) investigations conducted in areas of Montevallo soils in Carbon County, Pennsylvania, on 28 an 29 May 2014.

James A. Doolittle

Background:
The Montevallo series (loamy-skeletal, mixed, subactive, thermic, shallow Typic Dystrudepts) was established in Talladega County, Alabama, in 1907, and is extensively mapped in the southern Appalachian Region of Georgia, Tennessee and Alabama. Carbon County is the only county in Pennsylvania that contains mapped areas of Montevallo soils and is located some 420 miles north of the northern most county in Tennessee in which Montevallo soils are mapped.

According to the Carbon County Soil Survey Report (Fisher et al., 1962), areas mapped as Montevallo soils are confined to a "rectangle formed by NE-SW lines, extending from Jamestown on the north to the eastern boundary of the county and from Stony Ridge on the south to the western boundary of the county". As mapped, the Montevallo series consists of shallow, well-drain channery silt loams on uplands. Fisher et al. (1962) described Montevallo soils as having "formed in place from frost worked, gray, thin-bedded, acid shale and siltstone with some sandstone. They formed as an aftermath of Wisconsin glacial frost action."

In Carbon County, the Appalachian and Interior Plateaus Soil Survey Region (SSR 6) and the Northern Appalachian Ridges and Valley MLRA offices are planning to re-correlate areas of Montevallo into the Berks (loamy-skeletal, mixed, active, mesic Typic Dystrudepts) series. Montevallo is shallow and Berks is moderately deep to rock.

The large number of rock fragments in Montevallo soils limits the depth, accuracy, and number of observations that can be made with spade and auger. Transect data, collected using these traditional soil survey tools, are limited in depth, extent, and number of observations. Ground-penetrating radar can quickly and easily provide large, georeferenced data sets that are needed to help overcome issues of data insufficiency and incorrectness, and validate differences in depths to bedrock. Ground-penetrating radar has been used extensively to chart bedrock depths (Nováková et al., 2013; Gerber et al., 2010; Sass 2007; Sauer and Felix-Henningsen, 2004; Collins et al., 1989; Davis and Annan, 1989), changes in rock type (Davis and Annan, 1989), fractures and joint patterns (Doolittle et al., 2013; Mysaiah et al., 2011; Theune et al., 2006; Porsani et al., 2006 and 2005; Nascimento da Silva et al., 2004; Lane et al., 2000; Pipan et al., 2000) and faults (Demanet et al., 2001).

Montevallo soils are well suited to GPR because of their relatively shallow depth to electrically resistive bedrock, and comparatively low moisture, clay and soluble salt contents. Over a two-day period, GPR was used to collect vast and continuous data on the depth to shale bedrock along 63 traverse lines in delineations of Montevallo soils with different slope and erosion phases.

Equipment:
The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (here after referred to as the SIR-3000), manufactured by Geophysical Survey Systems, Inc. (GSSI; Salem, NH) (see Figure 1). [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

[1] Trade names are used for specific references and do not constitute endorsement.

about 4.1 kg (9 lbs.) and is backpack portable. Jol (2009) and Daniels (2004) discuss the use and operation of GPR.

A 270 MHz antenna was used in this study. The 270 MHz antenna provided a good balance of depth of investigation (DOI) and resolution of the soil/bedrock interface. A distance-calibrated survey wheel with encoder was bolted onto the antenna and provided control over signal pulse transmission and data collection along radar traverse lines (Figure 1).

The RADAN for Windows (version 7.0) software program (GSSI) was used to process the radar records.[1] Processing included: header editing, positioning the initial pulse to time zero, background removal, color table and transformation selection, horizontal high pass filtration, signal stacking, and migration (refer to Jol (2009) and Daniels (2004) for discussions of these techniques). The Interactive 3D Module of RADAN was used to semi-automatically picked the depths to the soil/bedrock interface. The picked data were exported to a worksheet (in an X, Y, and Z format; including longitude, latitude, and depth to bedrock).

Recent technological advances allow the integration of GPR and global positioning system (GPS) data. The SIR-3000 system has a setup for the use of a GPS receiver with a serial data recorder (SDR). With this setup, each scan on radar records can be georeferenced (position/time matched). During data processing, a subprogram within RADAN can be used to proportionally adjust the position of each radar scan according to the time stamp of the two nearest positions recorded with the GPS receiver. A Pathfinder ProXT GPS receiver (Trimble, Sunnyvale, CA) was used to georeferenced GPR data (Figure 1).[1] Position data were recorded at a rate of one reading per second.

Figure 1. Mike McDevitt verifies radar interpretation of the depth to bedrock in an area that is mapped as Montevallo soils as Jim Doolittle looks on. The center frequency of the antenna (red box) is 270 MHz

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., bedrock, soil horizon, stratigraphic layer) and back. To convert the two-way 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):

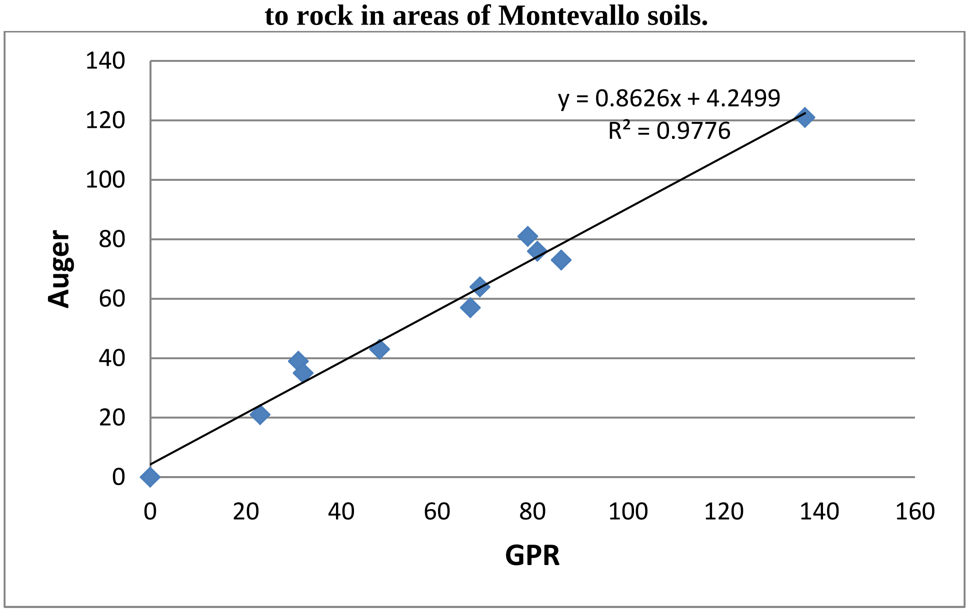
$$E_r = (C/v)^2 \qquad [2]$$

In equation [2], C is the velocity of propagation in a vacuum (0.3 m/ns). Typically, the velocity of pulse propagation 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.

Based on the measured depth and the two-way pulse travel time to a known subsurface reflector (metallic plate), the average velocity of propagations and the relative dielectric permittivity through the upper part of a Montevallo soil profile was estimated using equations [1] and [2]. The estimated E_r was 5.64. The v was 0.1263 m/ns.

During the course of the GPR surveys, 11 soil cores were extracted to determine the depth to bedrock and to confirm the radar interpretations. The measured depths (with soil augur) to bedrock ranged from 0 to 137 cm. The average difference between the auger measured and GPR interpreted depths to bedrock was 3.91 cm with a range of 0 to 16 cm. The correlation (r^2) between GPR and auger measurements was an impressive 0.9776 (see Graph 1).

Graph 1. Relationship between auger measurements and GPR interpretations of the depth to rock in areas of Montevallo soils.



Survey Sites:
Five study sites, each composed of delineations of Montevallo soils and located in open fields, were selected in Carbon County. Site 1 (40.8115 N, 75.7833 W) is located off of Breezewood Road, about 3.9 mi west-southwest of Lehighton, Pennsylvania. Access to Site 2 (40.8560 N, 75.6778 W) is off of Fairyland Road, about 2.4 mi northeast of Lehighton, Pennsylvania. Site 3 (40.8274 N, 75.6229 W) is located off of Hemlock Street, about 2.0 mi northwest of Aquashicola, Pennsylvania. Site 4 (40.8854 N, 75.5715 W) is located off of Pohopoco Drive, about 3.7 mi west of Kresgeville, Pennsylvania. Site 5 (40.8751 N, 75.5998 W) is located off of Pohopoco Drive, about 2.0 mi west of Kresgeville, Pennsylvania. Table 1 lists the names and the symbols of the map units that were traversed by GPR in this study.

Table 1. The names and symbols for the map unit traversed by GPR in Carbon County, Pennsylvania

Symbol	Map Unit Name
MoB2	Montevallo channery silt loam, 3 to 8 percent slopes, moderately eroded
MoC2	Montevallo channery silt loam, 8 to 15 percent slopes, moderately eroded
MoD2	Montevallo channery silt loam, 15 to 25 percent slopes, moderately eroded
MoD3	Montevallo channery silt loam, 15 to 25 percent slopes, severely eroded
MoE3	Montevallo channery silt loam, 25 to 35 percent slopes, severely eroded

GPR Procedures:
Multiple GPR traverses were completed across each site. Each radar traverse was stored as a separate file. Surveys were conducted by moving the antenna over the ground surface at a slow walking pace. Two of the sixty-three radar traverses were not properly georeferenced because of an insufficient number of satellites.

Each radar record was processed in RADAN 7.0. Following processing, the depth to bedrock was semi-automatically *picked* on each radar record using the Interactive 3D Module of RADAN. These measurements were grouped according to soil depth classes (shallow: < 50.8 cm; moderately deep: 50.8 to 101.6 cm; deep: 101.6 to 152 cm; and very deep: > 152 cm), and the frequency distribution of "picks" was determined for each GPR traverse.

Results:
Site 1:
Twenty-one radar traverses were completed across Site 1 providing a total of 87,493 soil depth measurements over a distance of 1,377 m. Based on these measurements, the average depth to bedrock is 0.65 cm with a range of 0.0 to 247 cm. Based on the averages from these 21 traverses, the depth to bedrock is largely moderately deep (59 %) and shallow (32 %) with some deep (8 %) inclusions. Figure 2 is a *Goggle Earth* image of Site 1 showing the distribution of soils based on soil depth classes. In this image, the locations of the GPR traverse lines are shown. Colors have been used to identify the different soil depth classes.

Site2:
Eight radar traverses were completed across Site 2 providing a total of 56,175 soil depth measurements over a distance of 879 m. Based on these measurements, the average depth to bedrock is 0.47 cm with a range of 0 to 122 cm. Based on the averages from the 8 traverses, depths to bedrock are shallow (59 %) and moderately deep (41 %). Figure 3 is a *Goggle Earth* image of Site 2 showing the distribution of soils based on soil depth classes. In this image, the locations of the GPR traverse lines are shown. Colors have been used to identify the different soil depth classes.

Figure 2. Variations in the depth to bedrock across Site 1, as interpreted from radar records, are shown on this Google Earth image.

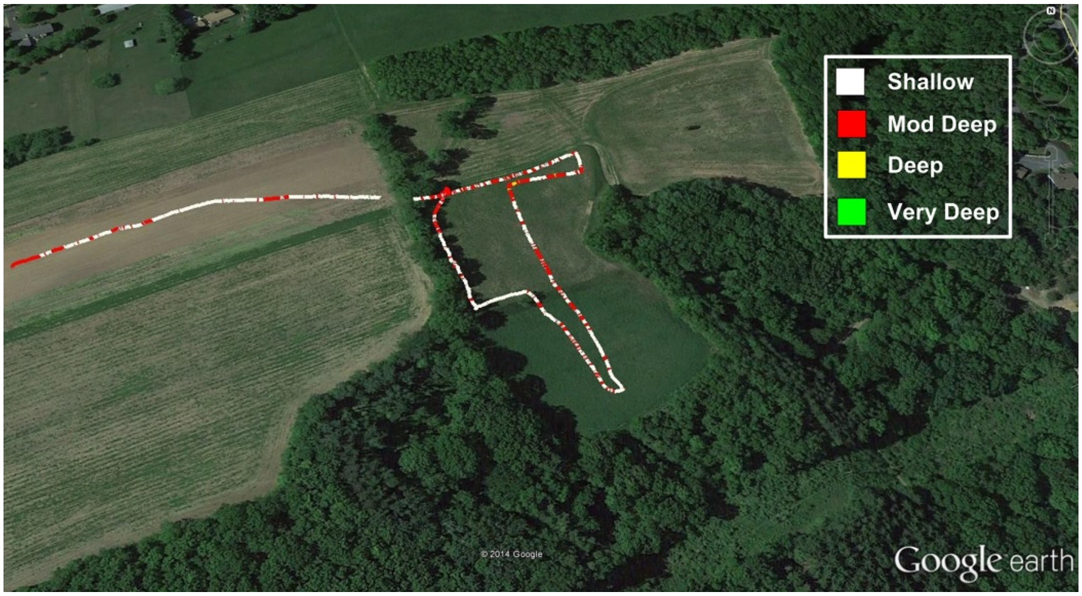


Figure 3. Variations in the depth to bedrock across Site 2, as interpreted from radar records, are shown on this Google Earth image.

Site 3

Eleven radar traverses were completed across Site 3 providing a total of 75,024 soil depth measurements over a distance of 1,173 m. Based on these measurements, the average depth to bedrock is 0.45 cm with a range of 0 to 147 cm. Based on the averages from the 11 traverses, depths to bedrock are moderately deep (52 %) and shallow (46 %) with a small inclusion of deep (2 %). Figure 4 is a *Goggle Earth* image of Site 3 showing the distribution of soils based on soil depth classes. In this image, the locations of the GPR traverse lines are shown. Colors have been used to identify the different soil depth classes.

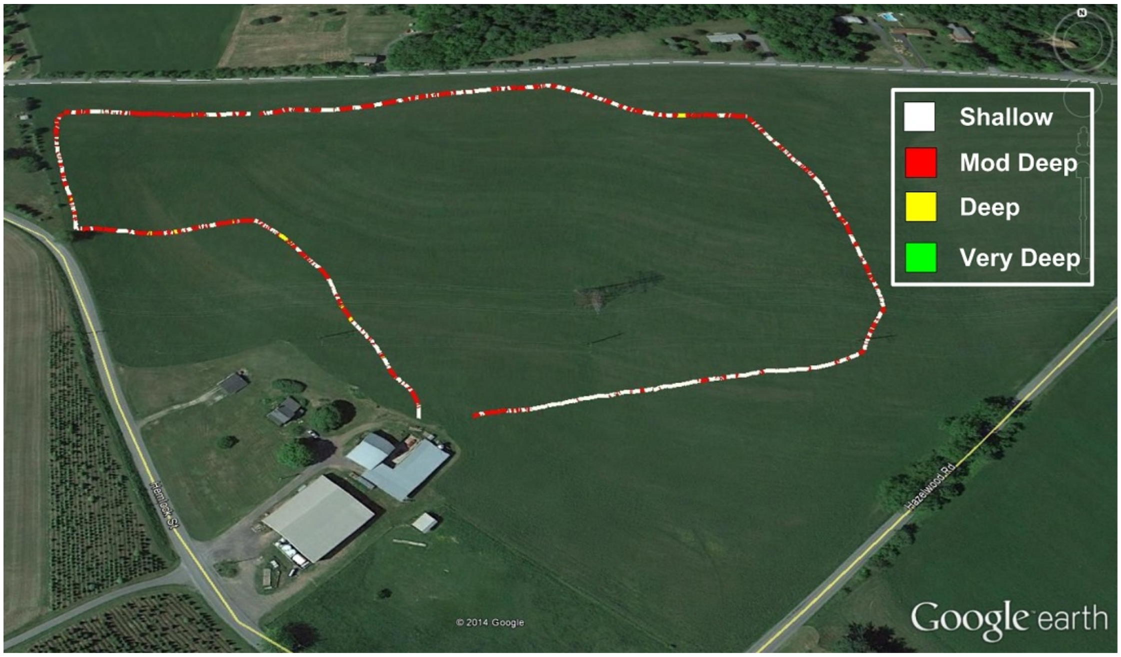


Figure 4. Variations in the depth to bedrock across Site 3, as interpreted from radar records, are shown on this Google Earth image.

Site 4
Fourteen radar traverses were completed across Site 4 providing a total of 117,760 soil depth measurements over a length of 1,842 m. Based on these measurements, the average depth to bedrock is 0.68 cm with a range of 0 to 163 cm. Based on the averages from the 14 traverses, depths to bedrock are moderately deep (67 %) and shallow (24 %) with a small inclusion of deep (9 %). Figure 5 is a *Goggle Earth* image of Site 4 showing the distribution of soils based on soil depth classes. In this image, the locations of the GPR traverse lines are shown. Colors have been used to identify the different soil depth classes.

Site 5
Nine radar traverses were completed across Site 5 providing a total of 72,531 soil depth measurements over a recorded distance of 1,139 m. Based on these measurements, the average depth to bedrock is 0.75 cm with a range of 0 to 174 cm. Based on the averages from the 9 traverses, depths to bedrock are moderately deep (70 %), shallow (20 %) and deep (10 %). Figure 6 is a *Goggle Earth* image of Site 5 showing the distribution of soils based on soil depth classes. In this image, the locations of the GPR traverse lines are shown. Colors have been used to identify the different soil depth classes.

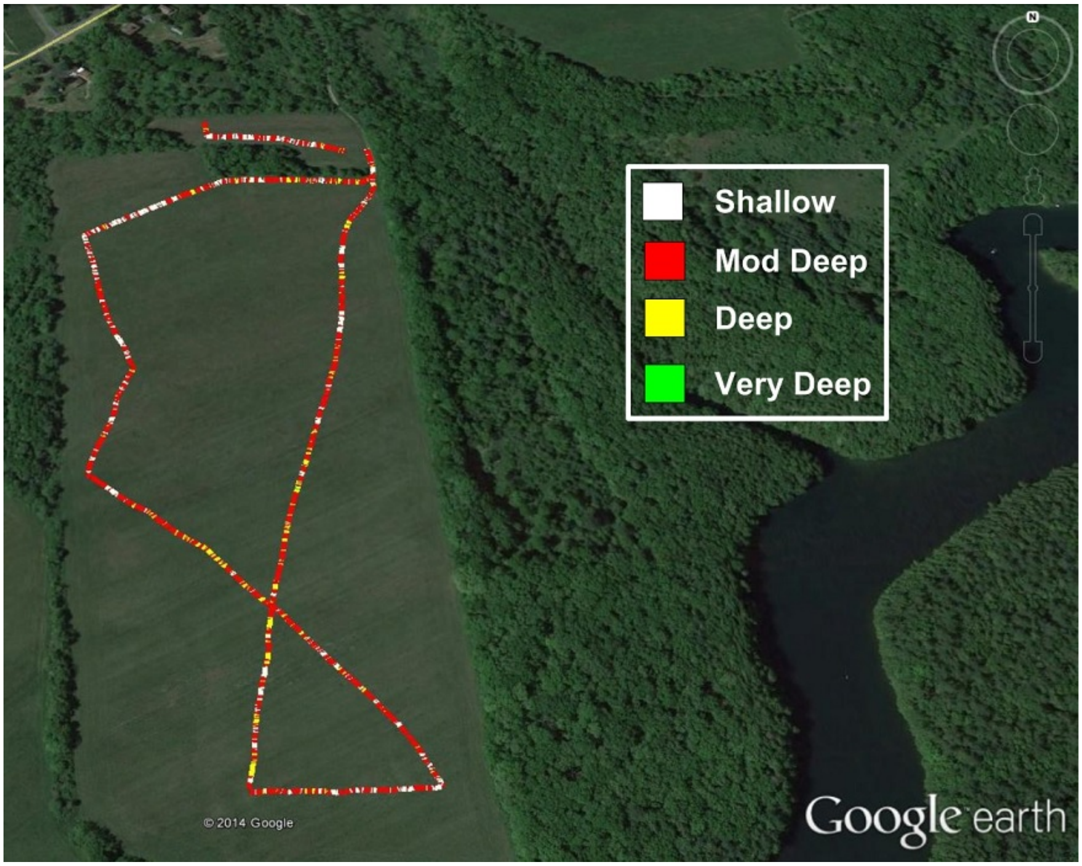


Figure 5. Variations in the depth to bedrock across Site 4, as interpreted from radar records, are shown on this Google Earth image.

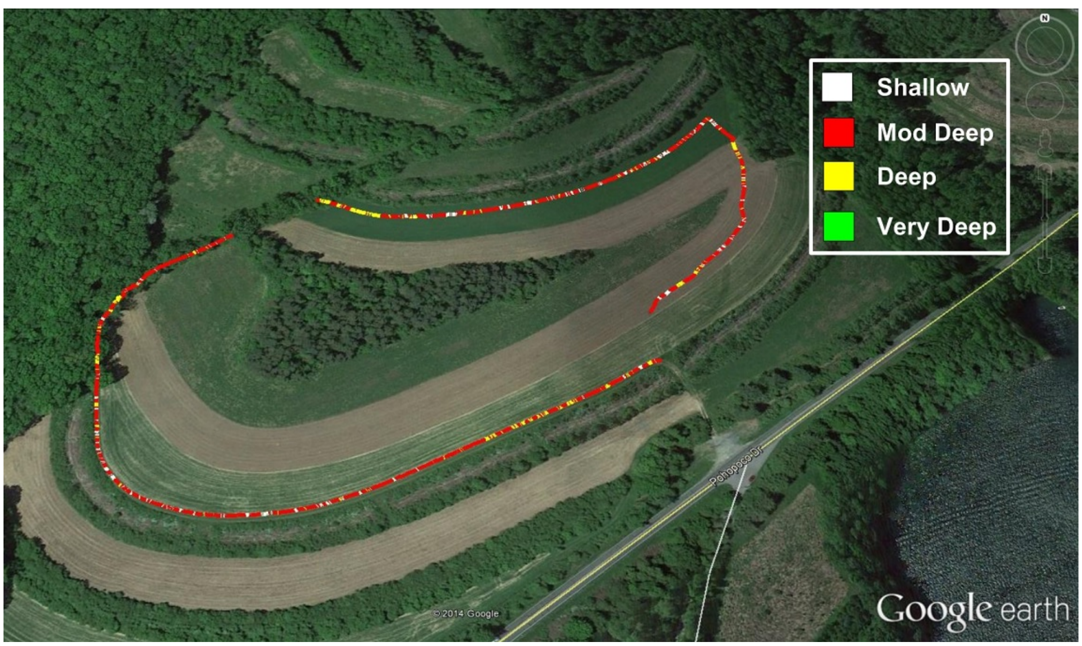


Figure 6. Variations in the depth to bedrock across Site 5, as interpreted from radar records, are shown on this Google Earth image.

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Addendum

Summary of GPR data collected on depth to bedrock in areas of Montevallo soils, Carbon County, Pennsylvania

. *File #*	*Length (m)*	*Obs.*	*Avg.*	*Min.*	*Max.*	*Shallow*	*Mod Deep*	*Deep*	*Very Deep*
1	28	1786	0.59	0.00	1.42	0.50	0.42	0.08	0.00
2	61	3899	0.59	0.00	1.39	0.37	0.56	0.07	0.00
3	88	5536	0.80	0.29	1.81	0.16	0.65	0.17	0.02
4	60	3800	0.63	0.13	1.28	0.31	0.61	0.07	0.00
5	73	4619	0.67	0.18	1.40	0.22	0.70	0.08	0.00
6	54	3414	0.49	0.00	1.25	0.58	0.41	0.01	0.00
7	90	5762	0.60	0.00	1.69	0.52	0.37	0.09	0.02
8	84	5342	0.70	0.00	1.38	0.27	0.61	0.12	0.00
9	52	3223	0.43	0.09	0.78	0.63	0.37	0.00	0.00
11	75	4713	0.69	0.28	1.20	0.19	0.72	0.09	0.00
12	31	1953	0.70	0.25	1.22	0.15	0.77	0.08	0.00
13	42	2668	0.84	0.14	1.53	0.16	0.56	0.28	0.00
14	17	1060	0.74	0.35	1.09	0.13	0.83	0.05	0.00
15	63	3974	0.70	0.32	1.65	0.15	0.78	0.07	0.00
16	42	2689	0.57	0.19	1.10	0.48	0.46	0.05	0.00
17	43	2756	0.67	0.32	1.05	0.14	0.85	0.01	0.00
18	147	9396	0.60	0.10	1.30	0.36	0.63	0.02	0.00
19	93	5944	0.82	0.22	2.47	0.15	0.60	0.23	0.02
20	107	6863	0.69	0.00	1.29	0.25	0.64	0.11	0.00
21	127	8096	0.44	0.00	0.91	0.64	0.36	0.00	0.00
22	65	4188	0.49	0.05	0.85	0.50	0.50	0.00	0.00
23	89	5677	0.40	0.00	0.87	0.78	0.22	0.00	0.00
24	102	6542	0.44	0.00	0.98	0.68	0.32	0.00	0.00
25	71	4546	0.49	0.00	1.22	0.53	0.47	0.00	0.00
26	105	6683	0.52	0.00	1.10	0.54	0.44	0.02	0.00
27	40	2534	0.52	0.07	0.80	0.44	0.56	0.00	0.00
28	228	14560	0.49	0.00	1.14	0.53	0.47	0.00	0.00
29	179	11445	0.40	0.00	0.88	0.73	0.27	0.00	0.00
30	91	5791	0.53	0.08	1.46	0.52	0.45	0.03	0.00
31	76	4836	0.61	0.00	1.30	0.38	0.52	0.10	0.00
32	92	5892	0.62	0.17	1.16	0.30	0.67	0.03	0.00
33	129	8219	0.53	0.00	1.03	0.47	0.53	0.00	0.00
34	111	7098	0.57	0.00	1.22	0.36	0.64	0.00	0.00
35	152	9686	0.52	0.09	0.95	0.46	0.54	0.00	0.00
36	100	6422	0.48	0.00	0.90	0.54	0.46	0.00	0.00
37	43	2742	0.72	0.32	1.47	0.14	0.75	0.11	0.00
38	65	4136	0.51	0.09	0.98	0.52	0.48	0.00	0.00
39	166	10745	0.48	0.00	1.05	0.59	0.41	0.00	0.00
40	148	9457	0.41	0.00	0.87	0.77	0.23	0.00	0.00

Addendum (continued)

File #	***Length (m)***	***Obs.***	***Avg.***	***Min.***	***Max.***	***Shallow***	***Mod Deep***	***Deep***	***Very Deep***
41	122	7819	0.71	0.16	1.36	0.18	0.73	0.09	0.00
42	139	8902	0.58	0.00	1.25	0.38	0.59	0.03	0.00
43	249	15928	0.63	0.00	1.34	0.36	0.56	0.08	0.00
44	144	9213	0.58	0.00	1.09	0.38	0.61	0.01	0.00
45	33	2118	0.67	0.12	1.19	0.21	0.75	0.04	0.00
46	66	4181	0.65	0.14	1.15	0.26	0.70	0.04	0.00
47	122	7831	0.81	0.00	1.63	0.09	0.72	0.19	0.00
48	163	10402	0.72	0.00	1.37	0.16	0.74	0.10	0.00
49	151	9631	0.66	0.07	1.26	0.26	0.71	0.03	0.00
50	154	9828	0.79	0.00	1.55	0.21	0.57	0.22	0.00
51	171	10908	0.78	0.21	1.57	0.12	0.73	0.15	0.00
52	77	4922	0.67	0.00	1.27	0.27	0.66	0.07	0.00
53	120	7705	0.71	0.21	1.53	0.22	0.67	0.11	0.00
54	131	8372	0.64	0.00	1.17	0.27	0.70	0.03	0.00
55	137	8597	0.84	0.39	1.74	0.04	0.77	0.19	0.00
56	184	11731	0.68	0.00	1.20	0.13	0.85	0.02	0.00
57	50	3193	0.63	0.24	1.17	0.28	0.69	0.03	0.00
58	109	6927	0.79	0.24	1.49	0.08	0.76	0.16	0.00
59	137	8749	0.74	0.26	1.26	0.10	0.84	0.06	0.00
60	63	4044	0.97	0.22	1.65	0.06	0.47	0.46	0.01
61	121	7724	0.68	0.21	1.42	0.23	0.72	0.05	0.00
62	122	7770	0.66	0.20	1.30	0.22	0.75	0.03	0.00
63	216	13796	0.74	0.15	1.49	0.11	0.77	0.12	0.00