United States Department of Agriculture

Natural Resources Conservation Service

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Subject: SOI -- Geophysical Assistance --

Date: 9 June 2003

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PURPOSE:
Ground-penetrating radar (GPR) was used to determine the depths to bedrock within selected soil map units in Orleans and Caledonia counties. Data will be used to document the composition of soil map units.

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ACTIVITIES:
All field activities were completed during the period of 3 to 4 June 2003.

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. Antennas with center frequencies of 200 and 400 MHz were used in this investigation. However, the 200 MHz antenna provided a more interpretable image of the soil/bedrock interface and was preferred for field investigations.

Study Sites:
All sites discussed in this report were located in the northern portion of the *Vermont Piedmont*, Orleans and Caledonia counties. In Orleans County, multiple radar traverses were completed in a hay field that had been mapped as Vershire-Dummerston complex on B and C slopes (map unit 3B and 3C), near the town of Derby Line. In Caledonia County, a special study to verify and improve radar interpretations was conducted over a vertical road cut near the town of Peacham. The road cut was located in an area that had been mapped as Vershire-Dummerston complex, 15 to 35 percent slopes, very stony (map unit 214D). Multiple traverses were also completed in a wooded area that had been mapped as Vershire-Dummerston complex, 8 to 15, and 15 to 60 percent slopes, very rocky (map unit 56C and 56E) near the town of Barnet.

[1] Trade names are used to provide specific information. Their mention does not constitute endorsement by USDA-NRCS.

Vershire and Dummerston soils formed in loamy till on uplands. The underlying bedrock consists of the Devonian Waits River formation. This formation is composed of metamorphosed phyllites, marble, and schist. Layers of saprolite are commonly encountered in these soils. The moderately deep, well-drained Vershire soil is a member of the coarse-loamy, mixed, active, frigid Humic Dystrudepts family. The very deep, well-drained Dummerston is a member of the coarse-loamy, mixed, active, frigid Typic Dystrudepts family.

Field procedures:
Pulling the 200 MHz antenna by hand across a selected area of a map unit completed a radar survey. Although, GPR provides a continuous record of subsurface conditions, interpretations were restricted to reference points. For each transect, reference points were spaced at distances of about 25 feet. At each reference point, the radar operator impressed a dashed, vertical line on the radar record. This line identified a reference point on the radar record. A total of 195 observations were recorded during this brief field assignment.

The depth and nature of the underlying saprolite or bedrock were measured at several reference points during survey work. This was done to verify radar interpretations and to confirm the depth scale. Radar records were more interpretable on the SIR-2000's VGA video screen. All interpretations were made from color-enhanced images visible on this computer screen. Different color transforms were use to interpret the depths to saprolite or bedrock. At each reference point, the depth to bedrock was interpreted from the radar record.

Discussion:
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, saprolite) 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 (Morey, 1974):

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

The velocity of propagation is principally affected by the dielectric permittivity (E) of the profiled material(s) according to the equation (Morey, 1974):

$$E = (C/V)^2 \qquad [2]$$

Where C is the velocity of propagation in a vacuum (0.3 m/nanosecond). Velocity is expressed in meters per nanosecond (ns). A nanosecond is one billionth of a second. The amount and physical state of water (temperature dependent) have the greatest effect on the dielectric permittivity.

The velocity of propagation and the depth scale were determined by comparing the interpreted depth to a known reflector (buried metallic reflector) on the radar records with the measured depth. Based on the measured depth and the two-way travel time to a buried metallic reflector, and equation [1], the velocity of propagation was estimated to be about 0.07 m/ns. The dielectric permittivity was 18. These estimates were confirmed by repeated observations made in soil pits and exposures.

Interpretation of radar records:
Saprolite consists decomposed igneous and metamorphic rock that has weathered in place. Saprolite can be excavated easily with shovel. Saprolite is characterized by preservation of original rock structure, foliation and jointing (Pavich et al., 1989). As saprolite is typically found in landscapes where rocks have been exposed to weathering for long periods of time, its occurrence in glacially scoured areas has been slowly recognized.

As with previous studies in Orleans County, the soil/bedrock interface was identified and traced on all radar records. Segmented reflectors of varying amplitudes that suggest a boundary consisting of both saprolite and hard bedrock characterized the soil/bedrock interface. Though the soil/bedrock interface was identified at each reference point, because of its varying expression, no clear interpretation could be made as to whether the underlying bedrock materials were highly weathered or unweathered. Typically, the greater degree of weathering and the higher moisture content of saprolite would make this material more *soil-like*, and produce a lower amplitude radar reflection. Unweathered bedrock would contrast more with the overlying soil and consequently produce a high amplitude radar reflection. Both interfaces were highly irregular. Laterally, these interfaces were interspersed with both high and low amplitude reflectors. Pavich and others (1989) reported that "the contacts between saprolite and weathered rock and between weathered and unweathered rock are typically gradational, highly irregular, and difficult to define precisely." As a consequence, these contacts are often difficult to detect and trace laterally on radar records.

Figure 1. Road cut in an area of Vershire-Dummerston complex, 15 to 35 percent slopes, very stoney. Survey flags are spaced at 1-m intervals. The soil/saprolite boundary has been identified with orange flagging.

Figure 1 is a picture of the road cut surveyed with GPR. Seven survey flags have been inserted in the soil surface near the edge of the exposure at an interval of 1-m. Beneath each flag the soil/saprolite interface has been identified with orange flagging. Depths to saprolite varied from 0.48 to 0.94 m.

Figure 2 is the radar record collected with the 200 MHz antenna over the road cut. The white vertical marks at the top of the radar record represent the equally spaced reference points that were marked by survey flags (see Figure 1). In Figure 2, the soil/saprolite boundary has been highlighted with a green line. This interface varies in amplitude; areas of high amplitude correspond to more harden saprolite, while areas of lower amplitude correspond to more weathered and easier to excavate saprolite. A strong ($r = 0.982$) and significant (.001 level) relationship exists between the measured and radar interpreted depths to saprolite. While with different sites and in the absence of adequate ground-truth observations, the nature (saprolite or hard bedrock) could not be consistently determined.

Interpretations of radar records could not consistently distinguish saprolite from unweathered bedrock. GPR did distinguish an interface that separated the till mantle from either saprolite or bedrock.

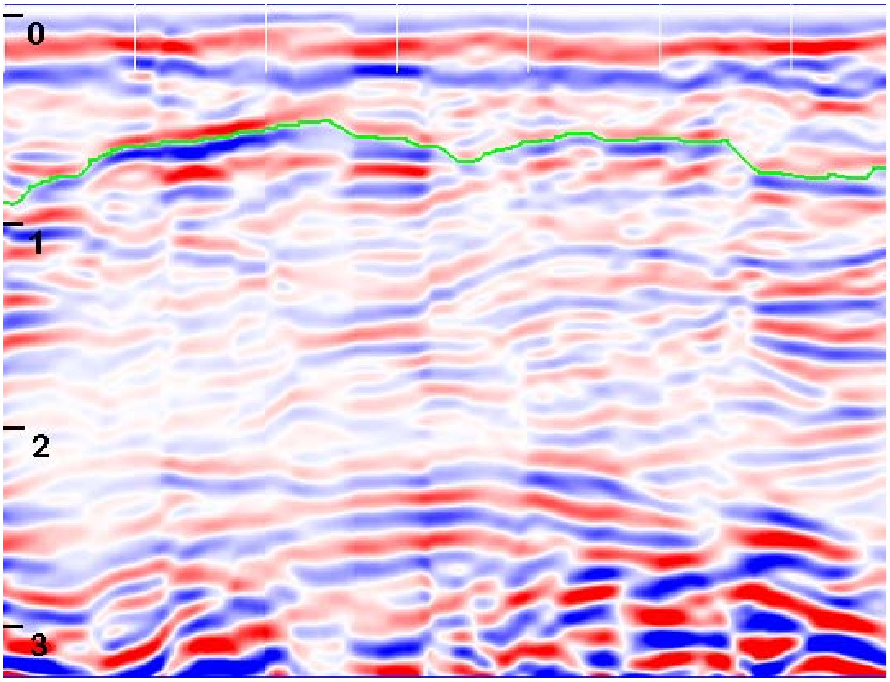

Figure 2. Radar profile of the road cut seen in Figure 1. Depth scale is in meters. The soil/saprolite boundary has been identified with a green line.

RESULTS:
The results of this investigation are summarized in tables 1 and 2, and Appendix 1. The tables summarize the interpreted depths to bedrock by soil depth classes. For each transect the radar record number, the number of observations as well as the frequency observations for each depth class are given. Depth classes are shallow (0 to 20 inches), moderately deep (20 to 40 inches), deep (40 to 60 inches) and very deep (>60 inches). Where bedrock was exposed at the surface the soil depth class was noted as *outcrop*.

Appendix 1 summarizes the interpreted depths to bedrock for each transect. Depths are expressed in meters. For each transect, the radar record number has been provided. Where bedrock was exposed at the surface the depth was recorded as *0*.

Table 1. Summary of Transect Data for an area of Vershire and Dummerston soils in Orleans County Frequency Distribution of Depths to bedrock by Soil Depth Classes

		------- Soil Depth Classes (inches) -------				
File	**obs.**	**outcrop**	**shallow**	**Mod.deep**	**deep**	**very deep**
3	14	0.00	0.14	0.57	0.29	0.00
4	9	0.00	0.00	0.89	0.11	0.00
5	20	0.00	0.05	0.95	0.00	0.00
6	16	0.00	0.75	0.19	0.06	0.00
7	15	0.00	0.20	0.40	0.40	0.00
8	17	0.12	0.06	0.76	0.06	0.00
9	16	0.00	0.25	0.69	0.06	0.00
10	11	0.10	0.45	0.45	0.00	0.00
11	9	0.11	0.44	0.33	0.12	0.00

Table 2. Summary of Transect Data for areas of Vershire and Dummerston soils in Caledonia County
Frequency Distribution of Depths to bedrock by Soil Depth Classes

		------- Soil Depth Classes (inches) -------				
File	**obs.**	**outcrop**	**shallow**	**mod deep**	**deep**	**very deep**
15	9	0.00	0.22	0.56	0.22	0.00
16	9	0.00	0.22	0.56	0.11	0.11
17	12	0.25	0.33	0.25	0.17	0.00
18	13	0.08	0.46	0.46	0.00	0.00
19	16	0.06	0.44	0.38	0.12	0.00
20	9	0.00	0.67	0.33	0.00	0.00

The bedrock surface is highly irregular and grades both laterally and vertically into materials of different resistance to weathering.

As always, it was my pleasure to work in Vermont and with members of your fine soil staff.

With kind regards,

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References:

Daniels, D. J. 1996. Surface-Penetrating Radar. The Institute of Electrical Engineers, London, United Kingdom. 300 p.

Doolittle, J. A. 1987. Using ground-penetrating radar to increase the quality and efficiency of soil surveys. 11-32 pp. In: Reybold, W. U. and G. W. Peterson (eds.) Soil Survey Techniques, Soil Science Society of America. Special Publication No. 20. 98 p.

Morey, R. M. 1974. Continuous subsurface profiling by impulse radar. p. 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.

Pavich, M.J., G.W. Leo, S.F. Obermeier, and J.R. Estabrook. 1989. Investigations of the characteristics, origin, and residence time of the upland residual mantle of the Piedmont of Fairfax County, Virginia. U.S. Geol. Survey Prof. Paper No. 1352.

Appendix 1

File 3

Obs.	Depth
1	0.81
2	1.05
3	0.86
4	0.71
5	0.93
6	0.98
7	1.01
8	1.40
9	1.24
10	0.66
11	0.53
12	0.4
13	0.68
14	0.48

File 4

Obs.	Depth
1	0.73
2	0.95
3	0.66
4	0.51
5	0.84
6	0.58
7	0.62
8	0.60
9	1.50

File 5

Obs.	Depth
1	0.56
2	0.62
3	0.46
4	0.69
5	0.68
6	0.93
7	0.61
8	0.91
9	0.58
10	0.8
11	0.54
12	0.78
13	0.65
14	0.71
15	0.66
16	0.71
17	0.69
18	0.77
19	0.51
20	0.75

File 6

Obs.	Depth
1	0.73
2	0.67
3	0.71
4	0.63
5	0.86
6	0.96
7	0.84
8	0.75
9	1.58
10	0.80
11	0.64
12	1.08
13	1.11
14	0.79
15	1.49
16	0.74

File 7

Obs.	Depth
1	0.59
2	0.82
3	1.01
4	0.73
5	1.35
6	1.00
7	0.93
8	1.05
9	1.10
10	0.47
11	0.40
12	0.47
13	1.48
14	1.00
15	1.04

File 8

Obs.	Depth
1	0.91
2	0
3	0.6
4	0.73
5	0
6	0.53
7	0.91
8	0.55
9	0.49
10	0.65
11	0.86
12	0.82
13	0.95
14	0.63
15	0.57
16	0.78
17	1.44

File 9

Obs.	Depth
1	0.5
2	0.68
3	0.58
4	0.53
5	0.48
6	0.78
7	0.97
8	1.19
9	0.5
10	0.66
11	0.65
12	0.93
13	0.86
14	0.47
15	0.92
16	0.75

File 10

Obs.	Depth
1	0.45
2	0.51
3	0
4	0.72
5	0.14
6	0.66
7	0.91
8	0.6
9	0.49
10	0.41
11	0.44

File 11

Obs.	Depth
1	0.11
2	0.81
3	0.45
4	0.43
5	0.61
6	1.23
7	0
8	0.51
9	0.32

File 15

Obs.	Depth
1	0.62
2	0.51
3	0.53
4	0.73
5	0.47
6	0.40
7	0.61
8	1.17
9	1.03

File 16

Obs.	Depth
1	0.40
2	0.71
3	0.62
4	1.04
5	1.58
6	0.47
7	0.55
8	0.80
9	0.58

File 17

Obs.	Depth
1	0.32
2	0.55
3	0.49
4	0.00
5	0.00
6	0.34
7	0.73
8	1.21
9	1.34
10	0.00
11	0.47
12	0.60

File 18

Obs.	Depth
1	0.60
2	0.52
3	0.00
4	0.48
5	0.49
6	0.34
7	0.29
8	0.37
9	0.45
10	0.67
11	0.68
12	0.69
13	0.67

File 19

Obs.	Depth
1	0.36
2	0.33
3	0.77
4	0.78
5	0.40
6	1.15
7	0.65
8	0.57
9	1.10
10	0.93
11	0.36
12	0.46
13	0.37
14	0.00
15	0.20
16	0.81

File 20

Obs.	Depth
1	0.36
2	0.34
3	0.52
4	0.82
5	0.45
6	0.50
7	0.45
8	0.54
9	0.28