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Natural Resources Conservation Service
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Subject: SOI – Geophysical Field Assistance **Date:** 9 September 2004

To: William E. Frederick
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Purpose:
The purpose of this field investigation was to assess the suitability of ground-penetrating radar (GPR) for soil and bedrock investigations in Schoolcraft County.

Participants:
Matthew Bromley, Soil Scientist, USDA-NRCS, Manistique, MI
Joseph Calus, Soil Survey Project Leader, USDA-NRCS, Manistique, MI
Lawrence Carey, Project Leader, USDA-NRCS, Marquette, MI
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Gregory Whitney, Soil Survey Project Leader, USDA-NRCS, Manistique, MI
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Activities:
All activities were completed during the period of 26 to 27 August 2004.

Summary:

1. While GPR provided adequate penetration depths in most soils, interpretations of radar records were challenging. In areas of poorly drained Minnow and somewhat poorly drained Charlevoix soils, the depth of penetration was limited to the loamy glacial till. In areas of well drained Amadon and Cookson soil, the depth of penetration was adequate for soil survey investigations and the bedrock was evident on radar records. However, in some areas the soil/bedrock contact was indistinguishable because of superimposed and multiple reflections from near surface soil horizons (Bhs, Bs, 2Bt horizons), and clutter from the large number of rock fragments in the soil and the highly fractured and thinly bedded limestone bedrock. As a consequence, the use of GPR can not be recommended as a quality control tool for bedrock determinations in areas of Charlevoix-Minnow complex, 0-3% slopes, and many areas of Cookson-Amadon complex, 0-6% slopes.

2. In an area of Eastport-Deford complex, 0 to 60 percent slopes, the internal stratigraphy of a stabilized sand dune and the depth to a water table were mapped with a 200 MHz antenna. Knowledge was obtained on the general performance of SIR-3000 radar system and the 200 MHz antenna in areas of sandy eolian deposits that border Lake Michigan. A soil sample was taken from this area for analysis at the National Soil Survey Laboratory. This will help assess mineralogical parameters that affect the performance of GPR in sandy soils.

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

With kind regards,

James A. Doolittle
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cc:
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GPR:

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 (see Figure 1). The use and operation of GPR are discussed by Morey (1974), Doolittle (1987), and Daniels (1996). The 200 and 400 MHz antennas were used during this investigation.

Radar records contained in this report were processed with the RADAN for Windows (version 5.0) software program (Geophysical Survey Systems, Inc, 2003). [1] Processing included setting the initial pulse to time zero, color transformation, marker editing, distance and surface normalization, migration, and range gain adjustments.

Figure 1. Greg Whitney pulls the 200 MHz antenna while Joe Calus operates the SIR-3000 system in an area of Eastport-Deford complex, 0 to 60 percent slopes.

Study Sites:

All study sites were located in southern and southeastern portion of Schoolcraft County. On the morning of 26 August, an area of Cookson-Amadon complex, 0 to 6 percent slopes, was traversed with GPR in the northern half of Section 10, T. 42 N., R. 13 W. Later that morning an area of Charlevoix-Minnow complex, 0 to 3 percent slopes, was traversed with GPR in the northern half of Section 11, T. 42 N., R. 13 W. On the afternoon of 26 August, a large sand dune that was mapped as Eastport-Deford complex, 0 to 60 percent slopes, was traversed with GPR in the northern half of Section 7, T. 41 N., R. 14 W. On the morning of 27 August, an area of Charlevoix-Minnow complex, 0 to 3 percent slopes, was traversed with GPR in the southern half of Section 13, T. 42 N., R. 14 W. An area of Gulliver-Amadon complex, 0 to 6 percent slopes, was also traversed with GPR in the

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

southern half of Section 26, T. 42 N., R. 14 W. Finally, an area of Cookson-Amadon complex, 0 to 6 percent slopes, was traversed with GPR in the southern half of Section 17, T. 42 N., R. 13 W.

Table 1 contains the taxonomic classifications of the soils that were traversed with GPR. The Cookston, Gulliver, and Minnow are proposed soil series.

Table 1. Taxonomic composition of soils

Soil Series	Taxonomic Classification
Amadon	Loamy, mixed, active, frigid Lithic Haplorthods
Charlevoix	Coarse-loamy, mixed, active, frigid Argic Endoaquods
Cookson	Coarse-loamy, mixed, active, frigid Alfic Haplorthods
Deford	Mixed, frigid Typic Psammaquents
Eastport	Mixed, frigid Spodic Udipsamments
Gulliver	Coarse-loamy, mixed, active, frigid Alfic Oxyaquic Haplorthods
Minnow	Coarse-loamy, mixed, active, nonacid, frigid Aeric Endoaquepts

Calibration of GPR:
Ground-penetrating radar is a time scaled system. This 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 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 relative dielectric permittivity (E_r) of the profiled material(s) according to the equation:

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

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

Results:
Eastport-Deford complex, 0 to 60 percent slopes :
The site (573241 East and 5090424 North) is on a portion of a large sand dune located near the shore of Lake Michigan about 4.6 km southwest of the town of Gulliver. The traverse was conducted in an area that had been mapped as Eastport-Deford complex, 0 to 60 percent slopes. This map unit consists of sandy eolian deposits on vegetated and stabilized sand dunes.

A 42-m traverse line was established across a south-facing slope of a large dune. Survey flags were inserted in the ground at intervals of 3-m and served as reference points. The elevation of each reference point was measured with a level and stadia rod. Relief was about 6.6 m. Elevations were not tied to a benchmark; the lowest recorded point was chosen as an arbitrary 0.0 m datum. The datum was located about 2.19 m above Lake Michigan. Surveys were completed with the 200 MHz antenna and with a scanning time of 270 ns.

The radar traverse extended from a depression to the crest of a nearby dune. In the lowest part of the depression, the depth to the water table was less than 60 cm. The depression is dominated by the very deep, poorly drained and very poorly drained Deford soils. At the crest of the dune the water table was at a depth of about 6.2 m. The dune is dominated by the very deep, excessively drained Eastport soils.

Based on measured depths to the water table at two reference points (observed depths of 1.39 and 1.9 m), the velocity of propagation through the relatively dry sands was an estimated 0.15 m/ns. The E_r was 3.85. Using a scanning time of 270 ns, a velocity of 0.15 m/ns, and equation [1], the maximum depth of penetration through dry sands is about 20 m (66 ft). However, as shown in equation [2], the velocity of propagation is principally governed by the E_r of the profiled material(s), which will vary with water content. Below the water table, the sands are saturated and will have an E_r of between 15 and 30 (Daniels, 1996). This higher relative dielectric permittivity results in a slower velocity of propagation (0.05 to 0.08 m/ns) below the water table.

The radar record obtained with the 200 MHz antenna was of good interpretive quality (see Figure 2). Not only was the water table clearly distinguishable beneath this landscape, but also the geometry and structure of major stratigraphic layers were well expressed on the radar record. The water table, major stratigraphic boundaries, and some internal features and bedding planes within stratigraphic units are evident in Figure 2.

In Figure 2, the horizontal scale is a distance scale expressed in meters; the vertical scale is a time scale expressed in nanoseconds. A time scale was required as the velocity of signal propagation varied with depth and ranged from 0.15 m/ns in relatively dry sands to 0.05 m/ns in the saturated sands below the water table. In the portion of the radar record that is shown in Figure 2, the water table varies in depth from about 6.2 to 2.2 m along the left- and right-hand margins, respectively. The elevation of the water table slopes slightly towards the interior of the dune and away from Lake Michigan (located to the right of the radar record).

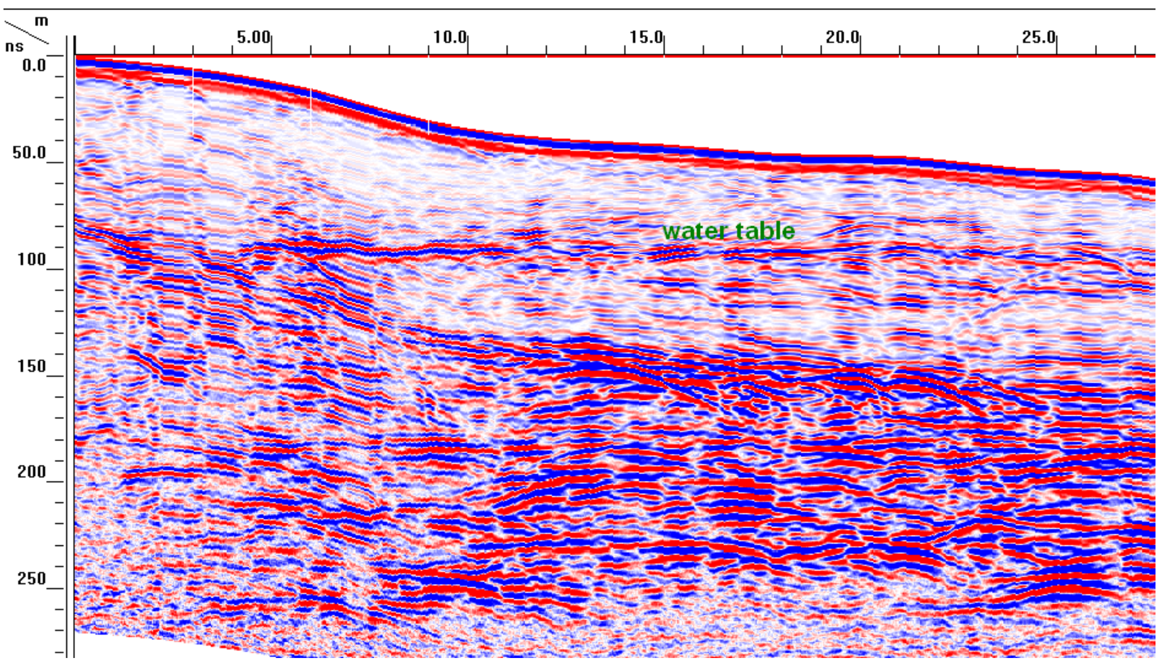

Figure 2. Representative radar record from an area of Eastport-Deford complex, 0 to 60 percent slopes.

In Figure 2, the surface has been *terrain corrected* to improve the visual presentation. Through a process known as *surface normalization*, elevations are assigned to each reference point and the image is corrected for changes in elevation. Surface normalization adjusts the vertical scale to conform to changes in topography. After surface normalization, water tables appear as a horizontal or near horizontal reflectors.

Map unit composition :

Radar surveys were completed by pulling either the 200 or 400 MHz antenna by hand across several delineated areas. Although, GPR provides a continuous record of subsurface conditions, interpretations are restricted to reference points. For each GPR traverse, reference points were spaced at distances of from 4 to 8 meters. At each reference point, the radar operator impressed a mark on the radar record. This mark identified the reference point on the radar record.

Each radar traverse was stored as a separate file on a hard disc. For each radar traverse, depth to bedrock was interpreted directly on the SIR-3000's VGA video screen. All interpretations were made from color-enhanced images visible on this computer screen. Different color tables and transforms were use to assist interpretations.

Figure 3 is a representative radar record that was collected with a 400 MHz antenna in an area of Cookson-Amadon complex, 0 to 6 percent slopes. In this figure all scales are in meters. The depth scale is based on an E_r of 12.2 and a velocity of about 0.09 m/ns. In Figure 3, the interpreted bedrock surface has been highlighted with a green-colored line.

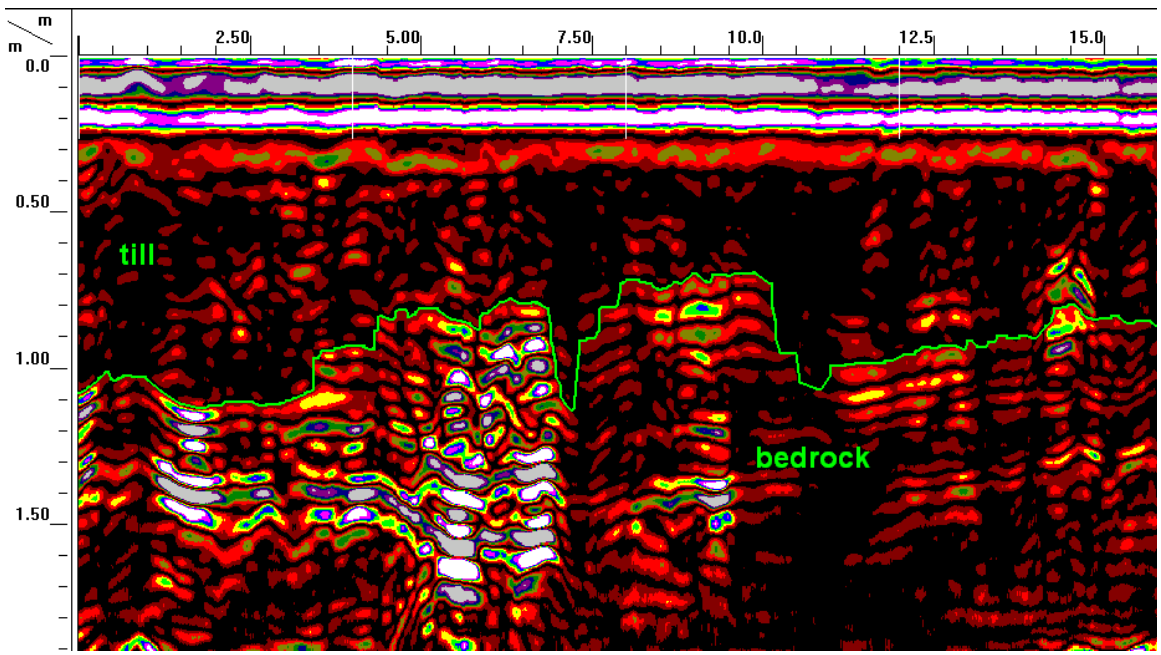

Figure 3. A radar record from an area of Cookson-Amadon complex, 0 to 6 percent slopes..

The proposed Cookson series formed in loamy glaciofluvial deposits over loamy till that are underlain by limestone bedrock. Cookson soil is moderately deep to bedrock. The glaciofluvial deposits range from about 17 to 46 cm thick and are silt loam, fine sandy loam, or very fine sandy loam. The underlying till does not differ greatly in clay content (generally averages about 20% by weight) and is typically sandy clay loam, loam, fine sandy loam, or silt loam. In Cookson soil, multiple (E, Bhs, 2E′ and 2Bt), thin (5 to 30 cm thick) horizons are present in the upper part of the radar record. The interfaces separating these horizons are too closely spaced and, as a consequence, reflections from these interfaces are superimposed upon one another in the upper part (< 50 cm) of radar records. The till is characterized by a chaotic arrangement of point reflectors. The chaotic pattern provides a *graphic signature* for till, which aids in its identification.

The results of the GPR traverses from one area of Cookson-Amadon complex, 0 to 6 percent slopes, are summarized in Table 2 and Appendix 1. Table 2 summarizes interpreted depths to bedrock by soil depth classes. For each traverse, the frequency (%) of observations for each soil depth class is given. Depth classes are shallow (0 to 50 cm), moderately deep (50 to 100 cm), deep (100 to 150 cm) and very deep (>150 cm). Appendix 1 summarizes the interpreted depths to bedrock for each traverse. In Appendix 1, depths are expressed in meters. These interpretations were confirmed by auger observations.

Soil moisture profoundly increases the relative dielectric permittivity, slows the velocity of propagation, and increases the loss tangent and attenuating effects of soils (Daniels, 1996). In areas of poorly drained Minnow and somewhat poorly drained Charlevoix soils, because of higher rates of attenuation, the depth of penetration was limited to the loamy glacial till. On day two of this investigation, in areas of well drained Amadon and Cookson soils, the soil/bedrock contact was indistinguishable because of superimposed and multiple reflections from near surface soil horizons (Bhs, Bs, 2Bt horizons), clutter produced by the large number of rock fragments in the soil and the highly fractured and thinly bedded limestone bedrock, and possibly thicker layers of stratified drift and thinner deposits of till. As a consequence, the radar records from these areas of Cookson-Amadon complex, 0-6% slopes, were considered unreliable and could not be used..

Table 2. Depth to bedrock in an area of Cookson-Amadon complex, 0 to 6 percent slopes.

File	shallow	mod-deep	deep	very deep
2&3	0.00	0.92	0.08	0.00
4	0.00	0.93	0.07	0.00
5	0.11	0.89	0.00	0.00
6	0.00	0.84	0.16	0.00
7	0.09	0.78	0.13	0.00
8	0.00	1.00	0.00	0.00
9	0.27	0.73	0.00	0.00
10	0.00	1.00	0.00	0.00
11	0.32	0.64	0.04	0.00
12	0.50	0.43	0.07	0.00
13	0.00	0.62	0.38	0.00
14	0.00	0.42	0.58	0.00
15	0.04	0.87	0.09	0.00
AVERAGE	**0.10**	**0.77**	**0.12**	**0.00**

Reference:

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. 11-32 pp. In: Reybold, W. U. and G. W. Peterson (eds.) Soil Survey Techniques, Soil Science Society of America. Special Publication No. 20.

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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.

Schoolcraft County, Michigan
Depth to Bedrock (m)
Area of Cookson-Amadon complex, 0 to 6 percent slopes in the N1/2 of Section 10, T. 42 N., R. 31 W.

File	OBS	Depth
2&3	1	0.80
	2	0.83
	3	0.92
	4	0.92
	5	0.68
	6	0.63
	7	0.61
	1	0.95
	2	0.94
	3	1.01
	4	0.71
	5	0.75

File	OBS	Depth
4	1	0.83
	2	1.02
	3	0.72
	4	0.61
	5	0.52
	6	0.69
	7	0.88
	8	0.77
	9	0.70
	10	0.73
	11	0.93
	12	0.72
	13	0.69
	14	0.64

File	OBS	Depth
5	1	0.70
	2	0.74
	3	0.60
	4	0.58
	5	0.55
	6	0.48
	7	0.63
	8	0.56
	9	0.55

File	OBS	Depth
6	1	1.01
	2	0.99
	3	0.79
	4	0.95
	5	1.15
	6	0.92
	7	0.94
	8	0.96
	9	0.89
	10	0.92
	11	0.94
	12	0.87

File	OBS	Depth
6	13	0.78
	14	1.02
	15	0.69
	16	0.70
	17	0.97
	18	0.68
	19	0.84

File	OBS	Depth
7	1	0.49
	2	0.95
	3	0.87
	4	0.57
	5	0.55
	6	0.57
	7	0.75
	8	0.76
	9	0.70
	10	0.76
	11	0.67
	12	0.88
	13	1.01
	14	1.10
	15	0.98
	16	0.77
	17	1.03
	18	0.91
	19	0.43
	20	0.71
	21	0.81
	22	0.85
	23	0.93

File	OBS	Depth
8	1	0.93
	2	0.94
	3	0.84
	4	0.73
	5	0.67
	6	0.63
	7	0.51
	8	0.74
	9	0.71
	10	0.68
	11	0.97
	12	0.93
	13	0.97
	14	0.89
	15	0.87

File	OBS	Depth
9	1	0.97
	2	0.99
	3	0.78
	4	0.57
	5	0.60
	6	0.66
	7	0.59
	8	0.36
	9	0.37
	10	0.75
	11	0.33

File	OBS	Depth
10	1	0.55
	2	0.84
	3	0.60
	4	0.56
	5	0.72
	6	0.69
	7	0.78
	8	0.70
	9	0.98
	10	0.69
	11	0.82
	12	0.80
	13	0.63
	14	0.80
	15	0.78
	16	0.57
	17	0.67
	18	0.84
	19	0.63
	20	0.74
	21	0.72
	22	0.62
	23	0.69

File	OBS	Depth
11	1	0.65
	2	0.56
	3	0.71
	4	0.65
	5	0.64
	6	0.45
	7	0.85
	8	0.41
	9	0.67
	10	0.66
	11	0.79
	12	0.38
	13	0.51
	14	0.53
	15	0.50
	16	0.42
	17	0.55

File	OBS	Depth
11	18	0.78
	19	0.62
	20	1.01
	21	0.47
	22	0.35

File	OBS	Depth
12	1	0.46
	2	0.45
	3	0.56
	4	0.61
	5	0.82
	6	0.48
	7	0.46
	8	0.56
	9	0.49
	10	0.52
	11	1.48
	12	0.44
	13	0.64
	14	0.46
	15	0.63

File	OBS	Depth
13	1	0.72
	2	0.74
	3	0.79
	4	0.64
	5	0.90
	6	0.58
	7	0.89
	8	0.90
	9	1.18
	10	1.22
	11	1.30
	12	1.30
	13	1.29

File	OBS	Depth
14	1	1.12
	2	1.06
	3	1.11
	4	1.08
	5	1.24
	6	1.26
	7	1.06
	8	0.95
	9	0.97
	10	0.93
	11	0.92
	12	0.89
	13	0.80
	14	0.80

File	OBS	Depth
14	15	0.66
	16	1.31
	17	1.04
	18	1.09
	19	1.15

File	OBS	Depth
15	1	0.75
	2	0.78
	3	1.09
	4	0.94
	5	0.85
	6	0.66
	7	0.55
	8	1.01
	9	0.81
	10	0.75
	11	0.52
	12	0.65
	13	0.89
	14	0.91
	15	0.65
	16	0.62
	17	0.83
	18	0.60
	19	0.91
	20	0.54
	21	0.44
	22	0.54
	23	0.54