United States Department of Agriculture	**Natural Resources Conservation Service**	**11 Campus Boulevard Suite 200 Newtown Square, PA 19073**

Subject: SOI – Geophysical Field Assistance **Date:** 28 May 2003

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 Gogebic County. In addition, in Ontonagon County, electromagnetic induction (EMI) was used to assess the variability of soils and soil properties within a mapped area of Amnicon soil.

Participants:
Bill Anzalone, Soil Scientist, USDA-NRCS, Ontonagon, MI
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
John Eversoll, Soil Survey Project Leader, USDA-NRCS, Ontonagon, MI
Mark Farina, Soil Scientist, USDA-NRCS, Ironwood, MI
Jennifer Maziasz, Soil Scientist, USDA-NRCS, Ashland, WI
Bill Perkis, Soil Survey Project Leader, USDA-NRCS, Ironwood, MI

Activities:
All activities were completed during the period of 3 to 6 May 2004.

Summary:

1. Jennifer Maziasz, soil scientist and GPR specialist from the Soil Survey Office in Ashland, Wisconsin, assisted with this investigation. Jennifer Maziasz received training on the operation of Wisconsin's GPR unit and experience on radar interpretations while providing needed data to soil scientists in Michigan. The cooperation among soil scientists in northern Michigan and Wisconsin is most commendable.

2. Thirty GPR traverses were competed in 4 soil map units. These traverses provided 444 depth to bedrock observations within these map units. Additional traverses were completed by Jennifer Maziasz and will be reported in a separate report.

3. An EMI survey was completed of an areas of Amnicon silt loam, 2 to 8 percent slopes, to confirm the adequacy of soil mapping and the appropriateness map unit designation.

4. Integration of EMI, GPS, and GIS techniques provides a more expedient and cost-effective method for soil mapping and displaying multiple data sets. As an example of this integration, Scott Eversoll provided the ArcGIS presentations of the EMI and GPS data shown in this report

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

With kind regards,

James A. Doolittle
Research Soil Scientist
National Soil Survey Center

cc:
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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. The 200 and 400 MHz antennas were used in this study. The use and operation of GPR are discussed by Morey (1974), Doolittle (1987), and Daniels (1996).

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 selections, marker editing, distance normalization, and range gain adjustments.

Geonics Limited manufacturers the EM38DD and the EM38-MK2 meters.[1] Both meters are portable and require only one person to operate. No ground contact is required with either meter. Geonics Limited (2000) describes the use and operation of the EM38DD meter. The EM38DD meter consists of two EM38 meters bolted together and electronically coupled. One meter acts as a master unit (meter that is positioned in the vertical dipole orientation and having both transmitter and receiver activated) and one meter acts as a slave unit (meter that is positioned in the horizontal dipole orientation with only the receiver switched on). Each meter has a 1-m intercoil spacing and operates at a frequency of 14,600 Hz. The EM38DD meter has effective penetration depths of about 75 and 150 cm in the horizontal and vertical dipole orientations, respectively (Geonics Limited, 2000).

The EM38-MK2 meter is being developed and has not been marketed by Geonics Limited. The National Soil Survey Center has been requested to evaluate this meter. The EM38-MK2 meter consists of transmitter and two receiver coils. The transmitter coil is positioned at distances of 0.5 and 1.0 meters from the receiver coils. It operates at a frequency of 40 KHz. The meter can be operated in either dipole orientation, but is most conveniently operated in the vertical dipole orientation. In this orientation, effective depths of penetration are 1.5 times the intercoil spacing. In the vertical dipole orientation, the EM38-MK2 meter provides depth-weight apparent conductivity (EC_a) measurements for the upper 75 and 150 cm of the soil profile.

The Geonics DAS70 Data Acquisition System was used to record and store both EMI and GPS data.[1] The acquisition system is made up of either an EM38DD or an EM38-MK2 meter, and an Allegro field computer and a Trimble AG114 GPS receiver.[1] With the acquisition system, the meters are keypad operated and measurements are automatically triggered every second.

To help summarize the results of the EMI study, SURFER for Windows (version 8.0) software developed by Golden Software, Inc.,[1] was used to construct two-dimensional simulations. Grids were created using kriging methods with an octant search. Scott Eversoll kindly provided the ArcGIS presentation of the data shown in this report.

GPR:
Background:
In many upland areas of Michigan's Upper Peninsula, it is exceedingly difficult and impractical to determine bedrock depths with traditional soil survey tools. Rock fragments restrict the effectiveness of shovels and augers. Soil scientists spend excessive amounts of time and energy attempting to determine the depth to bedrock only to be refused, in many instances, by rock fragments. In addition, uncertainties arise as to whether auger penetration was restricted by a large rock fragment or bedrock. Backhoes provide accurate and reliable soil depth information; however, this information is typically widely spaced and limited in number and extent. Inferences on the depth to bedrock must be extended across the more expansive areas between the limited number of excavations. As a consequence, the composition of soil map units based on soil-depth criteria is constrained by limit exposures and burdened by partial, detached, or inadequate information.

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

In many areas, ground-penetrating radar is well suited to soil-bedrock determinations. Collins and others (1989) demonstrated that GPR is more reliable and effective than soil augers for bedrock determinations. These researchers found a high (r = 0.98) and significant (0.01 level) correlation between excavated and radar interpreted depths to bedrock. In the study conducted by Collins and others (1989), the average difference between actual and radar interpreted depths to bedrock was only 6 cm with 87% of the observations within 10 cm. Where the depth to bedrock is less than 4 m, Birkhead and others (1996) measured an average error between observed and radar interpreted measurements of 4.4 %.

Field Procedures:

Radar surveys were completed by pulling either the 200 or 400 MHz antenna by hand across a soil map unit. Although, GPR provides a continuous record of subsurface conditions, interpretations are restricted to observation points. For each GPR traverse, observation points were spaced at distances of either 7 or 10 paces. At each observation point, the radar operator impressed a mark on the radar record. This mark identified the observation 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 interpret the depths to bedrock.

EMI surveys were competed with the EM38DD and EM38-MK2 meters held about 2 to 3 inches above the ground surface with their long axes parallel to the direction of traverse. Surveys were completed by walking with either meter at a fairly brisk and uniform pace, in a random back and forth pattern across a survey area. The operator of one meter followed the path of the other operator and meter at a distance of about 25 feet to avoid interference.

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 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.

Based on the depths to known buried reflectors and a hyperbola-matching program in RADAN Windows NT, the velocity of propagation was observed to decrease with increasing depth. The velocity of propagation averaged about 0.13 m/ns through the upper part of the Finch soil (E_r of 5.4) and 0.08 m/ns through the upper part of Gogebic soil (E_r of 13.9). Using these velocities, scanning time of 60 ns provided maximum penetration depths of about 3.9 and 2.4 m for Finch and Gogebic soils, respectively.

Interpretations:

Figure 1 is a representative radar record that was collected with a 400 MHz antenna near a filled pit of Finch soil. In this figure all scales are in meters. The depth scale is based on a dielectric permittivity of 5.4. On this radar record, stratified, sandy outwash forms distinct, plane to wavy, inclined bands of varying amplitudes. These inclined bands represent distinct stratigraphic layers of different grain-size materials. Though indistinct and partially obscured by the strong surface reflections, the Bhsm horizon is evident in the upper part of this record.

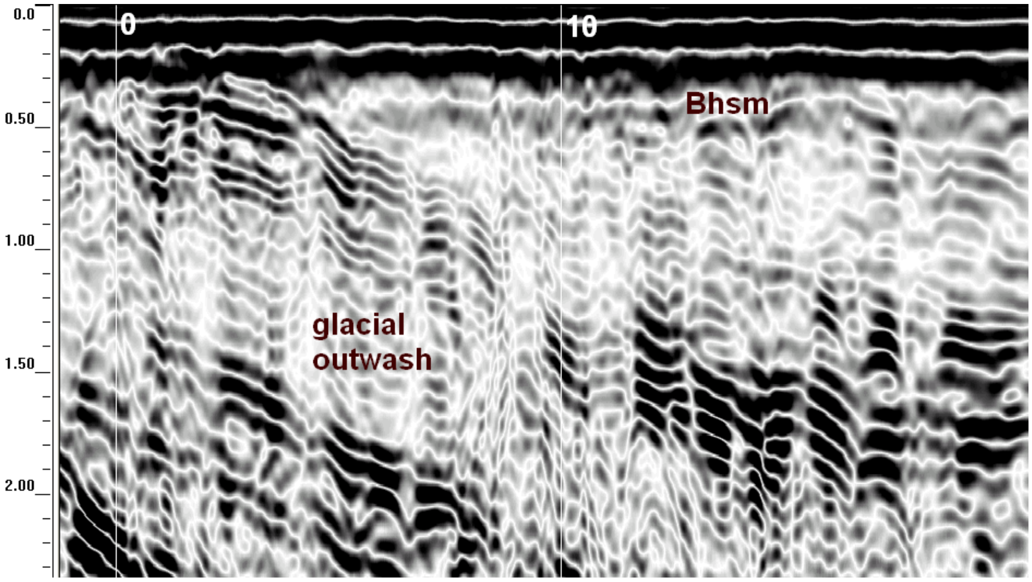


Figure 1. Distinct stratigraphic layers are evident in this radar record of Finch soil.

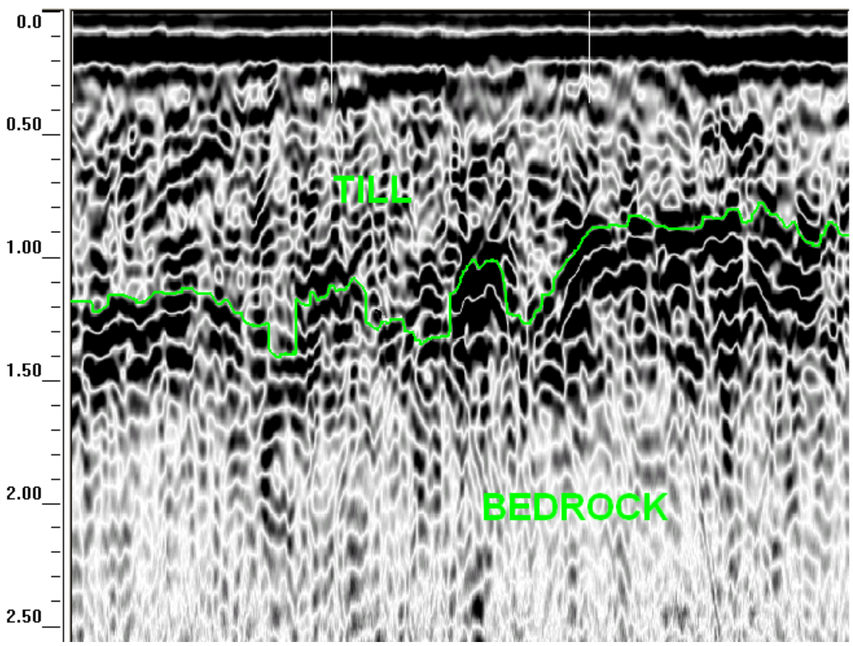
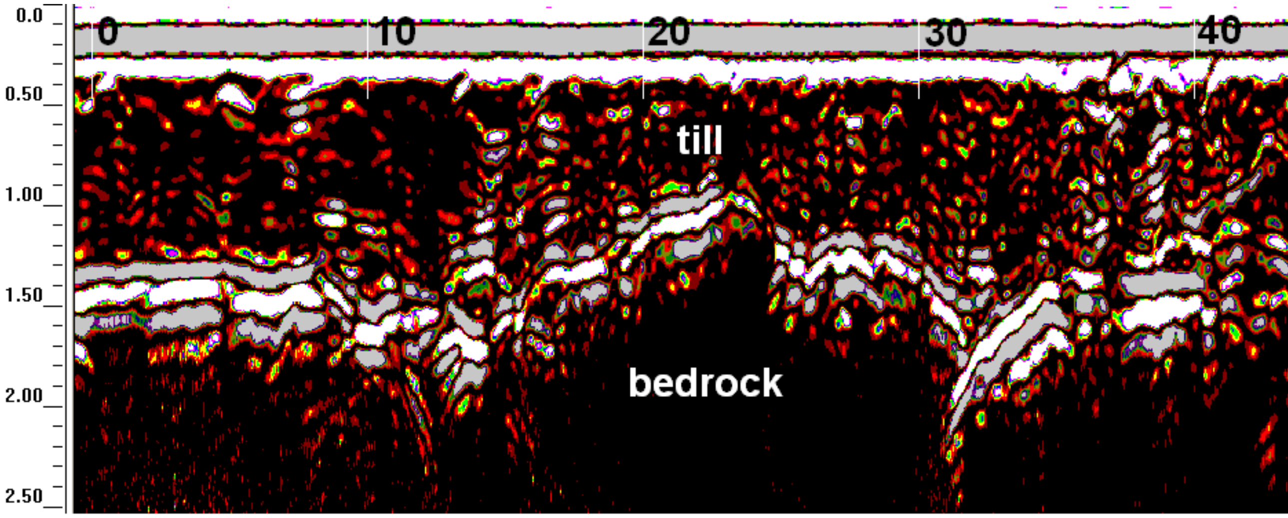


Figure 2. The soil/bedrock interface is traced across this radar record that was collected in an area of Dishno-Gogebic–Peshekee complex, 18-35% slopes.

Figure 2 is a representative radar record that was collected with a 200 MHz antenna in an area of Dishno-Gogebic-Peshekee complex, 18 to 35 percent slopes. On this radar record, all scales are in meters. The depth scale is based on a dielectric permittivity of 13.9. On radar records, till characteristically appears as a chaotic assemblage of point reflectors of varying sizes and amplitudes. These point reflectors represent rock fragments. A green colored line has been used in Figure 2 to approximate the depth to bedrock. The bedrock is Keweenaw



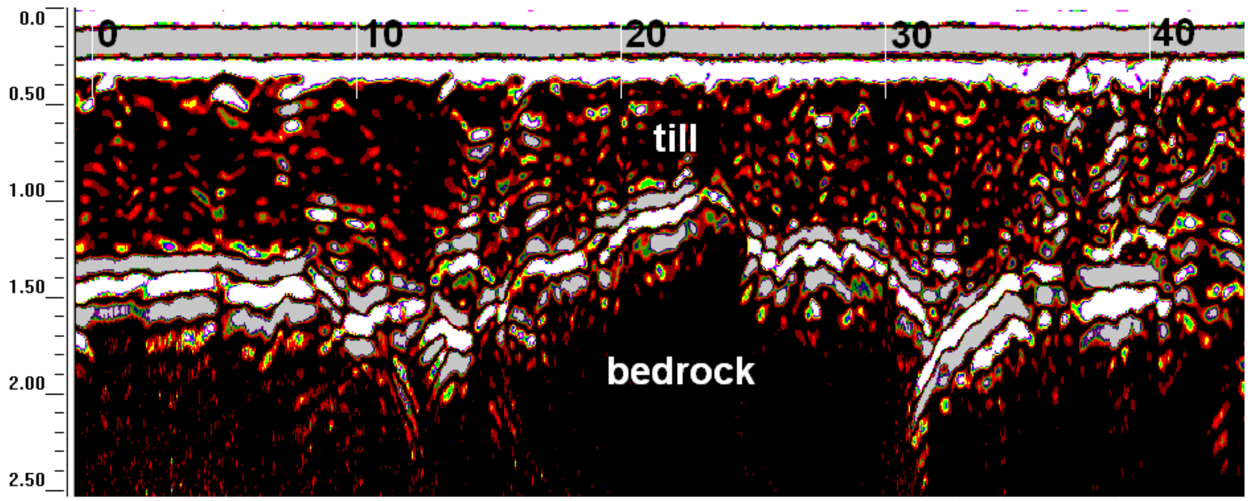


Figure 3. The soil/bedrock interface is traced across this radar record that was collected in an area of Gogebic-Peshekee complex 6-18% slopes, very stony, very rocky.

<u>Results:</u>

Sites for bedrock-depth estimations were located in different parts of Gogebic County. Table 1 lists the radar record file numbers and the names and locations of the traversed soil map units. Thirty radar traverses were conducted in four different areas and soil map units.

Surveys were conducted in areas of Arcadian, Dishno, Finch, Gogebic, and Peshekee soils. The taxonomic classifications of these soils are listed in Table 2. All of these soils have high contents of rock fragment, which ranged in size from gravels to boulders. The shallow, well drained Arcadian and Peshekee soils overlie igneous, metamorphic or conglomerate bedrock. The deep, moderately well drained Dishno soil formed in a silty or loamy eolian deposits over sandy and gravelly till underlain by bedrock. The very deep, moderately well drained Gogebic soil formed in modified loamy eolian deposits and in the underlying loamy and sandy till. Gogebic soil is shallow to moderately deep over a fragipan. The very deep somewhat poorly drained Finch soils formed in sandy glacial outwash, sandy lacustrine deposits or sandy glacial till. Finch soils have strongly cemented subsoil.

Table 1. Locations of map units surveyed with GPR

File	Soil	Location
2	Finch silt loam, 1-6% slopes	SEC 9 T 48 N R 1 E
3	Finch silt loam, 1-6% slopes	SEC 9 T 48 N R 1 E
4	Finch silt loam, 1-6% slopes	SEC 9 T 48 N R 1 E
5	Finch silt loam, 1-6% slopes	SEC 9 T 48 N R 1 E
6	Finch silt loam, 1-6% slopes	SEC 9 T 48 N R 1 E
7	Finch silt loam, 1-6% slopes	SEC 9 T 48 N R 1 E
8	Arcadian cobbly sandy loam, 18-35% slopes	SEC 8 T 48 N R 1 E
9	Arcadian cobbly sandy loam, 18-35% slopes	SEC 8 T 48 N R 1 E
10	Arcadian cobbly sandy loam, 18-35% slopes	SEC 8 T 48 N R 1 E
12	Dishno-Gogebic–Peshkee complex, 18-35% slopes	SEC 28 T 49 N R 47 W
13	Dishno-Gogebic–Peshkee complex, 18-35% slopes	SEC 28 T 49 N R 47 W
14	Dishno-Gogebic–Peshkee complex, 18-35% slopes	SEC 28 T 49 N R 47 W
17	Dishno-Gogebic–Peshkee complex, 18-35% slopes	SEC 28 T 49 N R 47 W
19	Gogebic-Peshekee complex 6-18%slopes, very stony, very rocky	SEC 10 T 46 N R46W
20	Gogebic-Peshekee complex 6-18%slopes, very stony, very rocky	SEC 10 T 46 N R46W
21	Gogebic-Peshekee complex 6-18%slopes, very stony, very rocky	SEC 10 T 46 N R46W
22	Gogebic-Peshekee complex 6-18%slopes, very stony, very rocky	SEC 10 T 46 N R46W
23	Gogebic-Peshekee complex 6-18%slopes, very stony, very rocky	SEC 10 T 46 N R46W
24	Gogebic-Peshekee complex 6-18%slopes, very stony, very rocky	SEC 10 T 46 N R46W
25	Gogebic-Peshekee complex 6-18%slopes, very stony, very rocky	SEC 10 T 46 N R46W
26	Gogebic-Peshekee complex 6-18%slopes, very stony, very rocky	SEC 15 T 47 N R 46 W
27	Gogebic-Peshekee complex 6-18%slopes, very stony, very rocky	SEC 15 T 47 N R 46 W
28	Gogebic-Peshekee complex 6-18%slopes, very stony, very rocky	SEC 15 T 47 N R 46 W
29	Gogebic-Peshekee complex 6-18%slopes, very stony, very rocky	SEC 15 T 47 N R 46 W
30	Gogebic-Peshekee complex 6-18%slopes, very stony, very rocky	SEC 15 T 47 N R 46 W
31	Gogebic-Peshekee complex 6-18%slopes, very stony, very rocky	SEC 22 T 47 N R 46 W
32	Gogebic-Peshekee complex 6-18%slopes, very stony, very rocky	SEC 22 T 47 N R 46 W
33	Gogebic-Peshekee complex 6-18%slopes, very stony, very rocky	SEC 22 T 47 N R 46 W
34	Gogebic-Peshekee complex 6-18%slopes, very stony, very rocky	SEC 22 T 47 N R 46 W
35	Gogebic-Peshekee complex 6-18%slopes, very stony, very rocky	SEC 22 T 47 N R 46 W

Table 2. Classification of soils surveyed in GPR bedrock investigations.

Soil	Taxonomic Family
Arcadian	loamy-skeletal, mixed, active, frigid Lithic Haplorthods
Dishno	coarse-loamy over sandy or sandy-skeletal, mixed, superactive, frigid Oxyaquic Haplorthods
Finch	sandy, mixed, frigid, ortstein, shallow Typic Duraquods
Gogebic	coarse-loamy, mixed, superactive, frigid Alfic Oxyaquic Fragiorthods
Peshekee	loamy, mixed, semiactive, frigid Lithic Haplorthods

The results of the GPR traverses are summarized in Table 3 and Appendix 1. Table 3 summarizes interpreted depths to bedrock by soil depth classes. For each transect, the total number of observations as well as the frequency (%) of observations for each soil 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 observation depth is 0 and the depth class is "*outcrop*." Appendix 1 summarizes the interpreted depths to bedrock for each traverse. In Appendix 1, depths are expressed in inches.

Table 3. Summary of Transect Data
Frequency Distribution of Depths to Bedrock by Soil Depth Classes

File	Soil	Obs.	Outcrop	Shallow	Mod. Deep	Deep	Very Deep
8	Arcadian cobbly sandy loam, 18-35% slopes	11	0.00	0.45	0.55	0.00	0.00
9	Arcadian cobbly sandy loam, 18-35% slopes	9	0.00	0.44	0.44	0.11	0.00
10	Arcadian cobbly sandy loam, 18-35% slopes	12	0.00	0.25	0.60	0.08	0.00
12	Dishno-Gogebic–Peshkee complex, 18-35% slopes	11	0.00	0.09	0.64	0.27	0.00
13	Dishno-Gogebic–Peshkee complex, 18-35% slopes	13	0.00	0.00	0.62	0.38	0.00
14	Dishno-Gogebic–Peshkee complex, 18-35% slopes	14	0.00	0.00	0.57	0.29	0.14
15	Dishno-Gogebic–Peshkee complex, 18-35% slopes	14	0.00	0.00	0.36	0.57	0.07
16	Dishno-Gogebic–Peshkee complex, 18-35% slopes	14	0.00	0.00	0.57	0.36	0.07
17	Dishno-Gogebic–Peshkee complex, 18-35% slopes	11	0.00	0.09	0.55	0.36	0.00
19	Gogebic-Peshekee complex 6-18%slopes, very stony, very rocky	18	0.11	0.06	0.33	0.50	0.00
20	Gogebic-Peshekee complex 6-18%slopes, very stony, very rocky	15	0.11	0.04	0.11	0.21	0.54
21	Gogebic-Peshekee complex 6-18%slopes, very stony, very rocky	18	0.00	0.00	0.00	0.56	0.44
22	Gogebic-Peshekee complex 6-18%slopes, very stony, very rocky	18	0.00	0.00	0.00	0.11	0.89
23	Gogebic-Peshekee complex 6-18%slopes, very stony, very rocky	23	0.00	0.00	0.00	0.22	0.78
24	Gogebic-Peshekee complex 6-18%slopes, very stony, very rocky	21	0.00	0.00	0.24	0.43	0.33
25	Gogebic-Peshekee complex 6-18%slopes, very stony, very rocky	21	0.00	0.05	0.14	0.57	0.24
26	Gogebic-Peshekee complex 6-18%slopes, very stony, very rocky	24	0.00	0.00	0.29	0.58	0.13
27	Gogebic-Peshekee complex 6-18%slopes, very stony, very rocky	18	0.06	0.11	0.33	0.44	0.06
28	Gogebic-Peshekee complex 6-18%slopes, very stony, very rocky	20	0.00	0.00	0.15	0.80	0.05
29	Gogebic-Peshekee complex 6-18%slopes, very stony, very rocky	18	0.06	0.11	0.28	0.50	0.06
30	Gogebic-Peshekee complex 6-18%slopes, very stony, very rocky	12	0.00	0.00	0.50	0.50	0.00
31	Gogebic-Peshekee complex 6-18%slopes, very stony, very rocky	15	0.00	0.07	0.07	0.86	0.00
32	Gogebic-Peshekee complex 6-18%slopes, very stony, very rocky	17	0.00	0.06	0.06	0.71	0.18
33	Gogebic-Peshekee complex 6-18%slopes, very stony, very rocky	16	0.06	0.06	0.25	0.56	0.06
34	Gogebic-Peshekee complex 6-18%slopes, very stony, very rocky	20	0.00	0.00	0.10	0.85	0.05
35	Gogebic-Peshekee complex 6-18%slopes, very stony, very rocky	41	0.00	0.00	0.10	0.68	0.22

EMI:
Alternative methods for mapping soils and soil properties are being evaluated by NRCS. The availability of computers, global positioning systems (GPS), geographical information systems (GIS), and geophysical tools are changing the way we view and map soils. Because of speed and ease of use, electromagnetic induction (EMI) has significant advantages over conventional soil survey techniques. The efficiency of EMI promotes the collection of larger data sets than is possible with conventional soil survey techniques. Because of the larger number of observations, maps prepared from EMI data provide higher levels of detail and resolution than soil maps prepared with conventional methods (Jaynes, 1995). In many areas, spatial patterns of apparent conductivity (EC_a), which are detected with EMI, correspond well with the soil patterns shown on soil survey maps. For high intensity soil mapping, maps of EC_a have been recommended as a *surrogate* for soil survey maps (Jaynes, 1995).

EMI uses electromagnetic energy to measure the EC_a of earthen materials. Apparent conductivity is a weighted, average conductivity measurement for a column of earthen materials to a specific depth (Greenhouse and Slaine, 1983). With EMI, a transmitter produces a magnetic field that induces current to flow through the subsurface. This induced current sets up a secondary magnetic field within the soil. By comparing the magnitude and phase difference in these magnetic fields, the device measures the EC_a of the profiled materials. No ground contact is needed with EMI.

Variations in EC_a are produced by changes in the electrical conductivity of earthen materials. The EC_a of soils is influenced by the type and concentration of ions in solution, the amount and type of clays in the soil matrix, the volumetric water content, and the temperature and phase of the soil water (McNeill, 1980). The EC_a of soils increases with increased soluble salt, water, and clay contents (Kachanoski et al., 1988; Rhoades et al., 1976).

Interpretations of EMI data are based on the identification of spatial patterns within data sets. Though seldom diagnostic in themselves, lateral and vertical variations in EC_a have been used to infer changes in soils and soil properties. EMI integrate the bulk physical and chemical properties of a soil within a defined depth into a single value. As a consequence, measurements can be associated with changes in soil properties, soils, and soil map units (Hoekstra et al., 1992; Jaynes et al., 1993; Doolittle et al., 1996). For each soil, intrinsic physical and chemical properties, as well as temporal variations in soil water and temperature, result in a unique or characteristic range of EC_a.

Study Site:
An EMI survey was completed of a hay land near Bruce’s Crossing in Ontonagon County, Michigan. The field is bounded on the north by a wooded, more steeply sloping area; on the south by a farm road; on the east by a US Highway 45, and on the west by another field.

The field is mapped as Amnicon silt loam, 2 to 8 percent slopes. The terrain has a rolling appearance, which is considered uncommon for this map unit. Soil scientists were concerned as to the composition of this delineation and the amount of included Cuttre and Froberg soil present. The very deep, moderately well drained Amnicon and somewhat poorly drained Cuttre soils formed in clayey till. For both soils, depth to the base of the very fine textured argillic horizon ranges from 40 to more than 60 inches. The weighted average clay content in the particle-size control section ranges from 60 to 85 percent. Depth to free carbonates ranges from 20 to 40 inches. The very deep, well drained and moderately well drained Froberg soil formed in clayey material overlying loamy material. The thickness of the clayey sediments ranges from about 15 to 36 inches.

Table 4. Taxonomic composition of soils

Amnicon	**Very-fine, mixed, active, frigid Oxyaquic Vertic Glossudalfs**
Cuttre	Very-fine, mixed, active, frigid Aeric Glossaqualfs
Froberg	Clayey over loamy, mixed, active, frigid Glossic Hapludalfs

Survey Procedures:

The EM38DD and the newly developed EM38-MK2 meters were used in this study. Walking in a back and forth pattern across the survey area, the EM38DD and EM38-MK2 meters recorded 3298 AND 3318 geo-referenced measurements, respectively. The operator of EM38-MK2 meter followed the path of the operator of the EM38DD meter in the same track and at a distance of about 25 feet to avoid interference. The results obtained with each meter were discussed in the field. The results obtained with the experimental EM38-MK2 meter were reported to Geonics Limited, but are not included in this report. Table 5 shows the basic statistics for the EMI survey conducted with the EM38DD meter.

Table 5. Basic Statistics for the EMI survey of an Amnicon silt loam, 2 to 8 percent slopes, conducted with the EM38DD meter in Ontonagon County, Michigan.

	Horizontal	Vertical
Mean	30.2	43.5
Standard Dev.	4.8	4.3
Minimum	12.9	28.6
Maximum	60.5	75.4
25% tile	27.2	41.0
75% tile	32.2	45.2

With the EM38DD meter, EC_a increased with increasing depth. In the shallower-sensing, horizontal dipole orientation (0 to 0.75 m), EC_a averaged about 30.2 mS/m with a standard deviation of about 4.8 mS/m. One-half the observations had values of EC_a between about 27.2 and 32.2 mS/m. In the deeper-sensing, vertical dipole orientation (0 to 1.5 m), EC_a averaged 43.5 mS/m with a standard deviation of about 4.3 mS/m. One-half the observations had values of EC_a between about 41.0 and 45.2 mS/m. The increased EC_a with increasing depth was attributed to greater moisture and clay contents at lower soil depths.

Plots of EC_a collected with the EM38DD meter are shown in Figure 4. In each plot similar color ramps and isoline (8 mS/m) intervals have been used. Apparent conductivity is essentially invariable across most of the site (standard deviations of 4.3 and 4.8 mS/m in the horizontal and vertical dipole orientations, respectively). This confirms the uniformity of soil properties and the dominance of Amnicon soil across the study site. Higher EC_a were recorded along the drainageway and in the swales and depression. The higher conductivity is attributed to increased soil moisture contents that are associated with Cuttre soil. Ground-truth soil observations confirmed that areas with higher EC_a were Cuttre soil. Areas of lower EC_a were generally confined to drier, convex knolls. In the eastern and northeastern portions of the study site, areas of lower EC_a were associated with a thinner clay cap and shallower depths to the underlying loamy till. These areas represent Froberg soil.

Even though the terrain appeared atypical for an area of Amnicon silt loam, 2 to 8 percent slopes, results from the EMI survey confirmed the adequacy of soil mapping and the appropriateness of map unit design.

Geographical information systems (GIS) are available to soil scientists and field offices. I am impressed by the knowledge and proficiency of NRCS soil scientists that use GIS. Integration of EMI, GPS, and GIS techniques provides a more expedient and cost-effective method for soil mapping and displaying multiple data sets. As an example of this integration, Scott Eversoll provided the ArcGIS presentations of the EMI and GPS data shown in Figure 5. NRCS has the tools and trained soil scientists to display these data sets and to expeditiously and economically accomplish similar tasks.

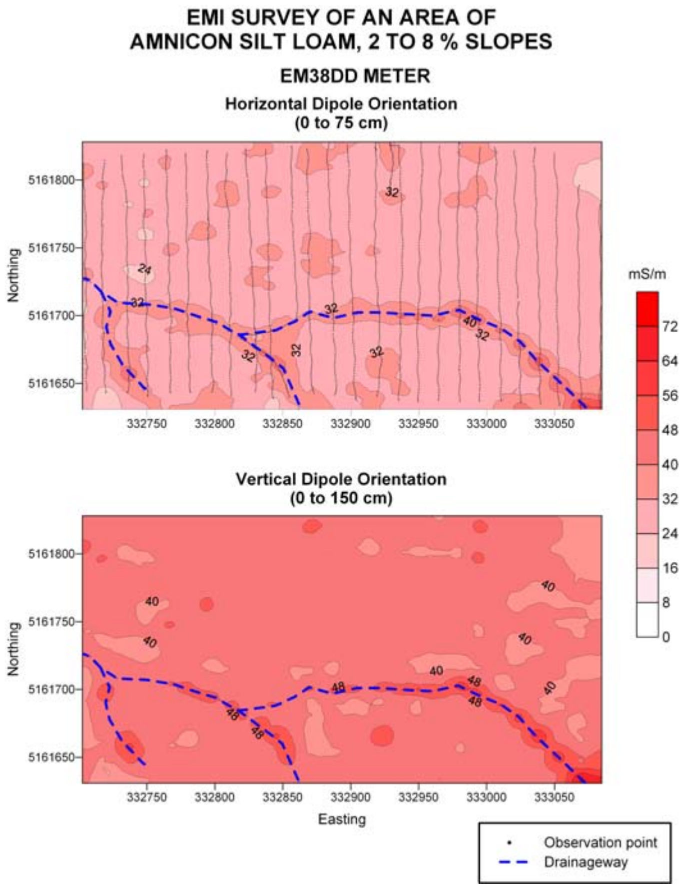


Figure 4. Plots of EC_a collected with the EM38DD meters in Ontonagon County, MI.

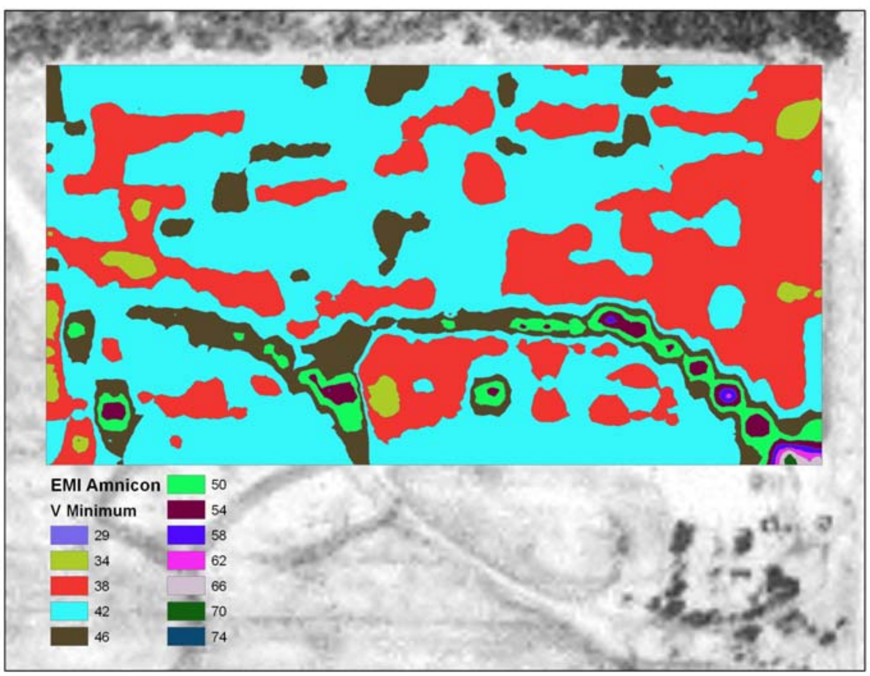


Figure 5. ArcGIS plot of EC_a data collected with the EM38DD meter operated in the vertical dipole orientation from the site in Ontonagon County, MI.

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Appendix 1

377D- ARCADIAN COBBLY SANDY LOAM, 18-25% SLOPES

File #	*Depth (cm)*
10	41
	74
	46
	35
	45
	76
	55
	35
	63
	68
	56

377D- ARCADIAN COBBLY SANDY LOAM, 18-25% SLOPES

File #	*Depth (cm)*
9	89
	73
	114
	94
	116
	106
	113
	83
	152

377D- ARCADIAN COBBLY SANDY LOAM, 18-25% SLOPES

File #	*Depth (cm)*
8	89
	101
	77
	98
	33
	53
	62
	43
	48
	70
	69
	65

551D-DISHNO-GOGEBIC-PESHKEE COMPLEX 18-25%SLOPES

File #	*Depth (cm)*
12	82
	75
	50
	105
	98
	89
	78
	82
	96
	118
	126

551D-DISHNO-GOGEBIC-PESHKEE COMPLEX 18-25% SLOPES

File #	*Depth (cm)*
13	118
	112
	76
	89
	103
	59
	96
	86
	89
	90
	118
	115
	66

551D-DISHNO-GOGEBIC-PESHKEE COMPLEX 18-25% SLOPES

File #	*Depth (cm)*
14	82
	84
	71
	128
	82
	183
	155
	129
	69
	109
	85
	108
	79
	98

551D-DISHNO-GOGEBIC-PESHKEE COMPLEX 18-25% SLOPES

File #	*Depth (cm)*
15	138
	55
	102
	102
	182
	132
	117
	88
	80
	70
	105
	101
	117
	81

551D-DISHNO-GOGEBIC-PESHKEE COMPLEX 18-25% SLOPES

File #	*Depth (cm)*
16	80
	114
	122
	165
	79
	116
	102
	94
	79
	91
	83
	75
	106
	98

551D-DISHNO-GOGEBIC-PESHKEE COMPLEX 18-25% SLOPES

File #	*Depth (cm)*
17	91
	85
	139
	56
	49
	102
	131
	93
	86
	110
	96

429C-GOGEBIC-PESHEKEE COMPLEX 6-18% SLOPES, V STONEY, V. Rocky

File #	*Depth (cm)*
19	133
	164
	203
	252
	280
	242
	193
	78
	0
	11
	58
	99
	275
	0
	72
	102
	56
	88

429C-GOGEBIC-PESHEKEE COMPLEX 6-18% SLOPES, V STONEY, V. Rocky

File #	*Depth (cm)*
20	290
	113
	0
	59
	278
	290
	290
	206
	204
	134
	0
	38
	251
	113
	0
	84
	102
	120
	90
	158
	290
	290
	290
	290
	290
	277
	172
	106

429C-GOGEBIC-PESHEKEE COMPLEX 6-18%SLOPES, V STONEY, V. Rocky

File #	*Depth (cm)*
21	145
	142
	266
	176
	165
	116
	157
	144
	115
	127
	133
	139
	149
	130
	161
	262
	172
	153

429C-GOGEBIC-PESHEKEE COMPLEX 6-18%SLOPES, V STONEY, V. Rocky

File #	*Depth (cm)*
22	201
	335
	259
	173
	189
	164
	175
	202
	169
	180
	215
	264
	157
	147
	225
	179
	130
	223

429C-GOGEBIC-PESHEKEE COMPLEX 6-18%SLOPES, V STONEY, V. Rocky

File #	*Depth (cm)*
23	363
	294
	224
	180
	144
	223
	217
	223
	103
	155
	171
	145
	145
	124
	169
	157
	187
	192
	192
	184
	184
	157
	198

429C-GOGEBIC-PESHEKEE COMPLEX 6-18%SLOPES, V STONEY, V. Rocky

File #	*Depth (cm)*
24	160
	109
	106
	102
	95
	76
	98
	89
	60
	111
	114
	157
	131
	238
	194
	192
	205
	136
	169
	146
	104

429C-GOGEBIC-PESHEKEE COMPLEX 6-18%SLOPES, V STONEY, V. Rocky

File #	*Depth (cm)*
25	113
	73
	144
	124
	162
	141
	103
	143
	132
	197
	129
	48
	146
	97
	100
	124
	281
	127
	118
	198
	184

429C-GOGEBIC-PESHEKEE COMPLEX 6-18%SLOPES, V STONEY, V. Rocky

File #	*Depth (cm)*
26	135
	122
	131
	146
	106
	121
	131
	77
	83
	107
	77
	81
	84
	155
	142
	146
	149
	99
	92
	109
	155
	152
	134
	146

429C-GOGEBIC-PESHEKEE COMPLEX 6-18%SLOPES, V STONEY, V. Rocky

File #	*Depth (cm)*
27	149
	124
	117
	69
	57
	148
	156
	114
	121
	92
	120
	38
	70
	78
	79
	28
	0
	124

429C-GOGEBIC-PESHEKEE COMPLEX 6-18%SLOPES, V STONEY, V. Rocky

File #	*Depth (cm)*
28	79
	109
	147
	115
	134
	122
	105
	233
	140
	128
	111
	105
	112
	94
	86
	129
	133
	112
	123
	138

429C-GOGEBIC-PESHEKEE COMPLEX 6-18%SLOPES, V STONEY, V. Rocky

File #	*Depth (cm)*
29	112
	122
	39
	60
	137
	133
	147
	149
	51
	0
	81
	153
	49
	59
	102
	74
	106
	138

429C-GOGEBIC-PESHEKEE COMPLEX 6-18%SLOPES, V STONEY, V. Rocky

File #	*Depth (cm)*
30	114
	102
	119
	115
	103
	93
	100
	101
	84
	75
	81
	80

429C-GOGEBIC-PESHEKEE COMPLEX 6-18%SLOPES, V STONEY, V. Rock

File #	*Depth (cm)*
31	108
	127
	110
	108
	122
	149
	112
	105
	138
	124
	95
	124
	30
	149
	112

429C-GOGEBIC-PESHEKEE COMPLEX 6-18%SLOPES, V STONEY, V. Rocky

File #	*Depth (cm)*
32	146
	122
	124
	136
	153
	72
	39
	133
	176
	136
	138
	197
	106
	147
	108
	149
	125

429C-GOGEBIC-PESHEKEE COMPLEX 6-18%SLOPES, V STONEY, V. Rocky

File #	*Depth (cm)*
33	118
	88
	0
	50
	137
	120
	93
	157
	146
	131
	94
	142
	123
	132
	95
	138

429C-GOGEBIC-PESHEKEE COMPLEX 6-18%SLOPES, V STONEY, V. Rocky

File #	*Depth (cm)*
	136
	148
	121
	134
	112
	121
	106
	99
	133
	142
	109
	112
	106
	138
	207
	140
	129
	118
	127

429C-GOGEBIC-PESHEKEE COMPLEX 6-18%SLOPES, V STONEY, V. Rocky

File #	*Depth (cm)*
35	147
	160
	173
	120
	159
	150
	158
	177
	238
	146
	133
	174
	127
	124
	141
	138
	139
	143
	141
	84
	81
	156
	142
	130
	119
	114
	62
	130
	124
	108
	112
	131
	107
	109
	133
	59
	110
	113
	146
	162
	139