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

Subject: Soils – Geophysical Field Assistance **Date:** 8 June 2007

To: Donald J. Fehrenbacher
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Purpose:
The primary purpose of this visit was to provide further training and guidance to Mark Krupinski on the operation of the SIR System-2000 ground-penetrating radar (GPR), and the fundamentals of collecting and interpreting radar data. This visit also provided an opportunity for me to obtain some GPR records of the wonderful glacial and periglacial features in Wisconsin.

Participants:
Mark Buelke, Soil Conservationist, USDA-NRCS, Chilton, WI
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Dave Hart, Hydrogeologist, Wisconsin Geological and Natural History Survey, Madison, WI
Jim Hunt, Soil Conservationist, USDA-NRCS, Green Bay, WI
Mark Krupinski, Soil Scientist, USDA-NRCS, Juneau, WI
Peggy Lane, Soil Conservationist, USDA-NRCS, Juneau, WI
Fred Madison, Soil Scientist, Wisconsin Geological and Natural History Survey, Madison, WI
Philip Meyer, Resource Soil Scientist, USDA-NRCS, Appleton, WI
Kevin Traastad, Resource Soil Scientist, USDA-NRCS, Juneau, WI
Jesse Turk, Soil Scientist, USDA-NRCS, Stevens Point, WI

Activities:
All activities were completed during the period of 12 to 16 May 2007.

Recommendations:

1. Mark Krupinski has made remarkable progress with GPR. He is an excellent operator with very good interpretative skills. He is energetic and enthused with the technology and has initiated several studies that should result in the expanded use of GPR in Wisconsin.

2. The performance of GPR in the medium and fine textured soils of Brown, Calumet, and Kewaunee Counties was highly site specific and ranged from good to poor. In areas of shallow and moderately deep soils, the bedrock contact was apparent on most radar records. In very deep soils or soils with a thick, fine-textured argillic horizon, high rates of signal attenuation restrict the radar's profiling depth and the bedrock interface was typically not observed.

3. In areas of very deep and clayey soils within the Northeastern Wisconsin Drift Plain (MLRA 95A), electromagnetic induction (EMI) may provide a better means for determining the depth to bedrock and assessing the spatial distribution of different soils.

4. Mark Krupinski is in need of a shorter antenna cable to conduct GPR surveys in the field. He is presently using a 100-ft cable, which is heavy and difficult to handle especially in forested areas. I would recommend a lighter 7.5-m (25-ft) blue antenna cable. The cable is available from Geophysical Survey Systems Inc. (GSSI) and costs about $850. In addition, the batteries used to power his SIR-2000 radar control unit are nearly spent and will not hold a charge for acceptable periods of time to conduct radar

surveys. Mark is in need of two smart Li-ion batteries (10.8v, 6000 mAH), which are also available through GSSI and cost about $190 each.

5. The availability of computers with larger storage capacities and faster operating speeds, and more sophisticated software programs have greatly improved GPR data processing, interpretation, and visualization. Commonly today, radar records are stored, processed, and displayed using advanced processing techniques. There are ten NRCS radar operators in the United States. Presently, soil scientists who operate GPR in California, Massachusetts, New York, New Hampshire, North Carolina, and Pennsylvania are using the RADAN for Windows processing software. These soil scientists find that this software greatly improves the clarity of subsurface information and greatly facilitates interpretations. RADAN for Windows software enables the production of terrain corrected images which can greatly improve soil-landscape interpretations (see results of GPR studies in Sheboygan County). Three-dimension time sliced images can be used to better understand the spatial variability, geometry and structure of soil features (see results of GPR studies conducted in Adams and Calumet Counties). Color enhanced radar images not only improve interpretations, but provide impressive diagrams for inclusions in reports to customers.

   Mark presently lacks RADAN for Windows software and these capabilities.   If funds permit, I would recommend the purchase of the RADAN 6 software package with interactive 3D analysis module. These programs cost about $1950 each.   Although RADAN does not meet all CCE standards, a conditional waiver has been granted by the USDA-NRCS-ITC Software Test Laboratory (Fort Collins, Colorado) for the use of RADAN on CCE computers used by USDA-NRCS radar operators.

   In the last seven years, the SIR-2000 system radar unit, while highly functional, has been outpaced by technological advances and has been superseded by the TerraSIRch Subsurface Interface Radar (SIR) System-3000 ®. Operating systems and speeds on the SIR-2000 system radar unit are out-of-date and incompatible for transferring data to modern computers. Mark uses a Zip drive to presently transfer data from his radar unit into his PC. He uses the dated, but still effective, *Radan to Bitmap Conversion Utility* program to make images of his radar records for documents. Figure 1 provides an example of the relative quality of a radar record that was prepared using the *Radan to Bitmap Conversion Utility* program (A; upper plot) and RADAN for Windows software program (B; lower plot). The difference is strikingly obvious.

A

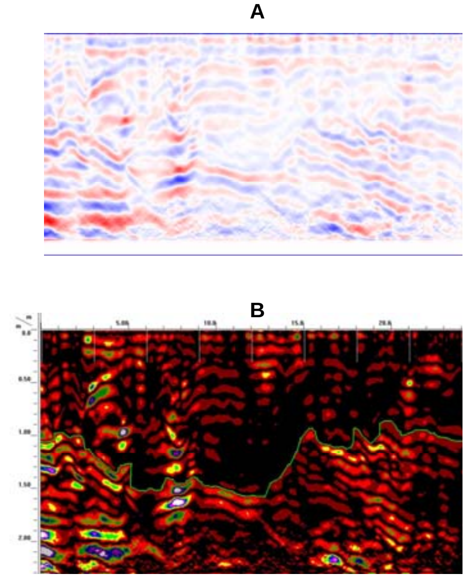

Figure 1. These two bitmap images compare the same radar record which was prepared with the Radan to Bitmap Conversion Utility (A) and RADAN for Windows (B) software programs.

6. During my visit to Wisconsin, we purposely collected radar data on my SIR System-3000 radar unit and have included in this report examples of radar data that were processed with the RADAN software. I think that you will agree that these visualizations are not only vastly superior to the grey-scale strip chart records and bitmap images prepared with the *Radan to Bitmap Conversion Utility*, but will greatly help to improve interpretations and enhance reports.

7. Responding to potential needs, I requested a quote (Sales quote # 04345) from Ken Corcoran (Applications Specialist, Geophysical Survey Systems, Inc.) that lists the individual items that I have recommended above (copy of requested quote appears on page 19 of this report). Also included in this quote for your information is the price of a new SIR System-3000 radar unit.

It was my pleasure to work in Wisconsin and with members of your fine staff. It was my pleasure to work once again with Jesse Turk and Mark Krupinski. I want to especially thank Jesse Turk for his assistance in this study. The National Soil Survey Center pledges its continued assistance in providing whatever GPR training and guidance is needed by the Wisconsin staff.

With kind regards,

James A. Doolittle
Research Soil Scientist
National Soil Survey Center

cc:
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Equipment:
The data shown in this report were collected with a TerraSIRch Subsurface Interface Radar (SIR) System-3000, manufactured by Geophysical Survey Systems, Inc. (Salem, NH).[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.

Radar records contained in this report were processed with the RADAN for Windows (version 5.0) software program. Processing included setting the initial pulse to time zero, header and marker editing, distance and surface normalization, color transformation, migration, horizontal high pass filtration, signal stacking, and range gain adjustments. The Super 3D QuickDraw program developed by GSSI was used to construct three-dimensional (3D) pseudo-image of the radar records collected at grid sites in Adams and Calumet Counties.

The EM38 meter is manufactured by Geonics limited (Mississauga, Ontario).[1] This meter weighs about 1.4 kg (3.1 lbs) and needs only one person to operate. No ground contact is required with this instrument. The EM38 meter has a 1-m intercoil spacing and operates at a frequency of 14,600 Hz. When placed on the soil surface, it has effective penetration depths of about 0.75 m and 1.5 m in the horizontal and vertical dipole orientation, respectively (Geonics Limited, 1998).

The Geonics DAS70 Data Acquisition System was used with the EM38 meter to record and store both apparent conductivity (EC_a) and position data.[1] The acquisition system consists of the EM38 meter, an Allegro CX field computer (Juniper Systems, North Logan, UT), and a Garmin Global Positioning System (GPS) Map 76 receiver (with CSI Radio Beacon receiver, antenna, and accessories that are fitted into a backpack)(Olathe, KS).[1] When attached to the acquisition system, the EM38 meter is keypad operated and measurements can be automatically triggered. The NAV38 and Trackmaker38 software programs developed by Geomar Software Inc. (Mississauga, Ontario) were used to record, store, and process EC_a and GPS data.

To help summarize the results of the EMI surveys, SURFER for Windows, version 8.0 (Golden Software, Inc., Golden, CO), was used to construct simulations of EC_a data.[1] Grids of EC_a data shown in this report were created using kriging methods with an octant search.

Field Techniques:
Short GPR transect lines were established at each site. Mark Krupinski was given the opportunity to setup and operate the SIR System-3000 unit. Radar records were collected with the 200 or 400 MHz antennas. The radar records were reviewed on the video screen, and display settings and interpretations were discussed. At each site ground-truth soil cores were taken to verify interpretations.

To collect the data required for construction of a 3D GPR pseudo-image, 30- x 30-m survey grids were established at sites in Adams and Calumet Counties. Two parallel 30-m lines, which were spaced 30-m apart, were established at each site. Along these two parallel lines, survey flags were inserted into the ground at a spacing of either 50-cm (Adams County) or 100-cm (Calumet County). A reference line was stretched between matching survey flags on opposing sides of the grid using a distance-graduated rope. GPR traverses were conducted along this reference line. An antenna (400 MHz at the Adams County site; 200 MHz at the Calumet County site) was towed along the graduated rope and, as it passed each 100-cm graduations, a mark was impressed on the radar record. Following completion of each radar traverse, the reference line was sequentially displaced to the next pair of survey flags to repeat the process. A total of 61 and 31 traverses were required for the grid at the Adams and Calumet County sites, respectively.

Electromagnetic induction (EMI) surveys were conducted with the EM38 meter at sites in Calumet and Brown Counties. The EM38 meter was operated in the deeper-sensing (0 to 1.5 m) vertical dipole orientation. Only quadrature phase data were collected and expressed as values of apparent conductivity (EC_a) in milliSiemens/meter (mS/m). The meter was held about 3-cm (about 1 inch) above the ground surface and orientated with its long axis

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

parallel to the direction of traverse. Surveys were completed by walking at a uniform pace, in a random or back and forth pattern across each site. The EM38 was operated in the continuous mode (measurements recorded at 1-sec intervals) with the DAS70 system. Using the NAV38 program, both GPS and EC_a data were simultaneously recorded on the field computer.

GPR Basics:
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., soil horizon, bedrock, 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 (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 the equation:

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

where C is the velocity of propagation in a vacuum (0.298 m/ns). Velocity 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 known, subsurface reflectors, and equation [1], the velocity of propagation and the relative dielectric permittivity through the upper part of the soil profiles were estimated at each site. For the upper part of the soil profiles, the estimated E_r ranged from 7.9 (Adams County Site) to 18.8 (Calumet (Site 3) and Brown County sites).

Study Sites:
In general, most soils in Brown, Calumet, Sheboygan, and Kewaunee Counties have moderate to low potentials for GPR soil investigations (ftp://ftp-fc.sc.egov.usda.gov/NGDC/ssatlas/gpr/wi_e.pdf). Most soils in Adams County have high potential for GPR. Large areas in northern and central Wisconsin have been rated as having very favorable properties for GPR applications.

<u>Adams County:</u>
The Adams County site is located in the SW ¼ of Section 4, T. 14 N, R. 6 E. (43.71635 N. Longitude, 089.79753 W. Latitude). The grid site is located on a terrace to the Wisconsin River about ½ mile northeast of Plainville. Dr. Lee Clayton of the Wisconsin Geological and Natural History Survey had previous identified an extensive system of ice-wedge polygons on an aerial photograph of this area. Ice-wedge polygons were evident in cultivated fields on this photograph because of optimal (and ephemeral) moisture differences in the overlying aeolian sediments, which created slight tonal differences on the aerial photograph. These polygons were described by Clayton (1987) as ranging from 10- to 50-m in diameter with ice-wedge casts ranging from 1- to 2-m wide.

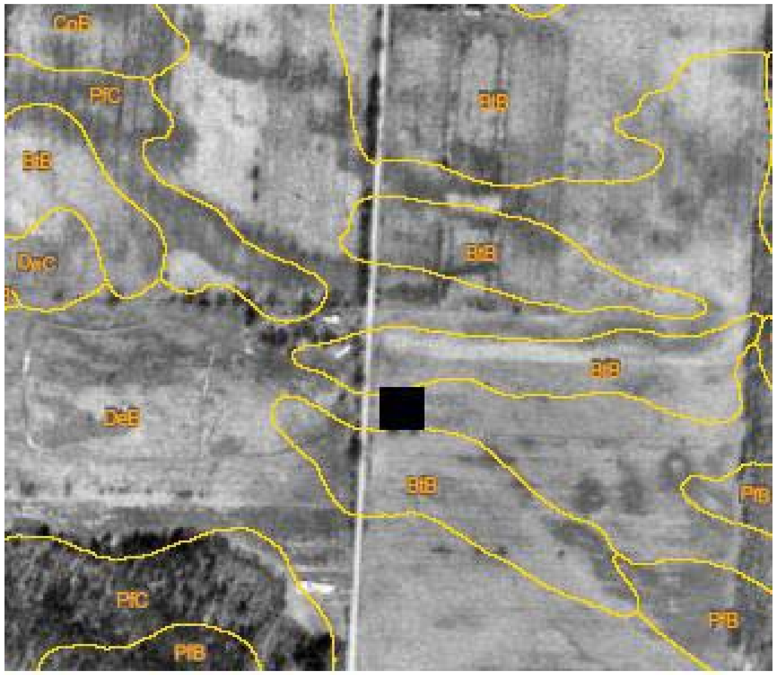

Figure 2. The Adams County grid site (black square) is located in an area of Delton sand, 2 to 6 % slopes (DeB), and Briggsville silt loam, 2 to 6 percent slopes (BrB).

The Adams County site is located in an area that was mapped as Delton sand, 2 to 6 % slopes (DeB), and Briggsville silt loam, 2 to 6 percent slopes (BrB). The very deep, well drained Delton soils formed in an aeolian sand mantle that overlies loamy and clayey lacustrine deposits on stream terraces. The thickness of the sand mantle ranges from about 50- to 100-cm. The very deep, well drained Briggsville soil formed in mostly clayey and silty lacustrine deposits. The taxonomic classifications of these soils are listed in Table 1.

Table 1. Taxonomic classifications of the soils identified in the Adams County site.

Soil Series	Taxonomic Classification
Briggsville	Fine, mixed, superactive, mesic Typic Hapludalfs
Delton	Loamy, mixed, active, mesic Arenic Hapludalfs

<u>Calumet County:</u>
Four sites were located in Calumet County. Site 1 is located off of Carney Road about 3 miles north of Stockbridge (44.03935 N. Longitude, 089.28123 W. Latitude). Site 2 is located off of Ledge Road about 3.5 miles southeast of Stockbridge (44.11098 N. Longitude, 089.29145 W. Latitude). Site 3 is located off of S. Mill Road about 5 miles southeast of Chilton (43.99564 N. Longitude, 088.12122 W. Latitude). All of these sites are located in cultivated fields and in areas that were principally mapped as Whalan silt loam, 2 to 6 percent slopes (WpB). The moderately deep, well drained Whalan soils formed in a mantle of loamy glacial till or drift and in a thin layer of clayey residuum weathered from limestone bedrock on glaciated uplands. The depth to limestone bedrock ranges from 50- to 100-cm. Site 4 is located in the Brillion Wildlife Area, northeast Calumet County (44.15816 N. Longitude, 088.09412 W. Latitude). Here, a 30- x 30-m grid was established across and area of Kolberg loam, 2 to 6 percent slopes (KoB). The moderately deep, well drained Kolberg soils formed mostly in clayey till that is underlain by dolomite. The taxonomic classifications of Kolberg and Whalan soil are listed in Table 2

Table 2. Taxonomic classifications of the soils identified in the Calumet County sites.

Soil Series	Taxonomic classification
Kolberg	Fine, mixed, active, frigid Haplic Glossudalfs
Whalan	Fine-loamy, mixed, superactive, mesic Typic Hapludalfs

Brown County:
The Brown County site is located off of Lark Road about 5 miles east of Greenleaf (about 44.31261 N. Longitude, 87.99104 W. Latitude). The site is located in a field of alfalfa. Soils recognized within this site include Bonduel, Summerville, and Waymor. The taxonomic classifications of these soils are listed in Table 3. These soils form over dolomite or limestone bedrock on ground moraines. Bonduel soils are somewhat poorly drained and moderately deep to bedrock. Summerville soils are well drained and shallow to bedrock. Waymor soils are well drained and very deep to bedrock. As described by Mark Krupinski, areas of Bonduel soils are in a drainageway, Summerville soils are on adjacent uplands, and Waymor on higher-lying slope positions. Table 4 lists the names and symbols for the soil map units recognized in the Brown County site.

Table 3. Taxonomic classifications of the soils identified in the Brown County site.

Soil Series	Taxonomic Classification
Bonduel	Fine-loamy, mixed, active, frigid Aquollic Hapludalfs
Summerville	Loamy, mixed, active, frigid Lithic Eutrudepts
Waymor	Fine-loamy, mixed, active, mesic Haplic Glossudalfs

Kewaunee County:
A radar survey was conducted across a site for a proposed manure storage facility in Kewaunee County. The site is located just east of Luxemburg (44.31261 N. Longitude, 87.99104 W. Latitude). This area is mapped Kewaunee silty clay loam, 6 to 12%, eroded (KpC2). The very deep, well drained Kewaunee soils formed in clayey till, typically with a thin mantle of loess, on moraines. Kewaunee is a member of the fine, mixed, active, mesic Typic Hapludalfs family.

Table 4. The names and symbols for the soil map units identified in the Brown County site.

Map Unit Symbol	Map Unit Name
BnA	Bonduel silt loam, 0 to 3 % slopes
SvB	Summerville silt loam, clayey subsoil variant, 1 to 6 % slopes
WoB	Waymor silt loam, 2 to 6 % slopes
WoC	Waymor silt loam, 6 to q2 % slopes, eroded

Sheboygan County:
Radar surveys of glacial landforms were completed in Sheboygan County. A moulin kame, know as Garriety Hill, was surveyed east of Long Lake near the intersection of County Road V and Scenic Drive E (43.689142 N. Longitude, 88.139350 W. Latitude). A portion of the Parnell Esker was also surveyed at the Flynn Springs Natural Area near Butler Lake and just off of Butler Road (43.663561 N. Longitude, 88.136383 W. Latitude). Both features were mapped as Casco- Rodman complex 20 to 30 percent slopes (CrE). The very deep, excessively drained Casco and Rodman soils formed in stratified, calcareous sandy and gravelly outwash on kames, eskers, moraines, outwash plains, and valley trains. The Casco soil has a thin mantle of loamy alluvium overlying the outwash deposits. The taxonomic classifications of these soil series are listed in Table 5.

Table 5. Taxonomic classifications of the soils mapped at the Sheboygan County sites.

Soil Series	Taxonomic classification
Rodman	Sandy-skeletal, mixed, mesic Typic Hapludolls
Casco	Fine-loamy over sandy or sandy-skeletal, mixed, superactive, mesic Inceptic Hapludalfs

Results:

Adams County

Figure 3 is a 14 m portion of a radar record that was obtained at the Adams County site. All scales on this record are expressed in meters. The depth scale shown is based on an estimated dielectric permittivity (E_r) of 7.9 and the resulting propagation velocity (*v*) of 0.106 m/ns through the surface layers. The white, vertical lines at the top of the radar record represent the equally spaced (1-m) graduations on the distance-graduated rope. The radar record was processed using migration, horizontal high pass filtration and signal stacking to remove unwanted background noise.

The radar record shown in Figure 3 was collected in an area of Delton sand, 2 to 6 % slopes. On this radar record, the contact between the aeolian sand mantle and the underlying clayey lacustrine deposits has been highlighted with a green-colored line. On this radar record, the sand mantle is mostly less than 50-cm thick, which is outside the range for Delton soils (50 to 100 cm). This contact appears highly irregular and varies in depth from 18- to 62-cm on this radar record.

Noticeable concavities (see "A" in Figure 3) with down-turned reflection patterns are apparent along the interface that separates the sand mantle from the underlying clayey lacustrine deposits. These concavities are presumably in-filled with sandy aeolian materials. Beneath these concavities, high amplitude reflections and signal reverberations indicate the presence of in-filled materials that contrast with the finer-textured, confining lacustrine deposits. The lacustrine deposits are characterized by a general absence or presence of only low-amplitude reflections (colored black and red). The in-filled materials appear to be layered as they consist of multiple reflectors of different forms (ranging from point to planar reflectors). These forms suggest the slump fabric ("stratification arcuate downward") that Black (1976) suggested as one of the criteria for the recognition of ice-wedge casts.

Questions remain as to the spatial pattern and arrangement of the ice-wedge cast observed on the two-dimensional (2D) radar records. Does the terrace contain detectable remnants of ice-wedge polygons that have been buried and masked by aeolian sediments? To answer this question a 3D GPR grid survey was conducted across a small portion of the terrace.

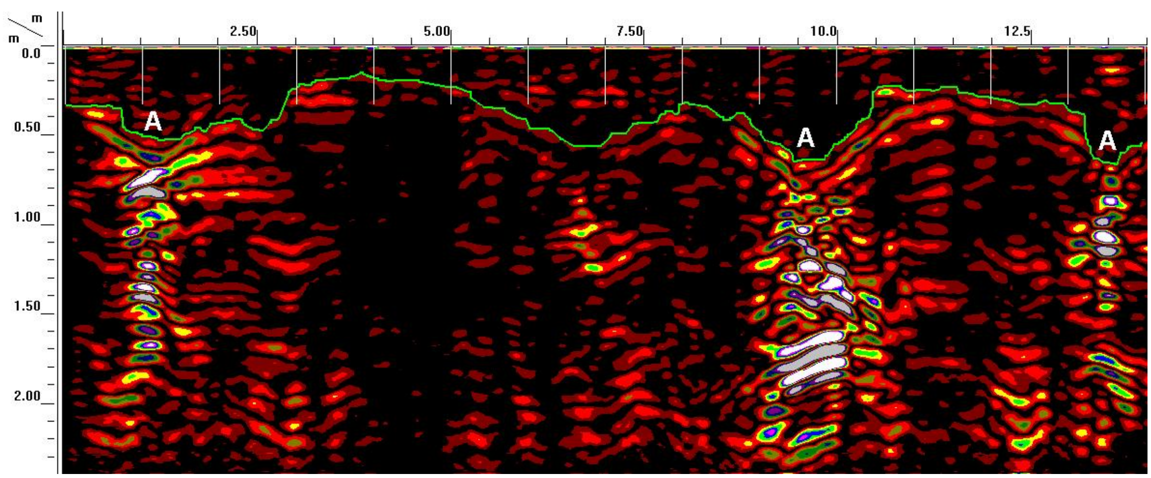

Figure 3. A representative portion of a radar record from the Adams County Site showing the irregular topography of the contact that separates the sand mantle from the underlying clayey lacustrine deposits.

The recent advent of digital GPR output and the availability of more powerful computers and advanced data-processing software allow the geometry and structure of subsurface features recorded on radar traverses to be analyzed from a three-dimensional (3D) perspective. Compared with 2D GPR records, 3D images often provide greater resolution and detail (Grasmueck and Green, 1996) and improve our ability to identify weakly expressed subsurface features and patterns. To construct 3D images, relatively small areas (generally < 50-m on a side) are surveyed intensively using closely spaced (typically 10- to 100-cm) parallel GPR traverses. Data from the traverses are assembled to create 3D pseudo-images of the subsurface, allowing arbitrary cross-sections, insets, and time-slices to be extracted from the data set.

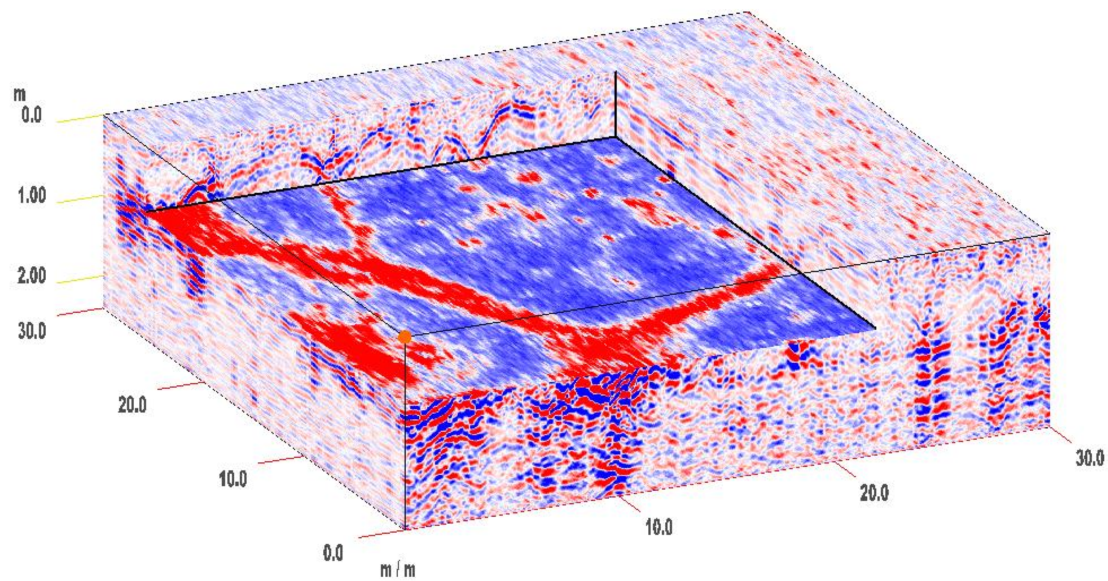

Figure 4. 3D GPR pseudo-image of the Adams County site with a 22- by 26- by 0.85-m inset removed to show the geometry of ice-wedge casts.

Figure 4 is a 3D GPR pseudo-image of the Adams County grid site. In this pseudo-image a 22- by 26- by 0.85-m inset has been graphically removed from the 3D cube. All radar traverses were conducted parallel to the X axis (right foreground), which was orientated in a north-south direction. Radar traces were more continuously sampled in this direction and reflectors are more strongly expressed, with little distortion to the data in this direction. Along the Y axis, however, data were not continuously recorded but interpolated over a 50-cm interval (the distance between radar traverses). As a result, some subsurface information was lost during interpolation and data along the Y-axis appear noticeably smudged, less resolved, and more generalized.

The interface separating the sand mantle from the clayey lacustrine deposits provides a highly contrasting boundary that produce high-amplitude (in Figure 4, colored darker red and blue) reflections. This interface is particular evident in the back wall of the cut-out cube. Along this cross section, the interface appears highly irregular with noticeable concavities over features presumed to be ice-wedge casts (the concavities observed in 2D radar record (see Figure 3)). The base of the cutout cube contains a series of linear and intersecting high-amplitude red-colored reflections. These reflectors represent the casts of ice-wedge polygons.

<u>Calumet County:</u>
Figure 5 is a 18-m portion of a radar record from Site 1 in Calumet County. All scales on this record are expressed in meters. The depth scale shown is based on an estimated dielectric permittivity of 10 and a propagation velocity of 0.094 m/ns through the surface layers. The white, vertical lines at the top of the radar record represent the locations of the equally spaced (1 m) survey flags along the traverse line. The radar record was processed using migration, horizontal high pass filtration and signal stacking to remove unwanted background noise.

The radar records obtained at Sites 1 and 2 in Calumet County were depth restricted and considered of poor interpretative quality. Both sites were located in areas of Whalan silt loam, 2 to 6 percent slopes (WpB). The moderately deep, well drained Whalan soils formed mostly in a mantle of medium textured till, but typically contain a thin layer of clayey residuum immediately above the limestone bedrock surface. The clay minerals are predominantly 2:1 expanding lattice clays that have relatively high cation exchange capacities. The high clay content and presence of 2:1 expanding lattice clay minerals of the Wahlen soil restrict penetration depths. The effectiveness of GPR will depend on the clay content, thickness of clay column and depth to parent rock.

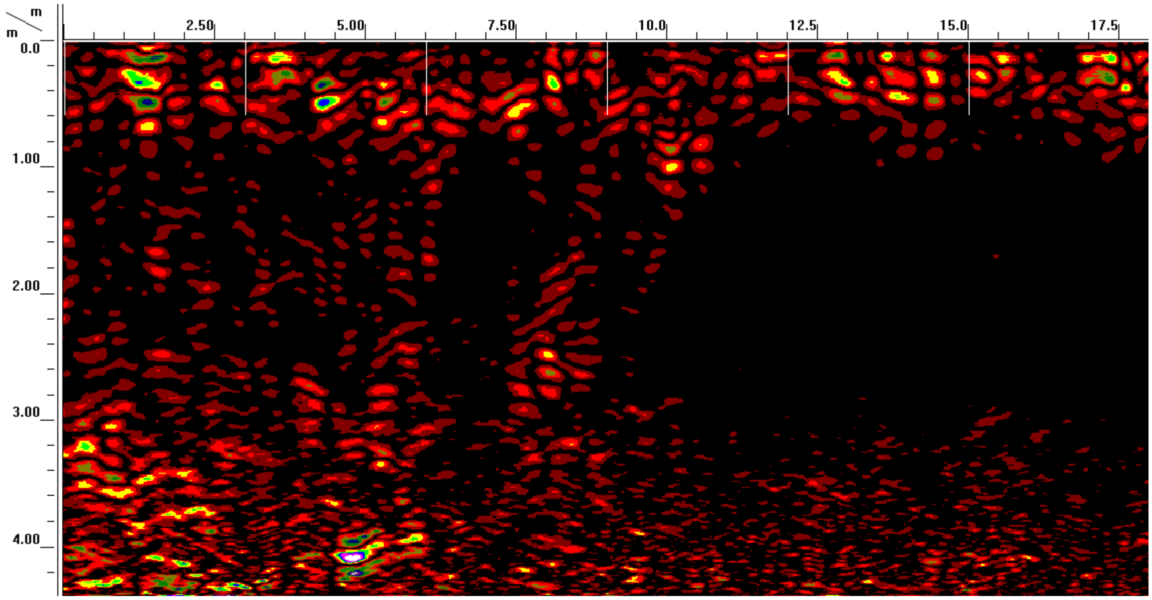

Figure 5. A representative portion of a radar record from Site 1 in Calumet County.

In Figure 5, the penetration depth of the 200 MHz antenna is noticeable deeper in the left-hand portion of the radar record. From the 0- to 11-m mark, the antenna crossed a higher-lying area with shallow to moderately deep soils. Here, penetration depths were greater than 3-m. Unfortunately, because of the large number of rock fragments in the soil, the soil/bedrock surface is less contrasting and impossible to identify and trace laterally across the radar record. From the 11- to 18-m mark, the antenna crossed a lower-lying area with deeper to bedrock and/or higher clay contents soils. Here, penetration depths were greatly reduced and meaningful reflections were not attained below depths of about 80-cm.

While radar records from sites 1 and 2 in Calumet County were disappointing and of limited value, the radar records from Site 3 in Calumet County provided a continuous and easily interpreted record of the soil/bedrock interface. This site was also located in an area of Whalan silt loam, 2 to 6 percent slopes (WpB). The dielectric permittivity estimated for this site (E_r = 18.8) was higher than the values estimated for sites 1 and 2. It was inferred from the higher E_r that the Wahlen soils at Site 3 were moister than the Whalen soils at sites 1 and 2.

Figure 6 is a 25-m portion of a radar record from Site 3 in Calumet County. All scales on this record are expressed in meters. The depth scale shown is based on an estimated E_r of 18.8 and a propagation velocity of 0.069 m/ns through the surface layers. The white, vertical lines at the top of the radar record represent the locations of the equally spaced (3-m) survey flags along the traverse line. The radar record was processed using migration, horizontal high pass filtration and signal stacking to remove unwanted background noise.

Parallel bands of subsurface reflections represents bedding planes in the underlying dolomite. Bedding planes consists of parallel layers of different textures, densities, and compositions. The closest point to which one of these parallel bands approaches the surface is considered the depth to bedrock. In this figure, bedrock depths range from about 5- to 170-cm. High amplitude (colored white, pink, green, and blue) reflections represent rather abrupt boundaries that separate highly contrasting materials. The segmented appearance of these reflectors suggests possible solution features within the bedrock. Vertical breaks in the radar records may represent fracture planes and solution cavities in the bedrock.

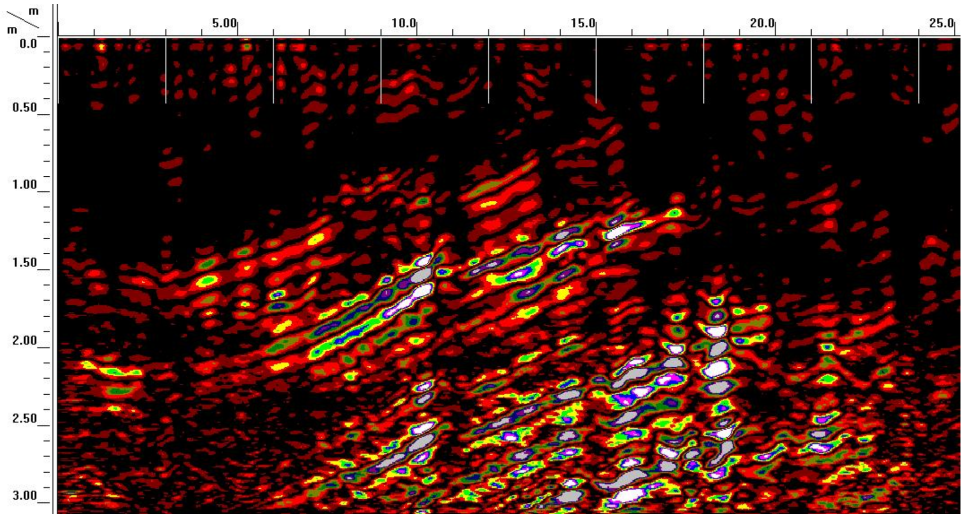

Figure 6 A representative portion of a radar record from Site 3 in Calumet County Site 3

In order to evaluate the effectiveness of 3D GPR pseudo-image analysis for depth to bedrock assessments, a 30- x 30-m grid was established across and area of Kolberg loam, 2 to 6 percent slopes, in the Brillion Wildlife Area. It was uncertain how effective GPR would be in an area of moderately deep to bedrock soils that formed mostly in clayey till.

Figure 7 is a 3D GPR pseudo-image of the Calumet County grid site. In this pseudo-image a 22- by 15- by 1-m inset has been graphically removed from the 3D cube. All radar traverses were conducted parallel to the X axis (right foreground), which was orientated in a north-south direction. Once again, because of the intensity of sampling and interpolation, reflectors are more strongly expressed with little distortion along the X-axis, and clearly smudged, less resolved, and more generalized along the Y-axis.

The soil/bedrock interface is clearly depicted in all visible side walls of the 3D cube shown in Figure 7. As seen in this pseudo-image, the bedrock surface is irregular and occurs at depth ranging from about 25- to 50-cm. This is outside the range for the Kolberg series. Breaks and variations in the amplitude of the bedding plane reflections are evident in this image and are believed to represent potential fracture planes and differences in density and/or composition, respectively.

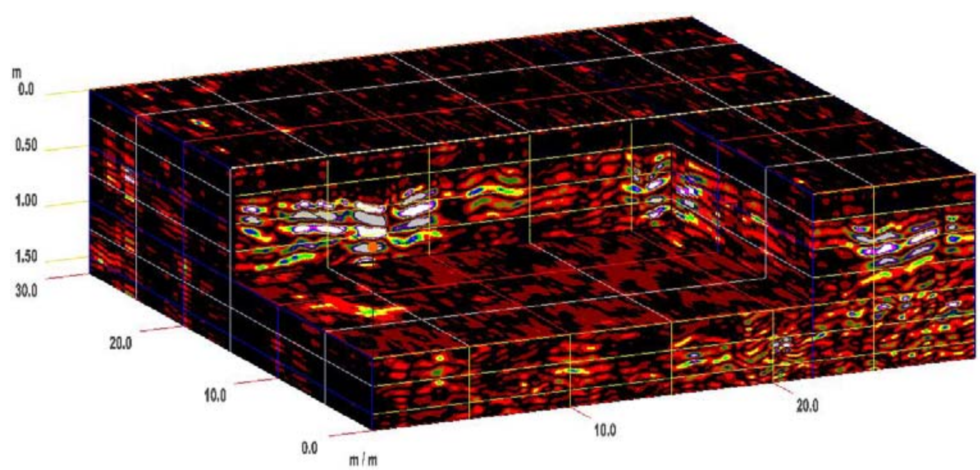

Figure 7. A 3D GPR pseudo-image of an area of Kolberg-like soil in Calumet Count. In this image, a 22- by 15- by 1-m inset has been removed to show the depth and geometry of the soil/bedrock contact.

Brown County:

Figure 8 is a 27-m portion of a radar record from the Brown County site. All scales on this record are expressed in meters. The depth scale shown is based on an estimated E_r of 18.8 and a propagation velocity of 0.069 m/ns through the surface layers. The white, vertical lines at the top of the radar record represent the locations of the equally spaced (3-m) survey flags along the traverse line. The radar record was processed using migration. Unlike other records shown in this report, horizontal high pass filtration and signal stacking were not performed on this record.

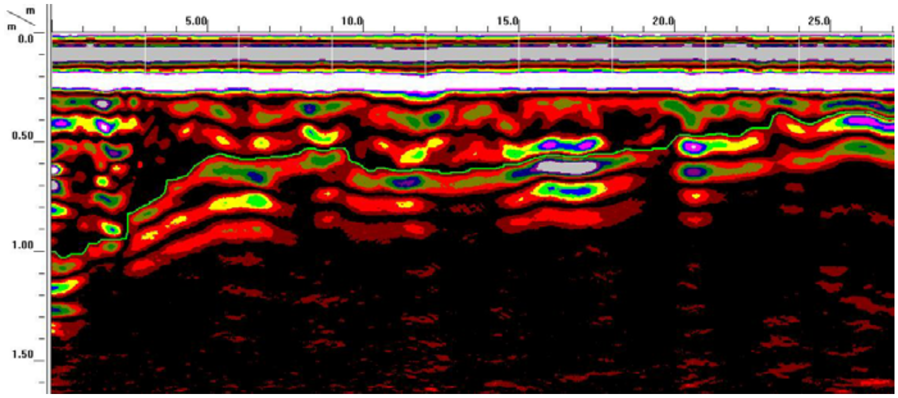

Figure 8 A representative portion of a radar record from the Brown County Site. A green-colored line has been used to highlight the interpreted bedrock surface.

In Figure 8, the interpreted bedrock surface has been highlighted with a green colored line. On this radar record the bedrock is relatively shallow and ranges in depth from about 40- to 100-cm. Though reflections from this interface are spatially continuous, they vary in signal amplitude. No reflections are evident below this interface. At this site, the soils were attenuating and depths were restricted to less than 150-cm. The relatively high clay contents and presence of 2:1 expanding lattice clay minerals with relatively high cation exchange capacities of these soils are believed to be responsible for limiting the depth of signal penetration. Once again, the effectiveness of GPR for determining the soil depth class will depend on the clay content, thickness of clay column and depth to parent rock.

Kewaunee County:

Ground-penetrating radar was used at this site to determine the depth to bedrock in advance of construction of an animal waste-holding facility. In this area of Kewaunee soil, GPR was effective in determining the depth to bedrock. This was unanticipated as Kewaunee is fine-textured soil. However, the soils were moderately deep and deep to bedrock and the fine-textured Bt horizon was relatively thin at this site.

Figure 9 is a 24-m portion of a radar record from the site in Kewaunee County. All scales on this record are expressed in meters. The depth scale shown is based on an estimated E_r of 13.14 and a propagation velocity of 0.082 m/ns through the surface layers. The radar record was processed using migration, horizontal high pass filtration and signal stacking to remove unwanted background noise. In Figure 9, a green-colored line was used to highlight the interpreted bedrock surface.

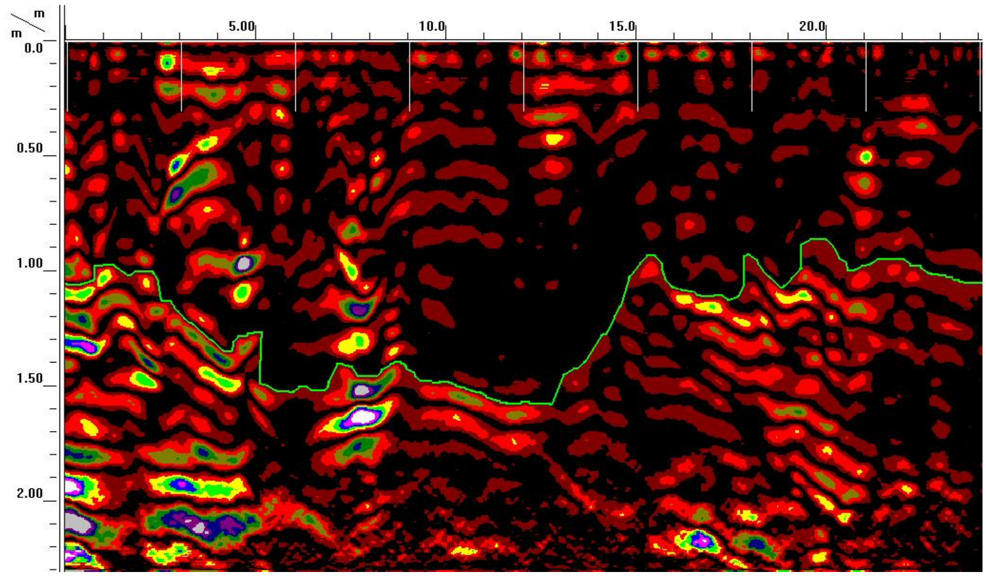

Figure 9 A representative portion of a radar record from the Kewaunee County Site. A green-colored line has been used to highlight the interpreted bedrock surface.

Based on 22 interpretations made at flagged locations along 7 radar transect lines and assuming a propagation velocity of 0.082 m/ns, the depth to bedrock averaged 99.9 cm and ranged from 66- to 150-cm. One half of the observations had depths to bedrock between 83.8- and 119.2-cm.

Sheboygan County:

Short radar traverses were completed across portions of two glacial landforms: a moulin Kame (Figure 10) and an esker (Figure 11). The purpose of these investigations was to obtain a better understanding of the internal stratigraphy of these features. A moulin kame is formed where supraglacial meltwater falls into the glacier, loses its gradient and velocity, and deposits its load in a pile. Carlson et al. (2005) noted that the moulin kames in the northern Kettle Moraine contain poorly-sorted, relatively angular debris, laminated silts, and diamicton. These sediments were observed to be steeply dipping and interbedded with one another (Carlson et al., 2005). An esker is a sinuously curving, narrow deposit of coarse gravel that forms along a meltwater stream channel that flowed in a tunnel within or beneath the glacier. Within the northern Kettle Moraine, Carlson et al. (2005) observed that the two prominent esker ridges contain well-sorted, well-rounded sands and gravels. Carlson et al. (2005) suggests a supraglacial origin for both the moulin kames and eskers. With the retreat and wastage of glacial ice, some slumping and mixing of the materials within these features occurred.

Figure 10. A photograph of Garriety Hill, a moulin kame view to north (From: Louis J. Maher, Jr. (2001) http://www.geology.wisc.edu/~maher/air/air11.htm). A radar traverse was conducted from apex of kame down slope and towards the east (right).

Figure 11. Photograph of portions of Parnell Esker and Butler Lake about 3 miles northeast of Dundee, WI. (From: Louis J. Maher, Jr. (2001) http://www.geology.wisc.edu/~maher/air/air11.htm).

Figures 12 and 13 are radar records from the Moulin kame and esker, respectively. In these figures, the surface has been *terrain corrected* to improve the visual presentation. Through a process known as *surface normalization*, measured elevations are assigned to each reference point and the image is corrected for changes in relief. Surface normalization helps to improve the interpretative quality of radar records and the association of subsurface reflectors with landscape components.

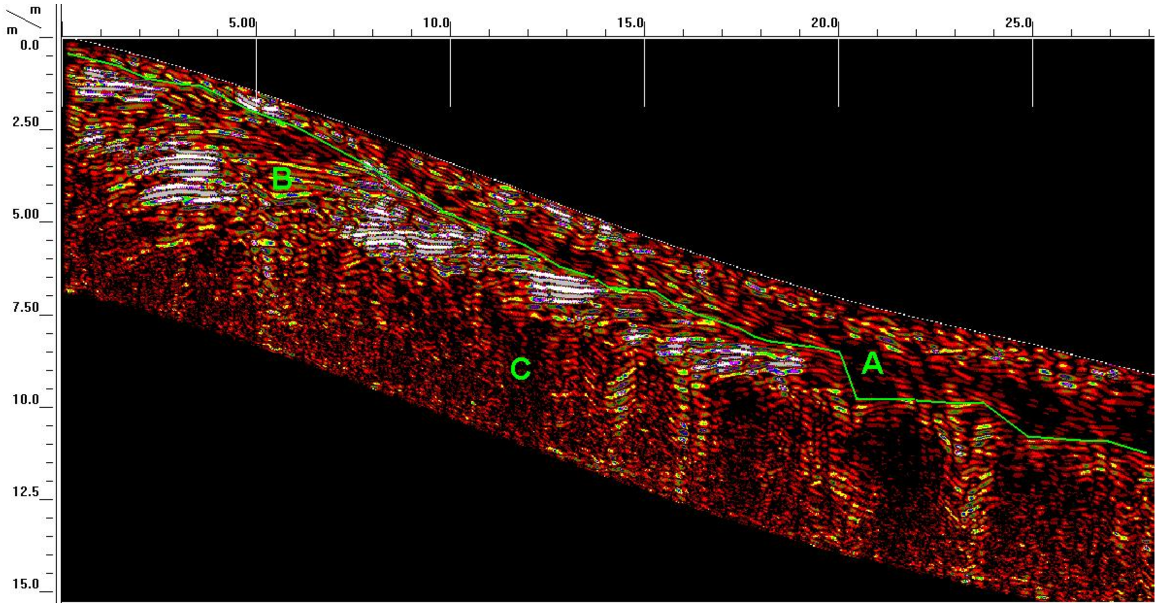

Figure 12. A terrain corrected radar record from the Moulin kame known as Garriety Hill.

In Figure 12, a region of reflectors (see A) that generally parallel the soil surface characterize the slumped debris along the kame's upper side slopes. Beneath this zone is a region of high amplitude (colored white, grey, and blue) parallel reflectors (see B) that characterize the stratified and interbedded materials of the kame. Near the summit of the kame, these strata appear to dip downwards into the core of the kame. The lowest identifiable region (see C) appears to consist of weak chaotic, highly segmented reflectors. Chaotic segmented reflectors are more typical of diamicton.

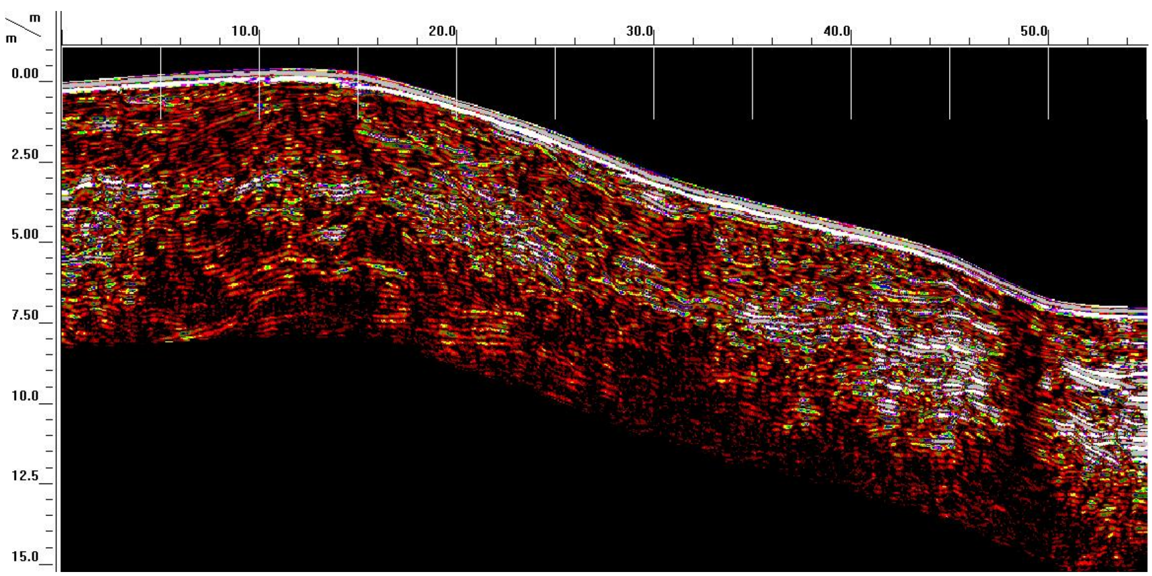

Figure 13. A terrain corrected radar record showing a portion of the Parnell Esker.

In Figure 13, wavy, more continuous, planar reflectors signify the glaciofluvial origins of the materials that form the esker. High amplitude reflections represent abrupt and highly contrasting materials (probably differences in grain size distributions and moisture contents). Slightly greater depths of penetration were achieved in the esker (Figure 13) than in the moulin kame (Figure 12). This difference is believed to reflect the lower clay and silt content (more attenuating fractions to GPR) of the esker. The radar signatures from the kame (Figure 12) and esker (Figure 13) are different and reflect the unique origins of the two landforms.

EMI Surveys:
Electromagnetic induction (EMI) is an accepted tool for the refinement and improvement of soil maps. Because EMI data are rapidly and effortlessly gathered, with apparent conductivity (EC_a) measured on a second-by-second basis, data populations are relatively large and sites can be more comprehensibly covered in shorter periods of time than with conventional soil survey tools and methods. As such, EC_a data provide an additional, more detailed layer of soil information that can be useful in making soil mapping decisions.

Areas with different EC_a have been associated with different soils, soil properties, and management zones. Electromagnetic induction has demonstrated potential for identifying dissimilar inclusions in some soil delineations (Fenton and Lauterbach, 1999) and general soil patterns within fields (King et al., 2005). Anderson-Cook et al. (2002) used crop yields and EC_a data, to classify four different soils with an accuracy of over 85 percent. In precision agriculture, field-scale EC_a mapping is used to identify management zones and to direct soil sampling (Johnson et al., 2001). However, EC_a is not diagnostic of soils or soil properties in itself. Spatial EC_a patterns often reflect variations in more than one soil property and do not always correspond to changes is soil types. Relationships between EC_a and soil properties vary at different spatial scales and can change over surprisingly short distances. As more than one soil property can influence EC_a, spatial variations in different soil properties can confound interpretations and foster inconsistent and ambiguous results (Carroll and Oliver, 2005). The effectiveness of EMI as a soil mapping tool greatly depends on the degree to which differences in soil properties correspond to measurable differences in EC_a.

Fenton and Lauterbach (1999) noted that "one of the objectives of soil mapping is to delineate soil bodies that contain less variable soil conditions than the population of soils as a whole." In high-intensity soil surveys, map units are fairly homogenous and the size and number of contrasting or dissimilar inclusions are limited. A major contribution of high-intensity soil surveys is the identification and delineation of small areas of dissimilar soils (Fenton and Lauterbach, 1999). EMI has proven itself useful in delineating dissimilar soil map unit inclusions.

<u>Calumet County Site 1:</u>
Four separate EMI surveys were conducted: three surveys were conducted in Calumet County (sites 1, 2 & 3) in areas of Whalen soil, and one survey was conducted in Brown County in areas Bonduel, Kolberg, Summerville, and Waymor soils. Table 6 summarizes the basic EC_a statistics for these surveys. Within the three areas of Whalen soil in Calumet County, EC_a ranged from about -6.0 to 33.0 mS/m. Negative values are attributed to metallic artifact scattered across each study area and improper initial calibration of the meter. The soils with the Brown and Calumet County sites are characterized as being electrically resistive and displayed relatively low EC_a. The area of Whalen soil at Calumet County Site 2 is slightly more conductive. Here the soils were presumably deeper and moister.

Table 6
Basic statistics for the EC_a data that was collected with the EM38 meter at sites located in Calumet and Brown Counties.
(EC_a measurements are expressed in mS/m)

Site	Observations	Minimum	25%-tile	75%-tile	Maximum	Mean	Standard Deviation
Calumet County Site 1	980	-3.13	9.63	15.88	22.00	12.64	4.35
Calumet County Site 2	1030	8.38	18.50	22.50	33.25	20.71	3.49
Calumet County Site 3	806	-5.88	2.13	6.00	14.75	4.02	3.02
Brown County	1253	0.50	7.25	11.13	20.25	9.16	3.04

Differences in EC_a are attributed to differences in clay and moisture contents and depth to bedrock in the soils at these sites. The spatial distributions of EC_a within the four sites are shown in Figures 14 thru 17. In these plots, to aid site comparisons, the same color scale and isoline interval (2 mS/m) are used. In each plot, areas of low (<10 mS/m) EC_a are presumed to be shallower to bedrock. Areas of higher EC_a are presumed to be deep or very deep to bedrock, wetter, and/or have higher contents clay contents. At each site ground-truth auger observations were made along a traverse line. EC_a measurements were obtained at each of these observation points to confirm interpretation and to develop regression equations to predict the depth to bedrock. Unfortunately, the EC_a data was inadvertently purged and predictive equations could not be developed.

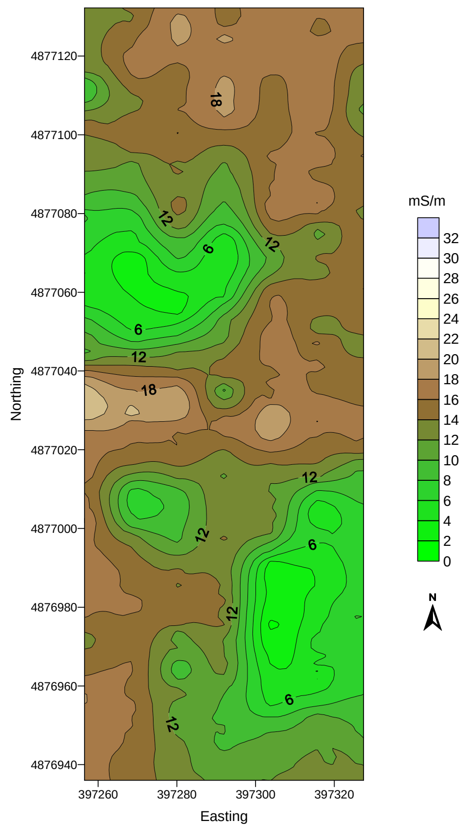

Figure 14. Map of soil EC_a collected with the EM38 meter at the Calumet County Site 1

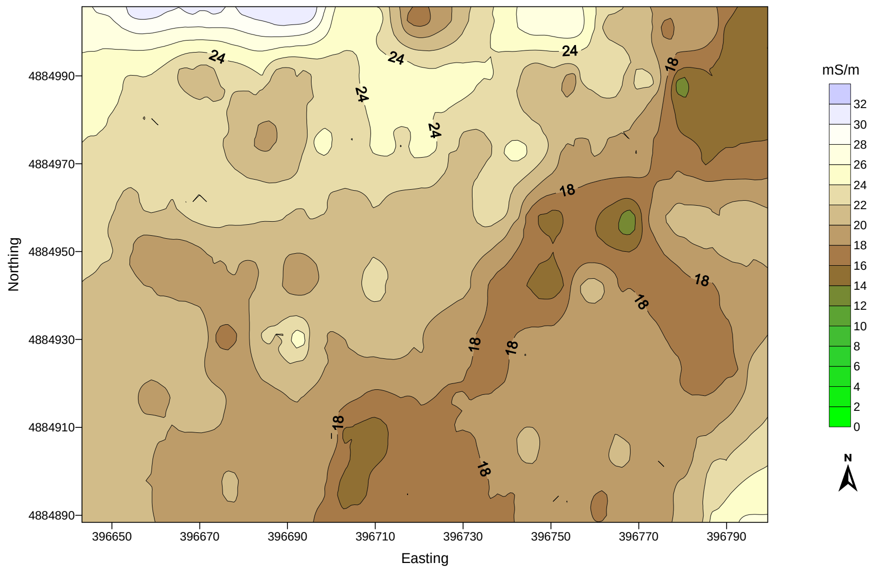

Figure 15. Map of soil EC_a collected with the EM38 meter at the Calumet County Site 2

Figure 14 shows the spatial distribution of EC_a within Calumet County Site 1. Within this site, the depth to dolomite was shallower on slightly higher-lying convex knobs. In Figure 14, these knobs are characterized by low (< 12 mS/m) EC_a. Depth to bedrock is deeper on lower-lying plane and concave areas that have higher EC_a (> 12 mS/m).

Figure 15 shows the spatial distribution of EC_a within Calumet County Site 2. This site had the highest EC_a with an averaged value of 20.7 mS/m and a range from about 8.4 to 33.2 ms/m. Presumably, bedrock depths and clay contents are greater in the soils at this site. Wet and rainy conditions precluded the use of GPR and extensive auger observations.

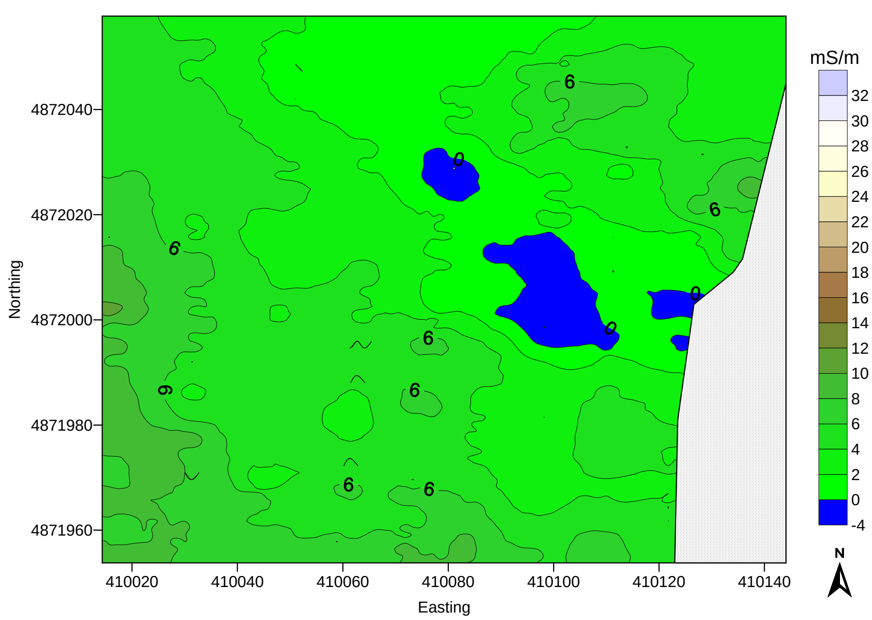

Figure 16. Map of soil EC_a collected with the EM38 meter at the Calumet County Site 3

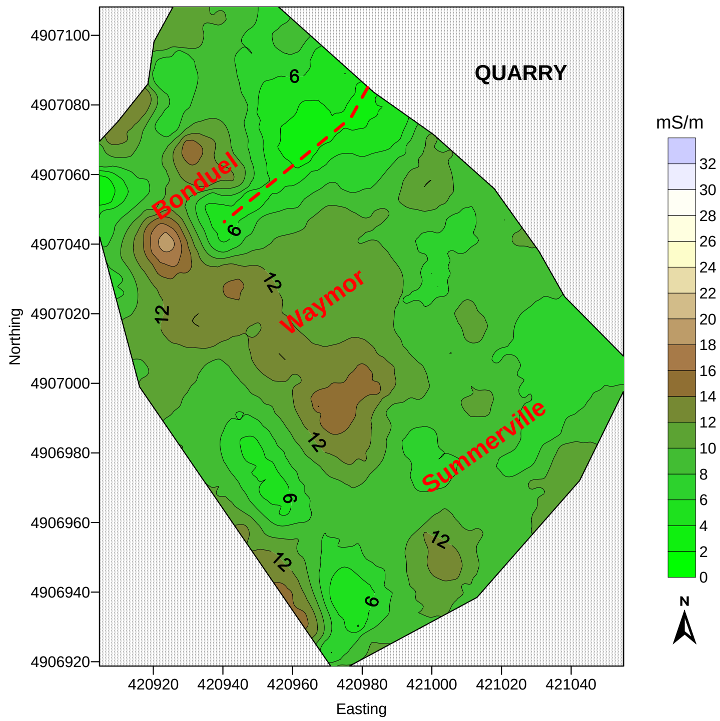

Figure 15. Map of soil EC_a collected with the EM38 meter at the Brown County Site.

Figure 15 shows the spatial distribution of EC_a within Calumet County Site 3. Within this site, based on 10 auger observations, the depth to dolomite ranged from 122 to 174 cm. The low EC_a reflects the noticeably lower clay content of the Whalen soil at this site than at the other sites in Calumet County. In Figure 14, negative EC_a values were recorded on a higher-lying convex surface where the bedrock was very hallow.

Figure 16 shows the spatial distribution of EC_a within the Brown County site. Bedrock was exposed along a drainage line (red segmented line in Figure 16) that extended across the northeast portion of the site and into a neighboring quarry. The low EC_a along this drainageway reflects the shallow depths to bedrock. Areas of somewhat poorly drained Bonduel soil had a higher EC_a while areas of shallow Summerville soils on ridgetops displayed relatively low EC_a. Areas of very deep Waymor on intermediate slope positions displayed relatively higher EC_a

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