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

Subject: Soils – Geophysical Field Assistance **Date:** 23 January 2007

To: Roylene Rides at the Door
State Conservationist
USDA-NRCS
60 Quaker Lane, Suite 46
Warwick, RI 02886-0111

Purpose:
The purpose of this visit was to deliver an EM38 meter, Allegro field computer, and laptop computer to Jim Turenne for use principally by soil scientists tasked with geophysical responsibilities in the northeast. Repetitive field and classroom training exercises were provided on the operation of the EM38 meter and the transfer, processing, and visualization programs contained in the field and laptop computers. In conjunction with these exercises, training was also provided to Rob Tunstead (soil, scientist, USDA-NRCS, West Wareham, MA) on ground-penetrating radar (GPR) field data collection, and processing and visualization procedures available through the RADAN for Windows software program.

Participants:
Eric Boettger, Soil Conservation Technician, USDA-NRCS, Warwick, RI
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Maggie K. Payne, Biological Technician, Soil Science Laboratory, USDA-NRCS, Kingston, RI
Donald Parizek, Soil Scientist, USDA-NRCS, Windsor, CT
Debbie Surabian, Soil Scientist, USDA-NRCS, Tolland, CT
Robert Tunstead, Resource Soil Scientist, USDA-NRCS, West Wareham, MA
Jim Turenne, Assistant State Soil Scientist, USDA-NRCS, Warwick, RI

Activities:
All activities were completed during the period of 8 to 11 January 2007.

Summary:

1. An EM38 meter (S/N 064623; AG0002943084), Allegro CX field computer (S/N 36642), and Gateway laptop computer (S/N 0032653261) were loaned to Jim Turenne from the National Soil Survey Center. It is hoped that this equipment will be used not only in Rhode Island, but throughout New England and New York by soil scientists with geophysical responsibilities. This region has the highest concentration of USDA-NRCS ground-penetrating radar specialists (one in MA, NH, NY, and RI) in the country. In Connecticut, soil scientists are knowledgeable of electromagnetic induction and have used this geophysical method for soil and archaeological investigations. In addition, soil scientists in MA, NH, and RI have had access to this technology. It is hoped that these specialists will expand the use of these geophysical methods among the varied disciplines in this region. Jim has agreed to act as system manager for this equipment.

2. Rob Tunstead received training on GPR data transfer, editing, processing, and display options available in the RADAN for Windows program. In addition, instructions were also provided on the procedures used to collect detailed GPR grid data files and the construction of three-dimensional (3D) pseudo-images of radar data with the Super 3D QuickDraw program.

3. At the Slocum site, a GPR investigation of buried ice-wedge casts was completed. 3D imaging aided interpretation of radar records, and allowed the generation of time-slice images that effectively illustrate the geometry of a buried ice-wedge network that was not evident on conventional two-dimensional (2D) radar records.

It was my pleasure to work in Rhode Island and to be of assistance to your staff.

With kind regards,

James A. Doolittle
Research Soil Scientist
National Soil Survey Center

cc:
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Equipment:
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 is 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) are 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.

The radar unit used in field exercises is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (here after referred to as the 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. With an antenna, this system requires two people to operate. Daniels (2004) discusses the use and operation of GPR. A 400 MHz antenna was used in all the field exercises discussed in this report.

Radar records contained in this report were processed with the RADAN for Windows (version 5.0) software program developed by GSSI.[1] Processing included setting the initial pulse to time zero, header and marker editing, distance normalization, color transformation, and range gain adjustments. The Super 3D QuickDraw program developed by GSSI was used to construct 3D pseudo-images of radar records.

Figure 1. An EMI survey being carried out with an EM38 meter, Allegro field computer, and Garmin GPS receiver in the West Warwick- West Study Area.

Field Methods:
EMI Surveys:
A *random walk* or *wild-cat* EMI survey was conducted with the EM38 meter at the Portsmouth and West Warwick sites. 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 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. The meter was held about 3 cm (about 1 inch) above the ground surface and orientated with its long axis 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.

Figure 2. A detailed GPR grid survey being carried out at the Slocum Study Site. Survey flags are spaced at 50-cm intervals along one of the axis lines.

GPR:
Transect lines were established at the West Warwick and Bridgetown sites. To collect the data required for construction of 3D GPR pseudo-images, survey grids were established at Portsmouth and Slocum sites. Grids were established with axis lengths of 10 m at the Portsmouth site, and 30 and 40 m at the Slocum site, respectively. Along two parallel axes, survey flags were inserted into the ground at a spacing of 50 cm (see Figure 2), and a reference line was established between matching survey flags on opposing sides of the grid using a distance-graduated rope. GPR traverses were conducted along these parallel reference lines. The 400 MHz antenna was towed along the graduated rope on the soil surface and, as it passed the 100-cm graduations, a mark was impressed on the radar record. Following data collection, the reference line was sequentially displaced 50-cm to the next pair of survey flags to repeat the process. A total of 21 traverses were required for the smaller (10-m^2) grid at the Portsmouth site and 81 traverses for the larger (40-by 30-m) grid at the Slocum site.

Ground-penetrating radar is a time scaled system. This system measures the time that it takes electromagnetic energy to travel from the antenna to an interface (e.g., bedrock, soil horizon, 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.

At the Portsmouth and Slocum sites, based on the measured depth and the two-way pulse travel time to a known, subsurface reflector, and equation [1], the velocity of propagation and the relative dielectric permittivity through the upper part of the soil profiles were estimated. At the Portsmouth site, the estimated E_r was about 8.0 (v = 0.105m/ns). These values were also used at the West Warwick Site. At the Slocum site, the estimated E_r was about 15.1 (v = 0.076 m/ns). At the University of Rhode Island Graduate School of Oceanography site, the estimated E_r was about 18.0 (v = 0.070 m/ns). Soils were relatively moist at the time of this investigation.

Study Sites:
Sites were located in pastures, cultivated fields, or cleared areas in Newport, Kent, and Washington Counties. The Portsmouth (Chappelle Farm) site is located off of West Shore Road near Arnold Point in Portsmouth. This site consists of two paddocks and an open field (see Figure 3). The area is mapped as Poquonock loamy fine sand, 0 to 3 percent slopes (PsA), Newport silt loam, 0 to 3 percent slopes (NeA), and Newport silt loam, 3 to 8 percent slopes (NeB). These soils formed on glaciated uplands. The very deep, well drained, Poquonock and Newport soil formed in a sandy mantle overlying till, and in loamy till, respectively. These soils are moderately deep to a densic contact.

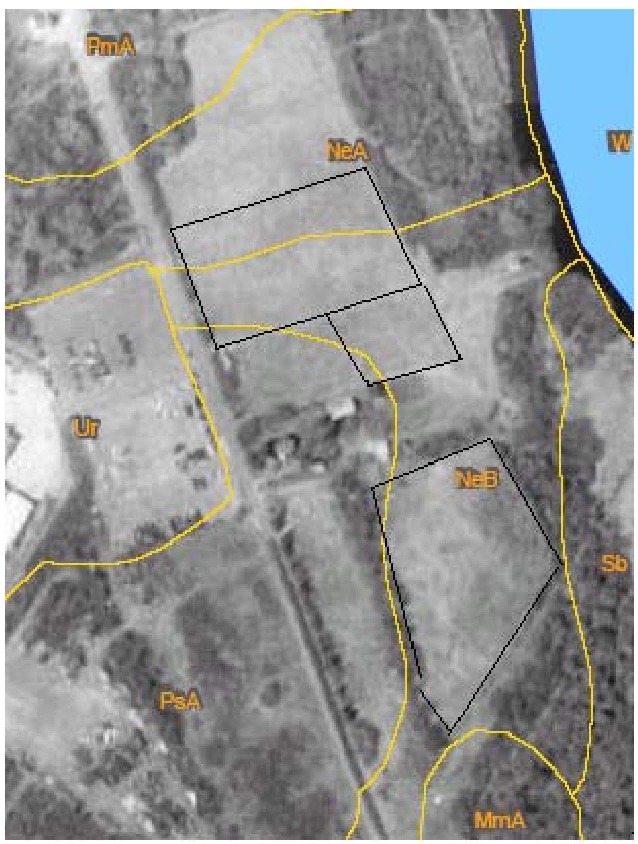

Figure 3. A soil map of the Portsmouth site showing the locations of the three survey areas (enclosed with black lines).

The West Warwick (Barton Farm) site is located off of Centerville Road in West Warwick (see Figure 4, left-hand plot). This is a Wetland Reserve Program (WRP) site that is presently in hay land. The areas is mapped as

Narragansett silt loam, 3 to 8 percent slopes (NaB), Narragansett silt loam, 8 to 15 percent slopes (NaC), Wapping silt loam, 3 to 8 percent slopes (WbB), and Canton and Charlton very rocky silt loam, 3 to 15 percent slopes (CeC). These soils formed on glaciated uplands. The very deep, well drained Narragansett and Canton soils formed in a loamy mantle underlain by till. The very deep, well drained Charlton soils formed in till. The very deep, moderately well drained Wapping soils formed in a silty mantle that is underlain by till.

The Slocum site is located along Indian Corner Road in Slocum (see Figure 4, right-hand plot). The study site is located on a sod farm in a large delineation of Bridgehampton silt loam, 0 to 3 percent slopes (BhA). The very deep, well drained and moderately well drained Bridgehampton soil formed in silty mantle that is underlain by glacial drift on outwash terraces. At this site, mining of sod has removed considerable portions of the silty mantle.

The University of Rhode Island Graduate School of Oceanography site is located near a volleyball court that was constructed on a miscellaneous area that had been mapped as Beaches. The site is located along Narragansetttown Beach. Radar records from this site were forwarded to Jim Turenne for analysis, but are not discussed in this report.

Figure 4. Soil maps of the West Warwick (left-hand plot) and Slocum (right-hand plot) sites showing the approximate locations of the survey areas.

The names of the soil map units identified in the study areas are listed in Table 1. The taxonomic classifications of the soils identified in the study areas are listed in Table 2.

Table 1. The names and symbols for the soil map units identified in the study areas.

Map Unit Symbol	Map Unit Name
Ba	Beaches
BhA	Bridgehampton silt loam, o to 3 percent slopes
CeC	Canton and Charlton fine sandy loam, very rocky, 3 to 15 percent slopes
NaB	Narragansett silt loam, 3 to 8 percent slopes
NaC	Narragansett very stony silt loam, 8 to 15 percent slopes
NeA	Newport silt loam, 0 to 3 percent slopes
NeB	Newport silt loam, 3 to 8 percent slopes
PsA	Poquonock loamy fine sand, 0 to 3 percent slopes
WbB	Wapping silt loam, 3 to 8 percent slopes

Table 2. Taxonomic classifications of the soils identified in the study areas.

Soil Name	Taxonomic Classification
Bridgehampton	Coarse-silty, mixed, active, mesic Typic Dystrudepts
Canton	Coarse-loamy over sandy or sandy-skeletal, mixed, mesic Typic Dystrudepts
Charlton	Coarse-loamy, mixed, mesic Typic Dystrudepts
Enfield	Coarse-silty over sandy or sandy-skeletal, mixed, active, mesic Typic Dystrudepts
Narragansett	Coarse-loamy over sandy or sandy-skeletal, mixed, mesic Typic Dystrudepts
Newport	Coarse-loamy, mixed, mesic Typic Dystrudepts
Poquonock	Sandy over loamy, nixed, nonacid, mesic Typic Udorthents
Wapping	Coarse-loamy, mixed, mesic Aquic Dystrudepts

Results:

Portsmouth Site:

Three separate EMI surveys were conducted for training purposes at the Portsmouth site. Surveys were conducted across areas referred to as the South Paddock, Center Paddock, and North Field. These areas can be identified by there relative locations on the soil map in Figure 3. Table 3 summarizes the results of these surveys. Within the three sites, EC_a ranged from about -280 to 256 mS/m. The large range and extreme values (both negative and positive) are attributed to metallic artifact and cultural features that are scattered across each study area and influenced the EMI response. The soils at the Portsmouth site are characterized as being electrically resistive and displayed relatively low EC_a.

Table 3

Basic Statistics for the EC_a data that was collected with the EM38 meter at the Portsmouth Study Site.

(EC_a measurements are expressed in mS/m)

Site	Observations	Minimum	25%-tile	75%-tile	Maximum	Mean	Std. Deviation
South Paddock	1888	-280.13	2.50	15.00	132.88	9.61	12.31
Center Paddock	502	-38.75	-1.00	1.00	255.63	1.70	18.07
North Field	1317	-29.50	1.38	3.75	90.88	4.34	7.90

Apparent conductivity was variable across the South Paddock study area. This study area is situated in a polygon of Newport silt loam, 3 to 8 percent slopes. Within the study area, EC_a averaged 9.61 mS/m with a standard deviation of 12.31 mS/m. One-half of the EC_a measurements were between 2.50 and 15.00 mS/m.

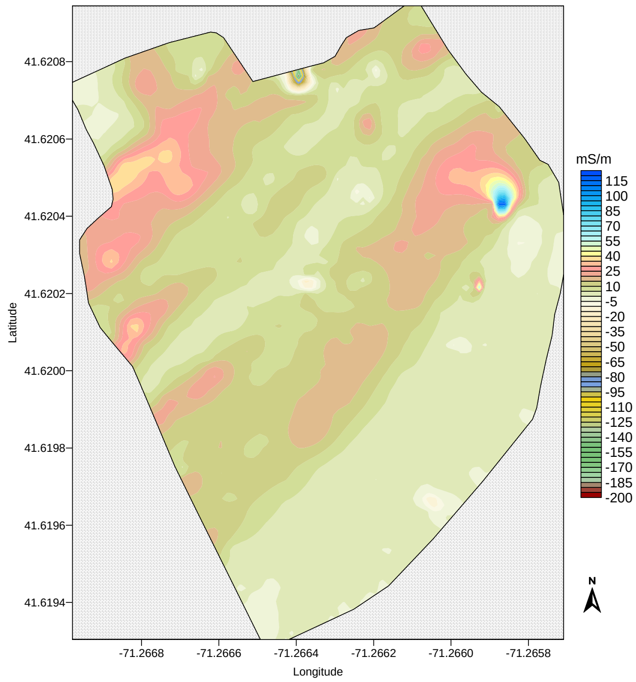

Figure 5. This plot shows the spatial EC_a patterns within the South Paddock study area at the Portsmouth Site.

The spatial distribution of EC_a within the South Paddock study area is shown in Figure 5. In this plot, the isoline interval is 5 mS/m. The study area appears pockmarked by small, insular areas of what are considered anomalously high (> 30 mS/m) or low (< 0 mS/m) EC_a. These atypical areas are assumed to represent interference to the electromagnetic fields caused by magnetic permeability of metallic artifacts, which are either buried or scattered on the surface (e.g., implements, fences, utility lines, and debris) across the study area. Also evident in this plot, is a sequence of southwest to northeast trending bands. Because of their linearity and parallelism, these bands are believed to represent alternating buried (by drift) ridges and swales in the underlying bedrock. Areas of lower EC_a are believed to represent areas that are shallower to bedrock. Areas of higher conductivity are believed to represent areas that have thicker soil columns, with associated greater clay and moisture contents, and deeper depths to bedrock. A relatively coarse-textured mantle of eolian deposits and till has covered these buried lithologic features. As the relatively level landscape provides no indication as to the locations and patterns of these features, EMI appears to be an acceptable tool for mapping soil depth patterns in areas of Newport soil.

Apparent conductivity is very low and relatively invariable across the Center Paddock study area. This study area is situated mostly in a polygon of Newport silt loam, 3 to 8 % slopes (see Figure 3). Though the South Paddock and the Center Paddock are located in the same soil delineation, these study area have significantly different EC_a. The reason for this difference is unknown. However, the concentration of animal wastes and soluble salts in surface layers may be higher in the South Paddock study area. Within the Center Paddock study area, EC_a averaged 1.70 mS/m with a standard deviation of 18.07 mS/m. One-half the EC_a measurements were between -1.00 and 1.00 mS/m.

The spatial distribution of EC_a within the Center Paddock study area is shown in Figure 6. In this plot, the isoline interval is 5 mS/m. Uncharacteristically high and low EC_a measurements were record along the northeast perimeter of the study area. These anomalies represent visible, metallic cultural features (viz. lawn chairs and fence posts). The majority of this study area displays exceedingly low and invariable EC_a. These characteristics reflect the electrically resistive nature of the soils and earthen materials and attest to the low variability in chemical and physical properties within this study area. Generally, the use of EMI for soil investigations is considered inappropriate where the field scale variability of EC_a approaches the errors of the EMI sensor. As observation and measurement errors frequently account for variations of 1 to 2 mS/m, the exceedingly invariable EC_a (50 % of observations were between -1 to 1 mS/m) across this study area makes the use of EMI questionable. However, EC_a data do produce very faint indications of southwest to northeast trending bands believed to represent variable depths to bedrock. Once again, the relatively level landscape provides no indication as to the locations and patterns of these features.

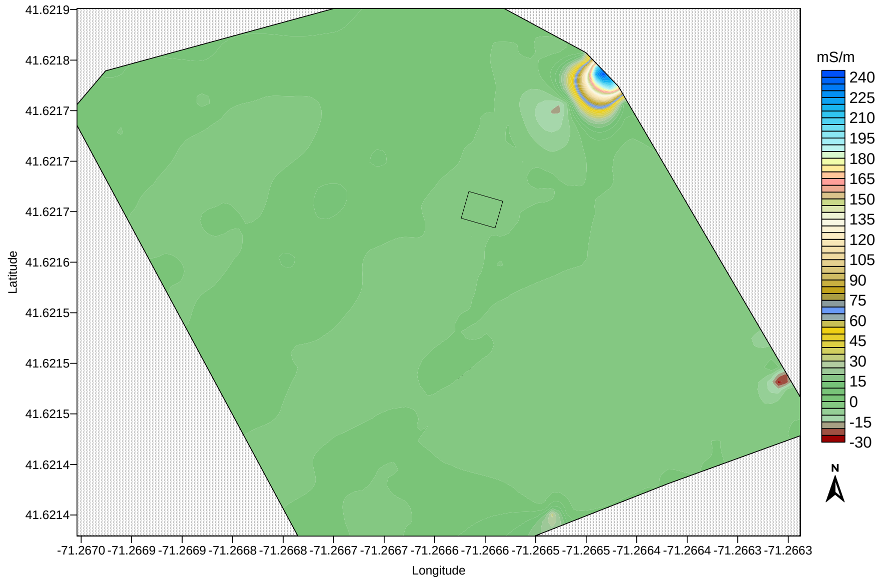

Figure 6. Spatial EC_a patterns of the Center Paddock study area at the Portsmouth site. The rectangle identifies the location of the GPR grid.

The square located in the northeast portion of the Center Paddock study area (see Figure 6) identifies the location of a refilled pit in which a horse had been buried in August 2006. The pit had been partially backfilled with sawdust. This square marks the location of a detailed GPR survey, which will be discussed latter in this report.

Low, but relatively intermediate values of EC_a were measured across the North Field study area. Compared with the other two study areas located in the same or similar polygons of Newport soil, the North Field study area had in-between EC_a measurements. The North Field study area is situated in polygons of Newport silt loam, 0 to 3 % slopes, and Newport silt loam, 3 to 8 % slopes. Within the study area, EC_a averaged 4.34 mS/m with a standard deviation of 7.90 mS/m. One-half the EC_a measurements were between 1.38 and 3.75 mS/m.

Spatial EC_a patterns within the North Field study area is shown in Figure 7. In this plot, the isoline interval is 5 mS/m. Across most of this site, EC_a varies between 0 and 5 mS/m. Conspicuous lineations with comparatively more extreme EC_a values (EC_a > 5 or < -5 mS/m) run north to south across the center, and east to west across the southern and northeastern boundaries of the study area. A buried utility is known to be present and believed to have produced the inconsistent EC_a values along the southern boundary of the study area. As several houses occupy the land just to the northeast of the study area, buried utility lines are also suspected to have produced the anomalous EC_a values in this portion of the study area. It is plausible that the north-south lineation in Figure 7 represent additional buried utilities.

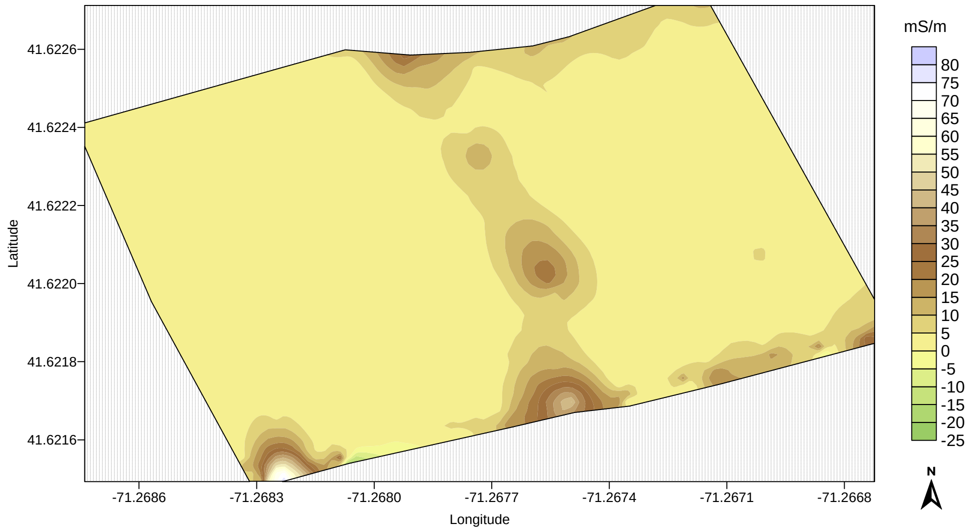

Figure 7. Spatial EC_a patterns within the North Field study area.

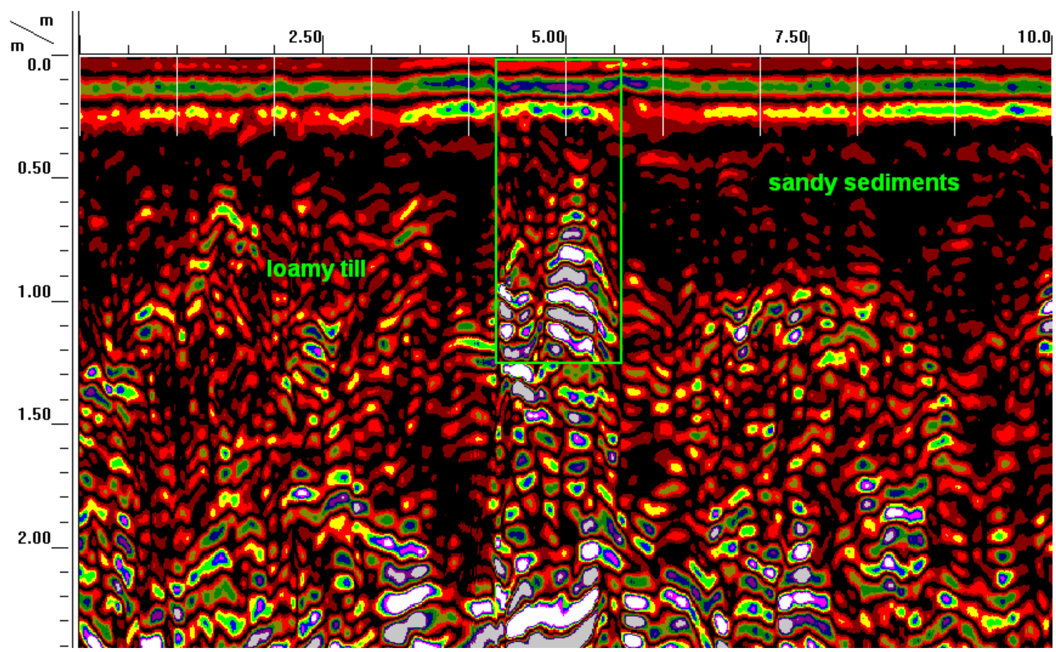

Figure 8. The location of a refilled pit containing a buried horse is shown on this radar record from the Center Paddock study area.

Soils at the Portsmouth site are electrically resistive and generally lack sufficient contrast to make the use of EMI appropriate. However, the low conductivity of these soils makes them highly suited to GPR. In the Center Paddock study area, a small, 10 by 10 m grid was setup across an area that is known to contain a recently (August 2006) buried horse. The purpose of this grid was principally for field training, but it did result in identifying the location of the buried horse. In Figure 8, the radar record shows the location (enclosed in green colored rectangle) of the refilled trench and the buried horse. Though mapped as Newport soil, the soil identified near the pit is Poquonock. The Poquonock soil formed in a sandy mantle that overlies till. These materials display contrasting graphic signatures on the radar record. The sandy mantle is relatively free of coarse fragments and is characterized on the radar record by a modest number of low to moderate amplitude (colored in shades or red) reflections. The underlying till contains and abundance of coarse fragments and is characterized by chaotic patterns of moderate to high amplitude (colored yellow, green, blue, pink, and white) reflections.

A distinctive feature of this burial is the disturbed soil materials that fill the pit's shaft.   In Figure 8, the outline of the refilled soil pit has been enclosed in the box delineated by a green-colored line. The refilled soil materials provide reflections whose radar signature contrasts with those from the bounding undisturbed soil materials. The backfill contains mixed soil materials. These mixed materials contrast with the undisturbed soil materials in grain size distributions and moisture contents, and produce distinct disturbance signatures that are detectable with GPR.   On this radar record, a large and reflective portion of the decaying horse was passed directly over with the radar antenna and produced the conspicuous, high-amplitude reflections and reverberations that are evident in the enclosed box.

In recent years, a sophisticated type of 3D GPR data manipulation known as "amplitude slice-map analysis" has been used in several investigations (e.g. Conyers and Goodman, 1997). In this procedure, amplitude differences within the 3D image are analyzed in "time-slices" to isolate differences within specific time (i.e. depth) intervals (Conyers and Goodman, 1997). Time-slice data are created by averaging the reflected radar energy horizontally between each set of parallel radar traverses within a specified time window to create a time-slice. The resulting time-slice displays the spatial distribution of reflected wave amplitudes, which can be interpreted as representing lateral changes in soil properties or the presence of subsurface features.

Figure 9 is a three dimensional GPR pseudo-image of the grid site in the Center Paddock study area. In this image a 7 by 4 by 1.1 m volume has been removed to show the pit, buried horse (shown in a sidewall and base of the cutout cube), and stratigraphic features. Three-dimensional GPR imaging offers considerable potential for displaying and interpreting near-surface soil features. However, in this example, the increased collection and analysis time needed to prepare this 3D GPR datasets did not provided information in excess of that which was extracted from the individual radar records (see Figure 8) alone.

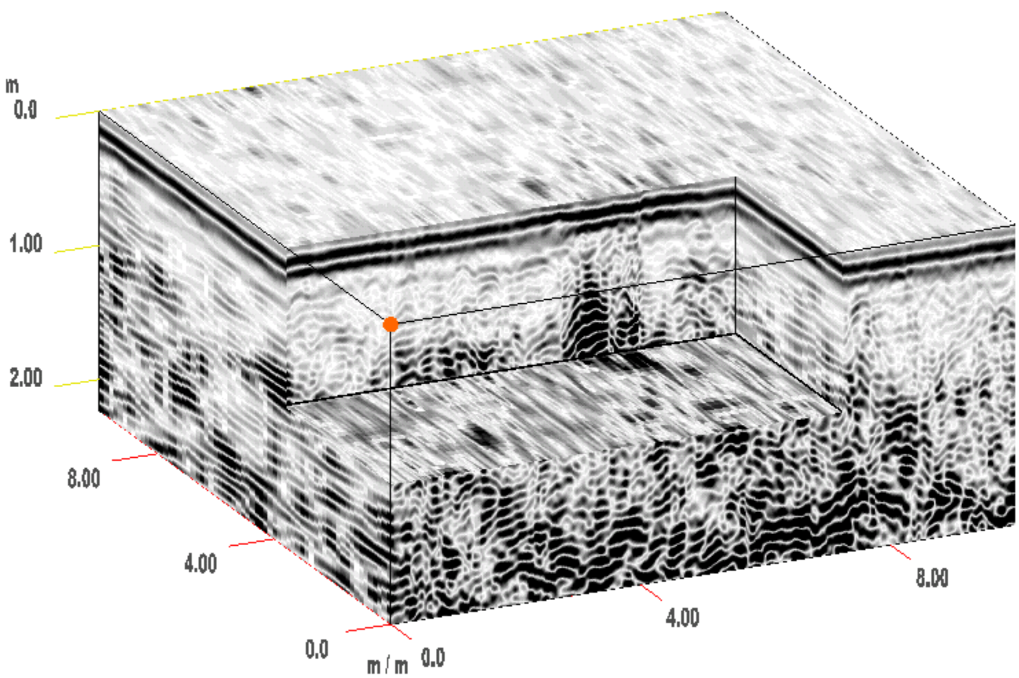

Figure 9. Three dimension GPR pseudo-images from the Center Paddock study area. In this image, a 7 by 4 by 1.1-m volume has been removed.

West Warwick Site:

Two separate EMI surveys were conducted by different soil scientists for training purposes at the West Warwick site. Surveys were conducted across areas referred to as West Warwick *East* and West Warrick *West*. These areas can be identified by there relative locations in the left-hand image in Figure 4. The West Warwick *West* study area is noticeably larger than the West Warwick *East* study area. Table 4 summarizes the results of these surveys.

The averaged EC_a was higher within the East study area, but was more variable within the West study area. The higher conductivity within the East study area is attributed, in part, to a band of higher (>8 mS/m) EC_a that crosses the site from northwest to southeast. While the source of the higher conductivity is unknown, it is not attributed to interference from metallic cultural features. Limited field verifications and visual correlations ruled out the presence of a buried utility line or other artifacts. Bedrock exposures testify to the relative shallowness of bedrock across large portions of this study area. Apparent conductivity was more variable across the West Warwick West study area. The greater variability is attributed to the remnants of former farm structures and metallic artifacts.

Table 4
Basic Statistics for the EC_a data that was collected with the EM38 meter at the West Warwick Study Site.
(EC_a measurements are expressed in mS/m)

Site	Observations	Minimum	25%-tile	75%-tile	Maximum	Mean	Std. Deviation
East	484	0.13	6.63	8.13	15.38	7.47	1.45
West	2238	-139.00	2.00	3.75	10.88	2.78	3.60

Within the Warwick East study area, EC_a averaged 7.47 mS/m with a standard deviation of 1.45 mS/m. One-half the EC_a measurements were between 6.63 and 8.13 mS/m. The spatial distribution of EC_a within this study area is shown in the right-hand plot of Figure 10. In this plot, the isoline interval is 2 mS/m. Segmented, red-colored lines have been use to denote the crest and base of a low, bedrock controlled slope. The boundary of a wetland has been identified by a segmented blue-colored line. A linear, northwest to southeast trending band of relatively higher (> 8 mS/m) EC_a is evident in this plot and is believed to represent an intruded vein of more conductive parent rock. The increased soil moisture content within the wetland has no apparent affect on the spatial EC_a patterns shown in this plot. In the Warwick East study area, differences in EC_a are assumed to reflect difference in the mineralogical composition of the parent rock.

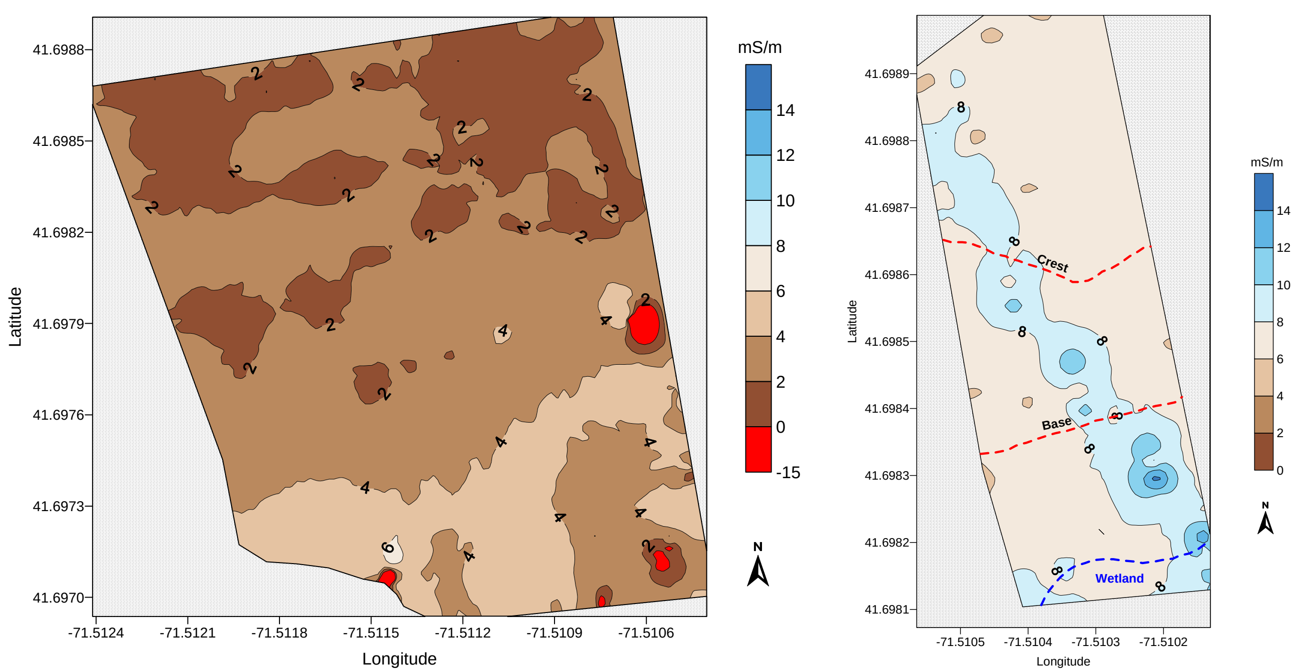

Figure 10. Spatial EC_a patterns of the West (left-hand plot) and East (right-hand plot) study areas at the West Warwick site.

Within the West Warwick *West* study area, EC_a averaged 2.78 mS/m with a standard deviation of 3.60 mS/m. One-half the EC_a measurements were between 2.00 and 3.75 mS/m. The spatial distribution of EC_a within the West Warwick *West* study area is shown in the left-hand plot of Figure 10. In this plot, the isoline interval is 2 mS/m. Extreme values and the higher variability of EC_a across the West study area reflect the presence of metallic artifacts from former farm operations. In left-hand plot of Figure 10, areas with negative EC_a, which are suspected to represent some of these artifacts, are shown in red. In the absence of ground-truth verifications, no further interpretations from this study area are warranted.

The two West Warwick study areas adjoin one another. The lack of consistence EC_a patterns across their boundary is of concern. It is felt that either the EM38 meter was not properly calibrated or that slight instrument drift occurred as the air temperature warmed.

Slocum Site:

During the construction of several homes (see Figure 2, fence line marks the boundary of a residential area with a sod farm) ice-wedge casts were observed in several excavation walls in an area of Bridgehampton silt loam, 0 to 3 percent slopes (BhA). Interest was expressed in knowing whether these ice-wedge casts form a connected polygonal pattern indicative of relict ice-wedge polygons created in a former periglacial environment. Aerial photographs of the outwash plain provide no indication of linear features. Eolian sediments have blanketed the area and were observed to have in-filled the ice-wedge casts observed in the excavations walls. These eolian sediments would mask the expression of buried ice-wedge polygons on aerial photographs.

Figure 11 is a 14-m portion of a radar record from the Slocum study site. All scales on this record are expressed in meters. The depth scale shown is based on an estimated velocity of propagation of 0.076 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 surface pulse and its reverberation mask features within the upper 25 cm of the soil profile. At a depth of about 50 cm a weakly expressed soil horizon (see"A" in Figure 11) is evident in the silt mantle. This layer was identified as a C1 horizon which is massive and has a noticeably firmer consistency than the overlying surface layers and subsoil.

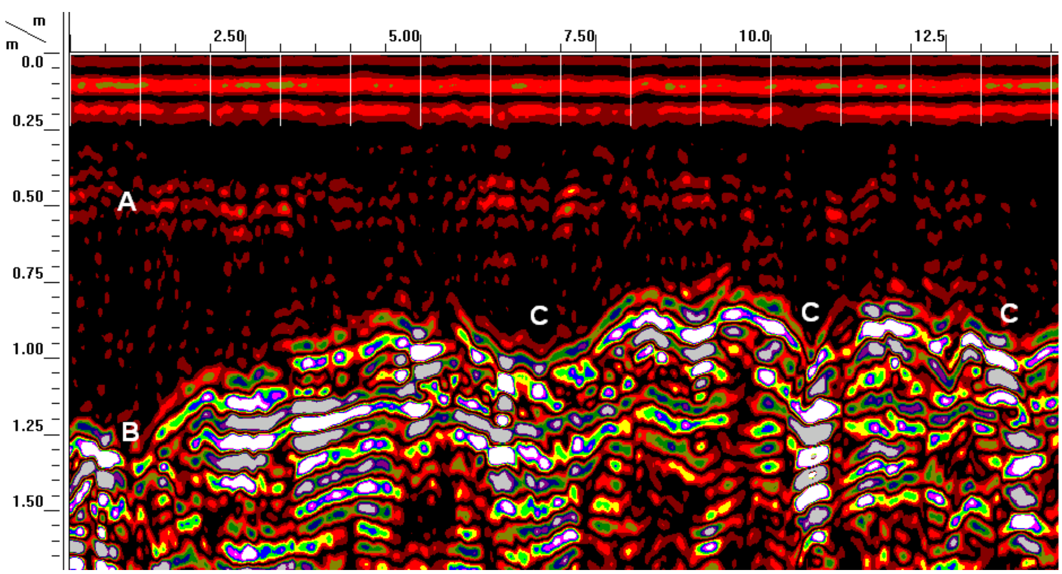

Figure 11. A representative portion of a radar record from the Slocum Site showing the irregular topography of the contact that separates the silty eolian mantle from the underlying stratified, coarse-textured glacial outwash.

The most clearly expressed interface on this radar record is the contact (see “B” in Figure 11) separating the eolian mantle from the underlying glacial outwash. This interface appears highly irregular and varies in depth from about 69 to 129 cm on this radar record. Only the first two observation points (0 and 1 m graduation marks) have an eolian mantle that is greater than 100 cm and represent Bridgehampton soil. Soils at the other observation points are moderately deep to outwash and represent the Enfield series. The very deep, well drained and moderately well drained Bridgehampton and the well drained Enfield soils form in a thick silty mantle over glacial drift on outwash plains. Bridgehampton and Enfield soils have solum thickness of 100 to 142 cm and 38 to 100 cm, respectively. These depths correspond to the depth to the contrasting coarser-textured and more rapidly permeable stratified outwash deposits.

Noticeable concavities (see “C” in Figure 11) with down-turned reflection patterns are apparent along the interface that separates the eolian mantle from the outwash. These concavities are in-filled with eolian sediments from the silt mantle. Beneath these concavities, high amplitude reflections and signal reverberations indicate the presence of in-filled materials that contrast with the coarser-textured, confining outwash. These features are presumed to represent the ice-wedge casts observed in the nearby excavation walls.

The question remained as to the spatial pattern and arrangement of the ice-wedge cast observed in the 2D radar records. Does the outwash plain contain remnants of ice-wedge polygons that have been buried and masked by eolian sediments? To answer this question a 3D GPR grid survey was conducted across a small portion of the outwash plain.

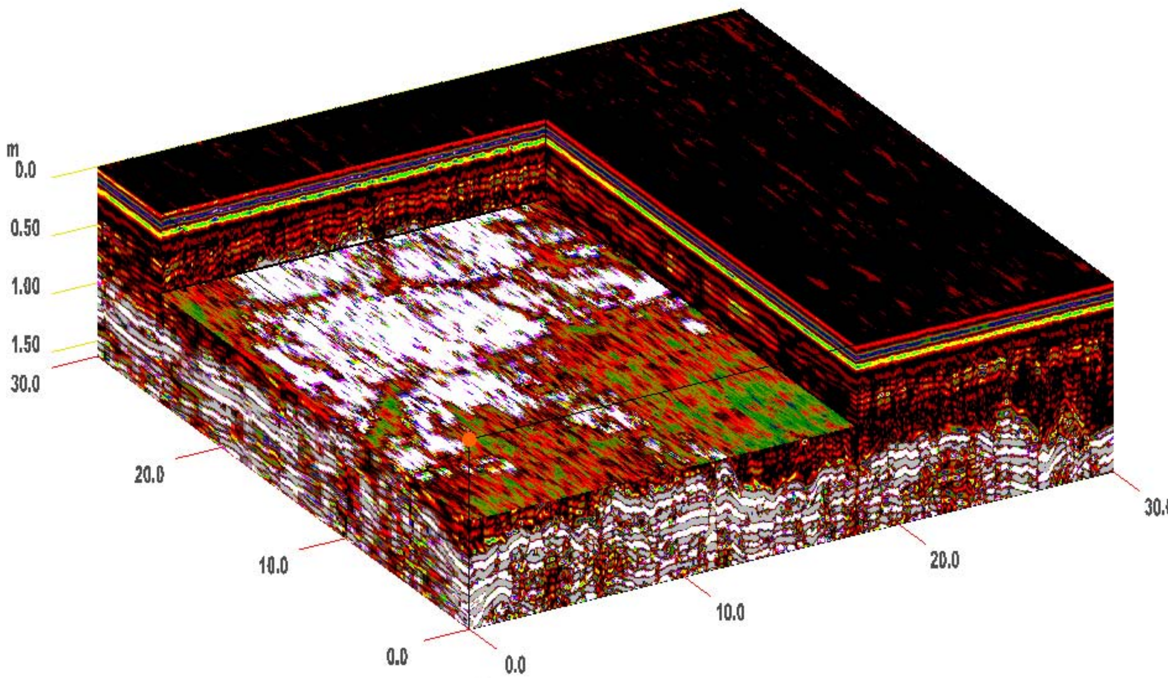

Figure 12. A 3D GPR pseudo-image from the Slocum grid site. In this image of a 30 by 30 m survey area, an 18 by 25 by 0.75-m volume has been removed. The high amplitude reflection on the base of the cube represents the uneven contact of the eolian mantle with the underlying outwash.

Figure 12 is a three-dimensional GPR pseudo-image with a cutout cube of a portion of the Slocum grid site. The eolian/outwash interface and strata within the outwash provide contrasting boundaries that produce high-amplitude (colored white and grey) reflections. The base of the cutout cube has a prominent area of high-amplitude reflections that represents the contact of the eolian mantle with the underlying outwash. The topography of this contact varies from wavy to irregular and shows considerable variations in depth (absolute range of 44 to 132 cm). Areas of low signal amplitudes represent areas in which the eolian/outwash contact is generally deeper than 75 cm. The portion of this contact that is *sliced* by the base of the cutout cube contains linear, intersecting features of moderate to low (colored red, green, and black) amplitudes. These represent the concavities observed in two-dimensional radar records and are interpreted as ice-wedge casts (see “C” in Figure 11). The linear and interconnecting geometry of these features is interpreted to represent ice-wedge polygons.

The topography of the eolian/outwash contact both confounds and assists interpretations. A level topography would facilitate the visualization of the contact across the entire site; an irregular topography facilitates the identification of some ice wedge casts, but prevents the visualization of all ice-wedge casts and ice-wedge polygons across the entire site.

The three-dimensional ground-penetrating radar (3D GPR) analysis of the Slocum site was successful in imaging remnants of a former ice-wedge polygon network. Overall, at this site, the collection and analysis of 3D GPR datasets provided information in excess of that which could be extracted from 2D profiles alone. When combined with soil coring to provide local information for verification and calibration, 3D GPR offers considerable potential for imaging and interpreting near-surface soil and periglacial features.

The thickness of the eolian mantle and depth to outwash was determined at each of the 1891 reference points that appeared on 81 radar records. The average thickness of the eolian mantle within the grid area is 84.78 cm with a range of 44 to 132 cm. One half of the observations had eolian mantles that are between 75 and 94 cm thick. Based on soil depth criteria, 87.8 % of the soils within the grid are Enfield and 12.2 % are Bridgehampton soils. Figure 13 shows the thickness of the eolian mantle thickness (or the depth to outwash) within the GPR survey grid.

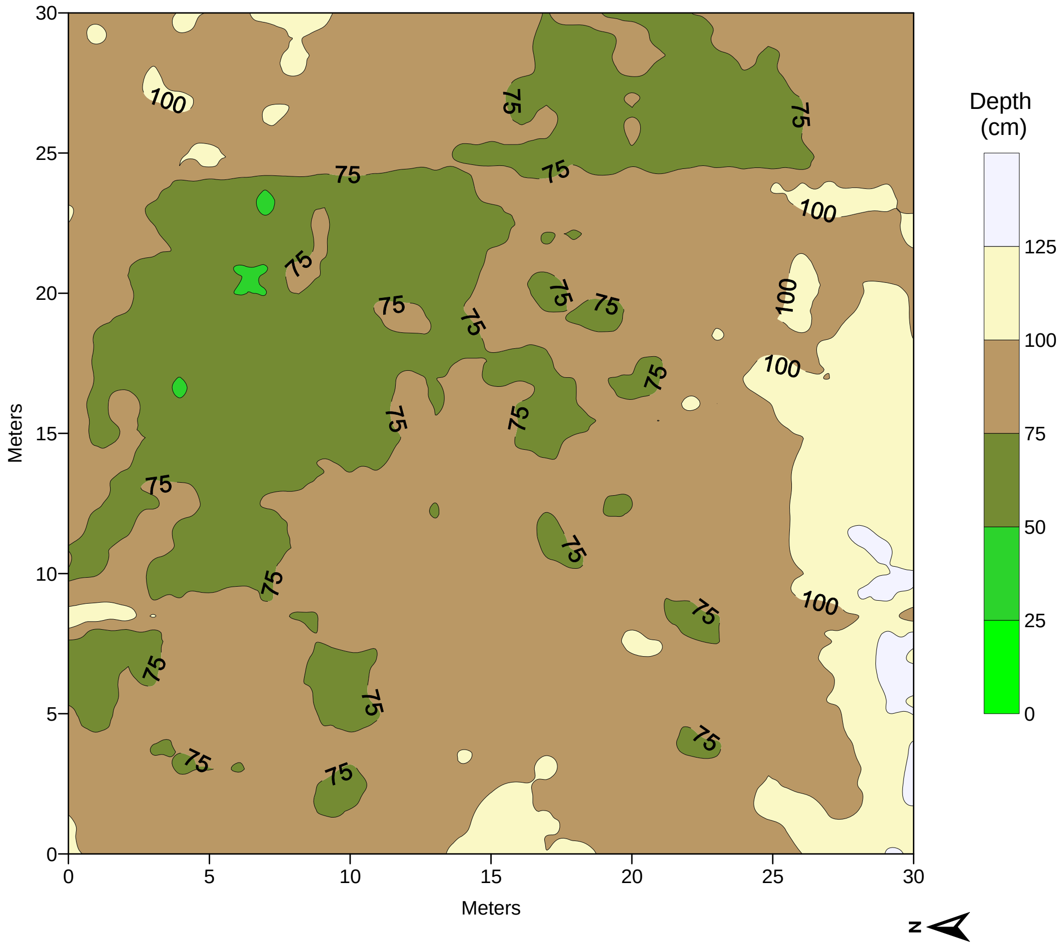

Figure 13. Thickness of eolian deposits and depth to outwash at the Slocum Site.

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