United States Department of Agriculture

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SUBJECT: SOI – Geophysical Assistance

May 6, 2010

TO: William J. Gradle
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File Code: 330-7

Purpose:
The main purpose of this investigation was to use electromagnetic induction (EMI) to characterize the depths to coarser-textured outwash materials on a paleoterrace composed principally of Plano soils in Tazewell County, and to assess spatial patterns of sodium-affect soils (SAS) in Montgomery and Clark Counties. Heavy rains and wet soil conditions made several sites unsuitable for EMI surveys. Alterative sites and projects had to be selected. Ground-penetrating radar (GPR) and EMI surveys were completed on dunes associated with aeolian deposits in Tazewell County. In addition, an EMI survey was completed at a research site of Dr. Leon Fulmer in Clark County.

Participants:
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Roger Windhorn, Resource Soil Scientist, USDA-NRCS, Champaign, IL
Dan Withers, Cartographic Technician, USDA-NRCS, Champaign, IL

Activities:
All activities were completed during the period of 26 to 29 April 2010.

Summary:
1. This field study was preceded by an unusually wet weekend in Illinois. As a consequence, extremely wet field conditions plagued our field investigations. Roger Windhorn and the Illinois Staff are commended for finding alternative sites and projects.

2. Vertical profiling with both the EM38MK2-2 and EM31 meters on a paleoterrace in Tazewell County suggest the presence of coarser textured outwash materials beneath medium-textured loessial deposits. Ten ground-truth cores confirmed the general uniformity of soil materials within this site, which accounts for EMI inability to better quantify the depths to coarser textured outwash deposits. Vertical profiling with the shallower-sensing EM38MK2-2 meter can be used

to map the spatial distribution of over-thickened surface layers and shallower argillic horizons developed in loessial soils.

3. Tonal patterns on aerial photographs of the visited paleoterrace in Tazewell County suggest the presence of periglacial features (ice-wedge pseudomorphs, relict polygonal pattern ground). If present, these features appear to have sufficient sizes or dimensions to be distinguished with EMI.

4. At a dune site in Tazewell County, the EM31 meter was ineffective because of the high electrical resistivity of Plainfield soils, which produced exceedingly low and invariable EC_a across the site. However, GPR effectively imaged the depth to the water table and imaged three unique facies composed of different soil materials and structures. Using a 200 MHz antenna, the water table was identified at depths ranging from about 5.2 to 2.0 m.

5. It was my and the groups good fortune to spend time in the field with Dr Leon Fulmer. Much was learned through casual conversations with this very caring and knowledgeable gentleman.

/s/ Jonathan W. Hempel

JONATHAN W. HEMPEL

Director

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Technical Report on Geophysical Investigations conducted in Illinois on 26 to 29 April 2010.

James A. Doolittle

Equipment:

The EM38-MK2 meter (Geonics Limited, Mississauga, Ontario) was used in this investigation.[1] The EM38-MK2 meter weighs about 2.8 kg (6.2 lbs) and requires only one person to operate. The EM38-MK2 meter consists of one transmitter coil and two receiver coils, and operates at a frequency of 14,500 Hz. The receiver coils are separated from the transmitter coil at distances of 100 and 50-cm. This configuration provides nominal penetration depths for the 100 and 50-cm intercoil spacings of 150 and 75 cm in the vertical dipole orientation (VDO) and 75 and 38 cm in the horizontal dipole orientation (HDO), respectively. Operating procedures for the EM38-MK2 meter are described by Geonics Limited (2008). The EM38-MK2 meter provides simultaneous measurements of both quadrature-phase (apparent conductivity; EC_a) and in-phase (susceptibility) components within the two depth ranges.

The EM31 meter (Geonics Limited, Mississauga, Ontario) was also used in this investigation.[1] This meter is portable and requires only one person to operate. McNeill (1980) has described the principles of operation for the EM31 meter. The EM31 meter weighs about 12.4 kg (27.3 lbs), has a 3.66 m intercoil spacing, and operates at a frequency of 9,810 Hz. When placed on the soil surface, the EM31 meter has effective penetration depths of about 3.0 and 6.0 meters in the HDO and VDO, respectively (McNeill, 1980).

A Pathfinder ProXT GPS receiver (Trimble, Sunnyvale, CA) was used to georeferenced EC_a data collected with the EMI meters.[1] During surveying, EC_a and GPS measurements were automatically recorded in the Allegro CX field computer (Juniper Systems, Logan, Utah).[1] The RTmap38MK2 and the RTmap31 software programs developed by Geomar Software Inc. (Mississauga, Ontario) were used to record, store, and process EC_a and GPS data.[2] All EC_a data are expressed in milliSiemens/meter (mS/m).

To help summarize the results of the EMI survey, SURFER for Windows (version 9.0), developed by Golden Software, Inc. (Golden, CO), was used to construct the simulations shown in this report.[1] Grids of EC_a data were created using kriging methods with an octant search.

The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (hereafter referred to as the SIR-3000), manufactured by Geophysical Survey Systems, Inc. (GSSI; Salem, NH).[1] The SIR-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-3000 weighs about 4.1 kg (9 lbs) and is backpack portable. With an antenna, the SIR-3000 requires two people to operate. Jol (2009) and Daniels (2004) discuss the use and operation of GPR. A 200 MHz antenna was used in this investigation.

The RADAN for Windows (version 6.6) software program (hereafter referred to as RADAN; developed by GSSI) was used to process the radar records shown in this report.[1] Processing included: header editing, setting the initial pulse to time zero, color table and transformation selection, range gain adjustments, signal stacking, migration, and high-pass filtration (refer to Jol (2009) and Daniels (2004) for discussions of these techniques).

Calibration of GPR:

[1] Trade names are used for specific references and do not constitute endorsement.

Ground-penetrating radar is a time scaled system. The system measures the time that it takes electromagnetic energy to travel from an antenna to an interface (e.g., soil horizon, stratigraphic layer, water table) 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 equation [1] (after 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 equation [2] (after Daniels, 2004):

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

Where C is the velocity of propagation in a vacuum (0.298 m/ns). Typically, 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 a known, buried subsurface reflector (metal plate buried at 50 or 52 cm), the v and the E_r through the upper part of the Plainfield (mixed, mesic Typic Udipsamments) and Cisne (fine, smectitic, mesic Mollic Albaqualfs) soil profiles were estimated using equations [1] and [2]. At the time of this study, soils were wet. In an area of Plainfield soil, the estimated E_r was 6.56. This relative dielectric permittivity results in an estimated v of 0.1163 m/ns. In an area of Cisne soil, the estimated E_r was 15.87. This relative dielectric permittivity results in an estimated v of 0.0748 m/ns.

Study Sites:

Tazewell County – Site 1:

The first study site is an 80-acre field of corn stubble, which is located in the SW ¼ of Section 19, T. 23 N. R. 4 W. Soils delineation mapped within this field include Plano silt loam on 0 to 2 % slopes (199A) and Edgington silt loam (272). Figure 1 is the soil map for this study site. The very deep, well drained Plano soils formed in loess or other silty material on terraces. At this site, Plano soils are known to be underlain by coarse-textured outwash deposits at depths ranging from about 2.1 to greater than 2.7 m (7 to greater than 9 ft). The very deep, poorly drained Edgington soils form in loess and are in swales and depressions. The taxonomic classifications of these soils are listed in Table 1. An aerial photograph of the general area of this site reveals tonal patterns that suggest the presence of relict periglacial polygonal patterns (Fig. 2).

Table 1. Taxonomic classification of soils.

Soil Series	Taxonomic Classification
Cisne	fine, smectitic, mesic Mollic Albaqualfs
Coloma	mixed, mesic Lamellic Udipsamments
Ebbert	fine-silty, mixed, superactive, mesic Argiaquic Argialbolls
Edgington	fine-silty, mixed, superactive, mesic Argiaquic Argialbolls
Hoyleton	fine, smectitic, mesic Aquollic Hapludalfs
Newberry	fine-silty, mixed, superactive, mesic Mollic Endoaqualfs
Plainfield	mixed, mesic Typic Udipsamments
Plano	fine-silty, mixed, superactive, mesic Typic Argiudolls

Figure 1. Site 1 in Tazewell County is dominated by two delineations: a larger delineation of Plano silt loam, 0 to 2 % slopes (199A) and a smaller delineation of Edgington silt loam (272). The soil map is from the Web Soil Survey.

Figure 2. This soil map includes the Tazewell County site (enclosed in rectangle). Tonal patterns on this image suggest relict periglacial pattern ground. The soil map is from the Web Soil Survey.

Tazewell County - Site2:
This study site is in CRP and is located in the SE ¼ of Section 9, T. 22 N., R. 5 W. Soils map units delineated within this site include Plainfield sand on 3 to 7 % slopes (54B), Plainfield sand on 7 to 15 % slopes (54D), and Coloma sand on 3 to 7 % slopes (689B). Figure 3 is the soil map for this study site with the approximate locations of GPR traverse lines. Ground-penetrating radar traverses were conducted mostly in map unit 54D (see Fig. 3). The very deep, excessively drained Plainfield and somewhat excessively drained or excessively drained Coloma soils formed in sandy drift. The taxonomic classification of these soils is listed in Table 1.

Figure 3. Site 2 in Tazewell County is dominated by delineations of Plainfield (54B and 54D) and Coloma (698B) soils. This soil map is from the Web Soil Survey. Black lines show the approximate locations of GPR traverse lines.

Clark County Site
This 40-acre site is located in the NW ¼ of Section 6, T. 9 N., R. 14 W. At the time of this study, the field was in corn stubble. Soil map units identified within the study site include: Cisne silt loam on 0 to 2 % slopes (2A), Hoyleton silt loam on 0 to 2 % slopes (3A), Ebbert silt loam on 0 to 2 % slopes (48A), and Newberry silt loam on 0 to 2 % slopes (218A). The very deep, poorly drained Cisne soils formed in loess and underlying gritty loess on till plains. The very deep, somewhat poorly drained Hoyleton, poorly drained Newberry, and the deep, poorly drained and very poorly drained Ebbert soils formed in loess and underlying silty or loamy deposits, which overlie a strongly weathered Sangamon-age paleosols developed in Illinoisan-age till. The taxonomic classifications of these soils are listed in Table 1. Figure 4 is the soil map of the study area from the Web Soil Survey.

Figure 4. The Clark County Site includes delineations of Cisne (2A), Hoyleton (3A), Ebbert (48A), and Newberry (218A) soils. This soil map is from the Web Soil Survey.

Results:

Paleoterrace Site in Tazewell County:

Ten soil cores were extracted at this site. Soils identified in these ten cores included Plano (7), Muscatune (2), and Edgington (1) (names and locations shown on upper plot in Fig. 5). The descriptions of these cores revealed relatively uniform soil materials developed in about 2.1 to greater than 2.7 m (7 to greater than 9 ft) of Peorian loess. With the exception of the Edgington soil, depth to water table ranged from 1.5 to greater than 2.7 m (5 to greater than 9 ft). A perched water table was observed in Edgington soil at a depth of about 61 cm (2 ft).

Apparent conductivity was relatively low and uniform across the surveyed area. Based on 4326 measurements made with the deeper-sensing (0 to 150-cm depth interval) 100-cm intercoil spacing on the EM38MK2-2 meter, EC_a averaged 19.8 mS/m and ranged from about 14.9 to 26.5 mS/m. One-half of these EC_a measurements were between 18.8 and 20.8 mS/m. Based on 4326 measurements made with the shallower-sensing (0 to 75 cm depth interval) 50-cm intercoil spacing on the EM38MK2-2 meter, EC_a averaged 8.9 mS/m and ranged from about 2.1 to 15.7 mS/m. One-half of these EC_a measurements were between 7.7 and 10.3 mS/m.

Results indicate that EC_a increases with increasing soil depth (measurements obtained with the deeper-sensing 100-cm intercoil spacing were higher than measurements obtained with the shallower-sensing 50-cm intercoil spacing). This vertical trend was attributed to the higher clay content of the subsoil compare with the surface layers. Surprisingly, the noticeably high moisture contents of surface layers and the soils had little impact on EC_a measurements. In fact lower EC_a were recorded on a ponded depression of Edgington soils with over thickened surface layers than on surrounding, higher-lying, convex surfaces of Plano soils where the depth to argillic horizon was shallower (see Fig. 5).

Spatial EC_a patterns that are evident in Fig. 5 suggest a very crude polygonal pattern consisting of intersecting lineations of lower EC_a. In light of the tonal patterns evident on the aerial photograph shown in Fig. 2, it is all too easy to envision similar spatial patterns in the EC_a data. However, a number of additional ground-truth soil cores are needed to confirm this interpretation. In the data collected with the 50-cm intercoil spacing (lower plot in Fig. 5) a linear artifact is evident near the southern (lower) boundary of the survey area. This linear strip of lower EC_a may represent the location of a former access road.

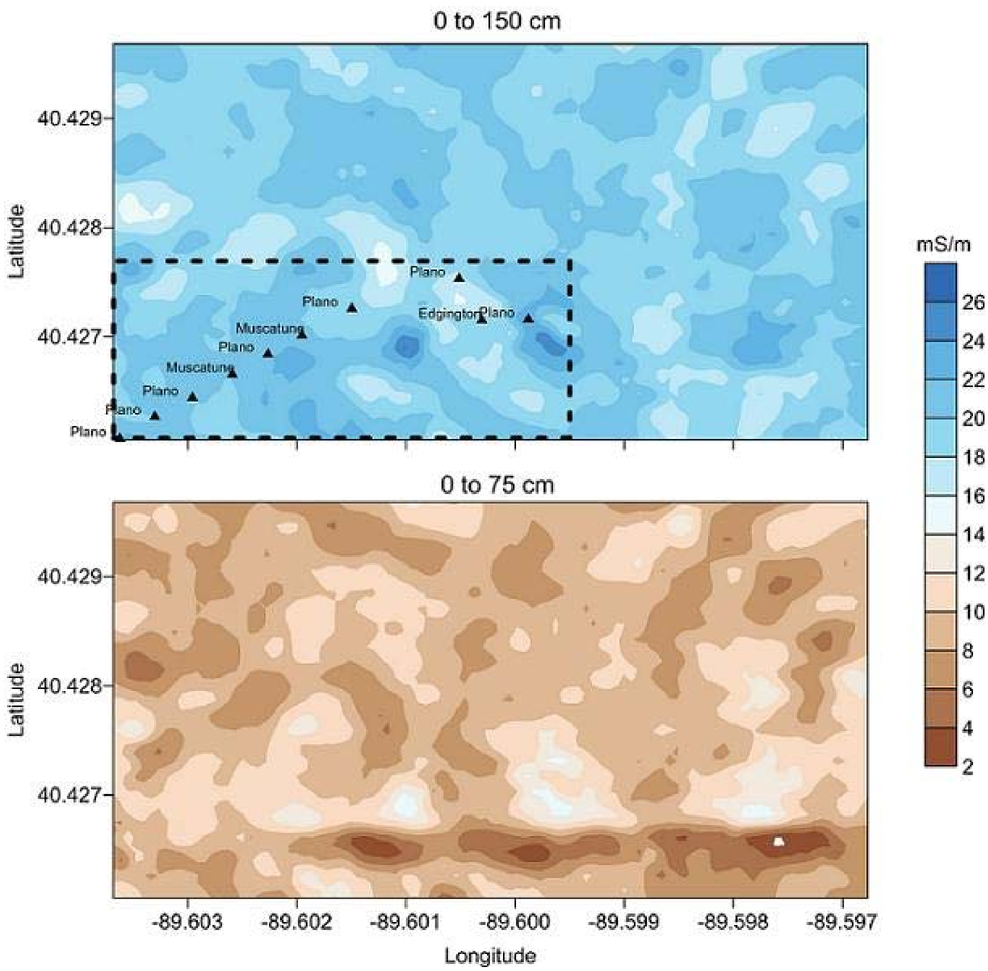

Figure 5. Plots of EC_a data collected on the paleoterrace in Tazewell County with the EM38MK2-2 meter in the deeper-sensing 100-cm (upper plot) and shallower-sensing 50-cm (lower plot) intercoil spacings. In the upper plot, the rectangular area enclosed with segmented lines was also surveyed with an EM31 meter (see Fig. 6)

A portion of the study site that was surveyed with the EM38MK2-2 meter was resurveyed using the deeper-sensing EM31 meter (see upper plot in Fig. 5). The EM31 meter was operated in the VDO, which provides a nominal penetration depth of about 5 m (pedestrian survey with meter held at hip-height). Based on 2751 measurements made the EM31 meter, EC_a averaged only 9.5 mS/m and ranged from about 5.9 to 12.5 mS/m. One-half of the measurements were between 9.1 and 9.9 mS/m. These lower measurements are attributed to the greater penetration depth of the EM31 meter. The greater penetration depth caused a larger proportion of the measured response to be influenced by the underlying coarser-textured and more electrically resistive outwash materials. Spatial patterns of EC_a data collected with the EM31 meter are shown in Fig. 6.

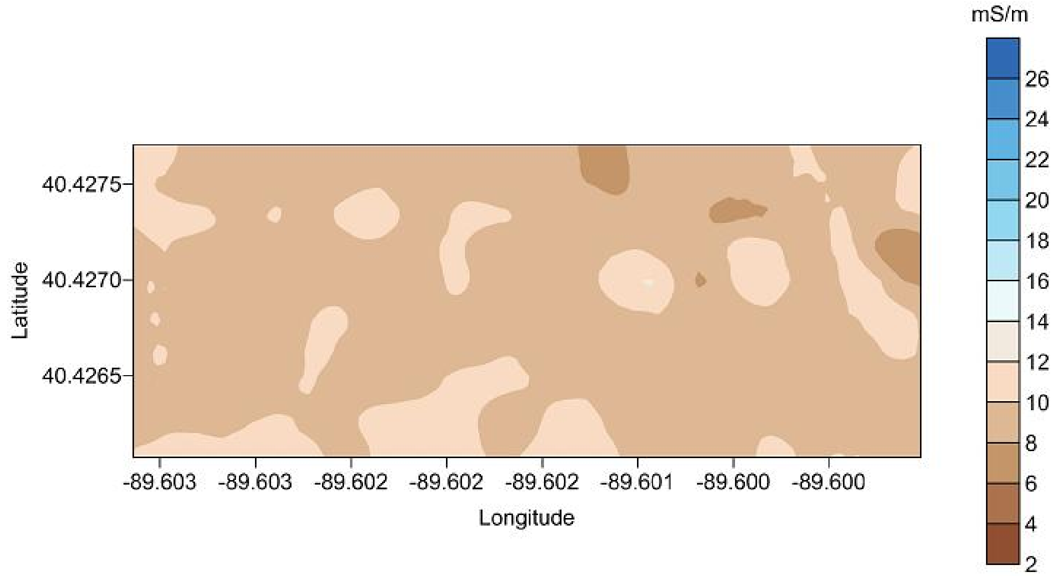

Figure 6. Plot of EC_a data collected at Site 1 in Tazewell County with the EM31meter operated in the deeper-sensing vertical dipole orientation. The nominal penetration depth is about 5 m.

The low variability of EC_a measurements testifies to the relative homogeneity and uniform layering of the soil materials within the study site. As measurements obtained with the deeper-sensing EM31 meter were lower than those obtained with the shallower-sensing EM38MK2-2 meter, it is assumed that the soil materials become more electrically resistive with increasing soil depths. The increased resistivity is attributed to coarser textured outwash materials at lower soil depths. This association was confirmed in core observations made at this site.

Measurements obtained with the EM38MK2-2 meter in the shallower-sensing 50-cm intercoil spacing were lower than those obtained in the deeper-sensing 100-cm intercoil spacing. This relationship is associated with the higher clay content of subsoil than surface soil layers. On higher-lying, convex surface, EC_a was noticeably higher than on lower-lying, plane and concave surfaces, which were wetter and some with ponded water. Surface layers were thinner on convex surfaces and thicker on concave surfaces.

Dune Site in Tazewell County:
Random traverses were completed across this site with the EM31 meter. These traverses include all slope components from concave toe slope to convex summit areas. Because of their low clay contents, Plainfield soils are electrically resistive. Variations in EC_a across the site are attributed to the number and thickness of finer-textured lamellae (Coloma soils) and differences in soil moisture contents and depth to water table.

The EMI survey revealed exceedingly low and invariable EC_a across this site. With the EM31 meter operated in the deeper-sensing VDO, EC_a averaged only 1.53 mS/m and ranged from 0 to 3.9 mS/m. Slightly higher EC_a measurements were recorded in a lower-lying depression that was located among the dunes. Here the water table was closer to the soil surface and slightly higher soil moisture contents were observed and presumed to be responsible for the slightly higher EC_a recorded in the depression.

Figure 7 is a processed radar record from the Dune Site in Tazewell County. In Fig. 7, the depth and distance scales are expressed in meters. In Figure 7 the water table may be traced across the entire radar record at depths ranging from 5.19 (extreme left) to 2.05 (extreme right) m. In coarse-textured materials, the electromagnetic gradient is abrupt and dielectric properties are strongly contrasting between saturated and unsaturated soil materials. Because of these properties, the upper boundary of the water table produces strong reflections and distinct images on most radar records.

In Figure 7, the continuous, near-horizontal reflections from the water table contrast in amplitude and form with the segmented, inclined reflections from strata within the dune. This aids identification. The detection of the water table may have been more difficult and ambiguous had reflections from the strata been continuous and more similar in amplitude and form. Abrupt and contrasting differences in density, grain size, and moisture contents produce high amplitude radar reflections (Schenk et al., 1993; Harari, 1996). In general, reflections from the interior of dunes are principally attributed to differences in moisture contents (Schnek et al., 1993; Bano et al., 1999; Bristow et al., 2000).

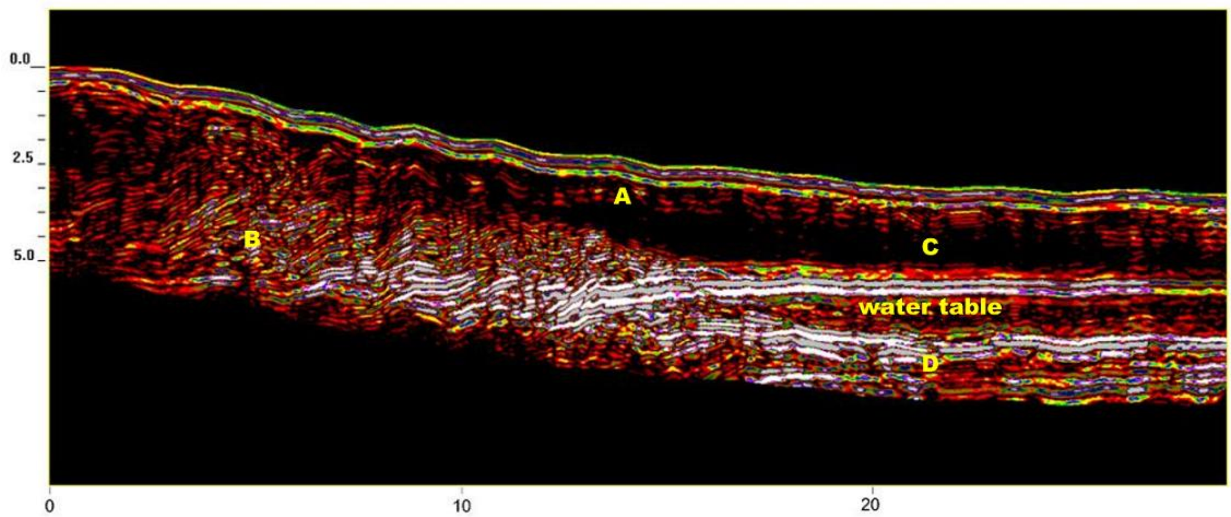

Figure 7. This processed radar record was collected at Dune Site in Tazewell County and shows various radar facies and a water table in an area of Plainfield soils.

On lower side and foot slopes a buried A horizon was observed in soil cores. This horizon has been labeled “A” in Fig. 7. Interpretations of radar records lead to the identification of three unique *radar facies*. A *radar facies* is a mappable three-dimensional unit composed of GPR reflections whose internal reflection patterns and characteristics differ from adjoining units. Each of the three radar facies defines different combinations of soil structures. Facies “B” consists of a high concentration of segmented reflectors from inclined strata within the dune. Facies “C” lacks reflectors and consists of colluvial materials on lower dune surfaces. Facies “D” consists of multiple linear reflectors that closely parallel the soil surface and the water table in this bowl-like inter-dune depression. Facies may help to define, characterize and differentiate soils and parent materials within these map units.

Clark County Site:

Apparent conductivity is moderate and variable across this site. Based on 2211 measurements made with the deeper-sensing (0 to 150-cm depth interval) 100-cm intercoil spacing on the EM38MK2-2 meter, EC_a averaged 38.9 mS/m and ranged from about 20.9 to 76.1 mS/m. One-half of these measurements were between 30.7 and 44.1 mS/m. Based on 2211 measurements made with the shallower-sensing (0 to 75 cm depth interval) 50-cm intercoil spacing on the EM38MK2-2 meter, EC_a averaged 25.9 mS/m and ranged from about 10.5 to 64.2 mS/m. One-half of these measurements were between 19.3 and 29.3 mS/m.

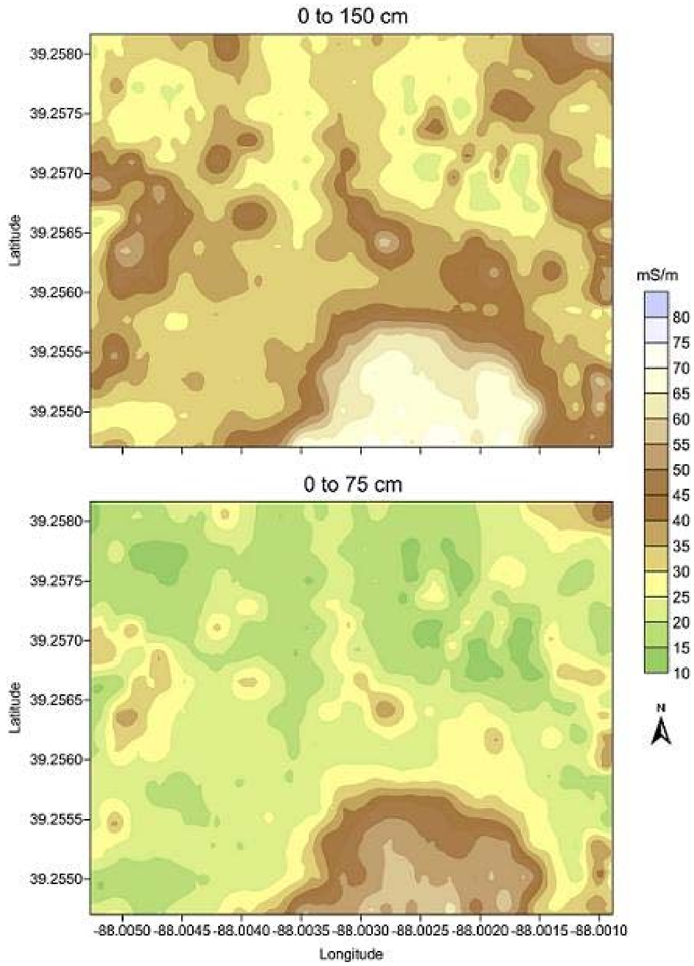

Figure 8. Plots of EC_a data collected at Clark County Site with the EM38MK2-2 meter in the deeper-sensing 100-cm (upper plot) and shallower-sensing, 50-cm (lower plot) intercoil spacings.

A comparison of the soil (Fig. 4) and EC_a (Fig. 8) maps for the Clark County Site reveals similar spatial pattern. Plots of spatial EC_a patterns clearly identify the wetter Ebbert map unit (48A). Plots of EC_a data reveal high values and a close conformity between isolines and the Ebbert map unit boundary. Areas mapped as Cisne (2A), Hoyleton (3A), and Newberry soils (218A) have lower EC_a than the area that is mapped as Ebbert soils. In general, EC_a data measured in the shallower-sensing (0 to 75 cm depth interval) 50-cm intercoil spacing renders areas of Hoyleton and Newberry soils as having slightly higher EC_a than areas of Cisne soils. However, pockmarked spatial patterns of higher and lower EC_a add inconsistency to this general rule. For all soils, EC_a increases with increasing observation depths (compare lower and upper plots in Fig. 8) and spatial similarities between EC_a and the Cisne, Hoyleton and Newberry map units becomes less.

Using the 200 MHz antenna a 50 m traverse was conducted in an area of Cisne soils. Figure 9 is the radar record from this traverse. The depth of penetration is restricted to the upper part of the argillic horizon by the high clay and moisture content of Cisne soil. One prominent subsurface interface, while varying in signal amplitude, can be traced across the radar record. This interface represents the contact of silt loam layers with the finer-textured subsoil. In the left-hand portion of this radar record, this interface corresponds with the Eg/Btg horizon boundary. In the right-hand portion of this radar record, this interface corresponds with a transitional Bt1g/Bt2g horizon interface. Differences in the abruptness and contrast in clay and moisture contents are responsible for variations in signal amplitudes. For the first 27 meters, this interface is characterized by high amplitude reflections, which signify highly contrasting materials and abrupt interface. In the last 23 meters, this interface is characterized by low amplitude reflections suggesting less contrasting and transitional or intermixed horizons.

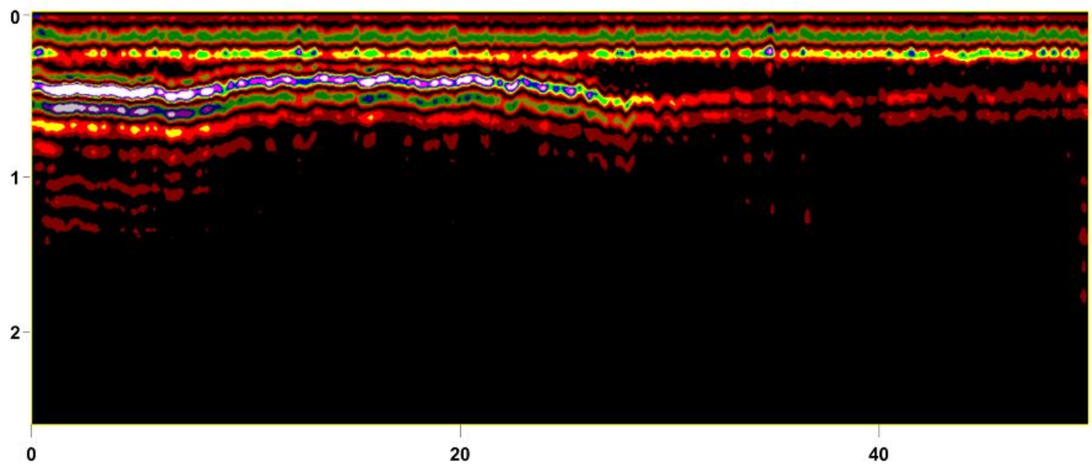

Figure 9. This radar record was collected in an area of Cisne and Newberry soils. The prominent subsurface interface is the boundary between horizons with contrasting clay and moisture contents. Where the interface is of higher amplitude (colored white, purple, blue and green) an E horizon overlies the Bt horizon.

Table 2. Cisne Soil Profile.

Horizon	Depth	Color	Texture
A	0-9”	10YR2/1	sil
E	9-14”	10YR6/2	sil
Bt1	14-21”	10YR5/2	sicl
Bt2	21-38”	10YR4/8	sicl
Bt3	38-46	10YR5/6	sicl
2Bt4	46-55	10YR5/1	sicl
2Bt5	55-78”	10YR5/4	sicl

Table 3. Newberry Soil Profile.

Horizon	Depth	Color	Texture
A	0-8”	10YR3/2	sil
Bt1	8-12”	10YR4/4	sil
Bt2	12-21”	10YR4/3	sicl
Bt3	21-33”	2.5Y5/1	sicl
Bt4	33-40”	10YR5/1	sicl
2Bt5	40-51”	10YR5/1	cl
2Bt6	51-64	2.5Y6/2	cl

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