United States Department of Agriculture

Natural Resources Conservation Service

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Subject: SOI -- Geophysical Assistance **Date:** 5 October 2005

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Purpose:
The use of ground-penetrating radar (GPR) to profile sandy soils and determine the depth to finer-textured materials was explored in Sargent County.

Participants:
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Activities:
All field activities were on 30 September 2005.

Summary:
Ground-penetrating radar can be effectively used to profile sandy soils in North Dakota, but penetration depths will be restricted by finer-textured materials, soluble salts, layers of calcium carbonate enrichment, and the high ionic concentrations of the groundwater. Where sandy soils are very deep to water table or finer textured materials, GPR can provide highly resolved images of the subsurface to depths greater than 2 m. Where the contact of sandy with finer-textured sediments is above the water table, GPR can provide detail records of this interface. In sandy soils, GPR can be used to detect and determine the depths to water tables. However, water tables will limit further penetration through soil profiles. In areas where the contact of sandy with finer-textured materials is below the water table, this interface can not be consistently detected with GPR. In undulating to rolling areas of well and excessively drained, sandy soils that are very deep to water table, lenses of coarser- and finer-textured *ice-thrusted* materials appeared to be intimately intermingled and the identity of individual subsurface reflectors is indistinguishable without extensive corings. Here, penetration depths can be limited to depths of less than 2 m by high calcium carbonate contents. Areas do exist in Sargent County where the contact of sandy with finer-textured materials is well expressed and mappable with GPR. Ground-penetrating radar can be most effectively used in these areas.

As always, it was my pleasure to work in North Dakota and with members of your fine staff.

With kind regards,

James A. Doolittle
Research Soil Scientist

cc:
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Study Areas:
All study sites are located on the *Sandy Plain Section* of MLRA 55B (Central Black Glaciated Plains). In this area, groundwater is hard and highly mineralized. As a consequence, radar penetration in sandy soils is limited to the unsaturated zone above the water table. In areas of sandy soils that are very deep to water table, the depth of penetration appears restricted by the content of calcium carbonate, soluble salts, and clays in the overlying materials. Ground-penetrating radar is unsuitable for use in saline or sodic soils. Lenses of finer-textured materials and zones of secondary calcium carbonate enrichment will also limit penetration depths. In well and excessively drained sandy soils that lack these restrictive features, penetration depths should exceed 2 m.

Study Site 1 was located in an area of Bantry-Hamar-Aylmer fine sands, 0-2 percent slopes, in the NW 1/4 of Section 10, T. 129 N., R. 57 W. Study Site 2 was located in an area of Bantry-Hamar-Aylmer fine sands, 0-2 percent slopes, in the SE 1/4 of Section 25, T. 129 N., R. 58 W. Study Site 3 was located in an area of Maddock fine sandy loam, moderately shallow, rolling, in the SE1/4 of Section 20, T. 130 N., R. 58 W. All sites were in native grass. Table 1 lists the map units that were traversed in this study with GPR. The taxonomic classifications of the soils traversed with GPR in Sargent County are listed in Table 2.

Table 1. Soil Map Units traversed with GPR in Sargent County, North Dakota

Name	Symbol
Bantry-Hamar-Alymer fine sands, 0-2 % slopes	VhC[1]
Hecla loamy fine sands, moderately shallow	HnAx
Maddock fine sandy loam, moderately shallow, rolling	MkCx

Table 2. Soil Series Profiled with GPR in Sargent County, North Dakota

Series	Taxonomic Classification
Aylmer	Mixed, frigid Aquic Udipsamments
Bantry	Mixed, frigid Typic Psammaquents
Hamar	Sandy, mixed, frigid Typic Endoaquolls
Maddock	Sandy, mixed, frigid Entic Hapludolls

The very deep, poorly drained Hamar, somewhat poorly drained Bantry, moderately well drained Alymer, and well drained or somewhat excessively drained Maddock soils formed in windblown glaciofluvial deposits on sandy delta plains and outwash plains. Earlier surveying protocol required observation of the soil profile to depths of 40 inches. Soils that lacked contrasting and restrictive layers to depths of 40 inches were described in published soil survey reports as being deep (> 40 inches). Soil depth criterion were latter revised to include deep (40 to 60 inches) and very deep (>60 inches) soil depth classes. Consequently, it is unclear what depth class should be used for several map units within this portion of the MLRA.

Equipment:
The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (here after referred to as the SIR System-3000), manufactured by Geophysical Survey Systems, Inc.[2] The use and operation of GPR are discussed by Daniels (2004). 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 4.1 kg (9 lbs) and is backpack portable. With an antenna, this system requires two people to operate. The 70 and 200 MHz antennas were used in this study. Because of its longer wavelength, the 70 MHz antenna was unable to resolve many soil features and was consider less suited to soil investigations. As a consequence, other than one calibration trial, the 70 MHz antenna was not used in this study.

[1] Area was formerly mapped as Valentine-Hecla fine sands, hummocky.
[2] Manufacturer's names are provided for specific information; use does not constitute endorsement.

Radar records contained in this report were processed with the RADAN for Windows (version 5.0) software program (Geophysical Survey Systems, Inc).[2] Processing included setting the initial pulse to time zero, color transformation, marker editing, distance normalization, horizontal stacking, background removal, and range gain adjustments.

Field Procedures:
Each radar traverse was completed by pulling the antenna by hand. Although, GPR provides a continuous profile of the subsurface, interpretations were restricted to observation points. For each transect, observation points were spaced at an interval of about 5 meters. At each observation point, the radar operator impressed a dashed, vertical line on the radar record. This line identified an observation point on the radar record. Each radar traverse was stored as a separate file on a hard disc. Soils were examined at selected observation points to confirm interpretations.

Calibration of GPR:
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., soil horizon, water table, 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). A nanosecond is one billionth of a second. The amount and physical state of water (temperature dependent) have the greatest effect on the dielectric permittivity of earthen materials.

Propagation velocities and depth scales were determined by comparing the two-way pulse travel time to a known reflector (buried metallic reflector) that appeared on the radar record with the measured depth. In the more imperfectly drained areas of Aylmer soils, based on the measured depth and the two-way pulse travel time to a known reflector, and equation [1], the velocity of propagation was estimated to be about 0.086 m/ns. The relative dielectric permittivity was 12. A scanning time of 60 ns was used in areas of Bantry-Hamar-Alymer fine sands, 0-2 % slopes. Using equation [1], a scanning time of 60 ns, and a propagation velocity of 0.086 m/ns, the maximum depth of observation was about 2.6 m.

In better drained areas of Maddock fine sandy loam, moderately shallow, rolling, the velocity of propagation was estimated to be about 0.124 m/ns. The relative dielectric permittivity was 5.8. A scanning time of 70 ns was used in areas of this map unit. Using equation [1], a scanning time of 70 ns, and a propagation velocity of 0.124 m/ns, the maximum depth of observation was about 4.3 m.

Interpretations:
Figure 1 is a representative radar record from an area of Bantry-Hamar-Alymer fine sands, 0-2 % slopes. Depth and distance scales are expressed in meters. The water table forms a prominent, planar reflector that is continuous across the radar record between depths of about 1.2 to 1.6 m. This radar record was not *terrain corrected* (adjustments made to the position of the surface reflection based on measured surface elevations). As a consequence, the reflection from the water table appears wavy because of variations in the micro-topography of the soil surface. The high ionic concentration of the groundwater rapidly attenuates the radar energy and limits penetration depths. In North Dakota, GPR will not provide images of subsurface reflectors below the water table. Weak reflections from subsurface interfaces within the substratum of these soils are evident in the upper part of this

radar record (Figure 1). These reflections are presumably caused by differences in grain or particle size distributions and/or density.

Figure 2 is from an area of Maddock fine sandy loam, moderately shallow, rolling. On this radar record, the contact of sandy deltaic sediments with silty lacustrine sediments provides a strong subsurface reflector between depths of about 1.5 to 1.8 m. This interface is easily traced across the radar record. Though occurring within a relative uniform depth interval, some of the undulations in this interface are attributed to the micro-topography of the soil surface. The interface separating sandy and finer-textured sediments is characterized by high to moderate amplitude (reflectors that are colored white, pink, blue, green, and yellow in Figure 2) reflections. Variations in signal amplitudes (different colors in Figure 2) suggest spatial differences in soil properties along this interface. The high amplitudes suggest more contrasting materials and a fairly abrupt boundary. Like the water table, this contact limits penetration. Rapid rates of signal attenuation below this interface are attributed to higher concentrations of fines, calcium carbonates and increased moisture contents. No meaningful subsurface reflectors are evident below this interface. In the overlying soil materials low amplitude (colored in shades of red) reflections signify horizons or layers with more weakly contrasting properties (i.e., clay content, grain-size, or density).

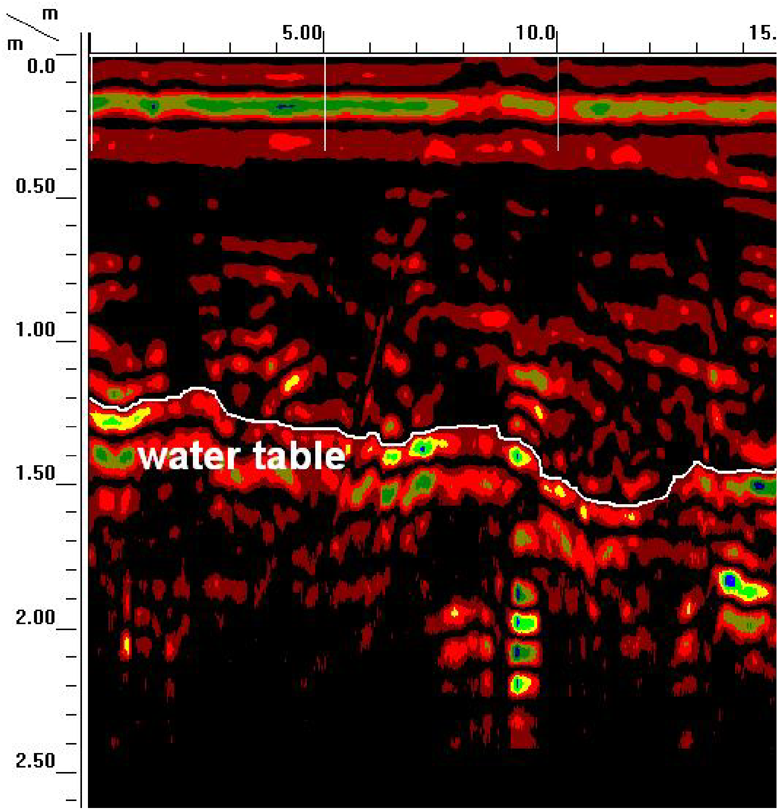

Figure 1. The water table provides a strong subsurface reflector in area of Bantry-Hamar-Alymer fine sands, 0-2 % slope.

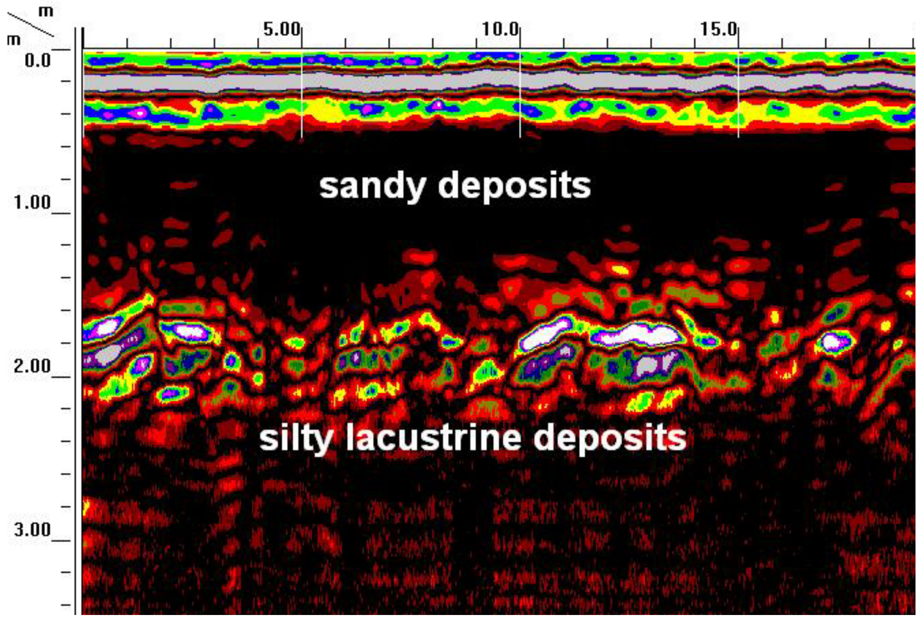

Figure 2. The contact of sandy deltaic sediments with silty lacustrine sediments provide a strong subsurface reflector in areas of Maddock fine sandy loam, moderately shallow, rolling.

Figure 3 is also from an area of Maddock fine sandy loam, moderately shallow, rolling. On this radar record, the multiple, similarly inclined subsurface reflections are assumed to represent *ice-thrusted* sediments. Limited auger observations indicate that some of these reflectors represent sandy deposits with different grain size distributions and density. However, without more extensive (too costly and unwarranted) field verification, the identity of individual reflectors is unclear. In Figure 3, the depth of effective signal penetration is limited to about 2 m. Comparatively high calcium carbonate contents of these sediments are presumed to be partially responsible for this restricted depth of penetration.

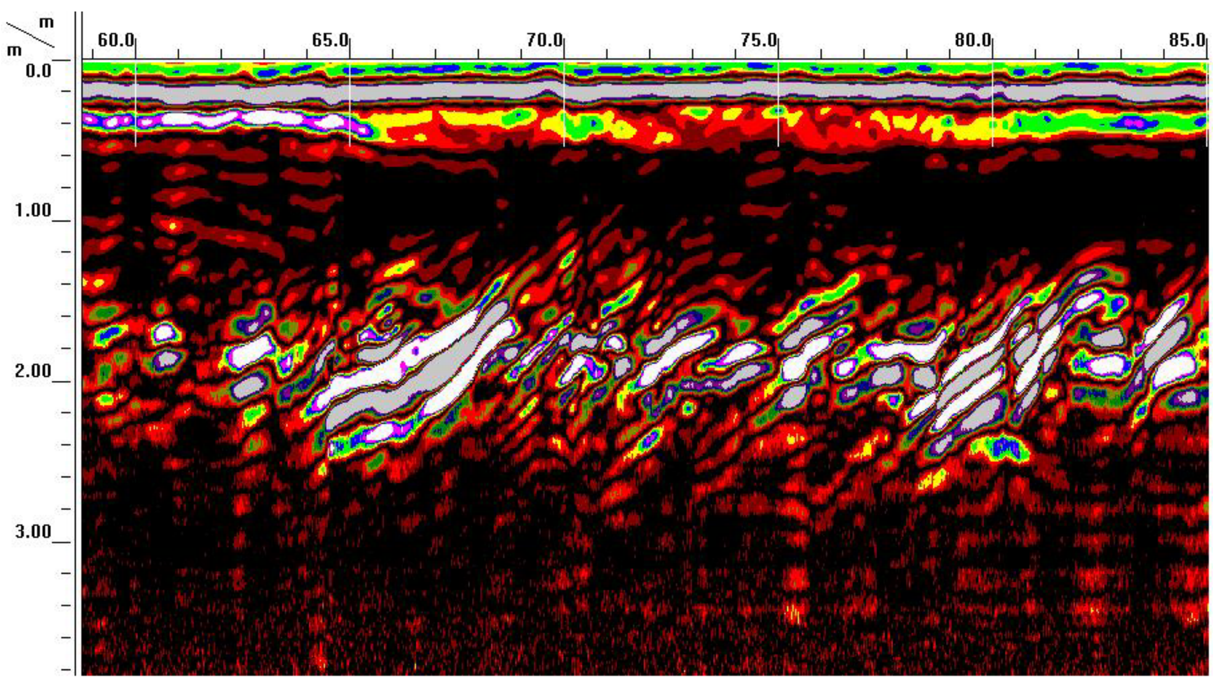

Figure 3. Ice-thrusted sediments provide a strong subsurface reflector in areas of Maddock fine sandy loam, moderately shallow, rolling.

References:

Daniels, D. J. 2004. Ground-penetrating radar; 2nd Edition. The Institute of Electrical Engineers, London, United Kingdom.