United States Department of Agriculture

Natural Resources Conservation Service

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Subject: -- Geophysical Assistance

Date: 19 October 2004

To: Doug Gahn
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Purpose:
The purpose of this investigation was to evaluate the penetration depth and resolution of ground-penetrating radar (GPR) in an area of Valentine soil in the Nebraska Sand Hills of McPherson County.

Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Roger Hammer, Soil Scientist, USDA-NRCS, North Platte, NE
Alvin Perez-Torres, Soil Scientist, USDA-NRCS, North Platte, NE

Activities:
All activities were completed on October 12, 2004. .

Results:

1. A GPR traverse was conducted in an area that had been mapped as Valentine fine sand, rolling, in the Nebraska Sand Hills of McPherson County. With a 200 MHz antenna, subsurface reflections were observable to depths of about 3.5 m. Compared with other dune or sand sheet landscapes, the depth of penetration was restricted in the Sand Hills. Depth restrictions were associated with the presence of lamellae composed of 2:1 expanding lattice clays. Ground-penetrating radar provides an excellent tool for charting the shallow stratigraphy of dunes.

2. Soils within the Nebraska Sand Hills contain lamellae. Lamellae attenuate the radar signal and restrict penetration depths. A soil sample was collected at the study site and has been taken to the USDA-National Soil Survey Laboratory, Lincoln, Nebraska, for analysis. Results of laboratory analysis will help assess the chemical, physical, and mineralogical parameters that affect the performance of GPR in sandy soils.

I greatly appreciated the assistance provided by Roger Hammer and Alvin Perez-Torres in this study. It was my pleasure to work in Nebraska.

With kind regards,

James A. Doolittle
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cc:
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Background:
The penetration depth of GPR is dependent on the conductivity of the earthen materials being probed (Daniels, 2004). Soils with high electrical conductivity rapidly attenuate the radar signal and limit penetration depths. The electrical conductivity of soils is highly variable and increases with increased water, clay, and soluble salt contents. It is significant that only small amounts of water, clay, or soluble salts are necessary to significantly increase the conductivity of soils and decrease the radar's penetration depths.

In excessively drained, sandy materials, GPR often achieves unsurpassed penetration depths and unmatched resolution of subsurface interfaces. As a consequence, little consideration is often given to the chemical, physical, and mineralogical properties of sandy materials. In sandy soils, the most significant form of signal loss and attenuation are related to the presence of saline pore waters and surface reactive clays (Olhoeft, 1998; Schenk et al., 1993). These losses are due to the migration of unbound ions through the soil solution and in the electrical double layer that surrounds clay particles.

In sandy soils with high fluid ionic contents, electrical conductivity is principally influenced by the amount of fluid saturation (Wildenschild et al., 1999). Conductive, alkaline or saline ground waters produce severe signal losses and therefore restrict penetration depths. In addition, relaxation losses (energy dissipated during polarization/depolarization) result from the rotation of dipolar water molecules (West et al., 2003).

Figure 1. Distinct, discontinuous, sub-horizontal to wavy, thin bands of lamellae are evident in this profile of Valentine soil.

In sandy soils with low fluid ionic concentrations, electrical conductivity is strongly influenced by surface conduction of mobile ions in the diffuse double layer that surrounds clay particles (Wildenschild et al., 1999). Olhoeft (1998) found that the presence of very small amounts of clays significantly increases signal attenuation and reduces penetration depths. The presence of even small amounts of clay will greatly increases pulse attenuation and reduce penetration depths (Harari, 1996). Clay contents of only 5 to 10 percent can reduce penetration depths to less than one meter (Walther et al., 1986). Differences in clay mineralogy have an affect on GPR performance. Soils dominated by clay fractions with a high percentage of smectite or vermiculite have a higher CEC and are more attenuating to GPR than soils with an equivalent percentage of kaolinite. Expanding 2:1 lattice clays produce strong dielectric dispersion (West et al., 2003).   In addition, mineralogical properties such as the concentration of heavy minerals are known to affect electromagnetic properties and GPR performance (Schenk et al., 1993).

Distinct, discontinuous, sub-horizontal to wavy, thin bands of lamellae are common in the soils of the Nebraska Sand Hills (see Figure 1). Lamellae are illuvial soil horizons that are less than 7.5 cm thick and contain an accumulation of orientated silicate clays on or bridging sand and silt grains (Soil Survey Staff, 1999). The depth to lamellae is believed to be related to the position of former wetting fronts and reflects the amount, frequency, and intensity of precipitation and surface runoff.

This study is being conducted by the National Soil Survey Center to assess the chemical, physical, and mineralogical properties of sandy aeolian deposits that affect GPR performance.

Equipment:
The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (here after referred to as the SIR System-3000), manufactured by Geophysical Survey Systems, Inc.[1] The SIR System-3000 consists of a digital control unit (DC-3000) with keypad, SVGA video screen, and connector panel. A 10.8-volt lithium-ion rechargeable battery powers the system. The SIR System-3000 weighs about 9 lbs (4.1 kg) and is backpack portable. With an antenna, this system requires two people to operate.   The use and operation of GPR are discussed by Daniels (2004). A 200 MHz antenna was used in this investigation.

The radar record contained in this report was processed with the RADAN for Windows (version 5.0) software program (Geophysical Survey Systems, Inc, 2003).[1] Processing included setting the initial pulse to time zero, color transformation, marker editing, distance and surface normalization, signal stacking, background removal, migration, and range gain adjustments.

Calibration of GPR:
Ground-penetrating radar is a time scaled system. This system measures the time that it takes electromagnetic energy to travel from an antenna to an interface (e.g., 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 (about 0.3 m/nanosecond). Velocity is expressed in meters per nanosecond (m/ns).   The amount and physical state (temperature dependent) of water have the greatest effect on the E_r of earthen materials and therefore the velocity of propagation.

Based on the measured depth (52.5 cm) to a buried metallic reflector, the velocity of propagation through the upper part of the Valentine soil profile was an estimated 0.123 m/ns. The E_r was 5.87. Using a scanning time of 80 ns, a velocity of 0.123 m/ns, and equation [1], the maximum depth of penetration through the sands is about 4.9 m.

Study Site:
The traverse site (0324894 Northing, 4585731 Easting) was located in the northwest quarter of Section 35, Township 17 North, and Range 33 West. The area had been mapped as Valentine fine sand, rolling (1 to 17 percent slopes) (Sherfrey, 1969). The very deep, excessively drained Valentine soil formed in eolian sands. Valentine is a member of the mixed, mesic Typic Ustipsamments family. The control section of Valentine soil is fine sand or loamy fine sand, but includes sand and loamy sand with less than 35 percent medium sand and less than 10 percent coarse or very coarse sand

Field Procedures:
A 48-m traverse line was established across a west-facing slope of a small dune. Survey flags were inserted in the ground at intervals of 3-m and served as reference points. The elevation of each reference point was measured with a level and stadia rod. Relief was about 3.78 m. Elevations were not tied to a benchmark; the lowest recorded point was chosen as an arbitrary 0.0 m datum. The radar survey was completed by pulling the 200 MHz antenna along the traverse line. As the antenna passed a reference point, a vertical mark was impressed on the radar record.

Results:
Figure 2 is a portion of the radar record that was obtained along the traverse line. In Figure 2, the surface has been *terrain corrected* to improve the visual presentation. Through a process known as *surface normalization*, elevations are assigned to each reference point and the image is corrected for changes in elevation. Surface normalization adjusts the vertical scale to correspond to changes in topography.

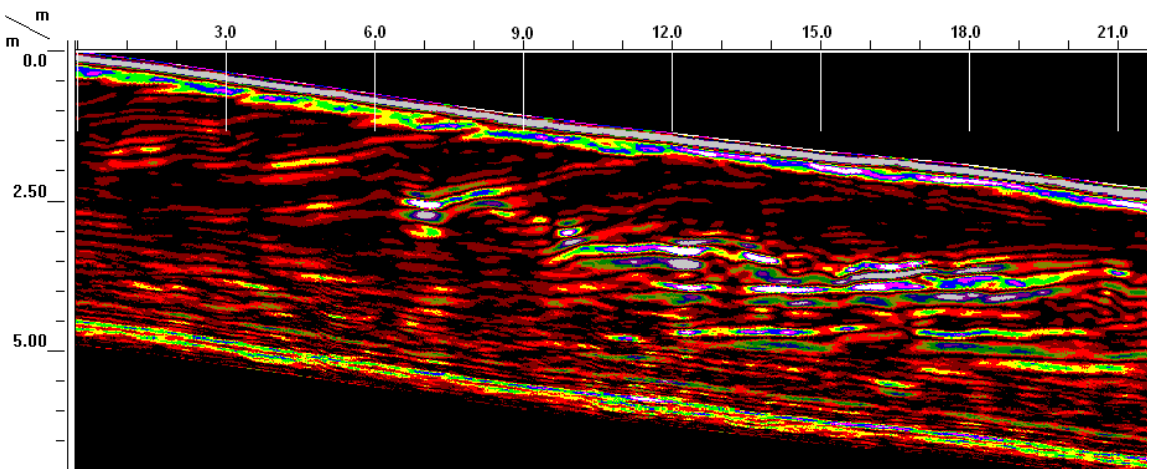

Figure 2. Radar record collected with the 200 MHz antenna in an area of Valentine fine sand, rolling (1 to 17percent slopes)

The radar record obtained with the 200 MHz antenna is of good interpretive quality. The geometry and structure of major stratigraphic boundaries are well expressed in Figure 2. Internal features and bedding planes within stratigraphic units are also evident in this figure. Abrupt and contrasting differences in density, grain size, and moisture contents produce the high amplitude reflections that are apparent in Figure 2. Based on ground-truth observations, some lamellae were discerned with GPR. Multiple reflections of the surface reflection and background noise clutters the lower part of the radar record (below about 3.5 m). The maximum depth of penetration is about 3.5 m. For a sandy soil, this depth of penetration is considered restricted. The presence of lamellae is believed responsible for the limited depth of penetration.

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