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

Subject: Soils – Geophysical Field Assistance **Date:** 14 November 2003

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Purpose:
The purpose of this investigation was to evaluate the performance of GPR on sandy soils in the San Luis Valley of south central Colorado.

Participants:
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Daryl Trickler, Consulting Soil Scientist, USDA-NRCS, San Luis, CO
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Activities:
All activities were completed on 26 October 2003.

Results:

1. A GPR survey was conducted with a 200 MHz antenna in an area of Dune land mapped within the Great Sand Dunes National Monument, Alamosa County. Radar reflections were observed at depths greater than 10 m. However, clear and interpretable reflectors were observed only within depths of about 7 m. These sands are known to contain relatively large amounts of magnetite. Magnetite is a conductive, heavy mineral that influences the electrical and magnetic properties of these deposits and restricts the depth of radar penetration.

2. The performance of GPR is strongly influenced by the presence of calcium carbonates in the soil. In an area of Costilla loamy sands, 0 to 3 % slopes, a radar record obtained with the 200 MHz antenna was of poor depth and interpretative quality. The clay and carbonate contents of this soil are believed to be responsible for the rapid attenuation of radar energy, limited penetration depths (< 2 m), and the presence of low frequency noise that plagued the radar record.

3. Soil samples were collected at each site for analysis at the National Soil Survey Laboratory. Results of laboratory analysis will help assess the chemical and mineralogical parameters that affect the performance of GPR in sandy soils.

We appreciate the efforts and enthusiasm of the Colorado Soil and the NRCS San Luis Office Staffs in facilitating this study.

With kind regards,

James A. Doolittle
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cc:
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Equipment:
The radar unit is the TerraSIRch SIR (Subsurface Interface Radar) System-3000, manufactured by Geophysical Survey Systems, Inc.[1] Morey (1974), Doolittle (1987), and Daniels (1996) have discussed the use and operation of GPR. The SIR System-3000 consists of a digital control unit (DC-3000) with keypad, color SVGA video screen, and connector panel. A 10.8-volt Lithium-Ion rechargeable battery powers the system. This unit is backpack portable and, with an antenna, requires two people to operate. The antennas used in this study have center frequencies of 70 and 200 MHz.

The RADAN for Windows (version 5.0) software program was used to process the radar records (Geophysical Survey Systems, Inc, 2003).[1] Processing included color transformation, time-zero adjustment, marker editing, distance normalization, surface normalization, and range gain adjustments.

Background:
The penetration depth of GPR is dependent on the conductivity of the earthen materials being probed (Morey, 1974). Soils with high electrical conductivity rapidly attenuate the radar signal and reduce penetration depths. The electrical conductivity of soils is highly variable and increases with increased water, clay, and soluble salt contents. It is significant that small amounts of water, clay, or soluble salts can appreciably increase the conductivity of soils and decrease the radar's penetration depths.

In excessively drained, sandy soil materials, GPR often achieves unsurpassed penetration depths and unmatched resolution of subsurface interfaces. In these materials, lowering the frequency of the antenna can often substantially increase penetration depths. Abrupt and contrasting differences in density, grain size, and moisture contents produce high amplitude reflections. Little consideration is often given to the chemical and physical properties of coarse-textured 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 (Schenk et al., 1993). The presence of even small amounts of clay will significantly increase signal attenuation and reduce the depth of penetration. In addition, mineralogical properties such as the concentration of heavy minerals affect the electromagnetic properties and have

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

explicit affect on GPR performance. In some areas (though especially in arid and semi-arid areas), high levels of calcium carbonate occur in soils. Soils with calcareous layers have been reported to severely limit the radar's penetration depth (Grant and Schultz, 1994)).

A study is being conducted by the National Soil Survey Center to assess the chemical and mineralogical properties of coarse textured aeolian deposits that affect GPR performance.

GPR:

Ground-penetrating radar is a time scaled system. The system measures the time it takes electromagnetic energy to travel from an antenna to an interface (i.e., soil horizon, stratigraphic layer) and back. To convert travel time into a depth scale requires knowledge of the velocity of pulse propagation. Several methods are available to determine the velocity of propagation. These methods include use of table values, common midpoint calibration, and calibration over a target of known depth. The last method is considered the most direct and accurate method to estimate propagation velocity (Conyers and Goodman, 1997). The procedure involves measuring the two-way travel time to a known reflector that appears on a radar record and calculating the propagation velocity by using the following equation (after Morey, 1974):

$$V = 2D/T \qquad [1]$$

Equation [1] describes the relationship between the propagation velocity (V), depth (D), and two-way pulse travel time (T) to a subsurface reflector. During this study, the two-way radar pulse travel time was compared with measured depths to known subsurface interfaces at each site. Computed propagation velocities were used to scale the radar records.

Results:

<u>Great Sand Dunes National Monument:</u>

Radar surveys were conducted on a portion of a large sand dune located in Great Sand Dunes National Monument, Alamosa County, Colorado. In an earlier study, Schenk and others (1993) used GPR to delineate the internal structure of these dunes. Using antennas with center frequencies of 300, 500, and 900 MHz, Schenk and others (1993) observed radar reflectors to a maximum depth of about 15 m. However, clear and continuous subsurface reflectors were limited to the upper 5 m of the dune (Schenk et al., 1993).

The sands within the National Monument are known to contain relatively large amounts of magnetite. This heavy mineral influences the electrical and magnetic properties of these aeolian deposits. The presence of magnetite is believed to substantially increase the electrical conductivity of these deposits and restrict radar penetration depths.

In this study, radar traverses were conducted in an area that had been mapped as Dune land (Pannell et al., 1973). This miscellaneous map unit consists of shifting sands dunes that are devoid of vegetative cover. In this miscellaneous map unit, dunes may be as much as 600 feet high. A 180 ft (54.9 m) traverse line was established across an east-facing slope of a small dune. Survey flags were inserted in the ground at intervals of 20 feet (6.1 m) and served as reference points. The elevation of each reference point was measured with a level and stadia rod. Relief was about 23 ft (7.0 m). Elevations were not tied to a benchmark; the lowest recorded point was chosen as an arbitrary 0.0 m datum. Surveys were completed with the 70 and 200 MHz antenna.

Based on a measured depth (50 cm) to a buried metallic reflector, the velocity of propagation through the relatively dry sands was an estimated 0.127 m/ns. The dielectric permittivity was 5.5. The velocity of propagation is considered low for relatively dry sands. However as noted by Parkhomenko (1967), the presence of heavy minerals such as magnetite will increase the dielectric permittivity of materials. Using a scanning time of 150 and 250 ns, a velocity of 0.127 m/ns, and equation [1], the maximum depth of penetration through dry sands is about 9.5 and 15.8m, respectively.

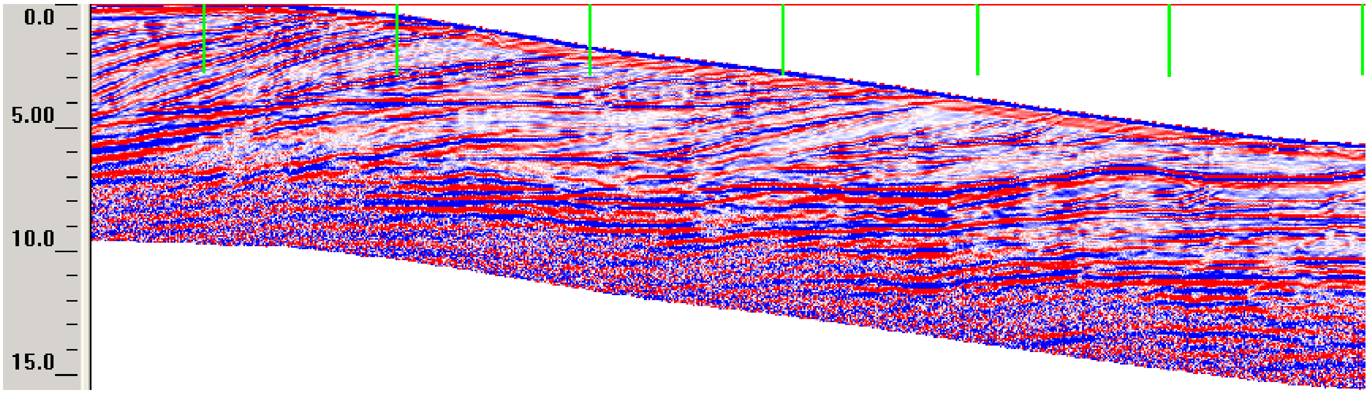

Figure 1. A representative radar record collected with the 200 MHz antenna in an area of Dune land, Great Sand Dunes National Monument, Colorado. The depth scale is expressed in meters.

Figure 1 is a representative radar record. The short, vertical lines at the top of the radar record represent the equally spaced (7.0-m) reference points along the radar traverse. The depth scale along the left-hand margin of this figure is in meters. In Figure 1, 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 conform to changes in topography.

The radar records obtained with the 200 MHz antenna were of good quality. Major bounding surfaces were evident and strata within these units were well expressed on radar records. Radar reflections were observed at depths greater than 10 m. However, clear and interpretable reflectors were observed only within depths of about 7 m. These depths are consistent with observations made by Schenk and others (1993). At the Great Sand Dunes National Monument, GPR penetration depths pale in comparison to the results obtained on aeolian deposits near Nags Head, North Carolina. At Nags Head penetration depths of 16 to 17 m were achieved with the 200 MHz antenna. The greater penetration depths in aeolian dunes at Nags Head are attributed to an abundance of quartz (87%), with minor inclusions of plagioclase feldspar (9%), and iron oxides (2%), and only traces of other minerals. The sands at Great Sand Dunes National Monument are known to contain relatively large amounts of magnetite. Magnetite is a conductive mineral that influences the electromagnetic properties of these deposits and restricts the depth of radar penetration.

<u>Area of Costilla loamy sands, 0 to 3 % slopes:</u>
Radar surveys were conducted in an area that had been mapped as Costilla loamy sands, 0 to 3 % slopes, to assess the influence of calcium carbonate and minor amounts of clays on the penetration depth of GPR. The deep, well drained to somewhat excessively drained Costilla soil forms in wind-reworked alluvium from mixed rock sources. The mapped area is on an alluvial terrace. Costilla is a member of the sandy, mixed, frigid Typic Haplocalcids family. Depth to secondary carbonates range from 10 to 40 inches.

A 15.25 m (50 ft) traverse line was established across a small area of this map unit. Survey flags were inserted in the ground at intervals of 3.05 m (10 feet) and served as reference points. Relief was less than 25 cm. Surveys were completed with the 200 MHz antenna using a scanning times of 60 ns.

Based on a measured depth (50 cm) to a buried metallic reflector, the velocity of propagation through the upper part of the soil profile was an estimated 0.100 m/ns. The dielectric permittivity was 8.82. Using a scanning time of 60 ns, a velocity of 0.10 m/ns, and equation [1], the maximum depth of penetration through dry sands is about 3.0 m.

Though sampled as Costilla, the soil is most similar to Cososa soil. Cososa soil is a tentative series and is a member of the coarse-loamy, mixed, superactive, frigid Typic Aridic Haplocalcids family. The soil was examined and described to a depth of 100 cm.

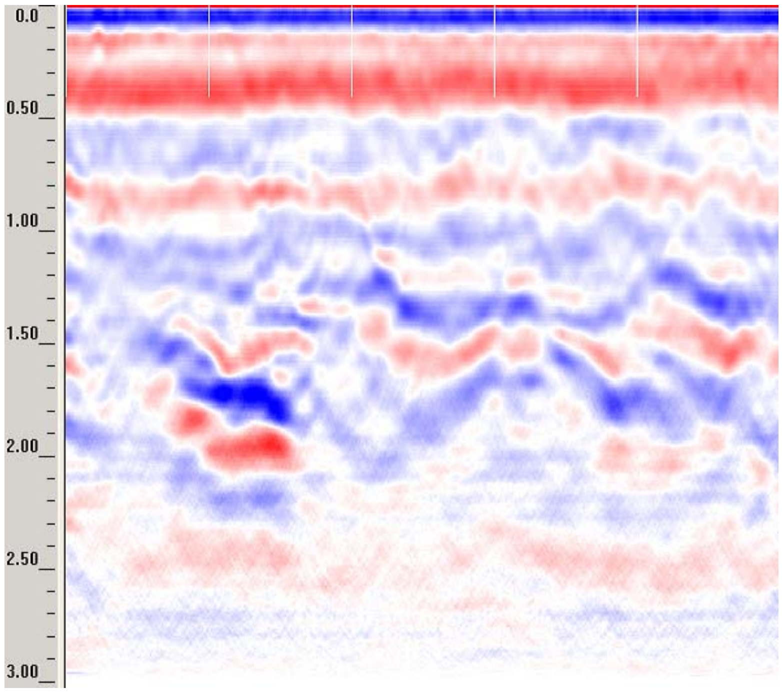

Figure 2. A representative radar record collected with the 200 MHz antenna in an area of Costilla sandy loam. The depth scale is expressed in meters.

Figure 2 is a representative radar record. The short, vertical lines at the top of the radar record represent the equally spaced (3.05-m) reference points along the radar traverse. The depth scale along the left-hand margin of this figure is in meters. The radar record is of poor depth and interpretative quality. The clay and carbonate contents of this soil limited the effective penetration depth to less than 2 m. In Figure 2, radar reflections appear broad and blurred suggesting severe attenuation and the presence of low frequency noise.

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