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Subject: -- Geophysical Assistance **Date:** 6 October 2004

To: William Dollarhide
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Purpose:
To evaluate the performance of GPR on calcareous sands and to assess its effectiveness for characterizing petrocalcic and petrogyspic layers.

Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Patrick Drohan, Associate Professor, Department of Geosciences, UNLV, Las Vegas, NV
Doug Merkler, Resource Soil Scientist, USDA-NRCS, Las Vegas, NV
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Activities:
All activities were completed on September 27 and 28, 2004.

Results:

1. In an area of Morman Mesa soil, GPR charted the depth to the petrocalcic horizon and characterized its internal structure. Interpretations were restricted to the petrocalcic horizon and the upper 1 to 2 meters of the soil. Below these depths, the radar energy was substantially attenuated and no clear reflections were detectable. Over horizontal scales of 1- to-5 m, GPR characterized the petrocalcic horizons as consisting of multiple, discontinuous, wavy, convoluted and variable in amplitude layers. In places, the identification of the petrocalcic horizon was unclear, resulting in some ambiguous interpretations.

2. In an area of Bluepoint soil, the maximum depth of penetration ranges from about 4.4 to 5.4 m. High rates of signal attenuation limited the depth of penetration and high levels of background noise impaired interpretations. Compared to other dune sites in the United States, depth of radar signal penetration is considered relatively shallow. Carbonates are believed to be responsible for the relatively high rates of signal attenuation and restricted penetration depths. A soil sample was collected at the study site and will be taken to the USDA-National Soil Survey Laboratory, Lincoln, NE, for analysis. Results of laboratory analysis will help assess the chemical, physical, and mineralogical parameters that affect the performance of GPR in sandy soils.

3. In an area of Drygyp soil, GPR charted the upper boundary of the petrogypsic horizon, which ranged in depth from 36 to 65 cm, and profiled the upper 2.2 meters of the soil. Below this depth, the radar energy

was significantly attenuated and no clear reflections were detectable. Data processing was required to clarify interpretations. Ground-penetrating radar may be used in areas of Drygyp and similar soils to assess the development of petrogypsic horizons and the affects of soil disturbances.

It was my pleasure to work in Nevada and with Doug Merkler.

With kind regards,

James A. Doolittle
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cc:
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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). The 200 and 400 MHz antennas were used during this investigation.

Radar records contained in this report were 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, 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 (Daniels, 2004):

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

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. At each study site the two-way travel time to a known reflector was measured and the velocity of propagation determined using Equation [1]. The relative dielectric permittivity of the soil at the time of the investigation was estimated using the calculated velocity of propagation and Equation [2].

Petrocalcic Horizon:
A petrocalcic horizon (Bkm) is an illuvial horizon that is cemented or indurated by secondary calcium carbonates. This horizon is either ≥ 10 cm thick or consists of a laminar cap that is ≥1 cm thick, which directly overlies bedrock (Soil Survey Staff, 2003). A petrocalcic horizon is a continuously cemented or indurated calcic horizon. It is continuous but may be fractured provided the lateral distance between fractures is ≥10 cm. Dry fragments from a petrocalcic horizon will not slake in water. A petrocalcic horizon is massive or platy, extremely hard when dry and very firm to extremely firm when moist. This cemented horizon is extremely difficult to penetrate with spade or auger. Figure 1 is a photograph of the petrocalcic horizon that forms the resistant cap to Mormon Mesa.

Study site:
The study site (36.74487^o N. Latitude, 114.29083^o W. Longitude) was located on Mormon Mesa at an elevation of about 1955 ft. The area was in rangeland and had been mapped as Mormon Mesa fine sandy loam, 0 to 8 percent slopes. The shallow over petrocalcic, well drained Mormon Mesa soil forms in alluvial deposits on summits of deeply dissected fan piedmont remnants and mesas. The Mormon Mesa soil has a petrocalcic horizon that ranges in depth from 25 to 50 cm. Mormon Mesa's control section contains 5 to 18 percent clay. Rock fragments range from 0 to 35 percent. Mormon Mesa is a member of the loamy, carbonatic, thermic, shallow Calcic Petrocalcids family. At the time of this investigation the soils were very dry.

Field Procedures:
A 20-m traverse line was laid out across the study site. Survey flags were inserted in the ground at 5-m intervals along this line. These flags served as reference points. Pulling the 200 MHz antenna along this line completed the radar survey. As the antenna was pulled passed each reference point, the operator impressed a vertical mark on the radar record.

The depth to the petrocalcic layer was measured and used to scale the radar record. Based on the measured depth to this reflector, the velocity of propagation was an estimated 0.136 m/ns. The E_r was 4.77. Using a scanning time of 60 ns, a velocity of 0.136 m/ns, and equation [1], the maximum depth of penetration was about 4.1 m. However, as will be discussed, the depth of observation was substantially less because of high rates of signal attenuation caused by the relatively high conductivity of Mormon Mesa soil.

Figure 1. A petrocalcic layer is exposed at a depth of about 40 cm on this exposure at Mormon Mesa.

Results:
Figure 2 is a portion of the radar record that was obtained with the 200 MHz antenna along the traverse line. The upper boundary of the petrocalcic horizon has been interpreted and identified by a green line on this radar record. In Figure 2, the interpreted depth to the petrocalcic horizon ranges from 44 to 109 cm. As seen in Figure 2, meaningful information appears largely restricted to the petrocalcic horizon and to the upper 1 to 2 meters of the soil. Below these depths, the radar energy was significantly attenuated and no clear reflections were detectable. Data processing was required to clarify interpretations. Without processing, the lower part of the radar record shown in Figure 2 was plagued by both low- and high-frequency background noise. Processing, which consisted of signal stacking and averaging of scans, improved the signal to noise ratio.

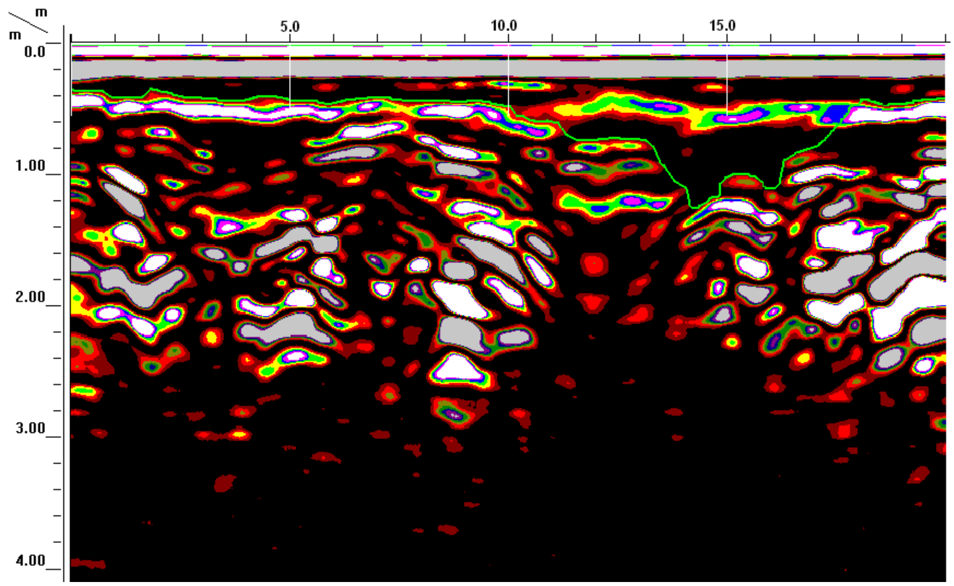

Figure 2. A processed radar record from an area on Mormon Mesa soil showing the interpreted depth to petrocalcic horizon.

Over distance scales of 1- to-5 m, reflections from the petrocalcic horizons appear discontinuous, wavy, convoluted and variable in amplitude (see Figure 2). The thickness of the layer appears to range from about 1 to 2 m. The petrocalcic horizon appears to consist of a number of segmented, essentially horizontal layers that are discontinuous over short horizontal distances (1- to 2-m), slightly contorted, and variable in expression (degree of induration or hardness (?)). The slight inclination of these layers at various angles creates a wavy and exceedingly complex pattern of short planar reflectors on the radar record. The official series description for Mormon Mesa soils does not mention these possible characteristics. The type location for the Mormon Mesa series is located in close proximity to the GPR study site. The official series description describes a massive Bkm horizon that is over 110 cm thick, but does not partition the petrocalcic horizon into sub-horizons or describe the structure that is apparent on the GPR record (see Figure 2).

In Figure 2, the upper contact of the petrocalcic horizon generally produces a high amplitude (white colored) reflection. Pebble and cobble occur in the upper part of the Mormon Mesa profile. Rock fragments produce discontinuous point reflections that have similar amplitudes to the petrocalcic horizon. In Figure 2, the depth to the petrocalcic horizon is deeper between reference points 10- and 18-m. The lower amplitude (colored pink, blue, and green) reflections in the upper 40- to 50-cm of this portion of the radar record are believed to represent rock fragments. In places, the identification of the petrocalcic horizon was unclear, resulting in some ambiguous interpretations.

Bluepoint Soil:
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 required to significantly increase the conductivity of soils and decrease the radar's penetration depths.

In excessively drained sands, GPR often achieves unsurpassed penetration depths and unmatched resolution of subsurface interfaces. Little consideration is often given to the chemical and physical properties of sands. 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 are known to affect electromagnetic properties and the performance of GPR. In some areas (though especially in arid and semi-arid areas), high levels of calcium carbonate or calcium sulfate occur in soils. Soils with calcareous layers are known to severely limit the radar's penetration depth (Grant and Schultz, 1994).

A dune that has been mapped as Bluepoint soil was surveyed in an attempt to gather data on the chemical and mineralogical properties of sandy aeolian deposits that affect GPR performance.

Study Site:
Radar surveys were conducted on in an area of Bluepoint soil (UTM: 11S, 730823 Northing and 4043652 Easting) at an elevation of about 1239 ft. The area had been mapped as Bluepoint loamy fine sand. The very deep, somewhat excessively drained Bluepoint soil forms in eolian materials from mixed rock sources on dunes and sand sheets. Bluepoint soil is calcareous in some or all parts of control section. The control section contains 2 to 10 percent clay. Bluepoint is a member of the mixed, thermic Typic Torripsamments family.

Field Procedures:
An 18-m traverse line was established across a west-facing slope of a small dune. Relief was about 3.9 m. Survey flags were inserted in the ground at intervals of 2-m and served as reference points. The elevation of each reference point was measured with a level and stadia rod. Elevations were not tied to a benchmark; the lowest recorded point was chosen as an arbitrary 0.0 m datum. The survey was completed with a 200 MHz antenna.

Based on the measured depth to a buried metallic reflector (47-cm), the velocity of propagation through the upper part of the sands was an estimated 0.148 m/ns. The E_r was 4.04. Using a scanning time of 100 ns, a velocity of 0.148 m/ns, and equation [1], the maximum depth of penetration through the sands is about 7.4 m.

Results:
Figure 3 is a portion of the radar record that was obtained with the 200 MHz antenna across the west-facing slope of the small dune. In Figure 3, 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.

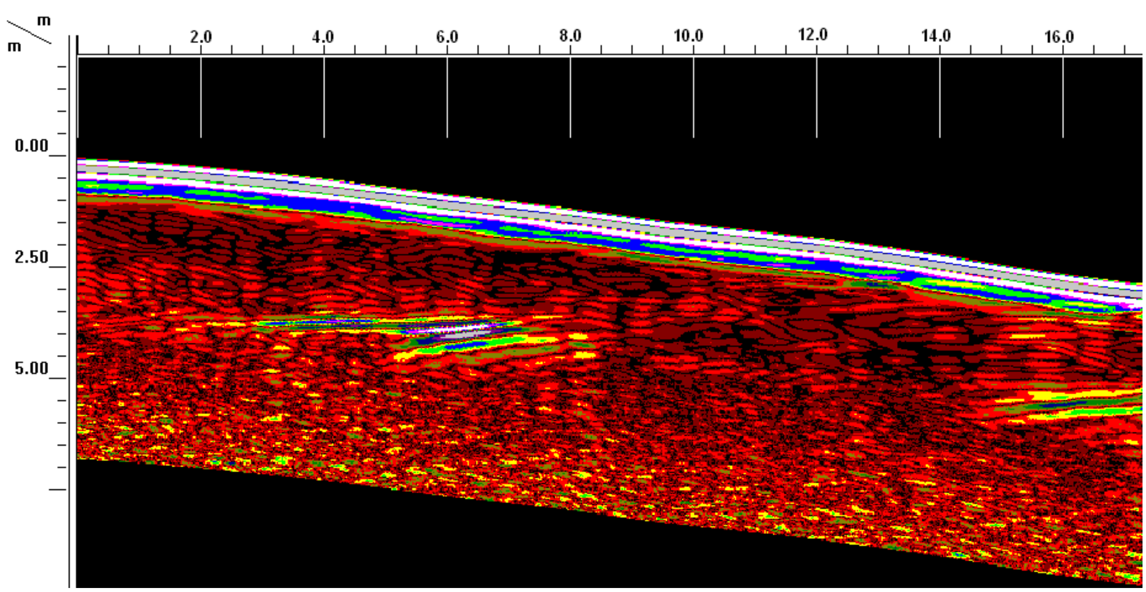

Figure 3. Radar record collected with the 200 MHz antenna in an area of Bluepoint soil

Some internal features and bedding planes within the dune are evident in Figure 3. In sands, abrupt and contrasting differences in density, grain size, and moisture content will produce high amplitude reflections (Schenk et al., 1993). In general, high-amplitude reflections from the interior of aeolian dunes are believed to be caused principally by changes in moisture contents (Schnek et al., 1993; Bristow et al., 1996; Bano et al., 1999).

The type location for the Bluepoint series is located in close proximity to the GPR study site. The official series description describes C horizons that consist of stratified loamy fine sand, fine sand, and fine sandy loam deposits. Low-amplitude planar reflectors are ubiquitous in Figure 3. These reflectors are assumed to represent bedding planes in the aeolian deposits. The general absence of high-amplitude reflectors suggests layers that have relatively similar densities, grain sizes, and moisture contents. Some layers show lateral variations in signal amplitudes which suggest changes in moisture, clay content, grain size distribution and/or density.

In this area of Bluepoint soil, the maximum depth of penetration ranges from about 4.4 to 5.4 m High levels of background noise plague the lower part of the radar record and no meaningful information was obtained below a depth of 5.4-m. Compared to other dune sites profiled with GPR in the United States, rates of signal attenuation, which limit penetration depths, are most severe in the Bluepoint soil. Carbonates are believed responsible for the relatively high rates of signal attenuation and restricted penetration depths. A soil sample was collected and will be taken to the USDA-National Soil Survey Laboratory, Lincoln, NE, for analysis. Results of laboratory analysis will help assess the chemical, physical, and mineralogical parameters that affect the performance of GPR in sandy soils.

Petrogypsic Horizon:

A petrogypsic horizon (Bym horizon) is an illuvial horizon that is cemented or indurated by secondary gypsum and is ≥ 10 cm thick (Soil Survey Staff, 2003). A petrogypsic horizon forms a continuous layer that may be fractured provided that the lateral distance between fractures is greater than 10 cm. Because of limited precipitation and shallow soil-moisture penetration, salts of limited solubilities such as calcite and gypsum, precipitate to form genetic horizons at shallow depths (Nettleton and Peterson, 1983). Petrogypsic horizons are cemented layers with more than 60 percent crystalline gypsum. Petrogypsic horizons exclude roots and dry fragments do not slake in water. When dry, petrogypsic horizons are difficult to chip with a spade.

<u>Study site:</u>

The study site (UTM: 11S, 730679 Northing and, 4029964 Easting) is located in the Lake Mead National Recreation Area about 2 miles north northwest of Stewarts Point. Radar surveys were conducted in an area of Drygyp-Bluegyp association. The very shallow to petrogypsic horizon, somewhat excessively drained Drygyp soil forms in alluvium derived from gypsum rock on fan remnants. The depth to petrogypsic horizon ranges 10 to 25 cm. In the typifying pedon, massive 2Bym horizons occur between depths of from 18 to 165 cm. Drygyp soil is a member of the loamy, gypsic, hyperthermic, shallow Typic Petrogypsids family. Figure 4 is a photograph of an exposure of Drygyp soil.

<u>Field Procedures:</u>

A 10-m traverse line was established across a representative area of the Drygyp soil. Survey flags were inserted in the ground at intervals of 2-m and served as reference points. The survey was completed with a 200 MHz antenna.

Based on the measured depth to a buried metallic reflector (46 cm), the velocity of propagation through the upper part of the Drygyp profile was an estimated 0.178 m/ns. The E_r was 2.8. Using a scanning time of 54 ns, a velocity of 0.178 m/ns, and equation [1], the maximum depth of penetration through the Drygyp soil is about 4.8 m.

Figure 4. A petrogypsic layer is exposed in an exposure of Drygyp soil.

Results:

Figure 5 is the radar record that was obtained along the traverse line. In Figure 5, multiple hyperbolic reflections from a buried metallic object can be seen below “A”. The upper boundary of the petrogypsic horizon has been interpreted and identified by a green line on the radar record. In Figure 5, the interpreted depth to the petrogypsic horizon ranges from 36 to 65 cm. As seen in Figure 5, interpretations are restricted to the upper 2.2 meters of the soil profile. Below this depth, the radar energy was significantly attenuated and no clear reflections were detectable. Data processing was required to clarify interpretations. Even after processing, the lower part of the radar record remains plagued by resonance (parallel lines of low frequency noise).

The petrogypsic horizon appears to consist of a number of segmented and highly contorted layers that are variable in expression. High amplitude reflections (colored whit, blue, or pink) are believed to represent indurated gypsic materials or fragments, low amplitude reflections (colored red or black) signify more homogeneous materials and the absence of interfaces. The type location for the Drygyp series is located in close proximity to this study site. The official series description describes massive 2Bym horizons, but does not describe the structure that is apparent on the GPR record (see Figure 5).

Not shown in Figure 5 is the portion of the radar record that crossed a disturbed area of soil. Over the disturbed ground, the high amplitude and convoluted reflectors that characterize the petrogypsic horizon were absence. Ground-penetrating radar may be used in areas of Drygyp and similar soils to assess the development of petrogypsic horizons and the affects of soil disturbances.

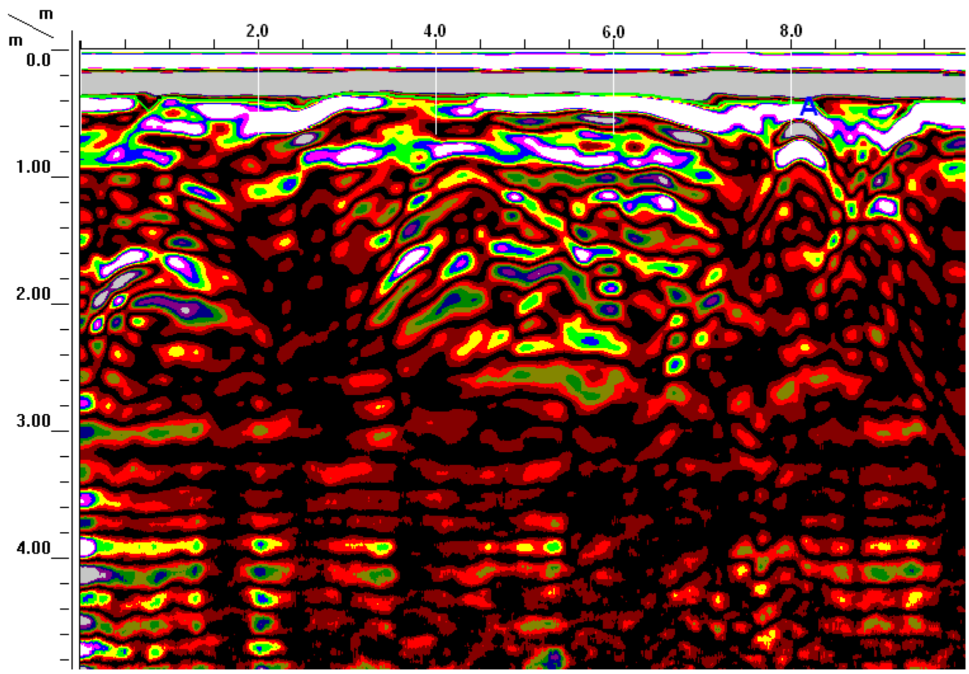

Figure 5. A processed radar record from an area on Drygyp soil showing the interpreted depth to petrogypsic horizon (thin, green colored line near the top of the radar record).

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