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

Subject: -- Geophysical Assistance **Date:** 27 September 2004

To: Jerry Daigle
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Purpose:
The effectiveness of GPR is generally considered low in soils that have high clay contents. Fine-textured soils that are dominated by low activity clays are known to be suited to GPR soil investigations. In the fall of 1983 a SIR-8 radar unit was used to investigate the depth to and continuity of petroferric layers in Claiborne Parish, Louisiana. The purpose of this investigation was to revisit areas of fine-textured soils with petroferric contacts and ironstone layers in northwestern Louisiana and to examine the effectiveness of modern ground-penetrating radar (GPR) system and signal processing to provide information on these subsurface features.

Participants:
Jerry Daigle, State Soil Scientist, USDA-NRCS, Alexandria, LA
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA

Activities:
All activities were completed on September 20, 2004. .

Results:

1. In the areas of highly weathered and fine textured Darley soil, GPR can be used to detect and characterize petroferric contacts and ironstone layers.

2. The petroferric contact and ironstone layers were detected with both a 200 and 400 MHz antenna. The penetration depth of each antenna was adequate for soil investigations and classification. The 400 MHz antenna provides greater resolution and appears to be more effective for the assessment of fractures and the lateral continuity of ironstone layers.

3. Advanced signal processing is required to improve the quality of the radar imagery. The use of advanced signal processing contributes to the achievement of successful GPR data interpretations.

It was my pleasure to work again in Louisiana. I greatly appreciate your help and that of Wayne Kilpatrick (retired soil scientist) in locating suitable sites.

With kind regards,

James A. Doolittle
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cc:

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Petroferric Contact:
Soil Taxonomy describes a petroferric contact as "the boundary between soil and a continuous layer of indurated material in which iron is an important cement and organic matter is either absent or presence only in traces" (Soil Survey Staff, 2003). The term "*petroferric*" comes from the Greek word "*petra*" meaning rock, and the Latin word "*ferrum*" meaning iron (Soil Survey Staff, 1999).

To be a petroferric contact, the ironstone layer must be continuous and limit root penetration. It can be fractured provided that the lateral distance between fractures is ≥ 10 cm. Petroferric contacts are generally horizontal. Ironstone layers are typically thin (a few centimeters) and contain high amounts of iron (≥30 percent Fe_2O_3) (Miller, 1983).

Alternating oxidizing and reducing conditions cause the segregation and concentration of Fe_2O_3 in soils. Under these conditions, the presence of firm, brittle, red mottles marks the beginnings of a *skeletal oxide matrix* (Miller, 1983). With increased segregation and concentration these materials become indurated and form ironstone. It is believed that ironstone bodies are common in road cuts (see Figure 1) and other similar places where exposure to sunlight and prolong oxidizing conditions are more likely to occur (Miller, 1983).

Figure 1. A road embankment in Webster Parish with an outcropping ironstone layer.

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

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

discussed by Daniels (2004). The 200 and 400 MHz antennas were used in 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 normalization, horizontal stacking, background removal, migration, and range gain adjustments.

Study Sites:
Two study sites were surveyed with GPR. Site 1 (32.64722° N latitude, 093.22488° W longitude) was in a borrow area located near the intersection of Highway 79 and 518, northeast of Minden in Webster Parish (see Figure 2). The Site 2 (32.65164° N latitude, 093.26597° W longitude) was on a road embankment located along Highway 534, north of Minden in Webster Parish (see Figure 1). Site 1 is located in an area that was mapped as Darley loamy fine sand, 5 to 12 percent slopes (Kilpatrick, 1998). Site 2 is located in an area that was mapped as Darley gravelly loamy fine sand, 1 to 5 percent slopes (Kilpatrick, 1998). The well drained Darley soil forms in iron-rich, clayey sediments on the uplands of the Western Coastal Plains. Darley soil contains layers of fractured ironstone. Darley is a member of the fine, kaolinitic, thermic Typic Hapludults family.

Figure 2. Thin bands of ironstone form a prominent reddish layer between depths of 40 and 90 cm in this exposure

In Darley soils, the depth to the ironstone layers ranges from 25 to 100 cm. Typically, the Bt/Bsm horizon consists of alternating layers of ironstone and sandy clay or clay. Ironstone fragments and ironstone layers, make up from 20 to 60 percent of the volume of the Bt/Bsm horizon. The ironstone layers are fractured and range in thickness from about 1 to 30 cm. The lateral distance between fractures ranges from about 5 to 50 cm and averages 10 to 20 cm. Typically, the ironstone layers are continuous for more than a meter, but in some pedons they are intermittent and extend only a few tens of centimeters horizontally. The average content of clay in the textural control section ranges from 40 to 60 percent.

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., ironstone 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 (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 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). A nanosecond is one billionth of a second. The amount and physical state (temperature dependent) of water have the greatest effect on the E_r of earthen materials.

Based on the measured depth to a buried (48 cm) metallic reflector, the velocity of propagation through the upper part of the soil profile was an estimated 0.1048 m/ns. The E_r was 8.1. With a scanning time of 60 ns and a velocity of 0.1048 m/ns, equation [1] estimates that the maximum depth of penetration is about 3.1 m with the 200 MHz. Soils are dispersive lossy mediums and, as a consequence, the relative dielectric permittivity and propagation velocity will vary slightly with center frequency and antenna.

Results:
Figures 3 and 4 are radar records that were obtained in the same area with the 400 and 200 MHz antennas, respectively. The lengths of the radar traverses depicted in figures 3 and 4 are about 11- and 11.5- meters, respectively. These traverses were paced and not measured (separate survey for each antenna). As a consequence, the end points were not the same and the radar imagery is slightly mismatched in each figure. However, similar features are evident in each radar record.

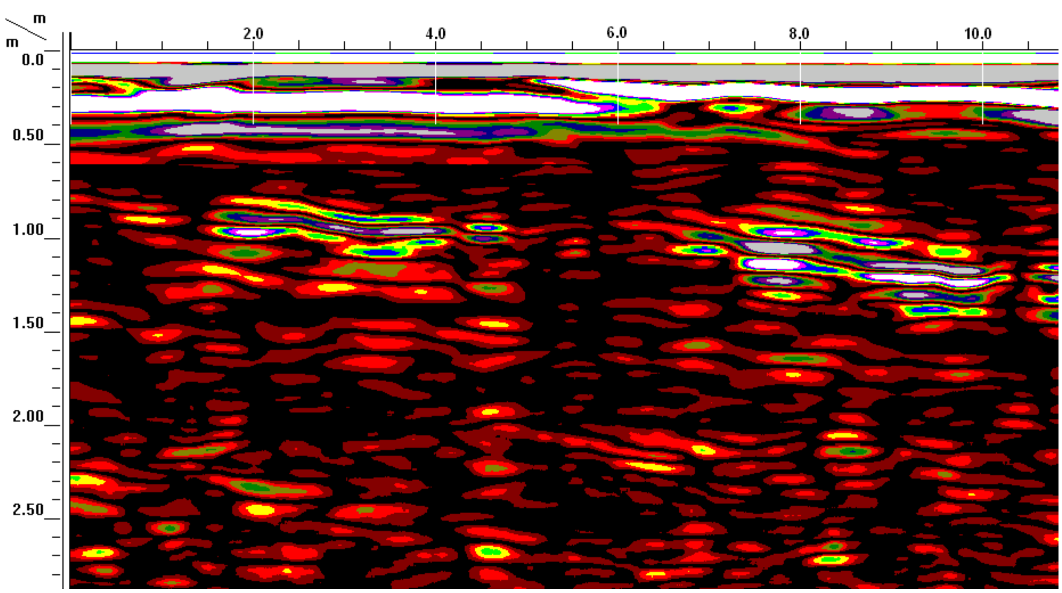

Figure 3. A radar record collected with a 400 MHz antenna from an area of Darley soil.

Processing was needed to improve the interpretative quality of the initial radar imagery. Advanced signal processing contributed greatly to the interpretation of data collected with each antenna. The penetration depth of each antenna was adequate for soil investigations and classification. Both antennas provided adequate penetration depths. Petroferric contacts and ironstone layers were successful imaged with both antennas. These features appear as planar, high amplitude reflections on radar records.

In Figure 3, the 400 MHz antenna detects multiple bands of ironstone. One band extends laterally from 0 to 9 m at a depth of 30 to 50 cm. This interface varies laterally in amplitude. A second, shallow ironstone layer extends across the upper part of the radar record from about the 5 to 11.5 m marks at a depth of 30 to 40 cm. A less contrasting (lower signal amplitude) ironstone band extends laterally from 0 to 5 m at a depth of about 60 cm. A series of fairly continuous bands, with noticeable fractures and discontinuities, extends laterally across the radar record between depths of 70 and 130 cm. Additional layers of ironstone can be discerned between depths of 140 and 290 cm.

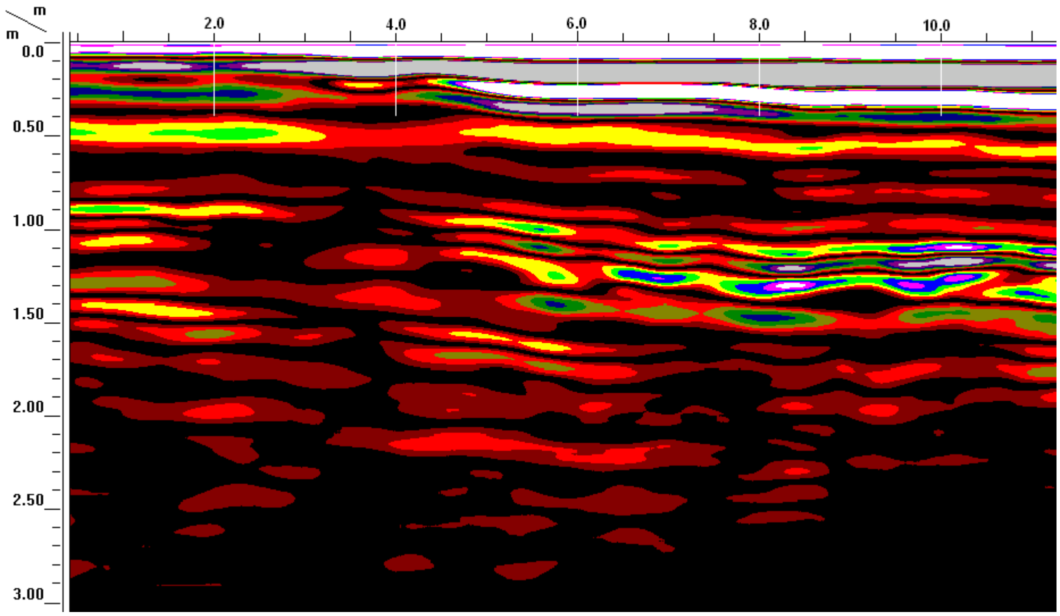

Figure 4. A radar record collected with a 200 MHz antenna from an area of Darley soil.

Similar bands of ironstone are depicted on the radar record collected with the 200 MHz antenna (see Figure 4). The wavelength of the 200 MHz antenna is longer than that of the 400 MHz antenna. As a consequence, the resolution of subsurface features is less with the 200 MHz than with the 400 MHz antenna. In this area of Darley soils, with an averaged velocity of propagation of 0.1048 m/ns, the wavelengths are about 50 and 26 cm for the 200 and 400 MHz antennas, respectively. It is generally assumed that resolution is about one-half of these wavelengths (25 and 13 cm for the 200 and 400 MHz antennas, respectively). Because of differences in resolution, the ironstone layers appear more continuous and are easier to chart in the radar record obtained with the 200 MHz antenna (Figure 4) than with the 400 MHz antenna.

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