United States Department of Agriculture

NRCS

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SUBJECT: SOI – Geophysical Assistance

July 10, 2012

TO: Kevin D. Norton
State Conservationist
NRCS, Alexandria, Louisiana

File Code: 330-20-7

Purpose:
An objective of this study was to use ground-penetrating radar (GPR) to assess the presence and continuity of ironstone layers in areas mapped as Darley soils in Union and Lincoln Parishes. In addition, exposure was provided to participants on the use of GPR and electromagnetic induction (EMI).

Participants:
Joel Bolin, Soil Scientist, USDA-NRCS, Ruston, Louisiana
Marc Bordelon, Soil Survey Project Leader, USDA-NRCS, Ringgold, Louisiana
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, Pennsylvania
Michael Lindsey, Assistant State Soil Scientist, USDA-NRCS, Alexandria, Louisiana
Richard Vaught, MLRA Soil Survey Project Leader, USDA-NRCS, Pine Bluff, Arkansas

Activities:
Field studies were completed during the period of April 10-12, 2012.

Summary:
1. Presently, the recently revised Major Land Resource Office 9 has a ground-penetrating radar unit and operator located in Pine Bluff, Arkansas. This field visit provided an opportunity for this radar operator to work directly with Jim Doolittle and to compare radar control settings, processing procedures and interpretations while conducting a study of ironstone occurrence and distribution in areas of Darley soils mapped in northern Louisiana.

2. In areas of Darley soils, GPR provided satisfactory penetration depths and resolution of subsurface features, and helped characterize ironstone layers. Antennas with center frequency of either 200 or 400 MHz can be used effectively in soil investigations in areas of Darley soils. In general, multiple ironstone layers were observed in most areas of Darley soils. These layers appear highly fractured and discontinuous with spheroid features intermixed.

3. Radar records from eight traverse lines were analyzed on the basis of the presence and expression of ironstone and ironstone layers. Based on 60,828 measurements recorded along 10 radar transects, 78% had well expressed ironstone layers, while 22% had no or weakly expressed ironstone layers and fragments.

4. In a training exercise, participants were provided the opportunity to operate an EM38 meter in an area of Bienville soils. Areas of higher EC_a were associated with shallower depths to a loamy Bt horizon and higher soil moisture contents.

It was the pleasure of Jim Doolittle and the National Soil Survey Center to work with and be of assistance to your staff in this study.

JONATHAN W. HEMPEL
Director
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Technical Report on the use of Ground-Penetrating Radar (GPR) to assess the presence, depth, and continuity of ironstone layers in Western Coastal Plains soils of Louisiana on April 10-12 2012

Jim Doolittle

Background:
Darley (fine, kaolinitic, thermic Typic Hapludults) is a benchmark soil series that contains fractured layers of ironstone and ironstone fragments. Ironstone is the *in situ* concentration of iron oxides that is at least weakly cemented (Soil Science Society of America, 1996). Typically, ironstone forms a roughly horizontal, continuous layer that is fractured at distances greater than 10 cm (see Figure 1). This layer is both root and water restricting. In this study, GPR was used to assess the presence and expression of ironstone layers in areas that were mapped as consociations and complexes of Darley soils in Lincoln and Union Parishes. Results from this investigation are expected to influence series concepts and affect map unit interpretations.

Figure 1. Mike Lindsey and Richard Vaught inspect ironstone layers along a wall of an excavation.

Equipment:
The radar unit is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (here after referred to as the SIR-3000), manufactured by Geophysical Survey Systems, Inc. (GSSI; Salem, NH).[1] The SIR-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-3000 weighs about 4.1 kg (9 lbs) and is backpack portable. With an antenna, the SIR-3000 requires two people to operate. Jol (2009) and Daniels (2004) discuss the use and operation of GPR. The 400 and 200 MHz antennas were used in this study.

The RADAN for Windows (version 6.6) software program (GSSI; here after referred to as RADAN) was used to process the radar records shown in this report.[1] Processing included: header editing, setting the

[1] Trade names are used for specific references and do not constitute endorsement.

initial pulse to time zero, color table and transformation selection, range gain adjustments, signal stacking, migration, and high-pass filtration (refer to Jol (2009) and Daniels (2004) for discussions of these techniques).

Figure 2. Richard Vaught and Joel Bolin conduct a GPR traverse along a measured and flagged traverse line.

Using the *Interactive 3D Module* of the RADAN, depths to ironstone layers were automatically and reasonably accurately picked, and outputted to a worksheet (X, Y, Z format; including latitude, longitude, depths to ironstone layer, and other useful data).

Recent technical developments allow the integration of GPR and global positioning system (GPS) data. During this visit, four different Garmin backpack units were tested. Batteries were recharged, but these relatively old and outdated units failed to operate. As a consequence, the synergy of GPR and GPS was not possible. All GPR traverse lines were measured and flagged at 3 m intervals (Figure 2). Although each lines start and end points were located with a handheld GPS, the radar data were not georeferenced and therefore not importable into geographic informational systems (GIS). It is imperative that Rick Vaught have access to a working GPS unit that can be successfully used with both his SIR-3000 GPR and EM38 soil conductivity meter.

Field Methods:
After initial field calibration trials, traverses were conducted using the SIR-3000 with a 200 MHz antenna. Traverses were completed by towing an antenna by hand along a traverse line. Along each line survey flags were inserted in the ground at intervals of about 3 meters. All radar records were collected and interpreted by Richard Vaught.

Calibration:
Ground-penetrating radar is a time scaled system. The system measures the time that it takes electromagnetic energy to travel from an antenna to an interface (e.g., soil horizon, 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 (from 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 (from Daniels, 2004):

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

where C is the velocity of propagation in a vacuum (0.3 m/ns). Typically, velocity is expressed in meters per nanosecond (ns). In soils, the amount and physical state (temperature dependent) of water have the greatest effect on the E_r and v.

As different antennas were used, separate calibrations were performed for each antenna. Both antennas were calibrated based on the measured depths to a known, buried reflector. Based on the two-way travel time, depth to a shallowly (50 cm) buried, metallic (30 cm diameter) reflector, and equations [1] and [2], the E_r for the upper part of Darley soil was estimated to be 6.22 and 6.18 with the 200 and 400 MHz antennas, respectively. Using equation [2], these estimated dielectric permittivities resulted in v of 0.1195 and 0.1199 m/ns for the 200 and 400 MHz antennas, respectively.

Study Sites:
The study sites are located in areas mapped as consociations and complexes of Darley soils in Union and Lincoln Parishes. The well drained, highly weathered and leached Darley soils formed on uplands of the Western Coastal Plains. Darley soils formed in iron-rich, clayey, Tertiary sediments. Darley soils formed in the Cook Mountain Formation of the Claiborne Group. The weathering of sideritic and glauconitic clays results in the accumulation of iron oxide and the formation of ironstone layers in Darley soils. In the official series description for Darley series the ironstone layers are described as:

> *"continuous for several feet; but in some pedons they are intermittent and extend only a few feet horizontally. In some pedons, the* [ironstone] *layers are parts of the large spherical configurations that are separated from one another by vertical flows of red clay, sandy clay or clay loam."*

Darley is a member of the fine, kaolinitic, thermic Typic Hapludults taxonomic family. Darley soils have low base status throughout. Although Darley soils have relatively high clay content, their low base status and dominance of low activity clays makes them suited to GPR.

The location and description of the study sites follows.

Site 1 (32.58595 N latitude, 92.68494 E longitude) is located in a pasture near Simmons Road in Lincoln Parrish. At this site, two transects were laid out and crossed areas of Darley gravelly fine sandy loam on 5 to 12% slopes (DRE) and Mahan fine sandy loam on 1 to 5% slopes (MhC). The deep, well drained Mahan soil is a member of the fine, kaolinitic, thermic Typic Hapludults taxonomic family. Mahan soils contain ironstone fragments. In addition, Mahan soils can contain small pockets and horizontal seams of whitish clay (kaolin), and thin to thick layers of weakly cemented sandstone. The radar files for this site are File 45 and 46.

Site 2 (32.58760 N latitude, 92.68341 E longitude) is located near Site 1 in an area above a cut bank in Lincoln Parrish. The transect crossed an area of Darley gravelly fine sandy loam on 5 to 12% slopes (DRE). The radar file for this site is File 47.

Site 3 (32.60589 N latitude, 92.64758 E longitude) is located along a trail in a wooded area near the intersection of Highway 63 and Rabb Road in Union Parrish. The transect crossed an area of Darley gravelly fine sandy loam on 1 to 5% slopes (DrC). The radar file for this site is File 1.

Site 4 (32.74283 N latitude, 92.72088 E longitude) is located in a pasture about 750 m south-southwest of Hico in Lincoln Parrish. The transect crossed areas of Darley gravelly fine sandy loam on 1 to 5% slopes (DrC) and Darley-Sacul association on 12 to 30 % slopes (DRF). . The very deep, moderately well drained Sacul soil is a member of the fine, mixed, active, thermic Aquic Hapludults taxonomic family. Sacul soils contain fragments of ironstone and quartz. This soil can have a paralithic contact, composed of soft, platy, clayey shale, at depths greater than 1.82 m. The radar file for this site is File 2.

Site 5 (32.74533 N latitude, 92.72681 E longitude) is located in a wooded area off of Herman Road in Union Parrish. The transect crossed an area mapped as Darley gravelly fine sandy loam on 1 to 5% slopes (DrC). The radar file for this site is File 3.

Site 6 (32.76028 N latitude, 92.39758 E longitude) is located in a wooded area about 1.67 km south-southeast of Farmersville in the Eagle Point Subdivision, Union Parrish. The transect crossed an area of Darley gravelly fine sandy loam on 5 to 12% slopes (DM). The radar file for this site is File 5.

Site 7 (32.75831 N latitude, 92.39547 E longitude) is located in an open area about 1.06 km south-southeast of Farmersville in the Eagle Point Subdivision, Union Parrish. Two transects were laid out and crossed an area of Mahan fine sandy loam on 1 to 5% slopes (Ma). The radar files for this site are File 6 and 7.

Site 8 (32.82481 N latitude, 92.30911 E longitude) is located in a wooded area about 1.67 km northeast of Farmersville, Union Parrish. The transect crossed an area of Darley gravelly fine sandy loam on 5 to 12% slopes (DM). The radar file for this site is File 8.

Interpretations:
All radar records were identically processed using the RADAN software package. Processing consisted of surface position adjustment (adjust time-zero), signal stacking, 2D constant velocity migration, distance normalization and FIR filtration. Signal stacking and FIR filtration are used to remove high (appears as snow) and low (appears as broad parallel bands) frequency noise, respectively. Migration is used to remove diffraction and to correctly position dipping reflecting layers. Distance normalization is used to establish a constant horizontal scale between the markers (spaced at 3 m intervals and representing flagged position markers along the transect line).

Figure 3 is a radar record from an area of Mahan fine sandy loam on 1 to 5% slopes (Ma) in Union Parrish. For display purposes, the gain setting has been set to a relatively low value of 2. Two horizontal reflectors are evident on this radar record: an upper reflector at a depth of about 30 to 54 cm and a deeper, less well-expressed and more discontinuous reflector at a depth of about 100 to 132 cm. The upper and lower reflectors represent the argillic horizon and a weakly indurated layer of iron-oxide accumulation, respectively. On examination in the field, the weakly indurated layer of iron –oxide was not considered ironstone. Although some harden fragments of ironstone were observed, boundaries were diffuse and gradual and most of the materials were weakly indurated. As all gradations in expression are possible, from very weakly to very strongly indurated, field identification and classification of ironstone layers are problematic in many instances. This is also true with GPR, Figure 4 is the same radar record as shown in Figure 3, with the display gain setting placed to 4 rather than 2 (as done in Figure 3). With the additional gain, all layers appear more strongly expressed. As a consequence, the inferred degree of induration

could be assumed to be greater in the underlying layer. Field experience is needed to achieve the most suitable radar settings, record, and interpretations.

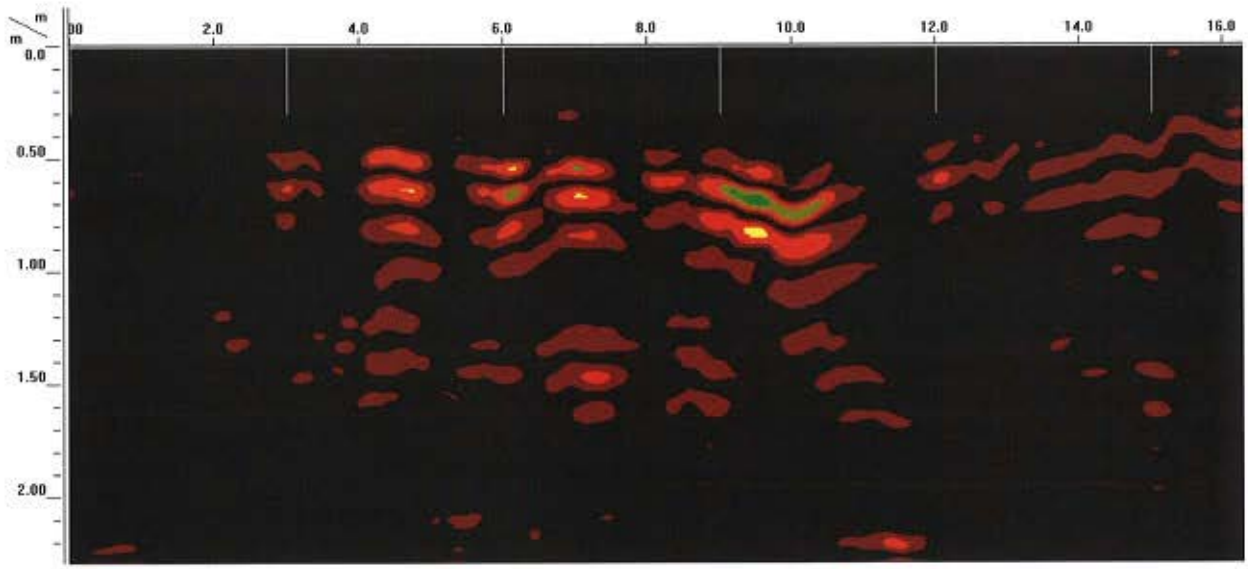

Figure 3. No or weakly expressed ironstone layers are evident on this radar record that was collected with a 200 MHz antenna. The upper, linear, segmented bands of varying signal amplitudes represent the argillic horizon. The lower, linear, segmented bands of weakly expressed amplitudes represent a very weakly expressed layer of iron-oxide accumulations.

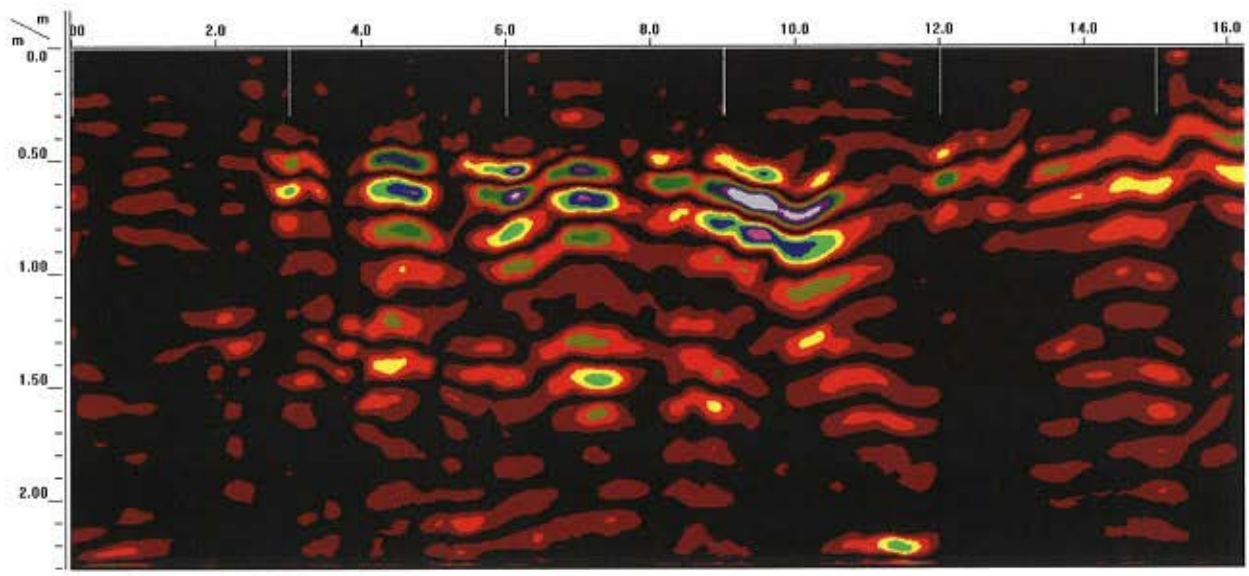

Figure 4. This is the same radar record that was shown in Figure 1 with the display gain setting set to 4 rather than 2. Here, the lower layer of iron-oxide accumulations is more strongly expressed and could be inferred to contain more indurated layer of ironstone. Just as with proper field observations, appropriate radar settings and interpretations must be based on experience and time spent in the field observing ironstone layers

Figure 5 is a portion of a radar record that was collected in an area Darley gravelly fine sandy loam on 1 to 5% slopes (DrC) in Union County. Well expressed layers of ironstone are evident on this radar record.

The display gain setting has been set to 2 in this radar record. This image of well-expressed ironstone layers should be compared with the area of more weakly-expressed and indurated iron-oxide accumulations shown in Figure 3. On the radar record shown in Figure 5, the ironstone layers appear continuous for several centimeters to meters, with wavy to broken topography, and what appears to be some spherical configurations.

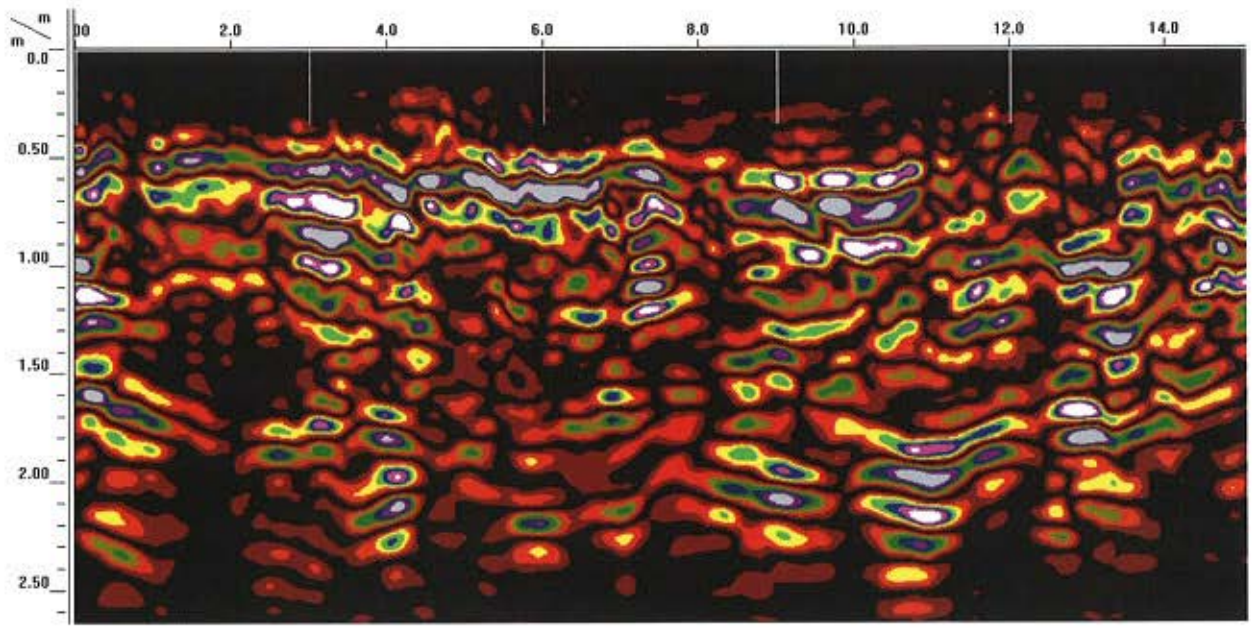

Figure 5. Strongly expressed ironstone layers are evident on this radar record that was collected with a 200 MHz antenna. While many layers can be traced laterally for some distances, all are segmented by fracture traces.

Figure 6 is a portion of a radar record from an area Darley gravelly fine sandy loam on 1 to 5% slopes (DrC) in Union County. The ironstone layers appear well-expressed, segmented and incline. As ironstone layers are understood to be the result of the translocation and deposit of iron-oxides in response to repeated wetting and drying cycles, ironstone layers should generally be parallel with the soil surface, not steeply inclined as shown in Figure 6. The apparent inclination in Figure 6 is an artifact from the vertical exaggeration of radar record and the lack of topographic control (regardless of slope gradient the surface is always horizontal on raw radar records). Elevation data were collected at each distance mark along the radar record shown in Figure 6. Using RADAN and a process known as *surface normalization*, at each distance mark appearing on the radar record, an elevation was assigned to the marker file and the vertical scale at that point was accordingly adjusted to changes in topography. Surface normalization helps to improve the interpretative quality of radar records and the association of subsurface reflectors with landscape components. The result of *surface normalization* is shown in Figure 7. The steeply inclined areas of ironstone shown in Figure 6 are less steeply inclined and more parallel with the soil surface in this surface normalized image. Ironstone layers are best expressed on higher-lying, convex surfaces and are generally absent on lower-lying, plane or concave surfaces.

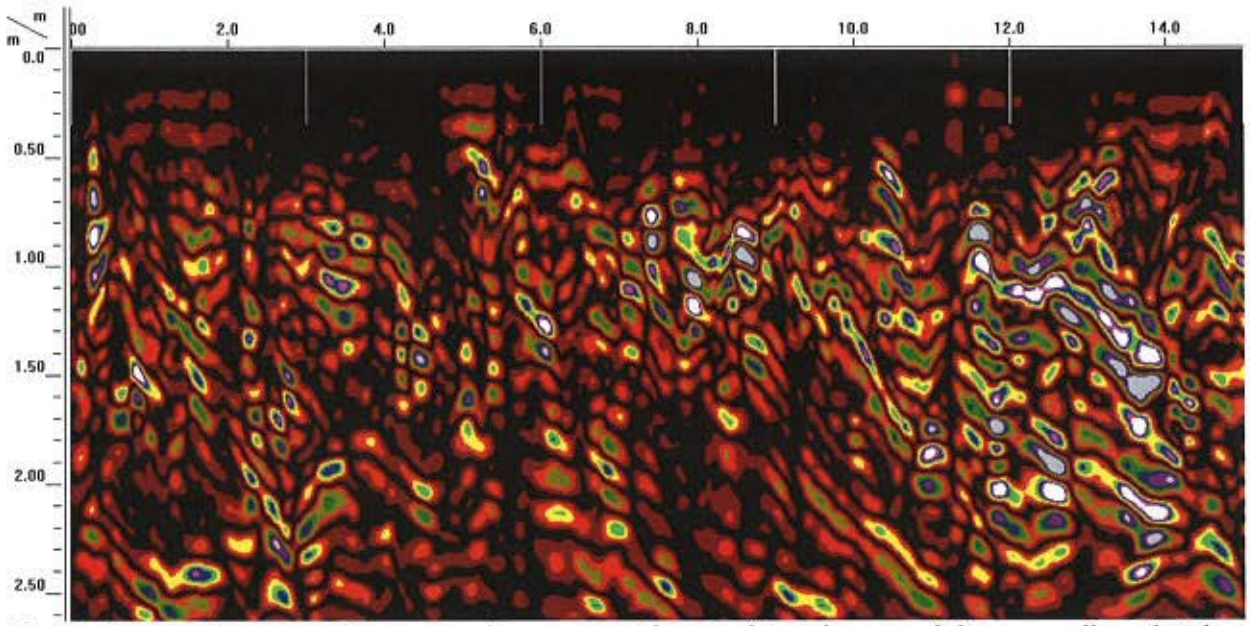

Figure 6. Strongly expressed ironstone layers are evident on this radar record that was collected with a 200 MHz antenna. The ironstone layers appear highly segmented and inclined.

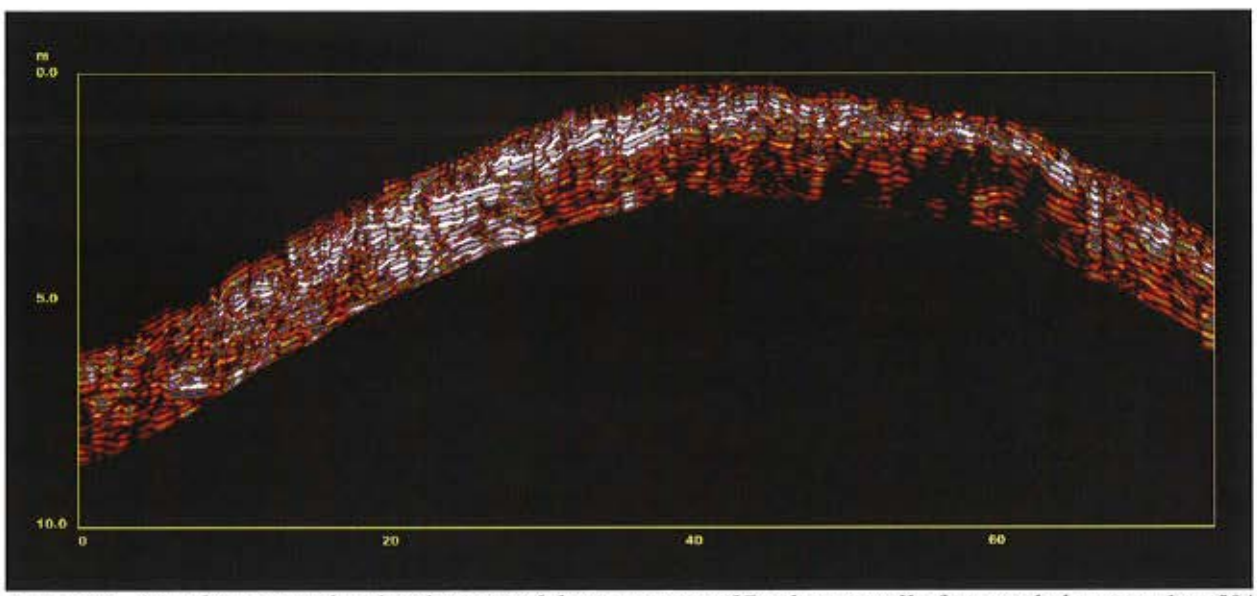

Figure 7. A surface normalized radar record from an area of Darley gravelly fine sandy loam on 1 to 5% slopes. The steeply inclined areas of ironstone shown in Figure 6 are less steeply inclined and more parallel with the soil surface in this surface normalized image.

Analysis of the Presence or Absence of Ironstone:

Radar records were analyzed on the basis of the presence and expression of ironstone and ironstone layers. Each scan of the radar record were interpreted as either 1) not having or having very weakly expressed ironstone layers and fragment, and 2) having well expressed ironstone layers. Based on 60828 measurements recorded on 10 radar transects, 78% had well expressed ironstone layers while 22% had no or weakly expressed ironstone layers and fragments. Table 1 summarizes the GPR transect data.

Table 1. Frequency distribution of the ironstone along 10 GPR transects lines conducted in Lincoln and Union Parishes, Louisiana.

Site	1	1	2	3	4	5	6	7	7	8
None or Weakly Expressed	0.10	0.10	0.00	0.00	0.55	0.00	0.00	0.40	0.56	0.59
Well Expressed	0.90	0.90	1.00	1.00	0.45	1.00	1.00	0.61	0.44	0.41

Electromagnetic induction (EMI):
As part of a training exercise an EMI survey was conducted with an EM38 meter. The apparent conductivity (EC_a) data were later processed in the office and a two-dimensional plot was prepared. Lacking a working GPS receiver that could be used with the EM38 meter, the survey was conducted in the station to station mode with survey flags placed in the ground to form a survey grid.

Study Area:
A 32 by 40 meter grid was established over an area of Bienville loamy sand on 1 to 3 % slopes (Be) in Union Parrish. The study area (32.8260 N latitude, 92.3054 W. longitude) is located in an open field used for hayland. The very deep, somewhat excessively drained, Bienville soils formed in sandy coastal plain sediments. Bienville soils are members of the siliceous, thermic Psammentic Paleudalfs family.

Equipment:
The EMI meter used in this study is the EM38 manufactured by Geonics Limited (Mississauga, Ontario).[2] This meter is portable and requires only one person to operate. McNeill (1986) has described the meter's principles of operation. The EM38 meter operates at a frequency of 14,600 Hz. The EM38 meter has theoretical observation depths of about 0.75 and 1.5 m in the horizontal and vertical dipole orientations, respectively (McNeill, 1986). Values of apparent conductivity are expressed in milliSiemens per meter (mS/m).

To help summarize the results of the EMI survey, the SURFER for Windows (version 10.0) software (Golden Software, Inc., Golden, CO) was used to construct the two-dimensional simulation shown in this report.[2] A grid file was created using kriging methods with an octant search.

Survey Procedures:
A 40 by 32 meter grid was constructed across the survey area. Flags were placed in the ground at intervals of 4 (x axis) and 8 (y axis) meters and served as reference or measurement points. A pedestrian survey was conducted with the EM38 meter operated in the station-to-station mode. The meter was held in the vertical dipole orientation. The pedestrian survey was completed by walking with the EM38 meter to each flagged reference point (56 grid intersect) on the grid, placing the meter on the ground, and taking a measurement.

Results:
Based on 56 measurements collected with the EM38 meter meter, EC_a averaged 11.48 mS/m and ranged from about -1 to 25 mS/m within the upper 150 cm of the soil profiles. One-half of the EC_a measurements were between 6.75 and 15 mS/m. Variations in ECa are associated principally with differences in the depth to the loamy Bt horizon and variations in soil moisture content.

[2] Trade names are used for specific references and do not constitute endorsement.

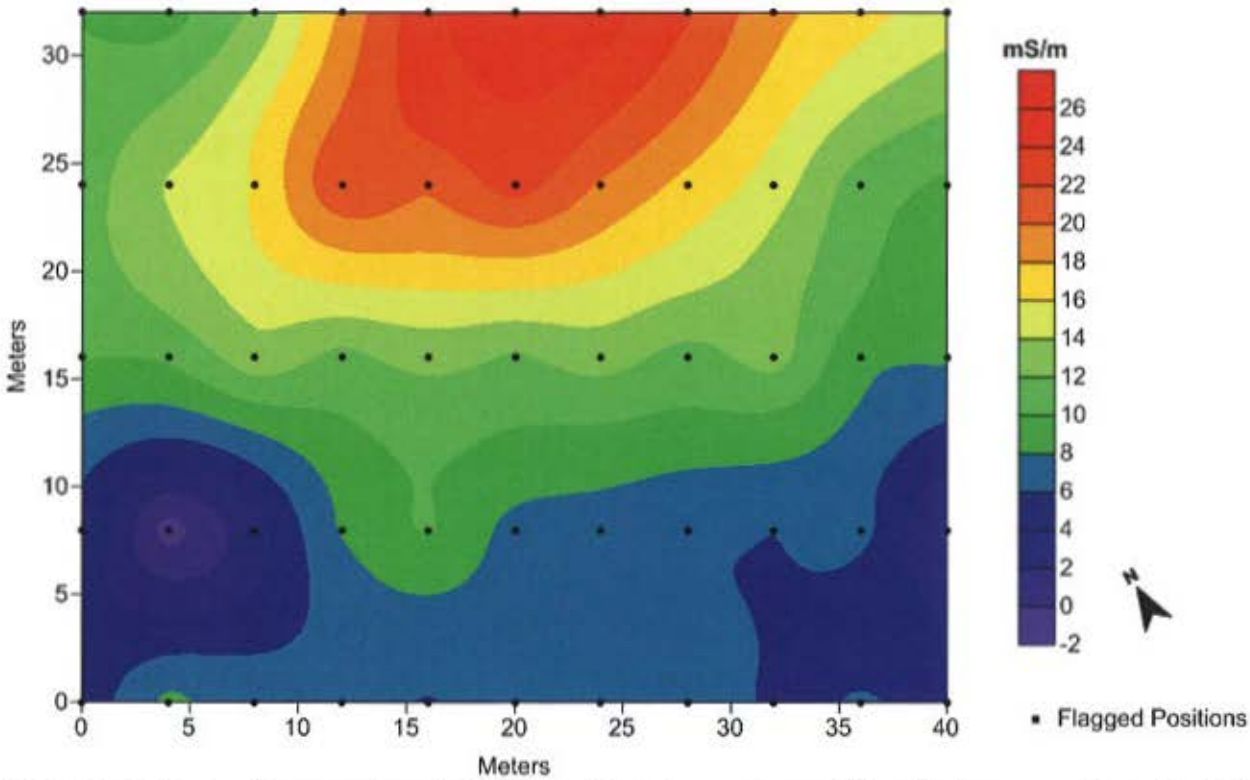

Figure 8. This map of apparent conductivity was taken from an area of Bienville loamy sands on 1 to 3 % slopes.

Figure 8 is a plot of the EC_a data collected with the EM38 meter. Areas of higher EC_a are associated with shallower depths to a loamy Bt horizon and higher soil moisture contents. An anomalous value (-1 mS/m) at the 4 (x) and 8 (y) meter grid intersect is believed to be associated with a metallic artifact that is buried or on the surface. The artifact is assumed to be related to farming practices.

References:

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