United States Department of Agriculture

Natural Resources Conservation Service

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Subject: Soils – SIR-3000 and RADAN for Windows training **Date:** 11 February 2009

To: Carlos Suarez
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Purpose:
Training was provided on the operation of the SIR-3000 ground-penetrating radar (GPR) unit and basic procedures that should be used to process radar data through the RADAN for Windows software program. In addition, field procedures used to construct detailed GPR grids were demonstrated and discussed. Processing procedures used for the development of three-dimensional (3D) pseudo images of grid sites were also demonstrated. The use of the *interactive interpretation module,* RADAN for Windows, to quickly pick and record depths to contrasting soil materials was reviewed.

Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
Martin Figueroa, Soil Scientist, USDA-NRCS, Quincy, FL
Victoria Gardner, Soil Scientist, USDA-NRCS, Quincy, FL
Doug Lewis, Resource Soil Scientist, USDA-NRCS, Sebring FL
Milton Martinez-Rodriguez, MLRA Project Leader, USDA-NRCS, Quincy, FL
Willie Nelson Jr., Soil Scientist, USDA-NRCS, Quincy, FL

Activities:
All activities were completed on 27 thru 29 January 2009.

Background:
Florida is the home of ground-penetrating radar (GPR) within USDA and soil science. Presently, there are two soil scientists in Florida who have been designated as radar operators: Doug Lewis and Martin Figueroa. These operators are highly skilled and will carry on this GPR tradition. Doug Lewis has been using GPR for over twenty years and has a wide breath of experiences. His willingness to share his GPR knowledge and expertise with Martin Figueroa is opportune and most commendable. The purpose of this visit was to introduce these operators to new GPR technologies and to review field procedures and data processing techniques.

Summary:

1. Training was provided on the setup and operation of the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (SIR-3000). This GPR unit was recently purchased by the Florida State Office.

2. Training was provided on some of the basic processing procedures contained in the RADAN for Windows program (version 6.6). These processing procedures can be used to prepare, edit, display, and print radar data. During training, proper file management and storage were stressed. Procedures covered included: color table and transformation options, header and marker editing, time zero

adjustments, horizontal distance normalization, signal stacking, migration, and range gain adjustments. All participants successfully processed a series of radar records using these procedures.

3. All radar data were collected by Martin Figueroa. I am very impressed by how much Martin has mastered since my last visit. Martin is a quick learner and I am impressed by his interest and enthusiasm. Present plans are to redeploy Martin to the Fort Meyers MLRA office. Here he can benefit from closer contact with Doug Lewis. Doug has operated GPR for over twenty years, is a master GPR technician, and has developed unique field procedures and interpretive skills, which he can share with Martin.

4. The RADAN for Windows program (version 6.6) purchased by Florida includes the *Interactive Interpretation* module. This module affords the capability to automatically pick and scale depths to subsurface interfaces (e.g., soil horizons, stratigraphic or lithologic layers; subsurface features) and automatically output the data to files, which can be read in *Notepad* or *Excel*. Using this module, data can be quickly compiled and exported for analysis and summary.

5. Recent technical developments allow the integration of GPR and global positioning systems (GPS) data. This integration effectively geo-references each scan on radar records. Though this option is presently not available in Florida, the Quincy MLRA office has a GPS receiver (Trimble Pathfinder), which may be acceptable for the automatic integration of GPR and GPS data. The Garmin Map76 receiver, which is commonly used by USDA-NRCS, will not work with GPR as it outputs too many unnecessary NMEA codes and is outdated. In the future, if the integration of GPR, GPS, and geographic information systems (GIS) is desired, a serial data recorder (SDR) for logging GPS data will need to be purchased from GSSI. It presently costs $1112.

6. It had been previously planned by Deanna Peterson (former State Soil Scientists) to staff each of the MLRA office located in Florida (Quincy, Tavares and Fort Meyers) with a GPR operator and equipment. With the recent updating of the RADAN for Windows software, two additional (three total) USB security keys (needed to open this program on GPR operator's computers) were purchased. Doug Lewis and Martin Figueroa each have one USB security key. The location of the third key was unknown to the group. It may be with Andrew Williams in Milton, Florida. If not already done, I recommend that the state soil staff maintain a record on the locations of these security keys ($750 each).

It was my pleasure to work in Florida and with members of your fine staff. The National Soil Survey Center promises its continued support to you and your soil and GPR staffs.

With kind regards,

James A. Doolittle
Research Soil Scientist
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Equipment:
The radar unit used in this study is the TerraSIRch Subsurface Interface Radar (SIR) System-3000 (SIR-3000), manufactured by Geophysical Survey Systems, Inc. (GSSI; Salem, NH).[1] This is a state-of-the-arts GPR system. Florida has one SIR-3000 and two SIR-2000 radar units. 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 9 lbs (4.1 kg) and is backpack portable.

Antenna with center frequencies of 200 and 400 MHz were used in this study. With an antenna, the SIR-3000 requires two people to operate (see Figure 1). Jol (2009) and Daniels (2004) discuss the use and operation of GPR.

Figure 1. Martin Figueroa and Willie Nelson Jr. complete a radar survey with the SIR-3000 GPR, AG114 GPS, and 200 MHz antenna.

All radar records were processed with the RADAN for Windows (version 6.6) software developed by GSSI.[1] Processing was used to improve interpretations. Processing included: header editing, GPS positioning, time zero adjustments, signal stacking, migration, and range gain adjustments.

Recent technical developments allow the automatic picking and scaling of depths to subsurface interfaces (e.g., soil horizons, stratigraphic or lithologic layers; subsurface features) and the automatic outputting of this data to files, which can be read in *Notepad* or *Excel*. Using this module, data can be quickly compiled and exported for analysis and summary. This technology is presently available in Florida, and its setup, use, and outputs were demonstrated during this visit. Using the *interactive interpretation module* of the RADAN processing software, depths to argillic horizons were interpreted, automatically picked, and outputted to files (X, Y, Z format; containing latitude, longitude, and depth).

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

The SIR-3000 system provides a setup for the simultaneous use of a GPS receiver and serial data recorder (SDR). This integration effectively geo-references each scan on the radar record. This setup is helpful for surveying soil delineations and showing the locations of traverse lines, scans, depths to subsurface interfaces, and map unit components. Florida presently does not have a SDR, but this innovative technology was demonstrated to all participants. With this setup, scans on several radar records were georeferenced (position/time matched). Using the *Interactive Interpretation* module of the RADAN for Windows program (version 6.6), depths to the contact of the sandy/loamy interface (argillic) were quickly, automatically, and reasonably accurately picked and outputted to a worksheet (X, Y, Z format; containing latitude, longitude, and depths to argillic, and other useful data). An example of a portion of a data set that was recorded during this visit is shown in Table 1. Using the *Interactive Interpretation* module, and the *EZ tracker* or *single point* options, data can be easily compiled and exported into GIS for plotting and visualization. As evident from the positions (longitude and latitude) of the sequentially numbered radar scans (column 1) in Table 1, the system has hardly moved in the time required to collect the 15 radar scans shown in this sample.

Table 1

Shown is a portion of the data, which is picked from the radar record and exported using the Interactive Interpretation Module of the RADAN processing software.

Scan#	Longitude	Latitude	Feature	Depth (cm)	v(cm/ns)	t(ns)
131	-93.69686	34.4695	bedrock	33.77	14.53	4.65
132	-93.69686	34.4695	bedrock	33.77	14.53	4.65
133	-93.69686	34.4695	bedrock	33.77	14.53	4.65
134	-93.69686	34.4695	bedrock	33.77	14.53	4.65
135	-93.69686	34.4695	bedrock	33.77	14.53	4.65
136	-93.69686	34.4695	bedrock	33.77	14.53	4.65
137	-93.69686	34.4695	bedrock	33.77	14.53	4.65
138	-93.69686	34.4695	bedrock	34.76	14.53	4.79
139	-93.69686	34.4695	bedrock	34.76	14.53	4.79
140	-93.69687	34.4696	bedrock	34.76	14.53	4.79
141	-93.69687	34.4696	bedrock	34.76	14.53	4.79
142	-93.69687	34.4696	bedrock	41.72	14.53	5.74
143	-93.69687	34.4696	bedrock	42.71	14.53	5.88
144	-93.69687	34.4696	bedrock	44.70	14.53	6.15
145	-93.69687	34.4696	bedrock	45.69	14.53	6.29
146	-93.69687	34.4696	bedrock	46.68	14.53	6.43
147	-93.69687	34.4696	bedrock	47.68	14.53	6.56
148	-93.69687	34.4696	bedrock	47.68	14.53	6.56
149	-93.69687	34.4696	bedrock	48.67	14.53	6.70
150	-93.69687	34.4697	bedrock	48.67	14.53	6.70

Ground-penetrating radar readings (scans) are not continuous, but are taken at exceedingly short intervals along traverse lines. In this study, radar data were collected at a rate of 40 scans/sec. Position data were recorded at a rate of one measurement/sec with a Trimble AgGPS114 L-band DGPS (differential GPS) antenna (Trimble, Sunnyvale, CA).[2] In RADAN for Windows program (version 6.6), the position of each radar scan is proportionally adjusted according to the time stamp of the two nearest positions recorded with the GPS receiver. As each scan of the radar is georeferenced, the integration of GPS with GPR results in an unimaginably large data set (8865 data points were collected at the Montgomery County Site 2 alone). This data can be filtered

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

(reduced in sample size) and quickly imported into GIS where it will provide an additional data layer for display and analysis. In Florida, these techniques will have impact on how soil scientists will use GPR in the future to support soil survey operations.

Although GPS receivers might need only 3 satellites, the SIR-3000 requires a minimum of 4 satellites in order to somewhat accurately triangulate locations and provide a good solution. Any less and the GPS data will not be recorded with GPR. In addition, GPS signal reception is critical at the start and end of each radar traverse, as the first and last positions must be stored in the header of each radar file. This will be problematic in some steeply sloping and/or densely forested terrains of Arkansas. When working in areas of low satellite visibility, some GPS data will be lost (bad signal).

Survey Procedures:
Random, pedestrian surveys were conducted with the SIR-3000 and the 200 MHz antenna across accessible areas of three sites. The 200 MHz antenna provided good resolution of subsurface features and adequate penetration depths. For the grid survey of the cemetery site, a 400 MHz antenna was used. Each radar traverse was stored as a separate file. All radar records were reviewed in the field.

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, 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 (0.298 m/ns or 0.0978 feet/ns). Velocity can be either expressed in meters or feet per nanosecond (ns).

Based on measured depths to the argillic horizon in an areas Foxworth soils and the interpreted depths to this interface on radar records, using equations [1] and [2] the E_r (4.62) and v (0.1386 m/ns and 0.4545 ft/ns) were determined. These values are appropriate for slightly moist, excessively drained, sandy soils. However, as the dielectric properties of soils are spatially variable, all measurements provided in this report should be considered as close approximations only.

Study Sites:
All study sites are located in Gadsden County. Each site was named for its dominant soil or feature. The Foxworth 1 (latitude 30.4482 N, longitude 84.6085 W) and Foxworth 2 (latitude 30.4420 N, longitude 84.6093 W) sites are located in the Wallwood Boy Scout Camp off of Lakeview Point Road in southern Gadsden County. The Foxworth 1 site is located in an open area of Foxworth-Lakeland complex, 0 to 5 % slopes (map unit (MU) 80). The Foxworth 2 site is located in a wooded area of Foxworth-Lakeland complex, 5 to 15 % slopes (MU 83). The Dothan-Fuquay Site (latitude 30.58608 N, longitude 84.6927 W) is located next to the Greensboro Highway in western Gadsden County. The Dothan-Fuquay site is in a recently harvested pine forest and in an area of Dothan-Fuquay complex, 2 to 5 % slopes (MU 19). The cemetery site is located in a wooded area of the Wallwood Boy Scout Camp. The cemetery is located in an area mapped as Foxworth-Lakeland complex, 0 to 5 % slopes (MU 80).

The taxonomic classifications of the soils identified at these sites are listed in Table 2. The moderately well drained to excessively drained Foxworth soils are distinguished from the excessively drained Lakeland soils by the occurrence of a water table within depths of 2 meters (80 inches) at some time in the year. The well drained Dothan and Fuquay soils are shallow and moderately deep to argillic horizon, respectively.

Table 2

Taxonomic classifications of the named soils at the study sites.

Soil Series	Taxonomic Classification
Dothan	Fine-loamy, kaolinitic, thermic Plinthic Kandiudults
Foxworth	Thermic, coated Typic Quartzipsamments
Fuquay	Loamy, kaolinitic, thermic Arenic Plinthic Kandiudults
Lakeland	Thermic, coated Typic Quartzipsamments

Results:

Foxworth 1 Site:

Three radar traverses were conducted across an area of Foxworth-Lakeland complex, 0 to 5 % slopes. Based on 6,571 interpreted measurements along these traverse lines, the average depth to the loamy sediments and thickness of the sand mantle is about 301 cm with a range of about 266 to 349 cm. Over one-half of these measurements were between about 291 and 308 cm.

Figure 2 is a radar record from this site. In Figure 2, the depth and distance scales are expressed in centimeters and meters, respectively. Arrows have been used to identify hyperbolic reflectors suspected to represent larger tree roots or other inhomogeneities (e.g., artifacts, clay balls) in the soil. The soils along this traverse line lack an abrupt boundary separating the sandy mantle from underlying loamy marine sediments. At depths ranging from about 350 to 400 cm, higher-amplitude and contrasting reflection patterns are evident on this radar record. Judging from the transparency of these reflectors, these reflections are believed to be the result of lamellae and textural inhomogeneities and possibly reflect higher moisture contents. Below depths of 600 cm, higher-amplitude, more continuous reflectors may signify the loamy marine sediments.

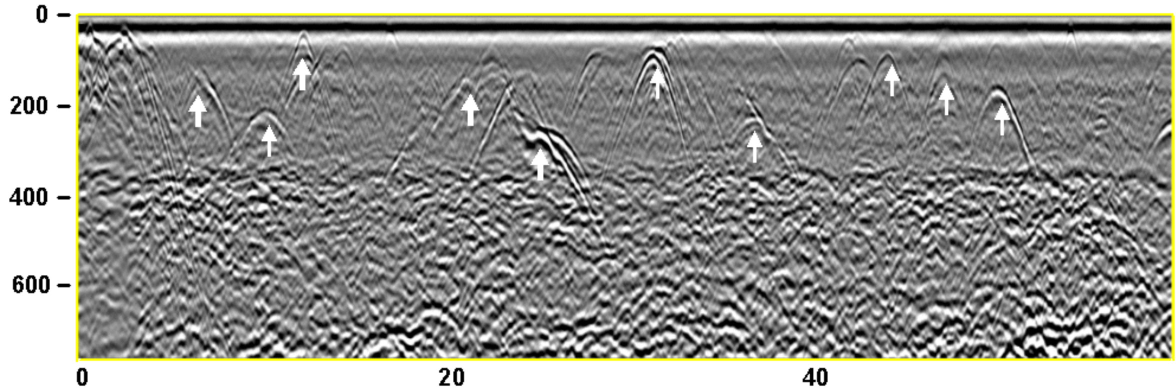

Figure 2. In this radar record from the Foxworth 1 site, the appearance of radar reflection patterns and amplitudes change at a depth of 350 to 400 cm. This change suggests more attenuating conditions resulting from higher clay and or water contents. Hyperbolas represent large tree roots (white arrows).

Figure 3 is a Google Earth image of the area traversed with GPR. The locations of these traverse lines as well as the interpreted depths to loamy sediments along these lines are shown. In the areas traversed with GPR at Foxworth 1, soils are very deep to loamy sediments (colored yellow), which is representative of Foxworth and Lakeland soils.

Figure 3. In this Google Earth image of the Foxworth 1 site, the locations of georeferenced GPR traverse lines are shown. Colors indicate the depths to loamy sediments (all depths are expressed in cm).

<u>Foxworth 2 Site:</u>

Three radar traverses were conducted across an area of Foxworth-Lakeland complex, 5 to 15 % slopes. Based on 11,315 interpreted measurements along these traverse lines, the average depth to the loamy sediments and thickness of the sand mantle is about 181 cm with a range of about 48 to 283 cm. Over one-half of these measurements were between about 161 and 206 cm. Tables 3 and 4 summarize the results of these surveys. Table 3 lists the number of observations of the depth to loamy sediments for each traverse according to soil depth classes. Table 4 provides the frequency distribution of these observations also according to soil depth classes. Soils are dominantly very deep to loamy sediments along each traverse line.

Table 3. These depths to loamy sediments statistics are for the GPR traverses completed in an area of Foxworth-Lakeland complex, 0 to 5 % slopes. Observations are grouped according to soil depth classes.

Depth Class	File 1	File 2	File 3
Shallow	0	0	30
Moderately deep	84	0	318
Deep	437	137	939
Very Deep	1694	5601	2069

Table 4. Frequency distribution of radar interpretations of the depth to loamy sediments in traversed areas of Foxworth-Lakeland complex, 0 to 5 % slopes. Interpretations are grouped according to soil depth classes.

Depth Class	File 1	File 2	File 3
Shallow	0.00	0.00	0.01
Moderately deep	0.04	0.00	0.09
Deep	0.20	0.02	0.28
Very Deep	0.76	0.98	0.62

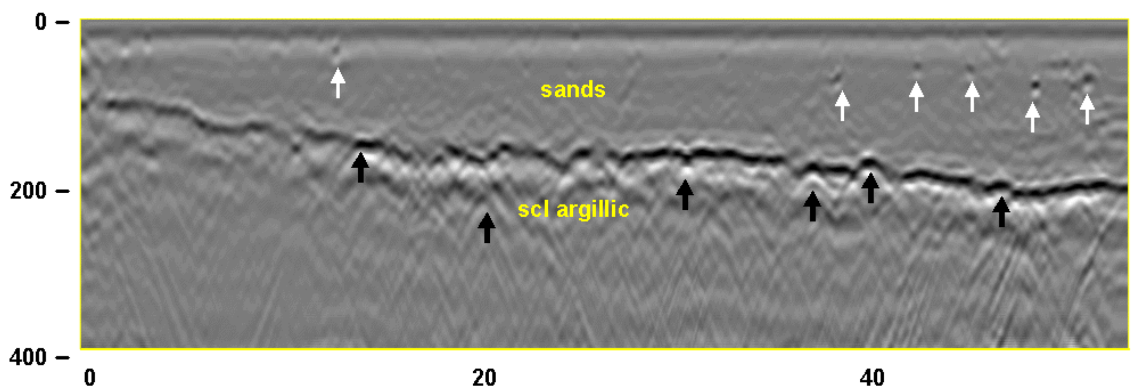

Figure 4. In this radar record from the Foxworth 2 site, the high-amplitude, planar radar reflection represents the contact of the sand mantle with the underlying argillic horizons. Hyperbolas represent roots (white arrows) and inhomogeneities in the underlying loamy sediments.

Figure 4 is a migrated radar record from Foxworth 2 site. In Figure 2, the depth and distance scales are expressed in centimeters and meters, respectively. The continuous, planar reflector that extends across the radar record between depths of about 100 and 190 cm is the contact separating the sandy mantle from the underlying, loamy marine sediments. White arrows have been used to identify hyperbolic reflectors suspected to represent larger tree roots. Black arrows have been used to identify hyperbolic reflectors that represent textural inhomogeneities in the upper part of the loamy sediments and/or more sloping or irregular portions of the sandy/loamy interface. Compared with the radar record shown in Figure 2, in Figure 4, the sandy/loamy contact is more abrupt and contrasting (higher signal amplitude) and the underlying marine sediments are more opaque (i.e., more attenuating) to the radar signal.

Figure 5 is a Google Earth image of the area traversed with GPR at Foxworth 2 site. The locations of these traverse lines as well as the interpreted depths to loamy sediments along these lines are shown in Figure 5. In the areas traversed with GPR at Foxworth 2 site, soils are dominantly very deep to loamy sediments (colored yellow), except along convex slope breaks.

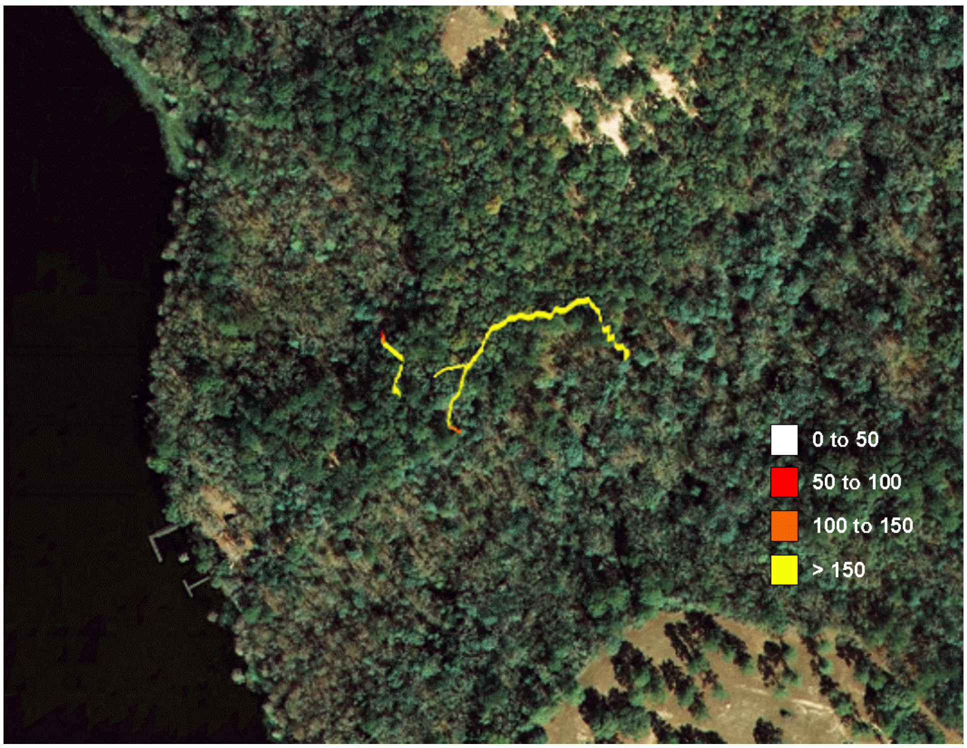

Figure 5. In this Google Earth image of the Foxworth 2 site, the locations of georeferenced GPR traverse lines are shown. Colors indicate the depths to loamy sediments (all depths are expressed in cm).

Dothan-Fuquay Site:

One radar traverse was conducted across an area of Dothan-Fuquay complex, 2 to 5 % slopes. Based on 3,714 interpreted measurements along this traverse line the average depth to the argillic horizon and thickness of the sand mantle is 89.2 cm with a range of about 73.0 to 100.9 cm. Soils along this traverse line were overwhelming Fuquay (loamy, kaolinitic, thermic Arenic Plinthic Kandiudults) and moderately deep (3,705 measurements) to loamy marine sediments. Because of the thickness of the sand mantle, no Dothan soils (fine-loamy, kaolinitic, thermic Plinthic Kandiudults) were identified. Soils representing the Grossarenic subgroup were identified at 9 measurement points.

Figure 6 is the complete radar record from this traverse. In Figure 6, the depth and distance scales are expressed in centimeters and meters, respectively. As apparent on this radar record, the underlying, loamy marine sediments are relatively transparent to GPR and contain a large number of point (hyperbolic patterns) and segmented and inclined planar reflectors. This suggests a great heterogeneity in soil materials; possibly alternating balls and layers of clayey admixed with sandy materials within these marine sediments. In a core extract from this site, the texture of the argillic horizon was textured as a sandy clay loam. As over 1 meter of penetration was achieved with the 200 MHz antenna through these saturated, loamy materials, the clay minerals are assumed to be dominantly low activity clays (e.g., kaolinite, gibbsite, goethite) as describe in the taxonomic classifications of these soils (Kandiudults). Better drained areas of Dothan and Fuquay soils are considered to have a high potential for GPR[3].

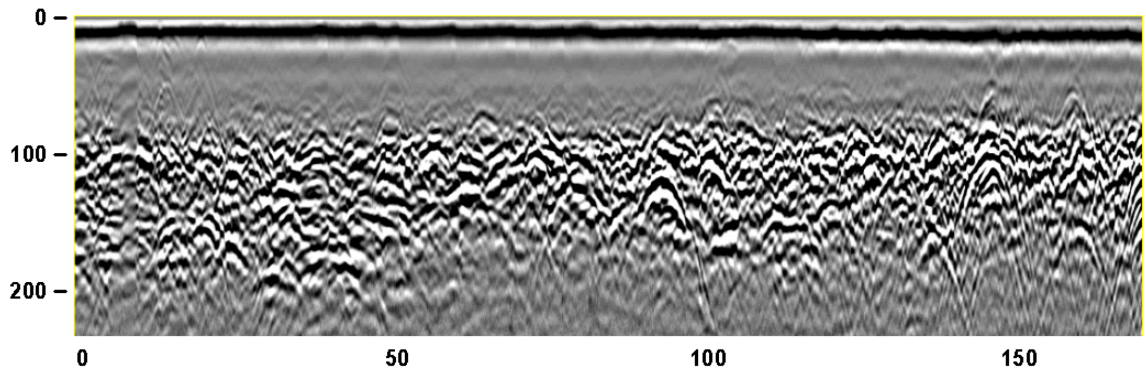

Figure 6. In this radar record from the Dothan-Fuquay site, the contact of the sandy with the loamy marine sediments is easily interpreted. High-amplitude, point and planar radar reflection represents inhomogeneities within the argillic horizons.

Cemetery Site:
A small 2 by 2 meter area of a cemetery located within Wallwood Boy Scout Camp was surveyed with the 400 MHz antenna. This small area is located immediately in front of (and to the west of) the headstones for John (1818-1868) and Mary (1827-1902) Pittman. The site was accessible and relatively free of debris. Two parallel lines were laid out and served as grid axis lines. Along these two parallel axis lines, survey flags were inserted into the ground at a spacing of 10 cm. A distance-graduated rope was stretched between matching survey flags on these two axis lines, which formed the opposing sides of the grid area. GPR traverses were conducted along this line. The 400 MHz antenna was towed along the graduated rope on the soil surface and, as it passed each 100-cm graduation, a mark was impressed on the radar record. Following data collection along a line, the distance-graduated rope was sequentially displaced 10-cm to the next pair of survey flags to repeat the process.

The survey was conducted as a training exercise. Participants learned how to setup a small grid for a very detailed radar survey. This information was later processed and 3D pseudo images constructed. Figure 7 contains two 3D GPR pseudo-image of the grid site. For the 3D pseudo-image, processing was kept to a minimum. Hyperbolas in the upper part of each 3D pseudo image are believed to represent larger tree roots. A sequence of stratigraphic layers is evident in lower part of each image. The sandy surface mantle is characterized by lower-amplitude reflections; the lower substratum is composed of loamy marine deposits that are characterized by higher-amplitude reflections. Planar reflections characterize the underlying loamy marine deposits.

No indications of a burial were revealed within the grid area. Behind and to the east of the headstones (this area was not surveyed) an elongated depression was evident. The long axis of this shallow depression stretched away from the headstones and was suspected to represent the effects of a collapsed coffin. This area had not been survey with GPR because of interfering and obstructing trees. However, this area was latter traverse with a

[3] http://soils.usda.gov/survey/geography/maps/GPR/index.html

single pass of the radar. A hyperbolic reflector was observed within the depression and was inferred to be the remnants of Mary Pittman's coffin.

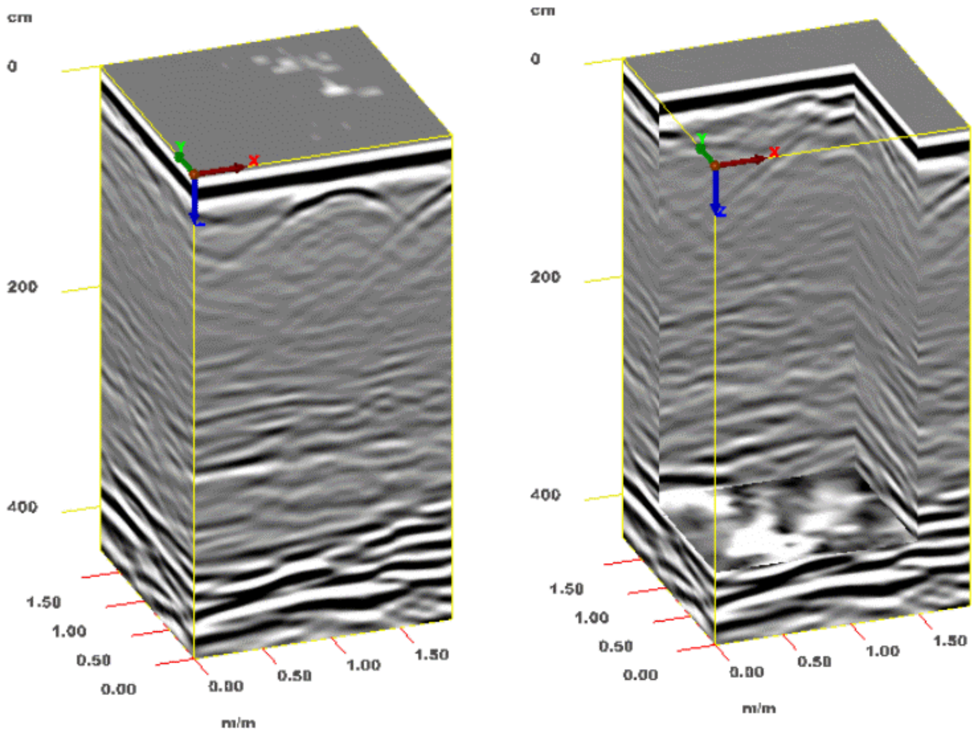

Figure 7. Two 3D GPR pseudo-images of the small grid area within the surveyed cemetery. The image on the right is a solid cube; the image on the right has a 150 by 130 by 375 cm inset cube removed to view geometry of layers and to search for potential graves.

Reference:

Daniels, D. J. 2004. Ground Penetrating Radar; 2nd Edition. The Institute of Electrical Engineers, London, United Kingdom.

Jol, H., 2009. Ground Penetrating Radar: Theory and Applications. Elsevier Science, Amsterdam, The Netherlands.