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

Subject: Soils – Geophysical Field Assistance **Date:** 9 January 2004

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Purpose:
The purpose of this investigation was to further characterize the suitability of Piedmont soils for electromagnetic induction (EMI) and ground-penetrating radar (GPR). This study evaluates the affects of different clay contents and clay minerals on the effectiveness of these geophysical tools.

Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS-NSSC, Newtown Square, PA
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Wes Tuttle, Soil Scientist (Geophysical), USDA-NRCS-NSSC, Wilkesboro, NC

Activities:
All activities were completed on 12 December 2003.

Equipment:
The electromagnetic induction meter used in this study was the EM38DD, manufactured by Geonics Limited.[1] Operating procedures are described by Geonics Limited (2000). The EM38DD meter is portable and requires only one person to operate. No ground contact is required with this meter. The EM38DD operates at a frequency of 14,600 Hz. It has effective penetration depths of about 0.75 and 1.5 m in the horizontal and vertical dipole orientations, respectively. The EM38DD meter consists of two EM38 meters bolted together and electronically coupled. One meter acts as a master unit (meter that is positioned in the vertical dipole orientation and having both transmitter and receiver activated) and one meter acts as a slave unit (meter that is positioned in the horizontal dipole orientation with only the receiver switched on).

The Geonics DAS70 Data Acquisition System was used to record and store both EMI and GPS data.[1] The acquisition system consists of the EM38DD meter, an Allegro field computer, and a Trimble AG114 GPS receiver.[1] With the logging system, the EM38DD meter is keypad operated and measurements can either be automatically or manually triggered.

To help summarize the results of this study, the SURFER for Windows, version 8.0, developed by Golden Software, Inc., was used to construct two-dimensional simulations.[1] Grids were created using kriging methods with an octant search.

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] 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, SVGA video screen, and connector panel. A 10.8-volt lithium-ion rechargeable battery powers

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

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. A 200 MHz antenna was used in this study.

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

Study Sites:
The site is located in fields on the east side of North Carolina Highway 87 between the towns of Ossippe and Altamahaw on the Troxler Farm. Soils were recently mapped by Roger Leab as part of his initial reconnaissance survey of Alamance County. Major soil delineations recognized in the study area include map units 57B, Vance sandy loam, 2 to 6 percent slopes; 61B, Sedgefield-Pittsboro complex, 2 to 6 percent slopes; 61C, Sedgefield-Pittsboro complex, 6 to 10 percent slopes; and 457B, Vance sandy loam, 2 to 6 percent slopes, bouldery.

The very deep, moderately well and somewhat poorly drained Sedgefield and moderately well drained Pittsboro soils formed in residuum weathered from intermediate and mafic crystalline rock in the Piedmont. Sedgefield is a member of the fine, mixed, active, thermic Aquultic Hapludalfs family. Sedgefield soil has a solum that ranges from 20 to 40 inches thick. Depth to bedrock is more than 5 feet. Content of rock fragments in the surface layers ranges from 0 to 15 percent.

Pittsboro is a member of the fine, mixed, active, thermic Oxyaquic Hapludalfs family. Pittsboro soil has a solum that ranges from 20 to 40 inches thick. Depth to saprolite (soft, highly weathered bedrock) ranges from 20 to 40 inches (paralithic contact; Cr horizon). Depth to hard bedrock ranges from 40 to more than 60 inches (lithic contact; R)

The well drained, Vance soil formed in residuum weathered from acid crystalline rocks in the Piedmont. Vance soil is moderately deep to saprolite and very deep to bedrock. Vance is a member of the fine, mixed, semiactive, thermic Typic Hapludults family. Solum thickness is 24 to 40 inches over saprolite. Depth to hard bedrock ranges from 6 to l0 feet or more.

Survey Procedures:
The EM38DD meter was operated in the continuous mode with measurements recorded at 1-sec intervals. The EM38DD was held about 3 inches above the ground surface with its long axis parallel to the direction of traverse. Walking at a fairly brisk and uniform pace, in a random back and forth pattern across the fields, the EM38DD meter recorded 2936 geo-referenced measurements.

Based on the results of the EMI survey, a 50 m line was established for a radar traverse. Along this line, survey flags were inserted in the ground at 5 m intervals and served as reference points. Pulling the 200 MHz antenna along the traverse line completed a radar survey file. As the radar antenna was pulled passed each flagged reference point, the operator impressed a vertical reference mark to identify the location of the point on the radar record.

The depth to a known reflector was used to determine the velocity of propagation. The velocity of propagation and the dielectric permittivity is moisture dependent and varies with antenna frequency. At the time of this investigation, soils were moist. For the upper part of the soil, with the 200 MHz antenna, the estimated average velocity of propagation was about 0.10 m/ns and the dielectric permittivity was about 8. These estimates were based on the depths (47 cm) to a buried metallic reflector.

Base on EMI response, Roger Leab collected samples at reference points 10-m and 50-m along the radar traverse line. These reference points corresponded to areas of Helena (10-m) and Sedgefield (50-m) soils. The very deep, moderately well drained Helena soil formed in residuum weathered from a mixture of felsic, intermediate, or mafic igneous or high-grade metamorphic rocks on the Piedmont. Helena is a member of the fine, mixed, semiactive, thermic Aquic Hapludults family.

Table 1
Apparent Conductivity Data collected with the EM38DD meter.
All values are in mS/m.

	Horizontal	Vertical
Average	12.68	15.78
Standard Deviation	7.08	6.71
Minimum	0.03	1.04
Maximum	42.99	48.69
25% Quartile	7.15	10.90
75% Quartile	17.09	19.56

Interpretations:

EMI Survey:

Basic statistic for the apparent conductivity (EC_a) data recorded with the EM38DD meter is listed in Table 1. In general apparent conductivity increased and became slightly less variable with increasing soil depth. Apparent conductivity averaged about 12.7 and 15.8 mS/m for measurements obtained in the shallower-sensing, horizontal and in the deeper-sensing, vertical dipole orientations, respectively. Apparent conductivity ranged from about 0 to 43 mS/m with a standard deviation of about 7.2 mS/m in the horizontal dipole orientation. Apparent conductivity ranged from about 1 to 49 mS/m with a standard deviation of about 6.7 mS/m in the vertical dipole orientation.

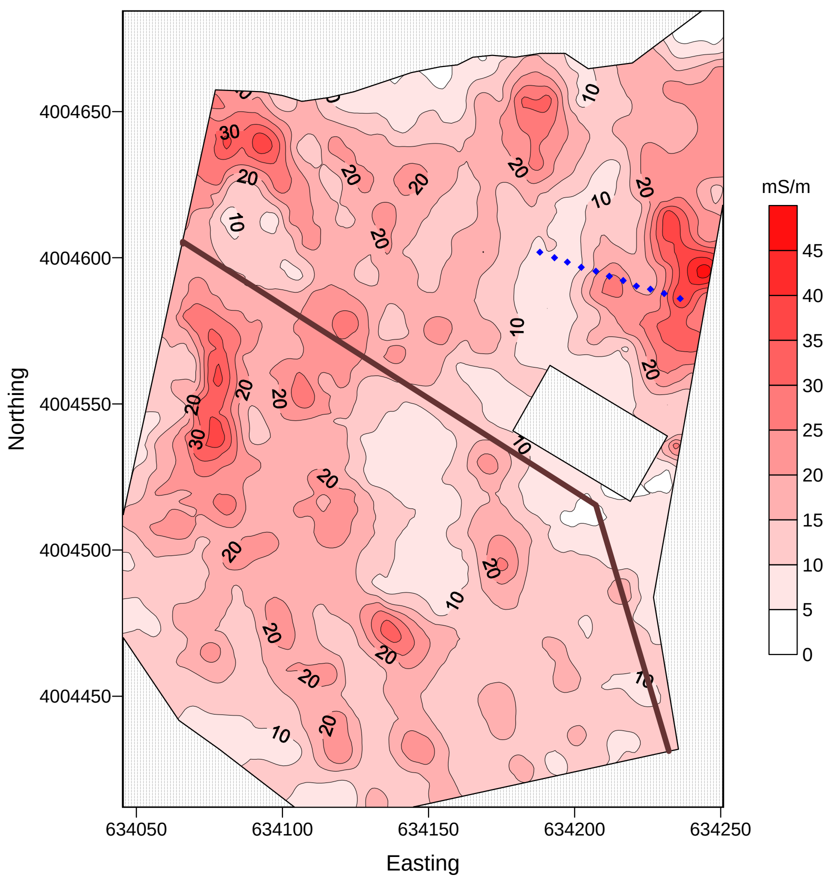

Figure 1. Plot of ECa collected with the EM38DD meter in the vertical dipole orientation.

Figure 1 is a choropleth map that shows the spatial distribution of EC_a collected with the EM38DD meter. Color variations have been used to show the distribution of apparent conductivity. The color interval is 5 mS/m. To reduce spurious measurements and lines, the *grid node editor* of Surfer 8 was used to remove or make slight changes (0.1 to 0.2 mS/m) to some of the measurements. The locations of the radar traverse line and reference points are shown in this figure. Also shown are the farm road and the general location of the Troxler family house and yard (area not surveyed in the east central part of the site).

The EMI survey characterized the study site as being high variable in terms of ECa. Patterns of ECa appear to be arranged as a series of rows that repetitively alternate as bands of higher and lower ECa in an east-west direction across the site. Each row extends in an north-northwest to south-south west orientation across the site. Within each row, bead-like patterns of higher ECa punctuate the rows and give them a chain-like or *paternoster* appearance. The bands are presumed to represent changes in the clay content and mineralogy of the underlying lithologies and soils.

Soils dominated by clay fractions that have a higher percentage of smectite or vermiculite clay minerals have a higher CEC and respond as being more conductive to EMI and more attenuating to GPR than soils with an equivalent percentage of kaolinite. In the southern Piedmont, kaolinite is the dominant clay mineral in most soils (Buol et al., 2000). Soils formed in residuum weathered from granitic gneiss have saprolite that contains large amounts of halloysite, gibbsite and amorphous aluminosilicate clays (Buol and Weed, 1991). Soils weathered from gabbro and metagabbro have saprolite that contains large amounts of smectite, vermiculite, and chlorite (Buol and Weed, 1991). In addition, Buol and Weed (1991) observed that argillic horizons formed over basic and/or fine-grained rock contain larger amounts of 2:1 expanding lattice clays. Subsoils developed over quartzofeldspathic rocks are not as clay rich and contain greater amounts of kaolinite and nonexpanding vermiculite clay minerals (Pavich et al., 1989). The higher cation exchange capacity of 2:1 expanding lattice clays increases attenuation and restricts penetration of radar energy.

Within the Troxler Farm site, soil and bedrock patterns are highly complex. Areas of lower (< 10 mS/m) ECa are more common in lower-lying, more imperfectly drained swales and foot slope positions. Areas of higher (> 20 mS/m) ECa are more common on higher-lying, better drained summit and shoulder slope positions. It is postulated that areas of lower ECa form over more quartzofeldspathic rocks, which are less resistant to weathering and weather into coarser-textured residuum. It is proposed that areas of higher ECa form over more mafic rocks, which are more resistant to weathering and weather into finer-textured residuum.

<u>Traverse Line:</u>
A 50-m traverse line with reference flags spaced at 5 m intervals was established across an area with contrasting ECa. Figure 1 shows the location of this line relative to ECa patterns. Figure 2 shows the relative topography of the traverse line. The referenced points are spaced at 5 m intervals

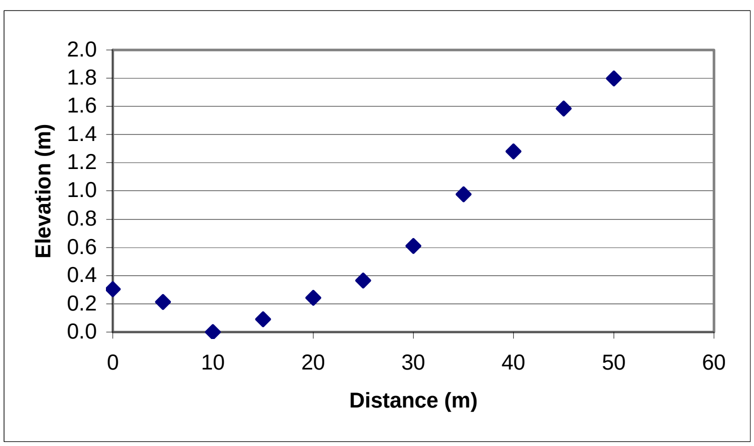

Figure 2. Topography of the radar traverse line.

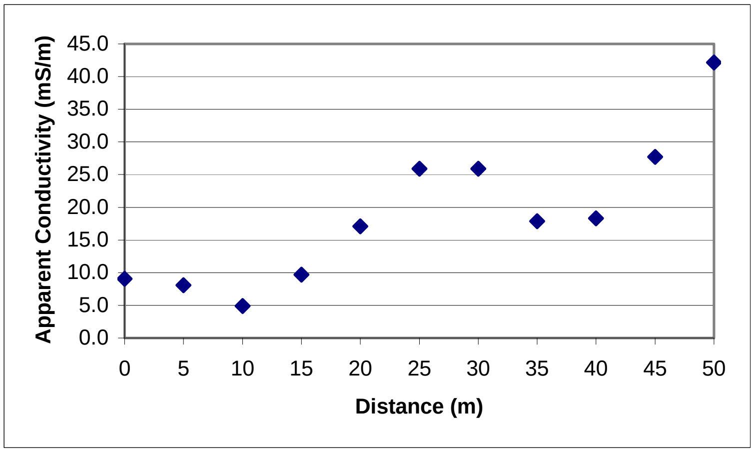

Figure 3. ECa along the radar traverse line

Figure 3 shows the ECa of each reference point as measured with the EM38DD meter in the vertical dipole orientation. Apparent conductivity varies with landscape position being generally lower on lower-lying slope components and higher on higher-lying slope components. Along the radar traverse line, ECa was fairly strongly (r = 0.79) and significantly (0.003 level) related to elevation.

Figure 4 is a portion (5 to 48 m) of the radar record of the traverse line. A scale (in meters) is located along the left-hand side of the radar profile. This scale is based upon the two-way travel time of the radar pulse in the soil. For the upper part of the soil profile, with the 200 MHz antenna, the estimated velocity of propagation was about 0.10 m/ns. Based on this velocity of propagation, a two-way travel time of 80 ns provides the maximum potential depth of penetration is about 4.2-m. The short vertical lines at the top of the radar profile represent equally spaced (5 m) reference marks.

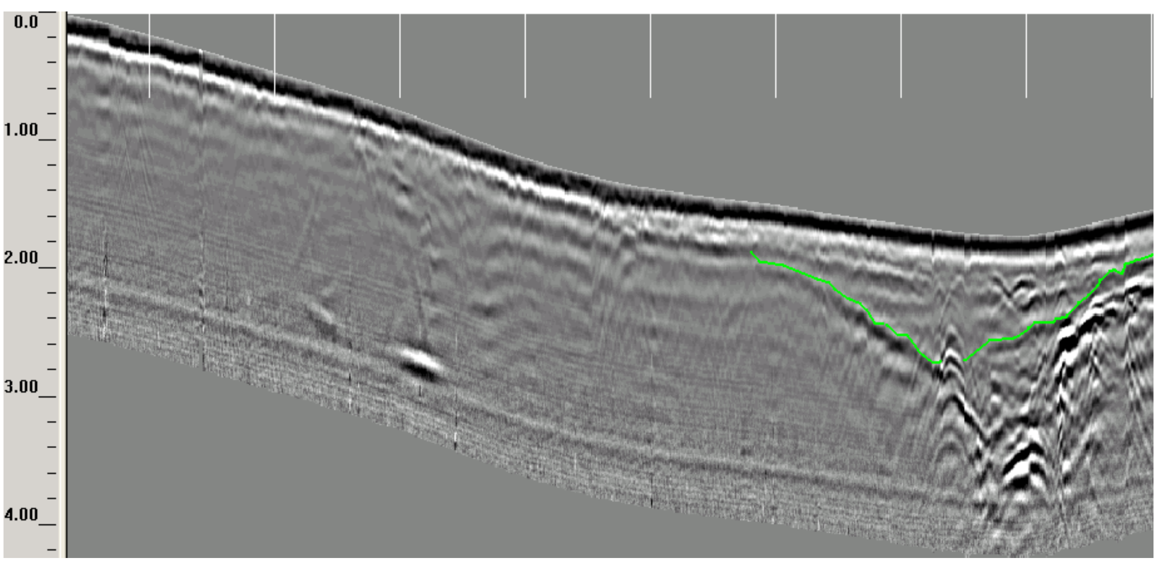

Figure 4. Radar record from the traverse line at the Troxler Farm, Alamance County.

In the radar record shown in Figure 4, the depth of penetration is generally restricted to the upper boundary of the argillic horizon. The high clay content of soils along the traverse line severely attenuated the radar energy and restricted the depth of penetration. Throughout the higher-lying and more conductive left-hand portion of this record, reflectors are indistinct and not interpretable below a depth of about 50 cm in areas of Sedgefield soil. The depth of penetration is greater in the lower-lying swale. Here the upper surface of the argillic horizon has been highlighted with a green line. Beneath the reflections from the argillic horizon, reflections from what appears to be the upper surface of the saprolite are apparent. Though recognized as being most similar to Helena soil, coarse-loamy overwash materials mantled soils in this portion of the radar record.

Results:

1. Patterns of apparent conductivity were highly complex within the Alamance County site and are presumed to reflect difference in lithology and soils. Areas of lower (< 10 mS/m) ECa were more common in lower-lying, more imperfectly drained swales and foot slope positions. Areas of higher (> 20 mS/m) ECa were more common on higher-lying, better drained summit and shoulder slope positions. It is postulated that areas of lower ECa form over more quartzofeldspathic rocks, which is less resistant to weathering and form coarser-textured residuum. It is proposed that areas of higher ECa form over more mafic rocks, which are more resistant to weathering and form finer-textured residuum.

2. A short traverse line was established to help confirm the suspected relationship between ECa and elevation. Along this line, ECa was fairly strongly (r = 0.79) and significantly (0.003 level) related to elevation.

3. The performance of GPR varied with site conditions. The quality of radar interpretations and the depth of penetration were significantly better in lower-lying areas. These areas have lower ECa soils and lithologies. This relationship is believed to be a manifestation of differences in clay content and mineralogy.

4. To help confirm these interpretations, samples have been collected for analysis at the National Soil Survey Laboratory in Lincoln, Nebraska.

It was Wes Tuttle's and my pleasure to work in Alamance County with Roger Leab.

With kind regards,

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Profile descriptions of soil that were sampled.

Samples were collected for laboratory analysis from the A (Sample 1, 0 to 43 cm) and Bt (Sample 1, 72 to 90 cm) horizons of Helena soil and the Bt (Sample 2, 15 to 35 cm) of Sedgefield soil.

Soil Pedons 10 m - Helena soil

Horizon	Depth (in)	Color (m)	Texture	Structure	Consistency
Ap	0-5	10YR4/4	SL	2mgr	fr
Ap	5-17	10YR5/4	SL	2mgr	fr
Ab	17-22	10YR3/4	SL	2mgr	fr
BA	22-29	10YR6/6	GR SCL	2msbk	fr
Bt1	29-32	10YR6/6	C	2csbk	fi
Bt2	32-36	10YR6/6	C	2csbk	fi
Bt3	36-50	10YR6/8	SC	2csbk	fr
CB	50-60	10YR6/8	SCL	1cvsbk	fr

Soil Pedons 50 m - Sedgefield

Horizon	Depth (in)	Color (m)	Texture	Structure	Consistency
Ap	0-6	10YR4/3	SCL	1cgr	fr
Bt	6-14	2.5Y5/3	C	3csbk	vfi
BC	14-18	2.5Y4/4	C	1csbk	fi
C1	18-33	gr sap	L	mass	fr
C2	33-50	gr&rd sap	L	mass	fr
Cr		50-60		gr gabbro	