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Subject: MGT – Trip Report - Geophysical Field Assistance

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To: J. B. Martin, Jr.
State Conservationist, NRCS
Raleigh, North Carolina

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Purpose:

To use geophysical methods (ground-penetrating radar (GPR) and electromagnetic induction (EMI)) to help assess soils and soil properties at the Upper Piedmont Experiment Station, Reidsville, North Carolina. Soil investigations were part of a collaborative effort between USDA/NRCS and North Carolina State University to determine whether and how GPR and EMI can help elucidate the spatial variability of soil profile characteristics that affect soil-plant-water relationships in these Piedmont soils.

Participants:

Josh Heitman, Assistant Professor, Environmental Soil Physics, North Carolina State University, Raleigh, NC
Adam Howard, Research Technician, North Carolina State University, Raleigh, NC
Alan Meijer, Extension Associate/Graduate Student, North Carolina State University, Plymouth, NC
Wes Tuttle, Soil Scientist (Geophysical), USDA-NRCS-NSSC, Wilkesboro, NC
Robert Walters, Agricultural Research Specialist, North Carolina State University, Raleigh, NC

Activities:

All field activities were completed on March 31 and April 1, 2010.

Summary:

1. Changes in apparent conductivity were thought to be associated with changes in soil characteristics across the survey areas. Areas of higher apparent conductivity were associated with thicker subsoils containing more clay and moisture. Anomalous spikes in apparent conductivity were associated with the presence of subsurface metal objects and appeared as point features and linear features in the radar records. Features were verified with soil borings.
2. Radar records obtained with the 200 MHz antenna were generally of good to excellent interpretative quality. Observation depths were in excess of 2.5 m. Higher rates of signal attenuation observed in the radar records were thought to be attributed to increased amounts of clay and moisture within the soil profile. Soil borings confirmed an increase in clay and moisture in areas containing higher signal attenuation rates. Small localized

areas containing shallower soils (soil inclusions) were observed in radar records and were verified with soil borings.

3. After observing GPR records, there appeared to be more variability at site 2 (behind main office) as compared to site 1 with respects to changes in soils and soil characteristics (especially soil depth). A comparison between changes in EMI spatial patterns and associated changes in soil properties also suggested more variability at site 2. GPR and EMI interpretations were verified with soil borings.
4. Geophysical interpretations are considered preliminary estimates of site conditions. The results of geophysical site investigations are interpretive and do not substitute for direct ground-truth observations (soil borings and pits). The use of geophysical methods can reduce the number of coring observations, direct their placement, and supplement their interpretations. Interpretations contained in this report should be verified by ground-truth observations whenever possible.

It was a pleasure for Wes Tuttle to work again in North Carolina with members of your fine staff.

/s/ Craig Ditzler, Acting

JONATHAN W. HEMPEL
Director
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cc:

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**This technical report was prepared by Wes Tuttle, Geophysical Soil Scientist,
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Equipment:

Geonics Limited manufactures the EM38 meter.¹ This meter is portable and requires only one person to operate. No ground contact is required with this meter. McNeill (1980) and Geonics Limited (1998) have described principles of operation for the EM38 meter. Lateral resolution is approximately equal to its intercoil spacing. The EM38 meter has a 1 m intercoil spacing and operates at a frequency of 14,600 Hz. When placed on the soil surface, this instrument has a theoretical penetration depth of about 0.75 and 1.5 m in the horizontal and vertical dipole orientations, respectively (Geonics Limited, 1998). Values of apparent conductivity are expressed in millisiemens per meter (mS/m).

The Allegro CE/DOS field computer was used in combination with the Geonics EM38 meter to record and store EMI data. The field computer is keypad operated and measurements can either be automatically or manually triggered. EMI data was geo-referenced with a Trimble AG114 GPS receiver.¹

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. 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 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 200 MHz antenna was used in this study.

The RADAN for Windows (version 6.6) software program was used to process the radar records (Geophysical Survey Systems, Inc, 2008).¹

Electromagnetic Induction:

Electromagnetic induction is a noninvasive geophysical tool that is used for high intensity surveys and detailed site assessments. Advantages of EMI are its portability, speed of operation, flexible observation depths, and moderate resolution of subsurface features. Results of EMI surveys are interpretable in the field. This geophysical method can provide in a relatively short time the large number of observations that are needed to comprehensively cover sites. Maps prepared from correctly interpreted EMI data provide the basis for characterizing site conditions, planning further investigations, and locating sampling or monitoring sites.

Electromagnetic induction uses electromagnetic energy to measure the apparent conductivity (ECa) of earthen materials. Current flow is induced into the soil. This induced current flow is proportional to the electrical conductivity of the conducting body (ECa) for a given strength of EM field. The current flow creates a secondary electromagnetic field, the strength of which is proportional of the current flow, and hence, to ECa. ECa may be inferred from the magnitude of the induced secondary EM field generated upon imposition of a primary EM field on the conductor (soil) (Corwin and Rhoades, 1990).

Apparent conductivity is a weighted, average conductivity measurement for a column of earthen materials to a specific depth (Greenhouse and Slaine, 1983). Variations in apparent conductivity are caused by changes in the electrical conductivity of earthen materials. Electrical conductivity is influenced by the volumetric water content, phase of the soil water, temperature, type and concentration of ions in solution, and amount and type of clays in the soil matrix (McNeill, 1980). Apparent conductivity is principally a measure of the combined interaction of the soil's soluble salt content, clay content and mineralogy, and water content. The apparent conductivity of soils increases with increased soluble salts, clay, and water contents (Kachanoski et al., 1988; Rhoades et al., 1976). In any soil-landscape, variations in one or more of these factors may dominate the EMI response.

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

Though seldom diagnostic in itself, lateral and vertical variations in apparent conductivity have been used to infer changes in soils and soil properties. As EMI measurements integrate the bulk physical and chemical properties for a defined observation depth into a single value, responses can be associated with changes in soils and soil map units (Doolittle et al., 1996; Jaynes et al., 1993). For each soil, the inherent variability in physical and chemical properties, as well as temporal variations in soil water and temperature, will establish a unique and characteristic range of observable apparent conductivity values. Recently, EMI has been used as a soil-mapping tool to assist precision farming (Jaynes et al., 1993; Sudduth et al., 1995).

Electromagnetic induction is not suitable for use in all soil investigations. Generally, the use of EMI has been most successful in areas where subsurface properties are reasonably homogeneous. The effects of one property (e.g. clay, water, or salt content) dominates over the other properties, and variations in EMI response can be related to changes in the dominant property (Cook et al., 1992). Within a given geographic area, most similar soils should have comparable EMI responses. Dissimilar soils should have disparate EMI responses. However, the conductivities of some similar and dissimilar soils will overlap. This occurs where contrasts in EMI responses caused by differences in one property are offset by differences in another property. Some soil properties and soils can be inferred or predicted with EMI, provided one is cognizant of changes in parent materials, topography, drainage, and vegetation.

Ground-Penetrating Radar (GPR):

Ground-penetrating radar is a time scaled system. The system measures the time it takes electromagnetic energy to travel from an antenna to an interface (i.e., soil horizon, stratigraphic layer) and back. To convert travel time into a depth scale requires knowledge of the velocity of pulse propagation. Several methods are available to determine the velocity of propagation. These methods include use of table values, common midpoint calibration, and calibration over a target of known depth. The last method is considered the most direct and accurate method to estimate propagation velocity (Conyers and Goodman, 1997). The procedure involves measuring the two-way travel time to a known reflector that appears on a radar record and calculating the propagation velocity by using the following equation (after Morey, 1974):

$$V = 2D/T \quad [1]$$

Equation [1] describes the relationship between the propagation velocity (V), depth (D), and two-way pulse travel time (T) to a subsurface reflector. During this study, the two-way radar pulse travel time was compared with measured depths to known subsurface interfaces within each study site. Computed propagation velocities were used to scale the radar records.

Upper Piedmont Experiment Station, Reidsville, NC

GPR and EMI surveys were conducted of ~2 acres supporting two long-term tillage/no-tillage trials at the Upper Piedmont Experiment Station, Reidsville, NC. Substantial agronomic and soils data has been collected in these fields over the past 20+ years. Currently, Dr. Jeff White, NCSU Soil Science Dept. and Dr. Josh Heitman, NCSU Soil Science Dept. (soil physicist) are monitoring tillage treatment effects on profile soil moisture dynamics under soybean via multiple access tubes and a capacitance probe and plan to continue monitoring for three additional seasons of the corn-soybean rotation. The primary geophysical objectives are to determine whether and how GPR and EMI can help elucidate the spatial variability of soil profile characteristics that affect soil-plant-water relationships in these Piedmont soils. Ground truthing will be achieved via existing data and additional coring. Available soil moisture is frequently the single most important factor affecting crop production in the southeast US. Information gained from this study will be useful for agronomic soil management and also help determine the role that these geophysical methods may play in future high-intensity soil surveys of Piedmont soils.



Photo 1. Site 1



Photo 2. Site 2 (behind main office)

Soils: Taxonomic Classification and Description

Casville - Fine, mixed, semiactive, mesic Typic Hapludults family. The very deep, well drained Casville soils formed in residuum from felsic or intermediate igneous or metamorphic rock on ridges and interfluves on Piedmont uplands. These soils were formerly classified as Wedowee (thermic).

Fairview - Fine, kaolinitic, mesic Typic Kanhapludults. The very deep, well drained Fairview soils formed in residuum from felsic metamorphic or igneous rock on ridges and interfluves on Piedmont uplands. These soils were formerly classified as Pacolet (thermic).

Rhodhiss - Fine-loamy, mixed, semiactive, mesic Typic Hapludults family. The very deep, well drained Rhodhiss soils formed in residuum from felsic metamorphic or igneous rock on ridges and interfluves on Piedmont uplands. These soils were formerly classified as Rion (thermic).

Stott Knob – Fine-loamy, parasesquic, mesic Typic Hapludults family. The moderately deep to soft bedrock and deep or very deep to hard bedrock, well drained Stott Knob soils formed in residuum from felsic to intermediate metamorphic or igneous rock on hills and ridges of Piedmont uplands. (The Stott Knob series is a mesic Piedmont counterpart of the Cowee series).

EMI

Site 1 (Casville soils)

Survey Design:

A 90m x 50m grid was established across the site (*Figure 1*). Survey procedures were simplified to expedite fieldwork. Two parallel lines (90 m in length) defined the upper and lower boundaries of the survey site. The lines were spaced approximately 50 m apart. An EMI survey was completed by walking at a fairly uniform pace between similarly numbered lines in a back and forth pattern. An interval of

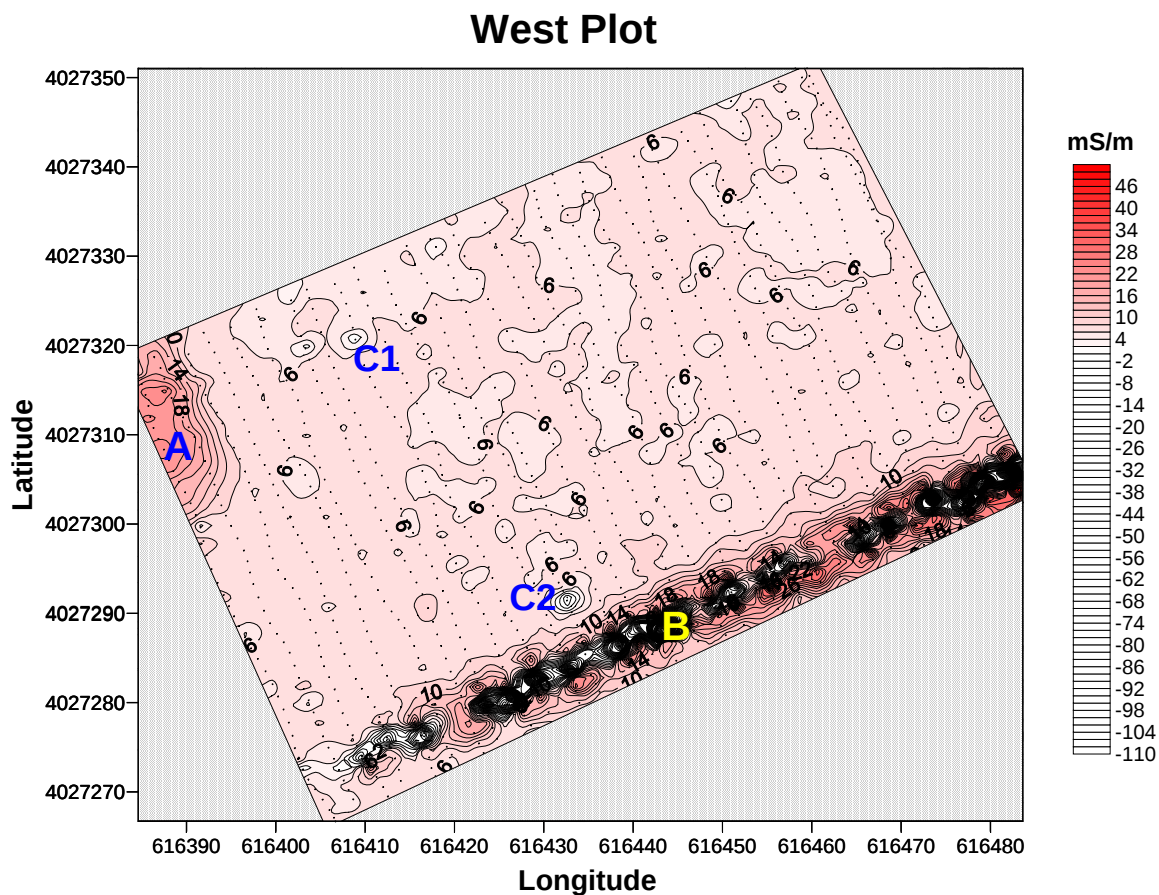


Figure 1 – Apparent conductivity measured with the EM38 meter in an area of Casville (Wedowee) soils. The soils are located on 2 to 8 percent slopes. Apparent conductivity values were measured in mS/m

(millisiemens/meter).

approximately 3 m was maintained between each survey line to ensure accuracy. The EM38 meter was carried at a height of approximately 8 cm (3 inches) above the surface and was operated in the continuous mode with measurements recorded at a 1-sec interval. The meter was carried in the vertical dipole orientation. Measurements of apparent conductivity were geo-referenced.

Results:

A total of 1235 measurements were recorded with the EM38 meter. In the vertical dipole orientation apparent conductivity averaged 7.1 mS/m and ranged from -175.4 to 79.4 mS/m. One-half of the observations had an apparent conductivity between 5.9 and 7.6 mS/m.

Higher apparent conductivity at “A” was thought to result from contributions and the close proximity to a metal boundary fence. There was also an overlying power transmission line, above this location of the survey area that may have contributed to higher conductivity measurements observed at “A”. The contrasting linear feature observed across the southern portions of the survey area at “B” was attributed to an underlying metal pipe line. The linear feature was verified with soil borings at multiple locations at depths ranging from 35 cm to 50 cm. Anomalous spikes in conductivity at “C1” and “C2” were thought to be attributed to buried metal objects and metal debris.

Changes in spatial patterns of apparent conductivity were thought to be associated with changes in soil characteristics across the survey area. Soils and soil characteristics were thought to be fairly homogenous across the site. Changes in apparent conductivity were relatively small and soil borings taken across the site confirmed relatively small variations in soils and soil characteristics.



Photo 3. Soil moisture measurements are being recorded in the foreground as an electromagnetic induction (EMI) survey is being conducted in the background with a Geonics EM38 meter at site 1. The test sites were located at the Upper Piedmont Experiment Station near Reidsville, NC.

Site 2 (Fairview and Rhodhiss soils)

Survey Design:

An EMI survey was conducted across site 2 (Figure 2). Survey procedures were simplified to expedite fieldwork. The survey area was semi-rectangular in shape. A 36 m x 70 m grid was established across the site. Survey procedures were simplified to expedite fieldwork. Survey lines were irregular in length to accommodate the survey area and ranged from 55 m to 70 m. An EMI survey was completed by walking at

a fairly uniform pace between similarly numbered lines in a back and forth pattern. An interval of approximately 3 m was maintained between each survey line to ensure accuracy. The EM38 meter was carried at a height of approximately 8 cm (3 inches) above the surface and was operated in the continuous mode with measurements recorded at a 1-sec interval. The meter was carried in the vertical dipole orientation. Measurements of apparent conductivity were geo-referenced.

East Plot (behind office)

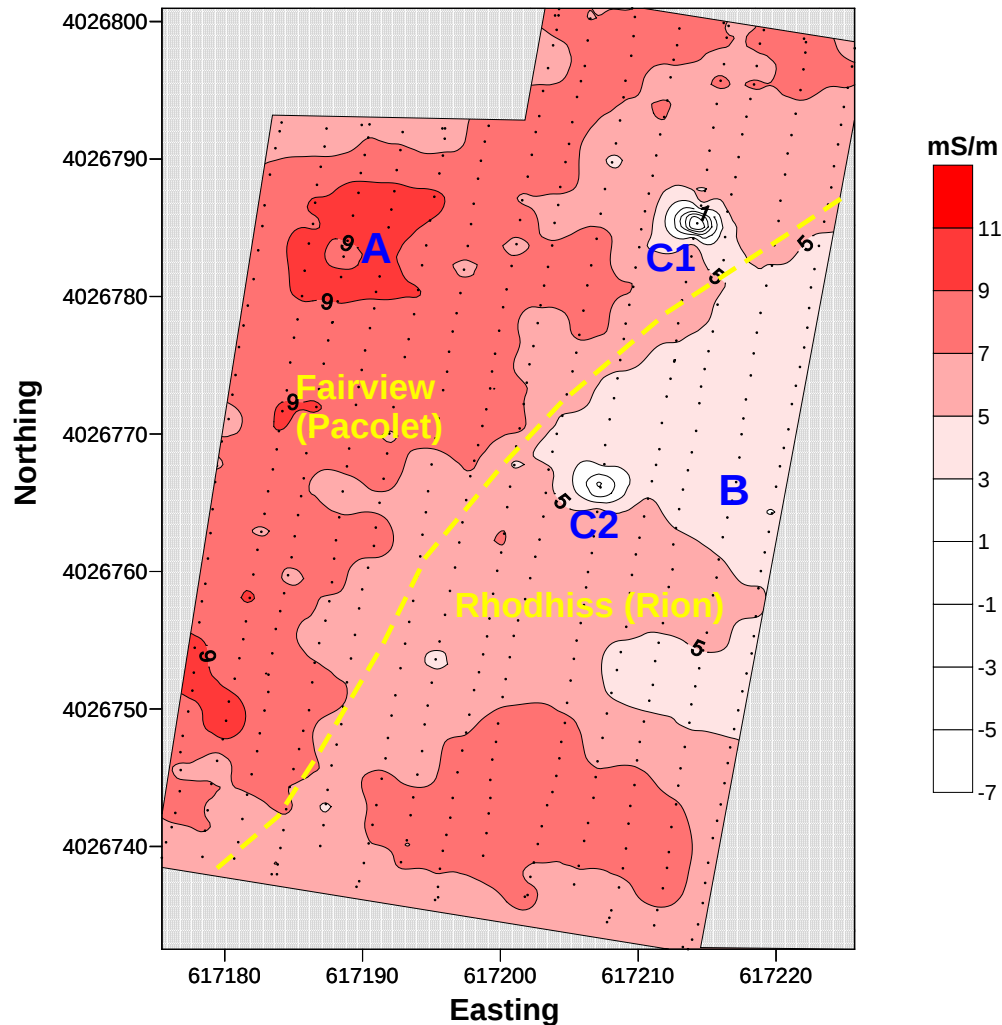


Figure 2 – Apparent conductivity measured with the EM38 meter in an area of Fairview (Pacolet) and Rhodhiss (Rion) soils. The soils are located on 2 to 8 percent slopes. Apparent conductivity values were measured in mS/m (millisiemens/meter).

Results:

A total of 587 measurements were recorded with the EM38 meter. In the vertical dipole orientation apparent conductivity averaged 6.5 mS/m and ranged from -12.4 to 10.4 mS/m. One-half of the observations had an apparent conductivity between 5.6 and 7.6 mS/m.

Changes in apparent conductivity were thought to be associated with changes in soil characteristics across the survey area. Areas of higher apparent conductivity were associated with thicker subsoils containing more clay and moisture. Soil borings at “A” revealed a thicker subsoil containing clay, clay loam and sandy clay loam textures (Fairview soils) with subsoil depths in excess of 100 cm, as compared to soil borings observed at “B”. Soil borings at “B” revealed a thinner sandy clay loam subsoil (Rhodhiss soils) with saprolite (sandy loam) occurring at 75 cm. A dashed yellow line approximates the soil boundary between Fairview soils (formerly Pacolet soils) and Rhodhiss soils (formerly Rion soils) and is consistent with

interpretations from resulting apparent conductivity spatial patterns across the site. Anomalous spikes in conductivity at “C1” and “C2” were thought to be attributed to buried metal objects and metal debris.

Associated changes in spatial patterns across site 2 suggest slightly more diversity between soils and soil characteristics as compared to site 1. Soil borings supported this assumption.

GPR

Survey Setup and Design

Multiple GPR transect lines were established across all plots at the two sites. A total of 52 plots were individually surveyed. Typical plot size was 5.75 m x 15 m (19 ft x 50 ft). Surveys were completed with a 200 MHz antenna. A calibration procedure was conducted to ensure consistent and accurate depth estimations. Based on a measured depth (50 cm) to a buried metal reflector, the velocity of propagation through relatively moist sandy loam/sandy clay loam was estimated to be about 0.098 m/ns at site 1 and 0.080 m/ns at site 2 (behind main office). The dielectric permittivity was 9.36 at site 1 and 13.89 at site 2.

Results

Radar records obtained with the 200 MHz antenna were generally of good to excellent interpretative quality. Observation depths were in excess of 2.5 m. Higher rates of signal attenuation (isolated areas) were thought to be attributed to increased amounts of clay and moisture within the soil profile. Soil borings confirmed an increase in clay and moisture in areas containing higher attenuation rates.

Figures 1 and 2 are representative GPR records collected at site 1. In *Figure 1*, soil borings at **A** revealed a contrasting layer of very moist clay at 78 cm which is consistent with GPR interpreted depths to the high amplitude linear feature observed in the radar record at this location. Higher rates of signal attenuation (loss of signal) observed at **B** along the radar record were thought to be attributed to increase in clay and moisture. Soil borings at **B** revealed a localized area (inclusion) within the plot containing higher amounts of clay in the subsoil estimated to be in excess of 50 percent clay and extending to a depth of approximately 75 cm.

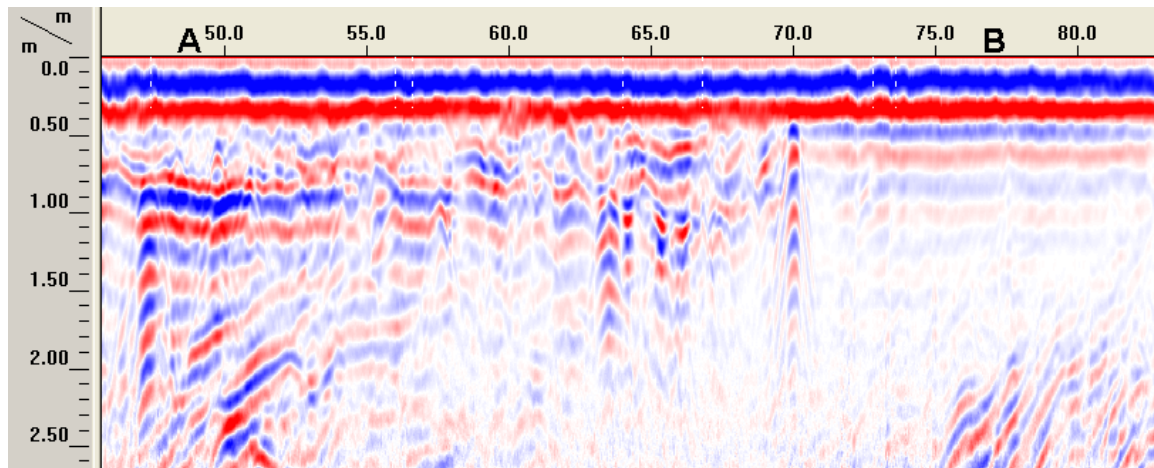


Figure 1. Representative radar record from an area of Casville soils, measured with the 200 MHz antenna at site 1. Scale is in meters. Depth scale is exaggerated.

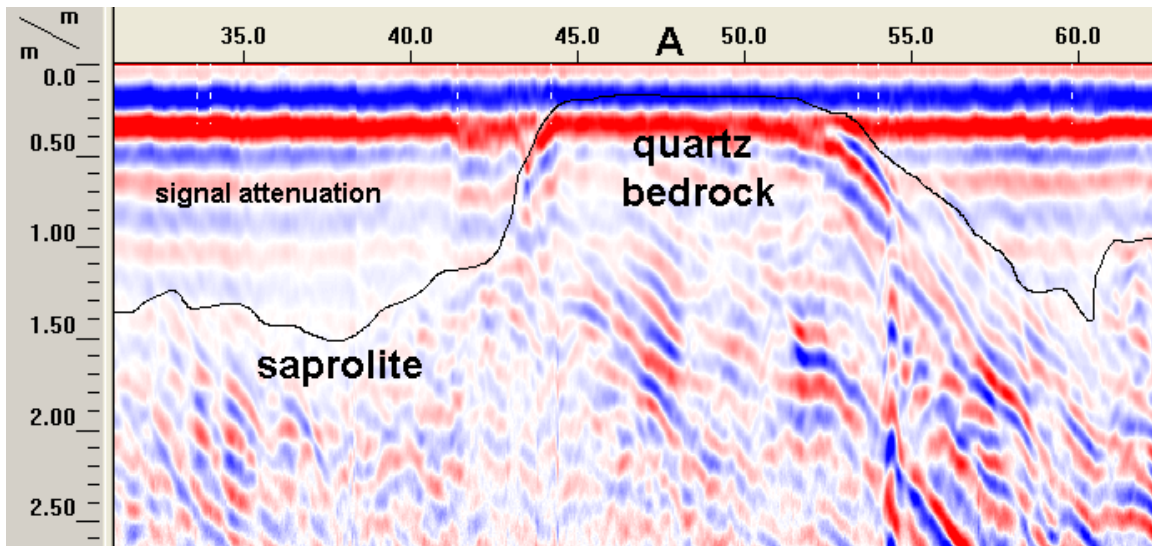


Figure 2. Representative radar record from an area of Casville soils, measured with the 200 MHz antenna at site 1. Scale is in meters. Depth scale is exaggerated.

In Figure 2, soil borings at A revealed hard quartz bedrock encroaching towards the surface. Bedrock occurred at a depth of 25 cm. The feature was localized on the radar record suggesting that the shallow soil component was a small isolated inclusion within the map unit. Higher rates of signal attenuation (horizontal banding) can be observed between 45 cm and 100 cm on the left-hand and right-hand portions of the radar record and are thought to result from higher amounts of clay and moisture in the upper soil profile.



Photo 4. A GPR survey is being conducted with a 200 MHz antenna across an area of Casville soils at site 1. GPR was used to determine depths to contrasting subsurface features such as bedrock and saprolite.

Figures 3 and 4 are representative GPR records collected at site 2 (behind main office). In Figure 3, soil borings at A revealed soft bedrock occurring at depths of approximately 80 cm to 90 cm which is consistent with GPR interpreted depths to the higher amplitude feature observed in the radar record. A black line highlights the soil/bedrock contact. The higher amplitude feature ends abruptly in the radar record. This was consistent with soil borings taken at B where bedrock was not encountered within 1.5 m.

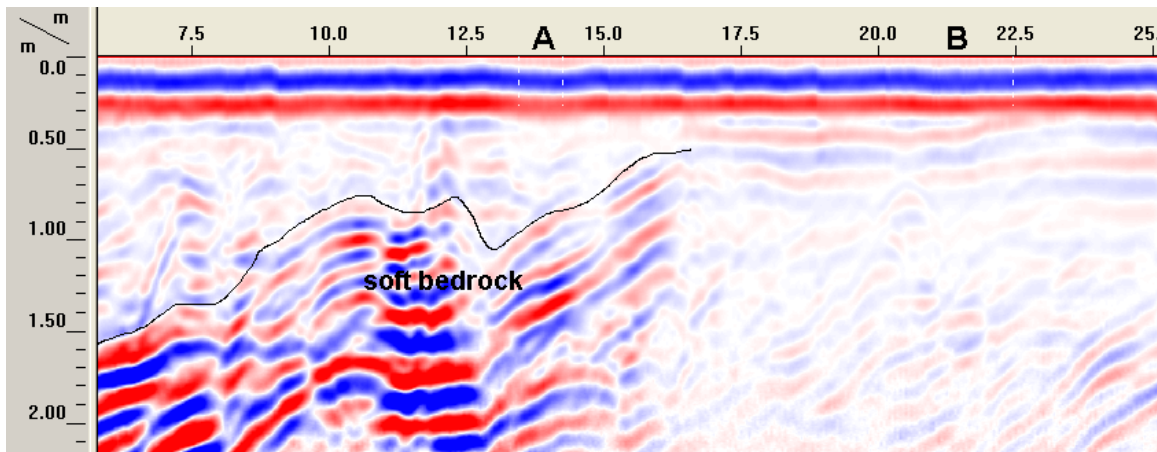


Figure 3. Representative radar record from an area with soft bedrock occurring at less than 1 m from the surface (inclusion of Stott Knob soils (A)) and Rhodhiss soils (B), measured with the 200 MHz antenna at site 2 (behind main office). Scale is in meters. Depth scale is exaggerated.

In Figure 4, soil borings at A revealed a very deep soil profile (Fairview soils) with saprolite occurring at a depth of approximately 1 m which is consistent with GPR interpreted depths at this location.

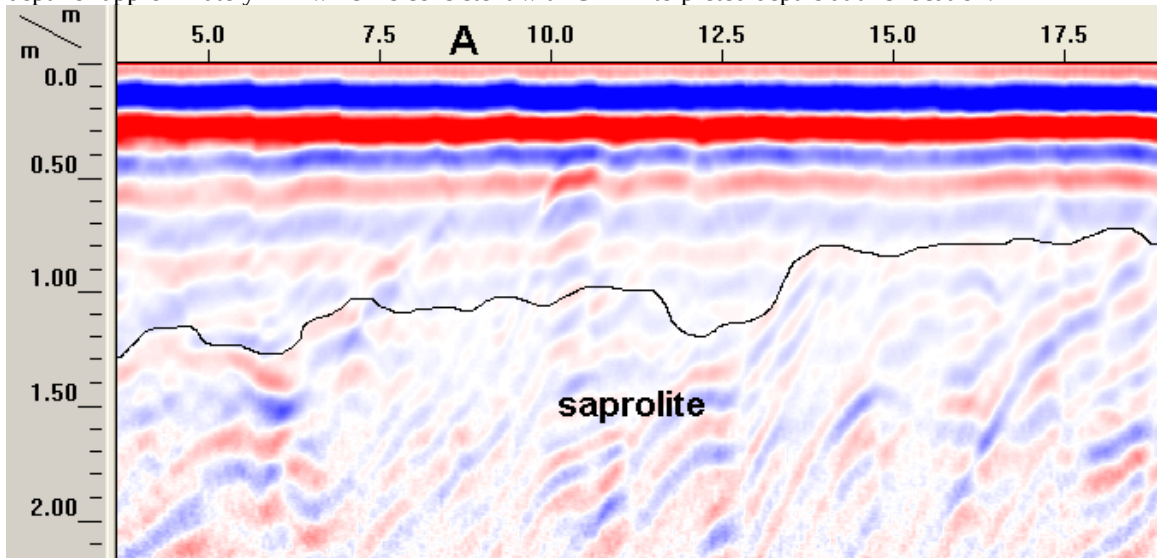


Figure 4. Representative radar record from an area of Fairview soils, measured with the 200 MHz antenna at site 2 (behind main office). 1. Scale is in meters. Depth scale is exaggerated.

Follow-up GPR and EMI surveys may be needed during drier soil conditions to assess changes in EMI spatial patterns and to collect additional GPR records while further addressing questions arising from this investigation.

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<http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx>