United States Department of Agriculture

Natural Resources Conservation Service

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Subject: SOI – Geophysical Field Assistance **Date:** 14 November 2011

To: John Chibirka
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Purpose:
To explore the potentials of using electromagnetic induction (EMI) to map differences in soil mineralogy and heavy metals in areas of serpentine soils.

Participants:
John Chibirka, Soil Scientist, USDA-NRCS, Leesport, PA
Jim Doolittle, Research Soil Scientist, USDA-NRCS, Newtown Square, PA

Activities:
All field activities were completed during on 31 October 2011.

Summary:

1. The affects of serpentinite rock on electromagnetic induction responses have been limitedly studied and are largely unknown. State-of-the-art EMI meters allow the simultaneous collection of quadrature and inphase data, as well as apparent conductivity. The inphase component is often referred to as the "metal detection" component, as it is sensitive to ferromagnetic materials. This study will attempt to increase our knowledge of EMI responses over serpentinite rocks and in the presence of naturally occurring heavy metals.

2. The brief preliminary surveys documented in this report find very anomalous EMI responses over soils formed in residuum weathered from serpentinite rock. Spatial patterns of apparent conductivity and inphase data may provide a means to differentiate soils formed over different lithologies, assess mineralogical composition of soils, and detect concentrations of naturally occurring heavy metals (Cr and Ni).

3. 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 sampling). The use of geophysical methods can reduce the number of coring observations, direct their placement, and supplement their interpretations. Interpretations contained in this report need to be verified by ground-truth observations.

4. Further studies are warranted. It is proposed that the "field site" be returned to at a later date and data collected with both the Profiler and an EM38MK2 meter. Data from these two meters will be compared. Using the measured EMI data and a response surface sampling design model, the site will be

returned to and small grab samples will be collected from the 0 to 30 and 30 to 60 cm soil depths using a soil auger at 12 points within the surveyed area. These samples will be sent to Richard Shaw (New Jersey State Soil Scientist) for an analysis of heavy metals using an Olympus portable XRF (X-ray fluorescence). Correlations analysis will be performed on the EMI and XRF data and a report filed.

With kind regards,

James A. Doolittle
Research Soil Scientist

Equipment:
A Profiler EMP-400 sensor (Geophysical Survey Systems, Inc.; Salem, NH) was used in this study[1]. This meter requires only one person to operate and does not require ground contact. The Profiler EMP-400 sensor (here after referred to as the Profiler) has a 1.22 m (4.0 ft) intercoil spacing and operated at frequencies ranging from 1 to 16 kHz. Lateral resolution is approximately equal to the intercoil spacing. The Profiler is a multifrequency EMI meter that can simultaneously collect data at three discrete frequencies. For each frequency, inphase and the quadrature phase component data are recorded as well as apparent conductivity (EC_a). The calibration of the Profiler is optimized for 15 kHz. At this frequency, EC_a is most accurately measured (Dan Delea, GSSI, personal communication). A rechargeable Li-ion battery pack powers the sensor. Surveys can be conducted with the sensor held in the shallower-sensing (0 to 90 cm), horizontal dipole (HDO) or deeper sensing (0 to 180 cm), vertical dipole (VDO) orientations. The sensor's electronics are controlled via Bluetooth communications with a TDS RECON-400 Personal Data Assistant (PDA). To collect geo-referenced data, the PDA is configured with an integral 12-channel WAAS (Wide Area Augmentation System) GPS.

To help summarize the results of the EMI surveys, the SURFER for Windows (version 10.0) software (Golden Software, Inc., Golden, CO) was used to construct the simulations shown in this report. [1]

Background
Serpentinite rock outcrops in portions of southeastern Pennsylvania and north-central Maryland. Serpentinite is a Mg-rich, sub-siliceous rock, which is formed principally through the metamorphic alteration of dunite, peridotite, or pyroxenite, and comprised of antigorite, chrysotile, and lizardite serpentine minerals (Istok and Hayward, 1982). Soils formed over serpentine have low Ca/Mg ratios, are low in essential nutrients, and have high concentrations of heavy metals (nickel and chromium) that are toxic to many plant species. Unique plant communities grow on these soils. These unique plant communities contain few species that are common in the surrounding forest or fields. Known as *serpentine barrens,* prairie grasses, greenbrier, and pitch pines are the dominant communities.

In Chester County, moderately deep, well-drained Chrome soil has been mapped on the serpentine barrens (Kunkle, 1963). The Chrome is a rare and unique series and is a member of the fine, mixed, superactive, mesic Typic Hapludalfs taxonomic family. However, the taxonomic classification, in particular the mineralogy, of this series is being reexamined. The deep, moderately well to somewhat poorly drained Conowingo soils also form in materials weathered from basic rocks high in magnesium, usually serpentine, and are members of the same catena as Chrome. The Conowingo series is a member of the fine-loamy, magnesic, mesic Aquic Hapludalfs taxonomic family.

Typically, electromagnetic induction (EMI) surveys have focused on the electrical properties of earthen materials and neglected the magnetic properties. An EMI sensor generates a primary electromagnetic field that induces eddy currents in the soil. The strength of these currents is measured in the inphase and quadrature phase wave components. The component that is in phase with the primary electromagnetic field is referred to as the *inphase component*. The other component, which is always 90° out of phase with the primary electromagnetic field, is referred to as the *quadrature component*. Inphase and quadrature phase data are expressed in parts per million (ppm).

The inphase component is strongly influenced and is considered proportional to the magnetic susceptibility (χ) of the soil materials. The magnitude of the inphase response can therefore be used to infer χ. Magnetic susceptibility is a measure of the ease with which earthen materials are magnetized when subjected to electromagnetic fields. Magnetic susceptibility influences all EMI data to some extent, but, in most soils, the affects are generally small. However, in areas of serpentinite rocks and serpentine soils, the affects of magnetic susceptibility are assumed high.

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

The magnetic properties of soils principally reflect the affects of soil mineralogy (Magiera et al., 2006). For most soils, magnetic susceptibility is low, its affects on electromagnetic field strengths minimal, and its presence generally ignored. However, some ferromagnetic minerals, such as maghemite, magnetite, titanomagnetites magnetite, siderite, hematite, ilmenite, pyrrhotite, and chromite, exhibit noticeable levels of magnetic susceptibility (Takahashi et al., 2011; van Dam et al. 2004; Mullins, 1977). Magnetic susceptibility depends on the concentration, size, and shape of these minerals and the method of measurement (Mullins, 1977). Magnetic susceptibility has been associated with several soil properties including parent material, soil age, particle size, organic matter and soil moisture contents (Maier et al., 2006; van Dam et al. 2004; Mullin, 1977).

Under conditions known as operating under *low induction numbers*, the quadrature phase component is linearly related to the apparent conductivity (EC_a) of the soil. The Profiler automatically converts data recorded in the quadrature phase into apparent conductivity. 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 produced by changes in the electrical conductivity of earthen materials. The electrical conductivity of soils is influenced by the volumetric water content, type and concentration of ions in solution, amount and type of clays in the soil matrix, and temperature and phase of the soil water (McNeill, 1980). The apparent conductivity of soils increases with increased soluble salts, water, and clay contents (Kachanoski et al., 1988; Rhoades et al., 1976).

Areas of Chrome and Conowingo soils are suspected to exhibit conspicuous levels of magnetic susceptibility. To measure magnetic susceptibility, a magnetometer is typically used. However, EMI sensors can be used as a surrogate to infer levels of magnetic susceptibility. Early EMI sensors, such as the EM38 meter, could only measure one component (inphase phase or apparent conductivity) at a time. As a consequence, operators mostly opted to measure the EC_a and therefore the inphase component was seldom measured. This has lead to a lack of understanding of the affects of magnetic susceptibility on EMI data. The objective of this study is to use EMI in areas of Chrome and Conowingo soils to attain a better understanding of its response in areas of serpentinite rocks.

Study Sites:

The study sites are located in Nottingham County Park. The park is located near the town of Nottingham in extreme southwestern Chester County near the Maryland state line. Figure 1 is a soil map of a portion of Nottingham County Park showing the areas that were surveyed. An EMI survey was conducted across a hay land and a cultivated field of corn. This survey area is identified by segmented lines that form its boundaries. A second survey was conducted near the Park Office (see “A” in Figure 1). A seepage area has developed immediately west of the Office and park officials requested an EMI survey of the area.

Field Methods:

The Profiler was properly calibrated according to instructions prior to conducting a pedestrian surveys at each of the sites. The Profiler was operated in the deeper-sensing, vertical dipole orientation (VDO) and at a frequency of 15000 Hz. The instrument was operated in the continuous mode with measurements recorded at a rate of 1/sec. The long axes of the meter was orientated parallel to the direction of traverse, and held, where possible, about 5 cm above the ground surface.

During the survey of the two fields, Bluetooth communication was lost. The Profiler was turned “off” then “on”, and Bluetooth communication between the Profiler and the PDA was restored. Unknown to the operator was the fact that all data recorded prior to the communication failure was lost. As a consequence, only data from the higher-lying corn field were recorded; the data from the hay land was lost. The cultivated field is largely mapped as Glenelg silt loam on 3 to 8 % slopes (GgB) and 8 to 15 % slopes (GnC), but does contain a small strip of Chrome silt loam on 8 to 15 % slopes, moderately eroded (ChC2) along its southern boundary (see Figure 1). The very deep, well drained Glenelg soils formed in residuum weathered from micaceous schist. Glenelg series is a member of the fine-loamy, mixed, semiactive, mesic Typic Hapludults family. The hay land is mapped as Chrome silt loam on 8 to 15 % slopes, moderately eroded (ChC2).

Figure 1. This soil map of the areas surveyed in Nottingham County Park is from the Web Soil Survey

Results:

Corn Field:

Basic statistics for the EMI data collected in the cultivated field at Nottingham County Park are provided in Table 1. The large number of negative values measured in the quadrature phase and apparent conductivity suggest very resistive soil materials, presence of metals, and/or improper calibration. Calibration guidelines were followed, but the site selected for calibration may have been unsuitable. The magnitude of the inphase response is anomalous and suggests the presence of ferromagnetic materials.

Table 1. Basic Statistics for the EMI Data measured with the Profiler in the Fields at Nottingham County Park

	Inphase (ppm)	Quadrature (ppm)	EC_a (mS/m)
Number	1602	1602	1602
Minimum	-2705	-1002	23.05
25%-tile	4407	-555	-12.66
75%-tile	7263	-88	-2.03
Maximum	17285	877	19.96
Mean	6112	-277	-6.33
Std. Deviation	2576	342	7.79

Figure 2 contains plots of spatial apparent conductivity (left-hand plot) and inphase (right-hand plot) patterns across the field. The soil boundary lines have been digitized from Web Soil Survey data[2]. It is unfortunate that, for comparative purposes, the lower-lying, hay field data, which included a large area of Chrome soils, were lost. In Figure 2, the lower portion of each plot is considered a transitional area between soils formed over

[2] Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at http://websoilsurvey.nrcs.usda.gov/ accessed [11/7/2011].

schist and serpentinite. Each plot provides a slightly different perspective of the surveyed area. Comparing the two plots, areas of Chrome soils have noticeably higher EC_a and lower inphase values than areas of Glenelg soils. Differences in lithology and mineral logy are believed to be the principal factors responsible for these dissimilarities. Linear pattern evident in the plot of EC_a , and to a certain extent in the plot of inphase data, are believed to be the result of tillage or other management practices (e.g., grassed waterway, tiles, erosion). High spatial variability in soil mineralogy and underlying lithology is suggested by the intricate spatial patterns in the inphase data.

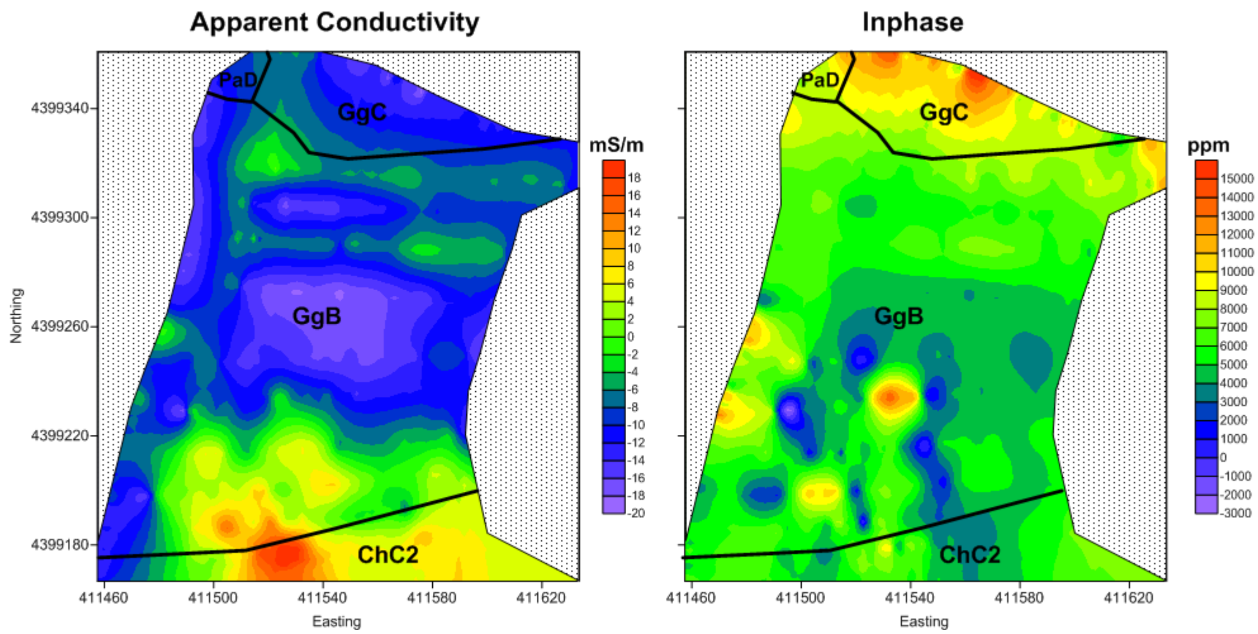

Figure 2. Spatial EC_a (left-hand) and Inphase (right-hand) data are shown in these plots of the Cultivated Field that adjoins Nottingham County Park.

<u>Grounds near the Park's Office:</u>
A seepage area has recently developed in the lawn of the Park Office adjacent to the park's entrance road (Whippoorwill Drive). A cursory EMI survey was performed in the area south of Park Road. The survey area is located in an area of Neshaminy silt loam, very deep over mafic gneiss on 3 to 8 % slopes (NvB). The deep and very deep, well drained Neshaminy soils formed in materials weathered from diabase and other dark colored basic rocks. Neshaminy series is a member of the fine-loamy, mixed, superactive, mesic Ultic Hapludalfs family.

Table 2. Basic Statistics for the EMI Data measured with the Profiler near the Park Office at Nottingham County Park

	Inphase (ppm)	Quadrature (ppm)	EC_a (mS/m)
Number	630	630	630
Minimum	-10544	-2814	-64.08
25%-tile	3584	-1146	-26.12
75%-tile	7790	-682	15.56
Maximum	73026	11905	271.03
Mean	9015	-754	-17.19

Basic statistics for the EMI data collected at this site are provided in Table 2. Once again, a large number of unusually high positive and negative values were measured in the inphase, quadrature phase, and apparent conductivity. These values are considered anomalous and suggest very resistive soil materials and the presence of heavy metals and ferromagnetic materials. In addition, park artifacts, buried utility lines and other cultural features produced anomalous responses that are evident in the spatial EMI data.

Figure 3 contains plots of spatial inphase (upper plot) and apparent conductivity (lower plot) patterns across the investigated area. Each plot provides a slightly different perspective of the surveyed area. The general locations of the entrance road and Park Office have been identified in each plot. In each plot, the approximate position of the seepage area is indicated by the circle with an enclosed letter "S". The inphase data are noticeably affected by objects (e.g., utility lines) buried beneath Park Road (A) and a monument (B) near the park entrance.

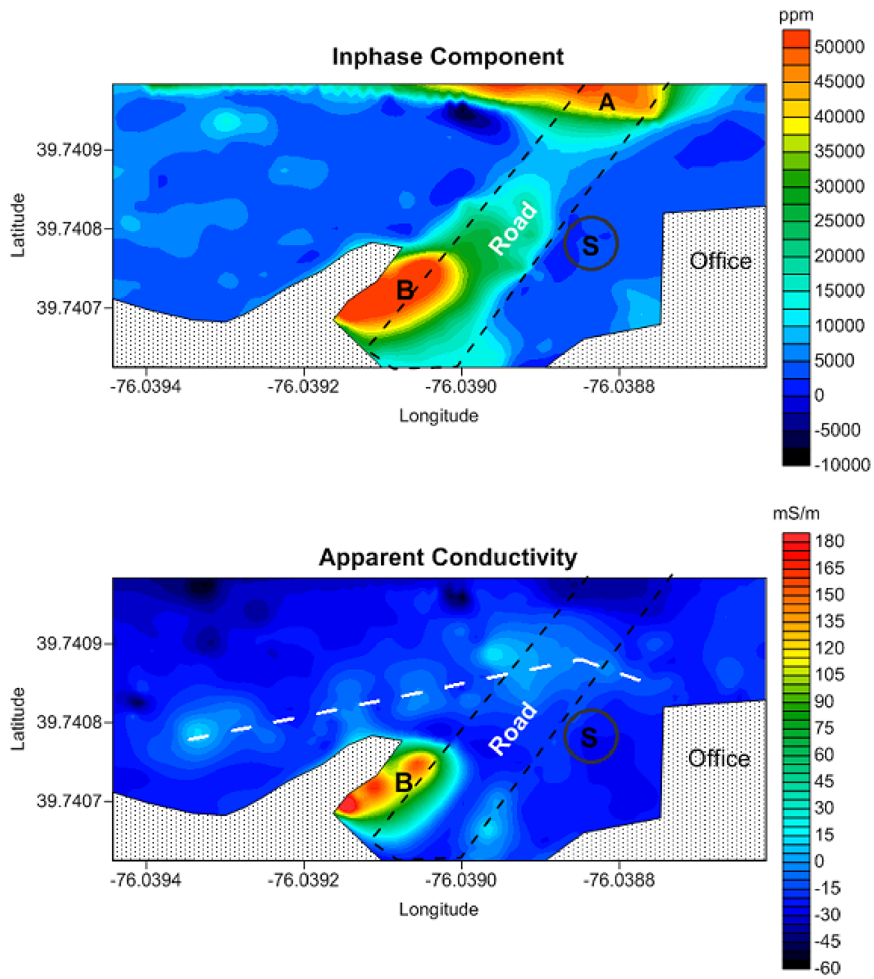

Figure 3. Spatial Inphase (upper) and EC_a (lower) data are shown in these plots of the area near the Nottingham County Park's Office.

In the lower plot shown in Figure 3, a white-colored, dashed line has been drawn to bring attention to a segmented linear pattern that stretches east to west across the survey site and appears to terminate near the seepage area. The feature(s) that are responsible for this spatial pattern is unknown. The limited size of the study area restricts further analysis and comparison with other spatial patterns.

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