United States Department of Agriculture

NRCS

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SUBJECT: MGT – Trip Report - Geophysical Assistance

April 16, 2013

TO: Deena M. Wheby
Acting State Conservationist
NRCS, Annapolis, Maryland

File Code: 330-20-7

Purpose:
Ground-penetrating radar (GPR), electromagnetic induction (EMI) and Portable X-ray fluorescence (P-XRF) methods were used to characterize soils formed over serpentinite in the *Soldiers Delight Natural Environmental Area*, Owings Mills, Maryland. This information will be used to improve MLRA data map unit's interpretations and develop Ecological Site Descriptions for soils formed on serpentinite.

Participants:
Dean Cowherd, Acting State Soil Scientist, NRCS, Annapolis, MD
Jim Doolittle, Research Soil Scientist, NSSC, NRCS, Newtown Square, PA
Aaron Friend, Soil Scientist, NRCS, Frederick, MD
David Verdone, Acting MLRA Project Leader, NRCS, Frederick, MD

Activities:
Field activities were completed during the period of February 19-21, 2013.

Summary:

1. In the areas traversed with GPR, soils are dominantly shallow (96 %) with minor inclusions of moderately deep soils (4 %). Based on 35,551 radar measurements, the average depth to serpentinite within the traversed areas is only 25.1 cm with an estimated range of 0.0 to 76.2 cm.

2. Measurements obtained with an EMI meter at two sites within the *Soldiers Delight Natural Environmental Area* were highly variable and, on the resulting computer simulations, spatial patterns had a noticeable pockmarked appearance with a large number of small, isolated areas of exceedingly high and low values. These spatial patterns are characteristic of soils formed over serpentinite. However, at one site, spatial patterns were disrupted and masked by interference caused by overlying power lines.

3. Using EMI data and a response surface sampling design model, twelve sampling points were identified. Soil samples were collected from surface layers (0 to 30 cm depth interval) at each of these sampling points. These samples were forwarded to Edwin Muniz, Assistant State Soil Scientist, NRCS in Somerset, New Jersey, for analysis using an X-ray fluorescence spectrometer. For the soil samples collected at the 12 optimal sampling points, the concentrations of different metals vary over several orders of magnitude. The eight most abundant metals in the surface layer were identified as Fe, P, K, Ti, Cr, Ni, Mn and Ca.

4. Low correlations were obtained between the measured EMI response (apparent conductivity, in-phase response and apparent magnetic susceptibility) and the concentration of heavy metals in the surface layers. The low correlations are attributed to electrical interference from power lines that overlie the study site. In future studies, only sites free from electrical interference and overloading will be selected for similar studies.

It was the pleasure of Jim Doolittle and the National Soil Survey Center to be of assistance to you and your fine staff.

ACTING

DAVID R. HOOVER
Acting Director
National Soil Survey Center

Attachment (Technical Report)

cc:
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Technical Report on Geophysical Investigations conducted within the Soldiers Delight Natural Environmental Area, Owings Mills, Maryland

James A. Doolittle
February 19-21, 2013

Background

Serpentinite rock outcrops in a belt of ultramafic rocks that extends from Newfoundland, Canada, to Alabama, USA. In Maryland, bodies of ultramafic rocks form a slightly curved, discontinuous arch that extends across the Piedmont from western Montgomery County into northwestern Cecil County (Means, 2010). At the boundary between neighboring ultramafic and higher silica rocks, noticeable changes in soils, mineralogy and vegetation can be observed. Soils formed over serpentinite have low Ca/Mg ratios, are low in essential nutrients, and have high concentrations of heavy metals (i.e., nickel and chromium) that are toxic to many plant species. As a consequence of these conditions, unique plant communities grow on these soils. These unique plant communities contain few species that are common with the species found in the surrounding forest or fields. Known as *serpentine barrens,* prairie grasses, greenbrier, and pitch pines are dominant plant communities.

In areas of serpentinite rocks and residuum, the magnetic properties of soils are elevated and affect the use of both ground-penetrating radar (GPR) and electromagnetic induction (EMI) methods. Strongly magnetic soils have significant concentrations of ferromagnetic minerals, such as magnetite, maghemite and titanomagnetite, and to a lesser degree pyrrhotite and chromite (Takahashi et al., 2011; van Dam et al. 2004; 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).

The purpose of this study was to extend the geophysical study of serpentine soils that was begun in Nottingham Park in Chester County, Pennsylvania, to the Soldiers Delight Natural Environmental Area in Baltimore County, Maryland. Ground-penetrating radar was used to chart the depth to bedrock across different serpentine soil map units. Electromagnetic induction was used to map the spatial variability of apparent conductivity (EC_a), in-phase response (IP) and magnetic susceptibility (MS) across different serpentine soil map units. Results of this investigation will be presented at the 2013 National Cooperative Soil Survey National Conference, in Annapolis, Maryland (June 16-20, 2013).

Study Area:

The Soldiers Delight Natural Environmental Area (SDNEA) is located on the Northern Piedmont near Owings Mills, Maryland, and contains about 1,900 acres of protected "serpentine barrens" that are part of the Maryland Wildlands Preservation System. The site is protected because of the presence of serpentine soils and over 39 rare, threatened, or endangered plant species. Serpentine soils form in regolith weathered from serpentinite, a green-colored, ultramafic rock that formed principally through the metamorphic alteration of dunite, peridotite, or pyroxenite (Istok and Hayward, 1982). Serpentinite contains low quantities of silicon and high amounts of magnesium and iron (Means, 2010). The ultramafic rocks at SDNEA are part of a larger, tectonically emplaced, layered intrusion known as the Baltimore Mafic Complex (Crawford et al., 1999).

Soils formed over serpentinite have high Mg and low Ca levels (and consequently low Ca/Mg ratios that decrease with depth), are low in essential nutrients, and have high concentrations of heavy metals (i.e., Cr, Ni) that are toxic to many plant species (Burgess et al., 2009; Rabenhorst et al., 1982; Rabenhorst and Foss, 1981). Unique plant communities grow on serpentine soils. Known as "*serpentine barrens",* prairie grasses, greenbrier, and pitch pines are the dominant plant communities. Serpentine soils are

typically stony and nutrient-poor. Sparsely vegetated, these soil-landscapes are known as *serpentine barrens*.

Two study sites were selected within SDNEA. Study Site 1 is located along the right-of-way of a power line (34.4202 ° N latitude, 76.8409 ° W longitude). In general, it is considered unwise to conduct EMI surveys beneath power lines because of electrical interference. However, the right-of-way was accessible, opened to sampling, and mowed and cleared of dense vegetation that would obstruct EMI and GPR surveys. This site will be visited during the 2013 National Cooperative Soil Survey National Conference tour. The site is located in an area of Chrome silt loam on 3 to 8 (map unit CeB), 8 to 15 (CeC) and 15 to 25 (CeD) percent slopes. The moderately deep, well-drained Chrome (fine, mixed, superactive, mesic Typic Hapludalfs) formed in residuum weathered mostly from serpentinite in the Northern Piedmont.

Study Site 2 (34.4208 ° N latitude, 76.8308 ° W longitude) is located in an area of Chrome silt loam on 3 to 8 (CeB) and 8 to 15 (CeC) percent slopes and Travilah silt loam on 8 to 15 percent slopes (TrC). The moderately deep, somewhat poorly drained Travilah (fine-silty, mixed, active, mesic Aquic Hapludalfs) soils formed in residuum weathered mostly from serpentinite in the Northern Piedmont.

Equipment:
The EMI meter is the EM38-MK2 meter, manufactured by Geonics Limited (Mississauga, Ontario). [1] Operating procedures for the EM38-MK2 meter are described by Geonics Limited (2007). The EM38-MK2 meter operates at a frequency of 14.5 kHz and weighs approximately 5.4 kg (11.9 lbs). The meter has one transmitter coil and two receiver coils, which are separated from the transmitter coil at distances of 1.0 and 0.5 m. When measuring the apparent conductivity (EC_a) of soils, this configuration provides two nominal exploration depths of 1.5 and 0.75 m when the meter is held upright in the vertical dipole orientation (VDO), and 0.75 and 0.40 m when the meter is held on its side in the horizontal dipole orientation (HDO).

The in-phase (IP) response of EMI sensors has been used to measure and infer the magnetic properties of soils (Dalan, 2006). However, the interpretation of magnetic susceptibility from EMI data remains a challenge as a result of sensor drift (Tabbagh, 2009a), arbitrary "zero level" (North and Simms, 2007), more limited exploration depths (Dalan, 2006), and changes in the sign (±) of the response at certain depths and in relation to target position (Tabbagh, 1986). When operated in the VDO and the IP mode, Dalan (2006) and Tabbagh (2009b) reported that the EM38 meter has an effective penetration depth of only 40 to 50 cm.

The Geonics DAS70 Data Acquisition System was used with the EM38-MK2 meter to record and store both EMI and GPS data. The acquisition system consists of the EMI meter, an Allegro CX field computer (Juniper Systems, Logan, Utah), and a Trimble AgGPS 114 L-band DGPS (differential GPS) antenna (Trimble, Sunnyvale, CA).[1] With the acquisition system, the meter is keypad operated and measurements are automatically triggered. The RTmap38MK2 software program developed by Geomar Software Inc. (Mississauga, Ontario) was used to record, store, and process the EMI and GPS data. [1]

An Innov-X, Delta Standard portable X-ray fluorescence (P-XRF) spectrometer (manufactured by Olympus of Woburn, Massachusetts) was used by the New Jersey Soils Staff to assess the concentration of different metals in the soil samples collected from Study Site 1.[1] Samples were scanned with the P-XRF operated in a bench-top mode.

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

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

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. A 400 MHz antenna was used in this study.

The SIR-3000 system contains a setup for the use of a GPS receiver with a serial data recorder (SDR). With this setup, each scan of the radar can be georeferenced (position/time matched). Following data collection, a subprogram within the RADAN for Windows was used to proportionally adjust the position of each radar scan according to the time stamp of the two nearest positions recorded with the GPS receiver. A Trimble AgGPS114 L-band DGPS (differential GPS) antenna (Trimble, Sunnyvale, CA) was used to collect position data.[1] Position data were recorded at a rate of one reading per second. The scanning rate of the GPR was 40 scan/sec.

The RADAN for Windows (version 6.6) software program (developed by GSSI) was used to process the radar records.[1] Processing included: header editing, setting the initial pulse to time zero, color table and transformation selection, signal stacking, horizontal high-pass filtration, migration, and range gain adjustments (refer to Jol (2009) and Daniels (2004) for discussions of these techniques). The *Interactive 3D Module* of RADAN was used to semi-automatically "*pick*" the depths to the interpreted bedrock surface on radar records. The picked data were exported to a worksheet (in an X, Y, and Z format; including longitude, latitude, and depth to bedrock).

Calibration of GPR:

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, bedrock surface) 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 equation [1] (after 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 equation [2] (after Daniels, 2004):

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

Where C is the velocity of light 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 affect on the E_r and v. Dielectric permittivity ranges from 1 for air, to 78 to 88 for water (Cassidy, 2009). Small increments in soil moisture can result in substantial increases in the E_r of soils (Daniels, 2004). At the time of this study, soils were very moist and a perched water table was observed in a relatively shallow excavated pit To establish a depth scale, a metal disc was buried in the excavated pit at a depth of 50-cm. Based on the two-way pulse travel time to this disc, a propagation velocity of 0.0620 m/ns and a dielectric permittivity of 23 were derived for the upper part of the soil.

The vertical resolution of GPR is dependent on the propagated wavelength (λ). Vertical resolution is generally considered about ¼ of the wavelength, however, as noted by Annan (2009), two features must be separated in time by at least ½ their wavelength to be identified on radar records. In general, if two features are separated by less than this amount, they will interfere in a constructive manner, resulting in a signal reflection that will be interpreted as a signal event. Vertical resolution is controlled by the returned

wavelength, which is determined by dividing the propagation velocity (v) by the antenna frequency (f) as shown in equation [3] (see Daniels, 2004):

$$\lambda = v/f \cdots\cdots [3]$$

The wavelength of a 400 MHz antenna, in a medium where its propagation velocity is 0.0620 m/ns, is about 15 cm. Two features must be separated by at least ½ this wavelength to be identified (about 7.5 cm). As a consequence, the soil/bedrock interface was difficult to interpret and could only be approximated where it occurred within 7.5 cm of the soil surface. In some place, rock fragments caused reflections that obscured the reflection from the soil/bedrock interface and made interpretations more challenging.

Field Procedures:
At both study sites, pedestrian surveys were conducted with the EM38-MK2 meter operated in the VDO. Walking in a back and forth manner across each site, 1,507 and 1,966 georeferenced EMI measurements were collected at Sites 1 and 2, respectively. At Study Site 1, twelve sampling points were selected by submitting the collected in-phase EMI data to the *Response Surface Sampling Design* (RSSD) program of the *ESAP* (*EC_e Sampling, Assessment, and Prediction*) software (Lesch, 2005; Lesch et al., 2000). The ESAP-*Response Surface Sampling Design* (RSSD) program was used to statistically select a small number of sample locations based on the observed magnitudes and spatial distribution of the in-phase EMI data. Within Study Site 1, based on the in-phase data, twelve optimal sampling points were identified and samples were collected from the 0 to 30 cm depth interval. At each of the sampling points, the soil magnetic susceptibility was determined following instructions contained in Geonics Limited (2007).

At Study Site 1, multiple GPR traverses were completed by pulling the 400 MHz antenna along the ground surface. Each radar traverse was stored as a separate file. The GPS option was used with the SIR-3000 system, and all radar scans were georeferenced.

Results:
GPR:
Eleven GPR transect of varying lengths were completed across Study Site 1. Following signal processing, the interactive module in RADAN for Windows was used to semi-automatically pick and laterally trace the soil/bedrock interface across each radar record. Figure 1 is a representative two-dimensional radar record from the study site. In Figure 1, the depth scale is expressed in meters and the horizontal scale is expressed in degrees of longitude and latitude. The white-colored, segmented line shown in Figure 1 represents the interpreted soil/bedrock interface. This surface varies in depth from about 25 to 55 cm. Within this depth range, the microtopography of this interface appears highly irregular. Along this interface, the reflected signal varies in amplitude from weak (red-colored) to high (white-colored). Differences in signal amplitude reflect variations in the contrast of dielectric properties across interfaces. Here, variations in signal amplitude are principally associated with differences in rock hardness and density, and moisture contents.

The radar record shown in Figure 1 provides an indication of the internal serpentinite structure. Though convulsed and broken in several sections, the GPR reflection patterns suggest noticeable linear trends and sheet-like structures in the bedrock architecture. These patterns are associated veins of dissimilar mineral compositions.

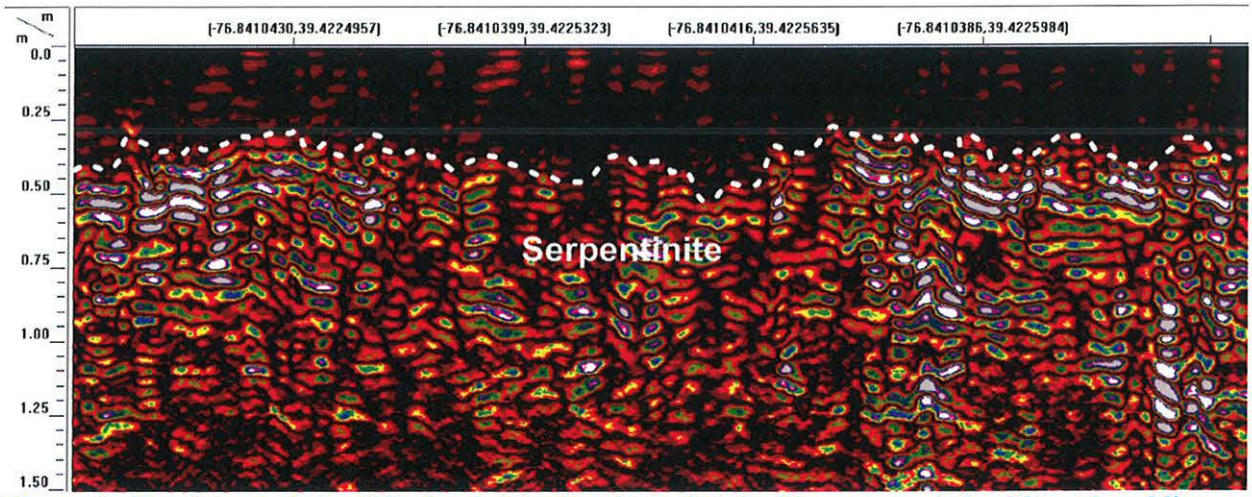

Figure 1. The interpreted soil/bedrock interface is depicted with a segmented, white-colored line on this radar record.

In the areas traversed with GPR, the soils are dominantly shallow (96 %) with minor inclusions of moderately deep soils (4 %). Table 1 summarizes the basic statistics for the depth to bedrock along each radar traverse. Based on 35,551 radar measurements, the average depth to bedrock within the traversed areas of Site 1 is 25.1 cm deep with an estimated range of 0.0 to 76.2 cm.

Table 1. Basic Statistics for the 11 radar traverses completed at Study Site 1 within the Soldiers Delight Natural Environmental Area.

Record #	Observations	Mean	Minimum	Maximum
3	1874	0.23	0.08	0.55
4	2290	0.16	0.00	0.41
5	2697	0.41	0.26	0.69
6	5105	0.41	0.13	0.76
7	1598	0.34	0.17	0.67
8	2115	0.20	0.02	0.47
9	5998	0.20	0.01	0.40
10	2860	0.30	0.16	0.58
11	3350	0.13	0.00	0.36
12	2482	0.18	0.00	0.48
13	5182	0.20	0.01	0.50

Figure 2 is a *Google Earth* image showing the distribution of soils by depth classes along the radar traverse lines that were completed within Study Site 1. Colors have been used to identify two different soil depth classes [shallow (0 to 50-cm) - white; moderately deep (50 to 100-cm) – red].

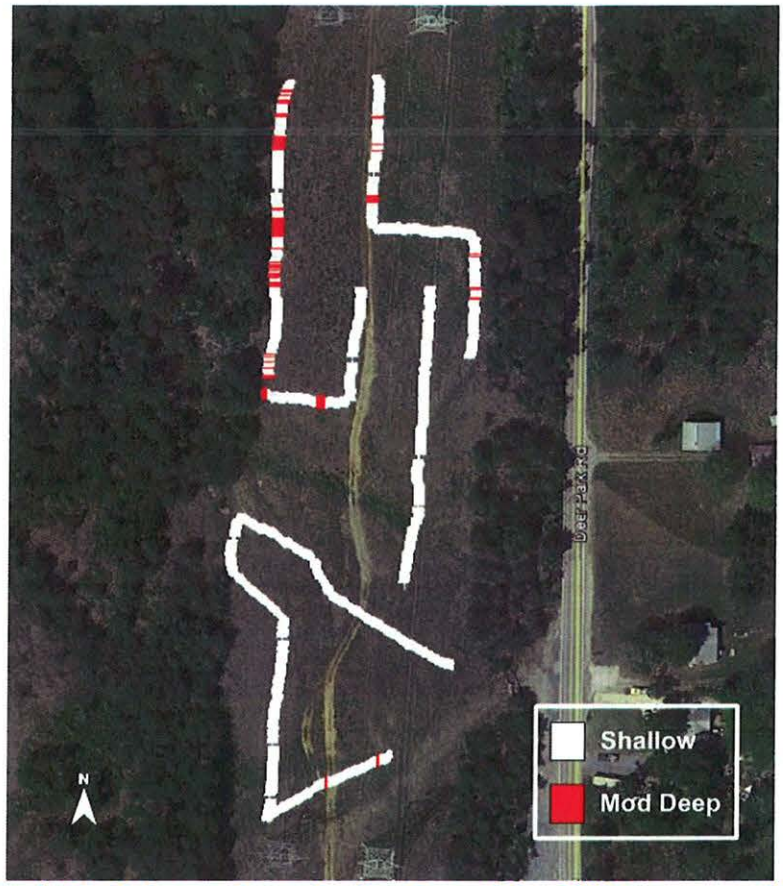

Figure 2. This Google Earth image shows the locations of the GPR traverses within Study Area 1. Major depth classes are indicated by color-codes used along each of these traverse lines. (Image courtesy of Brian Jones, GSSI)

EMI:

Site 1:

All EMI data collected at this site is suspected to have been affected by electrical interference stemming from the overlying power lines. Basic statistics for the EMI data collected at Site 1 are provided in Table 2. In general, apparent conductivity (EC_a) was low and relatively invariable across the study site. Apparent conductivity decreased with increasing depth (values are higher in the shallower-sensing 50-cm than in the deeper sensing 100-cm intercoil spacing). This was attributed to the thin mantle of highly weathered soil materials (having higher clay and moisture contents) overlying electrically resistive rock.

Table 2. Basic Statistics for the EMI Data measured with the EM38-MK2 at Study Site 1 within the Soldiers Delight Natural Environmental Area.

	EC_a-100	EC_a-50		IP-100	IP-50
Number	1507	1507		1507	1507
Minimum	-33.4	-61.3		-305.3	-708.1
25%-tile	7.8	12.7		-151.3	-492.5
75%-tile	10.9	18.4		82.2	-369.5
Maximum	61.6	43.2		137.7	-90.6
Mean	9.9	15.8		-113.8	432.4

For the shallower-sensing 50-cm intercoil spacing (nominal depth of 75 cm), the bulk averaged EC_a was 15.8 mS/m and ranged from -61.3 to 43.2 mS/m. However, one-half of the 1507 measurements were between only 12.7 and 18.4 mS/m. For the deeper-sensing 100-cm intercoil spacing (nominal depth of 150-cm), the bulk averaged EC_a was 9.9 mS/m with a range of -33.4 to 61.6 mS/m. However, one-half of the 1507 measurements were between 7.8 and 10.9 mS/m. For EC_a measurements collected with both intercoil spacings, the extreme values are believed to have been produced by artifacts scattered across the site and electrical interference from the power lines. However, the average values and inter-quartile ranges are considered representative of Chrome soils.

The IP data shown in Table 2 are considered indicative of serpentine soils. For the shallower-sensing 50-cm intercoil spacing, the bulk averaged IP response was 432.4 ppt (parts per thousand) with a range of -708.1 to -90.6 ppt. For the deeper-sensing 100-cm intercoil spacing (nominal depth of about 50-cm), the bulk averaged IP response was -113.8 ppt with a range of -305.3 to 137.7 ppt. These averaged values and ranges in IP values are considered indicative of soils formed over serpentinite, but are not commonly observed in relatively undisturbed soils developed over silica rocks. These extreme values are believed to reflect the affects of electrical interference and elevated levels of magnetic susceptibility in the soils.

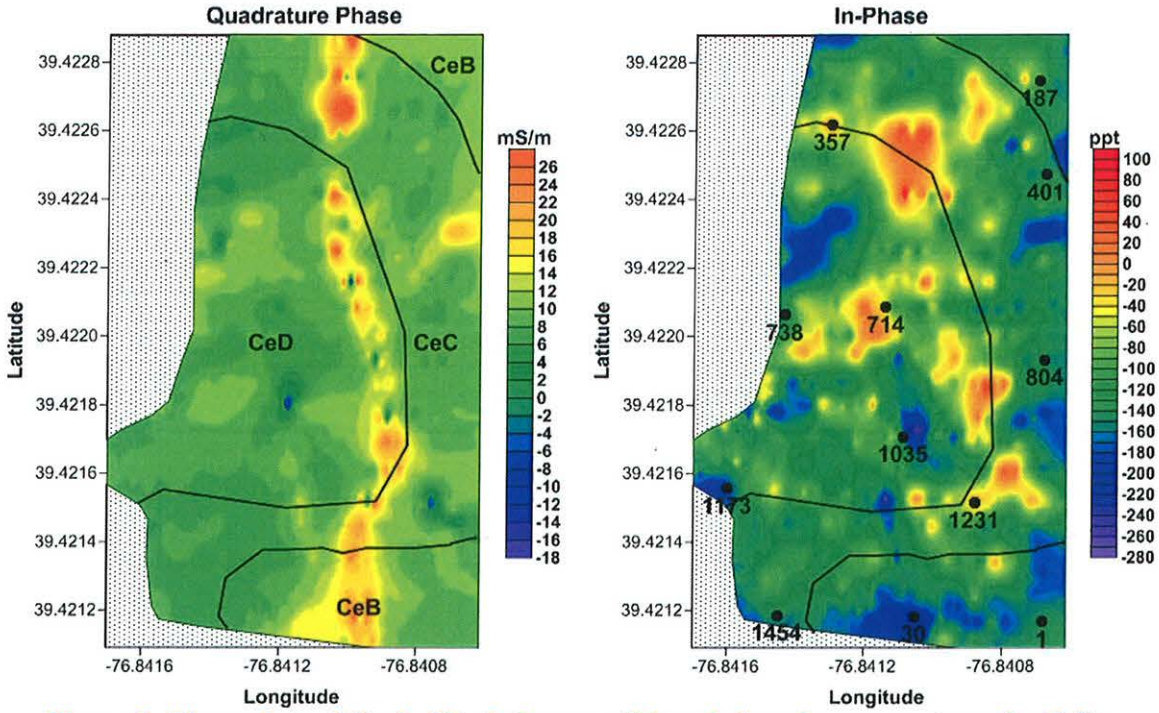

Figure 3. These plots of Study Site 1 show spatial variations in apparent conductivity (quadrature phase component) and susceptibility (in-phase component) for data collected with the 100-cm intercoil spacing of the EM38-MK2 meter. Soil lines have been imported from the Web Soil Survey.

Figure 3 contains plots showing the spatial distribution of apparent conductivity (left-hand plot) and in-phase (right-hand plot) measurements within the study site. In each plot, the boundaries of soil map units have been digitized from Web Soil Survey data.[2] A noticeable, linear pattern of higher EC_a measurements stretches from north to south across the left-hand plot in Figure 3. This pattern conforms

[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].

to the mid-line of two power transmission line sets. The linear pattern is an artifact produced by EMI signal interference. With the exception of this feature, EC_a measurements are relatively low and uniform across this site. This general pattern is disrupted by a few, small, isolated patches of higher and lower EC_a.

In general, IP measurements are highly variable across Study Site 1. The spatial IP patterns have a pockmarked appearance with a large number of small, isolated areas of exceedingly high and low IP values. These spatial patterns are characteristic of soils developed over serpentinite in the Northern Piedmont. Soils developed over serpentinite have a larger range and exhibit more irregular and unpredictable patterns of both IP and EC_a measurements than are commonly measured on non-serpentine soils.

Site 2:
Basic statistics for the EMI data collected at Site 2 are provided in Table 3. For the shallower-sensing 50-cm intercoil spacing, the bulk averaged EC_a was 8.2 mS/m and ranged from about -200.8 to 17.2 mS/m. However, one-half of the 1966 EC_a measurements were between 6.2 and 10.2 mS/m. For the deeper-sensing 100-cm intercoil spacing, the bulk averaged EC_a was 13.9 mS/m with a range of -6.9 to 25.8 mS/m. One-half of the 1966 measurements were between about 11.9 and 15.6 mS/m.

Table 3. Basic Statistics for the EMI Data measured with the EM38-MK2 at Study Site 2 within the Soldiers Delight Natural Environmental Area.

	Q-100	Q-50		I-100	I-50
Number	1966	1966		1966	1966
Minimum	-6.9	-200.8		-189.3	-376.7
25%-tile	11.9	6.2		-107.0	-202.2
75%-tile	15.6	10.2		-59.3	-122.9
Maximum	25.8	17.2		106.5	56.8
Mean	13.9	8.2		-82.0	-166.0

The IP data shown in Table 3 is considered representative of soils developed over serpentinite and reflects the elevated magnetic susceptibility of the soils. For the shallower-sensing 50-cm intercoil spacing, the bulk averaged IP response was -166 ppt with a range of -377 to 57 ppt. For the deeper-sensing 100-cm intercoil spacing (nominal depth of about 50-cm), the bulk averaged IP response was -82 ppt with a range of -189 to 106 ppt. These averaged values and ranges are considered representative of soils having elevated levels of magnetic susceptibility.

Figure 4 contains plots showing the spatial distribution of apparent conductivity (left-hand plot) and in-phase (right-hand plot) measurements across the study site. In each plot, the boundaries of soil map units have been digitized from Web Soil Survey data.[3] In both plots, intermittent, linear patterns appear to traverse this site in a northwest to southeast trend. This pattern does not conform to any noticeable soil-landscape feature and is believed to represent changes in the structure and fabric of the underlying serpentinite. For both the EC_a and IP measurements, values are highly variable across the site and spatial patterns have a pockmarked appearance with a large number of small, isolated areas of exceedingly high and low values. Soils developed over serpentinite have a larger range and exhibit irregular and unpredictable patterns of both IP and EC_a measurements than are commonly measured over non-serpentine soils.

[3] 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].

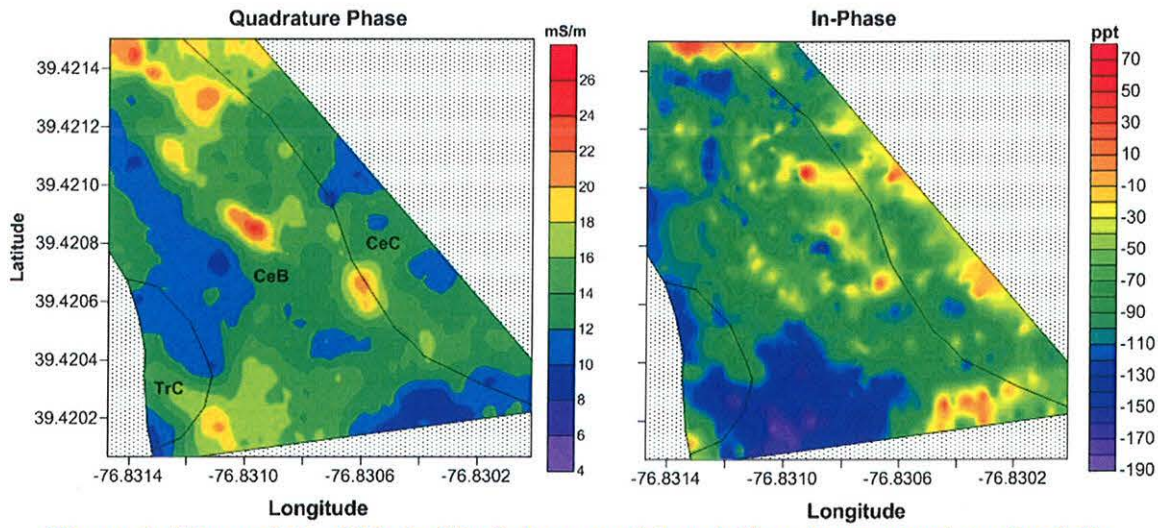

Figure 4. These plots of Study Site 2 show spatial variations in apparent conductivity (quadrature phase component) and susceptibility (in-phase component) for data collected with the 100-cm intercoil spacing of the EM38-MK2 meter. Soil lines have been imported from the Web Soil Survey.

In general, EC_a was slightly higher and spatially more variable across Site 2 than Site 1. The irregular, pockmarked EC_a patterns evident in Figure 4 are characteristic of serpentine soils. These patterns do not coincide with changes in soil type or hydrology, but appear to reflect linear trends in the structure and fabric of the underlying serpentinite. Unlike Site 1, the averaged EC_a increased with increasing soil depth. The presence of higher concentrations of heavy metals in the underlying serpentinite may explain this phenomenon.

X-ray Fluorescence:

At Study Site 1, for the soil samples collected from the 0 to 30 cm depth interval at 12 optimal sampling points (see Figure 3 for locations), the concentrations of different metals varied over several orders of magnitude (Table 4). The eight most abundant metals were Fe, P, K, Ti, Cr, Ni, Mn and Ca. In a similar study conducted in an area of Chrome soils at Nottingham Park in Pennsylvania, the eight most abundant metals were Fe, K, Ti, Ca, Ni, Mn, Co, and Cr. For both sites, Fe was the most abundant metal in the surface layers. However, the concentration of Fe in the surface layers was 2.5 times higher at Study Site 1 than at the Nottingham Park Site. At both sites, for each metal, noticeable differences in concentrations were evident among the sampling sites.

Because of the small number of samples collected at this site, non-parametric statistics were used to evaluate the associations among the measured heavy metals and the EMI responses. Table 5 summarizes the Spearman's rank correlation coefficients observed between the different EMI responses and the P-XRF data at the study site. With the exception of magnetic susceptibility (Ms) and the concentration of Co, correlations were all very weak and non-significant among the three measured EMI responses and the concentrations of the ten most abundant metals in the 0 to 30 cm depth interval. In the Pennsylvania study, moderate to high, significant correlations were observed among the measured EMI responses and the concentration of heavy metals in the 0 to 30 cm soil depth interval. The results from this study are very discouraging, but also, informative. The low correlations observed among the three measured EMI responses and the concentration of heavy metals in the 0 to 30 cm soil depth interval at Soldiers Delight are attributed to electrical interference from the power lines that overlie the site. It is impossible to predict how much noise one will get from a given power line. While the noise tends to increase with voltage and proximity, it is generally random from measurement to measurement, and will be least with a

sensor that has a strong transmitter, short array length, narrow frequency band and long measurement interval such as the EM38-MK2 meter (Rick Taylor, Dualem Inc., personal communication). In the futures, only sites free from electrical interference and overloading will be selected for similar studies. With access and permission to core and remove shallow soil samples from other areas of Soldiers Delight Natural Environmental Area, the results from this study may be improved.

Table 4. Concentration of elements in soil samples collected at Study Site 1. Data is expressed in parts per million (mg/kg).

OBS	*P*	*K*	*Ca*	*Ti*	*Cr*	*Mn*	*Fe*	*Co*	*Ni*	*Zn*
1	18122	4642	2494	1579	6831	2141	126570	897	3473	104
30	13567	14050	1148	5750	1180	1498	70623	716	1544	56
187	10051	7354	1104	3561	923	1165	60806	684	2131	51
357	15796	8600	2887	4290	3196	3566	128210	1103	2617	131
401	16172	8191	946	4011	2195	1246	117048	1065	3007	66
714	17807	8096	688	3337	4777	1325	131142	1142	3817	66
738	13256	12685	1569	5794	1633	1255	78873	897	1867	57
804	14891	5102	2029	1836	4213	1709	97952	867	3466	78
1035	12874	13194	1642	4880	2493	1715	90705	944	2479	75
1173	18400	4543	1594	1648	4131	2796	132493	819	3617	87
1231	18993	3303	1195	1187	2963	1846	128517	1236	3777	61
1454	20369	6185	1762	2682	3598	2884	115820	801	3314	112
Average	**15858**	**7996**	**1588**	**3380**	**3178**	**1929**	**106563**	**931**	**2926**	**79**

Table 5. Spearman's Rank Correlation Coefficients for magnetic susceptibility (Ms), apparent conductivity (EC_a), in phase response (IP), and the ten most abundant metals found in the 0 to 30 cm depth interval at Study Site 1.

	EC_a	*IP*	*P*	*K*	*Ca*	*Ti*	*Cr*	*Mn*	*Fe*	*Co*	*Ni*	*Ba*
Ms	-0.213	-0.589	-0.016	-0.107	0.393	-0.086	0.17	0.271	-0.173	-0.778	-0.17	0.133
EC_a	---	-0.044	-0.173	0.121	-0.558	0.114	0.467	-0.621	-0.348	0.016	-0.222	0.016
IP	---	---	0.294	-0.308	-0.028	-0.336	0.161	0.112	0.294	0.509	0.338	-0.454

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