United States Department of Agriculture

Natural Resources Conservation Service

c/o USDA Forest Service
11 Campus Boulevard
Suite 200
Newtown Square, PA 19073
(610) 557-4233; FAX: (610) 557-4200

Subject: SOI – Geophysical Field Assistance **Date:** 7 June 2001

To: Robin Heard
Acting State Conservationist
USDA-NRCS,
Suite 340, One Credit Union Place
Harrisburg, PA 17110-2993

Purpose:

Participants:
John Chibirka, Soil Scientist, USDA-NRCS, Leesport, PA
Jim Doolittle, Research Soil Scientist, USDA-NRCS, Newtown Square, PA
Elbert Wells, Delaware Estuary Project Leader, USDA-NRCS, West Chester, PA

Activities:
All field activities were completed during on 4 to 6 June 2001.

Equipment:
A GEM300 sensor, manufactured by Geophysical Survey Systems, Inc.,[1] was used in this study. This sensor is configured to simultaneously measure up to 16 frequencies between 330 and 19,950 Hz with a fixed coil separation (1.3 m). Won and others (1996) have described the use and operation of this sensor. With the GEM300 sensor, the depth of observation is considered "skin depth limited." The skin-depth represents the maximum depth of observation. It is frequency and soil dependent: low frequency signals travel farther through conductive mediums than high frequency signal. The theoretical observation depth of the GEM300 sensor is dependent upon the bulk conductivity of the profiled earthen material(s) and the operating frequency. Multifrequency sounding with the GEM300 allows multiple depths to be profiled with one pass of the sensor.

The radar unit is the Subsurface Interface Radar (SIR) System-2000, 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-2000 consists of a digital control unit (DC-2000) with keypad, VGA video screen, and connector panel. A 12-volt battery powered the system. This unit is backpack portable and, with an antenna, requires two people to operate. Antennas used in this study were the models 5106 and 5103 (200 and 400 MHz, respectively).

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

Results:
<u>**Chrome Soil:**</u>

[1] Trade names are used to provide specific information. Their mention does not constitute endorsement by USDA-NRCS.

Background
The soil survey of Chester County, Pennsylvania, is being digitized and updated. Serpentine rock outcrops in portions of Chester County as well as in adjoining counties of southeastern Pennsylvania and north-central Maryland. Soils formed over serpentine are often low in essential nutrients and have high concentrations of metals (nickel and chromium) that are toxic to many plant species. Unique plant communities grow on these soils. These unique plant communities have almost no species common with the surrounding forest or fields. Known as *serpentine barrens,* prairie grasses and pitch pines form dominant communities.

In Chester County, moderately deep, well-drained Chrome soil has been mapped on the serpentine barrens (Kunkle, 1963). The Chrome series is a member of the fine, mixed, mesic Typic Hapludalfs family. However, the taxonomic classification, in particular the mineralogy, of this series is being reexamined. Depth to bedrock is 20 to 40 inches. However, because of variations in weathering and mineralogy, the underlying bedrock may be lithic or deeply weathered and consist of paralithic materials. Both GPR and EMI were used to estimate the depth to lithic and paralithic materials and associated spatial patterns that could be described in map unit descriptions.

The study site was located in Nottingham County Park. The park is located near the town of Nottingham in extreme southwestern Chester County near the Maryland line. Radar traverses were conducted with both the 200 and 400 MHz antennas. With both antennas, the depth of observation was less than 20 inches. Observation depths were restricted by the fine textured Bt horizon. The soil/bedrock interface was beyond the depth of observation and not observable on radar profiles. Compared with the 200 MHz antenna, the 400 MHz antenna provided similar observation depths and superior resolution of subsurface features. With the 400 MHz antenna, the upper boundary of the Bt horizon could be identified and traced on radar profiles.

The velocity of propagation and the dielectric permittivity is moisture dependent and varies with antenna frequency. Soils were moist as the area had received about two inches of rain the over the preceding weekend. For the upper part of the soil profile, with the 200 MHz antenna, the estimated velocity of propagation was 0.062 m/ns and the dielectric permittivity was 23. With the 400 MHz antenna the estimated velocity of propagation was 0.070 m/ns and the dielectric permittivity was 18.

The appropriateness of EMI for soil investigations in areas Chrome soils was also evaluated. Using the GEM300 sensors differences in EMI response were observed over areas underlain by both Cr and R materials. However, because of limited sampling, no association could be made between EMI response and depth to or type of bedrock contact.

Differences in apparent conductivity are attributed to variations in soluble salt, clay, and moisture contents of the profiled materials. In areas of Chrome soil, higher values of apparent conductivity were presumed to occur over areas that have greater amounts of clay or moisture. In addition, as the more weathered rock materials (Cr) would have higher moisture contents, higher values of apparent conductivity were expected to occur over rocks with these properties. However, in areas of Chrome soil, the underlying bedrock exhibits ferromagnetism or magnetic susceptibility. Magnetic susceptibility is a measure of the ease with which particular earthen materials are magnetized when subjected to magnetic fields. For most earthen materials, magnetic susceptibility is low, its affects on electromagnetic field strengths minimal, and its presence ignored. However, some mineral such as magnetite, siderite, hematite, ilmenite, and chromite, exhibit high levels of magnetic susceptibility. Areas of Chrome soil exhibit noticeable levels of magnetic susceptibility.

EMI
Electromagnetic induction measures vertical and lateral variations in magnetic and/or electrical fields associated with induced subsurface currents. Data are expressed as in-phase, quadrature phase, or apparent conductivity. In-phase refers to the part of the signal that is in phase (has zero phase shift) with the primary or reference signal. The in-phase signal is sensitive to buried metallic objects or magnetic minerals, and has been referred to as the "metal detection" mode.

Quadrature phase refers to the part of the signal that is 90 degrees out of phase with the primary signal. The quadrature phase response is linearly related to the ground conductivity. With the GEM300 sensor, in-phase and quadrature phase data are expressed in parts per million (ppm).

Traditionally, EMI data are expressed as apparent conductivity. The GEM300 sensor automatically converts data recorded in the quadrature phase into apparent conductivity. Values of apparent conductivity are expressed in milliSiemens per meter (mS/m). 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).

Electromagnetic induction measures vertical and lateral variations in apparent electrical conductivity. Values of apparent conductivity are seldom diagnostic in themselves, but lateral and vertical variations in these measurements can be used to infer changes in earthen materials. Interpretations are based on the identification of spatial patterns within data sets.

Field Procedures

A 100 by 100 foot area (0.2 acre) was surveyed. The grid consisted of two 100-ft base lines that were spaced 100 feet apart. Along each base line, survey flags were inserted in the ground at intervals of 10 ft. Apparent conductivity and in-phase responses were recorded at 14790 Hz with the GEM300 sensor held at hip-height. Walking at a uniform pace between similarly numbered flags on the parallel base lines completed an EMI survey. The GEM300 sensor was operated in the continuous mode and recorded an observation every 0.5 second. Separate surveys were required for each dipole orientation. This resulted in 498 and 490 observations for surveys conducted in the horizontal and vertical dipole orientations, respectively.

Results

Figure 1 contains plots of in-phase (upper plots) and apparent conductivity (lower plots) responses collected at a frequency of 14790 Hz. Data collected in the shallower sensing horizontal dipole and the deeper-sensing vertical dipole orientations are shown in the left-hand and right-hand plots, respectively. The origin of the grid was located in the southeast corner of the site.

Each plot shows a slightly different picture of the surveyed area. The in-phase data is more sensitive to metallic minerals. Data collected in the shallower sensing horizontal dipole orientation shows a conspicuous band of comparatively low in-phase or apparent conductivity responses bordered by bands of higher in-phase or apparent conductivity responses. These alternating, linear patterns may describe variations in the underlying mineral fabric of the bedrock, differences in degree of weathering, or changes in clay and moisture contents. Further efforts and soil borings are needed to help simplify and confirm interpretations. If effective, EMI may be an appropriate method to determine depth to Cr or R materials. Plots of EMI data may help soil scientist describe spatial patterns of rock composition and weathering, and the distribution of soil map unit inclusions.

Joanna Soil:

Areas of Joanna loam, 8 to 25 percent slopes were surveyed with the GPR (with 200 MHz antenna) in southern Berks County. The very deep, well drained Joanna soil formed in residuum weathered from interbedded Triassic sandstone and conglomerate. Joanna is a member of the fine-loamy, mixed, mesic Typic Hapludults family. The purpose of this investigation was to estimate depths to bedrock in areas of Joanna loam, 8 to 25 percent slopes. All study sites were located within Nolde Forest Environment Educational Center in southern Berks County.

Table 1A thru 1E summaries the interpreted depth to bedrock. In these tables all depths are expressed in meters. Tables have been organized by landscape position defined by John Chibirka. The depth scale was determined based on the two-way travel time to a point reflector buried at 38 cm. The estimated dielectric permittivity was 23; the velocity of propagation was 0.062 m/ns

Table 1A. GPR Transect Data
Foot slope

File 6	
Obs.	**Depth (m)**
1	1.04
2	0.86
3	1.28
4	1.01
5	0.85
6	1.16
7	1.23
8	1.50
9	1.45
10	1.74

Table 1B. GPR Transect Data
Back slope

File 7		File 8		File 9	
Obs.	**Depth (m)**	**Obs.**	**Depth (m)**	**Obs.**	**Depth (m)**
1	0.76	1	1.32	1	0.88
2	0.75	2	0.75	2	0.68
3	0.63	3	0.87	3	1.18
4	0.87	4	0.71	4	0.98
5	0.81	5	1.39	5	0.75
6	1.80	6	2.00	6	1.01
7	1.64	7	0.83	7	1.04
8	1.07	8	1.13	8	0.87
9	1.33	9	0.76	9	0.75
10	1.03	10	0.82	10	0.90

Table 1C. GPR Transect Data
Shoulder of Nose Slope

File 10		File 11		File 12	
Obs.	**Depth (m)**	**Obs.**	**Depth (m)**	**Obs.**	**Depth (m)**
1	2.18	1	0.79	1	0.62
2	2.18	2	0.61	2	0.70
3	2.18	3	0.59	3	0.81
4	2.18	4	0.53	4	0.68
5	2.18	5	0.67	5	0.65
6	2.18	6	0.60	6	0.69
7	2.18	7	0.77	7	0.59
8	0.40	8	0.58	8	0.77
9	0.65	9	0.81	9	0.60
10	0.62			10	0.77
11	0.72			11	1.14
				12	1.12
				13	0.80
				14	1.52
				15	2.18

Table 1D. GPR Transect Data
Interfluve-Summit

File 13		File 14		File 15	
Obs.	**Depth (m)**	**Obs.**	**Depth (m)**	**Obs.**	**Depth (m)**
1	0.75	1	0.75	1	0.78
2	0.77	2	2.00	2	2.18
3	1.03	3	1.13	3	1.73
4	0.73	4	0.65	4	1.79
5	0.80	5	1.67	5	0.81
6	0.59	6	1.26	6	0.69
7	0.64	7	1.17		
8	0.73	8	0.98		
9	0.55	9	0.80		
10	0.51	10	0.61		

Table 1E. GPR Transect Data
Foot slope of Head slope

File 16		File 17		File 18	
Obs.	Depth (m)	Obs.	Depth (m)	Obs.	Depth (m)
1	2.18	1	0.96	1	2.18
2	2.18	2	1.17	2	2.18
3	2.18	3	2.18	3	2.18
4	2.18	4	2.18	4	2.18
5	2.18	5	2.18	5	2.18
6	2.18	6	2.18	6	2.18
7	2.18	7	2.18	7	2.18
8	2.18	8	2.18	8	2.18
9	2.18	9	1.46	9	2.18
10	2.18	10	2.18		
11	2.18				
12	2.18				
13	2.18				
File 19		**File 20**		**File 21**	
Obs.	Depth (m)	Obs.	Depth (m)	Obs.	Depth (m)
1	1.71	1	2.18	1	2.18
2	1.60	2	2.18	2	2.18
3	1.73	3	0.97	3	2.18
4	1.81	4	2.18	4	2.18
5	1.35	5	1.74	5	2.18
6	1.61	6	0.83	6	2.18
7	1.14	7	0.66	7	2.18
8	1.34	8	2.18	8	2.18
9	1.85	9	2.18	9	2.18
10	2.18	10	2.18		
11	2.18	11	2.18		
12	2.18	12	2.18		
File 22					
Obs.	Depth (m)				
1	2.18				
2	2.18				
3	2.18				
4	2.18				
5	2.18				
6	1.46				
7	1.15				
8	0.67				
9	0.72				
10	0.74				
11	0.73				
12	0.78				
13	0.89				

Based on radar interpretations made at 179 observation points the average depth to bedrock was 1.41 m, with a range of 0.4 to 2.18 m. Based on radar interpretations, 1 per cent of the observations were shallow, 39 percent were moderately deep, 16 percent were deep, and 44 percent were very deep. However, Statistics may be biased towards foot slope areas as a greater number of observations were obtained in foot slope areas (Tables 1A and 1E).An interpreted depth of 2.18 m was the maximum depth observable on the radar profiles. The depth to bedrock at these observation points is actually greater than 2.18 m. The compendium at the end of this report provides a breakdown of the distribution of observations into soil depth classes for each transect and landscape position.

Liberty Park, Philadelphia:

Background

Located on North 3rd Street, Liberty Park is the only "green park" in this portion of Philadelphia. It is on a site that was formerly occupied by manufacturing and warehouses. These structures were demolished and the site cleared. A one-inch clay liner and about four inches of topsoil mix were placed over the rubble and construction debris. Grasses and trees have been planted throughout the park. Portions of the park are used for a garden, drill field, and open space.

NRCS has committed resources to this park as part of the Philadelphia Urban Redevelopment Project. The project coordinator and the resource soil scientist wished to evaluate the site using geophysical tools. Compacted by sheep-foot rollers and foot traffic, the clay liner or pan forms a relatively impermeable barrier to roots throughout the park. However, the depth to the clay liner or pan was to shallow for the GPR antennas that are used by the National Soil Survey Center. It was proposed that EMI could be used to prepare electrical conductivity maps of the portion of the park used as a drill field. This area occupied the northwest part of the park.

Field Procedures

A 60 by 240 foot area (0.33 acre) was surveyed. The origin of the survey was located 20 feet east of North 3rd Street and 75 feet south of Widley Street. Grid axes paralleled both streets. The grid consisted of two 240-ft base lines that were spaced 60 feet apart. Along each base line, survey flags were inserted in the ground at intervals of 10 ft. Apparent conductivity and in-phase responses were recorded at 19950 Hz with the GEM300 sensor held at hip-height. Walking at a uniform pace between similarly numbered flags on the parallel base lines completed an EMI survey. The GEM300 sensor was operated in the continuous mode and recorded an observation every 0.5 second. Separate surveys were required for each dipole orientation. This resulted in 626 and 690 observations for surveys conducted in the horizontal and vertical dipole orientations, respectively.

Results

Figure 2 contains plots of in-phase (upper two plots) and apparent conductivity (lower two plots) responses collected at a frequency of 19950 Hz. For both sets of plots (in-phase and conductivity), data collected in the shallower sensing horizontal dipole and the deeper-sensing vertical dipole orientations are shown in the upper and lower plots, respectively. North 3rd Street is located at a distance of 20 feet from the lower border of each plot. Widley Street is located at a distance of 75 feet from the left-hand border of each plot.

All plots show a prominent area of high EMI responses located in the northwest corner of the site. This pattern is believed to reflect a large concentration of buried metallic objects or materials with a high metal content. In the plots of in-phase data, point anomalies are scattered throughout the site. These anomalies are believed to represent buried metallic features and are more conspicuous in the plot of in-phase data collected in the deeper-sensing vertical dipole orientation. A park bench is responsible for the anomalous EMI response near "A." This was the only above ground feature that could be associated with an EMI response within the surveyed area.

In the lower two plots of apparent conductivity, a large area of low (colored green) conductivity is apparent in the central portion of the survey area. This area is more extensive in the shallower sensing horizontal dipole orientation. This area may represent an area with lower clay content or thinner topsoil.

Growth of grasses and tree or water or nutrient requirements within this portion of the park can be compared with these plots. These plots may help managers partition the park into management zones and decide management practices.

Conclusions:

1. 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 should be verified by ground-truth observations.

2. In areas of Chrome soils, the use of GPR is inappropriate for soil or bedrock investigations because of limited penetration depths (less than 0.5 m). Electromagnetic induction may provide a suitable means for determining bedrock depths, showing the distribution of soils underlain by Cr or R materials, and improving map unit descriptions. Further testing is recommended.

3. In areas of Joanna soils, GPR provided satisfactory observation depths and resolution, and was used to chart the depths to bedrock. Bedrock depths on back slopes, noses, and summits were dominantly moderately deep. In foot slope areas of the same map unit, depths to bedrock were predominantly very deep.

4. Electromagnetic induction provided maps showing the distribution of in-phase and apparent conductivity responses across a drill field located in Liberty Park, Philadelphia. These maps indicated an area that is underlain presumably with high concentration of buried metallic objects or materials with a high metal content. Apparent conductivity data appeared to show an area with low clay content or thin topsoil. Plots of EMI responses may help managers partition the park into management zones and decide management practices

It was my pleasure to work in Pennsylvania and with members of your fine staff.

With kind regards,

James A. Doolittle
Research Soil Scientist

cc:
R. Ahrens, Director, USDA-USDA, National Soil Survey Center, Federal Building, Room 152,100 Centennial Mall North, Lincoln, NE 68508-3866
S. Carpenter, MO Leader, USDA-NRCS, 75 High Street, Room 301, Morgantown, WV 26505
J. Chibirka, Resource Soil Scientist, USDA-NRCS, Berks County Ag. Center, P.O. Box 520, Leesport, PA 19533-0520
C. Olson, National Leader for Soil Investigations, USDA-USDA, National Soil Survey Center, Federal Building, Room 152,100 Centennial Mall North, Lincoln, NE 68508-3866
H. Smith, Director of Soils Survey Division, USDA-NRCS, Room 4250 South Building, 14th & Independence Ave. SW, Washington, DC 20250

E. White, State Soil Scientist, USDA-NRCS, USDA-NRCS, Suite 340, One Credit Union Place, Harrisburg, PA 17110-2993

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Compendium
Areas of Joanna Soils
Distribution of GPR Observations into Soil Depth Classes

FOOTSLOPE

File 6

SHALLOW	0	0.00
MOD-DEEP	2	0.20
DEEP	7	0.70
VERY DEEP	1	0.10

BACKSLOPE

File 7

SHALLOW	0	0.00
MOD-DEEP	5	0.50
DEEP	3	0.30
VERY DEEP	2	0.20

File 8

SHALLOW	0	0.00
MOD-DEEP	6	0.60
DEEP	3	0.30
VERY DEEP	1	0.10

File 9

SHALLOW	0	0.00
MOD-DEEP	7	0.70
DEEP	3	0.30
VERY DEEP	0	0.00

SHOULDER OF NOSE SLOPE

File10

SHALLOW	1	0.08
MOD-DEEP	4	0.33
DEEP	0	0.00
VERY DEEP	7	0.58

File 11

SHALLOW	0	0.00
MOD-DEEP	9	1.00
DEEP	0	0.00
VERY DEEP	0	0.00

File 12

SHALLOW	0	0.00
MOD-DEEP	11	0.73
DEEP	2	0.13
VERY DEEP	2	0.13

INTERFLUVE-SUMMIT

File 13

SHALLOW	0	0.00
MOD-DEEP	9	0.90
DEEP	1	0.10
VERY DEEP	0	0.00

File 14

SHALLOW	0	0.00
MOD-DEEP	5	0.50
DEEP	3	0.30
VERY DEEP	2	0.20

File 15

SHALLOW	0	0.00
MOD-DEEP	3	0.50
DEEP	0	0.00
VERY DEEP	3	0.50

FOOTSLOPE OF HEADSLOPE

File 16

SHALLOW	0	0.00
MOD-DEEP	0	0.00
DEEP	0	0.00
VERY DEEP	13	1.00

File 17

SHALLOW	0	0.00
MOD-DEEP	1	0.10
DEEP	2	0.20
VERY DEEP	7	0.70

File 18

SHALLOW	0	0.00
MOD-DEEP	0	0.00
DEEP	0	0.00
VERY DEEP	9	1.00

File 19

SHALLOW	0	0.00
MOD-DEEP	0	0.00
DEEP	3	0.25
VERY DEEP	9	0.75

File 20

SHALLOW	0	0.00
MOD-DEEP	3	0.25
DEEP	0	0.00
VERY DEEP	9	0.75

FILE 21

SHALLOW	0	0.00
MOD-DEEP	0	0.00
DEEP	0	0.00
VERY DEEP	9	1.00

FILE 22

SHALLOW	0	0.00
MOD-DEEP	6	0.46
DEEP	2	0.15
VERY DEEP	5	0.38

EMI SURVEY OF AN AREA OF CHROME SOIL
CHESTER COUNTY, PENNSYLVANIA
GEM300 SENSOR

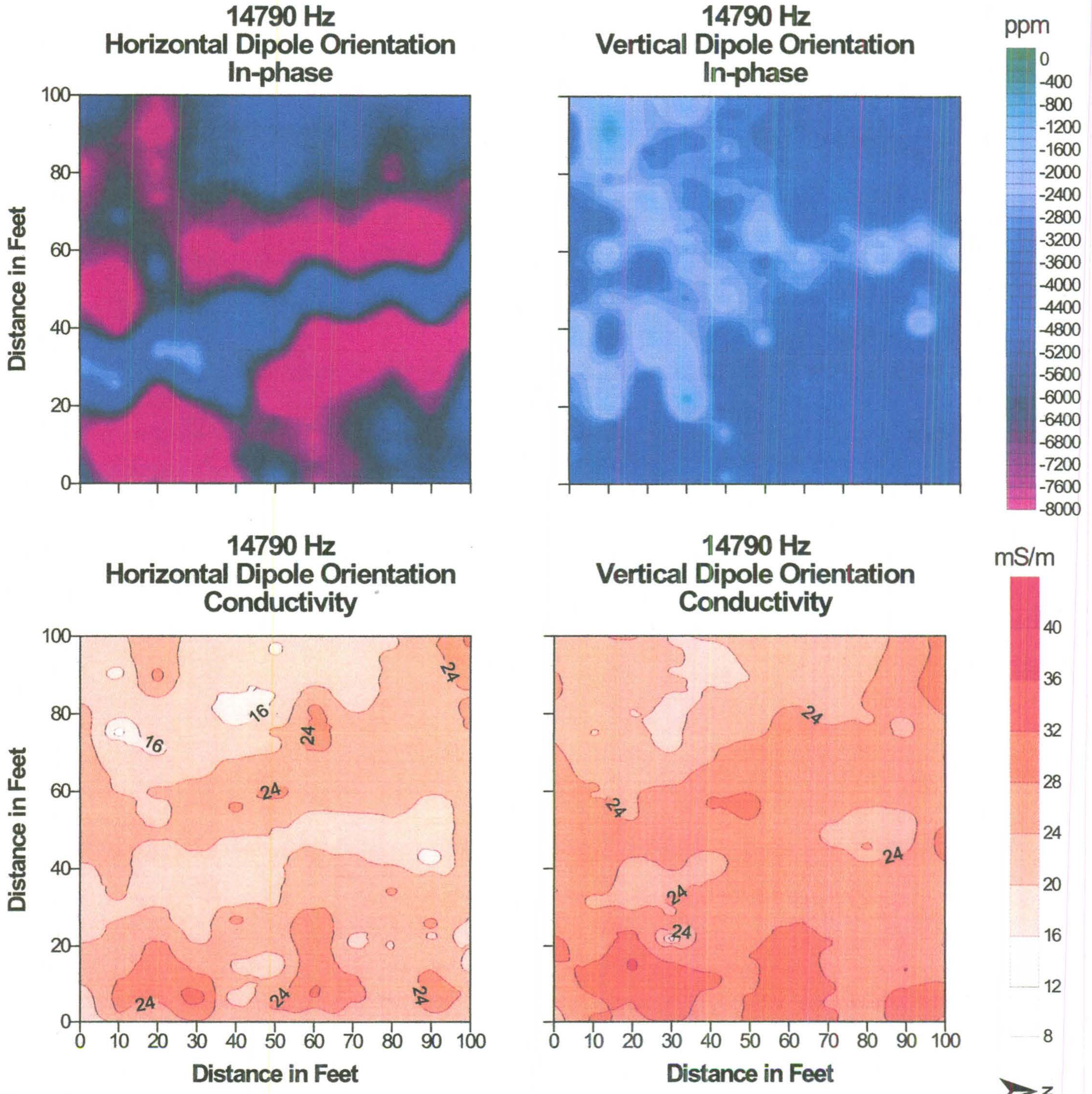

Figure 1

EMI SURVEY
LIBERTY PARK, PHILADELPHIA
GEM300 SENSOR
19950 Hz

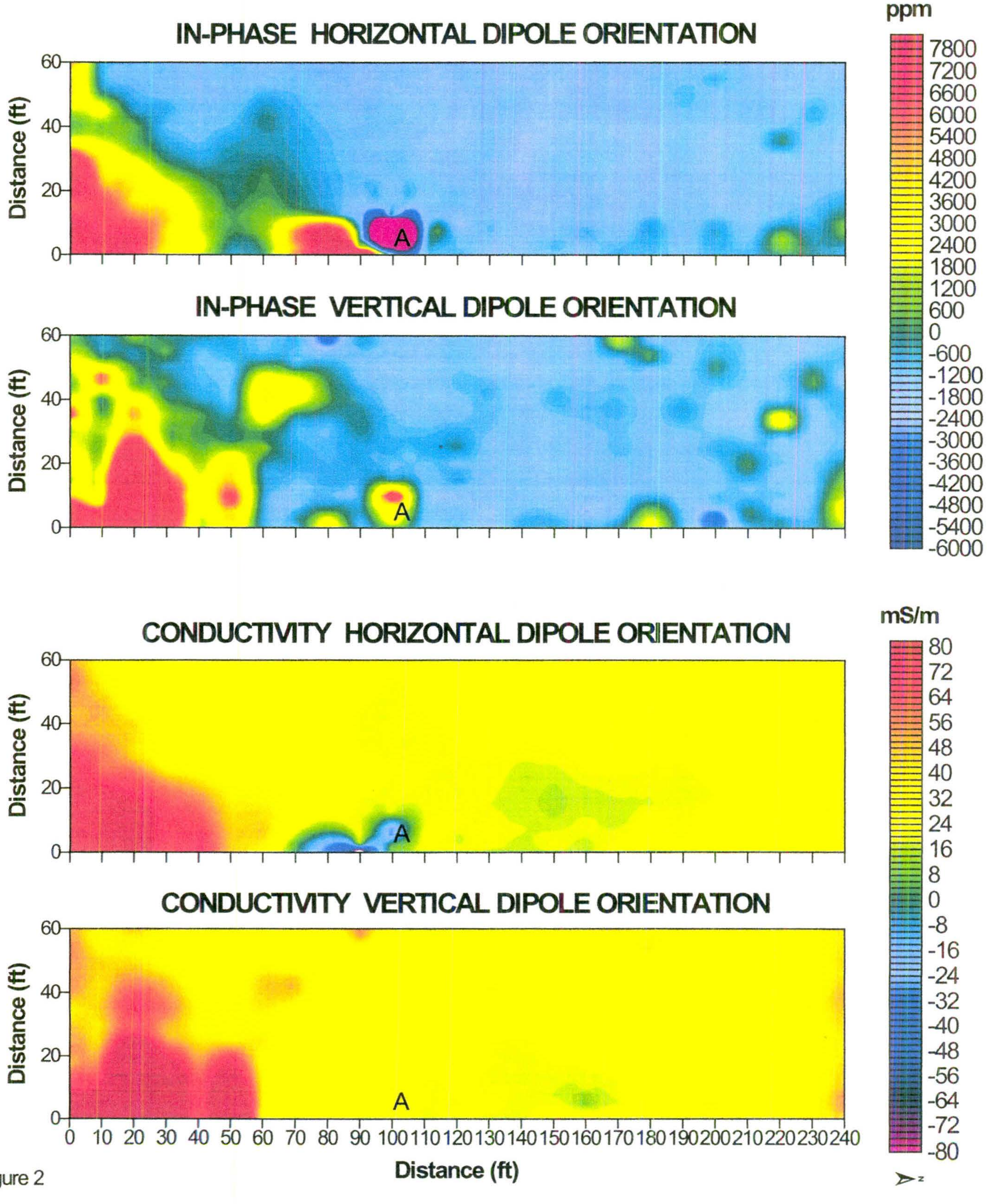

Figure 2