UNITED STATES DEPARTMENT OF AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE

CHESTER, PA 19013
610-490-6042

Subject: Geophysical Assistance - Cultural Resource Investigations; Maryland, September 7 and 8, 1995

Date: 14 September 1995

To: Jeri L. Berc
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Purpose:
To provide ground-penetrating radar (GPR) and electromagnetic induction (EM) field assistance to the staff of Maryland Historical Trust.

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Activities:
On 7 September, field investigations were conducted at the Smith Site, Jefferson Patterson Park and Museum, Calvert County (see Figure 1). On 8 September, field investigations were conducted at the Mattapany Site, Patuxent Naval Air Test Station, St. Marys County.

Equipment:
The radar unit used in this study was the Subsurface Interface Radar (SIR) System-2, manufactured by Geophysical Survey Systems, Inc. (GSSI). The use and operation of GPR have been discussed by Morey (1974), Doolittle (1987), and Daniels and others (1988). The SIR System-2 consists of a backpack portable, digital control unit (DC-2) with keypad, VGA video screen, and connector panel. Radar profiles were plotted on a model GS-608P thermal plotter/printer. The system was powered by a 12-VDC battery. The model 3110 (120 mHz) and 3102 (500 mHz) antennas were used in this investigation.

The electromagnetic induction meter was the EM38, manufactured by Geonics Limited. This meter is portable and requires only one person to operate. Principles of operation have been described by McNeill (1986). The observation depth of an EM meter is dependent upon intercoil spacing, transmission frequency, and coil orientation relative to the ground surface. The EM38 meter has a fixed intercoil spacing of about 1.0 m. It operates at a frequency of 13.2 kHz. The EM38 meter has effective observation depths of about 0.75 and 1.5 m in the horizontal and vertical dipole orientations, respectively (McNeill, 1986). Values of apparent conductivity are expressed in milliSiemens per meter (mS/m).

To help summarize the results of this study, the SURFER program, developed by Golden Software, Inc., was used to develop two-dimensional plots of the study sites. The simulated grids were created using kriging methods with an octant search. The data was smoothed using cubic spline interpolation.

The EM data (vertical dipole orientation) have been displayed in two-dimensional contour plots (figures 2 to 3). In these plots, to help emphasize the spatial distribution of apparent conductivity values, colors and filled contour lines have been used. Each plot represents the spatial distribution of apparent conductivity values over a specified observation depth. Other than showing trends in values of apparent conductivity (i.e. zones of higher or lower electrical conductivity), no significance should be attached to the colors themselves.

Theories of Operation:
Studies have documented the advantages of non-invasive measurements made with EM meters, the ease and accuracy of EM interpretations, and its applications over broad areas and soil types. The EM meters are highly portable and considered one of the most rapid and cost-effective geophysical methods available. For surveying, the meter is placed on the ground surface or held above the surface at a specified distance. A power source within the meter generates an alternating current in the transmitter coil. The current flow produces a primary magnetic field and induces electrical currents in the soil. The induced current flow is proportional to the electrical conductivity of the intervening medium. These electrical currents create a secondary magnetic field in the soil. The secondary magnetic field is of the same frequency as the primary field but of different phase and direction. The primary and secondary fields are measured as a change in the potential induced in the receiver coil. At low transmission frequency, the ratio of the secondary to the primary magnetic field is directly proportional to the ground

conductivity. Values of apparent conductivity are expressed in milliSiemens per meter (mS/m).

The depth of penetration is dependent upon the intercoil spacing, transmission frequency, and coil orientation relative to the ground surface. Table 1 lists the anticipated observation depths for various meters with different intercoil spacings and coil orientations. Information on variations in conductivity with depth can be achieved by varying coil orientation, intercoil spacing, and frequency.

TABLE 1

Depth of Measurement
(all measurements are in meters)

Meter	Intercoil Spacing	Depth of Measurement Horizontal	Vertical
EM31	3.7	2.75	6.0
EM34-3	10.0	7.5	15.0
	20.0	15.0	30.0
	40.0	30.0	60.0
EM38	1.0	0.75	1.5

Electromagnetic induction techniques measure the apparent conductivity of earthen materials. Apparent conductivity is a weighted average measurement for a column of earthen materials to a specified observation 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 (i) volumetric water content, (ii) type and concentration of ions in solution, (iii) temperature and phase of the soil water, and (iv) amount and type of clays in the soil matrix, (McNeill, 1980). The apparent conductivity of soils increases with increases in the exchange capacity, water content, and clay content (Kachanoski et al., 1988; Rhoades et al., 1976).

Electromagnetic inductive methods measure vertical and lateral variations in the apparent electrical conductivity of earthen materials. Meters provide limited vertical resolution and depth information. However, as discussed by Benson and others (1984), the absolute EM values are seldom diagnostic in themselves, but the lateral and vertical variations in these measurements are significant. Interpretations of the EM data are based on the identification of spatial patterns within data sets.

This technique is well suited to reconnaissance surveys requiring continuous, moderately resolved data. The EM methods have been used to locate and map buried structures, artifacts, mounds, and tombs (Bevan, 1983; Dalan, 1991; Frohlich and Lancaster, 1986).

The ground-penetrating radar is an impulse radar system designed for shallow subsurface site investigations (Daniels et al., 1988). Pulses of electromagnetic energy are radiated into the ground from a transmitting antenna. Each pulse consists of a spectrum of frequencies distributed around the center frequency of the antenna. Whenever a pulse contacts an

interface separating layers of differing dielectric properties, a portion of the energy is reflected back to the receiving antenna. The receiving unit amplifies and samples the reflected energy and converts it into a similarly shaped waveform in a lower frequency range. The processed, reflected waveforms are displayed on a graphic recorder or are recorded on magnetic tapes or discs for future playback or processing. The graphic recorder uses a variable gray scale to display data. It produces images by recording strong reflections as high amplitude signals and lesser intensity reflections in shades of gray.

Compared with other geophysical techniques, GPR provides the highest resolution of subsurface features. However, results of radar surveys are site specific and interpreter dependent. Interpretations depend on the experience of the operator, complexity of soil or geologic conditions, quantity and quality of independent observations, and the system and antennas used. In many terrains, unless mounted in a suitable vehicle, most systems are heavy and cumbersome to move and operate. In addition in some areas, conductive soil conditions limit profiling depths and applicability. Ground-penetrating radar is best suited for shallow (3 to 10 meters) investigations in electrically resistive mediums (i.e. dry, sandy soils). Ground-penetrating radars have been used to locate and map buried structures, buried artifacts, and graves (Bevan, 1991; Doolittle and Miller, 1991; King et al., 1993; Imai et al., 1987; Vaughan, 1986).

Discussion:

Electromagnetic Induction Survey of the Smith Site, Jefferson Patterson Park and Museum (7 September 1995)

The site is located is located near the mouth of St. Leonard Creek on the Patuxent River, Calvert County, Maryland. The site is believed to contain the remnants of the home and well of Charles Smith. The site was occupied from about 1660 to 1690. Charles Smith was Lord Baltimore's attorney general.

The site was located in an area of Mattapex silt loam, 0 to 2 percent slopes (Matthews, 1971). Mattapex is a member of the fine-silty, mixed, mesic Aquic Hapludults family. At the time of this investigation, the soils were exceedingly dry and the site was in soybeans. Ground-penetrating radar was considered the most appropriate tool for this investigation. Calibration trials disclosed that the SIR System-2 with the 500 mHz antenna (scanning time of 30 nanoseconds) provide adequate observation depths and superior resolution of subsurface features. However, as the field was in soybean, it was not practical to conduct a GPR survey of the site at this time.

A 30 by 24 meter grid (about 0.07 hectare) was established across the Smith Site. Survey flags were inserted in the ground at 2 meter intervals. At each of the 208 grid intersections, measurements were obtained with an EM38 meter placed on the ground surface in vertical dipole orientation.

Within the Smith Site, values of apparent conductivity were relatively low. Apparent conductivity averaged 4.3 mS/m in the vertical dipole orientation. Within the study site, values of apparent conductivity (obtained with the EM38 meter in the vertical dipole orientation) ranged

from 0.6 to 23.0 mS/m. One-half the observations (208) had EM responses between 2.9 and 5.6 mS/m.

Figure 2 is a two-dimensional plot of apparent conductivity measurements simulated from data collected with the EM38 meter in the vertical dipole orientation. The isoline interval is 2 mS/m. In Figure 2, spatial patterns reflect variations in soil properties, and the possible influence of debris from the 17th Century structure and modern cultural features. Values were higher in the eastern and southern, and lower in the western and northern portions of the site. The higher EM responses in the eastern and southern portions of the site were attributed to increased clay contents at shallower soil depths and their proximity to the road. Soils in these portions of the site were slightly higher-lying, assumed to be more vulnerable to erosion, and were presumed to be shallower to moderately fine-textured (silty-clay loams) soil materials. The slightly lower EM responses in the northern portion of the site were attributed to lower clay contents. Soils in these portions of the site were slightly lower-lying and suspected of containing coarser-textured (silt loams) colluvial materials.

The lower EM responses (< 3.0 mS/m) in the west-central portion of the site were attributed, in part, to bricks and other debris from the former structure. It was assumed that the bricks would be more resistive than the surrounding soil matrix. Based on this assumption, the lowest EM response would be recorded in the area that had the greatest concentrations of bricks.

An anomalously high EM response was recorded near the southeast corner (see Figure 2). Because of the high EM response (23 mS/m), the anomaly is believed to be a metallic object associated with agronomic practices. Higher EM responses along the eastern border of the study site were believed to be caused by cut-and-fill operations and possibly utilities associated with the adjoining road.

In Figure 3, areas that have EM response of less than 3 mS/m are depicted. In Figure 3, the isoline interval is 0.5 mS/m. Although this interval was well within the range of observation error (2 mS/m), it was needed to show implied spatial patterns and gradients. Areas with low apparent conductivity values were hypothesized to contain higher concentrations of cultural debris. In Figure 3, patterns suggest a localized but variable distribution of cultural debris.

Ground-Penetrating Radar Survey of Mattapany Site, Patuxent River Naval Air Station (8 September 1995):

Mattapany was the 17th Century plantation of Charles Calvert. Charles Calvert was the only Lord Baltimore to reside in Maryland. On 8 September 1995, three survey grids were established at Mattapany. Mattapany is located within the US Naval Patuxent Air Test Center, St. Marys County, Maryland (see Figure 1).

For each of the three survey grids, a 5 foot interval was used. Sites were located in open areas of Mattapex silt loam, 0 to 2 percent slopes (Gibson, 1978). At the time of this investigation, the soils were exceedingly dry and the sites were in overgrown grasses and weeds. Ground-penetrating radar was considered the most appropriate tool for

this investigation. Calibration trials disclosed that the SIR System-2, with the 500 mHz antenna (scanning time of 40 nanoseconds), provided sufficient depths of observation and excellent resolution of subsurface features.

Calvert's House

An irregularly-shaped 60 by 40 foot grid was established across the suspected site of the former home of Charles Calvert. The former structure is believed to have had a full basement. According to Dr. King, this was unusual for homes of this period in Maryland. While the foundation appears to measure 25 by 50 feet, the actual shape of the building is unknown.

The radar survey was completed by pulling the 500 mHz antenna along thirteen parallel (north-south) grid lines (radar profile files 1 to 13). This procedure provided 460 feet of continuous radar imagery.

The locations of subsurface anomalies detected with the 500 mHz antenna have been plotted in Figure 4. In Figure 4, the area shaded gray was not surveyed. The locations of two, filled, excavation pits have been identified by orange-colored squares. To aid interpretations, the locations of three large trees have been identified by symbols (green trees). Point anomalies occurring near these trees were presumed to represent tree roots.

Generally, most reflectors were small and weakly expressed. However, nineteen, fairly-well expressed point reflectors were distinguished on the radar profiles. In Figure 4, the locations of these reflectors have been indicated by triangles. Ten of these point reflectors form a conspicuous linear pattern across the northern portion of the site. These reflectors identify the location of a buried, modern pipe-line. Other conspicuous point reflectors are concentrated in the west-central portions of the plot (see Figure 4).

In Figure 4, colored lines have been used to indicate areas having distinct subsurface layers. These colored lines appear along the tracks of the radar traverses. Based on their expression, these layers have been interpreted to represent either soil horizons, fill or cultural layers. Several similar, well expressed, smooth, continuous layers were interpreted to represent soil layers, possibly the subsoil (Bt horizon). Red color lines have been used to identify the locations of these presumed, undisturbed, subsurface soil layers. These subsurface layers were detected principally in the north-central portion of the site (see Figure 4).

A depression believed to have been formed by the former structure was filled by the Navy with earthen materials. Dark and light blue lines have been used to identify the locations of the presumed fill and/or buried cultural layers. The dark blue lines represent well expressed and often multiple layers. These layers formed distinct, highly irregular and variable patterns. In places, these linear patterns are interrupted by point reflectors. Some of these point reflectors could represent structural debris from the former house; other point reflectors could represent buried debris, rocks, or fill materials. The light blue lines represent weakly expressed subsurface layers. These layers were presumed

to represent layers of fill or cultural debris. These interpretation should be confirmed through auger or pit observations.

Figure 5 is a representative radar profile from the site. The radar profile was obtained from the ten foot line (see Figure 4). This profile has been processed through the RADAN software package. Processing was limited to signal stacking, horizontal scaling, color transform and table customizing, and annotations. Signal stacking can reduce incoherent background noise while enhancing the images of subsurface features. Often, because of noise suppression, stacked traces have considerably more discernible features especially at greater depths. Normalization corrects the horizontal scale for variations in the speed of antenna advance along a grid line.

The horizontal scale represents units of distance traveled along a grid line. The numbers appearing at the top of the radar profile represent distances in feet. The short, vertical lines at the top of the radar profile are grid intersections and occur at 5 foot intervals. The vertical scale is a time or depth scale. The vertical scale is in nanoseconds.

In Figure 5, the hyperbolic reflection from the buried pipe or utility line has been identified (see annotated reflection to the left of "A"). The subsurface reflectors believed to be represent fill or buried cultural layers have been enclosed in a rectangular box (see "B").

The Out-Building Site

An irregularly-shaped 35 by 40 foot grid was established across the site of a former out-building of the Calvert Plantation. The radar survey was completed by pulling the 500 mHz antenna along eight parallel (north-south) grid lines (radar profile files 14 to 21). This procedure provided 240 feet of continuous radar imagery.

The locations of subsurface anomalies detected with the 500 mHz antenna have been plotted in Figure 6. In Figure 6, areas shaded gray were not surveyed. Colored lines have been used to indicate areas having distinct subsurface layers. These colored lines appear along the tracks of the radar traverses. The dark and light blue lines have been used to identify the locations of the presumed recent fill and/or buried cultural layers.

Several, strongly expressed point reflectors were distinguished on radar profiles from this grid site. Generally, most reflectors were small and weakly expressed. Some of these reflectors could represent tree roots. Most detected point anomalies appear to be concentrated in the northern portion of the grid site (see Figure 6).

In Figure 6, an areas having distinct subsurface layers has been identified. Subsurface layers, identified in the north-central portion of the site, are believed to represent buried cultural layers from a former out-building. These layers were characterized by multiple, strong reflections. These reflections were defined by abrupt, and sharply contrasting boundaries. Two small areas in the southern portion of the site appeared to have observable but indistinct subsurface layers. These

layers could represent strata of fill or soil materials. These interpretation should be confirmed through auger or pit observations.

Calvert's Armory

A 60 by 70 foot grid was established across the armory site. Large quantities of shot, brick, clay roofing tile, and flat-bottom pits have suggested the general location of the armory (Dr. King personal communication). However, no structural features have been identified. The radar survey was completed by pulling the 500 mHz antenna along fifteen parallel (north-south) grid lines (radar profile files 22 to 36). This procedure provided 460 feet of continuous radar imagery.

The locations of subsurface anomalies detected with the 500 mHz antenna have been plotted in Figure 7. In Figure 7, the areas shaded gray were not surveyed.

Ten point reflectors were distinguished on the radar profiles. Generally, most of these reflectors were small and weakly expressed. However, reflected signals from one of these anomalies were exceedingly strong and highly complex. This anomaly represents a small feature. The feature appears to be bounded by point reflectors which may represent foundation walls. In the center of the feature are metallic objects. This interpretation is based on the occurrence of reverberated signals from this portion of the anomaly. Reverberated signals often indicate the presence of metal. In Figure 7, this anomaly has been identified by a large circle (see line 35). This feature could indicate the location of Calvert's Armory. Base on the reconnaissance radar survey, this would be the best choice.

Results:

1. Geophysical techniques have considerable potential for rapidly examining archaeological sites with minimum disturbance. The enclosed plots of each survey site can help archaeologists assess site conditions and locate exploratory observation pits. These plots can help archaeologist decide whether and where to dig exploratory pits. These plots can help reduce unnecessary expenditures of resources on unsuccessful exploratory pits.

2. The reliability of EM and GPR techniques must be reevaluated based on the results of subsequent archaeological observations. In order to improve interpretations, radar profiles need to be reassessed based on the results of archaeological studies. I wish to encourage participants to keep me appraised of their findings and to evaluate the utility of these surveys.

3. All radar profiles have been returned to Dr. Julie King under a separate cover letter.

Route MS 33 + file

It was once again my pleasure to assist your staff, the Maryland Historic Trust, and to participate in these activities.

With kind regards.

James A. Doolittle
Research Soil Scientist

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