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Subject: ARCHAEOLOGY -- Geophysical Assistance

Date: 23 July 2001

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Purpose:
Ground-penetrating radar (GPR) and electromagnetic induction (EMI) were used to locate buried structures and features within the Fredericksburg National Military Park. Assistance was provided to the National Park Service and James Madison University.

Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS, Newtown Square, PA
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Activities:
All field activities were completed during the period of 17 and 18 July 2001.

Equipment:
The radar unit is the Subsurface Interface Radar (SIR) System-2000, manufactured by Geophysical Survey Systems, Inc.[1] The SIR System-2000 consists of a digital control unit 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. A 400 MHz antenna was used in this study. The scanning time was 30 nanoseconds (ns). Hard copies of the radar data were printed in the field on a model T-104 printer.

Geophysical Survey Systems, Inc. manufactures the GEM300 multifrequency sensor.[1] This sensor is portable and requires only one person to operate. No ground contact is required with the GEM300 sensor. 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). The GEM300 sensor is keypad operated. Measurements can be either automatically or manually triggered. With the GEM300 sensor, the depth of penetration is considered *skin depth limited*. The *skin-*

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

depth represents the maximum depth of penetration and is frequency and soil dependent: low frequency signals travel farther through conductive mediums than high frequency signal. The theoretical penetration 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.

Study Areas:
The study was confined to the portion of the National Park known as Marye's Heights. During the battle of Fredericksburg, the Confederates had positioned their artillery along the crest of Marye's Hill. On December 13, 1862, Major General Ambrose E. Burnside assaulted the ridge with nine Federal divisions. Before the battle had ended, 8,000 Union troops had fallen in an attempt to reach the *Sunken Road* at the steep base of Marye's Heights.

After the war, a portion of Marye's Heights was set-aside as a national cemetery. In 1948, Monfort Academy was established on eight acres adjoining the cemetery. In 1997 the land was sold to the National Park Service. This important tract is now part of Fredericksburg and Spotsylvania National Military Park. James Madison University is conducting archaeological investigations in this newly acquired portion of the park.

Field Procedures:
Reconnaissance EMI and GPR surveys were completed on Marye's Height. A small (1.5 acre) open area on the summit of Marye's Heights was selected for the EMI survey. Three, 68-feet long, parallel lines were established across the survey area. Each line was spaced 50 feet apart. Along each of these lines, survey flags were inserted in the ground at intervals of 4 ft. Apparent conductivity and in-phase responses were recorded at frequencies of 19950 and 14790 Hz with the GEM300 sensor held at hip-height. Walking at a uniform pace between similarly numbered flags on the three parallel lines completed an EMI survey. The GEM300 sensor was operated in the continuous mode and recorded an observation every half second. Separate surveys were required for each dipole orientation. This resulted in 855 and 810 observations for surveys conducted in the horizontal and vertical dipole orientations, respectively.

The most accepted and perhaps efficient procedure to detect and chart the location of buried cultural features with GPR is to establish a grid across the survey area. However, to quickly survey large areas for major buried structural features "wildcat" surveys are preferred. These surveys consist of random traverses that cover the areas of interest. Wildcat surveys provide an effective method to quickly reconnoiter large areas for prominent archaeological features or to locate sub-areas with higher concentrations or clusters of subsurface features that may indicate archaeological sites.

Results:
<u>EMI</u>
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 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. Some highly conductive targets with small cross-sections, such as pipes, may show up better in the quadrature phase because of the channelization of current. 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.

Figures 1 and 2 show the spatial distribution of EMI responses collected in the horizontal and vertical dipole orientations respectively. In each figure, in-phase (left-hand plots) and apparent conductivity (right-hand plots) responses collected at frequencies of 14790 (upper plots) and 19950 (lower plots) Hz are depicted. The depth of observation is assumed to increase as the frequency decreases. Presumably, data collected at 19950 Hz (higher frequency) indicates shallower features than data collected at 14790 Hz (lower frequency).

Each plot shows a slightly different picture of the surveyed area. A conspicuous, east west trending, linear anomaly is apparent in the lower-center portion of each plot. In the data set collected in the shallower sensing, horizontal dipole orientation (see Figure 1), this anomaly is centered on line X=26 feet, and extends from about Y = 10 feet to about Y = 50 feet. In the data set collected in the deeper sensing, vertical dipole orientation (see Figure 2), this anomaly appears as two separate linear features. As this linear anomaly (ies) is apparent in both in-phase and conductivity plots, it is suspected to represent a buried metallic features such as drainage or utility lines. Near the eastern apex of this buried linear feature, another linear feature is evident in the apparent conductivity plots. This linear feature is slightly inclined but essentially bisects the study area from X and Y coordinates of 0 and 50 feet, to 68 and 60 feet. A soil probe identified a layer of ash near this line. A third linear anomaly is apparent along the southeastern edge of the study area (upper right-hand corner of each plot between Y coordinates of 55 and 88 feet). In addition, two prominent point anomalies are observable in figures 1 and 2. These buried point anomalies are believed to represent metallic features and are centered near the X coordinates of 39 and 52 feet, and Y of 36 and 42 feet in figures 1 and 2, respectively.

GPR

Ground-penetrating radar is an impulse radar system designed for shallow, subsurface investigations. This system operates by transmitting short pulses of electromagnetic energy into the ground from an antenna. Each pulse consists of a spectrum of frequencies distributed around the center frequency of the transmitting antenna. Whenever a pulse contacts an interface separating layers of differing electromagnetic 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 color active matrix LCD VGA screen. Data can be printed on thermal recorder or stored on hard drive for future playback or processing.

The size, orientation, and depth to a subsurface anomaly affect detection. Large objects reflect more energy and are easier to detect than small objects. Small, shallowly buried features will be missed, unless located directly beneath the aperture of the radar antenna. With GPR surveys covering extensive areas, the detection of small cultural features is often considered fortuitous. Small, deeply buried cultural features are often difficult to discern on radar profiles. In many soils, signal attenuation limits observation depths. In addition, the reflective power of an object decreases proportional to the fourth power of the distance to the object (Bevan and Kenyon, 1975).

Large, electrically contrasting features reflect more energy and are easier to detect than small, less contrasting features. Foundation walls of a large buried structure are more likely to be detected than a small, isolated artifact. The size, orientation, and depth to buried features affect their discernment with GPR. The size and shape of a subsurface anomaly may suggest its identity. Subsurface anomalies that are narrow and linear may, depending on their dimensions, suggest a buried utility line, road, foundation wall, or burial. Multiple, randomly spaced, subsurface anomalies occurring at a common depth may suggest cultural features from a unique period of history. In instances where features are small, randomly distributed, non-aligned, and/or variable in depth, positive identification can not be assured from radar interpretations alone and a greater number of observation pits are required to verify interpretations.

The intent of this GPR survey was to cover an extensive area on Marye's Height and to locate major structural features. While the GPR detected numerous, small, shallowly buried features, these anomalies were not the focus of this investigation and were ignored.

A wildcat survey was completed across much of Marye's Height with the 400 MHz antenna. Three large buried cultural features were identified and located during this survey: a structural feature believed to be the cellar to the historic Willis House, a lunette, and a structural feature within a filled gulley on the slopes of Marye's Heights.

Figure 3 is a portion of a radar profile that was collected over the buried structural feature believed to be a cellar. In Figure 3, the horizontal scale is about 7.9 m. The short vertical lines at the top of the radar profile are spaced at 0.60 m intervals. The vertical scale is in meters. Though not confirmed by calibration tests, a nominal propagation velocity of 0.106 m/ns was used in this study. Using this velocity of propagation, an approximate depth scale was developed for the radar profiles. With a maximum two-way travel time of 30 nanoseconds and a propagation velocity of 0.106 m/ns the maximum observation depth is about 1.6 m.

The structure is defined by abrupt vertical interfaces. The surrounding soil materials lack noticeable subsurface reflectors. Along this radar traverse the structure is about 4.8 m wide and over 1.6 m deep. This feature is believed to be the filled cellar to a former house. The location of this structure on Marye's Height places it near the location of the former Willis House that occupied the site during the battle.

Figure 4 is a portion of a radar profile that crosses a feature believed to be a buried lunette. Today, a paved circular driveway covers most of this feature. A lunette was a projecting, crescent-shaped fieldwork. Several of these earthen features were constructed and used by the Confederate artillery on Marye's Height during the Battle of Fredericksburg. So intense and devastating was the Confederate artillery fire from Marye's Height on the advancing Union troops on the open lower slopes that a Confederate cannoneer bragged "A chicken could not live on that field when we open on it."

In Figure 4, the horizontal scale is about 12 m. The short vertical lines at the top of the radar profile are spaced at 0.60 m intervals. The vertical scale is an estimated 1.6 m. If interpretations are correct, the lunette is about 8.4 m long and a little over 1 m deep. The lunette has an abrupt east facing wall (fifth vertical line from the left margin of the profile) and a more gently sloping west entrance (fourth vertical line from the right margin of the profile). The steep slopes to Marye's Height and the direction of Union advance during the battle of Fredericksburg was from the east (left margin of profile) where the earthworks appear to be the steepest.

A third major structural feature was identified on the easting facing slopes of Marye's Heights. This buried feature was located within a filled gulley that was not clearly evident on the soil surface. An auger observation revealed brick, mortar, and cultural debris to depths of over 50 inches.

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. 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 a brief period, geophysical techniques were used to locate three major buried structural features. Knowledge of the presence and locations of these features will assist archaeologists by facilitating excavation strategies and reducing field time and costs.

It was my pleasure to work in Virginia, Fredericksburg National Military Park, and with members of your fine staff.

With kind regards,

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EMI SURVEY
MARYE'S HEIGHTS
FREDERICKSBURG NATIONAL BATTLEFIELD
GEM300 SENSOR - HORIZONTAL DIPOLE ORIENTATION

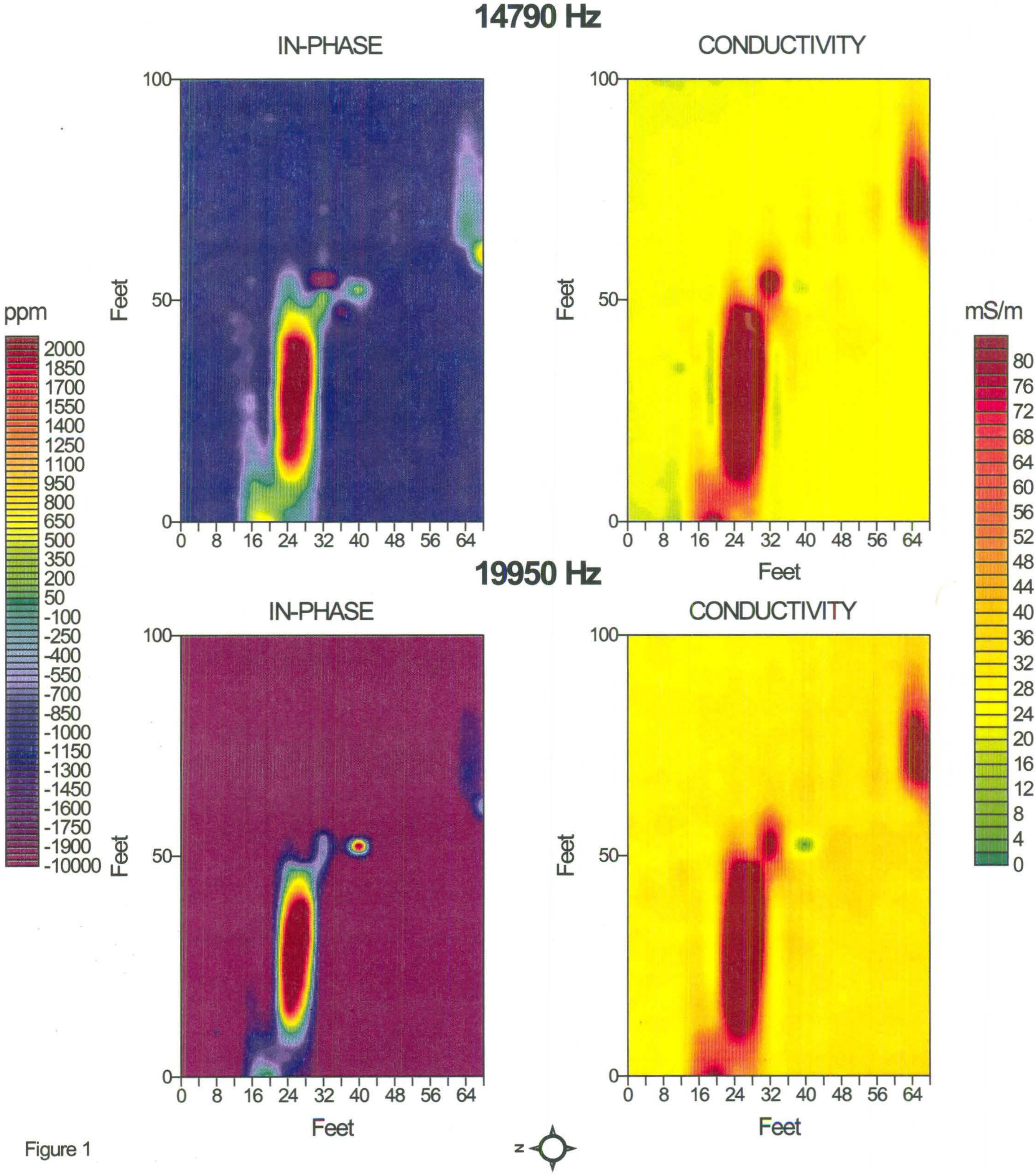


Figure 1

EMI SURVEY
MARYE'S HEIGHTS
FREDERICKSBURG NATIONAL BATTLEFIELD
GEM300 SENSOR - VERTICAL DIPOLE ORIENTATION

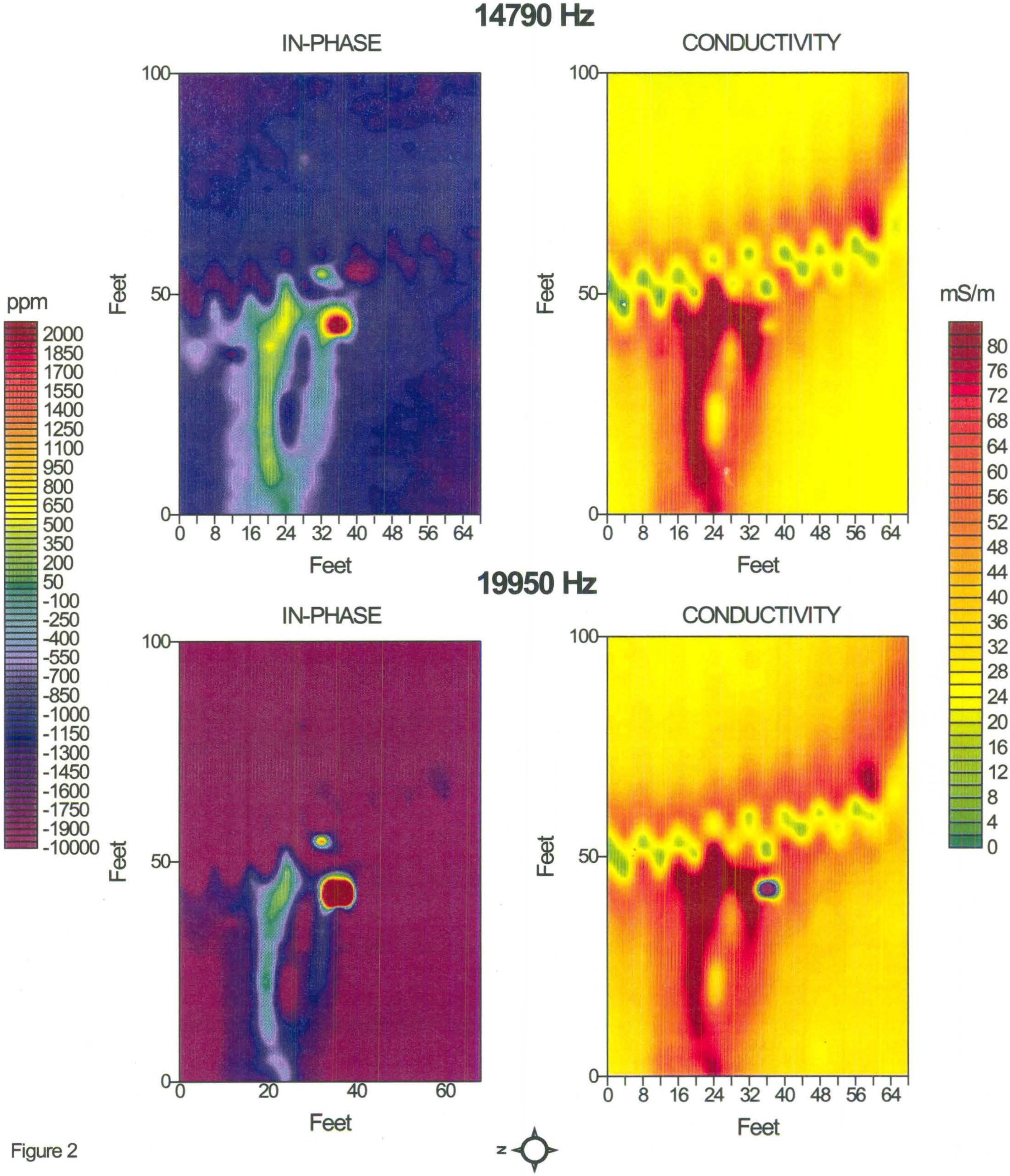
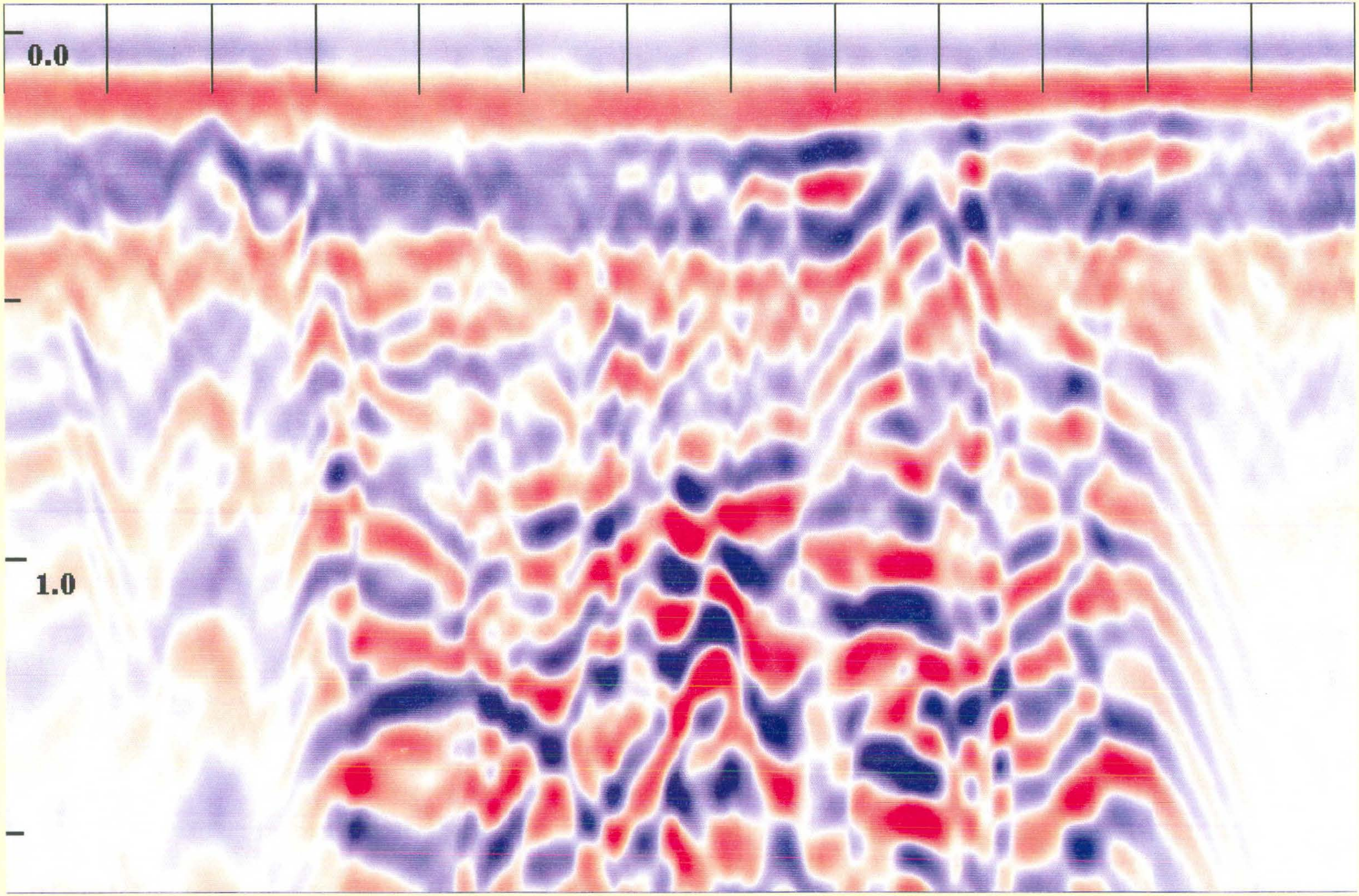
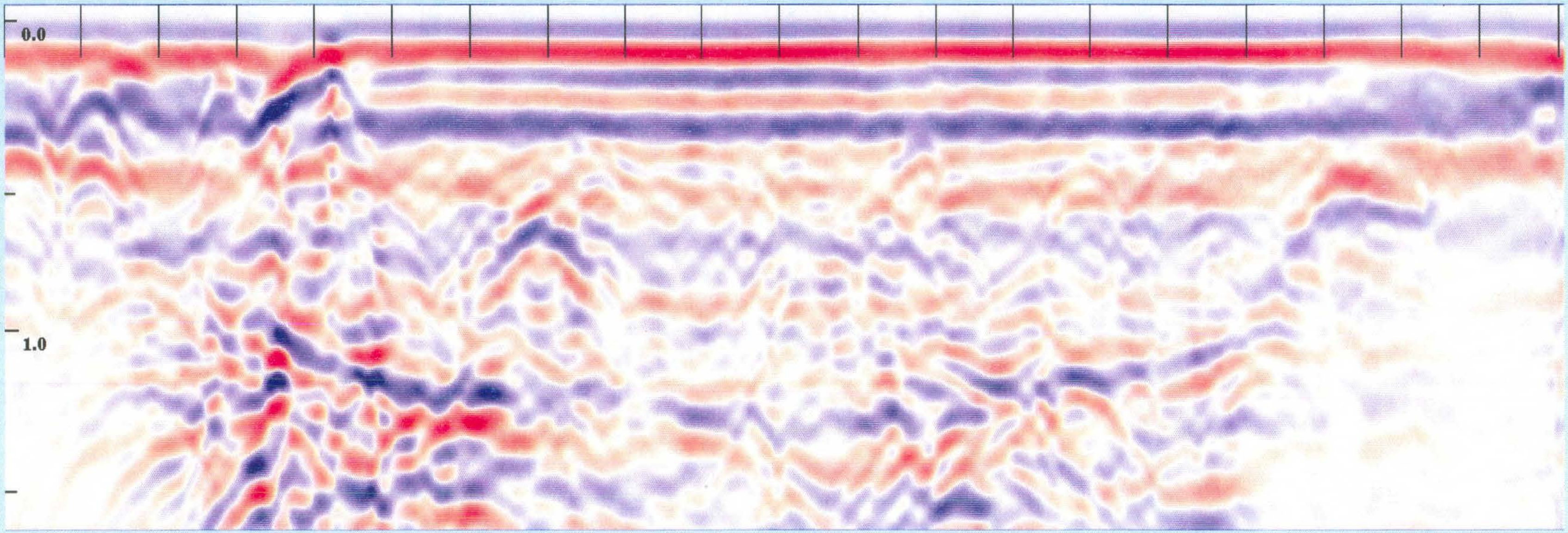


Figure 2



GPR PROFILE OF A BURIED STRUCTURAL FEATURE BELIEVED TO BE A CELLAR TO A HOUSE.

FREDERICKSBURG NATIONAL BATTLEFIELD, FREDERICKSBURG, VIRGINIA.



GPR PROFILE OF A SUBSURFACE FEATURE BELIEVED TO BE LUNETTE USED BY CONFEDERATE ARTILLERY ON MARYE'S HEIGHTS FREDERICKSBURG NATIONAL BATTLEFIELD, FREDERICKSBURG, VIRGINIA.