United States Department of Agriculture
Soil Conservation Service **Chester, PA 19013**

Date: 20 May 1993

Subject: Ground-Penetrating Radar (GPR) and Electromagnetic Induction (EM) studies at an archaeological site near Bradford, Vermont; 11 and 12 May 1993.

To: Richard Scanu
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Purpose:
To conduct an archaeological site investigation using ground-penetrating radar and electromagnetic induction techniques.

Participants:
Rudolph Chlanda, Geologist, SCS, Amherst, MA
Jim Doolittle, Soil Specialist, SCS, Chester, PA
Richard Fischer, Civil Engineer, SCS, Winooski, VT
Daniel Koloski, District Conservationist, SCS, Randolph, VT
Donald Hipes, Soil Conservationist, SCS, Winooski, VT
Fletcher Potter, Environmental Specialist, SCS, Winooski, VT
Richard Scanu, State Soil Scientist, SCS, Amherst, MA
Dave Skinas, Sate Historic Preservation Officer, Montpelier, VT
Jim Turenne, Soil Scientist, SCS, Middleboro, MA
William Van Fossen, CET, SCS, Randolph, VT

Activities:
Participants arrived on the site during the morning of 11 May. David Skinas provided an overview of the archaeological investigations conducted at the site. Following calibration trials, a grid was established across the site. The site was surveyed with GPR during the afternoon of 11 May. An electromagnetic induction survey of the site was completed with an EM31 meter during the morning of 12 May. Following the EM survey, Jim Turenne and I began our returns to our respective offices.

Equipment:
The radar units used in this study were the Subsurface Interface Radar (SIR) System-8 manufactured by Geophysical Survey Systems, Inc. The system was powered by a 12-volt vehicular battery. A Model 38 video display unit with a SONY Model TCD-D3 digital tape-corder was used. The model 3105 (500 mHz) antenna was used in the field studies.

The electromagnetic induction meter was the EM31 manufactured by GEONICS Limited. Measurements of conductivity are expressed as milliSiemens per meter (mS/m). Two-dimensional plots of the EM data were prepared using SURFER software developed by Golden Software, Inc.

Background
The Soil Conservation Service has been asked to stabilize a 1700 foot long section of eroding farmland located along the Connecticut River near Bradford, Vermont. Preliminary archaeological investigations conducted by the State of Vermont revealed the presence of dark, organic-enriched cultural layers buried at

depths of 16 to 145 cm. The thickness of these layers was reported to vary from 3 to 12 cm. These layers were described by the State Archaeologist to be "similar to small house floor features identified at other prehistoric Native American sites on the Connecticut River" (David Skinas letter of 7 December 1992). In his report, David Skinas identified these layers as being house floor features. The size of the features suggested the remains of long houses.

The study site is located on the flood plain of the Connecticut River. A short, steep escarpment to the Connecticut River forms the eastern boundary to the study site. The site is located on a nearly level area of Hadley very fine sandy loam. Hadley is a member of the coarse-silty, mixed nonacid, mesic Typic Udifluvents family. This soil formed in alluvium and can have an irregular decrease in organic carbon with depth.

Field Procedures

An irregularly shaped, 1100 by 40 to 180 foot grid was established across the study site. The grid interval was 20 feet. Survey flags were inserted in the ground at each grid intersects (300). A transit was used to establish grid corners and determine the elevation at each grid intersects. The lowest point in the survey area was used as the 0.0 datum. Figure 1 is a relative topographic map of the survey area. The contour interval is 1 foot. Within the survey area relief was 7.4 feet.

Survey procedure involves hand-towing the 500 mHz antenna along each north-south grid line at an average speed of about 1.8 km h-1. The operator attempted to maintain a constant speed of advance along each grid line and to record the position of each grid intersect as the antenna drew abreast of the survey flags.

With a scanning time of 45 nanoseconds (ns), a 500 mHz antenna was used to profile the subsurface to an observation depth of about 2.55 m. The apparent dielectric constant was estimated to be 7.2.

At each of the 300 grid intersects, measurements were obtained with the EM31 meter in both the horizontal and vertical dipole orientations. The EM31 meter scans depths of 0.0 - 2.75 meters in the horizontal and 0.0 - 6.0 meters in the vertical dipole orientations. For this survey, the meter was held and measurements were obtained at a height of 1 m above the ground surface.

Discussion:

Ground-penetrating radar survey

Figure 2 is a processed radar profile from the calibration site. This profile has been processed through the RADAN software package. The amplitudes of the reflected signals have been transformed to a color index and modified. The horizontal and vertical scales are in meters and measure distances along the transect line and depths, respectively. A metallic reflector was buried at a depth of 40 cm and used to calibrate the depth scale. Reflections from this features has produced the distinct hyperbolic pattern in the left-hand portion of this figure.

The layer immediately below the metallic reflector was identified as an Ab horizon. In Figure 2, reflections from an Ab horizon have been labeled. This horizon occurs in the left-hand portion of this figure. The Ab horizon is the dark, organic-enriched cultural layer that David Skinas had described in his reports. Stratified layers of coarser-textured alluvial deposits (2C) are evident in the lower and right-hand portion of this figure.

Figure 3 is a radar profile from a representative traverse along line X = 120 feet. This profile has been normalized and terrain corrected. The horizontal and vertical scales are in meters and measure distances along the transect line and depths, respectively. In this portion of the transect, the Ab horizon is present in the lowest portion of the landscape. This horizon is discontinuous and variable in expression. In Figure 3, the image of the Ab horizon is most pronounced between observations 12.2 and 18.3 meters. Between these observation points, the amplitudes of the reflected signals from this horizon are more intense and imply more contrasting materials. In some places, below the Ab horizon, a second sub-parallel layer is evident. The identity of this layer was not verified in the field. However, it is most probable that this layer represents either a contrasting textural layer and/or another buried A horizon.

Radar interpretations of the extent and depth to the Ab horizon were used to construct Figure 4. In this plot the contour interval is 0.2 foot. Areas containing contour lines represent areas underlain by a buried A horizon. Areas without contour lines lack buried A horizons and were underlain by stratified layers of coarse sands.

David Skinas conducted several soil probings to verify the radar interpretations. His observations confirmed the radar interpretations.

<u>Electromagnetic induction survey</u>
In Figure 4, the responses of the EM31 meter in the horizontal (left) and vertical (right) dipole orientations are shown. Generally, values of apparent conductivity are exceeding low and indicate the resistive nature of Hadley soils. At each observation site, values of apparent conductivity increase slightly with depth. This relationship is believed to reflect increases in volumetric moisture content with depth. Values of apparent conductivity increase with distance from the river. As a cultivated field is situated to the left (west) of the study area, changes in conductivity may be related to changes land management (i.e. application of fertilizer).

The EM survey failed to detect buried cultural features. Electromagnetic induction techniques were inappropriate for detecting buried cultural layers at this site

Recommendations:
1. The GPR survey charted the extent of buried A horizons within the Bradford site. The plot of this layer (Figure 3) should support the assessment of this site.

2. As my role was to provide assistance to Jim Turenne, I have asked him to prepare the final report. Jim is encouraged to use this report and my observations to prepare a final report to the State Conservationist in Vermont.

3. This assignment provided Jim Turenne and me an opportunity to exchange ideas on survey procedures for archaeological site.

4. Participants received exposure to and training on the use of the EM31 meter.

With kind regards

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Soil Specialist

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Review of Electromagnetic Induction Methods

Electromagnetic inductive (EM) is a surface-geophysical method in which electromagnetic energy is used to measure the terrain or apparent conductivity of earthen materials. This technique has been used extensively to monitor groundwater quality and potential seepage from waste sites (Brune and Doolittle, 1990; Byrnes and Stoner, 1988; Be Rose, 1986; Greenhouse and Slaine, 1983; Greenhouse et al., 1987; and Siegrist and Hargett, 1989)

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. The 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 milliSiemen per meter (mS/m).

Electromagnetic methods measure the apparent conductivity of earthen materials. Apparent conductivity is the weighted average conductivity measurement for a column of earthen materials to a specified penetration depth (Greenhouse and Slaine; 1983). The averages are weighted according to the depth response function of the meter (Slavich and Petterson, 1990).

Variations in the meters response are produced by changes in the ionic concentration of earthen materials which reflects changes in sediment type, degree of saturation, nature of the ions in solution, and metallic objects. Factors influencing the conductivity of earthen materials include: (i) the volumetric water content, (ii) the amount and type of ions in soil water, (iii) the amount and type of clays in the soil matrix, and (iv) the soil temperature. Williams and Baker (1982), and Williams (1983) observed that, in areas of salt affected soils, 65 to 70 percent of the variation in measurements could be explained by the concentration of soluble salts. However, as water provides the electrolytic solution through which the current must pass, a threshold level of moisture is required in order to obtain meaningful results (Van der Lelij, 1983).

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 depths of measurements for the EM31 meter. The actual depth of measurement will depend on the conductivity of the earthen material(s) scanned.

TABLE 1

Depth of Measurement

Meter	Intercoil Spacing	Depth of Measurement Horizontal	Depth of Measurement Vertical
EM31	3.7m	2.75m	6.0m

The conductivity meters provide limited vertical resolution and depth information. However, as discussed by Benson and others (1984), the absolute EM values are not necessarily diagnostic in themselves, but lateral and vertical variations in these measurements are significant. The seasonal variation in soil conductivity (produced by variations in soil moisture and temperature) can be added to the statement by Benson. Interpretations of the EM data are based on the identification of spatial patterns in the data set appearing on two-dimensional contour plots.

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