

**United States  
Department of  
Agriculture**

**Natural Resources  
Conservation  
Service**

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**Subject:** SOI -- Demonstration of Geophysical Tools

**Date:** 12 March 1999

**To:** William Hartman  
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**Purpose:**

Berkeley County, West Virginia, is experiencing rapid change and land development. Sanitarians are looking for tools that will provide more accurate and comprehensive information concerning depths to bedrock. Two geophysical tool, ground-penetrating radar (GPR) and electromagnetic induction (EMI), were demonstrated and evaluated at a selected development site in Berkeley County.

**Participants:**

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**Activities:**

All field activities were completed on 11 March 1999.

**Equipment:**

The radar unit is the Subsurface Interface Radar (SIR) System-2, manufactured by Geophysical Survey Systems, Inc.<sup>1</sup> The SIR System-2 consists of a digital control unit (DC-2) with keypad, VGA video screen, and connector panel. A 12-volt battery powered the system. Morey (1974), Doolittle (1987), and Daniels (1996) have discussed the use and operation of GPR. This unit is backpack portable and requires two people to operate. A 200 mHz antenna was used in this study. The scanning time was 80 nanoseconds (ns); the scanning rate was 32 scan/second were used in this survey.

The electromagnetic induction meter used in this study is the EM31 manufactured by Geonics Limited.<sup>1</sup> This meter is portable and requires only one person to operate. McNeill (1980) has described principles of operation. No ground contact is required with this meter. The EM31 meter operates at a frequency of 9,800 Hz and has theoretical observation depths of about 3 and 6 meters in the horizontal and vertical dipole orientations, respectively (McNeill, 1980). Values of apparent conductivity are expressed in milliSiemens per meter (mS/m).

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<sup>1</sup> Manufacturer's names are provided for specific information; use does not constitute endorsement.

## **Study Site:**

The study site was located in an open field. The site is being developed for residential use. Soils mapped within the site include Hagerstown and Funkstown. Hagerstown soil is a member of the fine, mixed, semiactive, mesic Typic Hapludalfs family. This deep, well-drained soil formed in limestone residuum on uplands. Depth to limestone bedrock ranges from 40 to 84 inches. Funkstown soil is a member of the fine-loamy, mixed, mesic Oxyaquic Hapludalfs family. This very deep, well-drained soils formed in colluvium and alluvial materials derived from limestone uplands.

## **Discussion:**

In areas underlain by limestone, selecting the most appropriate geophysical methodology often depends on soils, soil properties, and anticipated depths to bedrock. In comparative studies conducted by Byrnes and Stoner (1988), Rumbens (1990), and Doolittle and Collins (1998), EMI and GPR were used to detect bedrock surfaces and cavities and fractures within limestone bedrock. Both techniques were found to provide some useful subsurface information. However, neither GPR nor EMI provided totally satisfactory results. In these studies, layers of clayey soil materials restricted the observation depth of GPR. Electromagnetic induction provided less precise measurements and inferior resolution of subsurface features.

### EMI

Electromagnetic induction provides moderate resolution of subsurface features, but is insensitive to subsurface layers or features having similar electrical properties. Electromagnetic induction does not provide unique interpretations and is also susceptible to interference from cultural features. Generally, the use of EMI has been most successful in areas having reasonably homogeneous subsurface properties with a minimal sequence of dissimilar subsurface layers. Soils with highly variable properties or a large number of dissimilar layers are more likely to produce ambiguous interpretations that limit the effectiveness of EMI. Electromagnetic induction has been most effective in areas where the effects of one property (e.g., clay, water, or salt content) dominate over the other properties. In these areas, variations in EMI response can be directly related to changes in the dominant property (Cook et al., 1989). Commercially available meters have theoretical observation depths ranging from about 1 to 60 meters (McNeill, 1980).

Hagerstown and Funkville soils are slightly more conductive than the underlying limestone bedrock. The soils have greater clay and moisture contents, and consequently apparent conductivity, than the bedrock. Areas that are shallower to bedrock have lower values of apparent conductivity than areas that are deeper to bedrock. Broad spatial patterns of bedrock depths can be inferred from collected data.

Electromagnetic induction provided poorer resolution of subsurface features than GPR. Lateral resolution is purportedly equal to the intercoil spacing (12.66 feet). However test on buried objects have shown a footprint area of about 20 feet. This is too coarse to resolve the microtopography of the bedrock surface especially small pinnacle, solution features, ledges, and rock fragments. In this study, EMI was used to estimate the depths to bedrock. Interpretations of bedrock depths were generalized (areas of shallower or deeper depths to bedrock) from measurements of apparent conductivity. Broad spatial patterns can be discerned in the data (see Figure 1). However, a large number of backhoe observations are needed to confirm these interpretations and to establish predictive equations to convert apparent conductivity into measurements of bedrock depths.

Figure 1 contains two-dimensional plots of data collected with the EM31 meter in the horizontal (upper plot) and vertical (lower plot) dipole orientations. In Figure 1, the upper plot represents the spatial distribution of apparent conductivity within the upper 3 meters of the profiled materials. The lower plot represents the spatial distribution of apparent conductivity within the upper 6 meters of the profile materials. In each plot, the isoline interval is 1 mS/m. It was felt that the EM31 meter in the vertical dipole orientation provided a more reasonable interpretation of bedrock depths. In the lower plot of Figure 3, areas of shallower or deeper depths to bedrock have been inferred from EMI data and labeled. A bedrock ledge that extends in a north-south direction across the central portion of the study site is evident in Figure 1. However, the steep sidewalls of this ledge and the abrupt change from deep to shallow soils have not been captured in these plots because of the poor lateral resolution of the EM31 meter.

### GPR

The observation depth of GPR is dependent upon the presence, thickness, and electrical conductivity of the Bt horizon (argillic horizon) or layers of loamy and clayey materials within the substratum. Highly conductive soils are essentially radar opaque because the electrical properties of soil material attenuates the signal (Cook, 1973; Doolittle, 1987; Collins, et al., 1993). Radar signals are rapidly attenuated by loamy or clayey argillic horizons or layers of soil materials with properties mentioned above that cap limestone (Ballard, 1983; Barr, 1993; and Collins et al., 1994). In a study conducted in an area of Hagerstown and Opequon soils in central Pennsylvania (Doolittle and Collins, 1998), reflections from the limestone bedrock were only apparent on radar profiles where the bedrock outcrops or subcrops at shallow depths. In these areas, the argillic horizon was thin or not

present, the radar signals were less rapidly attenuated, and observation depths were greater. Similar results were obtained in this study.

## Conclusions:

The study demonstrated that while both EM and GPR provide some information on the depth to limestone bedrock, neither technique provides unambiguous results. Interpretations were often unclear because of limited observation depths or poor resolution of subsurface features. The observation depth of GPR is severely restricted by high rates of signal attenuation within the clayey argillic horizon and residuum. In many areas of Hagerstown soils observation depths will be less than 20 inches. Ground-penetrating radar is considered generally unsuitable for determining the depths to limestone bedrock within the Ridge and Valley Province. While EMI is considered a superior technique to GPR for bedrock investigations in areas of Hagerstown soil, low to moderate resolution of subsurface features limits in appropriateness to mapping broad spatial patterns within the landscape.

With kind regards,

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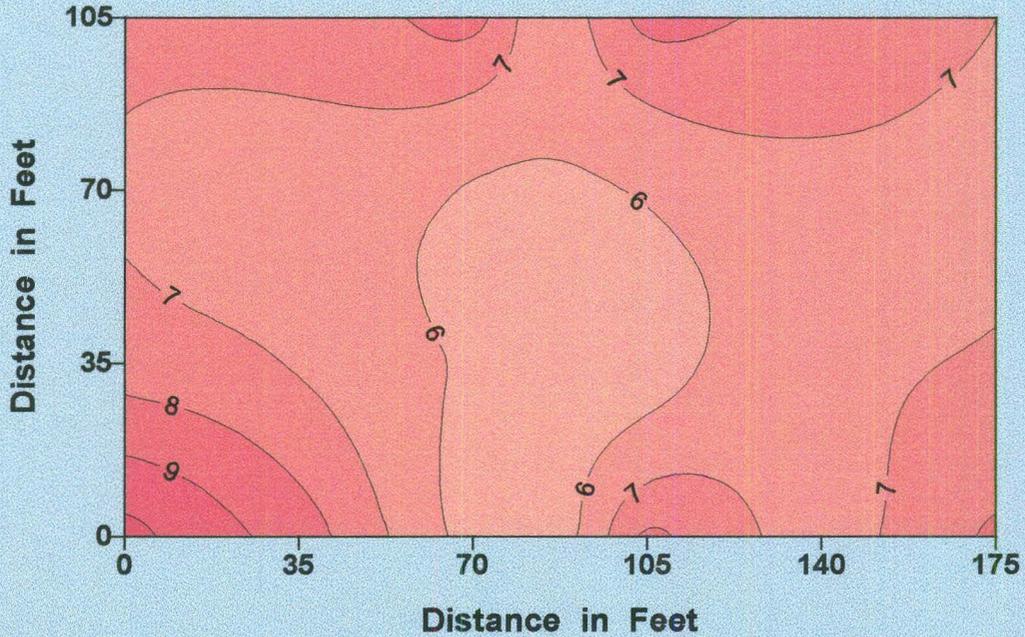
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# EMI SURVEY AREA OF HAGERSTOWN SOIL EM31 METER

## Horizontal Dipole Orientation



## Vertical Dipole Orientation

