United States Department of Agriculture
Soil Conservation Service

Northeast NTC
Chester, PA 19013

Subject: Ground-Penetrating Radar (GPR)
Electromagnetic Induction (EM)
Field Demonstration - 22 May 1992

Date: 3 September 1992

To: John M. Robbins, Jr.
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Purpose:
To provide a demonstration of the use of two geophysical techniques for the purpose of detecting solution features in karst areas of Christian County, Kentucky. Geophysical techniques used were ground-penetrating radar (GPR) and electromagnetic induction (EM). The demonstration was sponsored by the Pennyrile RC&D Council and the Soil Conservation Service.

Principal Participants:
Lorin Boggs, District Conservationists, SCS, Hopkinsville, KY
William Craddock, Acting State Soil Scientist, SCS, Lexington, KY
Jim Doolittle, Soil Specialist, SSQAS, SCS, Chester, PA
Kim Doolittle, Earth Team Volunteer, SCS, Chester, PA
Paul Howell, Geologist, SCS, Lexington, KY
Charles Turner, RC&D Coordinator, SCS, Hopkinsville, KY

Activities:
A 100 by 100 foot grid was established across an area of Pembroke silt loam, 2 to 6 percent slopes. Pembroke is a member of the fine-silty, mixed, mesic, Mollic Paleudalf family. The site was located on the properties of Charles Henderson and Shelia Raines in a field immediately north of the Hopkinsville field office.

On the afternoon of 12 August, in preparation for the demonstration, the field was surveyed with the EM31 meter. The radar equipment was calibrated and field tested on the morning of 13 August. Following a welcome by Charles Turner and an overview to the sinkhole problem in Christian County by Lorin Boggs, a brief slide presentation was given on the uses of GPR and EM techniques within SCS. Following lunch, the operations of EM meters and GPR were demonstrated in the study area.

Equipment:
The ground-penetrating radar unit used in this study was the Subsurface Interface Radar (SIR) System-8 manufactured by Geophysical

Survey Systems, Inc. [1]. Components of the SIR System-8 used in this study were the model 4800 control unit, ADTEK SR 8004H graphic recorder, power distribution unit, transmission cable (30 m), and the model 3110 (120 MHz) antenna. The system was powered by a 12-volt battery.

The electromagnetic induction meter used in this demonstration was the EM31 manufactured by GEONICS Limited [1]. Measurements of conductivity are expressed as milliSiemen per meter (mS/m).

Discussion:

EM Survey:

The grid covered a 100 by 100 foot area (approximately 0.2 acre). The grid interval was 10 feet. This provided 121 grid intersects or observation points. At each intersect, measurement were taken with the EM31 meter in both the horizontal and vertical modes (figures 1 and 2, respectively). Surface water is believed to be entering a solution feature through an opening identified in the extreme upper right-hand corner of the survey site. In these figures, north is toward the upper border of each plot.

Electromagnetic techniques produce qualitative results. Results depend on the adequacy of interpretations. Interpretations are based on available information concerning the nature and complexity of soil, geologic, and terrain conditions at a site, and the number and type of observations used to support or verify the inferences drawn from EM survey.

Interpretation of the EM data are based on the identification of spatial patterns within the data. Figures 1 and 2 represent spatial patterns of apparent conductivity simulated from data collected with the EM31 meter in the horizontal and vertical dipole modes, respectively. In each figure, the contour interval is 2 mS/m. The profiling depth of an EM meter is a function of frequency, intercoil spacing, and coil orientation. With the EM31 meter, values of apparent conductivity are integrated over the upper 2.75 meters in the horizontal dipole orientation, and over the upper 6 meters in the vertical dipole orientation. Table 1 (in compendium to this report) lists the effective profiling depths of this and other meters with varied orientations and/or intercoil spacings.

Several inferences can be made from the data simulated in Figures 1 and 2. First, at any observation point, values of apparent conductivity decrease with soil depth. This relationship is produced by variations in lithology. The underlying limestone bedrock is more resistive (less conductive) than the overlying, moderately-fine textured soil materials. Second, the effects of horizontal variations in the depth to bedrock are evident in these contour plots. Generally, depths to bedrock were observed to be shallower along the western and northern portions (lower EM values in these areas) and

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1. Use of trade names in this report is for identification purposes only and does not constitute endorsement by the author or SCS.

deeper in the southeast portion (higher EM values in this area) of the study site. Four auger borings were used to confirm this interpretation. Third, anomalous EM values are believed to delineate large, subsurface solution features. Anomallies having low values of apparent conductivities may reflect air-filled subsurface cavities. Anomallies having high values of apparent conductivities may reflect collapsed or filled solution features. Anomallies appear to be most prevalent in the upper right-hand corner of Figure 2 (near and to the southwest of the surface opening). This pattern may delineate a potentially "high risk" area which should be avoided as a site for construction.

GPR Survey:
Each east-west trending grid line was profiled with the radar. The range of the GPR was set at 125 nanoseconds. Assuming a dielectric constant of 19 (for wet, loamy soils), the GPR profiled to an estimated depth of about 4.3 meters. However, radar imagery was restricted to relatively shallow depths (see Figure 3). The relatively high silt and clay contents of the Pembroke soils rapidly attenuated the radar signals and restricted the profiling depth of GPR. The soil/bedrock interface was apparent in areas where it was less than 1.2 meters deep. Reflections from this interface were fragmentary between depths of 1.2 and 1.5 meters. With the exception of unwanted background noise, no radar reflections were apparent at depths greater than 1.5 meters.

The GPR is an inappropriate tool for the detection and delineation of solution features in Christian County. However, despite the limited profiling depth, the GPR can be used to study some soil features and chart the depth to the soil/bedrock interface in areas where the depth to bedrock is less than 1.2 meters.

Results:
1. Participants received an informal introduction and field demonstration on the use of GPR and the EM31 meter. Each participant was provided opportunities to evaluate the merits and limitations of both systems and to assess the applicability of these techniques to their work assignments.

2. Electromagnetic inductive techniques appear to be suitable for detecting some (larger) cavities in carbonate rocks. On the basis of the EM investigation, patterns of anomalous apparent conductivity values within the northeastern portion of the study site suggests the occurrence of a potentially cavernous area. The ability of EM techniques to locate solution features requires a favorable size to depth ratio (small features can not be resolved) and a significant contrast in apparent electrical conductivity across the solution features (large air-filled voids are more detectable than voids filled with rubble). In addition, detection depends on local ground conditions, presence of interfering cultural features, and the sensitivity and penetration depths of a particular meter.

.2 acre size

3. A general map of the depth to bedrock within the study site can be prepared from a regression equation of EM values and observed depth to bedrock data.

4. Results from these field studies do not replace the need for direct sampling. Interpretations can guide the placement of observation sites and provide supplemental information.

I feel that this session was rewarding to all participants. It was my pleasure to work in your state.

With kind regards.

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Review of Electromagnetic Induction Methods

Electromagnetic inductive (EM) technique is a surface-geophysical method in which electromagnetic energy is used to measure the terrain or apparent conductivity of earthen materials. Electromagnetic inductive (EM) methods have been used extensively to measure the apparent conductivity of saline (Corwin and Rhoades, 1982, 1984, and 1990; De Jong, 1979; Kingston, 1985; Rhoades and Corwin, 1981; Rhoades and Halvorson, 1977; Slavich and Read, 1985; Williams, 1983; Williams and Baker, 1982; Williams and Hoey, 1987; and Wollenhaupt et al., 1986) and sodic (Ammons et al., 1989) soils. In addition, this technology has been used to map bedrock surfaces (Zalasiewicz, 1985), thickness of clays (Palacky, 1987) or sand and gravel deposits (McNeill, 1988), measure soil water content (Kachanoski et al., 1988) and for groundwater investigations (McNeill, 1988). These studies have documented the ease and accuracy of EM interpretations and its applications over broad areas and soil types.

For surveying, an EM meter is placed on the ground surface or held above the surface at a specified distance. A power source within the EM meter generates an alternating current in the transmitter coil. The current flow produces a primary magnetic field which induces electrical eddy currents in the soil. The induced current flow is proportional to the electrical conductivity of the intervening medium. The eddy 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 ground conductivity. Values of terrain 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). 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. Variations in the meters response are produced by changes in sediment type, degree of saturation, nature of the ions in solution, and metallic objects.

The depth of penetration is dependent upon the intercoil spacing, transmission frequency, and coil orientation relative to the ground surface. Table 1 list the anticipated depths of measurements for the EM31, EM34-3, and EM38 meters. The actual depth of measurement will depend on the conductivity of the earthen material(s) scanned.

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

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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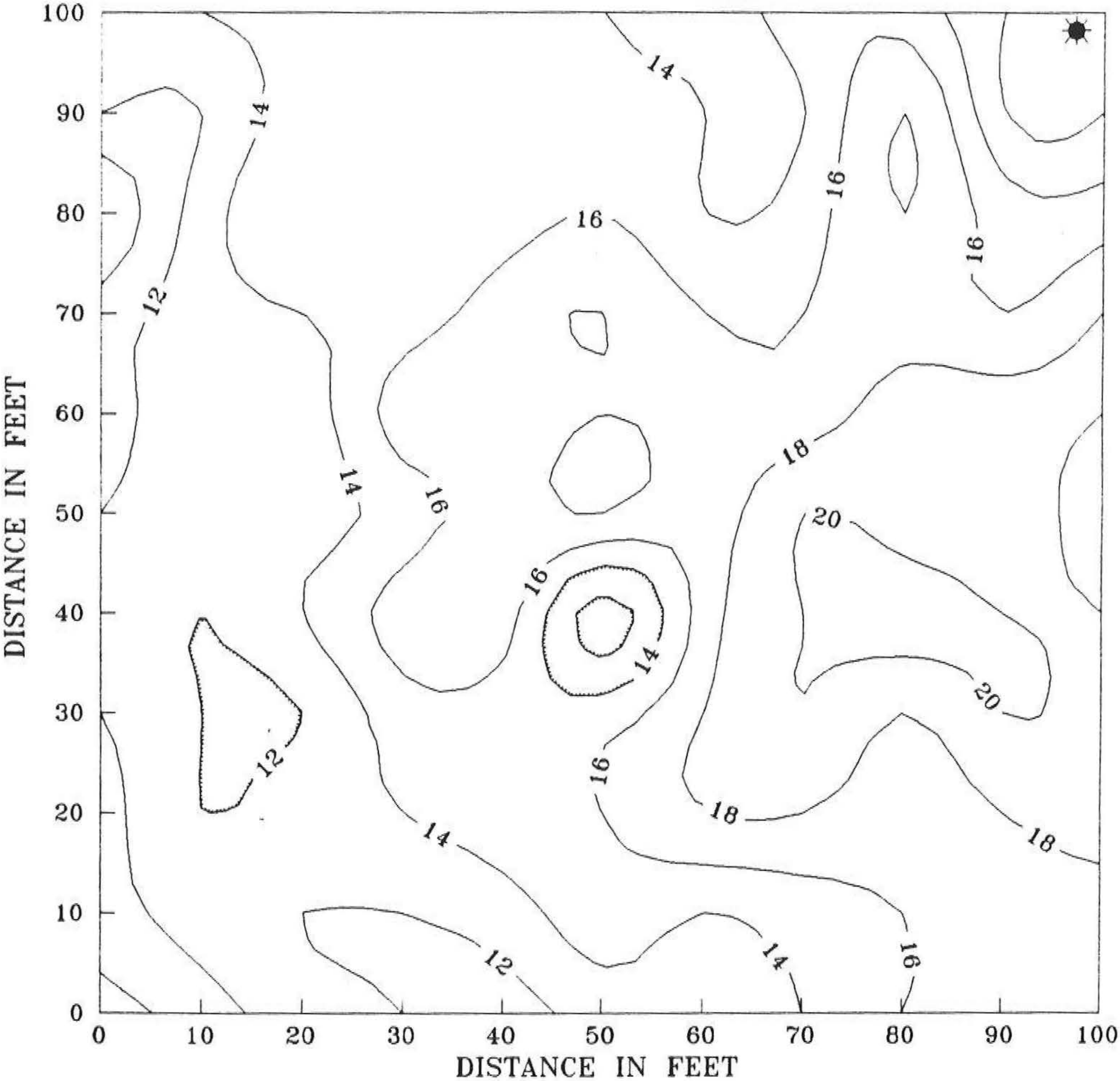
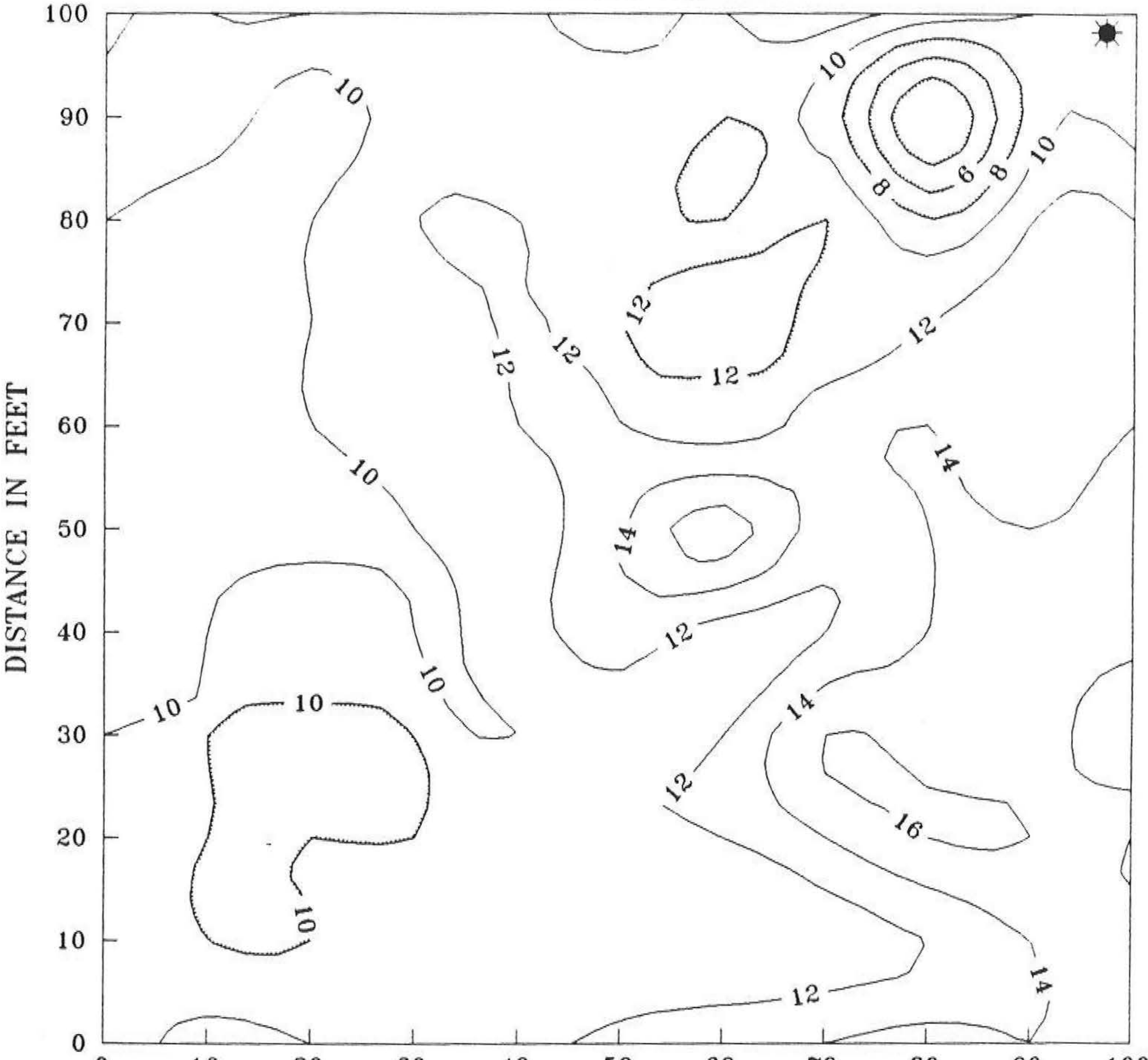
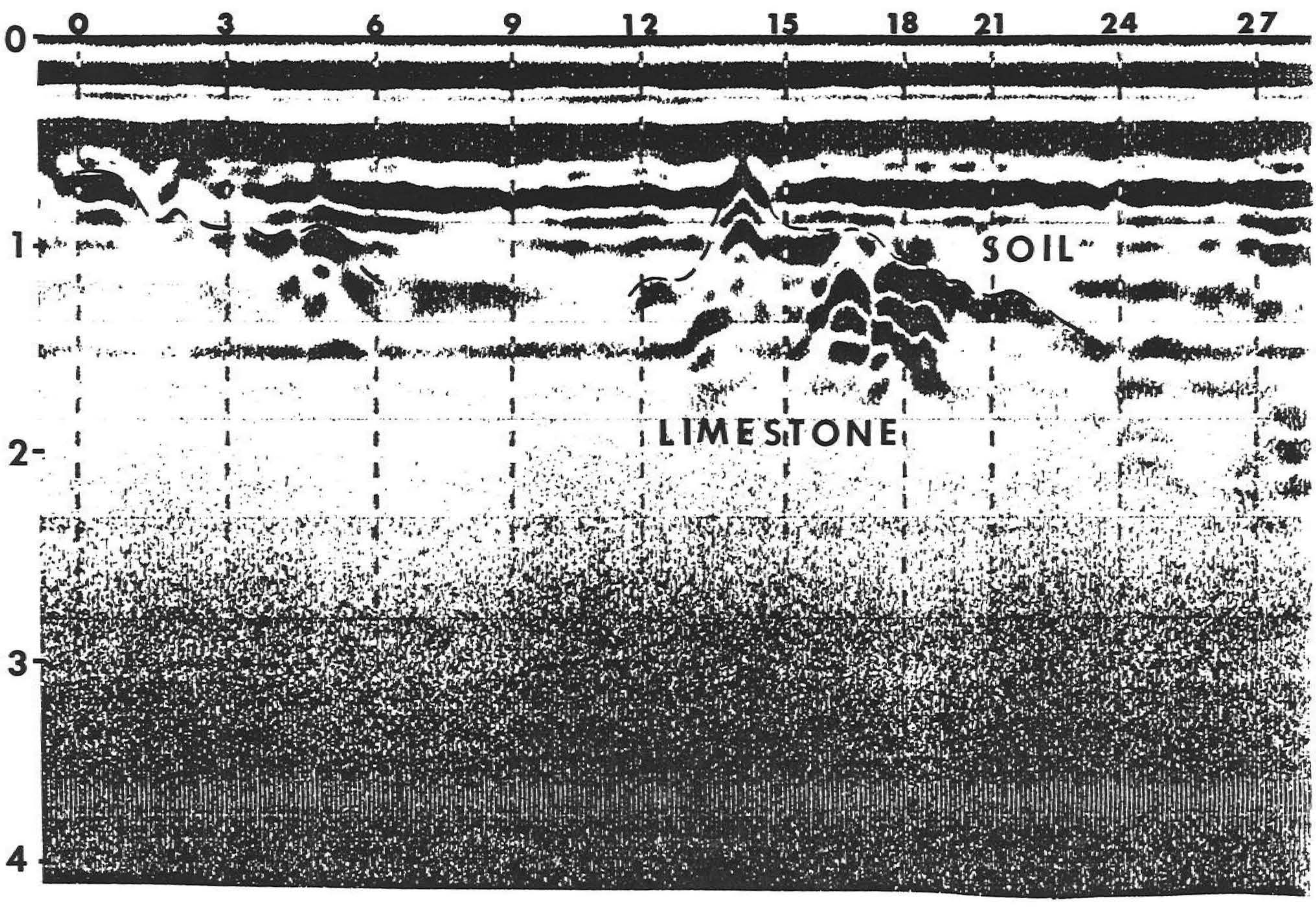
EM31 SURVEY OF KARST
NEAR HOPKINSVILLE, KENTUCKY
HORIZONTAL DIPOLE



EM31 SURVEY OF KARST NEAR HOPKINSVILLE, KENTUCKY VERTICAL DIPOLE

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SOIL
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