Return to all Soil ... tists

Return to file
Doolittle

United States Department of Agriculture | Soil Conservation Service | 160 East 7th Street, Chester, PA 19013-6092

Subject: Preliminary Report
1992 Geophysical Studies at
Ceren, El Salvador

Date: 18 September 1992

To: Jerry Hammond
International Activities Division
USDA-Soil Conservation Service
P. O. Box 2890
Washington, D.C. 20013

Enclosed is the draft copy of my final report on geophysical field work conducted at the Ceren Archaeological Site in El Salvador. The study was successful as it provided researchers with a definitive statement of the capabilities of the various geophysical tools used at the site in the last 13 years. While site conditions makes any investigation most "challenging," we feel that we made a positive contribution to the archaeological investigation at Ceren and have provided much needed direction for future geophysical applications.

This report will be edited by the Department of Anthropology staff at the University of Colorado (Boulder). The report will be included as a chapter in a report of field investigations and later in a new book on Ceren.

I remain indebted to your staff for their assistance.

With kind regards,

James A. Doolittle

James A. Doolittle

cc:
J. R. Culver, National Leader, SSQAS, NSSC, SCS, Lincoln, NE
C. S. Holzhey, Assistant Director, Soil Survey Division, NSSC, SCS, Lincoln, NE

SEP 21 1992

1992 GEOPHYSICAL INVESTIGATIONS AT THE CEREN SITE, EL SALVADOR

James Doolittle and Frank Miller
USDA-Soil Conservation Service and Mississippi State University

Introduction

Geophysical instrument are increasingly being used to aid archaeological investigations. These devices afford medium to high resolution and continuous measurements or profiles of subsurface conditions. Geophysical instruments can provide rapid, cost-effective, and non-destructive means of artifact detection, identification, and location. In addition, these techniques provide more comprehensive information about a site and minimize the number of exploratory pits.

Since 1979, several geophysical methods have been used at the Ceren Site in efforts to locate structures buried beneath 4 to 6 meters of pyroclastic materials from the Laguna Caldera eruption (circa A. D. 600). These methods included seismography, resistivity, and ground-penetrating radar (Loker, 1983; Sheets et al., 1985; Spetzler and Tucker, 1989; Spetzler and McKee, 1990). Interpretations of traces from seismic-refraction surveys provided no evidence that this tool could distinguish structural features buried within depths of 6 meters. Results from resistivity and ground-penetrating radar (GPR) surveys were more encouraging and indicated the effectiveness of these tools for locating archaeological features.

The 1992 field season involved an integrated approach using both electromagnetic induction (EM) and ground-penetrating radar (GPR) techniques. These complimentary geophysical techniques are non-intrusive and provide rapid means to cover large areas at different levels of intensity and resolution. It was anticipated that the use of these tools would provide more site information than a single method by increasing areal coverage, reducing field time, and facilitating excavation strategies. In addition, it was proposed that the following questions posed by previous investigations would be addressed:

1. what is the effective depth of penetration of GPR in the soils/substrata at the Ceren Site;

2. what is the capability of geophysical techniques to resolve subsurface features buried at depths of 3 to 6 meters; and

3. how do the results of EM compare with resistivity techniques?

Descriptions of Systems

Ground-Penetrating Radar

Ground-penetrating radar is an impulse radar system designed for shallow subsurface site investigations (Daniels et al., 1988). Compared with other geophysical techniques, GPR surveys are generally less time consuming and can provide higher resolution of subsurface features. The 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 include the model 4800 control unit, ADTEK SR 8004H graphic recorder, ADTEK DT 6000 tape recorder, power distribution unit, transmission cable (30 m), and the model 3205 (120 MHz) antenna with the 705DA and 705DA2 transceivers. The system was powered directly from a 12-volt vehicle battery. The operation of the SIR System-8 has been described by Doolittle (1987).

Results from radar surveys are site specific and interpreter dependent. In some areas, conductive soil conditions limit profiling depth and the applicability of GPR. Ground-penetrating radar is best suited for shallow (3 to 10 meters) investigations in electrically resistive mediums (i.e. dry, sandy soils). Successful interpretations depend on the experience of the operator, complexity of soil or geologic conditions, quantity and quality of independent observation data, and the system and antennas used. In many terrains, unless mounted in a suitable vehicle, the equipment is heavy and cumbersome to move and operate. Ground-penetrating radar has been used to locate and map buried structures, buried artifacts, and graves (Bevan and Kenyon, 1975; Bevan, 1984, 1991; Doolittle and Miller, 1991; Imai et al., 1987; Vaughan, 1986).

Electromagnetic Induction

This technique generates electromagnetic fields to measure the bulk or apparent conductivity of underlying 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). 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 EM meters with different intercoil spacings and coil orientations.

The electromagnetic induction meter used in this study was the EM34-3 manufactured by GEONICS Limited[1]. A 10 meter intercoil

---

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

spacing was used and measurement were obtained in both the horizontal and vertical dipole modes. Values of apparent conductivity are expressed in milliSiemens per meter (mS/m). The operation of the EM34-3 meter has been described in detail by McNeill (1980).

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

Because of the ease and efficiency of operation, EM can be used to rapidly survey large areas. Interpretations of EM results are based on the identification of spatial patterns in the data set appearing on two-dimensional contour plots or cross sections. Analysis of EM data provides stratigraphic information about a survey area and may reveal the location of buried cultural features. However, with increasing exploration depths and coarser resolution, detection is often limited to large buried structures or prominent stratigraphic features. As only the EM34-3 meter was available for this survey, there were concerns about the capability of this instrument to resolve structural features buried at depths of 4 to 6 meters. This technique is, however, well suited to reconnaissance surveys requiring continuous, moderate resolution 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).

Field Procedures

A large proportion of the field time was spent surveying grid lines across the study areas. At the time of the survey, only lots 189A and 189B were uncultivated and cleared of vegetation. Lots 190, 191 and 192 were in sugar cane or corn. The cane was closely planted, and over 2 m in height. Rows were narrow, winding, broken along field boundaries, and often impassible in areas of wind-thrown cane. These conditions precluded the use of GPR. The use of the GPR was restricted to Lot 189A and a cleared portion of Lot 192 near the road to Joya de Ceren.

Radar calibration studies were conducted along an exposed face of a cut bank near Operation 14. The 120 MHz was pulled adjacent to a 20 m section of the exposed face. Horizontal holes were augered into the exposure at depths of 60 and 100 cm, respectively, and metallic auger handles were placed in each hole. Because of multiple, closely spaced layers of pyroclastic materials, the embedded reflectors were difficult to discriminate with a high degree of confidence.

Additional radar scans were conducted on a line at right angles to the exposed face. Along this traverse, a paint can with a diameter of 15 cm was buried at a depth of 75 cm. Repeated passes were made with the antenna across this buried anomaly with ranges of 50, 100, 200, 300, and 400 nanoseconds on the control unit. Positive identification of the buried can was made on each pass. On the basis of the depth to this buried anomaly, each radar profile was depth scaled and a dielectric constant of 12 for the overlying soils was estimated.

Radar surveys were conducted at three additional sites. These surveys covered an area of about 1020 m^2 Two of these sites were located within Lot 189A. One area was adjacent to a test pit near Operation #4 and the other area was located near Operation #5. A 900 m^2 site was surveyed with GPR on summit of a hill near the road to Joya de Ceren. This site was located in an area where the Ceren sequence was between 200 and 300 cm thick (Miller, 1992). Grids were established at each site with either a 1 or 5 m grid interval. The antenna was pulled by hand along parallel grid lines to produce the radar profiles.

Portions of lots 189B, 190, 191, and 192 were surveyed using the EM34-3 meter. A total of 930 measurements were collected within the survey area. Grid interval was 10 m along lines which closely followed rows between the sugar cane and corn. A transit was used to triangulate the locations and elevations of each grid intersect from a base line tied to a site control point. At each grid intersect, measurements were made with the EM34-3 meter in both the horizontal and vertical modes.

Results and Discussion

Figure 1 is a representative radar profile from the Ceren Site. This profile was processed through RADAN software. The horizontal and vertical scales are in meters. The segmented vertical lines represent referenced positions which were impressed on the radar profile as the antenna was pulled passed the marked locations.

The Ceren Site is covered by volcanic deposits which have been separated into 15 major stratigraphic units (Miller, 1992). Units vary in thickness, texture, induration, and stratification. These strata create interfaces or boundaries which are detected by GPR. In Figure 1, the dark, horizontal lines represent these strata. High-amplitude reflections are produced by abrupt or strongly contrasting interfaces; low-amplitude reflections are produced by gradational or weakly contrasting interfaces. Individual units and layers create similar, sub-parallel signatures which are difficult to separate and identify on radar profiles without extensive auger observations. Many layers were too thin to be resolved with the 120 MHz antenna.

The soils at the Ceren Site are moderately attenuating to radar signals. Reflective loses occur as the radar signal intercepts each stratigraphic layer (see Figure 1). Finer-grained, indurated beds of ash appeared to be most attenuating to the radar signal. The maximum consistent depth of profiling for discrimination of buried structures was restricted to 3.0 meters.

The size, electrical properties, and depth to an artifact affects discrimination. Large, electrically contrasting features tend to produce substantial electrical responses and anomalous patterns which are easier to detect and identify than smaller, less contrasting features with resistivity or electromagnetic induction methods. At the Ceren Site, a "typical" buried structure has dimensions of about 3.5 x 4.0 m with relatively thin (15 cm wide), 1.6 m high, fired clay or sun-dried adobe walls (B. R. Mckee personal communication). Structures were built on clay platforms, 50 to 70 cm high, resting on relatively thin deposits of Tierra Blanca Joven tephra over clayey, pre-Ilopango eruption soils. These structures were assumed to have higher electrical conductivities than the overlying, coarser textured, volcanic materials. These structures were constructed from and are assumed to have electrical conductivities similar to underlying buried soil materials.

At depths of 3.5 to 6 meters, many structures may not be sufficiently large or dielectrically contrasting for resistivity and electromagnetic induction techniques to detect. In order to profile these depths, relatively large electrode or intercoil spacings are required. At these spacings, because of the large volume of earthen materials contributing to the electrical response, electromagnetic induction and resistivity methods provide relatively coarse resolution. While it was felt that neither method would discriminate individual structures, it was speculated that these tools would provide valuable information on the pre-eruption stratigraphy and terrain. This information may be useful in determining the most probable sites of habitation and the extent of culturally disturbed lands. In addition, it was presumed that clusters of cultural anomalies could be distinguished from broad terrain patterns.

Figure 2 is a two-dimensional, one-meter contour plot of the area surveyed with EM . The contour interval is 1 meter. Relief was slightly greater than 17 meters. The land slopes towards the Rio Sucio which is located to the east of the study area. The Ceren Site is immediately north of the study area.

Two-dimensional contour plots of apparent conductivities were prepared from results of the EM survey. These contour plots present data obtained with EM34-3 meter in the horizontal (Figure 3) and vertical (Figure 4) dipole modes. In each of these figures, the contour interval is 2 mS/m.

Interpretation of the EM data are based on the identification of spatial patterns in the data set. Several inferences can be made from Figures 3 and 4. A comparison of the two figures reveals that values of apparent conductivity increase with soil depth. This relationship is believed to reflect the greater conductivity of the underlying finer-textured, buried soil materials than the overlying pyroclastic deposits, and increases in volumetric water content with depth. Generally, values of apparent conductivity decreased with elevation. This "terrain affect" results from changes in moisture contents and lithology. Points at higher elevations generally have drier soils with water tables at greater depths, and may be lithologically different than lower positions.

Within the upper 7.5 m (Figure 3), values of apparent conductivity appear to be uniform across the site with an absolute range of 15 mS/m. Figure 3 depicts an anomalous zone of low apparent conductivities (< 9 mS/m) on backslope areas near the border of lots 189B and 190. This zone of low apparent conductivities is located in an area reported (Spetzler and Mckee, 1990) as having anomalously high resistivity values. This may represent a pocket of deeper pyroclastic or more resistive materials. A slight anomaly (> 13 mS/m) occurs on the upper backslope and summit area of Lot 190. This may represent a deposit of more conductive materials, an eroded area with thinner layers of pyroclastic materials, or the presence of a cultural anomaly.

The affects of increased volumetric water content and the water table are evident in Figure 4. Values of apparent conductivity increase at lower elevations where the depths to the water table are less and soils conditions are generally wetter. In addition, at lower elevations the isolines more closely conform with slope contours. A distinct trough of higher apparent conductivity values extends upslope near the border of Lots 189B and 190. This is believed to represent an old drainageway or seepage area which probably existed prior to the eruption of Laguna Caldera. Also in Figure 4, values of apparent conductivities are lower on the more sloping, upper backslope and summit positions. These lower values are believed to be a manifestation of terrain position. Higher-lying and more sloping areas are generally drier and less conductive than lower-lying areas. Several anomalous areas can also be identified (Figure 4). These areas are generally small and contrast only slightly with their surroundings.

Studies conducted by Arcone (1981) demonstrated the comparability of data collected with resistivity and EM. Resistivity was used at Ceren in 1979, 1980, 1989, and 1990. In these studies, a Wenner electrode configuration was used with either a 10 or 5 meter electrode spacing. These surveys resulted in the identification of several subsurface anomalies suspected of being cultural features. To verify interpretations, ten anomalies identified with resistivity were probed by core drilling. Coring revealed that only two of the ten anomalies represented cultural features and raised questions as to the suitability of resistivity for archaeological investigations at the Ceren Site.

In Figure 5, results from the electromagnetic induction and the 1990 resistivity surveys of Lot 189B are compared. Resistivity is inversely proportional to conductivity. The 1990 survey used a 5 meter electrode spacing, integrated resistivity over a 5 meter depth, and obtained more data points. The two-dimensional contour plot of resistivity values is base on 332 observation points with a contour interval is 40 ohm/meters. The EM survey used a 10 meter intercoil spacing, integrated apparent conductivity over a 7.5 meter depth, and is based on 91 data points with a 2 mS/m interval.

Although there are differences in the number of points and exploration depths, the results of the two methods are similar. In each plot, the earthen materials become more conductive (less resistive) at lower elevations towards the east. Earthen materials are more resistive (less conductive) on higher slope positions in the southwest corner of the survey area. In addition, anomalous values occur in the same general locations. As results are similar and the use of EM is many times faster than resistivity, EM appears to be a more efficient tool for reconnaissance surveys at Ceren.

Conclusions

The soils and substrata at the Ceren Site are moderately attenuating to radar signals. The finer-grained, indurated beds of pyroclastic materials appeared to be most attenuating features in the profile. Reflective loses occur as the radar signal is intercepted by each stratigraphic layer. Based on calibration trials, the maximum depth of consistent profiling with the 120 MHz antenna appears to be about 3 meter. Since the closest point that any part of a known buried structures approaches the present ground surface is about 3.6 m, the use of further reconnaissance investigations with GPR is discouraged at this site. However, GPR can be used to provide detailed stratigraphic information at Ceren during excavations to predict underlying anomalies, or in areas having cultural features buried at depths of less than 3 meters.

Structural features, found at depths of 3.5 to 5 m, are exceedingly difficult anomalies for resistivity and electromagnetic induction techniques to detect. To profile these depths, both methods require fairly large electrode or intercoil spacings. In order to profile depths of 5 to 7.5 meters, 5 to 10 meter electrode or intercoil spacings were used. These horizontal and vertical dimensions produce relatively coarse resolution of subsurface features. Both EM and resistivity techniques, however, provide vital subsurface stratigraphic information which may be used to reconstruct the pre-eruption land surface at Ceren. This information can indicate the most probable sites of habitation. In addition, several anomalies apparent in the data may indicate the location of major buried cultural features. In future studies, the use of an EM31 meter is encouraged. This meter is easier and quicker to operate than the EM34-3, and profiles depths of 2.75 and 6 meters.

References

Arcone, S. A. 1981. Some field studies of the correlation between electromagnetic and direct current measurements of ground resistivity, underground corrosion. Am. Soc. Test. Mater. Special Tech. Publ. 741:92-110

Bevan, Bruce W. 1983. Electromagnetics for mapping buried earth features. J. Field Archaeology 10:47-54.

Bevan, Bruce W. 1984. Looking Backwards: location of historic structures. p. 284-301. IN: Orr, D. and D. Crozier (eds.) The Scope of Historical Archaeology. Temple University, Philadelphia, PA. pp. 304.

Bevan, Bruce W. 1991. The search for graves. Geophysics 56(9):1310-1319.

Bevan, Bruce and Jeffrey Kenyon. 1975. Ground-probing radar for historical archaeology. MASCA (Museum Applied Science Center for Archaeology), University of Pennsylvania, Philadelphia. Newsletter 11(2):2-7.

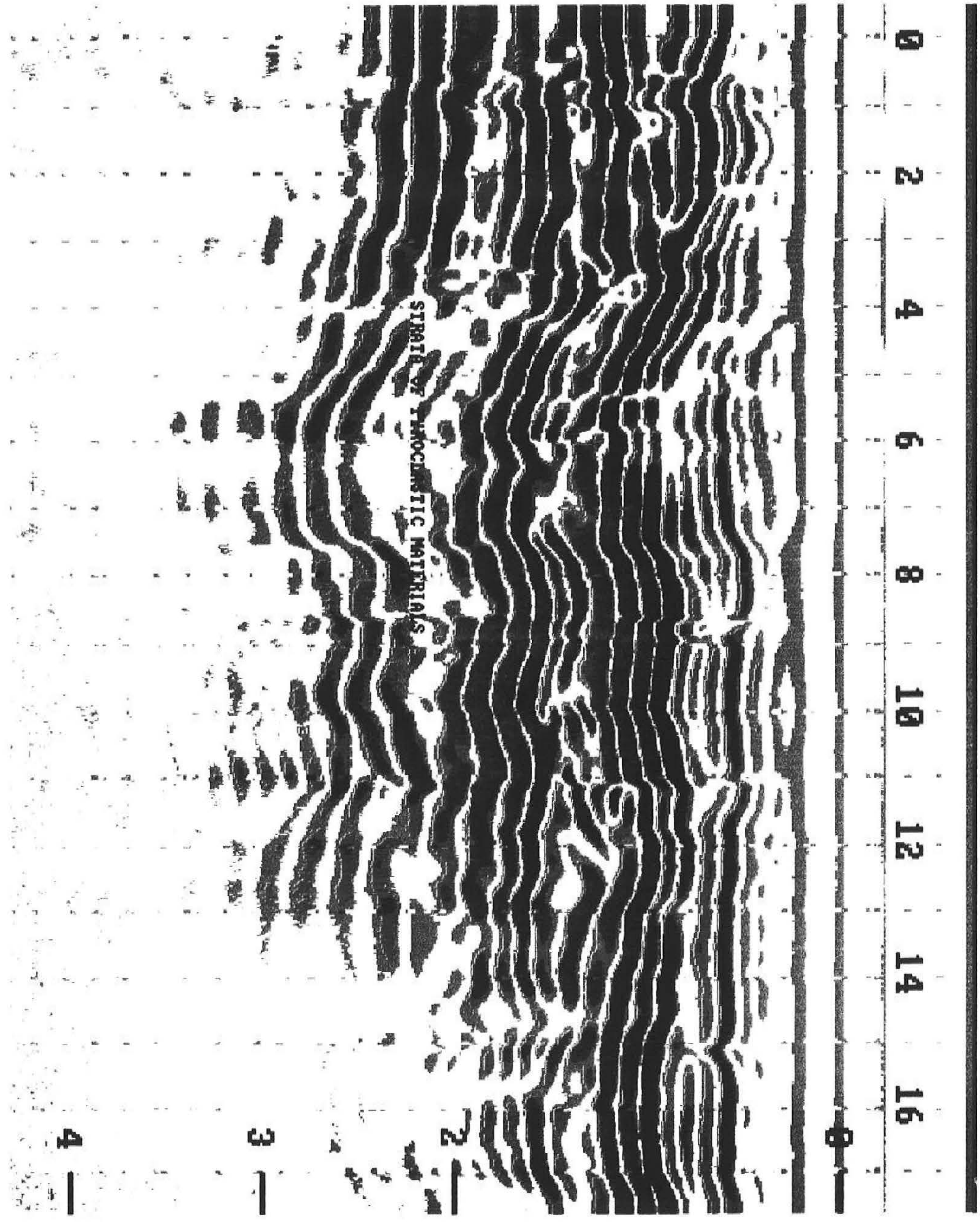
Dalan, Rinita A. 1991. Defining archaeological features with electromagnetic surveys at the Cahokia Mound State Historic Site. Geophysics 56(8):1280-1287.

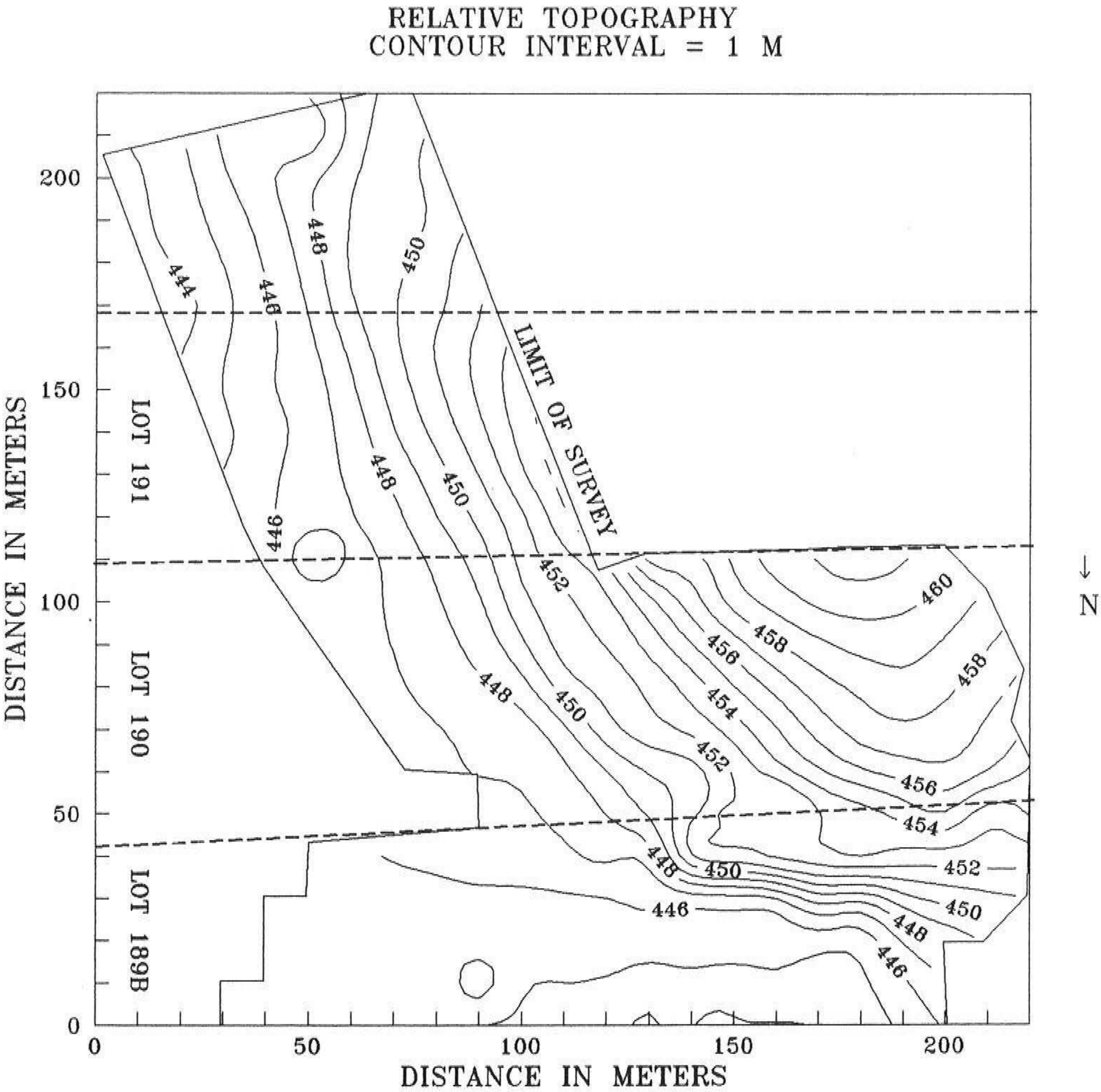
Daniels, D. J., D. J. Gunton, and H. F. Scott. 1988. Introduction to subsurface radar. IEE Proceedings 135F(4):278-320.

Doolittle, J. A. 1987. Using ground-penetrating radar to increase the quality and efficiency of soil surveys. p. 11-32. IN: Soil Survey Techniques. Soil Science Society of America Special Pub. no. 20. Madison, WI.

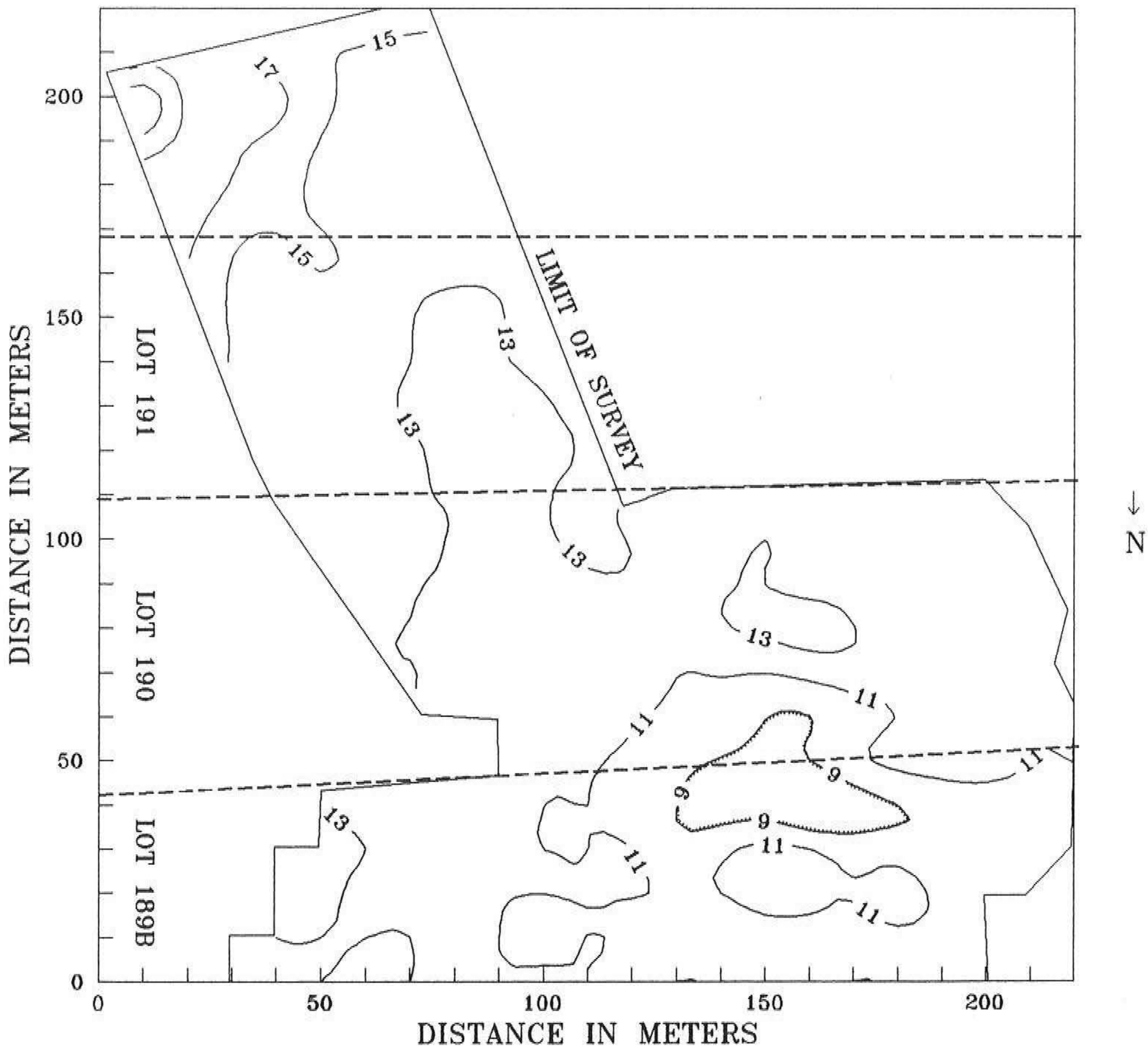
Doolittle, J. A. and W. F. Miller. 1991. Use of ground-penetrating radar in archaeological investigations. p. 81-93. IN: C. Behrens and T. Sever (eds.) Application of Space-Age Technology in Anthropology, November 28, 1990; Conference Proceedings. National Aeronautics and Space Administration John Stennis Space Center, Mississippi, p. 270.

Frohlich, Bruno and Warwick J. Lancaster. 1986. Electromagnetic surveying in current Middle Eastern archaeology: application and evaluation. Geophysics 51(7):1414-1425.

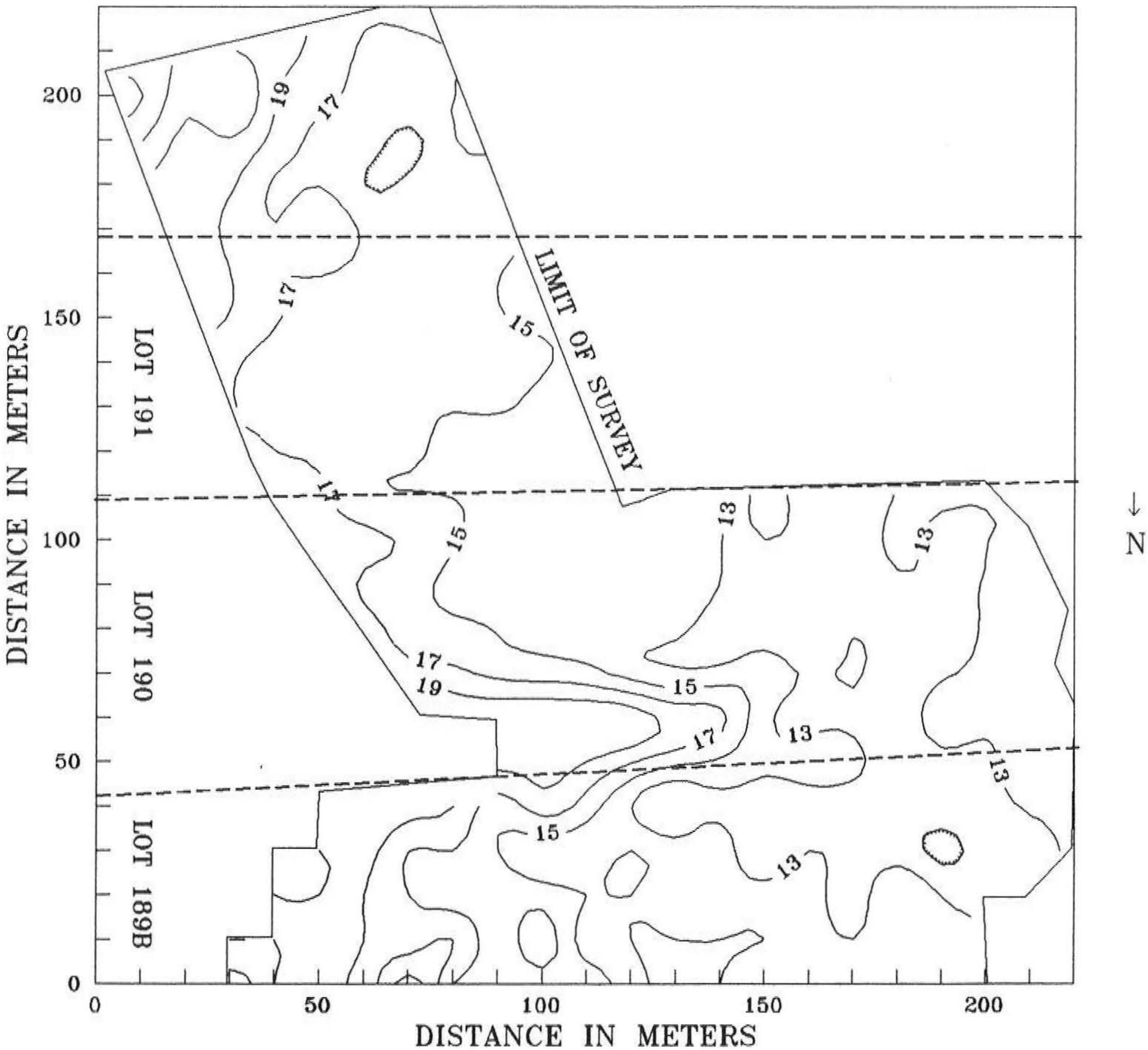

0
2
4
6
8
10
12
14
16
2
3
4
STRATA OF PYROCLASTIC MATERIALS


RELATIVE TOPOGRAPHY
CONTOUR INTERVAL = 1 M
DISTANCE IN METERS
DISTANCE IN METERS
LOT 191
LOT 190
LOT 189B
LIMIT OF SURVEY
N
444
446
448
450
452
454
456
458
460
0
50
100
150
200

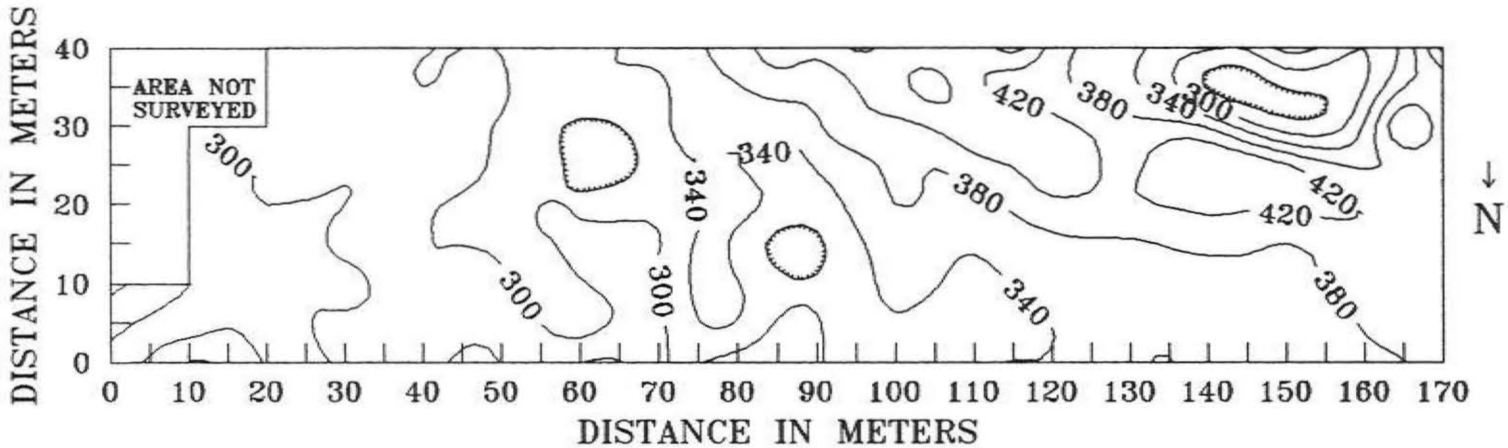
EM34
HORIZONTAL DIPOLE
10 M INTERCOIL SPACING



EM34
VERTICAL DIPOLE
10 M INTERCOIL SPACING



1990 RESISTIVITY SURVEY
WENNER ARRAY



EM34
HORIZONTAL DIPOLE
10 M INTERCOIL SPACING