

United States  
Department of  
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Conservation  
Service

Northeast NTC  
160 East 7th Street  
Chester, PA 19013-6092  
215-499-3960

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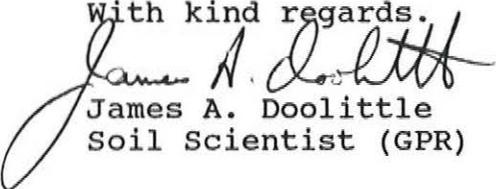
Date: 1 October 1992

To: Jerry Hammond  
Director  
International Conservation Division  
USDA-Soil Conservation Service  
Room 5116-S  
NHQ, Washington, D.C.

Enclosed is a copy of my report on the use of geophysical techniques at Tell Halif, Israel. The report is being sent to Frank Miller at Mississippi State University. He will review my draft and add it to the sections he is preparing on the use of remote sensing and geographic information systems. Our intent is to publish a paper describing the use of an integrated approach to archaeological investigations. This approach takes advantage of a variety of techniques to reduce field time and costs. Techniques discussed in our paper will include: remote sensing, geographic information systems, ground-penetrating radar, electromagnetic induction and traditional archaeological tools. The final draft will be delivered to the Cobb Institute of Archaeology and Mississippi State University.

I am pleased by the results of our efforts and feel that we have made a difference. Thanks once again for the fine and courteous services of your staff.

With kind regards.

  
James A. Doolittle  
Soil Scientist (GPR)

cc:

S. Holzhey, Assistant Director, Soil Survey Division, NSSC, SCS,  
Lincoln, NE

J. Culver, National Leader, SSQAS, NSSC, SCS, Lincoln, NE

## The Use of Geophysical Techniques in Subsurface Archaeological Investigations

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

### INTRODUCTION

Geophysical instrument are increasingly being used to aid archaeological investigations. These devices are, in essence, remote sensors that afford medium to high resolution, continuous measurements or profiles of subsurface conditions. Continuous spatial measurements or profiles of subsurface conditions have considerable benefits in archaeological investigations. By providing more comprehensive information about a site, detecting cultural features, and minimizing the number of unsuccessful exploratory pits, these techniques can provide a rapid, cost-effective, and non-destructive means of artifact identification and location. However, the use of geophysical techniques complements but does not replace the need for conventional archaeological methodologies.

Geophysical techniques have been used to detect, identify, and locate buried artifacts. In archaeological investigations, geophysical techniques have been used principally to assist reconnaissance and pre-excavation surveys and to obtain detailed site information.

Two complimentary geophysical methods which have been used in archaeological investigations are discussed in this report - ground penetrating radar (GPR) and electromagnetic induction (EM). Both have been used principally as surface-geophysical methods. Though each of these methods can be used autonomously, this study used an integrated or comprehensive approach. An integrated approach makes use of two or more geophysical and/or remote sensing tools as well as conventional archaeological techniques. This process provides more site information than a single method and can be used to reduce field time, increase coverage, facilitate excavation strategies, and better define the locations of subsurface anomalies. In addition, ambiguities inherent in interpreting data from a single technique can be reduced when two or more methods are employed.

An integrated approach using EM and GPR techniques can be used to assist archaeologist acquire subsurface information and to plan and carry out excavation in a more cost effective manner. Because of the ease of operation, EM methods can be used to rapidly survey large areas. Analysis of EM data provides stratigraphic information about the survey area and may reveal the location of large buried structures or areas having high levels of "cultural noise." However, the relatively coarse resolution of EM techniques limits detection of subsurface features to large structures or prominent stratigraphic features. Following an assessment of the

EM data and site characteristics at an initially, relatively coarse dimensional scale, smaller, included areas can be selected for more detailed investigations with GPR and EM techniques. Based on the map produced by this effort, a GPR survey scheme can be quickly developed and initiated to refine the reconnaissance survey. Because of its superior resolution, radar is an appropriate tool for locating and characterizing buried structures and isolated cultural anomalies.

## **SYSTEM DESCRIPTIONS**

### **ELECTROMAGNETIC INDUCTION**

Studies have documented the advantages of the non-contact, continuous readings with the EM meters, ease and accuracy of EM interpretations, and its applications over broad areas and soil types. The EM meters are highly portable and this technique is perhaps the most rapid and cost-effective geophysical method available. 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. These 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 milliSiemens 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).

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 various meters with different intercoil spacings and coil orientations. Information on variations in conductivity with depth can be achieved by varying coil orientation, intercoil spacing and frequency.

Electromagnetic inductive methods measure vertical and lateral variations in terrain or apparent electrical conductivity of earthen materials. The 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 the lateral and vertical variations in these

measurements are significant. Interpretations of the EM data are based on the identification of spatial patterns in the data set appearing on two-dimensional plots.

**TABLE 1**  
**Depth of Measurement**  
(all measurements are in meters)

<u>Meter</u>	<u>Intercoil Spacing</u>	<u>Depth of Measurement</u>	
		<u>Horizontal</u>	<u>Vertical</u>
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

This technique is 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).

The electromagnetic induction meters used were the EM31 and EM38 manufactured by Geonics Limited<sup>1</sup>. Principles of operation have been described in detail by (McNeill, 1980, 1986, 1989).

#### GROUND-PENETRATING RADAR

The ground-penetrating radar is an impulse radar system designed for shallow subsurface site investigations (Daniels et al., 1988). Pulses of electromagnetic energy are radiate into the ground from a transmitting antenna. Each pulse consists of a spectrum of frequencies distributed around the center frequency of the antenna. Whenever a pulse contacts an interface separating layers of differing dielectric 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 graphic recorder or are recorded on magnetic tape for future playback or processing. The graphic recorder uses a variable gray scale to display data. It produces images by recording strong reflections as black and lesser intensity reflections in shades of gray.

Compared with other geophysical techniques, GPR provides the highest resolution of subsurface features. However, results of radar surveys are site specific and interpreter dependent. 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. In addition in some areas, conductive soil conditions limit its profiling depth and applicability. Ground-penetrating radar is best suited for shallow (3 to 10 meters) investigations in electrically resistive mediums (i.e. dry, sandy soils). The GPR has been used to locate and map buried structures, buried artifacts, and graves (Bevan, 1991; Doolittle and Miller, 1991; Imai et al., 1987; Vaughan, 1986).

The ground-penetrating radar unit used in this study is the Subsurface Interface Radar (SIR) System-8 manufactured by Geophysical Survey Systems, Inc.<sup>1</sup>. Components of the SIR System-8 used in this study were 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. The system was powered by a 12-volt vehicle battery. The operation of the SIR System-8 has been described by Doolittle (1987).

#### **FACTORS INFLUENCING USE OF TECHNIQUES**

Variations in the response of EM meters and probing depths of GPR are produced by changes in the ionic concentration of earthen materials. Factors influencing the ionic concentration 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. Ground-penetrating radar techniques are not suited for use in all soils. The maximum probing depth of GPR is, to a large degree, determined by the conductivity of the soil. Soils having high conductivities rapidly dissipate the radar's energy and restrict the effective probing depth.

Both the GPR and EM have unique advantages and disadvantages but, when considered in a multistage sampling mode, they are highly complementary. Bevan (1984) compared a number of different geophysical techniques and rated the performance of each under different conditions; the following ratings are based on his work with 4 = excellent, 3 = good, 2 = fair, and 1 = poor potential.

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

**Table 2**  
**Comparison of GPR and EM Methods**  
 (from Bevan, 1984)

<u>Site Conditions</u>	<u>GPR</u>	<u>EM</u>
thickly wooded	1	3
prairie	3	4
rough terrain	2	4
soils: clayey	2	4
loamy	3	4
sandy	4	4
alkaline/saline	1	4
urban areas	3	3
cultivated fields	2	3
steep slopes	2	3

<u>Artifact/Subsurface Feature</u>	<u>GPR</u>	<u>EM</u>
<b>Size of Anomaly</b>		
less than 10 cm	3	1
10 cm to 100 cm	4	3
greater than 100 cm	4	3
<b>Depth to Anomaly</b>		
less than 25 cm	4	4
25 cm to 200 cm	4	4
200 cm to 400 cm	4	4
greater than 400 cm	3	4
<b>Depth/Size Ratio</b>		
less than 1/4	4	4
1/4 to 1	4	3
1 to 3	3	1
greater than 3	2	1

#### **CASE STUDY - TELL HALIF, ISRAEL**

##### Site Conditions

Site conditions, (i.e. soils, vegetation, terrain) often dictates search strategies. Steep slopes, large rock fragments on the surface, and dense vegetation precluded the extensive use of GPR. However, these terrain conditions offered only minor hindrances to EM. Because of the meters relatively light weight and portability, ease and efficiency of operation, EM was used as a reconnaissance tool to rapidly survey large areas. Following analysis of EM data, GPR can be used to provide detailed, high resolution profiles of selected areas.

The soils at Tell Halif are relatively conductive. These soils have formed in residuum, colluvium, and fill materials overlying marl and limestone bedrock. These soils are moderately-fine textured (18-34 percent clay) calcareous and contain relatively high amounts of soluble salts, principally soluble carbonates of

calcium and magnesium. These soil conditions while favorable to EM provided an unfavorable environment to GPR.

In the moderately-fine textured, calcareous soils of Tell Halif, radar signals were rapidly attenuated and profiling depths were limited. In areas of deep (>100 cm) soil materials, the maximum depth of consistent profiling with the 120 MHz antenna was about 1 meter. However, in areas of shallow (<50 cm) soils overlying more resistive layers of marl or limestone bedrock, rates of signal attenuation were less and probing depths of 3 to 4 meters were attained. The EM meters, while influenced by the soluble salt and clay contents of these soils, maintained depth of penetration and were sensitive to changes in the thickness and conductivity of layers. However, as buried cultural layers often had closely similar electrical properties, EM was often unable to discriminate individual stratum.

The size, orientation, and depth to an artifact affects their discernment with GPR and EM. Large, electrically contrasting features reflect more energy and are easier to detect than small, less contrasting features. Small cultural features, unless directly beneath the path of the radar antenna may be missed. In addition, more deeply buried features are difficult to discern on radar profiles. This is because the reflective power of an object decreases proportional to the fourth power of the distance to the object (Bevan and Kenyon, 1975).

Compared with GPR, resolution of EM is relatively coarse. The sampling volume of EM is relatively large as values of apparent conductivity are integrated within the slice of earthen materials defined by the meters intercoil spacing and depth of penetration. At the resolution used with electromagnetic induction methods, the discernment of singular features was doubtful. In addition, unless the EM response from a feature is substantially greater than background levels of apparent conductivity, it will be excluded from interpretations. While it was felt that electromagnetic induction methods would not discern individual structures, it was speculated that these tools would provide valuable stratigraphic information and may indicate the location of large, buried cultural features. This information may be useful in determining the most probable sites and the extent of culturally disturbed lands. In addition, it was presumed that clusters of cultural anomalies could be distinguished from broad terrain patterns.

#### EM Surveys

##### Tell Summit-

The survey site on the tell summit covered an irregularly-shaped 135 by 180 meter area. Figure 1 is a two-dimensional contour plot of the surface topography. The contour interval is 0.5-meter. The lowest point on the summit was used as the 0.0 meter datum. Within the survey site, relief was slightly greater than 6 meters. The surface descends toward the north and the steeper, shoulder slope areas. The summit area of the tell is bounded by steep side

slopes. Bedrock is exposed on the lower-lying northwest portion of the survey site. Point symbols (see figures 1, 2, and 3) have been used to identify the location of known cisterns.

The survey site was restricted to open, nearly level areas of the summit. The survey site was confined in several directions by steep slopes, excavated trenches, or fence lines. The grid interval for the reconnaissance survey was 7.5 meters. This provided 228 grid intersects or observation points. At each intersect, measurement were taken with the EM31 meter in both the horizontal and vertical modes.

Two-dimensional plots of apparent conductivities were prepared from results of the EM survey. These plots present data obtained with EM31 meter in the horizontal (Figure 2) and vertical (Figure 3) dipole modes. In each of these figures, the contour interval is 5 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 2 and 3. A comparison of the two figures reveals that values of apparent conductivity generally increase with soil depth. This relationship reflects the greater conductivity of the underlying soil materials or geologic strata. This relationship may be attributed to one or more of the following factors: greater concentrations of soluble salts (carbonates), finer textured soil materials, more conductive geologic strata (marl versus chert), or increases in volumetric water content with depth.

Areas having bedrock at or near the surface have values of apparent conductivity less than 10 mS/m. These areas are evident in the northwest portion of the survey site (upper left-hand corner of figures 2 and 3). Sub-site B is located within and is representative of this area. The majority of the known cisterns are found in this area. The area is bounded by relatively closely spaced isopleths. The abrupt gradient implies a rather precipitous subsurface drop in the bedrock surface. This inference suggests a buried mesa-like feature.

Areas having deeper layers of fill or soil materials have values of apparent conductivity greater than 15 mS/m. In figures 2 and 3, areas of deep fill or soil materials occur in the southern and eastern portions and along the western rim of the summit area. A prominent ridge of relatively high apparent conductivity values (and inferred deeper soil conditions) extends across the summit area in a southwesterly direction from the northeast corner of the survey site. Sub-site C is located in the extreme southwestern portion of this ridge.

The northwest corner of the study site is located near the edge of the tell and is known to contain buried structural features including a glacis. This area is characterized by closely spaced isopleths. Values of apparent conductivity increase towards the

edge of the tell (west) suggesting deeper layers of debris and soil materials. Sub-site A is located within and is representative of this area.

In the northeast corner of the study site, in vertical dipole measurements of Figure 3, a conspicuous subsurface anomaly occurs. As this anomaly is not apparent in Figure 2, a deeply buried feature is inferred. This anomalous zone may represent a buried feature such as a former Turkish bunker. However, this anomalous zone is located in an area which contains numerous trenches and barbed wire entanglements. It is possible that the vertical dipole orientation was more responsive to the barbed wire.

Results from the reconnaissance EM survey of the tell summit were reviewed in the field and three sub-site were selected for detailed investigations using the EM38 meter. Grids were established over each of the three, 10 by 10 meter sub-site areas. The grid interval for these detailed surveys was 1.0 meter. This provided 121 grid intersects or observation points on each sub-site. At each intersect, measurement were taken with the EM38 meter in vertical mode.

Two-dimensional plots of apparent conductivities were prepared from the results of the EM survey. Figures 4, 5 and 6 represent plots of apparent conductivity measurements obtained with the EM38 meter in sub-sites A, B, and C, respectively. In each of these figures, the contour interval is 2 mS/m.

Sub-site A is representative of sites underlain by multiple layers of debris (see Fig. 4). These layers are assumed to contain abundant cultural features. At sub-site A, values of apparent conductivity range from 7 to 29 mS/m. The lowest values of apparent conductivity are in the eastern portion of the sub-site where the depth to bedrock is less than 1.0 meter. The highest values of apparent conductivity are in the western portion of the sub-site adjacent to the convex shoulder slope area of the tell. Here, it was assumed, layers of debris are deepest and buried structures more abundant. In addition, the closely spaced isopleths with complex and irregular patterns in this area of the sub-site suggest disturbed and variable soil conditions. These conditions suggest the presence of buried cultural features.

Sub-site B is representative of sites with chert and limestone bedrock at or near the surface (see Fig. 5). Values of apparent conductivity were fairly uniform across this sub-site and ranged from 2 to 8 mS/m. In the eastern portion of the sub-site, two "depression-like" areas of apparent conductivity values may indicate the occurrence of shallow to moderately deep, air-filled cisterns. In Figure 5, the larger and more pronounced "depression-like" area has been labeled "A."

Sub-site C is representative of interior areas having deeper layers of fill or soil materials with values of apparent conductivity greater than 15 mS/m (see Fig. 6). This sub-site is located in the

prominent ridge of higher apparent conductivity values which extends across the summit area in a southwesterly direction. Within this sub-site, values of apparent conductivity range from 12 to 26 mS/m. Generally, within sub-site C, isopleths are relatively widely spaced and uniform suggesting natural or undisturbed soil conditions. However, the linear feature in the northern part of the sub-site invites exploratory investigations.

On the summit area of Tell Halif, EM techniques helped archaeologist identify unique areas of similar soil or geologic conditions and delineate the boundaries of disturbed soils which may contain buried cultural features and bedrock controlled surfaces underlain with cisterns.

#### Site 301A-

This survey site is located on the eastern lower backslope to Tell Halif. A 60 by 25 meter rectangular grid was established across this site. Figure 7 is a two-dimensional contour plot of the surface topography. The contour interval is 0.5-meter. The lowest point within the survey area was used as the 0.0 meter datum. Within the survey site, relief was slightly greater than 3.5 meters. The surface descends toward the east.

The survey site was in open woodland. The site contained an open excavation pit (from 1987) and the western extremity of a low, linear artificial mound (see "A" in figures 7, 8 and 9). The grid interval for this reconnaissance survey was 5.0 meters. This provided 76 grid intersects or observation points. At each intersect, measurement were taken with the EM31 meter in both the horizontal and vertical modes.

Two-dimensional plots of apparent conductivities were prepared from results of the EM survey. These plots present data obtained with EM31 meter in the horizontal (Figure 8) and vertical (Figure 9) dipole modes. In each of these figures, the contour interval is 2 mS/m.

Several inferences can be made from figures 8 and 9. A comparison of the two figures reveals that values of apparent conductivity generally increase with soil depth. The same relationship occurred on the summit of Tell Halif where it was attributed to greater concentrations of soluble salts (carbonates), finer textured soil materials, more conductive geologic strata (marl versus chert), or increases in volumetric water content with depth.

With the exception of the extreme southern part of the site, 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 and may be underlain by strata which are lithologically different than strata in lower-lying positions.

In the extreme southern part of the site, values of apparent conductivity increased toward the southwest, south, and southeast. As the isopleths in figures 8 and 9 are widely spaced and sub-parallel, these patterns suggest changes in soil type rather than the presence of buried cultural features.

In both figures 8 and 9, irregular isopleth patterns immediately to the northeast of the excavated area suggest the possible occurrence of disturbed soil conditions. As several silo-like structures were identified in the excavated area, the presence of additional buried cultural features in this area is highly probable.

At Site 301A, an EM survey did not reveal the presence of any large, highly contrasting subsurface anomaly. Isopleth patterns were considered normal and reflected gradational changes in soil type or features. However, a weakly expressed zone of irregular isopleth patterns in an area to the northeast of an excavated pit suggested the possible occurrence of buried cultural features.

#### Site 301B-

This survey site is located on the eastern lower footslope to Tell Halif. This site is located to the southeast of Site 301A. A 90 by 75 meter rectangular grid was established across this site. Figure 10 is a two-dimensional contour plot of the surface topography. The contour interval is 0.5-meter. The lowest point within the survey area was used as the 0.0 meter datum. Within the survey site, relief was slightly greater than 8.5 meters. The surface descends toward the east.

The survey site was in an open field. The site contained an open excavation pit and a low, linear artificial mound of earthen materials (see "A" in Figure 10). The grid interval for this reconnaissance survey was 5.0 meters. This provided 258 grid intersects or observation points. At each intersect, measurements were taken with the EM31 meter in both the horizontal and vertical modes.

Two-dimensional plots of apparent conductivities were prepared from the results of the EM survey. These plots present data obtained with EM31 meter in the horizontal (Figure 11) and vertical (Figure 12) dipole modes. In each of these figures, the contour interval is 5 mS/m.

Several inferences can be made from figures 11 and 12. A comparison of the two figures reveals that, like the other survey sites, values of apparent conductivity generally increase with soil depth. This relationship can be attributed to greater concentrations of soluble salts (carbonates), finer textured soil materials, more conductive geologic strata (marl versus chert), or increases in volumetric water content with depth.

With the exception of an area immediately upslope of the low, narrow earthen mound shown in Figure 10, values of apparent

conductivity decreased with elevation. This "terrain affect" results from changes in moisture and clay contents and/or lithology. Points at higher elevations generally have drier soils with water tables at greater depths, and may be lithologically different than those on lower-lying positions.

In the southwest portion of the site, a large anomalous area of higher apparent conductivity values occurs immediately upslope of the low, narrow earthen mound (around "A" in figures 11 and 12). In Figure 11, a conspicuous east-west trending linear trough of lower apparent conductivity values (centered on "A") divides the anomalous area. This linear feature is undoubtedly artificial. However, considering that a 5 meter grid interval was used in this survey, more observation points would be necessary to improve the definition and extent of this linear feature. In Figure 12, with a deeper depth of penetration and larger volume of soil materials averaged into the apparent conductivity measurements, this linear feature is no longer detectable. However, the anomalous area of high apparent conductivity values (centered about "A") remains well expressed.

In both figures 11 and 12, a point anomaly occurs at "B." This anomaly is believed to represent either a buried metallic object or a place where livestock congregate. The anomalous isopleth patterns near "C" may reflect a response from buried cultural features, the presence of a fence line, differences in management practices between fields, or variations in soil properties. As this area (near "C") is adjacent to an excavated area in which a large, buried structural feature was found, it is possible that the EM response reflects disturbed soil conditions and buried cultural features.

At Site 301B, an EM survey reveal the presence of several large, highly contrasting subsurface anomaly. Within these anomalous areas, isopleth patterns were irregular and highly contrasting. These strongly expressed zone of irregular isopleth patterns suggest the possible occurrence of buried cultural features.

#### GPR Surveys

In 1987, ground-penetrating radar surveys were conducted at Tell Halif. Results from these surveys have been reported by Cole (1988), Doolittle (1988), McAleer (1988), and Doolittle and Miller (1991).

Analysis of data from reconnaissance EM surveys revealed the general location of large or clustered subsurface anomalies and the gross characteristics of various sites. Once the general locations of anomalies within large areas have been defined, grids with smaller intervals (1 m) can be established over selected sites. The use of more closely-spaced grid intersects helps to pinpoint the location, define the spatial extent, and resolve the identity of subsurface anomalies and features. These smaller grids can be

more intensively sampled using either GPR and EM techniques, or both.

The sub-sites sampled with the EM38 meter on the summit of Tell Halif are examples of this approach. These sub-sites helped to define the spatial extent of subsurface anomalies. However, because of the low resolution of EM meters, it was difficult to infer the identity or characteristics of subsurface anomalies. In some soils, because of its superior resolution, radar is a more appropriate tool than EM for locating and characterizing buried cultural features.

The reconnaissance survey with the EM31 meter on the summit of Tell Halif revealed that areas having deeper layers of fill or soil materials have values of apparent conductivity greater than 15 mS/m. These areas are suspected of containing greater amounts of buried cultural features. One such area was located along the western rim of the tell in an area known to contain buried structural features including a glacis. It was inferred from the results of the reconnaissance survey that this area contained significant amounts of buried cultural features and consisted of deep layers of debris and soil materials. A portion of this area was more intensively sampled with the EM38 meter (Sub-site A). Two dimensional plots from the detailed EM38 survey revealed closely spaced isopleths with complex and irregular patterns. These patterns suggested disturbed and variable soil conditions and the most probable, general location of buried cultural features. However, resolution of subsurface features is generally poor with EM techniques.

Based on the two-dimensional plots produced from the EM surveys, a GPR survey scheme can be developed and initiated to refine the resolution of subsurface features. Radar surveys were conducted in the area immediately north of sub-site A. An irregularly shaped 55 by 17.5 meter rectangular grid was established across this site. The grid interval for a preliminary GPR survey was 2.5 meters. Radar surveys were conducted by pulling the 120 MHz antenna along parallel grid lines. As the radar antenna passed referenced grid intersects, the operator electronically inserts a dashed, vertical line on the radar's graphic profile.

After plotting the distribution of subsurface anomalies detected in the preliminary GPR survey (see Figure 13), a more detailed survey was conducted in an sub-area of the initial grid. This sub-area appeared to have a relatively high concentration of subsurface anomalies (see inset to Figure 13). The grid interval for this survey was 1.0 meter.

Figure 14 is a representative profile from the preliminary radar survey. This profile was obtained from a radar traverse along line 6 (from A to near H). Depth and distance scales are along the left and top margins of this figure, respectively. All measurements are in meters. Alternate, vertical reference lines have been labeled. In Figure 14, a metallic reflector (see A in

Fig, 14) was identified and located by recognizing its characteristic "ringing" pattern of reverberated signals. This object was latter identified as a piece of barbed wire. Several additional anomalies appear in this figure (see B, C, and D). These anomalies are nonmetallic and their arrangement suggests a buried structural feature.

While the GPR detects subsurface anomalies, it does not identify subsurface features. Unless sufficient probings are made using traditional archaeological techniques, the identity of images must be inferred. However, with experience and sufficient probing, many subsurface features can be identified by the uniqueness of their graphic signatures.

### CONCLUSIONS

The use of geophysical techniques for archaeological investigations is in an active stage of growth and development. This trend has been accelerated by growing commercialization and familiarity with these tool's applicability to archaeological investigations. The use of geophysical techniques compliment but does not replace traditional archaeological methods. Results from geophysical investigations are often tentative and incomplete until interpretations are confirmed by traditional archaeological methods.

Though each of these methods can be used autonomously, this study stressed the need for an integrated or comprehensive approach. An integrated approach makes use of two or more geophysical and/or remote sensing tools as well as conventional archaeological techniques. This process provides more site information than a single method and can be used to reduce field time, increase coverage, facilitate excavation strategies, and better define the locations of subsurface anomalies. In addition, ambiguities inherent in interpreting data from a single technique can be reduced when two or more methods are employed.

### REFERENCES

- 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.

Benson, R. C., R. A. Glaccum, and M. R. Noel. 1984. Geophysical techniques for sensing buried wastes and waste migration: an application review. IN: D. M. Nielsen and M. Curls (eds.) Surface and Borehole Geophysical Methods in Ground Water Investigations. NWWA/EPA Conference, San Antonio, Texas. p. 533-566.

Cole, D. P. 1988. Ground-penetrating radar-New technology won't make pick and trowel obsolete. Biblical Archaeology Review 14:38-40.

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. Ground-penetrating radar (GPR) survey at Tell Halif, Israel. p. 180-213. IN: Collins, M. E., G. Schellentrager, and W. E. Puckett (eds.) Technical Proceedings of the Second International Symposium on Geotechnical Applications of Ground-Penetrating Radar. Gainesville, FL, March 6-10, 1988. p. 305

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.

Greenhouse, J. P., and D. D. Slaine. 1983. The use of reconnaissance electromagnetic methods to map contaminant migration. Ground Water Monitoring Review 3(2):47-59.

Imai, Tsuneo, Toshihiko Sakayama, and Takashi Kanemori. 1987. Use of ground-probing radar and resistivity surveys for archaeological investigations. Geophysics 52(2):137-150.

McAleer, N. 1988. Pixel Archaeology. Discover Magazine 9(8):72-77.

McNeill, J. D. 1980. Electromagnetic terrain conductivity measurements at low induction numbers. Geonics Ltd., Mississauga, Ontario. Technical Note TN-6. p. 15.

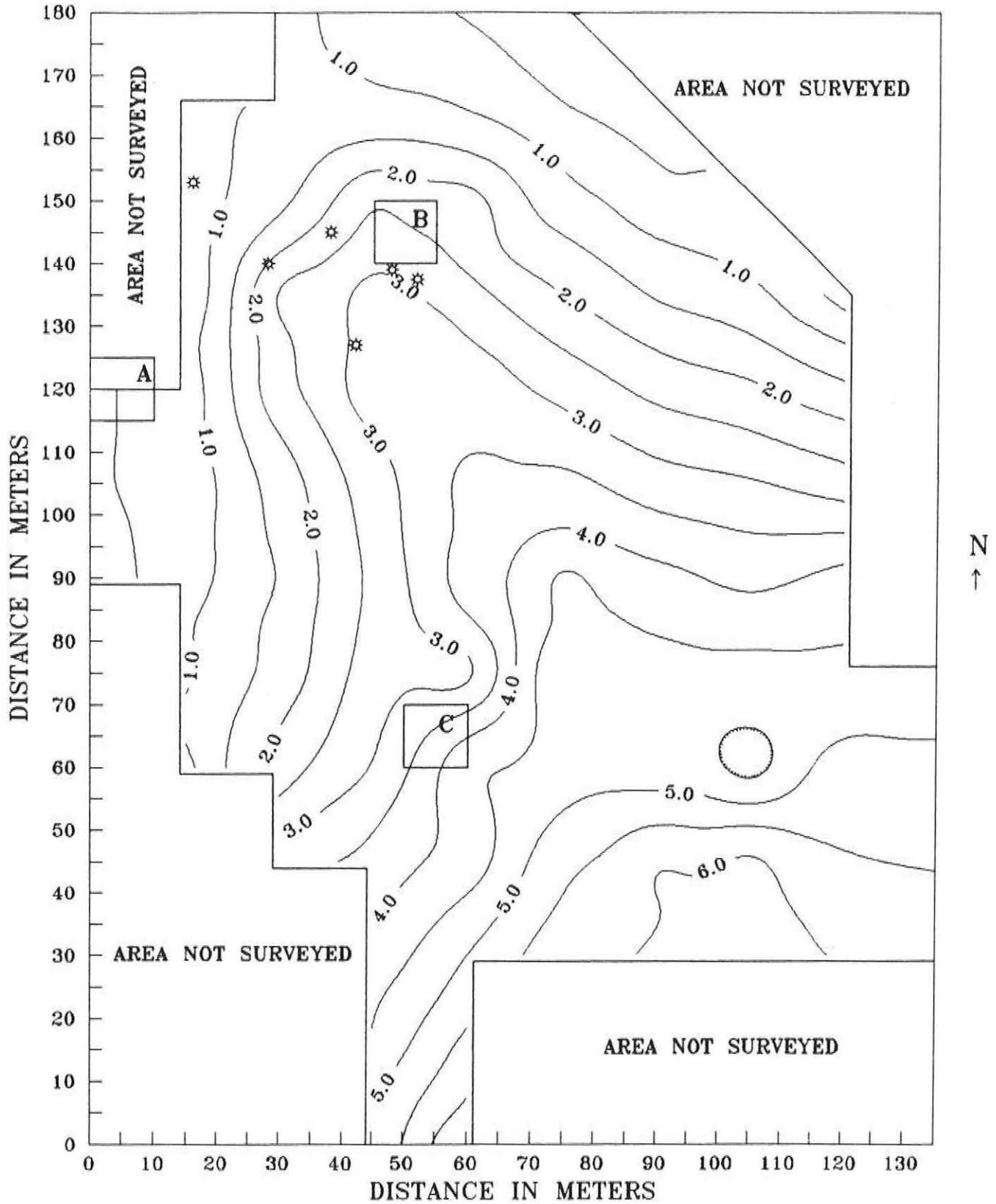
McNeill, J. D. 1986. Geonics EM38 ground conductivity meter operating instructions and survey interpretation techniques. Geonics Ltd., Mississauga, Ontario. Technical Note TN-21. p. 16.

McNeill, J. D. 1989. EM31 Operating Manual. Geonics Ltd., Mississauga, Ontario. p. 35.

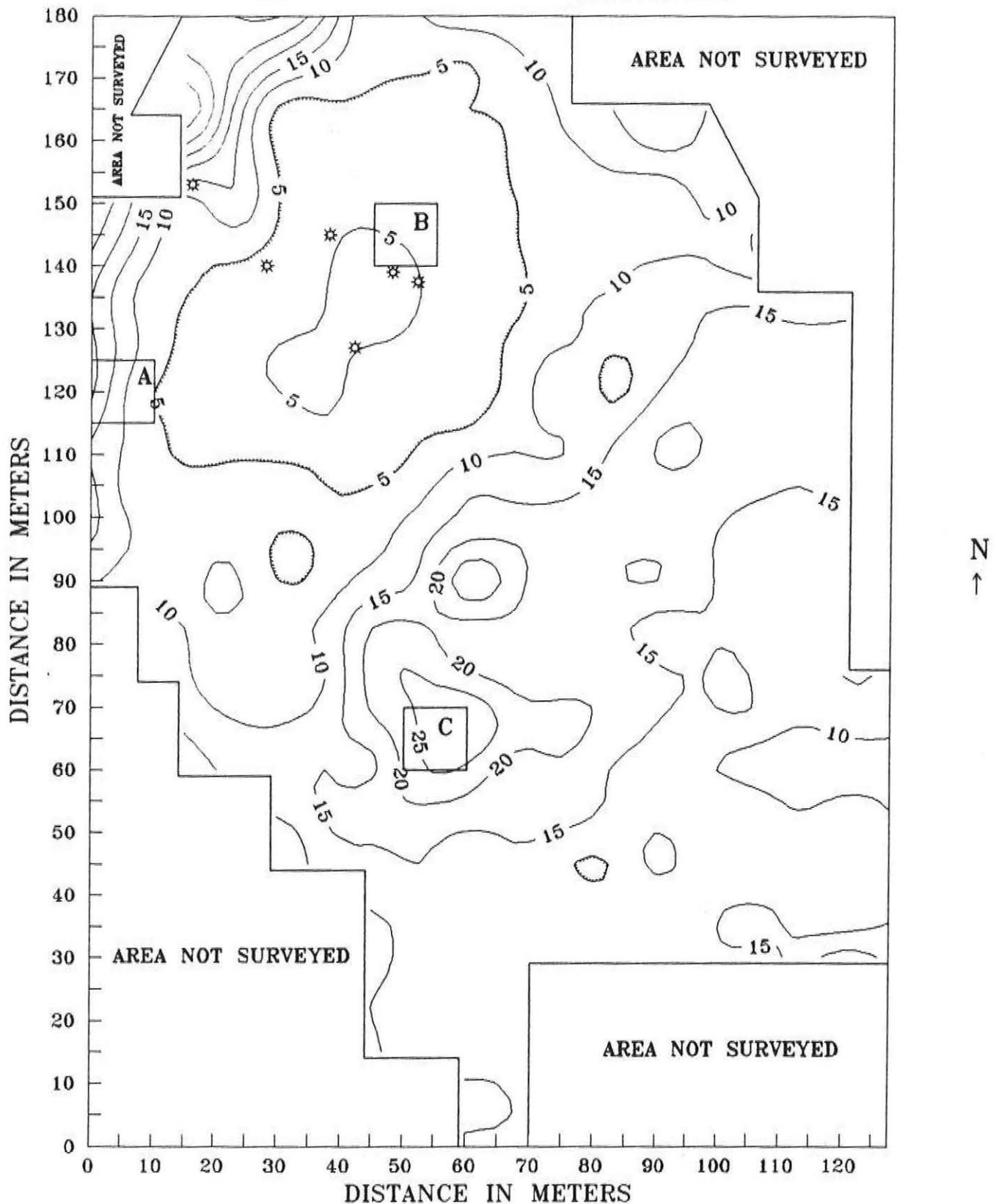
Slavich, P. G. and G. H. Petterson. 1990. Estimating average rootzone salinity from electromagnetic induction (EM-38) measurements. Aust. J. Soil Res. 28:453-463.

Vaughan, C. J. 1986. Ground-penetrating radar surveys used in archaeological investigations. Geophysics 51(3):595-604.

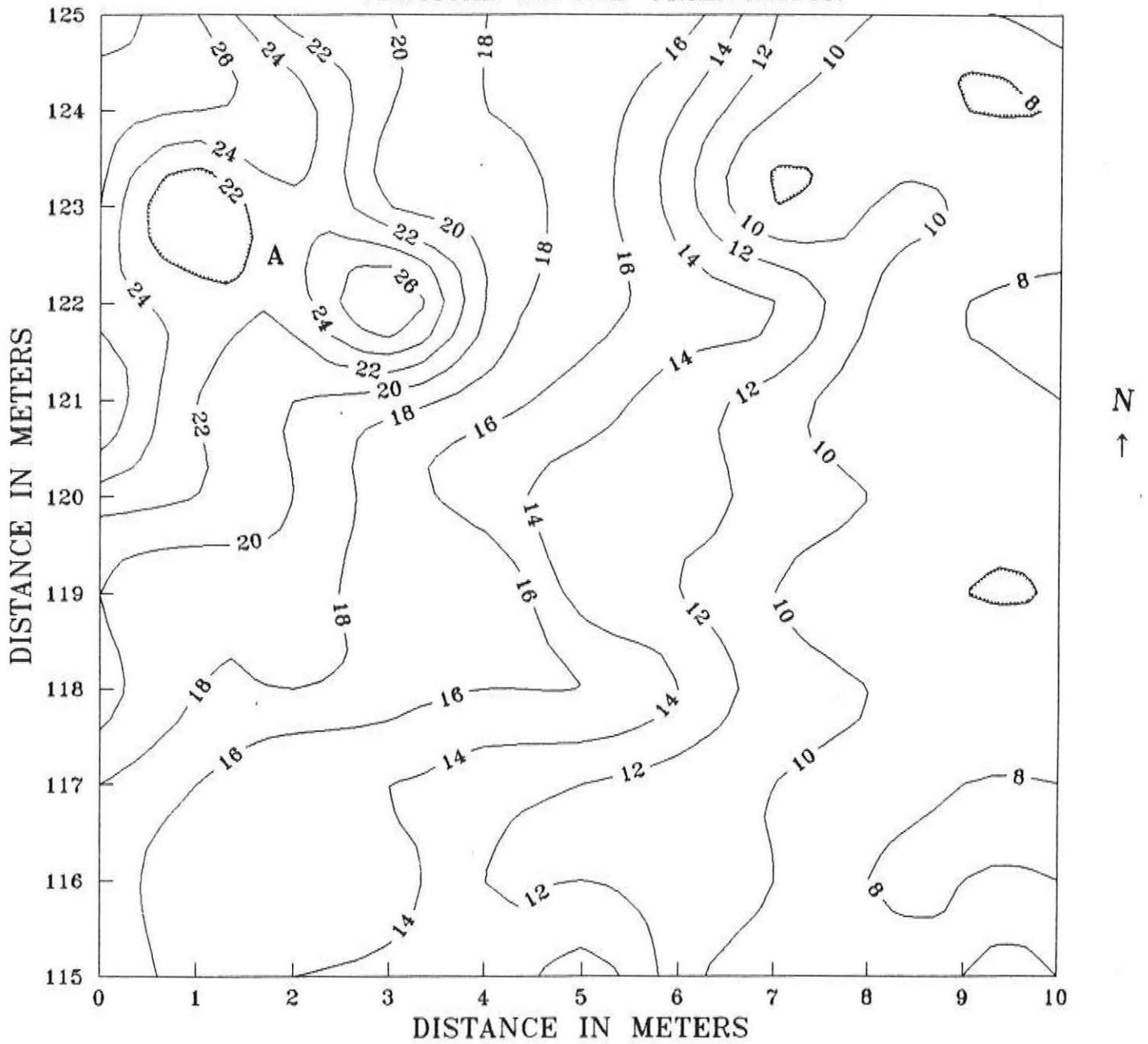
RELATIVE TOPOGRAPHY OF SUMMIT, TELL HALIF, ISRAEL



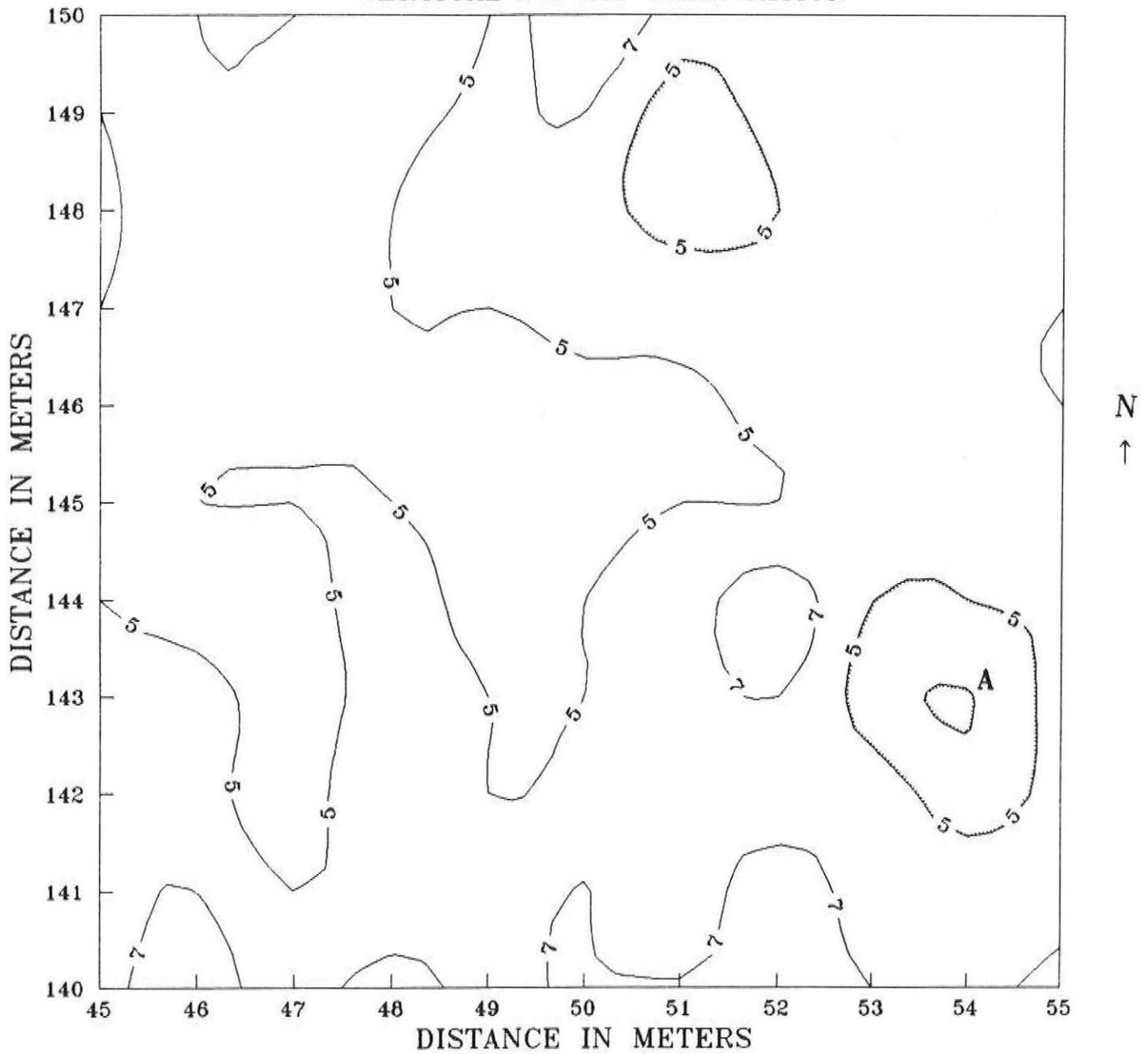
EM31 SURVEY OF SUMMIT, TELL HALIF, ISRAEL  
 HORIZONTAL DIPOLE ORIENTATION



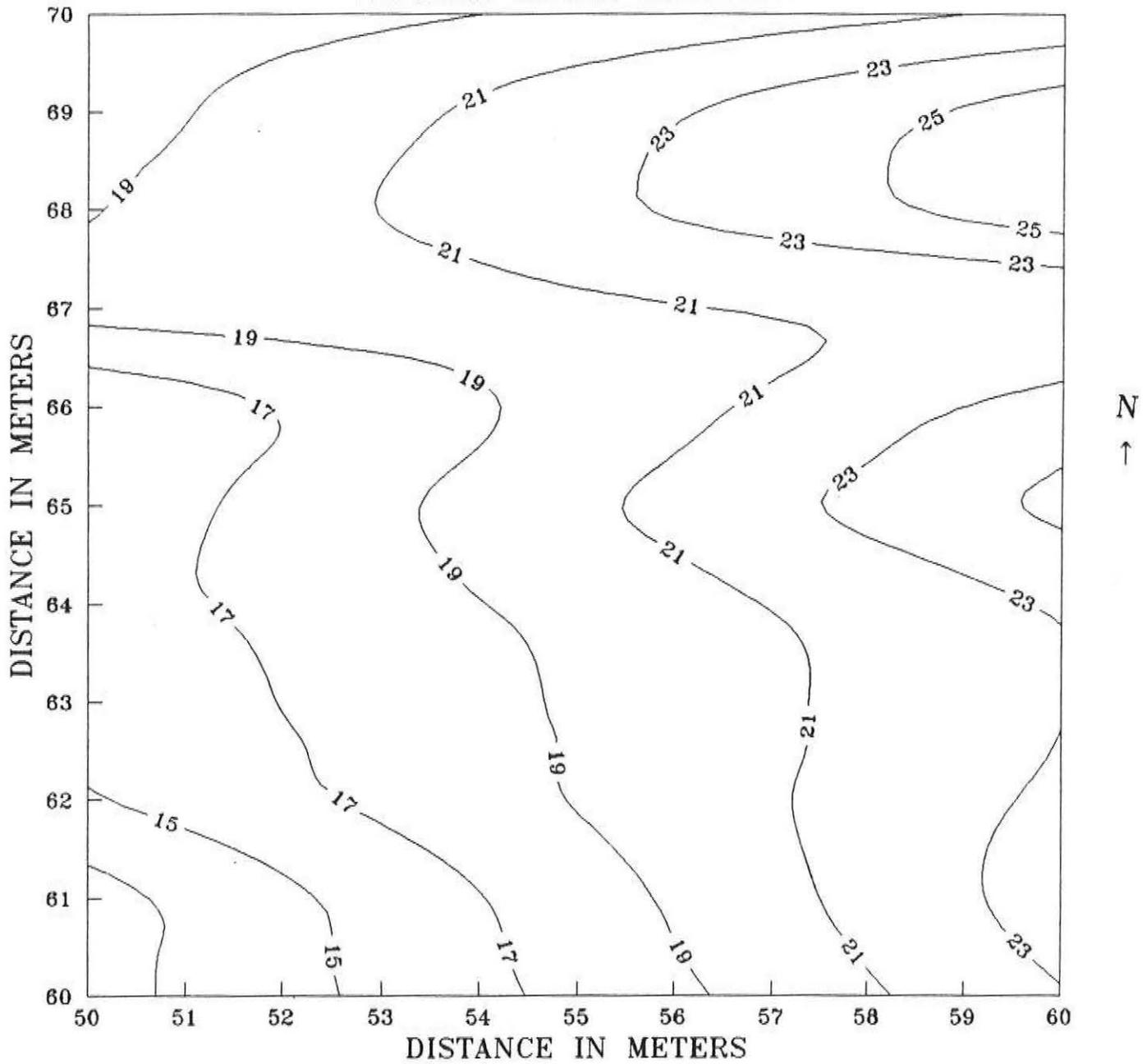
EM38 SURVEY OF SUB-SITE A ON SUMMIT OF TELL HALIF  
VERTICAL DIPOLE ORIENTATION



EM38 SURVEY OF SUB-SITE B ON SUMMIT OF TELL HALIF  
VERTICAL DIPOLE ORIENTATION



EM38 SURVEY OF SUB-SITE C ON SUMMIT OF TELL HALIF  
 VERTICAL DIPOLE ORIENTATION



# RELATIVE SURFACE TOPOGRAPHY OF SITE 301A

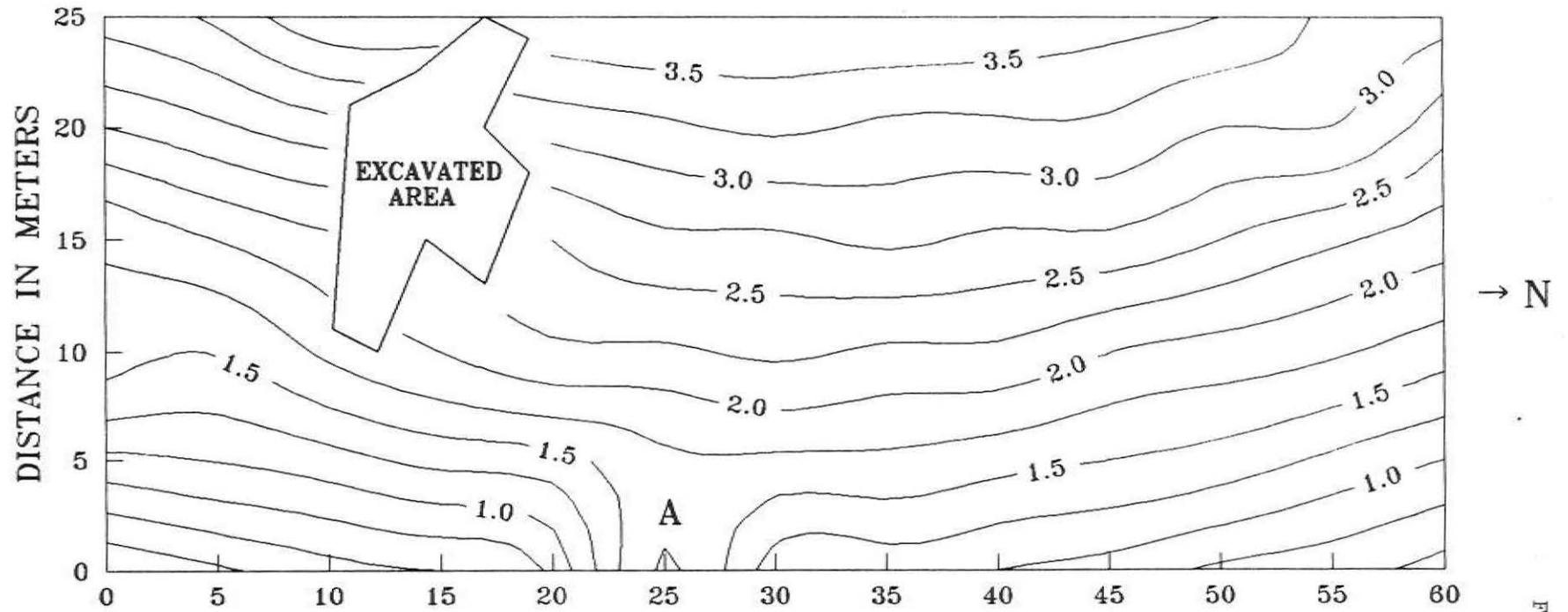


FIGURE 7

EM31 SURVEY OF SITE 301A, TELL HALIF, ISRAEL  
HORIZONTAL DIPOLE ORIENTATION

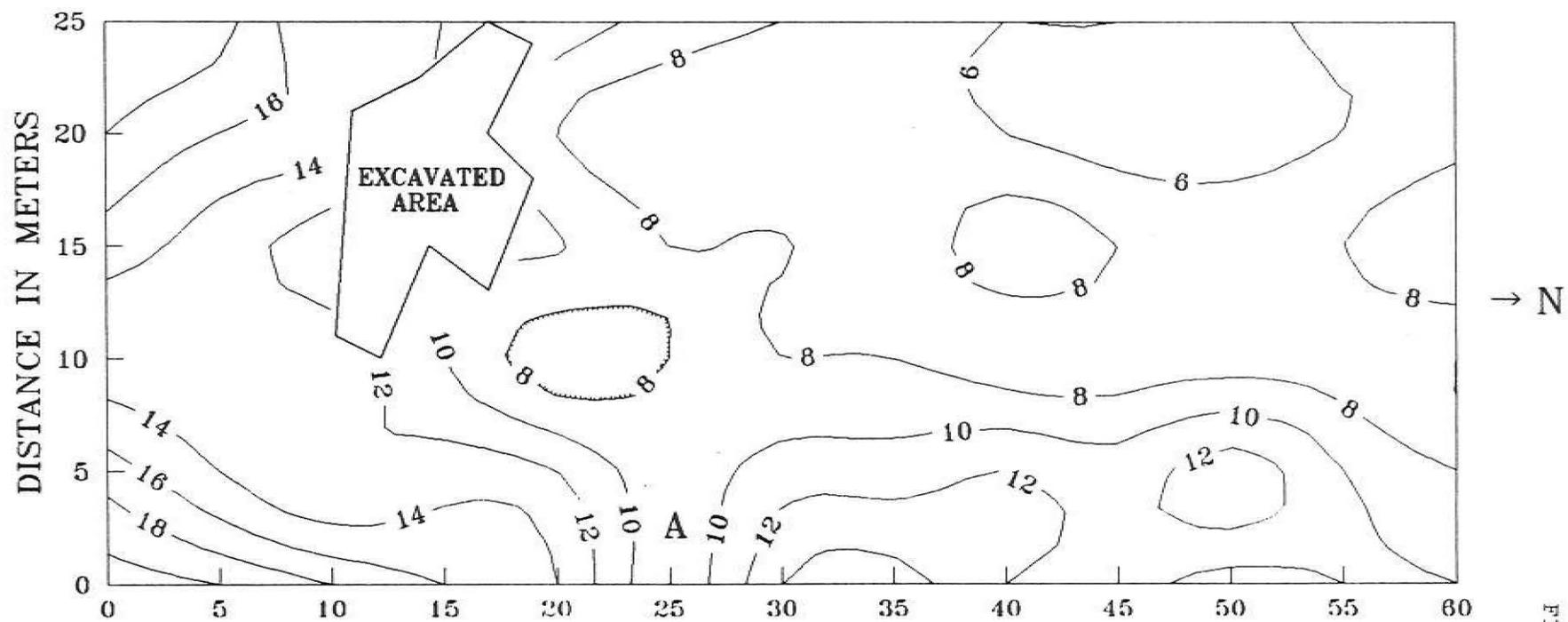


FIGURE 8

EM31 SURVEY OF SITE 301A, TELL HALIF, ISRAEL  
VERTICAL DIPOLE ORIENTATION

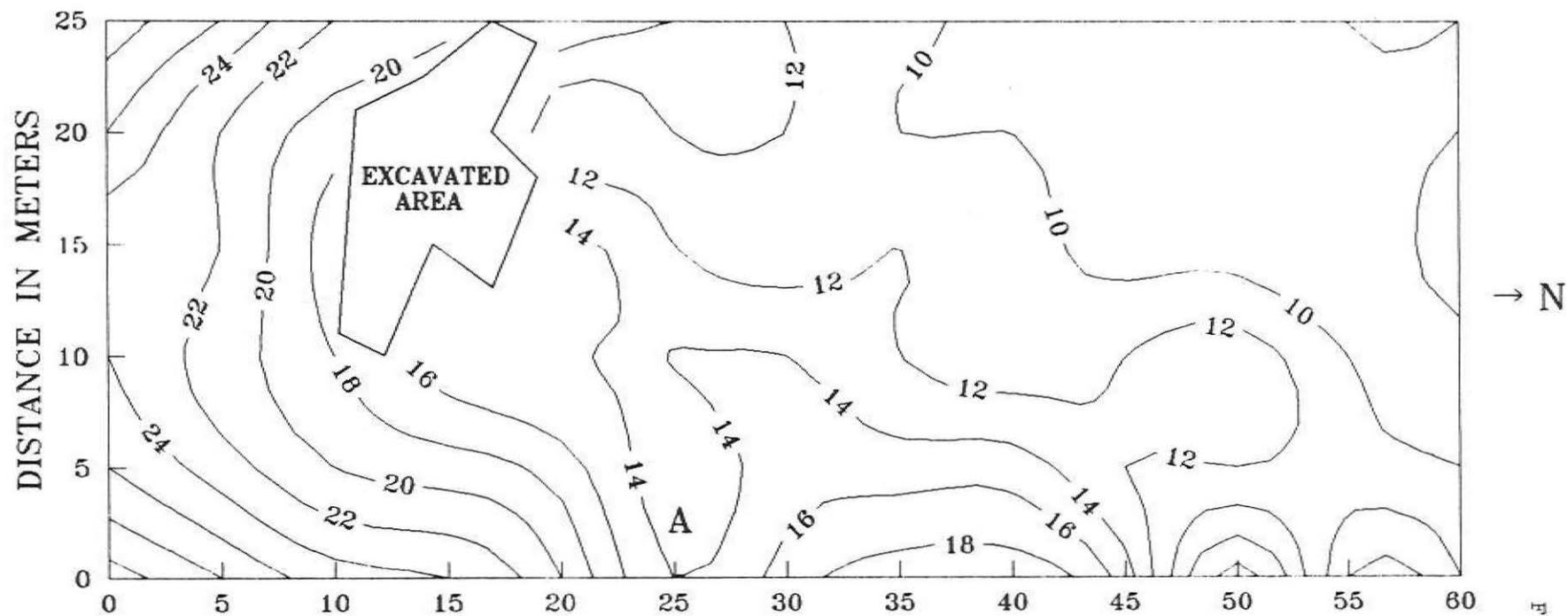
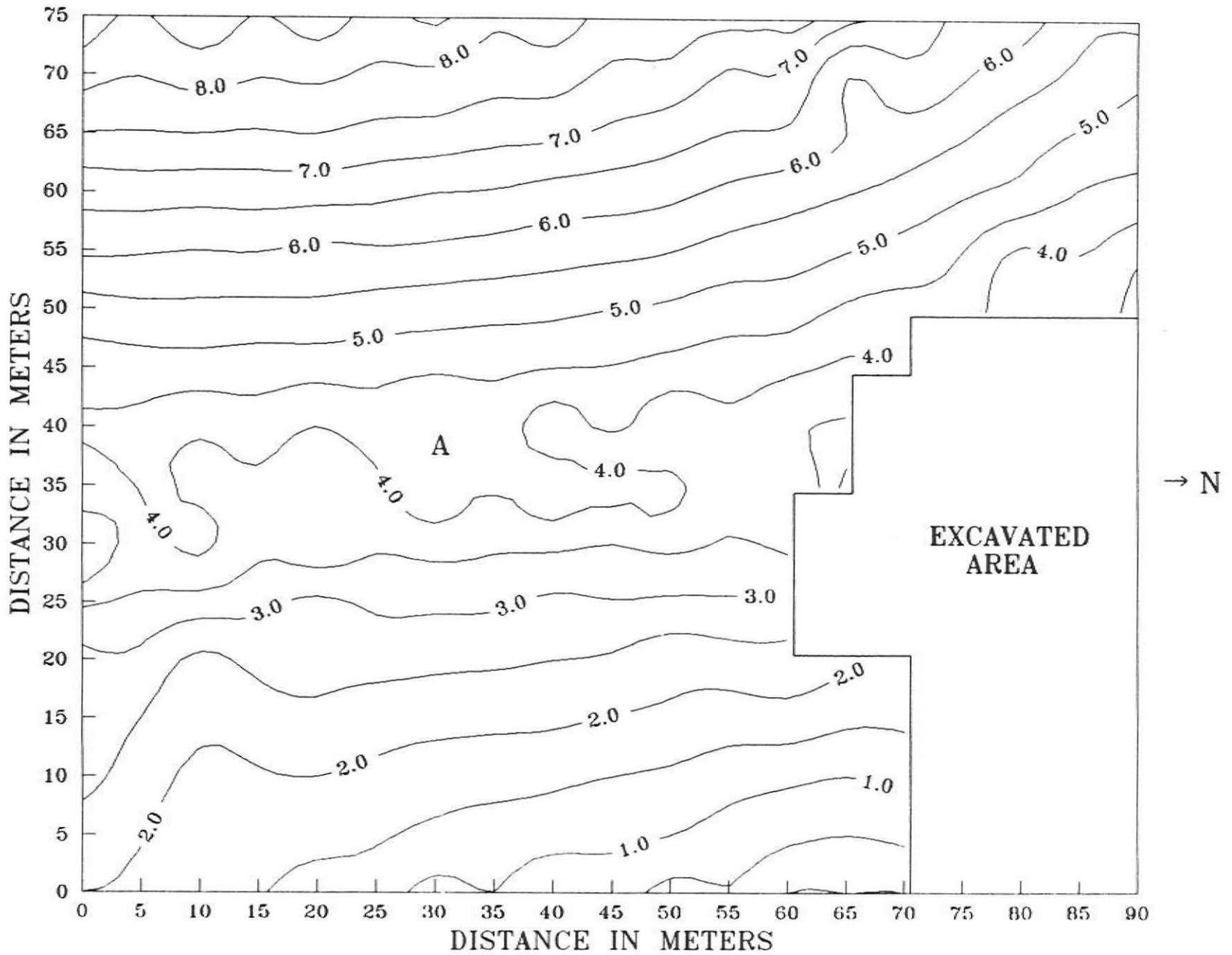


FIGURE 9

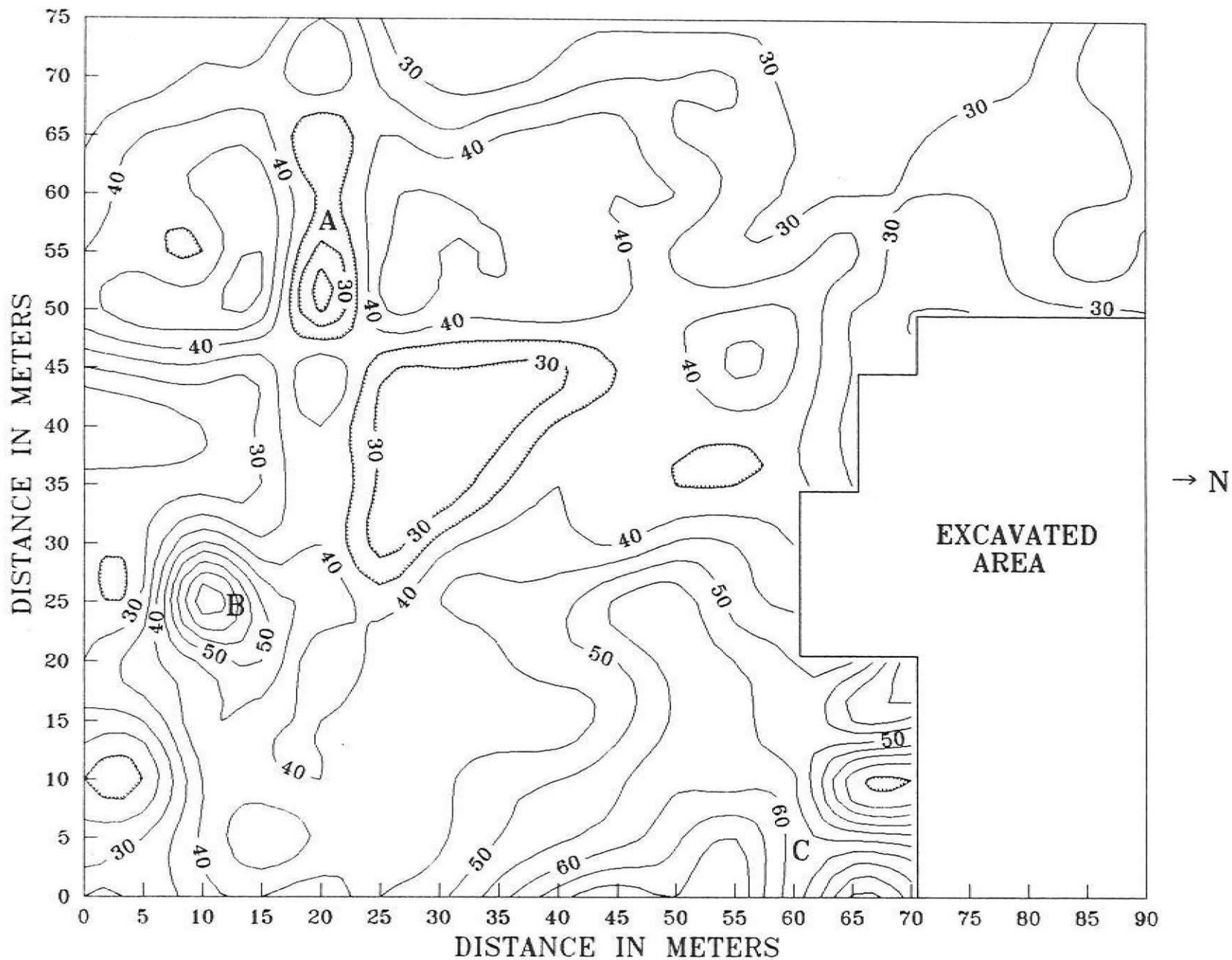
FIGURE 10

### RELATIVE SURFACE TOPOGRAPHY OF SITE 301B



EM31 SURVEY OF SITE 301B  
HORIZONTAL DIPOLE ORIENTATION

FIGURE 11



EM31 SURVEY OF SITE 301B  
VERTICAL DIPOLE ORIENTATION

FIGURE 1.2

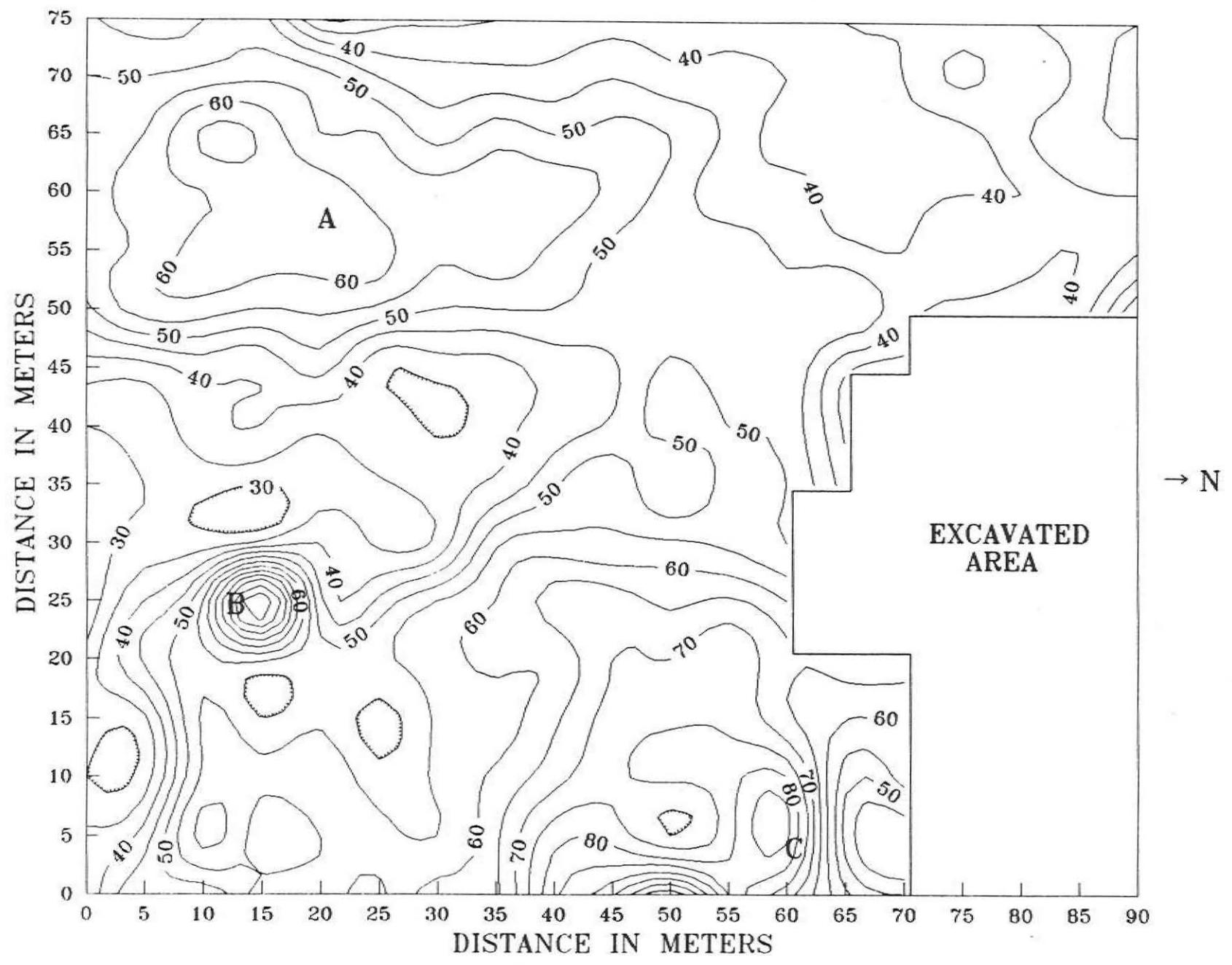
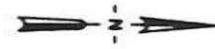
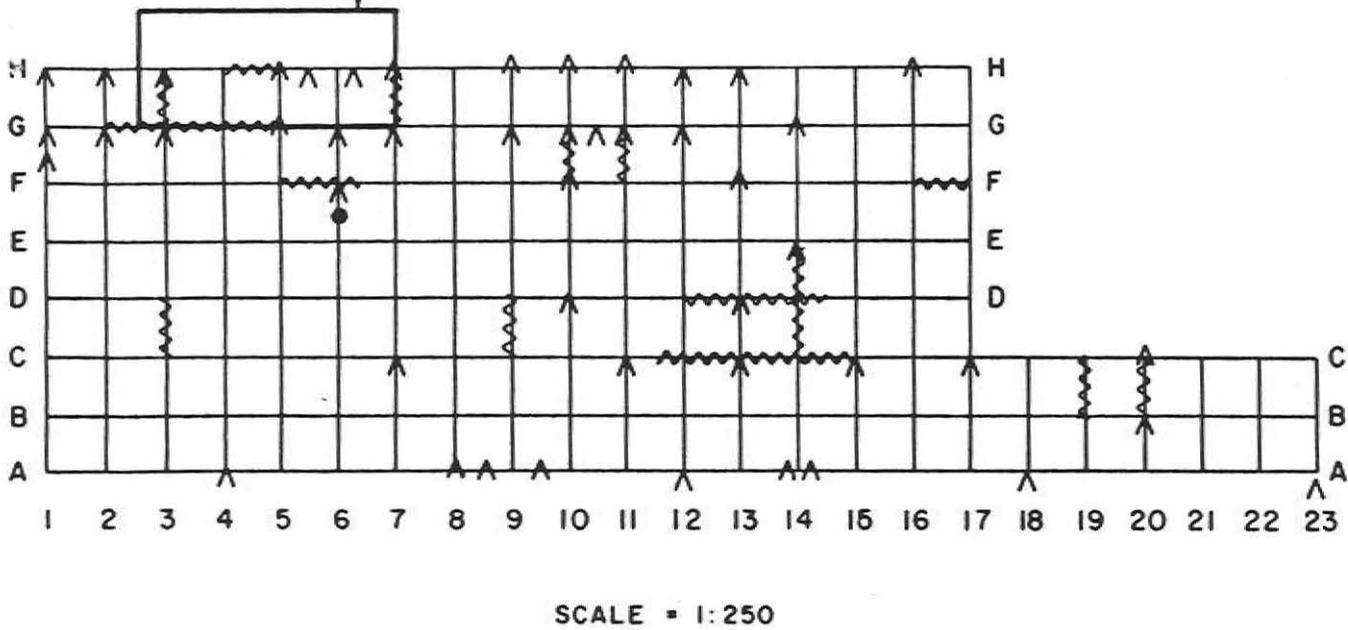
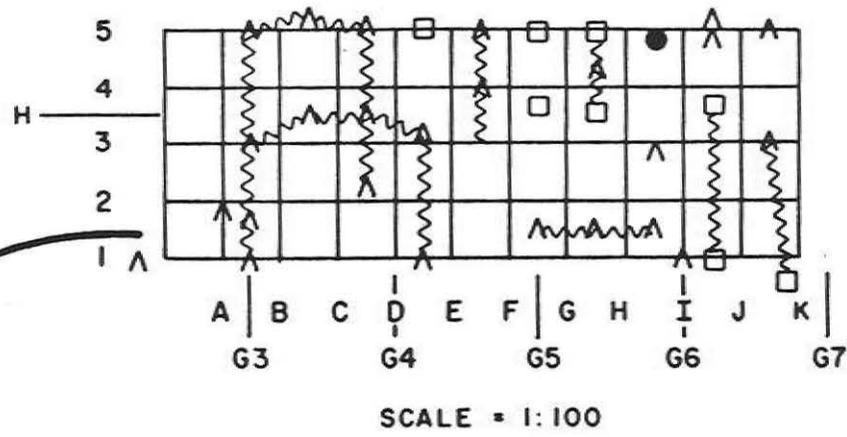


FIGURE 13



LEGEND

- △ SINGLE POINT OBJECT
- ~~~~ WALL or SURFACE
- COLUMN
- METALLIC

FIGURE 14

