UNITED STATES DEPARTMENT OF AGRICULTURE **160 East 7th Street**
SOIL CONSERVATION SERVICE **CHESTER, PA 19013**

SUBJECT: Soils - Geophysical Investigations in Harper County, Oklahoma; 21 to 25 June 1993

DATE: 17 August 1993

To: William E. Puckett
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100 USDA, Suite 203
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Purpose:
To explore the potential of using electromagnetic induction (EM) and ground-penetrating radar (GPR) techniques to assist the soil survey update of MLRA 77.

Participants:
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Gerald Sample, Asst State Soil Scientist, SCS, Stillwater, OK
Gregg Scott, Area Soil Scientist, SCS, Woodward, OK

Activities:
The morning of June 21 was spent in the Buffalo field office organizing a plan for field work. Ground-penetrating radar studies were conducted in areas of Pratt and Tivoli soils on the afternoon of 21 June. On June 22, a grid was established and EM surveys conducted in an area of Quinian-Woodward complex. On 23 and 24 June, random transects were conducted with the EM meters in areas of Woodward-Quinlan loams, 3-8 percent slopes and Quinlan-Woodward complex, 5 to 12 percent slopes. On 25 June GPR transects were conducted in areas of Tivoli and Pratt soils.

Equipment
The electromagnetic induction meters used were the EM31 and EM38 manufactured by Geonics Limited. Both meters are portable and require only one person to operate. Principles of operation have been described by McNeill (1,2). The depth of penetration is

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

dependent upon the intercoil spacing, transmission frequency, and coil orientation relative to the ground surface. The EM31 meter integrates values of apparent conductivity over the upper 2.75 m in the horizontal dipole orientation, and over the upper 6.0 m in the vertical dipole orientation. The EM38 meter integrates values of apparent conductivity over the upper 0.75 m in the horizontal dipole orientation, and over the upper 1.5 m in the vertical dipole orientation.

The radar unit used in this study was the Subsurface Interface Radar (SIR) System-8 manufactured by Geophysical Survey Systems, Inc. The system was powered by a 12-volt vehicular battery. The model 3110 (120 mHz) antenna and a model 705DA transceiver were used in this field study.

Discussion

EM Survey

Transect Lines

Four transects were established across areas of Quinlan - Woodward complex, 5 to 12 percent slopes, and Woodward - Quinlan loam, 3 to 8 percent slopes. These units occur on dissected, gently sloping to strongly sloping ridge crests and side slopes of the Central Rolling Red Plains. Quinlan and Woodward are members of the loamy, mixed, thermic, shallow Typic Ustochrepts and the coarse-silty, mixed, thermic Typic Ustochrepts families, respectively. Quinlan soils are shallow and Woodward soils are moderately deep over soft calcareous sandstone. However, in Harper County, these soils have been mapped in areas underlain by weakly consolidated sandstone, siltstone, or shale.

Transects were located in Sections 7, 18, and 17, T. 26 N., R. 23 W., and Section 1, T. 25 N., R. 25 W. Transects ranged from 120 to 490 meters long. Observation flags were placed in the ground at 15 meter intervals along each transect line. At each of the observation sites, measurements of apparent conductivity were taken with the EM38 meter in both the horizontal and vertical dipole modes. The relative elevation of the ground surface at each observation flag was obtained with a transit.

Figures 1 thru 4 record variations in relative surface elevations and apparent conductivity with depth and location along transect lines 1 thru 4, respectively. Along each transect line, soils were periodically examined with auger or power probes. In each figure, the location of these observation sites and the name of the soil at each of these sites has been identified.

Generally, along the transect lines, apparent conductivity values increase with soil depth (horizontal dipole orientation (0 to 0.75 m) is less than vertical dipole orientation (0 to 1.5 m)). Increases in

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2. 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.

apparent conductivity values with depth indicate a net downward accumulation of clays and/or movement of salts within the profile. Carey (fine-silty, mixed, thermic Typic Argiustolls), Ost (fine-loamy, mixed, thermic, Typic Argiustolls), and St. Paul (fine-silty, mixed, thermic Pachic Argiustolls) soils have argillic horizons. In addition, Carey, Enterprise (coarse-silty, mixed, thermic Typic Ustochrepts), Ost, St. Paul, and Woodward (coarse-silty, mixed, thermic Typic Ustochrepts) soils have Bk horizons in the lower part of the subsoil.

Transect 1 was conducted in an area of Ost and Carey soils. These closely similar soils formed in old alluvium and are very deep over Permian redbeds. At depths greater than 1.5 m, differences in lithology would not significantly influence the EM response. In transect 1, the first two observations were influenced by a buried pipeline.

In transects 2 and 3, EM responses were more variable. Dissimilar values are believed to reflect changes in soil type, soil depth, and lithology (resistive sandstone and more conductive shale). In a most general way, these figures disclose the highly complex and intricate soil patterns which exist across these landscapes. Areas of Quinlan soils underlain by siltstone displayed an elevated EM response. Areas of Ost soils have the lowest EM response.

The electromagnetic response is dependent on soil properties. Changes in EM response reflect variations in lithology, soil moisture, salt content, soil depth, soil texture, and mineralogy. Each of these factors will affect the apparent conductivity of soils. Soils can be differentiated by characteristic ranges of apparent conductivity. As the EM response is an integration of several soil properties, responses can be correlated within geographic areas to soil types (3). Generally, in geophysical research, the term "soil type" has been used to refer to the particle-size class of unconsolidated sediments. Zalasiewicz and Mathers (4) used EM techniques to map glacial sediments and distinguish areas of bouldery clays from arenaceous deposits. Sartorelli and French (5) charted

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3. Hoekstra, P., R. Lahti. J. Hild, R. Bates, and D. Phillips. 1992. Case histories of shallow time domain electromagnetics in environmental site assessments. Ground Water Monitoring Review. 12(4):110-117.

4. Zalasiewicz, J. A. and S. J. Mathers. 1985. New approach to mapping tills. pp. 55-59. IN: M. C. Forde (ed.) Proceedings of the International Conference on Construction in Glacial Tills and Boulder Clays. 12-14 March 1985. Edinburgh. (n.p. Engineering Technics Press).

5. Sartorelli, A. N. and R. B. French. 1982. Electro-magnetic induction methods for mapping permafrost along northern pipeline corridors. pp. 283-295. In: French, H. M.(ed.) Proceedings of the

the identity of grouping of the Unified Soil Classification System with characteristic apparent conductivity values. Kingston (6) used EM techniques to distinguish and map soil and geologic deposits and strata. In these studies different "soil types" and lithologies produced distinct and characteristic EM responses.

Each soil will have a characteristic EM response. The EM responses listed in Table 1 are based on limited observations made in Harper County. For a particular soil, the EM response will form a range of values which will be influenced by temporal variations in soil moisture and temperature. Furthermore, cultural and natural features can be expected to influence these ranges. Similar soils will have a similar range of EM responses. Within a given geographic area, the conductivities of some soils will overlap.

Table 1
Transects Conducted with EM38 Meter
in areas of map unit Qc,
Quinlan - Woodward complex, 5 to 12 percent slopes
(values are in mS/m)

	Horizontal			Vertical		
Soil	**minimum**	**maximum**	**average**	**minimum**	**maximum**	**average**
Carey	19	28	23	22	30	26
Ost	10	18	14	12	22	17
Quinlan*	34	64	43	42	60	48
Quinlan**	14	22	18	16	26	21
St. Paul	15	44	27	22	66	32

Areas of Quinlan soils displayed two distinct EM responses. Differences were attributed to variations in the underlying lithology. Areas underlain by siltstone produced higher EM response than areas underlain by soft sandstone. While this difference is recognized, Quinlan soils formed over different lithologies are not being separated under the current soil survey program.

Systematic Sampling - Grid Site
A 90 by 135 meter grid was established across an area of map unit Qc, Quinlan - Woodward complex, 5 to 12 percent slopes. The survey area

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Fourth Canadian Permafrost Conference. Calgary, Alberta 2-6 March 1991. National Research Council of Canada.

6. Kingston, G. 1985. Electromagnetic inductive instruments for use in surveys of soil salinity. Proc. Australian Soc. Sugar Cane Tech. Brisbane, Queensland. p. 74-84.

* Formed over shale.

** Formed over sandstone.

was located in the SW 1/4 of Sec. 17, T. 26 N., R. 23 W. Survey flags were inserted in the ground at 15 meter intervals. At each of the 70 grid intersects, measurements were obtained with the EM38 and EM31 meters in both the horizontal and vertical dipole orientations.

A transit was used to establish grid lines and determine surface elevations at each grid intersect. Elevations were not tied to an elevation benchmark; the lowest recorded surface point was chosen as the 0.0 datum. (Highest point within grid site was approximately 680 m). Figure 5 is a two-dimensional contour plot of the ground surface. Relief was about 10.3 meters.

The study site contains an intricate pattern of soils. Soils identified within the study site included Carey, Quinlan, Ost, and Woodward. Carey, Quinlan, and Woodward soils formed in materials weathered from Permian redbeds. The Permian redbeds consist of weakly consolidated soft sandstone and shale. Ost formed in calcareous alluvial deposits.

Computer Simulations:
Electromagnetic induction methods focuses on the rate and magnitude of change in EM response from place to place. Isarithmic maps prepared from EM data provide a graphic description of variations in soils and/or soil properties within a survey area.

Figures 6 and 7 represents two-dimensional isarithmic maps prepared from data collected with the EM38 and the EM31 meters, respectively. These simulations chart apparent conductivity values collected in the horizontal and the vertical dipole orientations.

Values of apparent conductivity are highest along the south-facing, lower side slope and summit areas. These areas are underlain at shallow and moderately-deep depths by Permian redbeds composed of soft siltstone. In figures 6 and 7, values of apparent conductivity are lowest on north-facing back slope areas. These areas are composed of deep and very deep alluvial deposits.

The rate and magnitude of change in soils and soil properties within the study site are plotted in Figure 6. Soil boundaries separate areas of one kind soil from another. In the field, some soil boundaries are obvious, sharply defined, and conform to breaks in the landscape. Others soil boundaries are gradational and difficult to identify. With EM techniques, the rate of change in soils and soil properties can be inferred. In figures 6 and 7, isarithms are closer and the rate of change in soil properties are presumed to be greater along the south and south-eastern portion of the site. However, isarithms are farther apart and the rate of change in soil properties are assumed to be more gradational along the northern portion of the site.

In preparing the isarithmic maps of the study area, it was hoped that these diagrams would produce a detailed soil map. Considerations were given to observation and equipment errors, the range of the data, and the purpose of the maps. Measurements collected with the

EM38 meter in the vertical dipole orientation were used to prepare a soil map. The selected intervals were based on observations made with a power probe at five observation sites (see asterisks) In Figure 8, three units have been identified. The delineations represent soils with low (<20 mS/m), intermediate (20 - 30 mS/m), and high (>30 mS/m) apparent conductivity values. These delineations represent areas of Ost (<20 mS/m), Carey (20 - 30 mS/m), and Quinlan (>30 mS/m) soils.

GPR Survey of Areas of Tivoli and Pratt Soils

The purpose of this survey was to chart the depth to an argillic horizon in areas of Tivoli (mixed, thermic Typic Ustipsamments) and Pratt (sandy, mixed, thermic Psammentic Haplustalfs) soils. Generally, areas of Pratt soil were found on large flats between dunes; Tivoli soils occurred on more hummocky and dunal terrains.

A continuous profile of the subsurface was made by towing the 120 mHz antenna behind a 4WD vehicle. The traverse extended for 1.3 miles across areas of Pratt and Tivoli soils. While conducting the survey, reference marks were inserted on the radar record at 0.1 mile intervals. Later, additional, equally-spaced reference marks were placed on the radar record.

Table 2
Depth to Argillic Horizon or Layer of Finer-Textured Materials
(in inches)

Area of Pratt Soils

30	22	21	20	22	21	22	26	22
21	25	23	32	26	39	35	26	22
23	26	36	29	27	35	24	24	22

Area of Tivoli Soils

30	30	28	35	24	24	24	22	61
47	101	132	118	117	127	103	110	117
132	160	195	88	138	79	124	127	102
75	65	58	55	92	91	65	37	36

Table 2 list the depth to argillic horizon or layer of finer-textured materials as interpreted from the radar profiles. The average depth to the argillic horizon was 26 inches and 82.5 inches in areas of Pratt and Tivoli soils, respectively. In areas of Pratt soils, one-half the observations had depths to the argillic horizon between 22 and 27 inches. In the transected area of Pratt soils, depths to argillic horizon were moderately deep at all of the equally-spaced referenced locations. In areas of Tivoli soils, one-half the observations had depths to finer-textured materials between 36 and 117 inches. In the transected area of Tivoli soils, depths to argillic horizon or layers of finer-textured materials were moderately deep at 28.6 percent, deep at 8.6 percent, and very deep at 62.8 percent of the equally-spaced referenced locations.

Results:

1. All participants received training in the operation and use of the EM38 and EM31 meters.

2. Electromagnetic induction is an imperfect geophysical tool and is not equally suitable for use in all soil investigations. The success of an EM survey depends on the nature and variability of soil properties. Electromagnetic induction methods have been most effective in areas where subsurface soil properties are fairly homogeneous, the effects of one factor dominants over the others, and variations in the EM response can be related to changes in a single factor (e.g. soil moisture, soluble salt content, clay content, soil depth, or mineralogy). The surveyed areas of Quinlan and Woodward soils were considered highly complex.

3. EM techniques can be used in Oklahoma to support transect data. Generally, changes in EM responses corresponded to changes in soil taxonomic types. In addition, EM techniques can be used to identify and chart variations in soils and soil properties across management units and to locate representative sampling sites (based on apparent conductivity values) for soil characterization.

4. Ground-penetrating radar techniques are well suited to the collection of data on depths to finer textured materials and taxonomic classification of soils in areas of coarse-textured sediments.

5. This field investigation provided soil scientists with an opportunity to assess the applicability of GPR and EM techniques to soil survey operations in Harper County. Based on the results of this study, field soil scientist are better prepared to assess the appropriateness of these techniques for future soil survey investigations in MLRA 77. Further specific applications of EM and GPR techniques are encouraged and should be recommended when considered appropriate.

It is my pleasure to work in Oklahoma and with the members of your fine staff.

With kind regards.

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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; De 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 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).

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 the 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 3 list the anticipated depths of measurements for the EM31 and EM38 meters. The actual depth of measurement will depend on the conductivity of the earthen material(s) scanned.

Table 3

Depth of Measurement

Meter	Intercoil Spacing	Depth of Measurement Horizontal	Vertical
EM31	3.7 m	2.75 m	6.0 m
EM38	1.0 m	0.75 m	1.5 m

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.

References

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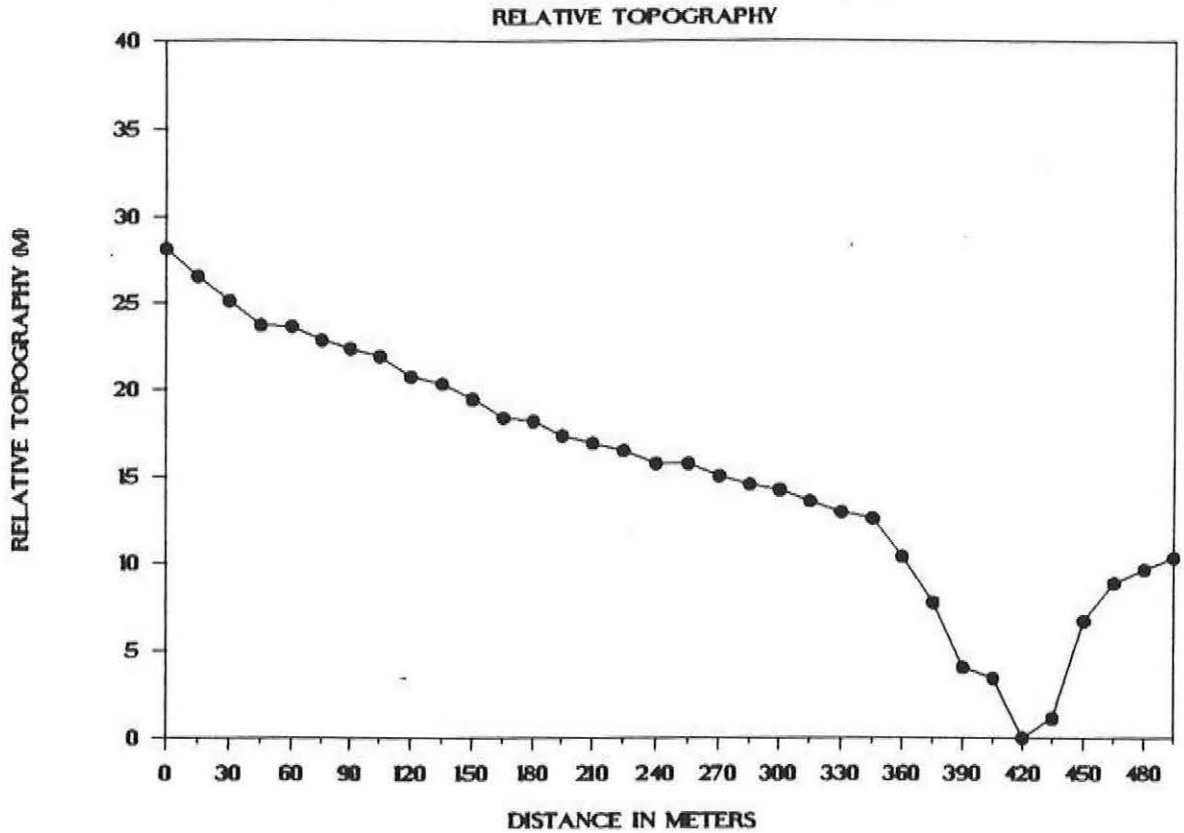
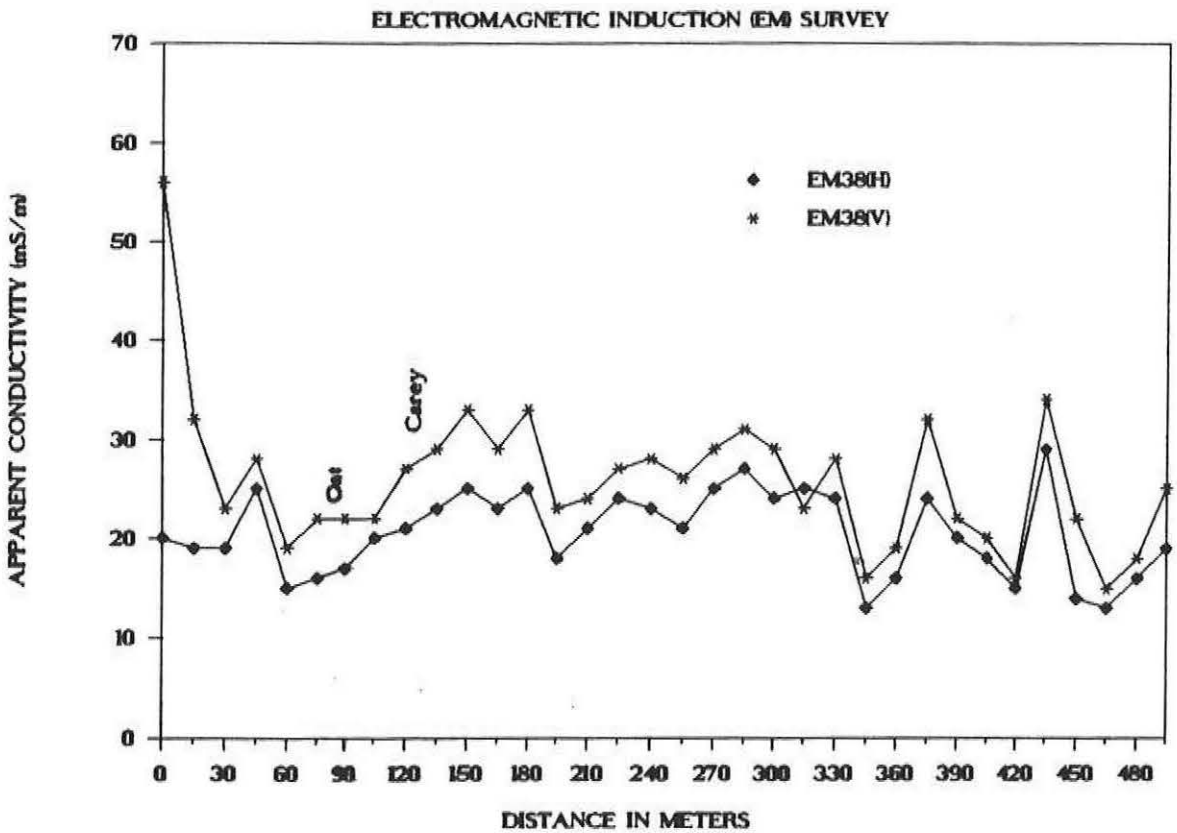
TRANSECT #1 - HARPER COUNTY, OKLAHOMA





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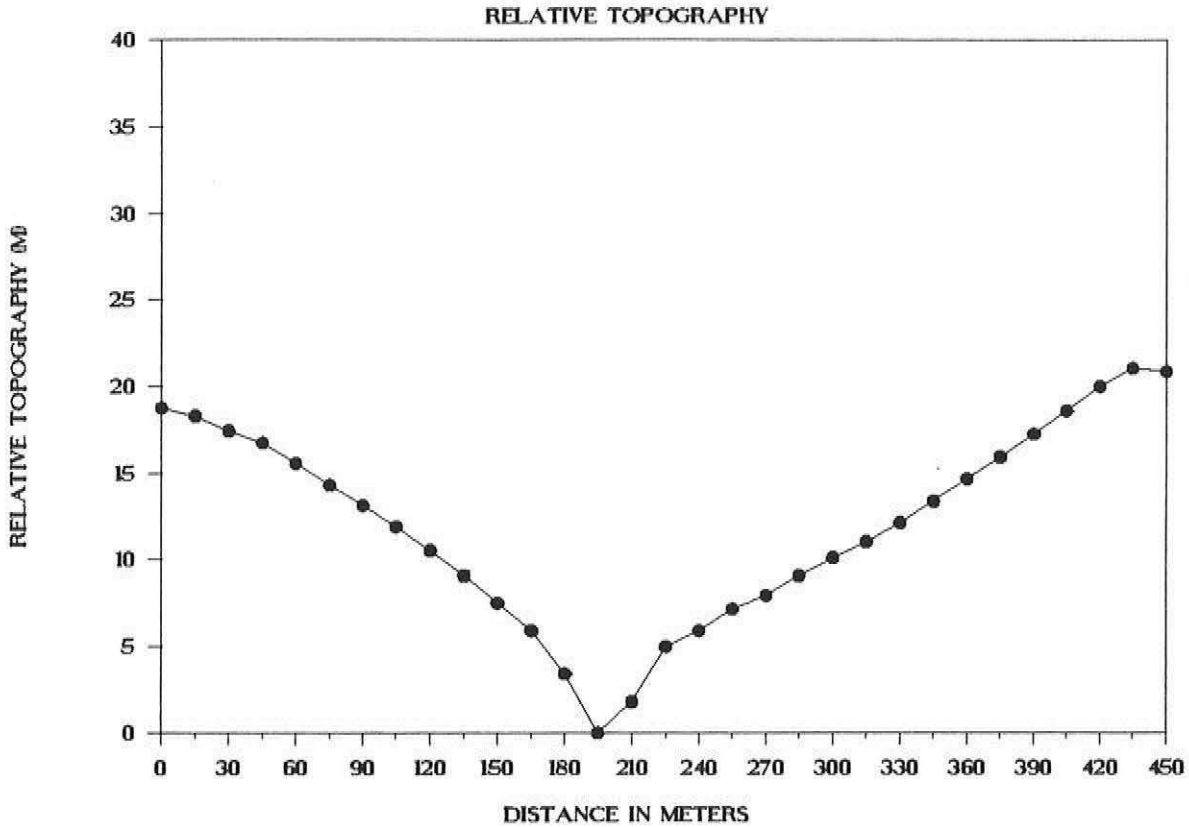

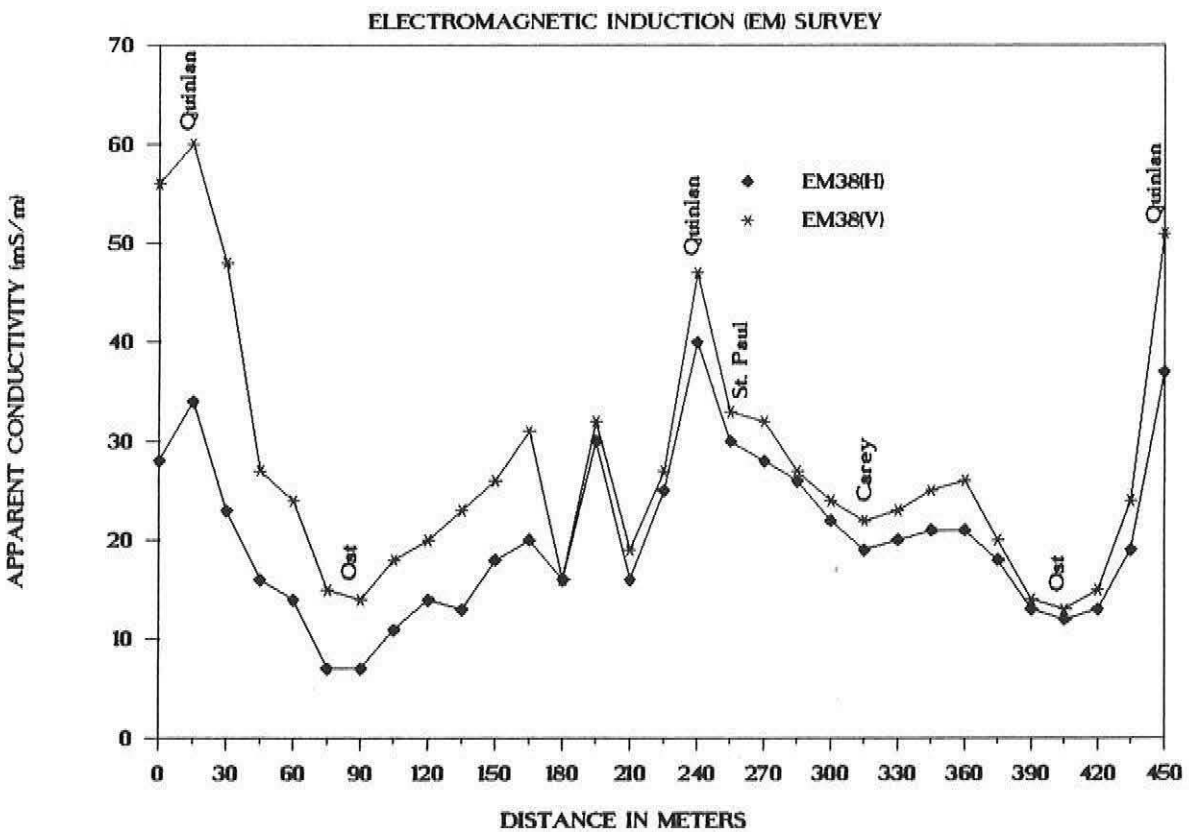

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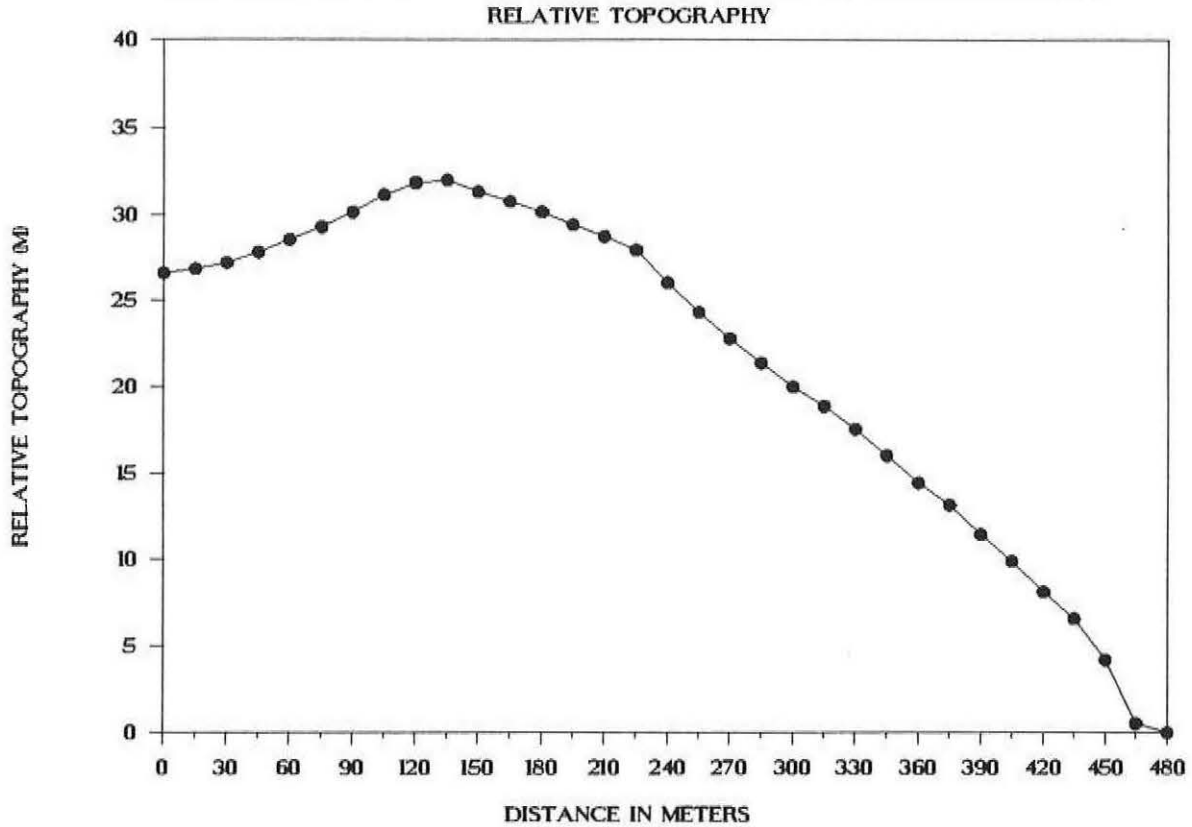

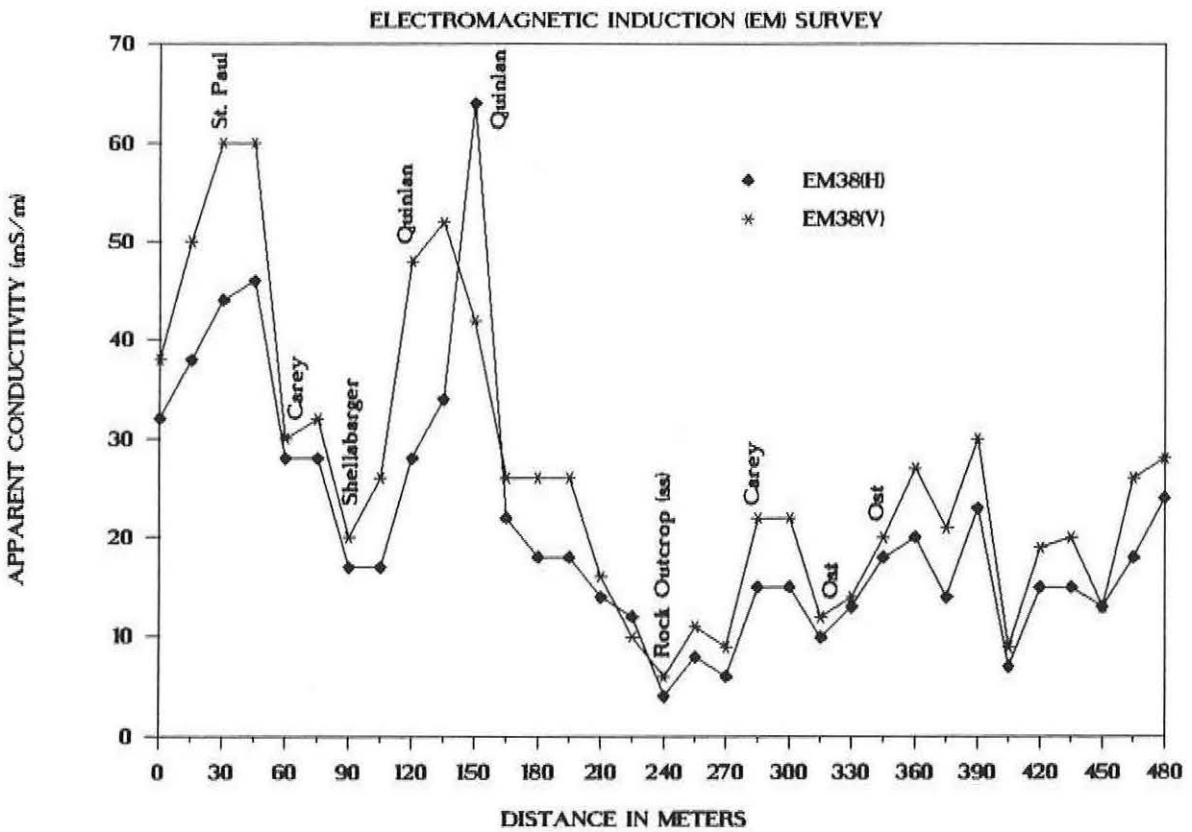

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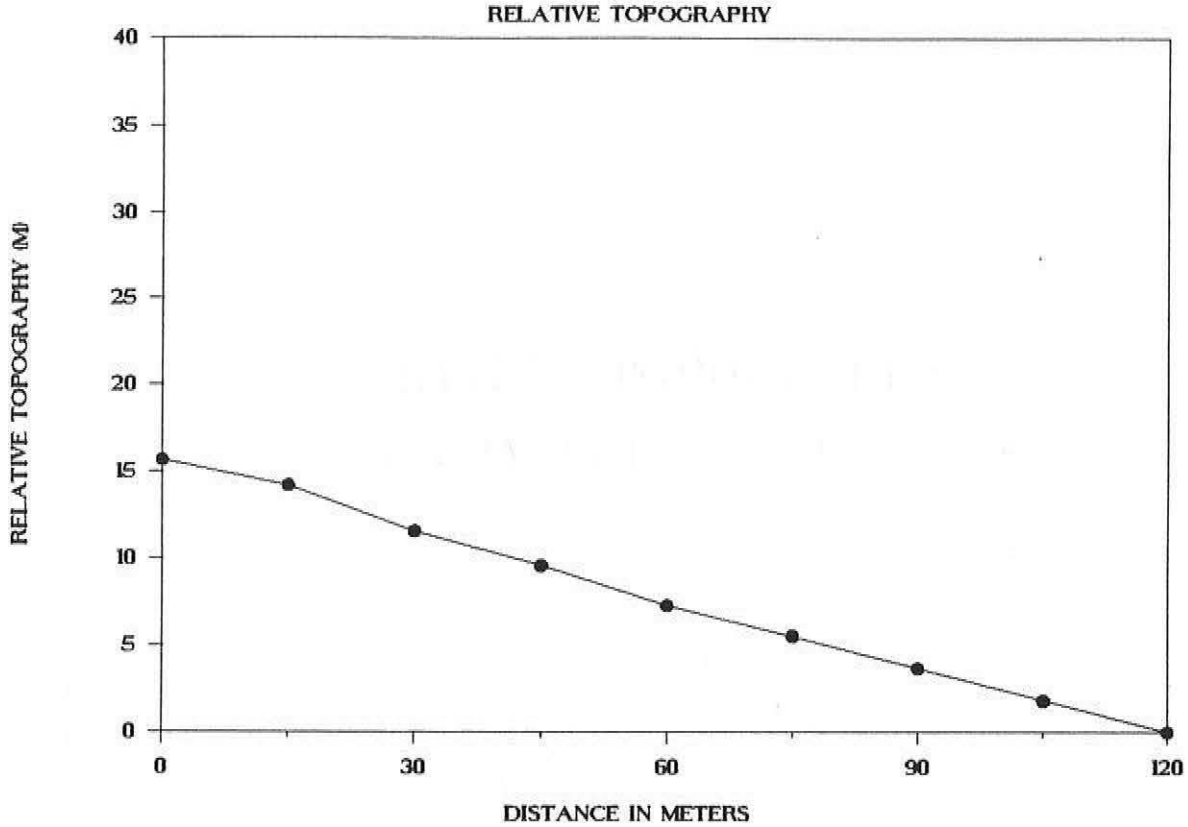

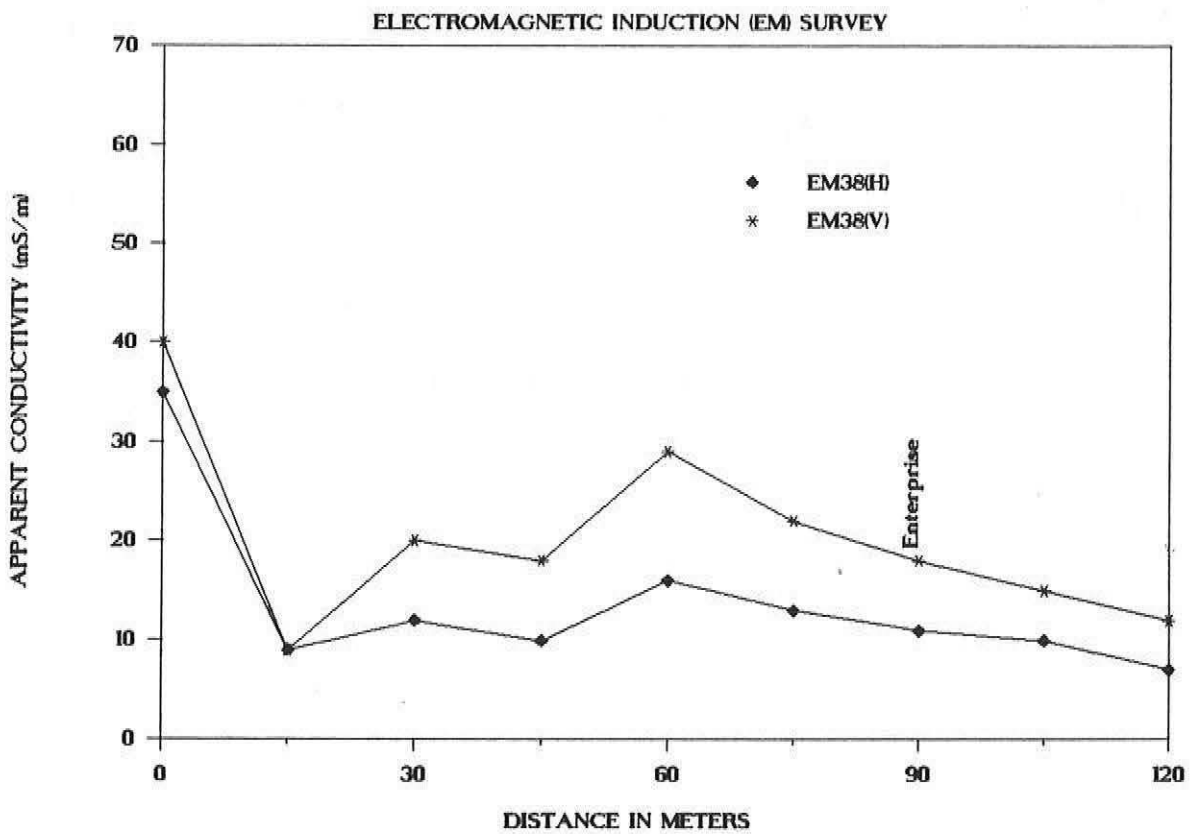

EM38 SURVEY OF AN AREA OF QUINLAN-WOODWARD COMPLEX

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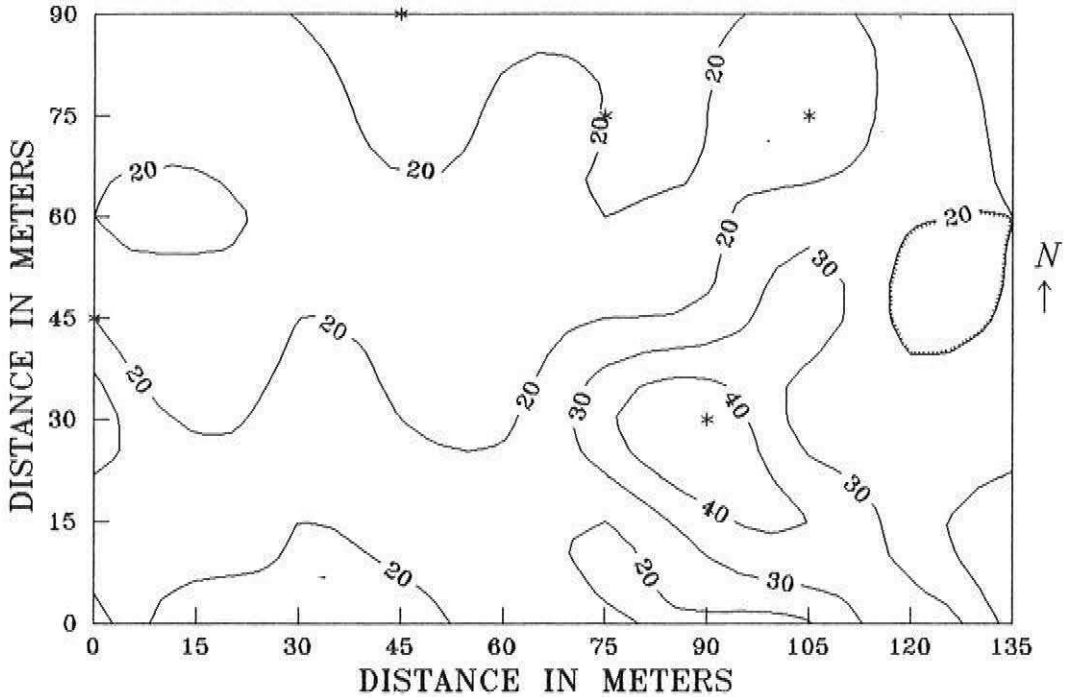
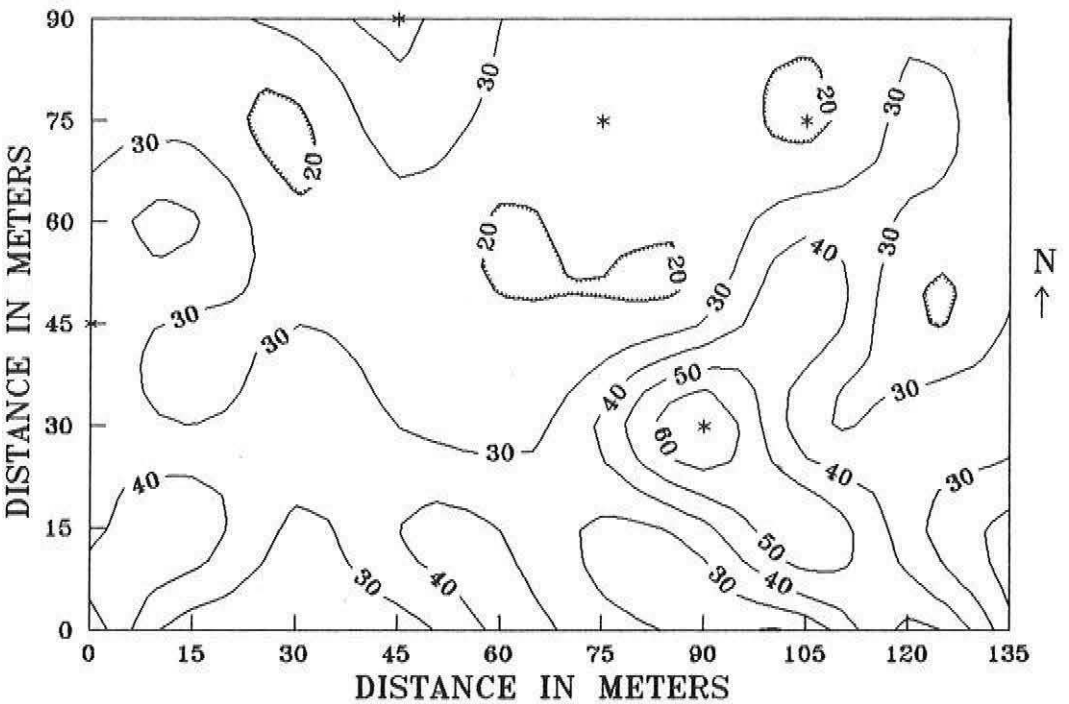
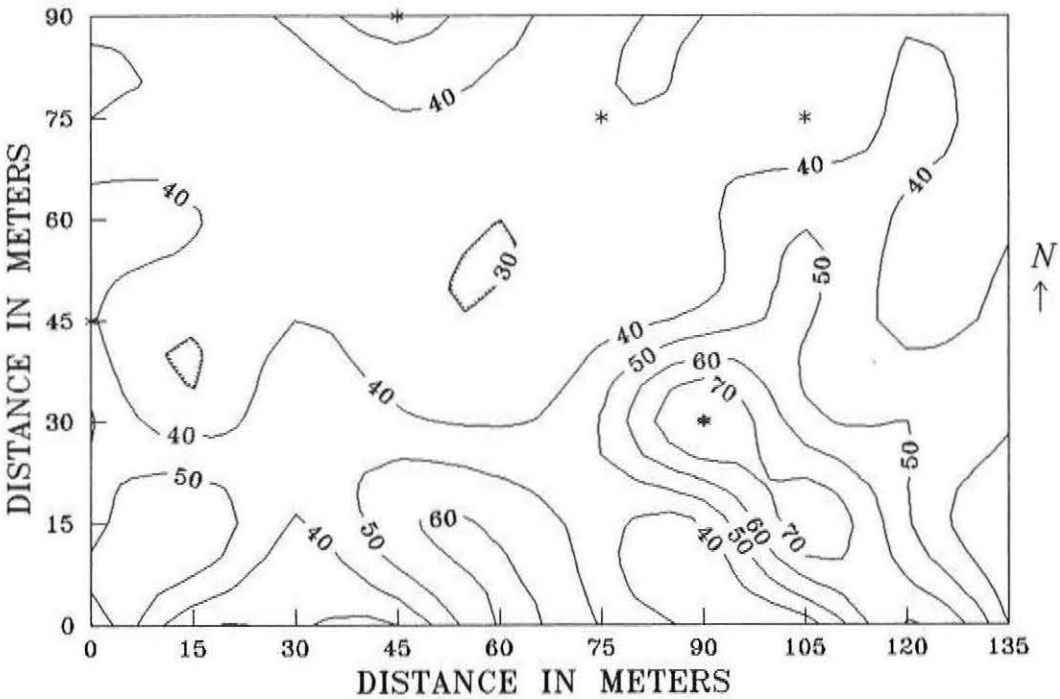


VERTICAL DIPOLE ORIENTATION

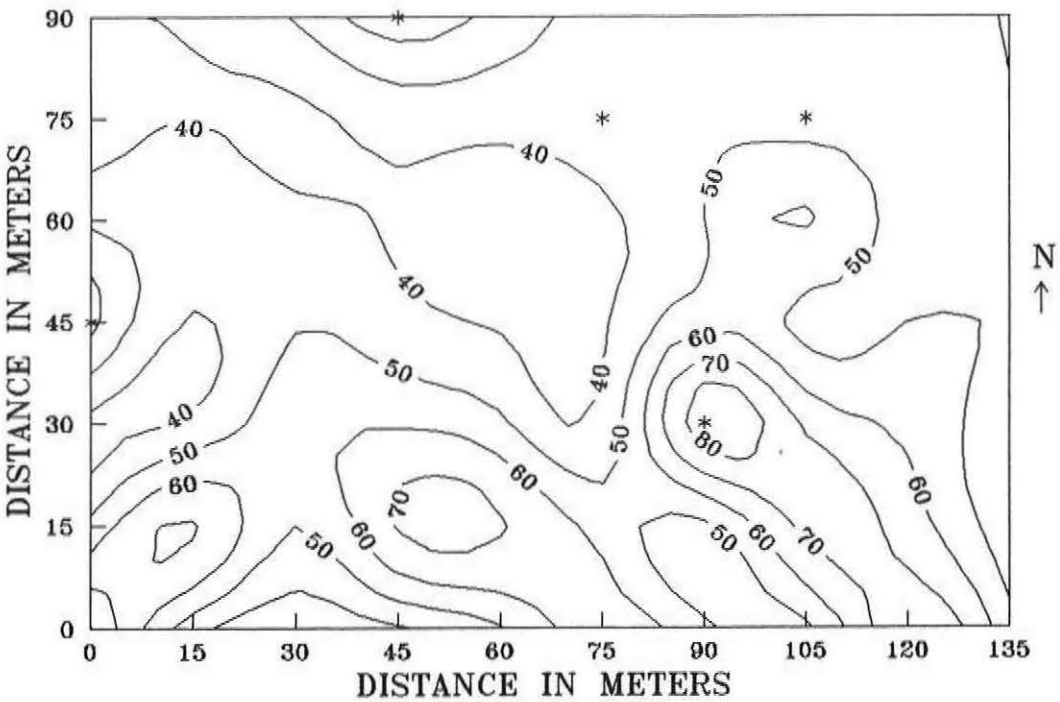
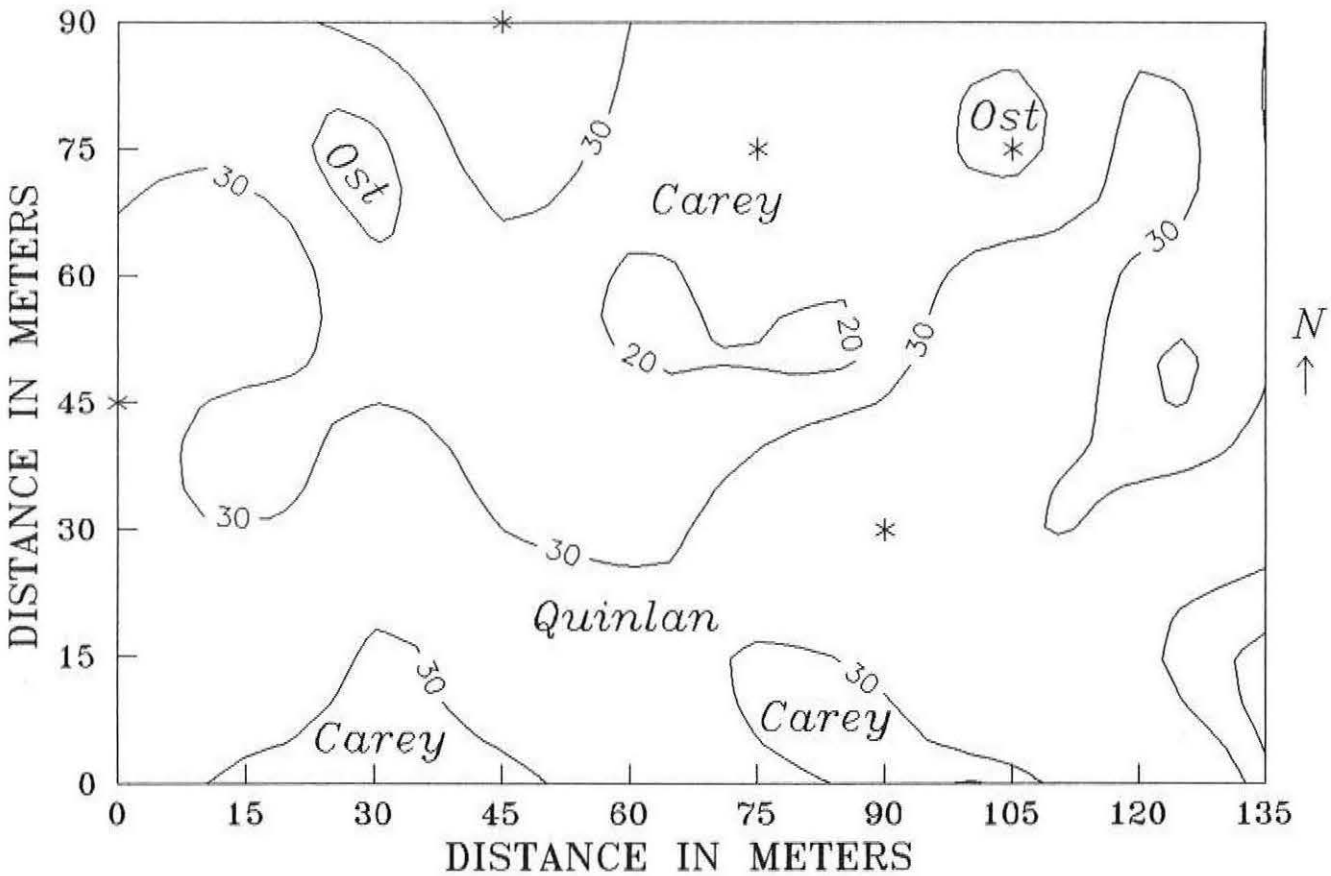


EM31 SURVEY OF AN AREA OF QUINLAN-WOODWARD COMPLEX

HORIZONTAL DIPOLE ORIENTATION



VERTICAL DIPOLE ORIENTATION



SOIL MAP UNITS – HARPER COUNTY, OKLAHOMA