United States Department of Agriculture
Soil Conservation Service **Chester, PA 19013**

Subject: Ground-Penetrating Radar (GPR) study of depth to paleosols in Reno County, Kansas; 20 to 30 June 1994.

Date: 28 July 1994

To: Richard L. Schlepp
State Soil Scientist
USDA - Soil Conservation Service
760 S. Broadway
Salina, Kansas 67401

Purpose:
To use GPR and EM techniques to characterize depths to water table, lamellae and paleosols, and salt contents of selected soils and map units in Reno County, Kansas.

Participants:
Brian Bergentine, Civil Engineer, SCS, Hutchinson, KS
Andy Broxterman, Agricultural Engineer, SCS, Hutchinson, KS
Ricky Cox, Area Resource Soil Scientist, SCS, Hutchinson, KS
Steve Graber, Area Soil Scientist, SCS, Dodge City, KS
Jim Doolittle, Soil Specialist, SCS, Chester, PA
Mary Doolittle, Earth Team Volunteer, NNTC, Chester, PA
Paul Finnell, Ass't. State Soil Scientist, SCS, Salina, KS
David Kacirik, Soil Scientist, SCS, Leavenworth, KS
Jim McDowell, Soil Survey Party Leader, SCS, Liberal, KS
Bob Murphy, Soil Survey Party Leader, SCS, Hutchinson, KS
Gary Parks, Soil Scientist, SCS, Hutchinson, KS
Mike Sucik, Soil Survey Party Leader, SCS, Leavenworth, KS
Robert Triggs, Area Resource Soil Scientist, SCS, Hays, KS
John Warren, Soil Scientist SCS, Hutchinson, KS
Bill Wehmueller, Area Resource Soil Scientist, SCS, Manhattan, KS

Activities:
During this field study, about 24 miles of continuous radar data were collected. Traverses were completed with GPR in areas of Carwile (fine, mixed, thermic Typic Argiaquoll), Dillwyn (mixed, thermic Aquic Ustipsamment), Pratt (sandy, mixed, thermic Psammentic Haplustalf), and Tivoli (mixed, thermic Typic Ustipsamment) soils. Traverses were also conducted in areas of the proposed Dillhut (sandy over loamy, mixed, thermic Aquic Ustorthent), Hayes (coarse-loamy, mixed, thermic Udic Haplustalf) Langdon (mixed, thermic Argic Ustipsamment), Plev (sandy, mixed, thermic Mollic Endoaqualf), and Solvay (fine-loamy, mixed, thermic Aquic Haplustalf) soils. These traverses were conducted principally in the northeast and west portions of Reno County.

A detailed GPR and EM site investigation was completed in an area of Langdon-Tivoli fine sands, 0 to 15 percent slopes. Several transects and a detailed grid were completed with the EM38 meter in areas of Tabler (fine, montmorillonitic, thermic Udertic Argiustoll) and the proposed Punkin (fine, mixed, thermic Aquic Natrustoll) soils.

Equipment:
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 with model 705DA transceiver was used in the investigation.

The electromagnetic induction meter was the EM38, manufactured by Geonics Limited+. The meter is portable and requires only one person to operate. The depth of penetration is dependent upon the intercoil spacing, transmission frequency, and coil orientation relative to the ground surface. 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.

Discussion:
Ground-Penetrating Radar Transects:
Field Procedures:
All transects were conducted in areas that had been preselected by the survey party. Transects were confined to delineated areas of recognized soil map units. A 100 foot interval (paced) was used between observation points. Though GPR provides a continuous record of the subsurface, estimates of the depths to paleosols were restricted to the observation points.

Calibration trials consisted of multiple traverses conducted across site 1A (see Table 1). A scanning time of 80 nanoseconds (ns) was used. As part of the calibration trials, a metallic reflector was buried at a depth of 17 inches (43 cm). Based on the scaled depth to this reflector, the calculated dielectric constant was 9.9. The velocity of propagation was 0.312 ft/ns (0.095 m/ns). With a scanning time of 80 ns, the observation depth was about 12.5 feet (3.81 m).

The depth of observation ranged from about 17 to 150 inches. Because of the strong reflected signal from the soil surface, features within a depth of 17 inches of the soil surface were poorly or not resolved with the 120 mHz antenna. Because of the restricted scanning time, features at depths greater than 150 inches were beyond the maximum observation depth.

During the course of this study, at twenty-six observation sites, a soil auger was used to determine the depth to paleosol. This information was used to verify interpretations and to scale the radar profiles. The correlation between auger observations and scaled radar depths was exceptionally high. Based on 26 observations, the coefficient of determination (r^2) between the observed auger and the interpreted radar depths to the paleosol was 0.9593 (see Figure 1). The average difference in the depth to paleosol measurements between soil auger and radar measurements was 2.62 inches (with a range of 0 to 8 inches).

+ Trade names have been used to provide specific information. Their mention does not constitute endorsement.

Ground-penetrating radar techniques are not appropriate for soil investigations in many areas of Reno County. This study was restricted to map units with components of coarse and moderately-coarse textured soils. However, in these units, depths of penetration were often restricted by thick bands of lamellae or layers of coarse-loamy or finer textured soil materials. In most areas of coarse-textured soil materials, GPR was a suitable investigation and research tool and provided adequate depths of penetration and good resolution of subsurface interfaces. However, in areas of coarse-textured materials, while the depth of observation and the resolution of subsurface features were good, the number and segmented nature of the subsurface layers plagued interpretations. To properly identify each layer, a prohibitive number of auger observations would have been required. One layer, the "paleosol", was distinct and recognizable in many areas and across most radar profiles.

The "paleosol" was defined as the lowest layer which limited the observation depth of the radar. Generally, this layer consisted of sandy loam or finer textured materials. Below this layer, no imagery was observed because of the high rates of signal attenuation. The paleosol appeared continuous on most radar profiles. However, in some areas, this layer was discontinuous. In addition, auger observations taken along the same transect line, confirmed that the texture of this layer can grade laterally.

The radar profiles contained numerous, segmented layers above the paleosols. These layers were assumed to represent stratified sand layers, buried A horizons, lamellae, or the water table. However, as ground-truth auger observations were limited, the identity of most of these layers could not be confirmed.

The map units, transect lengths, and locations are listed in Table 1. Ground-penetrating radar data were collected along eighty-five transect lines which ranged in length from 100 to 5400 feet. Several transects were omitted from this study because of limited profiling depths or the poor resolution of subsurface interfaces.

Results:
Transects were completed with the following map units: Ax - Hayes-Solvay complex, 0 to 5 percent slopes; Dp - Dillhut-Plev complex, 0 to 2 percent slopes; Ds - Dillhut-Solvay complex, 0 to 3 percent slopes; Dt - Dillwyn-Tivoli fine sands, 0 to 15 percent slopes; Pr - Pratt loamy fine sand, 1 to 5 percent slopes; Pt - Turon-Solvay-Carwile complex, 0 to 5 percent slopes; Px - Langdon-Tivoli fine sands, 0 to 15 percent slopes; and Tf - Tivoli fine sand 10 to 30 percent slopes. Table 2 summarizes the transect data for each map unit. Data from each transect are listed in the Addendum to this report.

Table 2 conveys comparative information but the use of averages and ranges is statistically inappropriate. The use of these statistics is incorrect as the minimum and maximum observation depths were 17 and 150 inches, respectively. Regardless of actual depths, because of the limitations of the equipment and the constraints of the survey, paleosols occurring at depths of less than 17 inches or greater than 150 inches were recorded as 17 and 150 inches, respectively.

In areas of the Hayes-Solvay complex, 0 to 5 percent slopes (map unit Ax), the average depth to the paleosol was 38.7 inches. One-half the observations had depths to paleosol between 33 and 42 inches. In the transected area of this map unit, depths to the paleosol were shallow

Table 1

LOCATION OF GPR TRANSECTS

Number	Symbol	Length (feet)	Location
1A	DT	900	SW1/4 SEC 11, T. 22 S., R. 6 W.
1	DP	1700	SW1/4 SEC 11, T. 22 S., R. 6 W.
2	DT	1100	S 1/2 SEC 11, T. 22 S., R. 6 W.
3	DT	1200	S 1/2 SEC 11, T. 22 S., R. 6 W.
4	TF	300	SE1/4 SEC 11, T. 22 S., R. 6 W.
5	DT	600	SE1/4 SEC 11, T. 22 S., R. 6 W.
6	DP	600	SE1/4 SEC 11, T. 22 S., R. 6 W.
7	DP	2400	SE1/4 SEC 5, T. 22 S., R. 5 W.
8	PR	100	SE1/4 SEC 5, T. 22 S., R. 5 W.
9	DP	2600	SE1/4 SEC 5, T. 22 S., R. 5 W.
10	DT	2500	NW1/4 SEC 5, T. 22 S., R. 5 W.
11	DS	2600	SW1/4 SEC 10, T. 22 S., R. 6 W.
12	PR	2500	S 1/2 SEC 15, T. 22 S., R. 5 W.
13	DT	2600	NW1/4 SEC 14, T. 22 S., R. 5 W.
14	DT	2100	SW1/4 SEC 13, T. 22 S., R. 5 W.
15	DT	2800	S 1/2 SEC 13, T. 22 S., R. 5 W.
16	PR	800	NW1/4 SEC 19, T. 22 S., R. 5 W.
17	DT	1900	NW1/4 SEC 19, T. 22 S., R. 5 W.
18	DT	3100	NE1/4 SEC 19, T. 22 S., R. 5 W.
19	TF	200	SW1/4 SEC 21, T. 22 S., R. 5 W.
20	DT	1000	SW1/4 SEC 21, T. 22 S., R. 5 W.
21	DP	1200	SW1/4 SEC 21, T. 22 S., R. 5 W.
22	DT	700	SW1/4 SEC 21, T. 22 S., R. 5 W.
23	DP	400	NE1/4 SEC 21, T. 22 S., R. 5 W.
24	TF	400	NE1/4 SEC 21, T. 22 S., R. 5 W.
25	DT	300	SW1/4 SEC 22, T. 22 S., R. 5 W.
26	DS	1000	SE1/4 SEC 22, T. 22 S., R. 5 W.
27	DT	900	SE1/4 SEC 22, T. 22 S., R. 5 W.
28	TF	300	SE1/4 SEC 22, T. 22 S., R. 5 W.
29	DS	200	SE1/4 SEC 22, T. 22 S., R. 5 W.
30	TF	100	SE1/4 SEC 22, T. 22 S., R. 5 W.
31	DS	100	SE1/4 SEC 22, T. 22 S., R. 5 W.
32	DP	1300	SW1/4 SEC 19, T. 22 S., R. 4 W.
33	PR	300	SW1/4 SEC 19, T. 22 S., R. 4 W.
34	DS	400	SW1/4 SEC 19, T. 22 S., R. 4 W.
35	DS	1100	SE1/4 SEC 24, T. 22 S., R. 5 W.
36	DT	1200	SE1/4 SEC 24, T. 22 S., R. 5 W.
37	DS*	1600	SW1/4 SEC 24, T. 22 S., R. 5 W.
38	DS	1200	SW1/4 SEC 30, T. 22 S., R. 4 W.
39	PT	2000	SE1/4 SEC 30, T. 22 S., R. 4 W.
40	DS	1100	SW1/4 SEC 28, T. 22 S., R. 4 W.
41	DS	1200	NW1/4 SEC 1, T. 23 S., R. 4 W.

* May contain more than one map unit.

Table 1 (continued)

LOCATION OF GPR TRANSECTS

Number	Symbol	Length (feet)	Location
42	DT	1100	NW1/4 SEC 1, T. 23 S., R. 4 W.
43	DS	1700	NE1/4 SEC 1, T. 23 S., R. 4 W.
44	DS	1500	NE1/4 SEC 11, T. 23 S., R. 4 W.
45	DT	4800	S 1/2 SEC 11, T. 23 S., R. 4 W.
46	DS	1500	NE1/4 SEC 14, T. 23 S., R. 4 W.
47	DS	2300	NE1/4 SEC 13, T. 23 S., R. 4 W.
48	DT	3600	N 1/2 SEC 7, T. 23 S., R. 4 W.
49	DT	800	SW1/4 SEC 1, T. 23 S., R. 5 W.
50	DS	900	SW1/4 SEC 1, T. 23 S., R. 5 W.
51	DT	1600	SW1/4 SEC 1, T. 23 S., R. 5 W.
52	TF	1400	SW1/4 SEC 1, T. 23 S., R. 5 W.
53	DS	1000	NW1/4 SEC 4, T. 23 S., R. 4 W.
54	DT	1300	NE1/4 SEC 4, T. 23 S., R. 4 W.
55	DT	1500	SW1/4 SEC 9, T. 23 S., R. 4 W.
56	TF	800	SW1/4 SEC 9, T. 23 S., R. 4 W.
57	DT	1100	SW1/4 SEC 9, T. 23 S., R. 4 W.
58	DS	2700	NE1/4 SEC 17, T. 23 S., R. 4 W.
59	DS	1700	SW1/4 SEC 17, T. 23 S., R. 4 W.
60	DS	3400	SE1/4 SEC 18, T. 23 S., R. 4 W.
61	DS*	3900	S 1/2 SEC 20, T. 22 S., R. 10 W.
62	DT	5400	S 1/2 SEC 21, T. 22 S., R. 10 W.
63	DT	1600	SW1/4 SEC 8, T. 22 S., R. 10 W.
64	DS	1200	SE1/4 SEC 8, T. 22 S., R. 10 W.
65	TF	1500	SE1/4 SEC 8, T. 22 S., R. 10 W.
66	DS	1400	SW1/4 SEC 5, T. 22 S., R. 10 W.
67	DT	500	SW1/4 SEC 5, T. 22 S., R. 10 W.
68	DT	1400	NE1/4 SEC 5, T. 22 S., R. 10 W.
69	TF	500	NE1/4 SEC 5, T. 22 S., R. 10 W.
70	DS	1000	NE1/4 SEC 5, T. 22 S., R. 10 W.
71	DT	800	NE1/4 SEC 5, T. 22 S., R. 10 W.
72	DS	300	NE1/4 SEC 5, T. 22 S., R. 10 W.
73	DT	1300	NE1/4 SEC 5, T. 22 S., R. 10 W.
74	PX	3900	N 1/2 SEC 8, T. 24 S., R. 10 W.
75	PR	500	NW1/4 SEC 8, T. 24 S., R. 10 W.
76	PX	300	NE1/4 SEC 3, T. 24 S., R. 9 W.
77	PT	1100	NE1/4 SEC 3, T. 24 S., R. 9 W.
78	PX	600	NE1/4 SEC 3, T. 24 S., R. 9 W.
79	PT	1200	N 1/2 SEC 3, T. 24 S., R. 9 W.
80	AX	1400	NW1/4 SEC 3, T. 24 S., R. 9 W.
81	PX	2400	NW1/4 SEC 11, T. 24 S., R. 9 W.
82	PX	2100	N 1/2 SEC 7, T. 25 S., R. 9 W.
83	PX	1900	NE1/4 SEC 13, T. 25 S., R. 9 W.
84	PX	3400	N 1/2 SEC 13, T. 25 S., R. 10 W.
85	PX	1200	SW1/4 SEC 10, T. 25 S., R. 10 W.

at 7 percent, moderately deep at 67 percent, deep at 20 percent, and very deep at 6 percent of the observation points (see Figure 2, upper).

In areas of the Dillhut-Plev complex, 0 to 2 percent slopes (map unit Dp), the average depth to the paleosol was 28.9 inches. One-half the observations had depths to paleosol between 17 and 34 inches. In the transected area of this map unit, depths to the paleosol were shallow at 52 percent, moderately deep at 30 percent, deep at 11 percent, and very deep at 7 percent of the observation points (see Figure 2, lower).

Table 2

GPR TRANSECTS

				Depth to Paleosol (in inches)		
Map Unit	Number	Observations	Length(ft)	Min.	Max.	Avg.
Ax	1	15	1400	17	91	38.7
Dp	6	102	9600	13	136	28.9
Ds	24	374	35000	17	150	45.3
Dt	30	531	49000	17	150	64.3
Pr	5	47	4200	15	76	38.9
Pt	3	46	4300	17	65	31.0
Px	8	165	15700	17	150	49.8
Tf	7	57	5000	17	150	87.5

In areas of the Dillhut-Solvay complex, 0 to 3 percent slopes (map unit Ds), the average depth to the paleosol was 45.3 inches. One-half the observations had depths to paleosol between 22 and 62 inches. In the transected area of this map unit, depths to the paleosol were shallow at 21 percent, moderately deep at 37 percent, deep at 16 percent, and very deep at 26 percent of the observation points (see Figure 3, upper).

In areas of the Dillwyn-Tivoli fine sands, 0 to 15 percent slopes (map unit Dt), the average depth to the paleosol was 64.3 inches. One-half the observations had depths to paleosol between 29 and 86 inches. In the transected area of this map unit, depths to paleosol were shallow at 14 percent, moderately deep at 23 percent, deep at 17 percent, and very deep at 46 percent of the observation points (see Figure 3, lower).

In areas of Pratt loamy fine sand, 1 to 5 percent slopes (map unit Pr), the average depth to the paleosol was 38.9 inches. One-half the observations had depths to paleosol between 26 and 51 inches. In the transected area of this map unit, depths to paleosol were shallow at 17 percent, moderately deep at 43 percent, deep at 26 percent, and very deep at 14 percent of the observation points (see Figure 4, upper).

In areas of the Turon-Solvay-Carwile complex, 0 to 5 percent slopes (map unit Pt), the average depth to the paleosol was 31.0 inches. One-half the observations had depths to paleosol between 17 and 38

inches. In the transected area of this map unit, depths to paleosol were shallow at 33 percent, moderately deep at 43 percent, deep at 20 percent, and very deep at 4 percent of the observation points (see Figure 4, lower).

In areas of Langdon-Tivoli fine sands, 0 to 15 percent slopes (map unit Px), the average depth to the paleosol was 49.8 inches. One-half the observations had depths to paleosol between 17 and 64 inches. In the transected area of this map unit, depths to paleosol were shallow at 27 percent, moderately deep at 22 percent, deep at 22 percent, and very deep at 29 percent of the observation points (see Figure 5, upper).

In areas of the Tivoli fine sand, 10 to 30 percent slopes (map unit Tf), the average depth to the paleosol was 87.5 inches. One-half the observations had depths to paleosol between 55 and 123 inches. In the transected area of this map unit, depths to paleosol were shallow at 2 percent, moderately deep at 12 percent, deep at 14 percent, and very deep at 72 percent of the observation points (see Figure 5, lower).

Systematic Sampling with EM Techniques

Introduction:

One of the most common uses for electromagnetic induction (EM) techniques has been to assess soil salinity (2, 3, 4, 5, 16, 17, 19) and sodicity (1). These techniques, however, have also been used to map bedrock surfaces (21), glacial deposits (20, 15), and permafrost (18, 9); estimate thicknesses of clays (14) or sand and gravel deposits (13); measure soil water content (11); and evaluate edaphic properties important to forest site productivity (12). These studies have documented some of the advantages of using EM interpretations and its applications over broad areas and soil types.

Electromagnetic induction techniques are a non-invasive geophysical method in which electromagnetic energy is used to measure the apparent conductivity of earthen materials. Apparent conductivity is the weighted average conductivity measurement for a column of earthen materials to a specified investigation depth (6). The averages are weighted according to the depth response function of the meter (19). Values of apparent conductivity are expressed in milliSiemens per meter (mS/m).

Apparent conductivity values are seldom diagnostic in themselves. However, lateral and vertical variations in these measurements can be used to infer changes in soils and soil properties. Electromagnetic responses are dependent on soil properties. Variations in electromagnetic responses are produced by changes in soil moisture, salt content, texture, and mineralogy (2). In nonsaline areas, soil texture, mineralogy, and moisture are the principal factors determining apparent conductivity (11). Each of these factors will affect the apparent conductivity of soils.

Soils and soil map units can be differentiated by characteristic ranges of apparent conductivity (7, 8). As EM measurements integrate several soil properties, responses can be correlated within geographic areas to soil types. Generally, in geophysical research, the term "soil type" has been used to refer to the particle-size class of unconsolidated sediments. Zalasiewicz and Mathers (20) used

EM techniques to map glacial sediments and distinguish areas of bouldery clays from arenaceous deposits. Sartorelli and French (18) defined grouping of the Unified Soil Classification System based on characteristic apparent conductivity values. Kingston (10) used EM techniques to distinguish and map soil and geologic deposits and strata. In these studies different "soil types" and lithologies induced distinct and characteristic EM responses.

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. This method has 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. volumetric moisture, soluble salt content, clay content, soil depth, or mineralogy).

Each soil will have a characteristic EM response. For a particular soil, the EM response will constitute 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 in EM responses. Within a given geographic area, the conductivities of some soils will overlap. Soil properties and types can be inferred with EM techniques provided one is cognizant of changes in parent materials, drainage, topography, and vegetation.

Area of Langdon-Tivoli fine sands, 0 to 15 percent slopes.

Study Area:

The study site consisted of 3.2 acres of rangeland in southwestern Reno County, Kansas. Relief was about 10.6 feet. The area consists of several low mounds and ridges of windblown sands. Most areas are nearly level to rolling. The study site was bounded on the south by a fence line and road.

The topography of study site has been simulated in Figures 6 and 7. Figure 6 is a two-dimensional contour plot and Figure 7 is a three-dimensional surface net diagram of the ground surface. In Figure 6, the contour interval is 1.0 foot. The line of spot symbols appearing in Figure 6 represents the location of a radar traverse. In Figure 7, the vertical exaggeration is 10.

The study sites contains an intricate pattern of soils. Soils identified within the study site include Langdon (mixed, thermic Argic Ustipsamment), Tivoli (mixed, thermic Typic Ustipsamment), and Turon (sandy, mixed, thermic Psammentic Haplustalf).

Within the study site, at the time of this investigation, it was presumed that variations in the electromagnetic response would be directly related to changes in the depth to paleosol or lamellae. It was assumed that EM responses would be lower in areas of Tivoli and Langdon soils than in areas of Turon soil. In areas of soils with similar particle-size distributions, variations in the EM response would be highly influenced by differences in the volumetric moisture contents, and the presence, thickness, and arrangement of lamellae and soil horizons.

Field Methods:
A 400 by 350 foot rectangular grid was established across the study site. Survey flags were inserted in the ground at 50 foot intervals. At each of the 72 grid intersections, measurements were obtained with an EM38 meter in both the horizontal and vertical dipole orientations.

A transit was used to establish grid lines and determine the surface elevation of each grid intersection. Elevations were not tied to a benchmark; the lowest recorded surface point was chosen as the 0.0 foot datum.

Results:
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 site.

Figures 8 and 9 represent two-dimensional isarithmic maps prepared from data collected with the EM38 meter in the horizontal and the vertical dipole orientations, respectively. The horizontal measurements integrates electromagnetic conductivity within the 0 to 0.75 m; the vertical measurements integrates values within the 0 to 1.5 m. At all observation points, values of apparent conductivity increased with increasing depth (horizontal dipole measurements < vertical dipole orientation). This relationship was believed to reflect increasing clay and volumetric moisture content with increasing soil depth.

Values of apparent conductivity were highest in the swales. These areas were inferred to have soils with higher clay contents (shallower depths to paleosol) and/or greater volumetric moisture contents. Values of apparent conductivity were lowest on the summits of dunes were the clay and volumetric moisture contents were lower. Intermediate values occurred on sideslopes.

A preliminary assessment of EM values was made in the field for the purpose of locating sampling sites. Based on this assessment, 5 observation points were selected and described. Table 3 list the soils and their averaged apparent conductivity values. Some soils can be differentiated by a characteristic range of apparent conductivity values. In Table 3, each soil appears to have a fairly unique EM response.

Table 3

EM38 TRANSECT DATA
AVERAGE APPARENT CONDUCTIVITY
(in mS/m)

Soil	# Observations	EMH	EMV
Langdon	1	4.0	7.0
Tivoli	2	2.0	5.0
Turon	2	7.5	15.0

Using EM responses, the distribution of soils described at the five observation points was extended to other portions of the survey site.

Measurements taken with the EM38 meter in the vertical dipole orientation were used to prepare a soil map (Figure 10). Observation points with low (< 6 mS/m), intermediate (6 to 11 mS/m), and high (>11 mS/m) EM responses were identified as Tivoli, Langdon, and Turon soils, respectively.

A radar traverse was completed along the grid line identified by the spot symbols in figures 6, 8, and 9. The enclosed radar profile is from this grid line. It has been processed through RADAN software. The profile has been normalized, terrain corrected, and the color tables and values have been transformed.

The numbers appearing at the top of the radar profile represent distances (in feet) and grid intersections. A paleosol (P) is evident beneath the dune in the left-hand portion of the radar profile. This layer varies in depth from about 3.0 feet in a swale near the 400 foot mark to about 7.5 feet on the summit of the dune near the 300 foot mark. Depths to this interface are moderately deep between the 150 and 50 foot marks. The strong and reverberated signals beneath "M" in the left-hand portion of the radar profile were produced by a buried metallic object.

Area of Tabler-Punkin complex.

Survey Area:
The study site consisted of about 3.6 acres of cropland in northeastern Reno County, Kansas. Relief was about 1.4 feet. The study site was bounded on the north by a road. Tabler is a member of the fine, montmorillonitic, thermic Udertic Argiustoll family. The proposed Punkin soil is a member of the fine, mixed, thermic Aquic Natrustoll family.

Field Methods:
A 350 by 450 foot rectangular grid was established across the study site. Survey flags were inserted in the ground at 50 foot intervals. At each of the 80 grid intersections, measurements were obtained with an EM38 meter 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 a benchmark; the lowest recorded surface point was chosen as the 0.0 foot datum.

Results:
The topography of study site has been simulated in Figures 11 and 12. Figure 11 is a two-dimensional contour plot and Figure 12 is a three-dimensional surface net diagram of the ground surface. In Figure 11, the contour interval is 0.2 foot. In Figure 12, the vertical exaggeration is 20. This scale and vertical exaggeration were needed to express an old field-boundary line in the south-central portion of the study area.

Figures 13 and 14 represent two dimensional plots of apparent conductivity values collected in the horizontal and vertical dipole orientations, respectively. In each figure, the interval is 10 mS/m.

For all but five observation points, EM response increased with increasing soil depth (response in the vertical greater than in the

conductive materials (i.e. greater clay, soluble salt, and/or water contents) with increasing soil depth. The reverse relationship at several observation points was attributed to high concentrations of soluble salts near the soil surface.

In both plots, EM responses appear to be highly variable across the site. Responses decreased toward the right-hand margin of each plot indicating a probable reduction in the amount of soluble salts and a change in soil type. In addition, in both plots, a noticeable linear pattern extends across the site from the northwest to the southeast corners. This feature may reflect a buried fluvial feature which exerts control over the soils.

Electromagnetic responses were relatively high across this site. Based on 80 observations, the average apparent conductivity was 103 mS/m, with a range of 27 to 180 mS/m in the horizontal mode. One-half of the observations collected in the horizontal dipole orientation had apparent conductivity values between 72 and 129 mS/m. The average apparent conductivity was 127 mS/m, with a range of 42 to 211 mS/m in the vertical mode. One-half of the observations collected in the vertical dipole orientation had apparent conductivity values between 96 and 158 mS/m.

Conclusions:

1. Ground-penetrating radar techniques are not appropriate for use in many soils of Reno County. Depths of penetration were restricted by thick bands of lamellae or layers of coarse-loamy or finer textured soil materials. In areas of coarse-textured soil materials, GPR was a suitable tool and provided adequate depths of penetration and good resolution of subsurface interfaces. However, in many areas of coarse-textured materials, while the depth of observation and resolution of GPR was good, the large number and segmented nature of subsurface layers plagued interpretations. To properly identify each layer, a prohibitive number of auger observations would have been required. One layer, the "paleosol", was distinct and recognizable across most radar profiles. Ground-penetrating radar techniques were used to characterize the depth to "paleosols" across extensive areas and several map units.

2. Continuous or discrete sampling with EM meters along transect lines can be used to detect variations in soils and soil properties. This tool can be used to provide objective description of soils, evaluate "modal" soil conditions, locate some map unit boundaries, and identify sites for more detailed observations. In Reno County, the EM38 meter appears to be a useful tool for assessing sodium-affected soils and map units. All participants received training and exposure to the uses of the EM38 meter. The NSSC has loaned an EM38 meter (serial number 8906008) to the survey party for the period of 1 August to 1 November 1994.

3. Isarithmic maps prepared from EM data can provide a graphic description of variations in soils and/or soil properties within selected map units. I encourage the soil survey party to avail themselves to these techniques.

It was my pleasure to work with and assist the soil scientists of Reno County.

With kind regards

James A. Doolittle
Soil Specialist

cc:
James Culver, National Leader, SSQAS, NSSC, SCS, Lincoln, NE
Paul Finnell, Assistant State Soil Scientist, SCS, Salina, KS
Steve Holzhey, National Leader, SSQAS, NSSC, SCS, Lincoln, NE
Robert Murphy, Soil Party Leader, SCS, Hutchinson Area Office,
West 28th Street, Suite B, Hutchinson, KS, 67502

REFERENCES

1. Ammons, J. T., M. E. Timpson, and D. L. Newton. 1989. Application of aboveground electromagnetic conductivity meter to separate Natraqualfs and Ochraqualfs in Gibson County, Tennessee. Soil Survey Horizons 30(3):66-70.

2. Cook, P. G. and G. R. Walker. 1992. Depth profiles of electrical conductivity from linear combinations of electromagnetic induction measurements. Soil Sci. Soc. Am. J. 56:1015-1022.

3. Corwin, D. L., and J. D. Rhoades. 1982. An improved technique for determining soil electrical conductivity-depth relations from above-ground electromagnetic measurements. Soil Sci. Soc. Am. J. 46:517-520.

4. Corwin, D. L., and J. D. Rhoades. 1984. Measurements of inverted electrical conductivity profiles using electromagnetic induction. Soil Sci. Soc. Am. J. 48:288-291.

5. Corwin, D. L., and J. D. Rhoades. 1990. Establishing soil electrical conductivity - depth relations from electromagnetic induction measurements. Communications in Soil Sci. Plant Anal. 21(11&12):861-901.

6. 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.

7. 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.

8. Jaynes, D. B., T. S. Colvin, J. Ambuel. 1993. Soil Type and crop yield determination from ground conductivity surveys. 1993 International Meeting of American Society of Agricultural Engineers. Paper No. 933552. ASAE, St. Joseph, MI. pp. 6.

9. Kawasaki, K. and T. E. Osterkamp. 1988. Mapping shallow permafrost by electromagnetic induction - practical considerations. Cold Region Science and Technology 15: 279-288.

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

11. Kachanoski, R. G., E. G. Gregorich, and I. J. Van Wesenbeeck. 1988. Estimating spatial variations of soil water content using noncontacting electromagnetic inductive methods. Can. J. Soil Sci. 68:715-722.

12. McBride, R. A., A. M. Gordon, and S. C. Shrive. 1990. Estimating forest soil quality from terrain measurements of apparent electrical conductivity. Soil Sci. Soc. Am. J., 54:290-293.

13. McNeill, J. D. 1988. Advances in electromagnetic methods for groundwater studies. Geonics Ltd. Mississauga, Canada.

14. Palacky, G. J. 1987. Clay mapping using electromagnetic methods. First Break 5(8):295-306.

15. Palacky, G. J. and L. E. Stephens. 1990. Mapping of Quaternary sediments in northeastern Ontario using ground electromagnetic methods. Geophysics 55(12):1596-1604.

16. Rhoades, J. D. and D. L. Corwin. 1981. Determining soil electrical conductivity-depth relations using an inductive electromagnetic soil conductivity meter. Soil Sci. Soc. Am. J. 45:255-260.

17. Rhoades, J. D., N. A. Manteghi, P. J. Shouse, and W. J. Alves. 1989. Soil Electrical conductivity and soil salinity: new formulation and calibrations. Soil Sci. Soc. Am. J. 53:433-439.

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

19. Wollenhaupt, N. C., J. L. Richardson, J. E. Foss, and E. C. Doll. 1986. A rapid method for estimating weighted soil salinity from apparent soil electrical conductivity measured with an aboveground electromagnetic induction meter. Can J. Soil Sci. 66:315-321.

20. 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).

21. Zalasiewicz, J. A., S. J. Mathers, and J. D. Cornwell. 1985. The application of ground conductivity measurements to geological mapping. Q. J. English Geol. London 18:139-148.

ADDENDUM

Transect data on the depth to paleosol collected with GPR in Reno County, Kansas:

TRANSECT 1A
MU: DT

DISTANCE	DEPTH
0′	79"
100	79
200	74
300	68
400	56
500	57
600	28
700	29
800	28
900	29

TRANSECT 1
MU: DP

DISTANCE	DEPTH
0′	54"
100	58
200	57
300	44
400	62
500	57
600	40
700	37
800	46
900	36
1000	37
1100	31
1200	32
1300	35
1400	17
1500	27
1600	29
1700	34

TRANSECT 2
MU: DT

DISTANCE	DEPTH
0′	36"
100	34
200	32
300	33
400	34
500	74
600	36
700	34
800	40
900	83
1000	19
1100	96

TRANSECT 3
MU: DT

DISTANCE	DEPTH
0′	45"
100	54
200	45
300	27
400	45
500	17
600	17
700	40
800	45
900	31
1000	17
1100	24
1200	17

TRANSECT 4
MU: TF

DISTANCE	DEPTH
0′	26"
100	92
200	106
300	70

TRANSECT 5
MU: DT

DISTANCE	DEPTH
0′	80"
100	27
200	34
300	17
400	17
500	28
600	62

TRANSECT 6
MU: DT

DISTANCE	DEPTH
0′	23"
100	17
200	17
300	17
400	17
500	17
600	35

TRANSECT 7
MU: DP

DISTANCE	DEPTH
0′	34"
100	33
200	17
300	17
400	17
500	17
600	25
700	24
800	25
900	26
1000	17
1100	17
1200	17
1300	17
1400	17
1500	17
1600	17
1700	17
1800	17
1900	17
2000	17
2100	17
2200	41
2300	25
2400	13

TRANSECT 8
MU: PR

DISTANCE	DEPTH
0′	26"
100	15

TRANSECT 9
MU: DP

DISTANCE	DEPTH
0′	17"
100	17
200	17
300	17
400	17
500	17
600	17
700	17
800	56
900	73
1000	49
1100	17
1200	17
1300	17
1400	17
1500	17
1600	17
1700	17
1800	17
1900	17
2000	41
2100	29
2200	34
2300	25
2400	17
2500	17
2600	17

TRANSECT 10
MU: DT

DISTANCE	DEPTH
0′	25"
100	54
200	54
300	32
400	19
500	31
600	28
700	17
800	17
900	17
1000	17
1100	17
1200	17
1300	20
1400	49
1500	25
1600	19
1700	29
1800	32
1900	17
2000	17
2100	35
2200	17
2300	27
2400	27
2500	34

TRANSECT 11
MU: DS

DISTANCE	DEPTH
0′	17"
100	17
200	17
300	17
400	17
500	17
600	17
700	17
800	17
900	17
1000	19
1100	37
1200	68
1300	118
1400	35
1500	34
1600	18
1700	69
1800	32
1900	31
2000	45
2100	17
2200	17
2300	17
2400	17
2500	36
2600	35

TRANSECT 12
MU: PR

DISTANCE	DEPTH
0′	17"
100	17
200	37
300	59
400	75
500	65
600	76
700	70
800	42
900	45
1000	49
1100	28
1200	62
1300	51
1400	31
1500	32
1600	17
1700	37
1800	40
1900	17
2000	27
2100	23
2200	17
2300	34
2400	32
2500	32

TRANSECT 13
MU: DT

DISTANCE	DEPTH
0′	28"
100	37
200	28
300	37
400	37
500	33
600	17
700	31
800	17
900	17
1000	37
1100	43
1200	17
1300	17
1400	80
1500	80
1600	80
1700	80
1800	80
1900	84
2000	52
2100	41
2200	41
2300	28
2400	34
2500	52
2600	68

TRANSECT 14
MU: DT

DISTANCE	DEPTH
0′	17"
100	25
200	35
300	23
400	34
500	52
600	71
700	53
800	29
900	17
1000	17
1100	17
1200	51
1300	62
1400	51
1500	52
1600	45
1700	34
1800	38
1900	39
2000	45
2100	67

TRANSECT 15
MU: DT

DISTANCE	DEPTH
0′	37"
100	28
200	26
300	34
400	17
500	36
600	56
700	77
800	95
900	69
1000	60
1100	56
1200	51
1300	46
1400	41
1500	49
1600	69
1700	40
1800	34
1900	27
2000	24
2100	31
2200	17
2300	17
2400	17
2500	26
2600	17
2700	72
2800	45

TRANSECT 16
MU: PR

DISTANCE	DEPTH
0′	32"
100	25
200	29
300	18
400	23
500	33
600	51
700	61
800	58

TRANSECT 17
MU: DT

DISTANCE	DEPTH
0′	71"
100	91
200	90
300	42
400	43
500	77
600	34
700	50
800	28
900	17
1000	100
1100	121
1200	72
1300	67
1400	127
1500	104
1600	51
1700	91
1800	82
1900	40

TRANSECT 18
MU: DT

DISTANCE	DEPTH
0′	54"
100	85
200	73
300	68
400	50
500	68
600	60
700	57
800	72
900	79
1000	34
1100	20
1200	56
1300	99
1400	17
1500	43
1600	91
1700	29
1800	17
1900	63
2000	134
2100	85
2200	17
2300	105
2400	100
2500	38
2600	150
2700	150
2800	150
2900	150
3000	150
3100	77

TRANSECT 19
MU: TF

DISTANCE	DEPTH
0′	34"
100	79
200	48

TRANSECT 20
MU: DT

DISTANCE	DEPTH
0′	33"
100	18
200	17
300	75
400	36
500	29
600	17
700	17
800	17
900	17
1000	17

TRANSECT 21
MU: DP

DISTANCE	DEPTH
0′	23"
100	29
200	21
300	29
400	17
500	17
600	17
700	18
800	26
900	34
1000	32
1100	31
1200	63

TRANSECT 22
MU: DT

DISTANCE	DEPTH
0′	65"
100	120
200	150
300	150
400	150
500	150
600	88
700	116

TRANSECT 23
MU: DP

DISTANCE	DEPTH
0′	57"
100	76
200	69
300	136
400	85

TRANSECT 24
MU: TF

DISTANCE	DEPTH
0′	68"
100	87
200	150
300	150
400	104

TRANSECT 25
MU: DT

DISTANCE	DEPTH
0′	28"
100	37
200	93
300	94

TRANSECT 26
MU: DS

DISTANCE	DEPTH
0′	84"
100	85
200	83
300	48
400	70
500	54
600	36
700	36
800	37
900	32
1000	63

TRANSECT 27
MU: DT

DISTANCE	DEPTH
0′	46"
100	93
200	127
300	150
400	150
500	150
600	150
700	136
800	150
900	88

TRANSECT 28
MU: TF

DISTANCE	DEPTH
0′	120"
100	150
200	138
300	130

TRANSECT 29
MU: DS

DISTANCE	DEPTH
0′	150"
100	150
200	150

TRANSECT 27
MU: DT

DISTANCE	DEPTH
0′	46"
100	93
200	127
300	150
400	150
500	150
600	150
700	136
800	150
900	88

TRANSECT 28
MU: TF

DISTANCE	DEPTH
0′	120"
100	150
200	138
300	130

TRANSECT 29
MU: DS

DISTANCE	DEPTH
0′	150"
100	150
200	150

TRANSECT 30
MU: TF

DISTANCE	DEPTH
0′	84"
100	119

TRANSECT 31
MU: DS

DISTANCE	DEPTH
0′	135"
100	123

TRANSECT 32
MU: DP

DISTANCE	DEPTH
0′	17"
100	29
200	18
300	29
400	25
500	17
600	17
700	17
800	17
900	17
1000	17
1100	17
1200	17
1300	17

TRANSECT 33
MU: PR

DISTANCE	DEPTH
0′	48"
100	52
200	61
300	41

TRANSECT 34
MU: DS

DISTANCE	DEPTH
0′	33"
100	20
200	18
300	21
400	32

TRANSECT 35
MU: DS

DISTANCE	DEPTH
0′	26"
100	17
200	17
300	17
400	17
500	17
600	17
700	17
800	21
900	25
1000	28
1100	32

TRANSECT 36
MU: DT

DISTANCE	DEPTH
0′	44"
100	57
200	24
300	29
400	29
500	41
600	49
700	91
800	37
900	79
1000	49
1100	117
1200	43

TRANSECT 37
MU: DS

DISTANCE	DEPTH
0′	25"
100	36
200	23
300	18
400	17
500	17
600	44
700	17
800	41
900	57
1000	28
1100	40
1200	43
1300	33
1400	57
1500	85
1600	87

TRANSECT 38
MU: DS

DISTANCE	DEPTH
0′	23"
100	20
200	17
300	23
400	28
500	43
600	17
700	17
800	17
900	23
1000	54
1100	54
1200	37

TRANSECT 39
MU: PT

DISTANCE	DEPTH
0′	42"
100	50
200	42
300	39
400	17
500	17
600	17
700	37
800	17
900	17
1000	17
1100	22
1200	29
1300	28
1400	34
1500	36
1600	27
1700	43
1800	36
1900	33
2000	48

TRANSECT 40
MU: DS

DISTANCE	DEPTH
0′	24"
100	23
200	25
300	23
400	25
500	23
600	22
700	24
800	29
900	28
1000	32
1100	25

TRANSECT 41
MU: DS

DISTANCE	DEPTH
0′	53"
100	58
200	62
300	31
400	17
500	31
600	31
700	57
800	44
900	56
1000	76
1100	76
1200	44

TRANSECT 42
MU: DT

DISTANCE	DEPTH
0′	34"
100	29
200	29
300	62
400	85
500	75
600	28
700	28
800	28
900	28
1000	34
1100	36

TRANSECT 43
MU: DS

DISTANCE	DEPTH
0′	45"
100	48
200	42
300	59
400	61
500	77
600	91
700	75
800	71
900	84
1000	52
1100	83
1200	91
1300	85
1400	74
1500	73
1600	94
1700	110

TRANSECT 44
MU: DS

DISTANCE	DEPTH
0′	78"
100	51
200	53
300	37
400	74
500	57
600	75
700	61
800	48
900	52
1000	62
1100	53
1200	48
1300	50
1400	28
1500	17

TRANSECT 45
MU: DT

DISTANCE	DEPTH
0′	150"
100	150
200	125
300	77
400	84
500	126
600	68
700	79
800	62
900	125
1000	119
1100	84
1200	74
1300	113
1400	91
1500	125
1600	136
1700	96
1800	35
1900	150
2000	51
2100	42
2200	150
2300	51
2400	42
2500	33
2600	39
2700	36
2800	62
2900	65
3000	108
3100	75
3200	113
3300	99
3400	49
3500	82
3600	84
3700	74
3800	65
3900	31
4000	57
4100	108
4200	82
4300	123
4400	150
4500	150
4600	86
4700	150
4800	150

TRANSECT 46
MU: DS

DISTANCE	DEPTH
0′	53"
100	32
200	34
300	28
400	35
500	32
600	28
700	49
800	92
900	49
1000	17
1100	17
1200	17
1300	47
1400	57
1500	70

TRANSECT 47
MU: DS

DISTANCE	DEPTH
0′	18"
100	23
200	21
300	21
400	24
500	23
600	22
700	26
800	20
900	42
1000	65
1100	36
1200	35
1300	21
1400	23
1500	32
1600	26
1700	24
1800	21
1900	22
2000	24
2100	23
2200	22
2300	22

TRANSECT 48
MU: DT

DISTANCE	DEPTH
0′	67"
100	96
200	66
300	77
400	46
500	53
600	49
700	37
800	45
900	45
1000	69
1100	96
1200	86
1300	113
1400	100
1500	87
1600	126
1700	62
1800	60
1900	150
2000	83
2100	70
2200	49
2300	74
2400	87
2500	59
2600	29
2700	37
2800	137
2900	57
3000	133
3100	85
3200	97
3300	150
3400	150
3500	150
3600	150

TRANSECT 49
MU: DT

DISTANCE	DEPTH
0′	23"
100	79
200	45
300	61
400	86
500	24
600	25
700	26
800	25

TRANSECT 50
MU: DS

DISTANCE	DEPTH
0′	25"
100	24
200	26
300	40
400	19
500	22
600	23
700	24
800	17
900	17

TRANSECT 51
MU: DT

DISTANCE	DEPTH
0′	29"
100	23
200	27
300	17
400	17
500	17
600	61
700	150
800	48
900	17
1000	17
1100	17
1200	17
1300	17
1400	17
1500	17
1600	20

TRANSECT 52
MU: TF

DISTANCE	DEPTH
0′	26"
100	65
200	108
300	134
400	86
500	82
600	59
700	25
800	71
900	147
1000	150
1100	150
1200	150
1300	150

TRANSECT 53
MU: DS

DISTANCE	DEPTH
0′	54"
100	37
200	49
300	150
400	150
500	150
600	91
700	64
800	91
900	46
1000	26

TRANSECT 54
MU: DT

DISTANCE	DEPTH
0′	40"
100	31
200	71
300	62
400	76
500	68
600	105
700	150
800	150
900	150
1000	130
1100	97
1200	113
1300	117

TRANSECT 55
MU: DT

DISTANCE	DEPTH
0′	54"
100	79
200	52
300	43
400	68
500	150
600	122
700	102
800	43
900	35
1000	26
1100	37
1200	49
1300	41
1400	102
1500	76

TRANSECT 56
MU: TF

DISTANCE	DEPTH
0′	74"
100	94
200	65
300	43
400	74
500	86
600	150
700	150
800	95

TRANSECT 57
MU: DT

DISTANCE	DEPTH
0′	130"
100	128
200	103
300	82
400	76
500	85
600	41
700	45
800	68
900	77
1000	45
1100	84

TRANSECT 58
MU: DS

DISTANCE	DEPTH
0′	36"
100	40
200	25
300	32
400	27
500	29
600	29
700	34
800	79
900	24
1000	26
1100	17
1200	17
1300	17
1400	17
1500	17
1600	17
1700	51
1800	27
1900	26
2000	23
2100	22
2200	66
2300	31
2400	17
2500	37
2600	17
2700	17

TRANSECT 59
MU: DS

DISTANCE	DEPTH
0′	40"
100	17
200	17
300	33
400	24
500	17
600	24
700	38
800	17
900	53
1000	27
1100	25
1200	63
1300	114
1400	78
1500	76
1600	128
1700	150

TRANSECT 60
MU: DS

DISTANCE	DEPTH
0′	68"
100	73
200	67
300	80
400	74
500	63
600	57
700	77
800	88
900	69
1000	67
1100	94
1200	88
1300	97
1400	93
1500	78
1600	71
1700	60
1800	67
1900	96
2000	150
2100	150
2200	77
2300	63
2400	31
2500	25
2600	26
2700	28
2800	17
2900	17
3000	17
3100	17
3200	17
3300	27
3400	32

TRANSECT 61
MU: DS

DISTANCE	DEPTH
0′	44"
100	22
200	31
300	23
400	17
500	17
600	74
700	42
800	21
900	36
1000	38
1100	83
1200	78
1300	80
1400	41
1500	33
1600	20
1700	28
1800	62
1900	40
2000	17
2100	26
2200	19
2300	32
2400	41
2500	28
2600	17
2700	17
2800	50
2900	17
3000	49
3100	48
3200	53
3300	85
3400	27
3500	68
3600	45
3700	62
3800	51
3900	65

TRANSECT 62
MU: DT

DISTANCE	DEPTH
0′	85"
100	65
200	68
300	56
400	108
500	150
600	150
700	150
800	150
900	150
1000	150
1100	150
1200	150
1300	150
1400	104
1500	59
1600	17
1700	31
1800	17
1900	42
2000	114
2100	150
2200	150
2300	129
2400	118
2500	82
2600	78
2700	26
2800	17
2900	28
3000	17
3100	17
3200	40
3300	29
3400	51
3500	17
3600	26
3700	32
3800	17
3900	17
4000	54
4100	58
4200	83
4300	47
4400	57
4500	42
4600	17
4700	17
4800	17
4900	62
5000	84
5100	93
5200	76
5300	150
5400	62

TRANSECT 63
MU: DT

DISTANCE	DEPTH
0′	121"
100	66
200	51
300	79
400	72
500	84
600	100
700	39
800	50
900	57
1000	96
1100	101
1200	103
1300	78
1400	88
1500	87
1600	72

TRANSECT 64
MU: DS

DISTANCE	DEPTH
0′	25"
100	17
200	27
300	29
400	29
500	17
600	17
700	17
800	32
900	17
1000	17
1100	17
1200	17

TRANSECT 65
MU: TF

DISTANCE	DEPTH
0′	68"
100	68
200	150
300	103
400	53
500	50
600	127
700	70
800	17
900	25
1000	113
1100	50
1200	80
1300	68
1400	110
1500	150

TRANSECT 66
MU: DS

DISTANCE	DEPTH
0′	46"
100	28
200	56
300	51
400	50
500	50
600	34
700	34
800	109
900	104
1000	126
1100	97
1200	126
1300	88
1400	117

TRANSECT 67
MU: DT

DISTANCE	DEPTH
0′	150"
100	91
200	78
300	97
400	70
500	87

TRANSECT 68
MU: DT

DISTANCE	DEPTH
0′	40"
100	17
200	27
300	26
400	31
500	28
600	88
700	105
800	59
900	74
1000	70

TRANSECT 69
MU: TF

DISTANCE	DEPTH
0′	28"
100	131
200	48
300	60
400	61
500	150

TRANSECT 70
MU: DS

DISTANCE	DEPTH
0′	108"
100	70
200	27
300	24
400	34
500	58
600	71
700	72
800	34
900	73
1000	101

TRANSECT 71
MU: DT

DISTANCE	DEPTH
0′	82"
100	103
200	86
300	75
400	61
500	74
600	104
700	46
800	71

TRANSECT 72
MU: DS

DISTANCE	DEPTH
0′	51"
100	34
200	17
300	54

TRANSECT 73
MU: DT

DISTANCE	DEPTH
0′	59"
100	150
200	102
300	150
400	150
500	150
600	73
700	29
800	66
900	150
1000	28
1100	51
1200	17
1300	36

TRANSECT 74
MU: PX

DISTANCE	DEPTH
0′	17"
100	31
200	17
300	17
400	23
500	32
600	17
700	41
800	80
900	80
1000	80
1100	36
1200	60
1300	40
1400	42
1500	31
1600	44
1700	31
1800	108
1900	27
2000	77
2100	17
2200	17
2300	20
2400	17
2500	34
2600	34
2700	17
2800	17
2900	33
3000	38
3100	17
3200	17
3300	41
3400	26
3500	88
3600	17
3700	38
3800	40
3900	26

TRANSECT 75
MU: PR

DISTANCE	DEPTH
0′	52"
100	35
200	17
300	52
400	37
500	31

TRANSECT 76
MU: PX

DISTANCE	DEPTH
0′	100"
100	94
200	82
300	48

TRANSECT 77
MU: PT

DISTANCE	DEPTH
0′	49"
100	51
200	23
300	17
400	28
500	27
600	20
700	57
800	28
900	34
1000	65
1100	23

TRANSECT 78
MU: PX

DISTANCE	DEPTH
0′	42"
100	79
200	42
300	35
400	99
500	54
600	31

TRANSECT 79
MU: PT

DISTANCE	DEPTH
0′	31"
100	44
200	17
300	17
400	26
500	17
600	34
700	35
800	17
900	17
1000	17
1100	17
1200	65

TRANSECT 80
MU: AX

DISTANCE	DEPTH
0′	36"
100	22
200	17
300	45
400	47
500	36
600	91
700	32
800	40
900	36
1000	34
1100	34
1200	34
1300	34
1400	43

TRANSECT 81
MU: PX

DISTANCE	DEPTH
0′	40"
100	47
200	17
300	66
400	22
500	24
600	150
700	150
800	104
900	33
1000	61
1100	34
1200	28
1300	27
1400	27
1500	27
1600	44
1700	76
1800	54
1900	45
2000	17
2100	35
2200	17
2300	36
2400	35

TRANSECT 82
MU: TX

DISTANCE	DEPTH
0′	150"
100	95
200	37
300	91
400	44
500	47
600	53
700	17
800	17
900	63
1000	17
1100	17
1200	17
1300	17
1400	17
1500	43
1600	61
1700	58
1800	17
1900	76
2000	69
2100	26

TRANSECT 83
MU: PX

DISTANCE	DEPTH
0′	17"
100	34
200	110
300	17
400	53
500	150
600	84
700	17
800	69
900	76
1000	17
1100	42
1200	150
1300	133
1400	26
1500	50
1600	71
1700	117
1800	150
1900	88

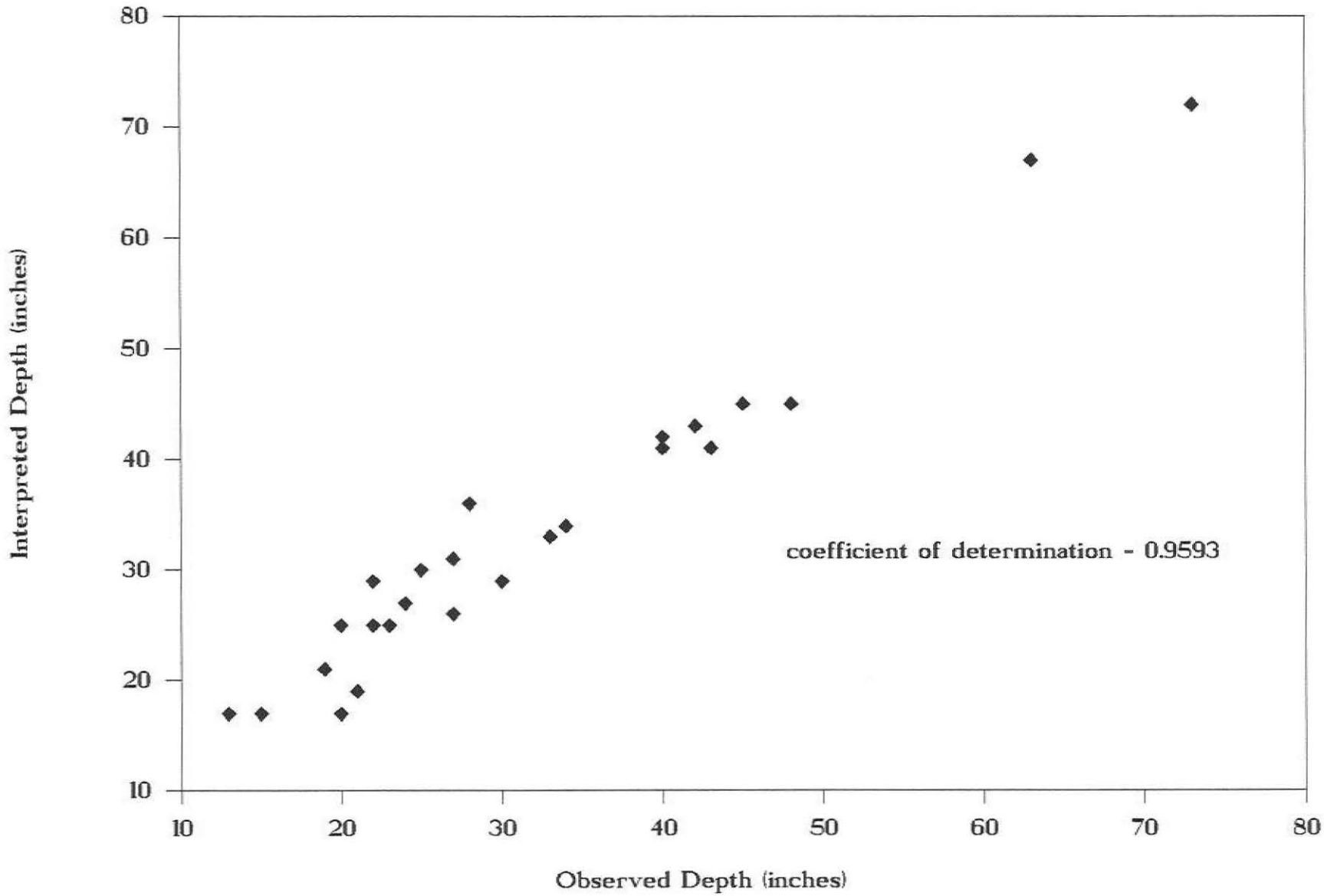
TRANSECT 84
MU: PX

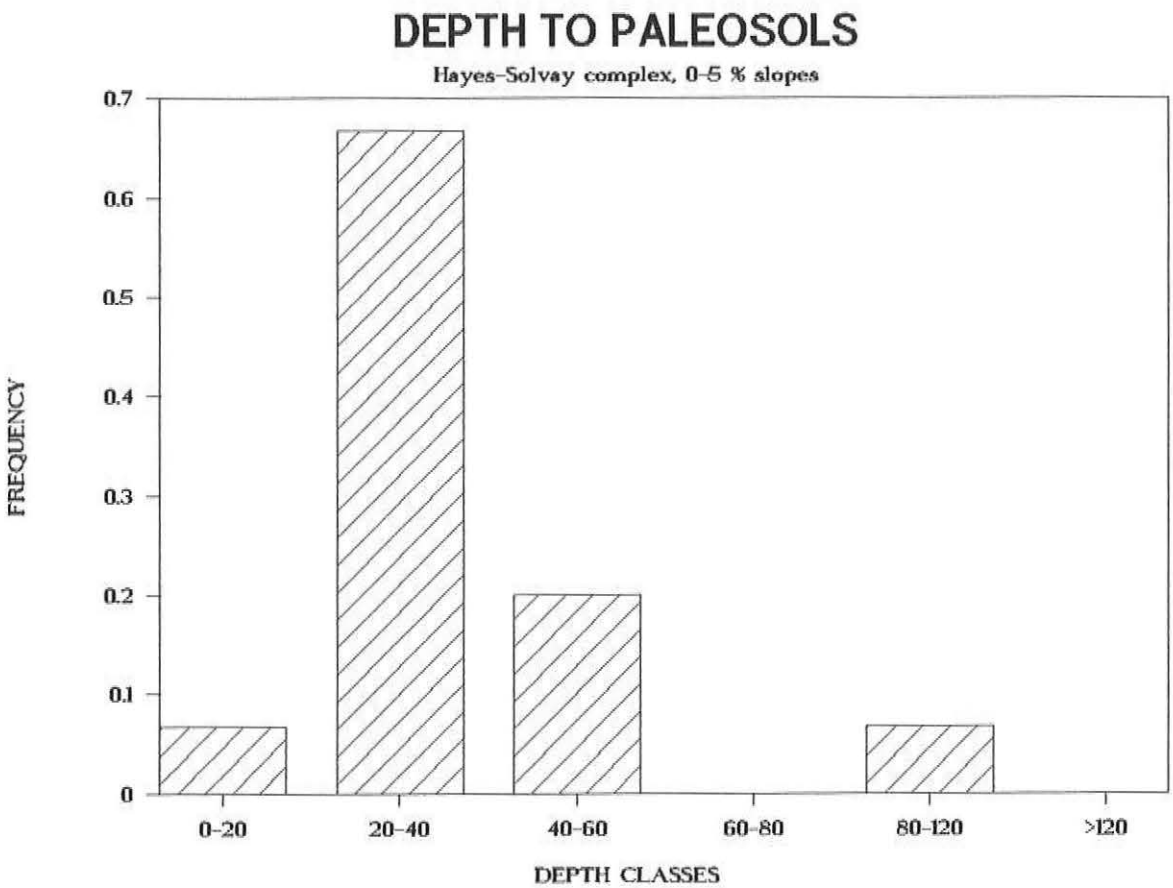
DISTANCE	DEPTH
0′	44"
100	17
200	26
300	41
400	83
500	99
600	33
700	52
800	17
900	57
1000	49
1100	17
1200	60
1300	60
1400	37
1500	17
1600	17
1700	17
1800	17
1900	45
2000	17
2100	59
2200	43
2300	57
2400	17
2500	136
2600	62
2700	17
2800	74
2900	50
3000	68
3100	118
3200	127
3300	57

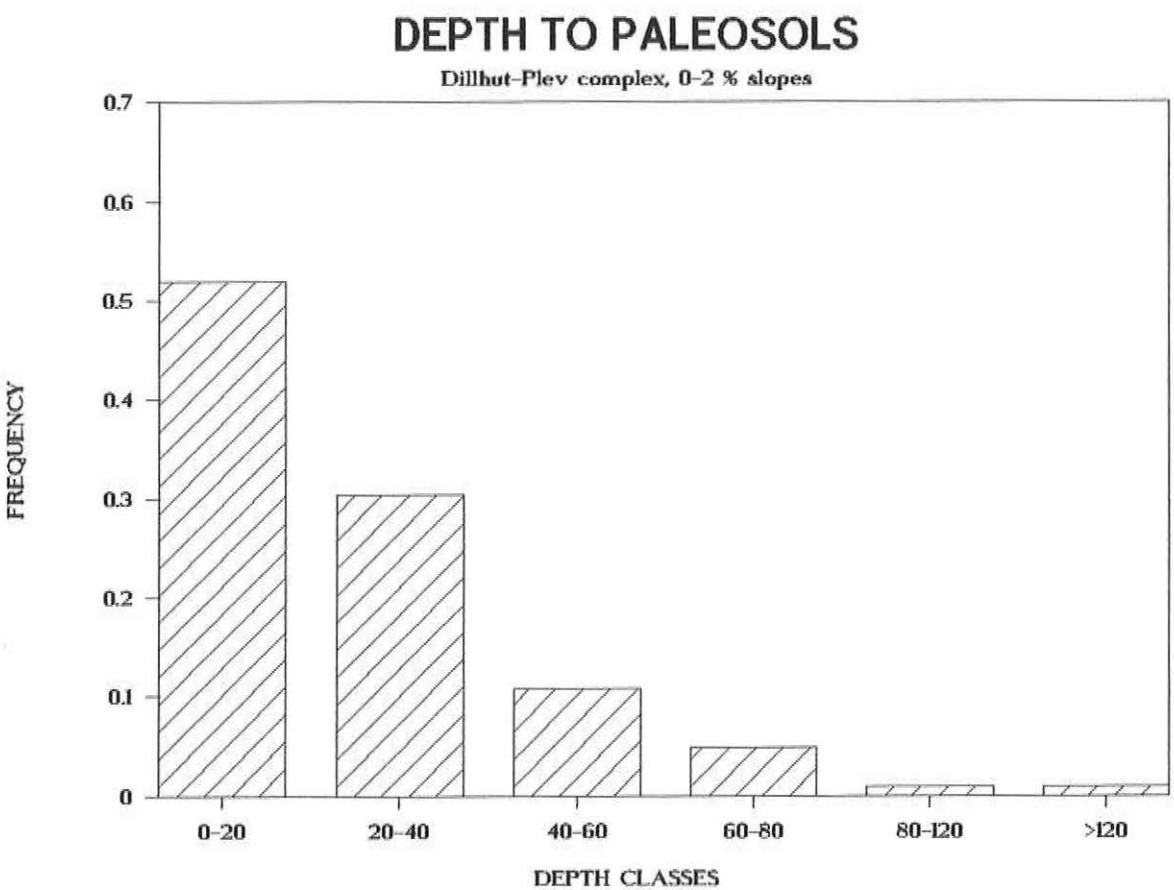
TRANSECT 85
MU: PX

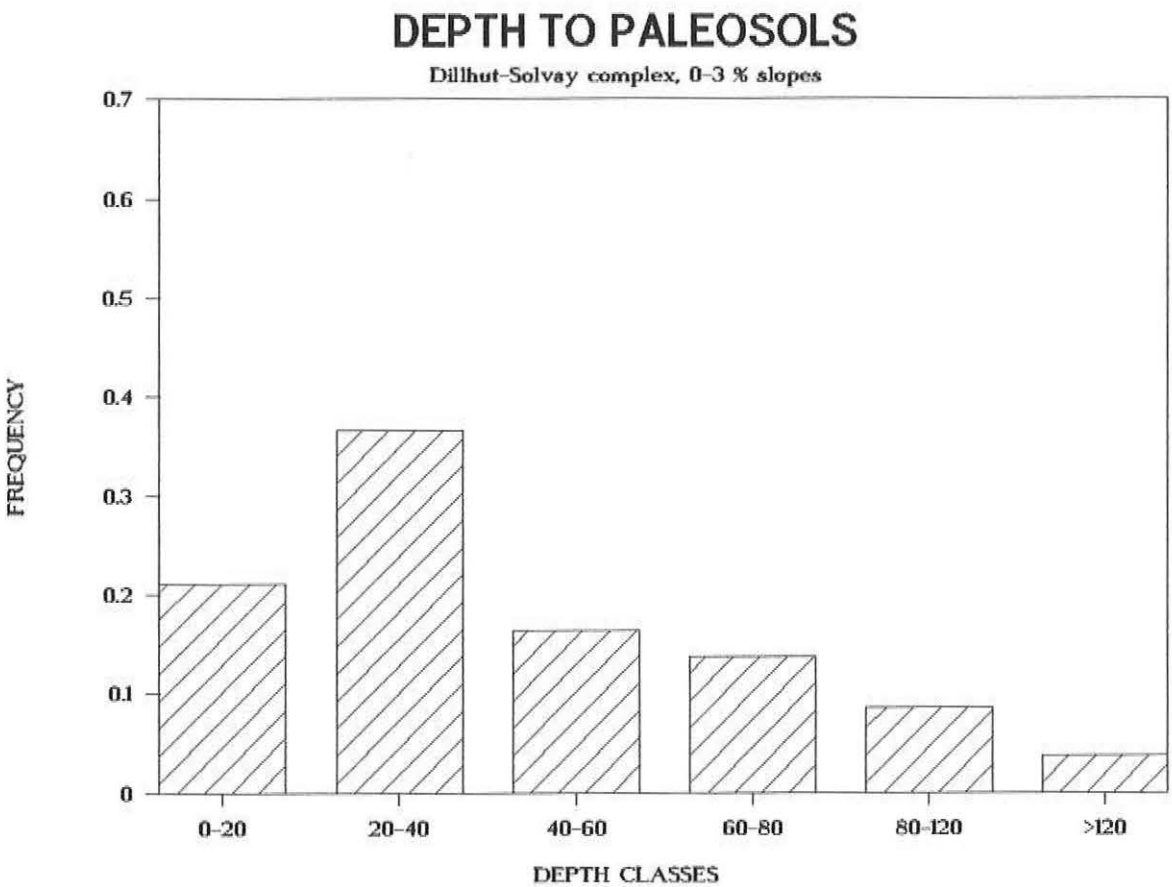
DISTANCE	DEPTH
0′	17"
100	54
200	150
300	94
400	42
500	17
600	49
700	17
800	17
900	17
1000	68
1100	17
1200	19

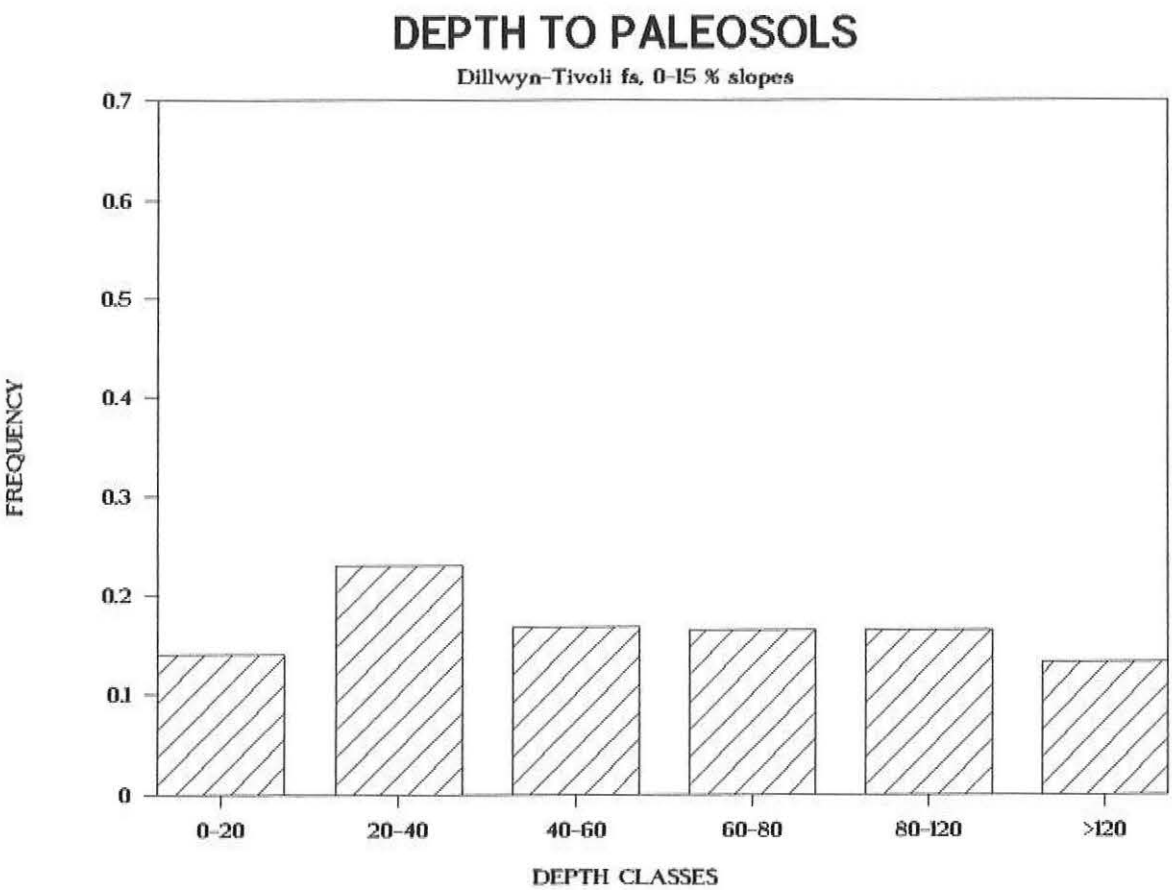
FIGURE 1

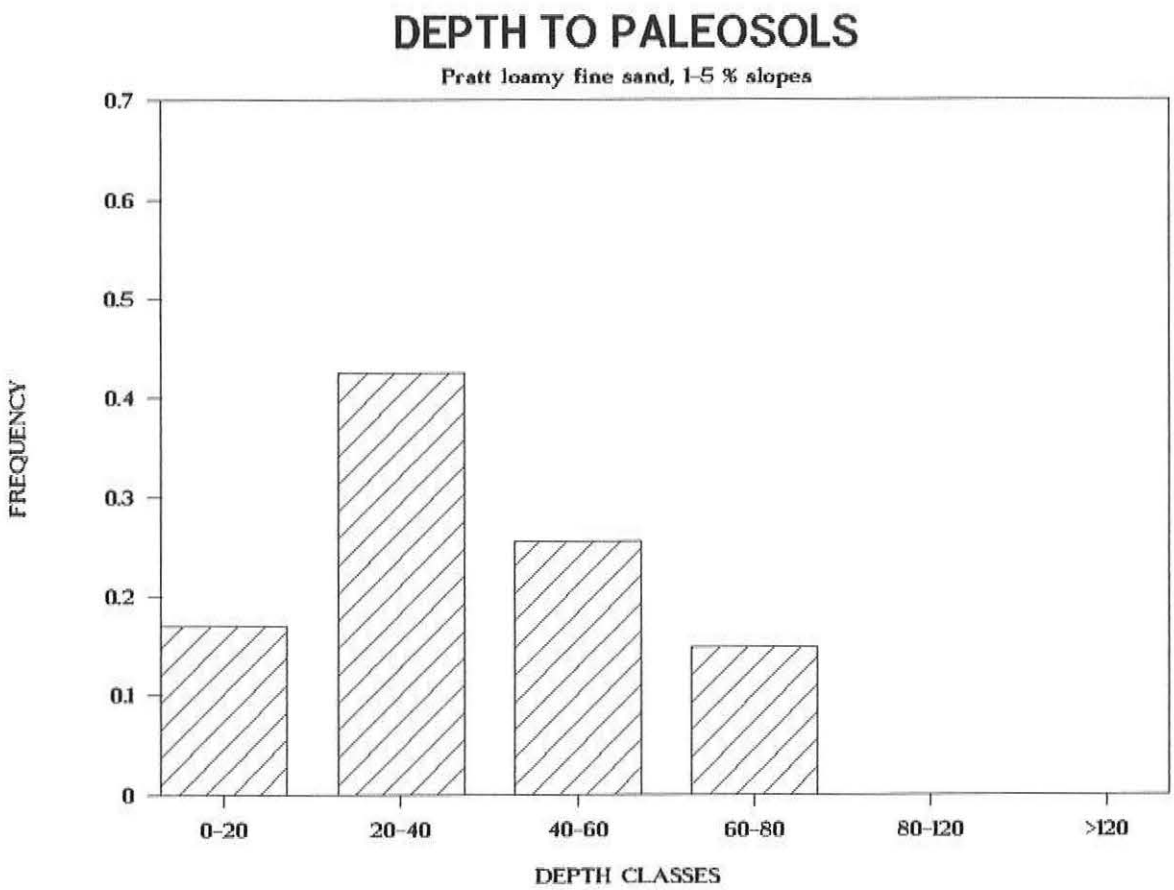

80
70
60
50
40
30
20
10
Interpreted Depth (inches)
10
20
30
40
50
60
70
80
Observed Depth (inches)
coefficient of determination - 0.9593

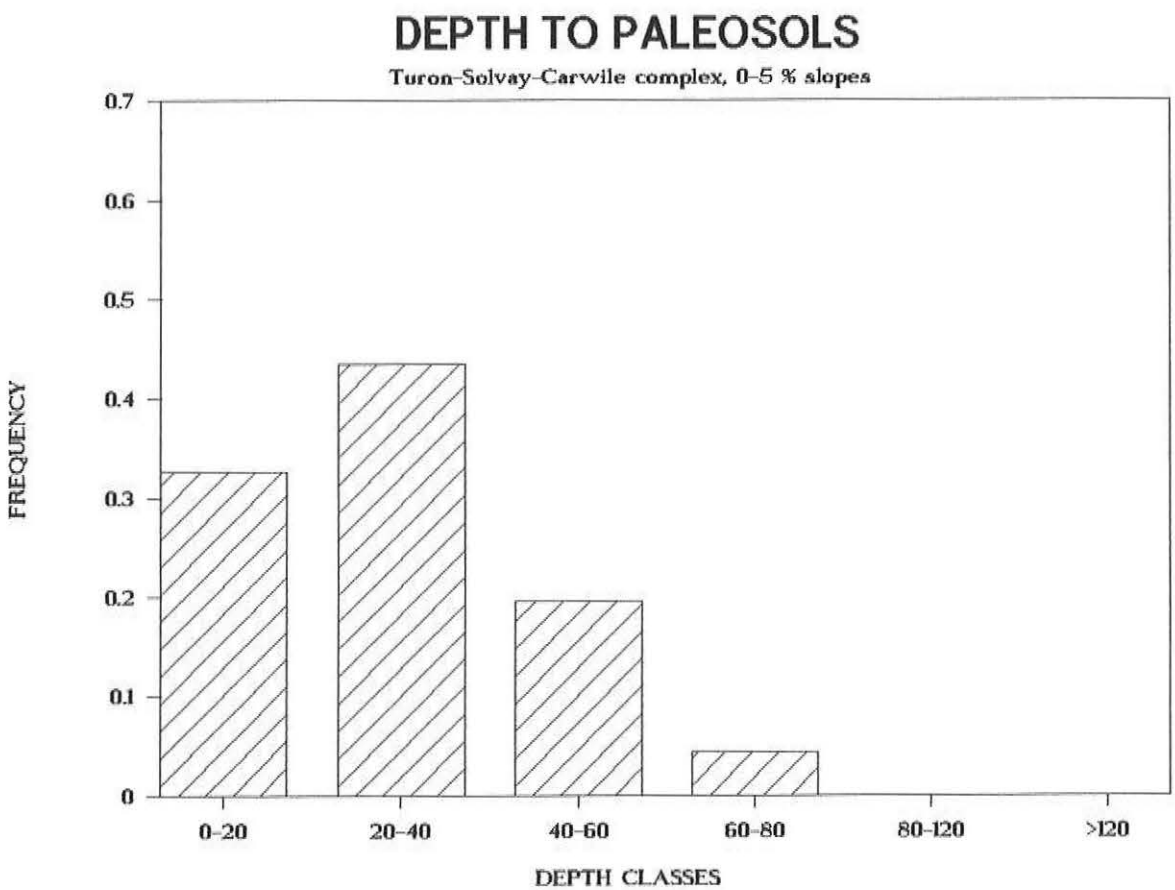

DEPTH TO PALEOSOLS
Hayes-Solvay complex, 0-5 % slopes
FREQUENCY
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0-20
20-40
40-60
60-80
80-120
>120
DEPTH CLASSES

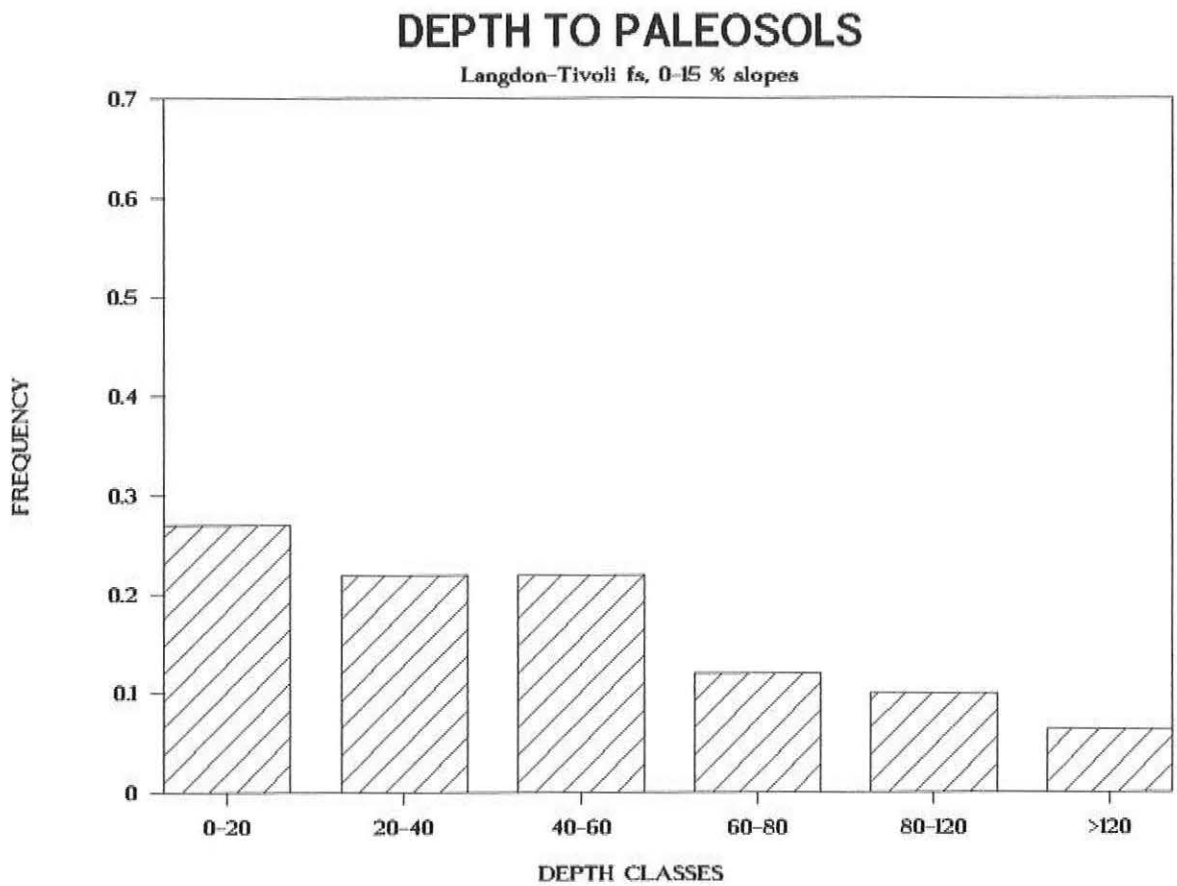

DEPTH TO PALEOSOLS
Dillhut-Plev complex, 0-2 % slopes
FREQUENCY
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0-20
20-40
40-60
60-80
80-120
>120
DEPTH CLASSES

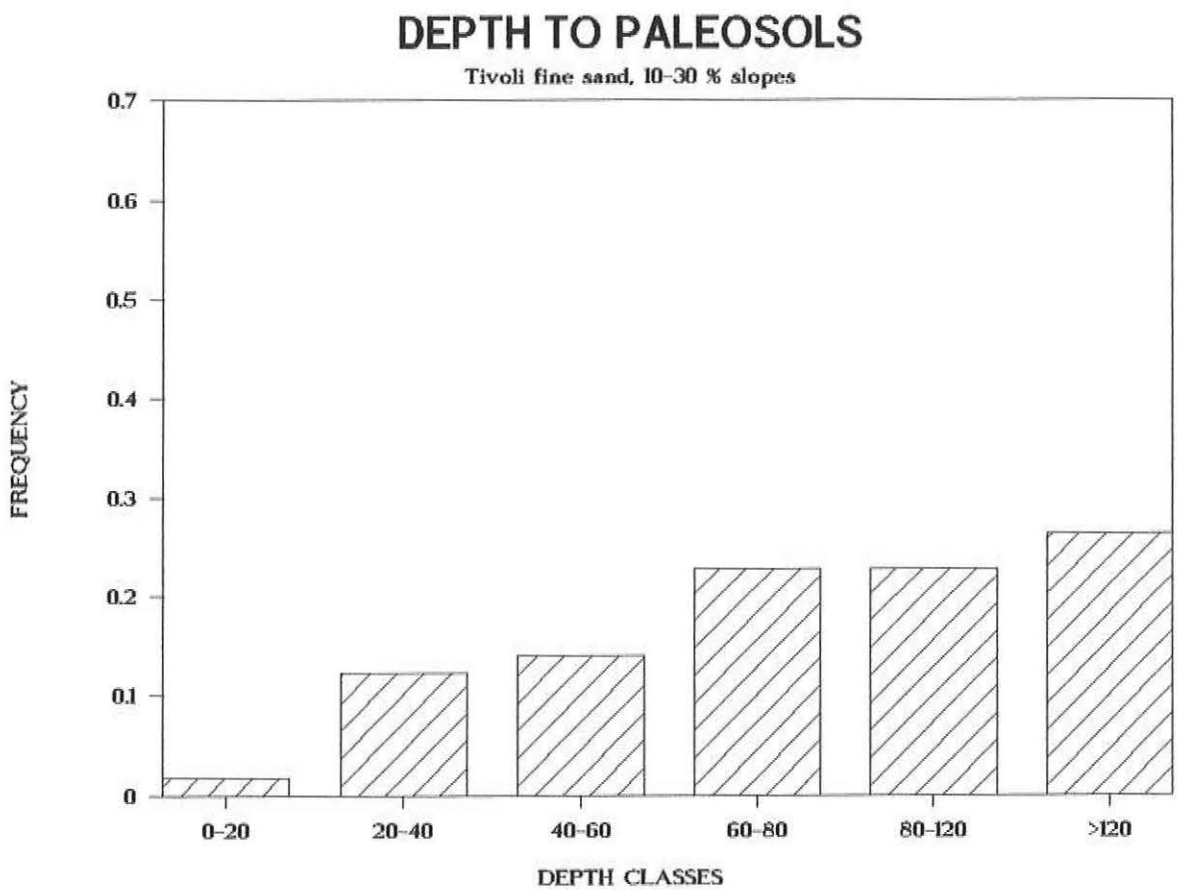

DEPTH TO PALEOSOLS
Dillhut-Solvay complex, 0-3 % slopes
FREQUENCY
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0-20
20-40
40-60
60-80
80-120
>120
DEPTH CLASSES


DEPTH TO PALEOSOLS
Dillwyn-Tivoli fs, 0-15 % slopes
FREQUENCY
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0-20
20-40
40-60
60-80
80-120
>120
DEPTH CLASSES


DEPTH TO PALEOSOLS
Pratt loamy fine sand, 1-5 % slopes
FREQUENCY
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0-20
20-40
40-60
60-80
80-120
>120
DEPTH CLASSES


DEPTH TO PALEOSOLS
Turon-Solvay-Carwile complex, 0-5 % slopes
FREQUENCY
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0-20
20-40
40-60
60-80
80-120
>120
DEPTH CLASSES


DEPTH TO PALEOSOLS
Langdon-Tivoli fs, 0-15 % slopes
FREQUENCY
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0-20
20-40
40-60
60-80
80-120
>120
DEPTH CLASSES


DEPTH TO PALEOSOLS
Tivoli fine sand, 10-30 % slopes
FREQUENCY
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0-20
20-40
40-60
60-80
80-120
>120
DEPTH CLASSES

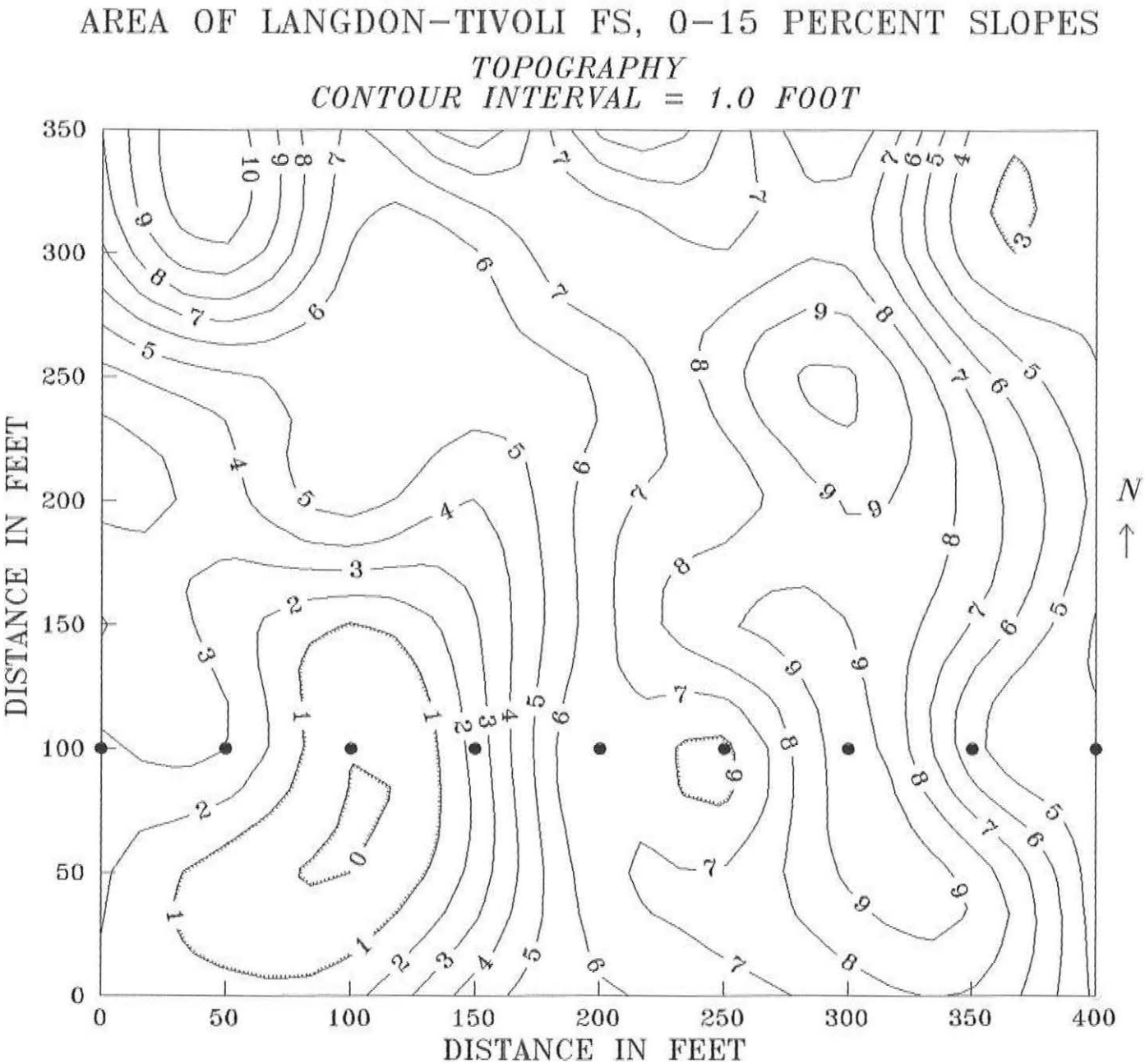
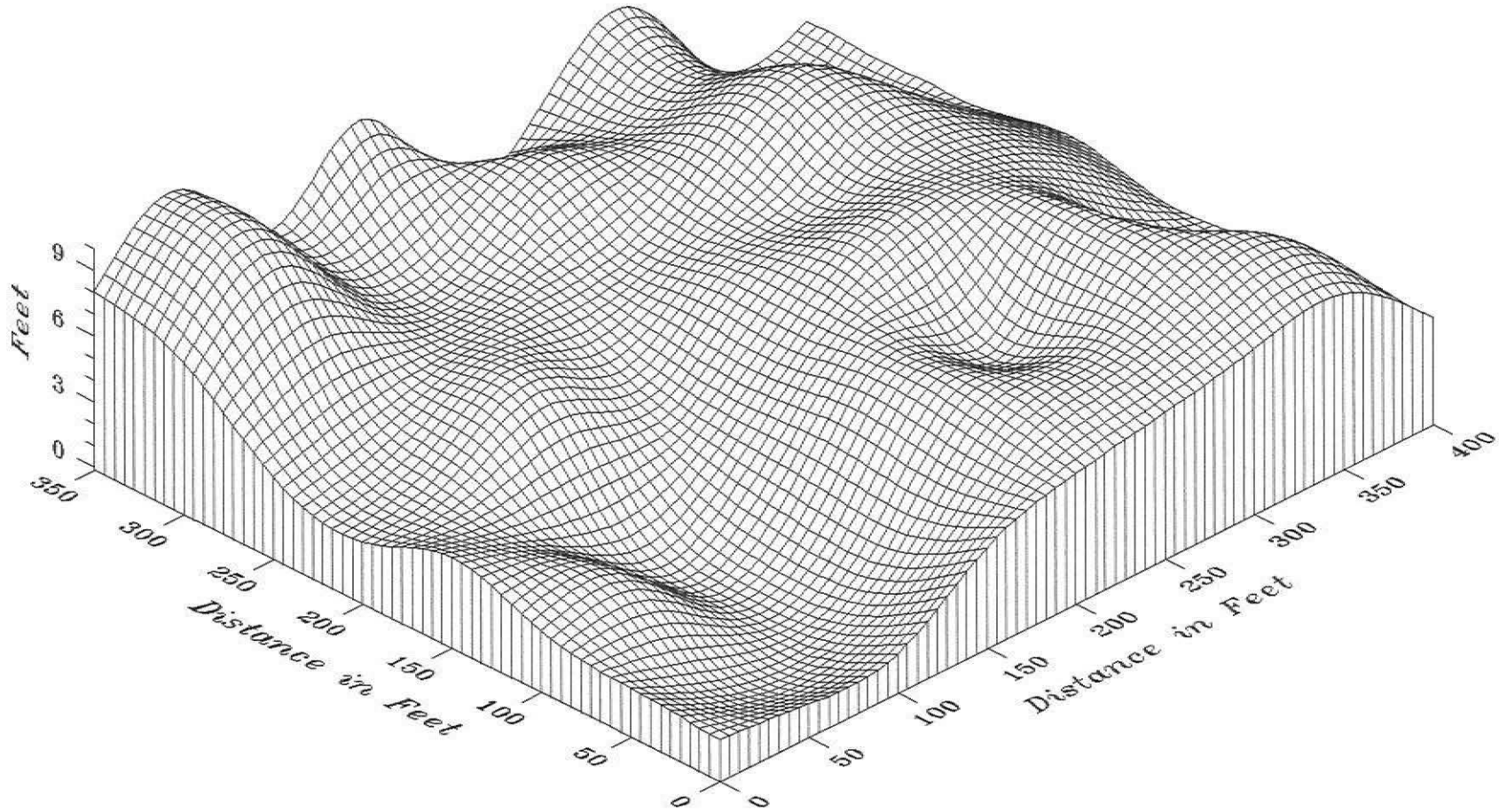
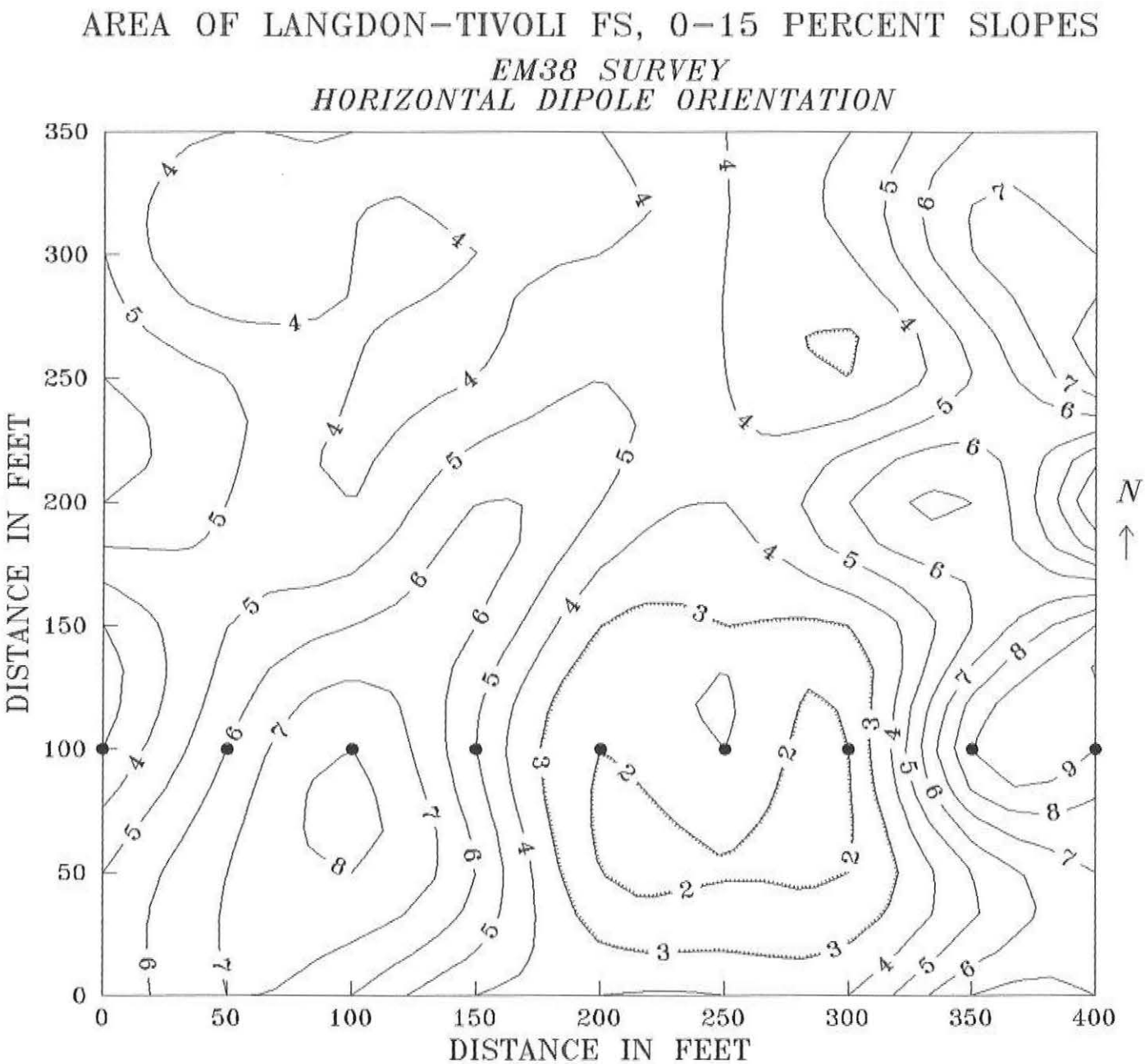
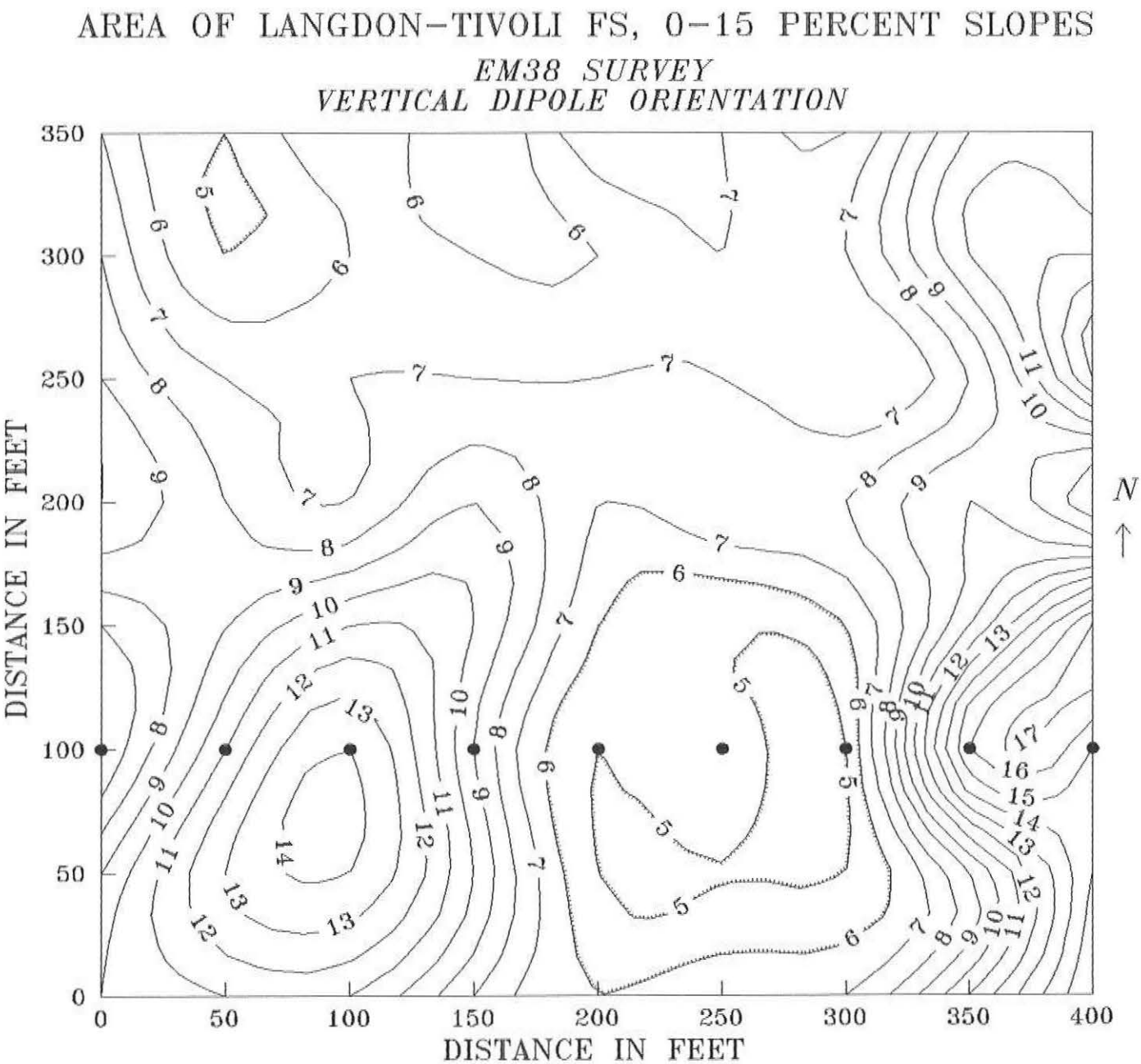

AREA OF LANGDON-TIVOLI FS, 0-15 PERCENT SLOPES
TOPOGRAPHY
CONTOUR INTERVAL = 1.0 FOOT
DISTANCE IN FEET
DISTANCE IN FEET
N
0
50
100
150
200
250
300
350
400

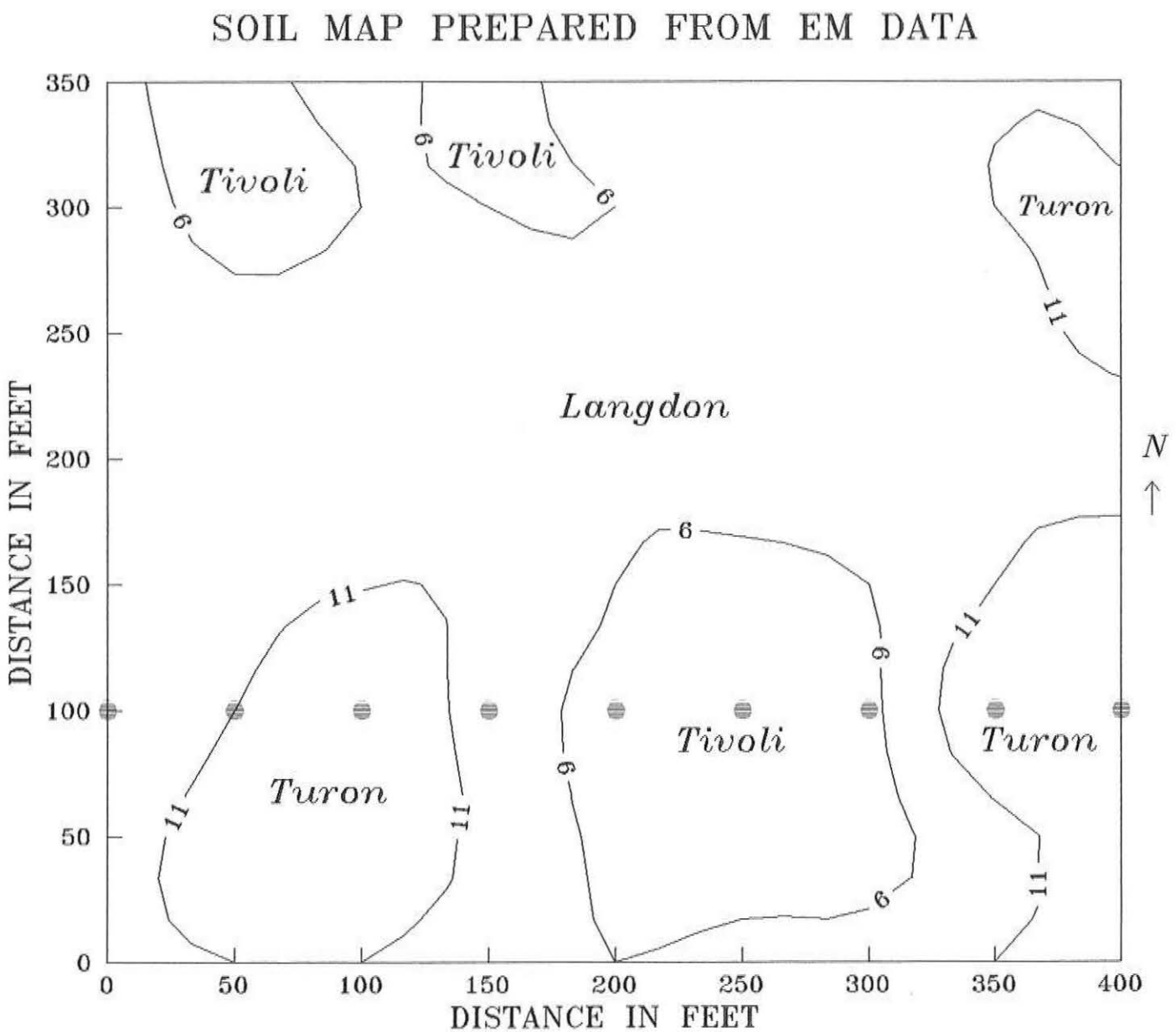
Figure 7

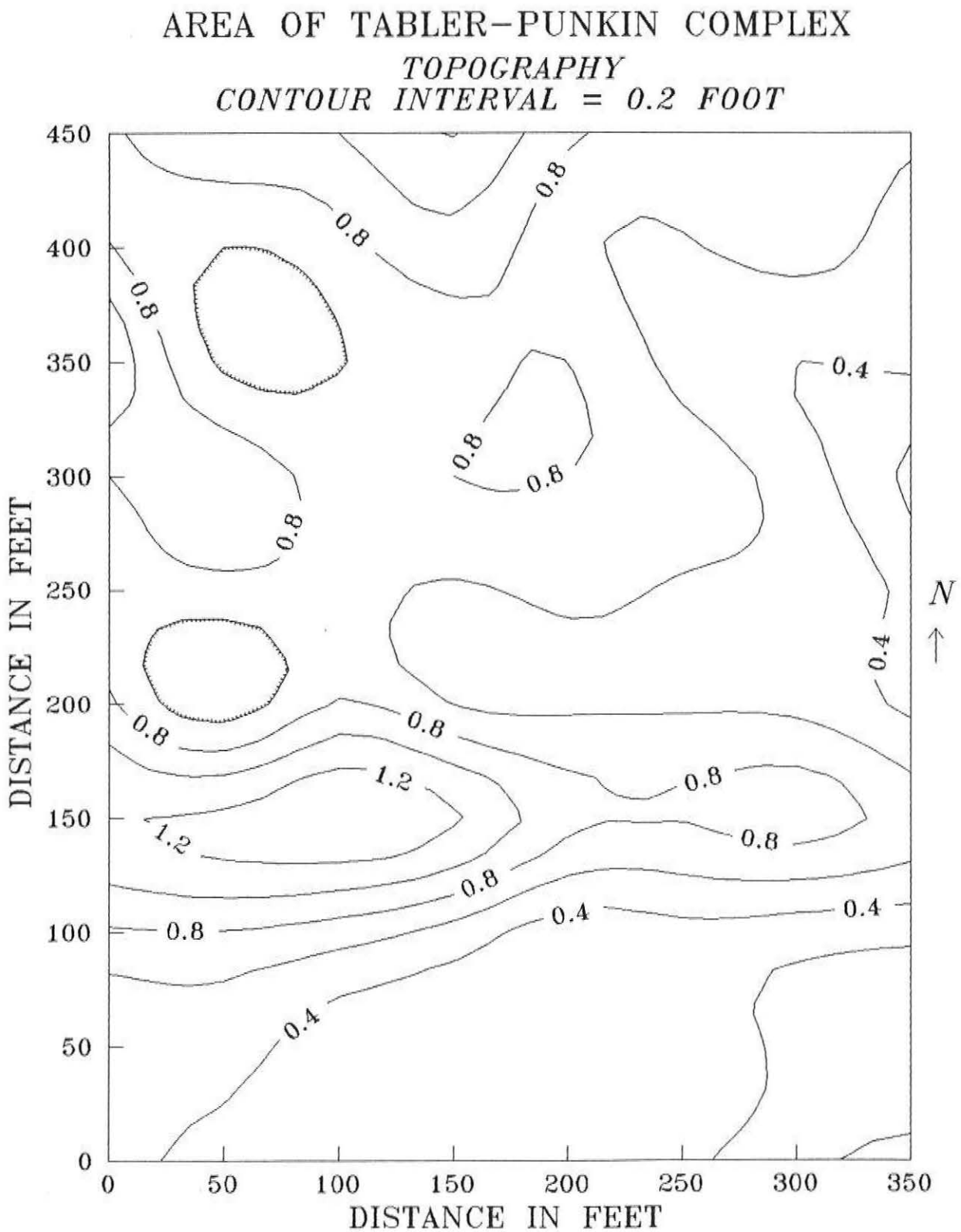
AREA OF LANGDON-TIVOLI FINE SANDS, 0-15 PERCENT SLOPES



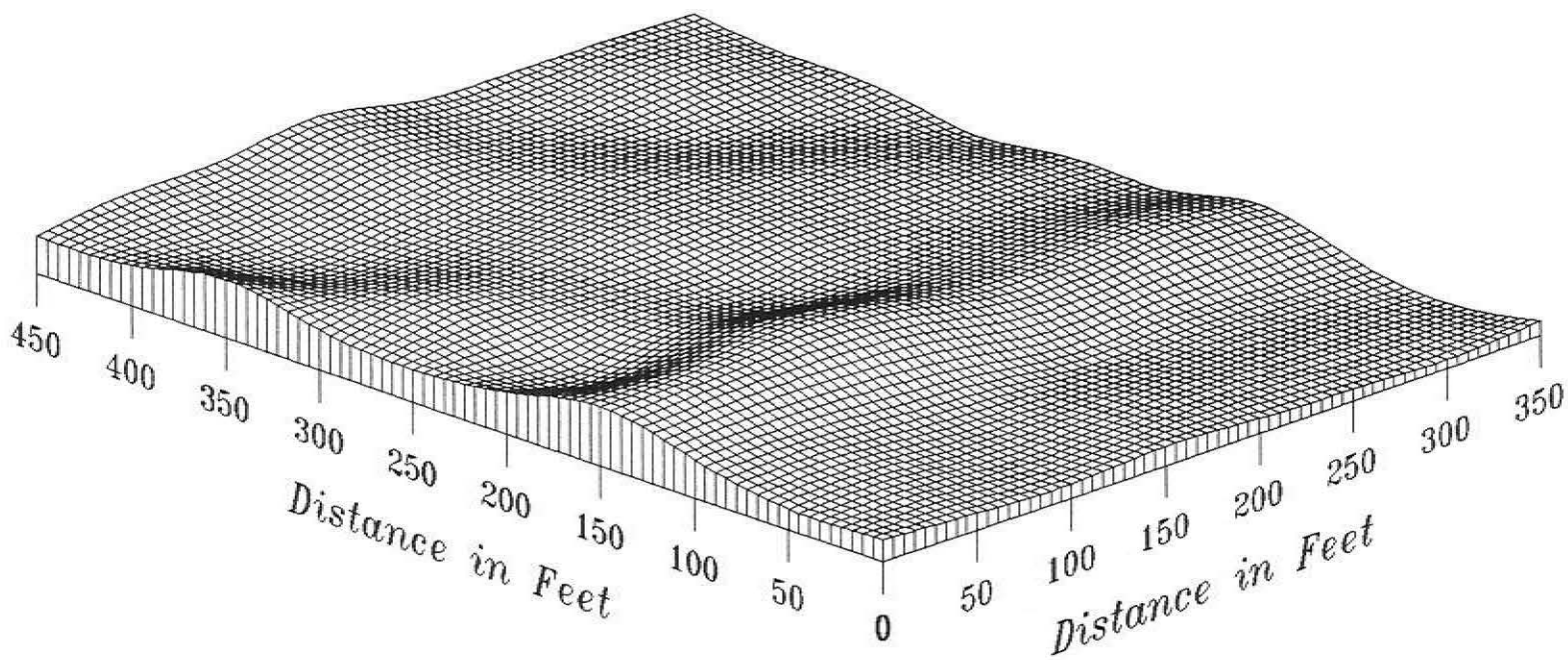

AREA OF LANGDON-TIVOLI FS, 0-15 PERCENT SLOPES
EM38 SURVEY
HORIZONTAL DIPOLE ORIENTATION
DISTANCE IN FEET
DISTANCE IN FEET
N
0
50
100
150
200
250
300
350
400

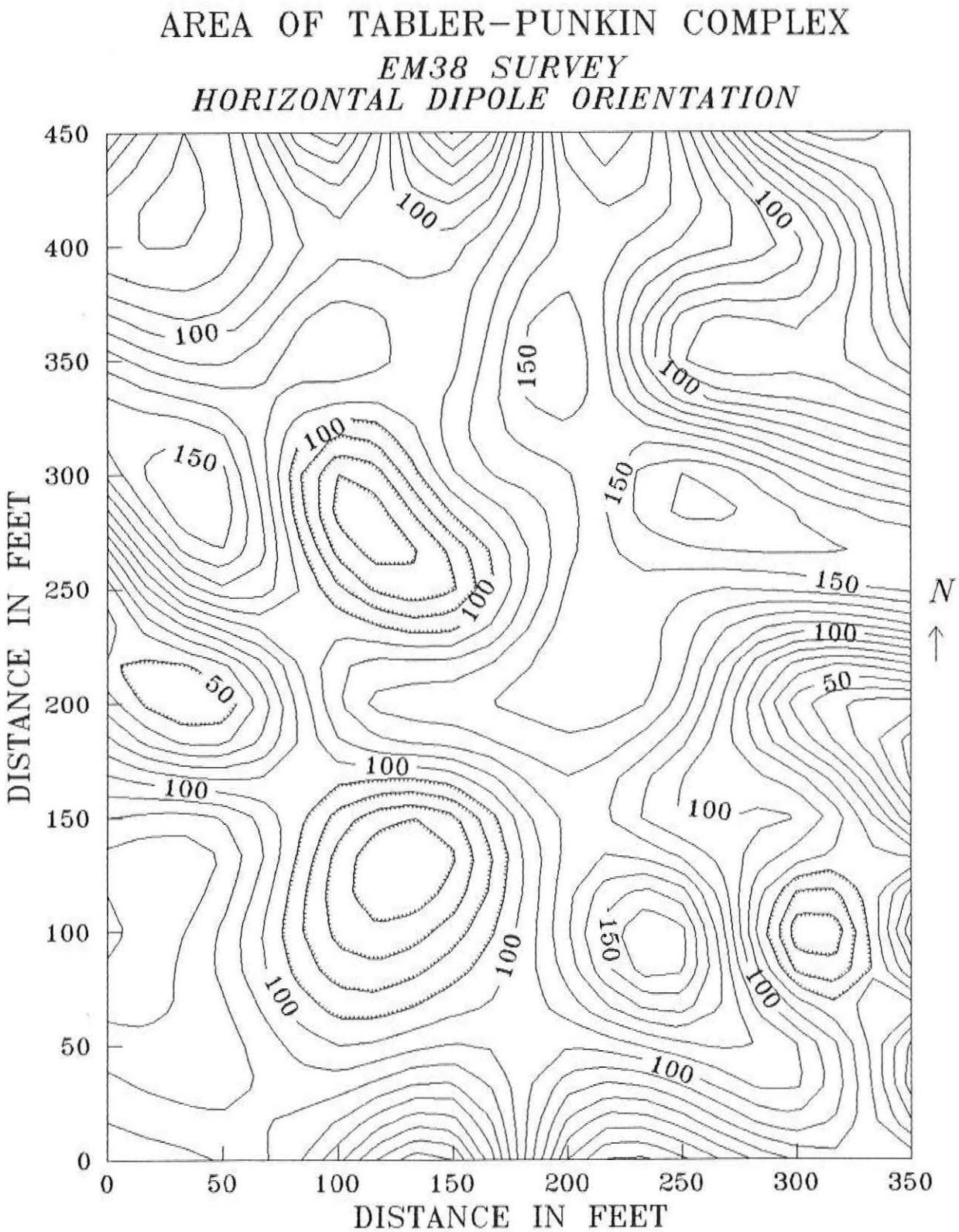

AREA OF LANGDON-TIVOLI FS, 0-15 PERCENT SLOPES
EM38 SURVEY
VERTICAL DIPOLE ORIENTATION
DISTANCE IN FEET
DISTANCE IN FEET
N
0
50
100
150
200
250
300
350
400

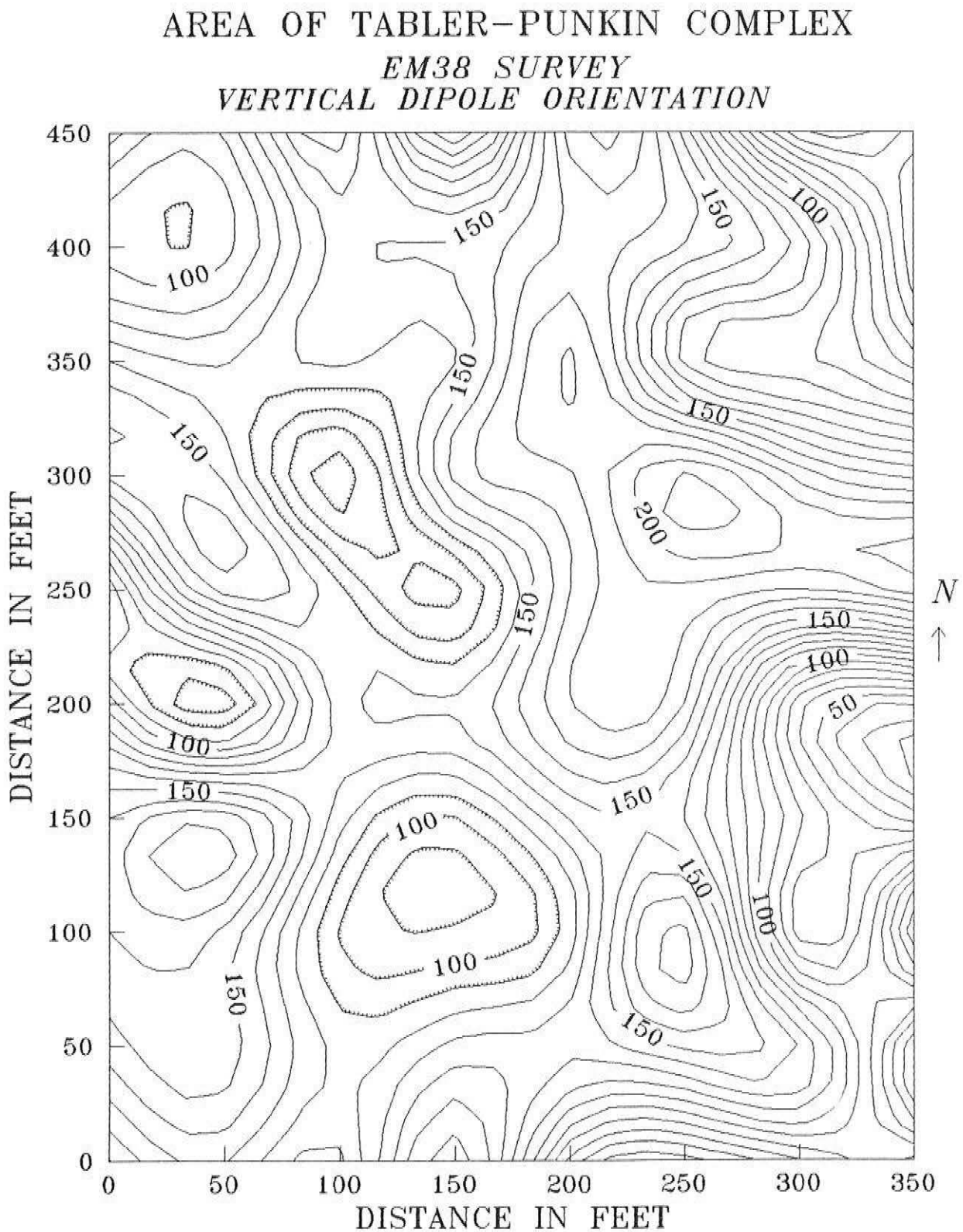

SOIL MAP PREPARED FROM EM DATA
Tivoli
Tivoli
Turon
Langdon
Turon
Tivoli
Turon
6
11
N
DISTANCE IN FEET
DISTANCE IN FEET
0
50
100
150
200
250
300
350
400


AREA OF TABLER-PUNKIN COMPLEX
TOPOGRAPHY
CONTOUR INTERVAL = 0.2 FOOT
DISTANCE IN FEET
DISTANCE IN FEET
N
0
50
100
150
200
250
300
350
400
450
0.8
0.4
1.2

AREA OF TABLER-PUNKIN COMPLEX




AREA OF TABLER-PUNKIN COMPLEX
EM38 SURVEY
HORIZONTAL DIPOLE ORIENTATION
DISTANCE IN FEET
DISTANCE IN FEET
N
0
50
100
150
200
250
300
350
400
450
100
150
50


AREA OF TABLER-PUNKIN COMPLEX
EM38 SURVEY
VERTICAL DIPOLE ORIENTATION
DISTANCE IN FEET
DISTANCE IN FEET
N
0
50
100
150
200
250
300
350
400
450
50
100
150
200