

41
QUARTERNARY GEOLOGY OF A BASIN NEAR
LINN (WASHINGTON COUNTY), KANSAS

by

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TABLE OF CONTENTS

	Page
Introduction	1
Purpose of Investigation	1
Physiography	2
Geology	5
Previous Investigations	5
Methods of Investigation	7
Field Procedure	7
Laboratory Procedure	11
Description of Cores	11
Grain Size Analysis	11
Pipette Analysis	13
Precision of Pipette Method	17
Sieve Analysis	20
Combination of Pipette and Sieve Data	20
Statistical Grain Size Parameters	22
Clay Mineral Analysis	22
Fractionation of Clay Minerals	22
Oriented Slides	26
Organic Liquid Treatment	26
Heat Treatment	26
Acid Treatment	27
Cation Saturation	27
X-Ray Diffraction	27

Organic Carbon Analysis	28
Hydrogen Ion Activity	30
Mineralogy of Sand and Sandstone	31
Surface Textures of Quartz Grains	31
Field Data	31
Laboratory Data	37
Cores of Samples	37
Surface Soil	38
Loess	38
Paleosol	39
Sand	42
Grain Size Analysis	43
Grain Size Nomenclature	43
Evaluation of Data	43
Clay Mineral Analysis	50
Identification of Clay Minerals	50
Abundance of Clay Minerals	50
Evaluation of Data	50
Organic Carbon Analysis	58
Hydrogen Ion Activity	58
Mineralogy of Sand and Sandstone	61
Surface Texture of Quartz Grains	67
Summary of Laboratory Data	68
Relationship Between Clay Minerals and pH	68
Relationship Between Clay Minerals and Grain Size	68
Relationship Between Organic Carbon and pH	70

Conclusion	70
Acknowledgment	76
References Cited	77

APPENDICES

Appendix	I. Test-Hole Logs	81
	II. Grain Size Data	95
	III. Scanning Electron Micrographs of Quartz Grains	111
	IV. Phi Percentile Values	120
	V. Reagents, Apparatus, and Procedure Used for Walkley-Black Method of Organic Carbon Determination	121

List of Figures

Figure		Page
1.	Location of study	3
2.	Geographic relationship between study area and western extent of the Kansan Ice Sheet	4
3.	Stratigraphic section of Quaternary and bedrock geology northeast of Linn, Kansas	6
4.	Stratigraphic section of Quaternary deposits and soil forming intervals in Kansas	8
5.	Location of test holes	10
6.	Flow sheet for laboratory procedures used in grain size analysis	14
7.	Cumulative curve of typical paleosol sample showing irregularity in size distribution	21
8.	Flow sheet for laboratory procedure used in clay mineral analysis	25
9.	Flow sheet for laboratory procedure used in Walkley-Black method of organic carbon analysis	29
10.	Flow sheet for laboratory procedure used in pH analysis	32
11.	Grain size nomenclature of sediments	44
12.	Grain size distribution patterns of major Quaternary units	46
13.	Vertical and lateral changes in mean grain size (M_z).	48
14.	Vertical and lateral changes in clay minerals	57
15.	Vertical and lateral changes in organic carbon	60
16.	Vertical and lateral changes in pH	63
17.	Relationship between pH and concentration of kaolinite and vermiculite in the clay fraction	69
18.	Relationship between mean grain size and concentration of kaolinite and vermiculite in the clay fraction	71
19.	Relationship between organic carbon and pH	72
20.	Tentative stratigraphic section of Quaternary and bedrock geology northeast of Linn, Kansas	73

LIST OF TABLES

Table	Page
1. Grain size scales for sediments	12
2. Settling times computed according to Wadell's Modification of Stokes Law at 24°C	16
3. Result of duplicate pipette analysis of four samples	18
4. Statistical grain size parameters proposed by Inman (1952) and Folk and Ward (1957)	23
5. Verbal classifications for standard deviation (σ_I), skewness (Sk_I), and kurtosis (K_G)	24
6. Sand, silt, and clay percentages and grain size nomenclature . .	45
7. Phi statistical parameter values	49
8. X-ray identification of clay minerals (<2.0 and <0.2 Microns) in oriented mounts	55
9. Result of clay mineral analysis	56
10. Result of organic carbon analysis	59
11. Result of pH analysis	62
12. Result of mineralogic count of sand grains from sand and sandstone	64
13. Chi-square test for total mineralogic data of sand and sandstone	66

LIST OF PLATES

Plate	Page
I. East-West Cross-section	34
II. North-South Cross-section	36
III. Photographs of Cores B-9 and B-11	41
IV. X-Ray Diffractograms of Sample B-3, C-1	52
V. X-Ray Diffractograms of Sample B-9, C-2	54
VI. Electron Micrograph of Quartz Grain Number Sd-1a	111
VII. Electron Micrograph of Quartz Grain Number Sd-1b	112
VIII. Electron Micrographs of Quartz Grains Numbers Sd-2 and Sd-3a .	113
IX. Electron Micrographs of Quartz Grains Numbers Sd-3b and Sd-4a .	114
X. Electron Micrographs of Quartz Grains Numbers Sd-4b and Ss-1a .	115
XI. Electron Micrograph of Quartz Grain number Ss-1b	116
XII. Electron Micrographs of Quartz Grains Numbers Ss-2a and Ss-2b .	117
XIII. Electron Micrographs of Quartz Grains Numbers Ss-2c and Ss-2d .	118
XIV. Electron Micrograph of Quartz Grain Number Ss-2e	119

INTRODUCTION

Purpose of Investigation

A basin with very low relief in the center occurs about two miles northeast of Linn (Washington County), Kansas. The geologic age and development of this basin have puzzled some geologists in the past. The area's proximity to the western boundary of the previous Kansan ice front suggests the basin may be as old as Kansan Age and developed as a drainage channel or lake during that time. Because little detail is known about the geology in Washington County, the geologic history of the basin has been subject to speculation.

This investigation is a study of the Quaternary geology of this basin and was undertaken to determine possible relationships between its development and geologic events of the Quaternary Period. The primary objectives were to 1) identify the Quaternary sediments in the basin, 2) determine the probable age and depositional origin of these sediments, and 3) describe and compare the sediments in terms of texture, sedimentary structures (laminations in loesses), clay mineralogy, mineralogy, organic carbon content, and hydrogen ion activity (pH).

Physiography

The area investigated covers approximately nine square miles directly east and northeast of Linn, Kansas (fig. 1). It includes sections 13, 14, 15, 22, 23, 24, 25, 26, and 27 of Township 4 South, Range 3 East in Washington County.

The area is in the Smoky Hills Division of the Dissected High Plains of the Great Plains Province and is within 10 miles of the Attenuated Drift Border Division of the Dissected Till Plains of the Central Lowland Province (Schoewe, 1949, p. 280). The boundary of the Dissected Till Plains was originally established as being just east of the Blue River in Marshall and Pottawatomie Counties. Schoewe (1939) proposed that this boundary, which marks the western extent of the Kansas ice sheet, be relocated to the west (fig. 2). This relocation included an area west of the Little Blue River in Washington County and added approximately 450 square miles to the ice-invaded region of Kansas. Evidence for the relocation was based on till deposits found west of the Little Blue River.

The surface of the area is a basin with a definite rim on the south and west which is partly truncated on the north and east (fig. 1). Topographic relief is very low in the center part (10 to 20 feet), but to the east, stream erosion has produced a more dissected landscape. Drainage is radial and drains outward from the center. Principal streams forming the drainage pattern are Ash Creek to the north, Peats Creek to the west, and Coon Creek to the east. Isolated bodies of water, covering a few acres, have persisted in depressions during periods of high precipitation (Wohler, personal communication, 1973).

Because of the low relief, outcrops are relatively scarce. Outcrops to the east of the area reveal reddish iron-stained sandstone and gray clayey shale of the Dakota Formation (Lower Cretaceous Series) overlain by a thin

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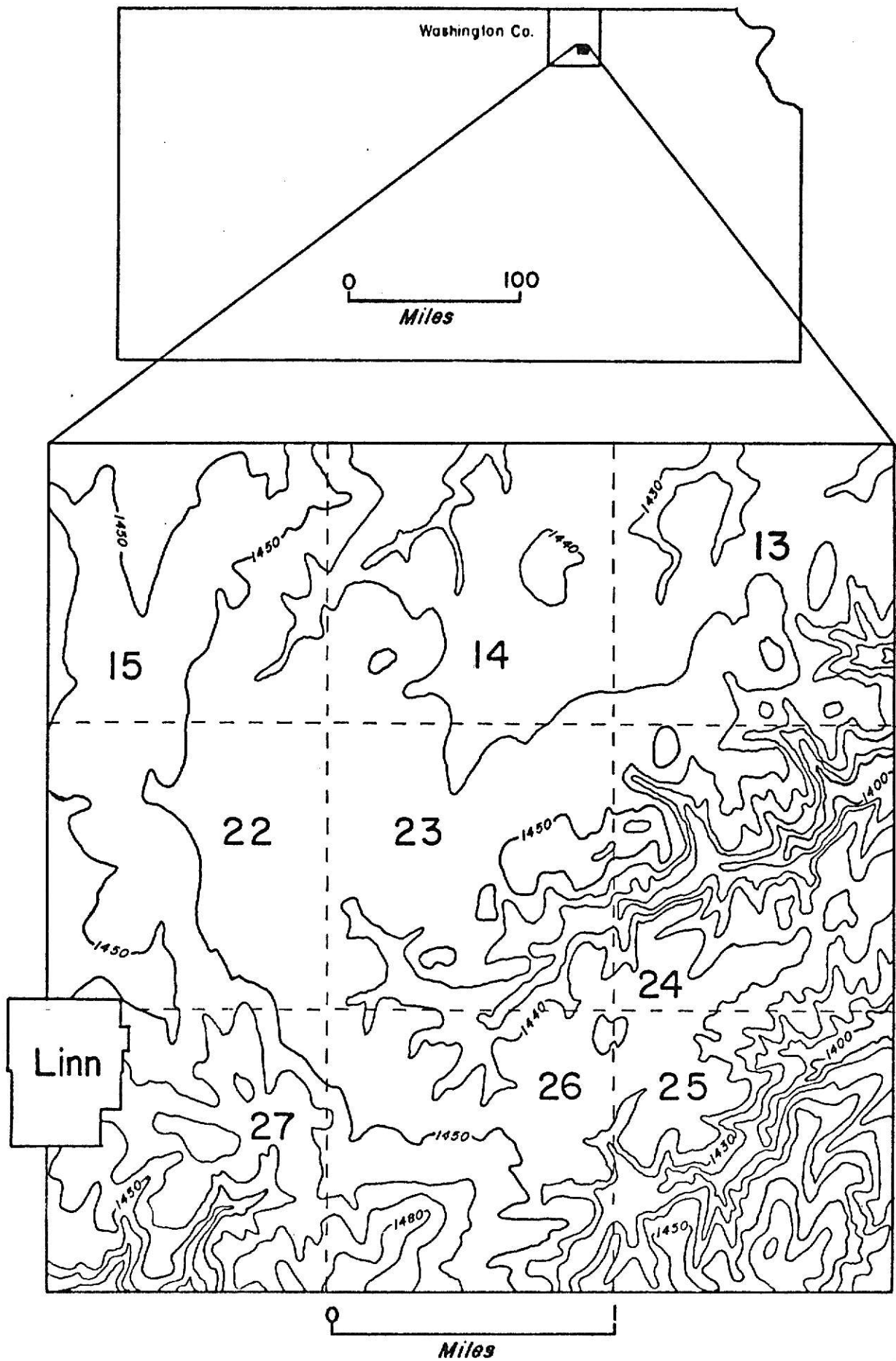


Fig. 1. Location of study.

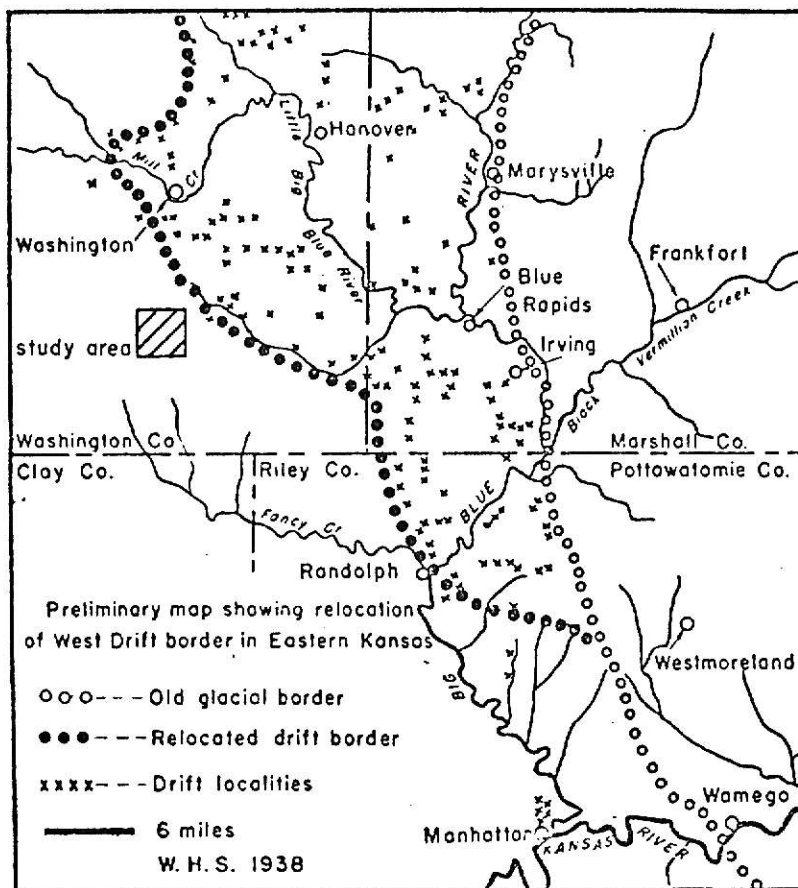


Fig. 2. Geographic relationship between study area and western extent of the Kansan Ice Sheet (adapted from Schoewe, 1939).

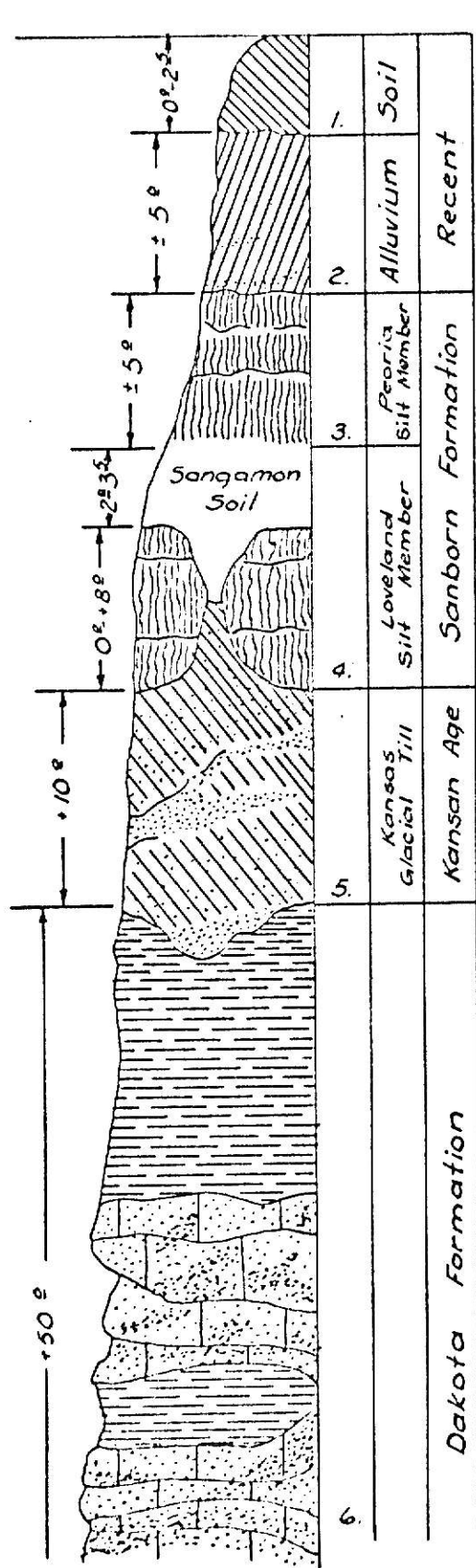
covering of Pleistocene loess. A streamcut in the NW 1/4, NW 1/4, NE 1/4 of Sec. 26, T. 4 S., R. 3 E., exposes a buried soil or paleosol, which can be traced laterally along the entire length of the outcrop.

Geology

Geologic information for areas northeast of Linn was obtained by Clark and others (1964). A generalized geologic profile and description of the geology encountered by Clark et al. is in Figure 3. Bedrock consists of sandstone and shale of the Dakota Formation. The thick mantle overlying bedrock is composed of glacial till, loess deposits and alluvium. The Sangamon Soil is well developed on Loveland Loess and in some localities on glacial deposits. Considerable relief on the bedrock surface (115 feet) was noted in these areas. Buried valleys were cut into bedrock and filled with sand and gravel.

Previous Investigations

The geology of Washington County has not been described in any detail; only general statements have been made about the bedrock and Quaternary geology (Greene, 1910; USDA, 1950; Frye and Leonard, 1952). Petrographic studies of Quaternary loesses and paleosols in Washington County and adjacent counties were made by Swineford and Frye (1951) and Metz (1954). Swineford and Frye reported similar grain size distributions of the Peoria Loess throughout the state. In a study of sediments west of Washington County, Metz reported the Peoria and Loveland Loesses could be differentiated by heavy and light mineral composition. Geologic reports by the State Highway Commission of Kansas provide most of the geologic information for the county and were used as a basis for geologic interpretations in this study. The Quaternary geology of these reports and subsequent results of the present study are correlated with the general Quaternary geology of Kansas described



Recent Soil

1. Clay, silty, dark brown.

Alluvium

2. Clay, silty, brown to dark gray, contains some sand.

Pleistocene Series

Sanborn Formation

Peoria Silt Member

3. Silt, tan, uniform texture, eolian.

Loveland Silt Member

4. Silt, red-brown, fairly uniform texture, predominantly eolian, contains the buried Sangamon Soil at the top.

Kansas Glacial Till

5. Glacial drift, silt and clay with scattered sand, light gray to gray-brown, contains stringers and lenses of sand and gravel.

Cretaceous System

Gulfian Series

Dakota Formation

6. Shale, tan to maroon, clayey with sandstone, lensing, fine to medium grained, loosely cemented.

Fig. 3. Stratigraphic section of Quaternary and Bedrock geology northeast of Linn, Kansas (from Clark et al., 1974).

by Frye and Leonard (1952). Their investigation provided the first report which compiled all available knowledge of the Quaternary system in Kansas. In an earlier publication, Frye (1951) presented a geologic column of the Quaternary system in Kansas. A later modification of this classification scheme was made by Zeller (1968, p. 60) and is shown in Figure 4.

METHODS OF INVESTIGATION

Field Procedure

A reconnaissance of the area provided information concerning the number of outcrops and the types of rock and sediment forming these outcrops. Geomorphic features, such as drainage patterns and topographic relief, were studied using 7.5-minute U. S. Geological Survey Topographic maps (Linn and Washington Quadrangles). Aerial photographs and soil maps obtained from the Soil Conservation Service were also reviewed.

A continuous-flight-auger drilling rig, equipped with a split tube sampling device, was used to obtain the necessary samples. A drilling plan was established to include several test holes in an east-west line along the county road bordering the south side of 22 and 23, T. 4 S., R. 3 E. ($39^{\circ} 40' 57''$ N. Lat.). A north-south series of test holes was also planned along the county road bordering the west side of sec. 23 and 26 T. 4 S., R. 3 E. ($97^{\circ} 04' 11''$ E. Long.). Drilling data were used to construct cross-sections of the bedrock and mantle across the study area. County roads were chosen for drilling localities because of their accessibility for drilling operations. Locations of test holes are in Figure 5.

It was originally decided that core samples of the sediments would be taken in each test hole. However, not all of the test holes were cored because of the great amount of time and expense involved with the coring

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Time-stratigraphic unit	Rock-stratigraphic unit					
	Northeastern area		Southeastern area		Central and Western area	
Recent Stage	Eolian and fluvial deposits					
Wisconsinan Stage	Bignell Formation	Fluvial deposits	Bignell Formation	Fluvial deposits	Bignell Formation	Fluvial deposits
	Brady Soil					
	Peoria Formation	Fluvial deposits	Peoria Formation	Fluvial deposits	Peoria Formation	Fluvial deposits
	Gilman Canyon Formation					
Sangamonian Stage	Sangamon Soil					
Illinoian Stage	Loveland Formation	Fluvial deposits	Loveland Formation	Fluvial deposits	Loveland Formation	
Yarmouthian Stage	Yarmouth Soil					
	Loess	Fluvial deposits*	Fluvial deposits*		Sappa Formation*	
Kansan Stage	Cedar Bluffs Till				Grand Island Formation	
	Fluvial deposits					
	Nickerson Till					
	Atchison Formation†					
Aftonian Stage	Afton Soil					
Nebraskan Stage	Loess	Fluvial deposits	Fluvial deposits		Fullerton Formation	
	Iowa Point Till				Holdrege Formation	
	David City Formation					

* Locally contains the Pearllette ash bed.

† Atchison Formation has been defined as proglacial outwash of early Kansan age. Similar deposits of sand are found between the Nickerson Till and the Cedar Bluffs Till.

Fig. 4. Stratigraphic section of Quaternary deposits and soil forming intervals in Kansas (from Zeller, 1968).

procedure. Three of the 14 east-west test holes were drilled the entire depth with the auger. All north-south test holes were strictly augered.

An advantage of core sampling is that undisturbed characteristics of the sediment are observed more accurately than by examining only auger cuttings. The cores were taken by driving a "split tube" sampler 1 to 1.5 feet with a 140 pound weight mounted on the drilling rig. The drive sample was recovered from the hole, wrapped in cellophane, and placed in a labeled box. The split tube was replaced in the hole and another drive taken and recovered. The procedure was repeated until the entire depth of cohesive sediments was sampled. This method of sampling works satisfactorily in clayey sediments, where cohesion of the particles permits the sample to remain in the split tube. However, in sandy sediments the sample will fall out of the tube as it is brought to the surface. In test holes where cohesive sediments overlaid noncohesive sand, only the sediments above the sand were sampled with a split tube. The underlying sand interval was then drilled with a continuous flight auger to unweathered bedrock. Some auger cuttings of the sand were sampled, however, in many test holes, the sand could not be augered to the surface. Most augered samples were contaminated by sediment falling from the walls of the drill hole. Fourteen of the 19 test holes were extended to bedrock. Depths for the completed drillings were recorded in the field.

Surface elevations for each test hole were determined for correlating stratigraphic units and constructing stratigraphic cross-sections. Elevations were measured to the nearest tenth of a foot by differential leveling using a Zeiss Ni no. 2 automatic level. The datum was a spot elevation taken from the topographic map (Linn Quadrangle).

One exposed outcrop (MS-1) was described in the field. Grab samples were taken from this outcrop in three stratigraphic intervals for further

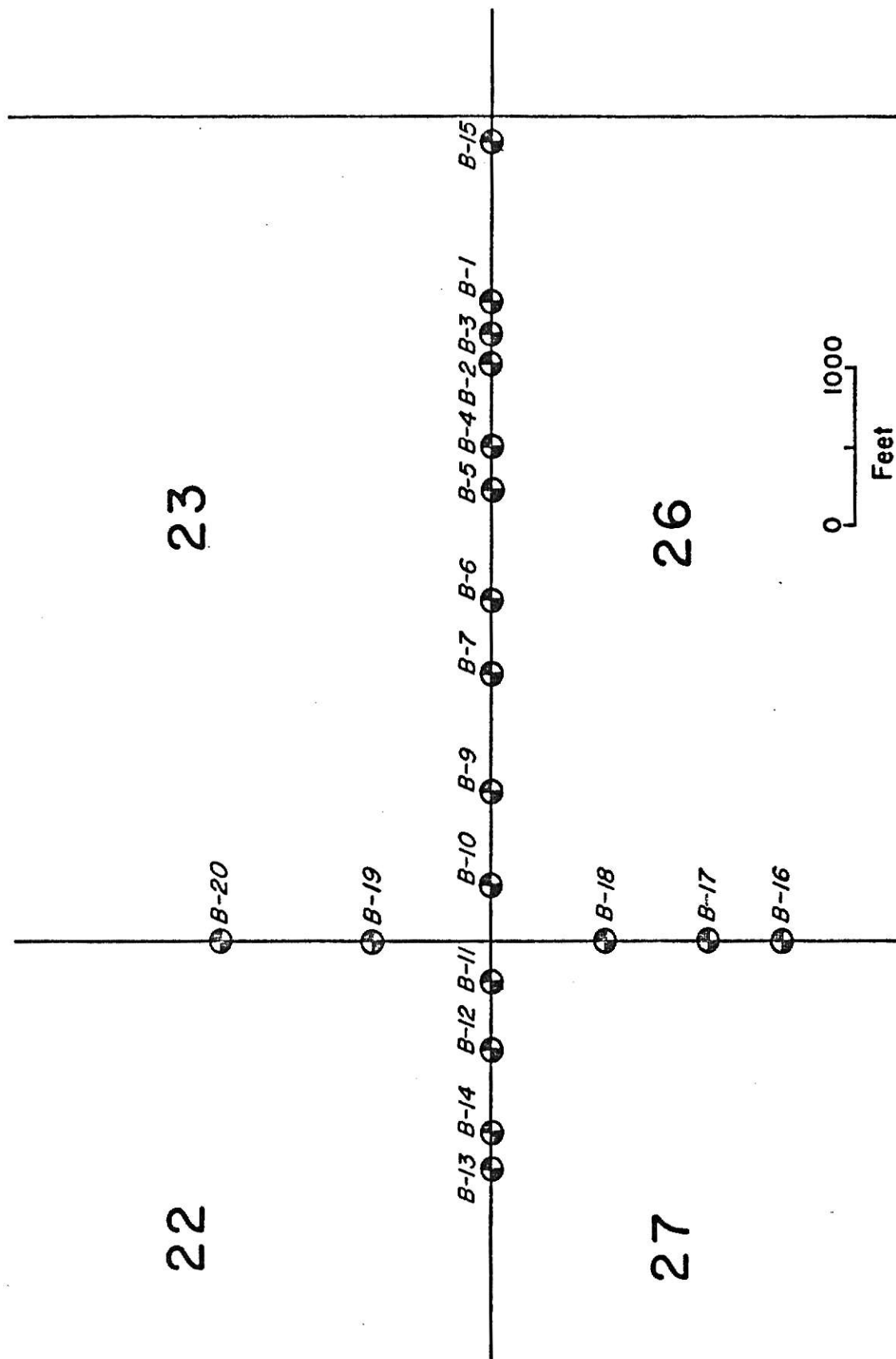


Fig. 5. Location of test holes.

testing. An outcrop of Dakota Sandstone (DK-1) was also sampled (SE 1/4, NE 1/4, SE 1/4 of Sec. 23, T 4 S., R. 3 E.), so as to compare the textural characteristics with sand recovered from the test holes.

Laboratory Procedure

Description of Cores.--Cores recovered from test holes were cut in half so that physical characteristics of the sediment could be observed more readily. The cores were then described according to: 1) grain size, 2) color, 3) calcium carbonate content, 4) iron content, and 5) other physical characteristics such as laminations, nodules, and root fillings. Contacts between major stratigraphic units were based primarily on changes of grain size and color. The depths and elevations of the contacts were recorded to the nearest tenth of a foot. Descriptions were aided by use of a hand magnifier (10X), and binocular microscope. Colors were classified according to a rock color chart (Goddard and others, 1963).

Grain Size Analysis.--Grain size distribution of sediments is important for four reasons: 1) for differentiating major stratigraphic intervals, 2) for correlating major stratigraphic intervals laterally, 3) for reconstructing depositional environments, and 4) for possibly interpreting source area.

The grain size scale used is taken from Folk (1974), as modified by Twiss (1973, personal communication) and shown in Table 1. Although grain size class limits may be expressed in several terms, the phi notation was used. Krumbein (1934) proposed the phi scale, which is based on the negative logarithm to the base 2 of the particle diameter in millimeters and is expressed as:

$$\phi = -\log_2 (\text{diam. in mm.})$$

Table 1

Grain size scales for sediments
(After Folk, 1968)

U. S. Standard Sieve Mesh #	Millimeters	Phi	Wentworth Size Class
	4096	-12	
	1024	-10	Boulder
	256	- 8	
	64	- 6	Cobble
	16	- 4	Pebble
5	4	- 2	
6	3.36	- 1.75	
7	2.83	- 1.5	Granule
8	2.38	- 1.25	
10	2.00	- 1.0	
12	1.68	- 0.75	
14	1.41	- 0.5	Very coarse sand
16	1.19	- 0.25	
18	1.00	0.0	
20	0.84	0.25	
25	0.71	0.5	Coarse sand
30	0.59	0.75	
35	0.50	1.0	
40	0.42	1.25	
45	0.35	1.5	Medium sand
50	0.30	1.75	
60	0.25	2.0	
70	0.210	2.25	
80	0.177	2.5	Fine sand
100	0.149	2.75	
120	0.125	3.0	
140	0.105	3.25	
170	0.088	3.5	Very fine sand
200	0.074	3.75	
230	0.0625	4.0	
270	0.053	4.25	
325	0.044	4.5	Very coarse silt
	0.037	4.75	
	0.031	5.0	
	0.0156	6.0	Coarse silt
	0.0078	7.0	Medium silt
	0.0039	8.0	Fine silt
	0.0020	9.0	Very fine silt
	0.00098	10.0	
	0.00049	11.0	
	0.00024	12.0	Clay
	0.00012	13.0	
	0.00006	14.0	

Because of the wide range in particle size of sediments in this study, both sieve analyses for sand fractions and pipette analyses for fine fractions were used. A flow sheet of general laboratory procedure is in Figure 6.

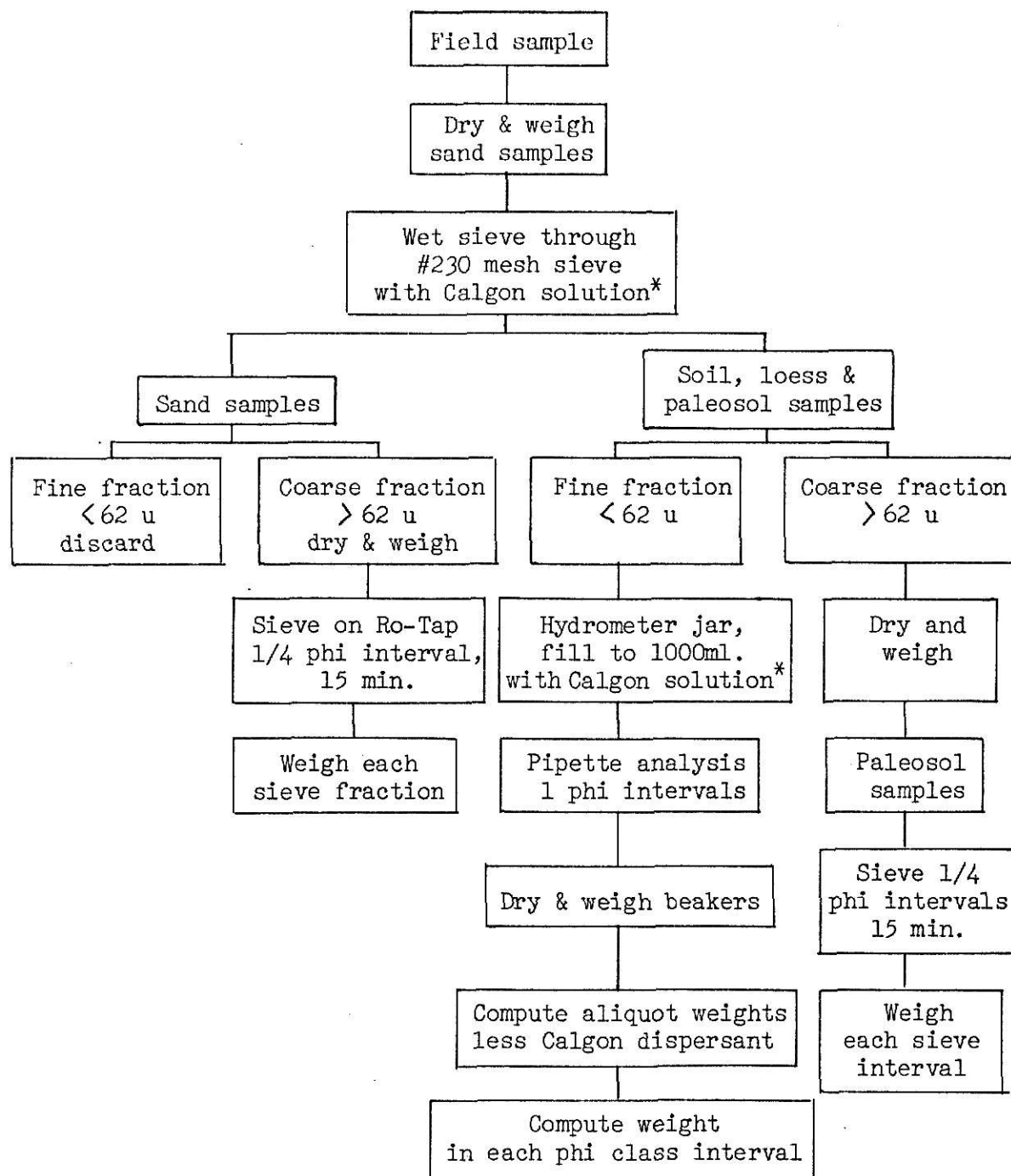
Samples representing major stratigraphic units were wet sieved through a 62.5 micron sieve to separate the coarse and fine fractions. The procedure is outlined as follows:

- 1) approximately 50 grams or less of sample (depending on the estimated sand content and moisture) placed in Waring blender with dispersing solution and mixed for 15 minutes;
- 2) disaggregated sample transferred to 62.5 micron sieve (230 mesh) and washed thoroughly with dispersing solution;
- 3) fine fraction either discarded or transferred to 1,000 ml. (milliliter) hydrometer jar for pipette analysis;
- 4) coarse fraction dried at 105°C and saved for dry sieving.

Pipette Analysis.--Because grain size distribution of particles finer than 62.5 micron (silt and clay) cannot be measured by sieving, other techniques must be used for this analysis. Decantation, centrifugation, pipette, and hydrometer methods have been used in the past for this purpose. The pipette method was used because 1) it is one of the most universally applied techniques, and 2) the laboratory apparatus was available already.

Wadell (1936) derived a formula to calculate settling velocities, based on the assumption that the particle shape is intermediate between a disc and sphere. Wadell's formula was used to derive withdrawal times for the pipette analyses done in this study.

The fine fraction, obtained by wet sieving, was first placed in a 1,000 ml. hydrometer jar and filled to the 1,000 ml. line with dispersing solution of 5.5 gm/l (grams per liter) of sodium hexametaphosphate (Calgon) (Royse, 1970, p. 27). The suspension was allowed to stand for eight hours to check



* Concentration of Calgon solution 5.5 gm./liter

Fig. 6. Flow sheet for laboratory procedures used in grain size analysis.

floculation and none was observed in any of the samples.

Royse (1970, p. 27) suggested that organic matter may affect particle settling and should be removed with treatment of hydrogen peroxide. However, because the organic content was low, this procedure was not used.

The hydrometer jar was placed in a Magni-Whirl hydrometer jar bath with a constant water temperature of 24°C and left overnight to allow thermal equilibrium to be reached between the suspension and the bath. After thoroughly mixing the suspension with a plunger, pipette withdrawals of 20 ml. were taken from the suspension at the calculated times and depths shown in Table 2. The 20 ml. aliquots were drained into pre-weighed 50 ml. beakers and dried. After cooling the beakers containing the dried aliquot, they were weighed to the nearest .001 gram.

The weights of the clean air-dried beakers were subtracted from the beaker plus aliquot weights. The weight of dispersant in the 20 ml. withdrawal was calculated and subtracted from the total aliquot weight. This weight was then multiplied by 50 because the pipette withdrawal represents only 1/50 of the weight of sediment within that size class. Differences in weights between successive size classes represent the total amount of sediment within each phi interval.

This method of analysis may be subject to many sources of error such as: 1) incomplete initial homogenization, 2) turbulence created during withdrawals of aliquots, 3) deficiency or excess of sample, 4) an abundance of very fine clays ($< .2\mu$) that remain in suspension, and 5) incomplete dispersion. Royse (1970, p. 32) stated that incomplete dispersion is probably the major source of error in most analyses.

A majority of the samples analyzed had over 26 percent of the sediment still remaining in suspension after 88 hours and 27 minutes settling time at a depth of 5 cm. Statistical parameters used by Folk and Ward (1957)

Table 2

Settling times computed according to
Wadell's Modification of Stokes' Law at 24°C.
(from Jeppesen, 1972)

Diameter (phi)	Diameter (mm.)	Depth (cm.)	(hours)	Settling Times	
				(minutes)	(seconds)
4	1/16	20	0	1	00
5	1/32	20	0	5	26
6	1/64	20	0	21	47
7	1/128	10	0	43	30
8	1/256	10	2	45	--
9	1/512	7	8	00	--
10	1/1024	5	22	57	--
11	1/2048	5	88	27	--

require that the 84th and 95th percentile values be obtainable, otherwise the median (50th percentile) is the only graphic statistic available. Folk and Ward (1957) proposed that the open end should be closed by drawing a straight line from the last point on the curve to 100 percent at 14 ϕ . Royse (1970, p. 57) suggested that the safest procedure was to work only with the known part of the curve, although he added that the closed-end method is justifiable when comparing samples of similar grain size distribution. In order to make vertical and lateral comparisons of grain size statistical parameters, the curves were closed to 100 percent at 14 ϕ .

One explanation for the large amount of clay remaining in suspension may be that the sample contained a significant quantity of very fine size clay minerals and colloidal X-ray amorphous alumina, iron oxyhydroxides, and silica. The electrical charges on the surface of these clays and colloids may exist in such a manner that cause repulsive forces which tend to keep the particles in colloidal suspension.

Precision of Pipette Method.-- The results of the initial pipette analysis proved that, in a majority of samples, the amount of silt and clay analyzed exceeded the suggested amount to be used. Folk (1974) indicated that 15 g/l is the maximum size of sample that should be used with the pipette method. Because of the range in differences in moisture and sand content of the samples, the actual dry weights of fines were difficult to determine. As a result, an excess of 15 grams of silt and clay was analyzed for many samples. Four sub-samples with dry weights of less than 15 grams were pipetted to test the effect of sample size on the analysis (Table 3).

Sternberg and Creger (1961) reported that in pipette analyses with concentrations ranging from 3 to 25 grams, the median is reproducible at the 95 percent confidence level within ± 0.4 phi units. Royse (1970, p. 33) stated that the median should be reproducible within ± 0.2 phi units.

Table 3

Result of duplicate pipette analysis of four samples

Grain Size Distribution
(Cumulative Weight Percent)

Class Interval (Phi Units)	Sample B-7, G-7		Spread Between Samples	Sample B-7, G-6		Spread Between Samples
	G-7	G ₁ -7		G-6	G ₁ -7	
4.0-5.0	13.50	18.24	4.74	17.27	22.01	4.74
5.0-6.0	32.11	33.38	1.27	43.27	46.41	3.14
6.0-7.0	42.66	41.92	0.74	54.20	57.10	2.90
7.0-8.0	48.25	46.76	1.49	59.81	62.52	2.71
8.0-9.0	53.24	51.40	1.84	64.48	67.69	3.21
9.0-10.0	56.18	55.54	0.64	67.61	72.49	4.88
10.0-11.0	59.92	59.22	0.70	72.51	76.44	3.93
11.0	100.00	100.00		100.00	100.00	

	Sample B-7, G-5		Spread Between Samples	Sample B-7, G-4		Spread Between Samples
	G-5	G ₁ -5		G-4	G ₁ -4	
4.0-5.0	32.03	38.07	6.04	34.37	42.53	8.16
5.0-6.0	46.71	51.27	4.56	48.32	54.20	5.88
6.0-7.0	55.58	58.75	3.17	56.67	59.42	2.75
7.0-8.0	60.85	62.21	1.36	61.16	62.90	1.74
8.0-9.0	65.41	65.64	0.23	65.75	65.42	0.33
9.0-10.0	67.64	68.21	0.57	67.48	67.56	0.08
10.0-11.0	69.67	70.35	0.68	67.74	69.97	0.23
11.0	100.00	100.00		100.00	100.00	

Table 3 (cont.)

Phi Statistical Parameter Values

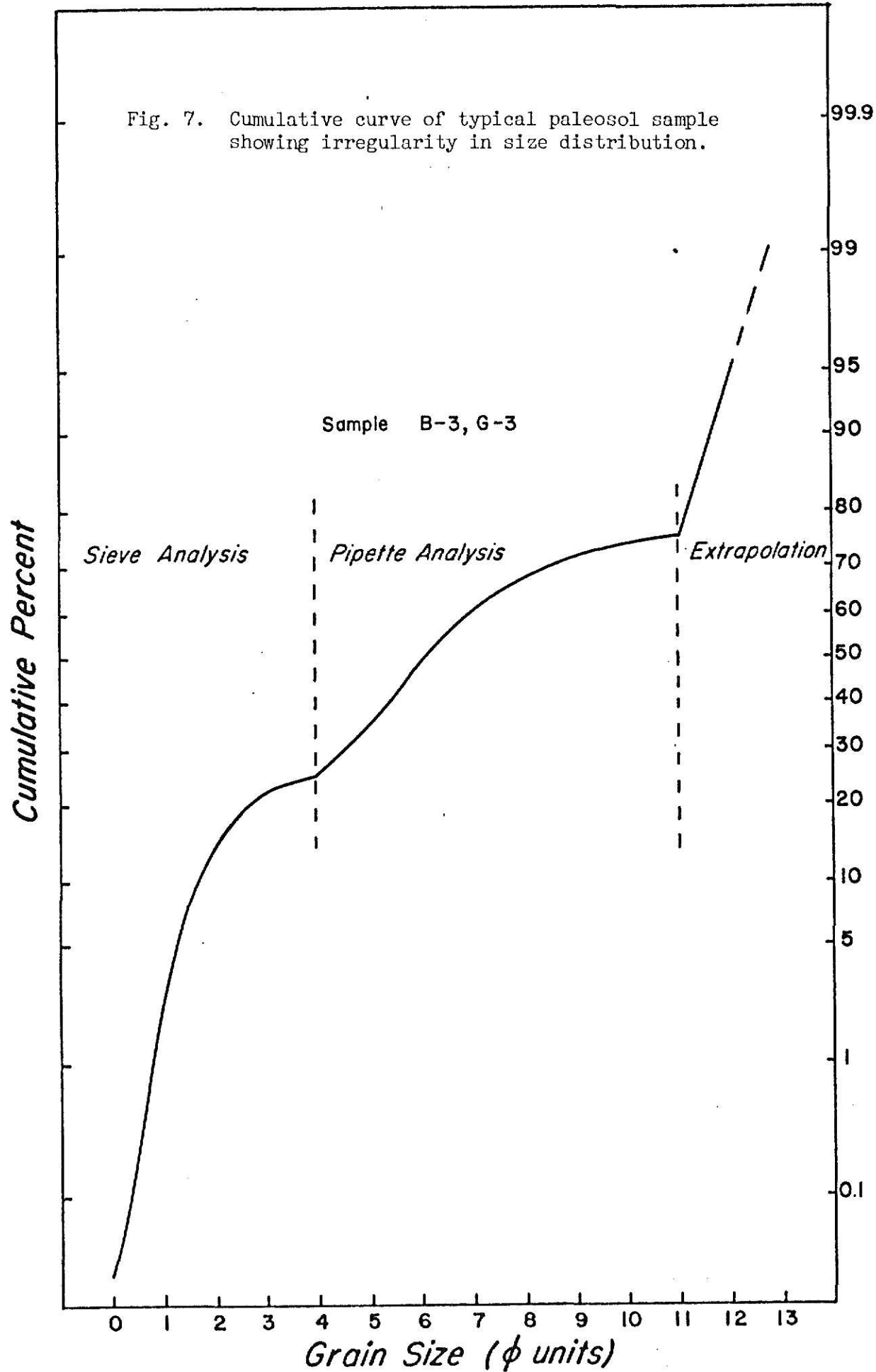
Statistical Parameters	Sample B-7, G-7		Sample B-7, G-6	
	G-7	G ₁ -7	G-6	G ₁ -6
Median (Md)	8.30 $\emptyset$	8.60 $\emptyset$	6.55 $\emptyset$	6.40 $\emptyset$
Graphic Mean (M_Z)	8.37 $\emptyset$	8.38 $\emptyset$	7.64 $\emptyset$	7.53 $\emptyset$
Standard Deviation (σ_I)	$\pm 2.81 \emptyset$	$\pm 2.88 \emptyset$	$\pm 2.73 \emptyset$	$\pm 2.72 \emptyset$
Skewness (Sk_I)	+0.02	-0.09	+0.49	+0.51
Kurtosis (K_G)	0.56	0.55	0.53	0.55
	Sample B-7, G-5		Sample B-7, G-4	
	G-5	G ₁ -5	G-4	G ₁ -4
Median (Md)	6.40 $\emptyset$	5.90 $\emptyset$	6.20 $\emptyset$	5.65 $\emptyset$
Graphic Mean (M_Z)	6.87 $\emptyset$	6.67 $\emptyset$	6.73 $\emptyset$	6.53 $\emptyset$
Standard Deviation (σ_I)	$\pm 3.77 \emptyset$	$\pm 3.73 \emptyset$	$\pm 3.83 \emptyset$	$\pm 3.81 \emptyset$
Skewness (Sk_I)	+0.13	+0.23	+0.16	+0.27
Kurtosis (K_G)	0.64	0.62	0.60	0.58

Differences between median grain size, shown in Table 3 range from ± 0.15 to ± 0.55 phi units which may indicate that the accuracy of some original analyses is questionable. Differences among mean grain sizes seemed to be less than differences among medians, therefore, mean grain size was used for correlation.

Sieve Analysis.--Sand retained on the 62.5 micron sieve after wet sieving was dried and weighed. For samples that contained over 15 percent sand, the sand fractions were dry sieved. If the sand was less than 15 percent, the sand-fraction weight was added to the weight of fines to obtain a total sample weight. All sieving was done with 8-inch, $1/4$ phi interval sieves on a Tyler Ro-Tap for 15 minutes. Each size fraction was carefully removed from the sieve and weighed to the nearest .001 gram.

Combination of Pipette and Sieve Data.--Weights of individual size classes were used to calculate cumulative weight percentages for each sample (Appendix II). Cumulative weight percentages were plotted against grain size (in phi units) on arithmetic - normal probability graph paper. An irregularity was encountered in curves representing paleosol samples where data from both sieve and pipette analyses were combined. An abrupt change in slope consistently occurred at the 4 ϕ size division, where data from the two analyses intersected; slopes decreased in the range of 3 to 4 ϕ , and then increased sharply to about 8 ϕ (fig. 7). This may represent 1) the actual sorting of the particles, or 2) the result of combining two different techniques of size analysis. The overall grain size sorting of the paleosol reflects the original sorting of the sand (parent sediment) and the addition of finer particles produced during soil development. Krumbein and Pettijohn (1938) reported that irregularities in cumulative curves may exist when results of two or more techniques are combined because each technique measures a different dimension of the particle. A sieve analysis represents measurements

Fig. 7. Cumulative curve of typical paleosol sample showing irregularity in size distribution.



of the smallest projection area of a grain that will pass through a certain size opening of a sieve. Pipette analysis is based on sedimentation and measures the largest projection area of the grain. When the two measurements are combined into one cumulative curve, an irregularity may exist.

Statistical Grain Size Parameters.--Statistical parameters proposed by Inman (1952) and Folk and Ward (1957), calculated with phi percentile values taken from cumulative curves, are summarized in Table 4. Verbal classifications of inclusive graphic standard deviation (σ_I), inclusive graphic skewness (Sk_I), and graphic kurtosis (K_G), as proposed by Folk (1974, pp. 44-36), are in Table 5. Statistical parameters by Folk and Ward were calculated with phi percentile values shown in Appendix IV.

Clay Mineral Analysis.--General procedure for clay mineral analysis is in Figure 8.

Fractionation of Clay Minerals.--About 100 grams of air-dried sample were placed in a beaker with 300 ml. of distilled water for 48 hours. The sample was stirred vigorously for disaggregation and then transferred into centrifuge tubes. Centrifugation of the sample was followed by decanting the clear liquid and adding more distilled water. The procedure was repeated until the clay remained in suspension. No dispersing agent was used in this analysis.

The washed slurry was stirred and again transferred to centrifuge tubes for collection of less than 2 micron and less than 0.2 micron fractions. Samples were centrifuged for 500 seconds at 500 RPM (revolutions per minute, using an International #2 centrifuge, 240 head) and the supernatant liquid containing the less than 2 micron fraction was collected (Jackson, 1956, p. 115). Centrifugation for 46 minutes, 36 seconds at 2,000 RPM's provided the less than 0.2 micron fraction.

Table 4

Statistical grain size parameters proposed
by Inman (1952) and Folk and Ward (1957)

Measure	Inman	Folk and Ward
Median	$Md_{\phi} = * \phi 50$	$Md_{\phi} = * \phi 50$
Mean	$M_{\phi} = \frac{\phi 16 + \phi 84}{2}$	$M_Z = \frac{\phi 16 + \phi 50 + \phi 84}{3}$
Standard Deviation (sorting)	$\phi = \frac{\phi 84 - \phi 16}{2}$	$\sigma_I = \frac{\phi 84 + \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$
Skewness	$\phi = \frac{M_{\phi} - Md_{\phi}}{\phi}$	$Sk_I = \frac{\phi 16 + \phi 84 - 2\phi 50}{2(\phi 84 - \phi 16)}$
	$2\phi = \frac{1/2(\phi 5 + \phi 95) - Md}{\phi}$	$+ \frac{\phi 5 + \phi 95 - 2\phi 50}{2(\phi 95 - \phi 5)}$
Kurtosis	$\phi = \frac{1/2(\phi 95 - \phi 5) - \phi}{\phi}$	$K_G = \frac{\phi 95 - \phi 5}{2.44(\phi 75 - \phi 25)}$

* ϕ indicates a ϕ percentile

Table 5

Verbal classifications for standard deviation (σ_I), skewness (Sk_I), and kurtosis (K_G) (from Folk, 1974)

Inclusive Graphic Standard Deviation (σ_I)			
σ_I	Value (phi units)		Verbal Classification
	0.35		Very well sorted
	0.35	to 0.50	Well sorted
	0.50	to 0.71	Moderately well sorted
	0.71	to 1.00	Moderately sorted
	1.00	to 2.00	Poorly sorted
	2.00	to 4.00	Very poorly sorted
		4.00	Extremely poorly sorted
Inclusive Graphic Skewness (Sk_I)			
Sk_I	Value		Verbal Classification
	1.00	to 0.30	Strongly fine-skewed
	0.30	to 0.10	Fine-skewed
	0.10	to -0.10	Near-symmetrical
	-0.10	to -0.30	Coarse-skewed
	-0.30	to -1.00	Strongly coarse-skewed
Graphic Kurtosis			
K_G	Value		Verbal Classification
	0.67		Very platykurtic
	0.67	to 0.90	Platykurtic
	0.90	to 1.11	Mesokurtic
	1.11	to 1.50	Leptokurtic
	1.50	to 3.00	Very leptokurtic
		3.00	Extremely leptokurtic

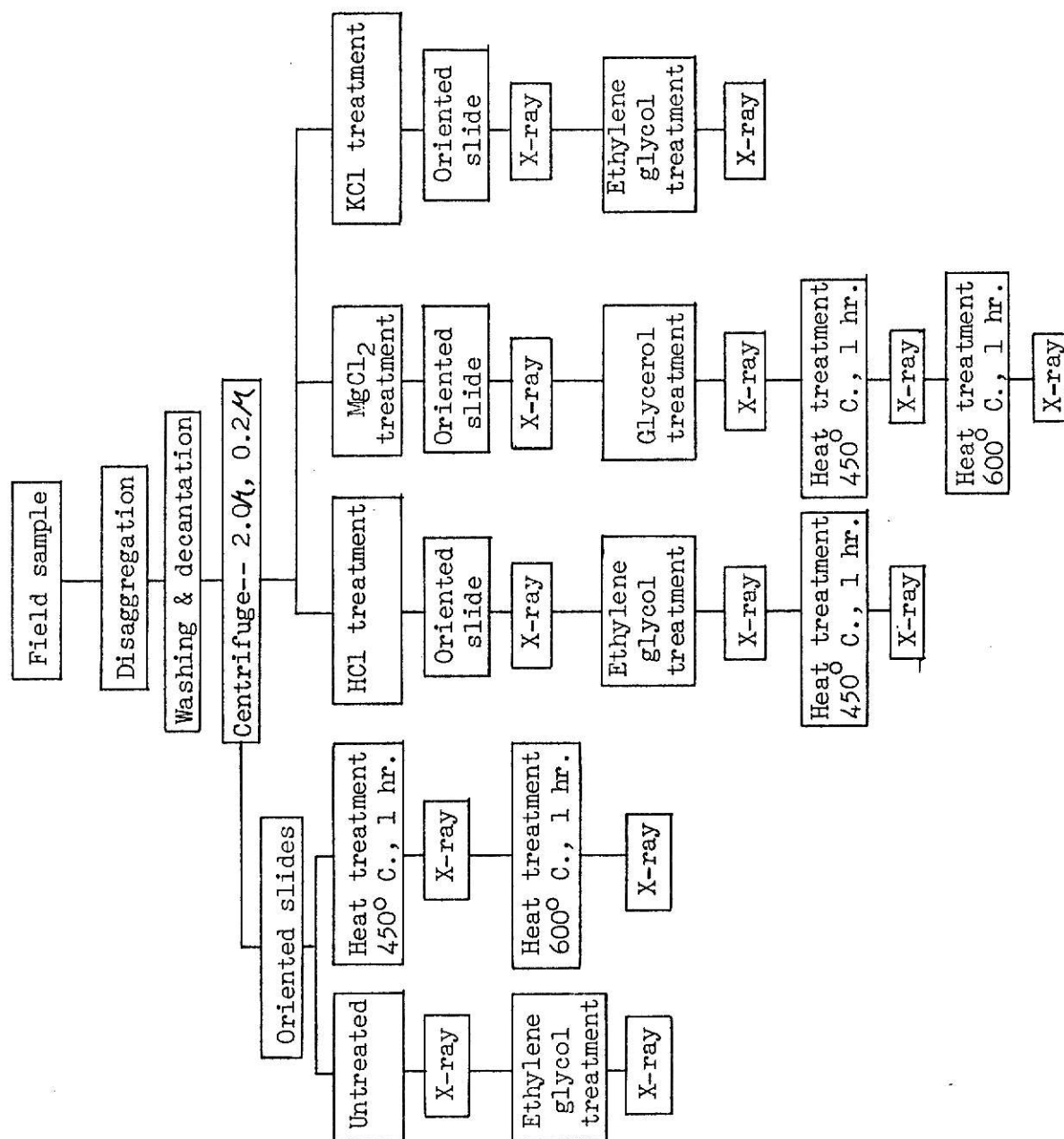


Fig. 8. Flow sheet for laboratory procedure used in clay mineral analysis.

Oriented Slides.--All X-ray analyses were done with oriented slides in which a portion of the slurry was placed on a glass slide and allowed to dry. Initially two slides were made for each sample, one to be used for untreated and glycolation analyses and the other for heat treatment analyses.

Organic Liquid Treatment.--Ethylene glycol [$C_2H_4(OH)_2$] and glycerol [$C_3H_5(OH)_3$] were used in clay mineral identification. Organic molecules enter the interlayer sites of certain 2:1 clay minerals, such as smectites, mixed-layer illites, some varieties of chlorite and vermiculite. Expansion of the clay structure results along the c-axis to as much as 3 Å.

Prior to X-ray analysis, slides were saturated with ethylene glycol or glycerol vapors for 48 hours to aid in differentiating vermiculite from smectite (Walker, 1961). Low charged Mg-saturated smectite expands under treatment with either organic complexes, whereas Mg-vermiculite will not expand with glycerol treatment.

Heat Treatment.--Changes observed in clay mineral structure under heat treatment are helpful in identification. However, the chemical composition and the degree of crystallinity of the clay minerals must also be considered. Samples were heated at 450°C and 600°C, then placed in a dessicator and X-rayed immediately.

Kaolin minerals lose structural water and crystallinity at 550°C (Brindley, 1961a, p. 84). Smectite minerals lose interlayer water in the range of 100° - 200°C giving a "collapsed" structure in dry atmosphere. The degree of collapsing depends largely on the interlayer cation. Upon further heating, smectites begin to lose water formed from hydroxyl groups in the layers. This depends on the chemical composition and may occur at temperatures ranging from 400° - 900°C (MacEwan, 1961, p. 189). Vermiculite, as do the smectites, shows some collapsing of structure upon heating but rehydrates and swells again quickly at low temperatures (Walker, 1961). Poorly crystalline

varieties of chlorite will decompose at temperatures as low as 450°C , whereas crystallized chlorite usually decomposes at 600°C (Brindley, 1961b, p. 263). Illite loses hydroxyl water between 200°C and 600°C , but retains its original structure up to 850°C (Bradley and Grim, 1961, p. 232).

Acid Treatment.--Treatment with HCl is useful in determining the stability of crystal structures of different clay mineral groups. Smectite minerals treated with HCl show decreases in basal spacing (MacEwan, 1971, p. 175). Chlorite is soluble in HCl (Brindley, 1961b, p. 264) and Lee (1972) reported that vermiculite may also be soluble under acid treatment. For this study, about 25 ml. of slurry was mixed with 20 ml. of 6 N HCl and warmed for 10 hours. The treated slurry was washed until a pH of 7 was reached. An oriented slide was then made from the slurry for determining the X-ray diffraction characteristics.

Cation Saturation.--Certain clay minerals have the ability to exchange cations in interlayer sites which may affect their hydration properties. The basal spacing of smectite minerals and vermiculite is dependent on the cation in the interlayer sites (Walker, 1961). Exchange properties of clay minerals may be used to differentiate the crystal chemistry of some minerals (Weaver, 1958).

Samples were saturated with K^{+} and Mg^{+2} by mixing one 25 ml. aliquot of clay slurry with 20 ml. of 1N KCl and another aliquot with 1N MgCl_2 . The mixtures were allowed to stand for 48 hours to allow for complete saturation of cations. The treated slurries were then washed thoroughly for removal of excess salts and oriented slides prepared for X-ray diffraction studies.

X-Ray Diffraction.--Identification of clay minerals was based on X-ray, Ni-filtered Cu-K-alpha radiation. A Norelco Wide Range Diffractometer was used, with the following mechanical settings: 35 kilovolts and 18 milliamperes,

scanning speed of 1° /minute, chart speed 30 inches/hour, time constant of 2 seconds, and proportional counter detector. The pulse-height analyzer was set at 5.04 volts, with a window of 2.20 volts and a detector voltage of 1.62 kilovolt. The goniometer slit system was composed of divergent and antiscatter slits of 1 degree, and a .003-inch receiving slit. Slides were generally scanned up to 45° two theta.

Organic Carbon Analysis.--According to Jackson (1965a, p. 205), carbon occurs in sediments in the following four forms: 1) inorganic carbonate mineral forms, chiefly CaCO_3 and MgCO_3 . CaCO_3 ; 2) condensed elemental or nearly elemental forms such as graphite and coal; 3) altered and resistant organic residues of plants, animals, and micro-organisms, sometimes called humus; and 4) slightly altered organic residues of plants, animals, and micro-organisms, subject to rapid decomposition. Total carbon content then includes all forms, whereas total organic carbon content includes the last three. Chemically active organic matter that is associated with soil genesis and fertility includes forms 3 and 4. These two forms of carbon are the most significant forms when studying relationships among paleosols, loesses, and recent soil horizons.

Methods for determining active organic carbon were described in Hesse (1971, pp. 242-254) and Jackson (1965a, pp. 206-226). Among those mentioned the Walkley-Black method is the simplest and most widely used procedure. This method measures only the active organic carbon and excludes 90 to 95 percent of the elementary carbon. An oxidation-reduction reaction is involved in the analysis, where organic carbon is oxidized and a dichromate solution is reduced. Oxidation is aided by the heat of reaction produced between the dichromate solution and concentrated sulphuric acid. The excess amount of dichromate is titrated with ammonium iron (II) sulphate and percent oxidizable organic

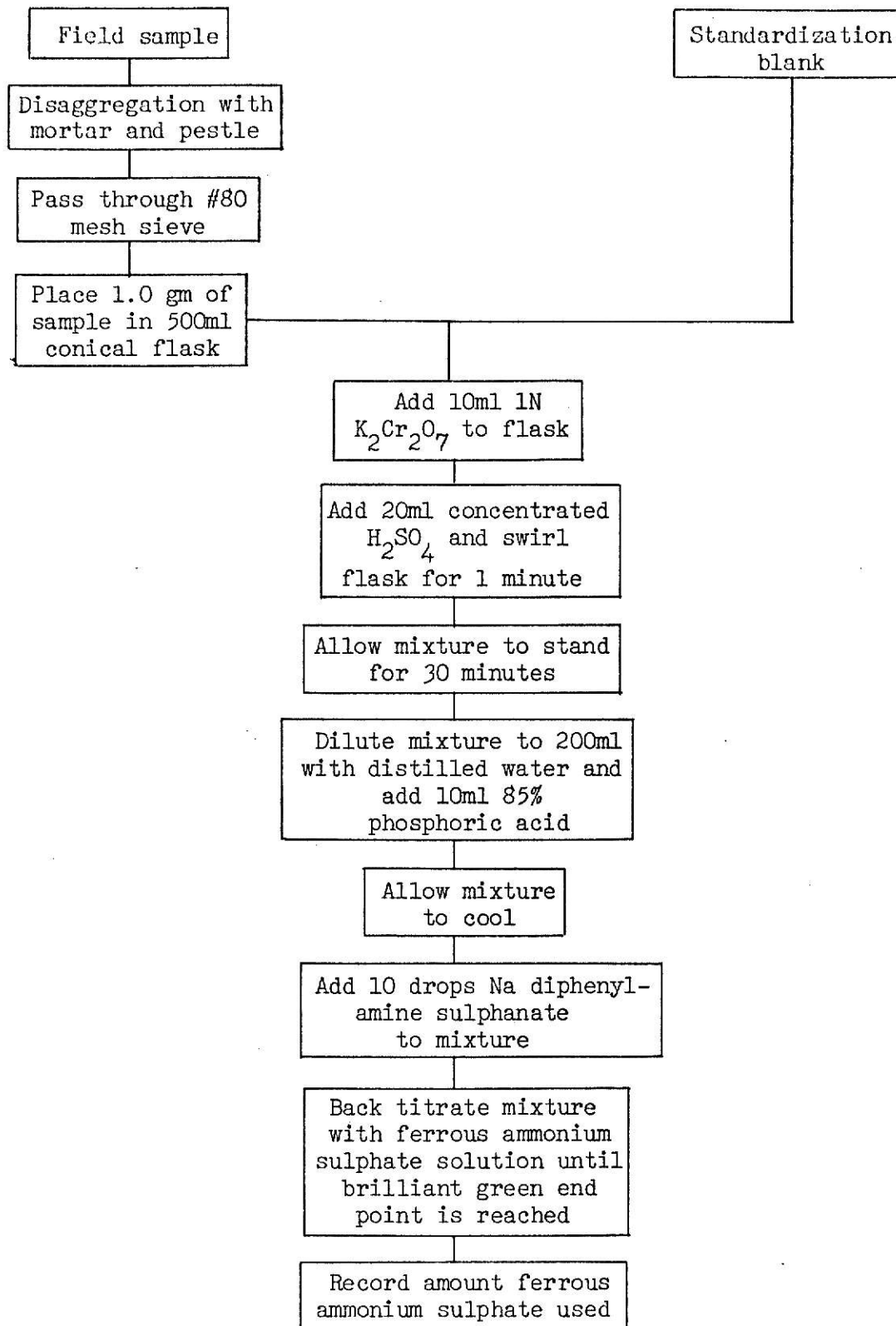


Fig. 9. Flow sheet for laboratory procedure used in Walkley-Black method of organic carbon analysis.

carbon is then calculated with this equation:

$$\frac{(\text{blank titre} - \text{actual titre}) \times 0.3 \times M}{\text{weight of oven-dry soil in gms.}}$$

where M is the concentration of ammonium iron (II) sulphate.

The result may be expressed as 1) the uncorrected form as readily oxidizable percent organic carbon, 2) percent total organic carbon by multiplying the original value by 1.33, or 3) percent organic matter by multiplying the original value by 2. The conversion factor, 1.33, is conventional for the Walkley-Black method and is based on 75 percent recovery of total organic carbon. The factor, 2, is a combination of the Walkley-Black conversion factor, 1.33, and the factor, 1.724, which is based on the conventional assumption that organic matter contains 58 percent carbon.

Samples representing major stratigraphic units were analyzed according to the flow sheet of procedure (fig. 9). The Walkley-Black method of determining oxidizable organic carbon is outlined in Hesse (1971, p. 245) and in Jackson (1965a, p. 219). A list of reagents and apparatus used for the analysis and details of the procedure are shown in Appendix V.

Hydrogen Ion Activity.--In the past, attempts have been made to compare hydrogen ion activity (pH) among Quaternary sediments (Simonson, 1941, 1954). Because many variables may affect the pH of a sediment, interpretation of past environments based solely on pH values should be avoided.

Jackson (1965a, p. 41) defined pH by the equation:

$$\text{pH} = \log \frac{1}{a_{\text{H}^+}} = -\log_{10} a_{\text{H}^+}$$

where the activity of H^+ in the soil suspension, a_{H^+} , is expressed as gm - ions per liter. By specifying activity rather than concentration, it is recognized that other hydrogen ions exist in the sediment but only the active H^+ is measured. Jackson (1965a, p. 42) listed several factors that may affect pH: 1) drying of the sample during preparation; 2) the amount of

water used for the suspension; 3) the content of soluble salts; and 4) the amount of grinding of the soil. Samples were prepared and pH values determined by a glass electrode direct-reading pH meter as in Figure 10. The method adapted from Jackson (1965a, p. 47) was followed.

Mineralogy of Sand and Sandstone.--Mineralogy of sand and sandstone was determined to support interpretations of the history of deposition. Samples were wet sieved through a 62.5-micron sieve (230 mesh) to separate the silt and clay fraction from the sand. Fine fractions were discarded and sand fractions were quartered with a sample splitter until approximately 100 grains remained.

Grains were examined using binocular and petrographic microscopes. Positive identification of representative grains was made with immersion oils and the petrographic microscope. About 100 grains from each sample were counted with a binocular microscope. The mineralogy and surface textures were determined for each grain.

Surface Textures of Quartz Grains.--In the past, the studies of quartz-grain surface textures have been greatly aided by using the scanning electron microscope (SEM). Most studies were concerned with the relationship between surface textures and sedimentary environments (Krinsley and Doornkamp, 1973; Krinsley and Margolis, 1969; Krinsley and Donahue, 1968; Krinsley and Takahashi, 1962a, 1962b, 1962c, and 1964).

For this study, the SEM was used to examine the surface textures of quartz grains from sand and sandstone. Preparation of samples for SEM analysis was adapted from Krinsley and Doornkamp (1973, p. 7).

FIELD DATA

Stratigraphic cross-sections were drawn from test hole data. (Plates I and II). The east-west cross-section (Plate I) indicates a topographic basin

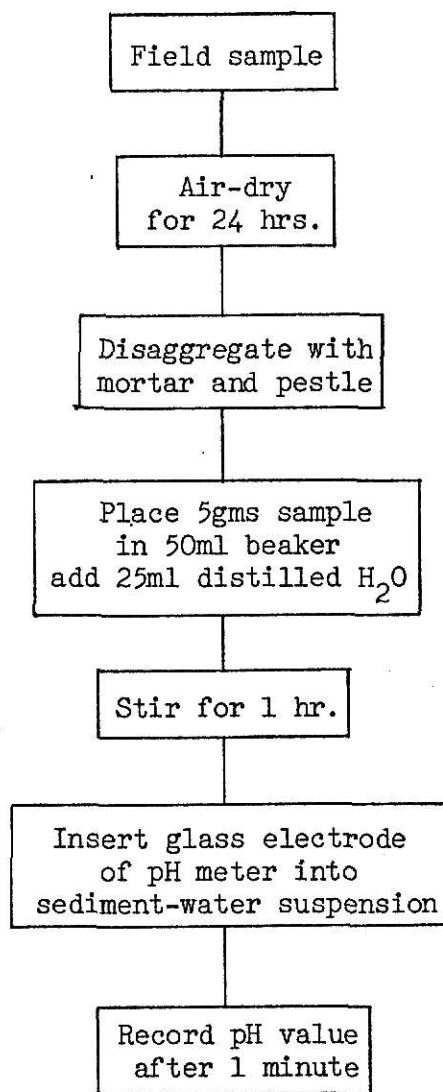
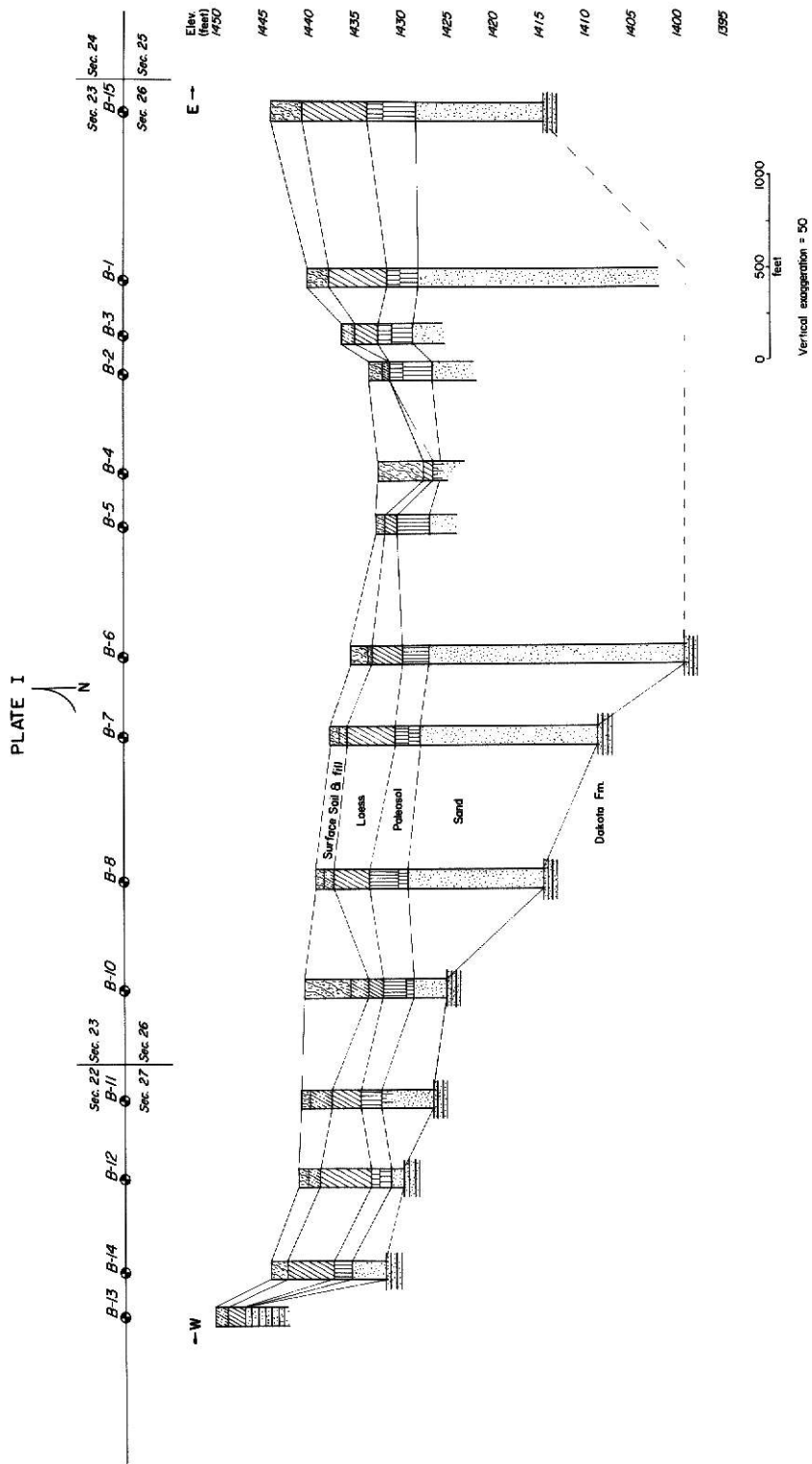


Fig. 10. Flow sheet for laboratory procedure used in pH analysis (adapted from Jackson, 1965a, p. 47).

EXPLANATION OF PLATE I

East-west cross-section showing the major Quaternary units and the topographic basin developed on bedrock.

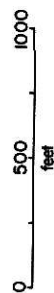
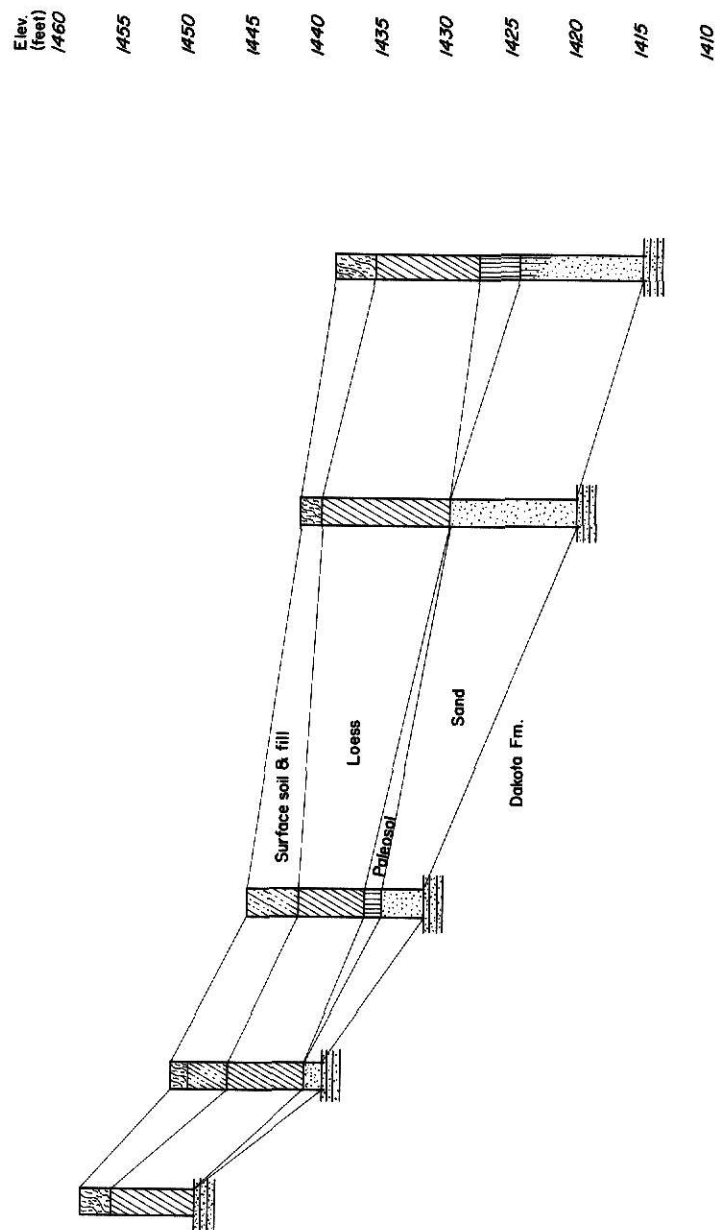
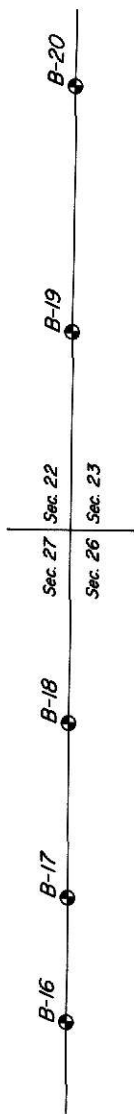


EAST-WEST CROSS SECTION

EXPLANATION OF PLATE II

North-south cross-section showing the major Quaternary units and decreasing bedrock elevations from south to north.

PLATE II



Vertical exaggeration = 50

NORTH-SOUTH CROSS SECTION

developed on the bedrock surface. Elevations of unweathered bedrock range from 1399.3 feet at test hole B-6, to 1447.0 feet at B-13. The stairstep profile of the bedrock in the western half of the cross-section resembles terraces. Sediments overlying bedrock are thicker in the center of the cross-section and become thinner towards both ends. Thicknesses of sediments range from more than 38 feet at test hole B-1, to 3.2 feet at B-13. The ground surface profile of the cross-section reflects a basin with less relief than the basin in bedrock.

The north-south cross-section (Plate II) shows decreasing bedrock elevations from south to north. The southernmost test hole (B-16) shows an unweathered bedrock elevation of 1448.6 feet, whereas the northernmost test hole (B-20) shows a lower elevation of 1414.5 feet. Sediments overlying bedrock, thicken in a northerly direction. Sediment thicknesses range from 8.8 feet at B-16 to 23.8 feet at B-20. As in the east-west cross-section, the ground surface profile also reflects the bedrock profile.

The bedrock consists of beds of sandstone and shale of the Dakota Formation. It was positively identified by auger cuttings and drilling characteristics in shallower test holes. In deeper test holes, however, classification was based entirely on drilling characteristics, because auger cuttings from those depths could not be brought to the surface.

LABORATORY DATA

Cores of Samples

Close visual examination of sample cores proved to be one of the more beneficial methods of distinguishing major stratigraphic units and correlating them across the study area. Four major units identified successively from top to bottom were 1) a surface soil horizon, 2) a gray-brown loess-like

sediment, 3) a dark brown sandy-clay silt paleosol, and 4) fine to medium, tan, uncemented sand. Within the major stratigraphic units, minor intervals were also distinguished. These distinctions were based primarily on color changes, grain size, zones of carbonate or iron oxide accumulations, and zones of prominent laminations. Complete descriptions of sample cores and augered test holes are in Appendix I.

Surface Soil.--Surface soil development could not be described adequately from the core samples. Road construction had destroyed much of the profile, making it difficult to distinguish specific horizons. The A-horizon and much of the B-horizon are absent in most cores. The entire soil profile was missing in one sample.

Distinctions between B and C horizons were based on color and grain size. B-horizons ranged from dusky yellowish-brown (10 YR 2/2) to dark yellowish-brown (10 YR 4/2) and generally had high clay contents ranging from 43 percent to 48 percent by weight. C-horizons were lighter in color, ranging from dark yellowish-brown (10 YR 4/2) to pale yellowish-brown (10 YR 6/2). Clay content in this horizon was mostly lower than in the B-horizon. Mottling of colors was evident in a few samples, which may indicate poor drainage through the soil (Soil Survey Staff, 1951, p. 166). Boundaries between horizons were gradational in the majority of profiles.

Thicknesses of the B- and C-horizons, where present, ranged from 0.3 feet, at B-6, to 1.9 feet at B-10. Iron oxide staining (light brown - 5 YR 5/6) and calcium carbonate accumulation were observed in the surface soil of some localities.

Loess.--The loess consists of uniform textured clayey silt. Colors ranged from yellowish gray (5 Y 8/1) to pale yellowish-brown (10 YR 6/2), except in zones where iron oxide staining created a moderate reddish-brown hue (10 R 4/6). Boundaries between the loess and the overlying soil profile

were generally gradational, whereas those separating the loess and paleosol were more distinct (plate III, fig. C). A few cores, however, had slight gradational boundaries between the loess and paleosol. The boundaries were characterized by dark laminations or bands ranging from a fraction of a millimeter to 0.5 centimeter in thickness which may represent temporary cessations in loess disposition (plate III, Fig. B). Frye and Leonard (1952, p. 130) noted similar occurrences of such bands in the basal zone of the Peoria Loess and stated:

"At a few localities in southwestern Nebraska distinct but very weak soil zones occur in the upper part of this basal zone and suggest minor pauses in loess accumulation."

Prominent zones of fine lamination were observed also above the basal contact in some core samples (plate III, fig. A). Laminations within the Peoria Loess in northeastern Kansas have also been reported by Frye and Leonard (1952, p. 129).

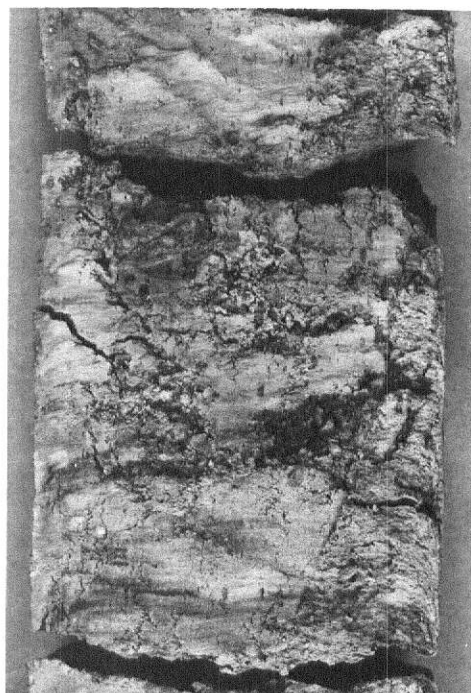
Iron oxide accumulated in different amounts ranging from randomly distributed thread-like fillings (less than 1 millimeter in diameter and up to 5 centimeters in length), to heavily concentrated zones. Particularly heavy concentrations of iron oxide existed in samples B-6 and B-11, giving the sediment moderate reddish-brown color (10 R 4/6) and a brittle texture. Precipitate of calcium carbonate within this unit was seen in several core samples at depths ranging from 1.5 to 4.0 feet from ground level. Thicknesses of the loess based on core samples only, ranged from 0.0 feet at B-2 to 6.4 feet at B-1.

Paleosol.--The unit below the loess is classified as a paleosol for three reasons: 1) its relatively sharp contact with the overlying loess; 2) its distinct dark color; and 3) its higher clay content than the underlying sand (34 percent as opposed to 9 percent). Color of the paleosol is similar to the surface soil and ranges from dusky yellowish-brown (10 YR 2/2)

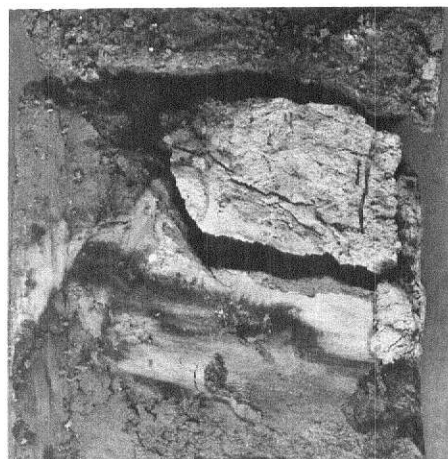
EXPLANATION OF PLATE III

- Figure A. Core of test-hole B-11 showing fine laminations in the loess at a depth of 6.1 to 6.3 feet.
- B. Core of test-hole B-11 showing thicker bands or laminations at the paleosol/loess contact. Depth of the band is 7.0 feet.
- C. Core of test-hole B-9 showing a sharp contact between the loess and paleosol at a depth of 5.7 feet and elevation of 1433.4 feet.
- D. Core of test-hole B-9 showing gradational contact between the paleosol and sand at a depth of 4.5 feet and elevation of 1430.2 feet.

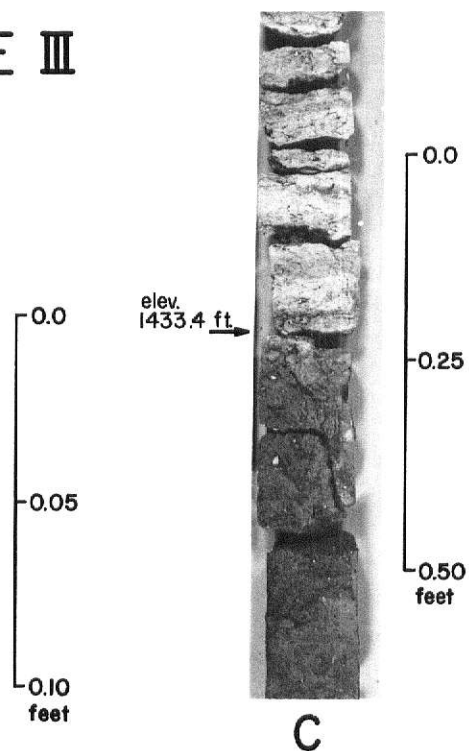
PLATE III



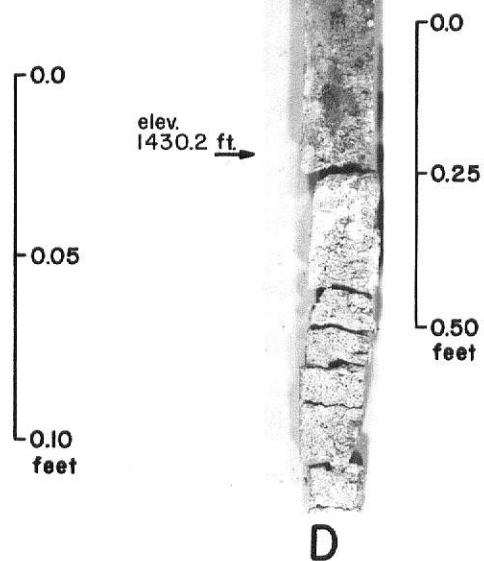
A



B



C



D

to pale yellowish-brown (10 YR 6/2). Irregular patches of these colors (mottling) were observed in a few samples, indicating impeded drainage through the paleosol. Contacts with the lower sand unit were gradational (plate III, fig. D). Color becomes lighter, and clay content decreases as the paleosol grades downward into the sand.

Horizons within the paleosol were difficult to recognize. Two horizons seemed to exist in several samples: 1) an upper horizon, usually dusky yellowish-brown (10 YR 2/2) with a higher clay content; and 2) a lower horizon, generally dark yellowish-brown (10 YR 4/2) to pale yellowish-brown (10 YR 6/2) with a lower clay and higher sand content. Boundaries between the two horizons were gradational and often indistinct. Based on the relative clay contents, the upper horizon may represent the B-horizon, whereas the lower represents the C-horizon. Thornbury (1969, p. 70) stated that B-horizons are characterized by higher concentrations of clay which have been mechanically removed from the A-horizon and transported downward by descending water.

Accumulations of iron oxide ranged from random thread-like fillings and nodules to thin concentrated zones up to 3 centimeters thick. Generally, the accumulations were not as concentrated as in the overlying loess. Calcium carbonate was in three core samples and was probably leached from the overlying loess. Many samples had fine laminations similar to those in the loess. Thicknesses of the paleosol ranged from 0.3 feet at B-4 to 4.9 feet at B-3.

Sand.--This unit consists of uncemented, fine to medium, quartz sand. An upper clayey zone, in most places two to three feet thick, was examined from core samples. The remaining depth of the interval was described from auger cuttings and drilling characteristics.

The sand ranged from grayish-orange (10 YR 7/4) to yellowish-gray (5 Y 8/1), depending on the amount of iron oxide staining. Iron oxide accumulation was low throughout most of the unit as shown by the grayish-orange color (10 YR 7/4). Upper boundaries between the sand and paleosol were gradational, but contacts between the sand and bedrock were more distinct (plate III, fig. D). The interval reaches a maximum thickness of 27.5 feet at B-6 and gradually thins to the east and west. The north-south cross section shows the thickness of the interval increases to the north.

Grain Size Analysis

Grain Size Nomenclature.--A major purpose for obtaining quantitative size data is to classify the sediment according to its relative amount of major size classes (gravel, sand, silt, and clay). Grain size classifications, although somewhat arbitrary, are convenient for describing and comparing sediments. Both binary and ternary classification systems have been proposed in the past, but ternary systems are now the most widely used. Ternary diagrams based on the Udden-Wentworth size scale have been proposed by Shepard (1954), Folk (1954), and Link (1966). The U. S. Department of Agriculture has developed a separate ternary system for the textural classification of soils that differs slightly, in that the boundary between sand and silt is set at 0.05 millimeter instead of 0.0625 millimeter on Wentworth's scale. Because recent soils and older sediments were studied in this investigation, both the USDA diagram and Shepard's diagram were used for grain size classification. Relative percentages of sand, silt, and clay were plotted on the two ternary diagrams (fig. 11). Data are in Table 6.

Evaluation of Data.--Grain size distributions within each of the four major stratigraphic units show minimal lateral differences (fig. 11 and fig. 12). Each pattern reflects the range of size distribution within that unit.

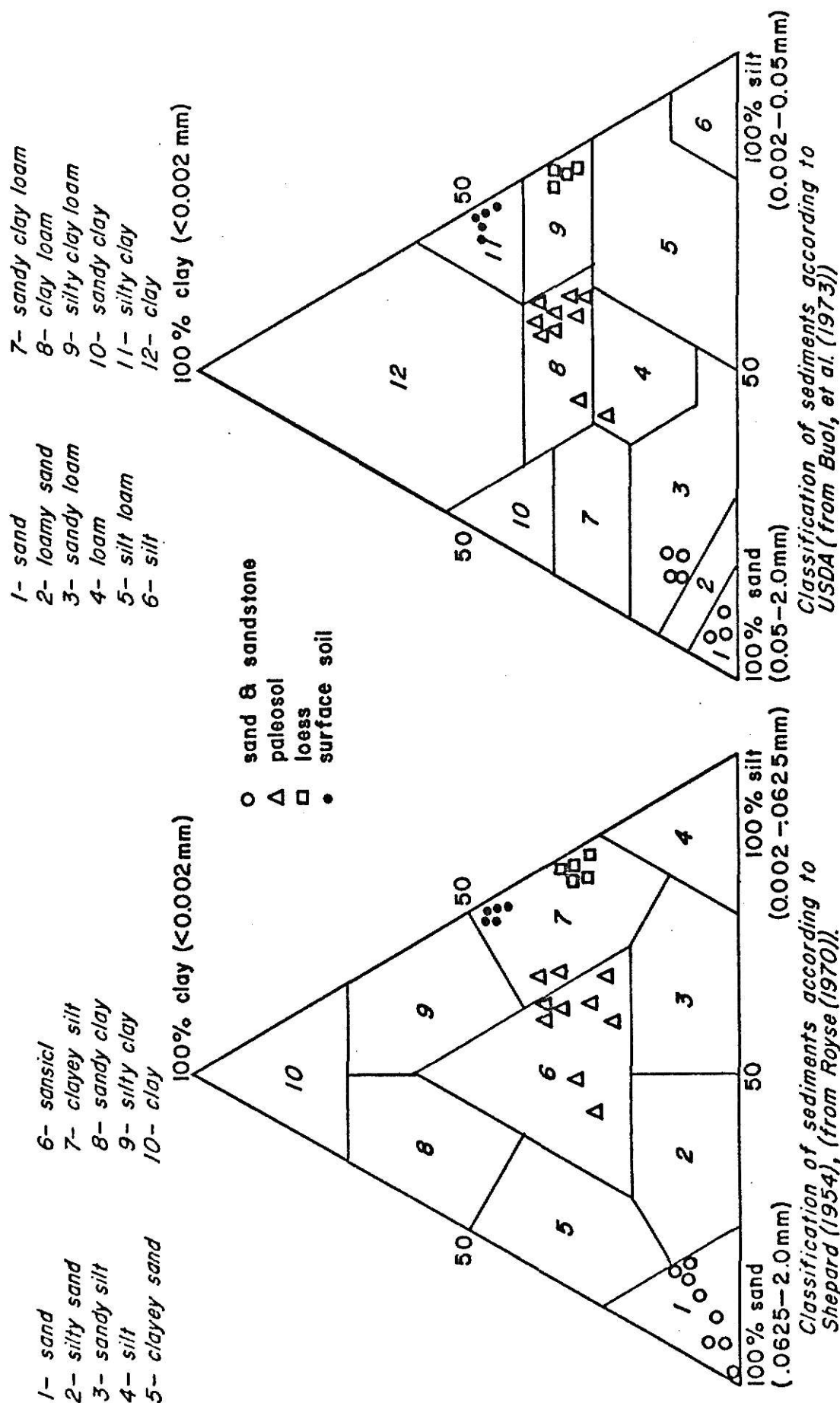


Fig. 11. Grain size nomenclature of sediments.

Table 6

Sand, silt, & clay percentages
and grain size nomenclature

Sample No.	Depth (ft)	Elevation (ft)	%Sand		%Silt		%Clay	Grain Size Classification Shepard (1954)	Grain Size Classification USDA
B-3, G-5	0.8	1435.6	1.68	2.80	51.14	50.02	47.18	Clayey silt	Silty clay
B-3, G-4	3.1	1433.3	0.65	2.50	69.89	68.03	29.47	Clayey silt	Silty clay loam
B-3, G-3	4.3	1432.1	24.73	26.00	46.87	45.60	28.40	Sansicl	Clay loam
B-3, G-2	6.6	1429.8	35.71	39.00	34.67	31.18	29.82	Sansicl	Clay loam
B-3, G-1	9.5	1426.9	90.48	91.00	9.52	9.00		Sand	Sand
B-5, G-3	2.7	1430.0	0.81	1.95	55.93	54.79	43.26	Clayey silt	Silty clay
B-5, G-2	4.9	1427.8	16.61	19.70	46.57	43.48	36.82	Clayey silt	Clay loam
B-5, G-1	6.7	1426.0	75.98	76.80	24.02	23.20		Sand	Sandy loam
B-7, G-7	1.3	1436.2	1.60	3.50	51.64	49.74	46.76	Clayey silt	Silty clay
B-7, G-6	4.4	1433.1	0.19	0.75	64.29	63.73	35.52	Clayey silt	Silty clay loam
B-7, G-5	7.4	1430.0	19.09	21.00	46.32	44.41	34.59	Sansicl	Clay loam
B-7, G-4	9.2	1428.3	22.92	25.40	42.83	40.45	34.25	Sansicl	Clay loam
B-7, G-3	10.2	1427.3	76.42	78.80	23.58	21.20		Sand	Sandy loam
B-7, G-2	12.2	1425.3	79.28	81.40	20.72	19.60		Sand	Sandy loam
B-7, G-1	24.8	1412.7	99.15	99.20	0.85	0.80		Sand	Sand
B-9, G-5	2.2	1436.8	0.19	1.00	53.93	53.12	45.88	Clayey silt	Silty clay
B-9, G-4	5.0	1434.1	0.10	0.80	64.99	64.29	34.91	Clayey silt	Silty-clay loam
B-9, G-3	7.2	1431.9	23.17	25.00	41.24	39.04	35.60	Sansicl	Clay loam
B-9, G-2	9.2	1429.8	24.34	26.80	40.47	38.01	35.19	Sansicl	Clay loam
B-9, G-1	10.8	1428.3	80.83	82.60	19.17	17.40		Sand	Sandy loam
B-11, G-5	2.2	1438.5	0.24	0.85	51.90	51.30	47.85	Clayey silt	Silty clay
B-11, G-4	4.7	1436.0	0.10	0.70	65.46	64.86	34.44	Clayey silt	Silty clay loam
B-11, G-3	6.6	1434.1	22.64	25.00	51.20	48.85	26.15	Sansicl	Clay loam
B-11, G-2	7.9	1432.8	31.88	35.50	45.99	42.37	22.13	Sansicl	Loam
B-11, G-1	9.7	1431.0	46.95	50.00	53.05	50.00		Sansicl	Loam
B-11, S-8	13.0- 18.0	1427.7- 1422.7	91.49	92.50	8.51	7.50		Sand	Sand
Dk#1		1425± 5ft	88.70	90.00	11.30	10.00		Sand	Sand

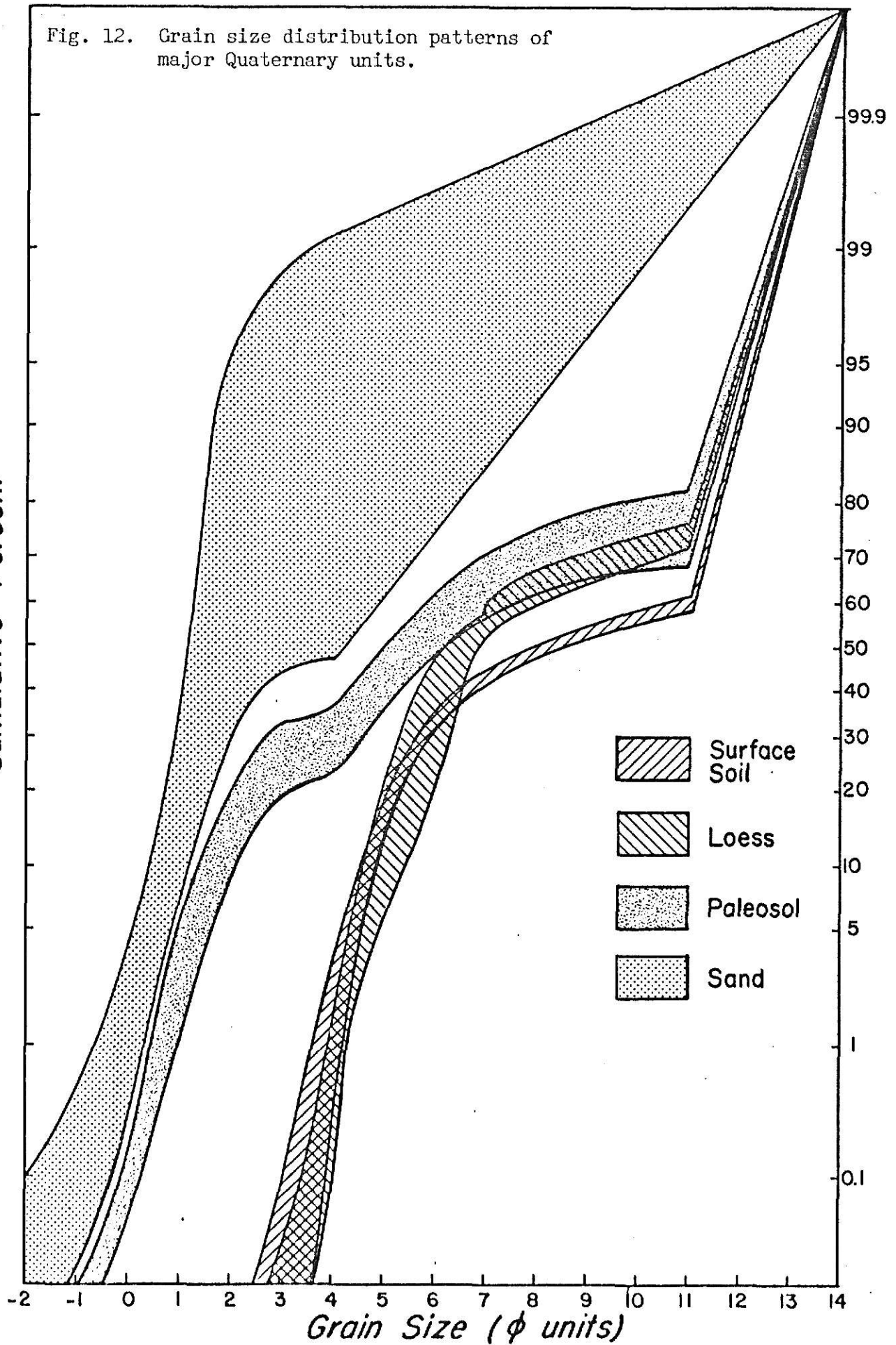
- Wentworth Grain Size Classification

* - USDA Grain Size Classification

+ - Total Silt and Clay

Fig. 12. Grain size distribution patterns of major Quaternary units.

Cumulative Percent



Lateral differences of mean grain size within the same unit are generally smaller than vertical differences of mean grain size among units (fig. 13).

Calculated statistical parameters (Table 7) show that surface soil samples range in mean grain size from 8.29 ϕ to 8.44 ϕ , are very poorly sorted, nearly symmetrical and very platykurtic. Loess samples have mean grain sizes ranging from 7.40 ϕ to 7.64 ϕ , are very poorly sorted, strongly fine-skewed, and very platykurtic. Paleosol samples range in mean grain size from 5.90 ϕ to 6.87 ϕ , are very poorly to extremely poorly sorted, fine-skewed, and platykurtic to very platykurtic. Sand samples have mean grain sizes ranging from 1.37 ϕ to 2.87 ϕ , are generally poorly sorted, strongly fine-skewed, and very leptokurtic. One sand sample (B-7, G-1), which was taken from auger cuttings was very well sorted, nearly symmetrical and leptokurtic. The two bedrock samples of Dakota Sandstone have mean grain sizes of 2.22 ϕ and 2.17 ϕ , are moderately sorted, strongly fine-skewed, and very leptokurtic to extremely leptokurtic.

Swineford and Frye (1951) determined that the Peoria Loess in north-eastern Washington County has a median grain size of 5.44 ϕ . Loess samples from the present study, however, have smaller median sizes ranging from 6.10 ϕ to 6.55 ϕ . Ruhe (1968) investigated the difference in grain size between paleosols and surface soils from Iowa and contended that both similarities and dissimilarities existed between the two. Comparing the surface soil and palaeosol from the present study, the surface soil has a consistently higher concentration of clay. This may be a reflection on the different types of parent material from which the two developed.

Relationships among grain size distributions of sand and depositional environments have been studied by Friedman (1961). He indicated that through comparisons of statistical parameters, distinctions among dune, beach, and river sands could be made. Dune and river sands are generally fine-skewed

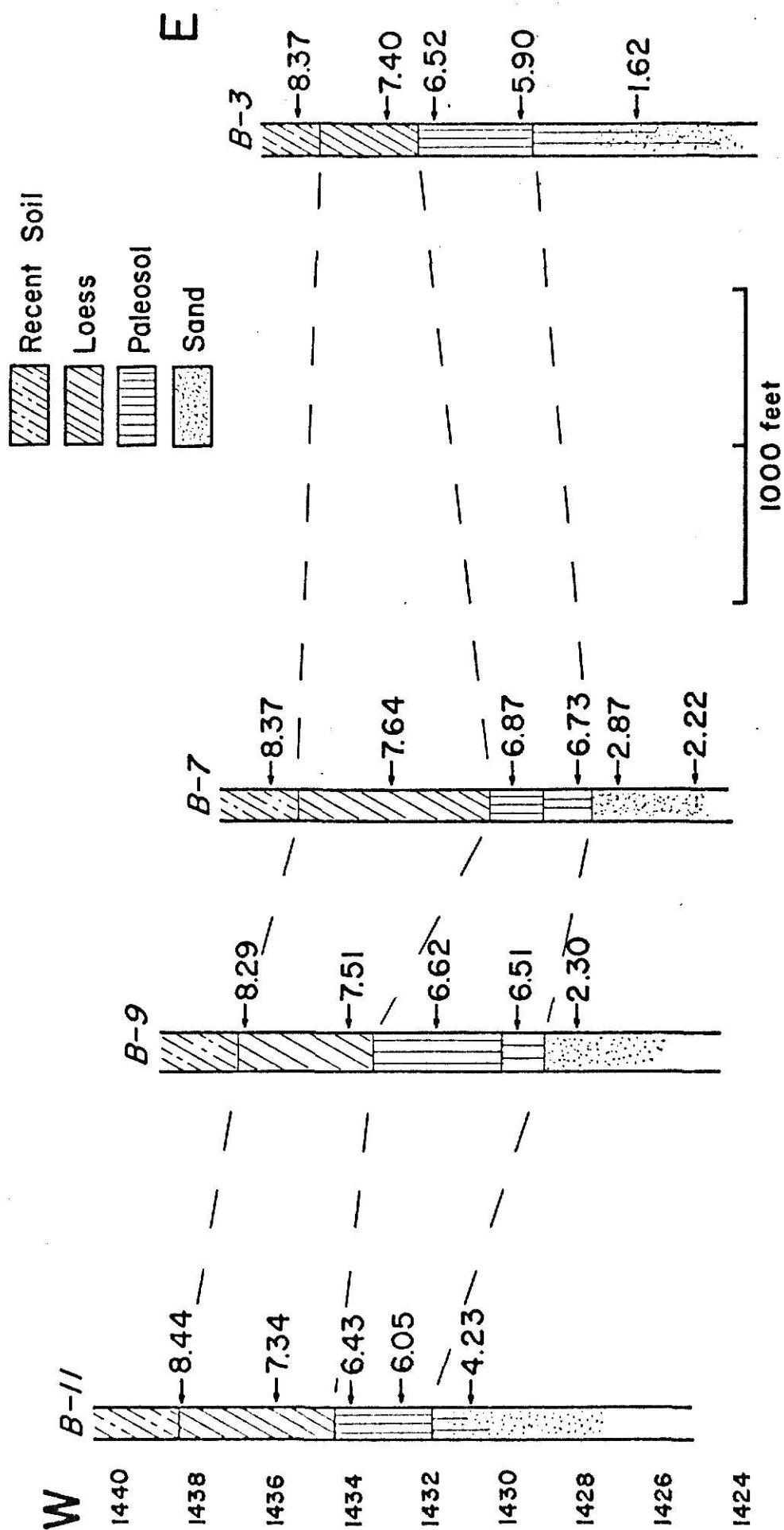


Fig. 13. Vertical and lateral changes in mean grain size (M_z).
(phi units)

Table 7

Phi Statistical Parameter Values

Sample No.	Md	M _Z	σ_I	Sk _I	KG
B-3, G-5 S	8.25	8.37	2.80	+0.04	0.55
B-3, G-4 L	6.10	7.40	2.73	+0.58	0.61
B-3, G-3 UP	6.08	6.52	3.92	+0.13	0.65
B-3, G-2 LP	5.10	5.90	4.04	+0.27	0.50
B-3, G-1 Sd	1.37	1.62	1.20	+0.52	2.30
B-5, G-3	7.50	8.08	2.67	+0.26	0.56
B-5, G-1	2.15	2.84	1.90	+0.54	1.57
B-7, G-7 S	8.30	8.37	2.81	+0.02	0.56
B-7, G-6 L	6.55	7.64	2.73	+0.49	0.53
B-7, G-5 UP	6.40	6.87	3.77	+0.13	0.64
B-7, G-4 LP	6.20	6.73	3.83	+0.16	0.60
B-7, G-3 Sd	2.10	2.87	1.72	+0.69	1.70
B-7, G-2 Sd	1.35	2.22	1.97	+0.67	1.85
B-7, G-1 Sd	1.35	1.34	0.29	+0.05	1.20
B-9, G-5 S	8.10	8.29	2.81	+0.09	0.53
B-9, G-4 L	6.30	7.51	2.73	+0.55	0.51
B-9, G-3 UP	6.15	6.62	3.98	+0.12	0.64
B-9, G-2 LP	6.15	6.51	4.03	+0.09	0.63
B-9, G-1 Sd	1.50	2.30	1.82	+0.68	1.73
B-11, G-5 S	8.50	8.44	2.77	-0.02	0.54
B-11, G-4 L	6.40	7.54	2.71	+0.52	0.52
B-11, G-3 UP	5.80	6.43	3.80	+0.19	0.79
B-11, G-2 LP	5.10	6.05	3.88	+0.29	0.78
B-11, G-1 Sd	4.25	4.23	3.02	+0.22	1.14
DK#1 Ss	2.10	2.22	0.84	+0.59	3.02
B-11, S-8 Ss	2.05	2.17	0.89	+0.45	2.22

S-- surface soil

L-- loess

UP-- upper horizon of paleosol

LP-- lower horizon of paleosol

Sd-- sand

Ss-- sandstone

whereas beach sands tend to be coarse-skewed and most dune sands are better sorted (lower standard deviation) than river sands. In the present study, sands and sandstones have sorting, skewness, and kurtosis values corresponding to those of river sands. Sandstone samples are better sorted and finer than most sand samples.

Clay Mineral Analysis

Identification of Clay Minerals.--Clay mineral identification was based on examination of X-ray diffractograms of untreated, glycolated, heated, acid treated, and cation saturated samples shown in Plates IV and V. Results of clay mineral identifications are summarized in Table 8.

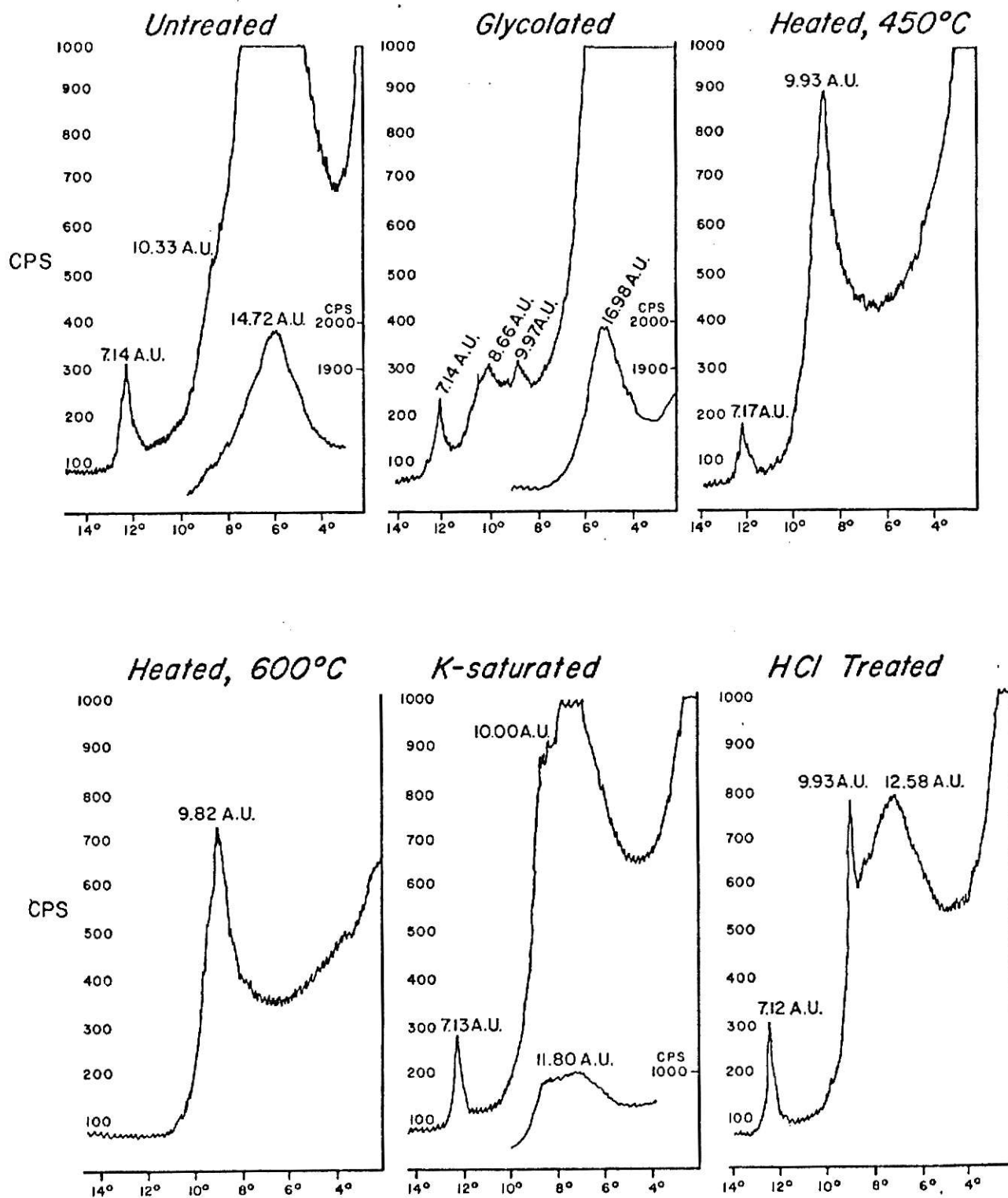
Abundance of Clay Minerals.--Relative abundances of the clay mineral species were measured to show vertical distributions at four localities. This was done by measuring the peak areas of the (001) reflections on glycolated patterns with a polar planimeter. The relative amounts of clay minerals were determined after considering the structural correction factors suggested by Maikelm and Campbell (1964). Areas for illite peaks were multiplied by a factor of 4, kaolinite peaks were multiplied by 1.6 and vermiculite peaks by 1.0. Relative proportions of clay minerals are shown in Table 9 and illustrated in Figure 14.

Evaluation of Data.--Vermiculite was the most abundant clay mineral, but traces of illite and kaolinite were present in minor amounts. In two sections (B-10 and B-9), vermiculite content decreased upwardly from the lower horizon of the paleosol to the loess, but in the other sections (B-6 and B-3), vermiculite reached minimum values in the paleosol and increased in the overlying loess. In three out of four vertical sections, illite increased from the base of the paleosol to the overlying loess, whereas in the other locality, a slight decrease was observed. Kaolinite content

EXPLANATION OF PLATE IV

X-ray diffraction patterns of sample B-3, C-1 (< 2.0 micron fraction). Vermiculite (14.72 A.U.), illite (10.33 A.U.), and kaolinite (7.14 A.U.) were present. Glycolation expanded vermiculite to 16.98 A.U. and heating at 450°C contracted it to about 10.0 A.U. Potassium saturation and HCl treatment contracted vermiculite to 11.80 A.U. and 12.58 A.U. respectively.

PLATE IV

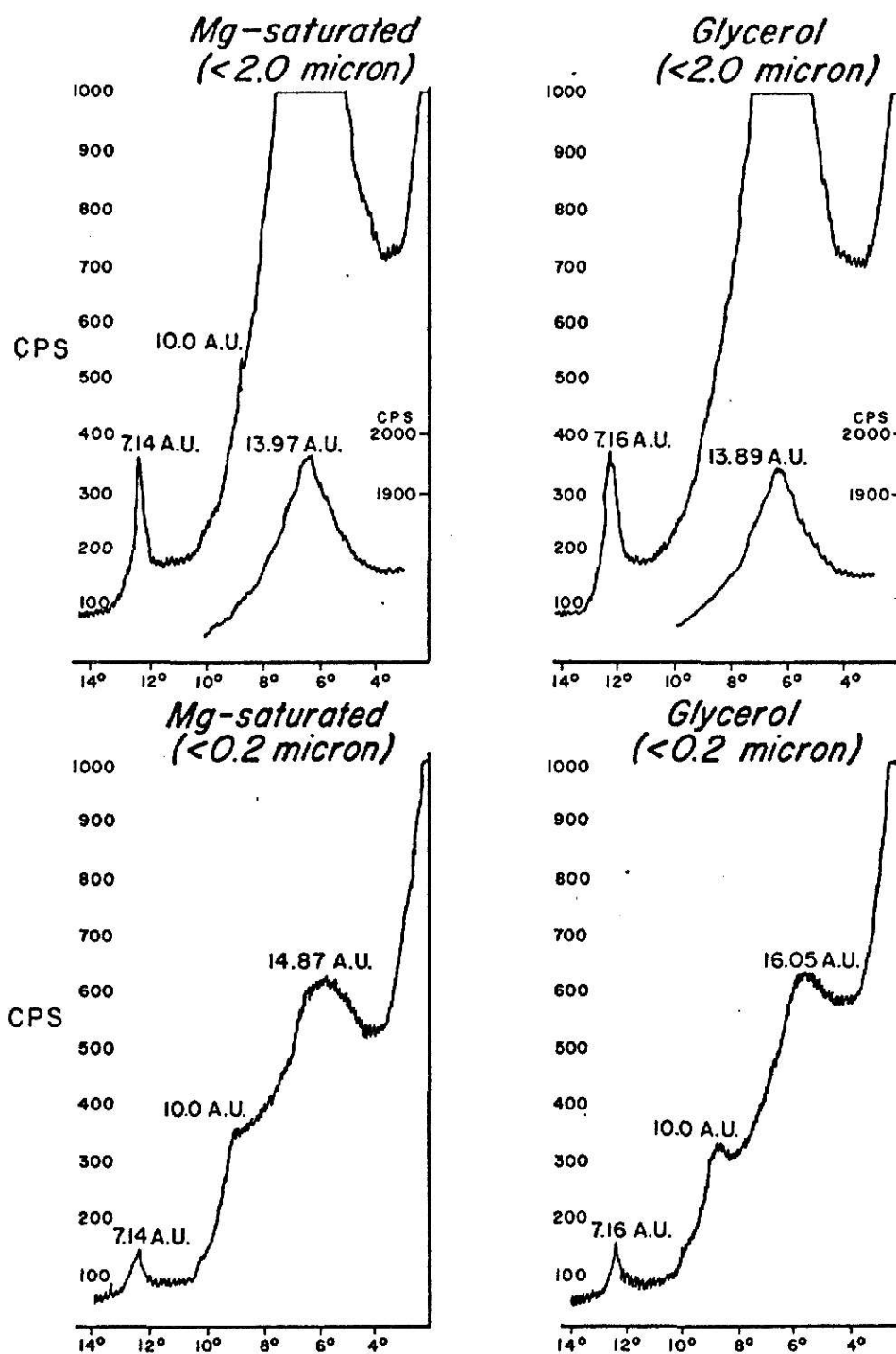


X-RAY DIFFRACTOGRAMS OF SAMPLE B-3, C-1

EXPLANATION OF PLATE V

X-ray diffraction patterns of sample B-9, C-2 (<2.0 micron and <0.2 micron fractions). Glycerol treatment of Mg-treated samples did not affect vermiculite in the less than 2.0 micron fraction, however, in the less than 0.2 micron fraction, a slight expansion of vermiculite after glycerol treatment (1.2 A.U.) suggests some low charge vermiculite or high charge smectite in the finer clay fraction.

PLATE V



X-RAY DIFFRACTOGRAMS OF SAMPLE B-9,C-2

Table 8

X-ray identification of clay minerals (≥ 2.0 and < 0.2 microns) in oriented mounts

Clay Mineral	Basal d-spacing (001)	Glycolation Effect	Glycerol Effect	Heating		Acid Treatment	Cation Saturation	
				450°C	Effect 450°C		K ⁺	Mg ⁺²
Vermiculite	14 A.U.	(001) expanded to 16.21 A.U.-16.92 A. U.	(001) 2 no change (001) 0.2 expanded to 0.38 A. U. 1.38 A. U.	(001) contracted to 10 A.U.	(001) decreased in intensity	(001) contracted to 12.5 A. U.	(001) contracted to 11.8 A. U.	no change
Illite	10 A.U.	no change	no change	(001) increased in intensity and sharpness	decreased intensity and broadening of all peaks	no change	no change	no change
Kaolinite	7.14 A.U.	no change	no change	(001) decreased in intensity	destruction of all peaks	no change	no change	no change

Table 9

Result of clay mineral analysis

Sample No.	Depth (ft)	Elevation (ft)	Vermiculite (% by weight)	Illite (% by weight)	Kaolinite (% by weight)
B-3, C-3 L	2.5	1433.9	84.05	11.40	4.56
B-3, C-2 UP	4.1	1432.3	76.18	13.85	9.97
B-3, C-1 LP	6.7	1429.7	91.06	4.97	3.97
B-6, C-3 L	3.1	1432.2	90.81	5.56	3.63
B-6, C-2 UP	6.0	1429.3	87.06	4.98	7.96
B-6, C-1 LP	6.7	1428.6	86.44	7.45	6.12
B-9, C-3 L	3.3	1435.8	80.06	14.04	5.90
B-9, C-2 UP	6.0	1433.1	90.43	2.92	6.64
B-9, C-1 LP	9.4	1429.7	96.08	1.51	2.41
B-10, C-3 L	7.0	1433.4	88.62	7.94	3.44
B-10, C-2 UP	8.6	1431.8	91.99	3.00	5.01
B-10, C-1 LP	10.8	1429.6	93.46	2.18	4.36
B-7, C-1 Sd	24.8	1412.7	---	33.63	66.37

L -- loess

UP -- upper horizon of paleosol

LP -- lower horizon of paleosol

Sd -- sand

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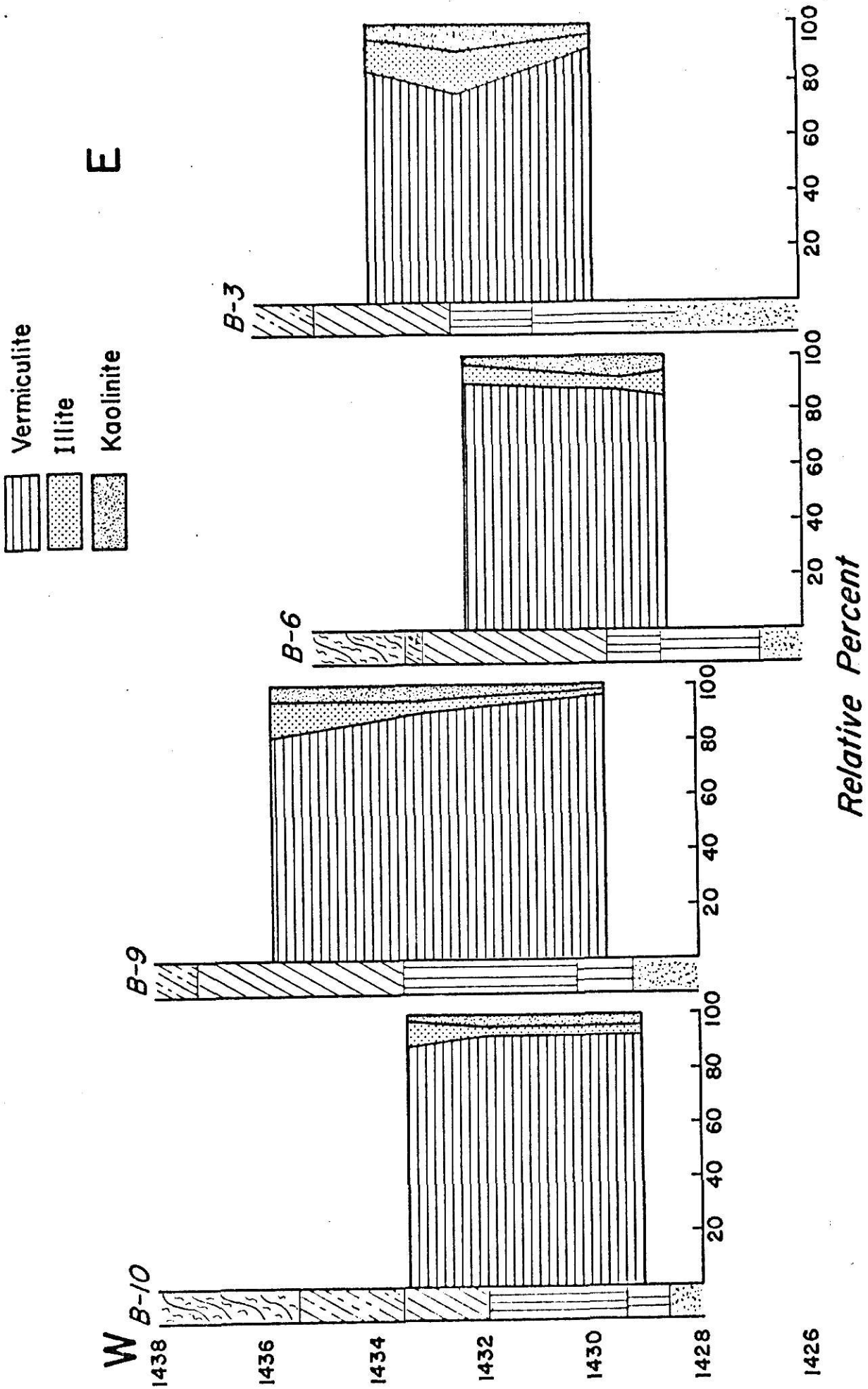


Fig. 14. Vertical and lateral changes in clay minerals

consistently increased from the lower to upper paleosol horizons and then decreased again in the loess.

Organic Carbon Analysis

Results of the organic carbon analysis were expressed as percent by weight of: 1) organic carbon (excluding elementary carbon, graphite, and coal, 2) total organic carbon (including elementary carbon), and 3) organic matter (2 X the value of percent organic carbon). These values are in Table 10. Vertical distributions of percent organic carbon are represented graphically in Figure 15.

The surface soil had substantially higher organic carbon values than the underlying loess and paleosol. Surface soil ranged from 0.38 percent to 0.78 percent organic carbon by weight. The loess unit usually contained the lowest percentages of organic carbon in the section, with values ranging from 0.09 percent to 0.21 percent. Upper horizons of the paleosol generally contained greater amounts of organic carbon than lower horizons. Values for upper horizons ranged from 0.12 percent to 0.30 percent, while lower horizons ranged from 0.08 percent to 0.32 percent organic carbon. The organic carbon content of the surface soil was two to six times that of the paleosol. Ruhe (1968) reported similar low organic carbon contents for the Sangamon Soil and overlying Wisconsin Loess, in Iowa.

Hydrogen Ion Activity

A majority of the suspensions of samples showed slight increases or decreases of pH during measurements with the pH meter, which made it difficult to decide upon a true value. Hesse (1971) suggested that in dealing with this problem, it is best to record that the pH is drifting and give the limits over a certain period of time. For this study, pH values were recorded one minute after the immersion of the electrodes into the suspension.

Table 10

Result of organic carbon analysis

Sample No.	Depth (ft)	Elevation (ft)	Readily Oxidizable Organic Carbon (% by weight)	Total Organic Carbon (% by weight)	Organic Matter (% by weight)
B-3, 0-4 S	0.5	1435.9	.784	1.040	1.568
B-3, 0-3 L	2.8	1433.6	.085	.113	0.170
B-3, 0-2 UP	4.5	1431.9	.123	.164	0.246
B-3, 0-1 LP	6.3	1430.1	.076	.101	0.152
MS-1, 0-3 L		1432.2	.134	.178	0.268
MS-1, 0-2 UP		1430.8	.259	.344	0.518
MS-1, 0-1 LP		1429.8	.165	.219	0.330
B-6, 0-3 L	2.8	1432.5	.212	.282	0.424
B-6, 0-2 UP	5.9	1429.4	.280	.372	0.560
B-6, 0-1 LP	8.3	1427.0	.166	.221	0.332
B-7, 0-4 S	2.0	1435.5	.625	.831	1.250
B-7, 0-3 L	4.1	1433.4	.123	.164	0.246
B-7, 0-2 UP	6.3	1431.2	.302	.402	0.604
B-7, 0-1 LP	8.2	1429.3	.317	.422	0.634
B-9, 0-4 S	1.4	1437.7	.759	1.009	1.518
B-9, 0-3 L	3.7	1435.4	.101	.134	0.202
B-9, 0-2 UP	6.0	1433.1	.270	.359	0.540
B-9, 0-1 LP	9.6	1429.5	.195	.259	0.390
B-11, 0-4 S	1.3	1439.4	.378	.503	0.756
B-11, 0-3 S	2.0	1438.7	.625	.813	1.250
B-11, 0-2 L	4.3	1436.4	.069	.092	0.138
B-11, 0-1 UP	7.3	1433.4	.200	.266	0.400

S -- surface soil

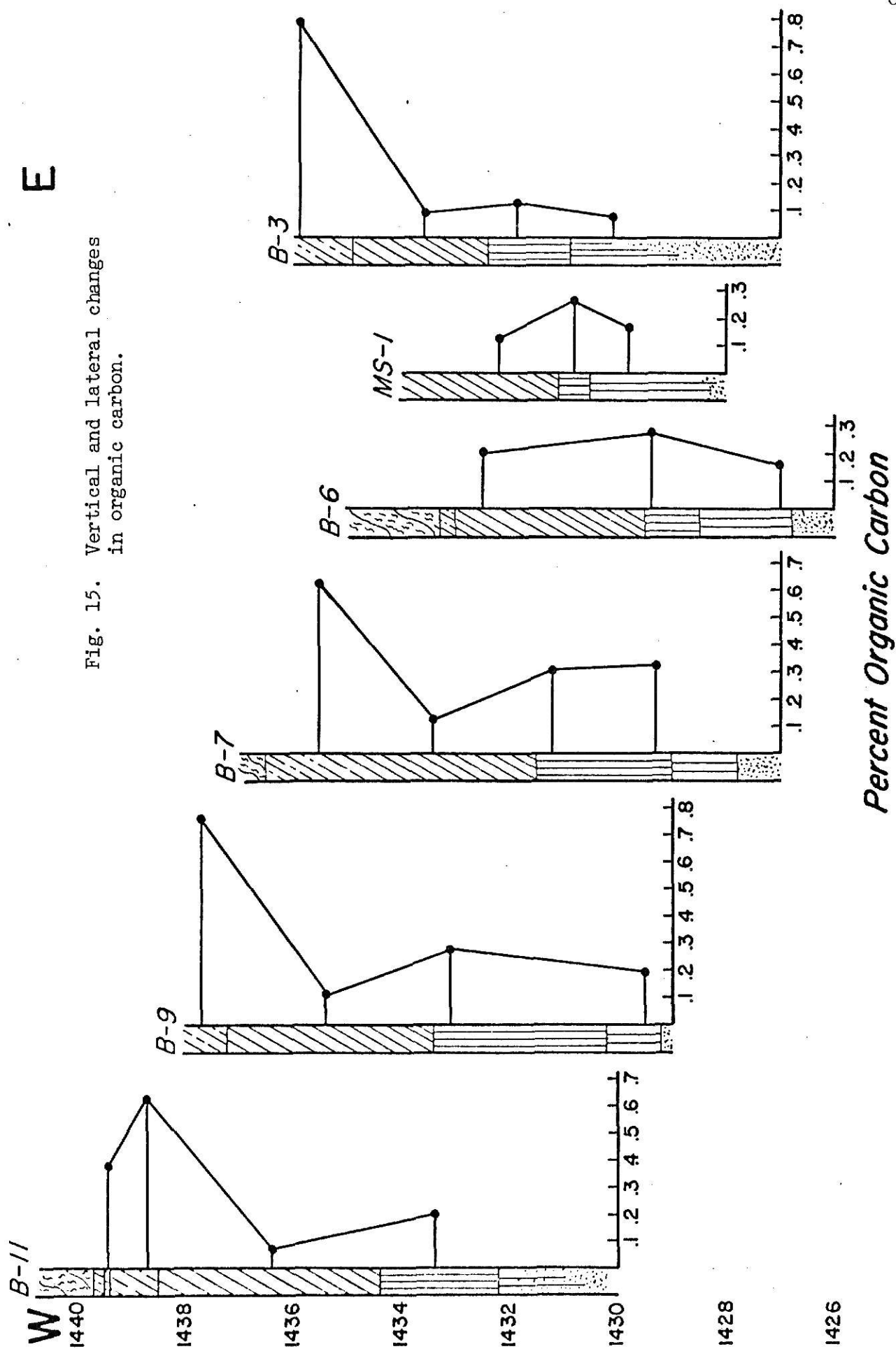
L -- loess

UP -- upper horizon of paleosol

LP -- lower horizon of paleosol

E

Fig. 15. Vertical and lateral changes in organic carbon.



Percent Organic Carbon

Direction and amount of drift was then recorded one minute after the initial recording. The pH measurement from a sediment-water suspension probably does not represent the true pH of the sediment. However, the values obtained are hopefully significant for relative comparisons. Results of the analysis, including drift observations, are in Table 11; vertical variations are illustrated in Figure 16.

The values of pH show relatively small vertical and lateral differences. Surface soil pH values ranged from 5.6 to 6.8. The majority of loess samples were neutral (7.0) or slightly above neutral. Upper horizons of the paleosol were consistently more acidic than the overlying loess and had pH values ranging from 6.1 to 7.1. Lower horizons ranged from 6.8 to 7.0 and generally had higher values than the overlying horizons.

The following vertical trends in pH were observed in a majority of the localities: 1) pH increased (became more basic) downward from the surface soil to the loess, 2) decreased (became more acidic) from the loess to the upper horizons of the paleosol, and 3) increased again from the upper to lower horizon of the paleosol.

The values of pH are often useful indicators of certain soil forming environments (Ruhe, 1970). In general, soils formed under forests have been more intensively leached, and therefore, have lower pH values than soils formed under grasslands where leaching is less. Similar pH values between the surface soil and paleosol of the present study suggests the possibility of similar soil forming environments.

Mineralogy of Sand and Sandstone

About one hundred grains were counted from each of five sand samples taken from cores and two samples of Dakota Sandstone to determine the mineral composition and surface textures. Results are in Table 12.

Table 11
Result of pH analysis

Sample No.	Depth (ft)	Elevation (ft)	pH Value	Drift Observations
B-3, P-4 S	0.5	1435.9	6.5	down - 0.5
B-3, P-3 L	2.8	1433.6	7.5	up - 1.0
B-3, P-2 UP	4.5	1431.9	7.1	up - 0.10
B-3, P-1 LP	6.3	1430.1	6.8	up - 0.2
MS-1, P-3 L		1432.2	5.3	up - 1.0
MS-1, P-2 UP		1430.8	6.9	up - 0.5
MS-1, P-1 LP		1429.8	7.0	up - 0.4
B-6, P-3 L	2.8	1432.5	7.0	up - 0.5
B-6, P-2 UP	5.9	1429.4	6.7	down - 0.2
B-6, P-1 LP	8.3	1427.0	6.8	steady
B-7, P-4 S	2.0	1435.5	6.6	steady
B-7, P-3 L	4.1	1433.4	7.0	up - 0.2
B-7, P-2 UP	6.3	1431.2	6.4	steady
B-7, P-1 LP	8.2	1429.3	6.9	up - 0.3
B-9, P-4 S	1.4	1437.7	5.6	steady
B-9, P-3 L	3.7	1435.4	7.1	up - 0.2
B-9, P-2 UP	6.0	1433.1	6.1	down - 0.2
B-9, P-1 LP	9.6	1429.5	7.0	up - 0.1
B-11, P-4 S	1.3	1439.4	6.8	up - 0.2
B-11, P-3 L	2.0	1438.7	6.5	steady
B-11, P-2 UP	4.3	1436.4	7.0	up - 0.2
B-11, P-1 LP	7.3	1433.4	6.8	steady

S -- surface soil

L -- loess

UP -- upper horizon of paleosol

LP -- lower horizon of paleosol

E

Fig. 16. Vertical and lateral changes in pH.

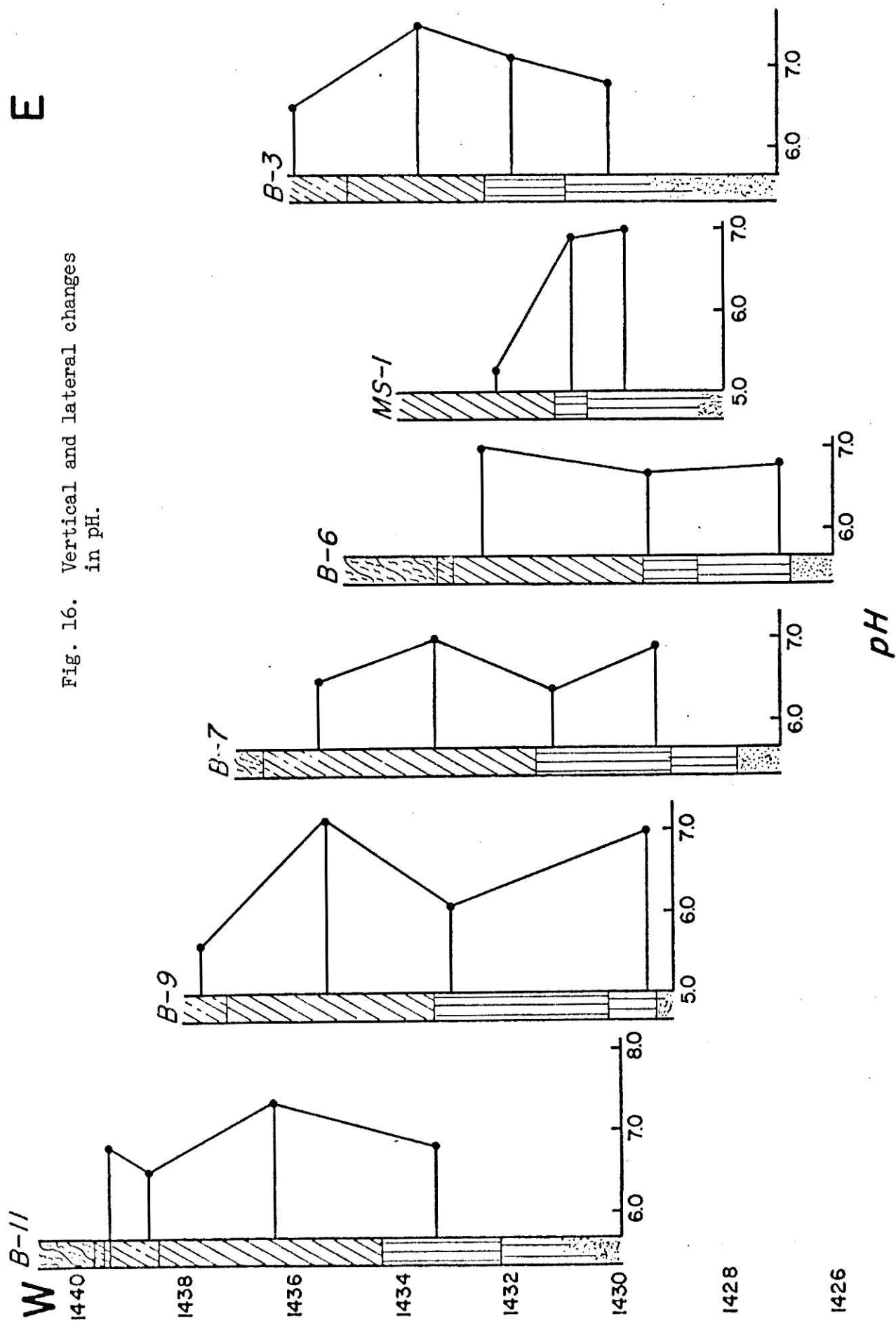


Table 12

Result of mineralogic count of sand grains from sand and sandstone

Sample No.	frosted		polished		Quartz			Other	
	no. of grains	%	no. of grains	%	pale yellowish-orange (10YR 8/6)	no. of grains	%	light red (5R 6/6)	no. of grains
B-3, G-1	73	71.6	13	12.7		14	13.7	2	2.0
B-5, G-1	77	76.2	9	8.9		14	13.9	1	1.0
B-7, G-2	89	89.0	7	7.0		4	4.0	0	0.0
B-9, G-1	85	81.7	12	11.5		6	5.8	1	1.0
B-11, G-1	79	79.0	8	8.0		10	10.0	3	3.0
B-11, S-8*	90	90.0	5	5.0		5	5.0	0	0.0
DK-1*	91	91.0	9	9.0		0	0.0	0	0.0

* indicates sandstone sample

Quartz was the only mineral encountered in all grain counts. However, a preliminary examination of the samples, before splitting to 100 grains, revealed some trace minerals, mostly heavy minerals such as tourmaline, zircon, and magnetite, that were not encountered in the grain counts. Frosted, polished, and colored varieties were the most noticeable types of quartz grains. Frosted grains were the predominant grain type and represented from 71.6 percent to 91.0 percent. The remainder of the quartz grains were polished grains and a pale yellowish-orange (10 YR 8/6) variety of quartz. A small amount (1 percent - 3 percent) of light red quartz (5 R 6/6) was identified in several samples.

Statistical X^2 tests were made on mineralogy and surface features to test whether significant differences existed between sand and sandstone (Table 13). The test showed that a significant difference existed at the 0.01 confidence level between sand and sandstone when overall mineralogy was considered, but differences between frosted and polished grains, only, were insignificant. The mineralogic difference suggests: 1) that the Dakota Sandstone at this locality was not a source rock for the sand, or 2) sandstone from this locality, if it was a source rock, was not the only source contributing to the sand deposit. Further petrologic investigation of the Dakota Formation would be required to substantiate this hypothesis.

Folk (1974), in discussing the petrology of sands and sandstones consisting of over 95 percent quartz (quartzarenites), stated that their origin is variable, but usually a long period of weathering and abrasion is necessary to remove the less stable minerals such as feldspar and rock fragments. Thus, sand and sandstone quartzarenites of the present study may have resulted from long periods of weathering and abrasion, either during their latest cycle of deposition or through a combination of previous cycles of reworking and deposition.

Table 13

Chi-square test for total mineralogic
data of sand and sandstone

		Sand	Sandstone
Frosted Grains	Observed	403	181
	Expected	418.8	165.2
	Corr. Diff.	15.3	15.3
Polished Grains	Observed	49	14
	Expected	45.2	17.8
	Corr. Diff.	3.3	3.3
Colored Grains	Observed	55	5
	Expected	43.0	17.0
	Corr. Diff.	11.5	11.5

$$X^2 = \frac{D^2}{E} \quad \text{where D is the corrected difference and E is expected frequency}$$

$$X^2 = \frac{15.3}{418.8} + \frac{15.3}{165.2} + \frac{3.3}{45.2} + \frac{3.3}{17.8} + \frac{11.5}{43.0} + \frac{11.5}{17.0}$$

$$X^2 = 13.69 \quad \text{which is significant at .05 and .01 confidence levels with 2 degrees of freedom.}$$

Chi-square test for frosted/polished textural
data of sand and sandstone

		Sand	Sandstone
Frosted Grains	Observed	403	181
	Expected	408.0	176.0
	Corr. Diff.	4.5	4.5
Polished Grains	Observed	49	14
	Expected	44.0	19.0
	Corr. Diff.	4.5	4.5

$$X^2 = \frac{4.5}{408} + \frac{4.5}{176} + \frac{4.5}{44} + \frac{4.5}{19}$$

$$X^2 = 1.72 \quad \text{which is not significant at .05 confidence level with 1 degree of freedom.}$$

Surface Texture of Quartz Grains

Electron micrographs of quartz grains, along with descriptions of surface features are in Appendix III. Krinsley and Doornkamp (1973) presented a thorough review of work that has been done in studying quartz grain surface textures with the SEM. It was compiled on the assumption that grain morphology is diagnostic of the environmental history of the deposit from which the grain has come. In general, they indicated that certain grain surface features or combinations of these features are characteristic of: 1) source materials, 2) diagenesis, 3) glacial, 4) subaqueous, 5) glacial and subaqueous combined, 6) eolian, and 7) high-energy chemical environments.

Scholle (1973) reported that some surface textures which have been previously described as being characteristic of certain depositional environments, also exist on untransported quartz grains from primary (non-sedimentary) sources. These include such features as V-shaped indentations, semi-parallel steps, arc-shaped steps, graded arcs, parallel striations, and bifurcating ridges and grooves. Scholle proposed that different surface textures should, perhaps, relate more to differing sources than to depositional environments.

The major types of surface features observed in this study are: 1) V-shaped indentations, 2) linear and crescent shaped grooves, 3) irregular breakage patterns, 4) chemical etching, and 5) quartz precipitation. Larger grains (> 0.5 mm.) have rounded edges, moderately smooth surfaces, and unoriented V-shaped pits. Smaller grains (< 0.5 mm.) generally have more surface irregularities and are chemically etched (silica solution) and have oriented V-shaped pits. Quartz precipitation is on both larger and smaller grains. The V-shaped depressions on the larger grains resemble those proposed as mechanical impact features (Krinsley and Doornkamp, 1973, p. 61).

Oriented V-shaped patterns on smaller grains resemble chemically etched V-indentations. Krinsley and Doornkamp (1973) reported the rate of silica solution usually rises very rapidly as particle size decreases. This may explain why chemical etching features are predominantly on smaller grains. Krinsley and Doornkamp suggested that silica solution occurs by weathering of the source rock or during diagenesis of the sediment. Sandstone grains predominantly possess chemically etched features, whereas sand grains have both chemically and mechanically formed features. The difference in surface features between the two is probably related to grain size because the sandstone grains examined were smaller than most sand grains from unconsolidated deposits.

Mechanically formed and chemically etched V-shaped patterns were proposed to be most representative of subaqueous environments (Krinsley and Doornkamp, 1973). If this suggestion is followed, then both sand and sandstone quartz grains of this study qualify for this classification of depositional environment. Possibly these surface features were inherited from a previous sedimentary origin and were not produced by the latest deposition environment. Also, as Scholle (1973) pointed out, these features may be formed by weathering of the source rock and not by transportation and deposition.

Summary of Laboratory Data

Relationship Between Clay Minerals and pH.--Scatter plots of pH against proportions of kaolinite and vermiculite were made (fig. 17). There was an indication of a linear array of points, where kaolinite increased with decreasing pH, however, no apparent relationship was observed between the vermiculites and pH.

Relationship Between Clay Minerals and Grain Size.--Kaolinite has been known to form authigenically in interstitial pore spaces in sandy rocks and

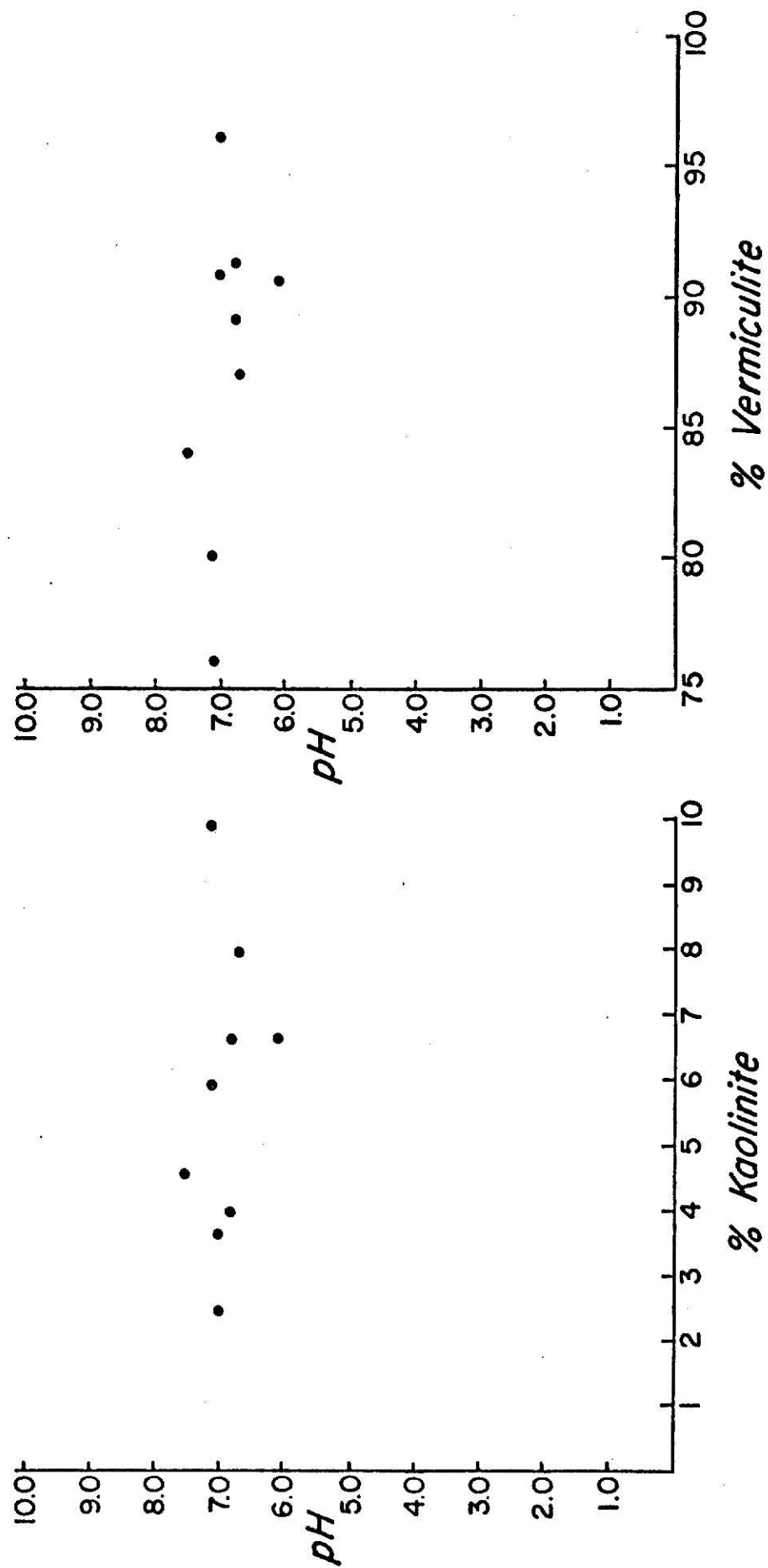


Fig. 17. Relationship between pH and proportions of kaolinite and vermiculite.

sediments (Jeppesen, 1972; Bucke and Mankin, 1971). Scatter plots of percent kaolinite and vermiculite against mean grain size indicates the clay minerals and mean grain sizes were not interdependent variables (fig. 18). This suggests that if kaolinite were authigenic, it was not dependent on the pore space size of the sediment. It is possible that kaolinite is not authigenic, but was transported into the area.

Relationship Between Organic Carbon and pH.--A scatter plot of percent organic carbon and pH indicates that no obvious relationship exists between the two parameters (fig. 19).

CONCLUSION

Test hole data revealed four major stratigraphic units of Quaternary Age northeast of Linn, Kansas, which are in descending order: 1) a surface soil profile, 2) a loess or loess-like sediment, 3) a paleosol, and 4) an uncemented fine to medium sand. The tentative stratigraphic nomenclature of these units was correlated with rock units of the Quaternary system in Kansas as proposed by Zeller (1968), and is in figure 20. Because these sediments lack assemblages of fossils proposed by Frye and Leonard (1952, pp. 144-180), the units cannot be positively identified. Further petrographic study of these sediments is also needed to substantiate their identification. The paleosol, classified as the Sangamon Soil, was used as a time-rock stratigraphic unit for the section. Frye and Leonard (1952) described the Sangamon Soil as being the most widespread, well-developed, and well-preserved paleosol in Kansas. Its typical profile is developed on the Loveland Loess (Illinoian Age) and is reddish-brown. However, morphologic differences of the paleosol exist and primarily result from differences in drainage conditions, parent material, and climatic factors. Assuming that this paleosol

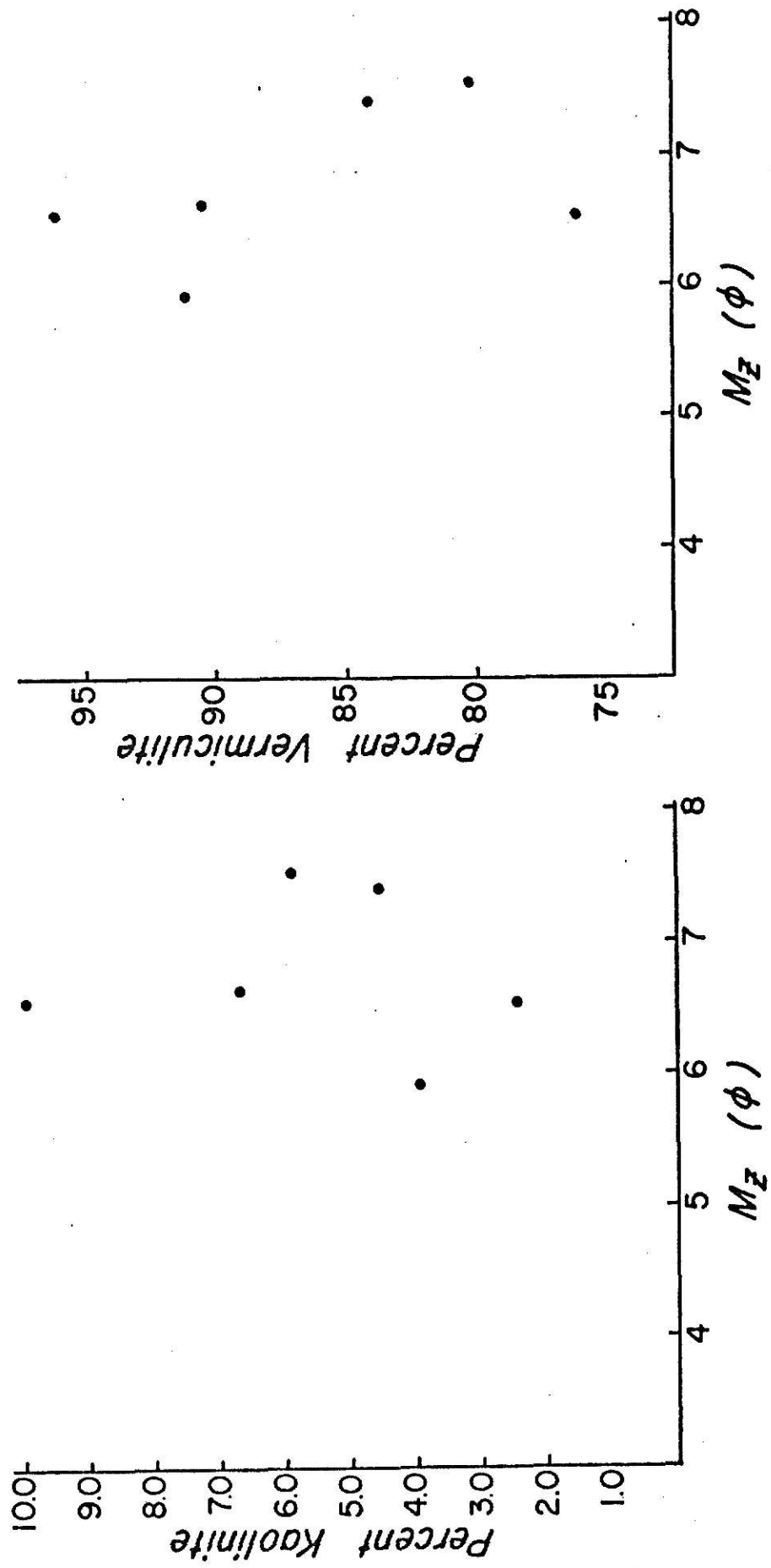


Fig. 18. Relationship between mean grain size and proportions of kaolinite and vermiculite in the clay fraction.

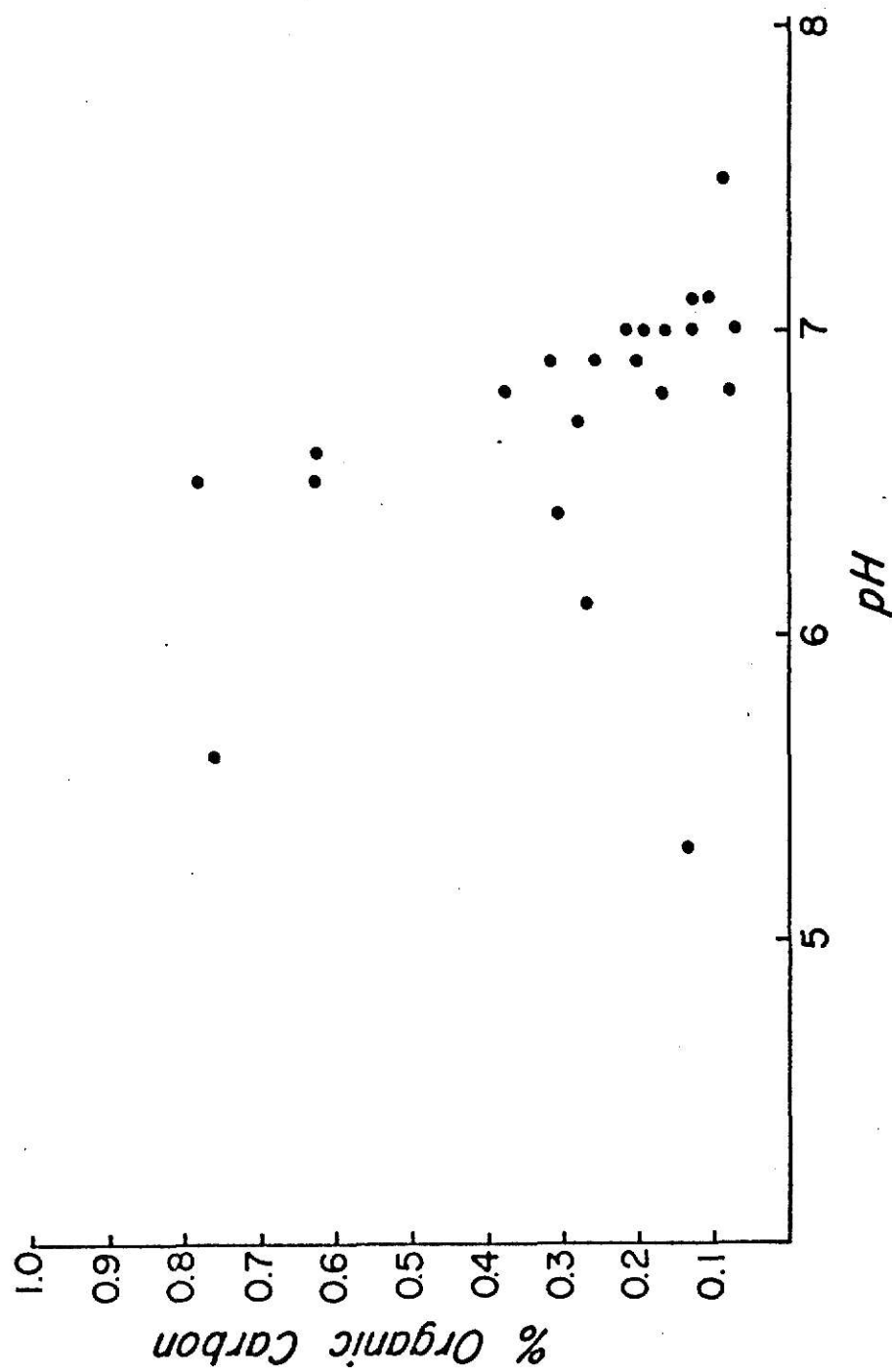


Fig. 19. Relationship between organic carbon and pH.

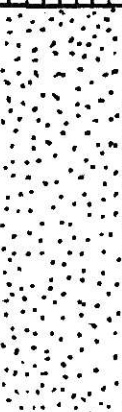
Cenozoic						Lithologic Description	Thickness (feet)						
ERA	Period	Epoch	Stage	Formation	Graphic Section								
Mesozoic	Cretaceous			Dakota Fm.		Alternating sandstone and shale; sandstone, moderate yellowish-brown (10 YR 5/4) to moderate reddish-brown (10 R 4/6), fine, 95% quartz; shale, clayey, yellowish-grey (5 Y 8/1).							
						Pleistocene	Illinoian	Crete Fm.		Sand, fine to medium, greyish-orange (10 YR 7/4) to yellowish grey (5 Y 8/1), poorly to very well sorted, 95% quartz, upper 2 to 3 feet more clayey than lower depths.	0.0 - 27.5		
							Sangamonian	Sangamon Soil			Sandy-clay silt, dusky yellowish brown (10 YR 4/2) to pale yellowish brown (10 YR 6/2).	0.3 - 4.9	
							Wisconsinan	Peoria Fm.				Clayey silt, yellowish-grey (5 Y 8/1) to pale yellowish-brown (10 YR 6/2), laminated and massive.	0.0 - 6.4
							Recent	Surface Soil					Silty clay, dusky yellowish (10 YR 4/2) brown to pale yellowish brown (10 YR 6/2).
Quaternary													

Fig. 20. Tentative stratigraphic section of Quaternary and bedrock geology northeast of Linn, Kansas.

correlates with the Sangamon Soil, the underlying sand is then Illinoian Age or older, and may be correlated with the Crete Formation (Illinoian Age). Frye and Leonard (1952) described the Crete Formation as an alluvial deposit, occurring as local gully fills, that closely reflects the lithology of the drainage basin containing the deposit. The loess-like sediment overlying the paleosol is recognized as the Peoria Loess Formation (Wisconsinan Age). Frye and Leonard reported the Peoria Formation includes both wind-blown and water-laid sediments. The surface soil profile, developed on the Peoria Loess, represents the Recent or Holocene epoch of the Quaternary Period.

Lateral correlation of the units was established by similarities in grain size, clay mineralogy, organic carbon, and pH. Mean grain size ranged from 1.34 ϕ in the sand unit to 8.37 ϕ in the surface soil. A gradual decrease in mean grain size was observed upward from the sand to the surface soil. Clay minerals consisted of vermiculite, illite, and kaolinite, with vermiculite the most abundant in all units except the sand. The amount of kaolinite generally increased with decreasing pH. No apparent relationship existed between the proportion of kaolinite and mean grain size. Organic carbon percentages were generally low throughout the section ranging from a high of 0.784 percent in the surface soil to a low of 0.069 percent in the loess. Proportions of organic carbon in the paleosol were in between these values. Changes in pH were relatively small and ranged from 7.5 to 5.3. The surface soil and upper horizon of the paleosol were generally more acidic than the loess or lower paleosol horizon.

The bedrock profiles reflect a topographic basin. The minimum bedrock elevation of 1399.3 feet is in the center of the east-west cross-section. Bedrock elevation increases toward both ends. The west end of the cross-section has a bedrock elevation of 1447.5 feet which is higher than the 1414.5-foot elevation of the east end, thus creating an asymmetrical profile.

The north-south cross-section reveals a high bedrock elevation of 1448.6 feet at the south and that gradually decreases to a low of 1414.5 feet at the north end.

An alluvial origin for the sand filling the basin is suggested by its morphology and by the textural properties of the sand. The uniform content of quartz of the sand suggests that either: 1) the sand was subjected to a long period of abrasion and weathering, or 2) it was derived from older, quartz-rich rock. Because the Dakota Sandstone bedrock in the area is rich in quartz, the sand deposit may have been derived locally from this rock unit. However, overall mineralogic differences between the sand and sandstone indicate that other source areas may have contributed. The paleosol, which developed on the sand, was truncated before deposition of the overlying loess. Dark bands or laminations at the paleosol/loess boundary suggest that deposition of the silt started very slowly and was interrupted with temporary periods of non-deposition. The very fine laminations in the silt at some localities may indicate sedimentation in small, isolated, and temporary bodies of water. The more uniform and massive loess sections were probably of eolian origin.

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APPENDIX I

Test Hole Logs

Locations and descriptions of 19 test holes are given on the following pages. Logs designated "sample logs" describe test holes from which core samples were collected. Logs described "drilling logs" were described in the field from auger cuttings.

Test Hole B-1

Sample log of test hole in SW1/4, SW1/4, SE1/4, SE1/4, Sec. 23, T. 4 S., R. 3 E., 1000 feet west of SE cor. Sec. 23, at edge of road. Surface elevation 1441.1 feet.

	Thickness feet	Depth feet
Road fill.....	2.3	2.3
Quaternary		
Pleistocene		
Peoria Formation		
Silt, clayey, yellowish-gray (5 Y 8/1) to light olive gray (5 Y 6/1); noncalcareous; contains small amount iron oxide staining.....	5.3	7.6
Silt, sandy, clayey, pale brown (5 YR 6/1) to pale yellowish-brown (10 YR 6/2); massive.....	1.1	8.7
Sangamon Soil		
Silt, clayey, sandy, dusky yellowish-brown (10 YR 2/2), blocky, very cohesive.....	1.4	10.1
Sand, fine to medium, silty, clayey, pale yellow- ish-brown (10 YR 6/2), to very pale orange (10 YR 8/2).....	2.1	12.2
Crete Formation		
Sand, fine to medium, very pale orange (10 YR 7/4); contains over 95% quartz.....	4.3	16.5
Sand, fine to medium, clayey, gray.....	2.6	20.9
Sand, fine to medium, tan, clean.....	3.8	24.7
Sand, fine to medium, clayey, gray.....	13.3	38.0
Total depth.....		38.0

Test Hole B-2

Sample log of test hole in SE1/4, SE1/4, SW1/4, SE1/4, Sec. 23 T. 4 S., R. 3 E., 1565 feet west of SE cor. Sec. 23, at edge of road. Surface elevation 1433.4 feet.

	Thickness feet	Depth feet
Road fill.....	1.5	1.5
Quaternary		
Holocene		
Soil		
Clay, silty, dusky yellowish-brown (10 YR 2/2), slightly calcareous.....	0.8	2.3
Pleistocene		
Sangamon Soil		
Silt, sandy, clayey, pale yellowish-brown (10 YR 6/2) to dark yellowish-brown (10 YR 4/2), calcareous, blocky.....	1.3	3.6
Sand, fine to medium, clayey, silty, greyish- orange (10 YR 7/4) to pale yellowish-brown (10 YR 6/2); contains small amount of iron oxide streaks and nodules.....	1.3	4.9
Sand, fine to medium, silty, pale yellowish-brown (10 YR 8/6) to greyish-orange (10 YR 7/4); con- tains high amount of iron oxide staining.....	1.0	5.9
Crete Formation		
Sand, medium, pale yellowish-orange (10 YR 8/6) to dark yellowish-orange (10 YR 6/6); contains moderate amount of iron oxide staining; greater than 95% quartz.....	1.0	6.9
Sand, medium, light brown (5 YR 5/6); contains high amount of iron oxide staining.....	1.0	7.9
Sand, medium, clayey, very pale orange (10 YR 8/2) to grayish orange (10 YR 7/4); contains small amount of iron oxide staining.....	1.0	8.9
Total depth.....		8.9

Test Hole B-3

Sample log of test hole in SE1/4, SE1/4, SW1/4, SE1/4, Sec. 23, T.
4 S., R. 3 E., 1366 feet west of SE cor. Sec. 23, at edge of road.
Surface elevation 1436.4 feet.

	Thickness feet	Depth feet
Quaternary		
Holocene		
Soil		
Clay, silty, dusky yellowish-brown (10 YR 2/2) mottled pale yellowish-brown (10 YR 6/2).....	1.5	1.5
Pleistocene		
Peoria Formation		
Silt, clayey, yellowish-gray (5 Y 8/1) to light olive grey (5 Y 6/1), highly calcareous; con- tains random iron oxide streaks; laminations prominent from 1.5 to 2.5 feet.....	2.5	4.0

	Thickness feet	Depth feet
Sangamon Soil		
Silt, snady, clayey, dark yellowish-brown (10 YR 4/2) to dusky yellowish-brown (10 YR 2/2); slightly calcareous, concentrated iron oxide staining at 4.7 feet; blocky.....	1.5	5.5
Sand, fine to medium, silty, clayey, pale yel- lowish-brown (10 YR 6/2); contains very small amount iron oxide staining.....	2.2	7.7
Crete Formation		
Sand, fine to medium, silty, grayish-orange (10 YR 7/4) to pale yellowish-orange (10 YR 6/2); contains small amount of iron oxide staining.....	1.2	8.9
Sand, medium, grayish-orange (10 YR 7/4), greater than 95% quartz.....	3.3	12.2
Total depth.....		12.2

Test Hole B-4

Sample log of test hole in SE1/4, SW1/4, SW1/4, SE1/4, Sec. 23, T. 4 S.,
R. 3 E., 2099 feet west of SE cor. Sec. 23, at edge of road. Surface
elevation 1432.4 feet.

	Thickness feet	Depth feet
Road fill.....	5.0	5.0
Quaternary		
Pleistocene		
Peoria Formation		
Silt, clayey, yellowish-gray (5 Y 8/1) to light olive-gray (5 Y 6/1), calcareous; contains small amount iron oxide staining.....	1.0	6.0
Sangamon Soil		
Silt, sandy clayey, pale yellowish-brown to dark yellowish-brown (10 YR 4/2); contains high amount of iron oxide staining.....	0.3	6.3
Crete Formation		
Sand, medium, silty, yellowish-gray (5 Y 8/1); greater than 95% quartz.....	1.6	7.9
Total depth.....		7.9

Test Hole B-5

Sample log of test hole in SW1/4, SW1/4, SW1/4, SE1/4, Sec. 23, T. 4 S.,
R. 3 E., 2384 feet west of SE cor. Sec. 23, at edge of road. Surface
elevation 1432.7 feet.

	Thickness feet	Depth feet
Road fill.....	1.0	1.0
Quaternary		
Pleistocene		
Peoria Formation		
Silt, clayey, light olive-gray (5 Y 6/1); highly calcareous (heavy from 1.8 to 2.0 feet); contains high amount of iron oxide staining at 1.5 feet; gradational contact with lower unit.....	1.3	2.3
Sangamon Soil		
Silt, clayey, sandy, dusky yellowish-brown (10 YR 2/2); highly calcareous (heavy from 2.8 to 3.0 and 5.7 feet); contains moderate amount iron oxide staining from 5.2 to 5.3, sharp contact with lower unit.....	3.6	5.9
Crete Formation		
Sand, fine to medium, silty, very pale yellowish-orange (10 YR 8/2) to greyish-orange (10 YR 7/4); greater than 95% quartz.....	3.4	9.3
Total depth.....		9.3

Test Hole B-6

Sample log of test hole in SW1/4, SE1/4, SE1/4, SW1/4, Sec. 23, T. 4 S., R. 4 E., 3087 feet west of SE cor. Sec. 23, at edge of road. Surface elevation 1435.3 feet.

	Thickness feet	Depth feet
Road fill.....	2.0	2.0
Quaternary		
Holocene		
Soil		
Clay, silty, dark yellowish-brown, (10 YR 4/2); contains moderate amount of iron oxide staining	0.3	2.3
Pleistocene		
Peoria Formation		
Silt, clayey, grayish-orange (10 YR 7/4); contains small amount of iron oxide staining, laminated.	0.3	2.6
Silt, clayey, dark yellowish-orange (10 YR 6/6) to moderate yellowish-brown (10 YR 5/4); contains high amount of iron oxide streaks and nodules, laminated.....	1.0	3.6
Silt, clayey, yellowish-gray (5 Y 8/1) mottled moderate reddish-brown (10 R 4/6); slightly calcareous; contains high amount of iron oxide staining, laminated.....	0.7	4.3
Silt, clayey, yellowish-gray (5 Y 8/1) to very pale orange (10 YR 8/2); contains small amount of iron oxide staining, laminated (prominent from 5.4 to 5.6 feet).....	1.3	5.6

	Thickness feet	Depth feet
Silt, clayey, sandy, moderate reddish-brown; contains very high amount of iron oxide staining.....	0.1	5.7
Sangamon Soil		
Silt, clayey, sandy, pale yellowish-brown (10 YR 6/2) to dark yellowish-brown (10 YR 4/2); contains small amount of iron oxide streaks and nodules.....	1.1	6.8
Silt, sandy, clayey, greyish-orange (10 YR 7/4); contains small amount iron oxide.....	0.2	7.0
Silt, clayey, pale yellowish-brown (10 YR 6/2) to dark yellowish-brown (10 YR 4/2); contains small amount of sand near top and bottom.....	0.5	8.5
Crete Formation		
Sand, fine to medium, greyish-orange (10 YR 7/4); greater than 95% quartz.....	27.5	36.0
Total depth		36.0

Test Hole B-7

Sample log of test hole in SE1/4, SW1/4, SE1/4, SW1/4, Sec. 23, T 4 S.,
R. 3 E., 3515 feet west of SE cor. Sec. 23, at edge of road. Surface
elevation 1437.5 feet.

	Thickness feet	Depth feet
Road fill.....	1.0	1.0
Quaternary		
Holocene		
Soil		
Clay, silty, dark yellowish-brown (10 YR 4/2) to dusky yellowish-brown (10 YR 2/2); weakly laminated.....	0.8	1.8
Pleistocene		
Peoria Formation		
Silt, clayey, yellowish-gray (5 Y 8/1) to light olive-grey (5 Y 6/1); calcareous; contains very small amount of iron oxide staining, lamin- ated.....	0.9	2.7
Silt, clayey, yellowish-gray (5 Y 8/1) to light olive-grey (5 Y 6/1); slightly calcareous; contains high amount iron oxide streaks and nod- ules; laminated.....	0.5	3.2
Silt, clayey, yellowish-gray (5 Y 8/1) to light olive-grey (5 Y 6/1); contains small amount of iron oxide streaks and nodules; laminated.....	2.3	5.5
Silt, clayey, very pale-orange (10 YR 6/1) to grayish-orange (10 YR 7/4); contains high amount of iron oxide streaks and nodules; prominent laminations.....	0.5	6.0

	Thickness feet	Depth feet
Silt, clayey, sandy, dark yellowish-brown (10 YR 4/2) to dusky yellowish-brown (10 YR 2/2); contains small amount of iron oxide staining; laminated.....	0.3	6.3
Silt, clayey, sandy, greyish-orange (10 YR 7/4); contains small amount of iron oxide staining; weakly laminated.....	0.7	7.0
Sangamon Soil		
Silt, sandy, clayey, dark yellowish-brown (10 YR 2/2); contains small amount of iron oxide streaks and nodules; weakly laminated.....	1.5	8.5
Sand, fine to medium, silty, clayey, dark yellowish-brown (10 YR 4/2) to dusky yellowish- brown (10 YR 2/2); contains some gravel size quartz grains; high amount of iron oxide stain- ing from 9.3 to 9.7 feet; weakly laminated....	1.2	9.7
Silt, sandy, clayey, yellowish-gray (5 Y 8/1) to light olive-gray (5 Y 6/1); contains small amount of iron oxide streaks and nodules; weakly laminated.....	0.6	10.3
Crete Formation		
Sand, fine to medium, very pale-orange (10 YR 8/2); greater than 95% quartz.....	4.2	14.5
Sand, fine to medium, dirty.....	8.6	23.1
Sand, medium, clean.....	5.8	28.9
Cretaceous		
Lower Cretaceous		
Dakota Formation		
Sandstone, fine, reddish-brown; contains high amount of iron oxide staining.....	1.1	30.0
Total depth.....		30.0

Test Hole B-9

Sample log of test hole in SW1/4, SE1/4, SW1/4, SW1/4, Sec. 23, T. 4 S.,
R. 3 E., 4294 feet west of SE cor. Sec. 23, at edge of road. Surface
elevation 1439.1 feet.

	Thickness feet	Depth feet
Road fill.....	1.0	1.0
Quaternary		
Holocene		
Soil		
Clay, silty, dark yellowish-brown (10 YR 4/2) to dusky yellowish-brown (10 YR 2/2).....	0.9	1.9

	Thickness feet	Depth feet
Pleistocene		
Peoria Formation		
Silt, clayey; upper 3.2 feet - yellowish- gray (5 Y 8/1) mottled moderate brown (5 YR 4/4), contains iron oxide streaks and nodules, weakly laminated; lower 0.6 feet - pale yellow- ish-brown (10 YR 6/2), prominent laminations; highly calcareous at 3.1 and 3.4 feet.....	3.8	5.7
Sangamon Soil		
Silt, sandy, clayey, blackish-red (5 R 2/2) to very dusky-red (10 R 2/2); contains iron oxide streaks and nodules; blocky.....	3.8	9.5
Sand, fine to medium, silty, clayey, pale yellow- ish-brown (10 YR 6/2); contains iron oxide streaks and nodules.....	1.0	10.5
Crete Formation		
Sand, fine to medium, silty, very pale orange (10 YR 8/2) to grayish-orange (10 YR 7/4); contains small amount of iron oxide staining; greater than 95% quartz.....	1.0	11.5
Sand, fine to medium, clean.....	5.3	16.8
Sand, fine to medium, silty, dirty.....	2.5	19.3
Sand, fine, iron oxide staining.....	4.6	23.9
Gravel chatter.....	0.7	24.6
Cretaceous		
Lower Cretaceous		
Dakota Formation		
Sandstone, reddish-brown; contains high amount of iron oxide staining.....		24.6
Total depth.....		24.6

Test Hole B-10

Sample log of test hole in SE1/4, SW1/4, SW1/4, SW1/4, Sec. 23, T. 4 S.,
R. 3 E., 4883 feet west of SE cor. Sec. 23, at edge of road. Surface
elevation 1440.4 feet.

	Thickness feet	Depth feet
Road fill.....	5.0	5.0
Quaternary		
Holocene		
Soil		
Clay, silty, dusky yellowish-brown (10 YR 2/2) mottled dark yellowish-brown (10 YR 4/2); weakly laminated.....	1.9	6.9
Pleistocene		
Peoria Formation		
Silt, clayey, pale yellowish-brown (10 YR 6/2) to dark yellowish-brown (10 YR 4/2); contains mod- erate amount of iron oxide staining; laminated.	1.6	8.5

	Thickness feet	Depth feet
Sangamon Soil		
Silt, clayey, dusky yellowish-brown (10 YR 2/2); contains very small amount iron oxide streaks and nodules; blocky.....	2.5	11.0
Silt, sandy, clayey, pale yellowish-brown (10 YR 6/4); contacts gradational with upper and lower units; laminated.....	0.8	11.8
Crete Formation		
Sand, fine to medium, silty, moderate yellowish- brown (10 YR 5/4); greater than 95% quartz.....	3.6	15.4
Cretaceous		
Lower Cretaceous		
Dakota Formation		
Sandstone, fine, contains high amount of iron oxide staining.....		15.4
Total depth.....		15.4

Test Hole B-11

Sample log of test hole at SE1/4, SE1/4, SE1/4, SE1/4, Sec. 22, T.
4. S., R. 3 E., 193 feet west of SE cor. Sec. 22, at edge of road.
Surface elevation 1440.7 feet.

	Thickness feet	Depth feet
Road fill.....		
Quaternary		
Holocene		
Soil		
Clay, silty, dusky yellowish-brown (10 YR 2/2) mottled moderate yellowish-brown (10 YR 5/4)...	0.2	1.2
Silt, clayey, pale yellowish-brown (10 YR 6/2) to moderate yellowish-brown (10 YR 5/4); weakly laminated.....	0.1	1.3
Clay, silty, dusky yellowish-brown (10 YR 2/2); upper contact sharp, lower contact gradational.	0.9	2.2
Silt, clayey, upper 0.2 feet - dark yellowish- brown (10 YR 4/2), lower 0.8 feet - light olive-gray (5 YR 6/1) to pale yellowish-brown (10 YR 6/2); contains small amount of iron oxide staining; calcareous (high accumulation from 2.4 to 2.7 feet); weakly laminated.....	1.0	3.2
Pleistocene		
Peoria Formation		
Silt, clayey, light olive gray (5 Y 6/1) to pale yellowish-brown (10 YR 6/2); contains iron oxide staining (prominent from 3.7 to 4.2 feet); lamin- ated.....	1.0	4.2

	Thickness feet	Depth feet
Silt, clayey, yellowish-gray (5 Y 8/1) to light olive-gray (5 Y 6/1); contains small amount of iron oxide streaks and nodules; laminated.....	1.0	5.2
Silt, clayey, pale yellowish-brown (10 YR 6/2) to dark yellowish-brown (10 YR 4/2); contains high amount of iron oxide in horizontal seams and nodules; strongly laminated at lower contact with paleosol.....	1.1	6.3
Sangamon Soil		
Silt, clayey, sandy, dark yellowish-brown (10 YR 4/2) to dusky yellowish-brown (10 YR 2/2); contains small amount of iron oxide staining; weakly to strongly laminated.....	2.2	8.5
Silt, sandy, clayey, very pale orange (10 YR 8/2); contains small amount of iron oxide staining; weakly laminated.....	0.3	8.8
Crete Formation		
Sand, fine to medium, very pale orange (10 YR 8/2); contains small amount of iron oxide staining; greater than 95% quartz.....	1.2	10.0
Cretaceous		
Lower Cretaceous		
Dakota Formation		
Sandstone, reddish-brown, weathered, loose.....	4.2	14.2
Sandstone, reddish-brown, cemented.....	3.8	18.0
Total depth.....		18.0

Test Hole B-12

Sample log of test hole in SE1/4, SW1/4, SE1/4, SE1/4, Sec. 22, T. 4 S., R. 3 E., 628 feet west of SE cor. sec. 22, at edge of road. Surface elevation 1441.1 feet.

	Thickness feet	Depth feet
Road fill.....	1.0	1.0
Quaternary		
Holocene		
Soil		
Clay, silty, dusky yellowish-brown (10 YR 2/2)...	0.7	1.7
Silt, clayey, dark yellowish-brown (10 YR 4/2); slightly calcareous; blocky; gradation; contacts.....	0.6	2.3
Peoria Formation		
Silt, clayey, yellowish-gray (5 Y 8/1); contains moderate amount of iron oxide in horizontal seams; laminated.....	5.5	7.8
Sangamon Soil		
Silt, sandy, clayey, dark yellowish-brown (10 YR 4/2) to dusky yellowish-brown (10 YR 2/2); contains very small amount of iron oxide staining; laminated.....	0.9	8.7

	Thickness feet	Depth feet
Silt, sandy, very pale orange (10 YR 8/2); contains small amount of iron oxide staining; laminated.....	1.3	10.0
Cretaceous		
Lower Cretaceous		
Dakota Formation		
Sandstone, fine, reddish-brown, weathered, loose....	1.4	11.4
Sandstone, fine, reddish-brown, cemented.....	1.6	13.0
Total depth.....		13.0

Test Hole B-13

Drilling log of test hole in SE1/4, SE1/4, SW1/4, SE1/4, Sec. 22, T. 4 S., R. 3 E., 977 feet west of SE cor. Sec. 22, at edge of road. Surface elevation 1450.2 feet.

	Thickness feet	Depth feet
Quaternary		
Holocene		
Soil		
Silt, clayey, dark reddish-brown.....	1.3	1.3
Silt, clayey, light reddish-brown mottled gray...	0.9	3.2
Cretaceous		
Lower Cretaceous		
Dakota Formation		
Sandstone, fine, shaly, grayish tan.....	2.9	6.1
Sandstone, fine, reddish-brown to orange.....	0.8	6.9
Shale, clayey, light grayish-brown.....	0.8	7.7

Test Hole B-14

Drilling log of test hole in SW1/4, SW1/4, SE1/4, SE1/4, Sec. 22, T. 4 S., R. 3 E., 727 feet west of SE cor. Sec. 22, at edge of road. Surface elevation 1444.1 feet.

	Thickness feet	Depth feet
Road fill.....	1.7	1.7
Quaternary		
Pleistocene		
Silt, clayey, gray; contains moderate amount of iron oxide staining.....	5.1	6.8
Cretaceous		
Lower Cretaceous		
Dakota Formation		
Sandstone, clayey, grayish-brown, weathered, loose	3.5	10.3

	Thickness feet	Depth feet
Sandstone, yellowish-brown, weathered, loose.....	2.1	12.4
Sandstone, reddish-brown, cemented.....		12.4
Total depth		12.4

Test Hole B-15

Drilling log of test hole is SE1/4, SE1/4, SE1/4, SE1/4, Sec. 23, T. 4 S., R. 3 E., 167 feet west of SE cor. Sec., 23, at edge of road. Surface elevation 1443.7 feet.

	Thickness feet	Depth feet
Road fill.....	3.4	3.4
Quaternary		
Pleistocene		
Peoria Formation		
Silt, clayey, gray.....	6.6	10.0
Silt, clayey, brown.....	1.8	11.8
Silt, clayey, gray, stiff.....	3.5	15.3
Silt, sandy, clayey, gray.....	2.5	17.8
Sangamon Soil		
Silt, sandy, clayey, dark reddish-brown.....	0.9	18.7
Crete Formation		
Sand, medium to coarse, clayey, stiff.....	3.5	22.2
Sand, fine to coarse, tan, stiff.....	1.6	23.8
Sand, fine to coarse, tan, soft.....	1.6	25.4
Sand, fine to coarse, tan, increasing stiffness..	3.8	29.2
Cretaceous		
Lower Cretaceous		
Dakota Formation		
Sandstone, fine, gray, dirty, cemented.....		29.2
Total depth.....		29.2

Test Hole B-16

Drilling log of test hole in SW1/4, NW1/4, SW1/4, NW1/4, Sec. 26, T. 4 S., R. 3 E., 1888 feet south of NW cor. Sec. 26, at edge of road. Surface elevation 1457.4 feet.

	Thickness feet	Depth feet
Road fill.....	2.4	2.4
Quaternary		
Pleistocene		
Peoria Formation		
Silt, clayey, gray.....	2.8	5.2
Silt, clayey, reddish-brown.....	3.6	8.8

	Thickness feet	Depth feet
Cretaceous		
Lower Cretaceous		
Dakota Formation		
Sandstone, fine, reddish-brown.....	1.8	10.8
Total depth.....		10.8

Test Hole B-17

Drilling log of test hole in NW1/4, NW1/4, SW1/4, NW1/4, Sec. 26, T. 4 S., R. 3 E., 1405 feet south of NW cor. Sec. 26, at edge of road. Surface elevation 1450.5 feet.

	Thickness feet	Depth feet
Road material.....	3.0	3.0
Quaternary		
Holocene		
Soil		
Clay, silty, brown.....	1.4	4.4
Pleistocene		
Peoria Formation		
Silt, clayey, gray.....	5.9	10.3
Cretaceous		
Lower Cretaceous		
Dakota Formation		
Sandstone, fine, clayey, light reddish-brown, weathered, loose.....	1.3	11.6
Sandstone, fine, reddish-brown, cemented.....		11.6
Total depth.....		11.6

Test Hole B-18

Drilling log of test hole in NW1/4, SW1/4, NW1/4, NW1/4, Sec. 26, T. 4 S., R. 3 E., 733 feet south of NW cor. Sec. 26, at edge of road. Surface elevation 1444.7 feet.

	Thickness feet	Depth feet
Quaternary		
Holocene		
Soil		
Silt, clayey, dark brown to black.....	4.1	4.1
Pleistocene		
Peoria Formation		
Silt, clayey, tan to gray, contains small amount of iron oxide staining.....	5.1	9.2

	Thickness feet	Depth feet
Sangamon Soil		
Silt, clayey, dark reddish-brown.....	1.2	10.4
Crete Formation		
Sand, medium to coarse, silty, clayey.....	3.1	13.5
Cretaceous		
Lower Cretaceous		
Dakota Formation		
Sandstone, fine, reddish-brown, cemented.....		13.5
Total depth.....		13.5

Test Hole B-19

Drilling log of test hole in SW1/4, NW1/4, SW1/4, SW1/4, Sec. 23, T. 4 S., R. 3 E., 763 feet north of SW cor. Sec. 23, at edge of road. Surface elevation 1440.7 feet.

	Thickness feet	Depth feet
Road fill.....	1.6	1.6
Quaternary		
Pleistocene		
Peoria Formation		
Silt, clayey, tan to gray, contains small amount of iron oxide staining at 6.0 feet.....	9.8	11.4
Crete Formation		
Sand, fine to medium, light brown.....	2.0	13.4
Sand, fine to medium, light gray.....	2.6	16.0
Sand, fine to medium, dirty.....	0.2	16.2
Sand, fine to medium, tan, contains small amount of iron oxide staining.....	5.0	21.2
Cretaceous		
Lower Cretaceous		
Dakota Formation		
Sandstone, fine, reddish-brown, cemented.....		21.2
Total depth.....		21.2

Test Hole B-20

Drilling log of test hole in NW1/4, SW1/4, NW1/4, SW1/4, Sec. 23, T. 4 S., R. 3 E., 1714 feet north of SW cor. Sec. 23, at edge of road. Surface elevation 1438.3 feet.

	Thickness feet	Depth feet
Road fill.....	3.2	3.2
Quaternary		
Pleistocene		
Peoria Formation		

	Thickness feet	Depth feet
Silt, clayey, gray.....	8.0	11.2
Sangamon Soil		
Silt, clayey, dark gray.....	3.1	14.3
Crete Formation		
Sand, medium to coarse, dark gray.....	7.9	22.2
Sand, fine to medium, light reddish-brown.....	1.6	23.8
Cretaceous		
Lower Cretaceous		
Dakota Formation		
Sandstone, fine, gray, cemented.....		23.8
Total depth.....		23.8

APPENDIX II

Grain Size Data

B-3,G-1

Class Interval (Phi Units)	Class Weight (gm.)	Weight Percent	Cumulative Weight (gm.)	Cumulative Percent
----- -1.00	0.547	0.491	0.457	0.491
-1.00- -0.75	0.337	0.303	0.884	0.794
-0.75- -0.50	0.303	0.272	1.187	1.066
-0.50- -0.25	0.900	0.808	2.088	1.874
-0.25- 0.00	1.157	1.038	3.244	2.912
0.00- 0.25	1.460	1.311	4.704	4.223
0.25- 0.50	2.695	2.420	7.340	6.664
0.50- 0.75	6.132	5.505	13.532	12.147
0.75- 1.00	10.808	9.702	24.340	21.849
1.00- 1.25	18.467	16.577	42.807	38.426
1.25- 1.50	22.818	20.483	65.624	58.909
1.50- 1.75	11.905	10.686	77.529	69.595
1.75- 2.00	6.964	6.251	84.492	75.846
2.00- 2.25	4.980	4.470	89.472	80.317
2.25- 2.50	2.308	2.072	91.780	82.389
2.50- 2.75	3.271	2.937	95.052	85.325
2.75- 3.00	1.146	1.029	96.198	86.354
3.00- 3.25	2.368	2.126	98.566	88.480
3.25- 3.50	1.148	1.031	99.714	89.511
3.50- 3.75	0.607	0.545	100.322	90.056
3.75- 4.00	0.470	0.422	100.792	90.478
4.00-	0.958	9.522	111.340	100.000

B-3,G-2

Class Interval (Phi Units)	Class Weight (gm.)	Weight Percent	Cumulative Weight (gm.)	Cumulative Percent
- -0.25	0.035	0.056	0.035	0.056
-0.25- 0.00	0.051	0.082	0.086	0.057
0.00- 0.25	0.012	0.165	0.188	0.304
0.25- 0.50	0.179	0.290	0.367	0.594
0.50- 0.75	0.895	1.448	1.262	2.042
0.75- 1.00	1.442	2.333	2.704	4.375
1.00- 1.25	2.184	3.543	4.888	7.909
1.25- 1.50	3.094	5.007	7.982	12.917
1.50- 1.75	2.888	4.673	10.870	17.589
1.75- 2.00	2.605	4.215	13.475	21.805
2.00- 2.25	2.604	4.214	16.079	26.019
2.25- 2.50	1.406	2.275	17.485	28.293
2.50- 2.75	2.151	3.481	19.636	31.775
2.75- 3.00	0.556	0.900	20.193	32.675
3.00- 3.25	1.143	1.850	21.336	34.525
3.25- 3.50	0.337	0.545	21.673	35.069
3.50- 3.75	0.224	0.362	21.896	35.431
3.75- 4.00	0.173	0.280	22.069	35.711
4.00- 5.00	7.885	12.795	29.954	48.470
5.00- 6.00	6.440	10.421	36.394	58.891
6.00- 7.00	3.155	5.105	39.549	63.996
7.00- 8.00	2.220	3.592	41.769	67.589
8.00- 9.00	1.600	2.589	43.369	70.178
9.00- 10.00	1.265	2.047	44.634	72.224
10.00- 11.00	0.220	0.356	44.854	72.581
11.00-	16.945	27.419	61.799	100.000

B-3,G-3

Class Interval (Phi Units)	Class Weight (gm.)	Weight Percent	Cumulative Weight (gm.)	Cumulative Percent
-0.50- -0.25	0.006	0.006	0.006	0.006
-0.25- 0.00	0.014	0.015	0.020	0.021
0.00- 0.25	0.037	0.039	0.058	0.060
0.25- 0.50	0.161	0.169	0.219	0.229
0.50- 0.75	0.703	0.737	0.922	0.966
0.75- 1.00	1.331	1.396	2.253	2.362
1.00- 1.25	2.262	2.372	4.515	4.734
1.25- 1.50	3.304	3.465	7.819	8.199
1.50- 1.75	3.073	3.222	10.892	11.421
1.75- 2.00	2.668	2.797	13.559	14.218
2.00- 2.25	2.692	2.823	16.252	17.041
2.25- 2.50	1.614	1.693	17.866	18.734
2.50- 2.75	2.381	2.496	20.247	21.230
2.75- 3.00	0.830	0.871	21.077	22.100
3.00- 3.25	1.333	1.398	22.410	23.498
3.25- 3.50	0.522	0.548	22.932	24.046
3.50- 3.75	0.393	0.412	23.325	24.458
3.75- 4.00	0.259	0.271	23.584	24.729
4.00- 5.00	8.915	9.348	32.499	34.077
5.00- 6.00	14.680	15.393	47.179	49.470
6.00- 7.00	10.765	11.288	57.944	60.758
7.00- 8.00	6.280	6.585	64.224	67.343
8.00- 9.00	4.060	4.257	68.284	71.600
9.00- 10.00	2.595	2.721	71.005	74.453
10.00- 11.00	0.680	0.713	71.685	75.166
11.00	23.810	24.966	95.369	100.000

B-3,G-4

Class Interval (Phi Units)	Class Weight (gm.)	Weight Percent	Cumulative Weight (gm.)	Cumulative Percent
- 4.00	0.326	0.647	0.326	0.647
4.00- 5.00	10.040	19.889	10.366	20.535
5.00- 6.00	14.645	29.011	25.001	49.546
6.00- 7.00	5.655	11.202	30.666	60.748
7.00- 8.00	2.680	5.309	33.346	66.137
8.00- 9.00	2.220	4.398	35.566	70.535
9.00- 10.00	1.920	3.803	37.486	74.338
10.00- 11.00	1.625	3.219	39.111	77.557
- 11.00	11.370	22.443	50.481	100.000

B-3,G-5

Class Interval (Phi Units)	Class Weight (gm.)	Weight Percent	Cumulative Weight (gm.)	Cumulative Percent
- 4.00	0.952	1.682	0.952	1.682
4.00- 5.00	6.290	11.121	7.242	12.803
5.00- 6.00	11.975	21.172	19.217	33.974
6.00- 7.00	5.520	9.759	24.737	43.734
7.00- 8.00	3.020	5.339	27.757	49.073
8.00- 9.00	2.120	3.748	29.877	52.821
9.00- 10.00	1.935	3.421	31.812	56.242
10.00- 11.00	0.960	1.697	32.772	57.940
-11.00	23.790	42.060	56.562	100.000

B-5,G-1

Class Interval (Phi Units)	Class Weight (gm.)	Weight Percent	Cumulative Weight (gm.)	Cumulative Percent
-1.25- -1.00	0.310	0.360	0.310	0.360
-1.00- -0.75	0.129	0.150	0.438	0.509
-0.75- -0.50	0.225	0.262	0.663	0.771
-0.50- -0.25	0.735	0.854	1.398	1.626
-0.25- 0.00	0.833	0.968	2.231	2.594
0.00- 0.25	0.884	1.028	3.115	3.622
0.25- 0.50	1.055	1.227	4.169	4.848
0.50- 0.75	1.432	1.666	5.602	6.514
0.75- 1.00	1.908	2.222	7.510	8.733
1.00- 1.25	3.026	3.518	10.535	12.251
1.25- 1.50	6.547	7.613	17.082	19.864
1.50- 1.75	9.442	10.980	26.524	30.843
1.75- 2.00	10.141	11.793	36.666	42.636
2.00- 2.25	9.770	11.361	46.436	53.997
2.25- 2.50	4.867	5.659	51.303	59.656
2.50- 2.75	7.802	9.072	59.105	68.728
2.75- 3.00	2.120	2.444	61.206	71.172
3.00- 3.25	2.825	3.285	64.031	74.457
3.25- 3.50	0.741	0.862	64.773	75.319
3.50- 3.75	0.233	0.271	65.006	75.590
3.75- 4.00	0.337	0.392	65.342	75.982
- 4.00	20.655	24.019	86.000	100.000

B-5,G-2

Class Interval (Phi Units)	Class Weight (gm.)	Weight Percent	Cumulative Weight (gm.)	Cumulative Percent
-4.00	8.751	16.612	8.751	16.612
4.00- 5.00	7.575	14.379	16.326	30.991
5.00- 6.00	7.990	14.787	24.116	45.778
6.00- 7.00	4.370	8.295	28.486	54.073
7.00- 8.00	2.570	4.878	31.056	58.951
8.00- 9.00	2.230	4.233	33.286	63.184
9.00- 10.00	1.975	3.749	35.261	66.933
10.00- 11.00	2.425	4.603	37.686	71.536
-11.00	14.995	28.464	52.681	100.000

B-5,G-3

Class Interval (Phi Units)	Class Weight (gm.)	Weight Percent	Cumulative Weight (gm.)	Cumulative Percent
-4.00	0.287	0.814	0.287	0.814
4.00- 5.00	3.270	9.281	3.557	10.096
5.00- 6.00	7.770	22.054	11.327	32.150
6.00- 7.00	4.880	13.851	16.207	46.001
7.00- 8.00	2.860	8.118	19.067	54.118
8.00- 9.00	0.925	0.230	19.992	56.744
9.00- 10.00	2.375	6.741	22.367	63.485
10.00- 11.00	1.850	5.251	24.217	68.736
-11.00	11.015	31.264	35.232	100.000

B-7,G-1

Class Interval (Phi Units)	Class Weight (gm.)	Weight Percent	Cumulative Weight (gm.)	Cumulative Percent
-1.00- -0.75	0.044	0.026	0.004	0.026
-0.75- -0.50	0.26	0.016	0.070	0.042
-0.50- -0.25	0.134	0.080	0.204	0.122
-0.25- 0.00	0.278	0.166	0.482	0.289
0.00- 0.25	0.500	0.300	0.982	0.588
0.25- 0.50	1.208	0.723	2.190	1.311
0.50- 0.75	1.009	0.604	3.199	1.915
0.75- 1.00	14.847	8.889	18.046	10.804
1.00- 1.25	35.392	21.190	53.438	31.994
1.25- 1.50	66.530	39.832	119.968	71.826
1.50- 1.75	30.569	18.302	150.537	90.127
1.75- 2.00	9.688	5.800	160.225	95.928
2.00- 2.25	2.650	1.587	162.875	97.514
2.25- 2.50	0.702	0.421	163.577	97.935
2.50- 2.75	0.827	0.495	164.404	98.430
2.75- 3.00	0.250	0.150	164.654	98.579
3.00- 3.25	0.433	0.259	165.087	98.838
3.25- 3.50	0.232	0.139	165.319	98.977
3.50- 3.75	0.130	0.078	165.448	99.055
3.75- 4.00	0.161	0.097	165.610	99.152
-4.00	1.417	0.849	167.027	100.000

B-7,G-2

Class Interval (Phi Units)	Class Weight (gm.)	Weight Percent	Cumulative Weight (gm.)	Cumulative Percent
-0.50- -0.25	0.641	0.691	0.641	0.691
-0.25- 0.00	1.288	1.389	1.929	2.080
0.00- 0.25	2.314	2.496	4.244	4.576
0.25- 0.50	4.568	4.926	8.812	9.502
0.50- 0.75	8.056	8.688	16.868	18.190
0.75- 1.00	11.020	11.883	27.888	30.073
1.00- 1.25	12.828	13.833	40.716	43.906
1.25- 1.50	12.080	13.062	52.797	56.932
1.50- 1.75	7.510	8.098	60.306	65.030
1.75- 2.00	4.947	5.334	65.253	70.364
2.00- 2.25	3.617	3.901	68.870	74.265
2.25- 2.50	1.241	1.339	70.112	75.604
2.50- 2.57	1.566	1.688	71.677	77.292
2.75- 3.00	0.424	0.457	72.101	77.749
3.00- 3.25	0.857	0.924	72.958	78.673
3.25- 3.50	0.361	0.390	73.319	79.063
3.50- 3.75	0.900	0.097	73.409	79.160
3.75- 4.00	0.116	0.125	73.525	79.285
4.00	19.211	20.715	92.736	100.000

B-7,G-3

Class Interval (Phi Units)	Class Weight (gm.)	Weight Percent	Cumulative Weight (gm.)	Cumulative Percent
-0.50- -0.25	0.688	0.886	0.688	0.886
-0.25- 0.00	0.349	0.450	1.037	1.335
0.00- 0.25	0.300	0.386	1.337	1.721
0.25- 0.50	0.394	0.507	1.730	2.228
0.50- 0.75	0.561	0.723	2.292	2.951
0.75- 1.00	0.816	1.051	3.107	4.001
1.00- 1.25	1.498	1.929	4.605	5.930
1.25- 1.50	4.370	5.627	8.975	11.557
1.50- 1.75	9.509	12.244	18.484	23.802
1.75- 2.00	14.055	18.099	32.539	41.901
2.00- 2.25	13.622	17.540	46.161	59.442
2.25- 2.50	4.589	5.909	50.749	65.351
2.50- 2.75	4.930	6.349	55.680	71.699
2.75- 3.00	1.140	1.467	56.819	73.166
3.00- 3.25	1.538	1.981	58.357	75.147
3.25- 3.50	0.507	0.653	58.864	75.800
3.50- 3.75	0.184	0.237	59.049	76.037
3.75- 4.00	0.296	0.381	59.345	76.419
4.00	18.313	23.581	77.657	100.000

B-7,G-4

Class Interval (Phi Units)	Class Weight (gm.)	Weight Percent	Cumulative Weight (gm.)	Cumulative Percent
-0.50- -0.25	0.039	0.052	0.039	0.052
-0.25- 0.00	0.027	0.037	0.066	0.088
0.00- 0.25	0.022	0.029	0.087	0.117
0.25- 0.50	0.093	0.124	0.180	0.240
0.50- 0.75	0.195	0.261	0.375	0.501
0.75- 1.00	0.341	0.456	0.716	0.956
1.00- 1.25	0.606	0.811	1.322	1.767
1.25- 1.50	1.303	1.741	2.625	3.508
1.50- 1.75	2.005	2.680	4.630	6.188
1.75- 2.00	2.389	3.193	7.019	9.381
2.00- 2.25	2.928	3.913	9.947	13.294
2.25- 2.50	1.542	2.060	11.489	15.355
2.50- 2.75	2.368	3.164	13.857	18.519
2.75- 3.00	0.905	1.210	14.762	19.729
3.00- 3.25	1.241	1.659	16.003	21.388
3.25- 3.50	0.583	0.707	16.586	22.167
3.50- 3.75	0.364	0.486	16.950	22.653
3.75- 4.00	0.203	0.271	17.153	22.924
4.00- 5.00	8.565	11.447	25.718	34.371
5.00- 6.00	10.435	13.946	36.153	48.318
6.00- 7.00	6.250	8.353	42.403	56.671
7.00- 8.00	3.360	4.490	45.763	61.162
8.00- 9.00	3.435	4.591	49.198	65.752
9.00- 10.00	1.295	1.731	50.493	67.483
10.00- 11.00	0.195	0.261	50.688	67.744
11.00	24.135	32.256	74.823	100.000

B-7,G-5

Class Interval (Phi Units)	Class Weight (gm.)	Weight Percent	Cumulative Weight (gm.)	Cumulative Percent
-0.50- -0.25	0.034	0.043	0.034	0.043
-0.25- 0.00	0.023	0.029	0.057	0.072
0.00- 0.25	0.032	0.041	0.090	0.113
0.25- 0.50	0.083	0.105	0.173	0.218
0.50- 0.75	0.173	0.218	0.346	0.437
0.75- 1.00	0.319	0.402	0.665	0.839
1.00- 1.25	0.619	0.781	1.284	1.620
1.25- 1.50	1.275	1.608	2.559	3.228
1.50- 1.75	1.872	2.361	4.431	5.589
1.75- 2.00	2.183	2.753	6.614	8.342
2.00- 2.25	2.689	3.392	9.303	11.734
2.25- 2.50	1.443	1.820	10.747	13.554
2.50- 2.75	2.034	2.566	12.781	16.120
2.75- 3.00	0.599	0.755	13.380	16.875
3.00- 3.25	0.913	1.152	14.293	18.027
3.25- 3.50	0.343	0.433	14.636	18.459
3.50- 3.75	0.262	0.331	14.898	18.790
3.75- 4.00	0.235	0.296	15.133	19.086
4.00- 5.00	10.265	12.946	25.398	32.033
5.00- 6.00	11.635	14.674	37.033	46.707
6.00- 7.00	7.035	8.873	44.068	55.580
7.00- 8.00	4.180	5.272	48.248	60.852
8.00- 9.00	3.615	4.559	51.863	65.411
9.00- 10.00	1.770	2.232	53.663	67.643
10.00- 11.00	1.605	2.024	55.238	69.668
11.00	24.050	30.332	79.288	100.000

B-7,G-6

Class Interval (Phi Units)	Class Weight (gm.)	Weight Percent	Cumulative Weight (gm.)	Cumulative Percent
4.00	0.116	0.185	0.116	0.185
4.00- 5.00	10.650	17.084	10.766	17.269
5.00- 6.00	16.210	26.002	26.976	43.271
6.00- 7.00	6.815	10.932	33.791	54.203
7.00- 8.00	3.495	5.606	37.286	59.810
8.00- 9.00	2.910	4.668	40.196	64.477
9.00- 10.00	1.950	3.128	42.146	67.605
10.00- 11.00	3.060	4.909	45.206	72.514
11.00	17.135	27.486	62.341	100.000

B-7,G-7

Class Interval (Phi Units)	Class Weight (gm.)	Weight Percent	Cumulative Weight (gm.)	Cumulative Percent
4.00	1.102	1.605	1.102	1.605
4.00- 5.00	8.170	11.894	9.272	13.498
5.00- 6.00	12.785	18.612	22.057	32.110
6.00- 7.00	7.245	10.547	29.302	42.657
7.00- 8.00	3.840	5.590	33.142	48.248
8.00- 9.00	3.430	4.993	36.572	53.241
9.00- 10.00	2.020	2.941	38.592	56.182
10.00- 11.00	2.570	3.741	41.162	59.923
11.00	27.530	40.077	68.692	100.000

B-9,G-1

Class Interval (Phi Units)	Class Weight (gm.)	Weight Percent	Cumulative Weight (gm.)	Cumulative Percent
-0.50- -0.25	0.482	0.713	0.482	0.713
-0.25- 0.00	0.554	0.820	1.036	1.533
0.00- 0.25	0.891	1.319	1.927	2.852
0.25- 0.50	1.788	2.646	3.715	5.498
0.50- 0.75	3.448	5.102	7.163	10.600
0.75- 1.00	5.358	7.930	12.521	18.529
1.00- 1.25	8.924	13.207	21.445	31.736
1.25- 1.50	12.412	18.368	33.857	50.104
1.50- 1.75	7.680	11.366	41.537	61.470
1.75- 2.00	4.230	6.259	45.767	67.729
2.00- 2.25	2.774	4.105	48.541	71.834
2.25- 2.50	1.098	1.625	49.639	73.460
2.50- 2.75	1.800	2.663	51.439	76.123
2.75- 3.00	0.566	0.837	52.004	76.960
3.00- 3.25	1.366	2.022	53.371	78.982
3.25- 3.50	0.617	0.913	53.988	79.895
3.50- 3.75	0.118	0.174	54.105	80.069
3.75- 4.00	0.513	0.759	54.618	80.828
4.00	12.955	19.172	67.573	100.000

B-9, G-2

Class Interval (Phi Units)	Class Weight (gm.)	Weight Percent	Cumulative Weight (gm.)	Cumulative Percent
-0.50- -0.25	0.044	0.047	0.044	0.047
-0.25- 0.00	0.064	0.068	0.108	0.115
0.00- 0.25	0.133	0.142	0.240	0.257
0.25- 0.50	0.603	0.644	0.843	0.901
0.50- 0.75	1.527	1.633	2.370	2.534
0.75- 1.00	1.900	2.031	4.269	4.566
1.00- 1.25	2.671	2.856	6.940	7.422
1.25- 1.50	3.940	4.213	10.880	11.635
1.50- 1.75	2.857	3.055	13.736	14.690
1.75- 2.00	1.633	1.746	15.369	16.436
2.00- 2.25	1.617	1.729	16.986	18.165
2.25- 2.50	0.974	1.042	17.960	19.207
2.50- 2.75	1.691	1.809	19.652	21.015
2.75- 3.00	0.660	0.706	20.312	21.721
3.00- 3.25	1.309	1.400	21.621	23.121
3.25- 3.50	0.516	0.552	22.137	23.673
3.50- 3.75	0.343	0.367	22.480	24.040
3.75- 4.00	0.282	0.301	22.762	24.341
4.00- 5.00	9.360	10.010	32.771	35.045
5.00- 6.00	11.805	12.624	45.395	48.545
6.00- 7.00	6.995	7.480	52.876	56.544
7.00- 8.00	3.820	4.085	56.961	60.913
8.00- 9.00	3.405	3.641	60.602	64.807
9.00- 10.00	2.155	2.305	62.906	67.271
10.00- 11.00	1.530	1.636	64.543	69.021
11.00	30.680	32.812	93.502	100.000

B-9,G-3

Class Interval (Phi Units)	Class Weight (gm.)	Weight Percent	Cumulative Weight (gm.)	Cumulative Percent
-0.50- -0.25	0.013	0.020	0.013	0.020
-0.25- 0.00	0.026	0.039	0.039	0.059
0.00- 0.25	0.080	0.120	0.119	0.179
0.25- 0.50	0.306	0.460	0.425	0.638
0.50- 0.75	0.696	1.044	1.121	1.682
0.75- 1.00	0.999	1.499	2.119	3.181
1.00- 1.25	1.425	2.139	3.545	5.320
1.25- 1.50	2.107	3.163	5.652	8.483
1.50- 1.75	1.861	2.793	7.513	11.276
1.75- 2.00	1.500	2.251	9.012	13.527
2.00- 2.25	1.762	2.645	10.774	16.171
2.25- 2.50	0.994	1.493	11.786	17.664
2.50- 2.75	1.499	2.249	13.267	19.913
2.75- 3.00	0.425	0.638	13.692	20.551
3.00- 3.25	0.894	1.342	14.586	21.893
3.25- 3.50	0.347	0.521	14.933	22.414
3.50- 3.75	0.215	0.324	15.149	22.738
3.75- 4.00	0.286	0.429	15.434	23.166
4.00- 5.00	8.660	12.998	24.094	36.164
5.00- 6.00	8.395	12.601	32.489	48.765
6.00- 7.00	4.965	7.452	37.454	56.217
7.00- 8.00	3.155	4.736	40.609	60.953
8.00- 9.00	2.300	3.452	42.909	64.405
9.00- 10.00	1.505	2.259	44.414	66.664
10.00- 11.00	1.245	1.869	45.659	68.533
11.00	20.965	31.468	66.624	100.000

B-9,G-4

Class Interval (Phi Units)	Class Weight (gm.)	Weight Percent	Cumulative Weight (gm.)	Cumulative Percent
4.00	0.047	0.098	0.047	0.098
4.00- 5.00	10.085	21.204	10.132	21.302
5.00- 6.00	12.025	25.283	22.157	46.585
6.00- 7.00	4.625	9.724	26.782	56.309
7.00- 8.00	2.490	5.235	29.272	61.545
8.00- 9.00	1.685	3.543	30.957	65.088
9.00- 10.00	1.575	3.316	32.532	68.399
10.00- 11.00	1.875	3.942	34.407	72.341
11.00	13.155	27.659	47.562	100.000

B-9,G-5

Class Interval (Phi Units)	Class Weight (gm.)	Weight Percent	Cumulative Weight (gm.)	Cumulative Percent
4.00	0.072	0.191	0.072	0.191
4.00- 5.00	5.355	14.333	5.427	14.524
5.00- 6.00	7.545	20.195	12.972	34.719
6.00- 7.00	3.465	9.274	16.437	43.993
7.00- 8.00	2.115	5.661	18.552	49.654
8.00- 9.00	1.670	4.470	20.222	54.124
9.00- 10.00	0.780	2.088	21.002	56.212
10.00- 11.00	0.535	1.432	21.537	57.644
11.00	15.825	42.356	37.362	100.000

B-11,G-1

Class Interval (Phi Units)	Class Weight (gm.)	Weight Percent	Cumulative Weight (gm.)	Cumulative Percent
-0.50- -0.25	0.352	0.395	0.352	0.395
-0.25- 0.00	0.273	0.306	0.625	0.701
0.00- 0.25	0.293	0.329	0.918	1.030
0.25- 0.50	0.521	0.585	1.439	1.615
0.50- 0.75	0.920	1.033	2.359	2.648
0.75- 1.00	1.736	1.948	4.095	4.596
1.00- 1.25	3.502	3.930	7.598	8.526
1.25- 1.50	5.698	6.394	13.296	14.920
1.50- 1.75	6.107	6.853	19.403	21.773
1.75- 2.00	6.081	6.824	25.484	28.587
2.00- 2.25	6.041	6.779	31.525	35.376
2.25- 2.50	2.665	2.990	34.189	38.367
2.50- 2.75	4.052	4.547	38.241	42.914
2.75- 3.00	1.053	1.182	39.295	44.096
3.00- 3.25	1.687	1.893	40.982	45.989
3.25- 3.50	0.531	0.596	41.512	46.584
3.50- 3.75	0.116	0.130	41.628	46.714
3.75- 4.00	0.214	0.241	41.843	46.955
4.00	47.270	53.045	89.112	100.000

B-11, G-2

Class Interval (Phi Units)	Class Weight (gm.)	Weight Percent	Cumulative Weight (gm.)	Cumulative Percent
-0.50- -0.25	0.009	0.018	0.009	0.018
-0.25- 0.00	0.033	0.068	0.042	0.086
0.00- 0.25	0.060	0.123	0.101	0.209
0.25- 0.50	0.156	0.323	0.257	0.531
0.50- 0.75	0.319	0.658	0.576	1.190
0.75- 1.00	0.606	1.253	1.182	2.442
1.00- 1.25	1.117	2.307	2.300	4.750
1.25- 1.50	1.757	3.629	4.055	8.379
1.50- 1.75	1.975	3.873	5.930	12.252
1.75- 2.00	2.071	4.280	8.001	16.532
2.00- 2.25	2.421	5.003	10.423	21.534
2.25- 2.50	1.266	2.616	11.689	24.150
2.50- 2.75	1.819	3.758	13.508	27.908
2.75- 3.00	0.494	1.020	14.001	28.928
3.00- 3.25	0.816	1.685	14.817	30.612
3.25- 3.50	0.303	0.625	15.119	31.238
3.50- 3.75	0.156	0.322	15.275	31.560
3.75- 4.00	0.156	0.322	15.431	31.881
4.00- 5.00	7.855	16.229	23.286	48.111
5.00- 6.00	6.815	14.080	30.101	62.191
6.00- 7.00	3.715	7.676	33.816	69.866
7.00- 8.00	2.630	5.434	36.446	75.330
8.00- 9.00	1.245	2.572	37.691	79.866
9.00- 10.00	0.965	1.994	38.656	79.866
10.00- 11.00	1.130	2.335	39.786	82.201
11.00	8.615	17.799	48.401	100.000

B-11, G-3

Class Interval (Phi Units)	Class Weight (gm.)	Weight Percent	Cumulative Weight (gm.)	Cumulative Percent
0.00- 0.25	0.002	0.005	0.002	0.005
0.25- 0.50	0.034	0.074	0.036	0.079
0.50- 0.75	0.134	0.292	0.170	0.371
0.75- 1.00	0.343	0.747	0.513	1.118
1.00- 1.25	0.760	1.655	1.273	2.773
1.25- 1.50	1.205	2.625	2.478	5.398
1.50- 1.75	1.489	3.244	3.967	8.641
1.75- 2.00	1.575	3.431	5.542	12.072
2.00- 2.25	1.694	3.691	7.236	15.763
2.25- 2.50	0.820	1.786	8.056	17.549
2.50- 2.75	1.222	2.662	9.278	20.211
2.75- 3.00	0.367	0.800	9.645	21.012
3.00- 3.25	0.418	0.911	10.064	21.923
3.25- 3.50	0.170	0.369	10.233	22.292
3.50- 2.75	0.095	0.206	10.328	22.498
3.75- 4.00	0.067	0.146	10.395	22.644
4.00- 5.00	6.665	14.519	17.060	37.163
5.00- 6.00	7.205	15.696	24.265	52.859
6.00- 7.00	4.865	10.598	29.130	63.457
7.00- 8.00	3.005	6.546	32.135	70.003
8.00- 9.00	1.765	3.845	33.900	73.848
9.00- 10.00	0.955	2.080	34.855	75.928
10.00- 11.00	1.110	2.418	35.965	78.346
11.00	9.940	21.654	45.905	100.000

B-11, G-4

Class Interval (Phi Units)	Class Weight (gm.)	Weight Percent	Cumulative Weight (gm.)	Cumulative Percent
4.00	0.038	0.099	0.038	0.099
4.00- 5.00	7.505	19.517	7.543	19.617
5.00- 6.00	9.635	25.056	17.178	44.673
6.00- 7.00	4.390	11.417	21.568	56.324
7.00- 8.00	2.315	6.020	23.883	62.110
8.00- 9.00	1.325	3.446	25.208	65.556
9.00- 10.00	1.380	3.589	26.589	69.114
10.00- 11.00	2.045	5.318	28.633	74.463
11.00	9.820	25.538	84.451	100.000

B-11,G-5

Class Interval (Phi Units)	Class Weight (gm.)	Weight Percent	Cumulative Weight (gm.)	Cumulative Percent
4.00	0.085	0.243	0.085	0.243
4.00- 5.00	4.630	13.251	4.715	13.495
5.00- 6.00	6.345	18.160	11.060	31.654
6.00- 7.00	3.250	9.302	14.310	40.956
7.00- 8.00	2.125	6.082	16.435	47.038
8.00- 9.00	1.785	5.109	18.220	52.147
9.00- 10.00	0.985	2.819	19.205	54.966
10.00- 11.00	1.150	3.291	20.355	58.257
11.00	14.585	41.743	34.856	100.000

B-11,S-8

Class Interval (Phi Units)	Class Weight (gm.)	Weight Percent	Cumulative Weight (gm.)	Cumulative Percent
-0.50- -0.25	0.040	0.032	0.040	0.032
-0.25- 0.00	0.058	0.046	0.098	0.078
0.00- 0.25	0.083	0.066	0.182	0.144
0.25- 0.50	0.249	0.197	0.430	0.341
0.50- 0.75	0.767	0.608	1.197	0.949
0.75- 1.00	1.746	1.384	2.944	2.333
1.00- 1.25	3.209	2.544	6.153	4.877
1.25- 1.50	6.401	5.074	12.554	9.951
1.50- 1.75	13.036	10.333	25.590	20.284
1.75- 2.00	26.955	21.544	52.544	41.649
2.00- 2.25	31.285	24.798	83.829	66.448
2.25- 2.50	8.925	7.075	92.755	73.522
2.50- 2.75	12.759	10.113	105.513	83.635
2.75- 3.00	3.573	2.832	109.086	86.468
3.00- 3.25	4.328	3.431	113.415	89.898
3.25- 3.50	1.239	0.982	114.654	90.881
3.50- 3.75	0.272	0.216	114.926	91.096
3.75- 4.00	0.491	0.389	115.416	91.485
4.00	10.742	8.515	126.157	100.000

DK-1

Class Interval (Phi Units)	Class Weight (gm.)	Weight Percent	Cumulative Weight (gm.)	Cumulative Percent
-0.50- -0.25	0.036	0.046	0.036	0.046
-0.25- 0.00	0.018	0.023	0.053	0.069
0.00- 0.25	0.022	0.028	0.075	0.097
0.25- 0.50	0.050	0.065	0.126	0.162
0.50- 0.75	0.055	0.070	0.181	0.232
0.75- 1.00	0.091	0.117	0.271	0.349
1.00- 1.25	0.182	0.234	0.453	0.583
1.25- 1.50	0.995	1.281	1.448	1.864
1.50- 1.75	5.183	6.671	6.631	8.535
1.75- 2.00	19.795	25.479	26.426	34.015
2.00- 2.25	25.411	32.708	51.838	66.708
2.25- 2.50	6.915	8.901	58.753	75.624
2.50- 2.75	6.766	8.709	65.519	84.333
2.75- 3.00	1.337	1.721	66.856	86.054
3.00- 3.25	1.495	1.924	68.351	87.978
3.25- 3.50	0.310	0.400	68.662	88.378
3.50- 3.75	0.042	0.054	68.703	88.432
3.75- 4.00	0.208	0.268	68.911	88.699
4.00	8.780	11.301	77.691	100.000

Appendix III

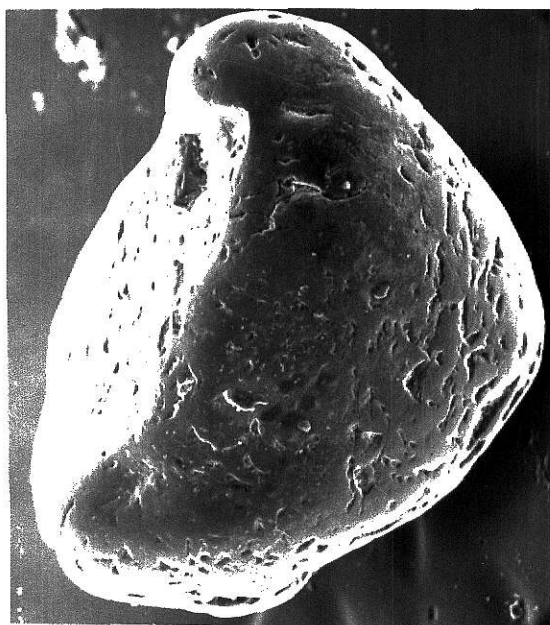
Scanning Electron Micrographs of Quartz Grains

The following micrographs are of quartz grains from the sand unit and from sandstone of the Dakota Formation northeast of Linn, Kansas. Grains Sd-1 through Sd-4 are from the sand unit and grains Ss-1 and Ss-2 are from the sandstone.

PLATE VI

Grain Number

Sd-1a

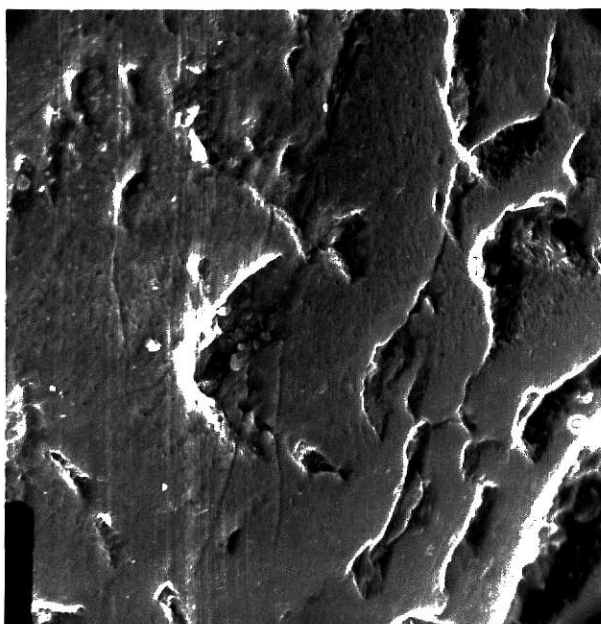
100 μ Description

Left side of grain shows evidence of previous mechanical fracturing with well rounded edges, possibly caused by solution-precipitation. Surface appears smooth with scattered V-shaped and linear to crescent-shaped impressions. Depressions are fairly deep, large and fresh. Looking at this view, the V's generally point in towards the center of the grain. Smoothness of the grain suggests precipitation has occurred, with impressions being formed on this surface.

PLATE VII

Grain Number

Sd-1b

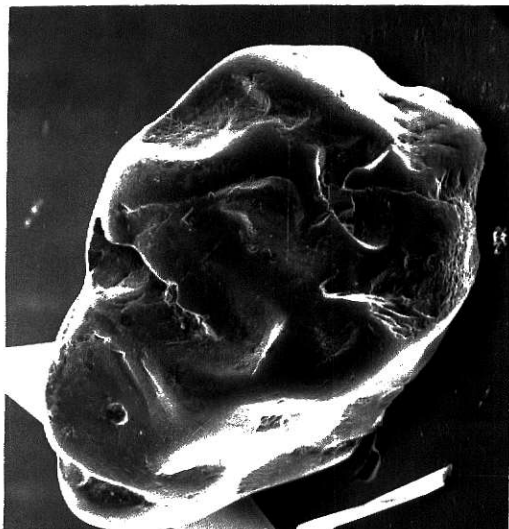
50 μ Description

Close-up of Sd-1a. Shows slightly curved breakage patterns (right side), V-shaped and crescent-shaped impressions (upper center and left center). Impressions are relatively large: crescent-shaped up to 48 microns in length; V-shaped up to 18 microns in length. Small platelets fill cavities of impressions (note filling in crescent-shaped impression left of center) which may be due to precipitation of quartz. Three linear scratches may be seen oriented vertically and lay across the large crescent shaped impression and to the left of it. Surface between impressions is smooth in lower right hand corner but appears to be etched in remaining 2/3 of the grain. Minute etched V's may be seen in this area.

PLATE VIII

Grain Number

Sd-2

500 μ

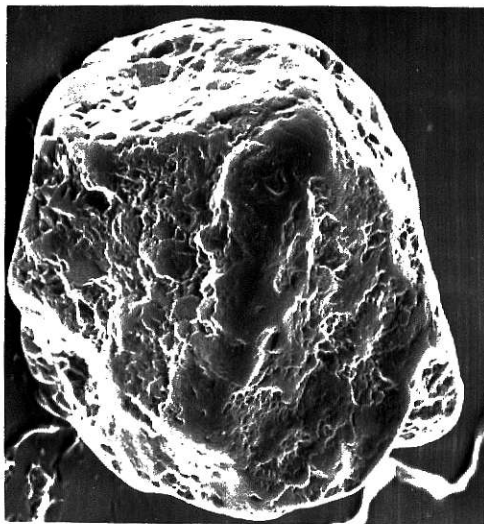
A

Description

Evidence of previous mechanical fracturing where edges have been well rounded. More recent fracturing is also present where edges have not been rounded. Protruding edge surfaces generally appear smoother than depressions. Triangular V-shaped impressions are seen in a depression in the upper left part of the grain. Several grooves are seen trending the same direction (the length of the grain in this position) and range in length from approximately 80 microns to 115 microns. Possible etching or solution-precipitation features may be seen on the extreme right of the grain.

Grain Number

Sd-3a

100 μ

B

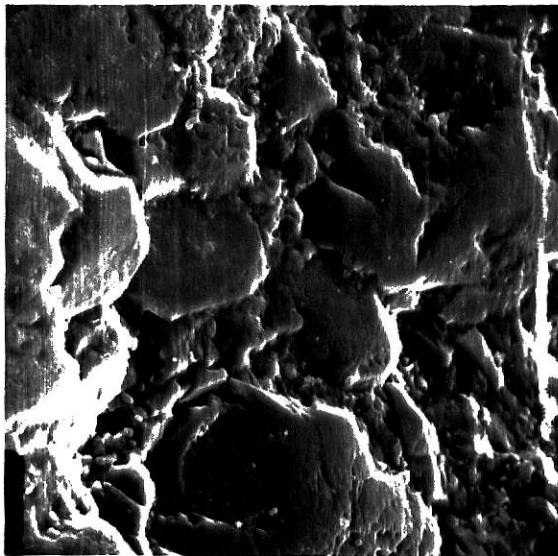
Description

Surface is very irregular giving rough appearance. Protruding edges are generally smoother than depressions. Plate-like structures protrude from surface which may be upturned cleavage plates. Chemical etching probably dominates surface texture on this grain.

PLATE IX

Grain Number

Sd-3b

50 μ

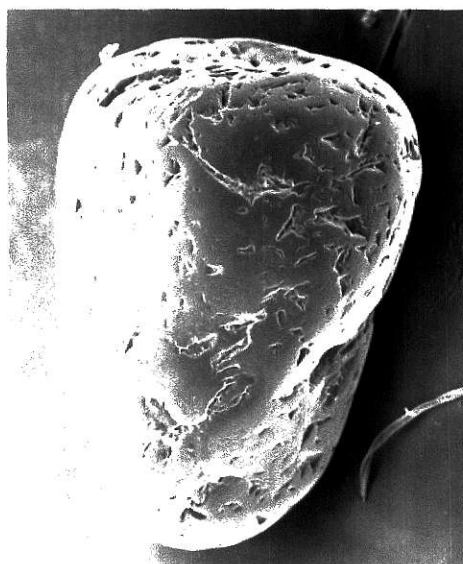
A

Description

Close-up of Sd-3a showing plate-like structures. Plates may be upturned and are irregularly oriented, however, some orientation may be seen with plates in the lower center of the grain. Small V-shaped depressions on some of the plate surfaces are probably the result of chemical etching. Solution-precipitation features fill depressions between plates. Some of the edges of the plates appear to be rather sharp with flat faces between edges.

Grain Number

Sd-4a

100 μ

B

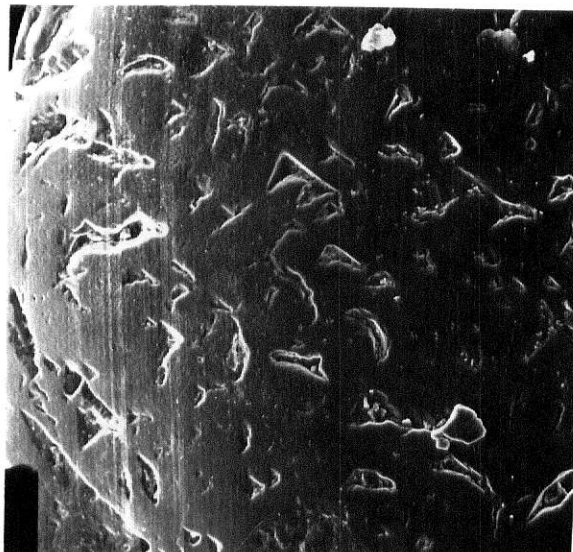
Description

Very well rounded edges with rather large and deep impressions scattered over a smooth surface. Impressions include V-shaped and linear to curved breakage depressions.

PLATE X

Grain Number

Sd-4b

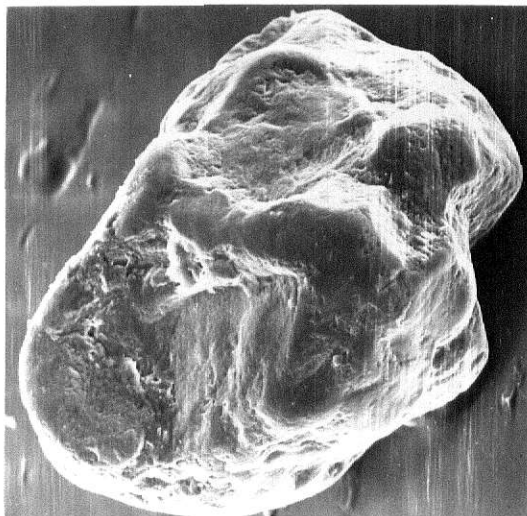


100 μ

A

Grain Number

Ss-1a



100 μ

B

Description

Close-up of Sd-4a. V-shaped depressions range in size from less than 10 microns to approximately 45 microns in width (measuring open end of V). Some V's are more crescent-shaped at the open end, whereas others form a perfect triangle. Linear and curved breakage depressions are also abundant and range up to about 75 to 100 microns in length. Surface between depressions is smooth. Precipitated quartz fills many of the depressions. No orientation of depressions is visible.

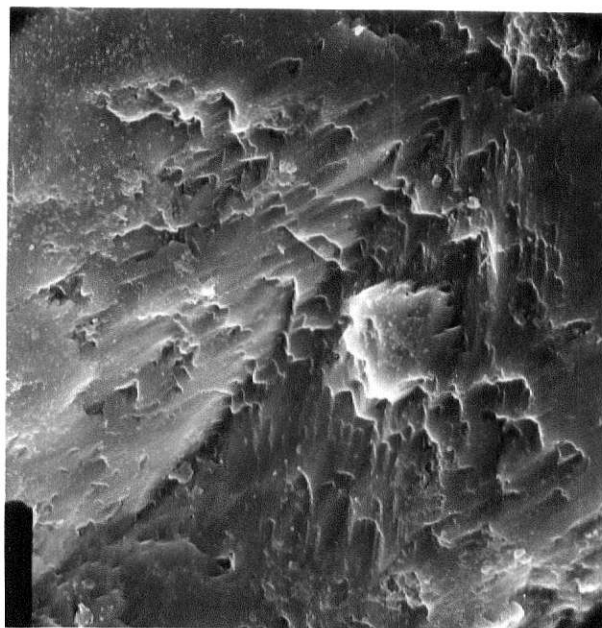
Description

Very irregular surface with rounded corners. Surface is heavily pitted with rough appearance. Protruding edges are slightly smoother than depressions.

PLATE XI

Grain Number

Ss-1b

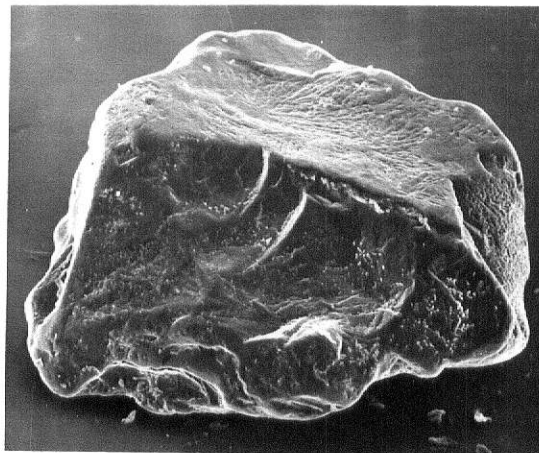
10 μ Description

Close-up of Ss-1a. Oriented V-shaped depressions ranging from less than 1 micron to 3 microns in width. V's may be formed from "notching" of edges of protruding plates or as a result of chemical etching. Upper left part of grain shows evidence of possible silica solution and precipitation.

PLATE XII

Grain NumberDescription

Ss-2a



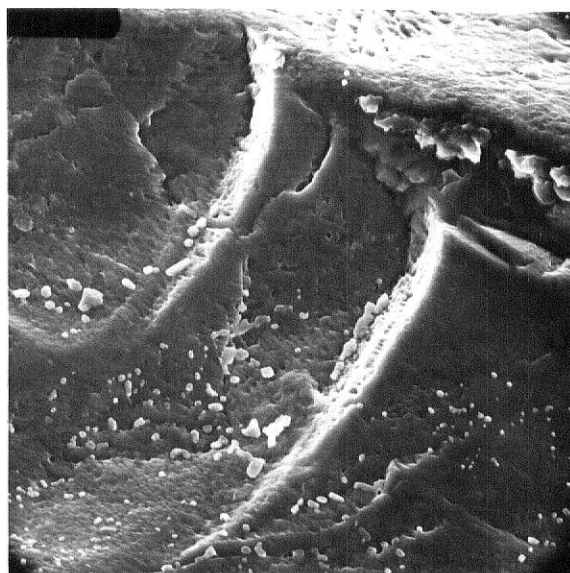
Evidence of mechanical fracturing with some relatively sharp edges and some more rounded. Precipitation of quartz occurs as scattered plates and in concentrated areas gives a rough texture (note extreme right of grain). Two V-shaped features occur in the center of the grain.

100 μ

A

Grain NumberDescription

Ss-2b



Close-up of Ss-2a showing two V-shaped features with positive relief that parallel each other. Small platelets of precipitated quartz are on the right of the grain and range from less than 1 micron to 5 microns in diameter. Very small V-shaped depressions, oriented, seem to be indented into the edges of cleavage plates. Irregular etching occurs between the two large V's.

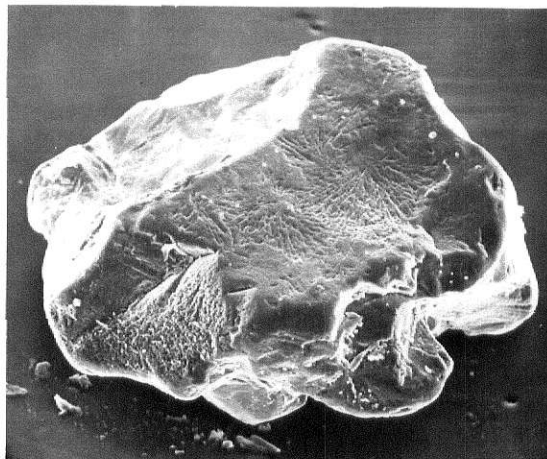
50 μ

B

PLATE XIII

Grain Number

Ss-2c

100 μ

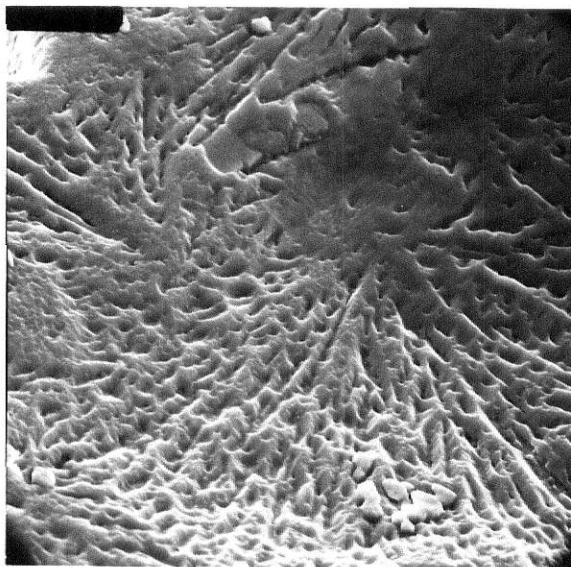
A

Description

A radial pattern of pitted grooves occurs on the right center part of the grain. Precipitation of quartz occurs as scattered plates and is concentrated in the lower left part of the grain causing a rough texture.

Grain Number

Ss-2d

50 μ Description

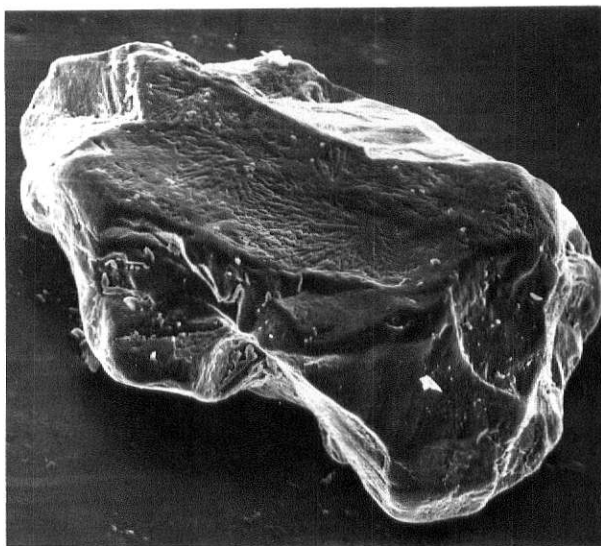
Close-up of Ss-2c showing radial pattern of pitted grooves, probably caused by chemical etching.

B

PLATE XIV

Grain Number

Ss-2e

100 μ Description

Again, the radial pattern of pitted grooves is noted on this grain. Plates of precipitated quartz are scattered across the surface.

APPENDIX IV

Phi Percenitle Values

Sample No.	5%	16%	25%	50%	75%	84%	95%
B-3,G-5	4.50	5.17	5.60	8.25	11.42	11.68	12.25
B-3,G-4	4.44	4.86	5.15	6.10	10.15	11.25	11.90
B-3,G-3	1.30	2.15	4.10	6.08	10.80	11.34	12.00
B-3,G-2	1.05	1.68	2.12	5.10	11.10	11.20	12.00
B-3,G-1	0.35	0.88	1.05	1.37	1.95	2.62	5.40
B-5,G-3	4.62	5.30	5.70	7.50	11.17	11.45	12.10
B-5,G-1	0.53	1.38	1.63	2.15	3.35	5.00	7.12
B-7,G-7	4.40	5.15	5.63	8.30	11.38	11.65	12.20
B-7,G-6	4.63	4.96	5.33	6.55	11.10	11.40	12.05
B-7,G-5	1.70	2.72	4.50	6.40	11.20	11.50	12.10
B-7,G-4	1.68	2.50	4.15	6.20	11.25	11.50	12.10
B-7,G-3	1.18	1.60	1.78	2.10	3.20	4.90	7.08
B-7,G-2	0.28	0.70	0.90	1.35	2.35	4.60	6.82
B-7,G-1	0.90	1.08	1.17	1.35	1.53	1.60	1.95
B-9,G-5	4.60	5.08	5.53	8.10	11.45	11.70	12.25
B-9,G-4	4.60	4.88	5.15	6.30	11.05	11.35	11.95
B-9,G-3	1.20	2.20	4.20	6.15	11.20	11.50	12.10
B-9,G-2	1.05	1.95	4.05	6.15	11.15	11.42	12.05
B-9,G-1	0.46	0.95	1.14	1.50	2.52	4.45	6.70
B-11,G-5	4.62	5.18	5.65	8.50	11.40	11.65	12.25
B-11,G-4	4.60	4.92	5.22	6.40	11.05	11.30	11.95
B-11,G-3	1.50	2.30	4.20	5.80	9.60	11.20	11.90
B-11,G-2	1.30	1.95	2.50	5.10	8.00	11.10	11.80
B-11,G-1	1.05	1.65	1.88	4.25	6.00	6.80	12.50
B-7,G ₁ -7	4.30	4.90	5.45	8.60	11.35	11.65	12.20
B-7,G ₁ -6	4.50	4.90	5.10	6.40	10.60	11.30	11.90
B-7,G ₁ -5	1.70	2.72	4.30	5.90	11.10	11.40	12.00
B-7,G ₁ -4	1.68	2.50	3.80	5.65	11.15	11.45	12.05
DK#1	1.65	1.83	1.93	2.10	2.48	2.72	5.70
B-11,S-8	1.25	1.68	1.80	2.05	2.53	2.80	5.20

APPENDIX V

Reagents, Apparatus, and Procedure Used for
Walkley-Black Method of Organic Carbon Determination

Required reagents include 85 percent H_3PO_4 , solid NaF, concentrated H_2SO_4 not less than 96 percent, and the following special reagents:

- 1) Standard 1N $\text{K}_2\text{Cr}_2\text{O}_7$.--Exactly 49.04 gm. of $\text{K}_2\text{Cr}_2\text{O}_7$ is dissolved in water, and the solution is diluted to 1 liter.
- 2) Diphenylamine Indicator.--Approximately 0.5 gm. of reagent grade diphenylamine is dissolved in 20 ml. of water and 100 ml. of concentrated H_2SO_4 .
- 3) Ferrous Solution.--The ferrous concentration may be made standard and preserved or made approximate and the chromate used as the standard of reference. A 0.5 N solution of ferrous is prepared by dissolution of 196.1 gm. of $\text{Fe}(\text{NH}_4)_2(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$ in 800 ml. of water containing 20 ml. of concentrated H_2SO_4 and dilution to 1 liter.

Required apparatus includes 500 ml. conical flasks, pipets of 10 ml. and 20 ml. volume and preferably self-adjusting to zero, a buret for the ferrous solution, and an analytical balance. A storage vessel to prevent oxidation of ferrous iron is a convenience and may be arranged to keep hydrogen or CO_2 over the solution.

Procedure for the Walkley-Black method is as follows:

- 1) 0.5 gm. to 1.0 gm. of sediment having passed through a 0.2 mm. (80 mesh) non-ferrous sieve, is placed in a 500 ml. conical flask.
- 2) 10 ml. of 1 N $\text{K}_2\text{Cr}_2\text{O}_7$ solution is added to the flask and the two are mixed by swirling the flask.

- 3) 20 ml. of concentrated H_2SO_4 is added and mixed by gentle rotation for one minute.
- 4) Allow mixture to stand for 30 minutes.
- 5) Add approximately 200 ml. of distilled water and 10 ml. of phosphoric acid. Allow to cool.
- 6) Add 10 to 30 drops of diphenylamine indicator (for this study sodium diphenylamine sulphonate was used).
- 7) Titrate excess dichromate with ammonium iron (II) sulphate solution delivered from a buret. The color is dull green to begin with and reaches a turbid blue as the end point is approached. At the end point, the color changes sharply to brilliant green, giving a one drop end point.
- 8) The amount of ammonium iron (II) sulphate used is recorded.
- 9) A blank determination is made following the above procedure, but without sediment. This serves to standardize the iron solution.

QUATERNARY GEOLOGY OF A BASIN NEAR
LINN, (WASHINGTON COUNTY), KANSAS

by

JOHN VINCENT MIESSE

B. S., Kansas State University, 1972

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Geology

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1974

A topographic basin northeast of Linn (Washington County), Kansas, was investigated to determine relationships between its development and geologic events of the Quaternary Period.

Test hole data reveal four major stratigraphic units of Quaternary Age which are in descending order: 1) a surface soil profile of Recent Age; 2) a loess, possibly the Peoria Formation (Wisconsinan Age); 3) A paleosol, possibly the Sangamon Soil (Sangamonian Age); and 4) an uncemented, fine to medium sand which is Illinoian Age or older and may possibly be correlated with the Crete Formation.

Bedrock profiles reflect a topographic basin with maximum relief of 48 feet. An alluvial origin is suggested for the sand filling the basin, by the poor sorting of the sand ($\sigma_I = 0.29 \phi$ to 1.92ϕ) and by the V-shaped impressions on quartz sand grains. Dark bands or laminations at the loess/paleosol contact indicate deposition of the loess started slowly and was interrupted by temporary periods of non-deposition. Fine laminae above the basal contact of the loess suggest sedimentation in small, isolated bodies of water.

Each stratigraphic unit is laterally similar in grain size, clay mineralogy, organic carbon, and pH. Mean grain size ranges from 1.34ϕ in the sand to 8.37ϕ in the surface soil. The clay mineral assemblage consists primarily of vermiculite, and small amounts of illite and kaolinite. Organic carbon percentages are generally low, ranging from 0.784 percent in the surface soil, to 0.069 percent in the loess. Changes in pH are small, ranging from 7.5 to 5.3. The surface soil and paleosol are more acidic than the loess.